POWER SYSTEM COMMUNICATIONS:

MICROWAVE LINE-OF-SIGHT (LOS) SYSTEMS

REA BULLETIN 66-6

RURAL ELECTRIFICATION ADMINISTRATION · U.S. DEPARTMENT OF AGRICULTURE

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FOREWORD

REA Bulletin 66-6, "Power System Communications: Microwave Line-of-Sight (LOS) Systems," is one of a series of REA bulletins dedicated to power systems communications. This publication is the first of its kind to specifically deal with rural electric cooperatives' design and implementation requirements for this particular communications transmission media and is an excellent reference guide for fundamental engineering considerations. The subject area covers systems engineering, design considerations, equipment and facilities, operating parameters, performance analyses, operations and maintenance.

The step-by-step presentation of the material in this bulletin should be of great benefit to all cooperative engineers and engineering firms and particularly helpful to relatively inexperienced engineers beginning their careers in power systems communications.

Assistant Administrator - Electric

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BULLETIN 66-6

POWER SYSTEM COMMUNICATIONS:

MICROWAVE

LINE-OF-SIGHT (LOS)

SYSTEMS

POWER SUPPLY AND ENGINEERING STANDARDS DIVISION
RURAL ELECTRIFICATION ADMINISTRATION
U.S. DEPARTMENT OF AGRICULTURE

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I. GENERAL

In the past 35 years, the use of microwave technology for the transfer of information has affected all aspects of modern industrial society. The complexity of microwave technology has likewise increased to achieve ever improved efficiencies, types of applications and cost effectiveness. In order to control the growth in recent years, there have been developed extensive microwave industry standards, engineering and equipment practices and regulatory policies and procedures.

As with many expanding technologies the associated literature is both voluminous and diverse. This Bulletin provides an overview of the existing information available and presents an introduction to the technology and system engineering practices.

A. Introduction to Microwave Systems

Microwave systems provide communications circuits for the transfer of information using the microwave radio spectrum as the transmission medium. The systems are used to interconnect communications points such as control centers with remote control points, office centers with each other, computers with remote users and major population centers with other cities. In the latter application microwave is used as a trunking facility to interconnect switching centers. Microwave is used to meet a wide variety of communications needs with the flexibility of interfacing with numerous types of devices that send and/or receive information. The outstanding feature of microwave is its relatively high reliability.

A typical microwave system consists of radio stations located in terminal sites with mountain or hill top repeater stations every 30-50 km. along the route interconnecting the terminals. The radio paths are designed with antennas mounted on towers (or high buildings) so that the antennas on a given link have a clear (unobstructed) view of each other. This is called line of sight (LOS) transmission. The signal is reamplified at each repeater and passed on to the next repeater and so on to its final destination.

The more common practices in microwave system engineering include:

- Point to point transmission between fixed locations
- Radio paths using unidirectional focused beam antennas (2-15 feet in diameter, 0.6-4.6 meters)
- Systems consisting of 1 to 100 radio paths
- Path lengths of 15-35 miles (24-56 km)
- Frequency modulated radio frequency carriers (also known as bearers) generally in the frequency range of 1-13 GHz
- Bidirectional or unidirectional transmission of voice, data, video, telemetry, facsimile etc.
- Radio channel capacities of 6-2700 voice channels per carrier.

B. Purpose

This Bulletin is a design and applications guide for REA borrower and consulting engineers with several years of experience. The purpose of the Bulletin is to guide engineers in the design, application and operation of microwave communications systems in the power industry. The Bulletin will serve to present design standards and procedures for the power industry.

C. Scope

The Bulletin is designed to cover the technical aspects of microwave system design from the initial consideration of communications needs through design, installation and operation. (Cost analysis is covered in REA Bulletin 66-4.) Bulletin 66-6 presents the steps required to engineer the microwave system including interfaces with user equipment. The Bulletin begins with a general introduction to the subject of microwave systems followed by explanations of equipments used, system technical characteristics, system design, analysis, and finally operations and maintenance. Elaborate mathematical proofs are eliminated where understanding is not necessary to the systems design engineer. However, the Bulletin does contain calculation procedures in detail to clearly demonstrate those procedures the design engineer must undertake to effectively engineer a system. To supplement the Bulletin's technical depth, an extensive bibliography is included.

D. History of Microwave Systems

The use of microwave for transmission facilities first became technically feasible shortly before World War II. Substantial research and development was being conducted at AT&T's Bell Laboratories. With the outbreak of the war, however, AT&T's technical resources were focused on the development of microwave radar. This stalled the development of microwave for communications until April 1944 when AT&T announced plans to construct an eight station system between Boston and New York in the 4 gHz band. The system was ready to demonstrate transmission of telephony and television 3½ years later. In 1948 the system was turned over to full time commercial use.

An improved version of this microwave system, the TD2 microwave system, capable of 480 voice channels was first manufactured in 1950 and placed into service during 1951 between New York City and Chicago, Illinois. Shortly thereafter this system was used for coast to coast operation. The TH1 system operating in the 6 GHz band appeared in the late 1950's. It had the distinct advantage of being easily added to existing TD2 systems. The TH1 was connected to the TD2 antenna system directly using combiner networks. This eliminated the need for additional antennas, towers, shelters etc. The technique continues today as a common practice in high density microwave routes.

In September 1960 the Federal Communications Commission allowed the entrance of private users into the microwave field. This allowed corporations such as oil companies, railroads, and power companies to build their own systems. This was accompanied by a significant growth of the microwave manufacturing industry outside the Bell System. The 1960's saw a rapid expansion of the AT&T microwave system as well as the increased use of the new technology by other large corporations as they realized the cost advantages of owning their own systems.

In the early 1970's the FCC granted licenses to a number of independent communications companies. These new common carriers, called "Specialized Common Carriers" (SCC), serve mainly the business community outside of the switched telephone network. The SCC services include private dedicated channels, data and voice transmission and other specialized circuits requiring unique interface and/or transmission features.

The birth of SCC's has added considerably to the growth of microwave in the common carrier radio frequency bands. Coupled with AT&T's growth in microwave, the bands are becoming crowded in the major population areas such as New York. This has pushed technology to higher and higher frequency bands to meet the ever increasing demand for transmission channels. Equipment is now commonly available up to 40 GHz for this purpose. The higher frequencies require shorter radio paths, however, and often prove not to be economically viable communications alternatives. Increasing emphasis is therefore being placed on other modes of transmission such as waveguides, optical fiber, and cable to solve the problems in the dense population areas where the common carrier microwave spectrum is being filled up.

The private microwave bands have not yet reached the stage of congestion that is observed in the common carrier bands. For the power industry, microwave today offers distinct advantages. The equipment technology has reached a high level of sophistication, and frequencies are generally available for use throughout the country.

E. Regulatory Constraints

The Federal Communications Commission was instituted in 1934 as the government's main agency to regulate interstate communications. The FCC's original charter has been interpreted to include regulatory power over all non-government electromagnetic radiators, including users of microwaves. The FCC has established regulations and procedures that apply to microwave users in the power industry. Numerous technical criteria are given, including frequency bands, transmitter power, and antenna size. To obtain a license to operate, the interested party or his representative must submit a comprehensive technical license application. Upon approval of the license application, the FCC will issue a license. The system must then be constructed within one year. Delays beyond one year may be authorized by the FCC.

The Utility Telecommunications Council (UTC) established in 1949 represents the REA Cooperatives and other utilities before the FCC in matters dealing with telecommunication interests. One of the primary functions of the UTC is to assist the REA Cooperatives in the area of radio frequency coordination.

The Federal Aviation Administration (FAA) may directly govern the allowable height of a microwave tower. When designing a tower over 200 feet above the ground level (lower if near an airport) the applicant must file with the FAA. The FAA in turn reviews that application for potential interference to air traffic. A tower of 200 feet normally is not rejected by the FAA. The intent of the criteria is to flag all potential hazards to aviation. Tall towers are more likely to be a hazard if they are near an airport or in the established flight patterns.

Since the early 1960's the public has become increasingly aware of environmental pollution, including the construction of tall towers. Most construction efforts require local governmental approval and perhaps zoning changes. Public hearings often become a step in the procedure. The urbanized areas are becoming increasingly resistant to structures that disturb the local setting. The FCC does not normally require an environmental impact statement unless the microwave towers are 300 feet in height or higher. For those cases requiring an environmental assessment or impact statement the following are among the factors that should be addressed:

- Will the proposed project involve drainage into a lake, stream, or other perennial water course?
- Will the project have an impact on utilities and services?
- Will the proposed project have an impact on air quality or create noise?
- Will the proposed project generate amounts of sewage?
- Will the proposed project remove or destroy trees or have an effect on other flora?
- Will the proposed project have any effect on the health and safety of the future occupants and/or existing population in the area?
- Will the proposed project have an effect on the employment and tax base of the county?
- Will the project conflict with existing land uses in the area?

- Will the proposed project aesthetically compare with the surrounding area?

- Does the proposed project conflict with applicable land use and other plans of the city-county planning board?

- Could the proposed project affect the use of a recreational area or area of important visual value?

- Will any natural or man-made features be affected by the proposed project?

- Will the proposed project involve construction of facilities on a slope of 20% or greater?

- Will the proposed project involve construction of facilities in an area of geologic hazard?

- Could the project change existing features, or involve construction on any flood plain, lake, stream, marsh or water course?

- Is the project, as part of a larger project, one of a series of cumulative actions?

- Could the project change existing features of any of the region's lake shorelines or stream beds?

- Could the project serve to encourage development?

- Will the project involve the application, use or disposal of potentially hazardous materials?

- Could the project significantly affect the potential use, extraction or conservation of a natural resource?

- Could the project result in damage to soil capability or loss of agricultural land?

F. Present Systems and Applications

Microwave since the early 1960's has become a major means of communications in the power industry. It is now widely used for point-to-point services such as voice, data, telemetry and facsimile. Critical control circuits are increasingly using microwave as a main, high reliability transmission medium. Microwave is also used as a trunking facility to feed mobile radio repeater stations as well. Figure I-1 shows the industry's present level of microwave use in the bands available to borrowers and co-ops. (The 960 MHz band is not included.) It will be obvious that the electric utility industry is heavily involved in the use of microwave. In fact, this industry is by far the largest user group of the microwave bands noted.

Frequency Band	1.8 GHz	2 GHz	6 GHz	12 GHz
* Number of Electric Utilities	106	52	129	15
* Number of Licenses Granted to Electric Utilities	1197	197	1970	43
* Total Number of Agencies, Companies, Etc.	258	204	300	248
* Total Number of Licenses Granted	3186	1198	5377	770

* Data effective November 1977

Figure I-1 Present Use of Microwave Bands

G. Trends

Microwave in the power industry, as elsewhere, has proven itself to be a highly reliable and versatile means of communications. Its use will increase in the future, keeping pace with other expanding technologies in the power industry. To insure the continued usefulness of this bulletin, several categories of trends are considered to reflect the pattern of the microwave industry's growth.

1. Equipment

Microwave equipment has undergone a number of evolutions. The most significant result perhaps is increased reliability. This has reduced outage times as well as the need for redundancy. The transmitting power sources for example at first were klystrons, followed by short-life travelling wave tubes, and were eventually replaced by solid state devices in the mid 1970's. Solid state technology has also replaced all previous tube functions; not only improving reliability but reducing routine maintenance.

Following established trends, microwave equipment will continue to improve in reliability, noise performance, transmitter power and packaging size.

As the lower frequency bands become increasing crowded, more and more equipment will become available in the higher bands. One notable design feature recently introduced by Bell Laboratories is the use of amplitude modulation (AM) in wideband microwave systems. This highly sophisticated procedure may become widely accepted in time providing on the order of 3 times as many voice channels as are available on conventional frequency modulated (FM) systems. Digital radio is also becoming more widely accepted and the number of manufacturers of this type of equipment has increased in recent years. Digital equipment has a number of inherent advantages over analog type modulation, principally less sensitivity to interference. Also, digital radio is compatible with digital multiplex, which is generally cheaper than analog multiplex. Microwave equipment, as with other electronics equipment, is moving steadily to complete modularization. This allows for maintenance in the field by less skilled personnel thus reducing operating costs.

2. System Design

Lower power consumption, digital/mixed modulation and upgraded system capacity are major design considerations that increasingly affect system design.

Numerous applications of microwave in remote areas have placed pressure on the designer to reduce prime power requirement. This has resulted in much higher equipment power efficiencies as well as innovation in power plant design. One promising technique is the use of solar energy. Several companies now provide the equipment and engineering required for solar power systems adequate for microwave repeaters. As mentioned above, digital modulation is finding increased acceptance. Digital radio has a particular advantage in a data transmission or telemetry environment (such as the power industry) since the digital radio often eliminates the need of D-A and A-D converters for the transmission of data.

The Bell System has been advancing the concept of mixing digital and analog modulation on the same RF carrier. The system called "data under voice" (DUV) can be expected in commercially available equipment in time as private industries' demand for mixed data and voice transmission increases. As old equipment is replaced, the system designer is often provided with the opportunity to install equipment with significantly advanced performance into the old system. For example, newer microwave systems often have greater capacity. Advances in filter designs also make it possible to reduce adjacent channel guard bands which, in effect, increases system capacity. In general, a tendency towards early obsolescence of equipment can be expected where maintenance costs of old equipment have become burdensome. This is particularly true of equipment installed in the early 1960's.

Radio frequency (RF) discrimination patterns of microwave antennas have always been a major concern to system designers. In recent years quantum step improvements in antenna patterns have been made and more can be expected as manufacturers continue to study factors such as hornfeed illumination patterns, shielding and RF absorption material applications. The improved antenna patterns will help greatly to eliminate potential RF interference providing for more extensive use of the microwave spectrum in a given area. The FCC has recently set a time schedule for implementing new antenna standards in crowded areas. Old antennas not meeting the new criteria will need replacement. As the private microwave bands become more crowded, the FCC's definition of "crowded areas" can be expected to include more and more areas. For the older systems, the new regulations usually mean replacing "fly swatter" type reflector antennas with parabolic tower mounted antennas. This in turn may mean entire system upgrade in order to meet performance requirements.

3. Impact of Microcircuitry

Established manufacturing techniques such as large scale integration (LSI) have invaded all areas of electronics. Microwave equipment is no exception. The most significant potential impact on system design is in the monitoring, alarm, and control area. Heretofore, microwave alarm systems normally remoted only major equipment failures such as a "receiver A" alarm. With the advent of LSI and allied technologies inexpensive microcircuitry can be built into every microwave equipment module. This allows for the monitoring of individual components throughout the equipment. The common term for the built in circuitry is "built in test equipment" or BITE.

In addition to binary states being sensed with BITE, analog functions can be monitored using simple analog to digital converters. Then a Central Control Station uses other microcircuitry to buffer the data for interactive alarm polling.

A central control technician using a monitor system with BITE can interrogate a "Receiver A" alarm and diagnose a problem remotely. The technician uses a microprocessor at his console position to address the Receiver A at the distant station. Such a system has available numerous command and control functions which can also rearrange remote equipment or circuits. This often prevents lengthy outages.

4. Applications

Microwave equipment has become more compact, lighter, more reliable and lower in power consumption. It is, also, becoming more portable. As a result, it lends itself to flexible uses where communications is required for short duration or between relatively inaccessible locations. Microwave is also proving to be cost competitive when compared to cable alternatives, especially in major cities. Microwave is now commonly used for transmitting sports events back to TV studios or relaying live news media events. It is also being used increasingly for interbuilding wideband data transmission in cities where the cable alternatives are both expensive and less reliable.

There is a present trend to the higher frequencies. As the higher bands are used, available bandwidth per carrier will increase. This means wideband data packages, like digitized television, may be transmitted in serial rather than parallel format. This will reduce digital multiplex costs as well as system complexity.

II. SYSTEMS ENGINEERING

This section of the Bulletin is an overview of microwave system engineering from a basic description of microwave application in the power industry, through the basic steps taken to design the system. The arrangement of the subject matter is designed to lead the reader sequentially through the concepts of microwave engineering.

A. Power Systems Communications

1. Introduction

The basic elements in a microwave system are shown in Figure II-1. This figure illustrates the functional system elements that appear in any basic transmission system.

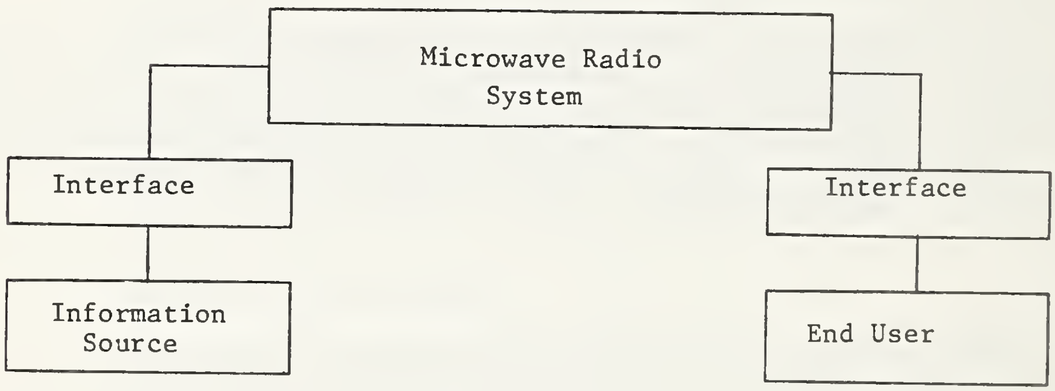


Figure II-1 Basic Microwave System

Figure II-2 illustrates the typical equipment configuration found in microwave systems. Several applications are shown to differentiate between repeaters and terminals including the different types of repeaters in Figure II-3. Figure II-4 shows the addition of order wire and alarm equipment.

2. Microwave Line-of-Sight Systems

The purpose of this section is to present the basic functional aspects of a frequency modulated analog microwave system in simplified terms. The case considered is a single RF bearer with a 600 voice channel system with two radio paths (2 terminals and one repeater). Figures II-5 and -6 show the basic system layout with typical electrical and mechanical aspects shown.

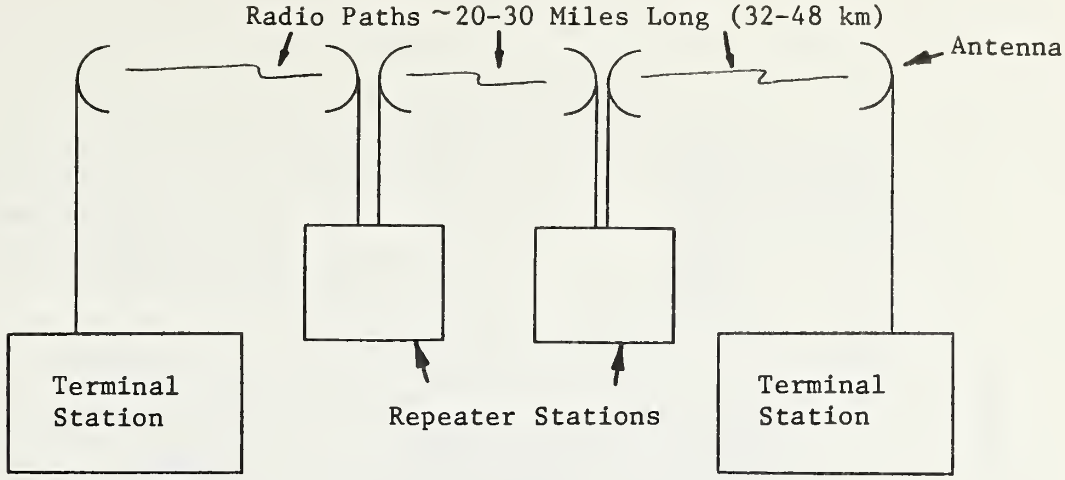


Figure II-2a Microwave System Overview

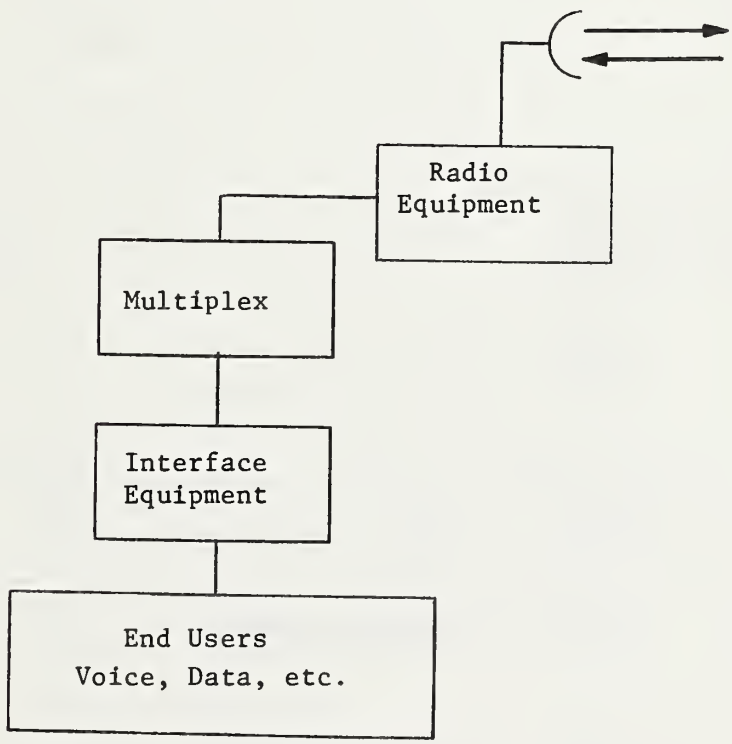


Figure II-2b Microwave Terminal Overview

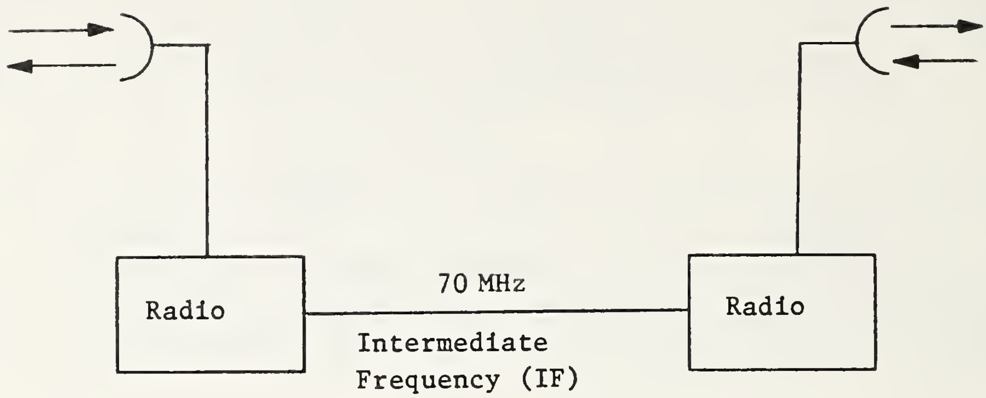


Figure II-3a IF Repeater Overview

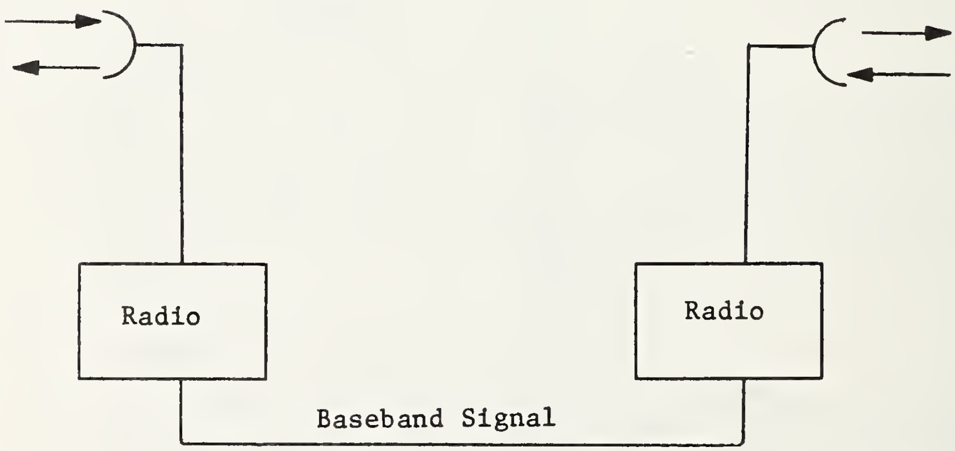


Figure II-3b Baseband Repeater Overview

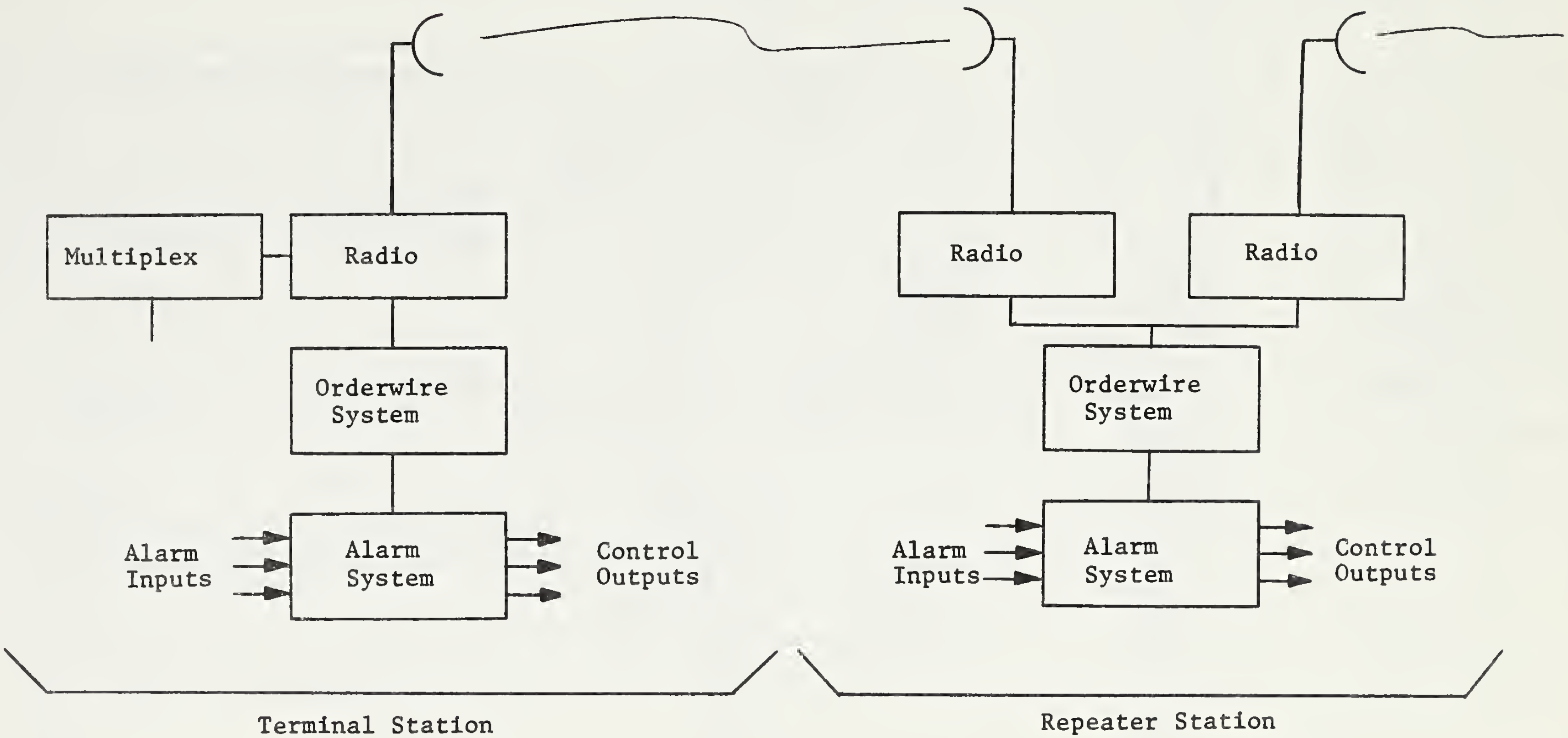


Figure II-4 Orderwire and Alarm System in a Microwave System

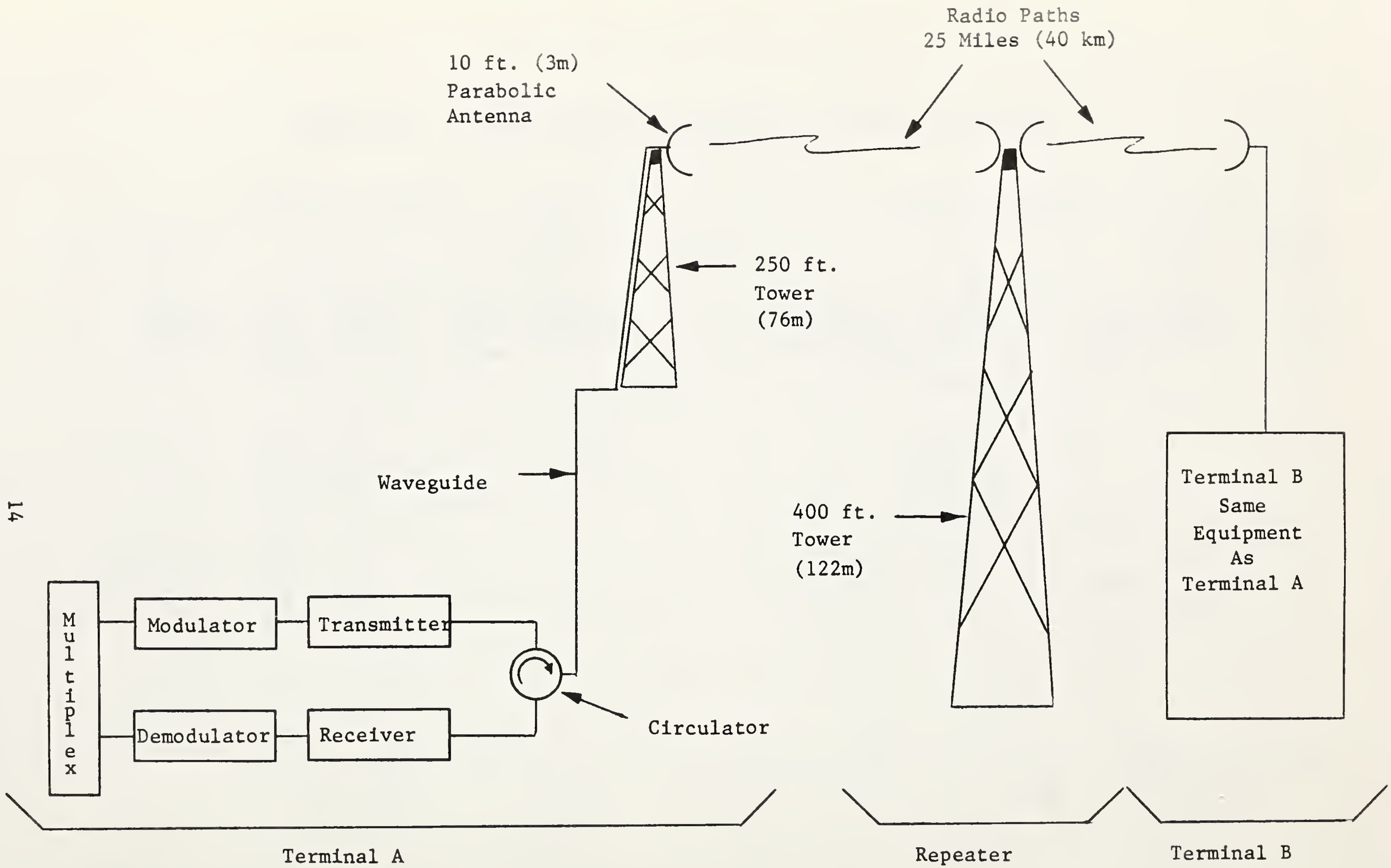


Figure II-5 Typical 2 Hop Microwave System Configuration

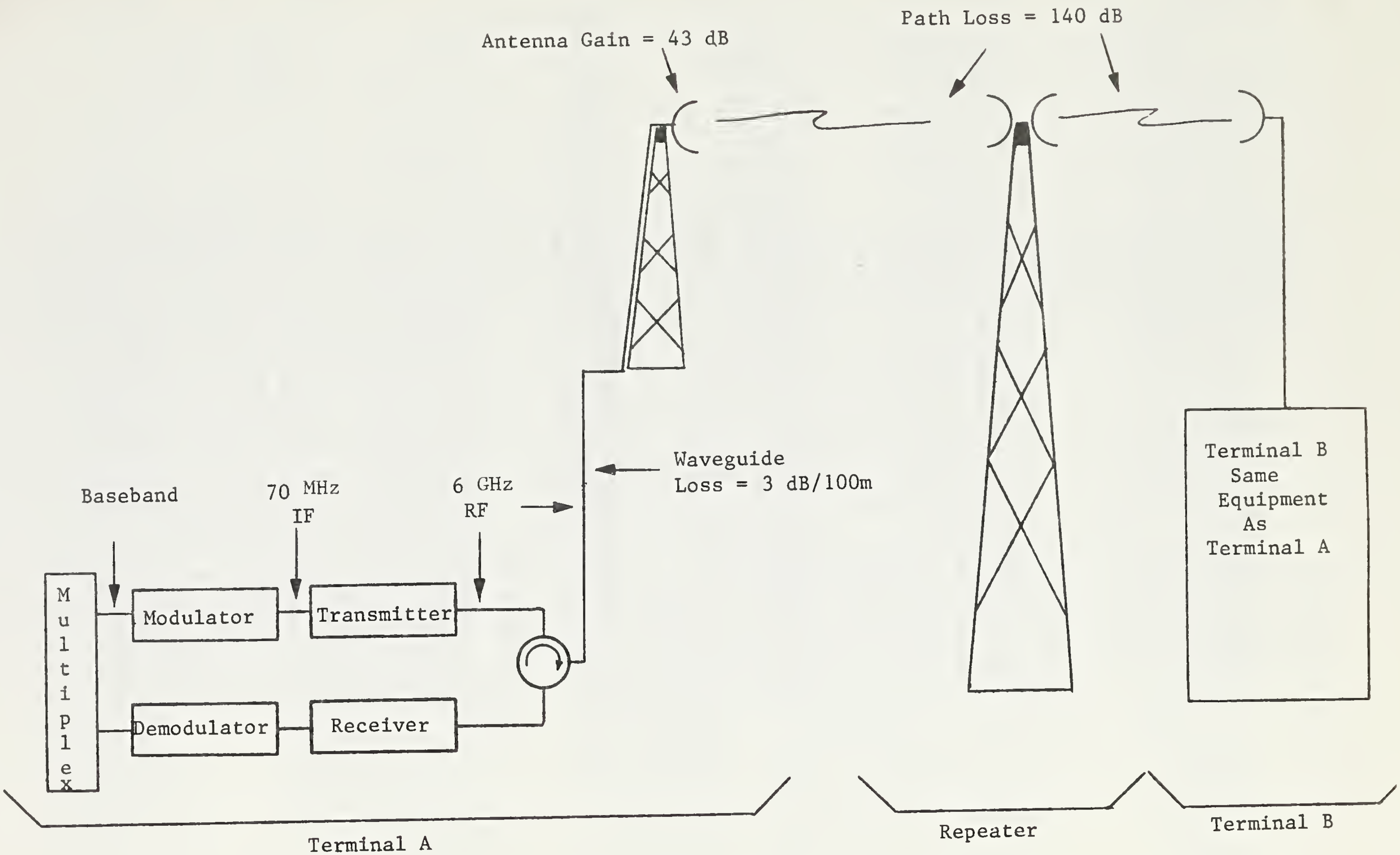


Figure II-6 Typical 2 Hop Microwave System, Electrical Characteristics

a. Multiplex

The transmit portion of the multiplex (mux) combines the voice channels by "frequency stacking" the channels. In a 600 channel system the mux output is an amplitude modulated signal occupying a spectrum from around 60 kHz to 2.5 MHz, each channel occupying 4 kHz of that spectrum. The receive end of the mux "demodulates" the mux signal into the original 600 voice channels.

b. Modulator

The mux output is fed to a voltage controlled oscillator, or equivalent circuit centered at 70 MHz. The variations in the mux signal level correspondingly vary the frequency of the oscillator producing a frequency modulated signal. This becomes the output of the modulator.

c. Transmitter

The transmitter's basic function is to convert the 70 MHz modulator output up to the desired RF frequency using multipliers or a mixer and associated oscillator. The signal level is also amplified to achieve the desired RF output level.

d. Receiver

The receiver converts the incoming RF signal down to 70 MHz. The 70 MHz signal is known as the intermediate frequency (IF). It is fed to the demodulator.

e. Demodulator

The demodulator extracts the modulating signal from the IF signal, thus reconstituting the mux signal that originally modulated the modulator at the transmit end. The demodulator's output is fed to the receive mux.

f. Circulator

Many microwave systems use only one electrical line to the antenna for both transmit and receive. To separate the transmit and receive signals, a circulator is placed in the transmission line of the equipment. The circulator is a magnetic device that "steers" the RF signals to the desired circulator port. Energy entering the transmit port goes to the antenna, energy from the antenna is steered to the receiver.

g. Waveguide

Waveguide is a hollow tube (rectangular, elliptical or circular) that electrically connects the equipment to the antenna. It is used in place of cable since waveguide usually does not attenuate RF signals as much as cable.

h. Antenna

Microwave antennas use parabolic reflectors in order to focus the RF energy in a single direction. The RF energy is fed to the reflector ("dish") by a hornfeed which is placed at the mathematical focal point of the parabola. The larger the reflector, the larger the gain of the antenna. The term "effective radiated power" (ERP) is associated with antennas. ERP is equal to the transmit power at the hornfeed times the antenna gain. The ERP is the amount of power that one would need to radiate from an omnidirectional antenna (antenna with no directional gain) to achieve the same energy level that is in the directional beam of the parabolic antenna.

Another characteristic of microwave antennas is their ability to isolate the hornfeed from undesired signals that arrive at the antenna at angles different from the main beam. Common terms used to describe this function are "discrimination pattern" and "front-to-back-ratio". Generally, the larger the antenna, the better its ability to reject the unwanted signals.

i. Tower

In order to achieve line-of-sight between radio stations, the antenna usually must be raised above the ground to clear local obstructions such as trees or distant path obstructions such as hills, buildings or mountains. Towers normally range from 10 to 120 meters in height (30-400 feet). They are normally either self supporting or guyed metal structures. Antennas are also mounted on building tops using short sub towers or mounts.

j. Radio Path

The microwave energy travels through the atmosphere at the speed of light in air. The path of the radio beam varies slightly, however, due to perturbations in the atmosphere, rain attenuation and other atmospheric phenomena. Therefore, the receive signal is not always constant. In fact, its level may drop by as much as 50 dB. The subject of propagation is treated more thoroughly in subsequent sections of this Bulletin.

k. Repeater

The repeater receives the RF signal from one direction, converts it with a mixer to 70 MHz and feeds it to the transmitter of the next radio path. This transmitter amplifies the signal, converting it back to another RF frequency and sends the signal to the antenna as shown in Figure II-3.

B. System Considerations

System Considerations are the managerial/planning considerations that initially receive attention in the conceptual stages of system development. They are the considerations that should be taken into account in planning the implementation of a microwave system.

1. Documentation and Analysis of Requirements

The initial step is to establish the communications needs. In the case of microwave this normally focuses on the quantity of circuits or trunks required as well as the number of terminal locations. The types of services such as PBX tie lines are addressed in REA Bulletin 66-7. For a microwave system one needs to consider the channel capacity of the radio initially and as a function of the future.

2. System Concept Options

Communications requirements are not always concerned with the transmission media used. In the power industry channel requirements may be met using a wide variety of techniques. The designer must consider:

a. The types of media available

b. Their comparative advantages of flexibility, performance, reliability, ease of expansion, potential obsolescence, maintainability

c. Alternate use or upgrade of existing facilities

d. Urgency of the requirements versus system availability

e. Regulatory matters concerning the use of shared systems, tariff schedules and user eligibility under FCC rules and regulations.

3. Cost Factors

As technology advances and equipment types diversify, the cost elements in a communications system become more flexible. Numerous technical/cost judgments need to be made in developing a system plan. Some of the major cost considerations are:

a. Purchase cost

b. Cost of maintenance

c. Future expansion cost

d. Equipment life

e. Purchase versus lease

f. Financing; staging of availability of funds, vendor financing, capital versus expense funds, economies of scale.

It is important to note that a communications system is rarely static and its associated costs are never clearly reflected in the purchase cost. No simple set procedure for cost analysis is universally valid and each system must be carefully considered in its own environment. REA Bulletin 66-4 addresses the subject more fully.

4. Grade of Service

The quality of service has a significant impact on the design of the system. Typical service characteristics that need addressing include:

a. Noise performance

b. Error rate

c. Reliability

d. Availability

When specifying quality of service, care should be taken to differentiate between technical limits and design objectives. In certain application, such as critical telemetry circuits, the error rate will have a limit requirement; whereas, many noncritical data transmission requirements have only error rate objectives. The same applies to noise levels on channels.

5. Company Resources

In addition to financial resources, the firm investigating the implementation of a microwave system should consider:

a. Personnel for various technical and managerial functions

b. "In house" capability of installing and/or maintaining the system

c. Level of outside consulting desirable

d. Capital plant such as building space, vehicles, test equipment available

e. Level of support activity available such as purchasing, accounting and personnel functions.

Generally, when a company becomes involved in a microwave system for the first time, there are many considerations to be made concerning allocation of resources. There are often a wide range of alternatives ranging from the use of outside consultants and contractors to the implementation of the entire project internally.

C. Design Considerations

The system designer begins the initial system design by considering a wide variety of technical factors that affect the system design. The basic design parameters that require consideration in the initial design of a microwave system are introduced in this section. Subsequent sections discuss the factors in considerable detail.

1. Channel Requirements

The plan includes a basic multiplex plan showing channel routing, drop points, terminals, through-patching and other indications of channel routing and use.

2. Performance Requirements

Channel performance characteristics, and reliability/availability/maintainability factors are reflected in the selection of equipment, redundancy requirements, alarm and reporting system, power system back up, type of switching and radio diversity or protection and in the design of the radio paths.

3. Meteorological and Climatic Considerations

Numerous meteorological and climatological factors can significantly affect system planning:

a. Winter weather may affect construction schedules

b. Rain attenuation may affect radio propagation

c. Wind loading and ice loading affect antenna and tower design

d. Refractivity variations affect radio propagation and thus system design

e. Snow may block radio site access.

4. Environmental Considerations

Examples of environmental considerations are:

a. Soil bearing strength

b. Soil resistivity

c. Local flood history

d. Access road construction feasibility.

5. Facilities Available

The designer will normally investigate the station locations and assess factors such as:

a. Available building space on site

b. Proximity, availability and reliability of local power

c. Proximity of telephone lines

d. Site accessibility

e. Local zoning restrictions and other local regulations.

The above considerations influence both the initial and the final detailed engineering design of a microwave system. The designer has a number of design choices associated with these factors and must perform a number of trade-off analyses during the system design phases. These are discussed throughout this Bulletin.

D. Conceptual Design Plan

1. Introduction

Communications systems normally employ a wide variety of subsystems in complex configurations. Conceptual design plans reduce this complexity to readily understood terms. The purpose of this section is to describe a set of documents that addresses the system and design considerations and presents an initial conceptual design plan.

2. Establishment of Needs

The basic factors presented in this section are simplified for clarity. For more detailed analysis of communications requirements, see REA Bulletins 66-4 and 66-7. The basic types of information required for establishing communications needs are:

- Types of user
- Terminal devices used
- Bandwidths
- Data speeds
- Locations of communications needs.

Figure II-7 presents a typical set of information.

The requirements listed in Figure II-7 are only representative of information required, indicating the types of basic data needed to develop a system concept. The system can also be represented pictorially as in Figure II-8.

In light of the established communication needs, the designer investigates the various possible transmission means. For the purpose of this Bulletin it is assumed that microwave has been selected.

3. Development of Engineering Requirements

A number of technical engineering requirements receive in-depth consideration during the engineering of a microwave system. This section deals with the more general requirements. As with other engineering requirements, they have cost impacts. The designer should always avoid either under or over designing a system. A clear understanding of user requirements is vital to specifying the various technical parameters.

Item	Description	Qty	Location 1	Location 2	Notes
1	200 Line PABX	1	City A		
2	200 Line PABX	1	City B		
3	Voice Grade Trunks	40	City A	City B	
4	" "	20	City B	City C	
5	" "	25	City C	City D	
6	Telemetry Circuits	1	Power Sta. 1	City A	UHF Links to Local M/W
7		1	Power Sta. 2	City A	Station
8		1	Power Sta. 3	City A	Station
9		1	Power Sta. 4	City A	Station
10		1	Power Sta. 5	City A	Station
11	Data Link to Central Computer	1	City B	City A	Full Duplex 19.2 kBs
12	Future Voice Channels	20	City A	City B	
13	" "	20	City B	City C	
14	" "	10	City C	City D	

Figure II-7 Basic Communications Needs

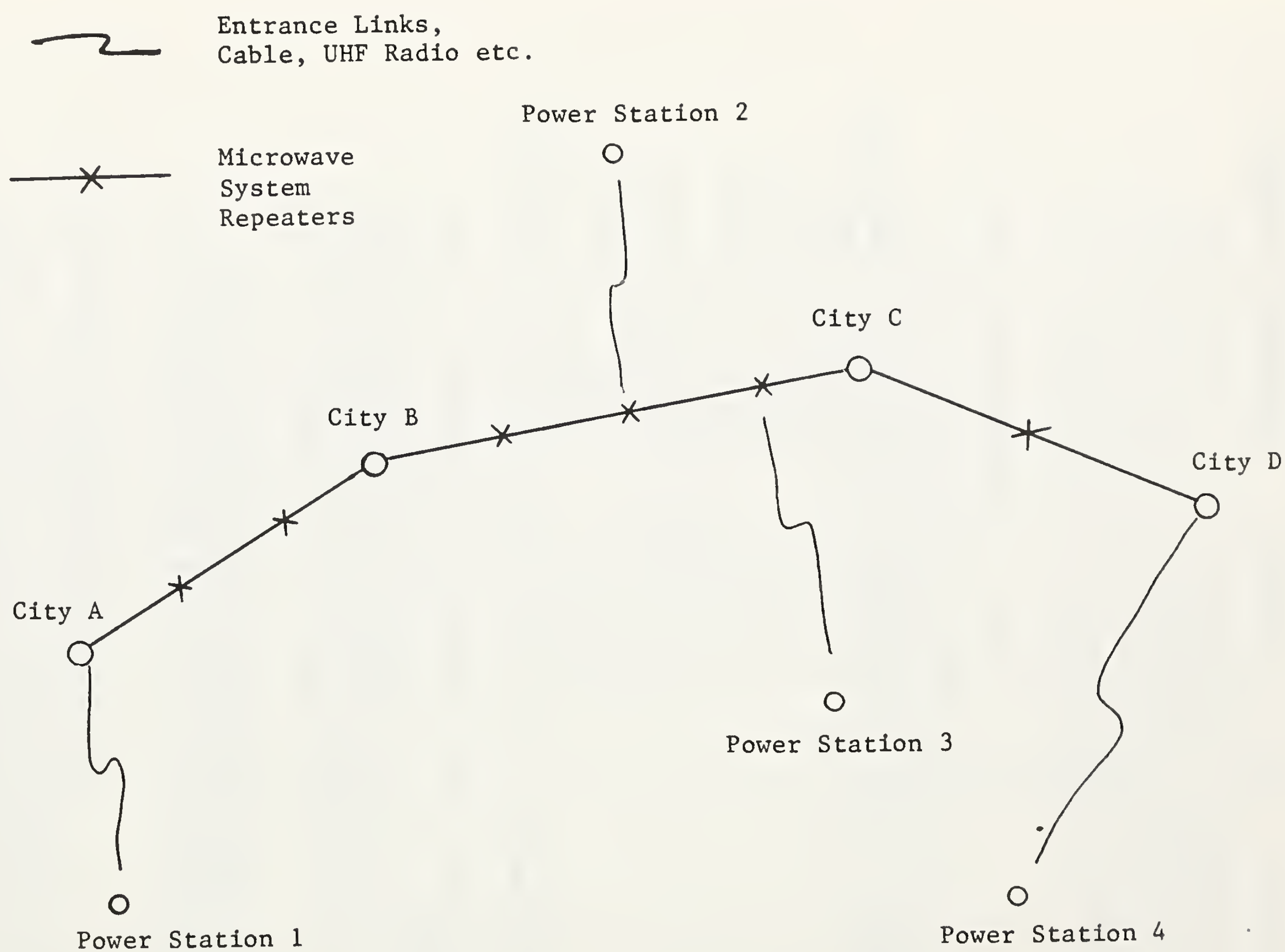


Figure II-8 Pictorial Sketch of Microwave System Application

a. Voice Transmission Objectives

Usable quality of voice transmission can range from high fidelity to extensively distorted transmission depending on the user. For example, concert music requires a fairly high quality circuit for transmission. On the other hand, a radio dispatcher can satisfactorily communicate with mobile units over a very poor grade circuit. Figure II-9 presents some representative values of technical parameters of voice circuits. Exact standards are discussed in later Sections. Figure II-9 is intended only to present the concept of voice transmission objectives and the types of factors involved. It is not an exacting list.

	Parameter Value	
Technical Parameter	Poor Quality	High Quality
Frequency Range	800-1700 Hz	300 -3400 Hz
Harmonic Distortion	10%	1%
Delay Distortion Across the Band	10 ms	500 us
Level Variations (Loudness)	± 15 dB	± 3 dB

Figure II-9 Voice Transmission Parameters

The designer gives consideration to the quality of voice transmission required for the system. Some guiding thoughts are:

- Poorer grade service is often satisfactory in a work environment where the information to be transferred is partially anticipated. For example, a stock controller can send orders to a warehouse satisfactorily over a poor grade circuit since the warehouse personnel already understand the context of the messages being sent.

- Higher grade service is required where the information is general in nature, that is, not anticipated. The same applies to circuits to be used by the general population who may not have the ability to decipher voice transmission over a poor grade circuit.

- Channels that will be or may be placed in tandem with other long distance transmission facilities should be higher quality since transmission degradations tend to be additive.

- Likewise, circuits that are designed for limited distance may have relaxed objectives and still perform satisfactorily.

b. Data Transmission Objectives

The basic parameter of interest in data transmission is error rate which is the ratio of errors to correct transmissions. Error rate is an indirect measure of numerous contributing transmission degradations. To the end user, however, error rate is normally the parameter of most concern.

Since error rate is dependent on the design of the data equipment used, it is not an independent function of the transmission medium. For example, a given circuit's error rate performance depends on the data modem's type of modulation. In specifying data transmission objectives, the technical parameters that affect error rate are normally addressed rather than error rate directly. Figure II-10 tabulates some of the common values used for data transmission objectives.

Parameter	Typical Values	Notes
Bandwidth	500 Hz to 3400 Hz	Dependent on data speeds. These values can normally be accommodated on voice circuits dependent on data speeds.
Frequency Stability	± 1 Hz, ± 100 Hz	Narrower channels are more sensitive.
Phase Jitter	± 3%, ± 15%	Sensitivity is governed by modulation type used.
Level Stability	± 3 dB, ± 7 dB	Sensitivity is dependent on the modems' ability to regulate incoming signal level.
Noise	16 to 30 dB below signal	See next section on Noise Transmission Objective.

Figure II-10 Voice Channel Characteristics

The term error rate has a number of interpretations and qualifications. The following list of terminology extracted from the Glossary may be helpful to understand the concept of error rate.

- Bit error rate - ratio of incorrectly received binary data bits to binary data bits sent.

- Character error rate - ratio of incorrect characters to characters sent. Each character is normally composed of several bits.

- Through put - percentage of blocks of data successfully transmitted. Typical block sizes are 800 bits long or 80 characters.

Error rates are normally specified for an end to end circuit rather than for the transmission medium alone. The circuit, therefore, includes the data modems and data terminal equipment in order to be able to specify the error rate. Typical bit error rates are shown in Figure II-11. The error rate can be improved by 2 to 3 orders of magnitude or more by using error correction techniques. The values in Figure II-11 are only representative. It is assumed that commonly available data equipment is in use.

Transmission Media	Typical Error Bit Rates
Microwave System	10^{-6} to 10^{-9}
Dial up Telephone Lines	10^{-4} to 10^{-7}
HF Radio	10^{-2} to 10^{-5}
Tropospheric Scatter Radio	10^{-3} to 10^{-5}
VHF and UHF Mobile Radio	10^{-2} to 10^{-4}
Buried Cable	10^{-5} to 10^{-9}
Satellite	10^{-6} to 10^{-9}

Figure II-11 Data Error Rates

In establishing the error rates of a given circuit, the designer should assess the use of the circuit. For example, critical control circuits may require very low error rates. The designer must make a number of technical judgments in designing to achieve the desired error rate. Factors that are considered include:

- Parallel versus serial transmission
- Static equalizers
- Adaptive equalizers
- Echoplexing
- Forward error detection
- Forward error correction
- Modulation schemes
- Time diversity transmissions
- Multiple circuit routings

In summary, the end user normally specifies the error rate. The designer considers the many factors discussed above and assesses the transmission objectives for the transmission media. The impact of these parameters on error rate is discussed in subsequent Sections.

c. Noise Performance Objectives

Several types of noise should be considered when designing communications systems:

- White noise-incoherent noise with a normal power time distribution
- Impulse noise-spikes, transients, noise peaks
- Weighted noise-incoherent noise with a power density that varies with frequency.

White noise affects both voice and data. Generally, the longer the circuit the higher the noise since noise tends to be additive. White noise is measured in units of power for a given bandwidth. Figure II-12 presents an overview of the impact of noise on voice and data.

Impulse noise is measured in "occurences above a given threshold for a given period"; for example, 15 counts in 15 minutes above a threshold of -30 dBm0. To refine the measurement one can also specify the duration of pulses above the threshold. For voice circuits this is typically 5-10 milliseconds.

The concept of weighted noise has been introduced into telephony to account for the fact that the impact of noise is dependent on its frequency. Noise in the top and bottom ends of a voice channel does not affect voice articulation as readily as noise in the center of the band. Also, telephony instruments are frequency selective further suppressing the band edge frequencies. Weighted noise measurements are measurements of noise that has been filtered by a weighting filter. The weighting filter attenuates the high and low ends of the voice spectrum. Different weighting filters are used for different instruments and applications. A common filter is the "C-Message" filter which has a certain frequency response peaking at 1000 Hz.

Type of Noise	Noise Level (S/N = Signal to noise rates)	Comment
White Noise	50 dB S/N	Typical voice circuit
	75 dB S/N	Very quiet circuit
	12 dB S/N	Barely usable circuit
	16 dB S/N	Usable data circuit depending on application
Weighted	60 dBrnCo	Minimum commercial grade
	35 dBrnCo	Typical voice circuit
Impulse	10 counts/15 min at a threshold of -15 dBm0	Marginal data circuit

Figure II-12 Typical Noise Levels in Voice Channels

When specifying noise objectives, the designer should consider what the worst acceptable case shall be. For example, the worst acceptable noise level should never exceed an hourly median of minus 40 dBm0. The designer then considers the worst (noisiest) possible system or circuit configuration and assesses the noise performance under those conditions. The worst configuration may include connection to an external network. To aid in the noise assessment, reference circuits are used as a tool to distribute noise allocations to equipments and distances involved. See Sections II.G.4, F.8 and H.4 through 9 for further discussion on noise performance.

d. Reliability/Availability

Reliability in a microwave system is composed of equipment reliability and propagation reliability. Propagation, discussed in later sections, typically contributes half of a system's "down time". The other half of "down time" is equipment outages.

The reliability factor associated with a given equipment is "Mean Time Between Failure", or MTBF. Manufacturers commonly publish MTBF figures for their microwave equipment. The figures may be based on calculations, factory tests and/or field experience.

The next reliability factor of concern is the time it takes to effect repairs. This is a function of how long it takes to discover that a fault has occurred, transit time of personnel to the place of the fault,and the length of time it takes to correct the fault or restore the system. The factor is "Mean Time To Repair" or MTTR. A common simplified practice is to calculate the outage ratio as

$$\text{outage ratio } (U) = \frac{\text{MTTR}}{\text{MTBF}}$$

If the system has 100% redundancy (back up equipment) the

$$\text{MTBF (Redundant)} = \frac{\text{MTBF}^2}{\text{MTTR}}$$

for the redundant system U is then defined as

$$U \text{ (Redundant)} = \frac{\text{MTTR}}{\text{MTBF (Redundant)}}$$

$$= \frac{\text{MTTR}}{\frac{(\text{MTBF})^2}{\text{MTTR}}}$$

$$= \left(\frac{\text{MTTR}}{\text{MTBF}}\right)^2$$

For example, if a nonredundant microwave system has an MTBF of 6,000 hours and it takes a mean 4 hours to get to the site of a failure and effect repair:

$$U = \frac{4}{6,000} = .000667$$

If the system is redundant

$$U = \left(\frac{4}{6,000}\right)^2 = .00000044$$

Availability is the time the system is available for use, commonly expressed in percent of time.

$$\text{Availability} = A = (1-U)\ 100\%$$

for the redundant case above

$$A = (1-.00000044)\ 100\%$$

$$99.999956\%$$

It represents a typical value for one hop of microwave equipment and equates to 14 seconds of outage per year.

The figure of 14 seconds is misleading, however, since any outage is expected to be 4 hours long (MTTR) and outages are only expected every few hundred years. A more meaningful figure is the possibility of a failure occurring in a given year.

The probability $P = e^{-T/MTBF}$

where $T = 8760$ hrs (1 year). In the redundant case above MTBF (Redundant)

$$= \frac{(6000)^2}{4} = 9,000,000$$

Therefore,

$$P = e^{-8760/\ 9,000,000}$$

$$= .99903$$

or there is a 99.903% probability that no failure will occur in a given year.

In the case of a nonredundant system the probability of failure is higher where

$$\frac{4}{6000} = .000667$$

Outage time per year is therefore an expected (.000667) (8760) = 5.84 hours, or 21024 seconds.

When designing a system for a given reliability, one should plan the propagation outage to be equal to the equipment outage. If a system has low equipment reliability, the system should not be over-engineered for high propagation reliability. For example, if the outage time due to equipment is expected to be 21000 seconds per year, the propagation reliability need not be 21 seconds per year. The sum of the two outages will yield total system outage of 21021 seconds which is a meaningless improvement over equipment outages alone.

Two commonly experienced phenomena not included in a simple MTBF figure are infantile failures and aging failures. They are both difficult to quantify, but do affect system performance. Infantile failures are known to occur in solid state deivces. On occasion a batch of transistors will become contaminated during manufacturing and may not become apparent until after several thousand hours of service. Another cause of infantile failure is components being overstressed in circuits where they are operating at the limits of their design capability or beyond.

Aging failures are failures that occur due to long term normal use.

For the purpose of initial design plan, the reliability of the most critical circuits should be determined. One should be careful not to confuse error rates with availability. If a system is not functioning (outage) the error rate is meaningless since

$$\text{error rate} = \frac{\text{errors}}{\text{correct transmissions}}$$

$$= \frac{0}{0}$$

which is not a valid mathematical expression. Error rates apply only during periods of transmission.

To calculate overall system reliability, assume that all MTBF's are large and MTTR's small. Then the total outage ratio

$$U_{total} = U_1 + U_2 + U_3 \ldots U_n$$

where U_1 through U_n represent the outage ratios of things in tandem such as microwave hops. The total system availability is (1- U_{total}) 100%. If the reliability of any equipment in tandem with a circuit is to be taken into account, its " U " is added to the U total.

The terms reliability and availability are often mistakenly interchanged. Reliability is expressed in MTBF. Availability is the fraction or percent of time an item or system is available for use.

4. Channelization and Routing

The channelization plan presents the basic circuit requirements of a system. The plan is a preliminary level of design and forms the basis for the multiplex plans and sizing of the radio. Figure II-13 is a simplified diagram of a channelization and routing plan.

City B could be engineered with "drop and insert" as well, which reduces the cost of multiplex hierarchy equipment. See Section II.E.2 for discussion of drop and insert principles.

The routing plan is a depiction of the bulk routing of channels or a summary of the requirements in Figure II-13. Assuming no "drop and insert" is used, the routing plan for the above is shown in Figure II-14.

If "drop and insert" is accounted for, the extra baseband occupation is due to over reach (see Section II.G.7). See Figure II-15.

A variety of system factors are immediately apparent by looking at Figure II-14.

- The eventual radio capacity is highest between cities B and C, 782 channels. A probable choice of radio size is a standard 960 channel capacity.

- No circuits are initially called for between cities D and E, but 14 in the future. These 14 channels may be served most cheaply by using a certain type of "direct line" multiplex. See Section II.G.5. The baseband spectrum must therefore have spectrum available for this use.

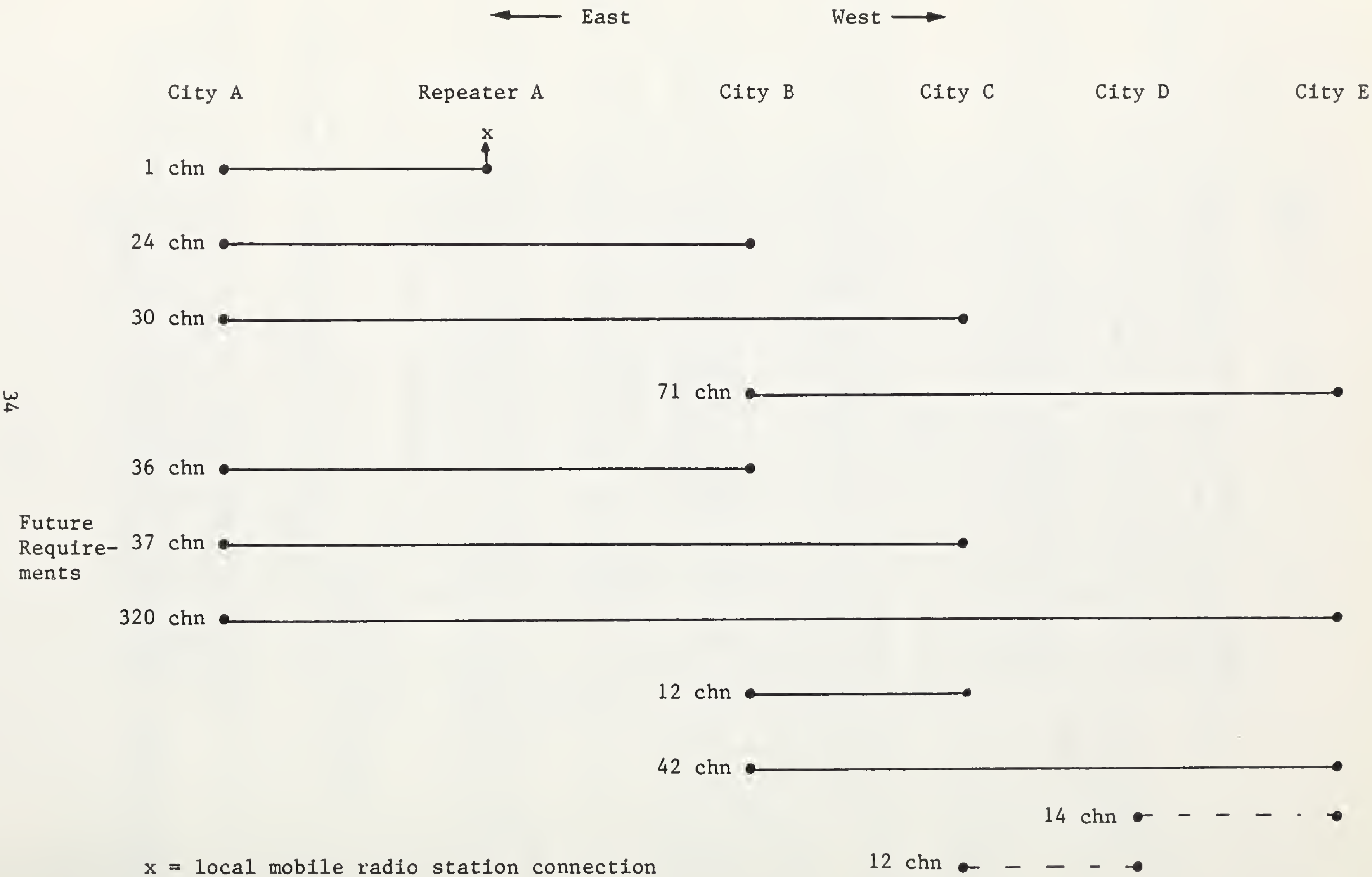


Figure II-13 Channelization Plan

City A City B City C City D City E

•— 718 Chn —•— 782 Chn —•— 445 Chn —•— 447 Chn —•

Figure II-14 Channel Density Without "Drop and Insert"

- The 12 future channels between cities C and D could be most cheaply served using a "drop and insert" type of radio. Baseband spectrum must also be made available for this application.

- "Drop and insert"can be used at all intermediate stations without exceeding the capacity of a 960 channel radio.

City A City B City C City D City E

•— 869 Chn —•— 869 Chn —•— 869 Chn —•— 869 Chn —•

Figure II-15 Channel Density Using "Drop and Insert"

It will be observed that the "drop and insert" method uses more of the available baseband spectrum. A measure of this is System Utilization Efficiency. This is a ratio of useful channel miles divided by occupied channel miles. If the distance between adjacent cities is 30 miles in all cases, the efficiency of the above system is

$$= \frac{71760 \text{ channel miles}}{104280 \text{ channel miles}}$$

$$= 68.8\%$$

In more complex systems with numerous baseband repeaters and alternate routings, the routing plan can be designed to increase system utilization efficiency.

5. <u>Frequency Planning and Allocation</u>

The power industry may use microwave frequencies in the following bands:

Frequency Band in MHz	Bandwidth per Carrier in MHz	Maximum Voice Channel Capacity
952 - 960	.100/.200	12
1850 - 1990	10	~ 600
2130 - 2150	.8/1.6	24/60
2180 - 2200	.8/1.6	24/60
6525 - 6875	10	~ 600
12200 - 12700	20	~ 1200

Figure II-16 Frequency Bands Used by Power Industry

The initial design of a microwave system normally includes the selection of a band with specific RF channel assignments. FCC Rules and Regulations Volume 5 Part 94 explains the details of eligibility and the various technical factors of concern.

The selection of a specific frequency band should reflect the following design considerations which are general in nature.

- The higher voice channel capacity systems use the higher RF frequency bands.
- Lower RF frequency equipment is cheaper.
- The lower frequency bands are more crowded.
- All bands are more crowded in the areas of denser population.
- Selection of usable frequencies in the crowded areas is often difficult.

Many system designers rely on commercial engineering firms or equipment vendors to select exact frequencies. This is particularly true in the more congested areas since an extensive data base and use of computers is required to do a comprehensive interference analysis of a proposed system. See Section II.H.3. Since there are so many factors that affect system design, the trial and error method is commonly used in frequency selection. The system designer selects candidate radio sites and requests a frequency interference analysis be performed. The analysis will provide the following types of outputs.

- Site feasible/unfeasible
- Selection of frequency pairs
- List of potential interference cases
- Suggestions for improving usability of the site such as better antennas or improved frequency stability.

If the report rejects the site outright as unfeasible, other sites or frequency bands may be tried. The end objective of the effort is to arrive at an RF frequency plan that will not cause unacceptable interference into others nor receive unacceptable interference from others. The plan may use different frequency bands for different paths. Throughout the planning stages the designer should make every effort to insure the feasibility of selected sites from all points of view. If a site later becomes unfeasible, it could drastically affect the overall system design due to a "rippling" or "domino" effect on the structure of the frequency plan. When one site becomes unusable, adjacent site(s) may also become unusable as a result.

6. Microwave "Backbone" Structure

The basic structure of a typical microwave radio system contains a bi-directional radio transmission medium. The system configuration has a number of possible alternatives, however, depending on reliability/cost/operational requirements. The following figures exemplify some of the basic alternatives of radio equipment configurations. For simplicity only one direction of transmission is shown.

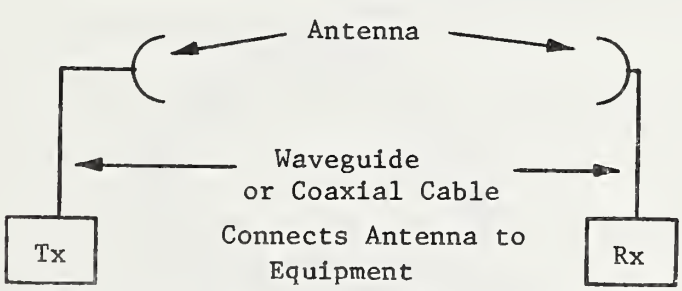


Figure II-17 Non Redundant Configuration

Figure II-18 Hot Standby Transmitter Configuration

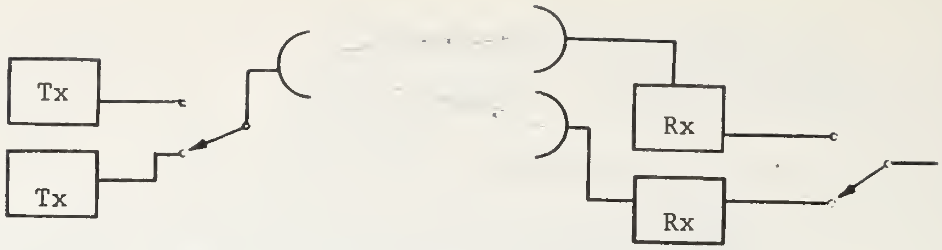


Figure II-19 Space Diversity Using Switched Receivers

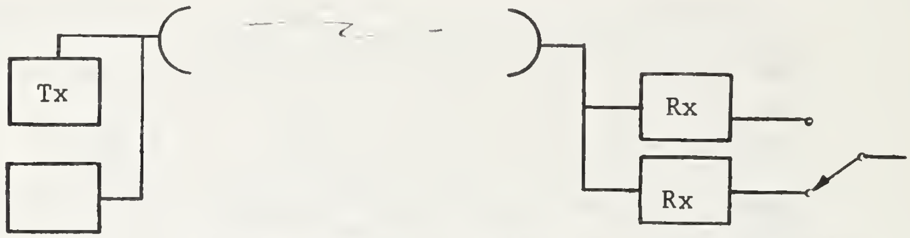


Figure II-20 Frequency Diversity Using Switched Receivers (Not Commonly Used)

In the initial system plan the designer determines the reliability requirements and uses this information in selecting the desired backbone structure. Most industrial applications of microwave use no diversity since modern equipment has sufficient reliability. In the power industry, however, some critical control circuits are routed via microwave. In such cases it is worth investigating the use of equipment redundancy and diversity.

When using the 12 GHz microwave band, rain attenuation can become a problem. A technique of avoiding outages is to construct parallel microwave routes separated by 8-10 km. Figure II-21 depicts the concept.

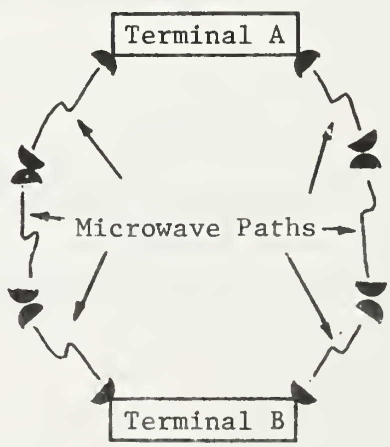


Figure II-21 Route Diversity to Minimize Rain Outages

7. System Expansion

Communications systems tend to expand continually. It is therefore practical to envisage future needs in the original design. Areas that normally receive close attention include:

- Future RF spectrum availability
- Multiplex hierarchy expandability
- Floor space requirements
- Prime power capacity
- Electrical and mechanical expansion feasibilities for equipments
- Future radio paths
- Tower extensions for future antenna height requirements.

The future requirements can be indicated in system plans to show the intended modes of expansion. Typical inputs are:

- Fully expanded RF waveguide branching
- Future floor space allocations
- Future block allocations on distribution frames
- Future power breaker allocations
- Fully expanded multiplex plan
- Intended direction of future building extensions
- Positions and sizes of future cable trays
- Future antenna sizes and positions on towers
- Future expansion of battery racks.

The significant concept to be realized is the high cost of future expansion that often results from poor initial planning. Therefore, every aspect of a system's design should be carefully examined in the face of future requirements.

E. Microwave System Equipment

1. Introduction

For the purpose of this Section the microwave system will include those equipments presented in Figures II-22 through II-28.

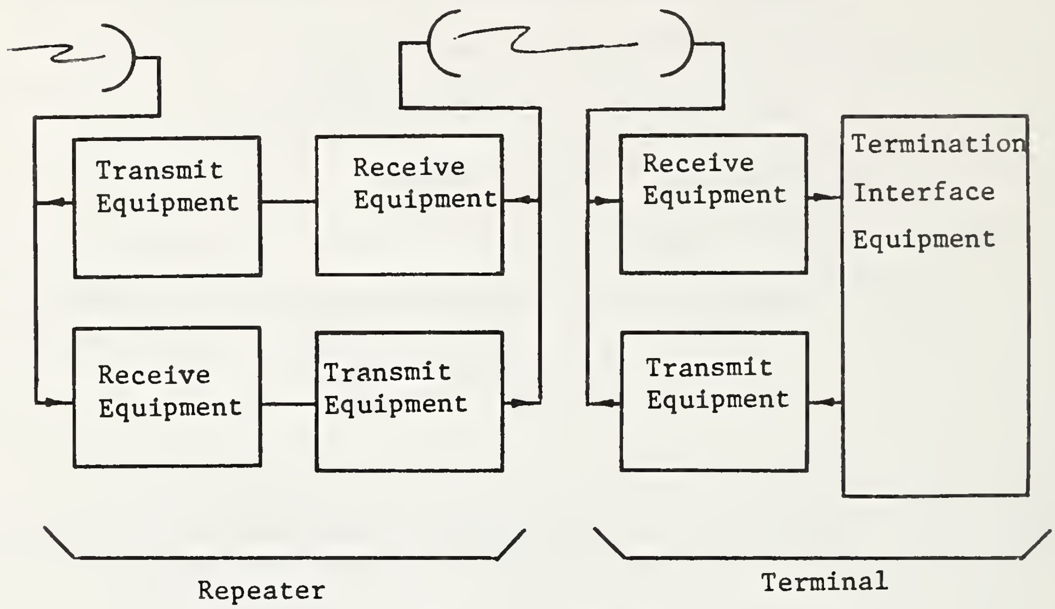


Figure II-22 Overview of Microwave Stations

Y: Orderwire system may interface with radios or the modulators and demodulators

Z: Alarm system VF signals may interface with radios, the modulators and demodulators, or the orderwire

X: Alarm sensor inputs and control lines

A: Alternate interface for TV

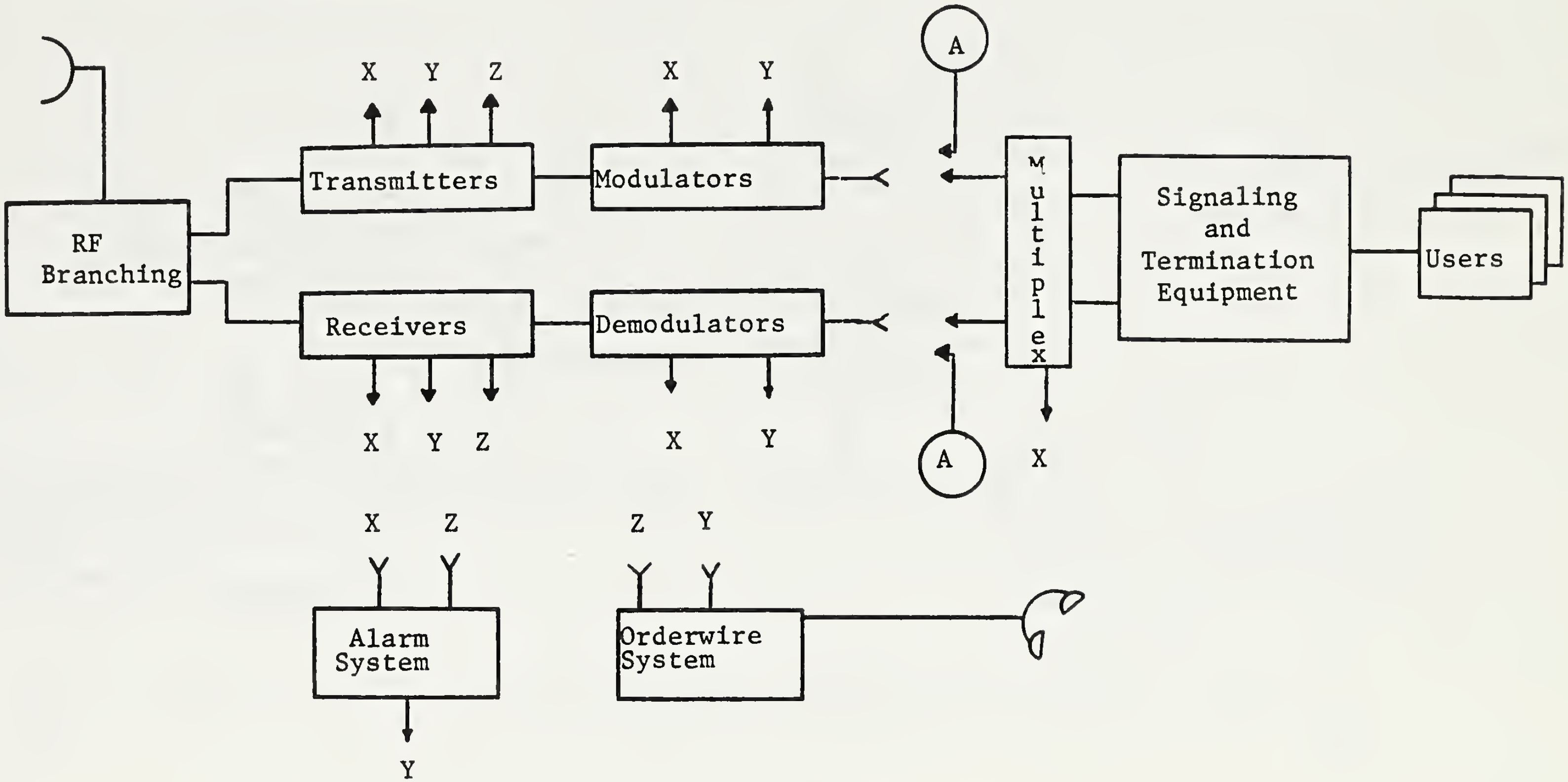


Figure II-23 Terminal Station

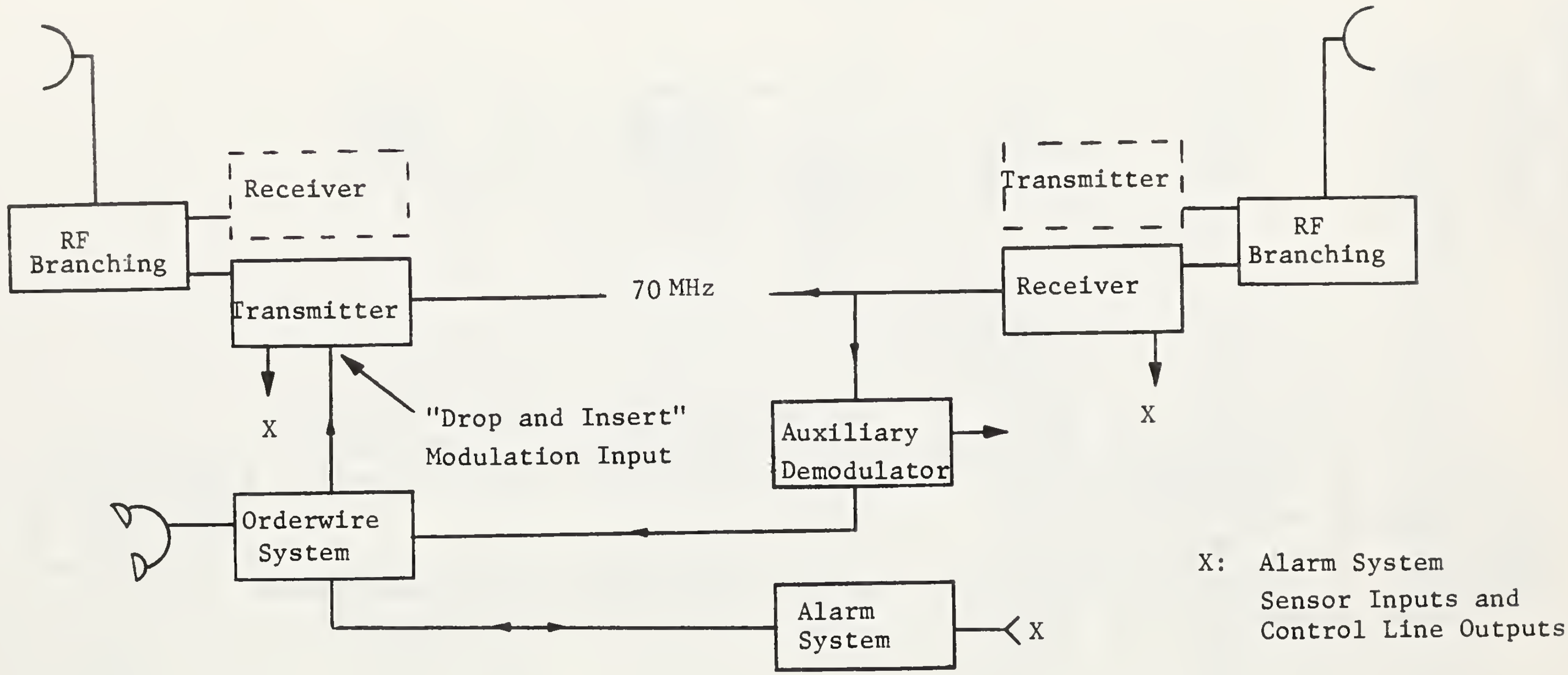


Figure II-24 Repeater Station (Only One Direction of Transmission Shown)

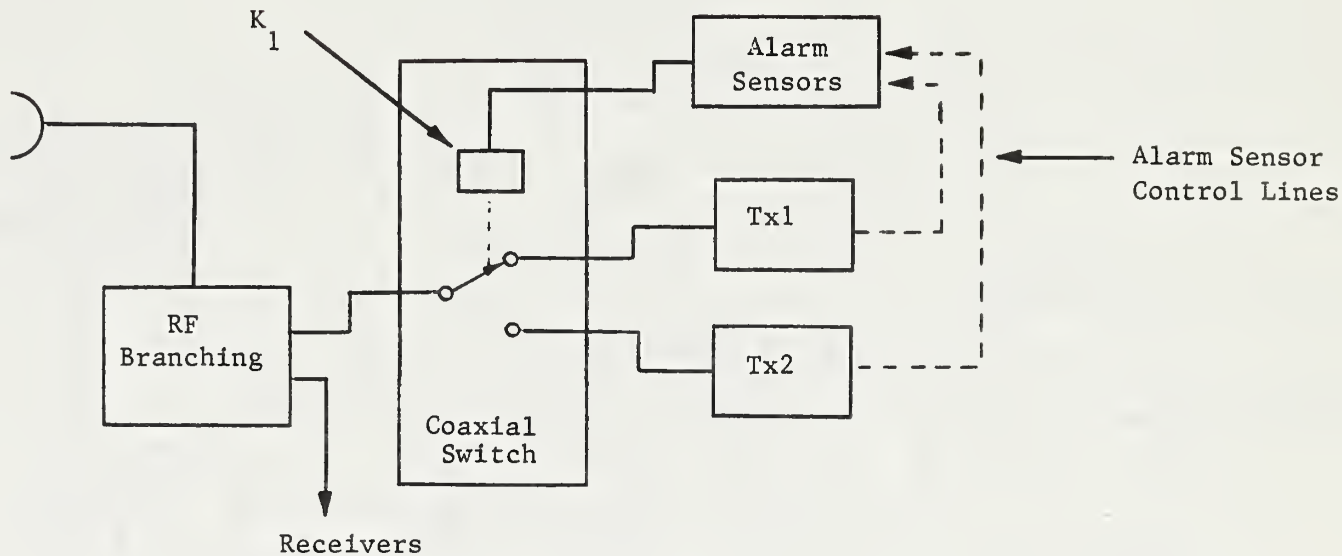


Figure II-25 Hot Standby Transmitters (Repeaters and Terminal Stations)

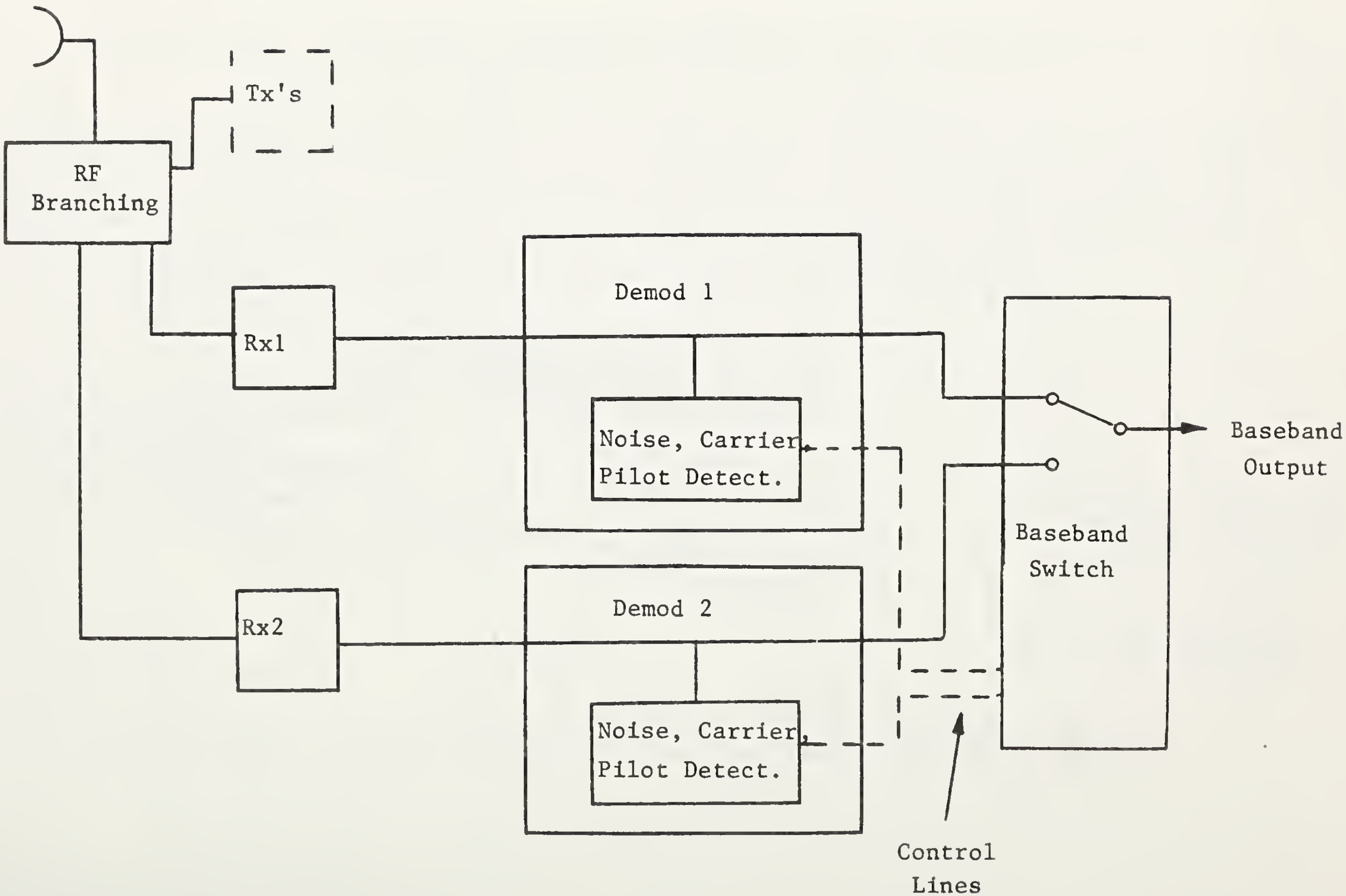


Figure II-26 Baseband Switching Receive System

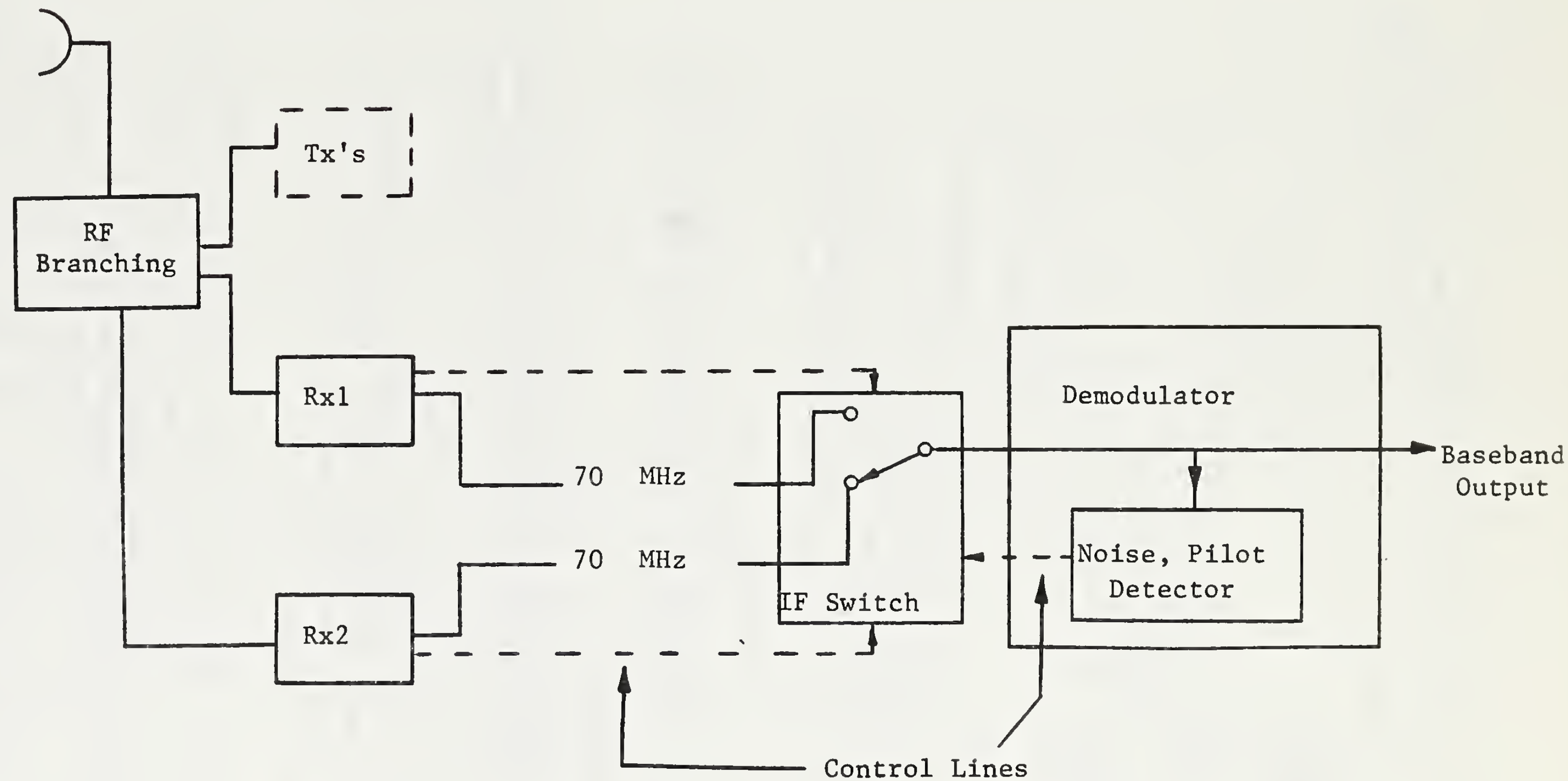


Figure II-27 Receive Switching Using Only One Demodulator

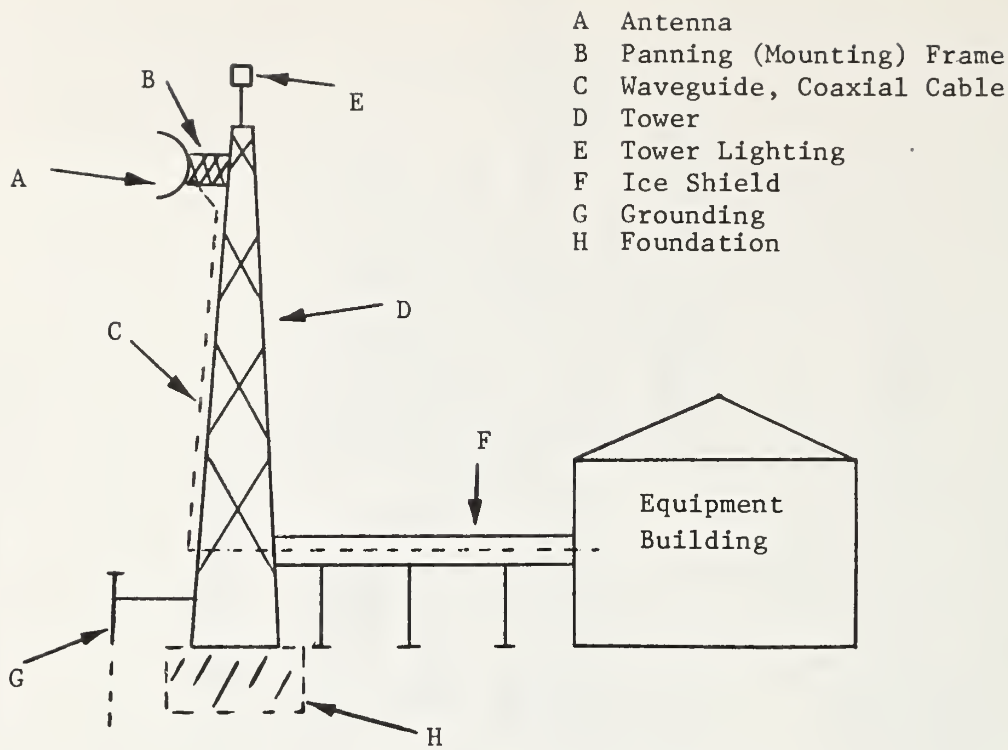


Figure II-28 Basic Elements of Antenna/Tower Construction

2. <u>RF Equipment</u>

RF or radio equipment is the equipment that either receives or emits energy at RF. It may include the message modulator and demodulator functions but not necessarily. With those functions the equipment is called "baseband" or "remodulating" radio; without, it is called "heterodyne" or "IF" radio. Generally speaking, the remodulating radios are less expensive but noisier and are used commonly on short haul systems. The IF radios tend to have greater baseband handling capacity and are used in repeaters of long haul systems.

The typical IF radio equipment is presented in Figures II-29 and II-30. Figure II-31 lists technical characteristics. The equipment is manufactured to several different mechanical standards. Most of the equipment available in the U.S. is rack mountable in standard 19 inch(480mm) wide racks. New European standards called Vertical Standard Equipment Practice (VSEP) has rack spaces 1.212m (48 inches) wide which allows for much denser equipment packaging. The racks for both standards tend to be 2.0 to 3.0 meters in height (6-9 feet). When radio equipment is designed to fit into stout equipment shelves, the rack height depends on the quantity of radios to be installed in the rack.

Radios designed in recent years tend to be all or almost all solid state. Design features that are commonly found include:

- Test meter with switch access to multiple internal test points

- Modular plug in circuitry

- Numerous fault detection/correction aids such as test points, test inputs, ease of in-service access to circuitry, ease of access to controls and adjustments, minimum of hypersensitive or critical adjustments, built-in test equipment (BITE), maximized use of commonly available multi-sourced components and standard connectors for ease of interface with test equipment

- Minimum use of blowers for cooling

- Flexibility of subunits to easily change frequencies, channel capacities and type of emphasis/deemphasis. This interchangeability of subunits lowers the echelon level of maintenance required in the field.

When specifying radio requirements for a microwave system, most designers attempt to use the same radio type throughout the system for ease of maintenance. The purchase price might be slightly higher; but, this can usually be offset by maintenance cost considerations. A number of technical characteristics of the radio need to be specified by the system designer. A number of others do not; for example, the designer need not normally specify the internal functional levels of the equipment. It is the external and variable functions that need to be specified. They include:

- Transmit power which is a result of antenna sizes, feeder lengths and types, path geometry etc.

- Frequency (RF)

- Channel capacity

- Drop and insert capability.

There are also other variables that may or may not be of concern to the designer such as:

- Interface levels

- DC power requirements

- Size of equipment

- Pilot frequencies
- Frequency stability

Other characteristics which can be specified but tend to be standard and not easily varied are:

- Noise figure
- Intermodulation performance
- VSWR's (see Sections II.F.9 and H.6.e)
- RF filter characteristics

In recent years these latter factors have stabilized at generally acceptable and cost effective standards.

The baseband or remodulating radio is similar to the IF radio with the following differences:

- Demodulator and modulator are an integral part of the baseband radio
- Transmitters do not normally use a mixer that converts the 70 MHz IF to the RF with the use of a local oscillator and one mixer.

The remodulating transmitter uses a VCO to generate the FM signal. The VCO's output is then multiplied up to the desired radio frequency where it can be amplified. The remodulating system method reduces cost by eliminating much of the 70 MHz IF circuitry in both transmitters and receivers. The disadvantage of the system is the fact that the message signal is reduced down to baseband at every station which tends to introduce more noise.

The remodulating receiver is essentially the same electrically as the IF radio receiver with the addition of a demodulator. The IF frequency used is often much higher than 70 MHz ; often 450-2000 MHz . At these higher IF frequencies the ratio of

$$\Delta F = \frac{\text{IF Bandwidth}}{\text{IF Center Frequency}}$$

is lower than equipment that uses a 70 MHz IF. It is therefore easier to achieve linearity across the IF bandpass since it is a much smaller percentage of the operating frequency.

Figure II-32 shows the typical technical characteristics of remodulating radio.

NOTES:

1. RF filter, called Sideband Filter since it rejects the unwanted sidebands of the mixer.

2. Isolators are one way transmission devices that reduce echo levels due to impedance mismatches.

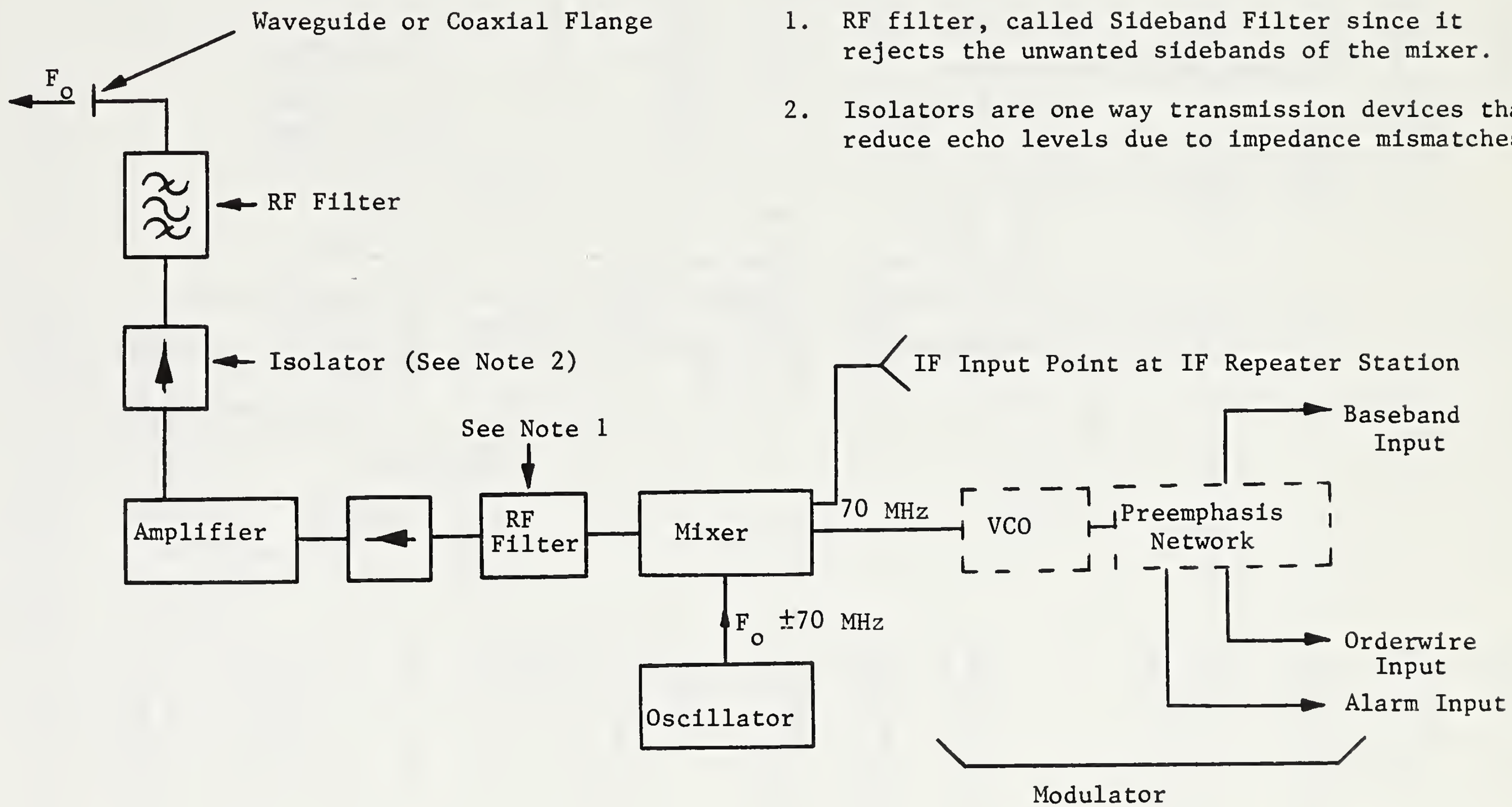


Figure II-29 Typical Transmitter

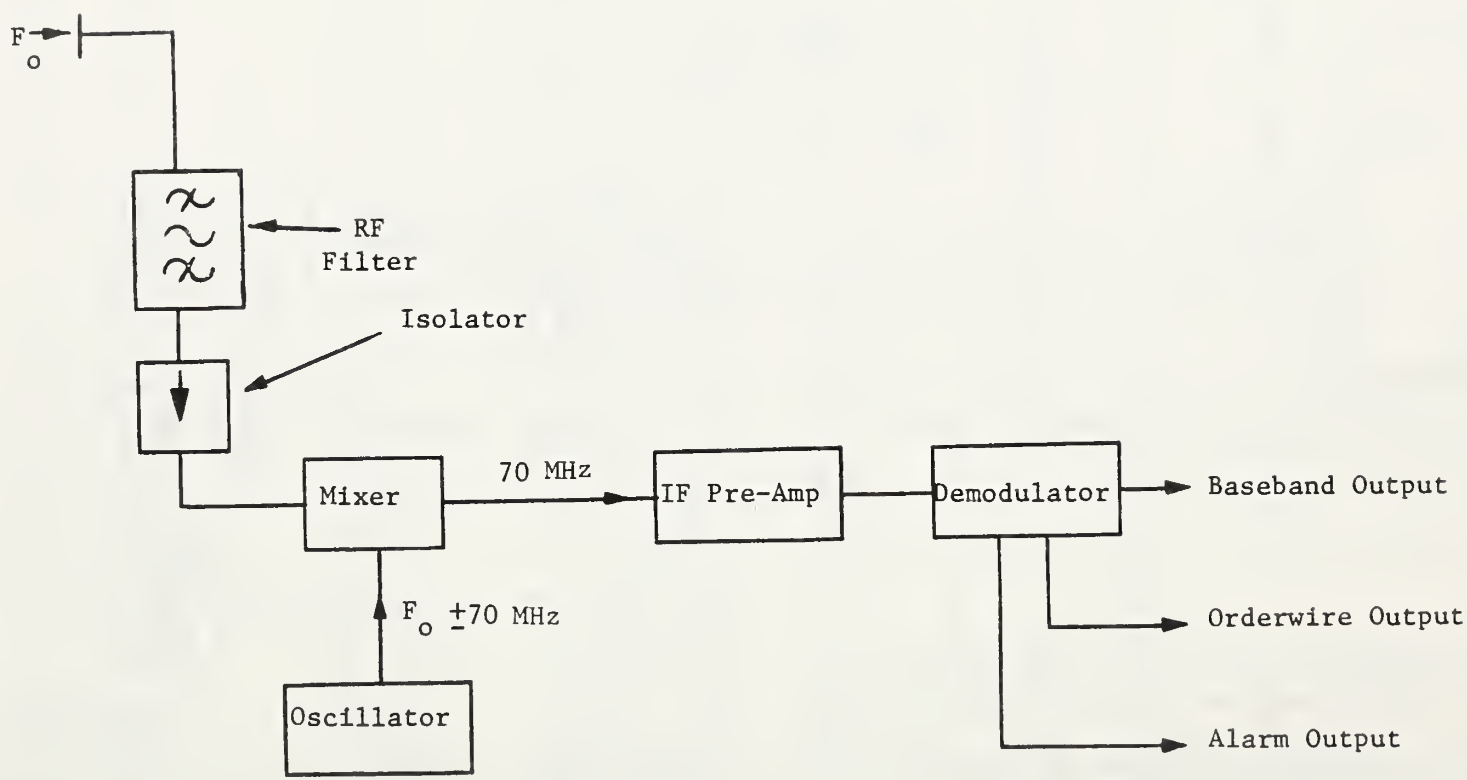


Figure II-30 Typical Receiver

Characteristic	Value	Notes
1. RF Frequency	i.e. .9, 2, 6, 12 GHz	Band over which equipment will operate
2. Frequency Stability	.005%-.001%	Stability of both Rx and Tx stated
3. Receive Noise Figure	7-10 dB	Lower values available using RF amplifiers before the mixer
4. Drop and Insert Capability	Qty of channels and Level	Specs should state if auxiliary IF outputs of Rx are available
5. Tx Power	1-10 watts	
6. Normal Receive RF Input	-20 to -40 dBm	
7. RF Bandwidth	Varies	May be critical in rejecting RF interference
8. System Figure	130-160 dB	Indirect measure of equipment noise performance
9. IF Bandwidth	Varies	Depends on channel capacity and deviation
10. Channel Capacity and Normal Deviation	Varies	Deviation in kHz RMS per channel
11. RF VSWR	1.05-1.1	For both Rx and Tx
12. IF Frequency	70 MHz	Rarely different from 70 mHz
13. IF VSWR	>26 dB return loss	For both Rx and Tx
14. IF Level	Varies	For both Rx and Tx
15. IF Impedance	Usually 75 ohms	For both Rx and Tx
16. IF to IF Frequency Response	±.2 dB	Bandwidth of measurement varies with channel capacity and deviation
17. IF to IF		
Linearity Delay	±.2 dB ±1, ±2 nsec	Bandwidth of measurement varies with channel capacity and deviation

Figure II-31 Technical Characteristics of IF Radio
(Continued on following page)

Characteristic	Value	Notes
18. Operating Temperature Range	$0^{\circ}C$ to $50^{\circ}C$	At extremes performance may be degraded
19. DC Power Consumption	3 to 10 times RF output	Varies with transmitter efficiency and quantity of ancillary functions provided
20. RF Flange Description	Waveguide or coax	Specs show details
21. Alarm and Control Interfaces	Types of interfaces, voltages, impedances current levels	
22. Protection Switching Interfaces	Definition of technical and electrical interface	

Figure II-31 Technical Characteristics of IF Radio

(Continuation)

Characteristic	Value	Notes
1. RF Frequency	i.e. .9, 2, 6, 12 GHz	Band over which equipment will operate
2. Frequency Stability	.005%-.001%	Stated for both Tx and Rx
3. Receive Noise Figure	7-10 dB	Lower values available using RF amplifiers before the mixer
4. Tx Power	.5-10 watts	
5. Normal Receive RF Input	-20 to -40 dBm	
6. RF Bandwidth	Varies	See Figure II-94
7. System Figure	130-160 dB	Indirect measure of equipment noise performance
8. Bandwidth	Varies	Depends on channel capacity and deviation
9. Channel Capacity and Normal Deviation	Varies	Deviation in kHz RMS per channel
10. RF VSWR	1.05-1.1	For both Rx and Tx
11. Receive IF Frequency	70 MHz	
12. Baseband to Baseband		
Linearity Delay	±.2 dB ±1, ±2 nsec	Bandwidth of measurement varies with channel capacity
13. Operating Temperature	$0^{o}C$ to $50^{o}C$	At extremes performance may be degraded
14. DC Power Consumption	3 to 10 times RF output	
15. Pre and Deemphasis	6-8 dB per octave	
16. RF Flange Description	Waveguide or coax	Specs show details
17. Alarm and Control Interface	Types of interfaces voltages, impedances current levels	
18. Protection Switching Interfaces	Definition of technical and electrical interface	

Figure II-32 Technical Characteristics of Demodulating Radio

3. Modems

"Modem" is a contraction of Modulator/Demodulator. A modulator modulates a carrier with an input or message signal. The demodulator extracts the message signal from a modulated carrier. For the purpose of this Section, Frequency Division Multiplex - Frequency Modulated (FDM-FM) systems are considered. That is, the message signal is the output of an FDM multiplexer; the type of modulation used in the modems is Frequency Modulation. FDM-FM is the most common system in use in telecommunications systems today.

The typical modulator uses a VCO or phase lock loop to impress the message signal on an IF oscillator by modulating its frequency. Figure II-33 shows a typical modulator.

When FDM-FM systems were first being developed, 70 MHz was chosen as a standard frequency for the modulation process. The decision was an attempt to reach the highest possible frequency that was technically feasible with components available at that time. The higher the frequency, of course, the smaller the ratio of

$$\Delta F = \frac{\text{peak deviation}}{\text{center frequency}}$$

The lower this ratio, the easier it is to design the required band limiting filters and achieve linearity across the pass band. As a result, many manufacturers now use center frequencies of 450-2000 MHz. Mixers are then used to bring the signal back down to 70 MHz if need be. This is avoided where possible, however, because the image frequencies using 450-2000 MHz IF's are much easier to control. This in turn reduces the cost and complexity of the RF branching and filtering.

Demodulators normally operate on a 70 MHz IF frequency. The demodulator consists of the basic elements noted in Figure II-34.

The demodulator can also be equipped with numerous other functional subunits such as:

- IF equalizers
- Baseband equalizers
- Auxilliary outputs with associated amplifiers.

Modulators and demodulators are physically similar in size to radio equipment.

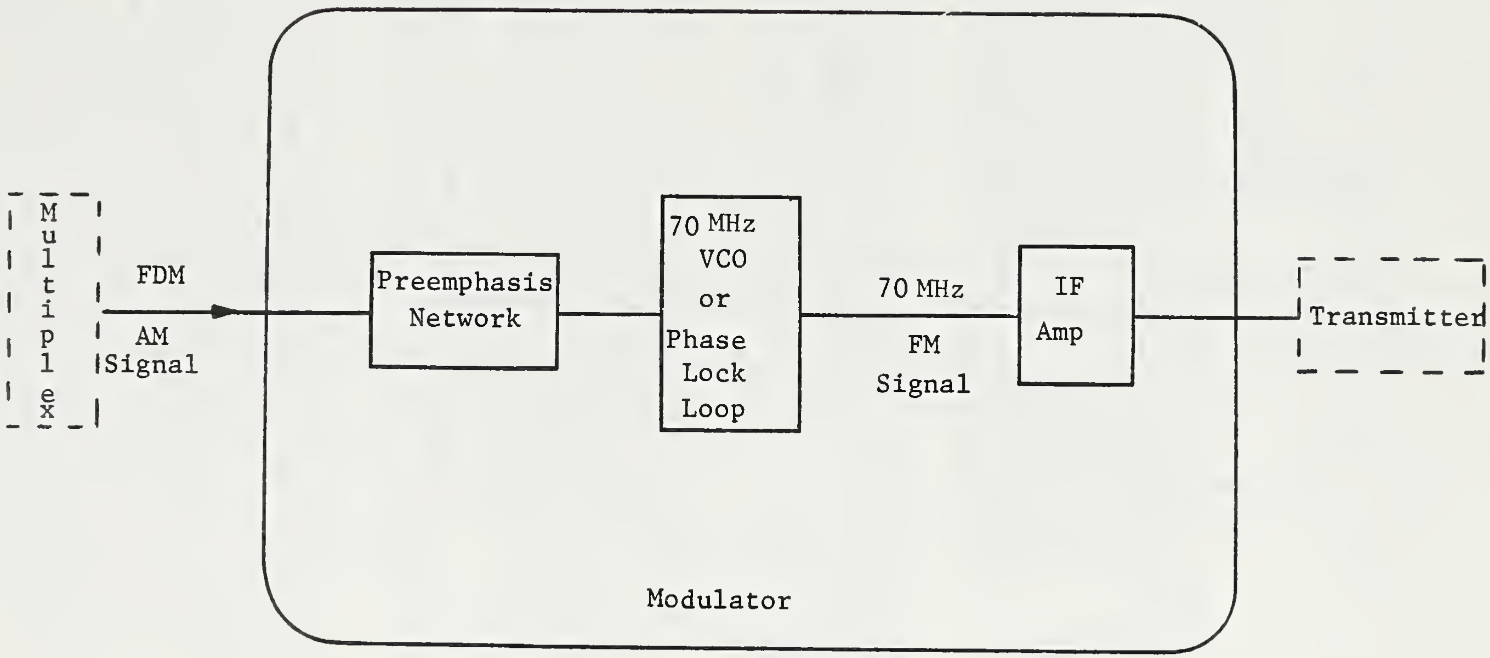


Figure II-33 Typical Modulator

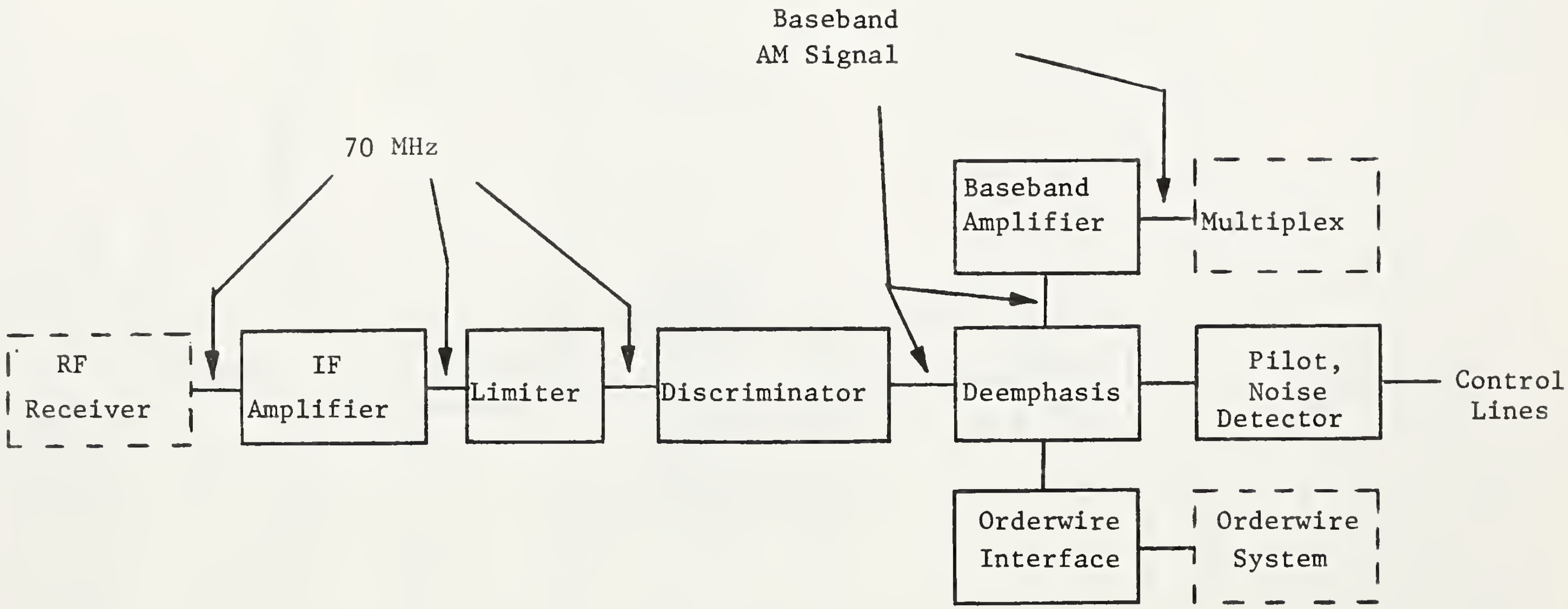


Figure II-34 Typical Demodulator

When specifying modems the system designer may include the requirements as part of the radio equipment. If the modems are specified separately, Figure II-35 lists the characteristics of concern in most applications. The most significant characteristic is the loaded noise performance or noise power ratio (NPR). Particular attention should be given to the modem's NPR sensitivity to overloads and impedance mismatches at IF. The impedance mismatch problem results in echo distortion which affects system relative delay, linearity and therefore NPR's. See Sections II.H.4.c, d and 6.e.

4. Protection Systems

Protection systems prevent the loss or degradation of signals in a microwave system by providing alternate path(s) for the signal. Signal failures are caused by excessive path fading and equipment failures. The basic concept is to provide an alternate transmission link for the signal and switch to the alternate link when the primary link fails. This is normally done using dual space diversity links whereby each received signal travels an independent radio path.

The transmission links involved in a protection scheme may be paths switched individually or a number of paths in tandem, switched together. Connecting 4 or 5 paths in tandem to form a "switching section" is common. In such a system the paths are not individually switched. If a failure occurs on one path, all the paths in the section are switched together.

It should be noted that many private microwave systems use no protection. The requirement for diversity is a function of desired system availability. For example, a system with a 90% availability requirement will most likely not require protection if modern solid state equipment is used. A system with 99.9999% will almost always require protection.

Protection systems consist of equipment that will detect signal fades and equipment failures, control logic circuitry and switches.

The fade detectors normally monitor either receive RF carrier level or system baseband noise. The receive carrier is detected indirectly by measuring the receiver's AGC voltage. The noise is measured by detecting noise above the baseband but within the passband of the receiver. Either carrier level or noise detection can be used as control logic inputs. Of the two, noise is the more commonly used since it is an indication of signal level as well as other system degradation. (If a system becomes noisy, it should be switched regardless of whether the noise is due to fading or some other cause.)

	Characteristic	Value	Notes
1.	IF Levels	Varies	Specified for both Rx and Tx
2.	IF Impedance	Varies	Specified for both Rx and Tx
3.	IF Return Loss	> 26 dB	Specified for both Rx and Tx
4.	Baseband Levels	Test tone level, varies	Specified for both Rx and Tx
5.	Channel Capacity	Varies	
6.	Deviation	kHz rms per channel	Specified for modulator
7.	Discriminator Sensitivity	Volts per MHz	Specified for demodulator
8.	Orderwire, Sound Channel and Radio Pilot Connections	Input and output points with levels and impedances	
9.	Back to Back (Baseband to Baseband)		
	Linearity Delay	$\pm .2$ dB ± 1, ± 2 nsec	Bandwidth of measurement varies with channel capacity and deviation
10.	Pre and Deemphasis	6-8 dB per octave	
11.	Alarm and Control Interfaces	Complete description	
12.	Protection Switching Interfaces	Complete description	
13.	DC Power Consumption	Varies	
14.	Operating Temperature	$0^{o}C-50^{o}C$	At extremes performance may be degraded
15.	Auxiliary Inputs and Outputs	Levels and impedances should be specified	IF and baseband

Figure II-35 Technical Characteristics of Modems

Equipment failure detection is done by monitoring various test points on the equipment. Locally (within a given station) hard wiring to audible and visual alarms provides the fault indications. To monitor equipment failures at the remote sites, indirect methods are used. As just mentioned, the incoming carrier level is monitored. This is an indirect monitoring of the remote end's transmitter output power. The protection system also indirectly monitors the presence of the desired modulating signal on the carrier. This is done by monitoring a pilot tone above the message baseband. At the transmit end a radio pilot is injected into either the transmitter (via the drop and insert port) or the modulator. The purpose of the pilot is to give an indication of the presence of modulation. The demodulator is equipped with a pilot filter and detector to check for the continued presence of the pilot. If the pilot is lost, so might the desired baseband signal. It is therefore judicious to switch the alternate radio receiver should the pilot disappear. Failure of the pilot might also be an indication of a demodulator failure which equally necessitates a switch to the protection link to occur.

The normal inputs to the control circuit logic circuitry of the protection switching system include the following:

- Noise — from both receivers
- Pilot — from both receivers
- DC power supply — from both receivers
- Output transmitter power — from both transmitters
- DC power supply — from both transmitters

A transmitter output failure causes the signal to switch to the alternate transmitter. If a fault is detected by the receive end, the receiver control inputs must be evaluated first, however, by the control circuit logic before a switch occurs. Otherwise, false or unwanted switching might take place.

The control logic circuitry at the receive end makes decisions accounting for the following principles:

- Loss of radio pilot is more important than high noise since loss of pilot indicates loss of modulation.
- At least a 6 dB difference in noise level should exist before switching occurs. This prevents constant switching of approximately equal signals.

- Both receivers should be squelched if both are too noisy. This prevents injection of excessive noise into the rest of the system.

- Maintenance personnel should be able to override the logic inputs for test purposes. In conjunction with the alarm and control system it is commonly possible to force one receiver or transmitter to be on line locally or remotely.

A more elaborate switching system is used if more than one baseband signal is transmitted over the same microwave system. When there is one primary link and one protection link the system is called a "one plus one" (1+1) system. It is also possible to have a 2+1 system or N+1, N+2 or N+A, where the first number indicates the number of baseband signals and the second the number of protection links. The most common method of protection scheme for N+A systems is frequency diversity.

The switching logic is more complicated than 1+1 protection systems. For example, when a failure occurs in a 2+1 system, the baseband of the failed link should be transferred to the protection link. Both the receive and transmit ends must know which of the two basebands is to be switched to the protection link. This is accomplished using logic circuitry and "handshaking" between the two ends. A voice channel in the Orderwire System is normally provided between the two ends for the "back signaling" or "handshaking". The Orderwire System is discussed in Sections II.E.8 and G.8.

In N+A systems the logic circuitry forms an integral part of the overall Alarm and Control System. When a failure occurs at either the transmit or receive end, the logic circuitry makes a number of decisions accounting for the following principles in addition to those mentioned above.

- The protection channel must be unoccupied before switching unless the failed link has a higher priority than a baseband occupying the protection link.

- The protection link must not be failed.

- When a switching procedure has been "approved" by the logic circuitry the two ends must switch to the protection channel at the same time.

- The baseband on the protection link must be restored to its primary link whenever the primary link is restored to service. This then frees the protection link at the earliest moment.

Obviously, to make the decisions, the two ends of the link must communicate with each other, thus the back signaling channel.

An alternative to a 2+1 system is two parallel 1+1 systems. This requires 4 radio links instead of 3 used in the 2+1 system. Two parallel 1+1 systems do not require back signaling nor the complex logic of a 2+1 switching system. In short systems it may be cheaper to install the fourth radio link rather than install and maintain the more complex protection switching.

The N+A system can be further complicated when the N basebands are of different size;i.e., 600 channels for one, 900 channels for another,and color TV for a third. In such a case the protection radio link must be capable of handling all three basebands including the largest. Of the three the color TV will require the most bandwidth. The switching machinery must also include switchable pre and de-emphasis circuitry for the different basebands since they all use different emphasis. Attenuators and amplifiers are also commonly switched to ensure level compatibility.

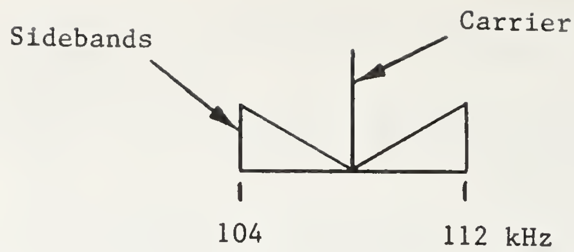
The system designer should also ensure that the radio pilot of the protection link does not interfere with any of the possible basebands. The common practice is to place the pilot above the widest of the basebands. In the case of color TV with sound channels and orderwire above the baseband, the radio pilot is commonly placed at 8.5 or 9.023 MHz.

Protection switching equipment is mechanically similar in size to radio and modem equipment in mounting design.

5. Multiplex

Frequency division multiplex (FDM) is designed to frequency stack voice channels for simultaneous transmission over a single transmission facility. The basic function of multiplex (Mux) uses AM mixers to translate 4 kHz voice channels up to a higher frequency. Each voice channel is translated up to a different frequency.

Multiplex standards have evolved over the past 25-30 years and most manufacturers now conform to a standard 4 kHz voice channel with an actual usable bandwidth of 300-3400 Hz. In FDM mux, the common practice is to translate the voice channel through a mixer up to the 60-108 kHz spectrum. At this point the signal is passed through a filter to eliminate one of the sidebands and the carrier leaving a single sideband suppressed carrier (SSBSC) 4 kHz wide signal. See Section II.F.3.The process uses one of 12 different channel carrier frequencies for the mixing process. See Figure II-36. The outputs of all the filters are combined using hybrids to form one discrete signal from 60-108 kHz containing 12 voice channels. At the receive end the process is reversed using the same carrier frequencies to mix the 60-108 kHz spectrum down to 12 discrete voice channels.



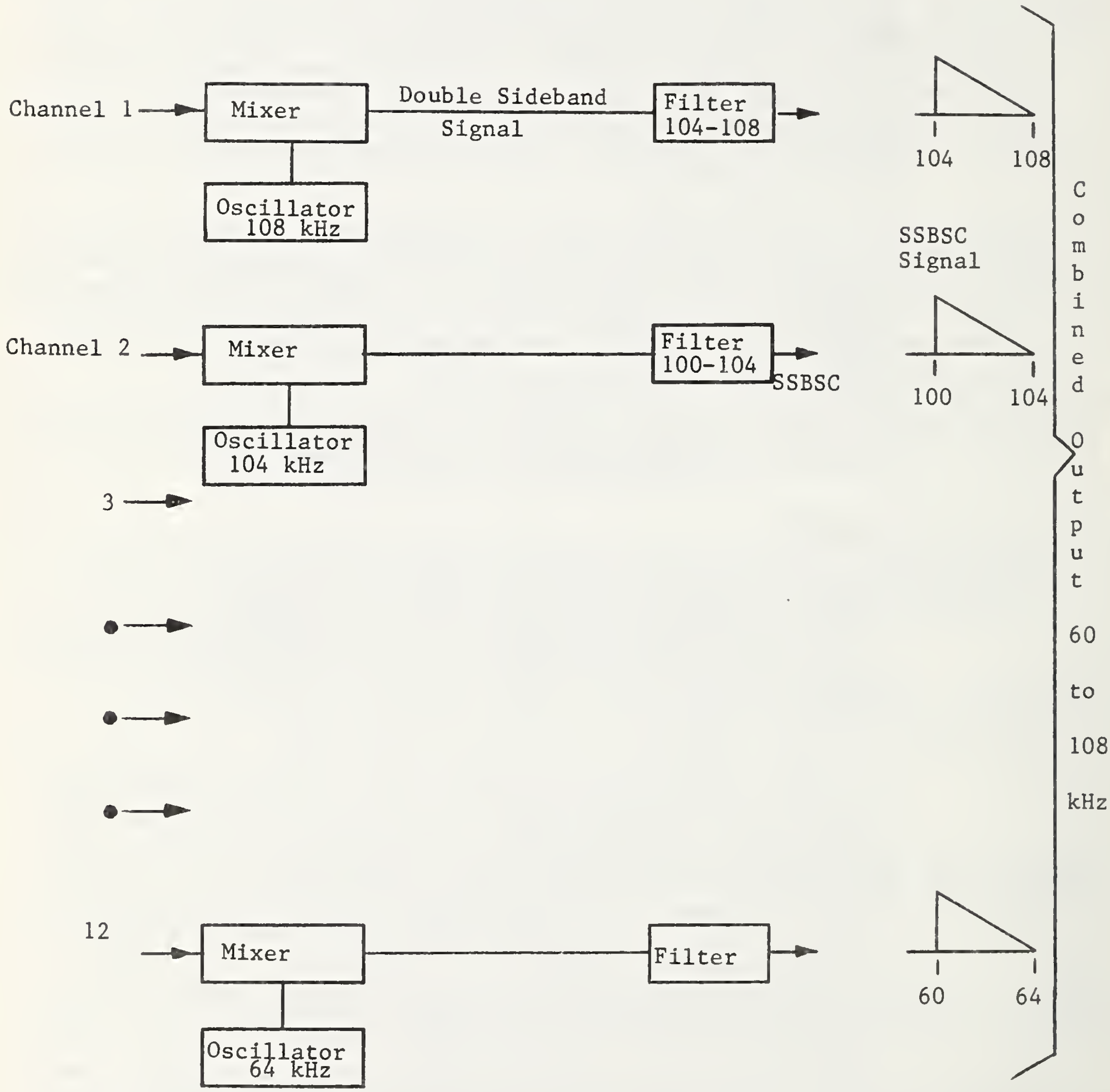


Figure II-36 Group Multiplexer

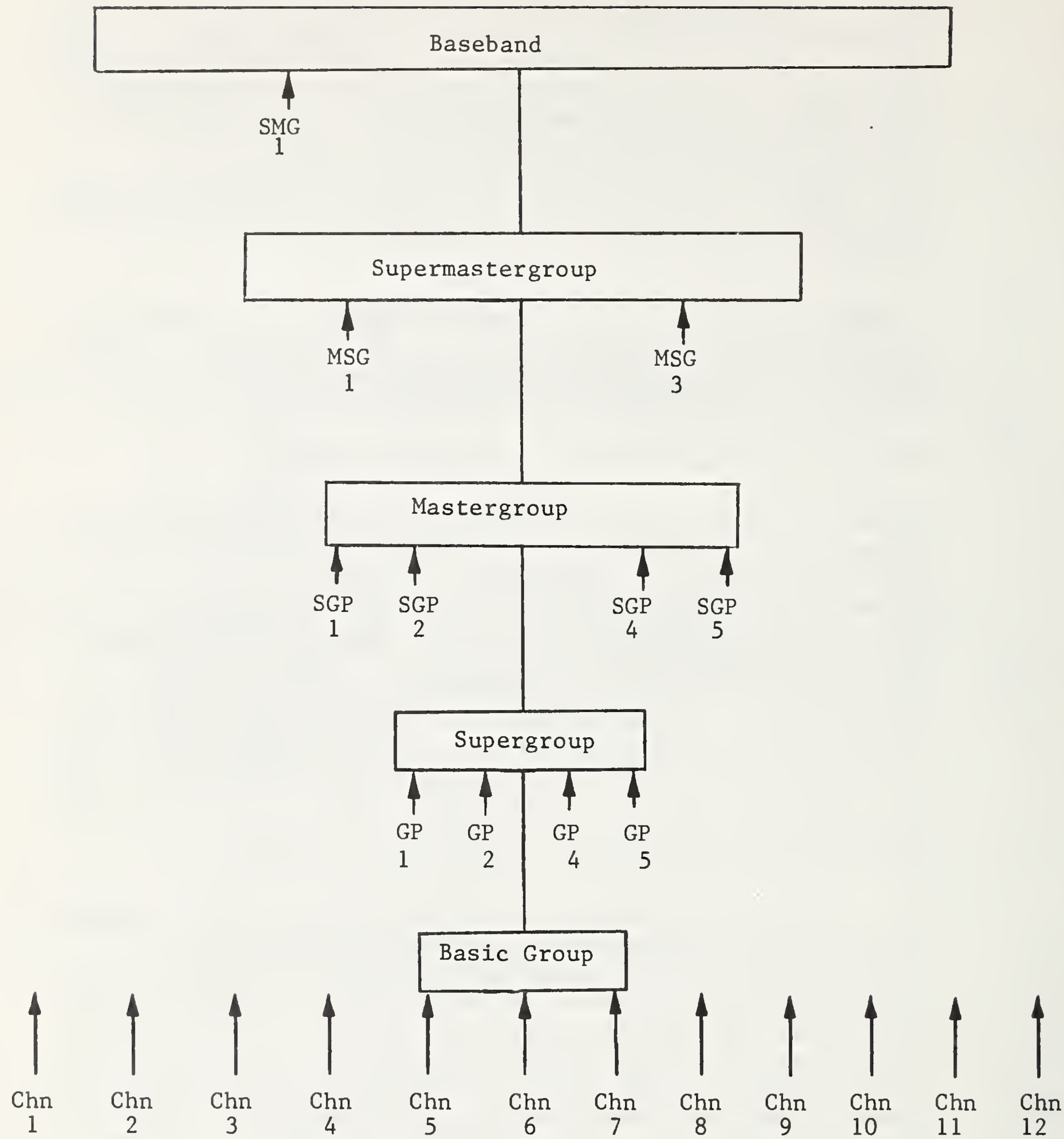
After forming 60-108 kHz Groups at the transmit end, additional mixers are used to translate the 60-108 kHz spectrums up to positions in the 312-552 kHz spectrum. Five Groups (GP) are thus fitted into the 312-552 kHz spectrum to form a Supergroup (SGP). Supergroups can then be combined to form Mastergroups (MSG). The next step is Supermastergroups (SMG), then baseband. On lower channel capacity systems the latter hierarchy steps are not required. It is possible, for example, to feed the 60-108 kHz spectrum directly into the baseband of a 12 channel radio system.

Not mentioned above is the uncommon Pregroup. The Pregroup is a combination of 4 channels in the 12-28 kHz spectrum. Three Pregroups are then combined to form a 60-108 kHz Group. This intermediate step is bypassed in many multiplexers.

Figure II-37 shows a typical multiplex hierarchy.

A Pilot (low level tone) is inserted in the Group at 84.08 kHz for monitor and control purposes. At 84.08 kHz, the pilot is at 80 Hz in channel 7 and causes no interference since the channel filter eliminates it. At the receive end, the pilot is detected. If the pilot disappears or drops in level by more than 6 dB, a Group alarm is activated. Pilots are likewise inserted in each Supergroup, Mastergroup and Supermastergroup. The pilot also provides a means of detecting level variations. Some multiplex systems provide for automatic gain control (AGC) of the Group, SGP, MSG and/or SMG levels by responding to changes in the pilot level. The response time of such AGC is very slow to prevent hunting and overshoot in level changes on long systems where numerous AGC circuits are in tandem.

One of the prime concerns in multiplex systems is the accuracy of the carrier frequencies. If carrier frequencies are off, the end result is a voice channel displaced in frequency. To avoid such problems, modern multiplex uses very high stability oscillators for carrier generation. A common technique is to use one extremely high stability oscillator at a station and use its output to generate all the other carrier frequencies needed. There are several methods of doing this: one is to have the oscillator operate at 4 kHz and generate a signal very rich in harmonics. Filters are then used to select the desired carrier frequencies. Another technique is to use a high frequency oscillator and digital circuitry to "count down" to the desired carrier frequencies. In the past, such stability in oscillators was not available economically. Instead, synchronization techniques were developed to phase lock all stations in a system to one master oscillator at a central station. The synchronization plan sends a sync pilot to all stations over the baseband. If the master oscillator drifted, all other oscillators in the system would drift with it.



Voice Inputs: Known as the "4 wire mux input", 2 wires for receive and 2 wires for transmit

Figure II-37 Typical Multiplex Hierarchy

Therefore, there were no frequency translation errors. The whole system, however, becomes dependent on the one master oscillator and the ability of the system to reliably distribute the mux sync pilot to all stations. This increases the system's susceptibility to failures; thus, high stability oscillators are commonly used in preference to the remote master clock system.

The various intermediate translation steps in FDM multiplex allow for re-routing of quantities of circuits without having to translate all channels down to voice level. A Group, for instance, can be routed as a 60-108 kHz signal from one transmission system to another. Consider the three way terminal station in Figure II-38.

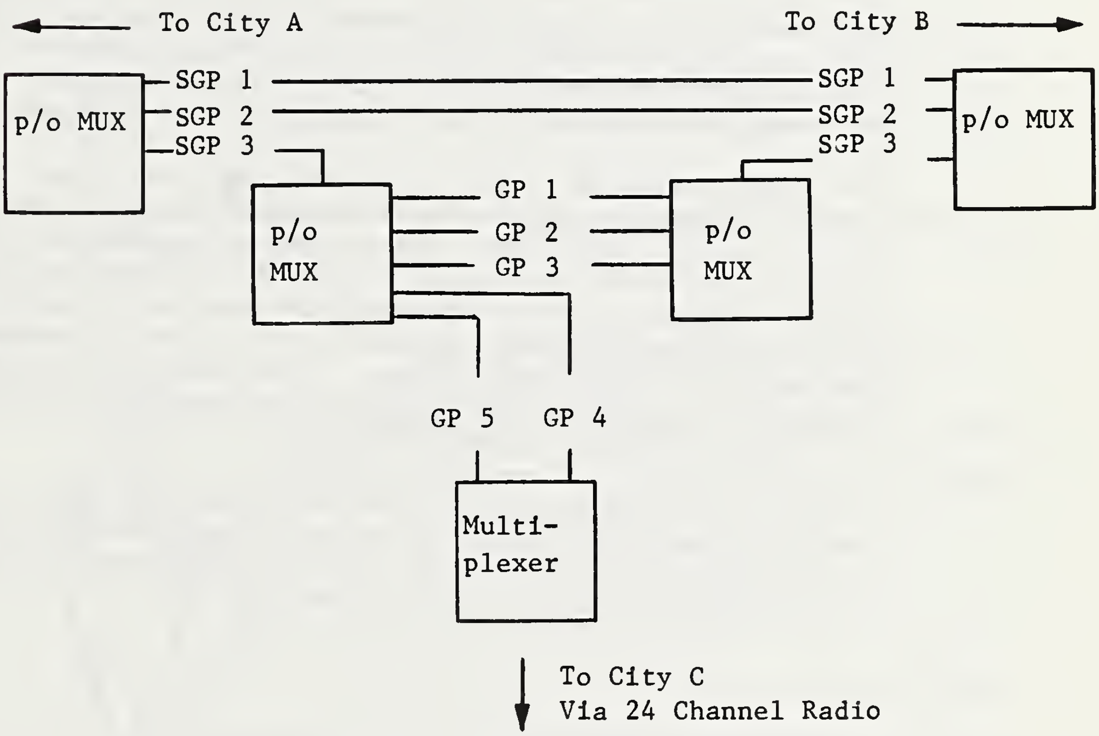


Figure II-38 Three Way Terminal

To provide this flexibility to re-route circuits, patching facilities are provided called "Through Group Patch Bays" or "Through Supergroup Patch Bays". They are not unlike VF Jackfields. The "through" patch bays re-route sections of the mux spectrum. In doing so they strip the pilot from the spectrum by use of a very narrow bandstop filter. The pilot is then reinserted before leaving the station. Using this method, if the pilot is lost in a group at its final destination, it is possible to locate the fault readily since each "through" station reinserts it.

The "through" patch bays also attenuate the signals for level compatibility between transmit and receive points in the mux.

The Group and Supergroup points in mux are often used for transmission of wideband data. A 50 kilobit signal, for example, can be inserted directly into the 60-108 kHz input port of a Supergroup multiplexer. The 312-552 kHz Supergroup spectrum is commonly used to handle 250 kilobit data. The normal mux filtering imparts delay and linearity distortion to these wideband signals. Additional equalization is often required to flatten the response for transmission of such wideband data signals.

Direct Line Multiplex

Some multiplexers use mixers to translate the voice channel directly to the baseband frequency instead of using intermediate translation steps. Such mux is called direct line mux. It is cheaper in low density systems but does not have the bulk rerouting flexibility of multi-stepped mux as discussed above.

For synchronization, direct line (DL) mux uses either highly stable oscillators or the transmitted carrier as a sync reference. In the latter mode, the carrier is transmitted along with the SSB voice at a level around 20 dB below test tone. It is detected at the receive end and used as a syncing reference. In these systems, the carrier can also be modulated at low rates for signaling purposes. Such mux has DC signaling leads that interface with signaling equipment, which can be very cost effective in small systems.

However, the majority of the mux available uses the intermediate frequency translation steps. Using intermediate steps for wideband systems in effect reduces the number of translation carriers needed at a given station.

6. Antenna Systems

The antenna system includes the antenna and the transmission line interconnecting the antenna to the RF branching equipment.

Antennas

Antennas in microwave systems perform several functions:

- Concentrate transmitters' RF output energy in a single direction
- Prevent excessive radiation in all other directions
- Receive RF energy from one desired direction only
- Discriminate against signals arriving at off beam directions.

Antennas are said to have a "gain". The antenna does not amplify the RF energy, it concentrates it into a "pencil" beam. The narrower the beam, the higher the concentration of the energy. The higher the concentration, the higher the effective gain of the antenna.

We will consider microwave antennas using parabolic reflectors. See Figure II-39.

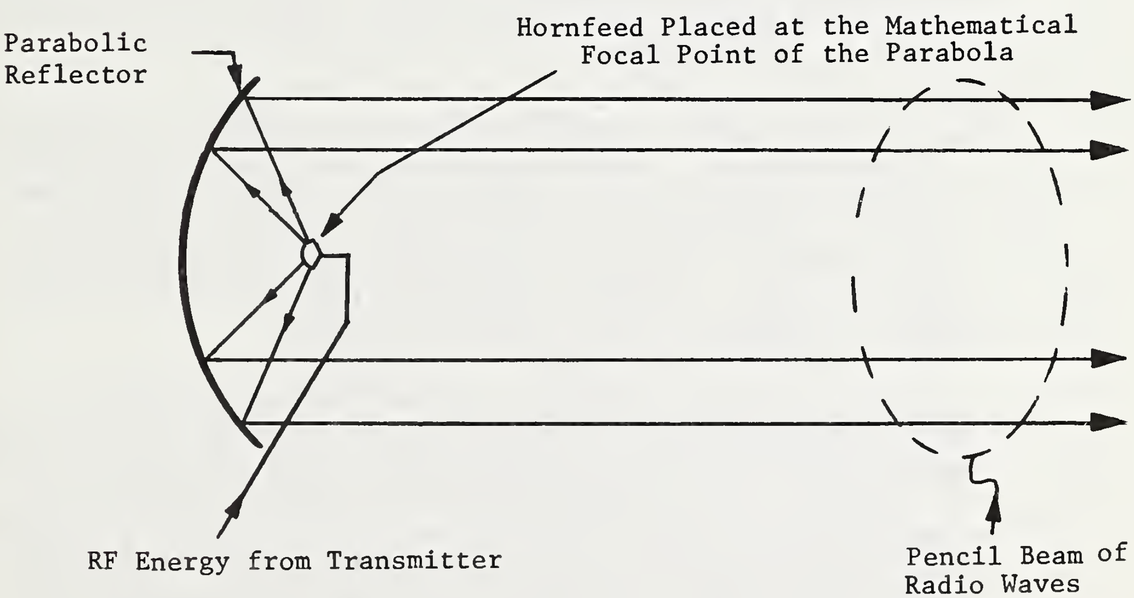


Figure II-39 Parabolic Antenna

The principle of a parabolic antenna that makes it useful to microwave systems is its ability to focus energy originating at its focal point into a narrow beam. The larger the reflector, the narrower the beam.

The effective gain of a parabolic antenna is theoretically limited by its size and the frequency of transmission.

$$G = \text{maximum effective gain possible} = \left(\frac{\pi D}{\lambda}\right)^2$$

where D is the diameter of the antenna's parabolic reflector and λ is the wavelength of the RF energy. In logarithmic terms this is

$$G = (20 \, \text{Log}_{10}(FD) - 39.9) \text{ dB}$$

where F is in megahertz and D is in meters. Antennas are not 100% efficient, however, largely because the hornfeed does not illuminate the entire parabola evenly. The energy concentration at the edges is lower reducing the overall antenna efficiency to 50-75% normally; 55% is typical of the economical antennas. The gain formula is adjusted to account for this.

$$G_{55\%} = (20 \, \text{Log}_{10}(FD) - 42.5) \text{ dB}$$

Antenna efficiencies are also affected slightly by VSWR losses and imperfections in the shape of the parabola. The 55% figure takes this into account.

Figure II-40 shows a typical radiation pattern for a parabolic microwave antenna. The pattern shows the level of radiation from the antenna at various angles relative to the main beam. It will be readily obvious that not all the energy goes into the main beam. Some is radiated in "sidelobes" at various angles as shown. The more suppressed the sidelobes are, the better the antenna's "discrimination pattern".

An alternate method of displaying the pattern is shown in Figure II-40A. In this figure patterns are shown for both the vertical and horizontal polarizations. They are usually slightly different at off beam angles due to pattern interference caused by the waveguide feeding the hornfeed as well as mechanical members used to support the hornfeed. Other mechanical inspections distort the signal in different polarities selectively. Such imperfections are bolt heads on the reflector used in construction, dents, distortion in reflector shape due

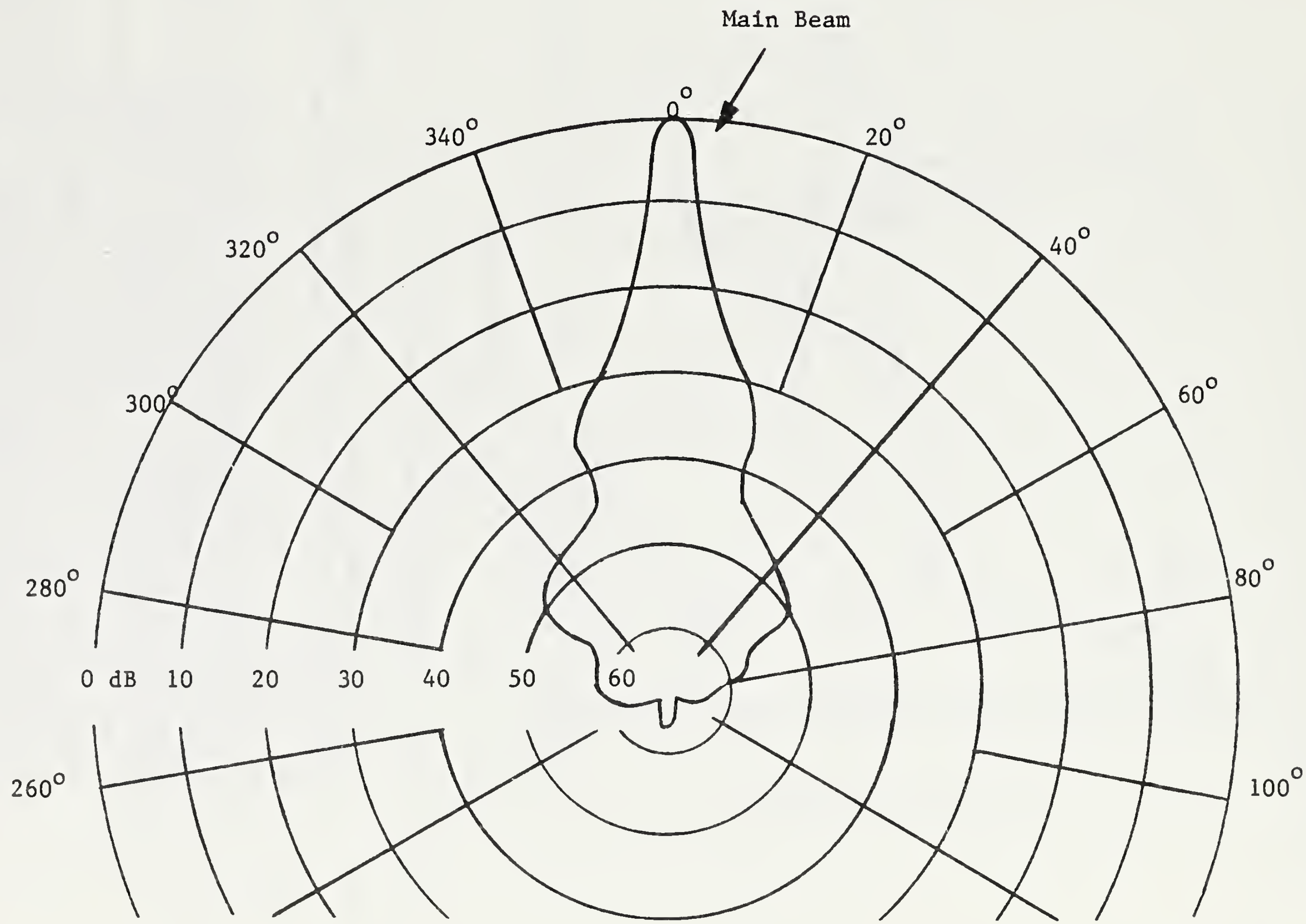


Figure II-40 Antenna Discrimination Pattern to poor installation and misalignment of the antenna's hornfeed. The hornfeeds themselves can also contribute to the differences between polarities.

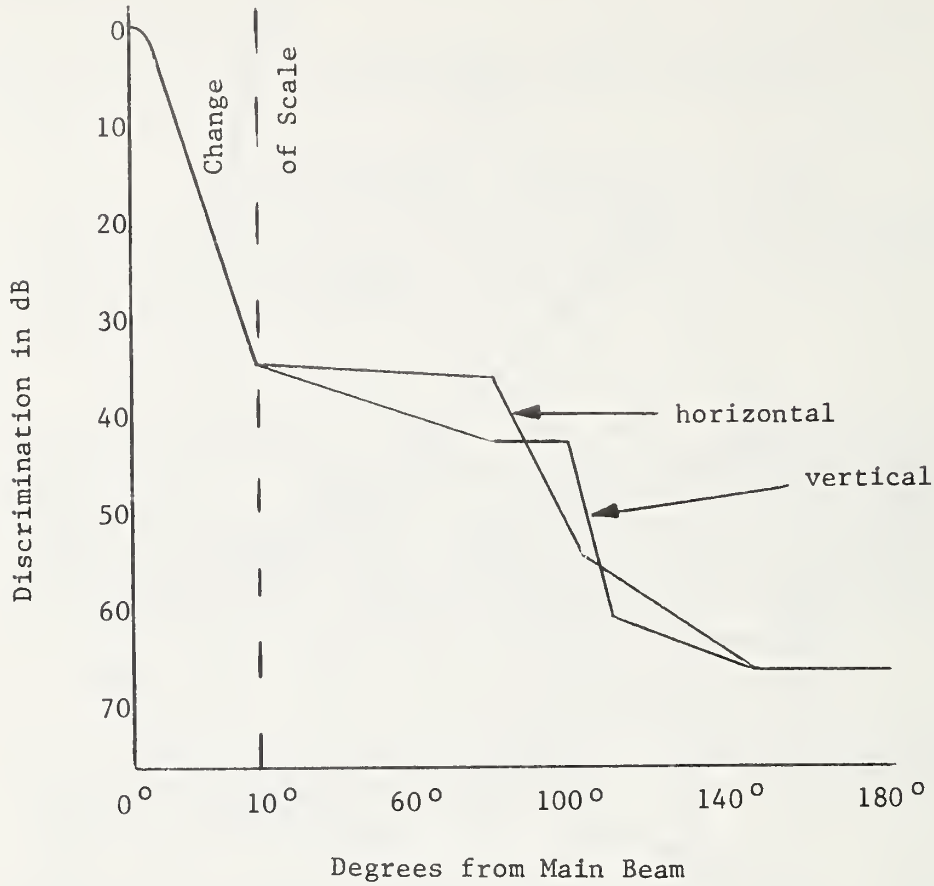


Figure II-40A Antenna Discrimination Patterns for Both Polarities

It should be realized that antenna patterns are "worst case" value filed with the FCC when an antenna is "type accepted" by the FCC.

To achieve the "worst case" pattern, the manufacturer measures a number of the same type antenna. The tests are run at frequencies across the band. The worst discrimination at each angle at all frequencies for all antennas is then used to plot the curve. It is, therefore, a guaranteed figure.

The actual pattern looks more like the highly variant pattern in Figure II-40B. The "actual patterns" are patterns taken on an antenna test range under ideal conditions. Once the antenna is installed in the field the effective pattern can very easily be affected by near field obstructions, poor installation procedures and RF leakage in the feeder. It is not uncommon to find discrimination patterns of installed antenna systems to be 20 dB out of spec due to the causes noted.

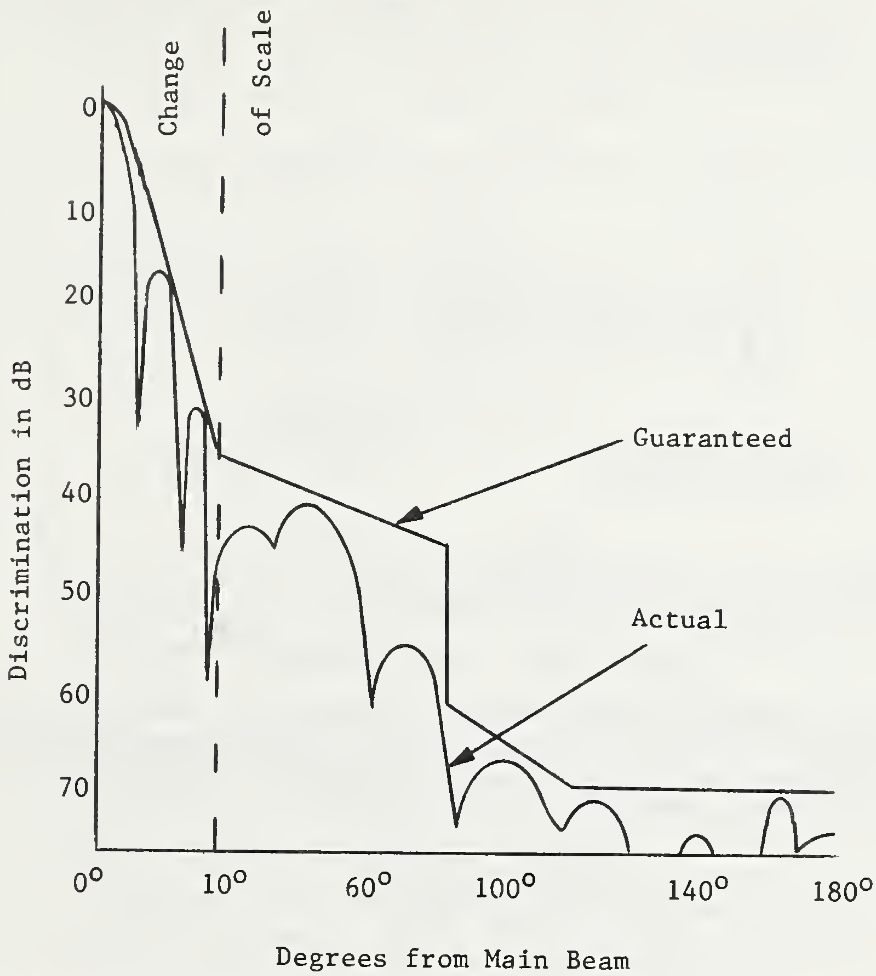


Figure II-40 Actual vs Guaranteed Antenna Discrimination Patterns

Another characteristic of interest in microwave antenna design is the angle of divergence of the radiated beam. (This is misleadingly called beamwidth.) The angle is naturally directly related to the effective gain since the narrower the beam the higher the gain. Both are functions of the physical laws of resolution. The rated "beamwidth" of an antenna is usually given in degrees or milliradians between the half power points of the main beam.

$$3 \text{ dB "Beamwidth"} \approx \frac{22600}{FD} \text{ degrees}$$

In Figure II-40B the actual pattern will be different for different frequencies in the RF band. The most noticeable changes occur in the sharp dips in the pattern. The same frequency sensitivity of the antenna discrimination characteristics applies to the cross patterns as Figure II-44.

An intuitive way to equate beamwidth to gain is shown in Figure II-41.

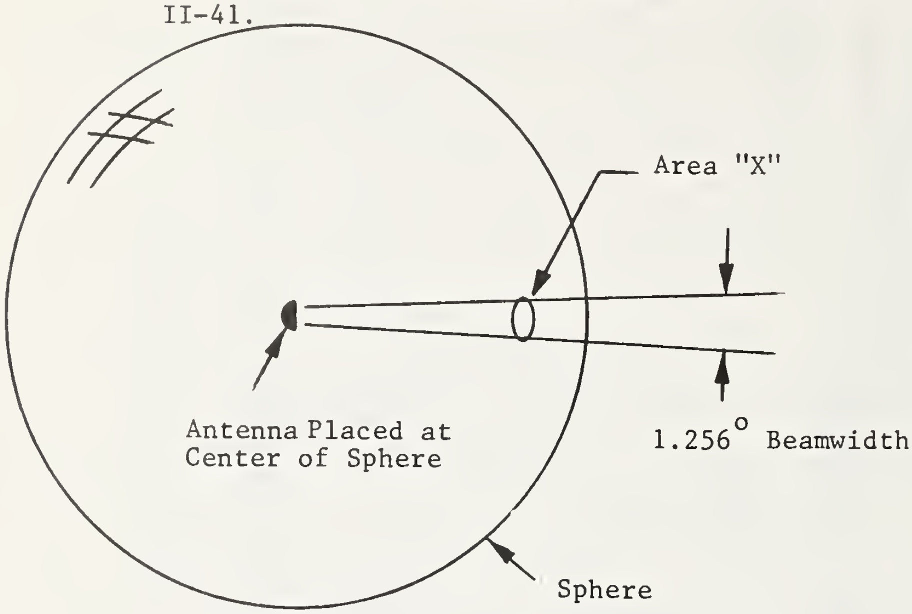


Figure II-41 Antenna Gain

The gain will be the ratio of the area of the entire sphere to the area of X. A 3 meter antenna operating at 6000 MHz has a beamwidth of 1.256°. Area X therefore equals 0.000377 square steradians. The gain is therefore

$$G = 10 \text{ Log } \left(\frac{\text{Total Sphere}}{X}\right)$$

$$= 10 \text{ Log } \left(\frac{4\pi}{0.000377}\right)$$

$$= 45.2 \text{ dB}$$

If we now reduce this by 55% due to inefficiencies of the antenna, the gain is 42.6 dB which agrees with the gain formula above.

Antennas are "reciprocal" and have effective gains in the receive mode as well. An intuitive way of imagining the antenna to have "receiving gain" is to visualize it as a dish intercepting radio waves. The larger the dish, the more waves it intercepts. The more waves, the larger the effective gain. An antenna's transmit gain and receive gain are identical in numerical value (reciprocity).

There is a practical upper limit to the usable size of microwave antennas. If the antenna is too large, the beam will become too narrow to track the incoming receive signal as its arrival angles change due to variations in the atmosphere's refractivity. The practical limit is an indirect function of path length since longer paths will produce larger variations in arrival angles. See Section II.H.2. Assuming a range of "K" values of 2/3 to infinity, the limit is roughly equal to

$$\text{Antenna Diameter Limit in Meters} \approx \frac{2.3 \times 10^6}{(\text{Path Length in km})(F_{MHz})}$$

This limit is usually not approached. A typical 6000 MHz microwave path is 40 km long. The normal antenna size is 2-4 meters in diameter, where the limit of antenna size is

$$= \frac{2.6 \times 10^6}{(40)(6000)} \text{ meters}$$

$$= 10.8 \text{ meters}$$

Other types of common microwave antennas are presented in Figure II-42. Figure II-43 shows their relative advantages and disadvantages.

In almost all applications, microwave antennas are polarized. Antennas with hornfeeds can be singularly polarized, either vertically or horizontally, or dual polarized, both polarities provided. The susceptibility of one polarity to a signal arriving with the opposite polarity is called the cross polar discrimination. Figure II-44 shows a typical cross polar discrimination pattern. Notice that the value of discrimination at zero degrees is 30 dB. This is taken advantage of in frequency plans where adjacent RF channels are placed on opposite polarities.

Antennas are mounted on adjustable mounts. Once in place, the antenna is swung back and forth to ensure that it is pointing in the right direction. The mount is called a panning frame. It is a rugged metal structure capable of being slowly moved manually even during high wind conditions that are common at the tops of towers. Once the antenna position has been optimized, the panning frame is locked in place.

Figure II-45 shows a list of typical antenna characteristics other than the discrimination pattern shown in Figure II-40.

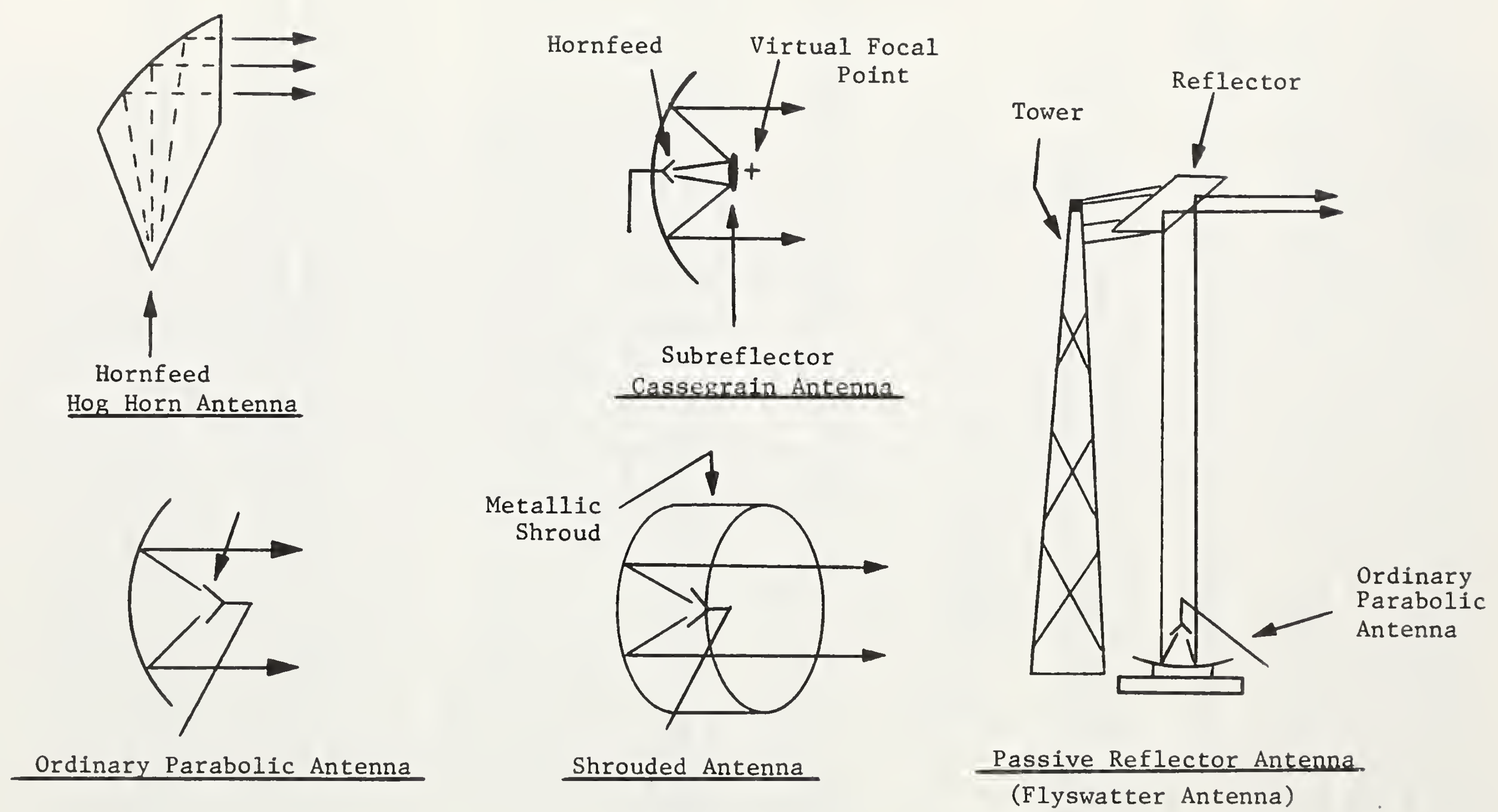


Figure II-42 Antenna Types

Type of Antenna	Advantages	Disadvantages
Horn	High discrimination, handle several microwave bands simultaneously, can use circular hornfeed *	Expensive, large, bulky, increases cost of tower
Cassegrain	High efficiency 72% typical,can use circular hornfeed *	Second sidelobes normally high
Ordinary Parabolic	Cheap, low wind loading, ease of installation	Moderate to poor in discrimination and efficiency
Shrouded	High discrimination	Bulky, more expensive high wind loading
Passive Reflector	No transmission lines required up the tower, reduces net system loss	Illegal except for grandfathered installations, very bad discrimination

* If an antenna can accept a circular hornfeed, circular waveguide can be used to carry both the horizontally and vertically polarized signals. With antennas that provide separate outputs for both polarities, two separate waveguide runs are required, one for each polarity.

Figure II-43 Antenna Comparisons

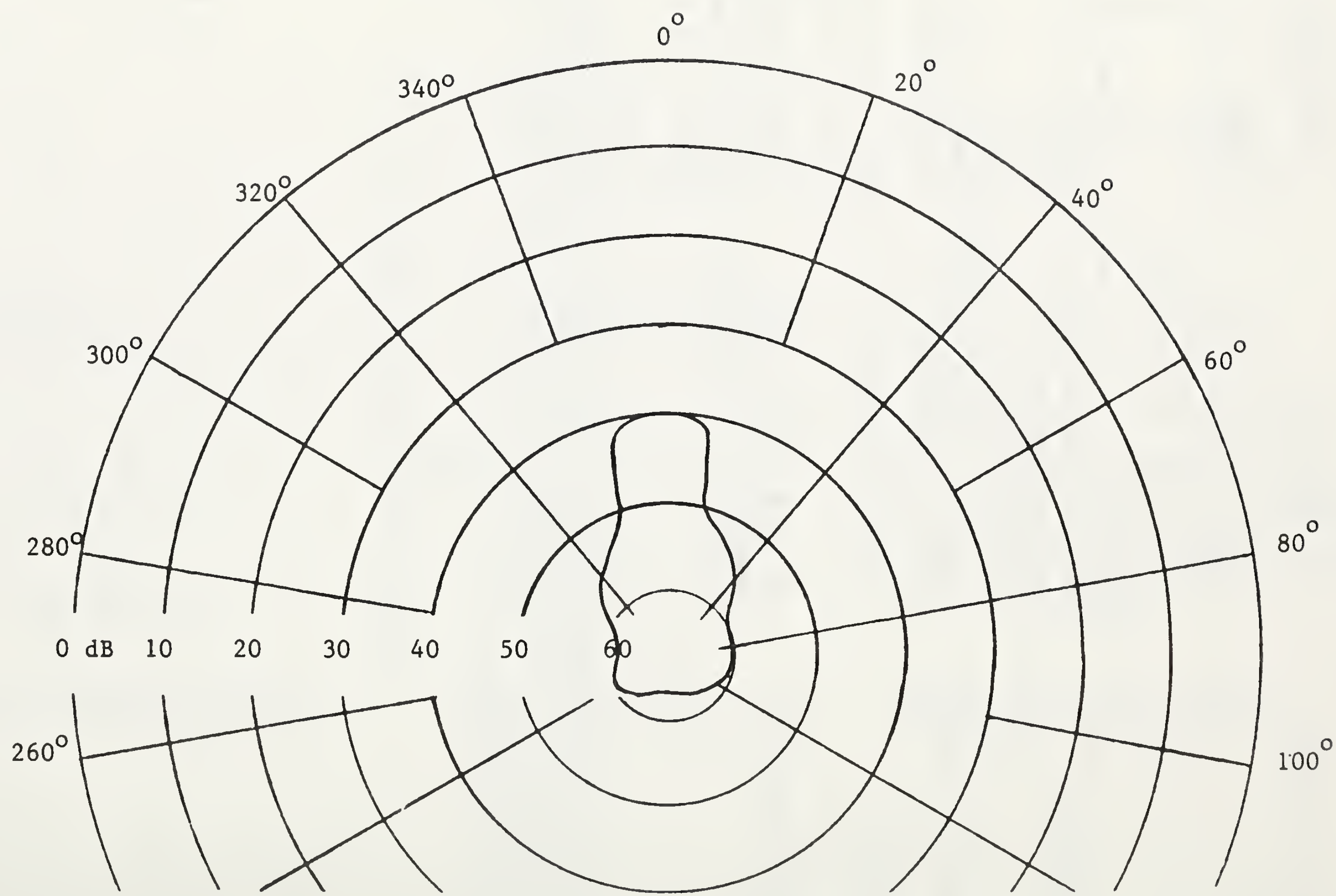


Figure II-44 Cross Polar Discrimination Pattern

	Antenna Characteristic	Value	Notes
1.	VSWR	1.2	For narrow band systems
		1.02 - 1.05	Required for wideband systems
2.	Effective Gain	Varies	Value normally given at mid band
3.	Gain Efficiency	55 - 75%	Depends on type of antenna
4.	Reflector Accuracy	2 - 20 millimeters	RMS deviation from true parabolic shape
5.	Panning Freedom	± 30%	Ability of antenna to be rotated in the panning frame
6.	Wind Loading	Varies	Specified for front, back and side wind directions
7.	Radome and/or Shroud	Physical dimensions	Durability normally given for radomes. Specs state whether radome is heated or not.
8.	Shipping Dimensions and Weights	Number of crates, sizes, is reflector one piece or sectionalized?	Over 10 ft. (3m) size antennas usually cannot be shipped by rail if not sectionalized
9.	Mechanical Dimensions	Varies	Significant in designing antenna mounting and tower dimensions

Figure II-45 Typical Antenna Characteristics

Transmission Lines

Transmission lines are used to carry RF energy between the antenna and the equipment. At the lower microwave frequencies coaxial cable is useful where its attenuation is low. Waveguide is more commonly used at the higher frequencies where it has lower loss than cable.

Figure II-46 gives the relative advantages and disadvantages of the different types of transmission lines. Figure II-47 gives the loss figures for a few coaxial cables. Figure II-48 gives losses for various sizes of waveguide.

Type of Transmission Line	Advantages	Disadvantages
Coaxial Cable	Low cost, easy to install, relatively insensitive to damage during installation, no mode conversion problems, smaller than waveguide at low frequencies.	High loss at higher frequencies.
Rectangular Waveguide	Easy to ship because it is normally made in small sized pieces, lends itself to mechanically complex arrangements, easy to stub tune.	Costly to install, fragile.
Eliptical Waveguide	Easy to install, rugged, small bending radius.	Normally shipped in large awkward drums.
Circular Waveguide	Low loss, easy to ship (small pieces).	Prone to mode conversion, large bending radius, fragile.

Figure II-46 Transmission Lines Comparisons

The major electrical characteristics of transmission lines that concern the microwave system designer are:

- Line loss
- VSWR (see Section II.F.9)
- Mode conversion (see below)
- Intermodulation

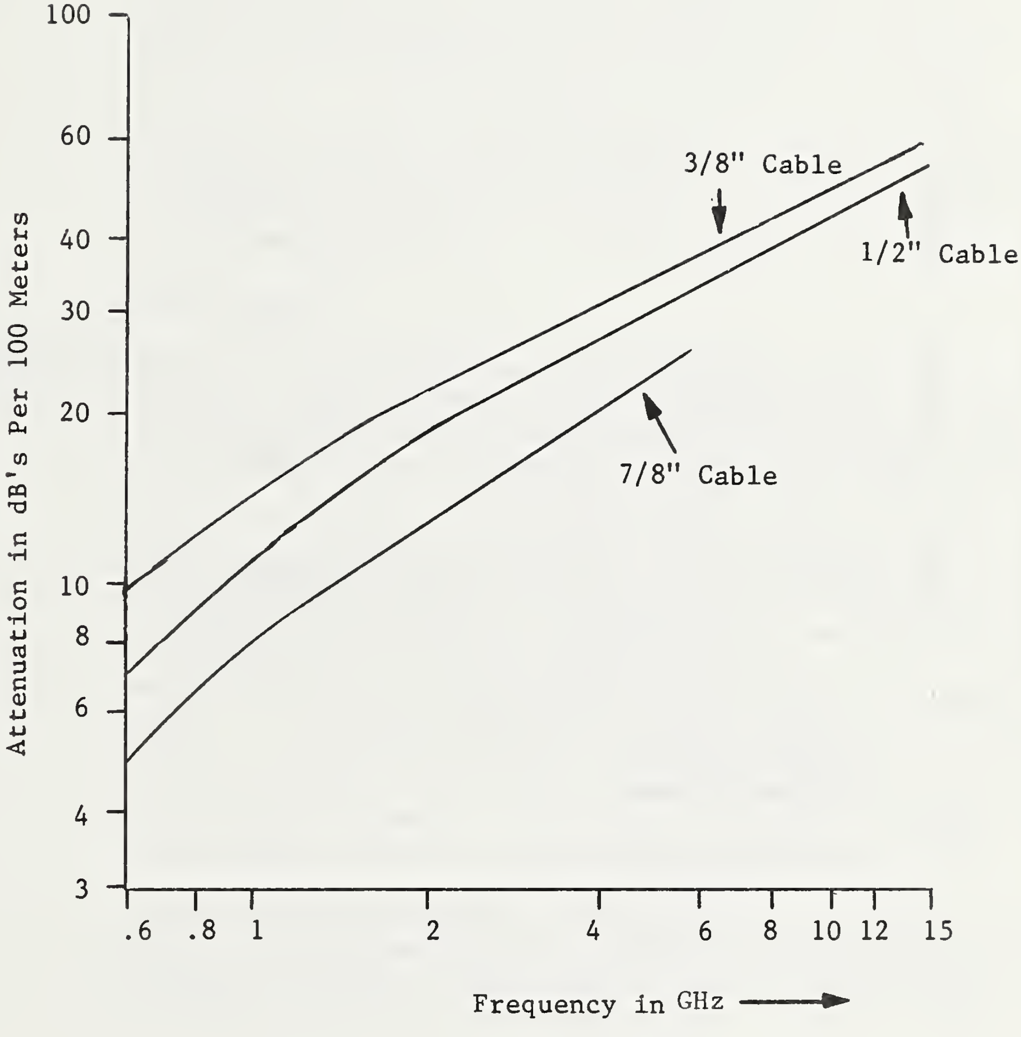


Figure II-47 Coaxial Cable Losses

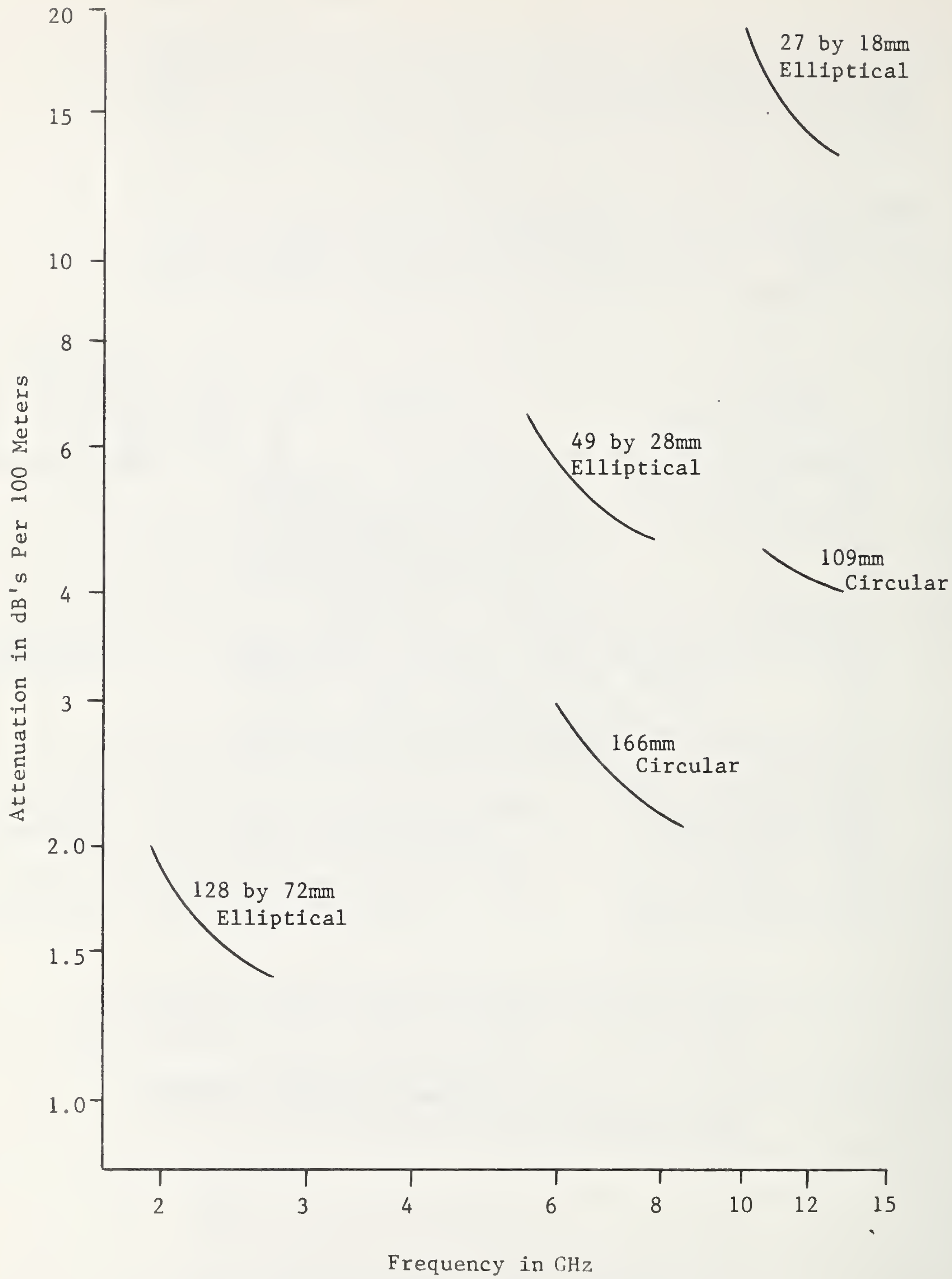


Figure II-48 Waveguide Losses

Line loss is one of the contributors to net path loss. Generally speaking, the higher the line loss, the lower the line cost for a given frequency. More specifically, coaxial cable tends to be cheaper than waveguide; eliptical waveguide is cheaper than circular. In reverse, the loss of cable is higher than waveguide and eliptical higher than circular. One often uses a mixture of transmission line types in a given system depending on each path's transmission loss requirements.

Transmission line loss can have a beneficial effect. If the antenna VSWR is high, the echoes it produces will be attenuated by the transmission line reducing their adverse impact on system performance. See Sections II.F.9 and H.6.e.

Transmission lines also cause VSWR's. The VSWR of an antenna or transmission line causes echoes which in turn may cause echo distortion. This appears as noise in an FDM-FM system. A typical value of VSWR for a transmission line is 1:1.05.

Waveguides

Waveguides are hollow tubes with metallic inner walls. RF energy propagates down the tube at approximately 2/3 the speed of light. The shape of the field in the tube can be one of many combinations of orthogonal electric and magnetic fields. The electric field, for example, might be straight up and down, circular, two fields side by side oppositely polarized, four fields or numerous others. Each configuration is called a "mode". The higher the frequency for a given waveguide, the higher the number of possible modes. More than one mode can be propagated down a waveguide simultaneously. The propagation velocities, called group velocities, of the different modes are slightly different from each other. It is therefore ideal for communications use to have only one mode propagating. To achieve this, the smallest possible waveguide tube is used for a given frequency. This allows the primary mode to propagate while significantly attenuating the higher order modes.

Below a certain frequency, a waveguide will no longer propagate. The frequency at which this occurs is called the "Cutoff" frequency. See Figure II-45 for usable frequencies for various waveguide types and sizes.

If a mode propagates at a slower speed, its frequency is still the same, i.e. 4000 MHz. To account for the same number of sine waves per unit time (so that the frequency remains constant) the phase velocity goes up. When the group velocity goes down, the phase velocity always goes up and vice versa.

Mode conversion is a problem primarily with circular waveguide. As mentioned above there are a number of discrete modes by which electromagnetic energy can propagate down a waveguide travelling at different speeds. Normally, a signal is excited in the waveguide in one mode only. Mechanical irregularities in circular waveguide tend to distort the electromagnetic field of the desired mode in such a way as to convert some of its energy into other modes. The other modes then propagate down the waveguide at different speeds. At the receiver input, the signal appears to be a main signal with echoes. The effect on the system is similar to other echoes which cause the introduction of additional system noise. See Sections II.F.9 & H.6.e.

To reduce the problem, mode traps are installed in the waveguide transmission line. The traps essentially extract the energy being propagated in the undesired modes.

Intermodulation

Discontinuities, corrosion and irregular surfaces in transmission lines can cause intermodulation. Twistable flexible sections of waveguide used for fine alignment of waveguide points are particularly susceptible to intermodulation as are dirty coaxial connectors. The main source of troublesome intermod products is transmission lines carrying two or more transmit signals simultaneously. Three types of intermod products in descending order of importance are produced at frequencies of:

- Receivers using the same waveguide
- Other microwave bands
- Adjacent transmit frequencies

The primary concern is products that interfere directly with receivers using the same waveguide. The products at the receive frequencies measured at the receiver must be some 120 dB below the transmitter power levels involved to avoid harmful effects. To avoid problems, the designer selects frequencies judiciously for both receive and transmit. See Section H for analytic detail. A second method of avoiding the problem is to use separate antennas and transmission lines for receive and transmit. This is a common practice on high density wideband microwave systems.

Products in other microwave bands occur due to intermodulation as well as harmonic distortion of the RF signals. Harmonic distortion will produce signals at 2, 3, 4...n times the fundamental. The higher frequencies have little trouble propagating down the waveguide at higher order modes. Low pass filters are often used in transmission line systems to control harmonic levels.

Intermodulation products may in serious cases interfere with adjacent transmit signals. It is easily detected by alternately turning transmitters on and off and observing the interference.

Waveguide Bends

Eliptical and rectangular waveguides are wider in one direction than the other. The ratio is called the waveguide aspect ratio. It is not a critical ratio and tends to be around 2 to 1. There must be a ratio greater than one in order to excite the proper propagation modes in the waveguide. The ratio cannot be too high or voltage breakdown will occur as the waveguide walls come too close together.

In waveguide the electric field normally peaks between the two closer walls. See Figure II-49.

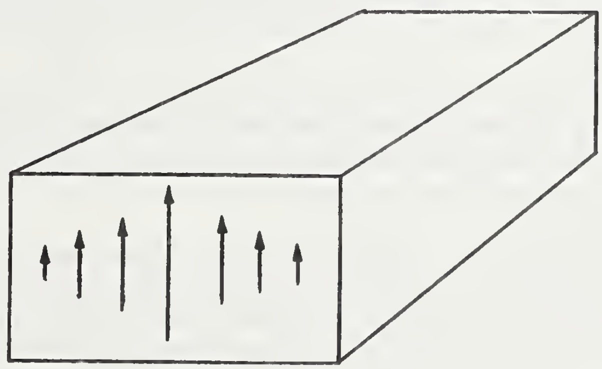


Figure II-49 E Field in a Waveguide

It is possible to bend waveguide. The field inside will turn with the bend. Waveguide can also be twisted and still propagate the signal. This is often done to line up waveguide flanges or joints that are otherwise at different angles.

There are two common types of waveguide bends. One is an E bend, the other is an H bend. The reason for the two types is strictly a matter of mechanical shaping to fit a particular bending requirement. The E bend bends the E field. See Figure II-50.

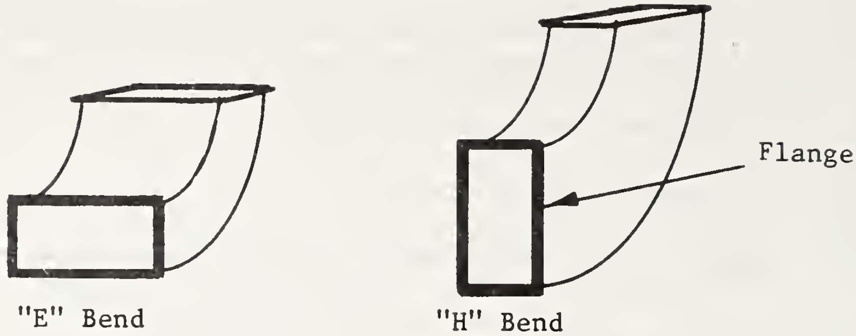


Figure II-50   Waveguide Bends

7. RF Branching

The purpose of RF branching is to connect more than one piece of RF equipment to a single transmission line. This eliminates the use of multiple transmission lines. In most cases it is cheaper to use RF branching than run multiple lines, but not always. A case by case examination will determine which is cheaper.

There are several methods of branching available. This section discusses methods using circulators only since it is the most commonly accepted method.

Circulators are passive magnetic devices with three RF ports or connections. Magnetic material inside the device rotates the phase of signals 180° in such a way as to cause desired cancellations in one direction and enhancement in the other. Figure II-51 is the common schematic symbol of the circulator.

Figure II-51   Circulator

Any RF energy entering port 1 comes out port 2 but not port 3 due to desired cancellations that take place in the circulator. Energy into port 2 comes out port 3 and not port 1. Energy in 3 comes out 1 only. The arrow indicates the direction of energy flow.

Figures II-52 through II-54 show circulator applications in RF branching.

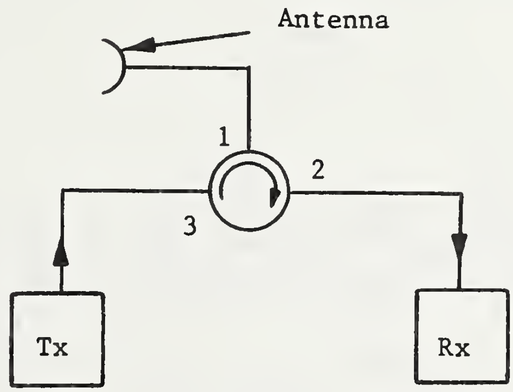


Figure II-52 Circulator Application 1

In Figure II-52 the transmit energy enters port 3 and comes out port 1. The receive energy from the antenna enters port 1 and comes out port 2 and on to the receiver.

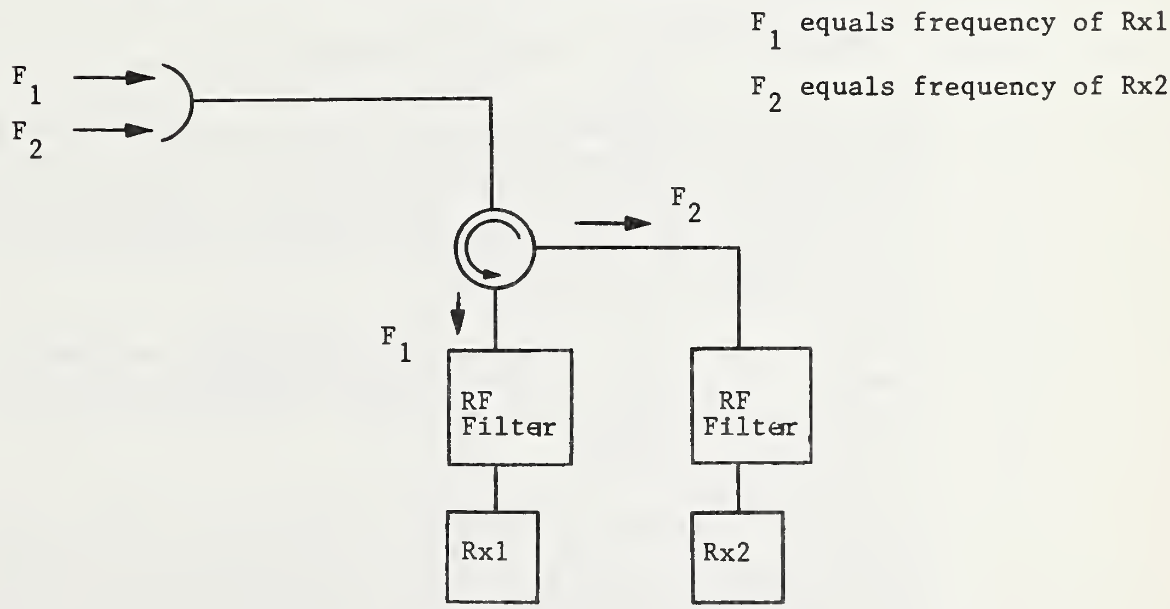


Figure II-53 Circulator Application 2

Both F_1 and F_2 enter port 1 and both exit at port 2. F_1 then goes through the RF filter 1. F_2 bounces off the face of RF filter 1 and returns to port 2. It then emerges at port 3 where it continues on to Rx2.

If we combine the principles of Figures II-52 and II-53 we can construct II-54.

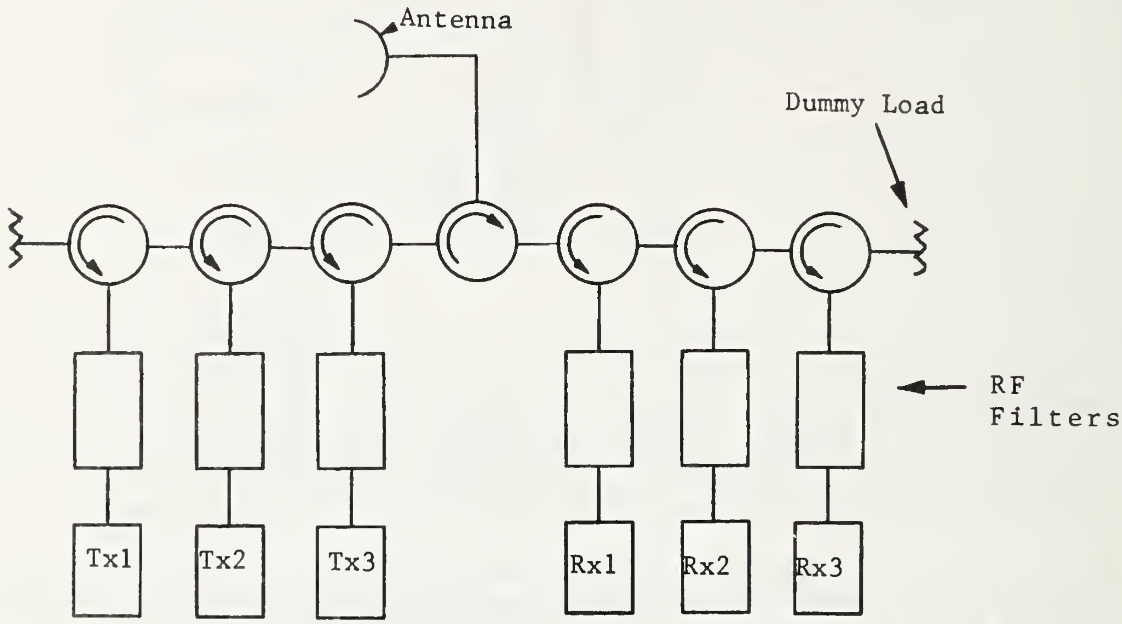


Figure II-54 Circulator Application 3

Circulators are installed on the ends and are connected to dummy loads. The dummy load is a resistive load that absorbs stray RF energy in the system caused by RF reflections. The circulator is installed to ensure that the stray energy is fed to the dummy load rather than be allowed to continue in the system causing echo distortion.

Circulator ports are either waveguide (usually rectangular flanges) or coaxial. They are normally mounted above the radio equipment in the RF branching. Typical loss through a circulator is 0.2 dB.

In microwave systems it is often necessary to install rejection filters to reject unwanted signals. The filters are normally included in the RF branching. Also, low pass filters are commonly placed in the branching to eliminate transmitter harmonics. Figure II-55 shows a more detailed layout of branching with these various elements installed.

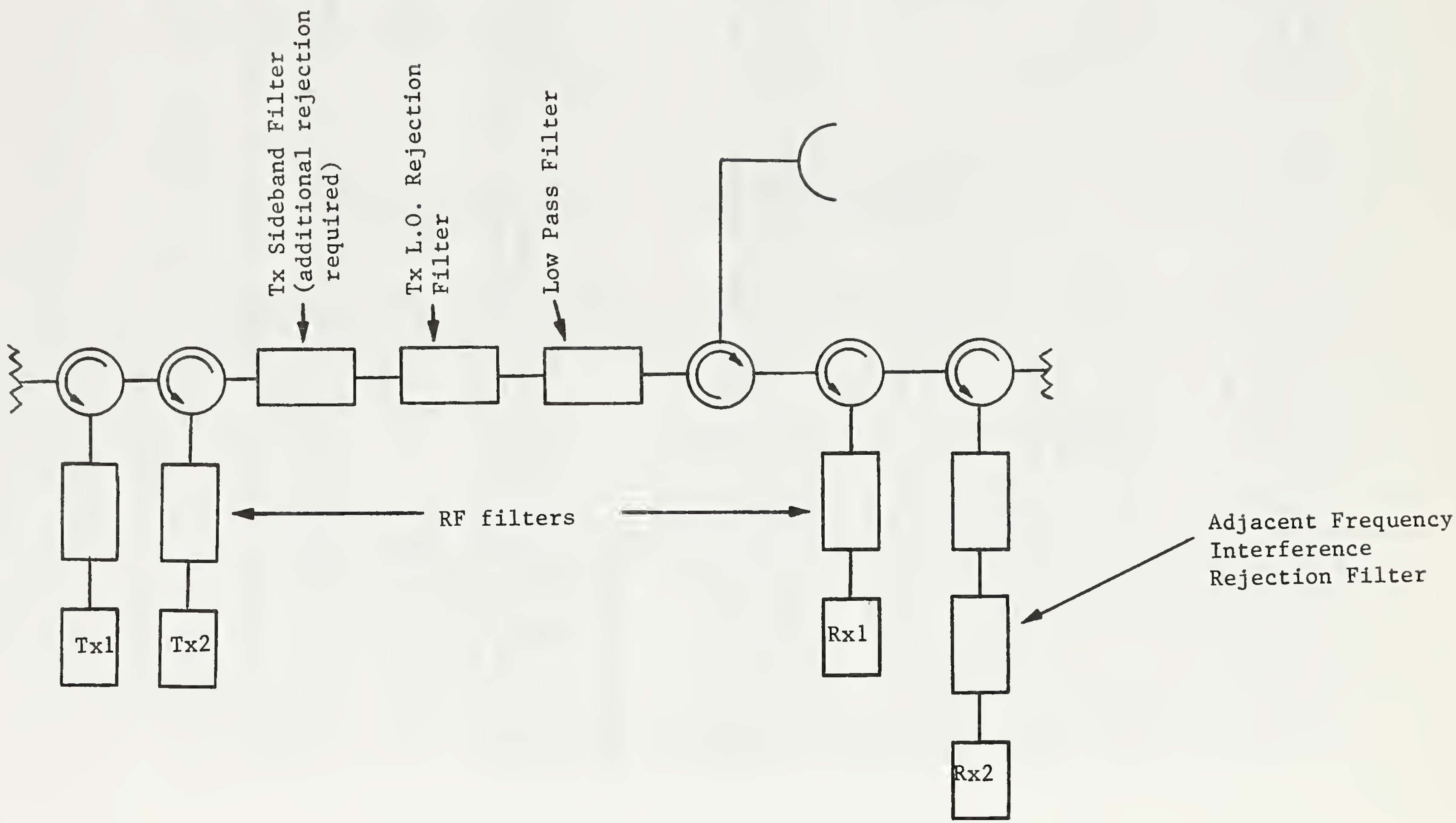


Figure II-55 RF Branching System

Circulators are not perfect. Some energy does leak to the wrong port. It is usually 30 dB or more below the energy at the correct port. This can appear as an echo signal in the system. Consider Figure II-53. At port 3 there will be the main signal F_2 which has bounced off RF Filter 1. There will also be F_2 30 dB down that has leaked across the circulator directly from port 1 to port 3. The receiver sees two signals displaced slightly in time, one 30 dB below the other. Since the two signals are identical in content they appear as a main signal and its echo. The impact of echo distortion is less if the time displacement between the main signal and the echo are small. See Section H.6.e. To achieve a small time displacement, the distance between the RF filter 1 and circulator port 2 should be kept to a minimum. The transmit and receive filters are therefore mechanically included in the RF branching. The distances involved are usually on the order of 10 cm but can in certain cases be 1-2 meters. It depends on system tolerances to noise and channel capacity.

A common practice in multi RF channel wideband systems is to place adjacent channels on opposite polarities. This adds an additional 30-35 dB of suppression of adjacent channels due to the antenna's cross polar discrimination. The branching can be configured as shown in Figure II-56.

8. <u>Orderwire System</u>

For intrasystem surveillance and maintenance many microwave systems are equipped with a voice communications system separate from the main message baseband spectrum. The basic types of orderwire channels are:

- Local orderwire - a party line with all radio stations having access
- Express orderwire - voice circuit between major terminals or control points only
- Alarm channels for routing system alarm and control data
- Special channels for external control functions, i.e. control circuits transmitted with TV signals to control the remote TV transmitter stations
- Low speed teleprinter channels.

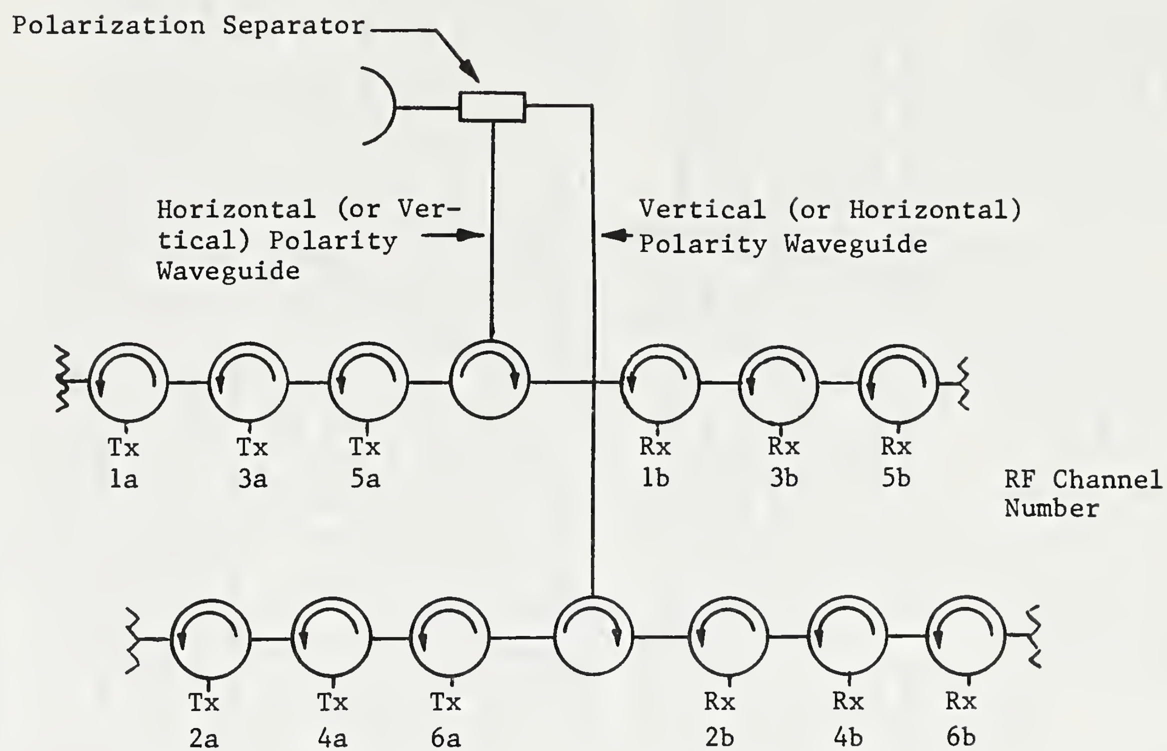


Figure II-56 RF Branching Uaing Both Antenna Polarities

The orderwire system consists of voice channel multiplex equipment and associated signaling and voice interface circuitry. Figure II-57 shows the basic equipment configuration of an order wire system.

Local and express orderwire systems are usually "holler down" or "dial up" types. In the "holler down" system, every station has a loud speaker permanently wired to the orderwire channel. To contact site personnel a tone or verbal announcement is sent simultaneously to all sites. The site personnel answer in kind using a hand telephone set or microphone.

The "holler down" system is a relatively inexpensive system but has no privacy. Also, irrelevant conversations become annoying when the system is used heavily. In such cases the speaker is often turned off, which breaks possible contact with personnel at the remote station. The "dial up" system, on the other hand, provides each station with an access code of its own plus an "all call" code. This system can be designed to lock out all stations except the called and calling stations to provide privacy. The dialing system can be provided with touch pad or rotary dialing.

Normally there are from 1 to 12 voice channels provided on orderwire systems. They are multiplexed together and occupy spectrum either below or above the baseband. In telephony systems, they can be placed either above or below. If the system is handling TV, however, the orderwire must go above the baseband because the TV signal occupies the entire baseband spectrum from DC up to the sound carriers. This leaves no room below the baseband for the orderwire. When designing an orderwire system, it is preferable to put the orderwire below the baseband because FM system noise is generally less there than above the baseband. Aside from echo and noise, orderwire channels have technical performance characteristics similar to message voice channels. Echoes can become a problem with orderwire systems because of the many party drop points that commonly exist on them. Push-to-talk microphones, careful impedance matching and proper system alignment are usually sufficient to avoid excessive echo problems.

Note: Frequency of 4 Way Bridge May Be Above or Below the Baseband

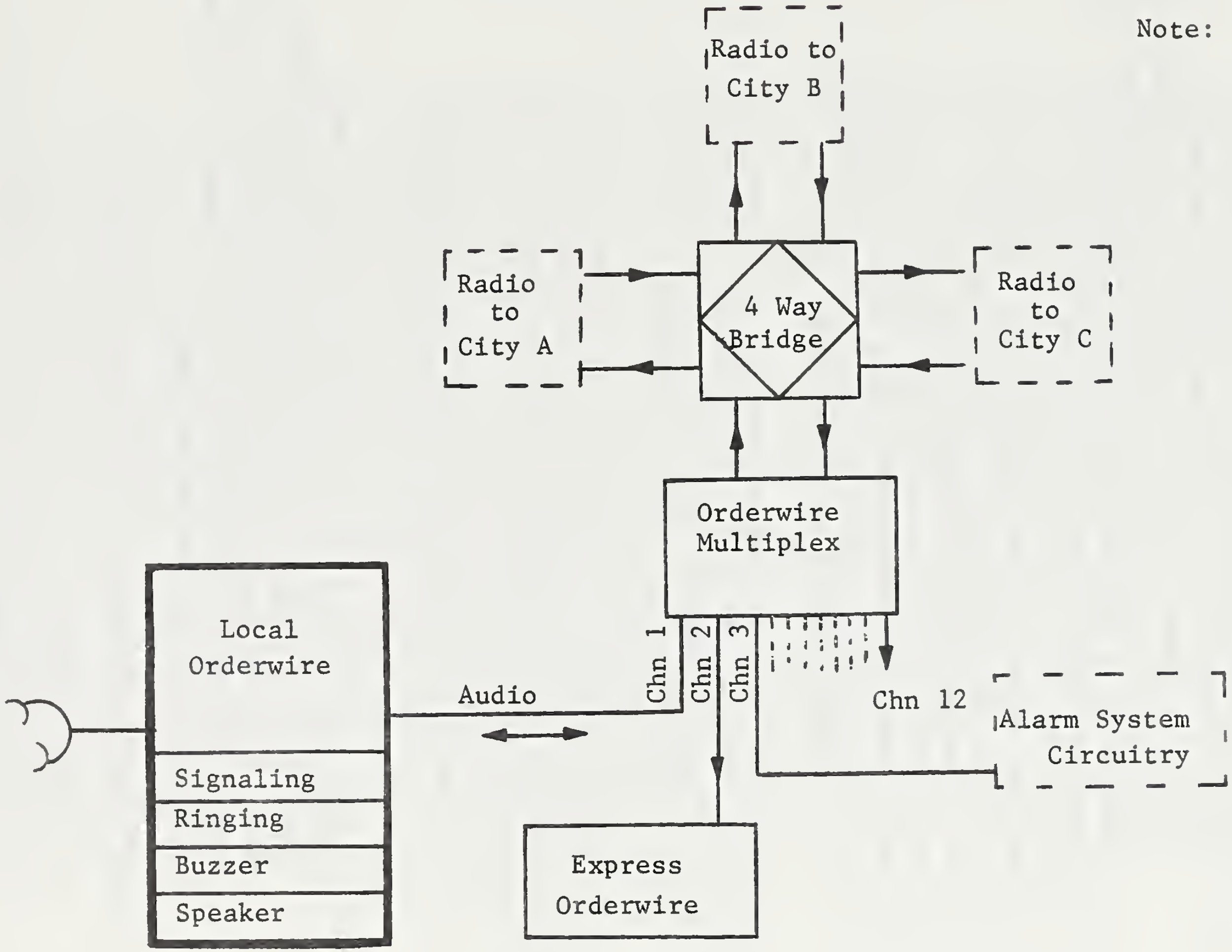


Figure II-57 Basic Orderwire Configuration at a Three Way RF Repeater

The noise performance requirements of orderwire systems are normally not as high as message baseband channels. It is often impossible to achieve good noise performance above the baseband; but communications maintenance personnel can normally function adequately with lower grade circuits. In recognition of this, the orderwire per channel deviation is usually much less than that of the message baseband. It is typically 10 dB in power less than test tones in the baseband, which helps to avoid overloads of the radio system.

9. Alarm and Control Systems

Because of the cost of labor and associated support expenses, modern microwave systems use unmanned repeater stations. It is therefore most useful to remote a number of important alarm and control functions back to the manned terminals. The more common remoted alarm or status functions are:

- Major/minor alarm (urgency of the alarm)
- Transmitter failure direction A
- Transmitter failure direction B
- Receiver failure direction A
- Receiver failure direction B
- Illegal entry
- Power failure
- Tower light failure
- Multiplex failure
- Transfer to protection channel direction A
- Transfer to protection channel direction B

These functions can be expanded considerably depending on the data carrying capacity of the alarm system itself. It is common to elaborate on equipment failure modes to allow for better diagnosis of system faults. For example, the Power Failure Alarm could be broken into:

- Low fuel alarm
- Over voltage
- Under voltage

- Failure of commercial power

- Failure of standby generator to activate

Even more elaborate information is possible such as exact fuel level status or exact voltage level. The system designer makes trade offs of reliability/availability and cost factors in the design of the system.

When additional radio channels are added to the system there will be a corresponding increase in the number of alarm functions to be remoted. This is normally accounted for in the original design.

The Major/Minor Alarm is an indication of whether a given failure has interrupted or excessively degraded the system. In a hot standby system one transmitter failure is a minor alarm. Both transmitters failed is a major. One transmitter failure and lack of switching to a protection channel is a major failure. Illegal entry is usually considered major. The system designer arranges the alarm system logic to evaluate all the possible failure modes for major/minor decisions. The major/minor decision alarm is then transmitted back to the central control point with the individual alarms.

Many towers are required to have aeronautical beacon lights on the top. If the light fails, the FAA must be notified if it is not turned back on again within 24 hours. An alarm function is therefore provided to monitor tower lights.

If the alarm system is limited in capacity, alarms can be grouped together. At a repeater, alarms for ancillary equipment, orderwire and test apparatus can be grouped together as one alarm function with the multiplex. Then, if the Orderwire System has a failure, the control station will receive a "Minor Multiplex" alarm. If the multiplex itself fails entirely, a "Major Multiplex" alarm could appear.

Remote Control functions can also be built into the system. The types of remote control functions include:

- Polling of alarm status (optional)

- Switch a channel to the protection channel

- Disconnect a transmitter or receiver from the link because of some equipment fault

- Transfer to or from commercial power

- Activate standby generator

- Activate audible alarms

Common uses of the control system include testing of the protection switching system. A command is sent to a station to switch one channel to the protection channel. The alarm system automatically will return a status report back stating the condition of the switch. Control systems can be used to monitor the functioning of standby power systems by activating switches and turning on standby power sources.

Alarms and control commands are normally sent via low speed data carried by voice channels in the Orderwire System. Alternate routes for the alarm data and control circuits are possible but are usually either more costly or less convenient. Three common alternate techniques are land lines, separate radio channels and the use of voice channels in the message baseband.

Figure II- 58 shows the basic structure of an alarm and control system. In Figure II-59 the 4 way audio bridge is provided to pass through alarm signals from repeater stations further down the system. With "drop and insert" radio, however, the bridge is not required since the signals from further down remain on the modulated carrier as it passes through the station.

The Control Display and Control Consoles are the central control facilities of the alarm and control system. These facilities contain features that depend on the type of alarm system used. Some of the design features often included are:

- Visual lighted displays of alarms and control status, wall maps of the system or banks of lights

- Data buffering for slow scanning techniques

- Hard copy printers for permanent status reports

- Orderwire appearances for voice coordination

- Alarm display, poling and command control activators.

There are numerous modulation schemes used in alarm and control systems. A simpler method is frequency division within a voice channel. Each remote station is assigned a single audio frequency on which to operate. A narrow band frequency shift keyed (FSK) data modem at each site is centered on the assigned station frequency. Alarm status is continuously transmitted back to the control station. The control station can then have on line or selective monitoring of all remote stations.

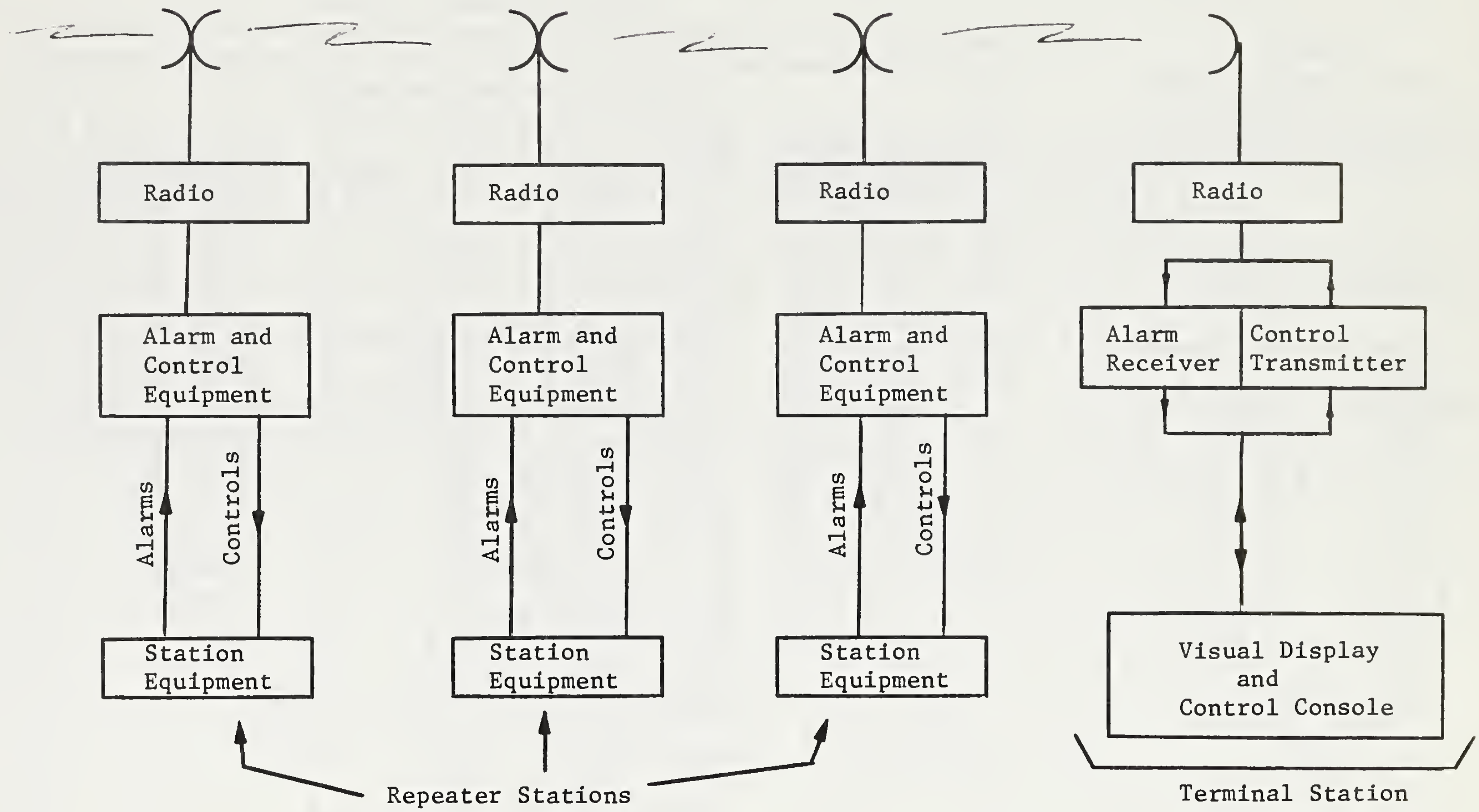


Figure II-58 Basic Structure of an Alarm and Control System

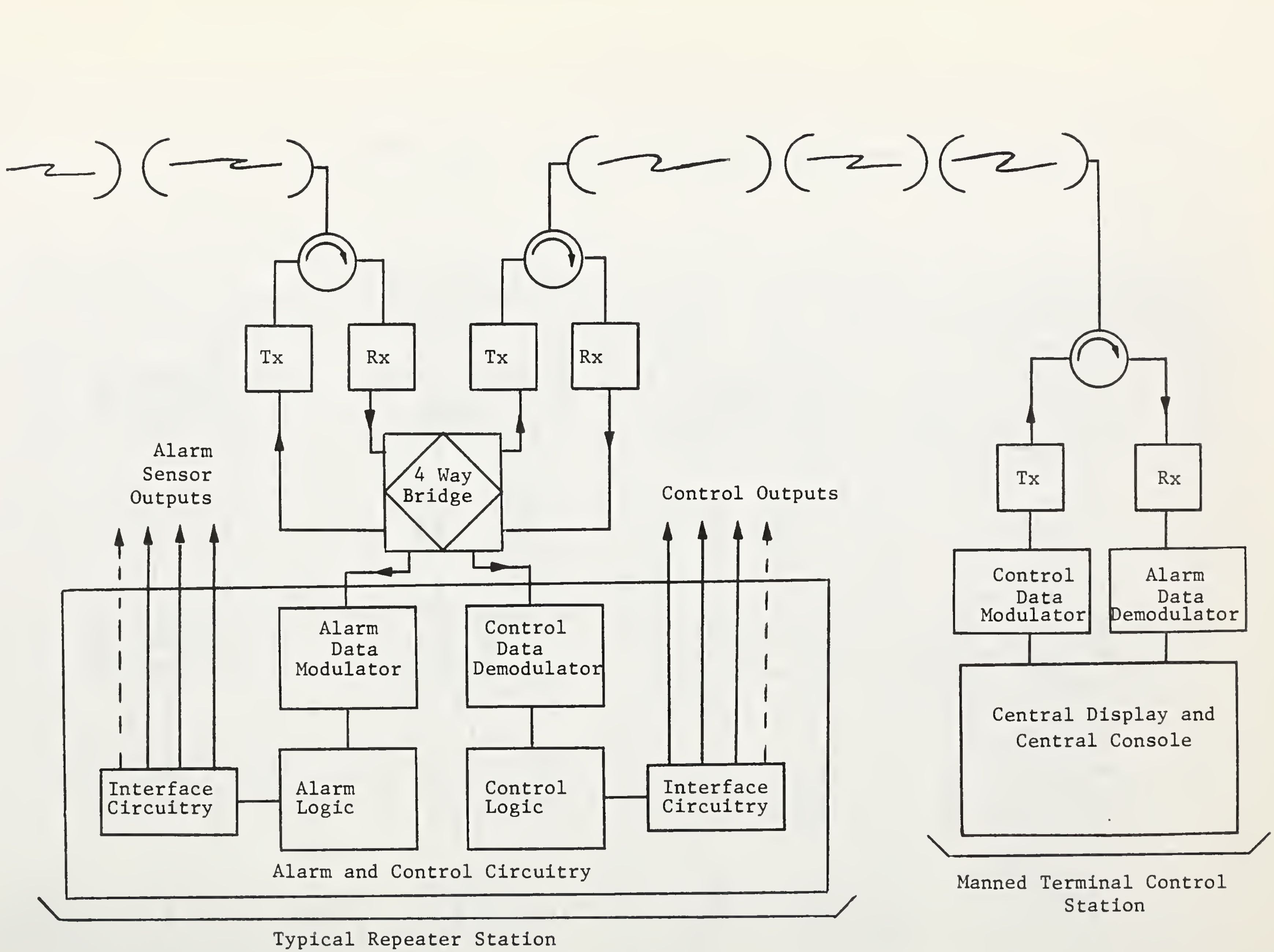


Figure II-59 Basic Equipment of an Alarm and Control System

This system has a practical limitation since the number of available FSK channels within a voice channel is normally limited to a maximum of 32. The maximum of the system would therefore be only 32 remote stations per channel.

An alternative to this limitation is the use of a polling system. In a polling system all the remote stations continuously monitor fault sensors, but no data is transmitted until the station is polled by the central controlling station. The central control station has an alarm "Master" station which automatically scans the remote stations polling them in order by sending out digitally encoded station call signs. All the remote stations continuously monitor the one polling frequency for their own call sign. When a remote station does receive its own call sign, it acknowledges the call by transmitting a burst of data back to the Master giving current alarm status. The number of remote stations that can be connected to the system is considerably greater since the number is limited only to the number of possible code combinations. If the station ID code is an 8 bit binary code, $2^8 = 256$ remote stations could be connected to the one voice channel. The practical limit becomes the time it takes the Master to survey all the stations. Typical cycle times are 10-100 seconds to complete the polling of all stations in a system.

When a Master receives a data burst back from a remote station with no faults to report, it cycles on to the next station. If there is a fault, an audible alarm is sounded to alert maintenance personnel. The Master might then store the alarm data in a buffer and continue cycling, or it might stop and wait for manual instructions from an attendant. The audio alarm is responded to by the resident maintenance person who analyzes the fault and takes appropriate action.

When designing an alarm and control system, the following factors are analyzed:

- Cost
- Number of stations
- Number of functions per station
- Cycle time requirements
- Future expansion requirements
- Hard copy requirements
- Automation of alternate route selection in the case of major failures

- Alternate routing of alarm signals
- Visual display requirements

10. Termination Equipment

By termination equipment is meant the voice channel equipment used to interface the 4 wire voice multiplex channels with end user items. These equipments are used to provide:

- Interface of 4 wire multiplex with 2 or 4 wire devices or circuits
- Generation and detection of signaling tones
- Level compatibility
- Impedance matching
- Frequency/amplitude equalization
- Delay equalization

a. Hybrid

Most telephone instruments are two wire devices yet transmission systems are 4 wire. To interface them a hybrid is used. Figure II-60 shows the basic function of a hybrid. Its functions are to direct the electrical energy coming into the hybrid from the phone to the transmit port and direct the receive port energy to the two wire port. The critical function of the hybrid is to prevent receive energy from leaking over to the transmit port. If energy does leak over, it returns to the distant end of the circuit as an echo. If the echo is at a high enough level, singing occurs as the circuit bursts into oscillation.

To comprehend the operation of an inductive hybrid (one using inductive transformers) observe Figure II-60. Voltage E_1 is the incoming receive signal. E_2 and E_3 are induced in the receive transformer. All the coil windings L_2, L_3, L_4 and L_5 are equal so E_2 is equal to E_3. Now, if the impedance of the telephone is the same as the compensation network, then i_1 is equal to i_2. In that case E_4 and E_5 are equal and opposite. The voltage E_6 is therefore zero and no energy goes out the transmit port. At the same time, half the energy entering the receive port is sent to the telephone and the other half is dissipated in the compensation network. The actual isolation between the receive and transmit ports is typically 50-60 dB if the compensation network exactly matches the impedance of the telephone or other device connected to the 2 wire port. Hybrids often have options to change the impedance of the compensation network to match various impedances connected to the 2 wire port. Some hybrids also provide wire terminals to connect external precision compensation networks. The ability of a hybrid to isolate the receive and transmit ports is called the trans-hybrid loss. In practice 8 to 30 dB is experienced due to variations in 2 wire local loop impedances and uncompensated reactive components of loop impedance or those of the instruments attached to the loop.

Figure II-61 shows a more complete diagram of a hybrid. C_1 is a DC blocking capacitor which is transparent to voice frequencies. The A and B leads are DC control leads derived from the 2 wire circuit. They are used for supervision and control. The F and G leads are the external connection points for connecting an external precision compensation network.

Care should be taken not to allow excessively unequal current on the A and B leads. T_3's primary coil will form a magnetic bias if the currents on the A and B leads are not equal and opposite. Most hybrids will handle up to 50 or 100 mA of current imbalance in the two leads. Beyond that point the transformer's magnetic field is no longer a linear function of its current. This nonlinearity upsets the impedance balance between the compensation network and the 2 wire port and therefore reduces the trans-hybrid loss. For this reason, a hybrid's rated trans-hybrid loss is specified for a maximum current imbalance on the 2 wire port. A typical specification is 50 dB trans-hybrid loss with a maximum of 100 mA 2 wire current imbalance.

Hybrids are usually mounted in equipment shelves that mount in standard equipment racks.

b. Single Frequency Signaling

Historically in the telephone environment, signaling pulses have been DC in nature. Dial pulses from a phone for example are DC pulses. DC will not pass through FDM multiplex, however, nor through many other transmission facilities. To transmit the signaling information over such facilities, the DC pulses are converted to VF tones that can be transmitted over a 4 kHz voice channel. At the receive end, the tones are detected and converted back to DC pulses, reproducing the original signaling pulses in DC format. The same technique is used for data transmission and telemetry.

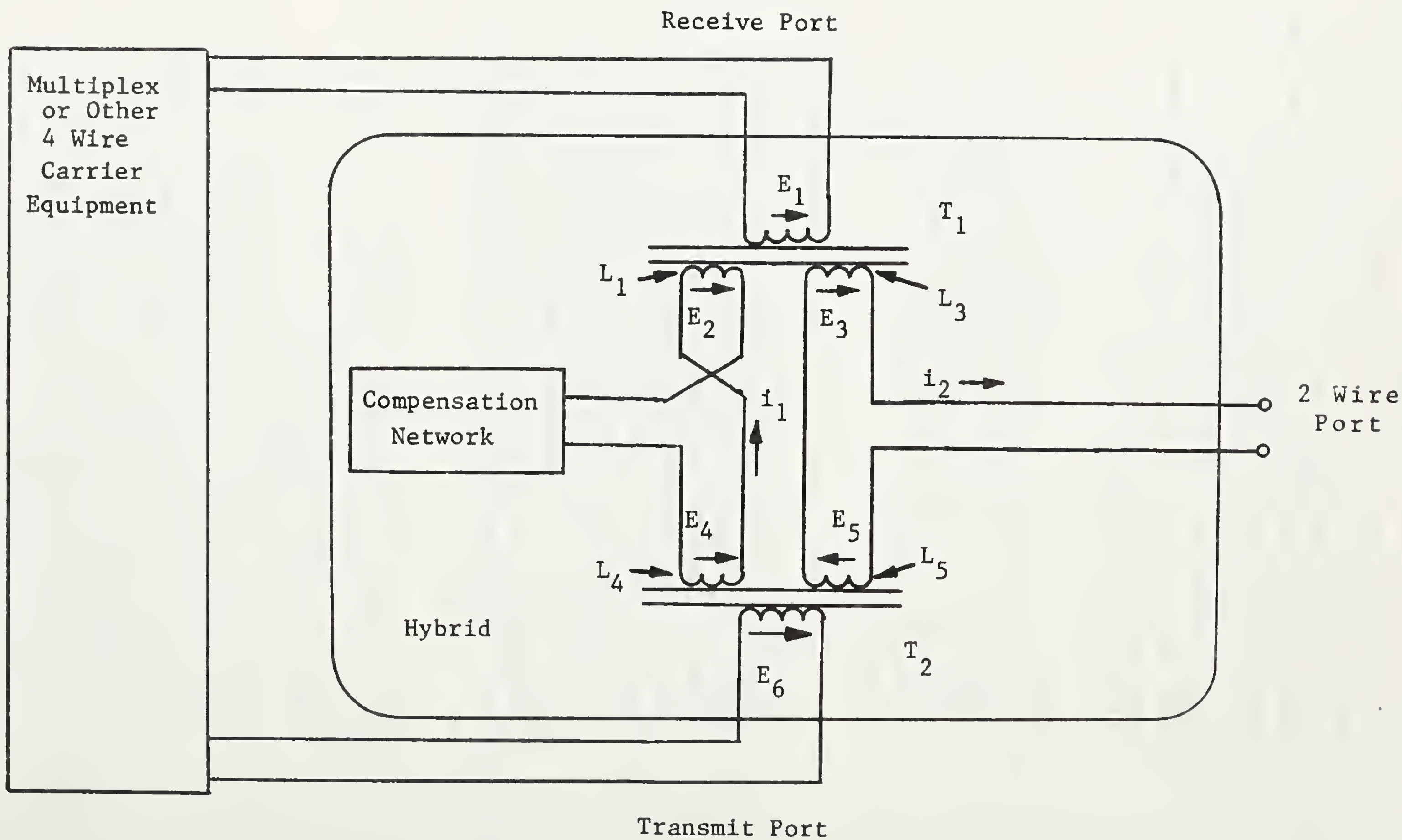


Figure II-60 Hybrid

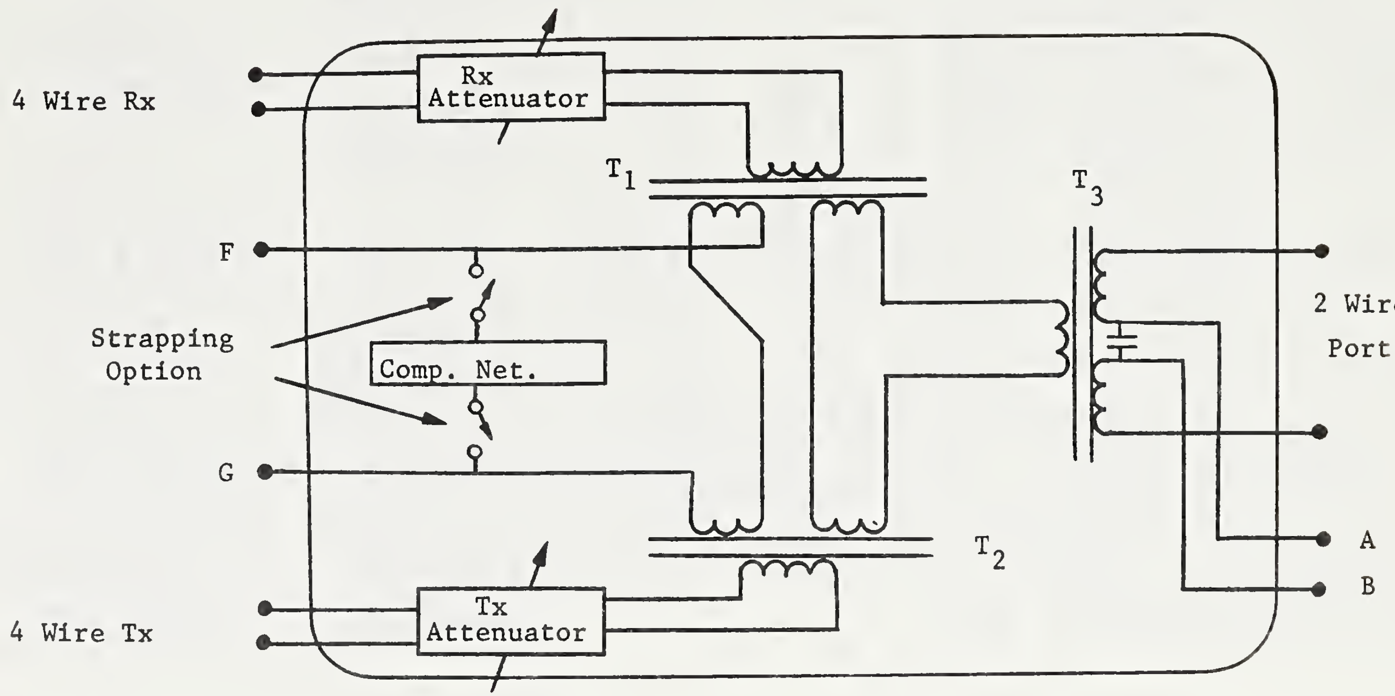


Figure II-61 Hybrid Connections

In converting the DC pulses to VF tones, numerous forms of modulation are possible. The one considered here is the Single Frequency (SF) method. (This is not to be confused with Signal Frequency.) In SF the DC pulses are used to turn on and off an oscillator which has a discrete single frequency. Industry practices tend to use the following frequencies for SF: 1600 Hz (military), 2600 Hz (telephone systems) and 3825 Hz or 3850 Hz (dedicated systems, private users and others). There are other frequencies used but these are the most prevalent. The 1600 Hz and 2600 Hz frequencies are called "in band" frequencies since they are within the passband of a mux voice channel. The 3825 Hz and 3850 Hz are called "out-of-band" frequencies since they lie just above the voice signal in a mux channel but within the 4 kHz assigned spectrum. The injection and detection of the in and out-of-band SF tones is shown in Figure II-62.

There are a number of technical parameters associated with single frequency equipment worth noting:

- Output pulse width should be standard.

- Rise time and fall time of the output DC pulses should be short to produce square pulses. Twelve microseconds is typical.

- In band tone detectors should not be overly sensitive to voice energy at the SF frequency. Detectors typically require a steady tone of 30-100 milliseconds to recognize a signaling pulse. This allows the detector to differentiate between SF tones and voice.

The advantage of inband SF is its ability to be sent over numerous tandem transmission systems without being reconstituted. An out-of-band SF must be reconverted back to DC or a lower frequency tone every time the circuit it accompanies passes through a channel demodulator, because most transmission facilities will not pass frequencies as high as out-of-band SF.

On the other hand, out-of-band SF is normally cheaper if reconstitution is not required. This is often an advantage in systems where traffic travels between two fixed points without the probability of being re-routed or switched onto other transmission facilities. Such is often the case with dedicated private systems such as the systems used in the power industry.

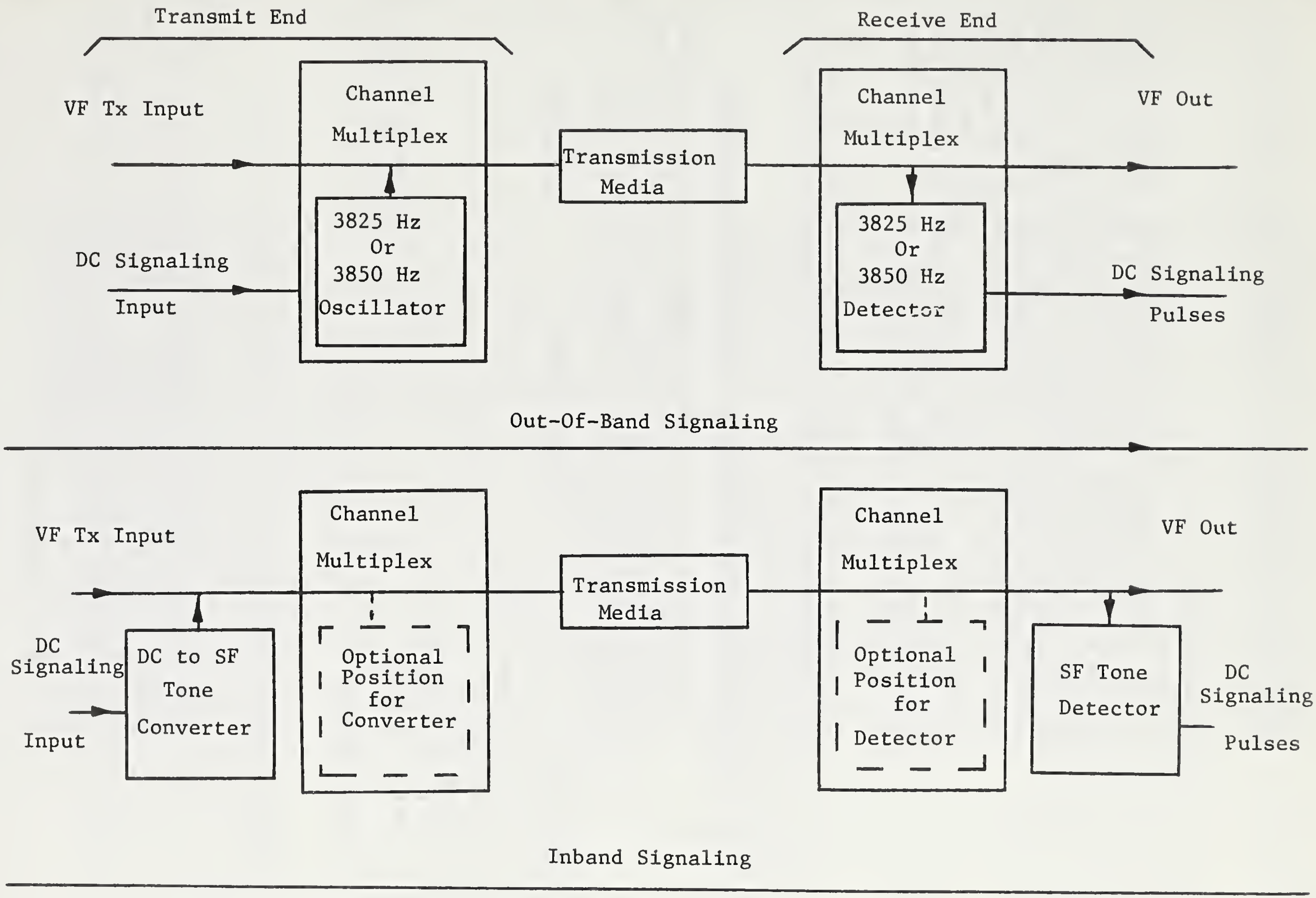


Figure II-62 Single Frequency (SF) Signaling Systems

Multiplex systems often have the signaling functions built in. An oscillator is provided in the channel modulator card and a detector in the demod side.

c. E&M Signaling

SF oscillator units are activated by a DC voltage of -48 Vdc on a two state control lead called the M lead. The M lead is grounded in one state and -48 Vdc in the other. Either state can be interpreted as "on" and the other "off". The two states are also called "busy" and "idle". Commonly the grounded state is considered idle. At the receive end, the SF unit detects the presence of the SF tone and causes a ground to be applied to a DC control lead called the E lead. The two states of the E lead are ground and open. As with the M lead either state can be considered idle although "open" is the more common.

To remember which lead is the M lead and which is the E lead, equate M with "mouth" (for transmit) and E with "ear" (for receive).

d. Amplifiers and Attenuators, System Level Adjustments

A comprehensive system design includes a complete diagram of all signal power levels throughout a system. The communications industry has evolved a number of standard levels for different system points as noted in Figure II-63.

System Point	Level in dBm	Impedance
Multiplex voice channel output	+7	
Hybrid receive input	+7	
Hybrid 2 wire output	+0	
Hybrid receive 2 wire input	+0 to -12.5	
Hybrid transmit output	-13.5 to -16	(Variable in the hybrid if required)
Input to multiplex Tx	-16	

Figure II-63 Standard System Voice Channel Test Tone Levels

Manufacturers often accommodate a range of levels in their specifications, so it is advisable to establish a fixed standard for each system point and ensure that given equipment is within the range of the established standards. It is possible to construct a system with little standardization of levels but such proves to be unwieldy in view of maintenance considerations.

To ensure level compatibility, attenuators and/or amplifiers may be inserted in the voice circuit. Attenuators are cheaper than amplifiers and good system design reflects this.

Attenuators are available in fixed, strappable and knob adjustable versions. They normally have excellent delay and frequency response characteristics. The only technical factors of concern generally are the range of adjustment, size of incremental steps and input signal power level limits. This latter point may be of importance in a circuit where the attenuator could be exposed to high voltages such as:

- Ringing voltage, i.e. 20 Hz 105 Vac
- Teletype signals 130, 260 Vdc
- Battery voltage 48 Vdc

Amplifiers are more costly and tend to cause greater signal distortion than attenuators. They also require some type of primary power. Besides the obvious problem of excessive input levels, amplifiers are specified to meet standards of:

- Gain stability
- Sensitivity to power voltage variation
- Dynamic range of gain adjustment
- Maximum output
- Harmonic distortion
- Noise
- Envelope delay distortion
- Frequency response.

Most systems have built in test facilities where all circuit levels are equal for all transmit levels and at a different level for all receive. A rare concept is a test facility where all receive <u>and</u> transmit levels are equal. It is called an "equi-level board" and exists in some unique systems. Additional amplifiers and/or attenuators are used to adjust levels to a common level for both transmit and receive. A common practice is to set all levels to -2 dBm at the equi-level board.

e. Impedance Matching Devices

An electronic voice equipment parameter of significance is impedance. Impedances have resistive and reactive components. In voice communications, it is usually sufficient to account for the resistive component. See Section II.F.9.

Voice equipments typically have rated input and output impedances. The output impedance of one device should be the same as the input impedance of the device it feeds. Mismatches cause a loss of power transfer and reflections (echoes). Figure II-64 lists some of the common impedance mismatch situations. If two impedances are different, an impedance matching device can be provided.

Resistive impedance matching devices are naturally the cheapest but they impose an additional circuit loss of at least 6 dB. If such a loss cannot be tolerated, the next cheapest device is usually an inductive transformer of sorts; the next an active device which includes an amplifier.

Device	Impedance	To Be Interfaced With	Impedance
Telephone Instrument	900 ohms	Hybrid	600 ohms
Group Multiplexer	75	Supergroup Multiplexer	150
Transmitter	50	Transmission Line	75
Radio	50	Modulator	75
SF Unit	600	Bridging Test Equipment	Infinite

Figure II-64 Typical Cases of Impedance Mismatches

Suffice it to say impedance mismatch is a commanding problem in communications that always requires the closest attention.

f. Amplitude Equalizers

Transmission facilities tend to amplify or attenuate some voice frequencies more than others. If we plot a graph of a circuit's net gain versus frequency, undoubtedly we find something other than a flat line. See Figure II-65.

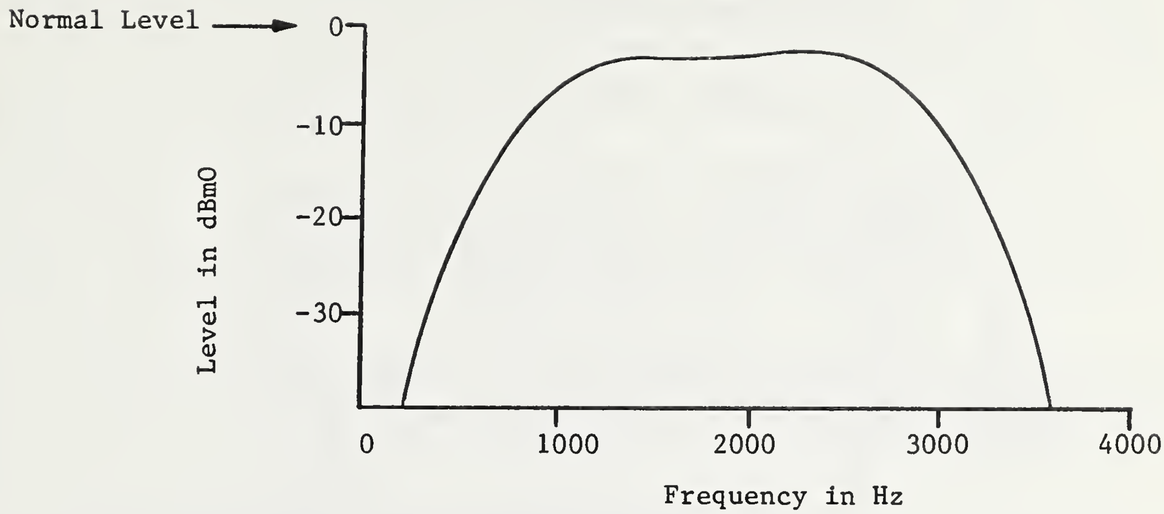


Figure II-65 Typical Plot of Amplitude vs. Frequency for a Voice Circuit

On some circuits the shape of the curve may be so misshapen as to require readjustment. This is commonly true on wideband data circuits that require a "flat" frequency response. To do this an amplitude equalizer is inserted in the circuit. It is adjusted to amplify more strongly the voice frequencies depressed by the circuit and attenuate those the circuit over-amplifies. In effect it is the mirror image of a curve like Figure II-65. The circuit tilts or distorts the frequency response in one direction, the equalizer in the opposite direction. The net result is zero distortion for the signal.

The simplest equalizer is one that copes with a simple slope in the pattern. A dip or double hump or multiple ripple in the frequency response pattern becomes increasingly more difficult to rectify. The more extensive the required amount of equalization, the greater the equalizer cost. Generally speaking, most transmission facilities of modern design require little equalization.

g. <u>Relative or Envelope Delay Equalizers</u>

If two tones of different frequencies are inserted in one end of a voice circuit, they may not arrive at the receive end at identically the same time due to delay distortion. It may take a tone of 1000 Hz 50.022 milliseconds to get through and another tone of 1800 Hz 50.012 ms. The difference between the times is 20 microseconds. This is called the differential delay. If we plot the differential delay between 1000 Hz and all other frequencies in that voice circuit, we can draw a differential delay pattern such as Figure II-66.

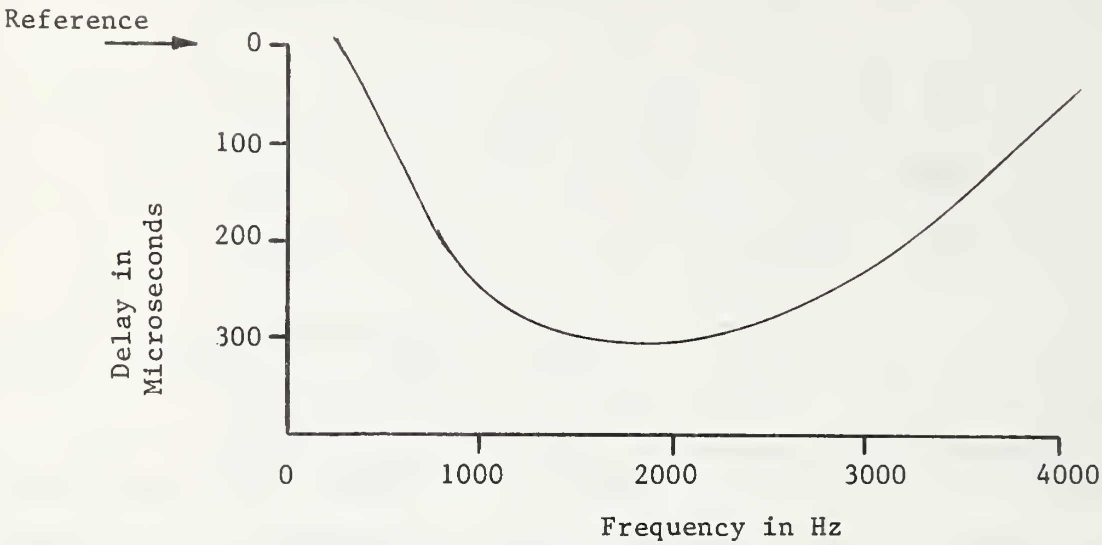


Figure II-66   Differential Delay Patterns for a Voice Channel

The shape of this delay curve is normally more important to data than to voice. It is correctable, however, so that the delay pattern is flat over the required bandwidth. The principle of a delay equalizer is to selectively delay those frequencies of the signal which have been less delayed by the circuit. The delay equalizer, therefore, has a delay pattern of its own which is the opposite or mirror image of the circuit's pattern. The net result is a signal delayed slightly longer, but with all frequencies arriving simultaneously. The delay response is therefore "flat". It should be noted that delay equalizers increase the absolute delay of the circuit.

As with the amplitude equalizers, the more complex the delay response pattern to be corrected, the more expensive the equalizer. Generally, delay equalizers are not required for voice except in special applications.

An adjustment of a delay equalizer may affect the amplitude response. Modern manufacturers now produce delay equalizers that either have amplitude compensating adjustments or do not affect the amplitude response. The relationship of delay to amplitude response in an equalizer should be kept in mind when selecting equalizers.

Amplitude and delay equalizers have a descriptive phrase called " quantity of pots". For example, a 15 pot equalizer has 15 variable "potentiometers" that directly affect 15 active or passive circuits within the equalizer. Generally speaking, the more the "pots", the more complex a distortion pattern it can help to equalize.

Intuitively, the deeper or more severe a discontinuity in the amplitude or frequency response, the tougher it is to equalize. A single very deep discontinuity in a response pattern can be more difficult to correct for than smooth ripples of limited number.

The concepts of envelope delay and amplitude response extend to the wider frequency band elements in the microwave system as well. See Sections II.F, G and H for further discussions.

11. <u>Technical Control Facilities</u>

Technical Control Facilities include the essential monitor, maintenance and operational facilities required for the supervision of VF channels on a microwave system. See Figure II-67.

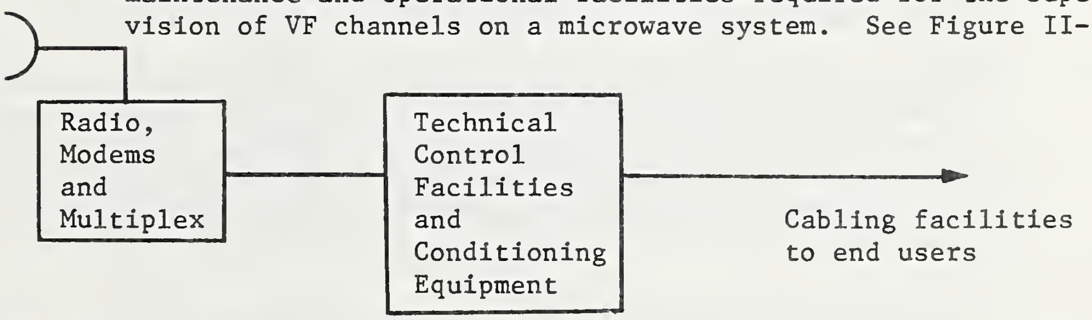


Figure II-67 Technical Control Position in a Microwave System

The intention of the "tech control" is to give the operator(s) quick direct diagnostic access to all of a system's communications transmission facilities and the ability to communicate likewise with end users. The main feature of the facility ideally is electrical appearance of all circuits for a given station at the same physical place. The operator then has direct plug in access to the circuits. This is normally accomplished using a "jack field" which consists of several plugs, sockets, or jacks for each circuit.

Variations on the theme shown in Figure II-68 are numerous. It is most common, however, to provide jack access for the following:

- Circuit access to end user local cable facilities before connection to any station equipment.

- Access to both sides of the station equipment. This includes any voice as well as DC signal paths.

- Access to the transmission facilities which is commonly done at the 4 wire channel multiplexer point.

- Access at all points in both directions using"normal thru" jacks which break the circuit.

- Bridging or monitoring jacks on the voice paths parallel to the "normal thru" jacks. Monitoring jacks do not break the circuit.

Figure II-69 exemplifies these points as applied to a voice circuit using out-of-band signaling.

The mod, demod, equipment in and out, monitor, and E&M jacks are mounted in what is commonly called a 4 wire jackfield. See Figure II-70.

The 2 wire jackfield is rack mounted similarly to the 4 wire jackfield. Each 2 wire circuit is assigned a line,drop and line monitor jack, all three together in a vertical column. If 4 wire circuits are used instead of 2 wire circuits, the circuit is assigned two adjacent columns, one for Tx and the other for Rx.

The technical control center is usually equipped with a complement of test equipment. Some of the more commonly required instruments are mounted in racks adjacent to the voice circuit jacks. Typical rack mounted test equipment includes:

- VF oscillator

- Dial pulse generator

- Voltmeter

- Harmonic distortion test set

A special set of jacks mounted in a "miscellaneous jack strip" is often supplied with tech control facilities. The miscellan-

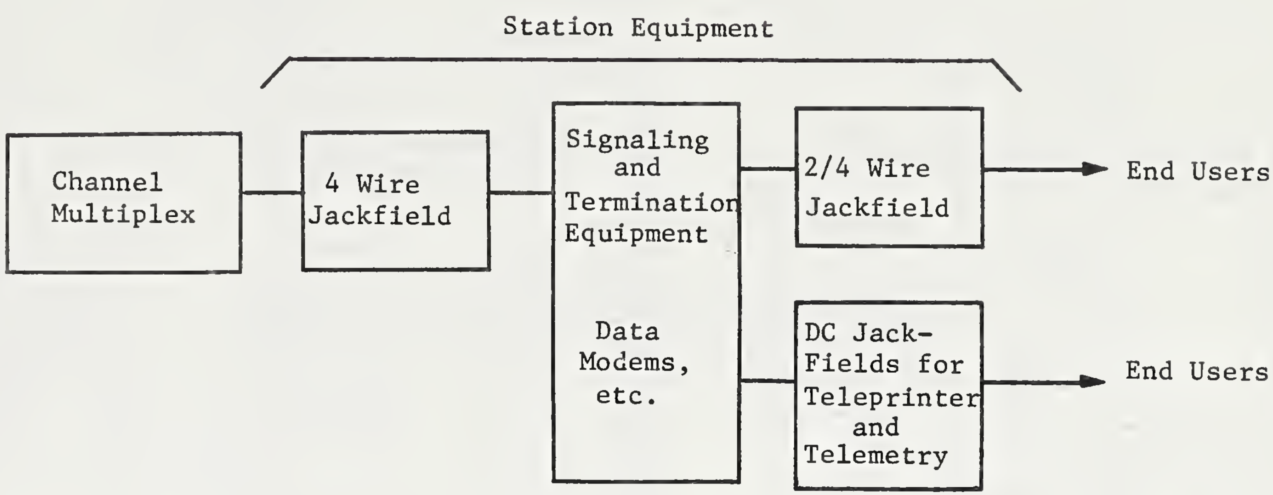


Figure II-68 Terminal Station Typical Configuration of Termination Equipment With Tech Control

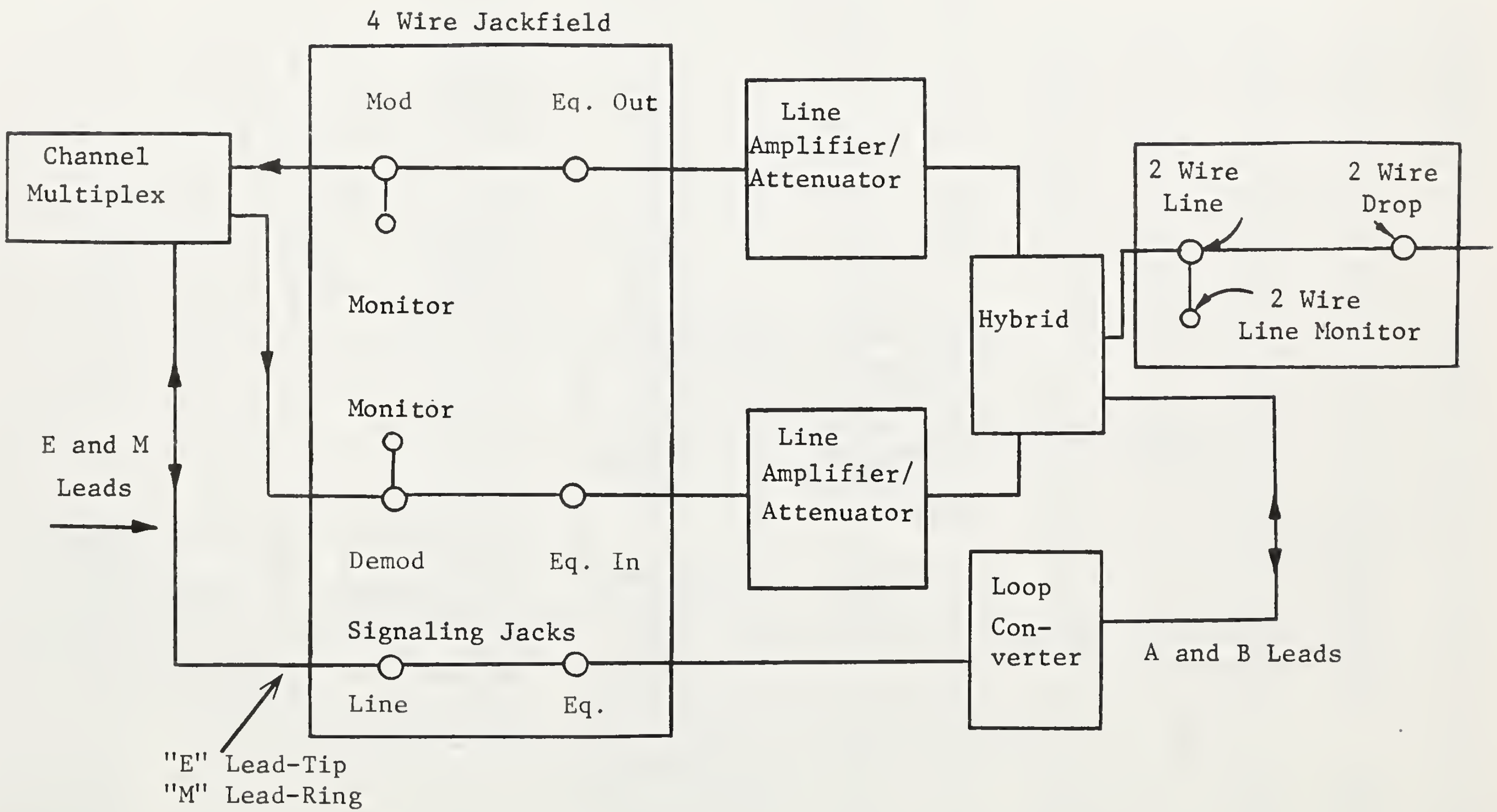


Figure II-69 2 Wire Circuit with In Band Signaling

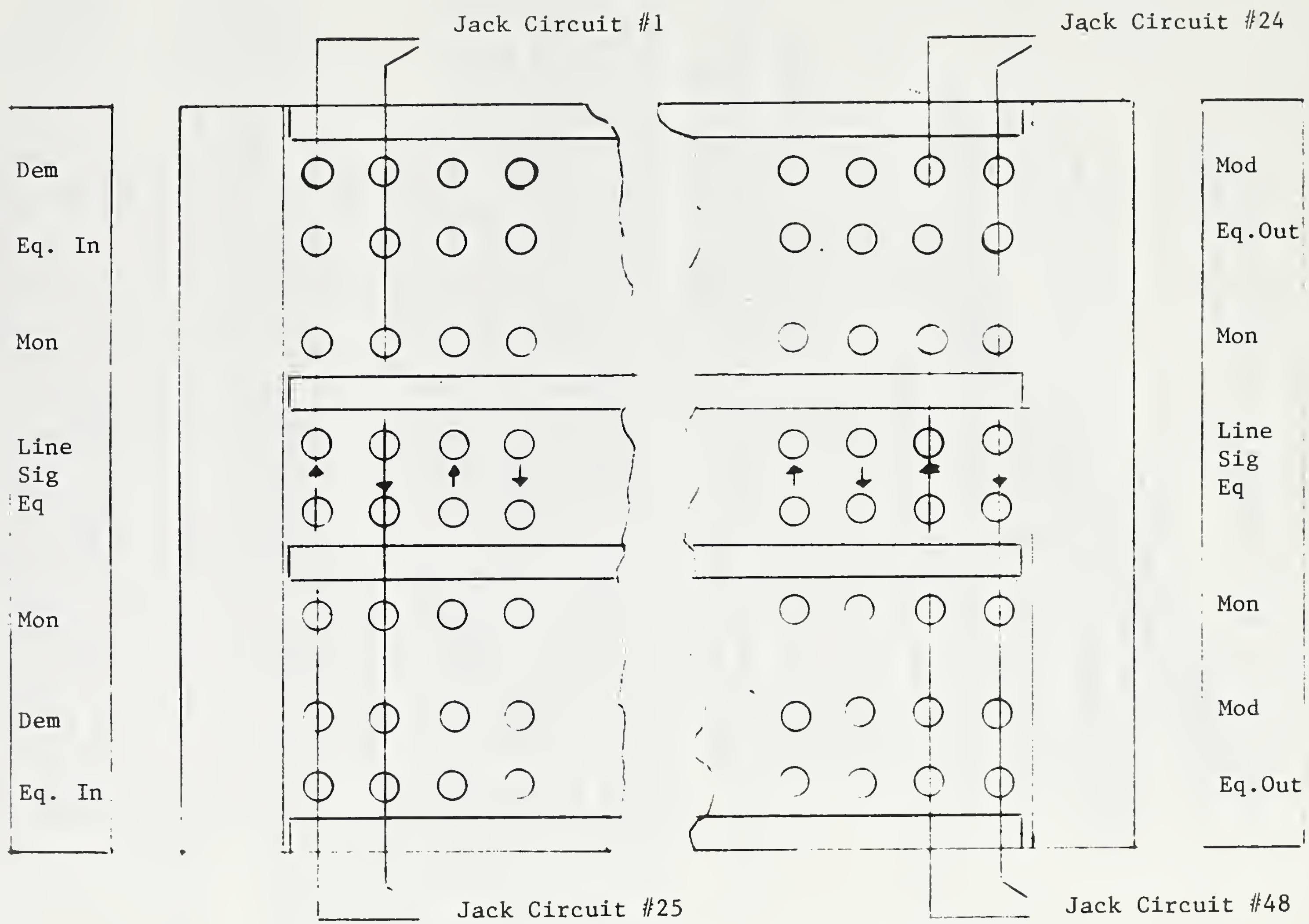


Figure II-70 Typical 6-Wire Jackfield

eous jack strip is normally a row of jacks at waist high level. These jacks are maintenance aids.

Typical functions available at these jacks are:

- 48 Vdc
- 20 Hz ringing voltage
- 1 kHz test tone normally at 600 ohms, 0 dBm
- 600 ohm terminations
- Remote Orderwire connections with ringing button
- DC teleprinter test patterns
- Inputs to voltmeter
- Multiples (several adjacent jacks wired in parallel)
- Interconnects (jacks wired to identical interconnects in miscellaneous jack strips elsewhere in the station)

Technical control facilities are also equipped with numerous other items that are designed to fit the needs of the system. It is common to have special testing circuits that use spare channels in the message baseband. Some terminal stations are equipped with samples of end user terminal equipments like data modems for the purpose of being able to analyze performance problems on circuits. It is also common to have an extensive complement of test equipment that may be rack mounted or set on dollies for mobility within the station.

12. Station Cabling

Station cabling includes the various HF, RF, power and VF cabling required for equipment interconnections. For utilitarian and cost reasons, station cabling is normally run in cable trays mounted above the equipment. The trays are metallic structures that resemble ladders in appearance. See Figure II-71.

The ladders are supported either from the ceiling or by the equipment racks. Future planning for cable ladder size should not be overlooked in the original design. The routing of the ladders as well as their size can become very critical as a station approaches its eventual design size limit.

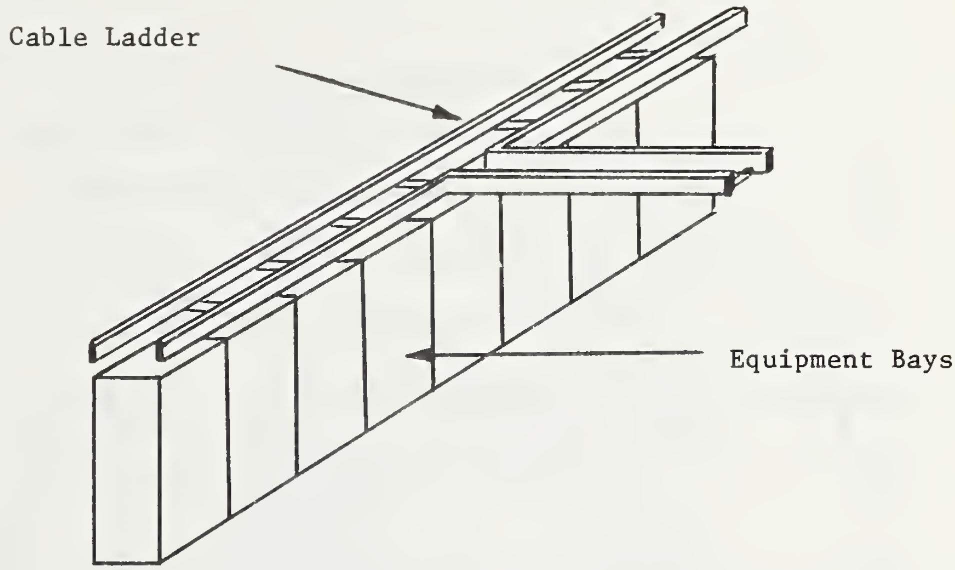


Figure II-71 Cable Ladders

The VF cables usually contain 12 to 100 twisted pairs of wire. Every wire is individually coded to aid in the installation. Each cable is tagged for identification.

In an FDM-FM system terminal, the majority of the required terminal cabling is usually VF cabling. The VF inputs and outputs of many VF units are cabled to a common point called a distribution frame where they are interconnected. For example, in Figure II-70 above, the Tx line jack is connected to the multiplex input. This interconnection is actually made at the distribution frame. The Tx line jacks are wired to the frame as are the channel multiplex transmit inputs. To connect a Tx line jack to a multiplex input, jumper wires are attached to the appropriate contact points on the frame. See Figures II-72, II-146 and II-147.

The primary reason for distribution frames is to accommodate changes in requirements of the communications system. If no changes were to occur, the equipment pieces could be hard wired directly to each other without the use of a distribution frame. This makes the system inflexible, however, and changes in a circuit's configuration become impractical. Flexibility in station wiring necessitates the use of some sort of distribution framing. It is possible to eliminate part of the frame

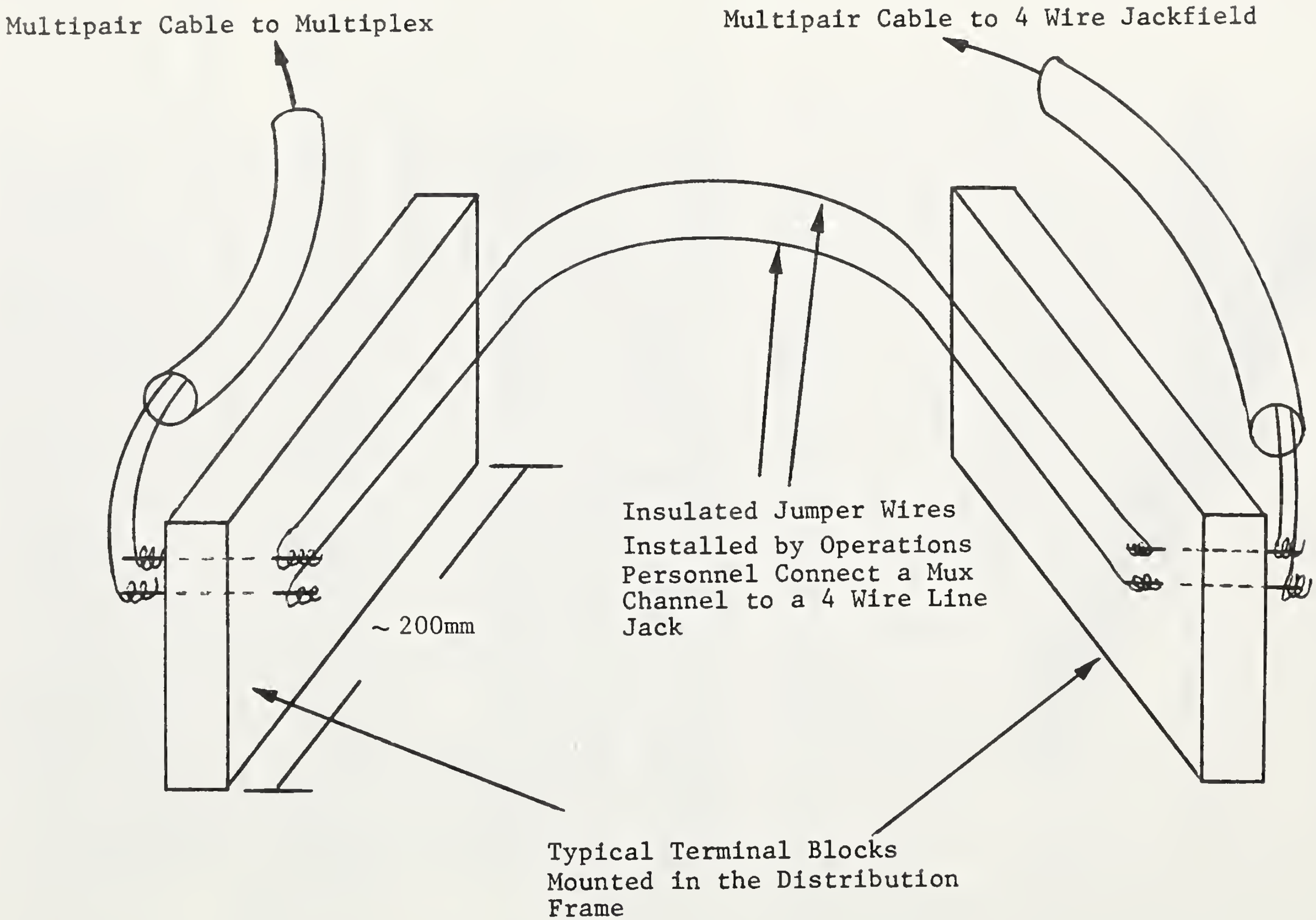


Figure II-72 MDF Cross Connects

requirements if change for a certain type of connection is not anticipated. A common example is the multiplex and 4 wire jackfield connections. These are often hardwired. It does lock a given 4 wire jackfield, however, to certain multiplex channels, which may or may not be desirable.

The types of functions that are commonly wired to the distribution frame are:

- Multiplex VF inputs and outputs
- E&M leads from the multiplex (if applicable)
- Inputs and outputs of jacks in jackfields
- Functions from miscellaneous jack strips
- Signaling and termination equipment VF inputs and outputs, E&M leads
- External cabling from end users
- Orderwires, VF and signaling
- Alarms, sensors, controls and VF

A fully allocated frame may have hundreds of terminal blocks. The frames may be wall mounted with blocks on one side only. Frames also may be double sided.The two sided version normally has a vertical size and a horizontal side which facilitates hand movements when stringing cross connect wires in the framework of the distribution frame. See Figure II-73.

The double sided frame has the advantage of being more compact. Cross connects therefore tend to be shorter. Both sides of the frame need access, however, which may or may not be feasible in a given floor plan. Thus, the use of single sided frames.

The blocks are usually 2 to 12 pins deep and 20 or 26 pins wide. Wire wrap and solder type pins are common.

If a station has only one distribution frame, it is called the Combined Distribution Frame (CDF).

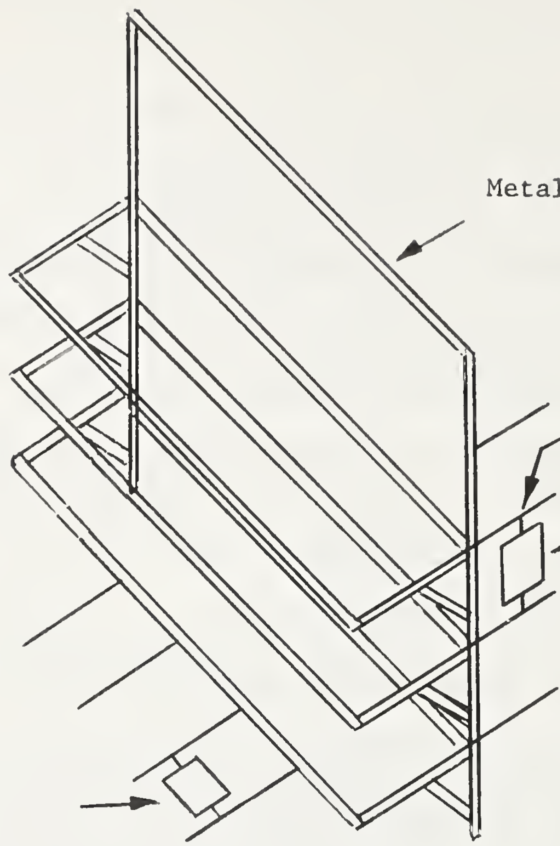


Figure II-73 Partially Constructed Double Sided Distribution Frame

13. <u>Towers</u>

Microwave systems require towers for the sole purpose of raising antennas above local and distant obstacles in order to achieve line-of-sight across the radio path.

Three basic types of towers that are useful to the communications industry are the self supporting towers, guyed towers (which use multistrand steel or aluminum support cables anchored at a distance from the tower) and building mounts.

Figure II-74 summarizes a number of advantages and disadvantages of various antenna supporting structures.

Type of Tower	Advantages	Disadvantages
Guyed Towers	Cost	Size of real estate required. See Section G.13.
Self supporting	Requires minimum real estate	Cost
Building mounts		
Roof top	Ease of access	Often requires complex mechanical arrangement to tie into mechanical structure of the roof, weight and cost implication
Building side mounts on the side face of a building	Simple mechanical support structure	Difficult to install and align antenna. Since it is on the side of the building, they can be unsightly.
Mounts inside the building	Simplicity of mounting, installation, and alignment	Requires adequate window size or aperture, subject to tampering by personnel

Figure II-74 Comparison of Tower Types

Tower heights are kept to a minimum to reduce construction costs. See Section II.G for tower height determination and mechanical design.

14. Video Transmission

The microwave system carrying video or television has a baseband composed of:

- Black and white "luminance" signal
- Color signal
- Sound channel(s)
- Microwave system internal orderwire
- Radio pilot

Figure II-75 gives a typical composite of these five signal components.

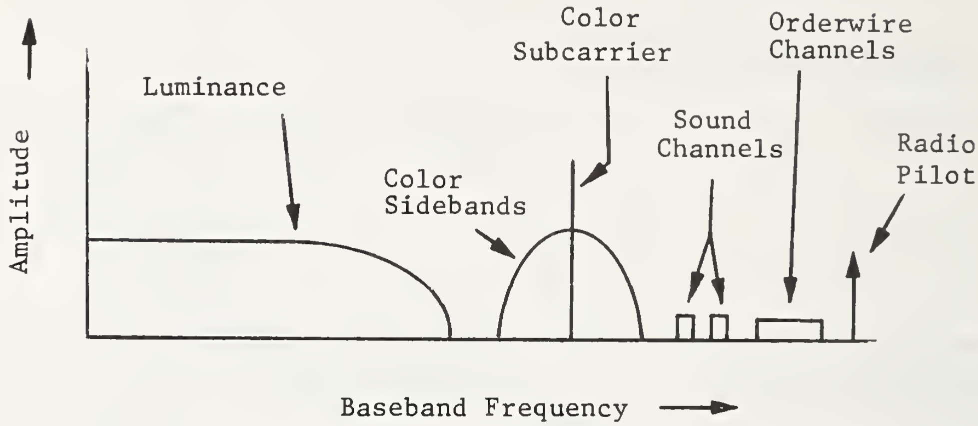


Figure II-75 Spectrum Occupation of the Baseband for Television Signal Transmission

Figure II-76 shows a terminal station's configuration when handling the transmission of TV.

The significant pieces of equipment used in a microwave system specifically for the transmission of TV are:

- Cable equalizers (to equalize frequency amplitude response of in station cabling)

- Amplifiers to raise the system output to 1.0 volts (full "white" signal)

- Pre and de-emphasis networks particular to TV

- Above baseband FM sound modulators. Normally one to four sound channels are carried by the microwave bearer. Modulators and demodulators for each sound channel are needed.

- Special protection switching circuitry to interface with multibearer transmission systems.

It should be noted that the sound channel modulators have an FM output. This FM signal is used to frequency modulate the main RF channel modulator VCO.

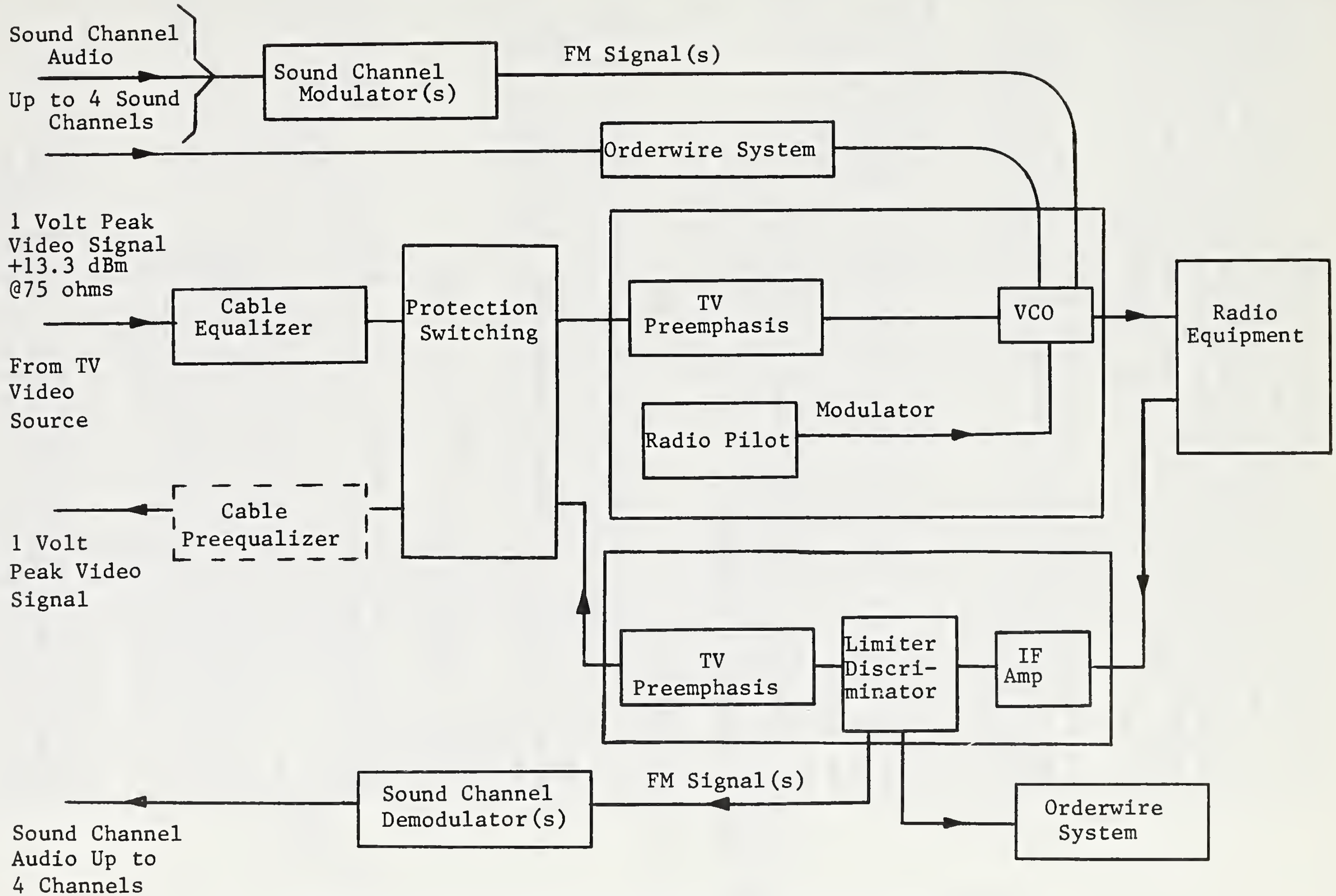


Figure II-76 Terminal Configuration for TV Transmission

The resultant signal is a double FM signal. It is also noted that the video and sound channel signals are handled separately. The frequency separation between the sound channel and the video in the baseband is usually greater than the separation during TV broadcast. In the baseband the color carrier is approximately 3.6 MHz while the sound channel carrier is at 6 to 8 MHz. During actual TV broadcast the separation may be only 900 kHz.

The additional sound channels noted are available for uses such as stereo, alternate languages, distribution for AM or FM broadcasting and mood music commonly piped through office buildings.

TV systems are often one way systems. Two way communications with sites are required, however, for Orderwire systems, alarm and control and backsignaling if necessary. Auxilliary communications facilities are supplied if the system is a one way system. Common means used are parallel telephony microwave systems using the same sites, land line telephone circuits or low density radio for the return direction.

F. System Operating Parameters

1. Introduction

System operating parameters are the technical parameters that define the basic operational principles of an analog FDM-FM microwave system. This section discusses a number of these parameters from a conceptual standpoint. The intent is to present a functional understanding of microwave transmission systems.

2. Carrier Transmission

Generally, information signals (voice, data, etc.) cannot be transmitted long distances in their original form. The human voice for example will not carry a sufficiently long distance through the air as an acoustical signal. To achieve long distance transmission, a carrier is used to "carry" the information signal. The carrier is a form of energy that can be modulated and will travel the long distance. The carrier may be electromagnetic energy anywhere from DC to light and beyond. The carrier is transmitted from one point(s) using an appropriate transmission facility to another.

The information signal is impressed upon the carrier by varying one of the carrier's parameters. The most common parameters are level (amplitude), frequency and phase. Figure II-77 shows the basic principle of carrier transmission.

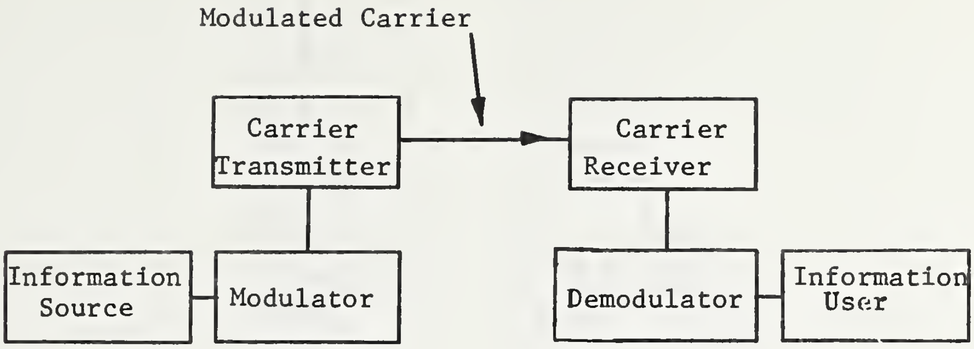
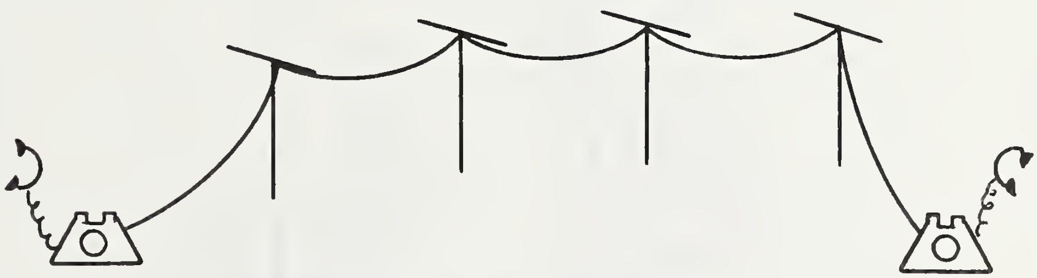


Figure II-77 Information Transfer Using a Carrier

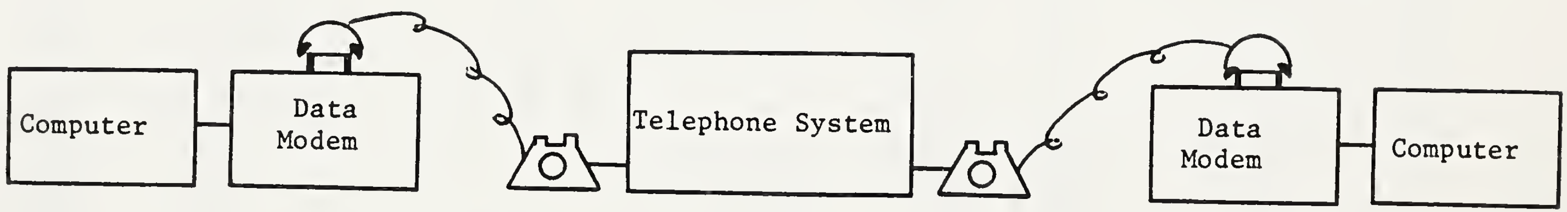
The transmission system consists of a transmitter and a receiver connected via a transmission path. The demodulator extracts the information signal from the carrier and delivers it to the end user.

Figures II-78 through II-82 are typical applications of the carrier transmission principle.



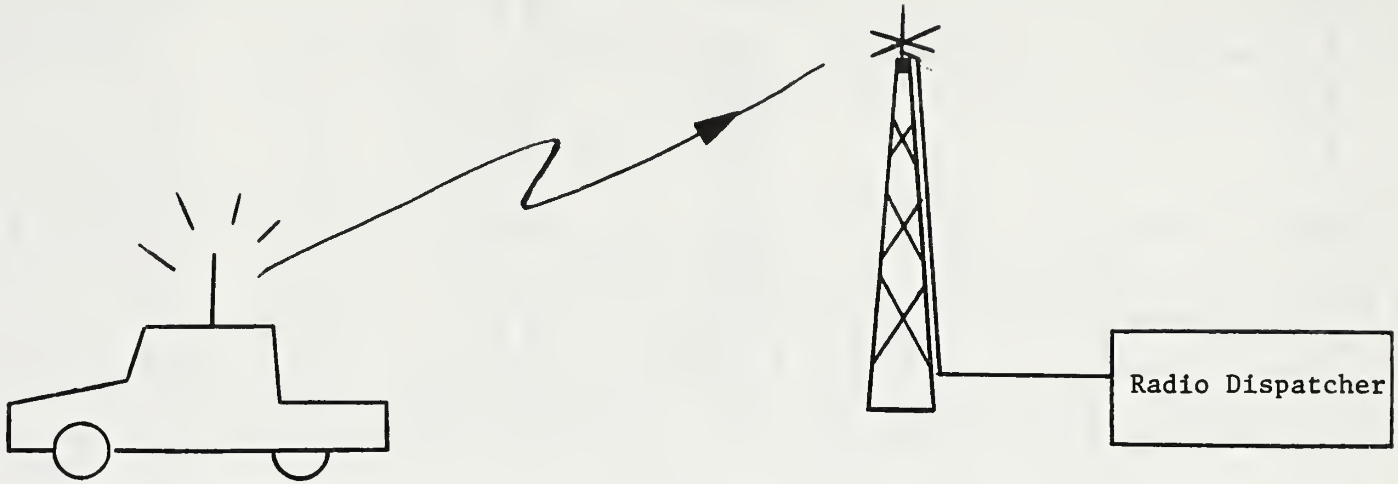
Information Source	=	Voice
Modulator	=	Telephone
Carrier	=	DC Signal
Transmission System	=	Wire
Demodulator	=	Telephone
End User	=	Ear

Figure II-78 Carrier Transmission Application A



Information Source	=	Computer
Modulator	=	Data Modem
Carrier	=	Voice frequency tone(s) generated in the data modem
Transmission System	=	Telephone System - mixture of different facilities likely
Demodulator	=	Data Modem
End User	=	Computer

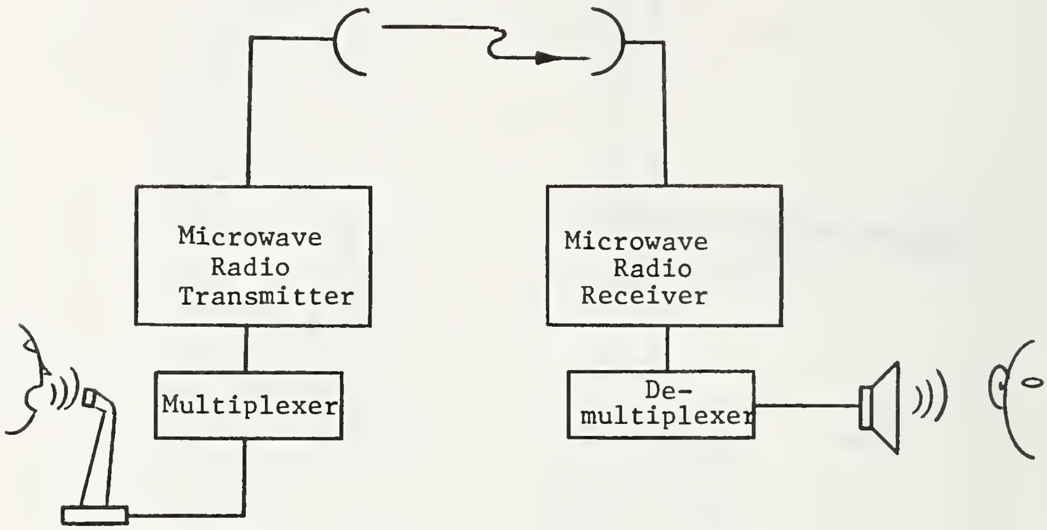
Figure II-79 Carrier Transmission Application B



Information Source	=	Mobile Operator
Modulator	=	Mobile Radio
Carrier	=	RF Signal
Transmission System	=	Radio Path
Demodulator	=	Base Station Radio Receiver
End User	=	Radio Dispatch Operator

Figure II-80 Carrier Transmission Application C

In long distance transmission systems, the original carrier with modulation is often used to modulate a second carrier before being sent over long distance transmission facilities. Figure II-81 demonstrates how the voice signal modulates a DC signal which modulates a multiplex channel carrier, which modulates a radio system.



Information Source	=	Voice
Modulator	=	Microphone, Multiplexer, Radio
Carrier	=	DC, Channel Carrier, RF Signal
Transmission System	=	Microwave Radio System
Demodulator	=	Radio, Demultiplexer Speaker
End User	=	Car

Figure II-81 Carrier Transmission Application D

The principle of carrier transmission can be applied to systems that use not only multiple forms of modulation but also multiple information sources, multiple transmission facilities and multiple end users. The number of variations is endless; the principle remains the same. Figure II-82 shows a system using a multiplicity of elements. Each segment of the transmission facilities will have modulation step(s) associated with it.

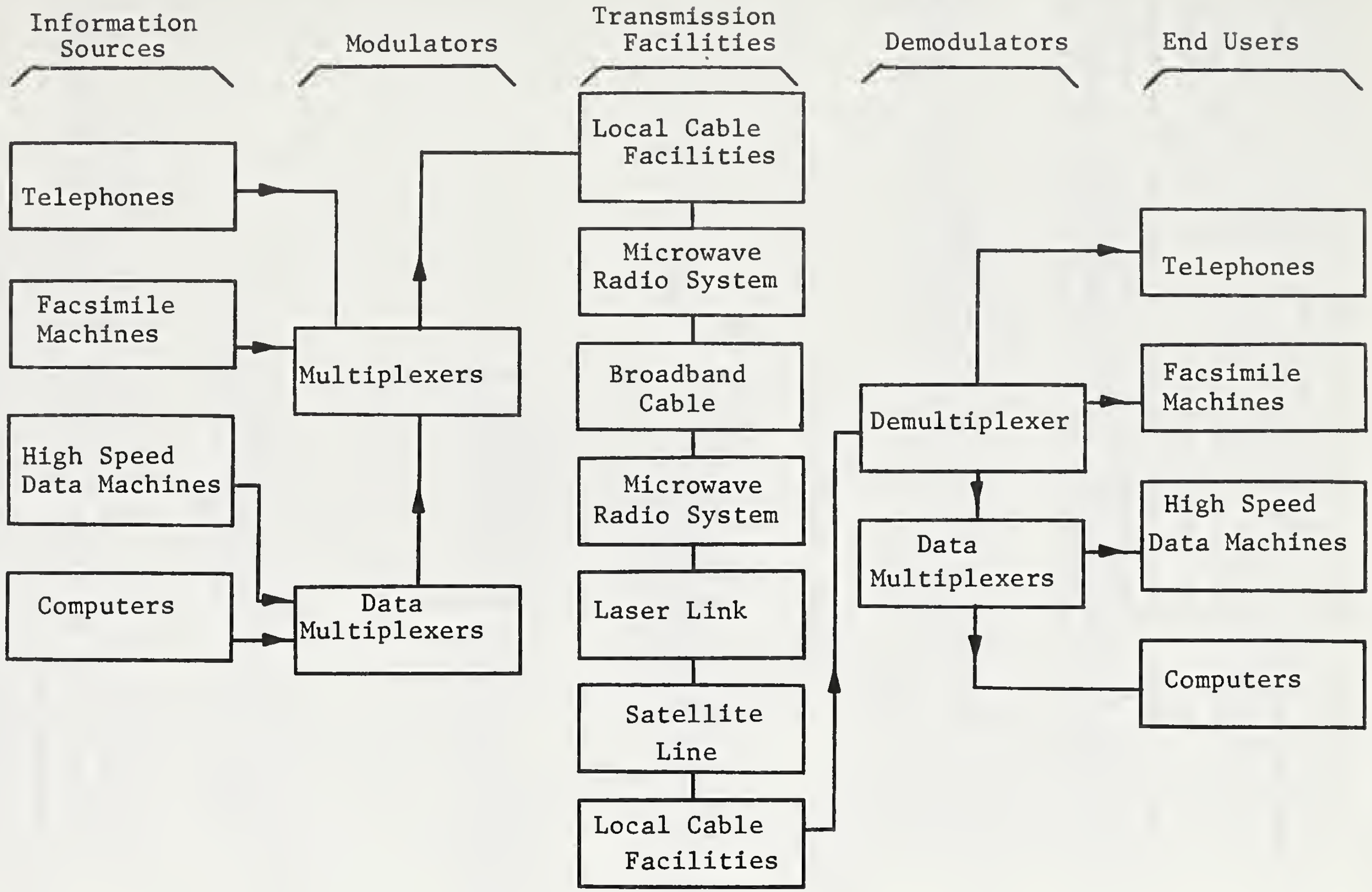


Figure II-82 Carrier Transmission Application E

3. Amplitude Modulation

a. Amplitude Modulation Principles

As discussed above in Carrier Transmission, modulation is the varying of one of a carrier's parameters. Amplitude modulation (AM) is the oldest form of modulation commonly used in communications. The simplest form of AM uses DC as the carrier and a telegraph key to turn the DC source on and off. This system modulates the DC level between zero to some fixed non-zero level. Voice can also modulate DC using a microphone as the modulator. The amount of change in the level of the DC signal going through the microphone depends on the instantaneous energy level of the voice.

A more complex form of AM is the modulation of a frequency carrier. A modulating frequency, i.e. 1000 Hz is used to modulate the amplitude of another frequency carrier. See Figure II-83.

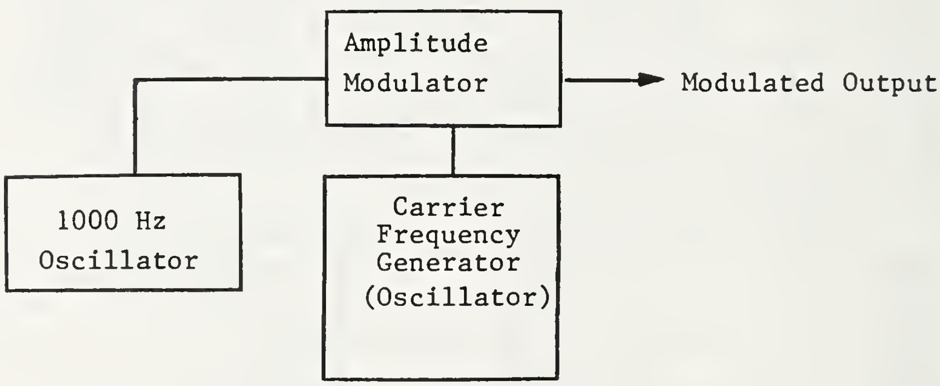


Figure II-83 Amplitude Modulation

The modulator is a non-linear device that mixes the input signals. The modulator's output includes the following frequencies:

- Modulating signal F_1

- Modulated signal F_2 (carrier)
- Mixer Products at frequencies $F_1 + F_2$ and $F_1 - F_2$

There are other possible products coming out of a mixer such as $2F_1 + F_2$ and $3F_1 + 2F_2$, but these are normally lower in power and not of concern presently.

The desired output is usually $F_1 + F_2$ and/or $F_1 - F_2$. Frequency filters are used to separate the desired signal(s) from the undesired.

It is significant that the modulator does not "add" the two frequencies; it mixes them. See Figure II-84 for the difference.

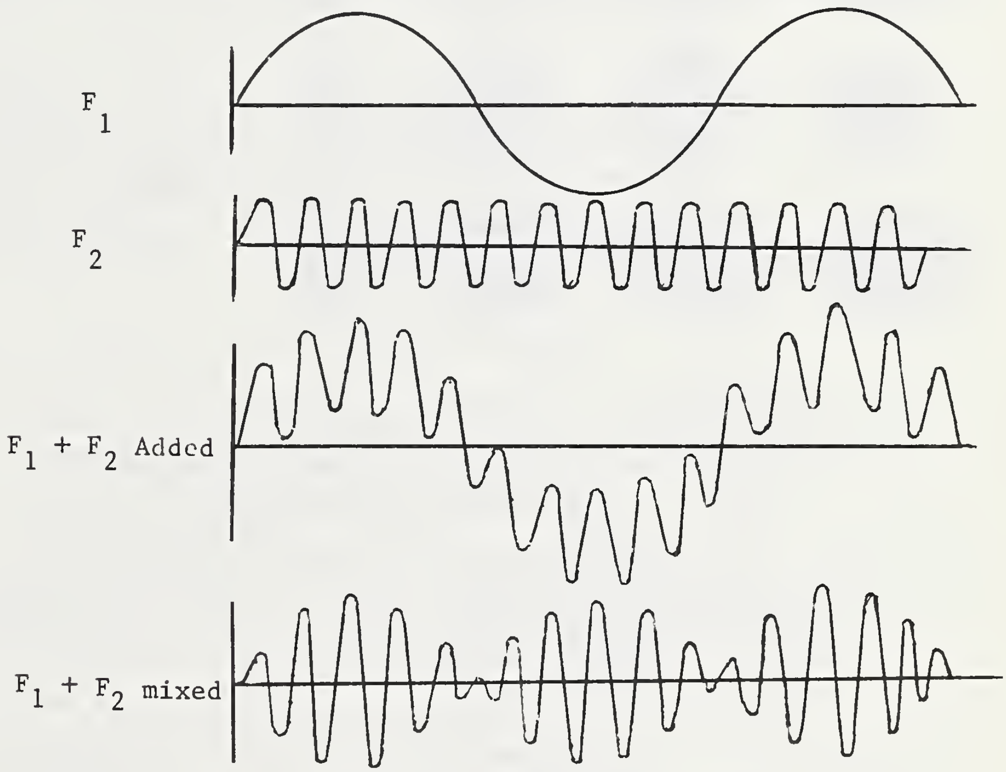


Figure II-84 Addition vs. Mixing of Frequencies

The modulator's non-linearity causes the mixing action. The carrier and/or modulating frequencies are distorted in such a manner as to produce the frequency products desired.

AM is used in numerous applications of communications technology. For example:

- Telephones
- AM broadcast
- Microwave radio RF mixers
- Frequency division multiplexers
- Data modems

The mixer input and output frequencies need not be related in frequency. For example, two high input frequencies can be used to generate a low frequency output or a high and a low input can produce a high frequency output. The principle that continues to apply is that the outputs are F_1, F_2, $F_1 + F_2$ and $F_1 - F_2$ whatever they may be.

In an AM communications system the transmitting end of a circuit uses a modulator. The receive end uses a demodulator to extract the desired information signal from the modulated carrier. Both the modulator and the demodulator use the same mixer principle. See Figure II-85 for an example of the circuit.

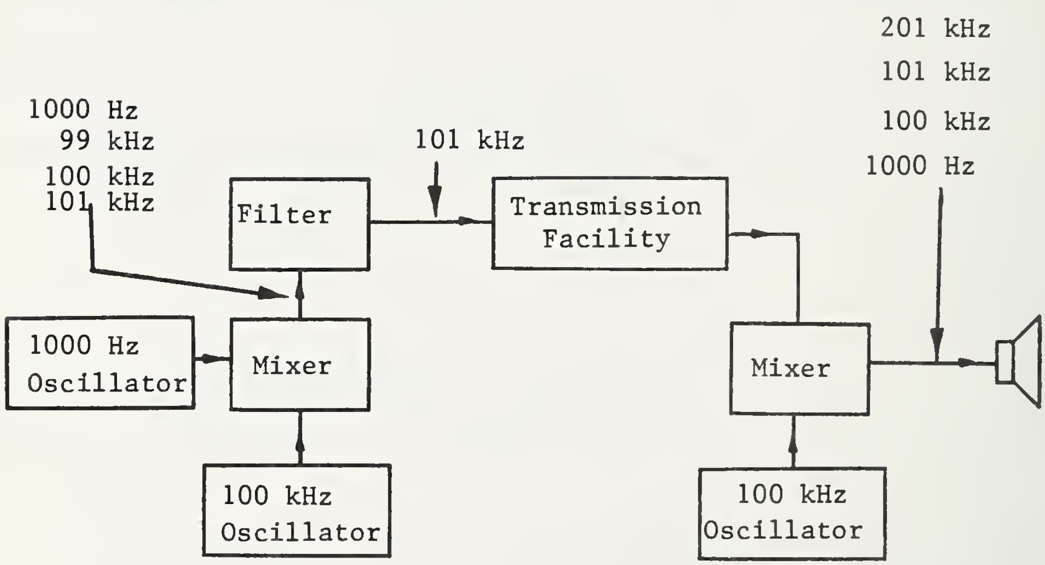


Figure II-85 Typical Circuit Using Amplitude Modulation

One of the parameters in AM is "percent modulation". It is a measure of how strongly the carrier's level is modulated by the modulating signal. See Figure II-86.

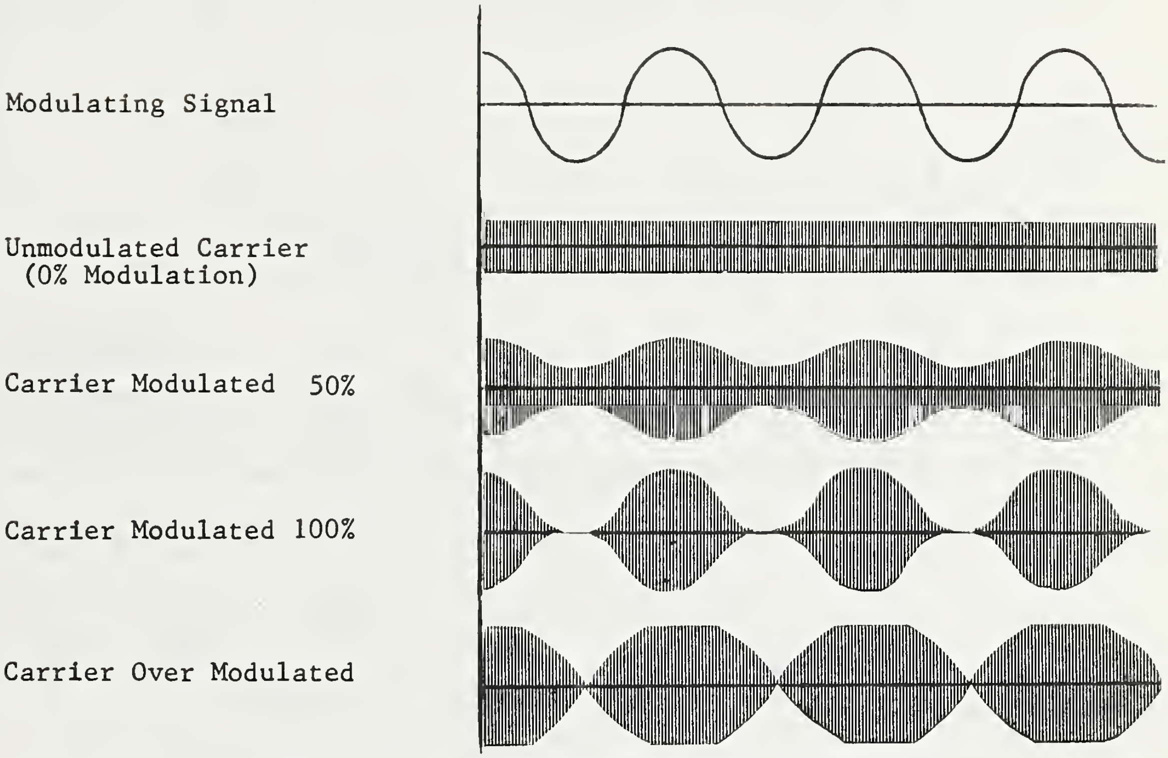


Figure II-86 Percent Modulation

Notice that the peaks and valleys of the modulated signal follow the modulating signal peaks. When the carrier is 100% modulated its peak is twice the average without modulation. This is shown on Figure II-86.

Over modulation occurs when the modulating signal input level is raised beyond the point where 100% modulation occurs. When this happens, numerous types of distortion may occur. The principle distortion products are:

- Noise and spurious response
- Harmonic distortion within a modulating voice channel
- Generation of carrier harmonics

Most systems are designed to operate below the 100% modulation point.

b. Modulation Types

As noted above, the products of a modulator include the carrier and products at frequencies $F_1 + F_2$ and $F_1 - F_2$. Before any filtering the energy spectrum has the components as presented in Figure II-87.

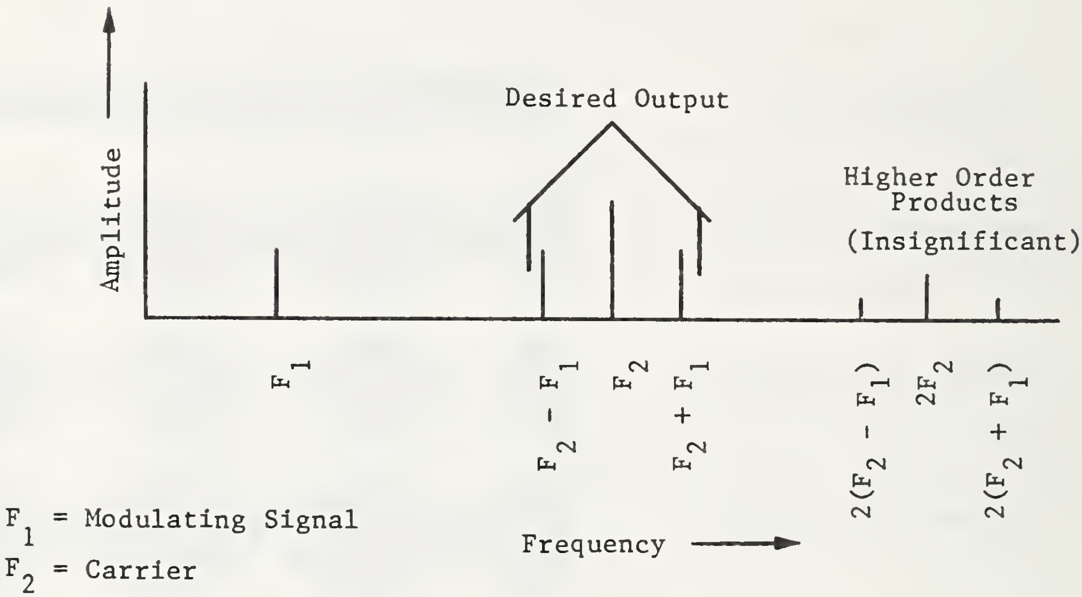


Figure II-87 Frequency Spectrum of AM Mixer Output

To achieve the desired output, a filter is used wide enough to pass only $F_2 - F_1$, $F_2 + F_1$. The output is said to include the carrier F_2 and the two sidebands $F_2 - F_1$ and $F_2 + F_1$.

The composite of the three is a linear AM signal as used in the AM broadcast industry. Figure II-88 presents a similar frequency spectrum using a 0-4 kHz voice spectrum as the modulating signal.

The carrier with both sidebands occupies 8 kHz of bandwidth vs. the original 4 kHz of voice energy. This is an inefficient use of the available frequency spectrum. To improve the spectrum use, filters are used to eliminate one of the two sidebands. If the lower sideband is eliminated, the upper sideband may be transmitted alone. Such is called Single Sideband (SSB) transmission or Upper Sideband (USB). If the upper sideband is eliminated, the resultant SSB transmission is Lower Sideband (LSB).

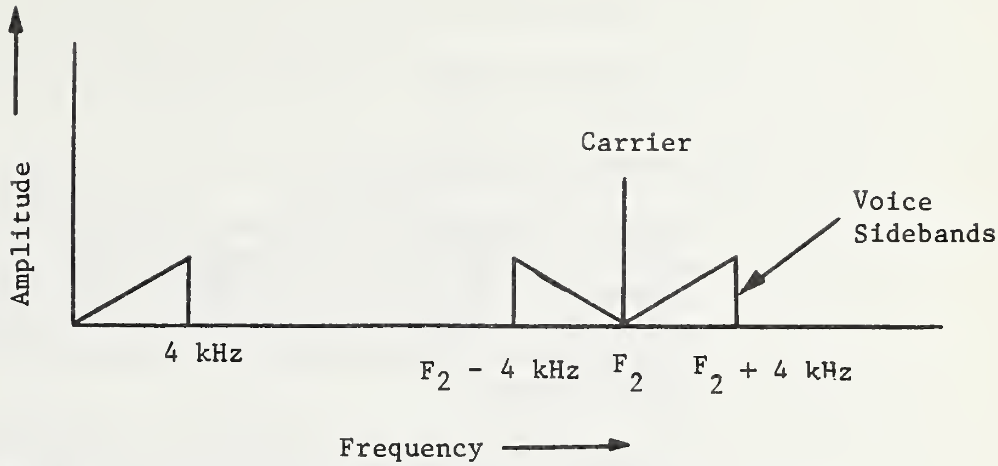


Figure II-88 Frequency Spectrum of a Mixer Modulated by Voice

The energy of an LSB signal is shown in Figure II-89.

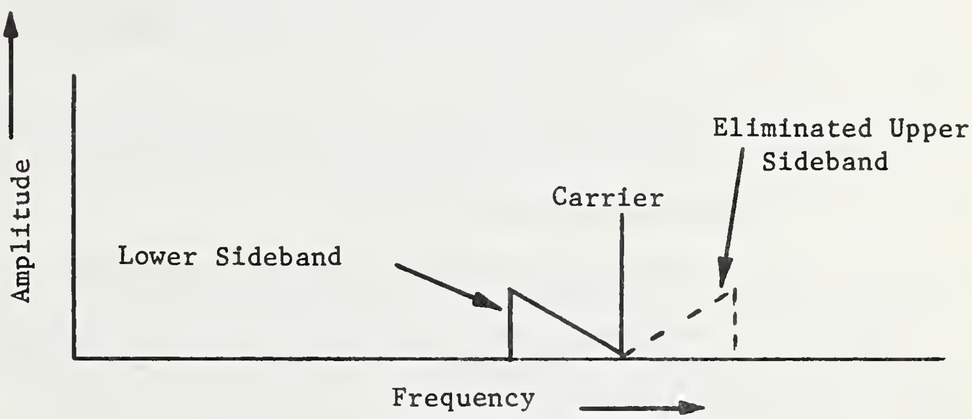


Figure II-89 LSB Frequency Spectrum

The LSB signal of Figure II-89 includes both the carrier and the lower sideband. Most of the energy is in the carrier. The carrier is not needed for transmission, however, since all the information is in the sidebands. Also, the sidebands are at such a frequency that they will be able to pass through the transmission facilities as would the carrier. The carrier can be eliminated using filters leaving only the sideband. The resultant signal in Figure II-89 would be a "lower sideband, suppressed carrier" LSBSC signal. The more general term is SSBSC.

There are three primary advantages to SSBSC:

- Lower power required for AM transmitters
- Improved signal to noise performance at the receive end
- Reduced system loading in FDM-FM systems

The first advantage, reduction in power, occurs because the required RF power level is reduced. That is, not as much RF power is required to achieve the same level of system performance. Double sideband (DSB) with carrier requires 4 times the RF energy to achieve the same performance as a SSBSC system.

The second advantage, improved noise performance, occurs because the receiver is "looking" at 4 kHz of spectrum instead of 8 kHz with DSB. The receive input noise is therefore halved with SSB.

The third advantage, reduced loading in FDM-FM systems, is largely a matter of eliminating the carrier. This greatly reduces the possible loading by as much as 5000 times due to high carrier levels in frequency division multiplex.

The disadvantage of SSBSC is its increased cost. This is dominantly overshadowed by the advantages, however.

4. Frequency Modulation (FM)

a. Principles of Modulation and Demodulation

Another parameter of carriers that can be modulated is frequency. Figure II-90 presents a simplified circuit of how this can be done.

C_1 and L_1 form a resonant circuit at the carrier frequency. C_1's capacitance changes, however, when an external voltage is impressed across it. A change in its capacitance naturally changes the resonant frequency of C_1, L_1. If the input signal is a time variant voltage, such as a voice signal, the carrier frequency will change as the input signal voltage changes. Therefore, the circuit's output is an FM signal. The circuit is known as a Voltage Controlled Oscillator (VCO).

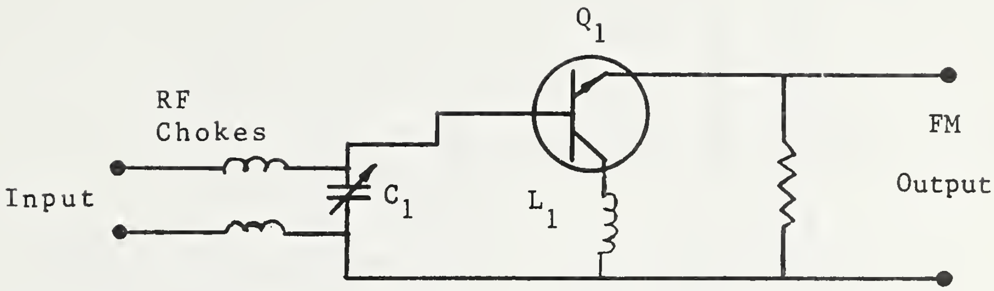


Figure II-90 FM Circuit

The FM demodulator extracts the modulation information from the carrier by using a discriminator. The typical discriminator has a circuit as shown in Figure II-91. The transfer function is also shown.

To achieve the transfer function, L_1 C_1 is tuned to F_1 and L_2 C_2 is tuned to F_2. Ideally the curve in the range of operation is a straight line.

F_0 is the unmodulated carrier frequency. If the carrier's frequency is raised, the discriminator's output voltage rises. If the carrier's frequency is lowered, the output voltage is lowered. Since the carrier's frequency is going up and down in accordance to the original modulating signal's voltage, the discriminator's output voltage will be the same as the original modulating signal, thus reproducing the original signal.

b. Multichannel Loading

In an FDM-FM system, the amount of frequency shift of the carrier is a function of the voltage of the multiplex output. This should not be so high as to push the radio's carrier frequency beyond the limits of the radio bandwidth. In practice, systems are designed so the deviation will not exceed the bandpass by more than 0.01% of the time. The total peak voltage output of the multiplex is the sum of

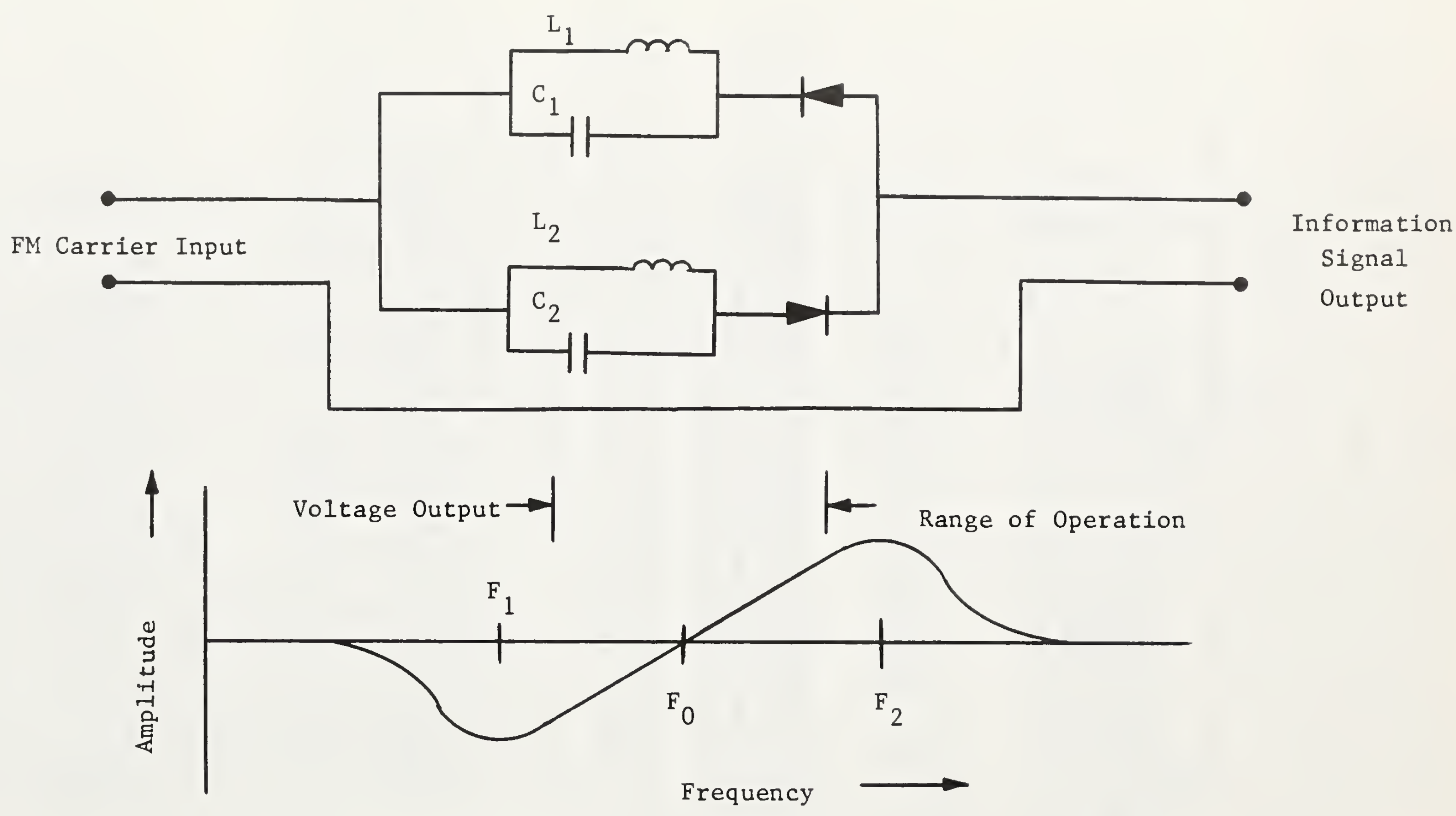


Figure II-91 FM Discriminator

all the individual channels. These vary with different talkers, types of signals and lengths of pauses. To sum the voltage contributions of the individual channel, estimating formulas are used that approximately match field observations of many wideband multi-user systems. The only parameter taken into account is the number of users. For convenience, the signal power instead of voltage is used. Experience shows that the total peak power, exceeded not more than 0.01% of the time, is calculated as follows. The loading factor is the total baseband power relative to a test tone in any one channel.

Number of Voice Channels	Loading Factor
12 to 240	P = (-1 + 4 Log N) dB
240 or more	P = (-15 + 10 Log N) dB

The lower channel capacity systems experience a higher activity factor with higher peaks. Intuitively, the peaks of only a few talkers are going to be more apparent. On the other hand, in a large system a given talker's peaks are insignificant compared to the total power. His peaks are, therefore, not going to be as significant.

The amount of FM carrier deviation is a direct function of the input signal voltage; therefore it is a square root function of the power. Double the power and the deviation goes up by $\sqrt{2}$.

c. Pre- and Deemphasis

FM theory predicts that in an FDM-FM system, there is more FM noise at the higher frequencies of the baseband than at the lower frequencies. In an FM system the Flat Signal-to-Noise

$$\text{Ratio} = C/N + 20\ \text{Log}\left(\frac{\Delta F}{F_{BB}}\right) + 10\ \text{Log}\left(\frac{B_{if}}{2B_{chn}}\right)$$

where C/N = Rx Carrier to Noise Ratio
= KTB_{if} or Noise in the IF bandwidth

KT = (Boltzmann's Constant)(Temperature ^{o}K)
= -174 dBm/Hz for room temperature

B_{if} = Receive IF bandwidth

ΔF = Peak voice channel deviation due to the applied channel test tone

B_{chn} = Channel bandwidth i.e. 3 kHz

F_{BB} = Frequency in the baseband where measurement is made.

Notice that the noise at a discrete frequency F_{BB} in the baseband is a function of F_{BB}. The higher F_{BB}, the worse the signal to noise ratio. This means channels at the top of the baseband will be noisier than those at the bottom end. To help compensate for this discrepancy, the modulating power of the top channels is increased and the bottom end decreased. This has the effect of improving the signal to noise ratio at the top end of the baseband. The bottom end channels are worsened slightly but are still quieter than the top channels. Care is taken to not over-emphasize the top end because this would generate excessive high frequency sidebands in the FM spectrum.

When the top end is emphasized and the bottom end depressed, it is done in such a way that the total power of the baseband is the same before and after the emphasis. Figure II-92 shows the energy of the baseband before and after the preemphasis circuit. The preemphasis circuit is normally an RC frequency selective circuit.

The top end of the baseband is emphasized by approximately 4 dB and the bottom end dropped by approximately 4 dB.

At the receive end of the microwave system, the receiver, after its discriminator, deemphasizes the baseband signal to flatten out the baseband back to its original form. The deemphasis circuit is usually an RC circuit with the opposite frequency selectivity of the preemphasis circuit.

Preemphasis for television follows the same principle but a different curve. Figure II-93 shows the preemphasis for a standard 525 line NTSC(U.S. Standard) transmission system.

d. Transfer Functions

This section compares the frequency spectrum requirements of various sizes of microwave FDM-FM basebands. Figure II-94 is a table of transfer functions that provides the comparison. It traces analog voice signals through the FM modulation/demodulation chain. The following list of explanations explains the various parameters:

$$\text{Preemphasis} = \left[8\left(\frac{F}{F_{BB}}\right) - 4\right] \text{ dB}$$

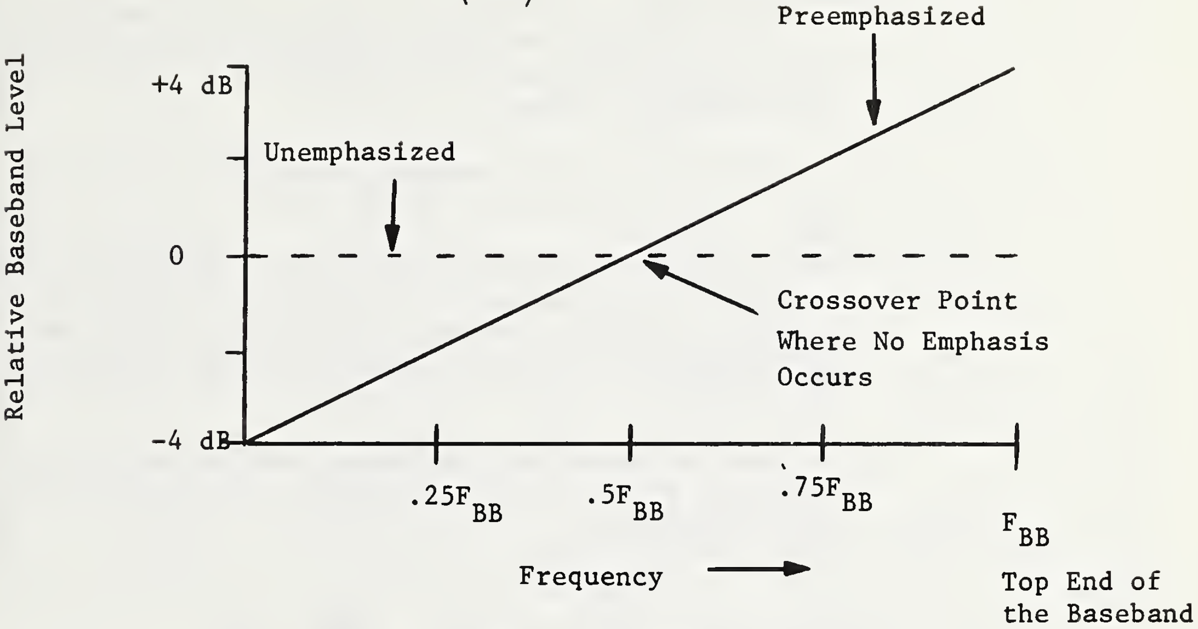


Figure II-92 Telephony Preemphasis Curve

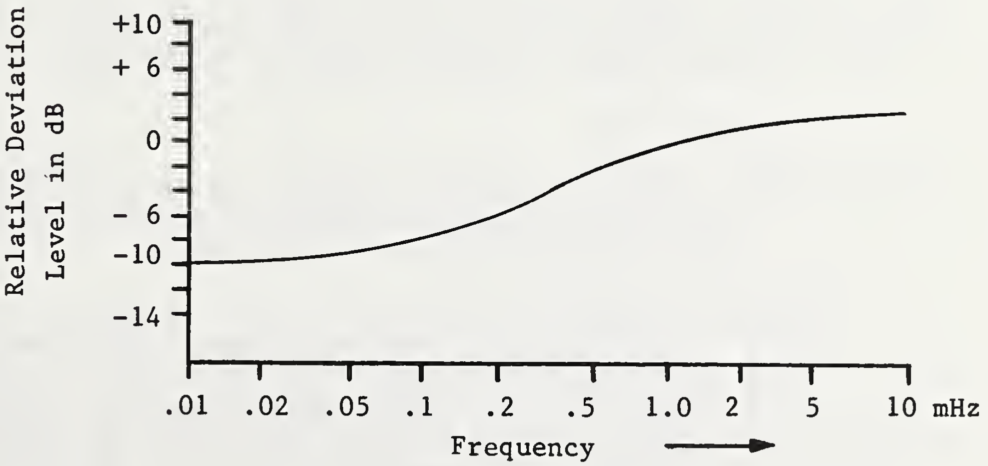


Figure II-93 TV Preemphasis Curve

M = Top baseband frequency in kHz, the commonly used frequency for the top end of the top message baseband channel. Above this frequency there may be orderwire systems or radio pilot. These are not considered normally in calculating loading.

d = Per channel deviation in kHz. It is a measure of how far a channel test tone will deviate the FM carrier. It is assumed that the measurement is made in an unemphasized channel.

P = RMS power of the baseband in dBm0 for $N < 240$ chn, $P = 1 + 4 \text{ Log } N$ for $N \geq 240$ chn, $P = -15 + 10 \text{ Log } N$.

C = Crest factor in dB is the ratio of peak power to RMS power of the baseband. The peak is defined as the level not exceeded more than 0.01% of the time. For white noise and high capacity systems this factor is 13 dB.

D = Peak deviation of the system which occurs when the power of the baseband exceeds the RMS power by the crest factor.

$$= \text{Log}^{-1}\left[\left(\frac{P}{20}\right)\left(d\right)\left(\text{Log}^{-1}\left(\frac{C}{20}\right)\right)\right]$$

$$= \left(d\right)\left(10 \exp\left(\frac{P+C}{20}\right)\right)$$

B_n = Necessary RF bandwidth in kHz required for transmission with acceptable levels of distortion

$= 2M + 2DK$

K = 1.0 for the present purpose. It is a relative value of merit reflecting allowable distortion criteria. The figure is used in calculating B_n.

S/N = dB signal to noise ratio in the top channel (worst) of the baseband. The signal is a 0 dBm0 test tone and the noise is 3.1 kHz of flat white noise. The noise is only the FM noise of the system. The assumed receiver input in all cases is -35 dBm and the receiver noise figure is assumed to be 8 dB. The S/N is calculated for unemphasized systems. To account for emphasis, add 4 dB.

Voice Channel Capacity	12	24	60	120	300	600	960	1200	1800
M = Top Freq. in BB in kHz	60	108	252	552	1300	2540	4028	5564	8204
d = Per Chn. Dev. in kHz	50-200	50-200	50-200	140-200	140-200	140-200	140-200	140-200	140
P = RMS Loading in dBm0	3.3	4.5	6.1	7.3	9.8	12.8	14.8	15.8	17.6
C = Crest Factor in dB	16	15	13.5	13.1	13	13	13	13	13
D = Peak Sys. Dev. in kHz	461-1845	472-1888	477-1910	1466-2094	1934-2763	2732-3902	3439-4913	3859-5512	4747
B_n = Necessary Bandwidth in kHz	774-2734	966-3218	1406-4112	4004-5248	6468-8126	10544-12884	14934-17882	18846 22152	25902
S/N = S/N in Top Chn. in dB	91.6-103.7	86.5-98.6	79.2-91.2	81.3-84.4	73.8-76.9	68.0-71.1	64.0-67.1	61.2-64.3	57.8

Figure II-94 Transfer Functions

5. Communications Channels

a. Types of Channels

The basic types of communications channels used over microwave systems are as follows. Bandwidths used are also indicated.

Type of Channel	Notes
Voice Channel	Normally occupies the spectrum of 300 to 3400 Hz.
Teleprinter 50, 75, 100 Baud	Usually transmitted using FSK tones in a subvoice channel.
Facsimile	Usually occupies an entire voice channel.
Data	Normal speeds of 300 to 9600 bits per second can be fitted into one voice channel.
Wideband Data	Wideband data is commonly considered data speeds above 9600 bps. Wideband data channels are placed in the baseband either directly or into various stages of the multiplex hierarchy. For example, a 48 kilobit data signal can normally be fitted into a 48 kHz wide multiplex group.
Video	TV is commonly transmitted via microwave. Various other bandwidths of video are also commonly transmitted over microwave systems. They usually occupy the entire message baseband.

b. Performance Characteristics

The characteristics of most importance in communications channels are:

- Bandwidth
- Frequency response
- Level

- Absolute delay
- Relative or envelope delay
- White noise
- Impulse noise
- Echoes
- Harmonic distortion
- Phase and frequency jitter
- Crosstalk
- Frequency offset

Bandwidth

The bandwidth of a channel is the difference between the upper and lower frequencies of the channel. Voice channels in FDM-FM systems are allocated 4 kHz apiece although only 3.1 kHz of this is usable. With all FDM channels there is always an allocated bandwidth and a usable bandwidth which is slightly less. This allows for guardbands between channels.

Frequency Response

Frequency response is a measure of the net gain at different frequencies within the passband of a channel. Normally the frequency response is static (nonvarying) and rolls off at the edges of the passband. The frequency response is also known as the gain response, linearity or amplitude response.

Level

The level of a channel is a measure of the net gain of a channel. The measurement is usually made at a standard reference frequency in the channel. 1000 Hz is commonly used for voice channels. Levels throughout a communications system have standards or objectives. Too high a level can cause annoyance to an end user and also overload the transmission facilities. Too low a level can cause unacceptable signal to noise ratios and data errors.

Absolute Delay

Absolute delay is the absolute time it takes for a signal to be transmitted through a system. For example, the absolute delay of a circuit going through a geostationary satellite is about 1/2 second.

Relative or Envelope Delay

Relative delay is a measure of the delay time through a system for different frequencies within the channel. In a voice channel the human ear can start to detect relative delay distortion when the relative delay between 1000 Hz and 2600 Hz exceeds 30 milliseconds. High speed data, however, may be sensitive to delay variations of no more than 1/4 of a millisecond over the same frequency range. The significant point here is that data is usually more sensitive to delay distortion than voice.

White Noise

White noise is random energy in a channel containing power at all frequencies of the channel. The energy per Hertz is the same across the channel. The ratio of signal to noise in a voice channel is usually 45 dB or better, typically 60 dB.

Impulse Noise

Impulse noise is random energy with a very high peak to average energy ratio. It sounds like clicks in voice channels and causes errors in data channels if high enough in level. Voice circuits normally have no more than 15 pulses in a 15 minute period above -30 dBm0.

Echoes

Echoes in communications are portions of a signal delayed (or advanced) in time traveling along the same transmission path. They cause annoyance in voice circuits and data errors in data transmission. If echoes are high enough in level, they can cause a circuit to burst into self oscillation. This is called "singing". Impedance mismatches are the most common cause of echoes.

Harmonic Distortion

All wave shapes which are not perfectly sinusoidal contain harmonics according to fourier theory. The converse is true: if a sinusoidal wave's amplitude is distorted, harmonics are generated. Such distortion occurs when an amplifier is overdriven and clipping occurs or if other nonlinearities are introduced in the channel. Such is called harmonic distortion. In a voice channel, harmonics are nominally 40 dB below test tone level.

Phase and Frequency Jitter

Phase jitter is the random movement of the phase position of a signal, a jittering of the time displacement of the signal. It normally appears as noise on a signal. Data modems using phase modulation are sensitive to phase jitter and sometimes require the peak jitter to be within $\pm 3^{\circ}$. Frequency jitter is the first derivative of phase jitter, and also appears as noise on the signal.

Jitter is normally produced in mixers where the local oscillator is unstable due to noise from its power supply or elsewhere.

Crosstalk

Crosstalk is the loose coupling of one channel to another. It occurs in multiplex systems and multi-pair cables. Intelligible crosstalk is crosstalk which appears as intelligent information such as a weak voice heard in the background. Unintelligible crosstalk is crosstalk that is distorted beyond recognition or frequency inverted as happens in multiplex. Subjectively, the human ear is more disturbed by intelligible crosstalk than unintelligible crosstalk. Crosstalk specifications are, therefore, usually 10 dB more stringent for intelligible crosstalk. Specifications for unintelligible crosstalk are similar to noise level requirements.

Frequency Offset

Frequency offset is the frequency displacement of a signal in a channel. It is a constant offset whereas frequency jitter is not constant. In frequency offset a 1000 Hz tone inserted in one end of a circuit may appear as 1002 Hz or 997 Hz at the distant end. Frequency offset can be caused by misadjusted equipment or multiplex equipment that has gone out of sync. Most applications of voice and data can tolerate many Hertz of offset. The standard limit, however, is ± 2 Hz. This stringent requirement is designed to avoid the buildup of offset when many systems are connected in tandem.

6. Video Transmission

a. Introduction

Video transmission is used for a number of applications both in the broadcast industry and in the private industrial community. The primary uses are:

- Relay signals to broadcast transmitters
- Relay video from mobile units to studios
- Relay Closed Circuit Television (CCTV) used for conferences, education, entertainment etc.
- Relay video signals from security monitors or operations monitors in remote facilities
- Visual transfer of data, drawings, printed material.

b. Performance Characteristics

Video, or television, can be transmitted over microwave. The bandwidth required for the U.S. standard NTSC black and white signal is equivalent to a 960 channel system. For NTSC color the equivalent of 1260 channels is required. The European standard color systems, PAL and SECAM require the equivalent of 1800 channel systems.

Video systems use a standard system and/or subsystem interface level of 1.0 volt peak to peak. In the NTSC systems the higher voltage is "black" and lower voltage "white". In the PAL and SECAM systems the reverse is true with peak voltage being white.

The emphasis used for Video is different than for telephony as noted in Section II.F.4.c above.

As mentioned in Section II.G.14 above, when relaying TV signals through a microwave system, the video (picture only) signal is handled separately from the voice. The audio is first used to modulate a sound carrier which is then combined with the video for transmission. The sound carrier is modulated with a high mod index, around 50 kHz peak deviation. For a 0-5 kHz audio signal this is a high mod index of around 10. This FM signal is then applied to the main FM modulator where the resultant spectrum is up to 300 kHz wide for the one audio signal. The resultant signal to noise ratio of the sound channel is 20 dB better than it would have been if the audio signal had been used to modulate the main FM carrier directly with a peak deviation of 300 kHz.

7. Radio Propagation

a. Introduction

This Section discusses the elementary phenomenon of microwave propagation. Analytic approaches are covered in subsequent sections.

Radio waves travel through free space uninhibited. Normally, radio waves traveling through space are diverging as they travel. The intensity of the electromagnetic energy decreases to 1/4 (-6 dB) every time its travel distance doubles. See Figure II-95. The energy at 2x is spread over 4 times the area as at x. The intensity is therefore 1/4 at 2x.

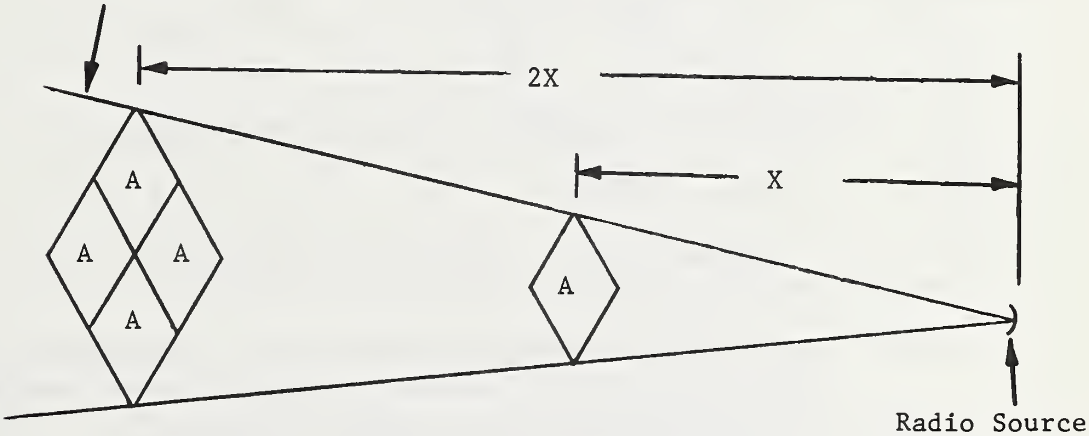


Figure II-95 Divergence of Radio Waves

The radio beam may be very narrow but the principle of divergence still applies. The radio attenuation therefore varies as 20 Log_{10} D. The ability of a radio antenna to radiate in free space is also a function of frequency. Radio path attenuation in free space can be calculated as:

$$\text{Loss}_{fs} = 20\ \text{Log}_{10} \frac{4\pi D}{\lambda}$$

where D = path length

λ = wavelength

For convenience this is usually calculated in distance and frequency using the following logarithmic formula,

$$\text{Loss}_{fs} \text{ in dB} = (32.5 + 20\ \text{Log}_{10}D + 20\ \text{Log}_{10}F)\,\text{dB}$$

$$= (32.5 + 20\ \text{Log}_{10}DF)\,\text{dB}$$

where D is in kilometers and F in megahertz.

The formula assumes that the measurements are made at some distance from the antenna (far field). If too close to the antenna, the field is not properly formed. Real antennas are not point sources and their radiation near the antenna consists of wavelets that eventually add to form a flat wave front at some distance from the antenna. This phenomenon is a function of frequency and antenna diameter. The generally accepted transition, R, between near field and far field for parabolic antennas is

$$F = \frac{2D^2}{\lambda}$$

where D = diameter of the antenna reflector.

In metric units

$$R \text{ in meters} = (.0066)\ (D \text{ in meters})^2\ (F \text{ in MHz})$$

The calculation above for free space loss holds approximately true for terrestrial systems using the atmosphere as a transmission media instead of free space. However, a number of phenomenon affect propagation at microwave frequencies that cause distortion and level variations in the signal.

The primary phenomenon causing these effects are:

- Changes in atmospheric refractivity
- Terrain and obstacle blockage
- Rain attenuation

- Reflections
- Diffraction
- Multipath
- Fading

b. <u>Refractivity</u>

Refractivity is a measure of the atmosphere's refractive index. The refractive index of a media is a measure of the speed of light through the media. The slower the speed, the denser the media and the higher the index. Elementary laws of physics dictate that light waves and radio waves bend towards the normal when entering a denser media. See Figure II-96.

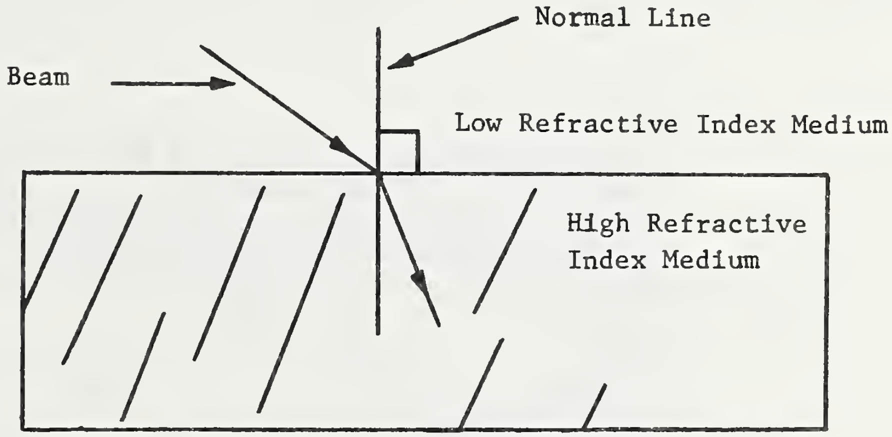


Figure II-96 Light or Radio Beam Entering a Denser Media

This also applies to a graduated change in density. See Figure II-97.

The earth's atmosphere tends to have a refractive index that is higher closer to the surface. The gradient of the index is not stable, however, and as a result the radio beam moves up and down in response to changes in the refractive index. See Section II.H.2 below. The radio wave is normally curved downward slightly and the beam tends to follow the curvature of the earth.

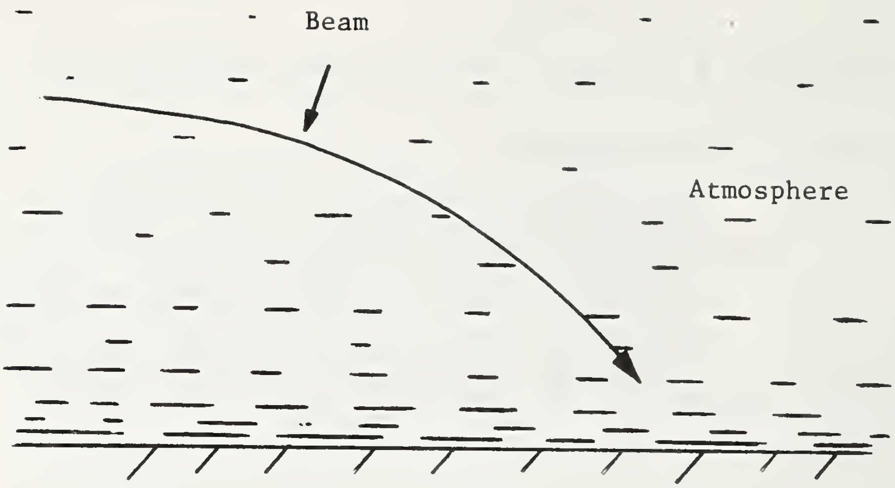


Figure II-97 Beam Bending in Media With Graduated Refractive Index

The refractive index variations with height can be such that a duct is formed which provides a tunnel for the transmitted energy. If the receive antenna is also in the duct, the signal will be considerably enhanced. The duct might also miss the receive antenna in which case the signal is lost.

c. Blockage

Blockage of the radio path can cause the signal level at the receive antenna to drop. Some obstacles are obvious like a building in front of the antenna. Others are not. Because of refractive index changes, the radio beam may be diverted to hit a hillside along the path rather than reach the receive antenna. The hill then becomes an obstacle. See Sections II.G and H for details of analyzing this phenomenon.

d. Rain Attenuation

Rain attenuation is a function of rain intensity and frequency. Generally speaking, it is not a problem in microwave systems operating below 8 GHz . See Section II.H.3.

e. Reflections

Reflections can occur on water surfaces, flat land, particularly wet flat land, roads and airports in line with the path and building surfaces. Like blockage due to obstacles, reflections can be time variant. They cause secondary signals to arrive at the receive antenna. If they are slightly out of phase they introduce delay and amplitude distortion in the path. If the reflected path is much longer than the main beam, there appears to be a separate signal which causes echo distortion or interference similar to a co-channel foreign interferer.

Reflections affect the signal amplitude. If the reflection is in phase with the main beam, enhancement takes place. If out of phase, cancellation. The phase relationship depends on the difference in path lengths of the two signals. This depends on the placement of the reflection. See Figure II-98.

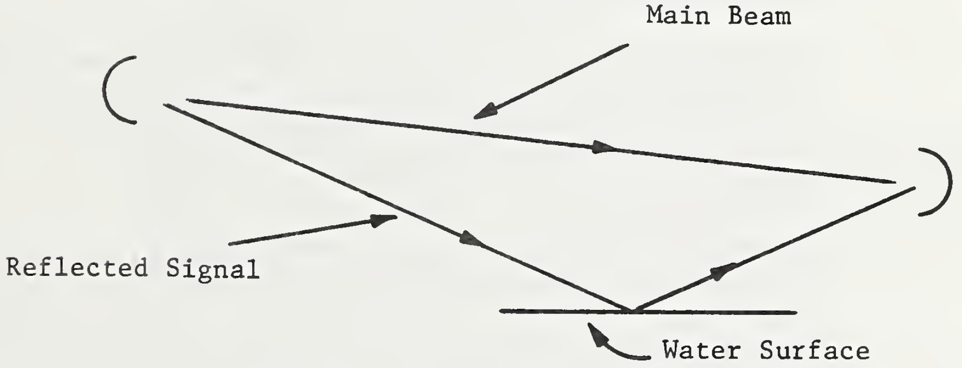


Figure II-98 Reflection Path

If the reflection is right under the main beam, the two paths are identical in length and cancellation occurs since the reflection causes a 180° phase shift. As the distance between the reflection and the main beam is increased, the reflected signal path length will increase. As it increases the reflected receive signal continues to change its phase relationship with the main beam. At certain distances under the main beam a reflection will cause in phase reflections, at others out of phase reflections. The method of calculating these various distances is a function of geometry. The term used is "Fresnel Zone" which is a zone or range of distances where enhancement or cancellation takes place. The center of the Fresnel Zones is calculated as:

$$\text{Nth Fresnel Zone} = \sqrt{N \lambda d_1 d_2 / D}$$

$$= 548\sqrt{\frac{N d_1 d_2}{FD}} \quad \text{meters}$$

where d_1 = distance from the reflection to one end of the path in km

d_2 = distance to the other end

D = $d_1 + d_2$ which equals the total path length

F = frequency in MHz

λ = wavelength in km

Odd Fresnel Zones (N is odd) are enhancing, even are cancelling (out of phase).

Reflections can be frequency selective and can distort the polarization of the signal. These effects further complicate the interference caused by reflections.

f. Diffraction

Diffraction occurs when a path is slightly obstructed. Some of the microwave energy "bends over" the obstacle or "diffracts" over it. The sharper or more knife edge like the obstacle is, the more the amount of energy that diffracts over the obstacle. If a path is blocked, the signal may not be lost if sufficient energy diffracts over the obstacle.

g. Multipath

The multipath phenomenon of microwave propagation is the phenomenon of more than one signal arriving at the receive antenna although they all originate at the same transmit antenna. This can occur due to reflections as mentioned above. The atmosphere also creates multiple signal paths when perturbations in the refractive index "break up" the signal into numerous wavelets. The result is a slight amount of splattering of the signal in the atmosphere. Some of the numerous signal wavefronts arrive at the receive antenna. Generally, they arrive at slightly different arrival angles but still within the main beam of the antenna. In fact, the wider an antenna's beamwidth, the more of these signals it sees arriving at off center angles.

Multipath signals add together at the antenna hornfeed. The sum of their amplitudes can be equal to zero or nearly zero. This causes a fade in the receive signal. Also, the sum of the signals may vary with frequency across the bandpass of the radio. This phenomenon is called frequency selective distortion. The phase and/or amplitude of the desired signal can be affected in this frequency selective manner.

h. Fading

Fading on microwave paths is the changing of the receive signal level at the receive antenna. Up fading is the enhancement of the signal; down fading is a reduction in its level. Several types of fading exist:

- Scintillations
- Long term fading
- Short term fading
- Upward fading

Scintillation is minor jittering in the signal level not unlike the twinkling of a star. It occurs to a larger degree on longer paths. Generally speaking, it varies the steady state receive signal up and down a few dB about the value calculated fcr free space transmission.

Long term fading is a measure of the general trend of the signal level on a given path as it varies from free space loss. Seasonal variations are often observed on some paths due to such effects as rain during rainy season or foliage attenuation during the summer.

Short term fading is the sharp instantaneous fading that occurs due to causes such as multipath. The deeper the fade, the shorter the duration. Short term fading is often called Rayleigh fading. See Figure II-99.

Upfading occurs most commonly during periods of ducting and during multipath fading. It rarely exceeds 6-10 dB on a given path and does not normally contribute to the design of a microwave system. The system designer should ensure, however, that receivers will not cause excessive distortion at the higher levels.

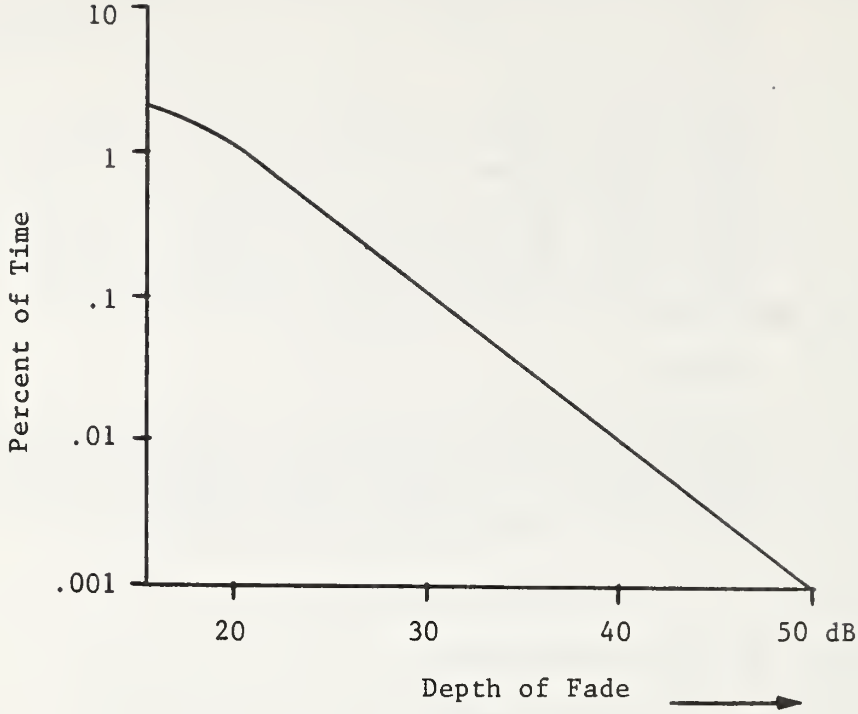


Figure II-99 Rayleigh Fading

i. Reciprocity

Reciprocity in a microwave system means RF propagation in one direction will occur in the reverse direction equally. This is instantaneously true for the same frequency in both directions. If the frequencies are not exactly the same, reciprocity does not hold true necessarily. Two different RF frequencies in the same band will, in the long run, average out to the same level, however. Exceptions do occur, though, where a path has some frequency sensitive characteristic. Common examples are distorted antennas, poor waveguide and unusual reflecting surfaces along the path.

8. Noise

a. Introduction

Noise is incoherent random energy. Noise in its various forms inhibits valid transfer of information in communications systems. Noise, as erroneous energy, competes with the desired information for acceptance as information at the receive end. It annoys voice communicators. It causes snow on television screens, unwanted spots and shadows on facsimile transmission, errors in data transmission, false alarms in control systems and numerous other false signals. The communications engineer assesses the levels of acceptable noise interference for different types of applications and designs to meet them.

b. Thermal Noise

Thermal noise is random energy with a constant energy spectrum across a given frequency band. Known as "White Noise", thermal noise consists of randomly generated pulses of energy that add to and subtract from other randomly generated pulses to produce an energy picture as shown in Figure II-100.

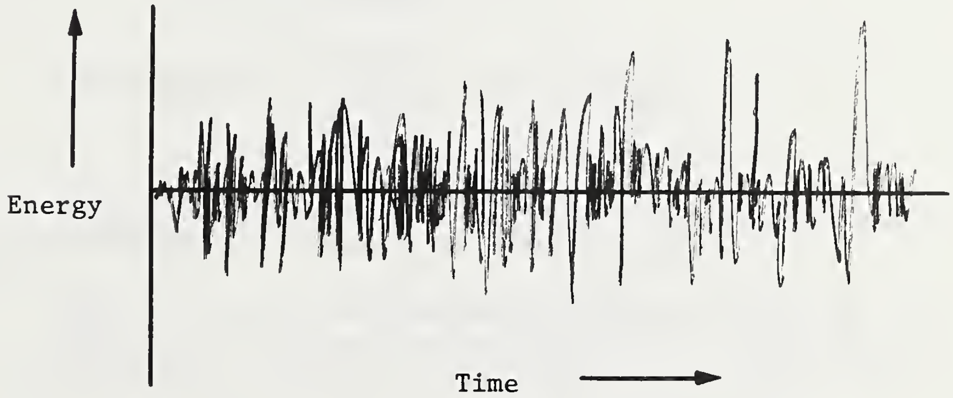


Figure II-100 White Noise Energy

Thermal noise has an average energy level as well as energy peaks that exceed threshold levels as presented in Figure II-101.

All physical matter with a temperature above absolute zero radiates electromagnetic energy. It is called black body radiation. The energy spectrum of this radiation shifts upwards in level and frequency with an increase in temperature. Figure II-102 examplifies this principle.

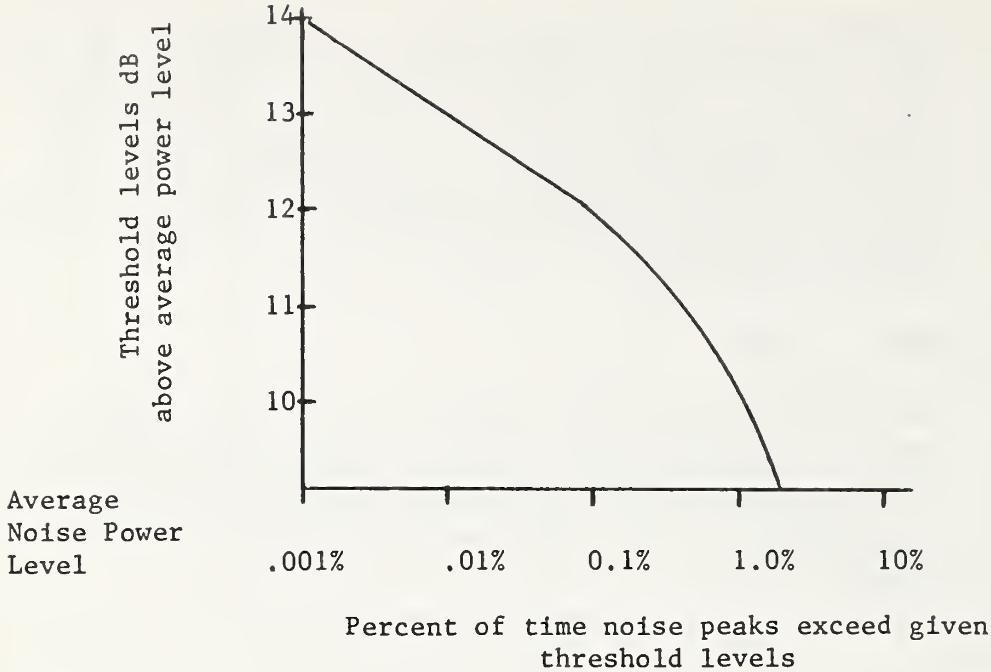


Figure II-101 Duration of Noise Peaks

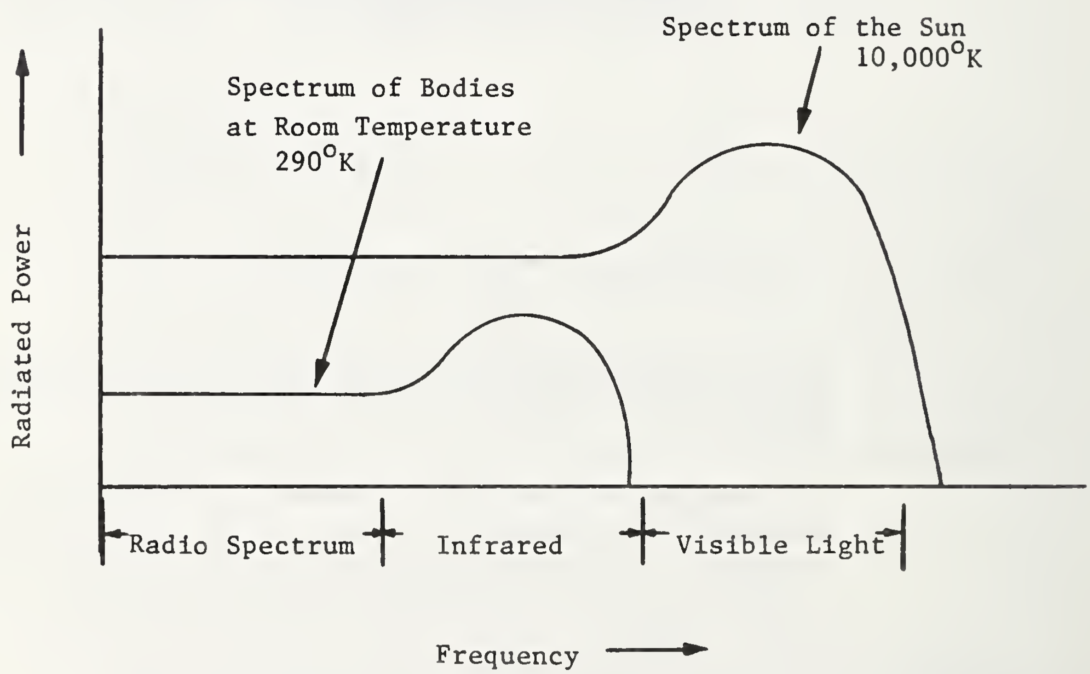


Figure II-102 Black Body Radiation

In the radio spectrum, bodies at room temperature and above have a flat spectrum. The energy per Hz is constant across the spectrum. The amount of energy is

$$\text{Energy} = KTB$$

where K = Boltzmann's Constant

1.38×10^{-23} joules per degree kelvin

T = Temperature in degrees kelvin

B = Bandwidth in hertz

At room temperature, the energy in a 1MHz bandwidth is dBm

$$= 10 \text{ Log}_{10} \left[(1.38 \times 10^{-23}) \ (290^{o}) \ (10^{6})\right]$$

$$= 10 \text{ Log}_{10} (4 \times 10^{-15})$$

$$= -144 \text{ dBW}$$

$$= -114 \text{ dBm}$$

In a receiver with a 1 MHz bandwidth operating at room temperature, the level of -114 dBm is the governing factor in the limit of possible noise performance.

Thermal or white noise exists in all communications channels to some extent. When loud enough to be audible, it sounds like a rushing noise with no discernible information such as tones or repeated bursts of energy.

Truncated and Weighted Noise

Thermal noise with an energy which is not constant with frequency is called truncated noise or weighted noise. See Figure II-103.

A common example of this is a truncated noise spectrum in hi fi systems similar to Curve C in Figure II-103 called "pink" noise. The noise tapers off at the higher audio frequencies. Curve A shows FM noise.

The human ear's sensitivity to noise depends on the frequency of the noise. To account for this in communications systems noise measurements, the unimportant frequency components of the noise are derated or suppressed before

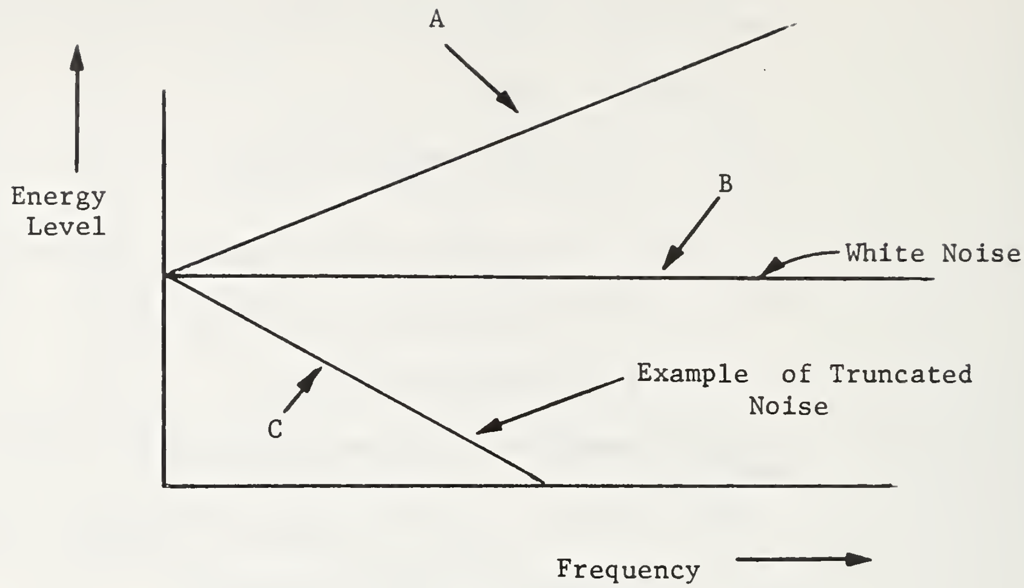


Figure II-103 Noise Energy Spectrum

the measurement is taken. This is done by passing the noise through a filter before making the measurement. Figure II-104 shows the frequency response of such a "weighting" filter.

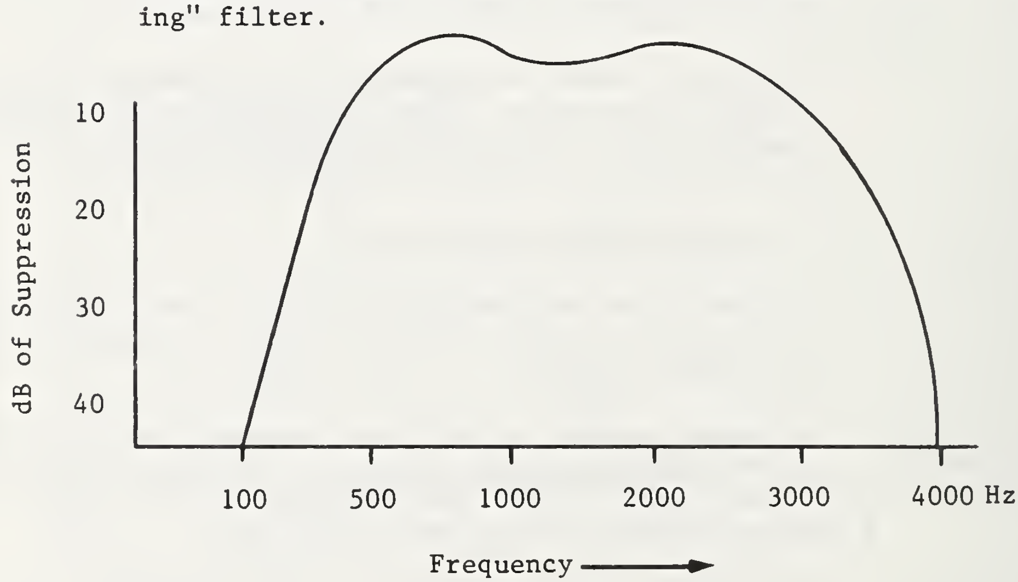


Figure II-104 Filter Characteristics of a Weighting Filter

Weighting filters also account for the frequency rolloff of common telephone equipment. The importance of noise or a reflection of its annoyance value across the noise spectrum is different for different types of telephones. Figure II-105 presents the weighting filters of several different standards.

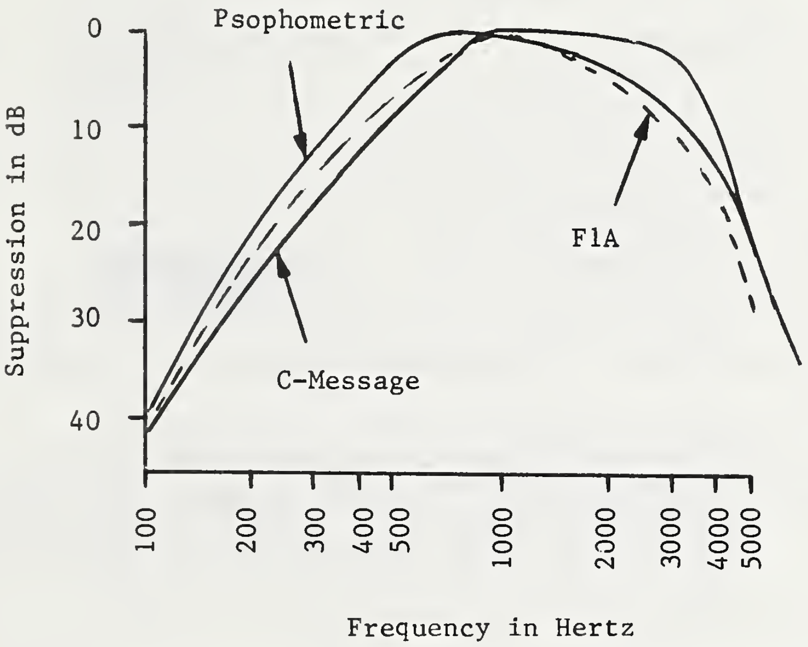


Figure II-105 Common Weighting Filters

The C-Message Filter has zero loss at 1000 Hz. The psophometric filter peaks at 800 Hz. When passing discrete tones through a weighting filter, the amount of attenuation depends on the tone's frequency.

The C-Message curve applies to the standard model 500 telephone used widely throughout the Bell System. FIA is a curve used with the model 500's predecessor, model 302. It is no longer in common use. The psophometric curve is a "European" standard established by the CCITT of ITU.

Numerous terms have arisen in the communications field to describe voice channel noise levels. The important concept to understand is the interpretation of the noise measurement. A given spectrum of noise may be described by numerous weighted measurement units although the noise may be unweighted itself (has a flat spectrum). See Figure II-106 for the principles involved in making weighted noise measurements.

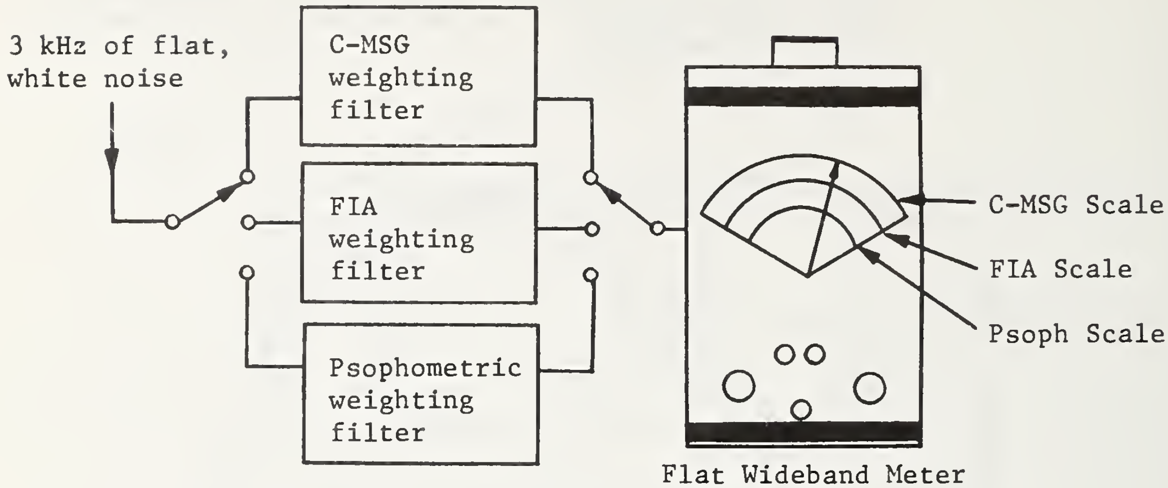


Figure II-106   Weighted Noise Measurement Procedure

Different filters will give different readings. Separate scales are provided on the meter for this purpose. Assuming that the white noise level is 1.0 mW (0 dBm), the readings in Figure II-106 will be as shown in Figure II-107.

Filter Used	Actual Noise Energy Level After Passing Through the Filter	Meter Scale to be Read	Meter Reading
C-Message	-2.0 dBm	C-MSG	88 dBrnC*
FIA	-3.0 dBm	FIA	82 dBa*
Psophometric	-2.5 dBm	Psoph	-2.5 dBmp*

* Dimensional units are explained below

Figure II-107   Noise Measurements

It should be remembered that a weighted measurement such as dBa or dBmp is not an exact measure of the noise power in a channel. It is a measure of the noise as it is subjectively perceived by the human ear. If the noise in a channel is not flat (white noise) then the loss through the weighting filter could be quite different from the values given in Figure II-107, column 2.

Noise Measurement Terminology

The various noise measurement systems normally use a reference power level. All measurements are then given in power levels relative to that reference. In the psophometric system, for example, noise after passing through the noise filter is called noise power in dBmp. If the absolute power of the noise after passing through the filter is 0 dBm we call this 0 dBmp since it has been weighted with a psophometric meter. The reference is therefore 0 dBm in the psophometric system. If the noise power after the filter is -10 dBm, this is called -10 dBmp or -10 dBm of noise which is psophometrically weighted.

C-Message uses -90 dBm after the filter as a reference. -90 dBm measured after the filter = 0 dBrnC. Using such a low noise power as a reference means most measurements will have a positive sign. 60 dBrnC for example is -30 dBm of C-MSG weighted noise.

FIA uses -85 dBm after the filter as the 0 dBa reference.

To expand on Figure II-107, C-Message and psophometric systems are compared in Figure II-108.

White Noise Power Level Before Filter	Noise Power After Passing Through the Weighting Filter		Weighted Noise Value	
	C-MSG	Psophometric	C-MSG	Psophometric
+20 dBm	+18 dBm	+17.5 dBm	108 dBrnC	+17.5 dBmp
+4.3	+2.3	+1.8	92.3	+1.8
+0	-2.0	-2.5	88.0	-2.5
-10	-12.0	-12.5	78.0	-12.5
-50	-52.0	-52.5	38.0	-52.5
-72.6	-74.6	-75.1	14.9	-75.1
-90	-92.0	-92.5	-2.0	-92.5
-95	-97.0	-97.5	-7.0	-97.5

Figure II-108 Noise Level Comparisons

Noise is also measured in picowatts. One picowatt = 1.0 pW = 10^{-12} watts = 10^{-9} mW = -90 dBm. There are two reasons for stating noise levels in picowatts.

- It is easier to add noise energy levels mathematically if these levels are in arithmetic form rather than logarithmic form.

- Using 1.0 pW or -90 dBm as the reference means almost all noise measurements will be whole positive numbers (easier to add).

Consider the circuit in Figure II-109. It shows a series of amplifiers which can represent a series of electronic functions in a communications system.

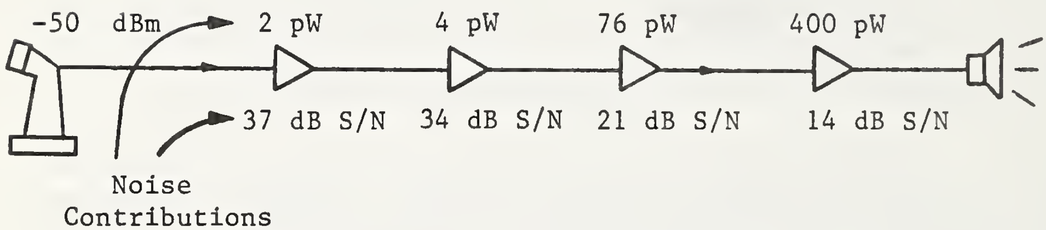


Figure II-109 Amplifier Chain with Noise Contributions

For simplicity assume unity gain for all amplifiers.

The problem is to figure out the signal to noise ratio at the output. The output signal will be -50 dBm since all amplifiers have unity gain. The noise contributions are a total of

$$2 + 4 + 76 + 400 = 482 \text{ pW}$$

$$= -63.2 \text{ dBm}$$

The S/N is therefore -50 - (-63.2) = 13.2 dB

If the picowatt contributions had not been given it would have been necessary to calculate using the S/N ratios of each amplifier. This is far more complicated a procedure.

<u>Relative Noise Measurements</u>

Relative measurements allow for even greater flexibility in determining noise. Noise measurements can be stated as signal to noise ratios using weighted or unweighted noise terminology. Consider the circuit in Figure II-110.

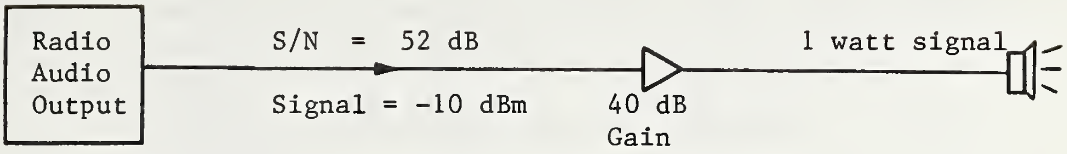


Figure II-110 Amplifier Circuit

In this figure the S/N is signal to white noise ratio. No weighting is used. If the amplifier contributes no discernible noise, then the S/N at the amplifier's output will be 52 dB. The noise and the signal will both be 40 dB higher, however. The noise is -62 dBm before the amp and -22 dBm after although the S/N is the same. The noise in the circuit can be assigned a relative value called dBm0. The letter"0" means "relative to" in noise terminology. In the Figure II-110 the noise is -52 dBm0 both before and after the amplifier. More specifically, a noise level of -52 dBm0 means the noise would be -52 dBm if the circuit level was adjusted to 0 dBm.

Likewise with picowatts, pW0 means level in picowatts at a point where the standard test tone level is 0 dBm. For example, if one point in a circuit has a standard tone level of -10 dBm and the actual noise is 24 pW at that point, the noise is 240 pW0. That is, the circuit level is mentally adjusted to 0 dBm which would require 10 dB of amplification. Such an amplification would also raise the noise level from 24 pW up 10 dB to 240 pW. Therefore, the noise is 240 pW0.

Again, 380 pW of noise at a circuit point with a level of +17 dBm would be 7.6 pW0 (380 pW attenuated 17 dB = 7.6 pW).

Let us now apply the pW0 principle to a noise analysis problem. Figure II-111 shows three amplifiers in a row with various gains and noise contributions.

The procedure for calculating the output S/N to the speaker is lengthy because all noise values must be converted to some arithmetic format for addition to take place. Figure II-112 shows the same circuit with pW0 ratings.

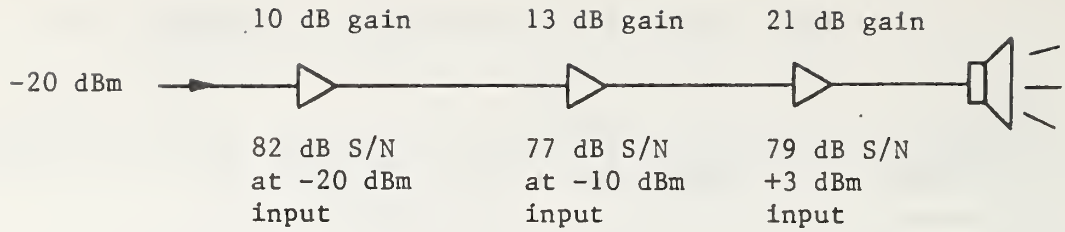
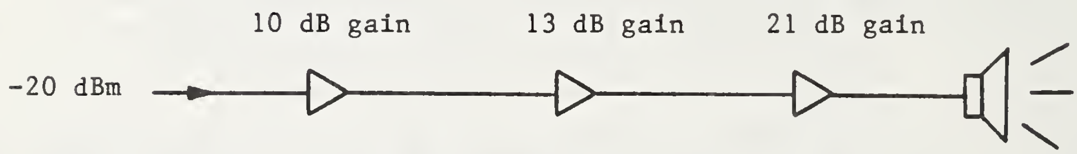


Figure II-111 Cascaded Amplifiers with Different Gains



Noise Contribution	= 630 pWO	20 pWO	13 pWO
Rated Input	= -20 dBm	-10 dBm	+3 dBm

Figure II-112 Amplifier Chain Rated in pWO

The pWO noise rating assumes the signal input level is fixed. In communications circuits, signal levels are adjusted to a specific value at all points along the circuit. Standardization of levels like this is common practice in communications systems.

The noise at the speaker input is simply 630 + 20 + 13 = 663 pWO. The S/N is 0 dBm (adjusted tone level) divided by the noise. 663 pWO = -61.8 dBm0

S/N = 61.8 dB

The communications industry often specifies equipment noise performance in the picowatt format. The "0" is often dropped leaving pW to mean pWO.

Besides dBm0 and pWO, several other terms are in common use like dBrnC0, dBa0 and pWp0. pWp0 implies psophometrically weighted noise. The term pWp means picowatts psophometrically weighted. If a circuit's white noise is 100 pWO, the pWp0 reading will be 2.5 dB below this or 56 pWp0. The term dBm0p is dBm0 psophometrically weighted.

Another letter commonly used in noise terminology is the lower case "r". It means relative to the standard or usual level. -16 dBr means 16 dB below whatever the standard test tone level is at that point. The term dBrnC used above is dB's relative to noise weighted by a C-message filter. Similarly, dBrnCO is dBrnC at a point adjusted to "0" dBm.

A number of other noise measurement terms are covered in the glossary.

c. Intermodulation Noise

Intermodulation is the process of mixing two or more signals in a nonlinear device to produce additional signals, generally unwanted. When many signals are involved, the intermodulation (IM) products tend to form a widespread spectrum of by-product signals that have the appearance of noise. Such is the case when two independent wideband FDM-FM signals intermodulate. The mixing by-products are so numerous as to be spread across the spectrum evenly like white noise energy.

The problem to be addressed in this section is an FDM-FM signal causing interference to itself. To understand the principle, it is noted that FDM-FM signals consist of sidebands. Each one of the sidebands is a contributing signal in any mixing process through which the modulated carrier may pass. In fact, each wideband has the potential of mixing with all other sidebands to produce products, i.e. at $f_1 + f_2$, $f_1 - 2f_{42}$, or $6f_7 - f_{19} + 3f_4$, where f_n is the nth sideband. The amount of mixer products depends on the extent of nonlinearity.

Great care is taken in FM systems to reduce nonlinearities as much as is feasible. It is not possible to entirely eliminate all nonlinearities, so there is always some level of intermodulation products. The system designer should account for all potential sources of FM during system design.

The two major causes of IM distortion in FM systems are nonlinearities in the frequency response and delay response of the modulation, demodulation, IF and RF equipment. (On occasion, the same nonlinearities exist in the propagation path but are not considered in this Section.) The frequency response of a typical radio path from transmitter IF input to receiver IF output is shown in Figure II-113. Such a measurement is known as an "IF to IF" measurement.

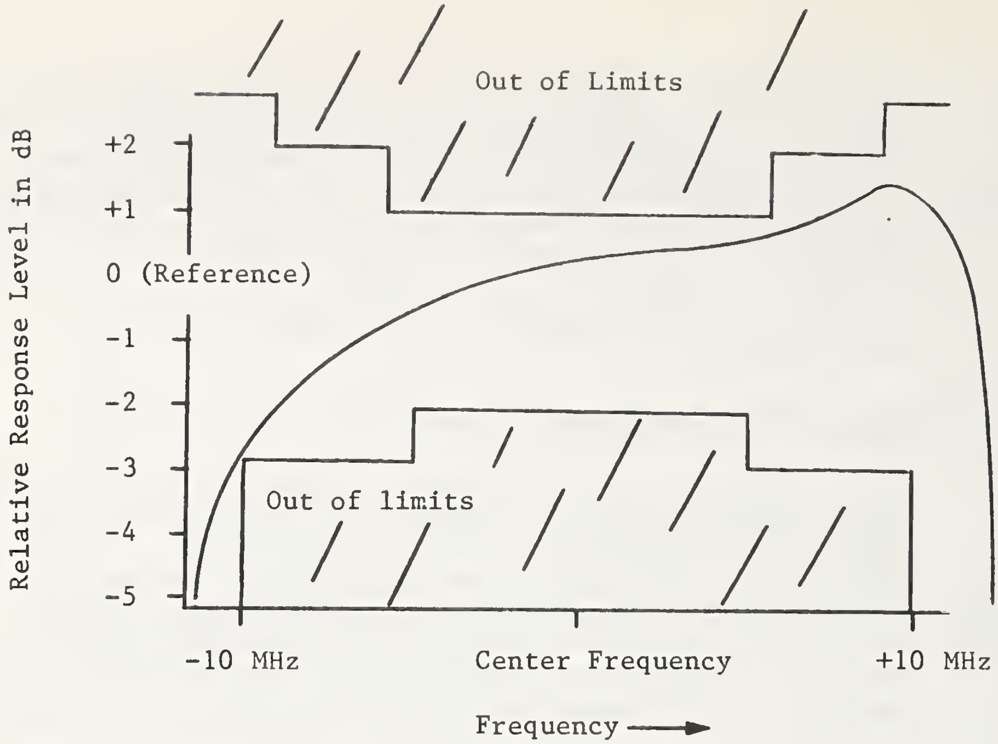


Figure II-113 Linearity

Figure II-114 shows a typical delay response measured from IF to IF. The delay pattern is a measure of how long it takes different frequencies to traverse the distance from transmit IF to receive IF. The flatter the curve, the better.

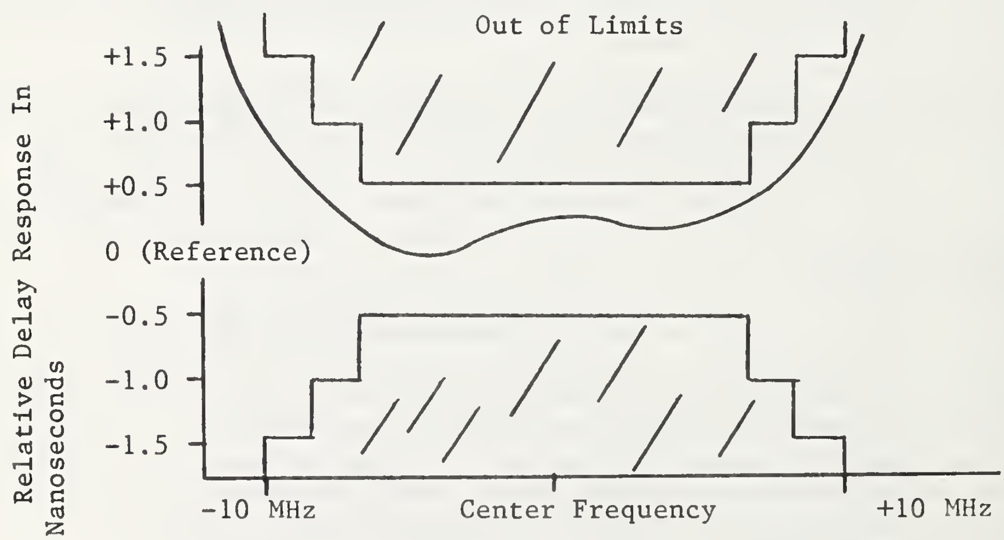


Figure II-114 IF to IF Delay Response

To understand the mechanisms of IM in FM systems, one must understand the spectrum structure of an FM signal. If a 1000 Hz tone modulates a 70 MHz carrier it produces sidebands at 70 MHz ±1000 Hz or 70.001 MHz and 69.999 MHz similar to amplitude modulation. In frequency modulation, however, additional sidebands are generated at 70 MHz ±2 kHz, ±3 kHz, ±4 kHz, ±nth kHz.

Mathematically, sidebands are produced out to infinity with decreasing levels. In practice, only sidebands within a limited range are accounted for. The number of and power in the sidebands depends solely on the ratio of how far the carrier frequency is deviated to the frequency of the modulating tone. The ratio is called the

$$\text{Modulation index} = \frac{F_{peak}}{F_{mod}}$$

The mod index is entered onto a table of Bessel functions and the power of the sidebands is read from the graph. See Figure II-115. The Bessel function is a mathematical solution to the complex mathematics used to describe frequency modulation.

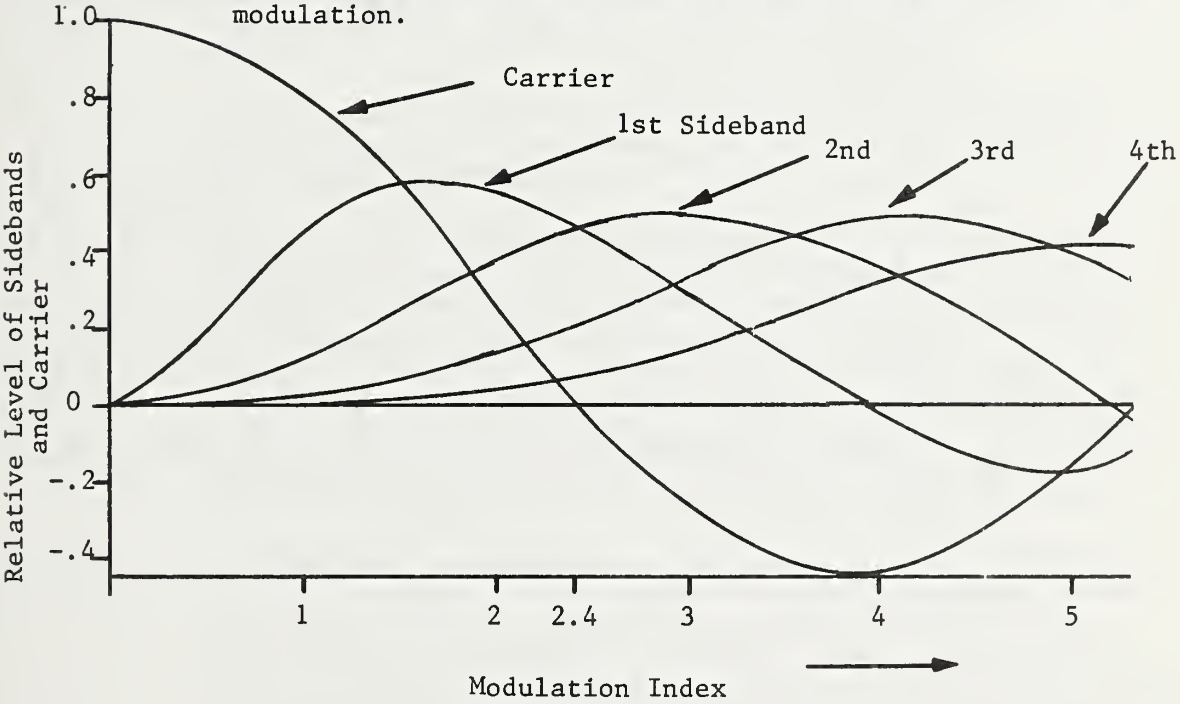


Figure II-115 Bessel Functions
(Only the First Four Are Shown)

In an unemphasized 1800 channel FDM-FM system, the mod index for the top channel may be

$$\text{Mod index} = \frac{\text{Peak Channel Deviation}}{\text{Baseband Frequency of the Channel}}$$

$$= \frac{(140 \text{ kHz rms}) (\sqrt{2})}{8 \text{ MHz}}$$

$$= .025$$

A mod index of .025 has very little energy in the sidebands. A channel in the bottom end of a baseband has greater energy in the sidebands since the mod index is higher.

$$\text{Mod index} = \frac{(140) (\sqrt{2}) \text{ kHz}}{60 \text{ kHz}}$$

$$= 3.3$$

Let us now assume we have a 60 kHz modulating tone with a mod index of 3.3. Its energy spectrum is shown in Figure II-116.

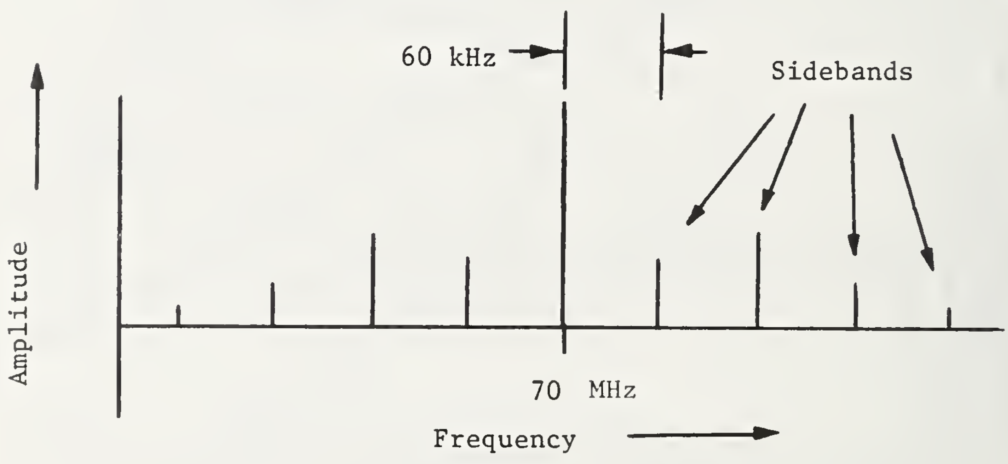


Figure II-116 Sideband Distribution

These sidebands with the carrier as shown in Figure II-116 are transmitted through the radio system finally being demodulated at the receive end. The demodulator reconstitutes the 60 kHz as a pure tone if and only if the original sidebands are all present and all have the same phase and amplitude relationship to each other as they did at the time of modulation. Assuming one and only one of the sidebands is over amplified during transmission, the demodulator produces the 60 kHz tone as well as a tone in the baseband at the frequency of the overamplified sideband. Likewise, if one of the sidebands is slightly reduced in level due to poor system frequency response, the demodulator will produce a slight tone in the baseband where the tone energy has been reduced. If the phase of one of the sidebands shifts, it is equivalent to adding another tone at the sideband frequency but shifted in phase. The net result is an erroneous tone in the baseband. Now, if there is slight frequency and delay distortion across the entire spectrum (as there always is to some extent) affecting all the sidebands, then small tones may be generated at 120 kHz, 180 kHz, 240 kHz and $\pm$N60 kHz. In an FDM-FM system, there may be 600 active voice channels all producing low level erroneous tones or noise energy across the spectrum due to intermodulation. The net result is noise across the baseband since the numerous tones or voice energy bursts are random in nature since the energy in the 600 voice channels is random.

The above explanation is meant to be tutorial and by no means rigorous. An exacting treatise is beyond the scope of this Bulletin.

The most common method of measuring IM in an FDM-FM radio system is to measure the ratio of the energy in a voice channel when the entire system is active to the energy in the same channel when that channel is idle and every other channel is fully active. The energy that does appear in the one idle channel will be a measure of the amount of IM products that "spill over" into that channel. The greater the system IM distortion, the higher the noise level in the channel. The ratio is called Noise Power Ratio (NPR).

In practice, the test is run without using the multiplex. Instead of loading every channel with voice activity or an equivalent amount of noise, the baseband itself is loaded with wideband white noise to simulate the condition of a fully loaded multiplex. Also, instead of measuring the noise in a given channel, a narrow band frequency selective voltmeter is used to look at a discrete point in the baseband where the test channel would have been located. This procedure eliminates the mux as a source of IM during the test of the radio. To make the idle channel measurement above, a narrow bandstop filter is used to reject the noise at a given spot in the baseband before modulation at the transmit end. This empty spot in the baseband spectrum simulates the idle channel. The two measurements taken to determine NPR are shown in Figures II-117 and 118.

The NPR is the ratio of the readings taken in Figure II-117 to the measurement in Figure II-118. The NPR test is one of the most demanding tests for a microwave system and is a most comprehensive check on overall nonfade related system performance.

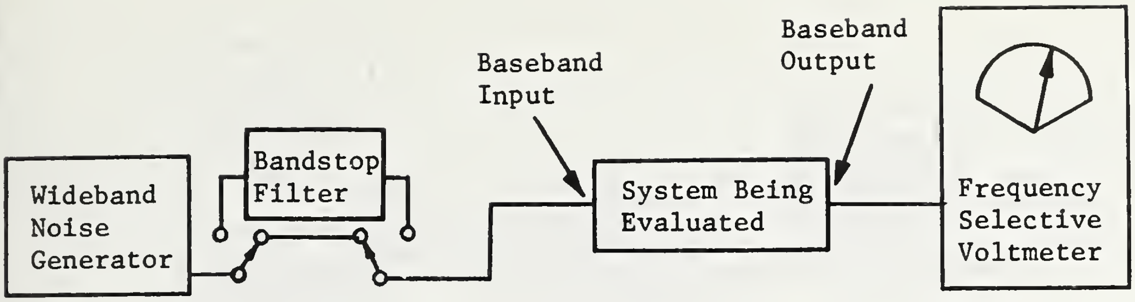
A third measurement is commonly made during the NPR test. The wideband noise is removed and a reading is taken in the idle "channel" with the system entirely unmodulated (all channels idle). This is a measure of all system noise other than intermodulation noise. The ratio of the measurement in Figure II-117 and this figure is called the Basic Intrinsic Noise Ratio, BINR.

It is usually checked to make sure that what appears to be IM noise is not noise due to some other source. For example, if IM noise is measured on a faded path, the FM thermal noise might be higher than IM noise causing false NPR readings.

NPR's are commonly measured at different frequencies in the baseband. Good NPR performance at one baseband frequency is not evidence of good performance elsewhere in the same baseband. Standard test frequencies for various size systems have evolved as shown in Figure II-119. The noise generator also uses high pass and low pass filters so the shape of the wideband noise is the same as the FDM multiplex output.

Not all available frequencies are tested at all times. Usually, measurements are made at the top and bottom of the baseband and at one or two of the middle frequencies.

Figures II-113 and II-114 show that the frequency and delay responses are normally worse the further away from the center frequency they are measured. Therefore, the more energy there is at the outer edges of the passband, the higher the probability of IM distortion. The greater a system's deviation, the greater the energy at the passband edges and the greater the IM noise. A measure of the amount of IM as a function of system deviation is shown in Figure II-120. For convenience Figure II-120 shows IM in terms of NPR.



Testing Configuration

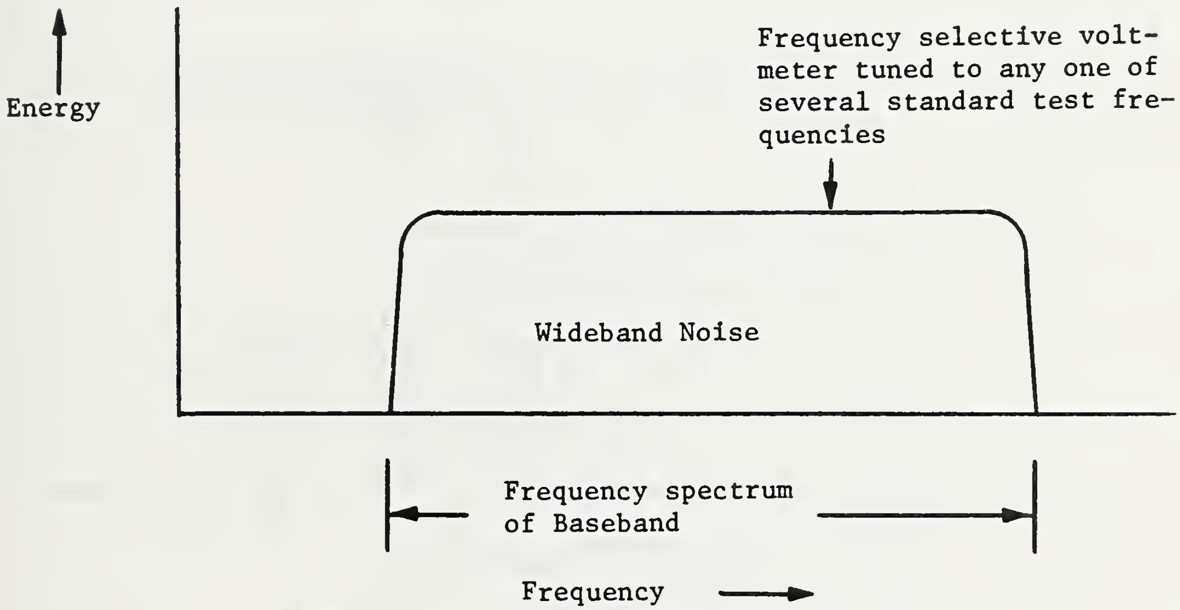


Figure II-117 NPR Test; Measurement of Busy Channel

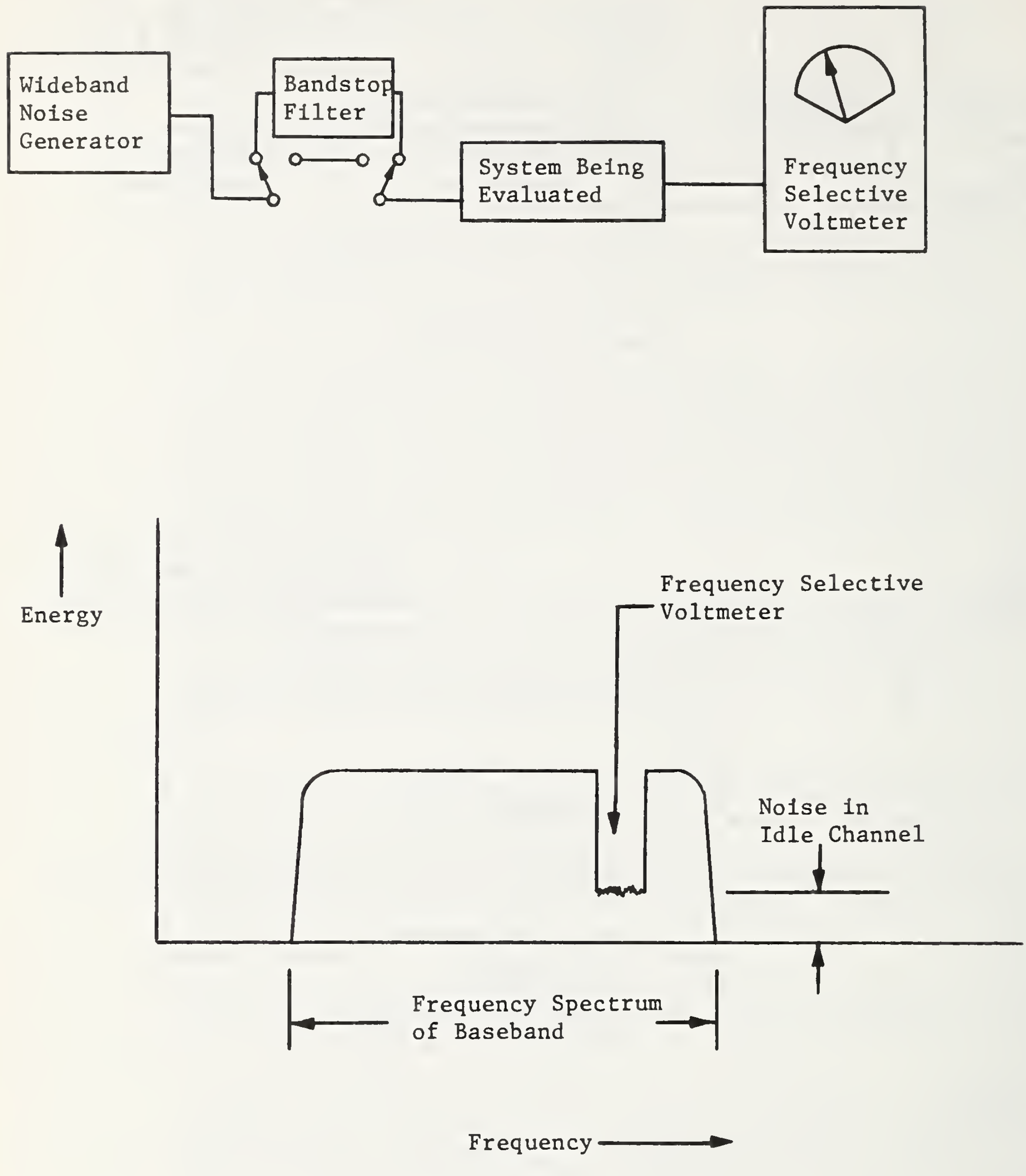


Figure II-118 NPR Test; Measurement of Idle Channel

System Channel Capacity	Highpass Filter Frequency	Lowpass Filter Frequency
24	12 kHz	108 kHz
60	60	252
120	60	552
300	60	1300
600	60	2540
960	60	4028
1200	316	5564
1800*	316	8204
2700*	316	12388

* Unavailable in present industrial microwave bands

Available Idle Channel Frequencies (Bandstop filter center frequency) in kHz
16, 70, 98, 140, 240, 270, 394, 534, 770 1002, 1248, 1730, 2438, 3150, 3886, 4650, 5340, 7600, 11700

Figure II-119 NPR Filter

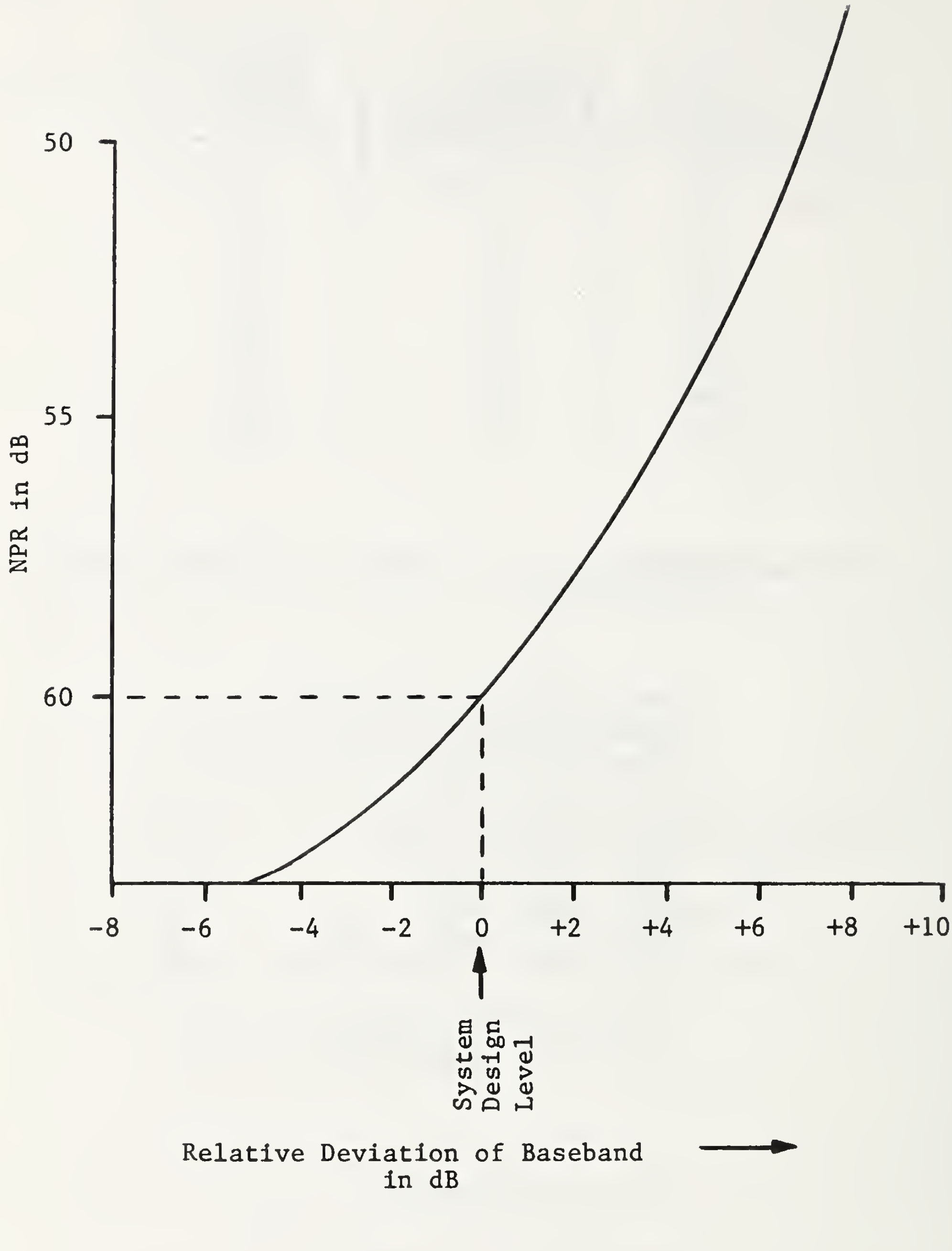


Figure II-120 NPR's, a Function of Deviation

It is readily apparent that a 1 dB increase in deviation can increase the IM noise several dB. It is advisable to set the deviation as high as possible, however, due to the improvement in FM noise it produces. See Section II.F.4.a. The ratio of signal to FM noise in a channel improves dB for dB as deviation is increased. We can combine the FM and IM noise contributions as a function of deviation. See Figure II-121.

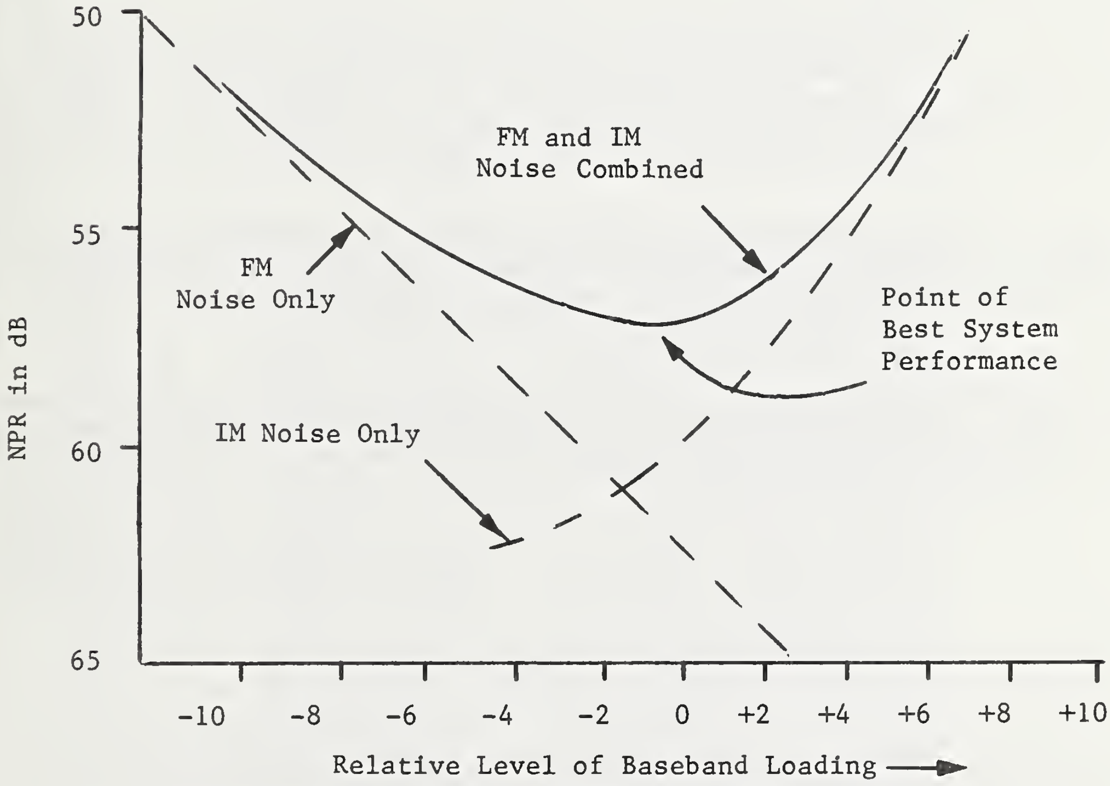


Figure II-121 NPR's; A Function of Deviation

The curve in Figure II-121 is called a "Bucket" curve due to its shape. The lowest point on the curve is the quietest. The "0" dB system design level is usually slightly to the left of this point to allow for some over deviation before serious degradation of the system begins to occur.

Microwave systems are sensitive to over deviation as Figure II-121 shows. An "overload" of 10 dB can make the system unusable. The levels of all signals going through a microwave system are tightly specified and controlled to prevent overloading. A single user on an 1800 channel system can seriously affect all other channels with a single loud tone. For example, if the system is loaded with 1800 channels at +18 dBm0 and a user inserts a +25 dBm0 tone into his phone, the resultant loading will be +26 dBm0. This is an 8 dB overload for the system. The result will be tones and IM products across the baseband.

Intermodulation noise is caused mainly by the electronic equipment associated with FDM-FM systems. Multiplex and radio equipment contribute most of the IM noise. Echoes in the system also produce IM noise, however, and are considered in Sections II.F.9.b and c.

NPR measurements have become standard measurement technique throughout the microwave industry. The technique is easily mastered. Theoretically it represents a true measurement of expected system performance. One assumption in NPR measurements is the fact that the wideband noise used in the technique closely approximates a diffused energy spectrum of a wideband multichannel FDM system. This assumption ignores the fact that high level discrete tones often exist in the baseband causing noticeable intermodulation products within the baseband. The level of these IM tone products is higher than might be anticipated from results of NPR tests. The discrepancy between NPR tests and IM generated by discrete tones is greater for narrowband systems. For example, if a high level tone of +2 dBm0 is applied to a voice channel of a narrowband system, the tone's power is a greater percentage of the overall baseband energy than it would be if applied to a wideband system. The IM impact due to discrete tones is therefore greater for narrowband systems.

In recent years, test sets have been developed to measure IM due to discrete tones. Common practice is to use two or three tones. The frequencies of the tones and the IM byproducts are arranged to fall below and above the message baseband. This technique can therefore be used to make measurements while the system is carrying traffic.

d. Coherence of Interfering Noise

White noise, by definition, is random, contains no information and is therefore incoherent. Weighted noise is slightly coherent in that it contains information about its energy spectrum. Garbled crosstalk is even more coherent since we tend to recognize it as data, voice or music, although it is not fully understood. Generally speaking, the more coherent noise is, the more annoying it is as an interferer. Coherent interference which sometimes occurs in adjacent RF channel interference is often measured as noise although interfering voice signals can be understood if such coherent interference occurs.

In overload situations in microwave systems, the resultant interference is perceived as discrete tones or voices if the cause of the overload is a single or very few offending signals in the baseband. The human ear is approximately 10 dB more sensitive to this coherent interference than to wideband, flat noise.

One often useful tool in tracing noise problems is the human ear. The ear is normally much superior to machine in quickly analyzing interference for the presence of coherence. Faint music below noise, morse code in the presence of other code signals and voice through a heavily distorting channel can all be instantly recognized if not fully understood. A meter reading of the same cannot discern the presence of coherence. Perceiving the coherence of interfering noise is obviously helpful in tracing its source.

e. Impulse Noise

Impulse noise is spasmatic intermittent noise with high peak values. It contains bursts of energy in single or multiple pulses. In between pulses, the energy normally drops to zero or a very low level. The height (energy) and width (time) of the pulses is normally varied as is the frequency of pulse occurrence. The frequency spectrum of impulse noise is random in nature but tends to have spectral characteristics that depend on the noise source and on the characteristics of the transmission media involved. Many impulse noise patterns have cyclically recurring pulses. The energy spectrum will therefore have noticeable energy at a frequency of occurrence plus its harmonics.

Impulse noise causes errors in data transmission and other signal distortions. Figure II-122 shows a typical example of impulse noise.

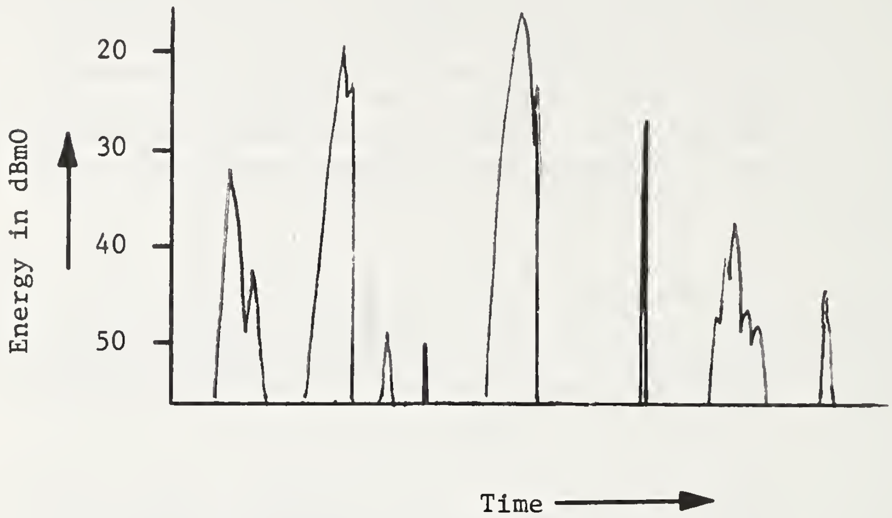


Figure II-122 Impulse Energy in a Channel

A typical value of impulse noise is 15 counts at -30 dBmO in a 15 minute period.

Figure II-101 in the section above on Thermal Noise,II.F.8.b, showed that white noise has a definite relationship between peaks and their duration. Impulse noise in general has no such predictable relationship. The peak values must be determined on a case by case basis.

Impulse noise is measured as pulses exceeding a certain level during a given period of time. To measure impulse noise, a counter is connected to the test point or circuit. The counter registers a count every time a pulse appears that exceeds a preset level. A reading of the register's accumulated total can be taken manually or automatically at predetermined intervals. The counter has a slow enough rise time to ignore pulses of extremely short duration and a slow enough decay time to avoid over counting when a burst occurs of pulses close together.

Counters can also be equipped with multiple threshold levels to count pulses of various energy levels. It is also possible to vary the rise and decay times in some models of test equipment. All of these techniques aid in the analysis of impulse noise.

Impulse noise in communications systems is caused mainly by the following:

- Lightning and related inducements of pulses
- Adjacent cable pairs carrying high energy such as DC pulses
- Circuit routings through telephone switching centers
- Misaligned or poorly designed diversity switching systems
- FM receivers operating near threshold
- Induction due to high tension lines or nearby motors
- Poor grounding system
- Overstressed system components
- Loose or intermittent connections

Troubleshooting impulse noise often requires imagination since the number of potential sources can be extensive. Variations in the strengths and frequency of pulse occurrence are often clues as to the source. High occurrence at night could mean fade related radio equipment problems or temperature sensitive cable joints outside. High rates during the day could indicate end user caused problems or excessive equipment sensitivity to overloads. If the occurrence is cyclical in any way, there may be a traceable reason. In troublesome cases, printed copy of occurrences and their levels often lead to solution.

Impulse noise can be eliminated or its effects abated by eliminating the source of the pulses, raising the signal to impulse noise ratio or rerouting the affected circuit over quieter facilities. A more exotic method is to introduce a large amount of delay distortion at the transmit end of a circuit and an equal but opposite amount of distortion at the receive end. The net impact on the signal is zero. Impulses introduced into the circuit, however, will only experience the delay distortion at the receive end. This receive end distortion tends to spread out the energy of the impulse thus reducing its impact on the desired signal.

9. Impedance

a. Concept of Impedances

Impedance is the opposition (resistance and reactance) of a device to the flow of electrical energy. In microwave systems we are concerned with characteristic impedances of devices and input/output impedances. The concern is to insure that two devices connected in parallel have matching impedances to ensure maximum transfer of energy. Figure II-123 exemplifies the principle of matching impedances.

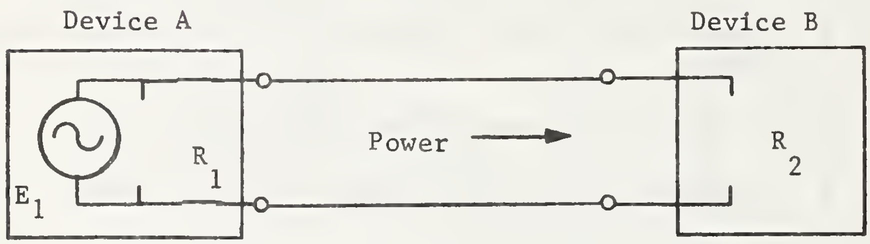


Figure II-123 Power Transfer

From elementary electronics, the power transfered to Device B is maximum for a given E_1 if $R_2 = R_1$. If we look into the input of Device B we measure an input impedance of R_2. Likewise, R_1 is the output impedance of Device A. In voice circuits, the reactive component of impedances is usually close to zero and is normally ignored.

Transmission lines (coaxial cable, waveguide, twisted pair) have characteristic impedances. If a cable is infinitely long, its input impedance is the same as its characteristic impedance. If a cable is finite in length, then the input impedance will depend on the termination at the other end of the cable. For example, if a short section of 50 ohm cable is terminated with 100 ohms, the cable's input impedance will vary from 3 to 100 ohms depending on the frequency and the cable's length and line loss. The same type of impedance variation occurs if the source impedance of the device generating the frequency does not have the same impedance as the cable or its termination. In the ideal situation the impedances of the source, line and termination are identical. Consider Figure II-124.

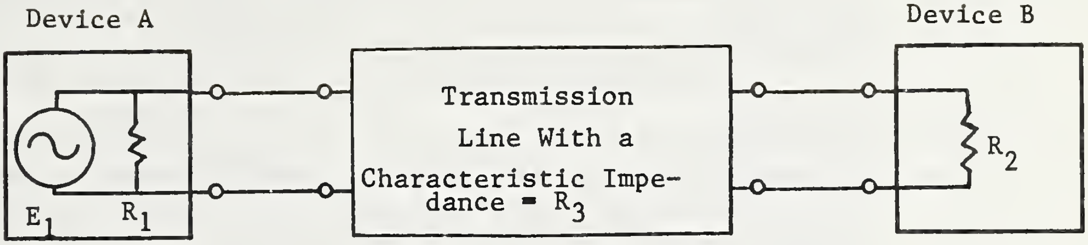


Figure II-124 Mismatched Impedance Case 1

The maximum amount of energy will be transfered from Device A to Device B if $R_1 = R_2 = R_3$. The importance of the transmission line's impedance is also a function of its electrical length and line loss.

If the line is a twisted pair of wires transmitting audio frequencies, its characteristic impedance is not important if the line is short. See Figure II-125.

With such a short (100mm) line the characteristic impedance is not significant since the line loss is insignificant and the line length is very short compared to λ of the voice frequencies. If the line were many kilometers long with 20 dB of loss, then Device A would be "looking" into 600 ohms as it attempts to insert power into the transmission line. A mismatch occurs, and little of the power enters the cable. At the other end of the line, the 600 ohm transmission line attempts to feed power into Device B which has an input impedance of 100 ohms. Another mismatch occurs.

With waveguides, the line loss is not as dominant a factor. A mismatch and resultant lack of power transfer is much more a matter of electromagnetic wave formations in waveguides and the ability of a source device to excite a suitable mode of propagation in the waveguide or the terminating point to absorb the mode being propagated.

When a mismatch is discovered to exist between two devices, an impedance matching device is often used. Figure II-126 shows two such devices.

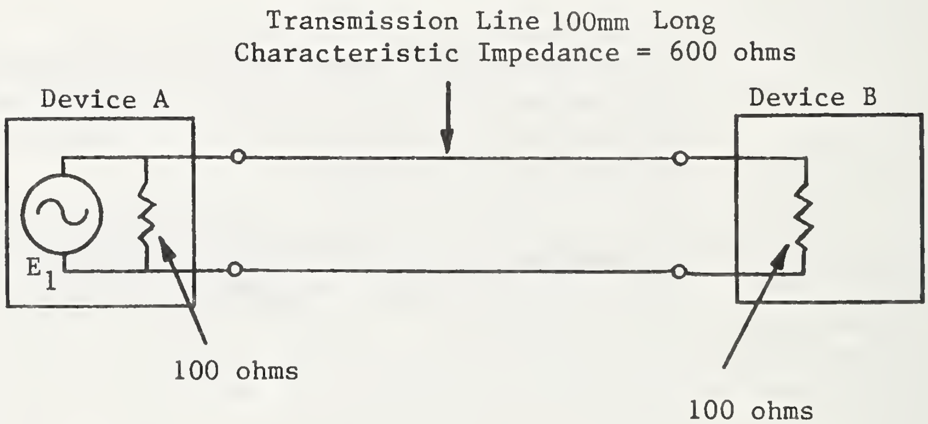
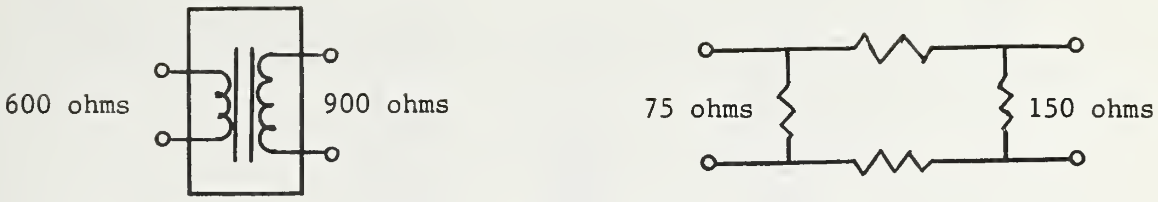


Figure II-125 Mismatched Impedance Case 2

In waveguide, impedance mismatches are more a matter of mechanical imperfections rather than different design impedances. Two practices are common in correcting waveguide impedance problems. The first is a tuning section that uses stubs to balance out the effect of the mismatch. See Figure II-127.



Transformer

Loss = "0" dB

Resistive Network

Loss = ≥ 6 dB

Figure II-126 Impedance Matching Devices

The alternate solution is the use of an isolator. The isolator simply absorbs any reflected energy caused by the impedance mismatch. See Section II.E for explanation of how an isolator functions.

A third method of impedance matching is an indirect method which controls the signal levels desired rather than directly match impedances. The method is used at lower wire line frequencies for resolving the impedance mismatching when multiple connections are to be made to the same point. A single source with an output impedance of R_1 can only be matched to one R_1 load. If a source of R_1 is to feed multiple loads of R_1 impedance, isolating bridges and amplifiers can provide the matches without causing reflections. See Figure II-128.

R_3 provides a proper termination for the source impedance of Device A. A_1 has an output impedance of R_1 to match the Device B (likewise for Devices C and D).

R_2 is such a high resistance as to effectively isolate A_1's from Device A. The gain of A_1 is set to overcome the loss through R_2's.

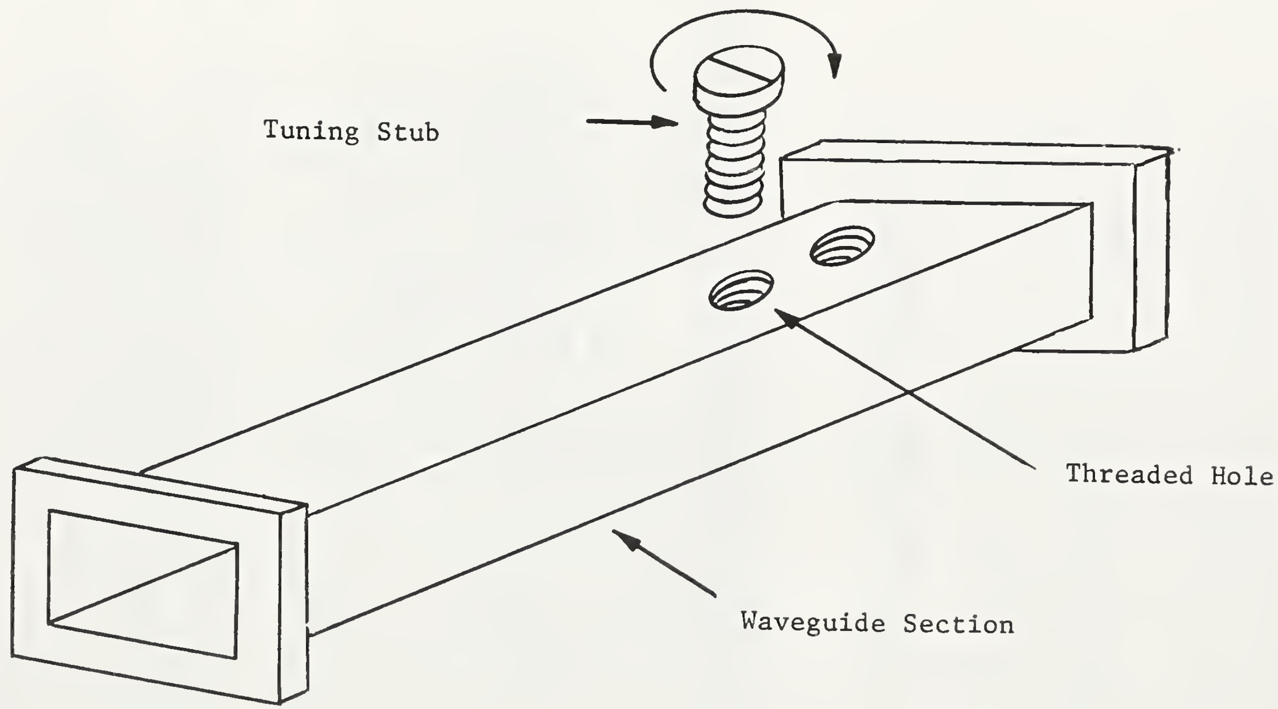


Figure II-127 Waveguide Tuning Section

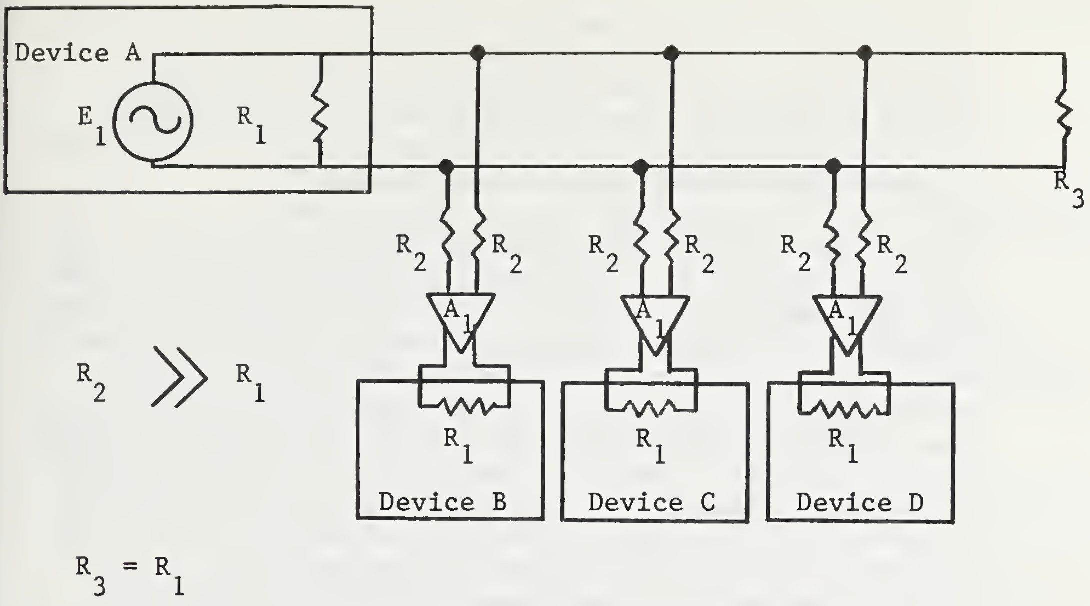


Figure II-128 Bridging Network

Besides matching of impedance in system design, it is important to understand testing procedures in measuring circuit levels. Measurement devices are designed to make measurements either in the bridging mode or terminating mode. Terminated measurements are used to measure the output of a device which is otherwise not terminated. Bridging measurements are made on "in service" circuits that are already properly terminated. See Figure II-129.

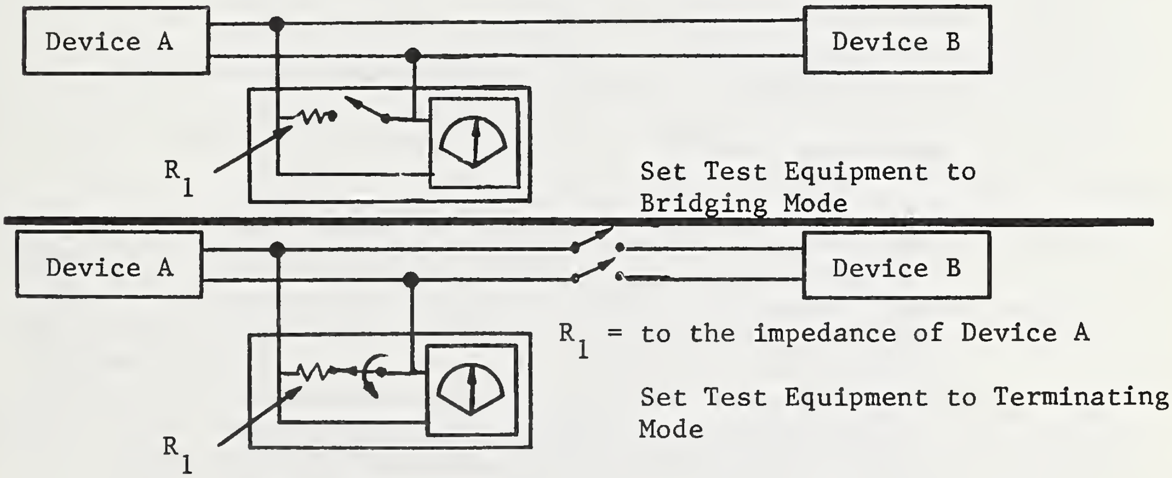


Figure II-129 Measurement Techniques

In the first test arrangement in Figure II-129, the input impedance of the test equipment is ≈ infinite or very high compared to Device A's output impedance. In the second arrangement, the test equipment's input impedance is set to match Device A's output impedance. This properly terminates Device A for the measurement.

So far, the reactive component of impedance has been ignored. In many circuits it is the cause of minor reflections. At VHF frequencies and above, the impedance mismatch is caused by slight imperfections in connectors, cables and components. Counteracting capacitance or inductance is often provided for tuning out reactive impedance imperfections. The compensating components are commonly placed in output/input circuitry. Generally speaking, the ideal impedance is purely resistive. In reality, they are almost purely resistive with frequency dependent variations in both the resistive and reactive aspects of the impedance. In the final adjustments of impedances, the system parameters that are monitored during the fine tuning are signal distorting parameters like frequency and delay response rather than impedances directly. Naturally, it is more important to have an undistorted signal than an almost perfect impedance.

Typical impedances in microwave systems are:

- Waveguide input 50 ohms
- Impedance within the waveguide ~400 ohms
- IF interfaces 75 ohms
- Multiplex voice channel inputs/outputs 600 ohms
- Group/supergroup points within the multiplex 75 and 150 ohms

When measuring signal power in a bridging mode across a given impedance many meters measure the voltage only. The meter face is equipped with a voltage scale as well as a power scale in watts, milliwatts, dBm or some other power scale. The bottom of the meter face will have a notation saying "600 ohm meter" or other ohmage designation. This means that the "power" scale(s) on the meter is only valid if the voltage reading is taken across a 600 ohm impedance. The voltage scale is valid for all impedances, of course.

If a 600 ohm meter is used to measure the power across a 75 ohm impedance, the voltage reading is used to calculate the power at 75 ohms.

$$P = \frac{E^2}{R(75\ \text{ohm})}$$

The power scale is not valid for 75 ohms since it represents power across 600 ohms only. The scale can be used, however, with the use of a correction factor:

$$\text{Correction Factor} = 10\,\text{Log}_{10}\left(\frac{\text{Meter Ohmage}}{\text{Actual Impedance}}\right)\ \text{dB}$$

$$= 10\ \text{Log}_{10}\frac{600}{75}$$

$$= 9\ \text{dB}$$

If the meter reads + 10 dBm and 2.45 volts across 75 ohms, the actual power is:

power reading + correction factor

= 10 dBm + 9 dB

= 19 dBm

b. Voltage Standing Wave Ratio

Improper impedance matching whether in system design or testing causes reflections and distortions of signals and can directly affect the operation of various circuit elements causing abnormal changes in signal characteristics. System equipment usually is specified with specific input and output impedances with a tolerance range. The most common tolerance value is known as Voltage Standing Wave Ratio (VSWR). VSWR is an indirect measurement of an impedance's imperfections. It is a measure of the reflected wave that occurs when a source of calibrated output impedance is used to feed a device with an imperfect impedance.

To understand the mechanism of standing waves, assume a source as in Figure II-130.

The source feeds energy into the transmission line whose characteristic impedance is the same as R_1. The energy reaches the short, is reversed 180° and returns back down the transmission line. (When it reaches R_1, it is fully absorbed since the transmission line matches R_1.) At the point of reflection, the incident and reflected waves always cancel each other because they are 180° apart. The voltage at the short is therefore always zero. As we move away from the short, however, the phase relationship between the two waves begins to shift until they are 360° apart at A. At this point they are in phase and add. The sum of the two waves is not constant, however, since the amplitude of the two waves at A is changing sinusoidally. The voltage at A is 2E at one moment, zero half a cycle later, then -2E, back to zero, up to 2E, and so forth. In other words, the voltage at A varies between -2E and +2E, sinusoidally at the frequency of E_1.

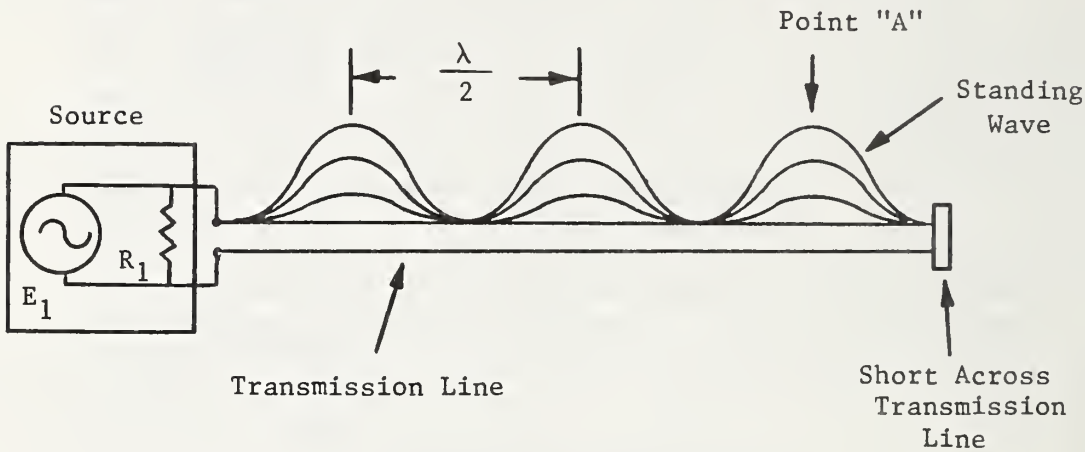
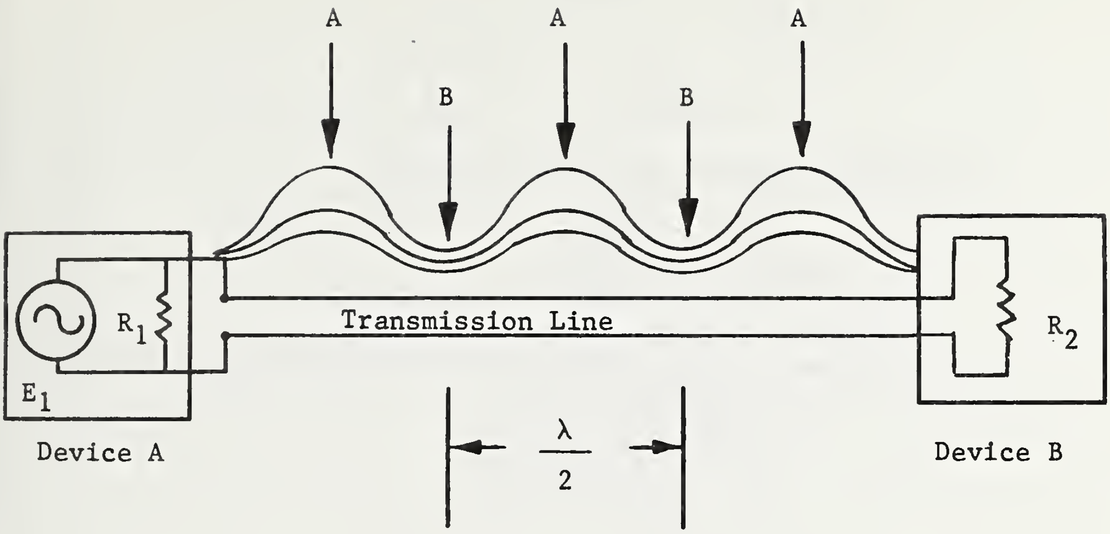


Figure II-130 Standing Wave Formation

When the reflection is due to only a partial short (impedance mismatch) the standing wave at the partial short is not zero but some finite level. The peaks likewise do not reach ±2E but something less. See Figure II-131. To measure the standing wave, a probe is used, connected to a meter tuned to the frequency of E_1. The probe is moved along the line to detect maximum and minimum values. In waveguides a section of waveguide with a lengthwise slot is used. A small probe is inserted in the waveguide and moved along the line. The device is called a "Slotted Line".

The voltage ratio of the peaks (A) and valleys (B) in Figure II-131 is called the VSWR. The larger the reflection, the higher the value of VSWR. An example of VSWR terminology is VSWR = 1:1.5. This is often abbreviated to VSWR = 1.5.



$R_1 \neq R_2$

Transmission Line Impedance = R_1

Figure II-131 Standing Wave Due To Partial Reflection

It should be noted in the condition of a partial short the standing wave at the peaks, A, never quite reached $\pm$ 2 E and the maximum level at B is always greater than zero.

Let us assume:

E_1 = 10 volt RMS

R_1 = 50 ohms

R_2 = 52 ohms (mismatch)

The power entering the transmission line is:

$$P_1 = \frac{E_1^2}{R_1} = \frac{100}{50} = 2 \text{ watts}$$

The power absorbed by R_2 is:

$$P_2 = \frac{E_1^{\;2}}{R_2} = \frac{100}{52} = 1.923 \text{ watts}$$

The difference is the reflected power

$$2 - 1.923 = .0769 \text{ watts.}$$

The voltage along the line due to the reflected power is:

$$E_R = \sqrt{(.0769)\ (50 \text{ ohms})}$$

$$= 1.961 \text{ volts}$$

The maximum of the peaks in the standing wave pattern is the sum of the E incident and E reflected.

$$= 10.0 + 1.961 = 11.961 \text{ volts}$$

The ratio of the two = VSWR

$$\frac{11.961}{8.039}$$

$$= 1.488 \quad \text{OR}$$

$$\text{VSWR} = 1:1.488$$

The criticality of impedance mismatches is apparent when VSWR requirements are often as low as 1:1.05. To achieve this, R_2 above would have to be between 49.97 ohms and 50.03 ohms.

There are other measurement terms for specifying mismatch. One is "return loss". It is a ratio of the incident power to reflected power. A typical value is 26dB.

To calculate the return loss in the example given for Figure II-131, we determine E_R which is half the difference between the peaks and valleys of the standing wave.

$$E_R = \frac{11.961 - 8.039}{2} = 1.961 \text{ volts}$$

$$P = \frac{E_R^{\ 2}}{50} = .0769 \text{ watts}$$

The incident power is 2 watts. The return loss is

$$\text{return loss} = 10 \text{ Log}_{10}\left(\frac{P_{incident}}{P_{reflected}}\right) \text{ dB}$$

$$= 10 \text{Log}_{10}\left(\frac{2}{.0769}\right)$$

$$= 14.15 \text{ dB}$$

A more direct conversion from VSWR to return power exists which says

$$\text{return loss} = 20 \text{Log}_{10}\left(\frac{\text{VSWR}+1}{\text{VSWR}-1}\right)$$

$$= 20 \text{Log}_{10}\left(\frac{1.488+1}{1.488-1}\right)$$

$$= 14.15 \text{ dB}$$

c. Echoes

The reflected wave can become an echo if it is again reflected. Figure II-132 shows the principle of double reflection and echo generation.

The antenna reflects part of the RF energy returning part of the signal typically 26 dB below the main transmit energy. The RF branching also has an imperfect impedance and returns part of the reflected wave another 26 dB down toward the antenna. The energy is then travelling along the transmission line 52 (26 + 26) dB below the main transmit signal. It is called an "echo"since it is the same signal delayed by twice the length of the transmission line. Echoes sufficiently delayed appear as unwanted cochannel interference. In wideband microwave systems echoes 52 dB down may cause unacceptable interference.

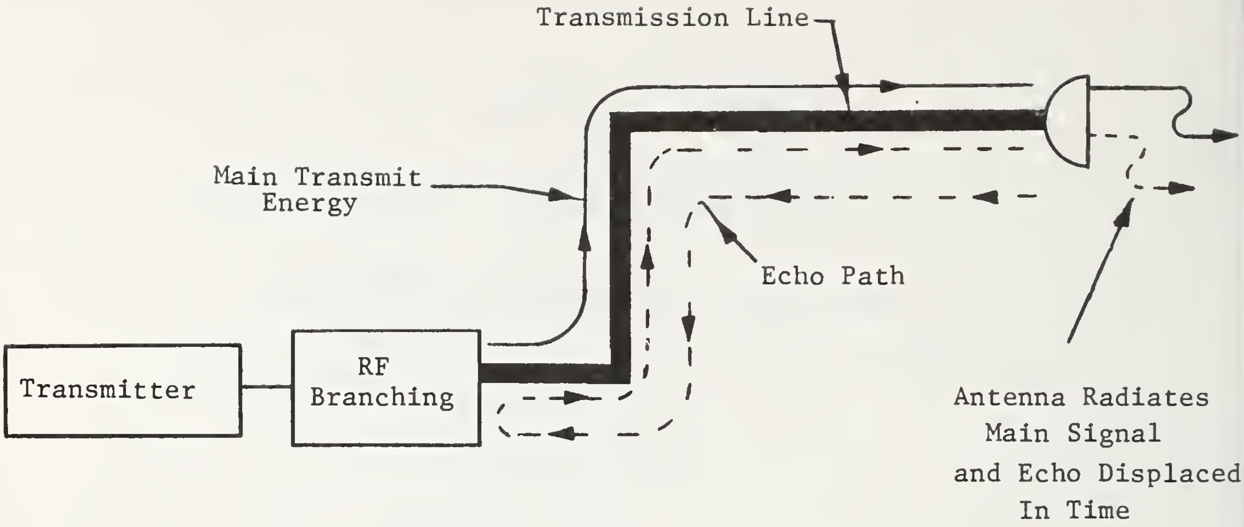


Figure II-132   Antenna System Echoes

In Figure II-132 the level of the echo will actually be further down than 52 dB due to line loss of the transmission line. If the one way transmission line loss between the RF branching and antenna is 4 dB, the echo will be 52 + 2 (4) = 60 dB below the transmit power at the antenna.

Echoes of this sort are unavoidable in microwave systems since impedances are not perfect. The system designer must ensure that echoes are within limits by properly specifying VSWR's or return losses on all pertinent system components.

10. Trunk/Circuit Definitions

The system designer should have an understanding of the difference between a trunk and a circuit. A circuit is a complete electrical path from terminal to terminal. A trunk is a fixed communications facility between two points which are not terminal locations. For example, a circuit is established when one telephone subscriber calls another one in a distant city. The caller uses a local loop of copper wire to dial into his local telephone switching office. The call is then carried over trunks to the distant switching office and out another local loop to the called party. Trunks are the communications facilities commonly used to interconnect switching offices and are normally shared facilities.

The technical performance requirements of interest to the end user are the circuit requirements. To achieve overall circuit requirements it is necessary to apply more stringent requirements on the trunks that are used to make up a circuit. In a microwave system the voice channel from multiplex channel input to output at the distant end can be considered a trunk and should meet trunk performance standards.

G. System Design

1. System Planning

A system design plan incorporates a variety of disciplines required at different stages for the successful implementation of a microwave system. The primary objectives of a plan are:

- Optimum use of resources
  - Personnel
  - Financing
  - Time
- Successful completion of the project

The most common approach in large systems is a time schedule of activities and/or completion milestones. Documentation also schedules the various support functions and financial aspects of the project. Separate schedules can be developed for project activities such as:

- Engineering design phase
- Acquisition
- Construction/Installation
- Test and evaluation
- Commissioning
- Operations and maintenance

The engineering design phase contains:

- Project planning
- Requirements analysis
- System design and specifications

- Equipment specifications
- Implementation planning
- Field implementation support and engineering

The acquisition phase contains:

- Acquisition planning
- Preparation of requests for proposals (RFP's), requests for quotes (RFQ's), solicitations
- RFP, RFQ, Solicitation response(s) evaluation
- Preparation of requisitions, contracts, subcontracts
- Delivery evaluation, scheduling and monitoring

The Construction/Installation phase is the majority of the field effort. This phase contains:

- Site preparation
- Road construction
- Building and tower foundations
- Fencing and gates
- Grounding system
- Building erection
- Tower erection
- Antenna and feeder installation
- Power plant installation
- Electrical system
- Air conditioning and heating
- Telephone installation
- Electronic equipment installation
- Station cabling

The test and evaluation phase contains:

- Test and evaluation plan
- Electrical and mechanical checkout
- Calibration of test equipment
- Electronic equipment initial evaluation
- Path alignment
- System alignment
- Acceptance testing
- Final acceptance

Commissioning contains:

- Detailed end user interface engineering
- Installation of circuits
- Circuit checkout

Operations and Maintenance is covered in Section IV below.

Throughout the system planning activity, use of resources should be continually borne in mind. Generally speaking, the larger the system being planned, the more dedicated the resources will be. For example, some personnel on large systems may be engaged full time from conception through operations and maintenance. The staging of the use of these people can be done in such a way as to optimize their productivity. Also, the larger the system, the more important the time schedule is. On large systems, the schedule becomes more complex because of the interdependency of project activities. Financing also becomes more entailed due to larger cash flows, volume of accounting activity, increased number of suppliers, contractors and subcontractors and the considerable number of possible financial arrangements between the various parties involved. Commonly, with larger systems the amount of engineering and implementation activity increases whereas program management becomes more complex. Adequate planning in advance goes far to avoid costly mistakes.

Figure II-133 shows an overview of a system planning schedule. For more detail, see REA Bulletin 66-4. Figure II-133A is a copy of the form used to file for a microwave license with the FCC.

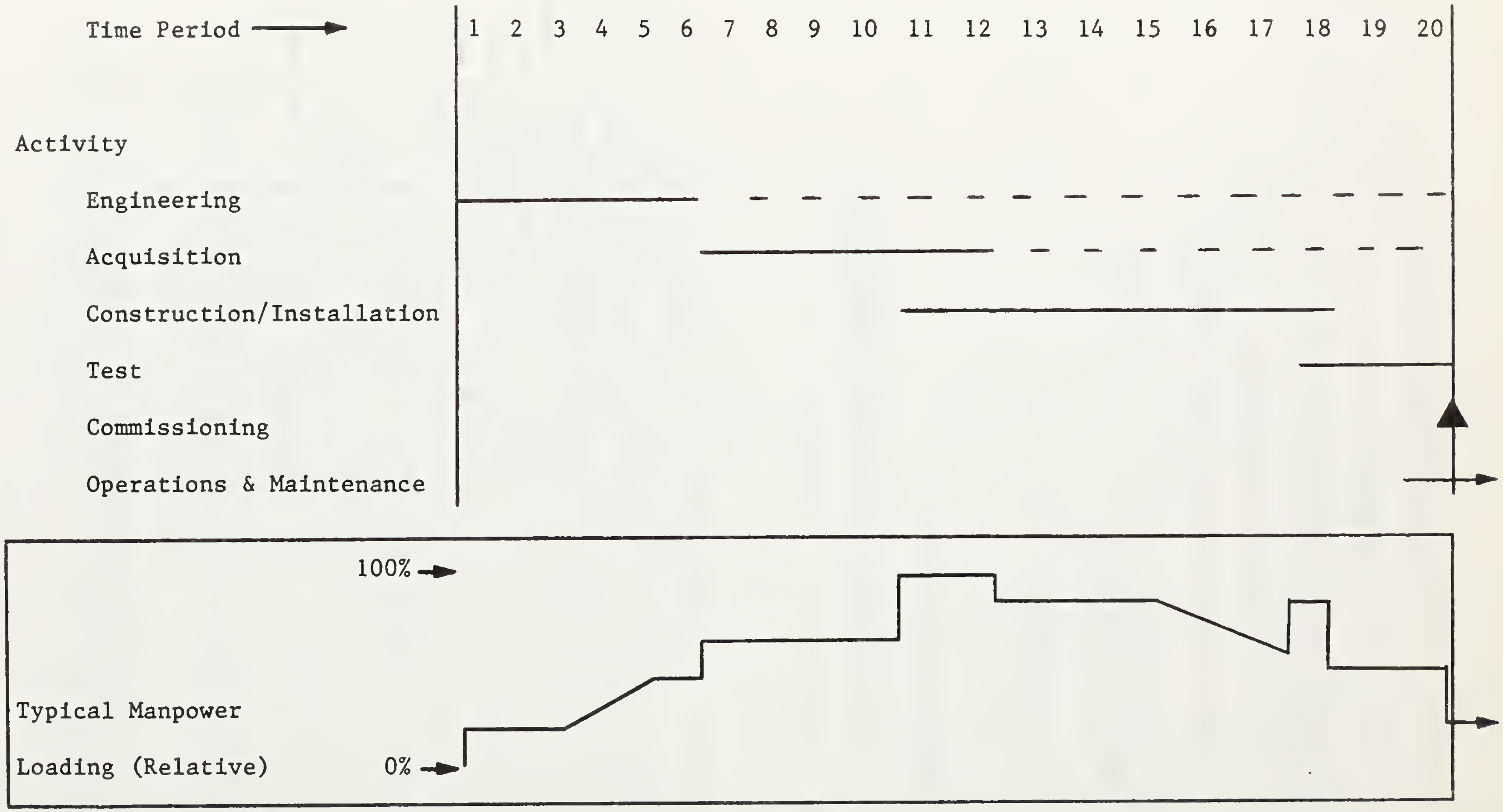


Figure II-133 System Planning

FCC FORM 402
JULY 1976

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

APPROVED BY GAO
B-180227 (R0375)

APPLICATION FOR LICENSE IN THE PRIVATE OPERATIONAL FIXED MICROWAVE RADIO SERVICE

FOR COMMISSION USE ONLY

FILE NUMBER	NEPA	SEND TO ASB ☐ YES ☐ NO
PUBLIC NOTICE REQUIRED ☐ YES ☐ NO	☐ MINOR ☐ MAJOR DATE OF NEPA PUBLIC NOTICE	ASB REMARKS

FOR APPLICANT: Use instructions, FCC Form 402-10, dated July 1976 for reference in completing form.

SECTION I - IDENTIFICATION INFORMATION

1. CALL SIGN *(If application refers to an existing station)*	2. LICENSEE IDENTIFICATION NUMBER *(if previously assigned by the commission)*
3A. NAME OF APPLICANT	4. MAILING ADDRESS *(No., street, city, state, ZIP code)*
3B. NAME OF PERSON TO CONTACT REGARDING APPLICATION	
3C. TELEPHONE NO. OF THE CONTACT	☐ Check here if you are a current licensee and your mailing address, item 4, IS NOT the address on file with us

5. LOCATION OF STATION RECORDS	6. TYPE OF APPLICANT (check one)
NO. AND STREET *(or other specific indication)*	☐ (I) INDIVIDUAL
CITY	☐ (A) ASSOCIATION ☐ (P) PARTNERSHIP
STATE	☐ (C) CORPORATION ☐ (G) GOVERNMENTAL ENTITY
7. CLASS OF STATION *(enter code from instruction 7).*	8. RULE SECTION UNDER WHICH YOU ARE ELIGIBLE

9A. PURPOSE OF APPLICATION

(A) ☐ NEW STATION (B) ☐ MODIFICATION (C) ☐ MODIFICATION WITH RENEWAL (D) ☐ ASSIGNMENT OF AUTHORIZATION (E) ☐ OTHER *(specify)* ►

9B. FOR MODIFICATION, LIST ALL ITEM NUMBERS YOU ARE CHANGING OR THAT HAVE CHANGED SINCE YOU WERE LAST ISSUED AN AUTHORIZATION FOR THIS STATION. COMPLETE ITEMS 22, 45, 46 AND 48 ON THIS FORM FOR ONLY THOSE PATHS BEING MODIFIED. SEE INSTRUCTIONS (ITEM 9A) IF YOU ARE ADDING OR DELETING A PATH OR CHANGING ITEMS 22, 45, 46 OR 48.

10. Will the use of this station be shared by another Party? ☐ NO ☐ YES If yes, attach the information required by Rule Section 94.17 *(see instruction).*

SECTION II - ANTENNA INFORMATION

11. LOCATION OF TRANSMITTING ANTENNA STRUCTURE

A. NUMBER AND STREET *(or other specific indication)*

B. CITY	C. COUNTY	D. STATE

E. COORDINATES

LATITUDE *(degrees, minutes, seconds)*	LONGITUDE *(degrees, minutes, seconds)*
NORTH	WEST

12A. Is the antenna to be mounted on an existing antenna structure? ☐ NO ☐ YES If yes, answer items 12B, C, D and E.

12B. Will the antenna increase the height of the existing structure? ☐ NO ☐ YES If yes, by how many feet?

(CONTINUED ON REVERSE SIDE)

Figure II-133A FCC Application Sheet 1 of 3

SECTION IIB - ANTENNA INFORMATION (continued)

12C. NAME OF CURRENT LICENSEE USING STRUCTURE	
12D. CURRENT LICENSEE'S RADIO SERVICE	12E. CURRENT LICENSEE'S CALL SIGN

13. For antenna towers (or poles) mounted on the ground

Enter the overall height above ground of the entire antenna tower (or pole) including all antennas, dishes, lighting rods, obstruction lighting, etc., mounted on it .... FEET

14. For antennas or antenna towers (or poles) mounted on a supporting structure such as a building, water tower, smoke stack, etc.

A. What is the overall height above ground of this supporting structure? Include in this height any elevator shafts, penthouses, lighting rods, lights, etc. which are not a part of the antenna tower (or pole) .... FEET

B. How many feet does the antenna tower (or pole) *(including all antennas, dishes, lighting rods, lights, etc.)* increase the height of the supporting structure in Item 14 A? If this antenna or antenna tower (or pole) does not increase the height of the supporting structure, enter zero (o) .... FEET

C. What is the overall height above ground of this supporting structure plus the antenna tower (or pole)? .... FEET

14 A + 14 B = 14 C

15. Give the ground elevation above mean sea level at the antenna site .... FEET

16A. NAME OF NEAREST AIRCRAFT LANDING AREA	16B. DIRECTION AND DISTANCE TO NEAREST RUNWAY

17A. Has notice of construction been filed with the FAA on FAA Form 7460-1? If "Yes", answer items 17B, C, and D. ☐ YES ☐ NO

17B. NAME UNDER WHICH YOU FILED	17C. FAA REGIONAL OFFICE *(city)*	17D. DATE FILED

18. Will this antenna structure or associated passive repeaters (if any) be located on land under the jurisdiction of the U.S. Forest Service or Bureau of Land Management? If yes, see instruction 18 and attach the statement required by rule Section 1.70. ☐ YES ☐ NO

19. Would a Commission grant of this application be a major action as defined by Section 1.1305 of the FCC's Rules? See instruction 19, if you answer yes, submit the statement required by rule Section 1.1311. ☐ YES ☐ NO

20. Enter the year this station began or the date *(month, day, year)* it is expected to begin transmission ....

21A. Location of the first passive repeater (PR 1), if any, on each transmission path originating at this station. Reference each location with the Letter of the column which contains the frequency (Item 22) transmitting to this location. This is the PR 1 mentioned in items 62-72. See instruction 21A.

21 B. Location of second passive repeater (PR 2). If any, on each transmission path. This Item is to be used only if there are two passive repeaters on the same transmission path. Reference this item with the appropriate column letter as in item 21A. *(See Instruction 21 B)*.

SECTION III - TECHNICAL INFORMATION

NAME OF ITEM	A	B	C	D
22. Frequency (MHz)				
23. Emission				
24. Type of Message Service				
25. Initial Baseband Channel Loading				
26. 5 yr. Projected Baseband Channel Loading				
27. 10 yr. Projected Baseband Channel Loading				
28. Pre-emphasis *(enter Yes or No)*				
TRANSMITTER INFORMATION				
29. Transmitter Make				
30. Transmitter Model				
31. FCC Use Only				
32. Transmitting Operating Frequency Tolerance (%)				
33. Maximum Transmitter Output Power (WATTS)				
34. Mftr's. Guaranteed Transmitter Output Power (WATTS)				

TRANSMITTER INFORMATION (COND'T)				
NAME OF ITEM	A	B	C	D
35. Transmitter Median Output Power (Watts)				
36. Transmission Line Loss (dB)				
37. Antenna Make				
38. Antenno Model				
39. FCC USE ONLY				
40. Antenno Gain (dBi)				
41. Effective Rodiated Power (dBm)				
42. Beom Width (degrees)				
43. Type ond Size of Antenno				
44. Height to Center of Final Rodioting Element (Ft.)				
45. Polorizotion				
46. Azimuth to Next Station or Possive Repeoter No. 1 (PR#1)				
47. Poth Length to Next Stotion or PR #1 (miles)				

RECEIVER INFORMATION				
NAME OF ITEM	A	B	C	D
48. Associated Stotion's Coll Sign				
49. Path Loss (dB)				
50. Receiving Antenna Make				
51. Receiving Antenna Model				
52. FCC USE ONLY				
53. Receiving Antenna Gain (d Bi)				
54. Receiver Make				
55. Receiver Model				
56. FCC USE ONLY				
57. Median Received Signal Level At Input to the Receiver (dBm)				
58. Latitude N. *(degrees, minutes, seconds)*				
59. Longitude W. *(degrees, minutes, seconds)*				
60. Ground Elevation AMSL (Ft.)				
61. Height to Center of Receiving Antenna (Ft.)				

PASSIVE REPEATER NO. 1 INFORMATION (IF ANY)

→ ☐ If you have two passive repeaters on the same transmission path, check this box and answer Items 62-72 on a separate sheet of paper for the second passive repeater.

NAME OF ITEM	A	B	C	D
62. Lotitude N. *(degrees, minutes, seconds)*				
63. Longitude W. *(degrees, minutes, seconds)*				
64. Ground Elevotion AMSL (Ft.)				
65. Overall Height or PR 1 Structure Above Ground (Ft.)				
66. Possive Repeater Moke				
67. Possive Repeater Model				
68. Dimensions of Possive Repeoter (Ft. x Ft)				
69. Height Above Ground to Center of PR 1 (Ft.)				
70. Polorizotion				
71. Poth Length From PR 1 to Next Stotion (Miles)				
72. Azimuth from PR 1 to Next Stotion (degrees)				

SECTION IV - CERTIFICATION

READ CAREFULLY BEFORE SIGNING

Certification: 1) The applicont woives ony cloim to the use of any porticulor frequency or of the ether becouse of previous use of same, whether by license or otherwise. 2) The opplicont accepts full responsibility for the operotion ond control of the requested station licensed in occordance with applicable law and rules of the FCC. 3) The applicant will have unlimited access to and control of the radio equipment and will take effective measures to prevent its use by unauthorized persons. 4) Neither applicant nor any member thereof is a foreign government or representative thereof.

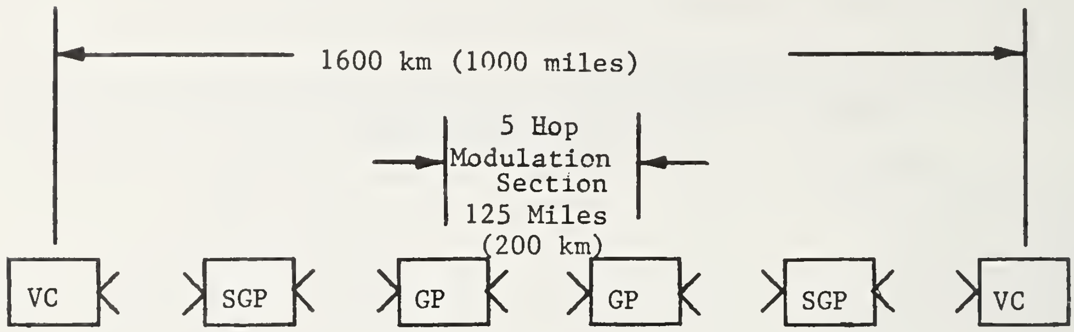
WILLFUL FALSE STATEMENTS MADE ON THIS FORM OR ATTACHMENTS ARE PUNISHABLE BY FINE AND IMPRISONMENT. U.S. CODE TITLE 18 SECTION 1001.

TYPED NAME	TITLE

SIGNATURE of individuol, portner, or outhorized person on beholf of o govt. entity, or on officer of o corporotion or ossociotion	DATE

2. Establishing a Reference Circuit

A reference circuit is a hypothetical communications channel designed to establish noise performance criteria for telecommunications circuits. It consists of a circuit design with an overall length and typical equipment configuration. Figure II-134 is such a reference circuit for an FDM-FM system.



VC = Voice Channel Multiplex

SG = Supergroup Multiplex Repeater

GP = Group Multiplex Repeater

Figure II-134 Reference Circuit

The reference circuit is not intended to represent an actual circuit. The purpose is to present the typical noise contributing elements of a representative circuit. The major factors are:

- Length in miles
- Radio equipment (number of hops)
- Multiplex (representative equipment configuration as given in the reference circuit)

In the power industry most systems will be less than 1000 miles in length (1600 km).

The noise performance for the reference circuit is specified as follows. Noise values are unweighted maximums and apply to circuits of 1000 miles in length (1600 km).

- Total multiplex and termination equipment (TE) noise 5000 pW

- Total hourly noise including mux and TE — 20000 pW

- One minute median noise values over 20000 pW not to exceed — 20% of a given month

- One minute median noise values over 100,000 pW not to exceed — 0.1% of a given month

The system designer compares his system's performance with that of an equivalent reference circuit. Noise values for mux are normally fixed and do not vary with circuit length. The hourly and minute median noise values are pro-rated to the length of a given circuit. For example, the hourly median noise for a 246 mile (395 km) circuit is:

$$= \frac{246}{1000} (20000-5000) + 5000 \text{ (mux \& TE)}$$

$$= 3690 + 5000$$

$$= 8690 \text{ pW}$$

3. Allocation of Noise

The reference circuit allocation of noise is limited to overall circuit performance. The system designer needs to consider a more definitive allocation of the noise. A microwave system has two basic types of noise, fixed (equipment) and variable (path fading). Figure II-135 presents a tabulation of typical fixed noise sources and their values of the hypothetical reference circuit above. For simplicity, equipment totals are given.

The total for the multiplex alone is only 560 pW with 5000 pW allowed. The actual configuration of multiplex and associated line equipment could be much more complex with more noise contributing elements in the circuit.

The total noise of 4140 pW is also far short of the total of 20,000 pW hourly median allowed. Noise due to microwave fading must also be added. To assess a rough approximation of the hourly fading noise, worsen the total receiver thermal noise (250 pW) by 10 dB and recalculate the total noise value. In the present case this becomes 4140 + 2500 = 6640 pW. This is still 4.8 dB better than the allowed 20,000 pW. For further details on long term and short term fading see Section H below.

Noise Source	Fixed Thermal Noise	Noise in pW Intermodulation Noise	Subtotal Per Source in pW	Qty	Total
Multiplex					
VC	40	40	80	2	160
SG	40	40	80	2	160
GP	40	40	80	2	160
Other	40	40	80	1	80
Radio					
Transmitters	10	40	50	25	1250
*Receivers	10	40	50	25	1250
Modems	15	100	115	2	330
Other					
Feeder Echo Distortion	0	15	15	50	750
			TOTAL		4140 pW

* Receiver thermal noise assumes unfaded input signal.

Figure II-135 Fixed Noise Contributions

4. Route Design Overview

Route design is the developing of an overall strategy for laying out a microwave route. The key objective of a good plan is to select sites that are acceptable from a technical standpoint as well as from cost and other nontechnical standpoints. Many factors affect site selection. The wise designer attempts to eliminate all risk of a site being rejected subsequent to the initial survey. The following preliminary steps assume that all the traffic requirements have been fully analyzed and radio basebands sized.

- Select system terminals, designate tall buildings where feasible for height and location.
- Examine the topology between terminal sites on large scale maps for candidate routings.
- Select tentative general routing taking advantage of existing mountainous terrain for height advantages.
- Determine whether the terminal locations are near existing stations in the same microwave bands. This may affect the number of repeater(s) between terminals. See frequency interference analysis in Section II.H.3.
- (Optional) Mobilize a field survey team who will continually verify site and path selections during the route planning process.
- Equip both the field team and the design office with detailed topological maps of the areas of interest.
- Collect aeronautical maps of the area for identifying the location of airports. Topological and aeronautical maps may be obtained at various map centers throughout the country.

The field team can perform a variety of time saving tasks that greatly reduce the risk of having to reengineer the system due to unforeseen site difficulties. The topological maps are often many years old. Construction or terrain changes since the map's making could affect the system design. The field team can examine:

- Site accessibility - easements, road construction
- Local obstructions - buildings, future buidlings, terrain, trees

- Nearby tower or structures that may be used for mounting antennas

- Property owners and their receptivity to use of their property

- Other radio users in the area

- Errors in the maps - contour errors, missing features

- Local soil conditions - rock content, bearing strength, flooding

- Proximity of local power and telephone lines.

Another useful tool for laying out a microwave route is a means of assessing potential frequency interference into or from other systems. Generally speaking, frequency interference analysis requires a considerable data base of licensee information and the use of fairly large computers to do the computation. Several commercial firms provide this service at a fee. As a rough tool, however, it may be possible to spot known users on a large scale map in the area and avoid the most obvious cases of interference during the route layout. This is most practical in the more sparsely populated mountainous areas where few stations are located. It is also possible to have commercial firms plot all licensees in a given area on maps. In proclaimed forest areas, radio stations are often assigned a limited number of specific site locations. It is, therefore, possible to document the stations in existence and on file for future development. In any case, the ability to determine potential interference initially greatly facilitates the route planning.

Four parallel and simultaneous design operations now take place to lay out the route:

- Site selections and availability/suitability analysis

- Initial profile and tower height analysis

- Examination of FAA Part 77 Criteria

- Frequency interference analysis

Failure of a site to meet the requirements associated with the above four steps could cause rejection of the site. More seriously, the rejection of one site can affect the rejection of adjacent site(s) causing considerable reengineering to be done. It is therefore important to examine all possible causes of site rejection during the initial route planning.

5. Radio Path Engineering Procedure

This section discusses the mechanics of engineering a microwave system containing a series of paths.

At the outset of designing a microwave system the designer should select the radio equipment type to be used. Its characteristics affect path engineering to a large extent. In order of descending importance, the following factors should be more or less fixed before commencing the path engineering:

- Voice channel capacity of the baseband
- RF frequency band to be used (see Section IID4)
- RF power output
- Receiver noise figure
- Diversity requirements (required availability)

The selection of the frequency band is dependent on channel capacity and frequency congestion for the given area of operation. It is normally possible to use different bands on different paths as long as the bands are capable of carrying the same FDM-FM signals. In rare circumstances a mix of cable and radio may be required where microwave frequencies are not available.

The objective of path engineering is to design a microwave system that meets system traffic and reliability requirements at a minimum cost. The finalized system path design documentation contains:

- Tower types and heights
- Antenna sizes and types
- Site layout reports
- Site acquisition reports
- Radio equipment configuration plan
- System transmission design
- Individual path analysis reports
- Frequency interference analysis report
- FAA clearance reports

- System performance analysis
- FCC application
- Environmental impact statement

With some variation the designer examines one path at a time. Once the next site has been found acceptable, the next path is examined. In practice, a paper study on topological maps is conducted by first laying out one or two tentative routings for the entire route. Field survey teams then visit the candidate sites in sequence while the designer analyzes the paths in detail. A survey team can normally conduct the initial site and path survey in an average of 1-5 man-days per site-path survey. During the survey the field personnel confirm site existence and exact geographic location, make initial contact with landowners where possible and discuss use of the land, investigate other site feasibility factors (see Section II.G.4) and communicate this information to the designer by telephone when possible. The designer draws profiles of the proposed path and estimates tower heights (see Section II.H.1). If tower height requirements are significant, he may examine alternate site locations on the map and relay this information to the field team for investigation. Parallel to this effort, the designer examines potential frequency interference (see Section II.H.3) and FAA criteria for each proposed site.

The FAA (Federal Aviation Administration) Rules, Part 77, require that all new proposed structures over 200 feet (61 meters) in height must be reported to the FAA for consideration of possible violations of airspace safety requirements. It does not mean they are in violation, only that they should be considered in detail by the FAA. Part 77 has more restrictive height criteria if the structure is near an airport or heliport.

The FAA must be notified of any proposed new construction or alterations of existing structures if:

- Total height will be greater than 200 feet (61 m) above ground level
- The structure is within 20,000 feet (6.1 km) of any airport runway
  - Longest runway at that airport is $\geq$ 3200 feet (975 m) and the tower $\geq \frac{\text{distance to runway}}{100}$

- Longest runway is < 3200 feet (975 m) and the tower $\geq \frac{\text{distance to runway}}{50}$

- Heliport; tower $\geq \frac{\text{distance to pad}}{25}$

The above criteria apply to airports (heliports) existing, under construction or proposed.

The FAA need not be notified, however, if the new structure is shielded by adjacent structures or terrain features. A 300 ft. (91 m) tower standing on the ground next to a 400 ft. (122 m) building need not be reported. Also, if an existing structure is increased by no more than 20 ft. (6.1 m), no notice need be filed unless the addition is to increase an existing antenna structure above the minimums in Part 77 noted above.

To file with the FAA, FAA form 7460-1 is filed with the local regional office of the FAA. Generally speaking it is possible to get verbal approval within 2 weeks by calling the appropriate office after they receive the forms. The regional office addresses are on the back of the 7460-1 work sheets.

Figure II-136 is an overview diagram of the workplan for radio path engineering. Figures II-137 through II-142 elaborate on steps in Figure II-136. The mathematics involvedare contained in Section II.H.

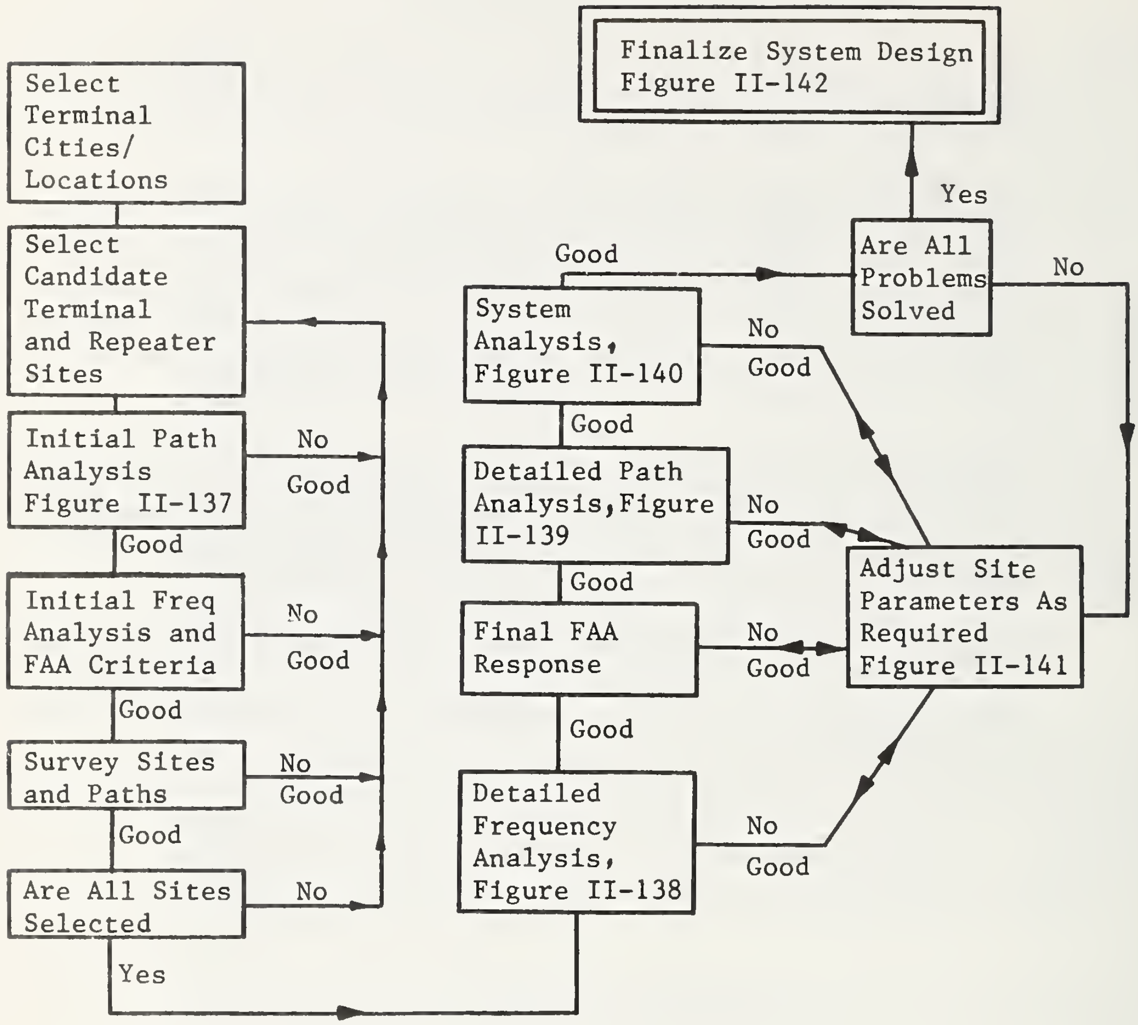


Figure II-136 Overview of Path Engineering Work Flow

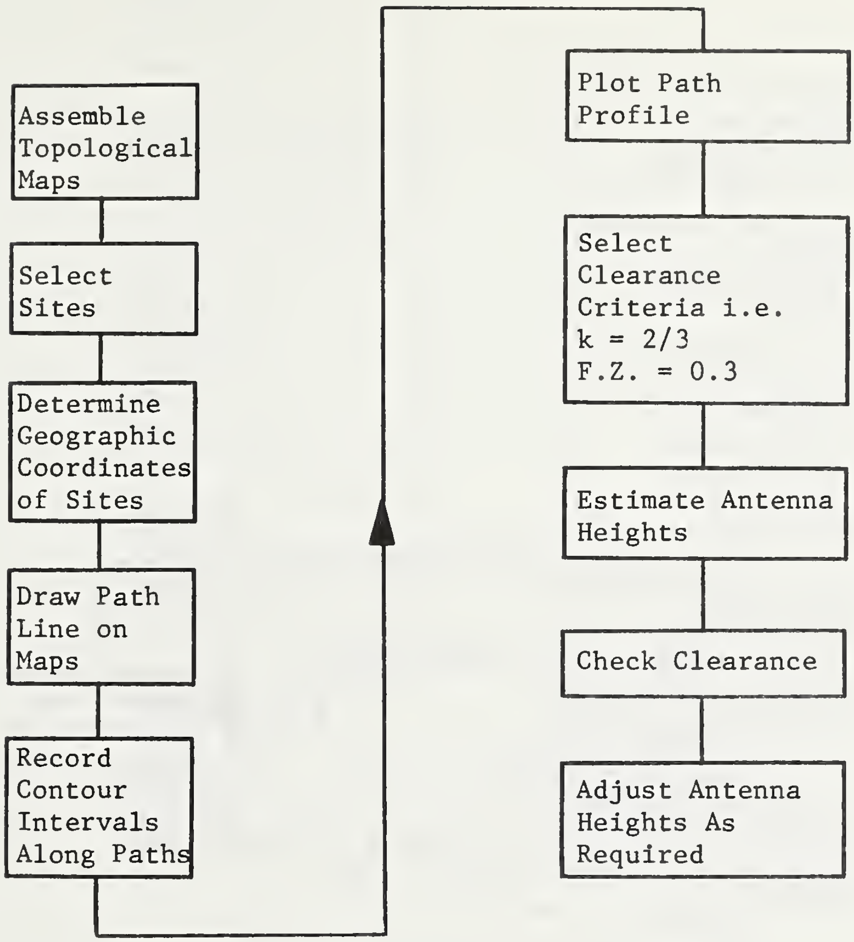


Figure II-137 Initial Path Analysis

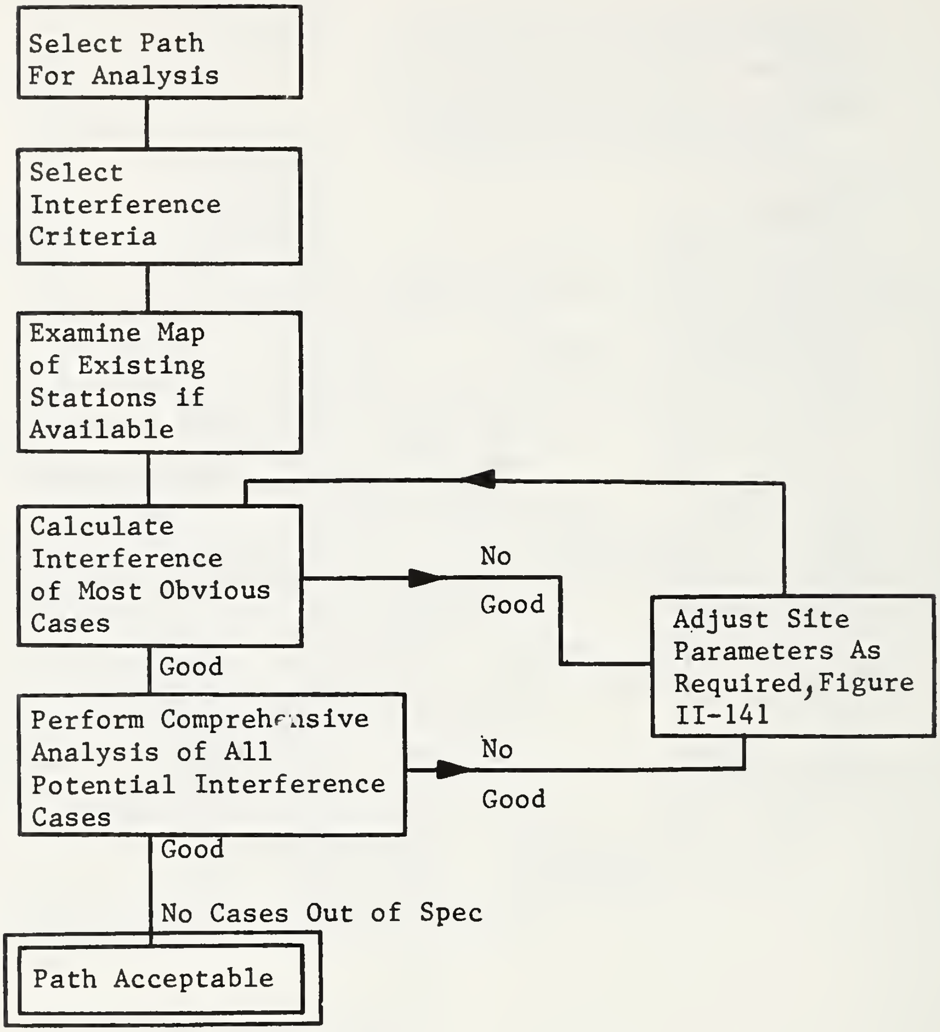


Figure II-138 Frequency Analysis

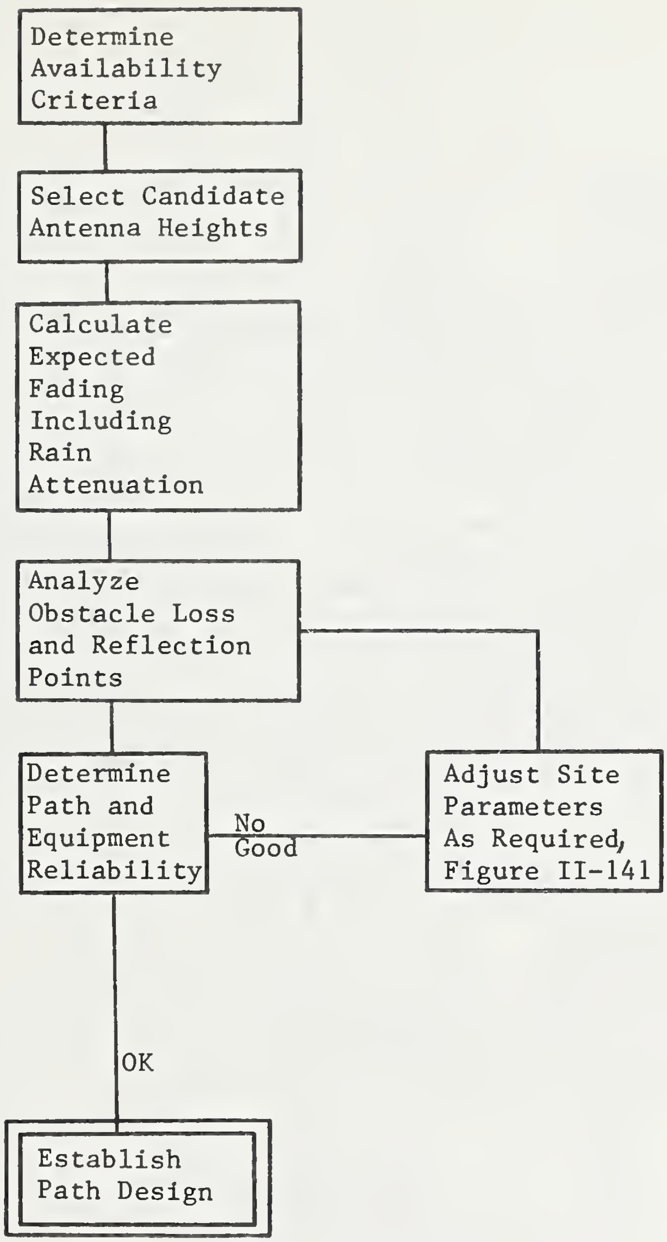


Figure II-139 Detailed Path Analysis

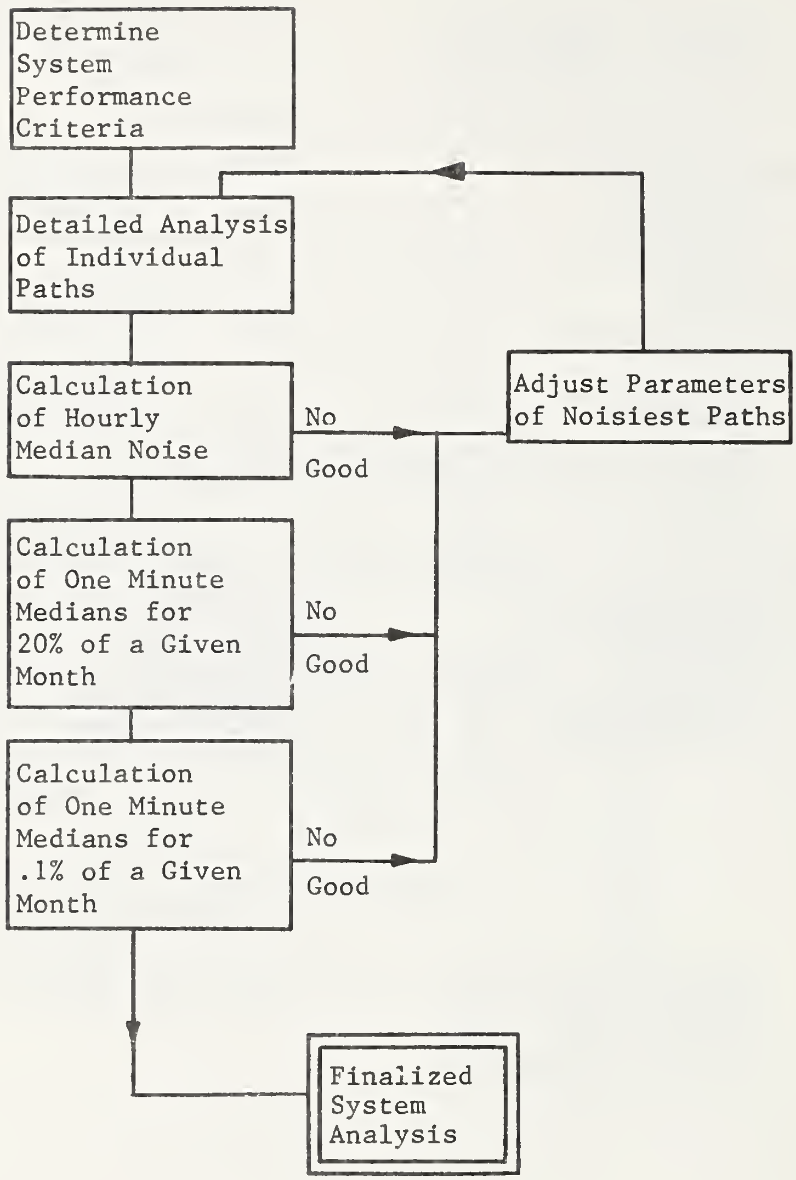


Figure II-140 System Analysis

PROBLEM AREA	System Noise Performance	Interference Analysis	Path and Equipment Reliability Performance
ADJUSTABLE SITE PARAMETERS	Increase Tx Power	Change Frequency	Reduce Net Path Loss
	Larger Antenna	More Discriminating Antennas	Diversity Scheme
	Diversity Scheme	Detailed Interference Path Analysis	Increase Tx Power
	Improved Rx Noise Figure	Change Frequency Band	Move Reflection Points by Adjusting Antenna Heights
	Lower Loss Trans. Line	Move Site	Equipment Redundancy
	Shorter Paths	Improved RF Filtration	Equipment with Better Reliability
		See Section II.H.4 for Additional Suggestions	

Figure II-141 Adjusting Site Parameters to Correct Problems

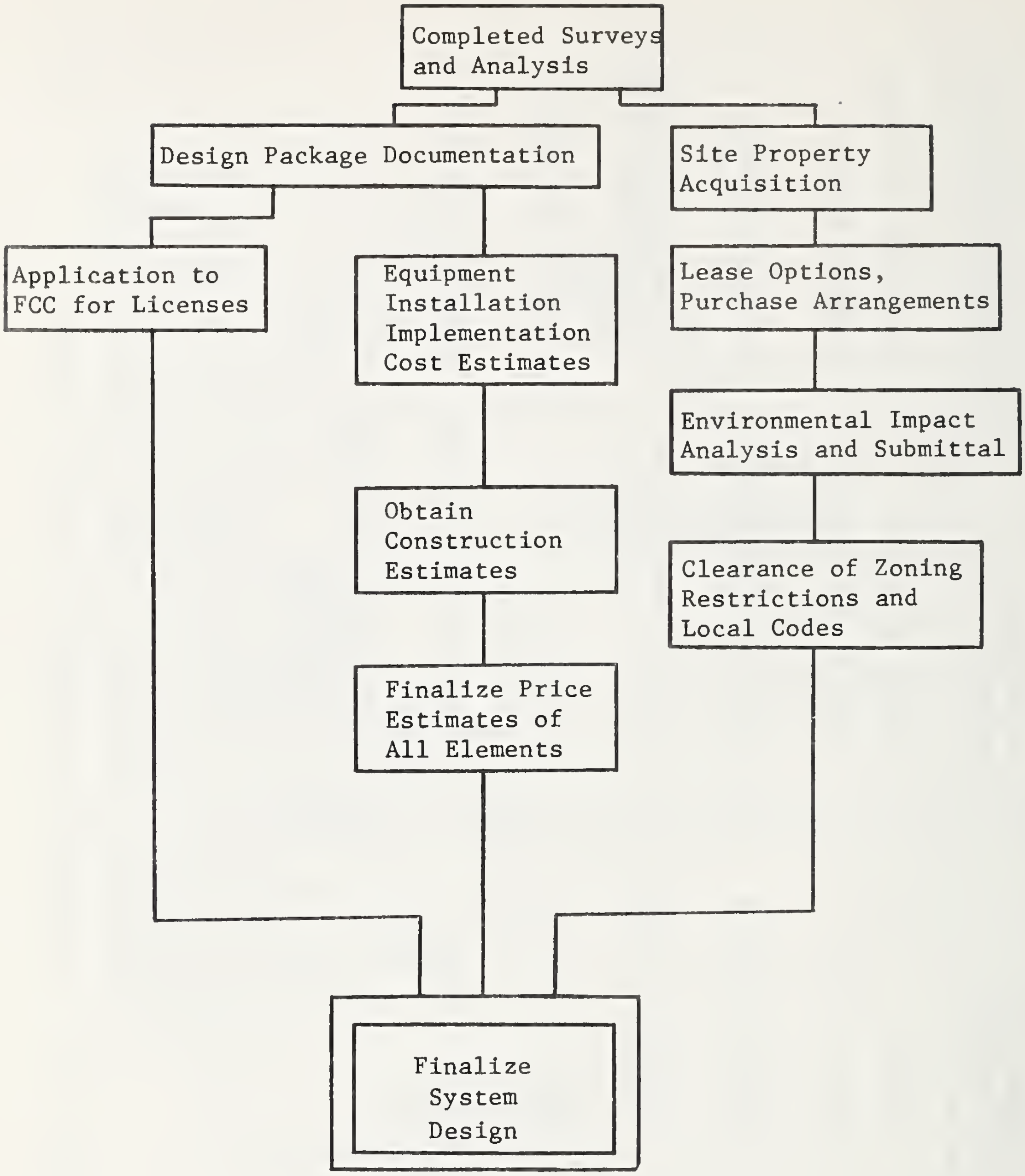


Figure II-142 Finalize System Design

6. Terminal Station Engineering

Numerous approaches to microwave station engineering are possible. This section lists the major steps taken in engineering most large systems stations. The same principles apply to smaller stations to a lesser degree.

Terminal sites are locations where a large number of circuits are connected to the microwave system and central operations and maintenance facilities are located. Normally this takes place in or nearby cities. For the purpose of the section, a large city is assumed where local telephone company cable facilities are available for intra and interbuilding voice channel connections.

The terminal site need not be the terminus of the microwave system. It can be a terminal station along the route. The essential difference between a terminal and repeater station is the quantity of end user interfaces and system control, operations and maintenance facilities. The essential physical difference is the amount of floor space, equipment and personnel facilities required.

It is often possible to build a new structure for terminal sites. Existing buildings tend to offer a number of advantages over new construction, however. Once the terminal city or location is determined, the following considerations are taken into account. The first step is to evaluate the relative advantages of using existing structures as shown in Figure II-143.

When investigating an existing building for use as a terminal site, one should also consider:

- Suitability for antenna location - generally speaking, a building that is not suitable for antennas is not suitable for microwave stations.
- Sufficiency of antenna height
- Path blockage by other buildings on initial and future radio paths
- Future building construction in the area and blockage
- Antenna access for alignment
- Capability of building to support roof mounted antenna(s) structure(s)
- Ability to get antenna onto roof
- Feasibility of antenna feeder(s) installation

- Cost of floor space and roof rental, various lease options
- Availability of cheaper utility space in basements or penthouses for equipment
- Sufficiency of floor space,initial and future
- Floor loading capacity, load spreading possibilities
- Existing telephone cable plant and its expandability
- Power availability, load limits, redundancy, dependability
- Adequacy of air conditioning to handle equipment generated heat
- 24 hour access (building not locked up certain hours)
- External ventilation for battery gases
- Sufficient overhead or underfloor space for fully expanded cabling requirements
- Ability to get equipment into equipment rooms
- Amenities - toilets, parking, building services

In some buildings it may become desirable if the radio equipment can be put on one floor and the multiplex and termination equipment in another location within the building or adjacent building(s). The radio baseband or IF is then cabled to the rest of the equipment. It also may become necessary to partition the multiplex or terminal equipment. In such a case extensive VF cabling will be necessary. Care should be taken to ensure that such cabling is feasible.

Design Factor	New Construction of Building and Tower	Use of Existing Building
Antenna Mounting	Short stub towers cheaper than building mounts. Purchase vs. rental of roof space.	If building is tall, roof mountings cheaper than towers if height is required.
Telephone Cabling		Usually, no new construction or installation required. Newer buildings already equipped.
Power Cabling		Already in place. Many buildings have alternate feeds for reliability.
Zoning		Less difficult to get zoning approval for antenna on a building than for a new tower.
Floor Space	Less difficulty with availability since initial plans can account for requirements. Also, floor loading requirements easily met.	Minimum initial space used with potential options of renting additional space as needed.
Facilities		Toilet, security, parking, etc. already provided.

Figure II-143 Relative Advantages, New vs. Existing Terminal Sites

When investigating the use of new construction one also considers:

- Tower height requirements, path profiles
- Land availability
- Land purchase price
- Land rental - lease options
- Use of a new building with an existing tower
- Floor space requirements

- Construction costs

- Zoning and environmental impact - types of construction allowed

- Availability of telephone and power cabling - cost of new construction if required

- Proximity to end user(s)

- Road, sewer, water, flood history

- Future city plans, road construction

See repeater site engineering for future discussions.

When laying out floor plans for terminal stations, the following factors require attention:

- Antenna feeder entrance

- Number of equipment bays

- Rear access requirements

- Aisle sizes

- Placement of MDF

- VF cable and cable trays

- Cable separation

- MDF Block Assignments

- Placement of power system

- Operations and Maintenance space

- Ancillary equipment space

Figure II-144 shows a nominal floor plan of a terminal station.

Antenna Feeder Entrance

The placement of radio is often dictated by the feeder entrance. To achieve desired waveguide loss, the length must be kept to a minimum in most applications. Thus, the placement of the radio is dictated by possible routings of the feeder from the antenna into the equipment room. In designing a floor layout plan, the first step is usually to situate the radio equipment.

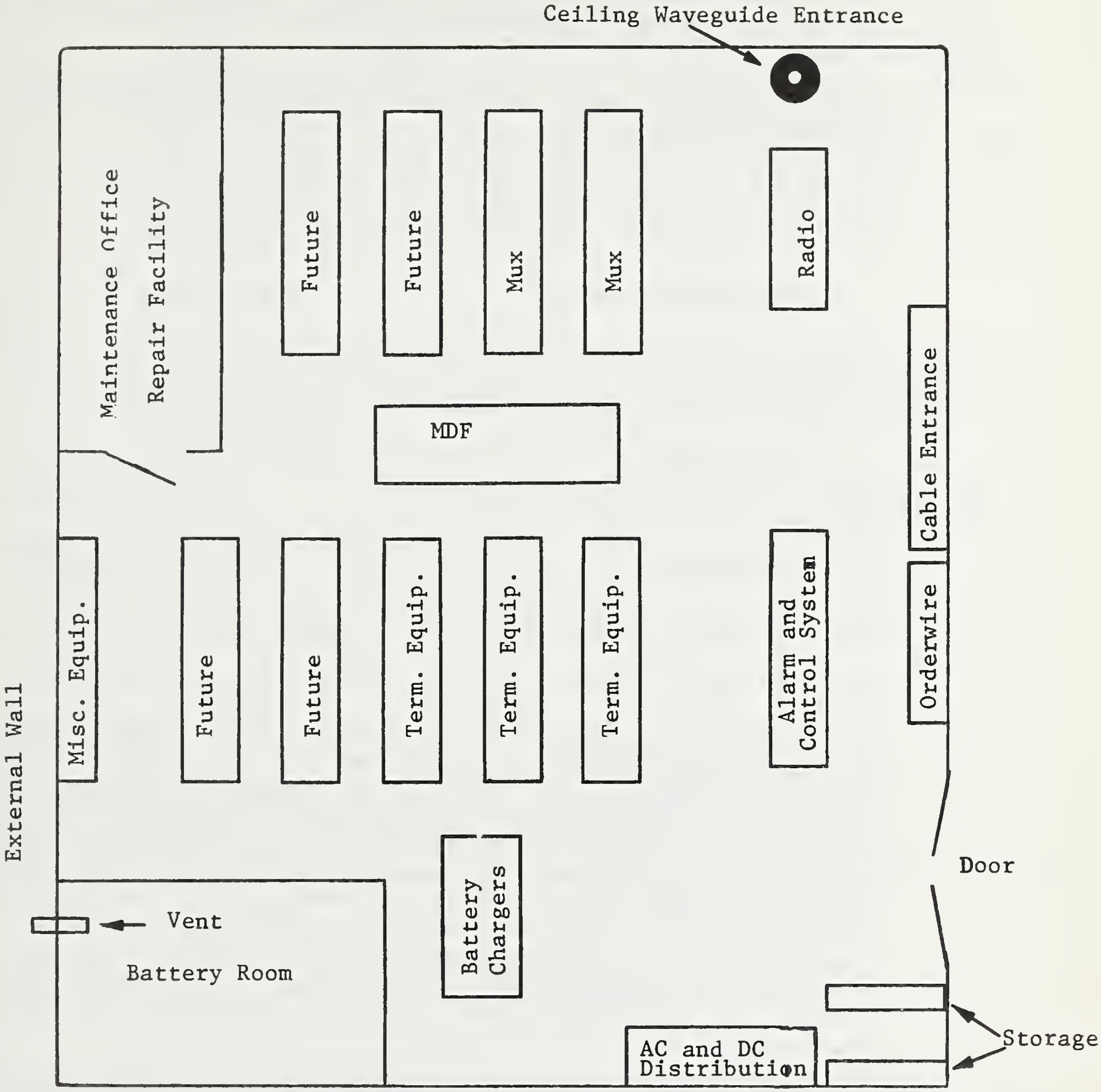


Figure II-144 Nominal Terminal Station Floor Plan

Equipment Racks (or bays)

The primary space requirement of a large terminal station's floor space is for electronic equipment. The floor plan is sized to accommodate the fully expanded system.

Quite a number of types of bays are required for terminal stations. They include:

- Radio
- Multiplex
- Termination equipment
- Jackfields
- Orderwire and alarm system
- Test equipment
- Control consoles
- Teleprinters
- Specialized equipment
- Ancillary equipment

The termination equipment tends to be the largest floor space consumer, especially in large stations. In some systems it is possible to predetermine the exact types and quantities of equipment required. In most cases this is a variable. To plan for rack space, the designer estimates typical circuit configurations and quantities. The amount of space can then be estimated. To handle the variability of module requirements, terminal equipment racks can be equipped with rows of general purpose plug in module receptacles. When a circuit is to be commissioned, the next available slots in the row receive the appropriate modules and cross connections are made on the MDF as required.

To further develop floor space requirements, the designer determines rack heights by examing available ceiling heights and station cabling requirements. The station cabling is run either under a false floor or over the equipment in cable trays. Either method affects the available vertical space in the room. Once rack heights are determined, the number of equipment bays can then be determined by examining the equipment sizes given by manufacturers and calculating the total number of racks required. The racks are arranged in the floor plan by grouping equipment types by function and leaving space for future expansion.

Rear Access

An optimized floor plan uses back to back equipment bays where possible to eliminate aisle space requirements. Some equipment requires rear access by virtue of its design. Other equipment is designed for front access only. Manufacturers have different interpretations of what level of accessibility is meant by "front access", and each case should be studied carefully. With some equipment, every item in a bay can be removed or fully tested easily without disturbing other equipment in the rack. With other equipment it is required to dismantle much of the rack to gain front access to only one unit in the rack.

Aisle Size

Selection of aisle size to some extent is a subjective judgment. Different aisles in equipment rooms do have different requirements, however. As a guide typical aisle sizes are shown in Figure II-145.

Aisle Placement	Width in Millimeters	Width in Feet
Rear of equipment where rear access is required	460	1.5
In front of jackfields	1070	3.5
In front of equipment bays	760	2.5
Around MDF	1070	3.5
Around power equipment	1220	4.0
General access aisles	760-1070	2.5-3.5
In front of displays	1830-3050	6-10

Figure II-145 Aisle Widths

When two bays are opposite each other across an aisle, the aisle space between them is the larger of the two requirements.

Placement of MDF

The two major design considerations in the placement of distribution frames are:

- Sufficient working space around the frame
- Shortest average cabling distance to equipment

The first consideration may dictate single sided wall mounted frames versus the double sided free standing type. The double sided has the advantage of shorter average cross connect lengths within the frame.

To achieve short cabling (reduce cost) the MDF is centrally located within the equipment area. The types of equipment that typically have cabling to the MDF in approximate descending order of quantity of cables are:

- Termination equipment
- Jackfields
- Multiplex (if 4-wire jacks are not hardwired to the multiplex)
- External circuit cabling (telephone cables)
- Alarm signals from equipment and alarm system itself
- Miscellaneous jacks and functions
- Orderwire system

On occasion, very large systems become unwieldy due to excessive frame cabling. It is possible to divide the frame into sections and place sections at different points in the room. This does reduce the system flexibility to some extent, however. This can be alleviated somewhat with a few interconnect blocks and associated cabling on the frames to provide interconnect access between the frames.

VF Cable and Cable Trays

As mentioned above, station cabling can be run under false floors or in overhead trays. The underfloor cabling is more attractive and useful in showcase stations or fixed installations without anticipated growth. Many computer installations fit these characteristics and the false floor is therefore commonly called "computer flooring". For communications systems, however, the cabling in a station is usually subject to additions and changes and computer floor cabling is not feasible.

A room's cable tray configuration is determined from the floor plan by placing the trays over equipment bay rows and aisles. The amount of cabling in and out of each bay is determined by counting up the requirements of all the equipments in the bay. For VF cabling 5% is added for spares and bad cable pairs. The VF cable usually contains 12 to 100 twisted pairs of 19-26 gauge color coded copper wire all in a plastic sheath. The cables lie side by side in the tray laced together. There are always prime power and grounding cable requirements, but the predominant amount of station cable is VF cable. The planner lays out the cable runs on paper and determines the amount of cabling that exists at all points along the cable trays. The amount of cable varies within the room and tends to be greatest near the MDF. Trays wide enough at all points are then selected. If the bunching of cable at given points in the cable tray network becomes too great for practical implementation, the planner uses alternate cable running arrangements to spread the requirements over the room more evenly. It may also become necessary to rearrange equipment bay positions to solve cable bunching problems. Another useful guide is to approach the MDF from several directions within the room. This avoids excessive bunching at the frame. It may also help to locate the frame in the center of the equipment area to reduce average cable lengths.

Cable trays are commonly mounted using suspension bolts from the ceiling or mechanical supports attached to equipment bays. In some cases the equipment bays are not free standing and require mechanical support from the cable trays. In such cases, heavier gauge trays are used with anchors into the walls and ceiling.

The typical tray is 300mm (one foot) wide and supports as high a stack of layered cables.

Cable Separation

In small stations, all cable is sometimes run in the same trays. As cable trays become larger, cable runs become longer on the average and more crosstalk between cables can occur. To avoid these crosstalk problems these major guidelines are commonly practiced:

- Shielded cable should be used where practical.
- Pulsed DC run separately, i.e. telegraph, dial pulses, digital data cables run in separate trays from VF cables.
- Widely different VF signal levels are separated, i.e. multiplex transmit and receive (23 dB difference) are run in different trays.

The separation can be accomplished using metallic wall dividers within the tray or by using separate trays. Often, all the multiplex transmit cables are run one way out of the multiplex bays and all the receive in the opposite direction down the same tray. The two cross over each other for short distances but for most of their runs they are separated. At the higher frequencies such as group and supergroup levels coaxial cable is used for isolation.

Distribution Frame Block Assignments

Cables terminated on terminal blocks follow set patterns whether they are terminating cables pairs or equipment functions. Cables are always terminated on the left hand side of a vertical block with the terminals used from front to rear, top to bottom. The right hand side of the block is reserved for cross-connects. On horizontal blocks, cables are terminated on the bottom of the block with terminals used from front to rear, left to right. The top of the block is reserved for cross-connects.

The terminals, often called "punchings" or "clips", on a line terminal block are exposed on both sides of the block and are encased in wood, hard rubber or high grade bakelite. Terminals are available to accept wire-wrap, solder or a combination of both connections. Today, with wire-wrap techniques most desirable for cable termination (cable pairs or equipment termination), the combination block is widely used in new installations; the solder terminal being the most desirable for the cross-connect side of the block.

Terminal blocks are available in standard sizes (numbers of terminals). The blocks are made in from 2 to 12 terminals deep with either 20 or 26 rows of terminals.

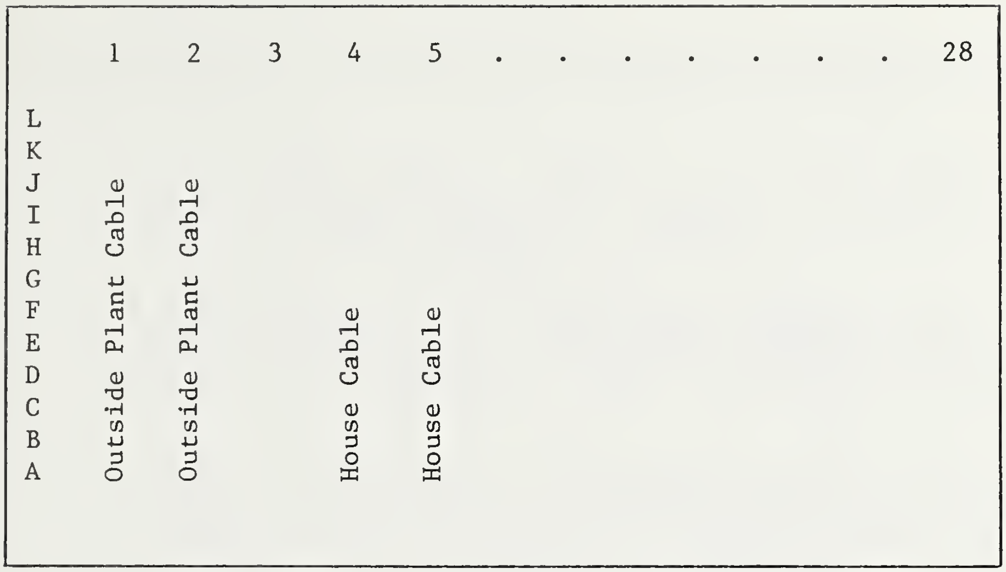
Most blocks are available with adjustable mounting brackets to allow for mounting on various size frames.

Normally, vertical blocks are used to terminate cables from the outside plant or from users. Horizontal blocks are used to terminate cables from equipment. The placement of cables is as stated above.

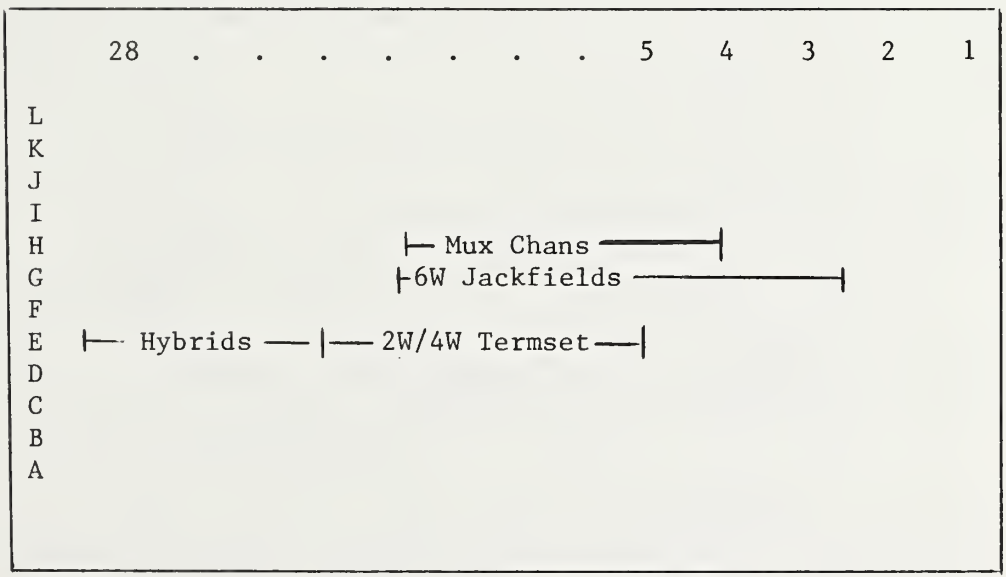
The block layout of the frame is shown in Figure II-147. It should be noted that the verticals are numbered from left to right on the vertical side and right to left on the horizontal side. The levels, or shelves, are lettered from bottom to top on both sides of the frame.

Block locations are indicated by a letter followed by a number, i.e. H-26, on the horizontal side and by a number followed by a letter, i.e. 14-G, on the vertical side.

Figure II-146 shows a typical block pin designation.



Vertical Side of Frame



Horizontal Side of Frame

Figure II-146 Terminal Block Positions (Typical)

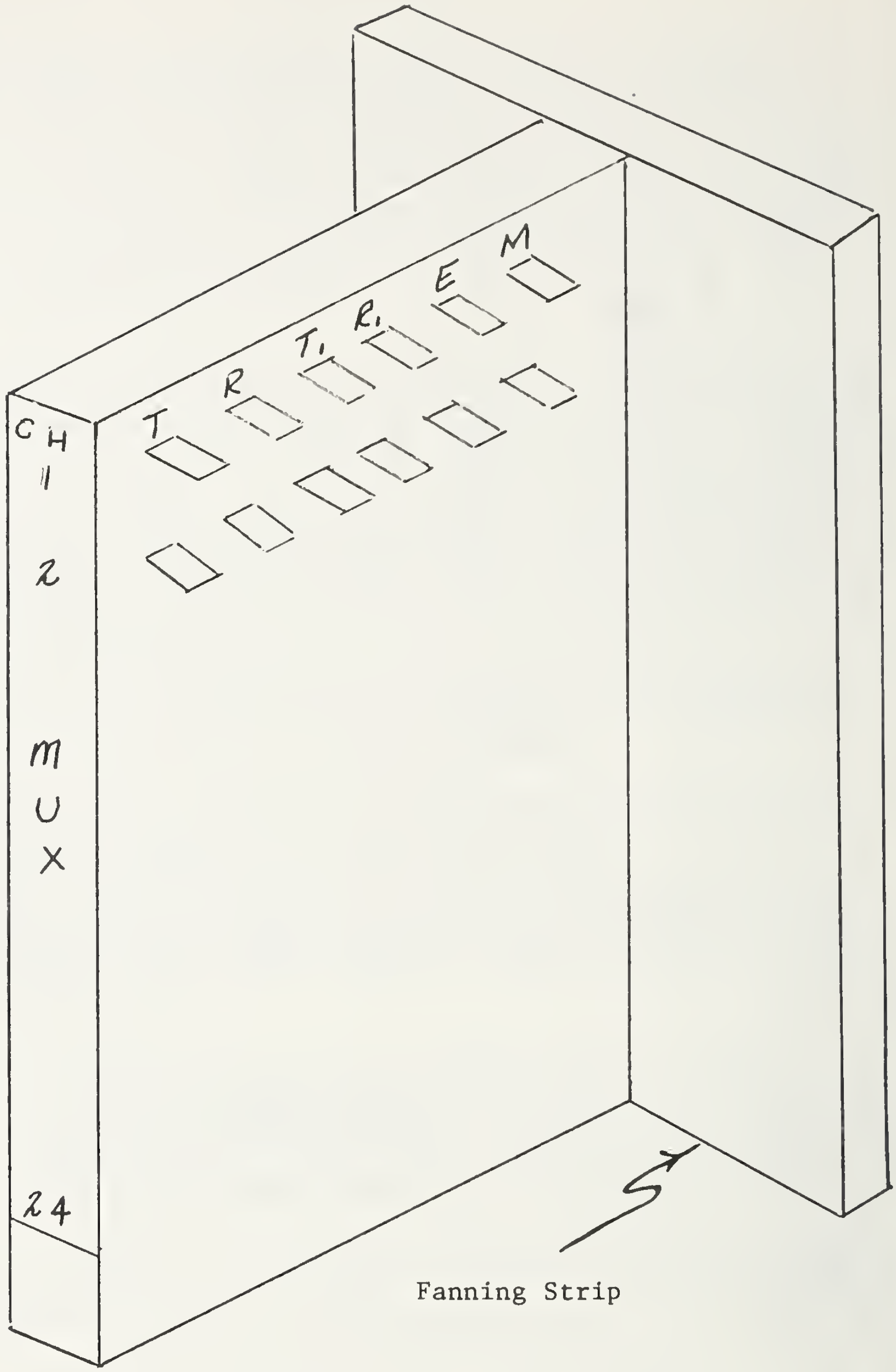


Figure II-147 Pin Assignment (Typical)

Placement of Power System

Several factors affect the placement of power equipment.

- Batteries, if lead acid type, give off hydrogen which should be automatically vented to the outside. Direct access to the outside is therefore necessary.
- Acid batteries can give off hydrosulphuric acid fumes which are corrosive to electronic equipment. Ventilation is therefore required.
- Battery chargers generate pulses that can affect other equipment. The chargers are therefore separated from other equipment by around 2 meters (6 feet) or more.
- Hazardous voltages are often present. To avoid cramped working conditions 1.22m (4 feet) should be left around power equipment including batteries except where they are mounted against a wall.
- In larger stations the current drain can be significant enough to cause noticeable line voltage drop on the station's DC distribution bus. The power is, therefore, placed as close as possible to the major uses of the DC.
- Standby diesel or gasoline power plants need full ventilation and noise abatement if used in buildings.

Operations and Maintenance Space

Additional space is required for:

- Offices
- Maintenance facilities (repairs, etc.)
- Storage - test equipment, line equipment, spares, installation material, safety equipment, etc.
- Amenities, i.e. kitchen, personal storage, toilets

In many terminal station designs much of this space is planned for future equipment expansion. See Figure II-144.

Ancillary Equipment Space

Invariably end user circuit requirements can only be met with special equipment being mounted at the terminal site. For example:

- Two way radios
- Data modems

- Program channel multiplexers
- Special circuit conditioning equipment
- Data concentrators

A nominal amount of space can be assigned in the floor plan to account for these unpredictable requirements.

7. Repeater Station Engineering

The repeater site requires limited attention to the items mentioned above for terminal station design. The complexity of equipment layouts and cabling is far less, of course.

Figure II-148 shows a diagram of the signal flow in one direction through a repeater with drop and insert.

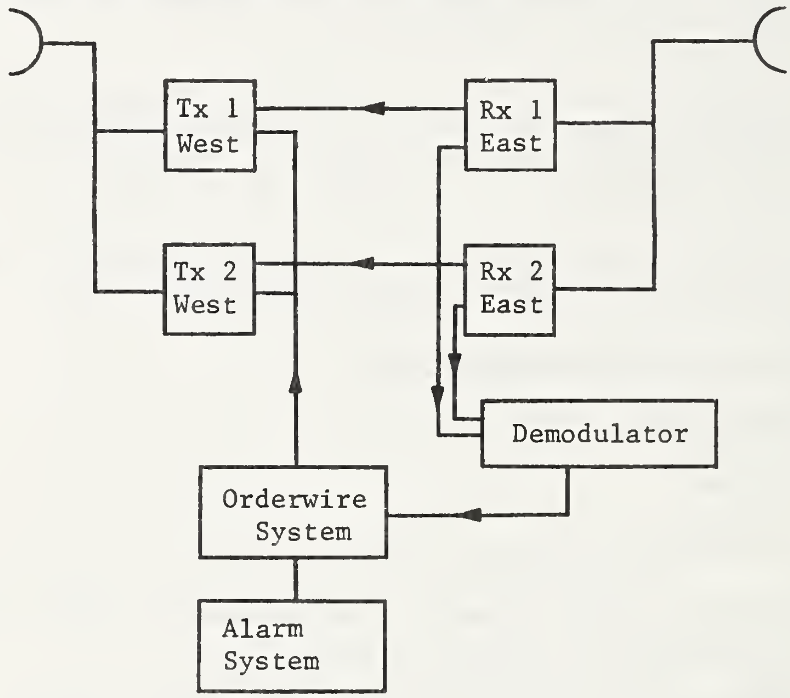


Figure II-148 Repeater Signal Flow, One Direction

The terms North, East, South and West or A to B, B to A are the common terms used to designate signal flow direction in repeaters.

The transmitter insert function at a drop and insert repeater can be accomplished in several different types of circuits. A typical method is shown in Figure II-149 along with the baseband spectrum before and after insertion.

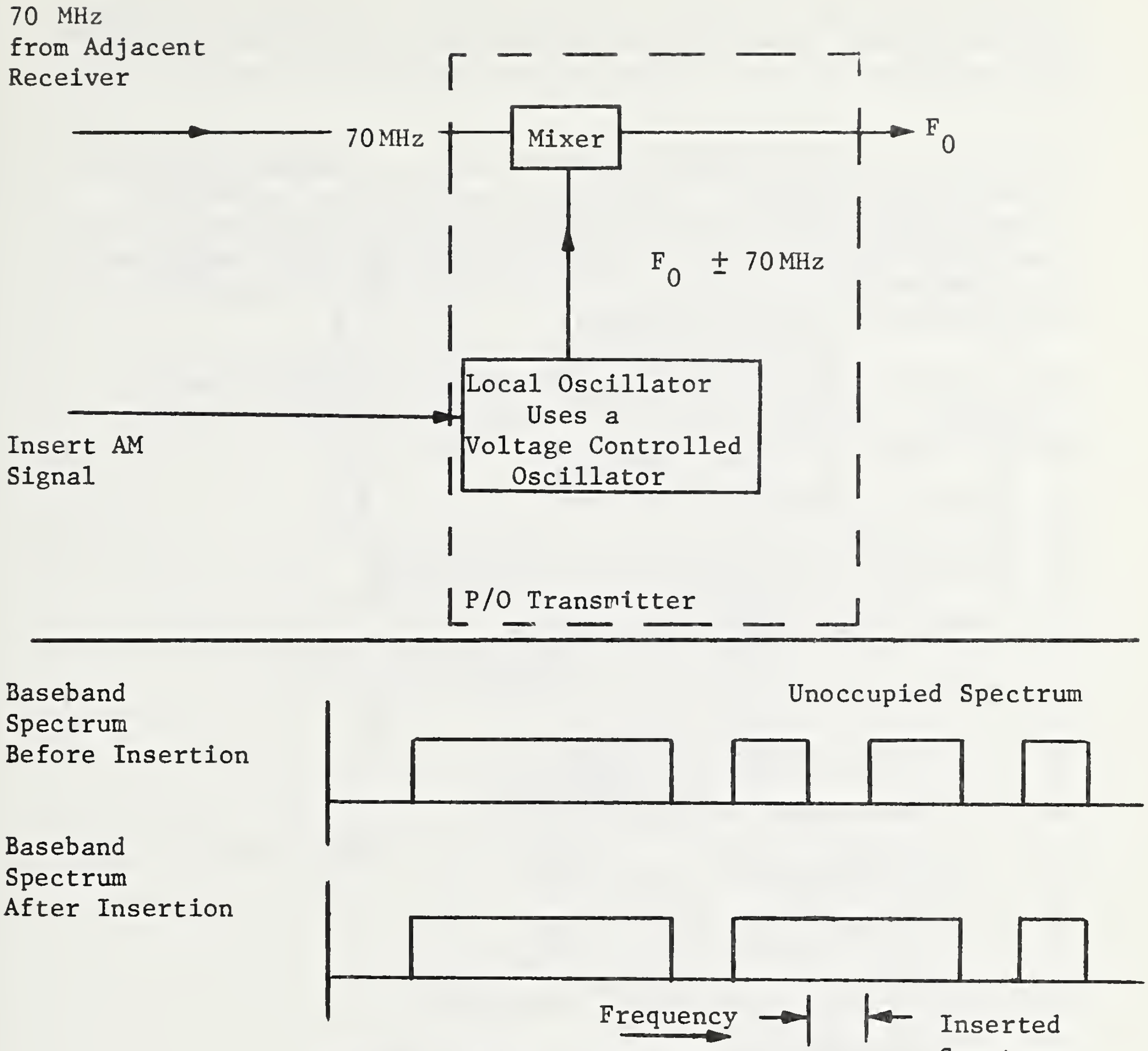


Figure II-149 Drop and Insert

The insert signal impresses information on the local oscillator to provide the additional required deviation. The Local Oscillator signal itself, with modulation, is then mixed with the incoming 70 MHz to combine the two signals into one FM signal.

It is noticed that all the occupied baseband spectrum before insertion remains occupied through the insertion process. It is therefore necessary to insert into only unoccupied segments of the baseband to prevent double occupancy. In Figure II-149 there remain two additional unoccupied segments in the baseband spectrum. These could be used by two additional repeaters, one in each segment.

An alternate method may be used for party line orderwire systems in which multiple occupancy is acceptable. Such double occupancy is not allowed, though, if independent message traffic circuits are connected to the microwave system via repeater drop and insert.

Drop and insert radios can usually handle from several dozen up to 600 voice channels. The channels usually need not all be grouped together but may be spread throughout the baseband since most insert ports are not frequency sensitive. The limitation on the number of channels is the deviation bandwidth capability of the transmitter local oscillator.

The repeater station normally contains the following types of equipment. Figure II-150 shows a typical floor plan showing most of them.

- Radio equipment
- Drop and insert demodulators
- Orderwire and alarm system
- Prime power circuit breaker panels
- AC outlets for test equipment
- Air conditioners and heaters
- Limited table space and storage
- Wall mounted distribution frame
- Multiplex for local circuit connections
- Local telephone
- Battery chargers
- Batteries in a separate room
- Antenna feeder entrance
- Overhead cable trays
- Grounding system
- Fire extinguishers
- Overhead lighting
- Emergency lighting

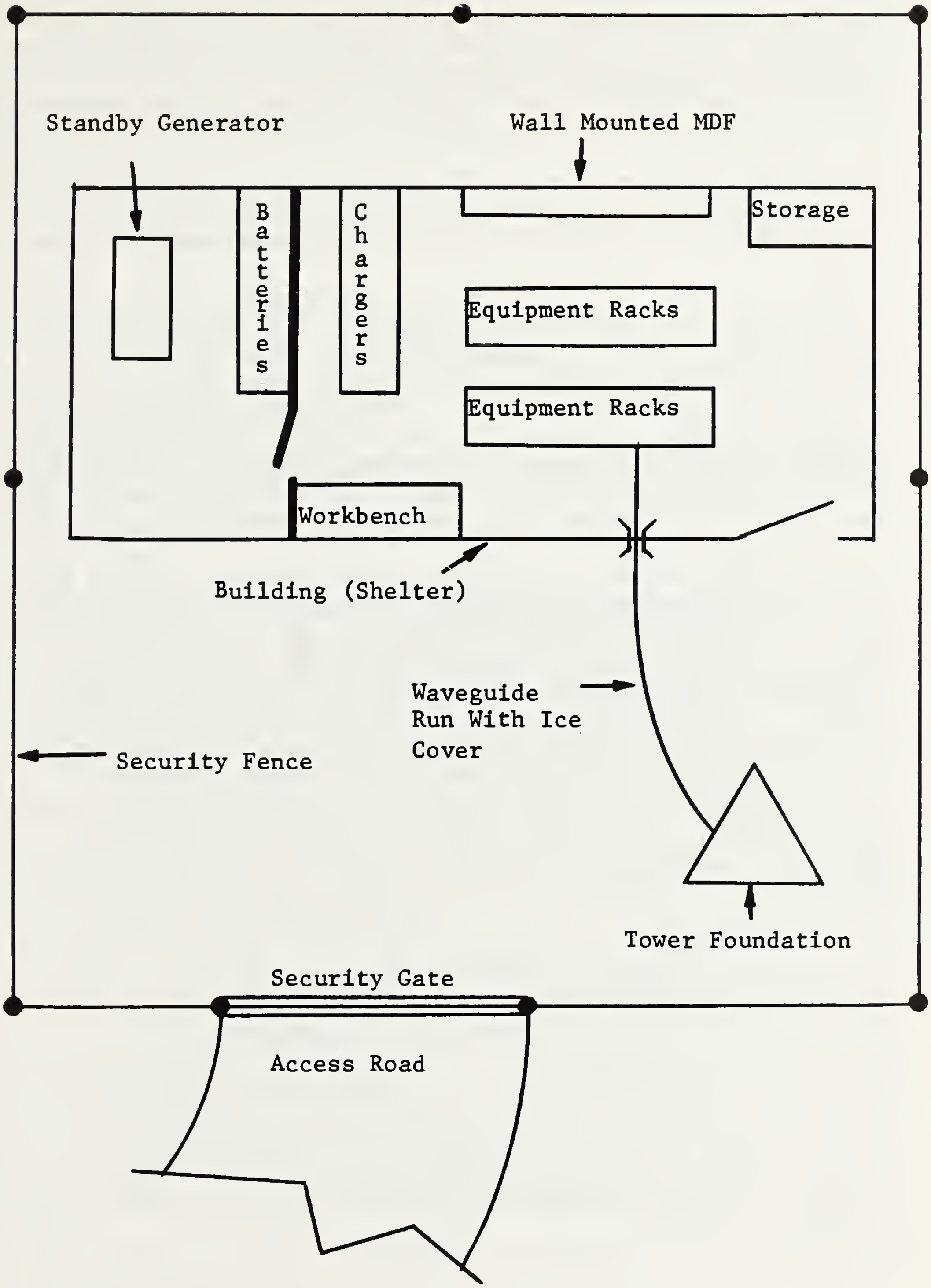


Figure II-150 Repeater Site Layout and Floor Plan

Lightning Protection

Lightning often strikes microwave repeater stations due to the height of the towers. The electronic equipment must be protected from lightning caused surges by using a grounding system that bypasses the equipment shelter.

Some areas are more prone to lightning than others, but all areas of the country are exposed to it. Therefore, all microwave systems are designed to protect equipment from lightning surges.

Essentially, all metallic connections to the shelter and the shelter itself must be connected to a ground. In the case of wires entering the shelter, each wire is connected to a "lightning protector". This is a device that shorts the wire to ground if the voltage on the wire exceeds a certain amount. Several types of protectors are common. The gas discharge type is often preferred because the short opens when the surge stops. Also, they are reusable where some of the carbon types are not.

The grounding system is connected to the earth by using a grid of buried, uninsulated cable (usually copper). The effectiveness of the grounding system depends on the configuration of the grid and the resistivity of the ground. Resistivity is measured in "ohm meters" and typical values are 3 to 10 ohm meters. If the resistivity is higher than 10, the grounding system may not be sufficient to protect the station. This is a common problem in very dry sandy areas such as deserts. In such cases two alternate methods of providing the protection are available. One is to increase the size of the battery plant by 4 to 6 times. The capacitance of the battery will then absorb a significant portion of the lightning surge. The other method is to use a corona discharge device on the tower to dissipate the ground-to-atmosphere voltage. Such devices are electrically connected to the ground and contain sharp point(s) which bleed electricity into the air. This tends to neutralize the voltage differential between the ground and the atmosphere thus preventing lightning strikes. Some corona discharge devices are equipped with rugged capacitors at the top of the tower to help absorb lightning energy. This is particularly useful on very tall towers where the grounding cable is long and its resistance may be high which affects the effectiveness of the grounding system.

The typical repeater is located on a hill top within a few miles of a major road. To reach the site there is usually an access road which is commonly a dirt farm road traversing cattle grids, and open fields passing through barbed wire fence gates on the way. Rock slides and erosion plague such roads as do fallen trees and stray cows. The original site surveyor documents these conditions.

The repeater site itself consists of:

- Flattened area for the site
- Rain drainage as required
- Security fence with locked gate
- Equipment building
- Power building (sometimes partitioned part of equipment building)
- Tower
- Pole line entrance for power and/or telephone

Often the significant cost factors in engineering a repeater site are the mechanical aspects of site construction and access:

- Cost of access road construction with adequate storm drainage
- Sufficient acreage for guyed towers as required
- Strength of foundations to suit soil bearing capability
- Layout of the site for
  - Tower base at highest point practical
  - Road entrance
  - Fence positioning
  - Level spot for buildings
- Pole route for power and/or telephone lines
- Ability to move prefabricated shelters and equipment onto the site
- Ability to move trucks, winches and machinery into place for construction efforts

- Access time to reach site (affects system availability calculations)

- Availability of toilet, restaurant and lodging in the vicinity

In addition to the facilities shown in Figure II-150, the more remote sites also have the following building options:

- Sleeping area

- Kitchen

- Bathroom

- Larger storage area for staging installation

- Bullet proof shelters

8. Subsystem Design

A microwave system contains a number of electronic subsystems. During the detailed design phase of a system, the designer generates reports for each subsystem. This section addresses the contents of those reports.

The only subsystems considered are:

- Radio Transmission System

- Multiplex System

- Orderwire System

- Alarm and Control System

- Facilities Engineering

Some reports are generated for all subsystems. The reports that apply to all subsystems are:

- Bill of Materials

- Rack Face Elevations

- Block and Level Diagrams

- Cable Running Lists

- Equipment Specifications

Bill of Materials

The bill of materials serves numerous purposes such as pricing, providing a basis for competitive quotation and as a working document for purchasing, delivery, and installation activity. The BOM is made up according to sites or location to facilitate delivery functions. This also makes the BOM easier to modify when there are system changes. On interstate systems it facilitates computation of taxes involved.

A typical bill of material form is shown in Figure II-151.

Rack Face Elevations

Rack face elevations assign equipment to specific locations. The drawing allows the designer to identify equipment proximities to each other; they serve as a tool in generating BOM's and the drawings serve to identify unused equipment spaces that occur. Racks normally come with threaded mounting holes in the front of the framework. The holes are a standard distance apart horizontally and vertically. The horizontal distance is commonly 19 inches (483 mm). Vertically they are .865 inches (22 mm) apart. One vertical rack space is two times this distance or 1.75 inches (45 mm). The vertical space occupied by a piece of equipment is expressed in rack spaces or actual inches (mm). Figure II-152 is a typical rack face elevation.

Block and Level Diagrams

Block and level diagrams serve as a tool in developing the BOM. They are also a useful tool in identifying all system interface points and problems of level and impedance compatibility. The information contained in block and level diagrams commonly includes:

- Signal flow drawing
- Power levels
- Impedance
- Interface definitions

Figure II-153 is a typical block and level diagram.

Cable Running Lists

Cable running lists are used to document all cabling requirements. They also serve in developing BOM requirements , and they serve as a tool for installation personnel. The types of information contained are:

BILL OF MATERIALS FORM

Line Item	Description	Qty.	Suggested Vendor(s)	Site Location	Subsystem	Unit Price	Total Price	Source of Price	Remarks

Figure II-151 Bill of Materials

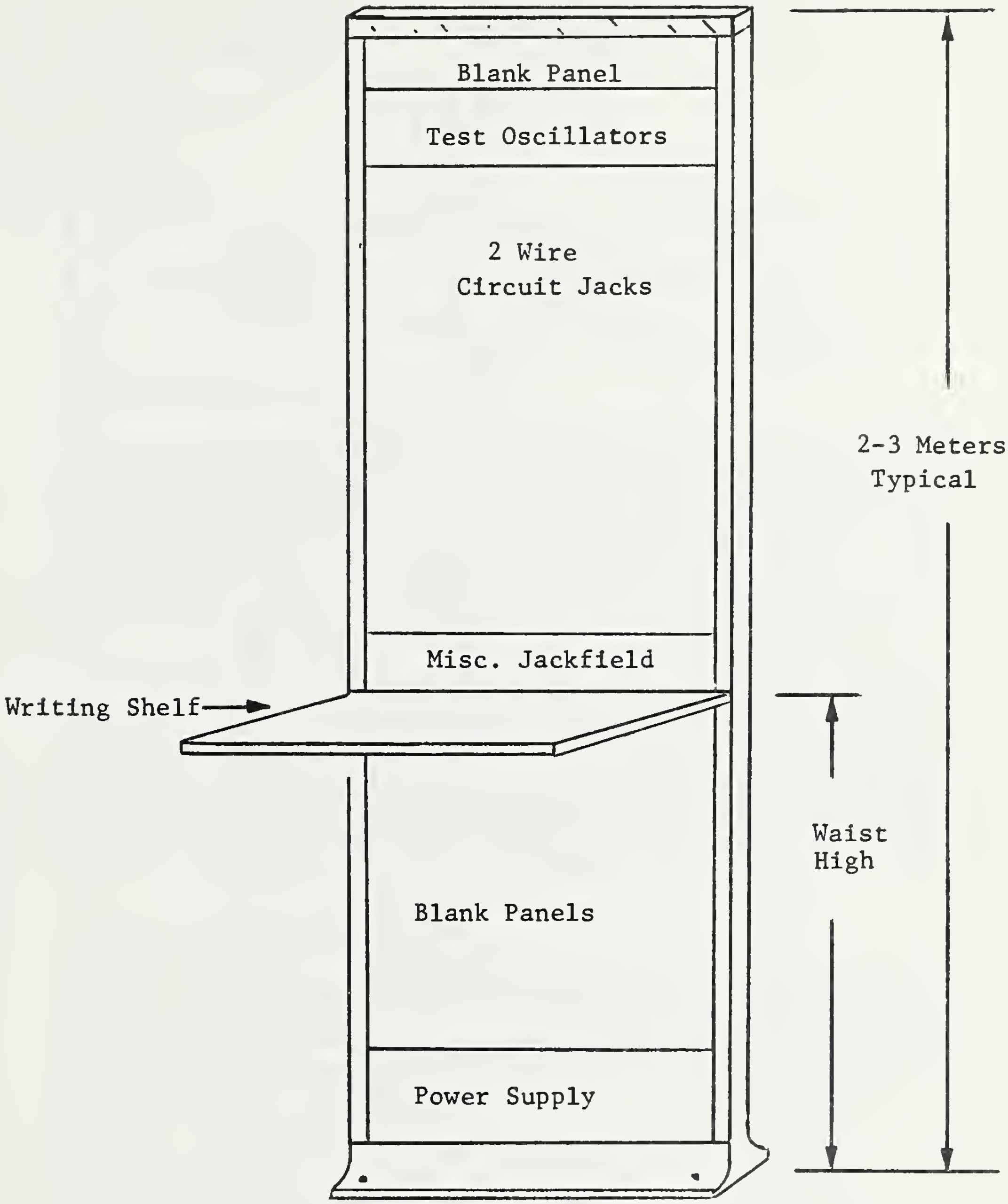


Figure II-152 Rack Face Elevation

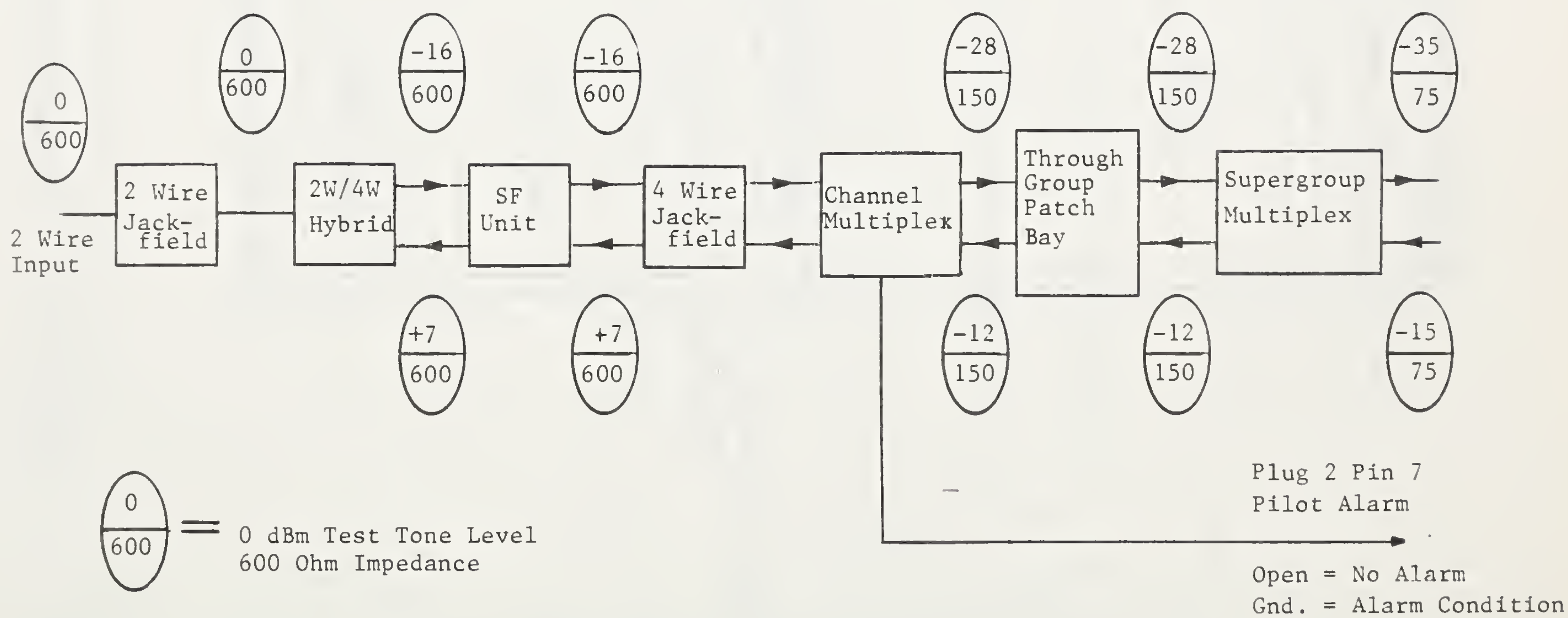


Figure II-153 Typical Block and Level Diagram

- Gage of wire
- Quantity of pairs per cable
- Cable lengths
- Identification codes for each cable
- Color code indexing
- Wire by wire terminal assignment keyed to color code
- Designation of the type of equipment being connected

In a large station the cable running lists are extensive.

Equipment Specifications

The details of equipment specifications are covered in Section II.E. In developing specifications, the designer should keep in mind what is available in the industry. Rigid specifications can by accident eliminate useful competition of vendors. It is often advisable to have objectives as well as limits for specified values. Reasonable exceptions taken to specification limits often result in cheaper prices.

Equipment specifications should be clear in content. Ambiguity can cause unequal interpretations by vendors resulting in non-comparable bids. Specifications should not cover unnecessary minutia unless they have a direct impact on system operation and performance. One area that should always receive adequate attention is subsystem interfaces. Failure to specify interface conditions between equipments that will come from separate vendors may result in costly reengineering.

a. Radio Transmission System

The radio transmission system includes the RF equipment, RF branching, transmission lines, antennas, switching equipment, and baseband modems. The detailed design of this subsystem will include the following reports detailing information for each site in the system.

- Route plan
- RF frequency plan
- RF branching
- Local oscillator assignments
- RF equipment configurations
- Transmission performance analysis

Route Plan

The route plan shows geographic coordinates, bearings, tower heights and antenna sizes. See Figure II-154.

It should be noted that bearings are not exactly 180° apart on a given path. This occurs on spheres where the path follows the great circle route.

RF Frequency Plan

The documentation for a frequency plan has two parts. The first is an entire plan for the frequency band being used. Figure II-155 is an example.

The second report is the channel assignments of the system. See Figure II-156.

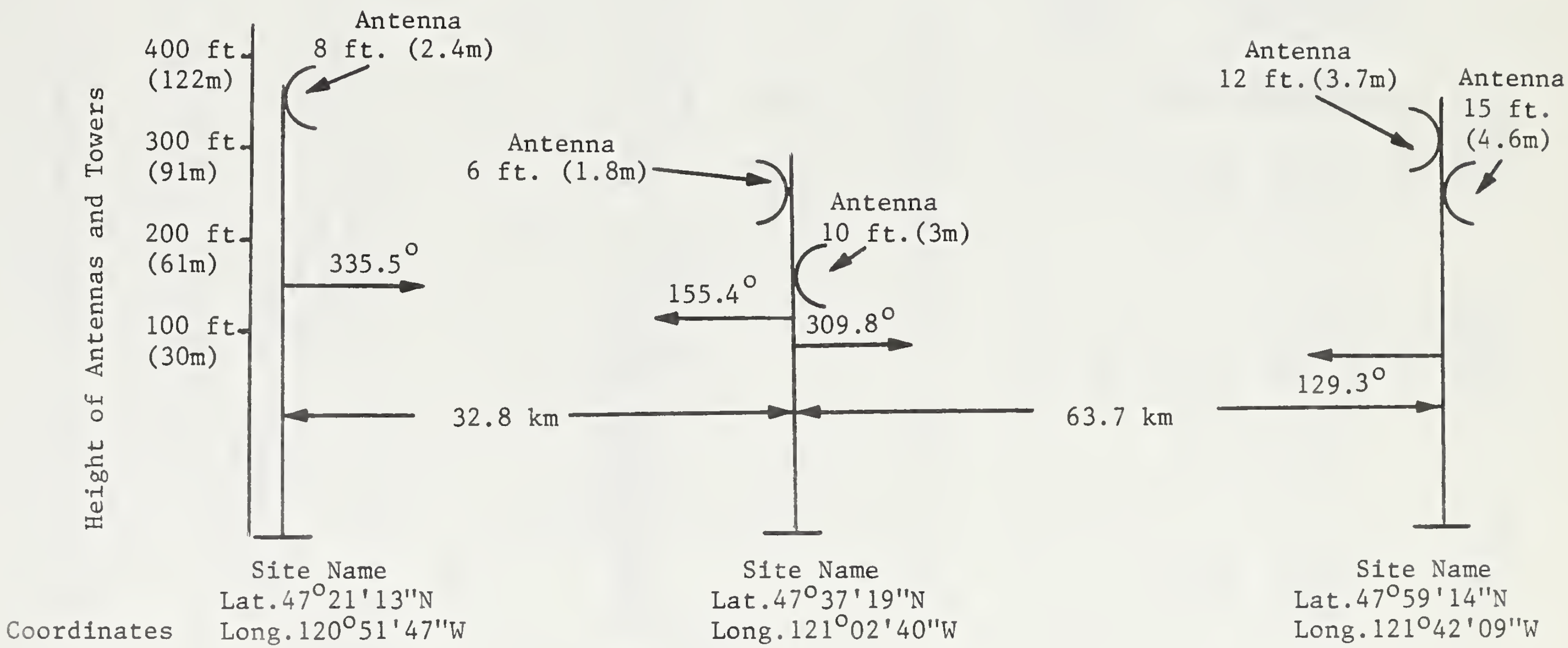
RF Branching

The RF branching shows the relationship of the various RF equipments and in what sequence they are connected to the branching. If a transmitter is placed furthest from the antenna in the branching, its signal will experience the greatest amount of RF branching loss. To counter balance this, the receiver at the other end of the path is placed closest to the antenna. Figure II-157 presents the data.

There are a number of alternate methods of arranging the RF branching. Some of the additional considerations are:

- If one antenna is used for transmit and another for receive, no TxRx circulator is needed and the branching for Tx and Rx are separate.
- If a transmitter is operating at a frequency close to a receiver, additional bandpass filtering may be required at the interfered with receiver. An alternate is to use a bandstop filter tuned to the transmit frequency.
- If a transmitter's local oscillator is near the frequency of a receiver in the same branching, it may be necessary to insert a bandstop filter in the transmit branching to reject the unwanted signal.
- The termination loads in the branching should be able to handle all the transmit energy of all the transmitters simultaneously.

Some of the above points are illustrated in Figures II-158 and II-159.



Bearings Given in Degrees from True North

Figure II-154 Typical Route Plan

Frequency in MHz	Channel Number	Frequency in MHz	Channel Number	
1900	1a	1980	1b	Frequencies Assigned in Pairs, i.e. 1a and 1b are Assigned Together
1890	2a	1970	2b	
1880	3a	1960	3b	
1870	4a	1950	4b	
1860	5a	1940	5b	
		1925	1c	Unpaired, Used for One Way Control Links
		1915	2c	

Figure II-155 Typical Frequency Plan

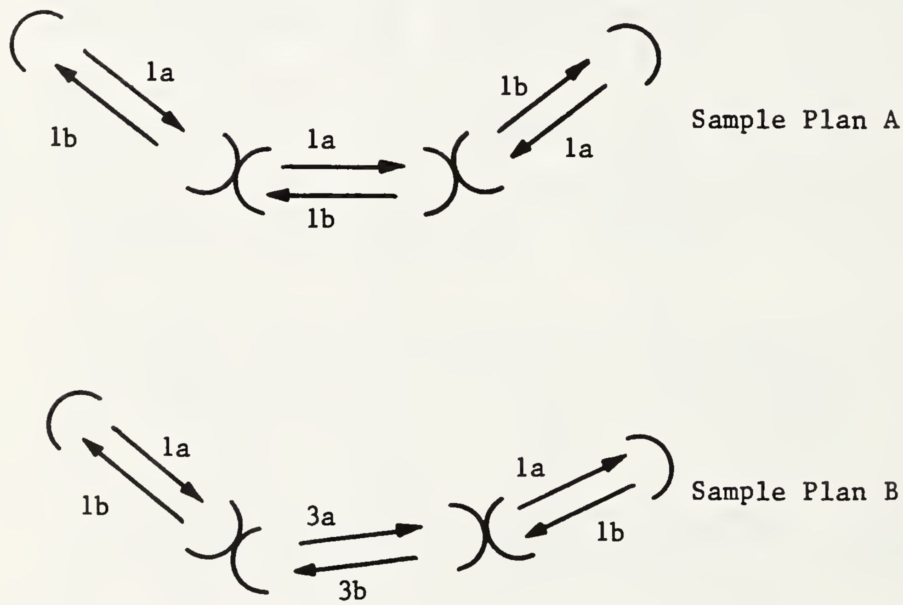
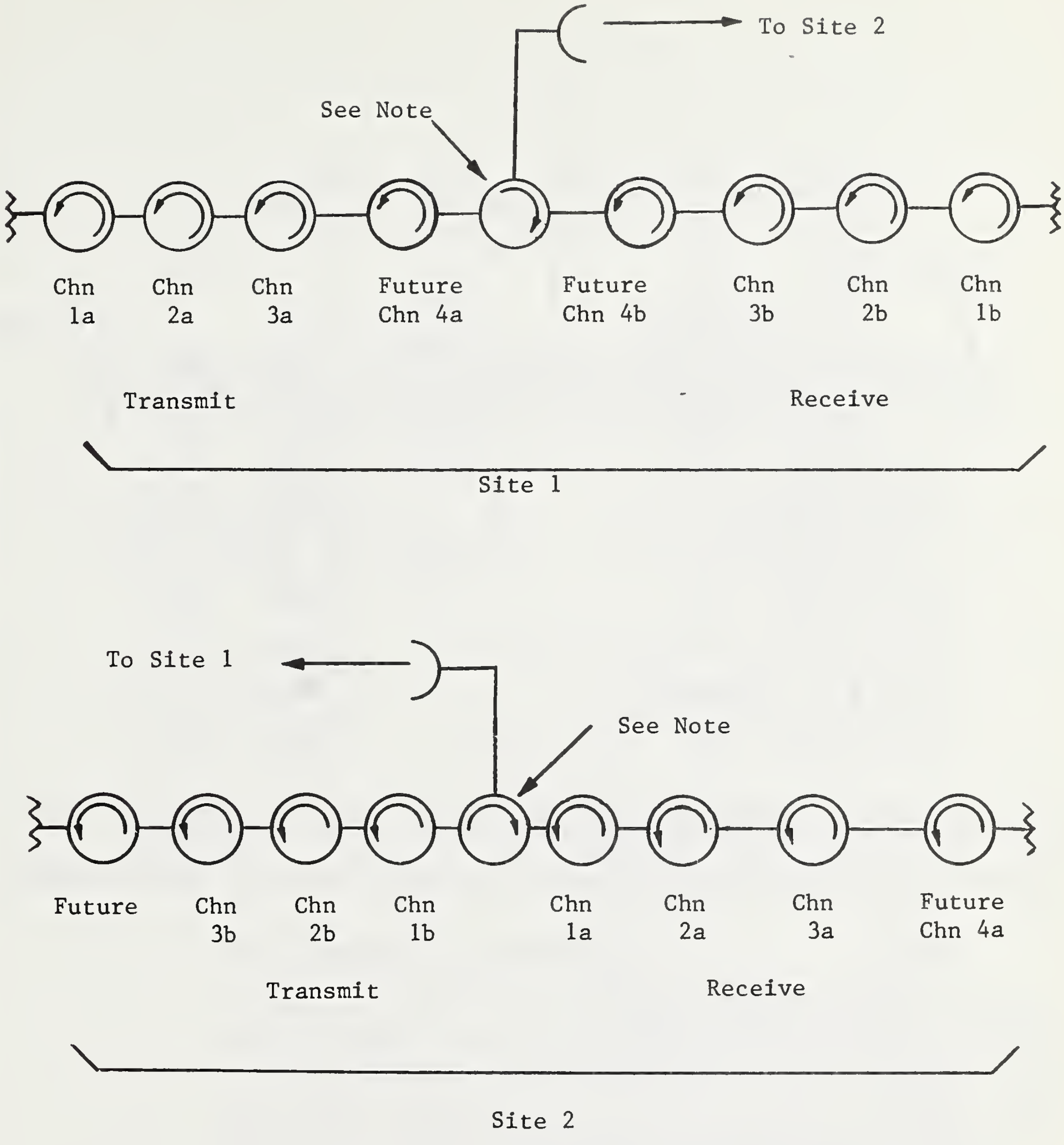
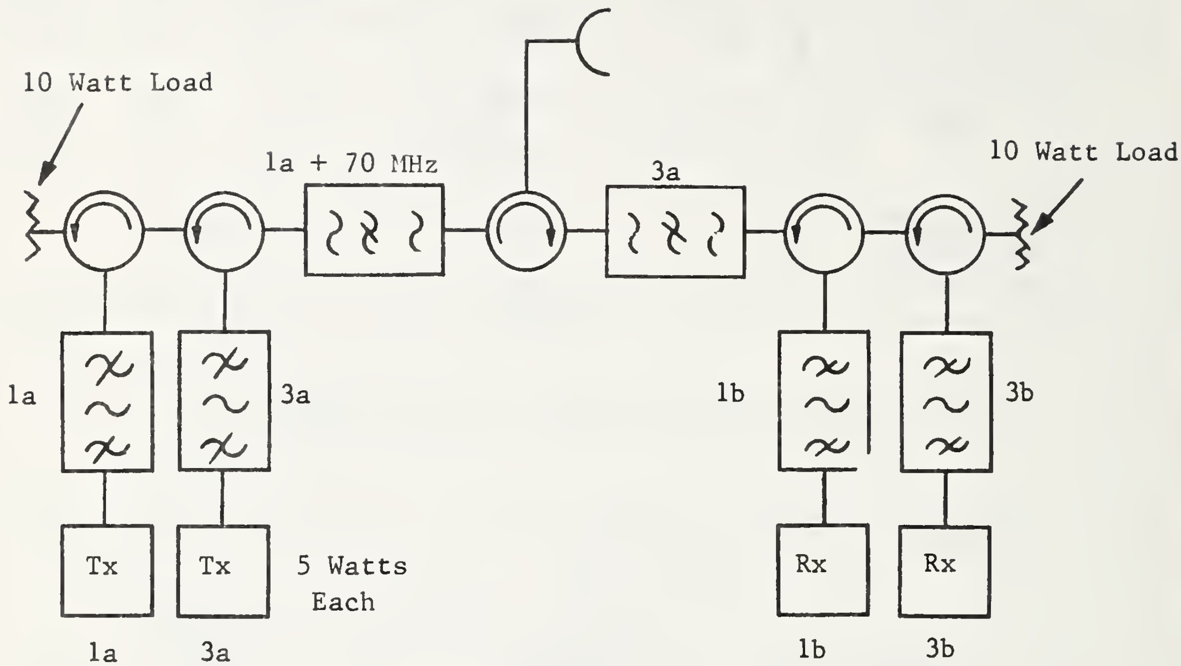


Figure II-156 RF Channel Assignment



Note: This circulator is known as the TxRx circulator since it separates the transmit and receive directions.

Figure II-157 RF Branching



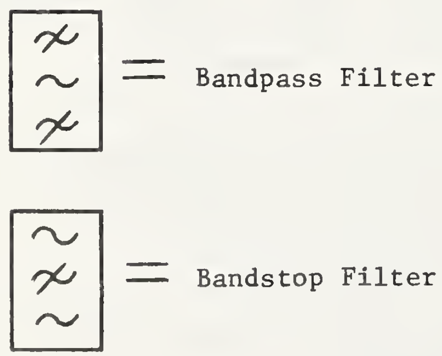
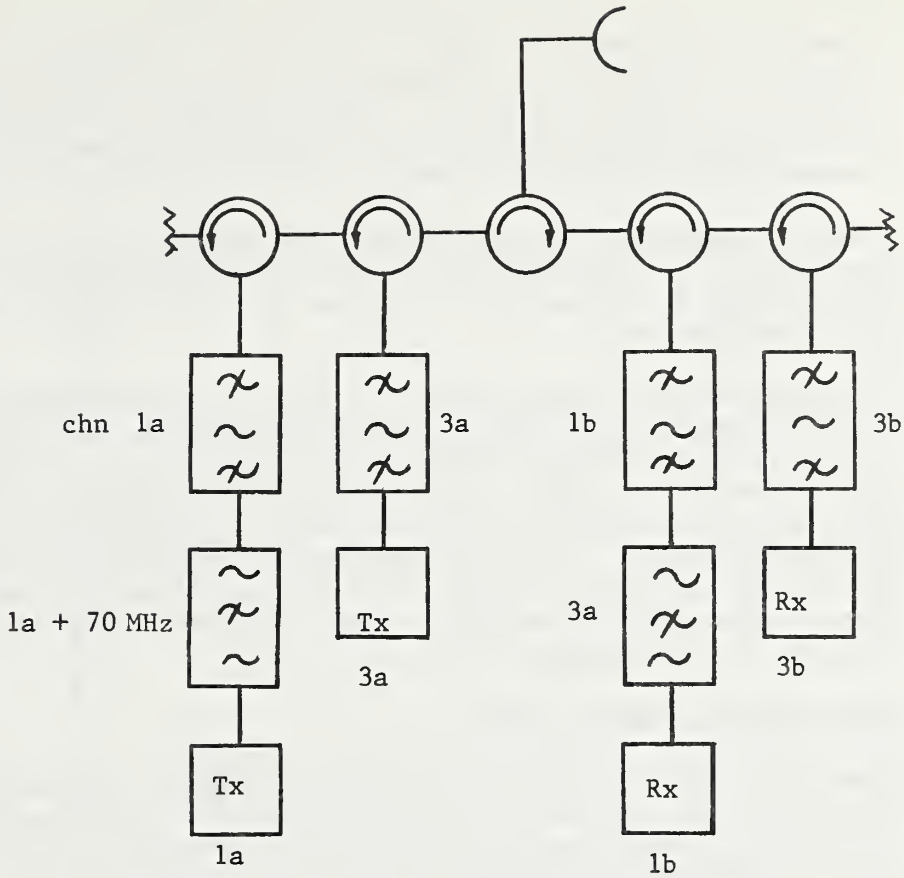


Figure II-158 RF Branching With Additional Filtering



Note: The bandpass filter and not the bandstop filter is connected to the circulator to allow for Rx 3b's signal to properly bounce off the Rx 1b filter.

Figure II-159 Alternate Method of Inserting Additional Branching Filters

Local Oscillator Assignments

Local oscillators (L.O.) of both transmitters and receivers leak RF energy into the branching. Manufacturers' specifications usually designate their level. Care should be taken that these signals are not allowed to interfere with reception within the branching nor at the other end of the path. The L.O.'s can be considered as unmodulated interfering carriers. (See Section II.H.3 for analysis.)

When an L.O. signal goes into the branching, it follows a path determined by the direction of the circulators. If an L.O. signal could interfere with a receiver locally, the equipment should be arranged so as to direct the L.O. signal to a load or the antenna before it has a chance to reach the victim receiver. If the signal will cause interference at the opposite end of the path, it should either be directed to a load or be blocked with additional filtering. To determine whether an L.O. signal will cause interference, select potential receivers at the same or near frequencies in the system and calculate the L.O. signal through the possible paths of the system to the victim receiver. Include the attenuation at the L.O. frequency of all the filters involved.

There are two methods of avoiding L.O. problems. One is to suppress it in the equipment by filtration, use of isolators and good RF mixer design. The other is to judiciously select L.O. frequencies.

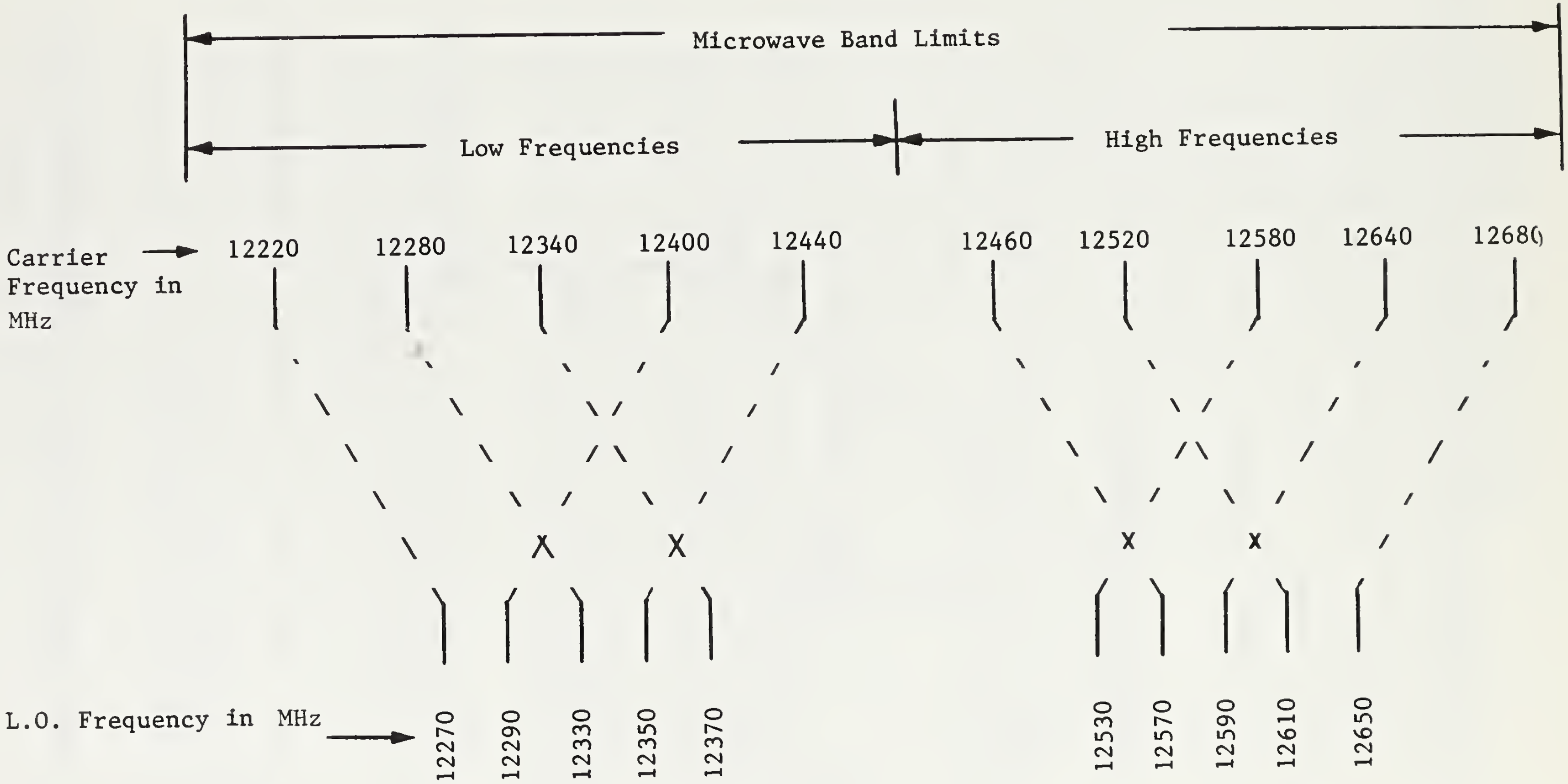
In selecting the frequencies, the radio equipment operating at the edges of the microwave band uses frequencies toward the center of the band. This avoids radiating L.O. signals at frequencies outside the microwave band being used. Equipment near the center of the band uses L.O. frequencies toward the outside but still within the band. This avoids equipment in the bottom half of the band from interfering with equipment in the top half and vice versa. Figure II-160 is a typical L.O. frequency plan.

RF Equipment Configuration

The mechanical design of radio systems becomes complex by virtue of the RF branching and waveguide runs. The matter is further complicated when a system is expanded using a different vendor's equipment with different mechanical dimensions. The initial design should have rack face elevations as well as detailed drawings of the branching arrangements. There should also be detailed drawings of the waveguide installation. The waveguide drawings should clearly show the orientation of the waveguide and all the interconnecting pieces of waveguide elbows, straight sections etc. Figure II-161 shows such a drawing. In this figure it is assumed that elliptical waveguide is used from the antenna down into the equipment room. From the room entrance to the equipment rectangular waveguide is used for neatness of appearance.

The RF equipment configuration report, in addition to physical descriptions, should contain block and level diagrams that show all the power levels and losses through the system. Particular factors that should be clearly visible are:

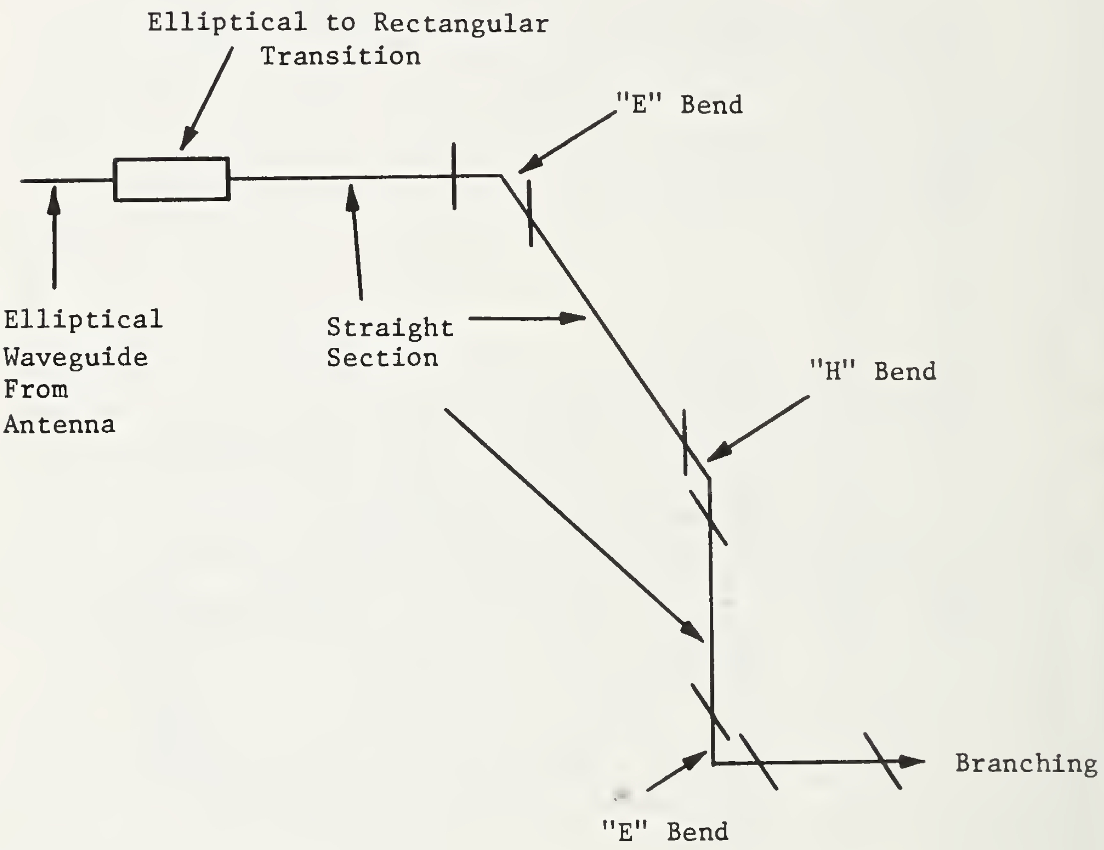
- Antenna gains
- Transmission line losses
- RF branching losses



Note: The dashed line connects L.O. frequencies with associated RF channel frequencies.

Figure II-160 Local Oscillator Frequency Plan

- Transmit power with clear statement of where the measurement is made (at which waveguide flange in the system)
- Receive levels at the receiver (state flange where measured)
- Filter losses
- Path loss (free space)



Note: The cross hatch marks show the direction of the larger waveguide dimension.

Figure II-161 Three Diemnsional Drawing of Station Waveguide Plan

Transmission Performance Analysis

The calculations for this analysis are shown in Section II.H. The transmission performance analysis report should include:

- Transmission system power budget
- Noise performance analysis
- Availability analysis
- Error rate analysis
- Frequency interference analysis

b. Multiplex

The multiplex plan for a microwave system should include:

- Channel routing
- Synchronization plan
- Frequency generation plan

The channel routing diagrams show schematically the routings of the channels, groups, supergroups, etc. Figure II-162 shows a section of a typical channel routing diagram. It describes the multiplex routing at a 3-way terminal. Also see Figure II-13.

As should be apparent, a fully expanded multiplex channel routing plan becomes extensive. It is often broken down into many drawings for the whole system and several drawings per site.

The symbol ——○ indicates that particular multiplex interface point is planned for but not equipped initially. The symbol ——● indicates functions equipped initially. Naturally, the through connections are also equipped initially; for example, the SMG interconnections.

Synchronization Plan

The decision is made whether to use remote references for the syncrhonization or highly stable independent oscillators at each site. If a remote master clock is used, a synchronization plan is developed. The plan details the following:

- Sync frequency
- Location of master clock

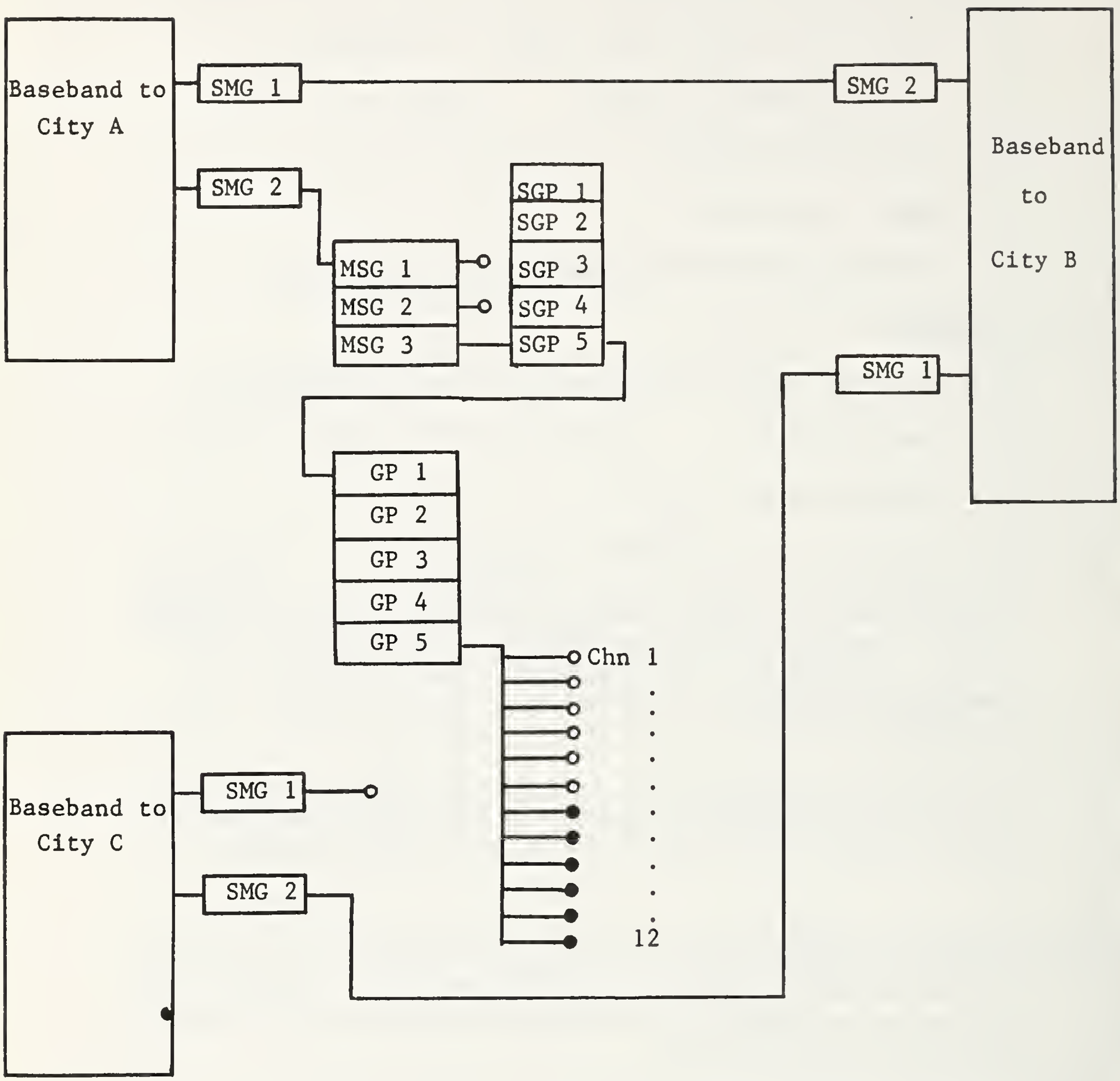


Figure II-162 Multiplex Channel Routing Plan

- Routing of the sync signal to the sites and alternate routing

- Loss of sync alarm reporting system

- Drift tolerance when sync is lost

- Location of alternate master clock

The documentation required depends largely on the system complexity and the selected manufacturer's equipment.

<u>Frequency Generation Plan</u>

The frequency generation plan describes the frequency spectrum of all the modulation steps in the mux. The plan also describes the carrier frequencies used.

The spectrum factors to be considered are the positions of signals during intermediate mux steps and the final position in the baseband.

In the mixing process in multiplex, the local oscillator is called a "carrier". Ideally it is a pure sine wave signal. The carrier frequency generation process is not as standardized as the mux output signal spectrum. In some mux systems, the carriers are all generated centrally in one set of equipment mounted in a carrier generation rack(s). The carriers are then routed by coaxial cable to the various mux units. (The routing of the cabling is included in the cable running lists.) The plan carefully considers the number of units connected to each generator to avoid overloading the carrier generators. Other types of mux have individual oscillators in the mux units which simplifies the carrier generation plan.

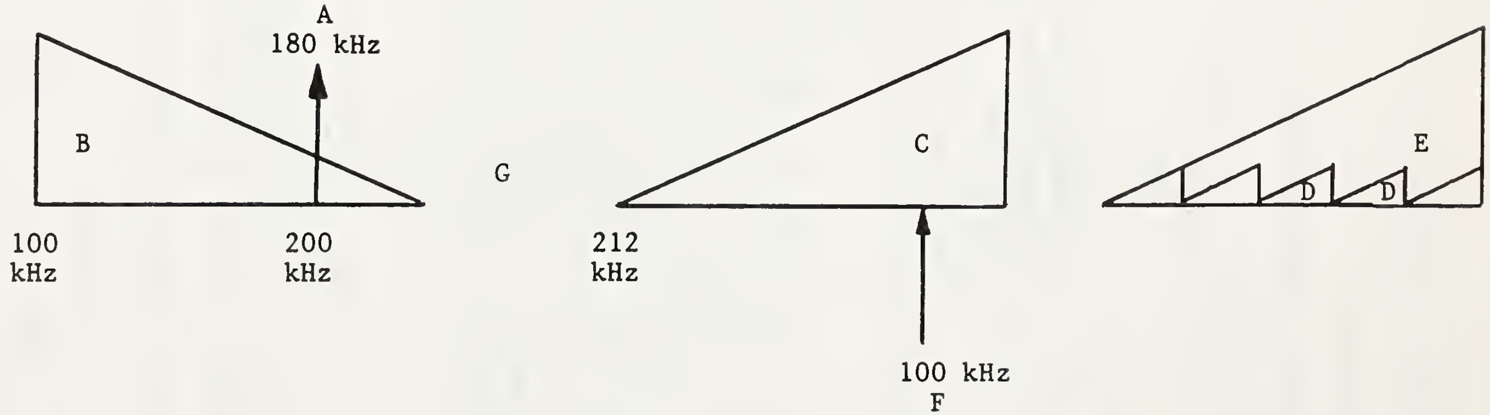
The symbology used in defining mux frequency plans are shown in Figure II-163.

When selecting the multiplex frequency spectrum to be used in a system one should consider the following factors:

- Standard frequency translation steps are:

0-4 kHz	Voice channel
60-108 kHz	Group
312-552 kHz	Supergroup
812-2044 kHz	Mastergroup
8516-12388 kHz	Supermaster group

Note: This diagram shows sections of multiplex spectrum. The symbology could be used for any mux section such as GP, SGP, MSG or SMG. The symbology is the same for all. The frequencies shown are only examples.



A - Pilot of B
B - Mux section that is the lower sideband of a mixing process
C - Mux section that is the upper sideband of a mixing process
D - Subsection of E
F - Carrier for C, used as a carrier in the mixer that produces the spectrum of C
G - Guard band between B and C, 12 kHz wide

Figure II-163 Multiplex Frequency Symbology

- Additional common muxing practices are:
    - Program channels for relaying broadcast audio are 10, 12 and 15 kHz wide. They are usually translated up to the 60-108 kHz spectrum and fed into a SGP multiplexer.
    - Pregroup 12-28 kHz, contains 4 channels
- The baseband spectrum or final multiplex output usually follows these standards:

Channel Capacity	Baseband Spectrum (kHz)
60 channels	312-552 or 60-300 or 12-252
900	312-4028
960	60-4028
1200	312-5564
1260	60-5564
1800	316-8024

- The pilots for the various steps are (options shown for GP and SGP):

Step	Pilot Frequency in kHz	Symbol
GP	60,64,84.08,84.14,104.08	
SGP	411.92,547.92,411.86	
MSG	1552	
SMG	11096	

- Guard bands are typically allowed as follows:

Guardband Position	Amount of Guardband
Between channels	None
Groups	None
SGP	8 kHz
MSG	88 kHz
SMG	144 kHz

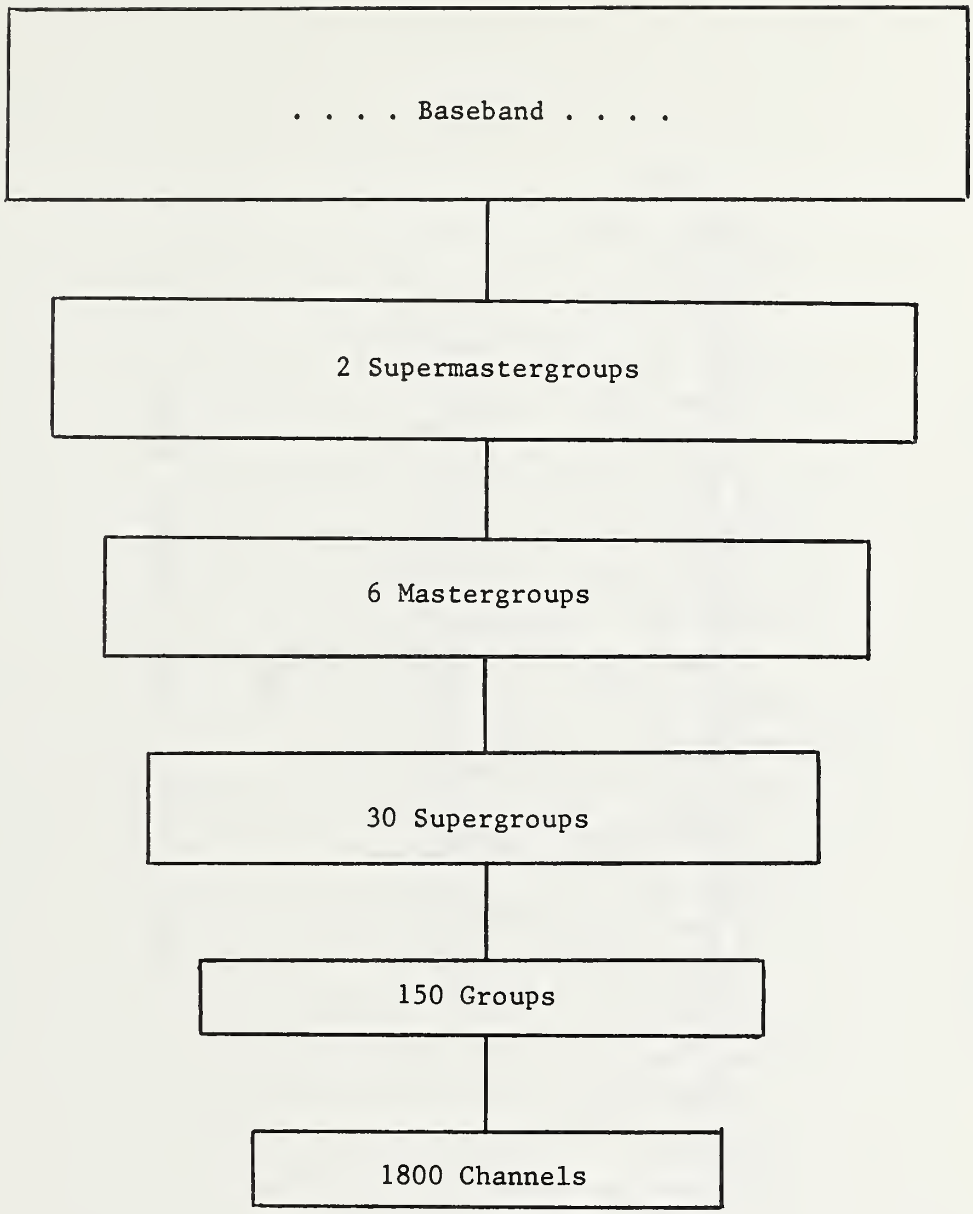
- One of the supergroups is often placed in the baseband directly, occupying the spectrum of 312-552 kHz. It is usually an upper sideband signal. Other than this supergroup, all other channels, GP's, SGP's, MSG's and SMG's are usually lower sideband signals as they appear in the baseband.

- The microwave systems often have to interface with other transmission facilities at the GP, SGP or MSG levels. The designer should investigate such interfaces for compatibility of:

  - Pilots
  - Upper/lower sideband positioning
  - Levels
  - Impedances
  - Frequency spectrums
  - Balance of the line

The following multiplex plans take the above factors into account and construct an 1800 channel baseband step by step. See Figures II-164 through II-169.

Figures II-170 and II-171 show the positions of the various multiplex hierarchies for the 960 and 1260 channel capacity systems. The 900 and 1200 channel systems are identical except SGP 1 is not included.



Fiugre II-164 1800 Channel Multiplex Hierarchy

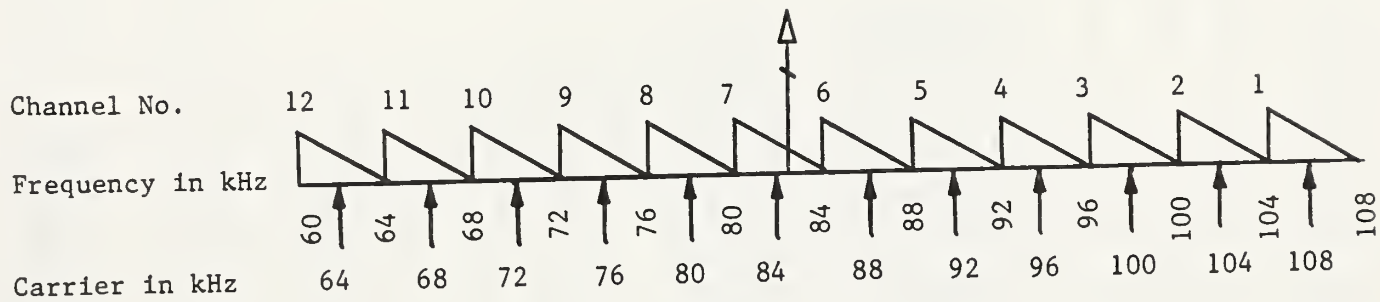


Figure II-165 Group Frequency Plan

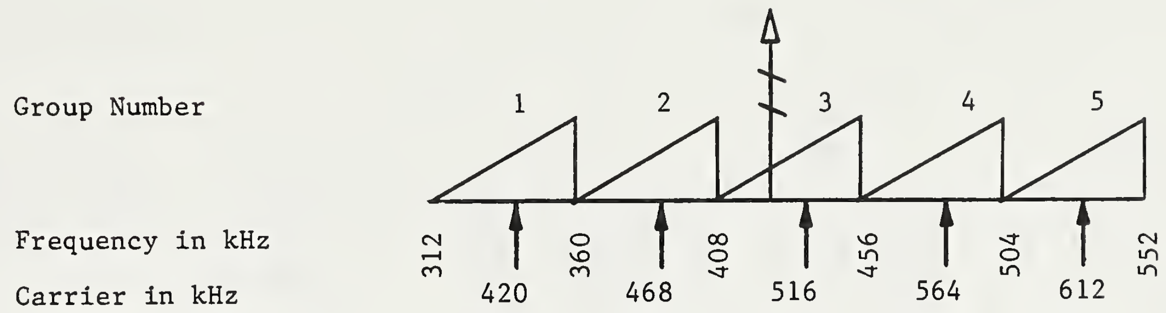


Figure II-166 Supergroup Frequency Plan

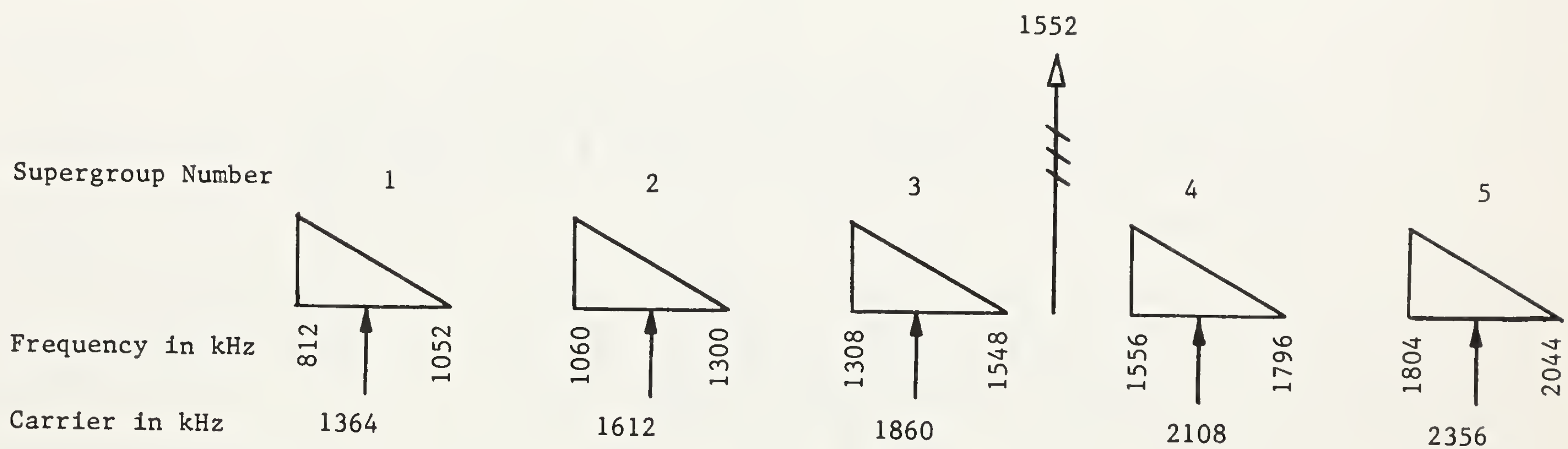


Figure II-167 Mastergroup Frequency Plan

Figure II-168 Supermastergroup Frequency Plan

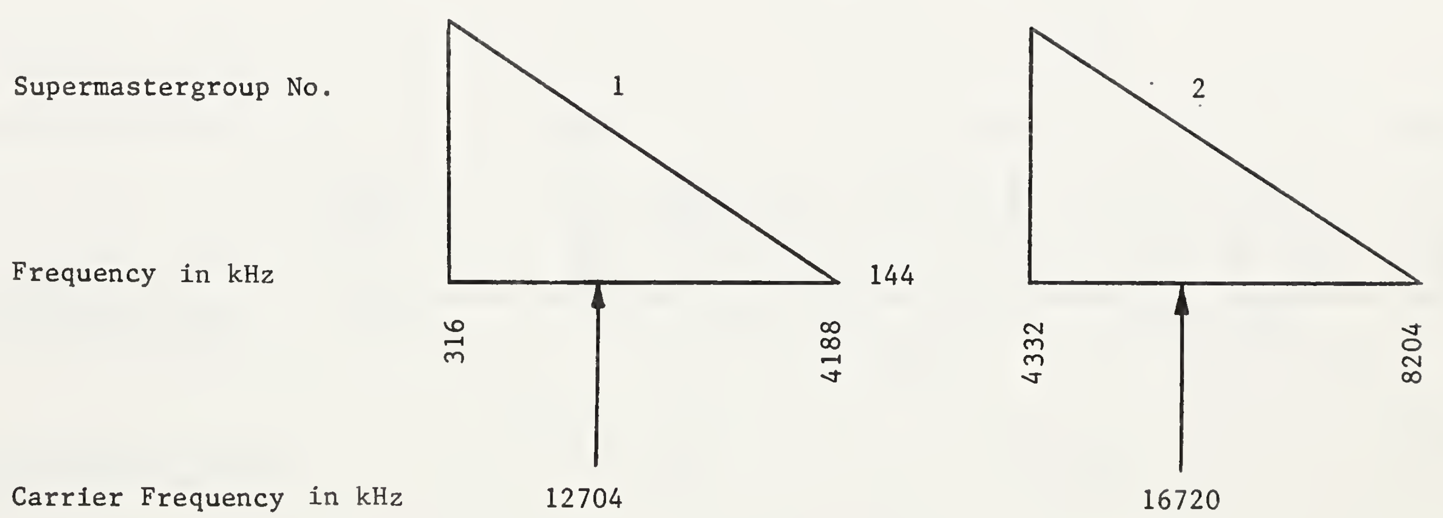


Figure II-169 Baseband Frequency Plan

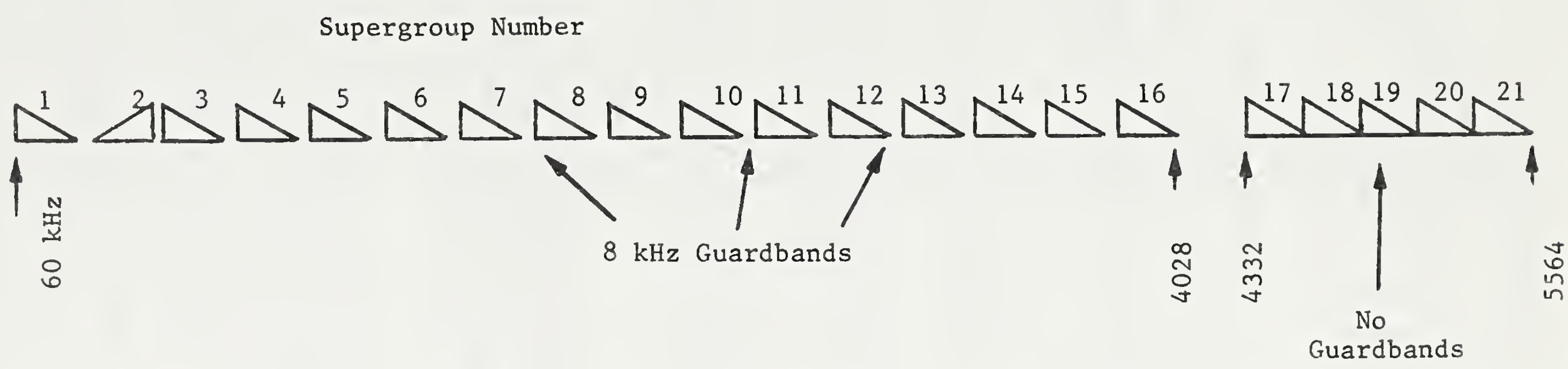


Figure II-170 1260 Channel Baseband

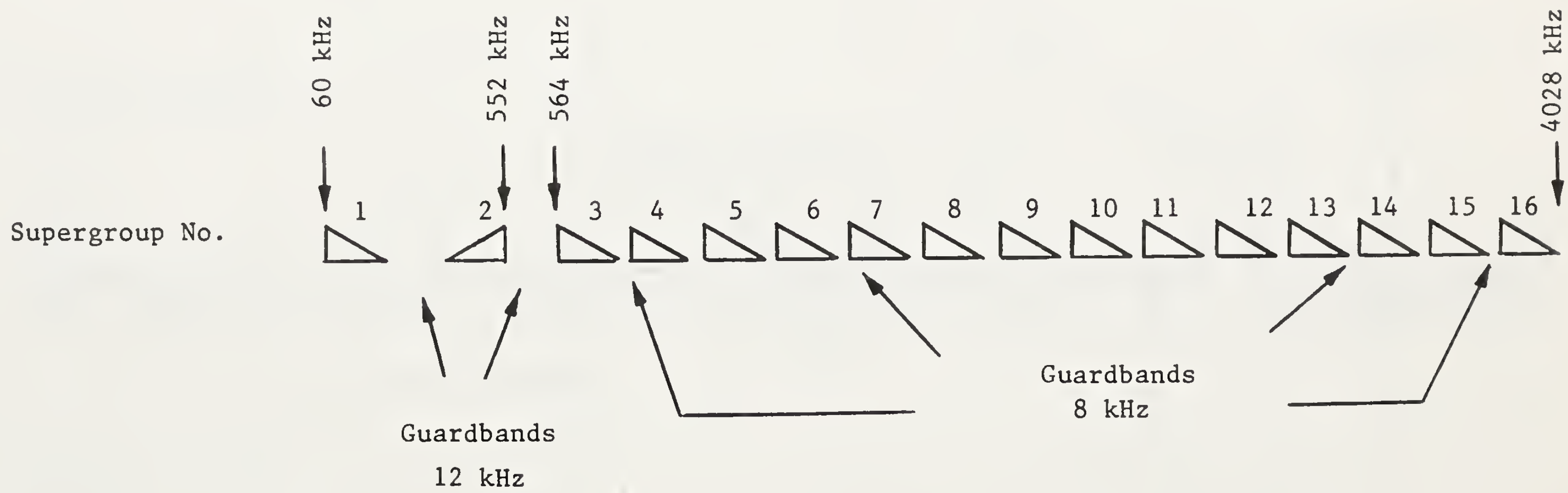


Figure II-171 960 Channel Baseband

c. Orderwire System

The orderwire (OW) system is a voice system of 1 to 12 channels used by the microwave system's Operations and Maintenance personnel. It is used primarily for transmission of the alarm and control system, administrative voice and data circuits, backsignaling for switching systems and testing circuits as required. The designer analyzes the system requirements and plans a system design based on factors such as:

- All OW circuits are normally dedicated; no switching.
- Orderwires are usually multiple user circuits.
- Long distance orderwires should have restricted access to prevent overcrowding; such OW's are known as Express Orderwires (XOW).
- XOW's normally use some sort of selective calling. Common techniques are rotary dial using SF signaling or touch pad signaling.
- Local Orderwires (LOW) are orderwire circuits used for communications to repeater sites. On long systems LOW's are usually equipped with signaling.
- LOW's are usually restricted to a limited area, possible 10-20 paths in tandem. This limits the number of potential users and also limits the circuit length and accumulated noise.
- To talk from one "area" to another, patching connections at a terminal station can be requested verbally. An alternative is to have some form of dial access, although this is uncommon. If extensive inter area communications is required, certain LOW's can be extended to cover larger areas.
- XOW's are often equipped with "speech-plus" equipment for transmission of low speed data. Speech-plus is a multiplexing scheme whereby a low speed data signal is multiplexed into the voice channel above the speech spectrum. Filters are used to separate the voice and data. The technique facilitates making a voice call and sending hard copy confirmation at the same time.

Figure II-172 shows the configuration of the orderwire facilities at a typical station.

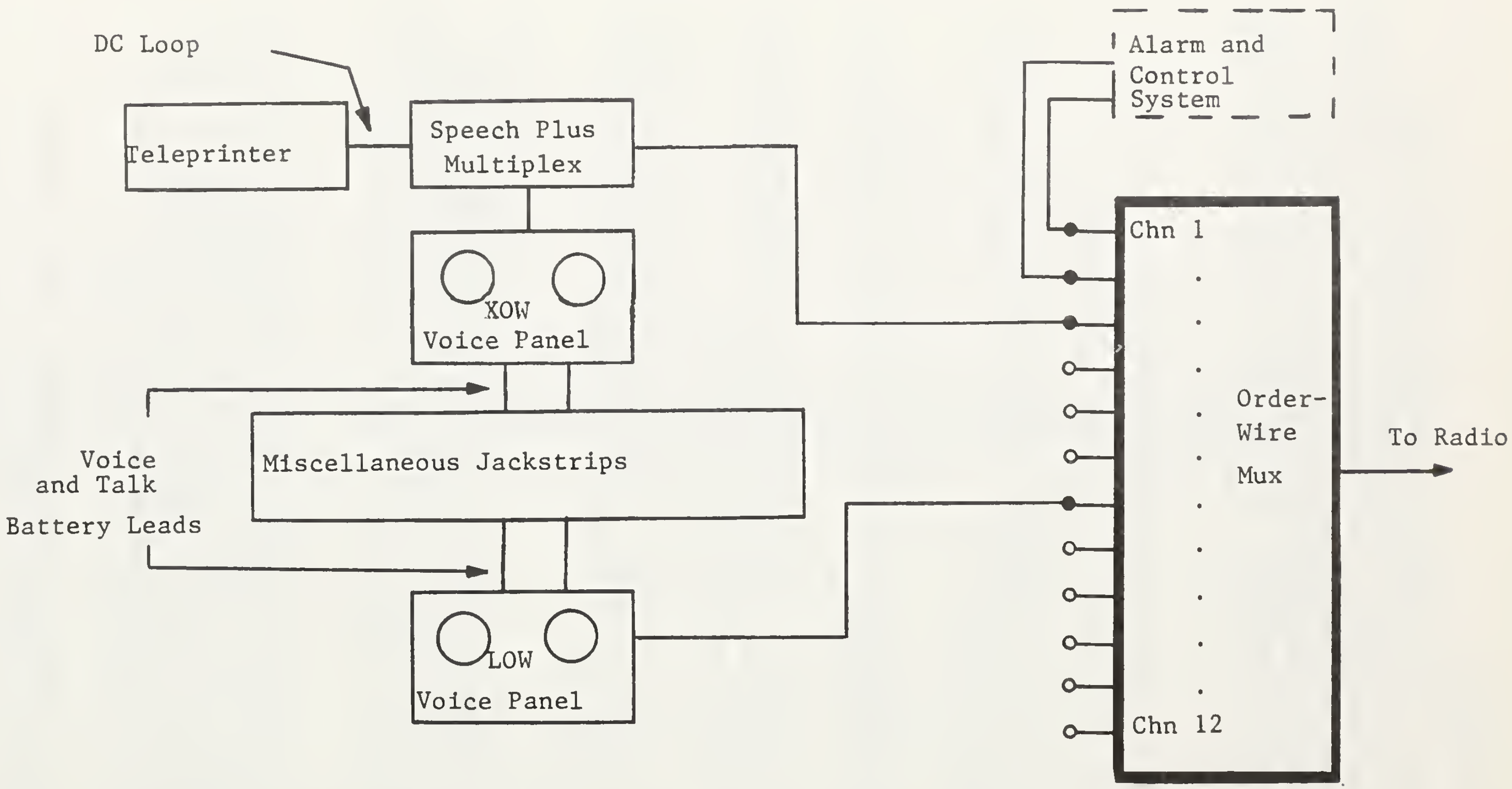


Figure II-172 Terminal Orderwire Configuration

The multiplex plan for the orderwire system is designed similarly to the main message baseband multiplex. The same design considerations are taken into account such as synchronization, spectrum and carrier generation. The complexity of the system, of course, is less. The one important factor to remember is the fact that orderwires must be above the baseband if the baseband is to carry normal video. In telephony systems the orderwire may be above or below. It is also advisable to place the orderwire above 12 kHz in the baseband to avoid carrier noise that appears at the very bottom of the baseband.

The design of the orderwire at microwave repeaters is slightly different from terminals by virtue of the fact that the orderwire signal must be passed on from one repeater to the next. Figure II-173 shows the basic configuration of the orderwire routing at baseband and IF repeaters. Only one direction of transmission is shown for simplicity.

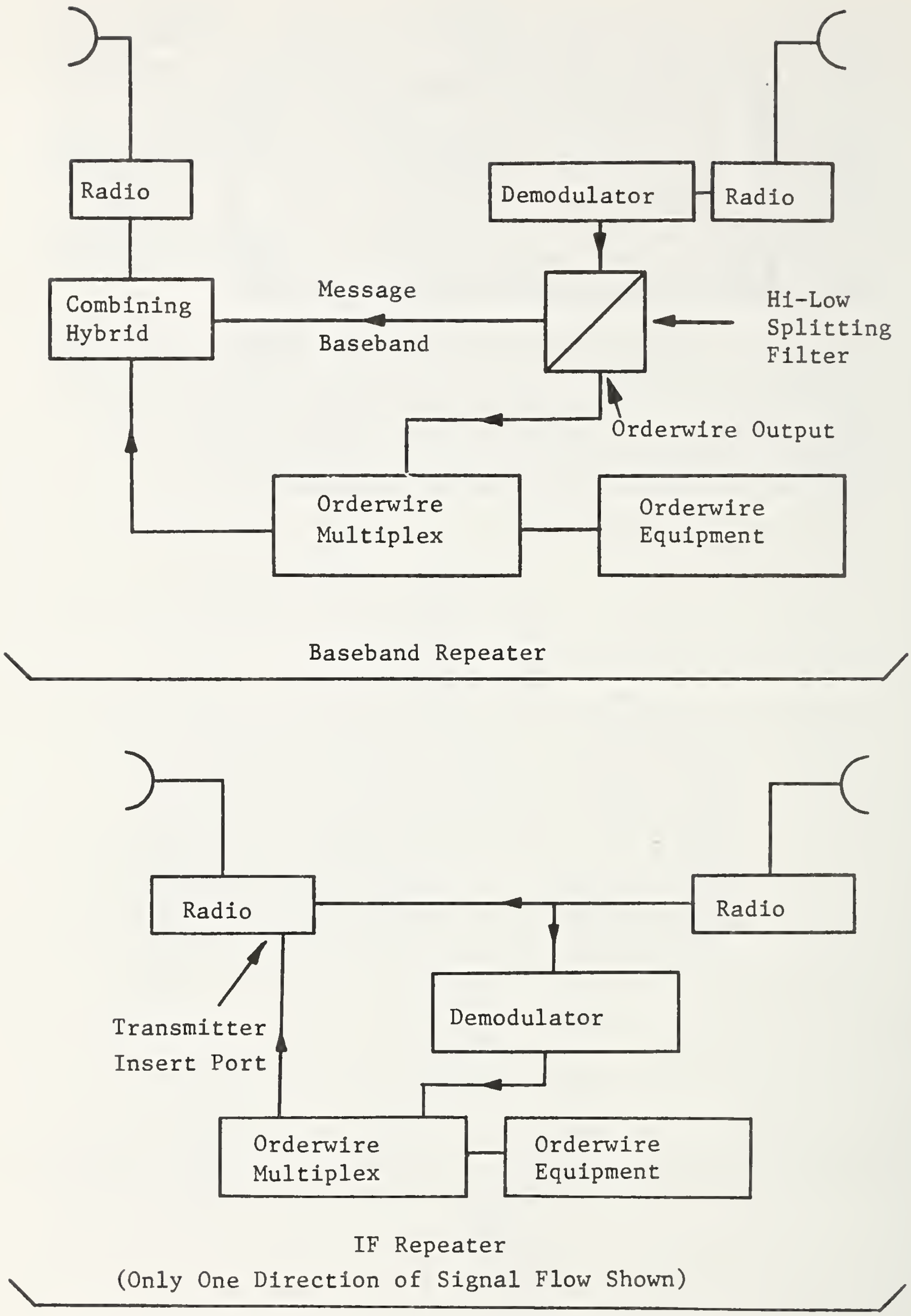


Figure II-173 Repeater Orderwire Configuration

d. <u>Alarm and Control System</u>

The alarm and control system normally contains local station alarms and a system of remoting functions to a central point(s). See Section II.E.9 for explanations of the principles involved.

When designing the local station alarm facility, the designer normally takes advantage of the alarm functional outputs available on the equipments involved. At a terminal station this includes all the functions noted in II.E.9 as well as alarms for the termination equipment. Normally the termination equipment is alarmed for power failure (blown fuse).

Alarms in a station are wired to "aisle" alarms which present audible and visual alarms at the end of each equipment aisle. Aisle alarms have cutoff switches to disconnect the audible alarms. Having indications on each aisle facilitates fault location. Each equipment bay is also equipped with an indicator which is usually visual only. The aisle alarms can use multicolored lights for various indications such as major, minor or cutoff key activated. In some stations different types of audible alarms are used to indicate different types of alarms.

It is common to wire all alarms within an aisle without cabling to the MDF. For connections to points outside of a given aisle and/or to the remote alarm system the functions are commonly cabled to the MDF for cross connection.

When the central alarm and control facilities for a microwave system are co-located with one of the microwave radio, mux and termination equipment, the question arises as to how to best interface the microwave transmission equipment alarms with the alarm and control system. When interfacing the station alarms with the central alarm and control system located at the same site, it is advisable to consider the station's transmission equipment as a remote site for purposes of interfacing with the alarm system. It is possible to hard wire equipment alarm functions to the central alarm reporting system directly but this makes the station nonstandard since all other stations report through the transmission media of the microwave system. Figure II-174 demonstrates the standard method of interfacing co-located equipment to the central alarm and control equipment. The local equipment appears as a remote station to the alarm and control system.

Routing of alarm and control signals is normally accomplished using voice channels in the orderwire system. Alternate routings are advisable where such a path is available. Without alternate routes, the failure of a nearby station can blind the central alarm and control system from seeing the

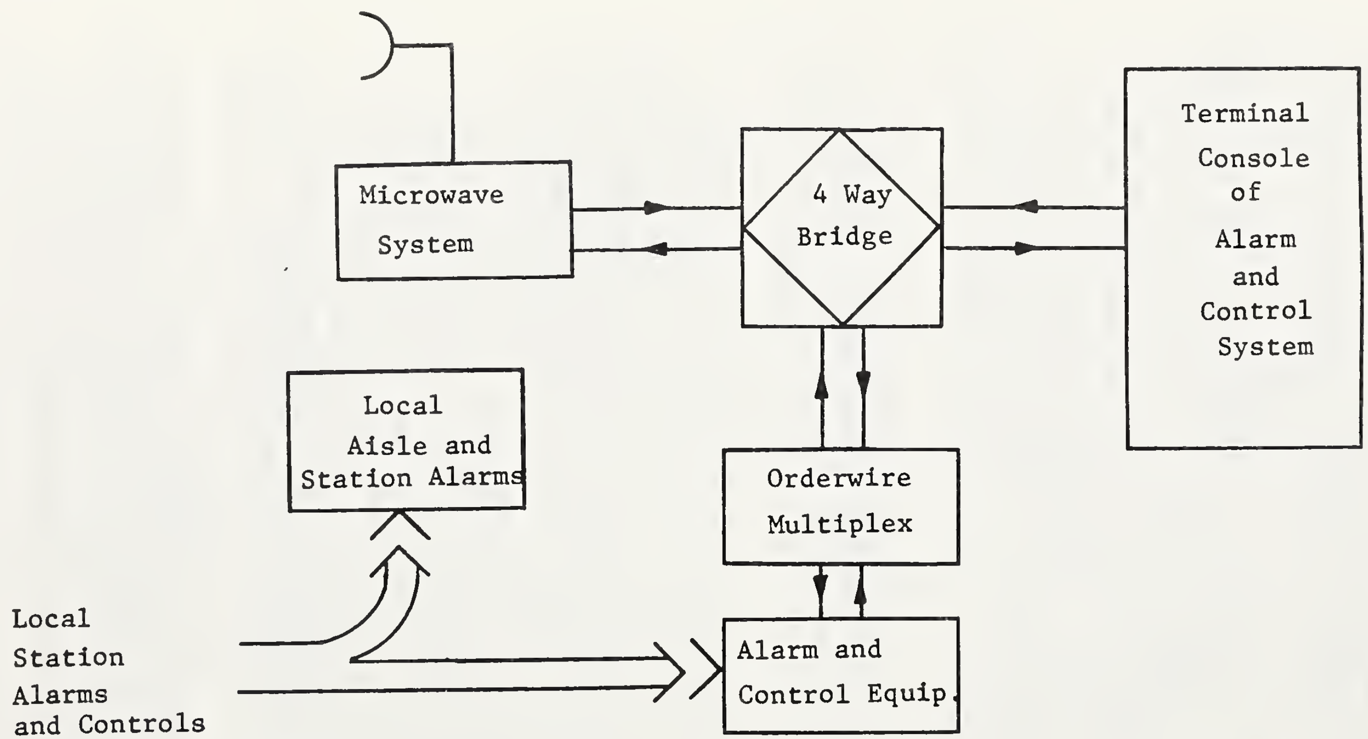


Figure II-174 Alarm Reporting of Local Equipment rest of the microwave system. Land lines (telephone lines) may be available to interconnect two ends of a system. The alarm system at either end then has access to all sites from two directions. See Figure II-175.

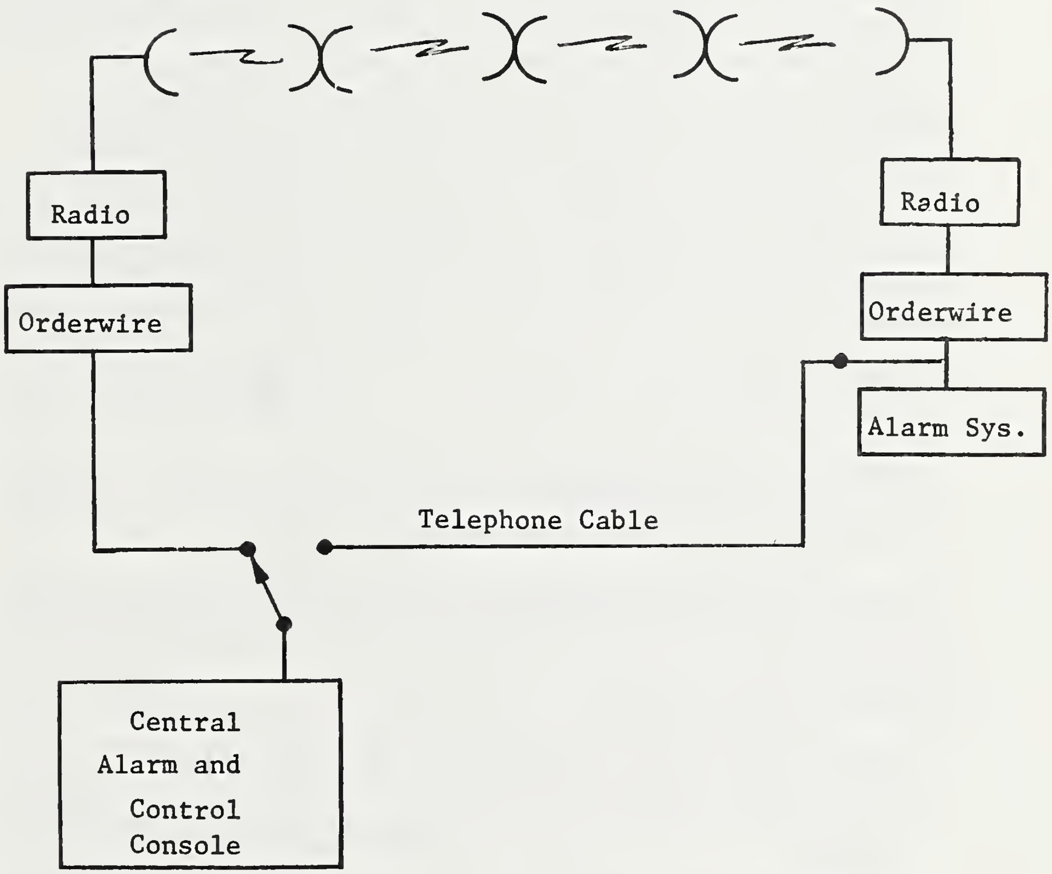


Figure II-175 Alternate Alarm Routing

Another method of providing alternate routing is the use of a separate radio channel dedicated to the alarm and order-wire system.

Some systems use master control stations at both ends of a system. The alarm signals are transmitted in both directions from each repeater. Either end can detect failures. Priorities must be built in for avoiding simultaneous command and control signals originating from both ends at the same time. This is usually done by "handshaking" between the two ends. If a polling system is used, one master station scans while the other is idle. After the first has completed a scan cycle, it turns off the carrier of its polling signal. This activates the other master to begin cycling.

Microwave systems consist of equipments from a variety of sources. There can therefore be a variety of electrical characteristics of alarm and control interfaces. Within a given piece of equipment, they can vary. The person with alarm and control integration responsibility documents every interface and determines compatibility. Some of the common problems between equipment and alarm system interfaces are:

- Both sides of the interface try to provide battery instead of just one
- Neither supplies battery (both dry contacts)
- Excessive or too little voltage or current
- Change of state required but only pulse given (or vice versa)
- Opposite polarities
- One side is transistor logic, the other relay
- Unbalanced input required, balanced supplied (or vice versa)
- Analog signal versus digital input (or vice versa)

When interfaces are incompatible, the following solutions are generally considered:

- Redesign of the alarm and control system
- Redesign of equipment interfaces
- Design interface devices that bridge incompatibilities

One other incompatibility may arise when the designer attempts to gang several alarm functions together. This may or may not be electronically feasible. A common problem is ganging a number of contacts together that all have a voltage for no alarm and open for alarm. If the points are tied together, the voltage will remain until a fault appears on all points rather than on only one. Each case of ganging should be studied on its own.

The reports that normally accompany the detailed design of the alarm and control system include:

- Definition of alarm and control functions
- Detailed listing of interface characteristics of all equipment alarm and control points noting their compatibility with the alarm system
- Modulation scheme, timing, frequency slots, etc.
- Routing methods
- Polling scheme (if used)

e. <u>Facilities Engineering</u>

Several aspects of facilities engineering not covered in sections above are heating, air conditioning and power systems.

Heating systems are normally electric with thermostatic controls integrated with the air conditioning system. It should be noted that much of the equipment used in microwave systems is temperature sensitive and its environment must be controlled. Heating and air conditioning units are normally supplied with redundant units. The temperature thermostatic control unit is alarmed and the alarm is fed into the remote alarm system either directly or ganged with another alarm such as illegal entry or power system failure.

When calculating heating and air conditioning requirements one considers:

- Thermal insulation of the equipment enclosure
- Inside control temperature range
- Outside temperature range
- Heat generated by the equipment

The amount of thermal insulation is given by the shelter manufacturer for repeaters. In existing buildings, the building engineer examines the "heat load" due to heat from the equipment and determines the additional air conditioning load.

The inside control temperature range for repeaters is commonly 60^{o} to 90^{o}F (16^{o} - 32^{o}C). The equipment may be able to operate over a wider range, but some consideration is given to the occasions of site personnel working on site. The temperature at terminal locations is normally that which is comfortable for office locations,65^{o} to 75^{o}F(18^{o} to 24^{o}C).

The amount of heat generated at the station increases as the system expands. One therefore considers the amount generated with the initial complement of equipment and that generated with a full complement of equipment. To this latter figure is added the heat generated by personnel and test equipment.

To calculate the amount of heat generated by the equipment, calculate the prime power consumed. This will approach the amount of heat generated. For a more exact figure, subtract the transmitter output power at the shelter exit point and any other external uses of power such as tower and security lights and any outside equipment. Another approximation can be achieved by calculating the amount of DC power consumed by the equipment in the shelter. The lowest heat figure will be this value for the initial equipment requirements. The highest heat generated will be the DC power for a full complement of equipment plus lights, test equipment and personnel. At a repeater this is typically 300 watts for lights, 1 kw for test equipment and 600 W for personnel ($\sim$200 watts each for 3 people).

To calculate the heating requirements, determine the maximum temperature differential between the coldest expected outside temperature and the lowest allowable inside temperature. From the manufacturer's specifications, determine the amount of heat required to maintain that differential. Subtract from this amount the heat generated by the equipment in its initial configuration. The net result is the minimum rating for the heaters.

To calculate the air conditioning requirements, determine the temperature differential between the hottest expected day and the highest allowable internal temperature. Determine the amount of air conditioning required to maintain that differential from the manufacturer's specifications. To this figure add the amount of heat energy generated with a fully expanded equipment configuration as shown above. This then is the air conditioning rating of each air conditioning unit.

Manufacturers specify insulation in various dimensional units. Btu is one of the most common terms used to describe air conditioning power.

1 Btu (British thermal unit)	=	778.3 foot pounds
	=	1054.8 joules
1 Btu per hour	=	17.6 watts
12,000 Btu per hour	=	211 kW
12,000 Btu per hour	=	4.7 horsepower-hours
12,000 Btu per hour	=	1.0 "ton"

To calculate the amount of insulation of a shelter:

Insulation = Manufacturer's differential rating in Btu's per degree per square unit of surface

times

total surface of walls, ceiling and floor

times

temperature differential

<u>Power Systems</u>

A large percentage of communications equipment requires DC power, either 24 or 48 Vdc. There are two main reasons for this. One is the fact that a station can use one central AC to DC converter rather than rectifiers in every piece of equipment. The second reason is the fact that DC can be stored directly in batteries for emergency use where AC cannot be easily stored. Thus, most stations are supplied with 48 or 24 Vdc batteries fed by a DC source. The DC source might be an AC rectifier, solar batteries or some sort of DC power generator. The most common application is the use of an AC rectifier. In addition to this, many stations have an AC generator which operates in the event of a power failure of the main AC source. Remote stations often require this redundancy because overhead power feeds are subject to outages and site access times are long. In certain cases, it may take days to reach a site due to bad weather. The station battery is normally designed to carry the station for 8-24 hours while discharging. The auxiliary generator is therefore necessary to carry the station until repair crews arrive or main power is returned to service. At some stations, no main AC power is available in the area of the site and the entire power requirement is met using stand alone redundant generators.

In certain cases the only equipment available from manufacturers for certain applications operates on AC. If the equipment is critical to system operation, it can be fed by a DC to AC converter which in turn is fed by the station battery. If the main AC fails, this AC equipment continues to operate off the battery through the DC to AC converter.

The more common power system applications are shown in Figure II-176.

To determine the size of the battery, amp-hour capacity, the designer determines the initial and eventual station DC power requirements. If there is a significant difference, the initial battery complement can be small with planned space for additions later. The designer must determine from availability analysis and site access times how long the system must be operated by the batteries alone. 8-24 hours is typical.

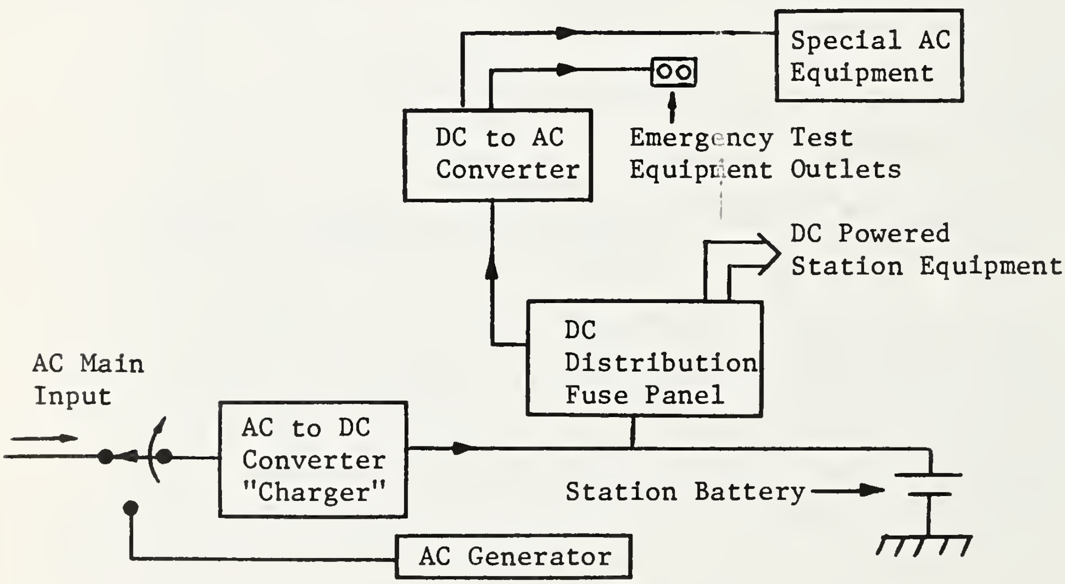


Figure II-176 Typical Power System

The chargers are designed to carry the entire equipment load and charge the batteries at the same time. The charger capacity is rated to carry the equipment and fully recharge completely dead batteries in a specified period of time. This is typically 24 hours. Chargers are normally redundant and parallel on line at all times. Either charger should be able to supply all station DC needs independently.

In recent years there has been a surge of interest in solar energy. Solar energy lends itself readily to a number of microwave applications. The factors that favor solar power applications to microwave transmission systems are:

- Low RF and overall power requirements
- Short hops
- Low channel capacity
- Short transmission lines
- Continual sun exposure
- Good environmental conditions for static solar arrays such as lack of sand storms and vegetation.

Sunlight is available in useful quantities between 10 AM and 2 PM on clear days. The actual amount of power collected can also be affected by zenith angle to the sun. The further one is away from the equator, the lower the angle and the less the power available. Cloud filled days also reduce the amount of sun power available.

As a rough estimate of the solar power requirements, multiply the steady state power requirements of the station by:

Multiplier	Description
6	Sun power available only 4 hours a day
1.5	Allows 50% for recharging batteries when low
2	Allowance for cloudy days

Power multiplication factor (estimate only) = 6x1.5x2 = 18

Seasonal variations in zenith angle, rain fall, snow fall and temperature affect the solar energy systems and each application should be studied in detail.

9. Transmission System Design Factors

This section discusses some additional engineering factors that apply to the design of a microwave transmission system. It is to be used in conjunction with other sections in the Bulletin to arrive at a finalized system design. The transmission system by definition includes the multiplex, modems, switching equipment, radio, RF branching, transmission lines and antennas. Each one of these equipment categories is presented with some of the engineering factors of concern that are not presented elsewhere in this Bulletin.

Multiplex

FM noise is greater in the top of the baseband. Because of this, it is common practice to place long haul traffic in the bottom of the baseband and short haul on the top. Thus, the long haul traffic does not accumulate noise as rapidly.

FM Modems

Modems are a chief source of IM noise. When selecting modems one should be conscious of the modem's ability to handle excessive overloads of up to 10 dB above normal.

Some modems are integral parts of the switching equipment. This should be analyzed when designing the system initially to prevent equipment obsolescence when expansion occurs.

In many systems the initial channel capacity is low. If system expansion is required, adjustments are required in the equipment configuration and performance. Ease and cost of expansion should be considered when selecting modems.

Switching Equipment

A number of factors should be examined when selecting switching equipment. If the modems and switching equipment come from different manufacturers, interfaces need close attention. One major problem is the fact that some functions may appear in either the modem or the switch such as level adjusting amplifiers, pre and deemphasis, auxiliary inputs such as orderwires and impedance matching. It should be ensured that functions are neither duplicated nor missing.

The switching equipment normally interfaces with the alarm and/or orderwire system for remote controlling and back signaling. Logic levels and interfaces should be examined for compatibility. It is common to have logic voltages and relay contacts wet or dry appearing in the same piece of equipment.

Switching Drop and Insert on N+1 Systems

As discussed in Section II.E.4, N+1 systems require backsignaling and handshaking between the two ends to make all the proper logic discussions before switching. The switching logic may be further complicated if drop and insert is used at repeater sites between the two switching points. If the bearer to be switched to protection is carrying drop and insert traffic, the traffic must also be switched to the protection channel at the repeater. This can be done by sending command or control tones to the repeater site once the two end switching points have made the logic discussions to switch. In essence, the repeater switch is slaved to the end points and does not participate in the discussion. In a typical N+1 system, all the alarm and orderwire circuits use drop and insert. In this case, all the repeaters are commanded to switch simultaneously.

Switching Multiple Drop N+1 Systems

Typical of TV distribution systems is the N+1 multiple drop network. Several methods of N+1 protection are available. The most expensive method is to use independent switching on each leg of the system. It is more economical, however, to switch several links and/or spurs together. This does not provide the optimum protection possible but significantly reduces costs. In such a system transmission is usually one way. For backsignaling land lines or parallel telephony routines are used. Each terminal point detects failures and reports back to the central feed point. This central point switching equipment conducts the normal handshaking procedure with the station reporting a failure. A priority system is commonly built into the switching, however, favoring main TV stations over spur links. In large systems, through traffic is favored over spurs as well. The handshaking in such a system is somewhat more complicated by virtue of the fact that the switching must check the availability of the protection channel on the favored route as well as the failed route before switching.

Additive Delay and Frogging Technique

RF filters have delay characteristics similar to Figure II-177.

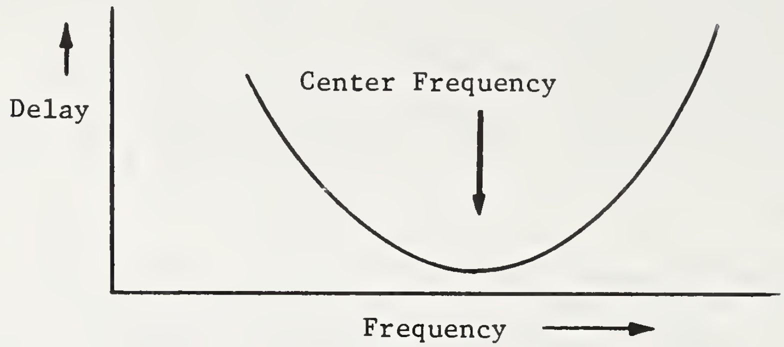


Figure II-177 Delay Characteristic Curve

If filters are in tandem as they are in a microwave system, the delay characteristics add arithmetically. The impact on IM adds faster than arithmetically. The IM adds at a rate of approximately 15 log (number of hops) when the delay characteristics are allowed to accumulate. There are two solutions to the problem. One is to use equalizers on every path to flatten the delay characteristics. The equalizers are usually installed in the receiver IF section.

The second solution is more complicated. To understand the principle involved, consider the instantaneous frequency of the deviated FM carrier when it swings farthest away from the center frequency. At this time it is riding up the delay skirts of the filter(s). The higher it rides the worse the IM caused by the delay distortion. If the carrier swings to the same side of the filters on a number of paths in tandem all at the same time, the delay changes add causing considerable impact on IM. To resolve the problem, it is advisable to scramble the FM signal in some way so the peak swings do not occur simultaneously on all paths at the same time. This is commonly done by bringing the IF signal at every fourth or fifth repeater down to baseband and transposing channel positions in the baseband. The technique is called "frogging". Commonly, the baseband frequencies of several supergroups are interchanged. The resultant FM deviation has a different instantaneous value and swings up the filter skirts at a different time. The process is costly because of the added mux and is therefore not done at every station. Up to 4 or 5 paths, the additive delay does not present too much of a problem.

The same general thinking applies to the frequency gain response of the filters.

Baseband Inversion

Placement of the local oscillator frequencies above or below the RF carrier frequency affects the direction of frequency deviation. That is, if a modulator 70 MHz carrier goes up in frequency in response to a positive going baseband voltage, the radio carrier frequency will go up if the local oscillator is below the carrier frequency.

$$\text{Carrier frequency} = F_{L.O.} + F_{FM}$$

$$= F_{L.O.} + 70 \text{ MHz} + \text{deviation}$$

$$= \text{erect baseband}$$

If the local oscillator is above the carrier frequency then the selected mixer output is

$$\text{Carrier frequency} = F_{L.O.} - (70 \text{ MHz} + \text{deviation})$$

$$= \text{inverted baseband}$$

and the carrier frequency decreases with a positive going baseband signal. At receive demodulator outputs, the two baseband signals resulting from the two types of RF signals are opposite in polarity. One is a positively swinging voltage, the other swings negatively.

The same principle applies to the position of the receive local oscillator. It is acceptable to have a mixer with oscillators above or below so long as the basebands that are being switched end up all "erect" or all "inverted". If they are different, and two radios with reversed baseband polarities are switched in a radio switching system, there is a 180^{o} phase reversal on all signals in the baseband at the time of switching. This causes data errors and pulses in the channels carrying traffic.

When selecting local oscillator frequencies, it should be noted that if the transmit and receive oscillators are both on the same side (above or below) of the RF carrier, the baseband will be erect. If they are all on opposite sides the baseband will be inverted.

Telephony systems are not sensitive baseband inversion. Video systems are, however. In an inverted baseband white becomes black and black becomes white. It is therefore necessary to ensure that the baseband position at the point of demodulation for video is erect.

RF Branching

RF branching has a couple of potential problems. One is the bandwidth of the circulators. Some are narrower than others. The problem can appear when additional RF channels are added to the system. The bandwidth of the circulators should be wide enough to cover the entire spectrum of future requirements to prevent obsolescence of the circulators.

In RF branching, a signal from one transmitter bounces off the output of other transmitter filters before reaching the transmission line. See Figure II-178.

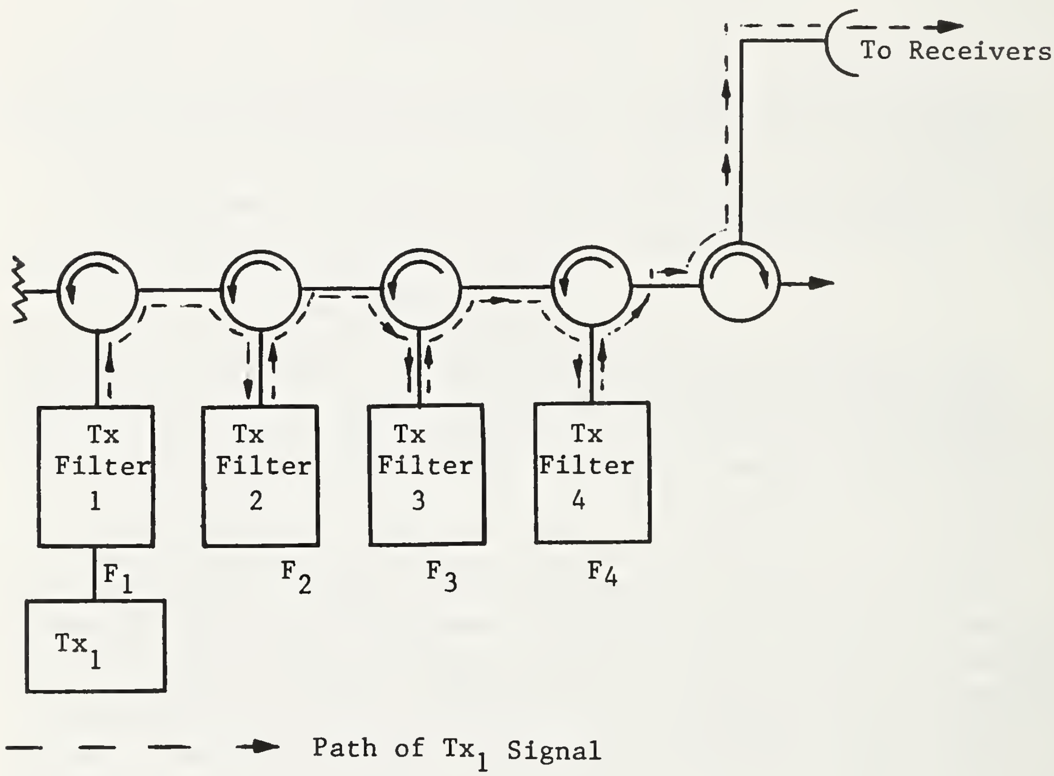


Figure II-178 Transmit Signals Bouncing Off Adjacent RF Filters

If the filter for F_2 is at a frequency adjacent to F_1 then the action of F_1 bouncing off the face of Filter 2 will cause a tilt in the delay slope of the signal F_1. If the filter is not adjacent (2 or more carrier channels away) the delay tilt is negligible. If not compensated for, the delay slope will cause IM noise. Two methods are commonly used to correct the problem. One is the use of mop up equalizers in the IF of the receivers. The other is to bounce the signal off another filter which has a frequency on the opposite side of F_1. This induces a delay slope tilting in the opposite direction. This compensates for the first tilt. The same principle applies to the receive RF branching. The RF branching is arranged so that all equipment has a chance to bounce twice off adjacent RF channel filters or none at all (the transmitter closest to antenna). If a transmitter bounces off only one filter (lowest or highest frequency) it is possible to insert a dummy filter with circulator in the branching to achieve the second bounce. The second bounce can also be accomplished by bouncing off another filter at the other end of the path. Usually transmit and receive filters are electrically and mechanically identical so the bouncing of the opposite end of the path has the same effect as bouncing of a filter in the same station. If no such filter is available at the receive end it is generally speaking cheaper to insert sufficient equalizing in the receiver IF to compensate for the tilt.

When designing the RF branching, the eventual sequence of RF filters should be kept in mind. If a filter is going to be needed in a certain spot in the future, mechanical space should be left for it. In some cases it may be feasible to install the filter with the original installation.

Transmission Lines

Waveguide joints are a source of VSWR and RF leakage. It is common to have a leakage in a waveguide joint 65 dB down. If the joint is at the antenna it could pick up interfering signals more readily than the antenna. It is therefore advisable to keep the number of field installed waveguide joints to a minimum. One effective way is to use elliptical waveguide which comes in rolls on wooden drums. Entire waveguide runs can be installed with only the joints on the two ends.

Antennas

The system path engineer normally specifies the desired antenna gain. The person conducting the frequency interference analysis specifies the actual antenna model depending on the specific interference rejection requirements. Often a single case of interference will arise that no standard antenna discrimination pattern can cope with. In such cases it is often possible to hand pick an antenna with particularly good discrimination at a desired angle, frequency and polarity. See Figure II-40B.

10. Tower Design

Towers in communications systems considered here are the self supporting, guyed and roof mount types. Normally, tower manufacturers provide the necessary design analysis on a case by case basis. The system designer need only specify antenna types, heights and bearings with a decision on what basic type of tower is to be used and a description of the available real estate.

Self Supporting Towers

As with the guyed towers, the most demanding mechanical stress is wind loading, not dead weight. The stress moment due to wind loading is often enough to cause up lifting on the tower legs. The tower loading is calculated knowing the wind velocity and the effective square surface of the tower and antennas. Variations with temperature are ignored.

Pressure in kilograms per square meter

$$P_{kilo} = .0079V^2$$

where V is the wind velocity in kilometers per hour.

The pressure in pounds per square foot

$$P_{lb} = .0042V^2$$

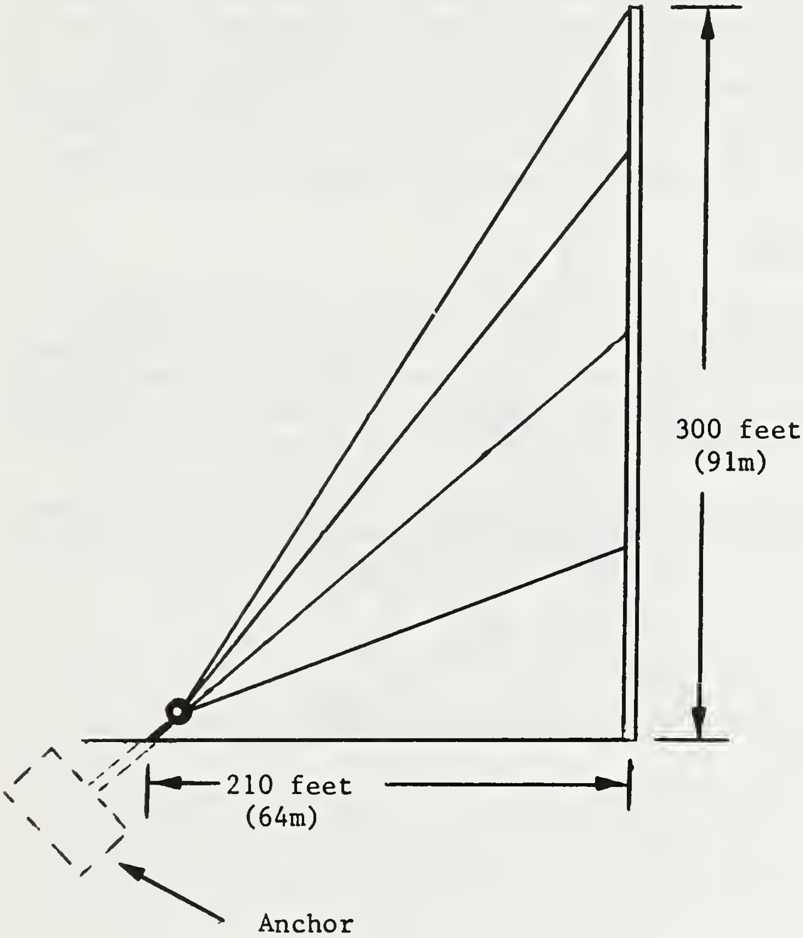
where V is in miles per hour.

Towers have ratings of maximum twist distortion for a given wind velocity and a survival rating for a higher velocity. Twist is caused by antennas that are usually mounted out away from the tower off one side. When the wind hits the antenna sideways a twisting force is exerted on the tower. The tower should not be allowed to twist so much that the antenna main beam goes off the desired path. Typical twist specifications for towers experiencing winds of 70 mph (113 km per hour) are 1/3 of the antenna main beamwidth. A tower supporting an antenna with a 2^{o} beamwidth would be allowed to twist $2/3^{o}$.

Guyed Towers

Guyed towers are much cheaper than self supporting towers and are preferred if the real estate is available.

Most guyed towers use three sets of guys 120^{o} apart. Figure II-179 shows a typical guyed tower with one of the three sets of guys. Normally the towers are designed with 3 to 6 guy wires in each set evenly spaced up the tower. The guys should not be placed in a position where they will block an antenna's view. Path bearings are therefore taken into account when siting the guy anchors.



$$\text{Percent Guying} = \frac{210}{300}$$

$$= 70\%$$

Figure II-179 Guyed Tower

The amount of real estate required for guy towers is a function of the "percent" of guying. The percent is the ratio of the distance from the tower base to the guy anchor divided by the tower height. In Figure II-179, the ratio is $\frac{210}{300}$ which is 70% guying.

Guying percentages normally range between 60% and 80%. To calculate the required real estate, lay out the guy positions, calculate the distances involved and add an additional 15 feet (4.6m) for fencing around the guy anchors. Controlling twist on a guyed tower is a mechanical problem due to the tower's small cross sectional area. To increase the area, "Star Mounts" are used with double guy wires. See Figure II-180.

Roof Mounted Towers

The same general wind loading problems apply to roof mounts. The major difficulty with roof mounts is tying the mount mechanically into the building structure. The design of the mounting structure normally requires the services of a mechanical engineer with sufficient knowledge of the building's construction.

Roof mounts can be any height from zero to many hundreds of feet. The major limitation is the mechanical strength of the building.

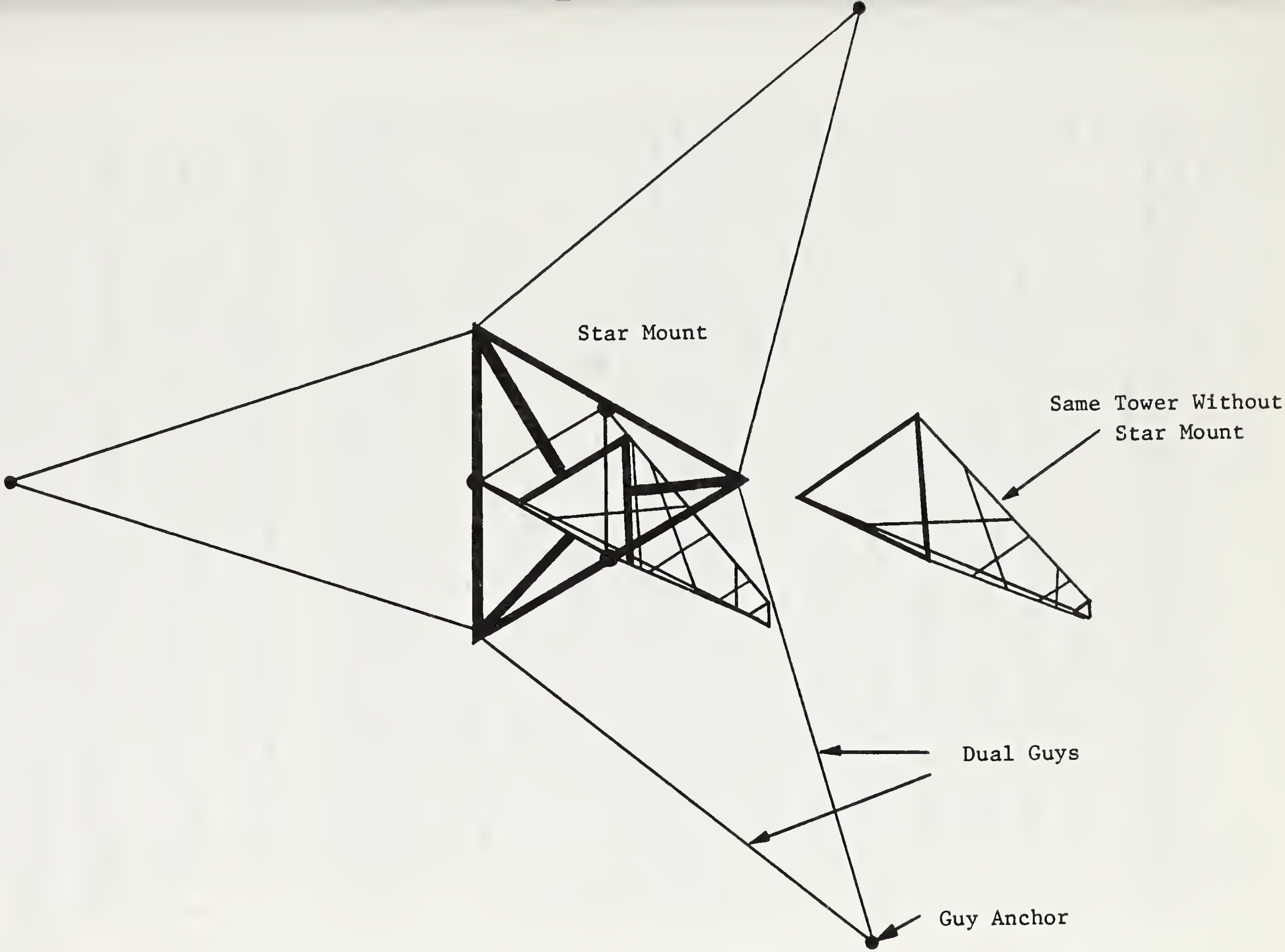


Figure II-180 Vertical View of Star Mount for Guyed Towers

11. Spares

During the detailed engineering phase of project development, consideration is given to the system spares requirements. The factors that affect the spares requirements are:

- Size of the system
- Level of redundancy built into the system
- Level of manpower skills available to effect repairs
- MTBF's of equipments/components
- System availability requirements and MTTR's
- Order cycle time of parts/components
- Cost of spares

With most electronics equipment the manufacturer has a recommended standard list of spare parts, modules and components. In the absence of such lists there are several rough guides used to develop spares lists.

- 1 to 5% of all components
- At least one of each component
- Smaller percentages if the quantity of a component in the system is high
- Buy in standard lot sizes (If the standard lot size for a given resistor is 100, the 100 may be cheaper than 42 resistors because of increased handling charges to sort out the 42.)
- Higher percentage of items with short MTBF's; 25% may not be unreasonable for TWT's on a small system
- Reduce field repair time by buying spare modules rather than just components

The microwave industry commonly spends on the order of 5% of the equipment cost on spares.

H. System Performance Analysis

This section addresses the mathematical tools and analytic techniques employed to design a microwave system. It is based on the foundation of knowledge presented in earlier sections.

1. Map Study and Profile Plotting

As discussed in Section II.F.7 Radio Propagation, one of the preliminary steps taken in the design phase of a microwave system is the map study of possible site locations. The initial study is a preview of the general terrain in the vicinity of the system. This study is normally done on 1:250,000 or 1:500,000 scale topological maps. When planning the routing of a microwave system, there is usually an advantage in staying in the mountainous areas where possible. This tends to allow for longer radio paths and fewer repeater stations. The sites cannot be too remote or site access becomes costly. To conduct a detailed profile of a path, the geographic coordinates of the two sites are marked on topological maps and a line drawn between the sites. For microwave paths in general it is advisable to use the smallest scale of map available. In most areas of the United States 1:24,000 maps are available. On very mountainous paths the large scale maps are adequate unless the intervening ground between the sites is not considerably below the path (path clearance). If the path clearance is high (i.e. > 300m all along the path) the detail of the large scale maps is usually sufficient. In most of the country, however, the small scale maps are preferred for feature definitions and terrain (altitude) contour line resolution. If more than one map is required to construct the entire path, the maps can be taped together. Once the line is drawn, mile or kilometer marks along the line are ticked off for reference. The distance scale on the map is used for this purpose. The line represents the path the radio beam will travel during normal propagation. The map features along the profile line are then analyzed.

Radio beams travel between two points along the great circle route. The straight line drawn on the map will be slightly South of the great circle route if the path is in the Northern hemisphere (unless the path is straight North and South). The deviation between the straight line and the great circle route increases:

- As the path length increases
- The further North the path is located
- The more East-West in direction the path is versus North-South

The deviation is generally not significant with paths under 30 miles (48 km) long. If a terrain feature is near midpath and just misses the drawn straight line, it might be advisable to calculate the actual great circle path position at that distance. Figure II-181 illustrates the case where a river might be a serious reflection along the path. Initially, the drawn line misses the river, but the great circle path may not.

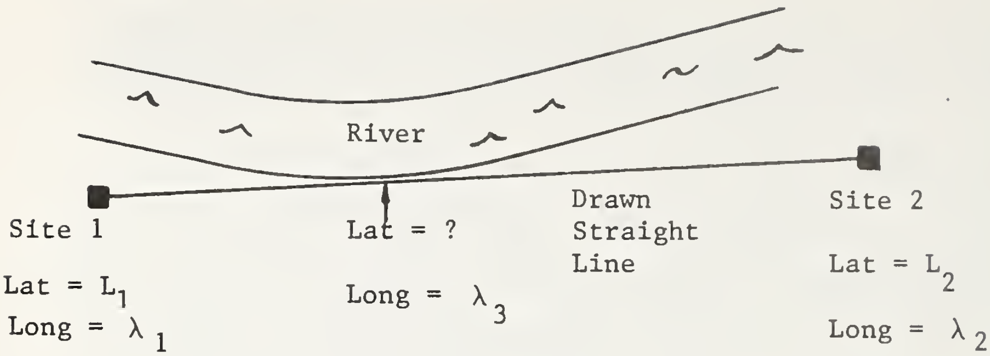


Figure II-181 Path Line Drawn on a Map

To determine if the great circle will pass over the river, the longitude where the river is closest to the drawn line is read off the map as λ_3. The latitude at that point L_3 may be calculated as

$$L_3 = \mathrm{Tan}^{-1}\left[\frac{A - B}{\mathrm{Sin}\,(\lambda_1 - \lambda_2)}\right],$$

where $A = (\mathrm{Tan}\,L_2\ \mathrm{Cos}\,\lambda_1 - \mathrm{Tan}\,L_1\ \mathrm{Cos}\,\lambda_2)\ \mathrm{Sin}\,\lambda_3$

$B = (\mathrm{Tan}\,L_2\ \mathrm{Sin}\,\lambda_1 - \mathrm{Tan}\,L_1\ \mathrm{Sin}\,\lambda_2)\ \mathrm{Cos}\,\lambda_3$

The point L_3, λ_3 is marked on the map and the profile line drawn through the point. The procedure for determining other intermediate points along the path may be advisable if the path is long and passes near other questionable features.

Once the line is drawn on the map, the terrain and obvious features are examined. The altitudes at points along the path are recorded as a function of distance. The altitude marks of greatest interest are the peaks of hills and the identification of reflection points such as lakes, rivers or airport runways.

The altitude data is then plotted on paper to show the geometry of the path. Figure II-182 shows just such a profile.

<u>Data</u>

Altitude in Meters	Distance from Site 1
730	0
710	1
690	2
682	3
635	4
640	5
660	6
685	7.0
710	7.4
723	7.5
723	7.7
710	8
650	9
600	10
610	12
625	14
610	15
600	16
650	18
700	20
739	21.2

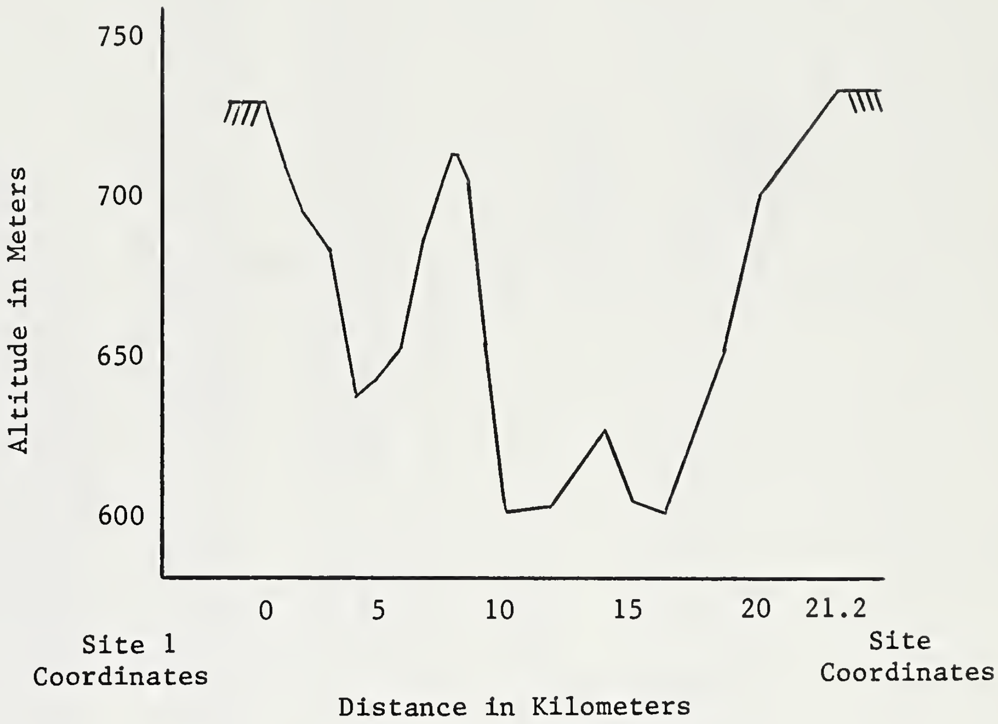


Figure II-182 Path Profile

To complete the profile, other major terrain features should be noted on the profile particularly features on the tops of hills at the ends or along the path. Features requiring notation are:

• Towers	Potential Blockages
• Trees	
• Buildings	
• City locations	
• Lakes, rivers	Potential Reflections
• Flat farm land	
• Major roads parallel to the path	
• Airports	

If the heights of potential blockages are known, they should be so noted. If in question they may be investigated during field surveys.

Air refractivity, as will be discussed in Section II.H.2, causes the radio path to bend with the earth's curvature. Some profile paper builds this factor in as is shown in Figure II-183. In this figure additional terrain features are shown.

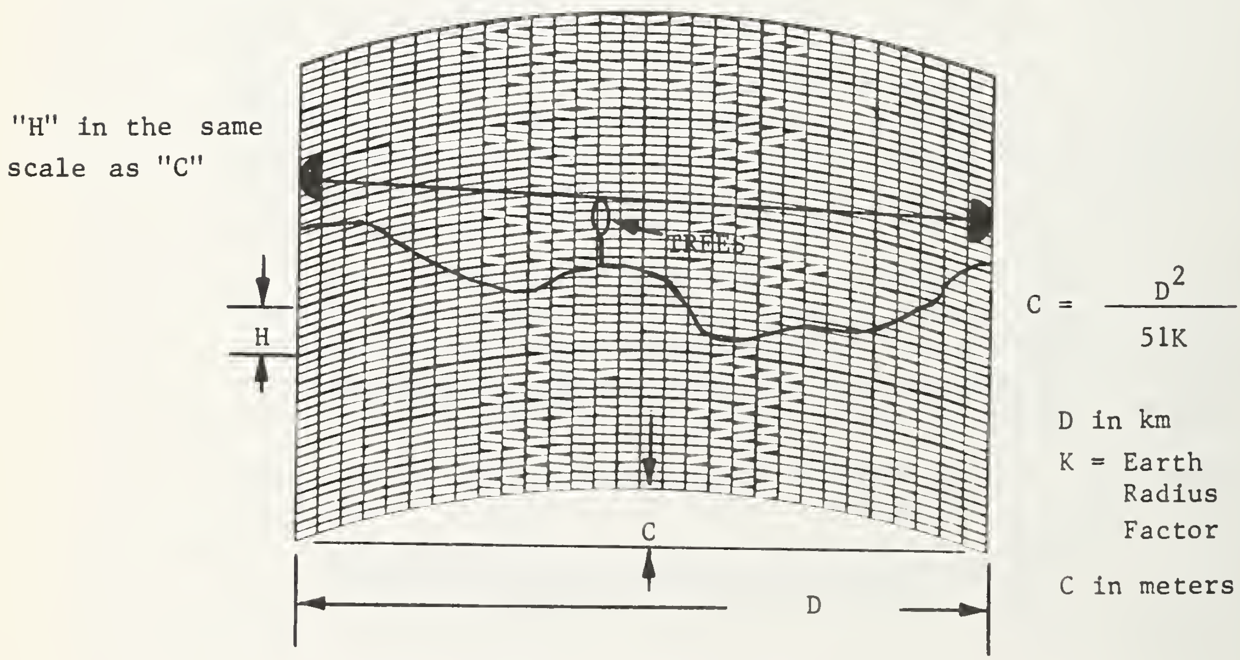


Figure II-183 Profile Paper

2. Meteorological Analysis

Meteorological analysis in this section is a study of the effects of atmospheric refractivity on microwave radio propagation. As discussed in Section II.F.7, the refractive index of air varies with height. This gradient also varies with time.

Refractive Index

The refractive index, "n", of air is a function of temperature, pressure and humidity. The value of "n" varies normally between 1.000240 and 1.000400. For convenience the last three digits 240 and 400 are normally used. The term used is N, radio refractivity.

$$N = (n-1) \times 10^6$$

N_o = N at sea level

N_s = N at the surface at a given altitude

The standard value of N_o is 289.

The nominal $N_s = (N_o)e^{-0.136\, h_s}$

where h is the height in kilometers and e = 2.718....

N_s can vary, of course, and

$$N_s = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{E}{T^2}$$

where P = atmospheric pressure in millibars

T = temperature in ^oK

E = partial atmospheric pressure due to water alone in millibars.

The value $77.6 \frac{P}{T}$ is known as the "dry term". $3.73 \times 10^5 \frac{E}{T^2}$ is known as the "wet term".

Refractivity Gradient

In microwave propagation we are interested in the gradient of N rather than its absolute level. The gradient is normally designated as dN/dh.

It was mentioned that the radio beam is normally bent downward so as to follow the curvature of the earth. The steeper the gradient of the refractive index, the more the bending. The gradient, dN/dh, is measured indirectly by measuring T, P and E at different altitudes above ground at a given spot and calculating the N_s for each set of T, P and E data. This is commonly done using a balloon lifted package of instruments with a telemetry radio link back to a ground site. The balloon is allowed to rise. The received telemetry data is recorded for different heights and dN/dh is calculated.

Such data collection is continuously carried out by the U.S. Government at a number of locations throughout the country. The data available extends to the 0.1% of recorded hourly medians.

An alternate method of calculating dN/dh is to use the empirical formula

$$dN/dh = -7.32\, e^{.005577 N_s} \quad \text{for the U.S.A.}$$

This relationship between N_s and dN/dh holds fairly true for most values of dN/dh.

Beam Bending, K Values

The next step is to calculate the amount of radio beam bending. For this purpose it is assumed that the dN/dh is the same along the entire path. This is usually a good approximation. An indirect method is normally used to calculate the beam bending. It is based on the analogy that a beam being bent by the atmosphere "sees" the earth changing its flatness or its effective radius, K. If no bending takes place, K is 1.0. If the beam is bent to follow exactly the curve of the earth, K is infinite. The nominal or average value of K tends to be 4/3. K typically ranges from 2/3 to infinity for 99.99% of the time.

$$K = \frac{157}{157 + \frac{dN}{dh}}$$

where dN/dh is the gradient of N units per kilometers.

This technique is only approximate but serves as an acceptable tool in most microwave path analyses.

To apply the concept of K, consider the case where K decreases, the effective earth radius becomes smaller. Two fixed points on the surface would then see the mid path terrain bulge upward due to the smaller radius. If the K value goes up, the mid path terrain would go down. This mathematical concept is known as "earth bulge". The bulge will be most noticeable at mid path decreasing toward the path ends to zero at the sites.

$$\text{earth bulge} = B_e = \frac{D_1 D_2}{12.75\ K}$$

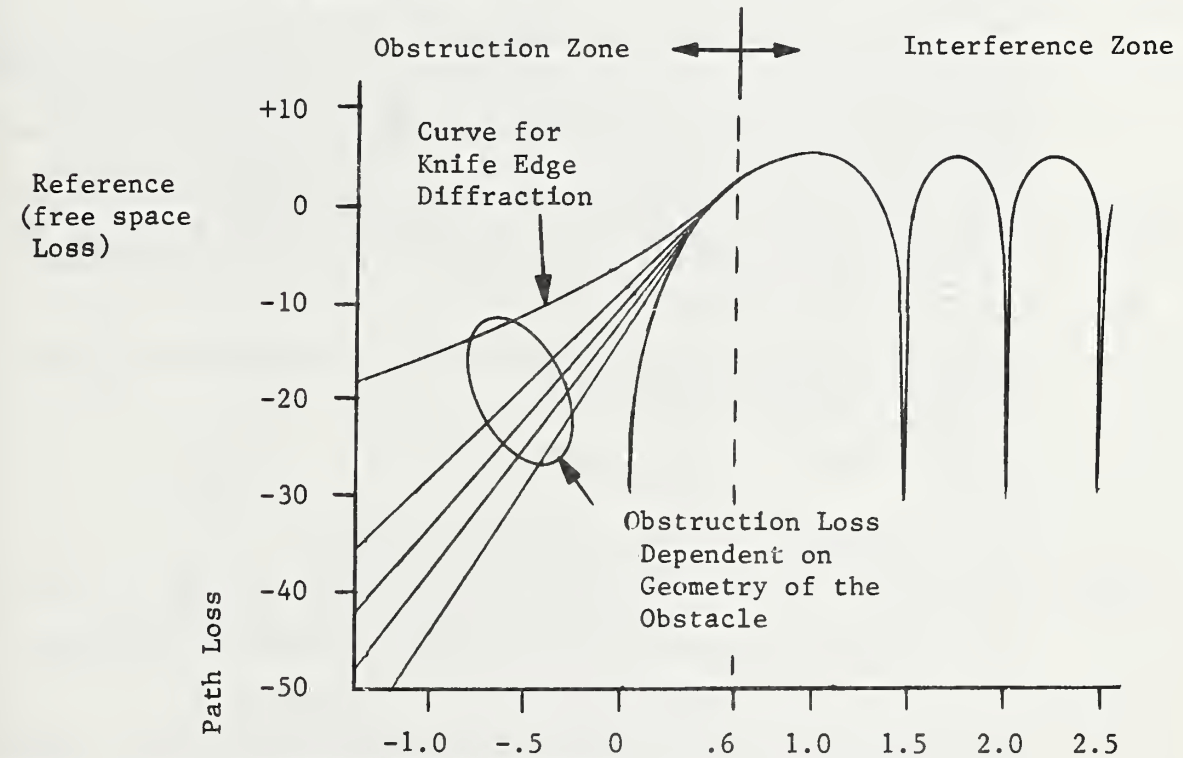
where D_1 = the distance to Site 1 from the point of interest in km

D_2 = the distance to Site 2 from the point of interest in km

The bulge is calculated for the high peaks along the path to determine if they will obstruct the path during low values of K.

Fresnel Zone

As discussed briefly in Section II.F.7, the Fresnel Zone has a direct bearing on the propagation of a path. Figure II-184 shows path propagation as a function of Fresnel Zone clearance over a given object.



$$\text{Ratio} = \frac{\text{path clearance above obstacle}}{\text{first fresnel zone at obstacle}} = \frac{H}{H_F}$$

Figure II-184 Effect on Path Propagation Due to Path Clearance Over a Single Obstacle

It should be noted that the Fresnel Zone is not constant along the path and must be calculated for each point of interest.

At the point where $\frac{H}{H_F} = 0.6$, the path loss is that of free space. The area of the figure where the ratio is less than this is called the "Obstruction Zone" because the signal is obstructed by the obstacle. Ratios greater are the "Interference Zone" since this is the zone where the obstacle can cause reflections that may add to or subtract from the main signal.

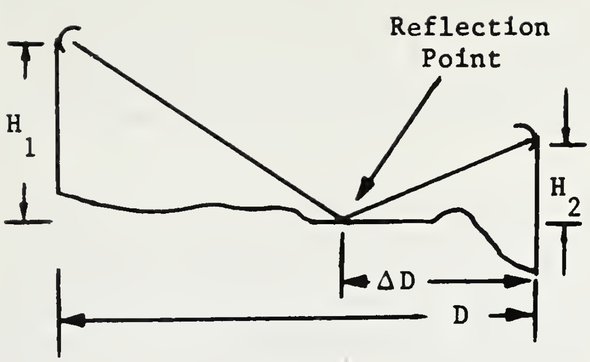
Calculating Reflection Points

The Figure II-184 is known as the Bullington Curve after its inventor, K. Bullington. It applies in the interfering zone to cases where the reflection is at the exact angle needed for the reflected wave to reach the receive antenna. Reflections off a flat surface along the path may or may not reach the receive antenna depending on the angle of the reflecting surface's tilt and the antenna heights at both ends of the path with respect to the reflection height.

Assuming the reflecting surface is flat as in the case of rivers or lakes, the point on the path where the reflection will be intercepted by the receive antenna can be determined using the nomograph in Figure II-185. It should be noted that if the two antennas are at different heights, the reflection point will move as K varies. The designer determines the spot on the path that could cause reflections. The Figure II-185 is used to determine if the selected spot is in the range of distances that will cause interfering reflections.

To calculate the range of places where reflections will take place for various values of K,

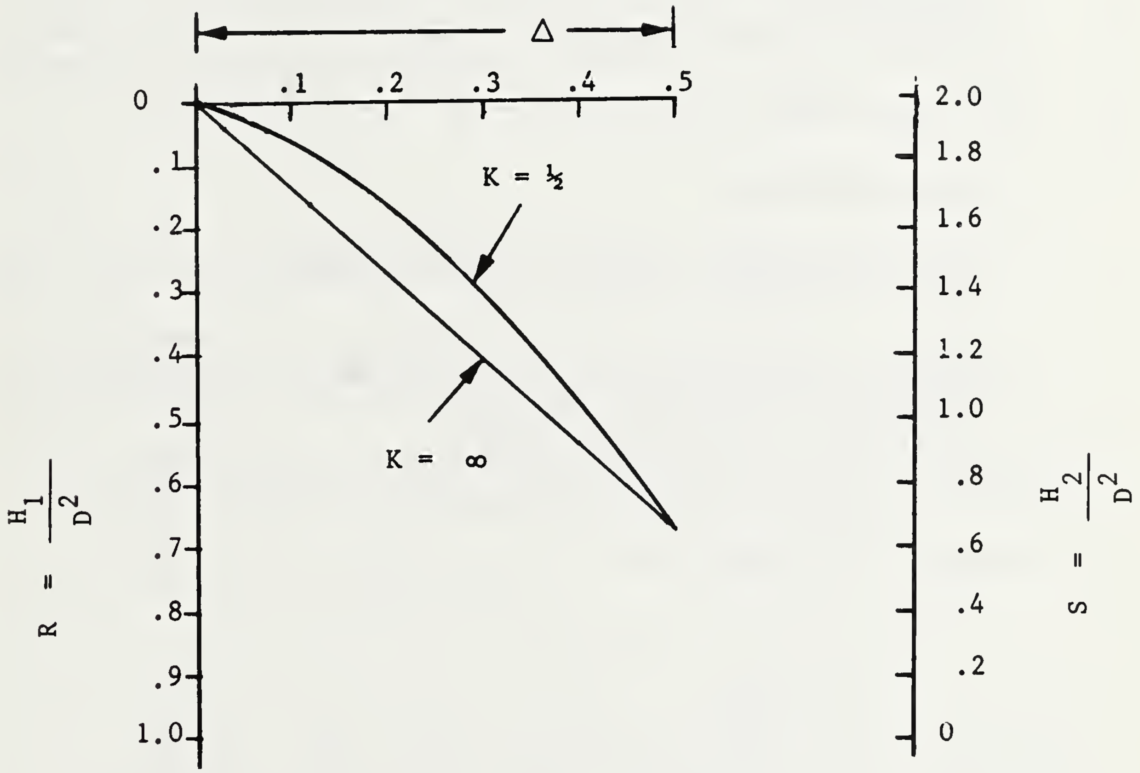
- Calculate $R = \frac{H_1}{D^2}$, plot on R scale
- Calculate $S = \frac{H_2}{D^2}$, plot on R scale
- Draw line from the R scale to the S scale where the marks are
- Mark on this line where it intersects the K values of interest
- From these points read upwards to the Δ scale on the top of the nomograph



H_1 = Antenna 1 height above reflection in meters

H_2 = Antenna 2 height above reflection in meters

D = Path length in kilometers



NOTE: To expand the number of K value curves of the nomograph in Figure II-185, use the reflection formula:

$$S = \left(\frac{1-\Delta}{\Delta}\right)(R) + \frac{(1-\Delta)\ (1-2\Delta)}{3/2K}$$

Figure II-185 Reflection Angle Calculations

The range of ΔD is then plotted on the profile of the path. If this range of ΔD's overlaps the suspected reflection, there is a potential reflection problem. If a potential reflection exists, check the path for blockage. Quite often bodies of water are surrounded by higher terrain which affords sufficient blockage of reflections.

The points of reflection at ΔD will always be closer to the lower of the two antennas at H_1 and H_2. This can be taken advantage of if a reflection problem occurs. By moving either of the antennas up or down, the range of ΔD will shift and can be moved off the potential reflection. On paths with considerable numbers of potential reflection points, it is common to put one antenna close to the ground and the other end up high. This moves the ΔD very close to the lower antenna. The above analysis holds true for only flat reflections parallel to the earth. It does not hold true for tilted or rounded reflections.

Obstruction Loss

Returning to Figure II-184, the Bullington curve, we see the values of $\frac{H}{H_F}$ less than 0.6 are in the obstruction zone. The amount of obstacle attenuation is normally not considered in microwave design unless the path performance is critical. As a guide to obstacle loss, calculate θ in milliradians of Figure II-186 using the following formula:

$$\theta_{mrad} = 17.45 \text{ mrad per degree } (180^{\circ} - (\text{Tan } A + \text{Tan } B))$$

where $A = \frac{d_1}{h_0 - h_1}$

$B = \frac{d_2}{h_0 - h_2}$

and h_1, h_0, h_2, d_1 and d_2 are all in meters or other equal dimensional units.

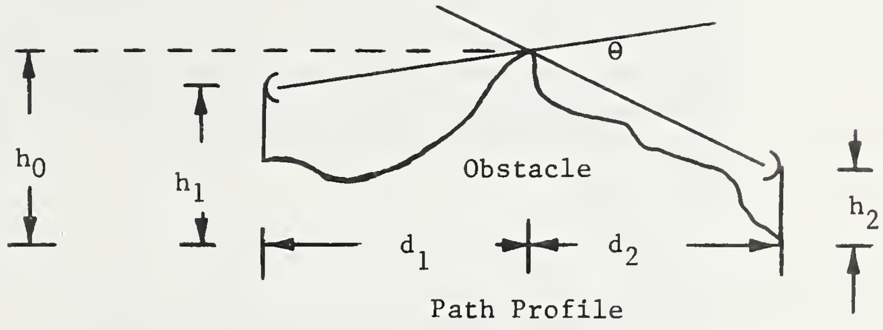


Figure II-186 Scattering Angle θ

The height of the obstacle, h_0, is the height of the obstacle including earth bulge factor for the K value of interest.

The obstacle loss above free space loss can then be estimated by the following formula:

$$L_{obstacle} = (19.2\ \theta^{.371} + 29.5 - 10 \text{ Log } F) \text{ dB}$$

where F is the operating frequency in mHz and θ is in milliradians. This is only an estimate. The loss over sharp obstacles will be less. Over rounder obstacles the loss may be greater.

Arrival Angle Variations

Variations in arrival angle of the signal at the receive antenna are approximately the same as angles A and B for Figure II-186 above. To calculate the variations possible, calculate A (B) for the two extreme values of h_0, remembering that h_0 changes with K. The difference between the two values of angle will be the range of arrival angles. This is a simplistic view and it should be realized that the signal at any given instant consists of many signal wavefronts at various arrival angles. The calculation does, however, give a good approximation of the trend of arrival angles.

3. Climatology

Rain Attenuation

The prime impact of climatology on microwave propagation is normally rain attenuation. The attenuation is a function of both rain intensity and the frequency of propagation. Empirical data has been collected to develop curves for estimating expected rain attenuation. Figure II-187 shows rain attenuation as a function of frequency and rain fall.

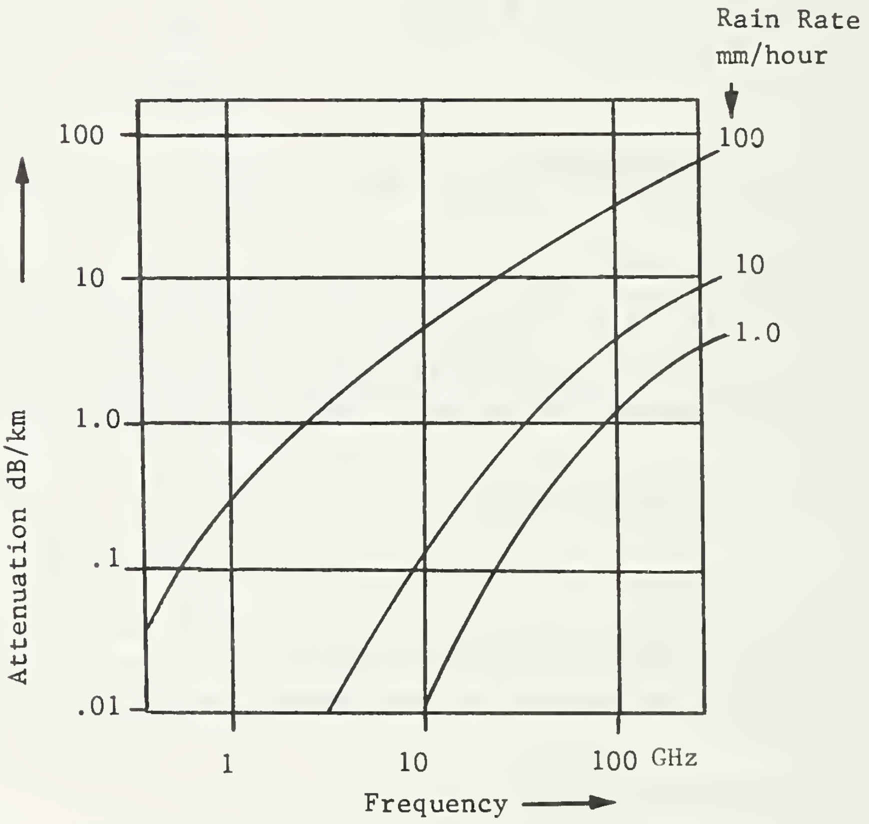


Figure II-187 Rain Attenuation

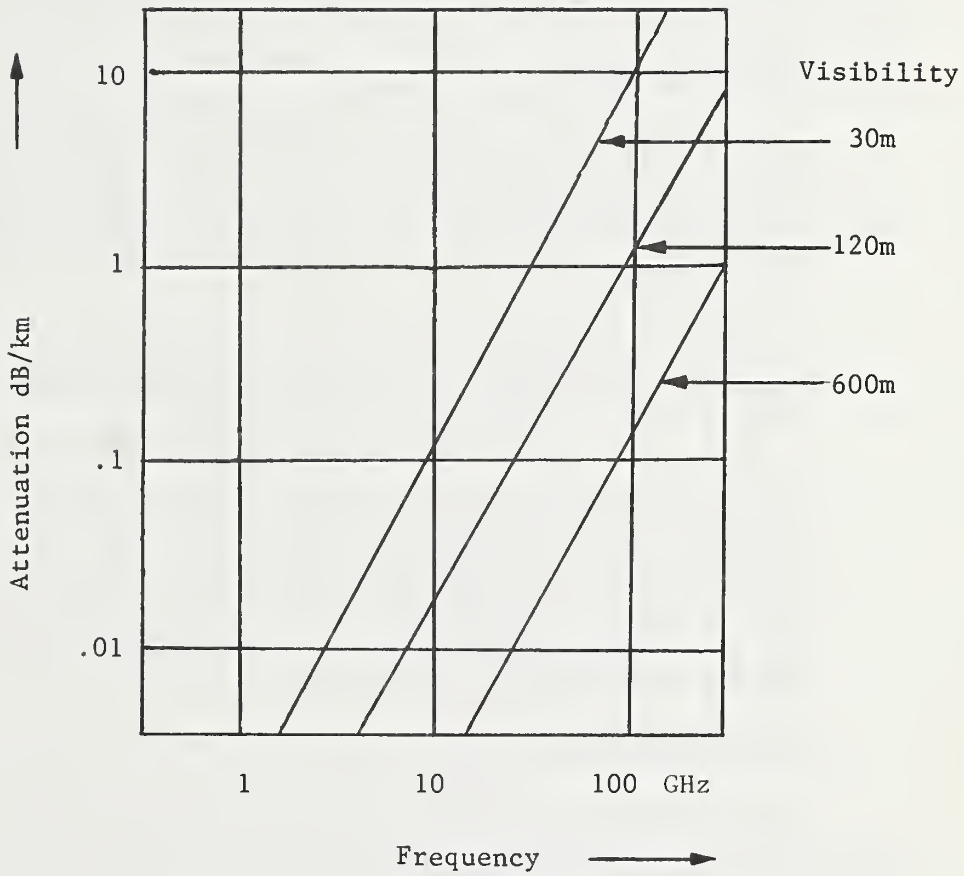


Figure II-188 Fog Attenuation

Different areas of the U.S. will have different rain rates. The worst area is the Mexican Gulf area from Texas to the Florida Keys. Normally, the design of microwave systems does not reflect the rain attenuation directly in system design if the frequency is below 8 GHz.

Fog Attenuation

Fog also affects propagation but not as severely as rain. Figure II-188 shows the attenuation as a function of frequency, fog density and fog visibility.

Ice Accumulation

In cold climates, ice can accumulate on outside surfaces. This can affect the effective size of a tower which increases the amount of wind loading for a given air velocity. In the northern states of the U.S., 1/2 of an inch (127mm) accumulated ice is usually assumed in the mechanical design of towers, guys and antennas.

Accumulated ice has a tendency to break off from the tops of towers. As a result, all horizontal above ground waveguide runs must have ice shields to prevent damage.

In extreme cases of ice buildup a hornfeed could be blocked. To prevent this an RF transparent sheet covers the front of the antenna. It is flexible and shakes off snow and ice when blown in the wind. A less effective but more durable solution is the use of radomes. Radomes are round sturdy plastic covers that fit over the hornfeed and bolt to the inside surface of the parabolic reflector.

Infrared Radiation

Some synthetic materials are sensitive to infrared radiation from the sun. Plastic materials used for radomes and antenna covers often need replacement after 5 years due to IR damage.

Lightning (See end of Section II.G.7.)

4. Frequency Interference Analysis

Interference from other signals causes noise in microwave systems and should be kept to acceptable levels. When designing a microwave system, one is not allowed to interfere with existing systems nor with proposed systems already on file at the FCC. One also ensures that other systems will not interfere with the system under design.

Interference Criteria

Interference noise is additive and the criteria for a single case of interference is based on the assumption that other interferers will exist within the system. The basic criteria is "all sources of interference into a system will cause no more than a 1 dB degradation in noise performance". This is translated into psophometrically weighted picowatts of noise in the most affected voice channel. Long haul systems (systems over 400 km (250 miles)) are allowed 5 pWpO in the most affected voice channel per case of interference from adjacent RF channels. The short haul criteria is 25 pWpO. If RF co-channel interference occurs, the criteria is 50 pWpO since this type of interference is less common. Co-channel means both desired and interfering carriers are the same frequency.

It is accepted practice in the microwave industry to ignore a number of factors that affect the impact of interference. They include:

- Type of information in the voice channels
- Importance of the system
- Nonstandard interference criteria
- Fading of desired signal
- Length of the microwave system other than long haul vs. short haul
- Actual accumulated interference noise in the system
- Characteristics of equipment used other than stability, channel capacity and power output

In adjacent channel interference, the level of interference noise in the voice channel is a function of the characteristics of both the desired and interfering signals. The characteristics of concern are:

- Channel capacity
- Deviation
- Relative power levels (ratio of desired to interfering signal levels)
- Frequency of separation

Adjacent Channel Interference

In adjacent RF carrier interference cases, the most affected channel is normally the top channel in the baseband. Consider the energy spectrums of two FDM-FM signals as in Figure II-188 measured at a receiver's input.

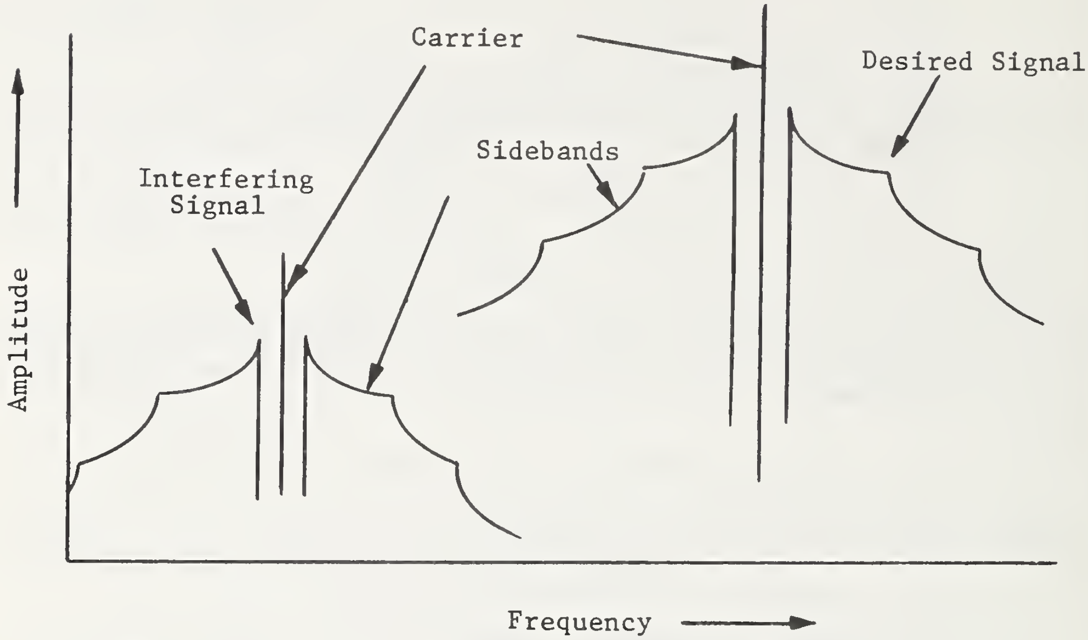


Figure II-188 Interfering FDM-FM Signals

The level of interference noise will be reduced if the amount of spectral overlap is reduced by increasing the frequency separation or decreasing the deviation of the interferer. The level of noise is also decreased if the desired signal deviation is increased or if the power ratio between the desired and undesired signals is increased. Figure II-189 shows some typical values for interference criteria. Equipment frequency stability is noted in Figure II-189. It should be realized that unstable frequencies can drift towards each other which in effect decreases their separation. This, in turn, affects the amount of spectral overlap and interference noise. The frequency band is shown in Figure II-189 and it will be noticed that the criteria is not as severe at the lower bands. This is because the RF equipment filters at the lower frequencies have sharper skirts which helps to reject the interfering signal.

If the separation between the two RF carriers is less than the top frequency of the baseband, the dominant interference in the baseband will be a tone equal in frequency to the carrier separation frequency. It is called carrier beat interference. Interference due to sidebands will normally not be as significant.

The carrier beat tone's amplitude is a function of the separation frequency. The worst case is when the separation is equal to the top baseband frequency. The interfering tone level in a channel due to carrier beat is calculated as a signal to interference ratio:

$$S/I = \text{Carrier to interference ratio} + 20 \text{ Log} \left(\frac{\text{RMS channel deviation}}{\text{Frequency Separation}} \right)$$

where the RMS deviation of the victim channel is used including any emphasis in the target system. The above formula assumes an RF carrier ratio of more than 10 dB.

Carrier Spreading

One way to reduce interference in such a case is to spread the carrier out by using a low frequency baseband tone to strongly deviate the carrier. If the deviation is 140 kHz using a 2 kHz tone then the modulation index is $\frac{140}{2} = 70$. As shown in

Figure II-115, the carrier's energy will be distributed among numerous sidebands. Compared to Figure II-188, the spectrum assumes a new shape as in Figure II-190. The technique is called "carrier spreading".

In some systems the presence of a discrete spreading tone causes problems and alternate low frequency energy is used. Two examples are a band of white noise from 0-4 kHz or a swept tone that is swept back and forth across the 4 kHz bandwidth.

With carrier spreading, if an interfering carrier appears with a separation frequency within the baseband, the carrier is now longer there to beat with it. The result is the interference is spread over the baseband as numerous smaller tones rather than one large one. Spreading occurs slightly due to the modulation of the baseband. It usually does not reduce the energy in the carrier by more than 3 dB. The carrier spreading technique further reduces the carrier by 10-20 dB.

Microwave oscillators often produce their own spreading. This is caused by shot noise in the power supplies, phase jitter etc. The effect is commonly called the "Burble" factor. The burble factor, however, has not been taken into account in the criteria established in Figure II-189. If one of the transmitters or the receiver has a spreading oscillator, the criteria can be realistically relaxed by 5-15 dB if the carrier beat tone otherwise appears in the baseband. The carrier spread improvement occurs if either the desired or the interfering carrier is spread. Spreading both carriers does not provide any significantly greater improvement than spreading just one of the carriers.

Frequency Band in GHz	Carrier Frequency Separation in MHz	Interferer Channel Capacity	Desired Signal Channel Capacity	Frequency Stability in Percent: Interfering Transmitter	Frequency Stability in Percent: Victim System Transmitter	RF Power Ratio, Desired to Interfering, Required for Per Voice Channel Interference Noise Levels of: 5pWpO	RF Power Ratio, Desired to Interfering, Required for Per Voice Channel Interference Noise Levels of: 25pWpO
2	.8	60	24	.001	.001	44	37
				.0003	.0003	42	35
2	.8	24	60	.001	.001	48	41
				.0003	.0003	47	40
2	.8	24	24	.001 or .0003	.001 or .0003	C	0
1.9	5	600	120	.02	.02	39	32
				.002	.002	38	31
6.7	5	600	120	.02	.02	57	50
				.002	.002	31	24
12.5	10	600	300	.02	.02	46	39
				.002	.002	11	4
		300	300	.02	.02	35	28
				.002	.002	>0	>0

Figure II-189 Adjacent Channel Interference Criteria

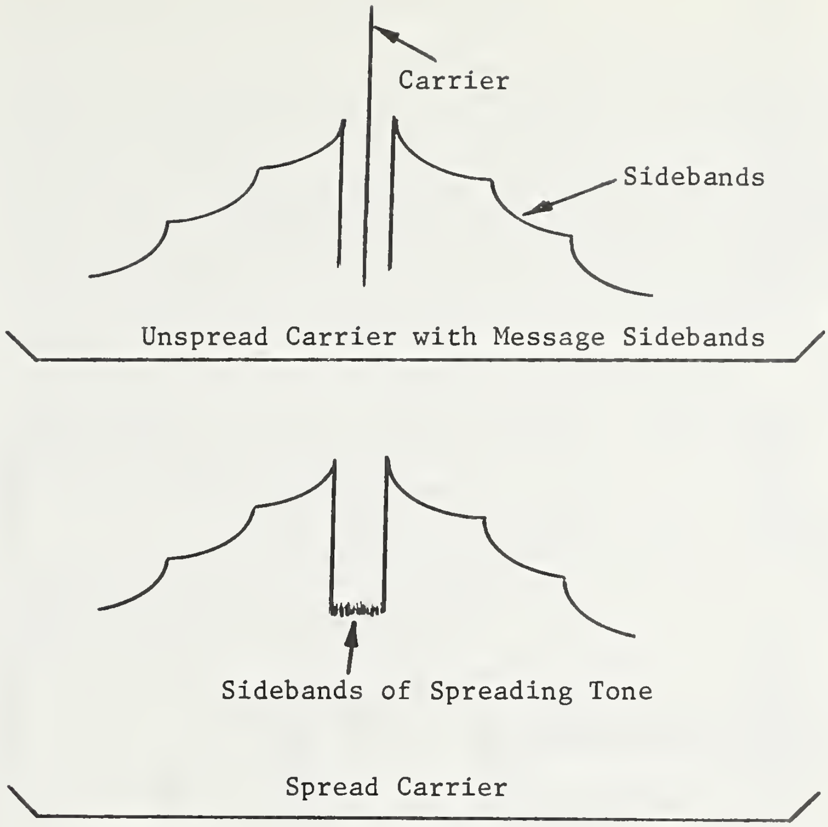


Figure II-190 Spectrum of Spread Carrier

The disadvantage of carrier spreading is the fact that it occupies the very bottom of the baseband which makes the system incapable of transmitting normal video signals. Video signals, it will be remembered, occupy spectrum down almost to DC.

Co-Channel Interference

If the two carriers are operating on the same frequency, the carrier beat tone will be under the lowest message baseband frequency, provided the frequency separation is less than the bottom of the baseband. The bottom of the message baseband may be 12, 60 or 312 kHz depending on channel capacity and multiplex hierarchy structure. The separation frequency will be less than required if both the receiver local oscillator and transmitter output are stable enough in frequency. The stability is normally expressed in percent of RF frequency. Figure II-191 shows the required carrier ratio requirements for different co-channel interference conditions. If the stability is sufficient to prevent carrier beats in the baseband, then sideband overlap becomes the dominant interference cause.

Frequency Band in GHz	Carrier Frequency Separation in MHz	Interferer Channel Capacity	Desired Signal Channel Capacity	Frequency Stability: Interfering Transmitter	Frequency Stability: Victim System Transmitter	RF Power Ratio, Desired to Interfering, Required for Per Voice Channel Interference Noise Levels of 50pWp0 (no burble factor used)
1.9	0	600	600	.002	.006	76
2		60	60	.001	.001	63
		60	24	.001	.001	64
6.7		600	600	.02	.02	89
12.5		1200	1200	.002	.002	55
		300	1200	.002	.002	53
		600	600	.002	.002	56
		600	600	.02	.02	66

Figure II-191 Co-Channel Interference Criteria

Calculation of Interference Levels

The above discussion established the interference criteria. Below is the procedure for calculating a case of interference. The principal objective is to determine the ratio of the desired to interfering carrier; not the actual interference noise in the voice channels. If the ratio meets the criteria established above, no interference is said to occur. If the ratio is less than the criteria, corrective steps are taken. This calculation procedure is much simpler than calculating the actual noise in the voice channels due to an interferer.

The carrier ratio is determined by first calculating the desired signal RF input to the receiver. Then the interfering signal's level at the receiver is calculated and the ratio of the two signals is calculated.

The first type of interference case to be considered is the foreign transmitter interfering with a receiver. Figure II-192 shows an aerial sketch of two microwave paths, one the victim and the other the interferer.

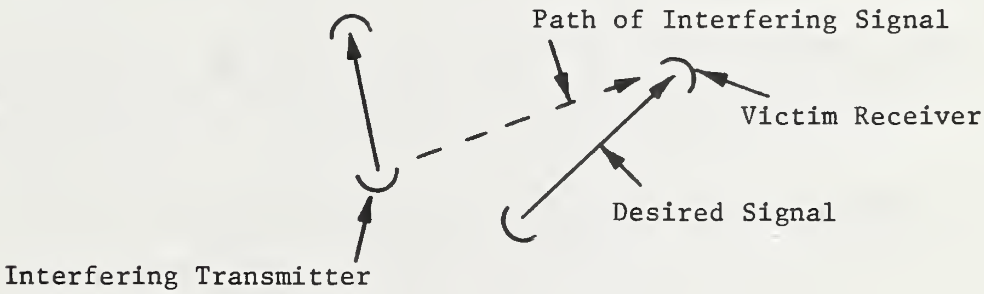


Figure II-192 Intersystem Interference

For simplicity's sake in calculating interference cases, the branching and waveguide losses are all set to zero loss. The desired receive signal is then typically calculated as:

Transmit power 1.0 watt	+30 dBm
Tx Antenna Gain	+42 dB
Rx Antenna Gain	+40 dB
Free space loss	-139 dB
Level at Receiver	-27 dBm

The same calculation is made for the interference path. The significant difference, however, is the fact that the interference path is not in the main beam of the antennas. It is therefore necessary to adjust the transmit and receive antenna gains to reflect this. Figures II-40 and II-44 show typical antenna discrimination patterns. To perform the calculations accurately one must have the actual antenna patterns for the antennas involved. Assume Figure II-40 fits both the receive and transmit antennas for this case. Figure II-193 shows the angles involved.

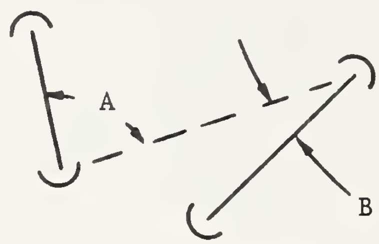


Figure II-193 Interference Antenna Angles

The angles A and B can be measured on a map. $\pm 1^{o}$ is usually sufficiently accurate except at small angles. Assuming A is 100^{o} and B is 20^{o} we can read the discrimination at these angles from Figure II-40. At 100^{o} the discrimination with respect to the main beam is 62 dB. At 20^{o} it is 43 dB.

We now calculate the interference signal level at the victim receiver using an assumed transmit power and typical free space loss.

Transmit power 5 watts	+37 dBm
Tx Antenna Gain 42-62	-20 dB
Rx Antenna Gain 40-43	- 3 dB
Free space loss	-137 dB
Interference Level at Victim Receiver	-123 dBm

The desired signal to interference ratio is therefore:

$$-27 - (-123) = 96 \text{ dB}$$

A more rigorous analysis of an interference case uses mathematical calculations of distances and bearing angles. The geographic coordinates of the four radio sites are determined. The distances are calculated between the normal transmitter and victim receiver to determine the free space loss. The distance between the interfering transmitter and victim receiver is likewise calculated, using the following formula:

$$D \text{ in km} = 111.18 \cos^{-1}\left[\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos(\lambda_2 - \lambda_1)\right]$$

where L_1 = Latitude of site 1

L_2 = Latitude of site 2

λ_1 = Longitude of site 1

λ_2 = Longitude of site 2

A bearing is a direction with respect to true North (0^o). The bearings between sites are calculated. Angles A and B above are calculated by subtracting the bearings from each other.

A bearing from true North is calculated

$$B = \cos^{-1}\left[\frac{\sin L_2 - \sin L_1 \cos R}{\sin R \cos L_1}\right]$$

where $R = \dfrac{D_{km}}{111.18}$

Other possible sources of interfering carriers or signals are:

- Intra system overshoot (one path interfering with another)
- Transmitters within a station interfering with the station's receivers
- Intermodulation products in waveguides. Such products look like foreign signals to a receiver.

Solving Interference Cases

Solutions to frequency interference cases are numerous depending on the flexibility of system design. The following is a list of potential guides to solutions for interference levels out of limits.

- Check interference path profile for blockage
- Change RF channel
- Change frequency band
- Change channel capacity
- Change deviation
- Change transmit power up or down
- Increase RF filtration by the addition of more filters
- Change sites
- Use more discriminating antennas
- Change antenna polarity
- Change pre and deemphasis (nonstandard approach)
- Improve stability of transmitter or receiver
- Add spreading oscillators
- Lower antennas to achieve blockage. This may or may not be feasible depending on path geometry.
- Use different transmission line. This may affect radiated power at the antenna.
- Perform interference calculations including all waveguide and branching losses. This may prove that interference is not actually as great as expected.
- Make actual field measurements in the baseband. The level of interference may not be as severe as calculated.
- Relax criteria. Hardship cases often accept a 10 dB relaxation of criteria. This is generally negotiated if the system under design poses potential interference into other systems.

- For severe cases of co-channel interference it may be possible to not equip the bottom of the baseband with voice channels or equip it with orderwire channels that are not as quality sensitive.

- Add attenuators to transmission lines

- Use higher or lower gain antenna

- In the case of intra station interference use opposite polarities in the antenna. This may provide an additional 30-35 dB of separation.

High-Low Frequency Concept

Frequency plans are all channelized and all users are required to follow the plans as established in FCC Rules and Regulations, Part 94. Also, most of the RF channels are paired. On bi-directional links, go and return frequencies are always selected in pairs.

Each frequency band is divided into a low half and a high half. Each pair has one frequency selected from both halves. This provides sufficient separation between transmit and receive frequencies. All transmit frequencies from a given station are either low or high. In rare circumstances they will be mixed. However, this reduces the number of RF channels available at the station. Receivers and transmitters at a given station need greater separation in frequency than the separation between receivers alone or transmitters alone. Thus, more of the available spectrum is used for guard bands rather than transmission. When a station mixes high and low frequencies it is called a "bucking" station.

The concept of high-low normally applies to a given station as well as nearby stations. In fact, a given city is usually all low or all high on a given frequency band. This greatly improves the number of non-interfering channels that can be used in the one city. When laying out a microwave system, the designer determines whether the terminal stations are located in high or low cities. If a microwave system connects two low cities, the number of microwave paths between the cities must be even or a "bucking" station is required. If two interconnected cities are opposite (one is high, the other low) then an odd number of paths is required. This should be known to the system designer when he begins to lay out the system. The system will then be layed out with every other station being high and alternate stations low. An alternate solution to the "bucking" station problem is to break up the high-low sequence of the paths in the system by using a different frequency band on one of the paths in the system.

When examining potential interference one can ignore the case of a high station transmitting into another high station since no high station has receivers at high frequencies. The reverse, of course, is also true. This essentially means one needs to coordinate with only half the stations in the band.

5. Noise Contributions

a. Noise Figure

Noise figure is a figure of merit which indicates the noise contribution of a device(s) carrying signals. It is commonly used to describe the noise contribution of an RF receiver to the RF signal passing through it. The noise figure (NF) of a device(s) can be defined as the arithmetic ratio:

$$NF = \frac{S/N_{in}}{S/N_{out}}$$

$$NF = \frac{P_{si}/P_{ni}}{P_{so}/P_{no}}$$

where P_{si} = power of signal in

P_{ni} = power of noise in

P_{so} = power of signal out

P_{no} = power of noise out

Now, let us derive a method for calculating the noise figure of a circuit composed of several devices whose individual NF's are known.

The derivation is intended to show that a device has an effective noise temperature T_e which is used to calculate the overall T_e of the circuit. The NF of the overall circuit is then calculated using the formula:

$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \frac{NF_n - 1}{G_1 G_2 \ldots G_{n-1}}$$

From discussions in Section II.F.8 on noise we know

$$P_{noise} = KTB$$

and

$$\frac{P_{so}}{P_{si}} = G \text{ (gain of device)}$$

$$NF = \frac{P_{si}/KT_iB}{P_{so}/P_{no}}$$

$$= \frac{P_{no}}{KT_iB} \cdot \frac{P_{si}}{P_{so}}$$

$$= \frac{P_{no}}{GKT_iB}$$

Therefore,

$$P_{no} = (NF)\ GKT_iB$$

Also,

$$P_{no} = P_{ni}G + GKT_eB$$

$$= KT_iBG + GKT_eB$$

$$= GKB\ (T_i + T_e)$$

where T_i is the noise temperature of the input source; so to speak, the temperature of a device that will produce P_{no} amount of noise.

Therefore,

$$P_{no} = (NF)\ GKT_iB = GKB\ (T_i + T_e)$$

and

$$NFT_i = T_i + T_e$$

$$NF = 1 + \frac{T_e}{T_i}$$

$$T_e = T_o \; (NF-1)$$

$$NF-1 = \frac{T_e}{T_o}$$

Assume a 2 device circuit as shown in Figure II-194 in which T_t is the effective temperature of the two devices in tandem

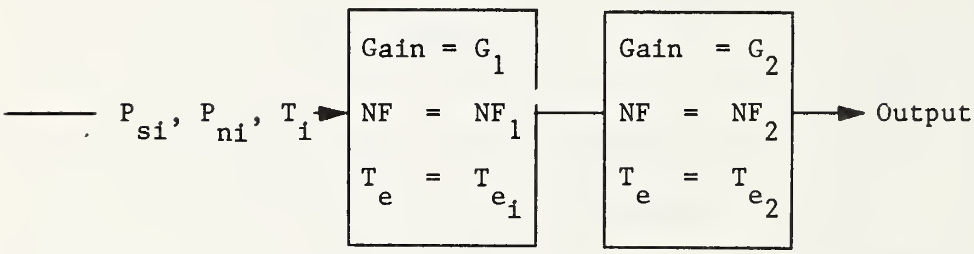


Figure II-194 Tandem Amplifiers

The $P_{so} = (G_1 + G_2) \; P_{si}$

The Noise Contributions are:

$$= (G_1)(G_2) \; KT_iB$$

$$+ \; (G_1)(G_2) \; KT_{e_1} B$$

$$+ \; (G_2) \; KT_{e_2} B$$

$$= KG_2 \; (G_1T_i + G_1 \; T_{e_1} + T_{e_2}) \; B$$

$$= KG_2 (G_1 T_{e_1} + T_{e_2}) B \text{ (Noise Due Devices)}$$

$$+ KG_2 G_1 T_i B \text{ (Noise due to amplified } P_{ni})$$

Since the noise due to the entire circuit is $KT_t B (G_1 G_2)$, then

$$KT_t B (G_1 G_2) = KG_2 (G_1 T_{e_1} + T_{e_2}) B$$

$$T_t = \frac{KG_2 (G_1 T_{e_1} + T_{e_2}) B}{KB (G_1 G_2)}$$

$$T_t = T_{e_1} + \frac{T_{e_2}}{G_1}$$

This says the importance of the noise temperature of the second circuit is reduced by the gain of the first. This applies in radio systems where the noise figure of the receiver front end is the most important.

Dividing both sides of the above equation by T_i and using

$$NF-1 = \frac{T_e}{T_i}$$

we arrive at

$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1}$$

The same analysis can be shown for

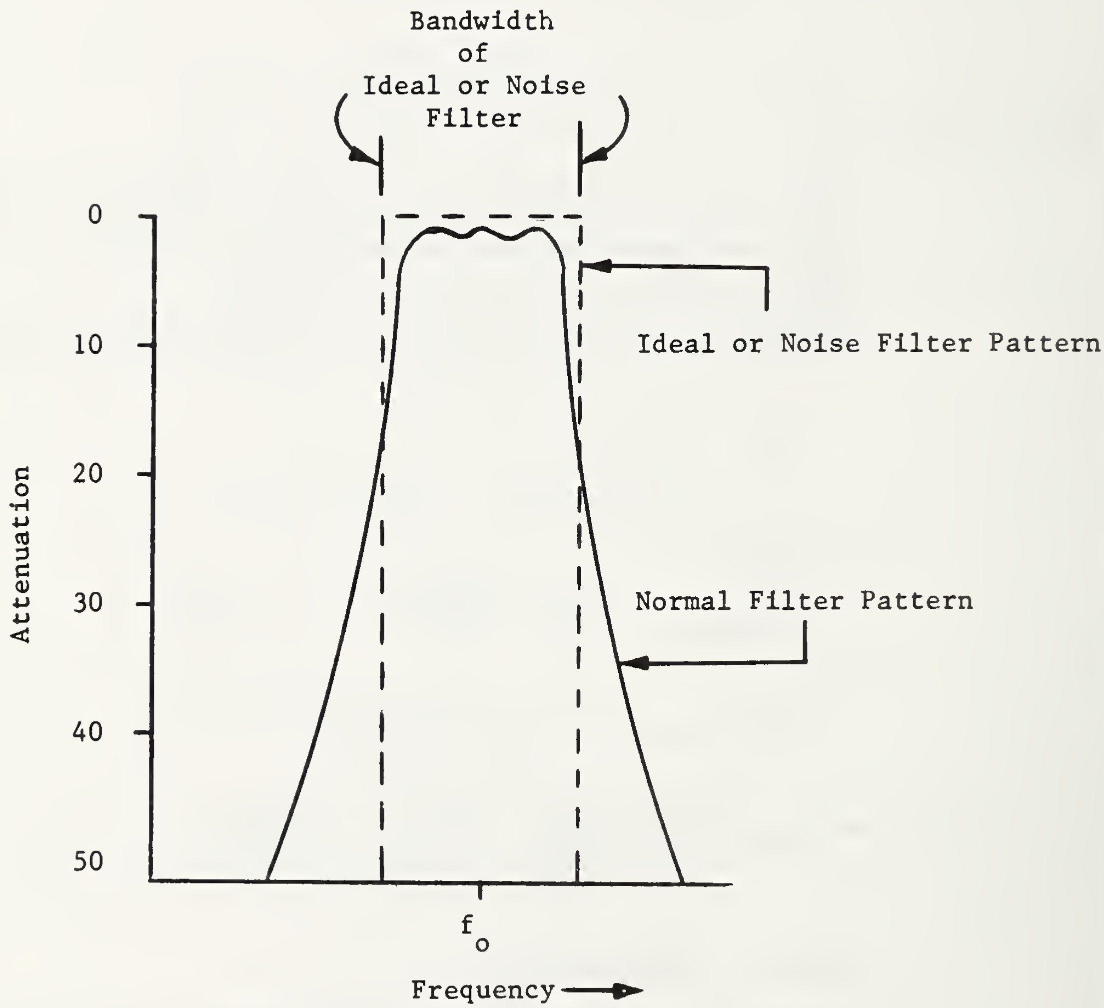
$$NF_{total} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \frac{NF_n - 1}{G_1 G_2 \cdots G_{n-1}}$$

b. Carrier to Noise Ratio

The carrier to noise ratio in an FM system is the ratio of the carrier signal level to the noise in the bandwidth of the device through which it passes. More exactly it is the ratio of the carrier to the integrated noise across the bandwidth of the device

$$\text{Noise} = \int_0^{\infty} (K)(T) \left[F\ (B)\right] dB$$

where F(B) is a function defining the input filter shape of the device as a function of frequency. Since F(B) is awkward to deal with, devices are assigned an ideal or noise bandwidth which is a bandwidth with infinitely sharp cutoff at the band edges. See Figure II-195.



The total area (power) under the two curves is the same.

Figure II-195 Ideal Bandwidth

The ideal filter has a perfectly flat frequency response across the ideal bandwidth and no response outside this spectrum.

Carrier to noise (CNR) calculations normally use the ideal or noise bandwidth figure in most applications.

The carrier to noise figure can also be measured after the RF Mixer of an FM receiver. As discussed above

P_{si} = carrier

P_{so} = (Mixer gain) (P_{si})

P_{ni} = KT_iB (-174 dBm per Hz at room temperature)

P_{no} = ($P_{ni}G$) (NF)

Carrier to noise after the mixer therefore equals

$$= \frac{P_{so}}{P_{no}}$$

$$= \frac{GP_{si}}{GP_{ni}NF}$$

$$= \frac{CNR_{in}}{NF}$$

In logarithmic terms

$$= CNR_{in} - NF$$

In FM receivers, the mixer gain is less than unity. Therefore the noise figure of the second device in tandem with the mixer must have a very good noise figure since

$$NF_{total} = NF_{mixer} + \frac{NF_2 - 1}{G_1}$$

G_1 may be .3. The second stage, usually the IF pre amp, must have an NF as close to 1 as possible.

Typically, the mixer has an NF of 5, a gain of .3; the IF preamp has a noise figure of 2 and a gain of 10,000.

$$NF_{total} = 5 + \frac{2-1}{.3}$$

$$= 6.3$$

in Logarithmic terms

$$= 8.0 \text{ dB}$$

The CNR at the IF preamp in logarithmic terms is therefore CNR_{in} -8.0 dB. The gain of the IF preamp is so high, the noise figures of following circuits or amplifiers is not important. To summarize, the CNR at the IF preamp output in FM systems is normally the dominant thermal noise factor.

c. <u>FM Noise</u>

As discussed in Section II.F.4.c, noise in an FM system is a function of the measurement position in the baseband.

Wideband noise in an FM system is given as the following arithmetic ratio:

$$S/N_o = \frac{3}{2} \frac{(\Delta F)^2 B_{if}}{(F_u^3 - F_l^3)} \left(\frac{C}{N} \right)$$

where S = baseband signal level out

N_o = baseband noise out

ΔF = peak deviation of carrier

B_{if} = ideal IF bandwidth

C = carrier level input

N_i = input noise

F_u = upper frequency limit of baseband measurement

F_l = lower frequency limit of baseband measurement

The above formula is the general form of FM noise and applies directly to wideband signals in the baseband such as wideband data or TV. In telephony, however, it is desired normally to measure the noise over a narrow 4 kHz voice channel bandwidth within the baseband. The above formula reduces by factoring $F_u^3 - F_l^3$.

$$F_u^3 - F_l^3 = (F_u - F_l)(F_u^2 + F_u F_l + F_l^2)$$

since $F_u \cong F_l$ for a narrow voice channel in the baseband,

$$F_u^3 - F_l^3 = (F_u - F_l)(3F_u^2)$$

$$= 3\,(F_{chn})^2\,(B_{chn})$$

where F_{chn} = frequency of the channel in the baseband and

$B_{chn} = (F_u - F_l)$ = bandwidth of the channel.

These two factors are applied to the general case replacing $(F_u^3 - F_l^3)$ producing

$$\text{Signal to FM}_{\text{noise in a channel}} = \frac{3}{2}\,\frac{(\Delta F)^2 B_{if}}{(F_u^3 - F_l^3)}\left(\frac{C}{N}\right)$$

$$= \frac{3}{2}\,\frac{(\Delta F)^2\,B_{if}}{B_{chn}^3 (F_{chn})^2}\left(\frac{C}{N}\right)$$

In logarithmic terms this is

$$\text{channel S/N} = \frac{C}{N} + 10\,\text{Log}\left(\frac{B_{if}}{2\,B_{chn}}\right) + 20\,\text{Log}\left(\frac{\Delta F}{F_{chn}}\right)$$

This formula is modified to account for receiver noise figure, pre- and deemphasis and noise weighting of normal channel noise measurements.

$$S/N = C/N - NF + 10 \text{ Log}\left(\frac{B_{if}}{2\, B_{chn}}\right) + 20 \text{ Log}\left(\frac{\Delta F}{F_{chn}}\right) + \text{Preemph.} + \text{Wghting.}$$

A typical case is that of a 1260 channel system. The question is, what is the signal to thermal noise ratio due to FM radio noise in channel 8, Group 2, Supergroup 10.

Other given factors are:

Carrier = -33.5 dBm

B_{if} = 20 mHz

ΔF = 140 kHz peak deviation

B_{chn} = 3.1 kHz (300 Hz - 3400 Hz)

NF = 8 dB

C-Message

Weighting Factor = 2.0 dB

The carrier to noise ratio is

$$C/N = -33.5 \text{ dBm} - \left[\left(\frac{-174 \text{ dBm}}{\text{Hz}}\right) + 10 \text{ Log}(20 \times 10^6 \text{ Hz})\right]$$

$$= -33.5 + 101$$

$$= 67.5 \text{ dB}$$

Refering to the multiplex plan of Section II.G.8 we determine F_{chn}. SGP 10 occupies the spectrum 2300-2540 kHz. GP 2 occupies frequencies from 360-408 kHz in the SGP, which is 2444-2492 kHz in the baseband. Channel 8 is 76-80 kHz in the GP which is 2472-2476 kHz in the baseband. F_{chn} is therefore the midchannel point or 2474 kHz.

The Preemphasis is calculated as given in Section II.F.4.c.

$$\text{preemphasis} = \left(8 \frac{F_{chn}}{F_{max}} - 4\right) \text{ dB}$$

$$= 8\left(\frac{2474}{5564}\right) -4$$

$$= -.4$$

These factors are now applied to the FM noise formula

$$S/N\ (RMS) = 67.5 - 8 + 10 \text{ Log}\left[\frac{20,000 \text{ kHz}}{2(3.1 \text{ kHz})}\right] + 20 \text{ Log } \left(\frac{140}{2474}\right) - .4 + 2.0$$

$$= 67.5 - 8 + 35.1 - 24.9 - .4 + 2.0$$

$$= 71.3 \text{ dB}$$

$$= 18.7 \text{ dBrnCo}$$

or

$$= 69.3 \text{ dB unweighted signal to noise ratio}$$

d. Intermodulation Distortion Noise

Intermodulation Distortion Noise or Intermodulation (IM) Noise was introduced in Section II.F.8.c. IM noise is always a function of deviation in an FM system. Therefore, Bucket Curves are the major tool for measuring IM noise.

IM has a number of sources in FM systems. Among them are poorly designed or tuned filters, improper deviation, baseband overloads, AM to PM conversion in the limiters and elsewhere, amplifier clipping, multipath and echoes. This section concentrates on delay and linearity responses of FM systems and their impact on IM noise.

As shown in Figures II-113 and II-114, FM systems must have relatively flat delay and gain (linearity) responses in order to achieve good noise response. The delay or gain distortion of the signal at a given point can be as severe as possible without causing noise provided the distortion is corrected before limiting and demodulation take place.

Therefore, when we talk about delay and gain distortion as a source of IM noise, we talk of the transmission system from modulator to receive limiter as a single source of distortion noise. The individual components such as antennas, filters, mixers and IF repeaters in the chain do not individually contribute IM noise, they contribute only to the delay and gain distortion. IM noise is a function of only the composite delay and gain distortion.

In describing the delay and gain distortion, the term "order" of distortion is used. The orders are the same for both delay and gain. They describe the shape of the curve.

1st = linear slope tilt

2nd = parabolic curve $\approx x^2$

3rd = cubic curve $\approx x^3$

4th = quadratic curve $\approx x^4$

5th = $\approx x^5$

=

=

nth = $\approx x^n$

Pictorially, these can be represented as shown in Figure II-196.

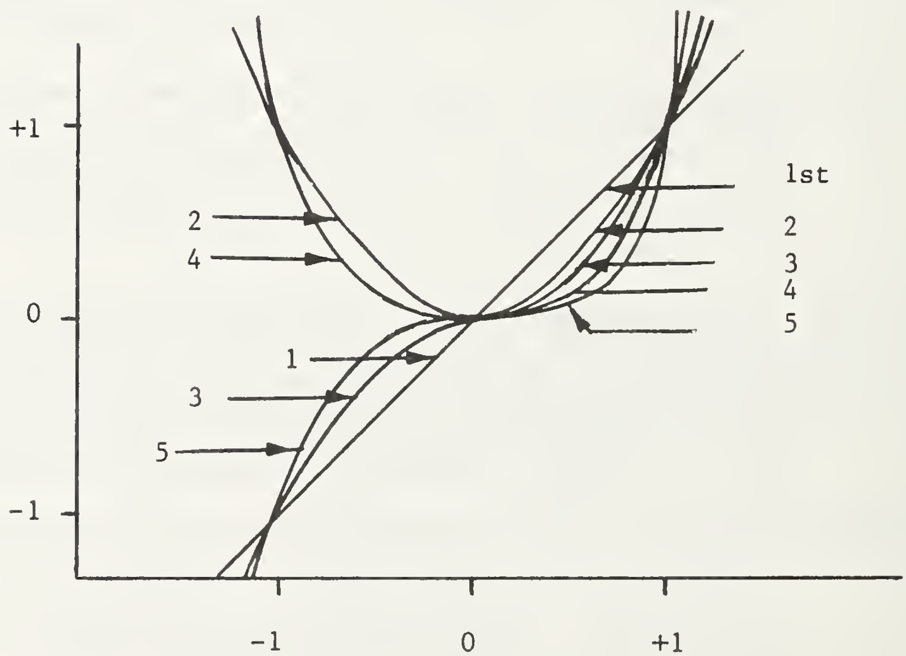


Figure II-196 Curves of Various Orders of Distortion

Generally speaking, the higher the order of distortion, the steeper the Bucket Curve in overload condition. See Figure II-197.

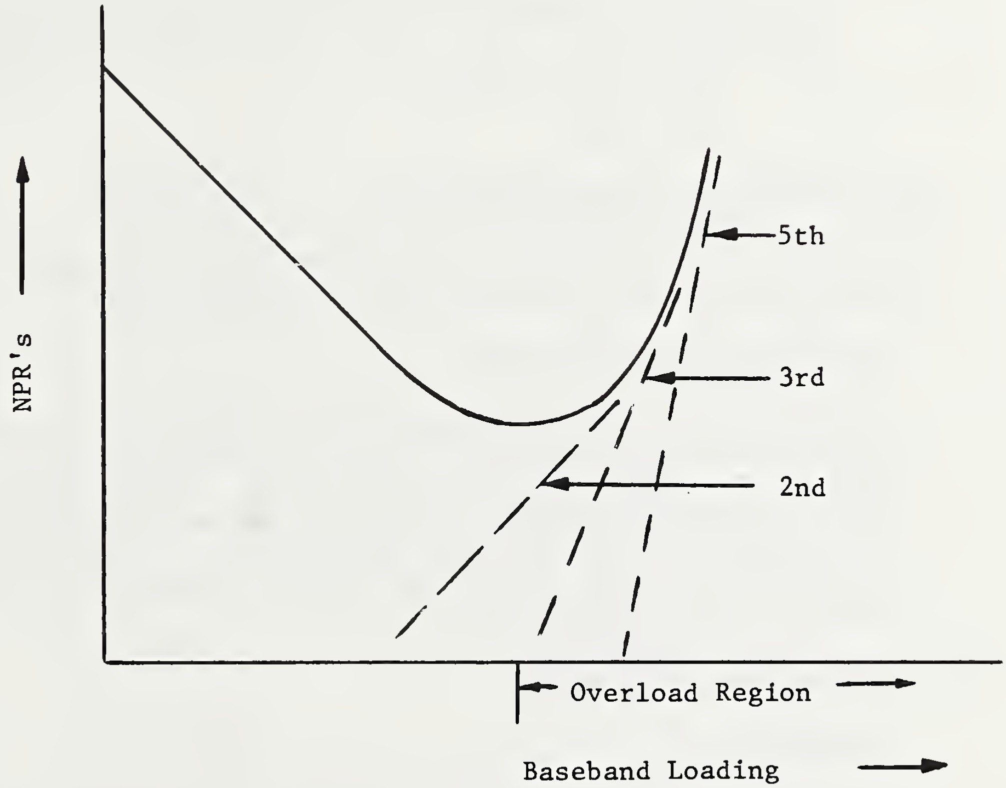


Figure II-197 IM Noise Asymptotes for Various Orders of Distortion

The dominant order of distortion at a given point on the curve can be determined by the slope of the curve. If the slope is a 4 dB increase in noise for a 1 dB increase in loading, the dominant order is the 5th.

$$\text{Order} = \text{Slope} + 1$$

The procedure for measuring NPR's is discussed in Section II.F.8.c. NPR values can be converted into other noise measurements as follows:

$$S/N = NPR + 10 \operatorname{Log}_{10}\left(\frac{N_{bw}}{3.1 \text{ kHz}}\right) - NLR$$

where N_{bw} = bandwidth of the loading noise = bandwidth of the baseband

NLR = noise loading rating

= i.e. $-15 + 10 \text{ Log}_{10}(\text{No. of Channels})$

In a 1200 channel system with an NPR of 55 dB the S/N is

$$S/N = 55 + 10 \text{ Log}_{10}\left(\frac{5564 - 312}{3.1}\right) - (-15 + 10 \text{ Log } 1200)$$

$$= 55 + 32.3 - 15.8$$

$$= 71.5 \text{ dB}$$

6. Basic Transmission System Performance

This section covers the basic analytic techniques to analyze the static and dynamic performance of a microwave path.

a. Determination of Path Loss

The fundamental calculation made for analysis of a microwave path is the unfaded net loss from transmitter to receiver. The basic technique is to add up all the gains and losses through the system. Figure II-198 shows a typical calculation. It is noted that calculation of path loss is not affected by such factors as emphasis, bandwidth, channel capacity, noise figure etc.

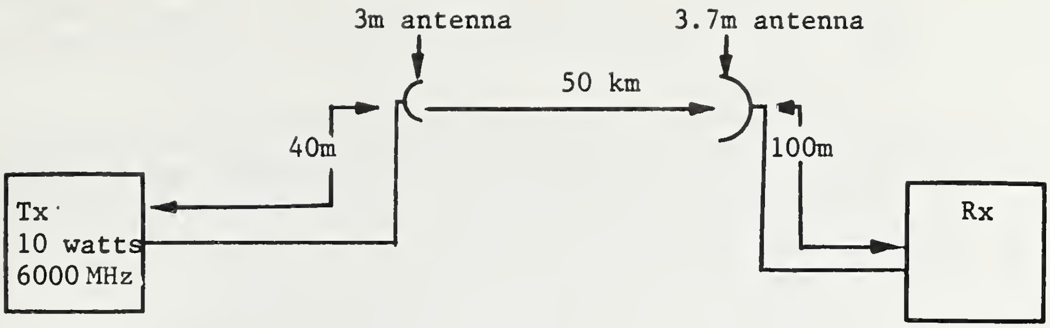
b. RF Equipment Performance

Transmitters

The primary transmitter characteristics of concern to path performance are:

- Deviation
- Idle noise
- Delay and linearity characteristics
- Other sources of intermodulation
- Filtration of out of band energy

The deviation is standardized for each system. The most common method of measuring deviation is to first remove all modulation and then insert a baseband tone that will result in a deviation index of 2.4. The spectrum of the trans-



Item	Description	Gain	Loss
1	Transmitter 10 watts	+40 dBm	
2	Tx Filter		.8 dB
3	Tx Branching		2.1
4	Tx Waveguide		2.2
5	Tx Antenna	42.6 dB	
6	Free Space Path Loss		142.0
7	Rx Antenna	44.4 dB	
8	Rx Waveguide		5.5
9	Rx Branching		3.2
10	Rx Filter		.8
	TOTALS	127 dBm	156.6 dB

Rx Level = 127 dBm - 156.6 dB
= -29.6 dBm

Figure II-198 Calculation of Unfaded Receive Level mitter or modulator output is then examined for the level of the carrier. As observed on the Bessel function diagram in Figure II-115, the carrier disappears (goes to zero) when the mod index equals 2.4 and all the energy appears in the sidebands. This is called carrier dropout.

Any frequency in the baseband will cause a peak deviation of 2.4 if the level is high enough. Select any frequency in the middle of the baseband. Insert the tone in the baseband and set its level above or below the normal baseband test tone level by the amount

$$\Delta \text{ level} = 20 \text{ Log} \left(\frac{(\text{tone frequency})(2.4)}{\sqrt{2}\ (\text{RMS chn deviation})} \right)$$

If Δ level is negative, reduce the tone level; if positive raise it.

Now observe the carrier level. Adjust the modulation level until the carrier level drops to zero. Care should be taken to avoid other carrier dropouts which can occur at higher mod indexes such as 5.5, 8.7 and 11.8.

Idle noise in a transmitter should be ~85 dB below test tone. It is normally measured indirectly. To measure idle noise, remove all modulation and couple part of the RF output into a receiver. Set the RF level into the receive high enough to saturate the receiver. Measure the noise in the baseband of the receiver. If the transmitter is generating excessive noise, it will show up in the receiver.

Delay and linearity characteristics of a transmitter are measured against a calibrated receiver. The measurement is made from transmitter IF input to a calibrated receiver's IF output. The delay and linearity measurements can also be made from baseband to baseband, IF to baseband and baseband to IF. The exact criteria for delay and linearity are a function of channel capacity and deviation. Manufacturers specify the characteristics for their own equipment to meet noise performance.

Under normal circumstances the following limits are used for a transmitter receive combination across a path.

Channel Capacity	120	900	1200	1800
Delay in nanoseconds	3	2	±10	±12

Frequency Range in MHz ±2

Linearity in dB	.5	.3	.2	.2
Frequency Range in MHz	±2	±8	±10	±12

Sources of IM may or may not be detectable directly. Once the delay and linearity are within specifications, NPR tests can be run to measure the IM of the system. If the delay and linearity are acceptable but IM noise is not, other sources should be suspect. Common sources of IM noise that do not show up in delay and linearity tests are AM-PM conversion and amplifier clipping.

Filtration of out of band energy should be 60 dB below the unmodulated carrier. In cases where this is not sufficient, additional filtration may be required.

Receivers

The primary receiver characteristics of concern to path performance are:

- Deviation sensitivity
- Noise figure
- Noise quieting performance
- Saturation noise
- Delay and linearity
- Other sources of intermodulation
- Rejection of out of band signals

Deviation sensitivity is a measure of the receiver discriminator's ability to change voltage output with changes in input frequency. It is measured in volts per megahertz. The output of the discriminator is amplified to meet the baseband level requirements.

Noise figures in microwave systems are normally specified as 7-10 dB. Receivers using an RF amplifier ahead of the mixer can achieve 2-5 dB noise figures with better performance at the lower frequency bands.

Noise quieting performance is a measure of the receiver's ability to reduce FM noise one dB for each dB increase in receive carrier input assuming the carrier is above the FM threshold of the receiver and below the saturation level. See Figure II-199.

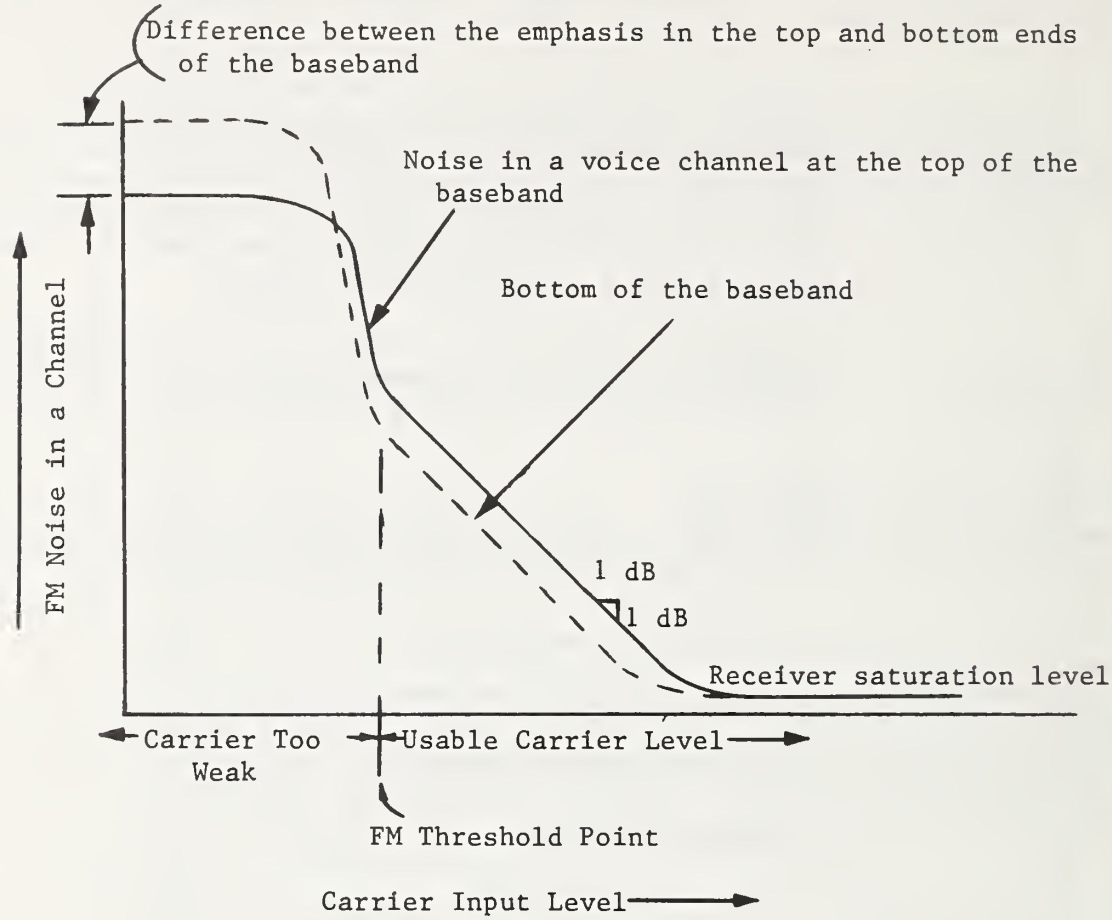


Figure II-199 Receiver Quieting Curve

If the noise figure is improved, the whole quieting curve moves to the left. Worsening of the noise figure moves the curve to the right. Increasing the deviation moves the curve down. Decreasing moves it up.

The threshold carrier level is calculated as

$$C_{th} = 10 \text{ Log}_{10} KTB_{if} + NF + 10 \text{ dB}$$

The voice channel noise at that point is calculated using the FM noise formula in Section II.H.4.c.

The saturation noise is intrinsic noise of the system that is independent of carrier level. Baseband amplifiers and discriminators contribute to this level. It is typically -70 to -90 dBm0.

Delay and linearity characteristics of receivers are usually stated in conjunction with an associated transmitter. The receiver is usually equipped with delay and linearity equalizers to compensate for distortions in the system. They are called "mop up" equalizers.

Other sources of intermodulation noise such as limiters are analyzed using NPR tests. The NPR limits of a radio system are dependent on the non-faded noise requirements of the system. NPR values are generally between 50 and 60 dB in wideband microwave systems.

Receivers should be able to reject out of band signals by 60 dB 70 mHz from the carrier. Signals that do reach the mixer around 70 mHz off the carrier mix with the desired carrier to produce erroneous ~70 mHz IF signals. These unwanted by-products produce noise in the baseband as a foreign interfering signal.

c. Microwave Fading Analysis

Fading occurs to some extent in all microwave paths. Section II.F.7 introduced the various types of fading common in microwave systems.

In this section only down fading is considered. Fading of a microwave signal is determined by its fade depth and duration. The depth of a fade is the amount the signal drops below the normal level or the level when the path loss is equal to the free space loss. Nominally, fading is 20 dB or more for around 1% of the time. The deeper the fade, the less the time spent at that depth. Microwave systems are designed to tolerate a considerable amount of fading before the noise in the system becomes unacceptable.

Figure II-200 shows the level of fading common in microwave systems.

When describing an amount of fading, the depth does not fully describe the fading. Duration must also be stated. In Figure II-200, the fading noted at 40 dB is for a duration of .01%. This means fading of 40 dB or greater will probably occur for 0.01% of the time. Individual fades may last for any length of time. The long term probability is .01%.

In communications systems, the level of noise or depth of fading is a function of time. It is impossible to build systems that are 100% reliable. Therefore, the level of degradation tolerated is a function of duration. A system can be designed to tolerate a 40 dB fade. The same system may not be able to meet specifications if the signal is faded by 40 dB 50% of the time, only 0.01% of the time.

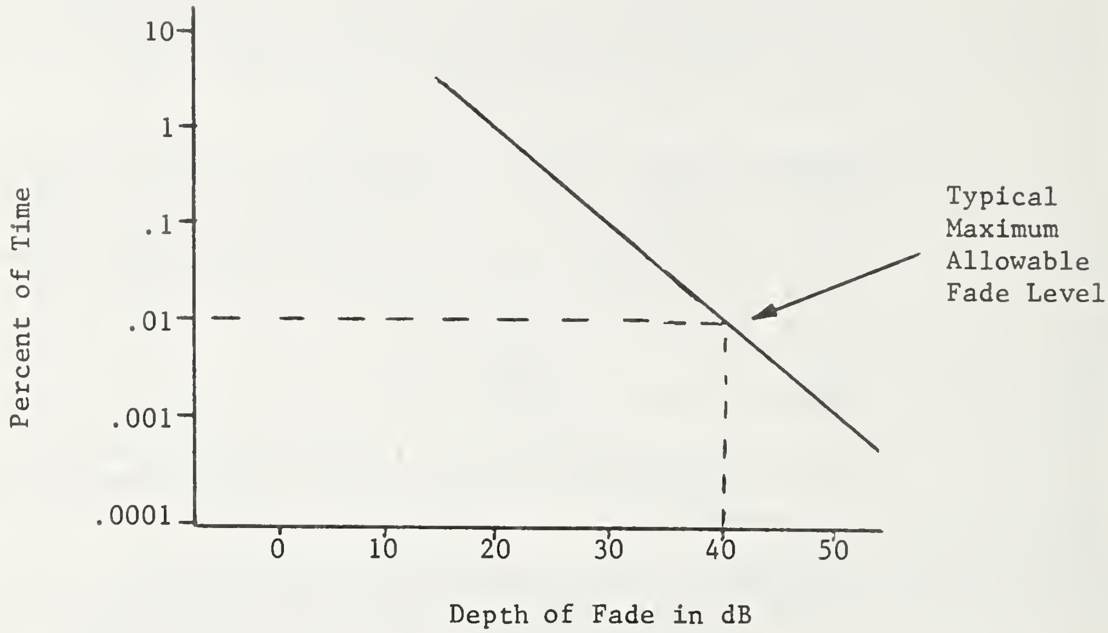


Figure II-200 Typical Fading on a Microwave Path

The difference between the worst acceptable fade level and the normal level is called the "Fade Margin". Fade margins are normally 30-45 dB. A common myth states that all paths in a system should have a certain fade margin. This is simply untrue unless every path in the system is identical in every way which does not happen in real systems. Fading objectives are an indirect result of noise and error rate requirements. Such requirements are based on end-to-end performance, not on the performance of individual paths in the system. Once the end-to-end performance requirements are established, the amount of tolerable noise is distributed among the paths involved. The fade margins of short paths can tolerably be much less than long paths since the probability of fading tends to be less on short paths.

The fade margin can be poor on one path provided the overall system performs satisfactorily. Systems are designed to meet noise objectives, not fade margin objectives.

Microwave fading is a function of path geometry, path length, frequency and the type of climate as it affects refractivity. The yearly fading probability or probability that fading of a given depth, F, will occur is

$$P = \frac{10^{-6}\ fD^{3}\ 10^{(-F/10)}}{4.2}$$

where f is in gHz, D is km and F in dB. The value P can vary an order of magnitude depending on climate. Dry mountain climate is about 10 times better; rainy coastal areas, 10 times worse.

To estimate the worst hourly fade probability, multiply the yearly probability by 4 for average terrain, 2 for dry mountain climate and 8 for wet coastal areas.

It should be noted that these fading probabilities are for discrete RF carrier frequencies; but, since fading is a frequency selective phenomenon, not all of the carrier's sidebands will be faded equally. This induces delay and linearity distortion into the signal which results in path intermod resulting in IM noise in the baseband. This impact is beyond the scope of this Bulletin but mention is made for the reader's interest. In severe fading thermal or FM noise dominates IM noise so the latter is not taken into account.

No all encompassing formula exists to calculate fading under all conditions. Much of the methodology is empirical and/or incomplete. As a result, a number of standard design practices are in common use. They are not rigid requirements by any means.

- Maximum path length for average terrain

2 GHz	80 km
6 GHz	40 km
12 GHz	20 km

- Initial design fade margin 30-40 dB for each path

- Path clearance at K = 2/3 plus 0.3 fresnel zones

- System redundancy or diversity for any system with reliability requirements above 90%.

d. Diversity and Combiner Analysis

Frequency Diversity - The discussion regarding frequency diversity as presented herein is for academic interests only. The FCC will not license these types of systems in the Power Radio Service frequency band. Some microwave paths have such a strong tendency to fade, they are not suitable for telephony or TV. In such cases, alternate paths are provided to carry the signal during excessive fading. One technique is to provide a separate path using the same antennas but a different frequency. As noted at the end of Section II.F.7 the atmosphere is somewhat frequency selective in path loss variations. The greater the difference between two frequencies, the more noticeable the difference in variations. If one of the frequencies fades deeply, the probability of the other fading equally is less, the further away in frequency it is. This is exemplified in Figure II-201.

Figure II-201 can be approximated for other microwave bands by multiplying the percentages by f/6 where f is in gHz.

The curve on Figure II-201 for S = 0% is the condition of full correlation and this curve is identical to the Rayleigh fading curve of Figure II-200.

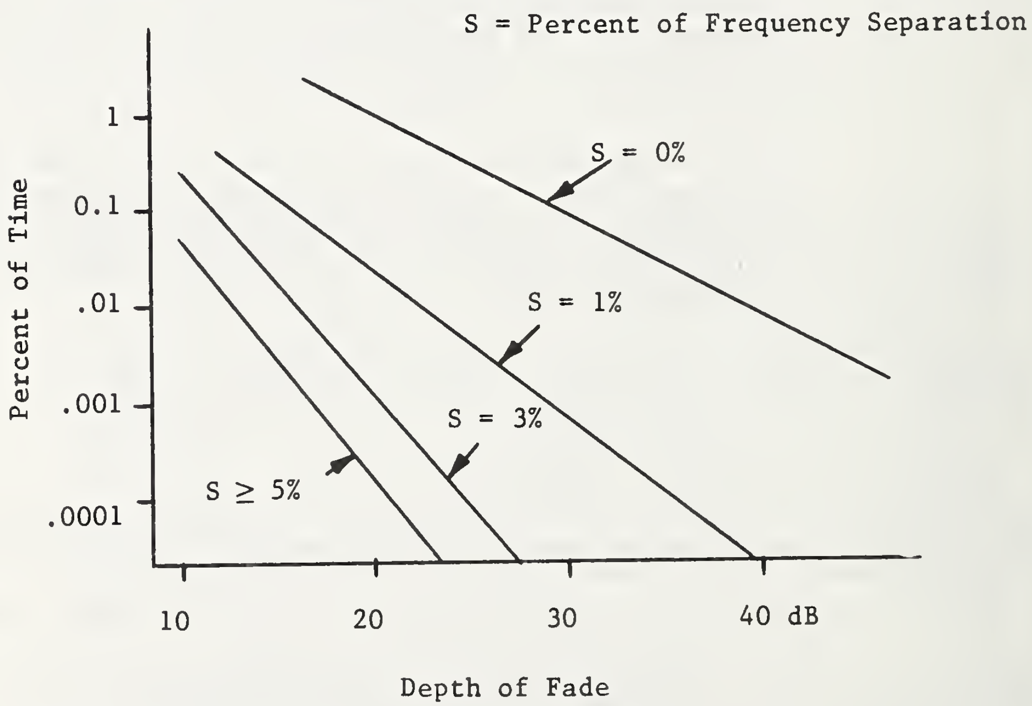


Figure II-201 Fade Improvement at 6 gHz With Frequency Diversity

The use of different frequencies over the same radio path for redundancy is known as "Frequency Diversity". On long nonredundant paths the fading may be too great to be overcome with larger antennas or more powerful transmitters. By adding a second, frequency diversity channel, the duration of fading can be greatly reduced. When one frequency fades, switching equipment automatically switches to the other frequency. It is likely the second frequency will not be faded at the same time. The probability they both will be faded is the percentage value read on Figure II-201.

The improvement due to diversity is measured as "decrease in the probability of fading for a given fade depth".

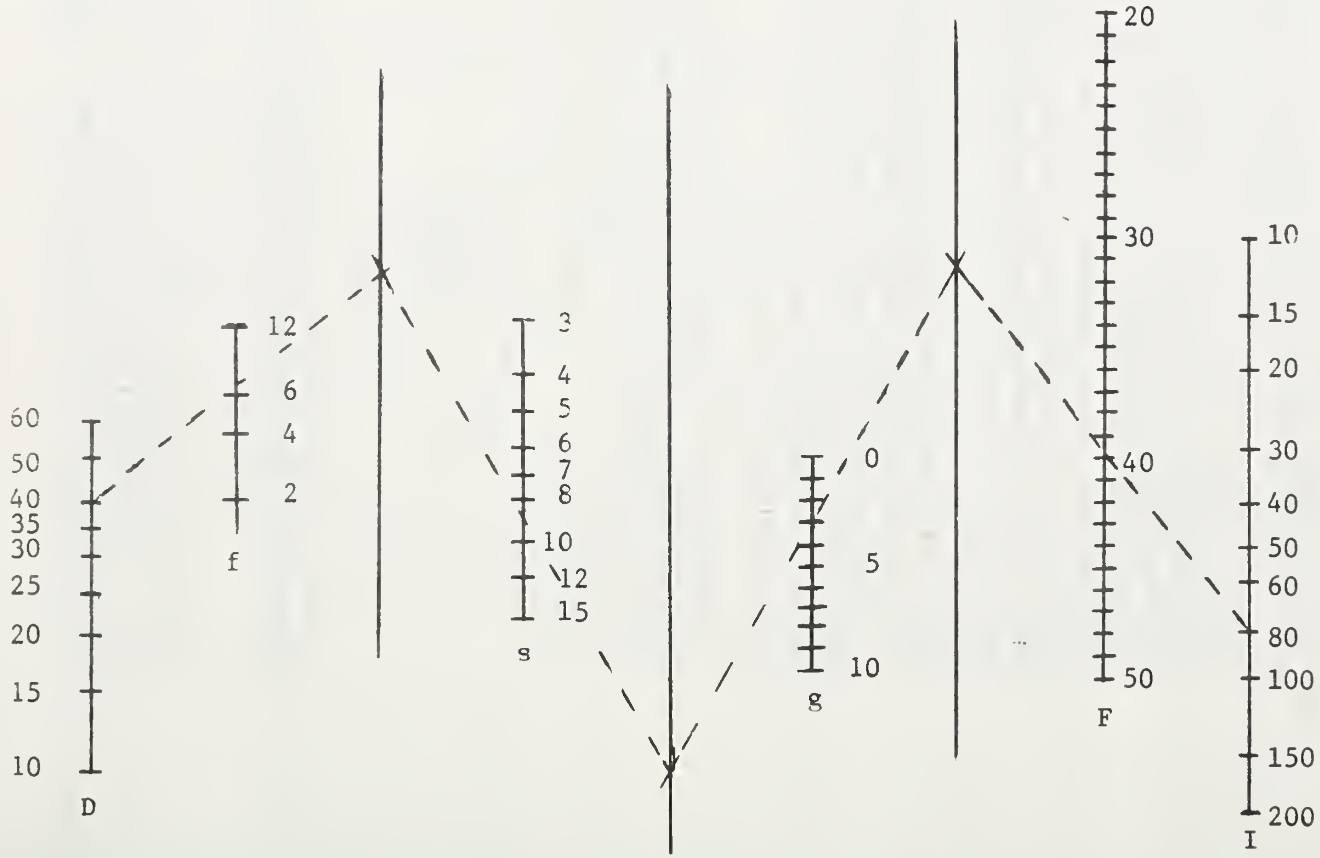
Space Diversity - A second method of diversity uses separate antennas for each receiver. In essence, this arrangement is composed of two separate radio paths since the signals to the two antennas travel through slightly different atmospheric paths due to the separation of the receive antennas. The antennas are placed one above the other rather than side by side. This is because there is less correlation between vertically separated paths than horizontally separated antennas. The further apart the antennas, the less the probability of simultaneous fades. This is true up to a separation of about 50 feet (15 meters). Since the antennas are at different heights, their transmission lines are likely to have different losses. The two antennas are not always the same size either. These factors are taken into account in the following Figure II-202.

To demonstrate the use of the nomogram in Figure II-202, a typical solution has been worked out on the nomogram for a path of the following description.

Path length	=	40 km
f	=	6 GHz
s	=	8 meters
g	=	4.5 dB

It should be noted that g is a measure of the difference between the two diversity antenna gains including any difference in transmission line loss or RF branching.

The separation between space diversity antennas provides an improvement in fading probability up to a separation of 15 meters. The separation can be considerably greater. Very wide separations are used so the lower antenna is just high



D = Path length in km

f = Frequency in GHz

s = Antenna separation center to center in meters

g = Difference in antenna system gains in dB

F = Fade depth in dB

I = Improvement factor

Dashed lines show a sample calculation of

D = 40 km

f = 6.7 GHz

s = 9m

g = 3 dB

F = 40 dB

I = 80

Figure II-202 Fading Probability Improvement Due to Space Diversity enough for line of sight when the upper antenna is experiencing a lot of reflections. When the value of k changes to small values, the lower antenna becomes blocked, but the upper antenna approaches grazing along the path and reflections become blocked. Fading on the upper antenna is therefore reduced.

Differential Absolute Delay Equalization (DADE)

Whenever diversity schemes are used, the absolute delay of all diversity links should be the same. If they are not the same, and a diversity switch switches from one receiver to the other, there will be a time displacement in the baseband. When the switch changes to the alternate receiver and the baseband signals are not "lined up", the baseband shifts slightly in time. This causes phase hits in data, clicks in voice channels and momentary loss of sync for video signals.

The problem is most apparent in space diversity systems where one antenna is further up the tower than the other. The transmission line is therefore longer. Differences can also occur due to RF branching configurations and variations in the use of additional RF rejection filters. In any case, all receivers should be equalized to match the link with the longest absolute delay. The objective is to equalize all receivers to the point where no switching will cause more than a 10^o phase shift in the top end of the baseband. For a 600 channel system the top frequency is 2540 MHz. A 10^o phase shift would be 11 nsec. Assuming a transmission speed of 2/3 the speed of light in the transmission line, this means the electrical length of all links must be within 7 feet (2 meters) of each other. This is easily accomplished by trimming or lengthening transmission lines. An alternate method is to add extra lengths of IF cable to the receivers after the IF pre-amp.

The DADE can be measured by feeding the transmitters with the same sine wave from a signal generator. At the receive end, look at the baseband output of two receivers at a time using a dual trace scope. Increase the sine wave frequency and observe the phase relationship of the two receiver outputs on the scope. If the system is properly "DADE'd", the two signals should not shift in phase by more than 10^o as the top baseband frequency is approached.

Additional Diversity Schemes - Another form of diversity is crossband diversity. This technique uses frequencies in separate microwave bands for frequency diversity. The technique is useful for protection against rain attenuation.

When it is raining, propagation at lower frequencies tends to be stable with little fading while the higher frequencies experience attenuation. When it is not raining the difference in frequency is considerable affording frequency diversity improvement.

Another form of diversity is time diversity. This is commonly used for digital transmissions. Two signals are transmitted, one being delayed in time. If one signal is fading, the probability is the other will not be. In some HF systems 7 or 8 time displaced signals are transmitted and the receive end "votes" the incoming signals to determine the correct signal.

Another form of diversity is route diversity. This is used at frequencies above 8 GHz to avoid rain attenuation. Common practice assumes rain occurs in cells of about 5 miles (8 km) in diameter. Two parallel systems over 5 miles (8 km) apart are not likely to fade due to rain attenuation simultaneously.

Another technique is called angle diversity. Antennas are pointed at slightly different angles. This can be expanded upon by phasing the antennas to null out energy coming from fixed reflection points.

Mixed Diversity - Diversity schemes can be mixed. It is possible to use space and frequency diversity on the same path. If 4 diversity signals are used, the technique is called "quad" diversity. Two signals is "dual" diversity. As the order of diversity is increased, so the fading probability, I, is decreased.

Combiner Analysis - To select the best signal, combiners are used. The combiner is controlled by sensors as described in Section II.E.4. There are several types of combiners. In microwave systems the most common is a simple switch. If two signals are approximately equal in level the combiner can be aligned to select the best signal, switching whenever the difference between the signals is greater than a fixed amount. This amount is usually 2, 6, 10 or 30 dB depending on the application. If the amount approaches 0 dB, the combiner will switch continually due to scintillation fading and the average signal to noise ratio will be improved by approximately 1.5 dB. See Figure II-203.

Instead of switching from one signal to another when the signals are approximately equal, an equal gain combiner adds the two signals together. When this is done the signals add in voltage for a 6 dB increase in power level.

The noise signals riding on the two baseband signals are not in phase with each other, however, and they add together in power rather than voltage. This produces a 3 dB increase in the noise. If the signal increases by 6 dB and the noise by 3 dB, there is a 3 dB improvement in signal to noise ratio. The two signals are not always exactly equal, however, so the improvement of an equal gain combiner only approaches 3 dB. See Figure II-203. When the difference between the two signals reaches about 4 dB the combiner cuts off the weaker signal so its noise does not pass through.

A third type of combiner is the maximal ratio combiner. This combiner operates on the same additive principle as the equal gain combiner, but automatically adjusts the gain of the two signals to maximize the S/N improvement. It, therefore, more closely approaches the 3 dB improvement figure.

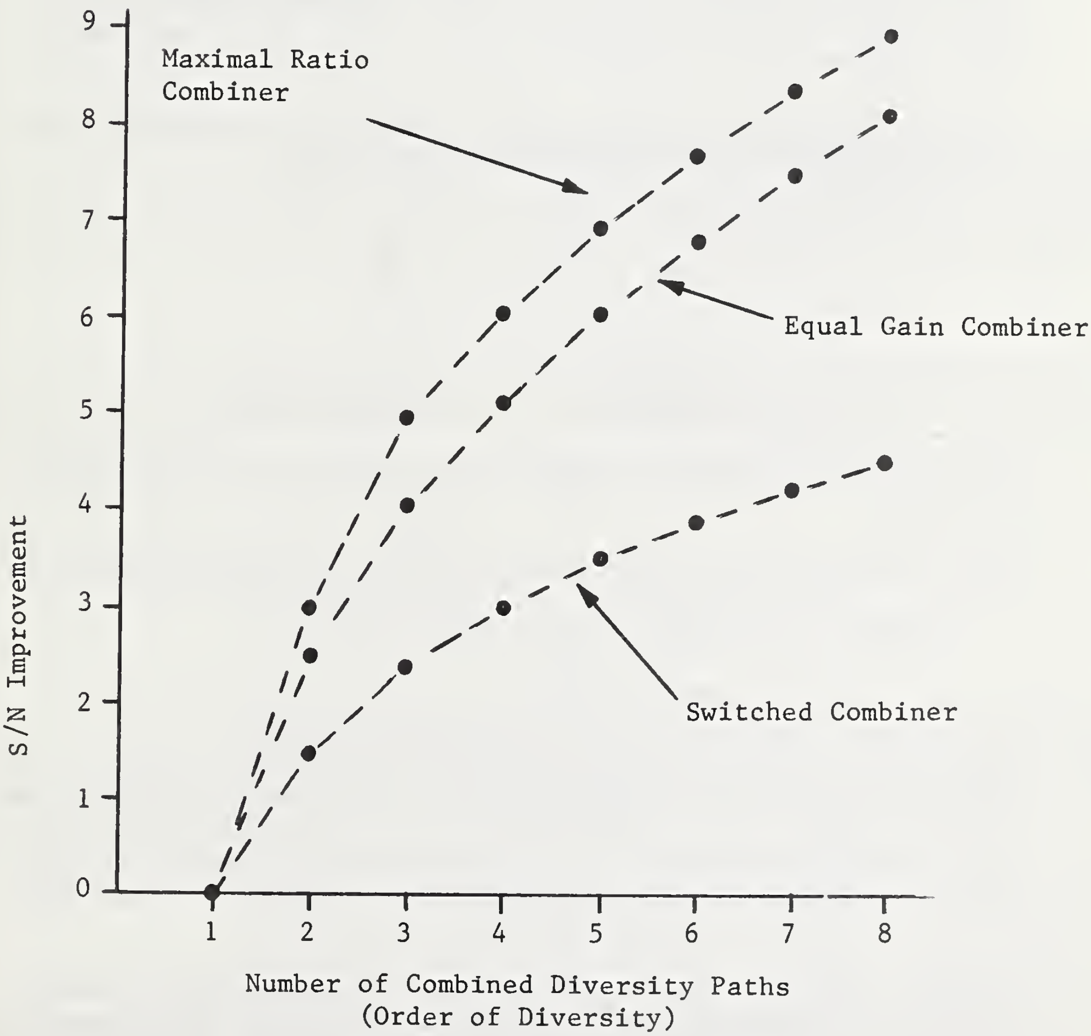


Figure II-203 Combiner Improvement

7. <u>Tandem Paths Performance</u>

As discussed above, the end to end performance of a system is the principle objective of good system design.

To determine the overall performance of a multihop system the performance of all the individual paths need to be taken into account. The major consideration is noise performance.

Two basic types of noise examined are faded noise and unfaded noise. Unfaded noise is composed of the noise contributions not affected by fading. See Section II.G.3.

The noise due to fading is more difficult to determine since individual paths do not fade together. When paths are faded, others may not be. The amount of correlation between path fading decreases with depth of fade. The probability of two paths with equal normal receive levels fading deeply at the same time to the same depth is roughly equal to the product of their independent probabilities.

If both paths fade 40 dB for .01% of the time, the probability of both fading 40 dB simultaneously is

P of both = .01% x .01%

= .0001 x .0001

= .00000001

= .000001%

The deeper the fade, the smaller the probability of simultaneous fades.

The probability of 3 equal paths fading 40 dB simultaneously is

P of 3 = .01% x .01% x .01%

= .0000000001%

One must also consider the probability of one path fading 40 dB while others fade by different amounts in order to arrive at an overall system noise probability curve. The calculation is further complicated by virtue of the fact that the normal receive levels of different paths are different. Therefore, equal fade depths contribute different amounts of noise.

To definitively calculate the complete range of noise probabilities in a tandem system of 10 paths over a 40 dB fade margin in one dB steps one would have to construct a matrix of millions of probability calculations, sum them and plot the results. The process is called "convolving". To calculate the probability of a system fading to just one noise level, one must calculate all the possible combinations of faded paths that will produce that much noise. All the path probabilities of a given combination are then multiplied together. This value for all the possible combinations is then added together to arrive at the probability of the whole system fading to that noise level. For example, assume a 3 hop system. The unfaded noise contribution of the paths is shown in Figure II-204.

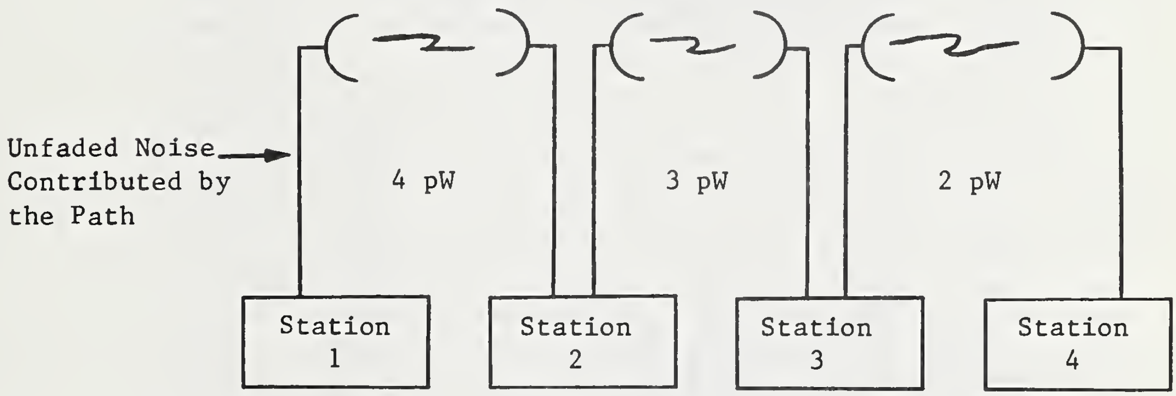


Figure II-204 Noise Contributions

For simplicity the probability of a path fading to produce more noise is

$$P = \frac{0.1}{pW} \%$$

The probability of a path fading enough to produce 2 more pW is therefore .05% or a probability of .0005.

The total unfaded noise is 4+3+2 = 9 pW. The problem is to determine the probability of the system fading to a point where the noise is 12 pW. Figure II-205 shows how the matrix is constructed. It is assumed that fading occurs in 1 pW steps.

Figure II-205 represents a simple convolution. The number of possible combinations is only 9 because of the very limited number of possible fading conditions. If a real system is analyzed, the size of one matrix becomes enormous. The process has to be repeated for each fading level as well. Assuming an infinite number of fading steps, the probability convolution matrix becomes infinite in size.

Possible Combination	Noise Contribution/Probability			Product of Probabilities
	Path 1	Path 2	Path 3	
1	4/.5	3/.5	5/.000333	.00008333
2	4/.5	4/.001	4/.005	.00000025
3	4/.5	5/.0005	3/.001	.000001375
4	4/.5	6/.000333	2/.5	.00008333
5	5/.0002	3/.5	4/.0005	.00000005
6	5/.0002	4/.001	3/.001	.0000000002
7	5/.0002	5/.0005	2/.5	.00000005
8	6/.000167	3/.5	3/.001	.0000000835
9	6/.000167	4/.001	2/.5	.0000000835

Addition Total of Products = P of 3 Paths = .0001685585

= .0169%

Figure II-205 Convolution of Three Hops

Fading in microwave systems tends to have long term variations that follow a Normal or Gaussian distribution curve. The short term fades follow a Rayleigh distribution curve which describes the fading probability of deep fades.

The Gaussian curve is a "Bell" curve that says fading will occur up and down from a median level with equal probability. Fading follows the Gaussian curve for about 90% of the time. For the remaining 10% of the time deeper fading occurs and the probability and depth of fading follow the Rayleigh curve.

To avoid the extensive amount of mathematics involved in convoluting various fading probabilities, rules of thumb have been developed. To determine the worst hourly median for many hops in tandem assume a 10 dB fade on the two noisiest hops or a 4 dB fade on all hops, whichever is worse. Add this faded noise to the unfaded noise to determine the worst hourly median. To determine the one minute mean noise requirement of 20,000 pW for 20% of the time, assume the two noisiest paths to be faded by 20 dB. For the 100,000 pW for .1% of a given month calculate the pW difference between the unfaded noise level and 100,000 pW. Check the noisiest paths to see how far they would have to fade before contributing that much additional noise. Now check to see what the probability is they will fade that far. If any path's probability exceeds .1%, the system does not meet the criteria. To achieve the objective all paths should be better than .1%.

8. <u>Composite Noise Calculations for Voice Channels</u>

Voice channel noise is composed of faded noise, unfaded noise and a third type of noise that is dependent on the presence of modulation in the voice channel.

The unfaded noise is composed of:

- Multiplex idle noise
- Multiplex intermod-noise
- Radio unfaded idle noise
- Radio intermod noise
- Antenna system echo distortion noise
- Idle noise in local loops
- Termination equipment idle noise
- Crosstalk

The faded noise is FM noise due to variations in the receive RF signal levels in the system. See Section II.H.7.

The modulation dependent noise factors are:

- Modulation noise
- Harmonic distortion
- PCM carrier quantizing noise
- Compandor/Expander noise reduction
- Echo distortion/echo suppressors

Modulation Noise

Multiplex, termination equipment and other analog voice components are not perfect devices. In the presence of modulating energy, they generate additional noise across the voice channel. This is called modulation noise. It is measured by inserting a tone in the voice channel at one end. At the other end the tone is notched out using a very sharp bandstop filter. The noise in the rest of the channel is then measured. The sources of this modulation noise are phase and frequency jitter, shot noise in the equipment, noise accompanying the signal itself and noise generated by the termination and mux equipments which are electrically stressed more under the presence of a modulating tone. Typical levels of modulation noise are minus 30-40 dBm0. Modulation noise is not as annoying as steady noise at the same level because it does not exist in between syllables since there is no modulation between syllables.

Harmonic Distortion

Harmonic distortion can be considered part of modulation noise since the harmonics exist only in the presence of modulation. To determine harmonic distortion levels, a 1000 Hz tone is sent through the channel and a narrow frequency selective voltmeter is used at the other end to measure the levels of the 2 kHz and 3 kHz harmonics in the channel. The 2 kHz harmonic is normally 40-50 dBm0 and the 3rd harmonic another 5-10 dB further down. Harmonic distortion for other frequency tones may vary, especially at the bottom end of the channel. Harmonic distortion of tones above 1700 Hz are of no significance since they fall outside the passband of the channel (300-3400 Hz). For this reason, many data modems operate with carrier frequencies of 1800 Hz and above.

PCM Carrier Quantizing Noise

Pulse code modulation equipment is used as a trunking facility on many voice circuits. If it appears on a circuit it introduces quantizing noise in response to modulating tones. Ideally the noise is -62 dBm0. The louder a tone, the worse the noise since the quantizing steps are larger at higher volumes. The figure of -62 dBm0 may be as much as 15-20 dB worse due to poor equipment alignment and loud voices.

Compandor Noise Reduction

In the presence of idle noise, weak talkers have a worse signal to noise ratio than loud talkers. To help overcome the poor S/N for weak talkers a compressor is used to amplify the weak talkers more than the loud talkers. It does this instantaneously so the quieter syllables of all talkers are "picked up" in level to improve their S/N. The compressed signal is transmitted through the system. At the receive end the compression process is reversed to restore the voice signal to its original form. The device to accomplish this is an expandor. The expandor and compressor together are called compandor.

The compressor also compresses very loud speech. The overall voice power being transmitted is approximately 6 dB higher than uncompanded voice. The compression allows a 5 dBm0 signal to pass through unaffected. Signals above and below this level are compressed 2 dB for every one dB of change from the 5 dBm0 reference. In the absence of voice modulation, the expandor will suppress idle channel noise by approximately 30 dB. During speech the noise rises but it usually is masked by the speech.

Echo Distortion/Echo Suppressors

Voice circuits use 2 wire devices which are sources of echo. Echo is annoying to voice users. The longer the echo delay, the more annoying is the echo. On circuits over 1500 miles(2415km) long, echo suppressors are often used to suppress annoying echoes. The echo suppressor places an additional 20 dB in the circuit whenever there is no modulation present. Echo suppressors transmit in one direction at a time. If one talker is talking, the talker at the opposite end of the circuit cannot transmit through the suppressor until the first talker stops.

To calculate the composite noise on a voice channel simply add the unfaded noise contributions for the median noise, add the faded noise for the worst hourly or minute median noise and add the compandor or echo suppressor improvements if they apply. See Figure II-206 which shows the noise of a voice circuit over a 1000 mile (1610km) channel. The object of such an exercise is to examine every piece of equipment a circuit passes through and determine its idle and loaded noise contribution. These factors are determined for faded and unfaded conditions as well as idle and busy states of the voice channel. The value of 2340 and 3540 pW in Figure II-206 is the noise levels considered in path engineering. It is these figures that are compared to the hypothetical reference circuit in Section II.G.2. The amount of allowed noise is equal to

$$= \left(\frac{\text{System length}}{1600\text{ km}}\right)\left(\begin{matrix}\text{Noise criteria}\\ \text{contributions}\end{matrix}\right) + \begin{matrix}\text{5000 pW for MUX and}\\ \text{other fixed noise sources}\end{matrix}$$

Type	Noise Source	Qty.	Idle Noise	IM Noise	Total
Unfaded	Channel Mux	1	40 pW	40 pW	80 pW
	GP Mux	2	40	40	80
	SGP Mux	2	40	40	80
	MSG Mux	4	40	40	80
	Radio	40	400	400	800
	Modems	5	45	500	545
	Echo Distortion in Waveguide	40	0	600	600
	Local Loop	2	5	0	5
	Termination Eq.	2	10	40	50
	Crosstalk	2	20	0	20
				Total Unfaded Noise	2340 pW
Worst Hourly Faded	Radio	40	1000	200	1200
				Total Channel Modulation Independent Noise	3540
Modulation Dependent	Modulation Noise	10000	0		10000
	Harmonic Distortion	0	10000		10000
	PCM Carrier	0	1000		1000
	Compandor Improvement		30 dB		(-30 dB)
				Total Idle Channel Noise	24.5 pW
				Total Busy Channel Noise	24500 pW

Figure II-206 Voice Channel Noise, Worst Hourly

9. <u>Composite Noise Calculations for Data Channels</u>

Calculations of noise in data channels within a voice channel begin with the calculations shown in Section II.H.8 above for total channel noise. This total is then reduced by the ratio of the data channel's bandwidth to the bandwidth of the voice channel. It is interesting to note that narrowband data channels can perform over very noisy voice channels because of the reduced bandwidth for the data channel. If 32 data channels are frequency multiplexed into a single voice channel with a 10 dB S/N, the S/N of a single data channel will be

$$= 10 \text{ dB} + 10 \text{ Log}_{10} 32$$

$$= 25 \text{ dB}$$

25 dB is normally quite adequate for slow speed data transmission. The voice channel itself, however, is unusable for voice.

If the voice circuit uses a compandor, the total composite data level in the voice channel must be held consistent or the compandor will vary the signal level as it tracts level changes.

For full duplex (two way transmission) over long circuits with echo suppressors the suppressor must be disabled. This is usually done with an inband tone that is sensed by the suppressor which then deactivates itself. Data is generally much less sensitive to echoes.

If wideband data is transmitted over the microwave system using GP or SGP bandwidths, the S/N is calculated using the general FM noise formula.

$$S/N = (C/N) \left(\frac{3(\Delta F)^2 B_{if}}{2\ (F_u^{\ 3} - F_1^{\ 3})} \right) (NF)\ (Weighting)$$

The weighting is the bandwidth reduction due to filter shirts in the GP, SGP filters. See Section II.H.4 for further explanation of FM noise.

Many data transmission systems use digital repeaters to reconstitute the data signal as it passes through the system. In essence, data signals consist of square pulses. Noise and other forms of distortion change the shape of the square pulses. If the shape is distorted too much, the receive data equipment has trouble detecting the presence of the pulse or its parameters. If the receive device ignores a pulse or falsely assumes there is one, then a data error is created. Digital repeaters "square up" the pulses before they become too distorted. If the repeater falsely detects or ignores a pulse, it imparts a data error to the data signal. Repeaters can thus convert excessive noise into data errors. In a system with numerous digital repeaters, such errors accumulate. The noise does not, however, since it is eliminated at each repeater. The overall data circuit noise is therefore meaningless. The overall data error rate becomes the factor of interest.

10. Error Rate Concepts

Data is transmitted through communications systems by modulating a carrier at the rate of a data signal and transmitting the modulated carrier. At the receive end a device detects changes in the carrier's parameter(s) to extract the data from the carrier. In doing so, the receive device must make decisions whether there is a change in a carrier's parameter(s) or not. If a wrong decision is made, an error is generated.

Errors can be detected by a number of methods. One is called "echoplexing". The signal such as a teleprinter character is transmitted. The receive end receives the character and also sends it back again to the originating end. The originating end then prints the letter as it detects it to check for accuracy. In other words, when an operator depresses a key on the keyboard, the letter printed on his machine is the signal returning from the intended receive end.

To test a transmission facility for its tendency to cause errors, a test modem is attached to both ends. The transmitter at one end transmits a series of data pulses generated in a test pattern generator. The sequence of the bits is constructed so the energy spectrum of the test pattern is more or less what would be expected with a random sequence. At the receive end, the modem compares incoming test pattern with an identical pattern generated internally. If the two patterns do not match, an error is recorded on an accumulating counter. The error rate is then the ratio of the number of errors to the amount of information sent. Bit error rate is the ratio of erred bits to bits sent. Character error rate is the ratio of erred characters to characters sent, where each character may have 5 to 11 bits.

The counting of errors has a number of interpretations that should be kept in mind. An error rate composed of single bit errors is more significant than the same error rate composed of bursts of multiple errors. For example, if the data being sent is ASCII 11 bit characters, one bit error will cause an erred character. Eleven errors in the same character, however, will also only cause one erred character. When specifying error rate, it is therefore useful to state that errors are single bit errors with error bursts counted as single errors or a limited number of errors. One way of stating this is to say all errors in a given 11 bits will be counted as one error. To achieve this, the receive end ignores the first 10 bits after an erred bit.

The transmission facility does not actually have a data error rate characteristic. The error rate experienced over a channel is a function of the channel transmission parameters as well as the bit speed, type of modulation and the energy spectrum of the data.

When a system is sending actual data instead of a test pattern there are ways of monitoring data errors. One method of error detection is to send data in blocks of known length. If the length of a receive signal changes because a data pulse is added or subtracted due to false detection, an error is known to exist. Another method is to encode the data block with a parity bit. The transmit end looks at the data block and counts whether the number of bits in the block is odd or even. If the number is odd, the transmitter adds one more bit to the block so the total is even. If the initial count is even already, no bit is added to the parity bit position in the word. At the receive end, the detector counts the number of bits in the word. If the count is odd, it knows there is an error. Of course, if there are two errors the count will still be even and the errors will go undetected. It is possible to add two parity bits to a word which allows for more powerful error detection. With two parity bit positions, the transmitter counts the number of bits in the word and electronically divides by 4. If the remainder is zero, no parity bits are inserted. Other remainders are as follows.

Remainder	Parity Bits
1	1 1
2	1 0
3	0 1
0	0 0

Now, the transmitted block will have a number of bits that is always divisible by 4. If two errors are caused, they will be detected. Three parity bits can be used which allows for division by 8. Four parity bits allows for division by $2^4 = 16$.

It is also possible to send error correcting codes that can be used at the receive end not only to detect but to correct errors. To understand the principle, assume a data block of Figure II-206.

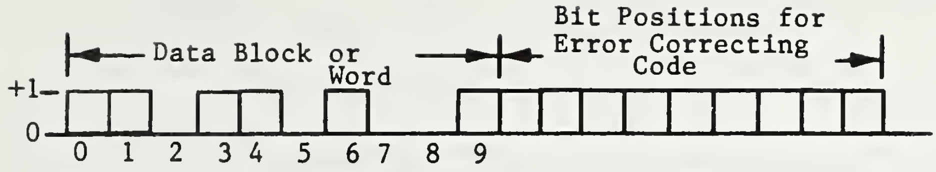


Figure II-206 Data Block with Error Detection Code

The bits in the data word are 0 through 9 for a total of 10 bits. The data word is now considered a series of coefficients of a polynomial whose coefficients are one or zero depending on the state of each bit. For the data word in Figure II-206 this means a polynomial of

$$= (1)\ 2^0 + (1)\ 2^1 + (0)\ 2^2 + (1)\ 2^3 + (1)\ 2^4 + (0)\ 2^5 + (1)\ 2^6 + (0)\ 2^7 + (0)\ 2^8 + (1)\ 2^9$$

$$= 2^0 + 2^1 + 2^3 + 2^4 + 2^6 + 2^9$$

$$= 1 + 2 + 8 + 16 + 64 + 512$$

$$= 603$$

The transmitter now encodes 603 in binary form as in Figure II-207.

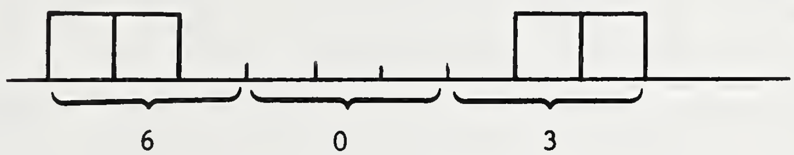


Figure II-207 Digital Encoding of the Number 603

At the receive end the detector creates the same polynomial as the transmit end and also detects the error correcting code 603. If the two do not match, say the data block's polynomial only adds to 587, the receiver subtracts the two 603-587 = 16. It now knows that $2^4 = 16$ is missing from the data block and it therefore inserts a bit in the 4th bit position of the data block. If the polynomial added up to 635, the receiver detects 635 - 603 = $32 = 2^5$ and knows that a bit was falsely detected in the block's fifth bit position.

The number 603 can be constructed by only one data bit sequence. No other series of 2^n can add up to 603. It is therefore possible to detect any combination of missing or falsely detected bits. In fact, the number 603 could be sent without the data word and the receive end could completely reconstruct the data block with just the 603. It will be noted that it took 9 bit spaces to send 603 but 10 to send the block itself. By sending 603, the system would have a 10% improvement in transmission efficiency.

The sequence of exponents of the polynomial can be reversed to generate another correcting code. Using the data block in Figure II- 206 this becomes:

$$= 2^9 + 2^8 + 2^6 + 2^5 + 2^3 + 2^0$$

$$= 512 + 256 + 64 + 32 + 8 + 1$$

$$= 873$$

The sequence of exponents can also be scrambled to generate additional correcting codes. It is also possible to use the number 3 instead of 2 for the polynomial. Sophisticated data reduction techniques can analyze a block of data, electronically arrange the sequence of exponents for the shortest code word and send the code. The receive end is told at the same time which polynomial to use in reconstructing the data block. A further expansion of this is to apply the same operation on a series of correcting codes. The technique reduces the data if the original data is not strictly random.

Returning to the first concept of generating the number 603, it is possible to send just the number 3. At the receive end, the polynomial is constructed and 603 is generated. The last digit, 3, is checked with the error detection code number 3 to determine if any errors have occurred. Most errors will be detected. One must also realize the code itself could be erred. There is a chance of the 3 being detected as 0, 1, 2, 4 9. The probability of the polynomial also generating the same wrong digit is small, however. The technique of using error detection codes reduces the number of undetected errors by about 2 orders of magnitude. An error rate of 10^{-5} will be reduced to an undetected error rate of 10^{-7}. It is common practice to send blocks of data 800 bits long with an error detection (not correction) code. If an error is detected, retransmission is requested. A typical performance in such a system is 98% of the transmissions go through without errors being detected. The term used to describe this is "throughput". In this case the system has a "98% throughput".

The theoretical limit of how much data can be transmitted through a channel is described by Shannon's law:

$$C = B \, Log_2 \, (1 + S/N)$$

where C = bits per second

B = channel bandwidth in Hz

Log_2 = logarithm to the base 2

S/N = data signal to noise ratio

The law says this is the maximum number of bits per second that can be transmitted without error through a Gaussian band limited channel, i.e. voice channel, assuming an infinitely long time to transmit data blocks and suitable error correcting codes.

For a voice channel with an S/N of 15 dB this is

$$C = 3000 \, Log_2 \, (1 + 31.6)$$

$$= 3000 \, Log_2 \, 32.6$$

$$= 15090 \text{ bps}$$

In practice the highest data speed that is usefully sent through voice channels is 9600 bps.

The measure of bit error rate is the ratio of erred bits to sent bits. The higher the noise on a channel, the higher the probability of error. If the signal to noise ratio is 13 dB, the noise peaks will reach the signal level for .01% of the time. See Section II.F.8. The noise peaks confuse the data detectors which falsely detect the noise peaks as data bits. The peaks can also cancel a true data pulse. Data error rate as a function of noise is shown in Figure II-209.

Delay and linearity distortion also affect error rate. Equalizers are used to flatten channel responses for data transmission. Some more sophisticated data modems have adaptive equalizers. The transmit end sends a pre-coded data block. The receive end knows what the block is supposed to be and adjusts its input equalizer until all the bits in the block are properly reconstituted. The equalizer should then match the transmission line to eliminate delay and linearity distortion. The modems have error detection codes attached to data blocks. If an error is detected the modems automatically go into an adaptive equalizer mode. The process of adaptive equalizing takes 7-200 milliseconds depending on the modem and circuit length. The modems then revert to normal operation.

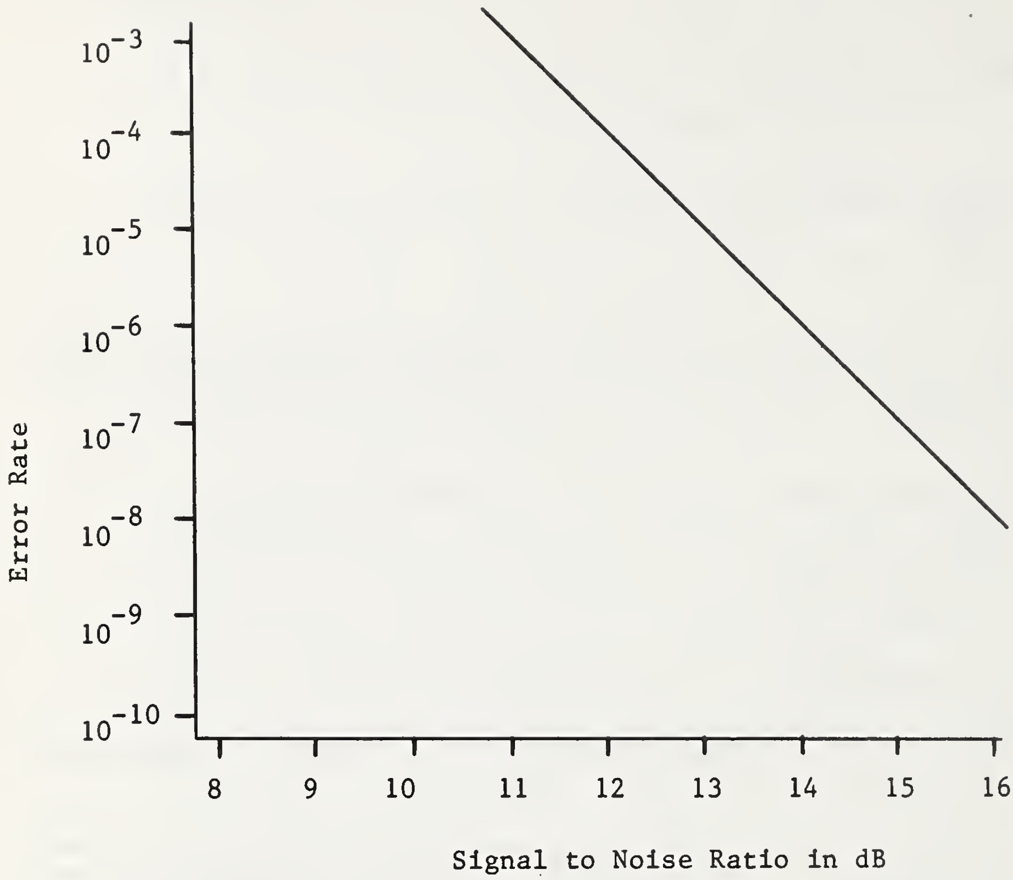


Figure II-209 Data Error Rate vs S/N

Figure II-210 is a list of the major formulas used in Section II.

Quantity	Equation	Page
Outage Ratio U	$\frac{MTTR}{MTBF}$	30
Antenna Gain	$\left(\frac{\pi D}{\lambda}\right)^2$	68
Loading Factors		137
12 to 240 chn	$-1 + 4 \ Log_{10} N$	
240 chn	$-15 + 10 \ Log_{10} N$	
FM Noise	$C/N + 20 \ Log_{10} \frac{\Delta F}{F_{BB}} + 10 \ Log_{10} \left(\frac{B_{if}}{2B_{chn}}\right)$	137, 319
Preemphasis	$\left[8 \left(\frac{F}{F_{BB}}\right) - 4\right]$ dB	139
Peak Deviation	$(d) \left(10 \ Exp \ \frac{P+C}{20}\right)$	140
Free Space Loss	$20 \ Log_{10} \frac{4 \pi D}{\lambda}$	147
Near/Far Field Boundary	$\frac{2D^2}{\lambda}$	148
N^{th} Fresnel Zone	$\sqrt{N \lambda d_1 d_2 / D}$	152
Thermal Noise	KTB	157
Mod Index	$\frac{F_{peak}}{F_{mod}}$	168
Return Loss	$20 \ Log \left(\frac{VSWR + 1}{VSWR - 1}\right)$	191

Quantity	Equation	Page
Wind Pressure	$.0079V^2$ or $.0042V^2$	282
Geographic Intercept	$\mathrm{Tan}^{-1}\left[\frac{A-B}{\mathrm{Sin}\,(\lambda_1 - \lambda_2)}\right]$	288
Radio Refractivity, N_s	$77.6\,\frac{P}{T} + 3.73 \times 10^5\,\frac{E}{T^2}$	291
Effective Earth Radius, K	$\frac{157}{157 + \frac{dN}{dh}}$	292
Earth Bulge, Be	$\frac{D_1D_2}{12.75\,K}$	293
Reflection Point Calculation, S	$\left(\frac{1-\Delta}{\Delta}\right)(R) + \frac{(1-\Delta)(1-2\Delta)}{3/2K}$	295
Obstruction Loss	$(19.2\,\theta^{.371} + 29.5 - 10\,\mathrm{Log}\,F)$ dB	297
Interfering Tone Level	$C/I + 20\,\mathrm{Log}\left(\frac{\Delta F,\ rms}{Freq.\ Sep.}\right)$	303
Distance	$111.18\,\cos^{-1}\left[\mathrm{Sin}\,L_1\,\mathrm{Sin}\,L_2 + \mathrm{Cos}\,L_1\,\mathrm{Cos}\,L\ \mathrm{Cos}\,(\lambda_2 - \lambda_1)\right]$	309
Bearing	$\mathrm{Cos}^{-1}\left[\frac{\mathrm{Sin}\,L_2 - \mathrm{Sin}\,L_1\,\mathrm{Cos}\,R}{\mathrm{Sin}\,R\,\mathrm{Cos}\,L_1}\right]$	309
Wideband FM Noise	$\left(\frac{3}{2}\right)\left(\frac{C}{N}\right)\left(\frac{(\Delta F)^2\ B_{if}}{F_u^{\,3} - F_1^{\,3}}\right)$	318, 346
S/N	$NPR + 10\,\mathrm{Log}\left(\frac{N_{bw}}{3.1\ kHz}\right) - NLR$	323

Quantity	Equation	Page
FM Threshold, C_{th}	$(10 \text{ Log}_{10}(KTB_{if}) + NF + 10)$ dB	328
Fading Probability, P	$\frac{10^{-6} fD^{3} 10^{(-F/10)}}{4.2}$	331
Data Speed Limit, C	$B \text{ Log}_2 (1 + S/N)$	351

Figure II-210 Formulas

III. OPERATIONS AND MAINTENANCE (O&M)

A. Introduction

Microwave systems require life cycle care and attention for two basic reasons:

- Equipment does fail or degrade.
- Equipment configurations do change to meet expanding and/or changing circuit requirements.

It is conceivable to construct a microwave system with such long MTBF's and a truly static configuration of circuit requirements that no operations or maintenance program is required. Such is not the case in practical applications, however. Microwave systems are comprised of many electronic subsystems and a vast number of types of circuitry and components. A fairly sophisticated level of expertise is required to operate and maintain even the simplest of systems. In the power industry it is paramount to have adequate O&M of microwave systems whenever critical control and telemetry circuits pass over the microwave system. Inadequate O&M can eventually render the communications system inoperative. This can indirectly cause damage to power system equipment and lost revenues. It is therefore judicious to carefully study all O&M requirements and plan accordingly.

B. Development of O&M Program

There are a number of primary considerations that need to be taken into account when developing an overall O&M plan. A number of these factors are given full attention during the initial conceptual design phases of the microwave system.

1. Traffic Criticality

How critical is the traffic being carried over the communications system? Is it routine voice, office to office communications or vital protective relay control lines? Microwave systems are often considered the most reliable form of long distance communications. They do fail, however; for no system can be designed to operate with 100% availability. There is always a calculated risk of failure. Proper O&M programs ensure and/or improve upon the risk by performing proper system surveillance and quick repair in the event of failure.

2. System Availability

As discussed in Section II.D.3 the availability of the system is a function of propagation outages, equipment failures and the mean time it takes to repair a failure. These three factors are "controllable" in the design phase and should be engineered to meet the required system availability as defined by the system operational objectives. Once the system is designed and equipment selected, it is possible to calculate allowable MTTR (Mean Time To Repair) and thus develop an O&M strategy for the system. MTTR is composed of the following elements:

- Time to reach the site
- Time to locate the trouble
- Time to isolate the fault
- Time to effect repair
- Time to restore the system to working order

On long microwave systems the site access time is a matter of time to alert O&M personnel and travel time to the site. Minor maintenance facilities are distributed along the system to reduce travel time.

It is common to have one such facility every 3-6 repeaters. When making the selection, estimates are made of travel time to each site from the proposed minor facilities. As a practical matter these times should be limited to 3-5 hours. The minor facilities may be staffed during the day time. As a minimum, there should be someone on call 24 hours per day. Repeater sites near terminals can be serviced out of the terminals.

3. <u>Logistics</u>

A major cost in an O&M program is material and logistics costs. The larger the system, naturally, the larger the complexity of the logistics operation. The major cost items other than salaries, overhead and financing are:

- Spares, parts and material inventory
- Test equipment and tools
- Vehicles and associated costs
- Repair, storage and office facilities
- Failed equipment replacements

In developing the O&M plan many options exist to cover the logistics requirements such as:

- Combined spares inventory with other existing inventories
- Contracting spares responsibility to vendors
- Rental of test equipment
- Contract out certain phases of O&M for equipment repairs
- Obtain long term equipment warranties with free and timely repairs clauses

The significant factor to consider is the fact that failures will occur and adequate means of effecting timely repairs must be planned for. The logistics involved can become complex and should receive close attention. On long systems, for example, it may be necessary to equip minor O&M facilities along the system to meet acceptable site access times.

4. Manpower Availability

As with logistics, the O&M plan must consider the manpower required to effect timely repairs. The planner must consider the work load as well as the level of technical expertise required to effect these repairs. The work load depends on the number of expected failures and the level of preventive maintenance selected. The level of expertise can be varied considerably depending on the resources of the co-op or borrower. Many systems can be maintained with a low echelon (simple) of maintenance. Failures in the field are commonly corrected by simply replacing modules. Such a system is given depth by having greater levels of expertise available from the vendors or professional consultants.

As the system size and complexity increases it often becomes more cost effective to have the expertise available internally. As a minimum, however, at least one technical staff member should be capable of administering the O&M program. Beyond having one person responsible, the balance of the manpower requirements may be supplied by:

- Vendors under contract
- Consultants
- In house capability
- Contracts with O&M firms (if available)

The important concept is to ensure that sufficient manpower is available to effect all levels of repair required to maintain the system. Sufficient manpower is also required to implement required operational changes such as system expansion, circuit modifications and new services.

5. Training

Unless the selected O&M staff has direct experience with the system's equipment, some level of training is normally required. The following major training activities are often found most useful:

- Participation in the system design and equipment selection
- Formal training by vendors at vendor locations
- Participation in the installation and testing phases
- Assist in developing O&M program
- Formal classroom instruction
- On the job training (OJT) on an operating system

A well constructed training program should:

- Clearly state the end objectives of the program including resultant skill levels, cost, schedule etc.
- Adequately define the skill level requirements of entering students
- Completely define all course activity in advance
- Prepare all instructional aids and student handouts in advance
- Employ instructors of greater skill than the course skill objectives
- Select personnel with teaching ability for instructors
- Arrange all housing and meals etc. for students in advance to avoid course disruptions

The significant knowledge that should be imparted to the technical staff undergoing training consists mainly of:

- Skills requisite with required maintenance echelon levels
- Operational procedures of the O&M program

It is also advisable to train personnel over as wide a range of technical disciplines involved as practical. This tends to reduce the number of personnel required to operate and maintain the system. In cases of emergency, it also gives management a greater depth of skill to draw upon.

C. Maintenance Programs

1. Preventive Maintenance

In order to assure continued operation of a communications system over a prolonged period with a minimum of outage time, it is essential that an adequate preventive maintenance program be established. The ultimate aim of this program should be the detection and elimination of possible component failures before these conditions cause system failure. For example, routine measurements at test points and panels of the equipment should be logged so that any changes can be detected and a component or other unit which is gradually becoming defective may be replaced. Thus preventive maintenance differs from troubleshooting and repair in that its objective is to prevent trouble from occurring rather than to correct troubles after the equipment has failed. The two main phases of preventive maintenance are:

- Mechanical and physical inspection
- Electrical measurement and testing

Mechanical and physical inspections will eliminate a large percentage of future electrical troubles. Among the items which this phase would address are:

- Impairments due to mechanical vibration
- Mechanical integrity of connectors and assembly bolts and screws
- Rack mounting integrity
- Dust and dirt removal from equipment
- Rust and corrosion inspection

The above are but a few of the items involved in mechanical and physical inspections.

The second phase of preventive maintenance is the electrical measurement and testing of the system. The electrical measurement and testing phase of the electrical maintenance program should include a complete test of overall system operation. Tests should be conducted periodically. Among the elements, but not necessarily limited to, that may be tested are:

- Signal to noise ratio
- Noise Power Ratio (NPR)
- Error rates as applicable
- Channel level stability
- RF frequency stability
- RF transmit power
- DC voltages in equipment
- Pilot levels
- DC battery liquid levels and specific gravity
- Operation of standby power systems
- Alarm and control functions

2. <u>Periodic Maintenance</u>

Preventive maintenance of microwave system equipment should be performed at periodic intervals, such as weekly, monthly, quarterly, etc. The possibility of occurrence of trouble in equipment can be reduced greatly by following a definitive preventive maintenance schedule. The schedule should provide for visiting each station at the designated time intervals to make routine checks and to correct any conditions which might otherwise lead to failure. The inspector should make certain that the entire station is kept clean, and that the equipment is kept free from dust, dirt and corrosion. Personnel should perform the minor duties of maintenance and refer all faults requiring specialized attention to qualified maintenance personnel.

It is essential that a complete system check and station inspection be conducted at regular short intervals, i.e. weekly after the system is first installed. This procedure will expose the actual operational characteristics of the system such as fading trends and infantile failures. To accomplish the weekly maintenance procedures, it may be necessary to interrupt service for an interval of time, the length of the interval depending upon the particular equipment being checked. If service must be interrupted for this maintenance, tests should be scheduled during hours when communications traffic is normally light. It is also important that the scheduled maintenance be performed at the designated time.

Once a system has been installed and operated successfully for a period of several months, the weekly tests can be reduced to a minimum. On some systems, this may be limited to weekly site visits to read minor meter functions and check for any obvious physical damage to the site. An old addage states "If it works, don't fix it." Weekly tests can be also extended to bi-weekly checks or checks due only to reported failures.

Monthly tests are normally more extensive. In general, monthly maintenance includes all checks performed during the weekly maintenance inspection and, in addition, other pertinent measurements required to check the overall system, condition and performance. Such additional tests are designed to ensure continued operation of the system and are not extensive in technical depth. They include:

- Basic operation of all transmitters, receivers and switching
- Functioning of the alarm and control system
- Continuity of the orderwire system
- Operation of standby power system
- Mechanical integrity of the building, tower, fencing, gates etc.

More extensive system operational testing should be done at longer intervals. Such tests are commonly done on quarterly to yearly schedules. Semiannual testing is usually adequate. During the semiannual testing tests are conducted to thoroughly examine performance of all equipment. Typical tests are:

- Delay and linearity of RF and modem equipment
- Complete system level check
- Tower guy wire tension
- Noise performance throughout the system
- All diversity switching operations
- Thorough examination of power systems
- Performance of all alarm and control systems

- Physical and electrical examinations
- Updating of all maintenance records
- Examination of all data for performance trends of equipment and system
- Debugging of all equipment where tests fail to meet specification objectives

During the semiannual testing, it is advisable to investigate the less obvious sources of system degradation if trouble is not otherwise resolved. Among such tests are:

- Recordings of receive carrier levels to examine fading performance
- Alignment of antennas if median receive levels are low
- VSWR's in RF and IF subsystems
- Level of prime power drain of equipment and level fluctuations
- RF intermodulation in antenna/transmission line system (due to corrosion, etc.)
- Examination for potential foreign RF interference signals
- Phase and level disturbances due to poor DADEing

As indicated, the semiannual testing program should be as comprehensive as is practical. The maintenance team should examine all records, station logs etc. for obvious faults as well as system performance trends. In this test program the team should address all problem areas, resolve all technical problems, make recommendations for changes in the maintenance program as appears necessary, revise logistics requirements such as spare parts, test equipment etc. and in general optimize the system from technical and logistic support viewpoints. Whether the test program is conducted quarterly, semiannually or at greater intervals, it should be a time of addressing fully all the performance objectives of the system as originally designed and/or subsequently modified. The program should be thought of as a complete "house cleaning".

3. Continuous Maintenance

The majority of the maintenance activity in a microwave system is often the day to day trouble shooting. This may be in response to trouble reports or internal system monitoring systems.

The maintenance program should have a well constituted reporting system for trouble shooting. Records are kept of fault reporting times, trouble description, personnel involved, solutions, restoral time etc. The records often become vital in debugging system faults. The amount of information to be recorded can become extensive depending on system size and complexity as well as borrower management requirements. The significant importance of the records should not be overlooked, however.

In recent years, the microwave industry has seen the significant growth of continuous performance monitoring systems. Essentially the systems contain unmanned equipment that monitors various system parameters and continuously records testing results on punched tape, hard printed copy or magnetic tape. Some systems also have alarm outputs to alert O&M personnel when specified testing limits are exceeded. These systems are often invaluable in monitoring system trends and isolating faults.

One type of monitoring system involves a device that automatically measures a number of channel operating parameters in a voice channel and records the results. Typical tests are test tone, harmonic distortion, frequency response, delay etc. After testing one channel, the device cycles to the next channel or to the next unoccupied channel. The device has some practical application but requires that all channels be wired through the device. It also requires some sort of equipment at the opposite end of each channel to perform operations like loop backs to return the test tone(s) for analysis. Another disadvantage is the fact that the device performs only spot checks on each channel and may miss intermittent trouble.

Another approach to continuous testing is to monitor a given channel continuously. By monitoring certain channel parameters it is possible to indirectly monitor the whole system for most common faults. The more important parameters are test tone level, tone stability, noise and phase displacement. These 4 parameters are indicative of the performance of the radio, mux and radio path. Harmonic distortion, frequency response and envelope delay of a voice channel are measurements of only the mux and associated voice equipment for just that channel. Monitoring test tone level and stability, noise and phase displacement on the other hand will indicate a wide number of system troubles. See Figure III-1 for a brief summary of fault indications.

Measured Parameter	Type of Degradation	Potential Faults Indicated
Test Tone Level	Steady state high or low level	• Maladjusted equipment • Incorrect terminations
Test Tone Stability	Fluctuating levels	• Frequency selective fading • Poor mux level regulation • Unequal baseband levels between switched diversity paths • Equipment faults such as unstable amplifiers
	Drop outs (Complete loss, usually momentary)	• Break in continuity of the system • All diversity paths cut due to high noise on all paths • Excessive level fluctuations (see above) • Intermittent connections (wires, cables, connectors, tracts on PC boards, etc.) • Improperly functioning diversity switches (i.e. break before make)
Noise	Steady high noise level	• Noisy radio equipment • Noisy mux equipment • Poor path performance due to damaged antenna system • Poor path performance due to inadequate path design • Other steady state contributing source of noise like interference, intermodulation etc.
	Fluctuating level	• Unstable equipment • Receive signal fading • Intermittent interference • Multipath • Structural instability of antenna
	Impulse	• Improperly designed or functioning switching (usually RF for IF switching) • External inducements such as power line transients, DC pulses from teleprinters

Measured Parameter	Type of Degradation	Potential Faults Indicated
Phase Displacement	Slow drift	• Moderate to severe temperature changes of equipment • Could also be caused by changes in path length due to swings in climatic conditions • Slow degradation of equipment
	Fluctuations	• Unstable equipment, usually mux carrier equipment • Frequency selective fading • May indicate diversity switches are not switching to the better signal. For example, if one signal fades badly in a frequency selective mode and the diversity switch does not operate, phase fluctuations can occur.
	Discrete jumps	• Improperly DADE'd RF systems being switched • Sudden shift from one signal to another under multipath conditions • Intermittent equipment troubles • Improperly DADE'd mux where redundant units are provided. For example, some mux is provided with redundant MSG equipment. Pilot sensors will switch equipment if the pilot is lost.

Figure III-1 Fault Detection Using Continuous Monitors

To facilitate continuous or occasional monitoring of systems, it is often useful to send a tone or signal down a channel and have the signal returned from the distant end for analytic purposes. To provide this, remote sensing units are often attached to the distant circuit end. A control tone is sent down the circuit, the remote sensor detects the tone and activates a relay looping back the channel. These remote sensors can be strategically situated throughout the system to aid in isolating faults remotely. Each sensor on a circuit can be activated by a different frequency tone or be selectively addressed digitally using a different code for each sensor. This approach can significantly reduce man days spent in the field attempting to detect and isolate faults.

D. Test and Evaluation

Test and evaluation is a quality assurance tool for evaluating the status, performance level, and operability of a communications system. The ultimate purpose of test and evaluation is to quantitatively ascertain the system's current capabilities for subsequent comparison to performance standards for a specific grade of service. Additionally, the data gathered as a result of test and evaluation may be further used to determine both the onset of potential equipment malfunction, and the system's performance during periods of gradual degradation. The parameters listed herein were derived from a set of overall performance parameters useful in determining the performance of microwave systems.

1. Significant Performance Parameters

Significant performance parameters are those characteristics which provide a measure or indication of the performance of an equipment unit, major subsystems, or the system itself. The following are indicative of such parameters, but are by no means exhaustive.

- Availability/Reliability
- Noise performance
- Median receive carrier levels and fading performance
- Voice channel performance characteristics
- Data error rates
- Performance of alarm, control and switching systems

There are numerous other parameters that often must be measured, but this list contains the parameters that most directly affect the performance of a system from the end user's standpoint.

2. Optimum Measurable Parameters

In any given set of conditions, some parameters are more representative than others. For example, if we are speaking of testing at the factory, "optimum measurable parameter" has one context. If, instead, we are concerned with the testing of a system in the field, then the number of measurable parameters is reduced drastically. In the factory voltages at individual transistor leads may be examined. In the field only input power to a unit or subassembly is measured. The most useful or optimum measurable parameters are thus a function of the conditions surrounding the tested item. In practical terms for operation and maintenance this means different tests are performed to isolate and correct a fault depending on the conditions. For example, faults in the field are often corrected by replacing modules in a judicious trial and error procedure. The faulty modules, however, are not examined in detail until brought back to a maintenance depot.

In developing an O&M program the optimum measurable parameters should be identified for all the anticipated fault conditions. This information is used to develop test equipment requirements, spare parts requirements, additional materials lists, tools, etc. The program also distributes these items among the following as required.

- Major maintenance depots
- Minor maintenance depots
- Field teams
- Supply inventory locations
- Individual repeater stations

To accomplish a sensible distribution of the items noted, it is necessary to understand what testing and repairs will be accomplished and where. Optimum measurable parameters for the various conditions involved is a major input to make the distribution decisions.

3. <u>In Service Tests</u>

In microwave systems it is desirable to be able to perform "in service" tests which do not interrupt or disturb traffic. With frequency diversity systems it is possible to access a protection channel and remove all traffic. This frees the protection channel for general testing.

With space diversity systems it is not possible to do this and run any wideband tests that will interfere with the other operating channel since they are both using the same RF frequency.

To overcome the problem of not being able to free one channel for testing in space diversity systems, the microwave industry has developed a number of testing techniques that can be applied to active systems. The most obvious technique is to run tests on one of the traffic channels as discussed above. Another is the use of multitone test sets to measure IM products. See Section II.F.8. Numerous other tests are possible using indirect measurement techniques such as:

- Measurement of AGC voltage to indirectly measure receive level

- Measurement of Tx power using a calibrated waveguide decoupler that extracts a portion of the Tx output

- Measurement of frequency stability by measuring a sample of the oscillator output or phase lock loop voltages if available

- Measurement of system level points via calibrated test points provided in the equipment

- Operating all the diversity switching equipment during periods of no fading

- Simulation of alarms and controls using "test" buttons provided on the equipment.

- Antenna alignment using AGC voltage to detect RF signal strength

In service testing of a given voice channel is possible but not much test equipment has been developed for this purpose. The two tests that are easily accomplished using a bridging meter are idle channel noise (measured during quiet periods) and traffic levels (during active periods). This second test is often quite useful in identifying sources of system overloads.

4. <u>Out-of-Service Tests</u>

A number of tests require access to an entire radio channel. On space diversity systems this means no traffic can be carried on the RF frequency. Among these tests are:

- System DADE'ing

- NPR's across the path

- Delay and linearity end to end

- Transmission system equalization

- Baseband frequency response across the path

- Antenna system VSWR

It is possible to conduct a number of equipment tests by taking the equipment out of service eliminating the diversity path.

For example, an entire receiver or transmitter can be taken out of service and disconnected from the system in order to conduct comprehensive equipment tests and/or calibrations. The same is generally true of all redundant equipment in the system.

5. <u>Acceptance Tests</u>

Acceptance tests are conducted throughout the manufacturing, installation and activation periods of system development. The objective of acceptance testing is to ensure that all system elements and the system as a whole perform according to standards established for the system.

The first step in an acceptance test program is to develop a comprehensive plan with schedules, objectives, standards, procedures and tolerances. It is vital to establish all these criteria before a given phase of system development occurs in order to ensure smooth system development. Typically, the initial part of the plan specifies the performance standards of the entire system in general terms. This is followed by like standards for the various subsystems, components or elements that directly affect overall system performance. Then, detailed testing procedures are developed for factory tests and initial checkout of equipment upon delivery. This part of the plan is also accompanied by a schedule agreed to by all parties concerned. The factory tests are normally established by the manufacturer. Customers usually witness only the final production line acceptance tests in the factory and not the intermediate tests such as component evaluations before assembly. The factory tests of significance are:

- Equipment electrical performance
- Mechanical integrity
- Visual inspection of component manufacture and assembly
- Verification of drawings and documentation
- Environmental testing (dust, shock, humidity, altitude, and temperature variation exposures as applicable)
- Packing and shipping procedures (optional)

The initial acceptance tests conducted upon delivery are designed to ensure that the delivered items are complete and working. One conducts the following inspections and tests:

- Verify accuracy of invoice for contents and destination. This is commonly done by cross referencing the bill of materials lists.

- Match invoice with delivered contents noting discrepancies

- Physical inspection of contents for shipping damage, corrosion, mechanical integrity etc.

- Electrical tests as applicable

These tests are normally "stand alone" tests designed to confirm the correctness of the delivery and basic operability of the equipment.

The next major category of acceptance tests is contained in the system Final Acceptance Test Program. This program is a comprehensive analysis of the entire system conducted after the system is installed. The primary steps taken in the development and execution of the program are:

- Establishment of system performance criteria. This includes performance objectives and test limits.

- Test procedures for all tests including step by step instructions and clear delineation of test equipment used

- Development of test forms describing in detail the data to be collected

- Testing schedule

- Specific guidelines for the allowance of system/equipment failures and/or adjustments during the test period

In defining a final Acceptance Test Program, one should keep in mind that the program is usually one of the bases upon which the borrower judges whether the system is acceptable or not. In this light, it should be clearly stated what constitutes completion of the program. Often, it is advisable to accept equipments or subsystems separately. This is particularly true if system elements are purchased from more than one contractor. Therefore, formal acceptance of equipment should be keyed to successful completion of specific tests.

IV. GLOSSARY OF TERMS

AGC - Automatic Gain Control

AM - Amplitude Modulation

Absolute Delay - Length of time for a signal to travel through a given segment of a system, subsystem, component etc.

Attenuate - Decrease the power level of a signal

Availability - Percent of time a system, subsystem, channel etc. is functioning properly

B - Bandwidth

BINR - Basic Internal Noise Ratio - term used in conjunction with NPR tests

BITE - Built In Test Equipment

BOM - Bill of Materials

Back to Back - Term used to indicate a test set up in which equipment is looped back at some intermediate point

Bandpass Filter - Filter that passes only a restricted spectrum

Bandstop Filter - Filter that blocks or greatly attenuates a given frequency while passing adjacent frequencies

Bandwidth - Difference between the highest and lowest frequency of a continuous spectrum

Baseband - The composite of all the signals modulating a given carrier

Bessel Function - Complex mathematical set of curves used to determine the value of sidebands in FM systems

Bit - Binary digit

Block and Level Diagram - Simplified drawing of a system, subsystem etc. that shows the standard energy level at various points; impedances are also commonly shown

Bridging - Attaching of a device with a very high input impedance to a test point

C - Carrier

CCITT - International Telegraph and Telephone Consultative Committee; part of ITU

CCTV - Closed Circuit Television; television system with limited distribution

C/N, CNR - Carrier to Noise Ratio

Channel Capacity - Number of independent channels a system is able to carry

Chn, Chan - Channel

D - Distance, usually in miles or kilometers

DADE - Differential Amplitude Delay Equalization - process of adjusting a number of parallel transmission paths for equal absolute delay

dB - Decibel = 1/10 Bel

$$= 10 \operatorname{Log}_{10}\left(\frac{P_1}{P_2}\right)$$

where P_1/P_2 is the ratio between two power levels; in terms of voltages

$$dB = 20 \operatorname{Log}_{10}\left(\frac{V_1}{V_2}\right)$$

dBa - Weighted noise measurement using an FIA weighting filter

dBaO - dBa measurement relative to a reference of -85 dBm of noise that is weighted with an FIA filter

dBm - dB relative to one milliwatt; 0 dBm equals one milliwatt

dBmO - Logarithmic power measurement relative to one milliwatt, i.e. +16 dBmO = 40 milliwatts

dBmOp - Noise power measurement of psophometrically weighted noise relative to 0 dBm

dBr - Power measurement relative to some arbitrary reference; 0 dBm is often assumed to be that reference; in such a case dBr is equivalent to dBmO.

dBrn - Unweighted noise power level relative to -90 dBm; i.e. -14 dBm of noise equals 76 dBrn

dBrnC, dBrnc - "C-Message" weighted noise power level relative to -90 dBm

dBrnCO, dBrncO - "C-Message" weighted noise power level relative to -90 dBm in a circuit with a test tone level adjusted to 0 dBm dBW - dB power level relative to one Watt

dN/dh - Gradient of radio refractivity with altitude

DSB - Double Sideband; used to describe an AM signal with both sidebands present

DUV - Data Under Voice; a transmission technique which places wideband data below FDM channels in the baseband

Data Block, Data Word - Set of data of fixed length

Data Error Rate - Ratio of erred transmissions to sent transmissions

Deemphasis - Process used in FM receivers to flatten the frequency response of the baseband

Delay Distortion - Variation with frequency in the absolute delay of a transmission path

Deviation - Term used in frequency modulation systems; a measure of the amount of change in frequency

Digital - Adjective describing systems or equipment that use, generate etc. digits

Discriminator - Device used in FM receivers to convert an FM signal to a baseband signal

Drop and Insert - Process of extracting and inserting baseband information into an FM wideband signal without demodulating the FM signal

E&M - Signal control leads used in telephony supervision and signaling

End User - The originator or final recipient of signals passing through a communications system

Equalizer - Device that counterbalances distortion in a channel in an attempt to achieve an undistorted circuit

FAA - Federal Aviation Administration; the FAA has jurisdiction over tower construction

FCC - Federal Communications Commission; regulates the use of all interstate communications

FDM - Frequency Division Multiplex; used to combine many independent signals into one wideband signal

FDMFM, FDM-FM - Frequency modulated system carrying an FDM signal

F, f - Frequency

FM - Frequency Modulation

FSK - Frequency Shift Keying; modulation technique whereby shifts in data levels cause a discrete shift of frequency of the modulated carrier

Fade Margin - The difference between the normal RF receiver input level and the minimum acceptable level

Frequency Response - Measure of amplitude response over a range of frequencies

Frequency Stability - A measure of a frequency generating device's tendency to drift in frequency; frequency stability is measured in drift as a percent of the generated frequency over a specified period of time

G - Gain; expressed either as a ratio of output to input levels in arithmetic or logarithmic terms

GHz - Gigahertz = 10^9 Hz

GP - Group; a modulation step in FDM multiplex; 12 voice channels are combined to form one group

HF - High Frequency; range of radio frequencies from 3 to 30 mHz

Hz - Hertz; term introduced in the mid 1960's to replace the term "cycles per second"

Hard Copy - Term used to describe all forms of permanent copies of information on paper, as opposed to information on TV screens, audible information, display boards etc.

Hop - Term used in microwave systems meaning a radio path

Hot Standby - Redundancy scheme where redundant equipment is provided to take over a function in case of failure of an operating piece of equipment; in hot standby systems, the redundant equipment is not in service until a failure occurs

IDF - Intermediate Distribution Frame

IF, if - Intermediate Frequency; in microwave 70 mHz is commonly used as an IF

IM - Intermodulation or intermodulation products

ITU - International Telecommunication Union; an organization of the United Nations that deals with telecommunications policies, procedures etc. on a worldwide basis

Idle Noise - Noise in a channel otherwise unoccupied

Isolator - A one way transmission device used in microwave transmission lines and RF branching; an isolator is equivalent to a circulator with one port terminated in an absorbing load

K - 1) Degrees Kelvin; 2) the ratio of the earth's effective radius to actual radius; 3) Boltzman's constant, $1.38 + 10^{-23}$ joules per degree kelvin

kHz - Kilohertz = 1000 Hz

KTB - Black body radiation level;
K = Boltzman's constant
T = Temperature in degrees kelvin
B = Bandwidth in hertz

L.O. - Local Oscillator; frequency generator used in receivers and transmitters in mixing process

LOW - Local Order Wire

LSB - Lower Sideband; term used in AM

Latitude - Geographic distance in degrees from the Equator

Limiter - A device in an FM receiver that eliminates AM components of an FM signal

Linearity - Complex form of frequency response; linearity is a measure of a device or system's ability to transmit a modulating tone through the system as the modulated carrier is shifted in frequency across the passband of the system. At the receive end the modulating tone is extracted from the carrier and a plot is made of the tone's amplitude versus frequency of the carrier.

Longitude - Geographic distance in degrees from a North- South reference line that passes through Greenwich, England

Loop Converter - Device used in telephony to interface DC supervisory/signaling signals that use different standards

m - Meter, milli

MDF - Main Distribution Frame

MHz - Megahertz - 10^6 Hertz

ms - Milliseconds = 10^{-3} seconds

MSG - Mastersupergroup; step of modulation used in FDM

MTBF - Mean Time Between Failure; term used to describe reliability

MTTR - Mean Time to Repair; a measure of time between the time of a failure to the time of completed repair and restoral

Mux - Acronym for multiplex

M/W - Microwave

Multiplex - Electronic equipment used to combine independent channels into a single channel

Multiplex Hierarchy - The frequency stacking structure of FDM systems

N - Radio refractivity

NF - Noise Figure

NLR - Noise Loading Rating

NPR - Noise Power Ratio

N_s - Radio refractivity at the surface

nsec - Nanosecond = 10^{-9} seconds

NTSC - National Television System Committee; U.S. organization chartered to establish TV transmission standards

Noise Figure - Measure of a device's noise contribution to a signal passing through the device

O&M - Operations and Maintenance

OW - Orderwire

Order Cycle Time (of spare parts)- Amount of time from issuance of order requisition to time of delivery, checkout and resupply of inventory

PABX - Private Automatic Branch Exchange; electronic telephony device used in offices for internal and external calls

PAL - Phase Alternate Lines - European TV color generating systems used in most of Europe, Asia, and Africa. An amplitude modulated (AM) signal.

Parabolic - Adjective used to describe the shape of an antenna reflector; the shape is the rotation of a curve $y = x^2$

Path Clearance - Vertical distance between a microwave radio beam and the ground directly below

Peak Deviation - Maximum swing in frequency of an FM carrier

Pilot - Steady state tone transmitted along with message signals; pilot tones are used to check continuity, level variations etc.

Polarity (of antennas) - Orientation of the antenna's transmitted signal; most microwave antennas orient the signals to be either vertically or horizontally oriented

Preemphasis - Technique of raising the level of channels in the top end of an FDM-FM system to help overcome the high noise level that is inherent in FM systems at the top end of the baseband

RF Branching - System of transmission line parts, circulators and RF filters used to connect various transmitters and receivers to a minimum number of transmission lines

RMS - Route Mean Square; mathematical expression

$$RMS = \sqrt{\sum_{0}^{N} (\overline{X} - X)^2}$$

where $\overline{X}$ is the mean value of all X's

Rx - Receive or receiver

Rack or Bay - Mechanical structure designed to hold equipment

Reference Circuit - A standard example of a channel passing through a system; the reference circuit is used as a guide in determining the amount of noise that should be allowed in a given circuit

Return Loss - Ratio of incident to reflected energy; term is used to describe the level of echoes caused by imperfect impedance matching

Ringing Voltage - Voltage applied to a telephone instrument to cause it to ring; ringing voltage is commonly 20 Hertz, 105 volts

SECAM - Sequential Color and Memory - French TV color generating system utilizing sequential frequency modulated (FM) subcarriers for the color signals.

SF - Single frequency (does not mean signal frequency)

SGP - Supergroup; modulation step in FDM

S/I - Signal to interference ratio

SMG - Supermastergroup; modulation step in FDM

S/N - Signal to noise ratio

SSB, SSBSC - Single Sideband, Single Sideband Suppressed Carrier

Sound Channel - Analog voice channel with a bandpass greater than the normal 300-3400 Hz; sound channels are used to carry broadcast channels to FM, AM and TV broadcast stations

Spectrum - Range of frequencies

Speech Plus - Modulation technique that combines voice and data into a single voice channel

Squelch - To break continuity of a channel or the baseband; normally done in the event of excessive noise

System Figure, SF   SF = S/N + net path loss
S/N = Signal to noise in a voice channel
Net path loss = Loss between Tx output and Rx input
SF is a function of Tx power, Rx noise figure path loss and antenna system gains and losses.

T - Temperature

TE - Termination Equipment

TWT - Traveling Wave Tube; device used to amplify microwave signals

Tx - Transmit or transmitter

Termination - Device used to absorb incident energy

UHF - Ultra-High Frequencies; 300-3000 MHz

USB - Upper Sideband

VCO - Voltage Controlled Oscillator; device whose internal frequency of oscillation can be varied by application of an external voltage

VF - Voice Frequency

VHF - Very High Frequency; 30-300 MHz

VSWR - Voltage Standing Wave Ratio

Video - Adjective describing the devices or systems handling wideband signals such as the visual portion of a TV signal

W - Watts

XOW - Express Orderwire

Zenith Angle - Vertical angle from the horizon to the sun

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International System of Units

In December 1975, Congress passed the "Metric Conversion Act of 1975." This Act declares it to be the policy of the United States to plan and coordinate the use of the metric system.

The metric system, designated as the International System of Units (SI), is presently used by most countries of the world. The system is a modern version of the meter, kilogram, second, ampere (MKSA) system which has been in use for years in various parts of the world.

To promote greater familiarization of the metric system in anticipation of the U.S. converting to the system, REA is including metric units in its publications. This bulletin has, therefore, been prepared with the International System of Units (SI) obtained from ANSI Z 210-1976 - Metric Practice. Approximately equivalent Customary Units are also included to permit ease in reading and usage, and to provide a comparison between the two systems.


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