UNITED STATES DEPARTMENT OF AGRICULTURE
Rural Electrification Administration

BULLETIN 1751H-701

SUBJECT: **Radio System Fundamentals and Point-to-Point Digital Microwave Radio Systems**

TO: Telephone Borrowers
REA Telephone Staff

EFFECTIVE DATE: Date of Approval

EXPIRATION DATE: Three years from the effective date.

OFFICE OF PRIMARY INTEREST: Transmission Branch, Telecommunications Standards Division

PREVIOUS INSTRUCTIONS: This bulletin replaces TE&CM Sections 930, 931, and 932 which are to be rescinded.

FILING INSTRUCTIONS: Discard existing TE&CM Sections 930, 931, and 932 and place this bulletin in Section 1751H, Transmission Design Bulletins.

PURPOSE: To provide basic information on radio telecommunications and specific information on general point-to-point microwave radio systems and on microwave radio propagation. Major emphasis is placed on digital systems, but some information on the carriage of analog television signals is included. This bulletin provides information on FCC frequency allocations and FCC application forms required from system operators. All information in this bulletin is advisory.

[signature]
Acting Administrator

3-16-92
Date

RADIO SYSTEM FUNDAMENTALS AND POINT-TO-POINT DIGITAL MICROWAVE RADIO SYSTEMS

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ACRONYMS AND ABBREVIATIONS
(with Definitions)

AC Alternating current
BER Bit error ratio or bit error rate
BETRS Basic Exchange Telecommunications Radio Service
CFR Code of Federal Regulations
CGSA Cellular Geographic Service Area
dB decibel - a power ratio commonly used by engineers. (Derived from Bel which is the logarithm to the base 10 of the actual power ratio)
dB_m decibels referenced to one milliwatt
DC Direct current
DS1, DS2, DS3 Designations used for digital carrier system line rates
FAA Federal Aviation Administration
FCC Federal Communications Commission
GHz Gigahertz (one billion Hertz)
$\log_{10}$ logarithm to the base 10
Mb/s Megabits (one million bits) per second
MHz Megahertz (one million Hertz)
NOAA National Oceanic and Atmospheric Administration
PCM Pulse Code Modulation
RF Radio frequency
SMRS Specialized Mobile Radio Service
USGS United States Geological Survey
Γ Greek letter gamma used for wavelength in the text
Θ Greek letter theta defined in the text
π 3.1416, a mathematical constant

NOTE: There are more than 50 single letters and combinations of letters used in <u>equations</u> and <u>figures</u> that are explicitly defined in the text. They have no significance outside of this bulletin, and have been arbitrarily chosen to explain some portion of the text.

1. POINT-TO-POINT MICROWAVE RADIO SYSTEMS

1.1 GENERAL

1.1.1 This bulletin is intended to provide REA borrowers, consulting engineers, and other interested parties with information on microwave radio systems and other fundamental topics concerning radio. In particular, it brings together in one place a large amount of basic information on Federal Communications Commission (FCC) requirements. The bulletin is divided into three parts so as to distinguish between three basic topics. All information and recommendations provided in this bulletin are advisory. The bulletin is not intended to be a tutorial. It is assumed that the reader already has a basic concept of radio and its use in electrical communications.

1.1.1.1 The first part discusses the factors affecting the use of microwave equipment currently available and should provide assistance in determining the applicability of microwave for use in telephony.

1.1.1.2 The second part of the bulletin provides technical information which can be used in making preliminary paper designs and economic studies for microwave systems. It discusses in particular the theory of radio path propagation and methods of making microwave path surveys.

1.1.1.3 The third part provides guidelines, information, and recommendations on forms required by the Federal Communications Commission (FCC).

1.1.2 Although emphasis is placed on general point-to-point microwave service, this first part mentions three other fixed microwave services that are licensed by the Federal Communications Commission (FCC) but not normally provided by small independent telephone companies in a rural environment. Two of these provide for point-to-multipoint service but this should not be confused with true area coverage.

1.1.3 Basic Exchange Telecommunications Radio Service (BETRS) and Cellular Radio systems are examples of general subscriber service to a large number of potential subscriber stations distributed throughout a specified geographic area. These provide true area coverage but utilize radio frequencies below microwave frequencies. Area coverage is not included in this part of the bulletin.

1.1.4 The FCC has only recently started on the long process of revising its extensive set of *Code of Federal Regulations* (CFR) volumes to place all referenced terms in the metric system. This process does not entail a simple mathematical conversion calculation. Rather, it involves an adjustment of a regulatory quantity now expressed as a simple (non-decimal) value in feet or miles to a new arbitrary but approximate value in meters or kilometers. Since a major portion of this bulletin discusses FCC requirements it cannot at this time be fully converted to the metric system. This will be accomplished through a revision at a later time. This bulletin is not a specification; nor is it an REA regulatory document.

1.1.5 Most manufacturers of microwave equipment conduct schools to provide technical training for customer maintenance technicians. The test equipment and methods recommended by the microwave supplier should be used to make equipment measurements.

1.2 FEDERAL COMMUNICATIONS COMMISSION REQUIREMENTS

1.2.1 A microwave radio station authorization (license) must be obtained from the FCC prior to commencement of any proposed station construction. All construction must be completed within an 18 month construction period extending from the date of the license grant. The license will specify the termination date of the construction period. The license will be issued for a period not to exceed 10 years. It will normally expire on February 1 in the year of expiration. The FCC reserves the right to grant or renew station licenses for a shorter period of time.

1.2.2 Microwave transmitting equipment must have an equipment authorization from the FCC before a radio station authorization (license) can be obtained. Either the manufacturer or the importer of the transmitting equipment must apply for an equipment authorization before it is offered for sale. Currently, the procedure to be followed for point-to-point microwave radio transmitters is called notification. In the past it was type acceptance. Either procedure will suffice. For more information on FCC equipment authorization procedures see 47 CFR 2.901 through 47 CFR 2.1065. This citation covers subpart J of Part 2 of the FCC Rules and Regulations. A brief discussion of this subpart can be found in paragraph 3.7 of this bulletin.

1.2.3 Part 21 (or 47 CFR 21) of the FCC Rules and Regulations covers the following four services:

(a) Digital Electronic Message Service
(b) Point-to-Point Microwave Radio Service
(c) Local Television Transmission Service
(d) Multipoint Distribution Service

1.2.3.1 Digital electronic message service is a two-way domestic end-to-end fixed radio service utilizing digital termination systems (point-to-multipoint systems consisting of nodal stations and their associated user stations) for the exchange of digital information.

1.2.3.2 Point-to-point microwave radio service is a <u>general</u> domestic public radio service between fixed stations. This service is the major topic being discussed in this bulletin. It is the only FCC Part 21 service currently being offered by REA telephone borrowers.

1.2.3.3 Local television transmission service is a domestic public radio communication service for the transmission of television and related material.

1.2.3.4 Multipoint distribution service is a one-way domestic public fixed radio service from a transmitting station to multiple receiving facilities.

1.2.3.5 The above four services utilize microwave radio frequencies which FCC Part 21 defines as frequencies of 890 MHz and above. They are available to all communication common carriers. The first three may only be used for common carrier purposes. The last may be used for both common carrier and non-common carrier purposes.

1.2.4 An FCC radio station authorization for Point-to-Point Microwave Radio Service may permit the transmission of broadcast television signals, closed circuit television signals and other non-broadcast television signals if the FCC Common Carrier Bureau determines that the applicant does not originate or control the content of the transmission. The FCC may, when certain conditions are met, authorize a radio station that will be used primarily to relay broadcast television signals. The FCC makes the above determinations, not REA.

1.2.5 Frequencies in the following bands may be used by REA borrowers for point-to-point microwave radio service:

(a) 932.5-935 MHz; 941.5-944 MHz
(b) 2110-2130 MHz; 2160 - 2180 MHz
(c) 3700 - 4200 MHz
(d) 5925 - 6425 MHz
(e) 10,550 - 10,565 MHz; 10,615 - 10,630 MHz
(f) 10,700 - 11,700 MHz
(g) 17,700 - 18,820 MHz; 18,920-19,160 MHz; 19,260-19,700 MHz
(h) 21,200 - 21,800 MHz; 22,400 - 23,000 MHz

The bands specified under (a) and (h) have little to offer REA borrowers and, consequently, do not appear in the REA List of Materials. The FCC lists four additional bands for point-to-point microwave radio service but no manufacturing company offers equipment for use at the present time. These bands are: 13,200 - 13,250 MHz; 27,500 - 29,500 MHz; 31,000 - 31,300 MHz and 38,600 - 40,000 MHz. The bands designated under (b) through (h) above are quite often referenced as 2GHz, 4GHz, 6GHz, 10 GHz, 11GHz, 18GHz, and 23 GHz.

1.2.5.1 There are many footnotes associated with the frequency table in 47 CFR 21.701(a) that are too numerous to mention in this bulletin. However, all telephone borrowers and their consulting engineers should become familiar with these footnotes. Many of them are informational in that they indicate other radio services that share the same frequency band. A frequency search (which is always required) will detect possible radio interference.

1.2.6 Bandwidth Limitations for Point-to-Point Microwave Radio. The maximum FCC authorized bandwidth for various radio bands are set forth below:

Frequency Band (MHz)	Maximum Bandwidth (MHz)
932.5 to 935; 941.5 to 944	0.2
2110 to 2130; 2160 to 2180	3.5
3700 to 4200	20.0
5925 to 6425	30.0
10,500 to 10,680	3.75
10,700 to 11,700	40.0
13,200 to 13,250	25.0
17,700 to 18,580; 19,260 to 19,700	220.0
18,580 to 18,820; 18,920 to 19,160	20.0

18,820 to 18,920; 19,160 to 19,260	10.0
21,200 to 22,000; 22,000 to 23,600	100.0
27,500 to 29,500	220.0
31,000 to 31,300	25.0 or 50.0
38,600 to 40,000	50.0

1.2.7 The FCC requires that microwave transmitters employing digital modulation techniques and operating below 20 GHz shall have a bit rate (in bits per second), equal to or greater than the occupied bandwidth in Hertz. Currently available microwave radios usually have spectral efficiencies of 2 to 5 bits per second per Hertz. As can be determined from the preceding table, the bandwidth limitations for 2 GHz and 10 GHz severely limit the capacity obtainable from these units. However, due to new modulation techniques offering high spectral efficiency, 2 GHz microwave radios have recently become available that permit bit streams high enough to handle 288 encoded voice channels.

1.2.8 Limitations on Path Lengths. Radio frequencies in the following bands are not permitted by the FCC to be used on transmission paths shorter than the indicated distances below:

2110 to 2130 MHz; 2160 to 2180 MHz	5km (3.1 miles)
3700 to 4200 MHz	17km (10.56 miles)
5925 to 6425 MHz	17km (10.56 miles)
10,700 to 11,700 MHz	5km (3.1 miles)

The FCC does grant exceptions to these limits if the rule would entail excessive cost in construction or maintenance.

1.2.9 Limitations on Channel Loading. Some of the commonly used frequency bands available to telephone companies under Part 21 regulations have a minimum traffic loading restriction intended to ensure that the radio spectrum is efficiently allocated among different users. These traffic loading restrictions require the prospective microwave user to demonstrate that within a reasonable growth period after installation, the traffic requirements will reach the minimum standard appropriate for licensing in that band.

1.2.9.1 There is one FCC requirement on initial channel loading that may offer problems to telephone borrowers wishing to apply for an initial working radio frequency allocation on the 4 GHz, 6 GHz or 11 GHz bands. An application for an initial working channel over a given route will not be accepted for filing where the anticipated loading (within five years or other period subject to reasonable projection) is less than 900 voice channels. An exception is made, however, for an 11 GHz channel radio that requires a bandwidth less than 20 MHz. The minimum for this case is 240 voice channels. Digital microwave radio equipment is available today at both 6 GHz and 11 GHz that provides 672 channels in a 10 MHz and a 20 MHz bandwidth, respectively. The above limitations were established many years ago in the age of analog microwave.

1.2.10 Digital Electronic Message Service. This is a two-way domestic end-to-end fixed radio service utilizing digital termination systems for the exchange of digital information. It may also make use of point-to-point microwave facilities, microwave satellite facilities or other communications media to interconnect digital termination systems to comprise a network. A digital termination system (DTS) is a point-to-multipoint radio system consisting of digital termination nodal stations and their associated digital termination user stations. They normally exist only in Metropolitan Statistical Areas. The user stations always have directive antennas. The nodal station antenna may be omnidirectional or directional. Only the 10 GHz band (10,550 - 10,680 MHz) and the 18 GHz band (17,700 - 19,700 MHz) are available for use in this common carrier service.

1.2.11 Local Television Transmission Service. Point-to-Point microwave radio can be used to furnish service to radio and television broadcasters as well as cable television system operators. However, the Rural Electrification Act does not permit REA funds to be used for radio broadcasting or commercial cable television. The FCC Common Carrier Bureau permits the use of the 4 GHz, 6 GHz, 11 GHz and 23 GHz bands (listed previously for point-to-point microwave stations) for studio to transmitter links. Separate sets of frequencies are provided for television non-broadcast pickup mobile stations. These are:

6,425 to 6,525 MHz*	21,200 to 22,000 MHz
11,700 to 12,200 MHz*	22,000 to 23,600 MHz
13,200 to 13,250 MHz	31,000 to 31,300 MHz
14,200 to 14,400 MHz*	(* different from above point-to-point microwave bands)

The FCC Mass Media Bureau will assign additional frequencies to common carriers.

1.2.12 Multipoint Distribution Service. This is a one-way domestic public fixed radio service from a station transmitting (usually in an omnidirectional pattern) to multiple receiving facilities. It may be operated as a common carrier or as a non-common carrier service. Although any kind of communication service may be rendered,it is usually used in connection with Instructional Television Service which is licensed by the Mass Media Bureau. Each channel may provide one standard television signal with a bandwidth no greater than 6 MHz for both visual signal and accompanying aural signal. It will normally employ vestigial sideband amplitude modulation for the visual signal and frequency modulation for the accompanying aural signal. Only microwave frequencies are employed for transmission. If the licensee wishes to insure that transmissions will not be received in intelligible form by unauthorized subscribers or licensees, the standard television signal may be varied provided that the encoded information is recoverable without perceptible degradation. The tariff must clearly describe the degree of privacy or security a subscriber can expect in ordinary service.

1.2.12.1 Instructional Television Service utilizes eight 6 MHz channels (designated as E and F Channels) within the band from 2596 to 2644 MHz. The Common Carrier Bureau usually calls this multichannel multipoint distribution service. There are some associated response channels for the reverse direction located in the 18 GHz band. For other types of service (e.g. non-broadcast omnidirectional radio) channels 1 and 2 located in the 2150-2162 MHz band may be used.

1.3 CAPABILITIES OF MICROWAVE

1.3.1 Microwave transmission is generally defined as the transmission of electromagnetic waves whose frequency falls approximately in the range between 1 Gigahertz and 50 Gigahertz (wavelengths of 30 cm to 6 mm). The propagation through the atmosphere of signals in this frequency range exhibits many of the properties of light, such as line-of-sight transmission, reflection from smooth surfaces, etc. Microwave systems have many applications in the telephone industry because high quality circuits can be derived for intertoll trunks, toll connecting trunks, extended area service trunks, subscriber service and special services. Microwave is also suitable for transmission of black and white or color television, data, and data under voice, with negligible impairment from impulse noise, delay distortion, frequency error, frequency response, or steady state noise.

1.3.2 Another attractive aspect of microwave is the ease with which channels can be added or removed after the basic radio frequency (RF) and carrier multiplex equipment is installed. Certain types of RF equipment will carry up to 2000 or more voice channels without any change in the basic RF equipment. The problems associated with cable facilities such as physical damage, induction noise, right-of-way problems, circuit expansion limitations and similar problems are reduced with the use of microwave.

1.3.3 The initial cost of a microwave system depends on the type of radio frequency and multiplex equipment used, the number of channels, the number of hops in a system, the terrain, the type of antennas, the cost of the necessary towers and other factors. In some cases microwave will require a lower initial investment, provide greater reliability, and have lower operating costs and maintenance than cable facilities.

1.3.4 It is highly desirable to use digital microwave equipment for all new installations in order to eventually achieve a complete integrated digital network. The only exception to this would be in the event that a borrower wants to use the microwave equipment to carry television signals. Analog equipment is the best choice for the current standard television channel.

1.3.5 The input and output baseband signal for a digital microwave radio is a single bit stream. This may range from approximately 1.544 Mb/s to approximately 144 Mb/s. The baseband signal is used to modulate a radio frequency carrier. The RF carriers used range from 2 GHz to 24 GHz.

1.4 SITUATIONS WHERE MICROWAVE MAY BE DESIRABLE

1.4.1 There are at least four conditions where microwave will often be more desirable than other types of facilities. These situations are discussed in the following paragraphs.

1.4.2 In some cases the length of a circuit route and the long range estimate of channel requirements will result in the use of microwave being more feasible than cable facilities. The expansion capabilities of microwave are such that many channels can be added without any changes or additional cost for the RF equipment. The cost per channel for additional channels on a microwave system will sometimes be less than for circuits derived on cable facilities, and as more channels are required, the per channel cost will become less.

1.4.3 Another situation where microwave offers definite advantages is in areas of difficult terrain. When communications must be provided in mountainous areas, microwave can usually be provided at less cost than cable facilities. In mountainous areas, the cable route will normally be long since it usually does not take a straight-line path like microwave, but follows a winding road. The necessity of crossing obstacles such as lakes and swamps is made more practical and more economical with the use of microwave, as well as other cases where topographical characteristics make the construction of cable facilities expensive or impossible.

1.4.3.1 In areas where PCM cable carrier is advantageous with the exception of an obstacle such as a lake or section of ground that is too hard for buried cable, digital microwave radio can be used as an "aerial insert" to bypass the obstacle. This application of digital radio allows the PCM signals on the cable to be continued over microwave radio without the need for any analog-to-digital or digital-to-analog conversions.

1.4.4 In many instances it is necessary for one telephone company to connect with another company's toll circuits. When the connecting company derives its toll circuits using microwave, the other company may be required to provide microwave radio and multiplex equipment such that the two systems can meet "mid-air" on a microwave frequency basis; the use of identical or closely similar radio equipment at both ends of such a link is recommended for ease of maintenance and administration between the connecting companies.

1.4.5 Microwave can also be used to provide video circuits. Most microwave equipment has sufficient bandwidth for transmission of the video portion of one television channel over each microwave RF channel. The audio for the television channel can be transmitted over the same RF channel using a subcarrier or it may be carried over a separate facility. Most microwave systems of current design will permit the application of several modulated subcarriers over the video channel without significant degradation. This frequently permits the transmission of FM stereo program material, voice and/or telemetry circuits in addition to the video sound carrier over the same RF channel as the video information.

1.5 COMPONENTS OF A MICROWAVE SYSTEM

1.5.1 Transmitters and Receivers. The basic building blocks of a microwave system are the radio frequency (RF) transmitters and receivers. These units make it possible to send and receive information at microwave frequencies. Most microwave transmitters are capable of an output power of one watt or more. A transmitter used in a terminal location has provisions for modulating the RF carrier with baseband signals from the carrier multiplex equipment. Receivers are capable of providing a useable baseband output with received microwave signal levels as low as -80 dB_m. A terminal receiver includes a demodulator to provide the baseband output to the carrier multiplex.

1.5.2 Carrier Multiplex. The microwave RF equipment has a wide bandwidth which is capable of carrying many channels of information. These channels are derived using multiplex equipment which can combine several hundred channels for transmission over one RF channel in a single bit stream.

1.5.3 Active RF Repeaters. Active or regenerating repeaters are used when the distance between terminal stations is too great to allow a received signal of acceptable level and also when it is necessary to insert and drop channels at points between terminal stations. An active repeater can be used at one or more intermediate points to regenerate the signal or to allow adding or dropping of channels.

1.5.3.1 In the case of digital radio transmission, a digital repeater can best be described as a regenerating repeater, in that the received pulses that are demodulated from the incoming RF frequency trigger the generation of new pulses to be modulated onto the succeeding transmitter, so that any pulse that has been degraded by noise is completely renewed. Thus, even though this process is continued at each repeater, noise and distortion is not added to the system, as in analog radio transmission. The noise and distortion contributed by an analog repeater can become serious in long-haul, high density toll routes where many repeaters are required, and a digital radio system could be more advantageous for this type of radio route. The receivers and transmitters used in a regenerating repeater are the same type as those used at a terminal station, and the repeater can be actually thought of as two terminal stations connected back-to-back at the baseband level. See Figure A1 for a block diagram of a regenerating repeater.

1.5.4 Passive Repeaters. A passive repeater is sometimes required when there is an obstacle such as a high mountain in the line-of-sight microwave path, where the cost, maintenance and power requirements for an active repeater would be prohibitive. The passive repeater is located in such a position as to act as a microwave mirror, reflecting the microwave signal as a mirror reflects a light beam, to bypass the obstruction. A passive repeater may be a large reflecting surface similar to a billboard, or it may be two parabolic antennas connected back-to-back through waveguide. Both types are used to change the direction of a microwave signal. The passive repeater does not use transistors, or other active devices and therefore requires no power source unless heating is necessary to prevent ice from accumulating on the antenna surfaces. See Figure A2.

1.5.4.1 Another type of repeater that is in use is an RF repeater which receives and amplifies a microwave signal and redirects it along another route. It is essentially two parabolic antennas connected back-to-back through a radio frequency amplifier, making this repeater arrangement much more efficient than two parabolic antennas connected directly. The power requirements of the RF repeater are such that solar energy can be used to power the repeater efficiently and economically. In many instances, the cost of this type of repeater is substantially less than the billboard passive repeater.

1.5.5 Antennas. A parabolic or a horn antenna is used in microwave systems to concentrate radiated energy into a narrow beam for transmission through the air. This results in the most efficient transmission of radiated power with a minimum of interference. An effective gain of 25 to 48 dB over an ommi-directional antenna is possible depending upon the size of the antenna and the microwave frequency used.

1.5.6 Radomes. A radome is a protective covering used to prevent snow, ice, water, or debris from accumulating on a microwave antenna. Heated radomes are available for use in areas where severe ice and snow conditions exist. The use of a radome results in lower antenna gain.

1.5.7 Transmission Lines. Transmission lines provide the means of coupling the transmitter and receiver to the antenna. There are two types currently available: waveguide and coaxial cable. The radiated output power of the transmitter will be substantially reduced if the transmission line is incorrectly used or if its length is too long, so precautions should be taken to use the correct type of line for the radio equipment used, and to keep all transmission line lengths short.

1.5.7.1 Waveguide. A waveguide is a hollow metal duct which conducts electo-magnetic energy. This type of transmission line can be used for distances of a few feet up to several hundred feet. A typical type of waveguide has a loss from about 1.7 dB per hundred feet at 6 Gigahertz (GHz) to about 3.0 dB per hundred feet at 11 GHz. It is used at microwave frequencies above 2 GHz and can have either a rectangular, elliptical, or circular cross-section, depending upon the system operation requirements. The length of a waveguide run is more critical at higher frequencies since attenuation increases with frequency. All waveguide runs are pressurized.

1.5.7.2 Coaxial Cable. At low microwave frequencies, 2 Ghz or less, coaxial cable can be used as the connecting facility between the transmitter, receiver and antenna instead of waveguide. The loss of coaxial cable depends on the type of conductor, the cable diameter, the type of dielectric, and the operating frequency. Coaxial cable with a diameter of one inch or more should be used for long cable runs; 7/8" diameter coax can be used satisfactorily for short runs. The coaxial cable can have either a pressurized air or expanded polyethelyne (foam) dielectric between conductors, however, the air dielectric coaxial cable has less attenuation for a given diameter. In general, pressurized air dielectric coaxial cable is used with higher capacity systems because the return loss characteristics of foam dielectric lines may be a significant distortion contributor in such systems. This is not usually a consideration in systems of low channel capacity. The cost of coaxial cable is less than waveguide and should be used when possible. Extreme attenuation of radio signals above 2 GHz in the coaxial cable generally prohibits its use at the higher microwave frequency bands.

1.5.8 Reflectors. A passive reflector can sometimes be used in systems operating near a power substation to avoid the electromagnetic interference (EMI) potential in place of using long runs of waveguide connected to a parabolic antenna at the top of the tower. A reflector may be mounted at a 45 degree angle at the top of the tower, while the antenna is mounted horizontally at the base of the tower, aimed at the reflector. The microwave signal is radiated from the antenna, reflected off the reflector, and sent in a direction of propagation to the other end of the radio path, just as though the antenna was radiating directly from the top of the tower. However, this type "periscope" or "fly swatter" antenna system will not be authorized by the FCC under ordinary circumstances because of its interference potential with communications satellites. A waiver from the FCC is required.

1.5.9 Towers. The towers used in microwave systems must be rigid to prevent antenna deflection during wind or ice loading conditions. Guyed or self-supporting towers are available for use on microwave systems. A guyed tower is about one-third the cost (per foot, installed) of a self-supporting tower, but in some cases the difficulty of acquiring enough land for guying prohibits the use of guyed towers. The height of the tower is determined by the terrain, the microwave frequency band used, the propagation characteristics, the distance between the transmitting and receiving ends of a path, and the required reliability. The tower must be high enough to provide a line-of-sight path above any obstructions. If reflection interference is a problem, the antenna mounting heights are critical and the optimum height may be less than the maximum height available on the tower.

1.5.10 Buildings. Microwave equipment should be located in the central office equipment building when possible. There are some situations, however, when RF equipment must be located remotely from a central office building, as in the case of an active RF repeater. In these situations some type of building must usually be provided for equipment protection. Usually a simple prefabricated building is sufficient. Where temperature and humidity variations exceed the operating limits of the microwave equipment, a heater or air conditioner is required to keep the equipment within its operating temperature range.

1.5.11 Primary and Standby Power Equipment. Primary power sources for RF equipment may be DC or AC as specified by the purchaser. Central office batteries or 117 volts AC commercial power may be used. In some cases, thermoelectric generators or fuel cells can be used when the power requirements of the microwave equipment are low. Standby power equipment should be provided at microwave terminals or active repeater locations to maintain system operation in the event of a commercial power failure. Communication circuits are very important during times of emergency such as storms, floods and other disasters which may cause commercial power outages. Therefore, it is imperative that some type of standby power source be available for circuits derived by microwave. When microwave equipment is located in a central office building, stand-by power is usually available from central office equipment batteries or an engine-generator. However, at remote sites standby power must be provided specifically for the microwave equipment. The stand-by power source may be batteries, an engine-generator or in some cases a thermoelectric generator, fuel cell or solar energy.

1.5.12 Alarm Systems. When a microwave system has remote unattended stations, it is desirable to have an alarm system which will report faults from the remote location to an attended office via the microwave signal. These alarms will expedite the maintenance of microwave systems and reduce the circuit outage time. Where alarms from a large number of unattended stations are reported to a central maintenance control center, consideration is often given to a computer-based alarm reporting system which prints out all changes in status at each station with time and date information.

1.6 MICROWAVE EQUIPMENT ARRANGEMENTS

1.6.1 Basic Equipment Arrangement. A microwave terminal is located at each end of a system and the basic arrangement consists of one transmitter and one receiver. An active regenerating microwave repeater can be thought of as two terminals back-to-back and a basic repeater arrangement consists of two transmitters and two receivers. See Figure A3.

1.6.1.1 The basic equipment arrangement is used when it is not necessary to provide duplicate equipment for protection against path outgages. This arrangement is not necessarily used since standby or diversity equipment is desirable to provide increased system reliability.

1.6.2 Hot Standby Arrangement. Hot standby is an arrangement where two transmitters are on and operating at the same radio frequency but only one is connected to the antenna. If the operating transmitter fails, the second or standby unit is automatically connected to the antenna and the defective transmitter is disconnected. The switching of transmitters occurs in a few milliseconds after sensing equipment has determined that a unit is defective. Two receivers are used and both are permanently connected to the antenna. The two receiver outputs are combined into one resultant signal. See Figure A4 for an example of a hot-standby arrangement. Hot standby provides increased equipment reliability, but does not increase propagation reliability. A variation of the hot standby arrangement involves the main and standby transmitters continuously feeding the antenna in a phase-locked configuration; fault conditions then cause the disconnection of the faulty transmitter. This arrangement has an RF power increase of 3 dB under normal conditions over the single transmitter output.

1.6.3 Space Diversity. For improvements in propagation reliability, a space diversity antenna arrangement can be used. In a space diversity system, one transmitter and its associated antenna radiates on a transmit frequency. This signal is received by two receivers which are tuned to the same frequency but connected to separate antennas located at different positions on the tower. The receiver output signals can be combined to give a composite output, or switching can be done between receivers, keeping the receiver with the best Bit Error Ratio (BER) (in the case of a digital radio system) connected to the line. Vertical spacing between the two receiving antennas should be approximately 60 to 80 feet at 2 GHz, 30 to 40 feet at 6 GHz and 25 to 30 feet at 11 GHz. Space diversity provides a substantial increase in reliability, especially over highly reflective surfaces such as water or desert. The necessity of two receiving antennas, two receiving waveguide runs, strong towers because of the two antennas and a taller tower required to give the necessary antenna spacing tends to make space diversity a more expensive means of increased path reliability. See Figure A5 for a diagram of a space diversity arrangement.

1.6.4 Frequency Diversity. A frequency diversity arrangement can be used at microwave frequencies above 2 GHz when equipment and propagation reliability is desired and required communications cannot practically be achieved by other means. This method increases the total system reliability by providing both path and equipment duplication. Two transmitters are on the air simultaneously and both are modulated with the same baseband signal but are tuned to different radio frequencies. The different frequencies can be either within the same operating frequency band, or in two different operating frequency bands. Both transmitters are connected to the same antenna which radiates the signals to the far-end of the path. At the far-end of the path there are two receivers and each receiver accepts the one incoming signal to which it is tuned. Each receiver then provides as an output the signal which modulated the transmitters. The two outputs are then combined using a combiner device to provide one output signal to the multiplex.

1.6.4.1 A frequency diversity system provides increased equipment reliability as a result of two transmitter-receiver combinations and increased propagation reliability as a result of using two different microwave transmitting frequencies on the air simultaneously. Studies and measurements have been made which indicate that increased propagation reliability is realized when two transmitters with a frequency separation of at least 2% to 5% are used. The amount of frequency separation is mainly determined by the availability of frequencies but the minimum separation for effective propagation protection is generally regarded as 2%. It is difficult to find two frequencies available giving the needed minimum separation.

1.6.4.2 In recent years the FCC has not permitted frequency diversity for digital microwave systems. There are now some indications of a possible change in attitude because of the increasing use of optical fiber on high density routes, resulting in freeing of radio frequencies now held. It is doubtful, however, that the high cost of frequency diversity can be justified for the usual borrower's light rural routes.

1.7 EQUIPMENT PRESENTLY AVAILABLE FOR COMMON CARRIERS

1.7.1 Radio Frequency Equipment. RF equipment is available for the 2, 4, 6, 10, 11, 18 and 23 GHz common carrier microwave frequency bands. This equipment is all solid-state (except for some models that incorporate traveling wave tube final amplifiers for high transmitter power output), has low power consumption, and requires little maintenance. These features are particularly important when using radio in remote areas. As a general guide for design purposes the following path lengths are appropriate:

2 GHz	3 to 40 miles	10 GHz	3 to 20 miles
4 GHz	11 to 30+ miles	11 GHz	3 to 20 miles
6 GHz	11 to 30+ miles	18 GHz	2 to 10 miles

1.7.1.1 2GHz Microwave. Current 2 GHz RF equipment is capable of carrying up to 288 digital multiplex channels on a single polarization. Propagation of radio waves at 2 GHz has higher reliability against multipath and rain fading and is often less subject to ground reflections than higher frequency bands; it is, therefore, preferable in difficult propagation situations. The situations most appropriate for the use of 2 GHz equipment are where only a relatively few trunks are required to serve an exchange, where a few special circuits must be provided for a customer, and where small groups of isolated subscribers are to be provided service. The important point to remember when considering the use of 2 GHz RF equipment is whether it is capable of providing initial and future channel requirements. If a five year forecast shows a greater requirement of circuits than the capacity of 2 GHz equipment, the use of a higher frequency band should be considered. If the minimum five year channel capacity requirements of the higher frequencies cannot be met as specified in the FCC Rules and Regulations, a second RF channel at 2 GHz should be considered.

1.7.1.2 <u>4 GHz Microwave</u>. This band was used primarily by interexchange carriers for long-haul high density toll routes and has not been used very much by independent telephone companies. However, 4 GHz equipment is available to independent telephone companies from some microwave equipment manufacturers.

1.7.1.3 <u>6 GHz Microwave</u>. 6 GHz RF equipment can be used to carry a large number of channels for long distances. Radio paths at 6 GHz can be longer than paths at 11 Ghz because the 6 Ghz radio wave is not affected as much by rain attenuation. High quality circuits for short, as well as, long haul applications can be obtained. The capacity of current 6 Ghz equipment is 672, 1344 and 2016 channels, using bandwidths of 10 MHz, 20 MHz, and 30 MHz.

1.7.1.4 <u>10 GHz Microwave</u>. In addition to point-to-point microwave the same radio may be used for digital electronic message service. At ideal sites it is possible to engineer path lengths up to 30 miles. However, it is affected by high rain rates. It is not difficult to find available frequencies since they have only recently been made available for point-to-point microwave service.

1.7.1.5 <u>11 GHz Microwave</u>. The capacities of current 11 GHz equipment are identical to those obtainable for 6 Ghz; however, the bandwidths are usually 20 Mhz, 30 MHz, and 40 MHz. The path lengths may be as short as 3 miles. The maximum path length depends on the amount of expected rainfall intensity over the area to be served. The worst areas are those near the Gulf of Mexico and the Atlantic Ocean in the Southeastern part of the United States. (See the discussion on Fading in section 2.8 of this bulletin.) Propagation studies should be made to determine the effect of rainfall over each contemplated path. Satisfactory service is obtainable throughout most of the United States if path lengths do not exceed 20 miles.

1.7.1.6 <u>18 GHz Microwave</u>. When intense rainfall is expected there will be a much greater amount of attenuation at 18 GHz than at 11 Ghz. It is not recommended for the worst areas mentioned above. However, since the required antennas are small and relatively light in weight it is possible to engineer a considerably lower cost system at these frequencies. Satisfactory operation may be obtained in most areas of the United States if path lengths do not exceed 10 miles.

1.7.2 Digital Multiplexing Equipment is used to derive voice or equivalent channels on the microwave baseband. The channels are time-division multiplexed onto the baseband carrier. The equipment can be used to derive a few channels or hundreds of channels. Some types of equipment are used to derive toll, extended area service, data or various special circuits while other types can be used for subscriber service.

1.7.2.1 Pulse Code Modulation (PCM) carrier can be transmitted over microwave radio at a DS1, DS2, DS3, or higher rate. The PCM carrier is phase modulated onto the RF carrier. There are many techniques used with the modulations of the radio to increase digital channel capacity. All digital carrier multiplex used for trunk circuits are the T type, which uses eight-bit pulse-code-modulation to convey signalling and message information. A compatible end-to-end transmitted bit rate must be realized in order to synchronize clock circuits that decode and encode information in a timed manner. For T carrier, an increase of channel capacity increases the transmitted bit rate, which in turn increases the RF spectrum that is occupied by the carrier signal. The digital channel is given a slot in time. For additional information see Bulletin 1751H-403.

1.8 MICROWAVE SYSTEM CONSIDERATIONS

1.8.1 The design of a microwave system involves engineering for adequate technical operating specifications at minimum cost. It is possible to over-engineer a system at great expense, when the same operating results could have been obtained without a lot of extras added and at less cost. Several design approaches should be examined before making a final decision. This can be done by examining different tower heights, different antenna sizes, different repeater locations, and different frequency bands.

1.8.2 Microwave system designs and costs are usually based on either ideal or average radio frequency propagation conditions. Ideal and average propagation conditions refer to the atmospheric conditions which are prevalent in an area. Ideal propagation is generally prevalent in hilly and mountainous areas where the air is in constant turbulence, ground reflections of the radio waves are at a minimum, and the radio wave is not diffracted from its line-of-sight path. This type path is economical to design for acceptable reliability. Average propagation conditions occur over plains and rolling hills where multipath reflections and radio beam diffraction occur more often. System design considerations must include the probability of these occurrences, increasing overall system cost. In some cases, paths with ideal propagation conditions will require a passive repeater to bypass obstacles such as mountains in the path. The cost of these paths may be higher than for a system over a path with average propagation which has no obstacles. Paths that go over bodies of water or flat land, or are in areas of high humidity are in the worst case propagation conditions and usually require special considerations, such as the use of space diversity, for protection against fading outages.

1.8.3 A digital radio system has three distinct advantages over an analog radio system: less degradation of quality due to fades above threshold, easy interface with PCM carrier and lower costs when adding channels.

1.8.4 For actual up-to-date costs, the various suppliers of microwave equipment should be consulted. To price a microwave system add the individual system components cost plus 20% to cover installation and contingencies. Costs for land, towers, passive repeaters, power, generators or other components which will be included in the system must also be added to estimate the complete system cost.

1.8.5 Reliability or availability of a digital microwave radio path relates to the time a given microwave link is operational during a specified period of time, typically a year. One should expect to achieve a reliability (or availability) of 99.99% or better. The following table illustrates the relationship between outage time and reliability:

RELIABILITY %	OUTAGE TIME %	OUTAGE TIME PER YEAR	OUTAGE TIME PER 3 MONTH FADE PERIOD	OUTAGE TIME PER MONTH (Avg.)	OUTAGE TIME PER DAY (Avg.)
99.9	0.1	8.8 hours	2.2 hours	43 minutes	1.44 minutes
99.99	0.01	53 minutes	13 minutes	4.3 minutes	8.6 seconds
99.999	0.001	5.3 minutes	1.3 minutes	26 seconds	0.86 seconds
99.9999	0.0001	32 seconds	8 seconds	2.6 seconds	0.086 seconds

2. MICROWAVE RADIO PROPAGATION AND PATH SURVEYS

2.1 CHARACTERISTICS OF MICROWAVE TRANSMISSION

2.1.1 Microwave frequencies are generally defined as those frequencies which have a wavelength short enough to display many of the properties of light waves. A wavelength of 30 centimeters (approximately a foot) or less is considered to be in the microwave region. Microwave energy may be refracted, diffracted, reflected, or absorbed. The direct rays of the radiated energy travel essentially in a straight line and there is little reflection from the ionospheric layers in the upper atmosphere. Because of the short wavelength of microwaves, the radiated energy can be concentrated by relatively small antennas into a narrow beam similar to that of a searchlight. Microwave energy can be obstructed or attenuated by solid objects such as trees, buildings, and mountains. It is for these reasons that microwave communication is almost always limited to unobstructed line-of-sight paths.

2.2 LOCATION OF STATIONS AND PATH SURVEYS

2.2.1 As soon as the points are determined between which microwave communication will be established, topographic maps should be obtained that show the contour lines of the area over which the microwave path is to traverse. Topographic maps can be ordered from the U.S. Geological Survey at either of two locations: (a) USGS Map Sales, Box 25286, Denver, CO 80225; Telephone (303) 236-7477 or (b) USGS Map Sales, National Center, Reston, VA 22092; Telephone (703) 648-6892 or (800) USA-MAPS [800-872-6277]. Free map indexes and information on computer generated topographic data files are available on request at these locations.

2.2.2 A microwave system manufacturer has the capability of performing a path survey. The survey for a <u>digital</u> system is usually based on the percentage of time that a given radio path is available for satisfactory performance with a specified bit error ratio. There are three or four contract service organizations in the United States that specialize in frequency coordination matters. Their work is accepted by the FCC.

2.3 LOCATION OF ANTENNA SITES

2.3.1 In general, the antenna sites should be located on high points so that there will be a line-of-sight path with some clearance over the intervening terrain between the transmitting and receiving antennas. The clearance required at any point along the path will depend upon the frequency used and the distance of the point from the ends of the path. The method of determining the clearance is discussed in paragraph 2.4.

2.3.2 The site's contour and soil characteristics, accessibility by all-weather roads, and availability of primary power should be determined and evaluated with respect to cost. In most cases it is less expensive to provide a taller tower at a site that is easily accessible than to build roads and power lines to a point of higher elevation. Passive repeaters can be used to an advantage in many cases. The active equipment can be placed near roads and power while at the same time adequate clearance (for the proposed path) is provided by the passive repeater. Passive repeaters are radio reflecting surfaces placed in a microwave path to reflect the signal around or over some obstruction. Passive repeaters are particularly effective in mountainous regions and in urban areas where nearby obstructions such as a mountain or building can be used to an advantage as a support for the passive repeater. The total path loss when passive repeaters are used is a function of the product of the individual leg lengths. Because of this, passive repeaters are most often used near the end of the path. Application manuals can be obtained from the suppliers of passive repeaters.

2.3.3 A site should be considered with respect to the availability and cost of land and applicable zoning regulations. The proximity of a potential site to an airport should be determined. Part 17 of the Federal Communications Commission rules should be consulted to determine the maximum tower height allowed at the location chosen.

2.3.4 Possible radio interference should also be a prime consideration in the selection of microwave sites. Before any large amounts of money are expended for the acquisition of sites or final path engineering, a study should be made of existing and proposed microwave systems in the area and alternate sites selected if a possibility of harmful interference exists. After a study of existing microwave systems is made, frequencies can be selected and sites located which will reduce the interference from other stations.

2.4 PATH PROFILE

2.4.1 If the selected station sites appear desirable from the general considerations under paragraph 2.3, the profile of the terrain between the proposed tower sites should be plotted. The path profile may be plotted on rectangular graph paper or on special curved coordinate graph paper. The three basic profile plotting methods are discussed in paragraph 2.4.3.

2.4.2 The potential tower sites for each microwave terminal station should first be accurately located on a recent topographic map. A straight line path should be drawn between the two sites and marked off in increments of one mile. The elevation points at the ends of the path and at each one mile increment are then transferred to the graph paper on which the profile is being plotted. If there are higher elevation points between the one mile increment marks, these points should also be plotted on the path profile. After the straight line path between the two sites has been plotted, it can be determined if a line-of-sight path can be achieved without requiring excessively tall towers. If the first direct path profile reveals that a path is not possible using that route, alternate path routes between the two sites should be plotted to determine if a more feasible path is possible. If a direct path between the sites cannot be provided, locations for active or passive repeater stations should be determined at points of high elevation. Profile plots can then be made between each end of the path and the potential repeater points and the path selected which will provide adequate clearance with minimum tower heights. The repeater location should be chosen on the basis of path clearance and the considerations of paragraphs 2.3.2, and 2.3.3.

2.4.3 The three methods generally used when plotting microwave path profiles are discussed in the following paragraphs:

2.4.3.1 The path profile can be plotted on transparent rectangular graph paper which represents a flat earth. Templates with curves which take into account the earth's curvature and the effects of refraction (refer to paragraph 2.5) on the beam are available from most microwave equipment manufacturers. It is extremely important that the vertical and horizontal scales indicated on the templates not be changed since errors are introduced if this is done. The line representing the beam would have a curvature of KR, where K is an equivalent earth factor accounting for the effects of refraction and R is the radius of the earth. The transparent graph paper with the profile plotted to the same scale as the template can be laid over the appropriate curve and critical points marked on the path profile. Figure B1 shows an example of a profile plot on rectangular paper with the microwave beam drawn with a true earth curvature (K = 1). (The points A, B, C, D and the Fresnel zone clearances shown on Figures B1, B2 and B3 will be discussed in paragraphs 2.6 and 2.10.)

2.4.3.2 A second method also using rectangular graph paper to plot the path profile is sometimes used. This method uses calculated corrections to account for the earth's curvature and refraction rather than a curved beam. Corrections are added above objects in the path to account for the curvature of the earth and refraction. The microwave beam is then drawn as a straight line. The correction to be added above a point in the path may be obtained from the following formula:

$$H = \frac{2d_1d_2}{3K} \qquad (2:1)$$

where the added height H is in feet, d_1 and d_2 (the distances from the point to each end of the path) are in miles. K is the equivalent earth radius factor. Therefore, trees and other high points of a path would be increased by the amount of H to take into consideration the earth's curvature and refraction. Corrections for the case of true earth curvature (K = 1) are indicated on Figure B2 by the dashed line AB. The earth profile is the same as used in Figure B1.

2.4.3.3 A third method of plotting profiles is to use curved graph paper which represents the appropriate KR curvature to account for refraction and the earth's curvature. The microwave beam is drawn as a straight line. This curved graph paper can be obtained from some suppliers of microwave equipment. No corrections are necessary since the curved paper has already accounted for refraction and the earth's curvature. Figure B3 shows a typical path profile plotted with a true earth curvature (K = 1). The center of the path must be centered on the curved graph paper to avoid errors. Figure B3 is the same earth profile as used for Figures B1 and B2.

2.4.4 The proposed path should be checked in the field since the contour lines on the map could be in error or obstructions such as trees (seasonal) or buildings not shown on the map may be in the path. Such obstructions should be taken into consideration in determining the tower locations and tower heights. The possibility of future building construction should also be considered at this time. A sensitive barometric altimeter may be used to take elevation reading along a proposed path. When a barometric altimeter is used, the manufacturer's instruction pertaining to the use of the instrument should be carefully followed to reduce errors.

2.4.5 The path may also be checked at night by the use of lights mounted on portable towers or balloons. Mirrors can be used to advantage during daylight hours. If a long path is checked by optical means, it should be done when the air is in motion rather than still since normal propagation is prevalent on windy days when the atmosphere is thoroughly mixed.

2.4.6 Microwave path planning kits can be obtained from most microwave equipment suppliers at no charge. These kits contain the necessary graph paper and information to plot a path profile. Not all microwave suppliers use the same technique to account for earth curvature and refraction, but one of the three procedures mentioned in the preceding paragraphs is used by major equipment suppliers.

2.4.7 The methods discussed should be adequate for making a preliminary survey to determine the feasibility of using microwave as well as to locate potential station sites. If the preliminary survey does indicate feasibility, it may be desirable to have an organization specializing in laying out microwave systems make a more detailed survey. In most cases the microwave equipment supplier will make a detailed survey before installation of the system.

2.5 REFRACTION

2.5.1 Refraction is one of the factors that must be considered when determining microwave path clearance. Under normal propagation conditions refraction results in the bending of the microwave beam beyond the optical horizon in the direction of the earth's curvature.

2.5.2 As a radio wave front moves forward, it will travel in a straight line if all points on the front travel at the same velocity. In air of uniform pressure, temperature and relative humidity all points on a wave front would travel at the same velocity. Since the pressure, temperature and relative humidity of the atmosphere are not uniform, but normally decrease with height, the upper portion of the wave front travels slightly faster than the lower portion as it moves forward. The difference in velocity causes the wave, under normal conditions, to be bent or refracted toward the earth. This is the reason that when a path profile is plotted, the radius of the earth must be corrected for refraction by the appropriate "K" factor.

2.5.3 The greater the difference in velocity between the upper and lower portions of the wave front, the more a wave will be bent toward the air having the highest index of refraction. The amount of bending thus depends upon the index of refraction of the air through which the wave front passes. The index of refraction varies with relative humidity, temperature, pressure, movement of air and other factors. The variation of these factors from minute-to-minute and day-to-day causes the amount of bending of a wave front to fluctuate.

2.5.4 Since normal atmospheric refraction results in the microwave beam being bent downward, this effect is the same as a change in the earth's radius and is expressed in terms of an equivalent earth radius factor K. The actual earth's radius multiplied by the K factor represents a fictitious earth with a radius which accounts for the refractive index. A factor of K = 1 would be the case where the curvatures of the actual earth and the effective earth are equal. A factor greater than K = 1, for example K = 4/3, would indicate that the effective earth has less curvature or is flatter than the true earth. It is also possible when abnormal propagation conditions exist for the beam to be bent upward, which would indicate a K factor less than 1. The K factor varies for different atmospheric conditions, but at microwave frequencies in the 4 GHz, 6 GHz, and 11 GHz common carrier bands a factor of K = 1 or K = 2/3 is used for most areas of the United States. For frequencies in the 2 GHz band a factor of K = 4/3 is normally used. The selection of the K factor is dependent on path location and path length.

2.5.5 Multipath propagation is a phenomenon that can be caused by irregular changes in the index of refraction. This may occur on a still night after a hot, humid day when there are both temperature and humidity inversions.

2.5.5.1 Temperature inversion (increase in temperature with height) is caused by the earth and the air adjacent to it cooling faster than the warm air above it. To cause a higher index of refraction in the air at some height above the ground rather than near it, the absolute humidity or vapor pressure at that point must be higher than near the ground. This is called humidity inversion and usually occurs when the air is super-saturated and the excess moisture appears as fog or dew.

2.5.5.2 Multipath propagation occurs when there exists a layer of air some distance above the ground which has a higher index of refraction than the air above or below it. Horizontal and vertical variations in temperature, pressure, and humidity cause more than one propagation path to exist between transmitter and receiver. For example, beam 1 in Figure B4 might be close to a layer with a high index of refraction. Another beam, such as 2, could cross the layer at a greater angle and it would be bent enough by the low density air near the earth to also arrive at the receiver.

2.5.5.3 Initially the separation would be slight and the electrical path lengths equal. The signal via each path would arrive in phase and the total signal received at the antenna would be doubled. However, as the paths become more divergent with cooling in the lower atmosphere, the signal will decrease until the energy received via both paths practically cancel. Thus the signal will fluctuate depending upon the difference in the electrical length of the paths. By morning, the temperature in the layer will become cooler and the two paths will come closer together until only one path remains. If the two paths still exist by morning, the sun will warm the earth and air adjacent to it faster than the air in the upper layer so that the temperature inversion will soon cease to exist. Frequency diversity and fade margin may be used to substantially reduce the adverse effects of multipath fading. Space diversity may also be used to provide increased propagation reliability. The FCC Common Carrier Bureau normally will not authorize the use of frequency diversity for digital systems.

2.6 DIFFRACTION AND WAVE INTERFERENCE

2.6.1 After correcting the profile of the path to take into consideration the bending of the radio rays by refraction, it is generally necessary that the rays clear the earth and obstacles along the path by a certain amount to prevent excessive attenuation of the signal by diffraction and wave interference.

2.6.2 Diffraction may be considered as a modification which waves undergo as they graze the surface of the earth, hills, or the edges of any opaque body by which the rays are apparently deflected or bent.

2.6.3 As a wave front travels from a transmitting to a receiving antenna, some portions of the wave front tend to cancel or reinforce other portions, depending on the difference in path length traveled. This is referred to as wave interference.

2.6.4 In order to understand the reason for apparent wave bending (diffraction) and wave interference, it is helpful to refer to Huygen's Wavelet Principle.

2.6.4.1 According to Huygen's Wavelet Principle, a wave front may be considered to consist of an infinite number of individual secondary radiators. Each of these secondary radiators sends out wavelets in directions away from the original source radiator. For example, assume in either Figure B5 or B6 that T is the primary source of radiation, and that the front will have traveled to position AB. Consider then that each vibrating particle such as 1, 2, and 3 in the wave front is a secondary source of radiation from which spherical wavelets spread out. Note that only a portion of a sphere ever reaches the desired destination. After a period of time, the surface which envelops (i.e., tangent to) all these wavelets constitutes a new wave front such as CD. The period of time between AB and CD is the time required for the wave front to progress one wavelength.

2.6.4.2 The energy that is radiated from each secondary source does not radiate equally in all directions as is the case with a nondirectional primary radiator (isotropic antenna) but radiates in the forward direction only. Also, the amount of energy radiated (from the secondary source) is greatest in the direction of the direct source ray and diminishes with the divergence from the direction of the primary wave. In Figure B6 the vibrating particle 2 will radiate more energy in the direction of 2P, the direction of the primary ray TR, than it will radiate oblique to the primary ray in the direction 2N. Similarly, particle 1 will radiate less in the direction 1N′ than in direction 1P′. Thus the amount of energy in a wavelet decreases as the angle Θ between it and the primary ray is increased.

2.6.5 An example of wave diffraction over a hill is shown in Figure B7. In that figure waves are moving forward in the direction of the primary ray TP. The numerals 1, 2, 3, and 4 represent the crests of the forward moving waves. If A2C represents a hill which is tangent to the primary ray at the grazing point 2, the disturbance at 2 will cause wavelets to be sent out from that point so that some energy will be directed below the horizon such as represented by the ray 2N. If the hill were broad in relation to a wavelength, such as A′ 2 C′, the amount of energy radiated below the horizon would be much less. On the other hand, if the distance 1-4 were only a fraction of a wavelength, the hill A' 2 C' may appear as sharp at that frequency as the hill A2C appears to the wavelength represented. With other things being equal, the energy diffracted beyond a given hill will increase as the frequency is decreased.

2.6.6 In 2.6.4.1 it was stated that a wave front (such as AB in Figure B8) may be considered to consist of an infinite number of secondary radiators such as 1, 2, 3. Since the distances from points on the wave front to a receiver R are not equal, the wavelets can arrive in- or out-of-phase, in varying degrees, with the primary ray and result in <u>wave interference</u>. The areas or zones around the axial between the transmitter and receiver that contribute energy either in- or out-of-phase are called Fresnel zones.

2.6.6.1 The first Fresnel zone is bounded by points through which the distance between the transmitter and receiver is 1/2 wavelength (1/2 Γ) longer than the direct ray. The second Fresnel zone is bounded by points through which the distance is one wavelength (1 Γ)longer than the direct ray.

2.6.6.2 Point 1 in Figure B8 was so chosen that ray T1R is 1/2 Γ longer than the direct ray TOR; T2R is 1/2 Γ longer than T1R; and T3R is 1/2 Γ longer than T2R. Figure B9 is a cross-section of the wave front AB in which points on the circles traverse paths that are 1/2 Γ, 1 Γ, and 1 1/2 Γ longer than the direct ray. The regions between these circles are called Fresnel zones. The diameter of the circles will vary along the radio path forming ellipsoidal envelopes as boundaries between the Fresnel zones as indicated in Figure B10.

2.6.6.3 There is an unlimited number of Fresnel zones even though only three are illustrated in the figures. The areas of all zones are equal. The energy received from each zone, however, decreases with distance from the primary ray as explained in paragraph 2.6.4.2. About one-fourth of the energy received from an unobstructed wave front is in the first Fresnel zone. The energy received from the second and other even-numbered Fresnel zones is negative with respect to energy received from the odd Fresnel zones. About half of the total energy received from an unobstructed wave front is cancelled by the waves received from the even numbered Fresnel zones. A sharp obstruction such as a sharply pointed hill, which cuts off most of the energy below the first Fresnel zone, would permit more energy to be received than if the obstruction were not there since part of the out-of-phase energy would be cut off by the obstruction.

2.6.6.4 If an obstacle cuts off the first Fresnel zone radius (non-line-of - sight path), some energy will be diffracted around and over the obstacle (paragraph 2.6.5) and will be received in the shadow portion of the radio beam. It is for this reason that a certain amount of radio energy is present beyond true radio (refracted) line-of-sight when the path is intercepted by the earth. In general, the lower the frequency, the farther the signal is diffracted beyond the point of interception.

2.6.6.5 The radius of the first Fresnel zone varies along the radio path. It is maximum at the midpoint between the transmitter and receiver and can be calculated by the formula:

$$F_m = 1140 \left(\frac{D}{f}\right)^{1/2} \qquad (2:2)$$

where F_m is the radius in feet of the first Fresnel zone at the midpoint of the path, D is the distance in miles between the receiver and transmitter, and f is the frequency in MHz. The first Fresnel zone radius at any point x miles from one end of the path is:

$$F_x = 2280 \left(\frac{x\ (D-x)}{fD}\right)^{1/2} \qquad (2:3)$$

2.6.6.6 Paragraph 2.10 discusses the application of the above formula in determining the necessary tower height for proper Fresnel zone clearance. It is desirable to receive as much of the first Fresnel zone energy as possible and still keep the cost of towers as low as possible. At frequencies of 4 GHz and higher, a clearance of 0.6 first Fresnel zone radius with K = 1 is a good design objective for most areas of the United States with hops of 25 miles or less. A more conservative design for hops greater than 25 miles to account for possible upward beam bending (earth bulging) would be 0.3 first Fresnel zone with K = 2/3. At 2 GHz, a value of K = 4/3 with a 0.6 first Fresnel zone clearance is a typical design.

2.7 REFLECTION

2.7.1 If the terrain between the antennas reflects radio waves efficiently, it is possible to receive strong reflected waves, either in- or out-of-phase with the direct wave, depending on the difference in the lengths of the direct and reflected wave paths. If we assume complete reflection with the reflected wave equal in magnitude to the direct wave, the resultant energy received would vary, depending on the location of the point of reflection, between zero and twice that of the direct path energy according to the following formula:

$$E = 2\ E_d\ \mathrm{Sin}\ \frac{2\pi}{\Gamma}\ \frac{d'}{2} \qquad (2:4)$$

E_d is the direct ray field strength and d' is the geometric length difference between the direct and reflected wave paths. E and E_d are in the same units, such as microvolts/meter. Wavelength Γ is in the same units as d'. Thus in Figure B10, the second Fresnel zone signal received from the reflection path TPR would practically cancel the signal from the direct path TR. If the reflecting plane were moved upward to P' so that it permits only the first Fresnel zone to be received, the reflected signal TP'R would then be added to the direct signal TR. The path difference d' is approximately:

$$d' = \frac{2\ h_r h_t}{d} \qquad (2:5)$$

where h_r and h_t are the heights of the receiving and transmitting antennas above the reflecting plane and d is the distance between transmitter and receiver in the same units as h_r and h_t.

2.7.2 Since the distance T1R in Figure B8 is 1/2 Γ longer than TR, the energy received from 1 as a secondary ray would be 180^{o} out-of-phase with the primary
ray TR. Also, the energy received would be less than that of the primary ray, as discussed in Paragraph 2.6.4.2. If, on the other hand, 1 were on a reflection plane, a reflected primary ray 1R would arrive at R in phase with the direct primary ray TR. The reason for its arrival in phase is that there is approximately 180^{o} phase shift when a wave is reflected. If the reflecting plane were a perfect reflector, large enough, and of the correct slope to reflect the energy in several Fresnel zones, almost as much energy would be received at the receiver from the reflected wave as from the direct wave.

2.7.3 If one of the heights such as h_r is varied so that E goes through a maximum and minimum, the difference in the two values of h_r is sometimes used as the spacing between two receiving antennas on a tower.

2.7.4 When two antennas are placed on a tower with this separation, the reception of the two signals and the selection of the stronger of the two is called space diversity reception. If one antenna is receiving a minimum signal, the other in all probability will be receiving a stronger signal. A particularly difficult problem exists when the reflection point is over tidewater which causes variations in the length of the reflected wave path contingent on the tidal change in water level. The amount of separation used on a space diversity system should be determined by someone very familiar with this type of design.

2.7.5 Reflections are greatest when the point of reflection is over calm water, level moist earth, desert sand, and other types of smooth terrain. It is desirable to adjust the tower heights or to reroute the radio path so the reflection point will be over rough terrain. Radio energy striking rough terrain will be either absorbed or scattered. Thus the amount of reflected energy reaching the receiver will be only a small percent of the total energy. The point of reflection can be determined by trial and error from the path plot. At the point of reflection the angle of incidence will equal the angle of reflection.

2.7.6 With zero clearance over a non-reflecting obstacle such as a hill covered with trees or brush, the signal will be 6 or 7 dB below the loss that would exist between two antennas in free space. If, however, the top of the hill were broad and barren and the soil had good reflection characteristics, the loss could be more than 16 dB greater than free space loss. Microwave systems should not be engineered for grazing paths except by someone with extensive experience in the area of microwave propagation and path design.

2.8 FADING

2.8.1 Fading is a condition which occurs during propagation of radio frequency energy that causes a reduction in the power being received. It may be caused by refraction, diffraction or reflection or by a combination of these conditions. This combination is usually referred to as multipath fading. In addition to multipath fading a very severe form of fading may also be caused by rainfall. The effect on the 4 GHz and 6 GHz bands is quite small and is usually ignored. The attenuation of the microwave radio signals increases substantially as the radio frequency carrier is increased. This attenuation is definitely noticeable at the 10.5 GHz and 11 GHz bands. It becomes extremely severe at 18 GHz and 23 GHz.

2.8.2 In the absence of rain, variations in received signals due to multipath conditions are greater in summer than in winter and greater during nighttime than daytime. These variations are smallest when the air is in a state of turbulence which prevents the formation of stratified layers of air.

2.8.3 Radio energy is absorbed and scattered by rain drops. These effects become more pronounced as the wavelength approaches the diameter of the raindrops. When the size of the drops becomes large enough and the drops are sufficiently concentrated, this scattering and absorption will attenuate the signal appreciably. In addition, since the drops represent a lossy dielectric, energy will be absorbed from the signal and converted into heat. These phenomena are entirely negligible below 3 GHz but will place a limitation on transmission through rain over appreciable distances at frequencies above 10 GHz.

2.8.4 The amount of attenuation caused by rain depends on the intensity of the rainstorm. The rate of rainfall and not total rainfall is the determining factor. Areas with high annual rainfall accumulations may seldom experience rainfall of a rate sufficient to interrupt service. Heavy rainfall rates are likely to accompany thunderstorms which may be confined to an area with a diameter of 1 to 2 miles. The fading margin may not be exceeded unless the heavy rainfall extends a sufficient distance along the radio path. System outages should be treated on a probabilistic basis by geographical area. The worst areas occur near the Gulf of Mexico and the part of the Atlantic Ocean adjacent to the southeastern area of the United States.

2.8.5 Major manufacturers of digital microwave equipment produce maps of the United States depicting how a given product is affected by the rainfall encountered in various geographical regions. Roughly, these regions are separated by diagonal lines that show the Northwest as the best area for radio signal propagation and the Southeast as the worst. They also produce diagrams showing the variation of signal attenuation with rain rate. The latter diagrams are quite accurate and reliable. The former maps are approximations since they depend on the statistical history of rainfall in all areas of the country. The usual source of such information is the U.S. Weather Service. Reporting stations are normally found only at airports in major metropolitan areas. These companies also produce diagrams depicting the annual system outage to be expected for given rain rates and given time durations of rainfall for those rates above a certain value.

2.8.6 The attenuation produced by rain is polarization dependent. A falling drop of rain is not spherical but flattened in the horizontal plane. This results in a greater attenuation of horizontally polarized waves. Rain attenuation over a given microwave band is almost independent of frequency.

Since vertical space diversity and frequency diversity do not protect a system against rain fading it is important that good fading margins be obtained in the system design. Reducing the hop length not only reduces the probability of severe rain fading but also increases the available fade margin.

2.8.7 A digital microwave system always uses regeneration at each intermediate terminal and each active repeater. Consequently, fading is not accumulative over a multi-hop system. Each hop stands alone. This, of course is true for noise, interference and other physical phenomena as well. Adaptive equalization reduces the multipath dispersive effect. (Dispersive means that it is frequency selective.) In the absence of specific route information during design, one may allot 50% of the total outage time to propagation fading (multipath, rain, upfades), 25% to obstruction fading and 25% to equipment and man-made failures. Upfading refers to the constructive (rather than destructive) effects of multipath and introduces some additional problems. The newer modulation technologies may have introduced more sensitivity to the dynamic impairments of fading.

2.8.8 The magnitude of the received signal varies continuously. This variation could cause a higher BER (see paragraphs 2.9.8 and 2.9.9); however if the system is designed with an adequate fade margin, this will be infrequent and not objectionable. Under extreme conditions a fade can cause service failure, but transmission usually returns to normal in a short time. The adverse effects of fading can be reduced through the use of horizontal space diversity and by provision of adequate fade margin to protect against both multipath and rain fades.

2.9 MICROWAVE PATH LOSSES AND GAINS

2.9.1 The system losses over a radio path can be calculated even though some of the loss factors, particularly those caused by atmospheric fades, may be difficult to obtain or estimate. Because of this, fade margins are added to the calculated normal losses to provide adequate reserve system gain to compensate for fluctuating atmospheric fades. If losses are calculated beginning with the transmitter, the levels at various points along the path can be obtained by the steps outlined in the following paragraphs.

2.9.2 The power of most microwave transmitters is given in watts. This can be converted to dB above or below a given reference. One milliwatt is a commonly used reference in telephony. If the transmitter power (P) is above one milliwatt, the power in dBm will be:

$$+\text{ dBm} = 10 \log_{10} \frac{P}{.001} \qquad (2:6)$$

(i.e., dB above 1 milliwatt). If the power is less than one milliwatt, then

$$-\text{ dBm} = 10 \log_{10} \frac{.001}{P} \qquad (2:7)$$

2.9.3 If the transmitter power is converted to dBm, the losses in the transmission line between the transmitter and the antenna are subtracted. The losses in dB per 100 feet of the most commonly used transmission lines are given in the following table. Coaxial cable is normally used for frequencies up to 2 GHz and in some cases a special coaxial cable is used at frequencies above 2 GHz. Waveguide is generally used at 4 GHz and above.

Typical Loss in dB per 100 Feet of Transmission Line

	2 GHz	4 GHz	6 GHz	11 GHz
7/8" Coaxial Cable (Air dielectric)	2 dB	-----	-----	-----
1 5/8" Coaxial Cable (Air dielectric)	1 dB	-----	-----	-----
Flexible Elliptical Waveguide	-----	1 dB	1.5 dB	3.5 dB
Rigid Rectangular Copper Waveguide	-----	1 dB	2 dB	3.5 dB

2.9.4 Power is effectively increased at the antenna. Microwave antenna gains are referred to a theoretical isotropic antenna which radiates energy equally in all directions. The following table shows the typical gain in dB of some commonly used parabolic antennas:

Antenna Size	2 GHz	4 GHz	6 GHz	11 GHz
4 foot	25	31	35	40
6 foot	29	35	38	43
8 foot	31	37	41	46
10 foot	33	39	43	48

2.9.5 Free Space Loss - The major loss between a transmitter and receiver is through the space between the antennas. The following formula gives the free space loss in dB:

$$A = 96.6 + 20 \log_{10} f + 20 \log_{10} d \qquad (2:8)$$

where f is the frequency in GHz and d is the distance between the antennas in miles. This loss may be increased or decreased somewhat by the type of path through which the radio waves travel. A free space loss condition exists only when the antennas are high enough that the ground and other obstacles and unusual air conditions do not affect the received signal.

2.9.6 The signal will be increased at the receiving end of the radio path by the gain of the receiving antenna. The transmission line loss between the antenna and receiver should then be subtracted.

2.9.7 Miscellaneous losses from circulators, radomes, and antenna system misalignment should be accounted for in making fade margin calculations. The amount of miscellaneous loss will vary with systems but a value of 2 dB per radio channel end is typical.

2.9.8 The result of subtracting the losses and adding the gains between the transmitter and receiver will give the signal power in dBm at the receiver input. The fade margin is the difference between the received power level and the power level required to produce a given Bit Error Rate (BER). Fade margins for digital radios are based on Receiver Sensitivity specified in dBm for a particular BER; for example, a certain radio may have a receiver sensitivity of -74 dBm at a BER of 10^{-6}.

2.9.9 Finally, in digital radios a Composite Fade Margin is used for calculations of availability. Composite Fade Margin is the power addition of the Flat Fade Margin, typically calculated in analog scenarios, and the Dispersive Fade Margin. Dispersive Fade Margins are equipment dependent and are provided by the equipment manufacturer. The above radio may have a Dispersive Fade Margin of >49 dB at a BER of 10^{-6}.

2.10 ILLUSTRATIVE EXAMPLE OF CALCULATION OF MICROWAVE ANTENNA HEIGHT

2.10.1 To illustrate the considerations involved in selecting a suitable microwave path, assume that the profile of the earth is AB in Figures B1, B2, and B3. All plots represent the same path profile. Figure B1 is plotted on rectangular paper with the microwave beam drawn with a curvature which represents the true earth's radius (K = 1). Figure B2 is plotted on rectangular paper with corrections made for true earth's radius. Figure B3 is the same path plotted on curved graph paper.

2.10.2 To determine the required antenna heights at A and B, the profile of the earth is first plotted directly on the graph paper. The profile should be plotted with the midpoint of the path centered on the graph paper.

2.10.3 When the path is plotted on rectangular paper with corrections added for earth curvature and refraction, the corrections are calculated from the formula in paragraph 2.4.3.2 and added to the profile plot. The corrections are shown by the dotted line in Figure B2.

2.10.4 At the high points in the path, the height of any obstructions such as trees or buildings should be added. The maximum height of trees is assumed to be 40 feet in this example.

2.10.5 The next step is to calculate the first Fresnel zone clearance for the high points in the path. In this example 0.6 of the first Fresnel zone is used. The required clearance at the high points is calculated from the formula in Paragraph 2.6.6.5, that is

$$.6F_x = .6 \left(2280 \left[\frac{x(D - x)}{fD} \right]^{1/2} \right) \qquad (2:9)$$

For example, at point P on the profile the clearance required above the tree would be

$$F_p = .6 \left(2280 \left[\frac{6\ (28 - 6)}{6000\ (28)} \right]^{1/2} \right) = .6\ (63.5) = 38.1 \text{ ft.} \qquad (2:10)$$

A safety factor of 10 feet or more is often added to the calculated Fresnel zone clearance to account for future tree growth and survey inaccuracies. Using a safety factor of 10 feet, the clearance at point P would be 48 feet.

2.10.6 The corrections for earth curvature and refraction are drawn on the profile as shown in Figure B2, and the Fresnel zone clearance is calculated and shown with the safety factor on all profile plots as in Figures B1, B2, and B3. The next step is to draw a line representing the microwave beam between the ends of the path. The beam line is drawn so that it clears all of the critical points marked on the profiles. When drawing a curved beam line using a template, the grid lines of the template and the grid lines of the profile graph paper must be parallel at all times to avoid errors. The distance AC (135 ft.) is the antenna height required at one end of the path while BD (70 ft.) is the antenna height required at the other end. If it is assumed that the antennas are mounted 5 feet below the top of the towers, the tower height at A and B would be 140 feet and 75 feet, respectively. If it is more desirable to have the antenna lower at A, the straight line DC in Figures B2 and B3 can be pivoted counterclockwise about point P to determine a lower tower at A and a taller tower at B. When a template is used to draw the curved beam line, the template can be moved horizontally to the left while keeping the grid lines on the template and profile paper parallel and a shorter tower determined at A.

3. RADIO SYSTEM GUIDE TO FORMS REQUIRED BY THE FEDERAL COMMUNICATIONS COMMISSION

3.1 GENERAL

3.1.1 The FCC forms apply to the construction and operation of the various radio services provided by REA Telephone borrowers. All forms are not needed for a given radio service. These forms are revised frequently and often replaced by others. A consulting engineer or a telephone company borrower should check the applicable rule or regulation applying to the given radio service.

3.1.2 Most of the material in this bulletin originates in the Rules and Regulations of the FCC. These are printed in Title 47 of the *Code of Federal Regulations* (*CFR*) which is revised once a year. Whenever the FCC revises, creates or eliminates a rule or regulation the changed version appears in the *Federal Register* (published daily except on Saturdays, Sundays and legal holidays). The *CFR* is an annual compilation of the current Rules and Regulations. Publication in the *Federal Register* constitutes official notification to the public of the change and will contain an effective date. Both the *Federal Register* and the *Code* are published by the National Archives and Records Administration.

3.1.3 To identify an FCC rule or regulation, one should use the title, the part and the section number. For example, 47 *CFR* 21.2 refers to Title 47, Part 21, Section 2. In this bulletin this reference will appear as FCC 21.2. In like manner FCC 90.81 will indicate section 81 of Part 90.

3.1.4 In the past, the FCC required both an application for a construction permit and an application for a radio station license. This no longer applies. At present, the FCC only requires an application for a radio station authorization.

3.1.5 There are three different FCC forms for the application for radio station authorization. Form 494 must be used for FCC Part 21 radio services. Form 401 must be used for FCC Part 22 radio services. Form 574 must be used for FCC Part 90 radio services. A Basic Exchange Telecommunications Radio Service (BETRS) utilizing Specialized Mobile Radio Service (SMRS) radio frequencies (800 MHz) may be applied for under FCC Part 22 rules.

3.1.6 FCC Forms may be obtained by telephone. Call (202) 632-FORM [(202)-632-3676]. A general form request may be made by calling (202)-632-7000. The forms may also be obtained in Room B-10 at 1919 M St. N.W., Washington, D.C. An alternate way is to contact any FCC Field Operations Bureau office. The addresses of all offices appear in the *U.S. Government Manual*. The above information is subject to change at any time.

3.1.7 Copies of any volume of the *Code of Federal Regulations* as well as the *U.S. Government Manual* can be obtained at any Federal Government Book Store.

Direct sales are handled by the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 (telephone 202-783-3238). Prices for individual volumes can be obtained at the same telephone number. The FCC Rules and Regulations appear in five different volumes under Chapter 1 of Title 47. These volumes are revised once a year and are current as of October 1 of a given year. They are printed and available at a considerably later date. Whenever the FCC revises a rule or regulation, the new material appears in the daily *Federal Register* prior to October 1 of the given year. There are no restrictions on the republication of material appearing in the *Code of Federal Regulations*.

3.1.8 For practical purposes, the FCC Rules and Regulations divide the common carrier radio services that are of interest to REA borrowers into two major Parts based on frequency. FCC Part 21 covers all radio services that utilize microwave radio frequencies (see definition in FCC 21.2 and FCC 22.2). FCC Part 22 covers all radio services that utilize radio frequencies below microwave. The exact dividing line (i.e. in the range between 890 MHz and 1000 MHz) is no longer clearly defined. Furthermore, the titles associated with the above mentioned parts suggest a different method of division.

3.2 POINT-TO-POINT MICROWAVE RADIO (FCC PART 21)

3.2.1 All radio services covered in FCC Part 21 use the same set of forms. The only radio service presently used by REA telephone borrowers is Point-to-Point Microwave Radio Service (Subpart I of FCC Part 21). Applications and licenses are covered in Subpart B of FCC Part 21. For a detailed discussion of the forms used see FCC 21.7 and FCC 21.11.

3.2.2 FCC Form 494 (Application for a New or Modified Microwave Radio Station License Under Part 21) must be submitted and a license granted for each station prior to commencement of any proposed station construction. There is a separate five sheet set of instructions for this form. This same form may be used to amend an application and to modify or delete a licensed facility.

3.2.2.1 FCC Form 494A (Certification of Completion of Construction) must be used to certify/notify completion of construction.

3.2.3 Two of the following five miscellaneous forms are also used for FCC Part 22:

3.2.3.1 FCC Form 430 (Common Carrier and Satellite Radio Licensee Qualification Report) must be filed by the telephone company on an annual basis by March 31 of each year. This will cover all changes of information that occurred in the preceding calendar year.

3.2.3.2 FCC Form 701 (Application for Additional Time to Construct a Radio Station) must be filed at least 30 days prior to the expiration of the time for construction noted in the license.

3.2.3.3 FCC Form 405 (Application for Renewal of Radio Station License in Specified Services) must be filed between 30 and 60 days prior to the expiration date of the license.

3.2.3.4 FCC Form 702 (Application for Consent to Assignment of Radio Station Construction Permit or License) must be submitted to assign the station authorization. In addition, the assignee must submit an FCC Form 430 (mentioned above) unless a current report is already on file with the FCC.

3.2.3.5 Partial Assignment. If only a portion of the facilities are to be assigned both the assignee and the assignor must file an FCC Form 494 (described above). Another FCC Form 494 must be filed to return the license to its original condition if assignment does not take place. The FCC Form 702 is used only for assignment of the entire license.

3.2.3.6 FCC Form 704 (Application for Consent to Transfer of Control of Corporation Holding Common Carrier Radio Station Construction Permit or License) must be submitted in order to transfer control of a corporation holding any licenses. In addition, the transferee must submit an FCC Form 430 (mentioned above) unless a current form is already on file with the FCC.

3.2.3.7 The maximum construction period is 18 months from the date on the license grant. The license period will extend for up to 10 years depending on the renewal cycle. See paragraph 3.4.1.

3.3 PUBLIC LAND MOBILE RADIO, RURAL RADIO, DOMESTIC PUBLIC CELLULAR RADIO TELECOMMUNICATIONS AND BETRS (FCC PART 22)

3.3.1 All radio services covered in FCC Part 22 use the same set of forms. All of the radio frequencies used are below 1000 MHz. The services that apply to REA borrowers are described in subparts G, H, and K of FCC Part 22. However, the general parts of Part 22 also apply unless they are in conflict with the mentioned subparts. Applications and licenses are covered in Subpart B of FCC Part 22. For a detailed discussion of the various forms see FCC 22.9, FCC 22.11, and FCC 22.39.

3.3.2 FCC Form 401 (Application for New or Modified Common Carrier Radio Station Authorization Under Part 22) must be submitted for each base station, rural central office station, rural interoffice station and auxiliary test station. Fixed subscriber stations that either exceed 60 watts effective radiated power or require notification to the Federal Aviation Administration (see Antenna Structures in this document) also require FCC Form 401. Mobile stations (except airborne) and fixed subscriber stations (except those mentioned above) are licensed as part of base station and central office authorizations. The application form has two parts, Schedule A and Schedule B. One Schedule A is required for each station. One Schedule (B) is required for each antenna location. Separate Schedule (B)s may be obtained from the FCC.

3.3.3 FCC Form 489 (Notification of Status of Facilities Under Part 22 of FCC Rules) is a general purpose form. It can be used for the following eleven purposes:

3.3.3.1 Notification of completion of construction.

3.3.3.2 Request for extension of time to complete construction.

3.3.3.3 Request for reinstatement within 30 days after expiration of authorization.

3.3.3.4 Notification that construction was completed with minor modifications of authorization.

3.3.3.5 Request to delete or change antenna obstruction markings.

3.3.3.6 Notification of a change in points of communication (Rural Radio Service).

3.3.3.7 Notification of the construction and operation of additional transmitters on same frequency (include a completed Schedule B from Form 401). See FCC 22.117 (b).

3.3.3.8 Notification of the return of license to original condition if partial assignment is not completed within 60 days.

3.3.3.9 Notification of a change in or addition of a radio frequency (cellular radio).

3.3.3.10 Notification of a change to or addition of a cell site as long as the composite 39 dBu contours remain totally within the cellular geographic service area (CGSA).

3.3.3.11 Notification that the initial phase of a cellular system has been completed and is ready to commence service to the public.

3.3.4 <u>FCC Form 405</u> (Application for Renewal of Radio Station License in Specified Services) must be filed between 30 and 60 days prior to the expiration date of the license.

3.3.5 <u>FCC Form 490</u> (Application for Assignment or Transfer of Control Under Part 22) must be completed for either assignment or transfer of control. The assignee or transferee must submit FCC Form 430 unless an up to date form is on file with the FCC.

3.3.5.1 Partial Assignment. Request for Partial assignment must be made on <u>FCC Form 401</u> by the assignee and on <u>FCC Form 489</u> by the assignor.

3.3.6 <u>FCC Form 430</u> (Common Carrier and Satellite Radio Licensee Qualification Report) must be filed by Mobile Service licensee only as required by FCC Form 490.

3.3.7 <u>FCC Form 409</u> (Airborne Mobile Radio Telephone License Application) is for use by subscribers and may also be used for modification and renewal. It may not be used for cellular radio.

3.3.8 A radio station authorization will specify the date of grant as the earliest date for the commencement of construction. (See paragraph 3.3.8.4)

3.3.8.1 Construction must be completed within 12 months (except for cellular radio) after the grant of authorization.

3.3.8.2 The construction of the initial phase of a cellular radio system must be completed and service commenced within 18 months. The entire CGSA (as specified in the existing Form 401) must be completed within 36 months.

3.3.8.3 Licenses will be granted for up to 10 years depending on the renewal cycle. See paragraph 3.4.1.

3.3.8.4 The FCC has made a recent change in its rules that may or may not apply to REA borrowers. (See paragraph 3.8.1 in this document.) It concerns permission to commence construction prior to the grant of a radio station authorization and applies to all Part 22 services. The general rule states that applicants must wait 90 days from the date of the public notice listing the application as acceptable for filing; cellular tentative selectees must wait 60 days from the date of the public notice announcing them as tentative selectees. After the waiting period, certain FCC Form 401 applicants listed in FCC 22.43(d)(1) may commence construction provided that the conditions listed in FCC 22.43(d)(3) have been met. This final rule was published in the *Federal Register* on November 8, 1990 (page 46952).

3.4 COMMON CARRIER LICENSE EXPIRATION DATES AND PROCESSING FEES

3.4.1 All Common Carrier Bureau radio station authorizations (licenses) expire on a calendar date specified in FCC 21.45, FCC 22.45 and FCC 23.29 or on the authorization itself during the year of expiration. If the Telephone Company does not renew its license, it will be operating illegally. Common Carrier Bureau licenses are generally granted for a period of up to 10 years. Most, but not all, licenses for a given service expire in the same year of a 10-year cycle. The chief purpose of this paragraph is to present a list of expiration years. (This information cannot be found in the above referenced *CFR*.) Recently, the Common Carrier Bureau resumed its practice of renewing individual licenses. Due to lack of manpower, this had not been done since 1978. For a period of 10 years licenses were simply extended by a general FCC public notice.

Common Carrier and Fixed Satellite Licensing

License Duration - up to 10 years

Cellular Radio:	October 1 of expiring year
Public Land Mobile:	
Wireline Common Carriers	July 1, 1998
Radio Common Carriers	April 1, 1999
Air-ground base stations	September 1, 1999
Rural Radio:	November 1, 1998
Point-to-Point Microwave and Local Television Transmission:	
AT&T	February 1, 2000
Bell Operating Companies	August 1, 2000
Other Carriers	February 1, 2001

(Table continued on next page)

Common Carrier and Fixed Satellite Licensing
(Continued)

Digital Electronic Message Service:	February 1, 2001
Multipoint Distribution Service:	May 1, 2001
Offshore Radio Telephone:	August 1, 2001
International Fixed:	December 1, 3 a.m. E.S.T., of expiring year
Satellite Service:	10 years from effective date

Effective date:
Earth Station - Date of grant
Space Station - Date satellite was placed in operation after a successful launch

As can be seen from the above table, Cellular Radio Service, International Fixed Radio Services, and Satellite Services have no specified year of termination. All the others do (these are Part 21 and Part 22 services). If an individual license expires before the common year, it will only be renewed for the remainder of the term. An application for renewal must be sent to the FCC between 30 days and 60 days prior to the expiration date.

3.4.2 Applications or filings requiring fees must be delivered or mailed to the FCC's lockbox bank in Pittsburgh, Pennsylvania with the correct fee and a completed FCC Form 155 (Fee Processing Form) attached to the application or filing. The lockbox bank is the Mellon Bank which maintains separate post office boxes with appropriate zip codes for the various forms being submitted. The current fee, Fee Type Code, and mailing address for a given form can be found in one of four lists contained in subpart G of FCC Part 1. The Common Carrier list is FCC 1.1105; the Private Radio list is FCC 1.1102. (A private radio application must be submitted to the appropriate certified frequency coordinator before filing.) Applications and filings not requiring fees must be sent directly to the FCC, Washington, DC 20554. Submitables without the correct address or the correct fee will be returned to the applicant without processing. The Fee Processing Form 155 will no longer be required when the various application forms have been revised to incorporate the information requirements of the form. For the latest up to date information call the FCC hotline (202) 632-FEES [(202) 632-3337].

3.5 TELEPHONE MAINTENANCE RADIO (FCC PART 90)

3.5.1 All radio services covered in FCC Part 90 use the same set of forms. If an REA borrower desires to purchase a new mobile radio equipment that would be used solely for telephone maintenance (at any part of the spectrum) it must be handled through the Private Radio Bureau of the FCC. There is at present no other service that would require the borrower to utilize the Private Radio Bureau. Applications and authorizations are covered in Subpart G of FCC Part 90. For a detailed discussion of forms see FCC 90.119 and FCC 90.135.

For discussion of Telephone Maintenance Radio Service see FCC 90.81. For a list of radio frequencies see Table in FCC 90.81 paragraph (c).

3.5.2 FCC Form 574 (Application for Private Land Mobile and General Mobile Radio Services) must be used for a new or modified Land Mobile Radio System authorization and for new components (such as, base, fixed, or mobile stations). There is a 32-page booklet available from the FCC which gives instructions for filling out the form. Most Part 90 applications must be coordinated with the FCC's Certified Frequency Coordinator, as described in the instruction booklet. Obtain a Form dated 1990 or later.

3.5.3 The following minor FCC Forms needed for various reasons are:

3.5.3.1 FCC Form 574B (Private Fixed, Mobile, and Radiolocation Services) contains supplementary information to accompany FCC Form 574. It is to be used for frequencies below 27.5 MHz and for frequencies above 27.5 MHz in counties bordering Canada and Mexico. It probably will be of limited use to most REA borrowers.

3.5.3.2 FCC Form 574-R(Application for Renewal of Radio Station License) must be used to apply for renewal of an existing authorization without modification. It is usually mailed to the licensee by the FCC prior to the expiration of the license.

3.5.3.3 FCC Form 405A (Application for Renewal of Radio Station License and/or Notification of Change to License Information) must be used to apply for a renewal without modification of a station or system license when the licensee has not received renewal Form 574-R in the mail from the FCC within 60 days of license expiration. It may also be used to notify the FCC that the licensee has discontinued station operation and wishes to cancel the license.

3.5.3.4 FCC Form 572 (Temporary Permit to Operate a Part 90 Radio Station) should be properly executed if the applicant desires to operate the station during the formal FCC processing of a Form 574. It does not have to be submitted to the FCC and is only valid for a period of 180 days from the date the required application forms are mailed to the FCC.

3.5.3.5 FCC Form 703 (Transfer of Control) must be submitted whenever it is proposed to change the control of a corporate licensee.

3.5.3.6 FCC Form 1046 (Assignment of Authorization) may accompany an FCC Form 574 being used for assignment (to another person) in order to inform the FCC that the assignor will submit the current station authorization for cancellation upon completion of the assignment.

3.5.4 Stations authorized under FCC Part 90 must be placed in operation within 8 months from the date of grant. Trunked stations on 800 MHz frequencies have one year to construct. The license term will not exceed 5 years from the date of the original issuance, modification or renewal.

3.5.5 It is suggested that REA Borrowers specifically examine the Specialized Mobile Radio service (SMRS) bands when they wish to purchase a new telephone maintenance radio system since the newest and most-up-to-date manufactured products will probably be for these bands. Frequencies are available from

806 MHz to 821 MHz, and from 851 MHz to 866 MHz. These bands also contain BETRS channel assignments. However, applications for BETRS must follow FCC Part 22 rules.

3.6 ANTENNA STRUCTURES (FCC PART 1, PART 17)

3.6.1 Antenna structures include the radiating and/or receive system, its supporting structures and any appurtenances mounted thereon.

3.6.2 The FCC developed standards for antenna structures in conjunction with the Federal Aviation Administration (FAA). The Communications Act of 1934, as amended, places full responsibility on the FCC to determine whether any antenna structure constitutes a menace to air navigation. The FCC will inform an applicant whether it is necessary to file a Notice of Proposed Construction or Alteration (FAA Form 7460-1) with the Federal Aviation Administration.

3.6.2.1 Antenna clearances are granted by the Antenna Survey Branch of the Public Services Division in the Field Operations Bureau of the FCC. If the Common Carrier Bureau receives either Form 494 or Form 401 from an applicant or the Private Radio Bureau receives Form 574 from an applicant, the antenna data is furnished to the Antenna Survey Branch if either operating bureau determines that antenna consideration is required.

3.6.2.2 Any communications between the FCC and the FAA are handled by the FCC Antenna Survey Branch and the FAA Airspace and Obstruction Evaluation Branch for the appropriate FAA Region. The Airspace and Obstruction Evaluation Branch of the FAA does not normally communicate with the REA borrower but with the FCC, since the FCC has the major responsibility.

3.6.2.3 If the FCC Antenna Survey Branch determines that an FAA Form 7460-1 is required the originating bureau will be so advised. If it determines that FAA Form 7460-1 is not required or if it receives a favorable airspace analysis from the FAA, the Antenna Survey Branch prescribes antenna tower painting and lighting specifications or other conditions in accordance with FCC Part 17 and forwards this information to the originating bureau. When the FAA disapproves of a proposed tower, a report of the unfavorable recommendation is forwarded to the originating bureau. (See FCC 1.61).

3.6.2.4 An REA borrower may submit an FAA Form 7460-1 to the FAA before it submits an FCC Form 494, FCC Form 401 or FCC Form 574 to the FCC. Each application form contains a place where the applicant can indicate whether or not an FAA Form 7460-1 has been submitted to the FAA. Form 7460-1 must be sent to the Manager, Air Traffic Division, FAA Regional Office having jurisdiction over the area within which the construction or alteration will be located. Copies of this form may be obtained from the regional offices or from FAA headquarters. In addition to FAA Form 7460-1, the telephone company must send FAA Form 7460-2 (Notice of Actual Construction or Alteration) to the above indicated Regional office. The addresses of the Regional Offices may be found on Form 7460-1.

3.6.2.5 If an antenna structure ceases to be licensed by the FCC, the owner is required to maintain the prescribed painting and illumination until the structure is dismantled. The FCC may require the owner to dismantle and remove the tower.

3.6.3 If the height of an antenna structure is 20 feet or less above the ground the FAA does not have to be notified. Nor does it have to be notified if it is shielded by an existing structure or by natural terrain or topographic features of equal or greater height and is located in the congested area of a city, town, or settlement. If the height of an antenna structure is greater than 200 feet above the ground the FAA must always be notified. If the height of an antenna structure is between 20 feet and 200 feet above the ground the criteria regarding notification depend on the nearness of an airport runway of any kind. When the antenna structure is more than 3.8 miles from the end of the nearest airport runway no notification is required. The details of the notification requirements can be found in FCC 17.7 and FCC 17.14. Consideration must always be given to the possibility of an airport runway being extended at some time.

3.6.4 All FCC requirements concerning obstruction marking and lighting appear in FCC Part 17 (Construction, Marking, and Lighting of Antenna Structures). Subpart B of FCC Part 17 (Criteria for Determining Whether Applications for Radio Towers Require Notification of Proposed Construction to Federal Aviation Administration) covers in detail the items mentioned above. Subpart C of Part 17 (Specifications for Obstruction Marking and Lighting of Antenna Structures) covers all painting and lighting specifications for antenna structures that exceed 200 feet in height above the ground. The painting requirements are relatively simple; however, nearly 20 different lighting specifications have been specified for different antenna heights. It is the responsibility of the FCC to see that all owners of antenna towers maintain these standards.

3.6.4.1 The FCC has two additional forms that are not application forms but rather concise specifications for marking and lighting. These are: FCC Form 715 (Obstruction Marking and Lighting Specifications for Antenna Structures) and FCC Form 715A (High Intensity Obstruction Lighting Specifications for Antenna Structures).

3.6.4.2 During construction, temporary warning lights must be installed at top of the structure, and at each level where permanent lights will be installed. The licensee of any radio station having antenna structures requiring illumination must inspect the functioning of the required lights daily and report immediately any malfunctions of any top steady-burning light or any flashing light regardless of its position on the structure to the nearest FAA Flight Service Station.

3.6.4.3 Whenever a licensee constructs or alters an antenna tower requiring obstruction marking or illumination that will change the antenna height or the location of the tower a National Oceanic and Atmospheric Administration (NOAA) Form 76-10 must be filed with the Aeronautical Chart Division of the National Ocean Service. NOAA Form 76-10 (Report of Radio Transmitting Antenna Construction, Alteration and/or Removal) must be submitted prior to the start of construction and at the completion of such construction or change in order that this information may be provided promptly for use on aeronautical charts and related publications.

3.7 EQUIPMENT AUTHORIZATION (FCC PART 2)

3.7.1 The REA borrower should distinguish between two kinds of FCC Authorization procedures. This bulletin has, up to this point, discussed applications made by the borrower for a Radio Station Authorization or License. The manufacturer or importer of radio equipment requests an Equipment Authorization from the FCC. Subpart J of FCC Part 2 covers Equipment Authorization Procedures.

3.7.2 Radio equipment must meet certain FCC technical standards. The FCC requires that parties marketing certain radio frequency equipment, subject to its technical regulation in the United States, must perform measurements to demonstrate compliance with the applicable technical standards. The equipment authorization procedures by which the FCC authorizes equipment are: type approval, notification, type acceptance, and certification. Request for authorization of equipment subject to these procedures is made on FCC Form 731. Marketing in the United States of equipment subject to the above-mentioned equipment authorization procedures is prohibited under FCC 2.803 marketing regulations until the FCC has issued the prerequisite Grant of Equipment Authorization.

3.7.2.1 <u>Verification</u> is a procedure where the manufacturer makes measurements or does whatever else is needed to ensure that the FCC technical standards are met. No samples, test data, or forms are sent to the FCC for verified equipment.

3.7.2.2 <u>Type Approval</u> is an equipment authorization issued by the FCC based on examination and measurements of specific equipment by the FCC's laboratory. New equipment and major modifications require testing, while changes in identification of presently type approved equipment or minor modifications do not.

3.7.2.3 <u>Notification</u> is an equipment authorization issued by the FCC for different classes of equipment operated without an individual license under Part 15, and certain transmitting equipment used pursuant to a <u>station license</u>. Notification is based on an applicant showing in writing that the required measurements have been made to demonstrate compliance with the applicable technical standards. Modifications and permissive changes to authorized equipment are normally allowed without the requirement to file an application, unless these changes are so extensive as to cause the equipment to be considered a new product, which would require a new identification and requisite fees. The requisite fees are also charged for abbreviated application procedures (changes in identification of presently notified equipment).

3.7.2.4 <u>Type Acceptance</u> is an equipment authorization issued by the FCC for many categories of transmitting equipment used pursuant to a station license, based on representations and test data submitted by the applicant. The requisite fees are also charged for abbreviated application procedures (changes in identification of presently type accepted equipment).

3.7.2.5 <u>Certification</u> is an equipment authorization issued by the FCC for equipment designed to be operated without an individual license under Part 15 and Part 18 of the Rules, based on representations and test data submitted by the applicant. The requisite fees are also charged for abbreviated application procedures (changes in identification of presently certificated equipment). Part 15 is entitled "Radio Frequency Devices." Part 18 is entitled "Industrial, Scientific and Medical Equipment."

3.7.3 With the exception of Point-to-Point Microwave Radio, all radio transmitters used by REA borrowers under FCC Parts 21, 22 and 90 require type acceptance. This includes signal boosters and repeaters. Radio transmitters for Point-to-Point Microwave require notification. More specific information on these equipment authorizations can be found in FCC 21.120, FCC 21.122, FCC 22.120, and FCC 90.201. For a description of procedures see FCC 2.951 through FCC 2.1045 within subpart J of FCC Part 2.

3.7.4 Cellular radio transmitters require type acceptance. They must also conform to the compatibility standard (specification) for the air interface between base stations and subscriber stations. The FCC requires that all conventional cellular radio systems conform to American National Standard-ANSI/EIA/TIA 553-1989. The newer interim standard for Dual-Mode Operation EIA/TIA IS-54 contains almost all of ANSI/EIA/TIA 553 but there are some minor differences.

3.8 REA REQUIREMENTS AND MISCELLANEOUS ITEMS

3.8.1 An REA rule in the *Code of Federal Regulations*, 7 CFR 1753.68 (a) (10) states the following: The borrower must obtain authorization from the Federal Communications Commission (FCC) to construct and operate radio transmitting equipment. Evidence of FCC authorization is required for REA contract approval.

3.8.1.1 This means that the borrower must have previously submitted an FCC Form 401, an FCC Form 494 or an FCC Form 574 to the FCC and obtained a grant of authorization (or a license) for a radio station. The effective date on the document is the first day on which construction may begin. (But see paragraph 3.3.8.4)

3.8.2 The FCC will not grant a Station Authorization (or License) unless the radio equipments specified for use at the station already have equipment authorization, if required. This implies that all transmission equipments in the REA List of Materials or covered by a letter of Technical Acceptance have equipment authorization, if required by the FCC. This information should be obtained from the manufacturer when request for product acceptance is received.

3.8.3 Most listed manufacturers have data sheets that state that a certain product has an equipment authorization and give the number identifying it (although not all do so). It may be difficult to obtain a data sheet on a new product.

3.8.4 FCC Form 730 (Application for Registration of Equipment to be Connected to the Telephone Network) is for use by any party wishing to register equipment which connects to the public telephone network. (REA does not make loan funds available for terminal equipment.) A general discussion can be found in FCC Part 68. Specific instructions can be obtained from the Domestic Facilities Division of the FCC Common Carrier Bureau.

REGENERATING REPEATER

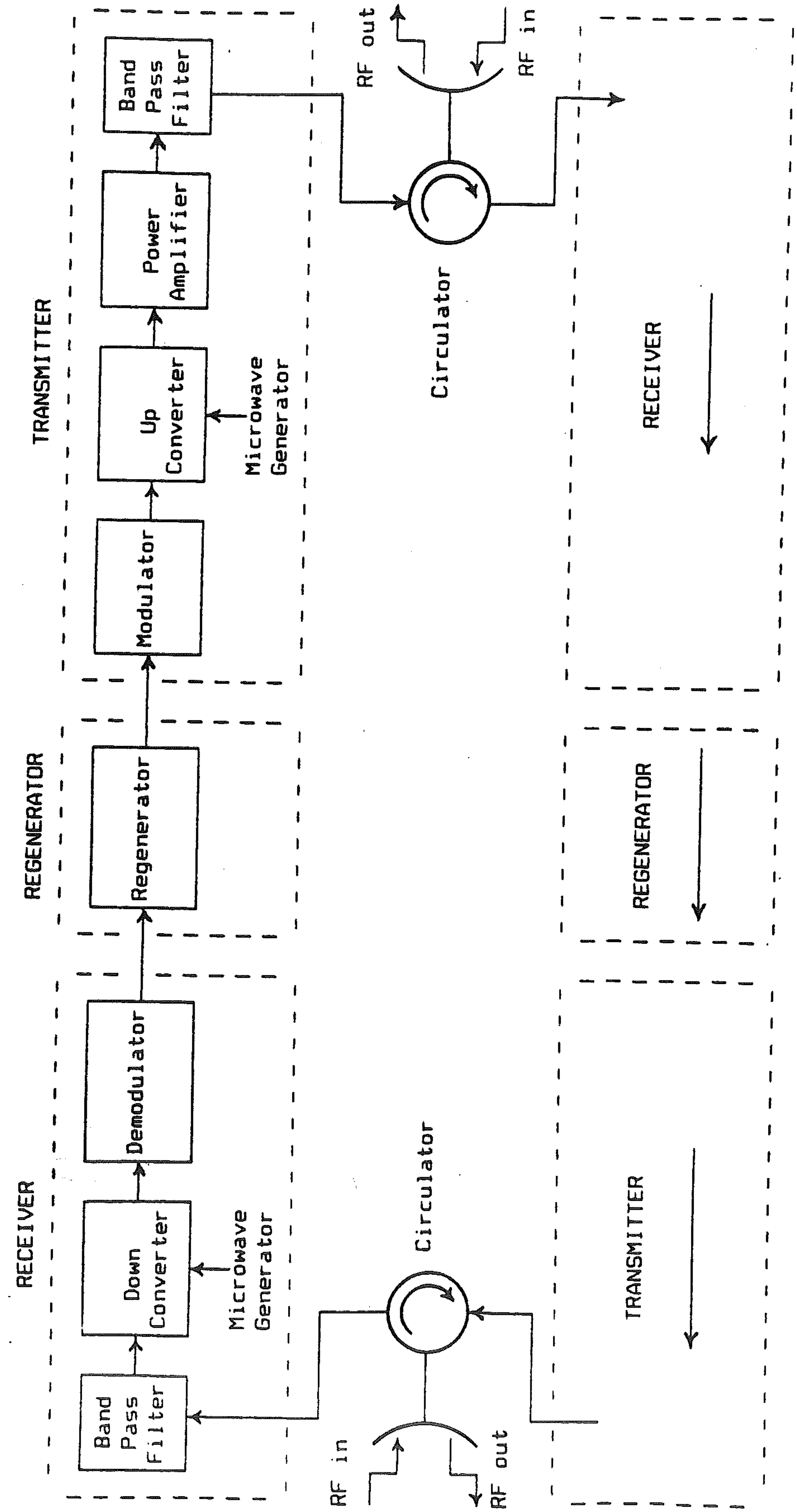


FIGURE A1

BLOCK DIAGRAM OF TYPICAL MICROWAVE SYSTEM

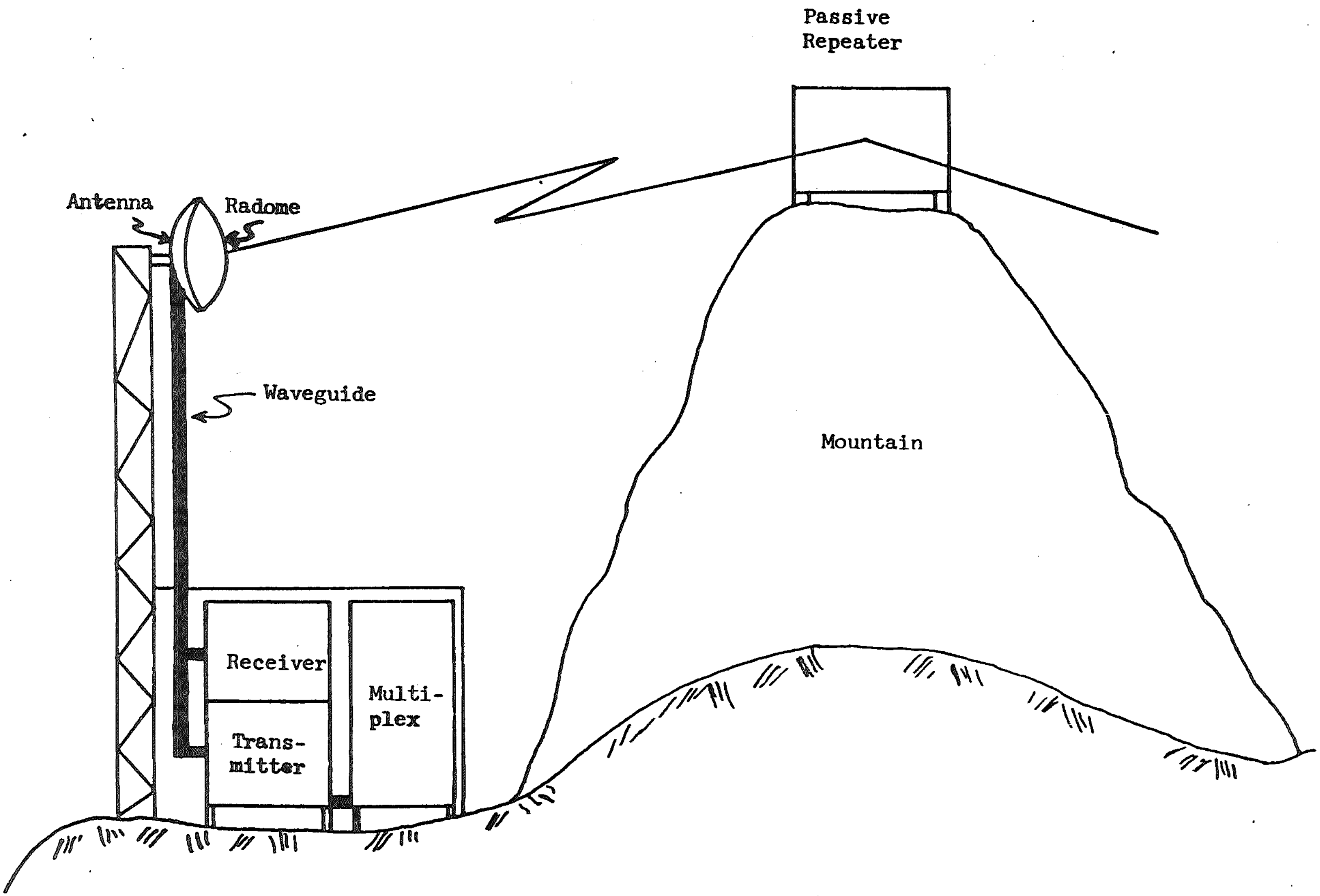


FIGURE A2

BASIC RF EQUIPMENT ARRANGEMENT FOR A TWO HOP SYSTEM

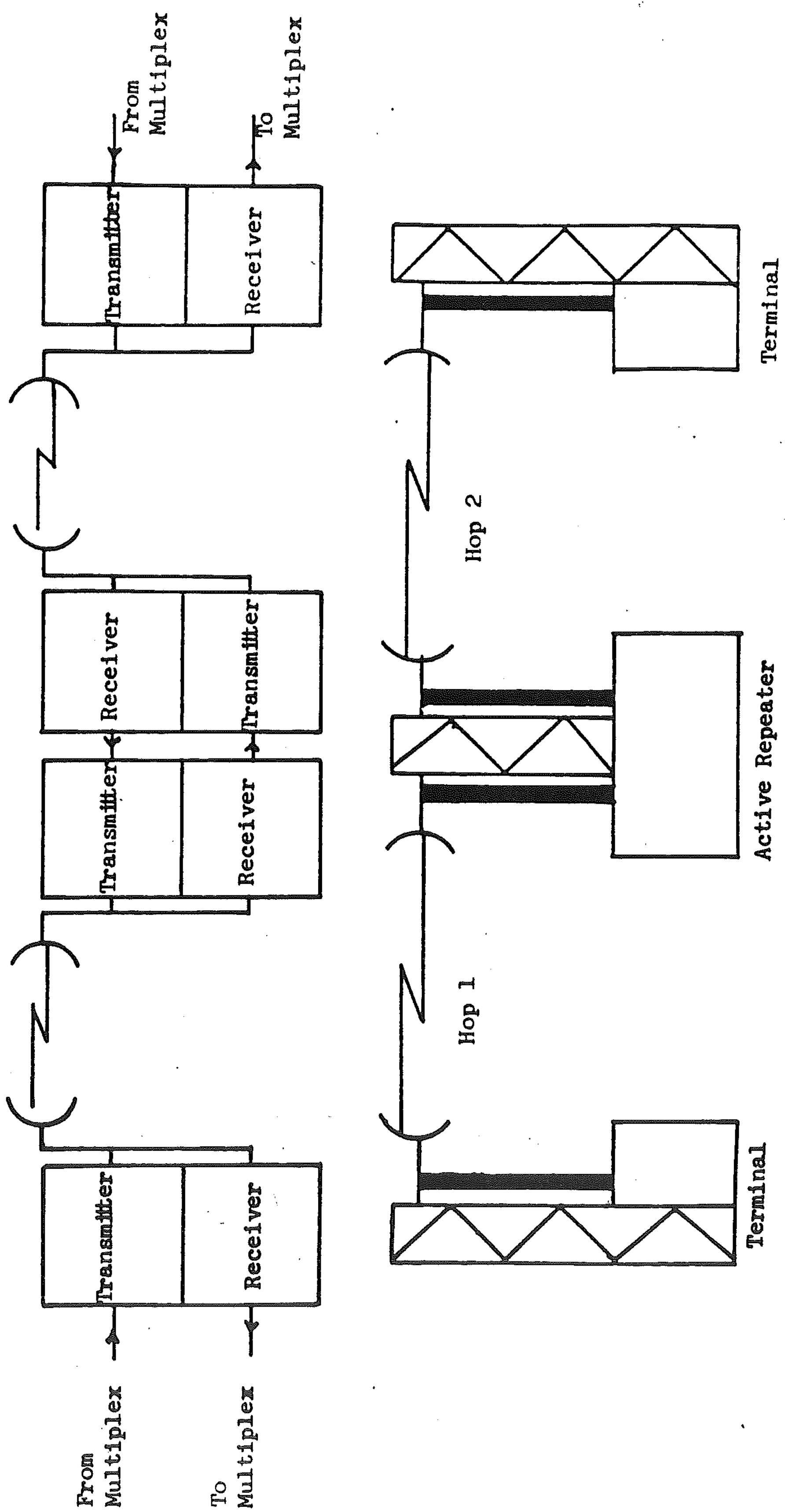


FIGURE A3

HOT STANDBY ARRANGEMENT FOR A TWO HOP SYSTEM

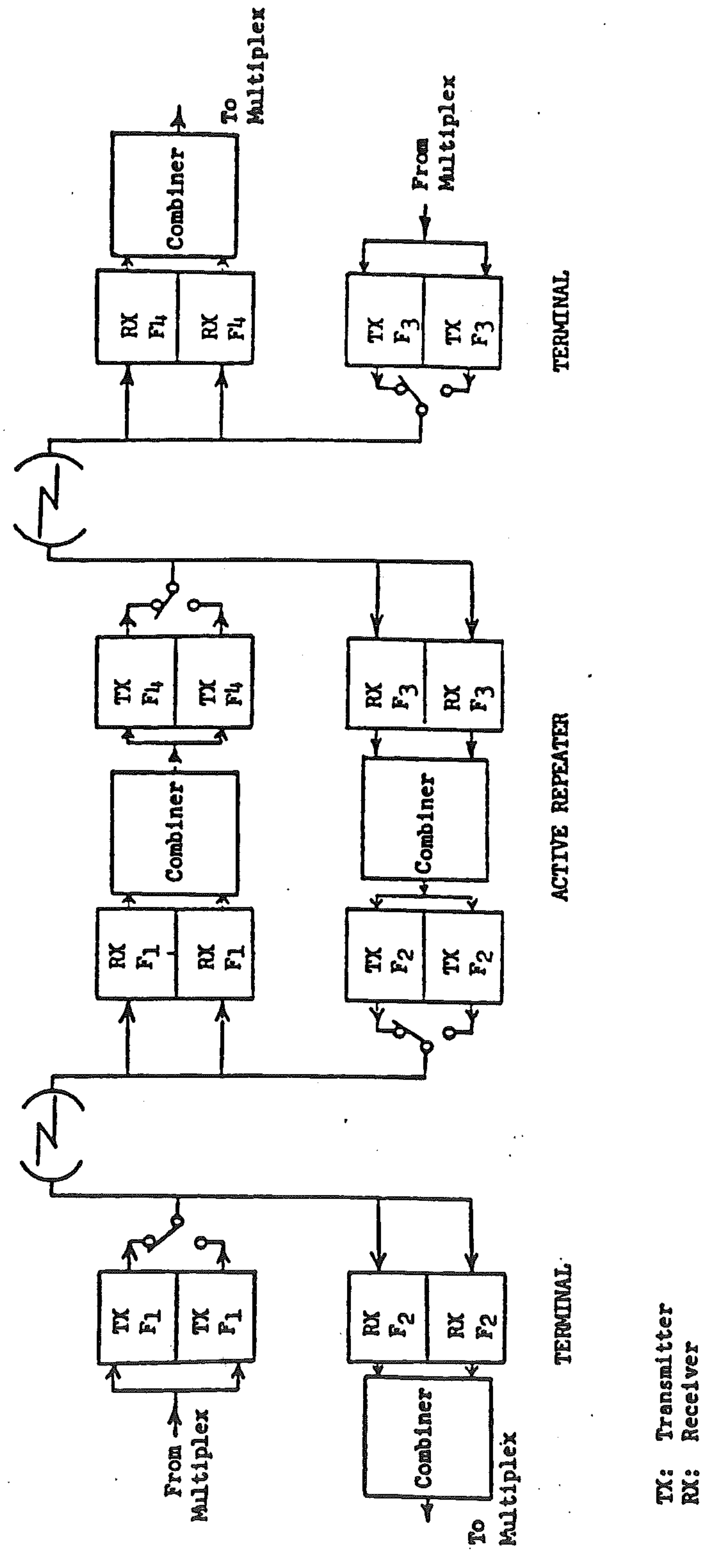


FIGURE A4

SPACE DIVERSITY EQUIPMENT ARRANGEMENT

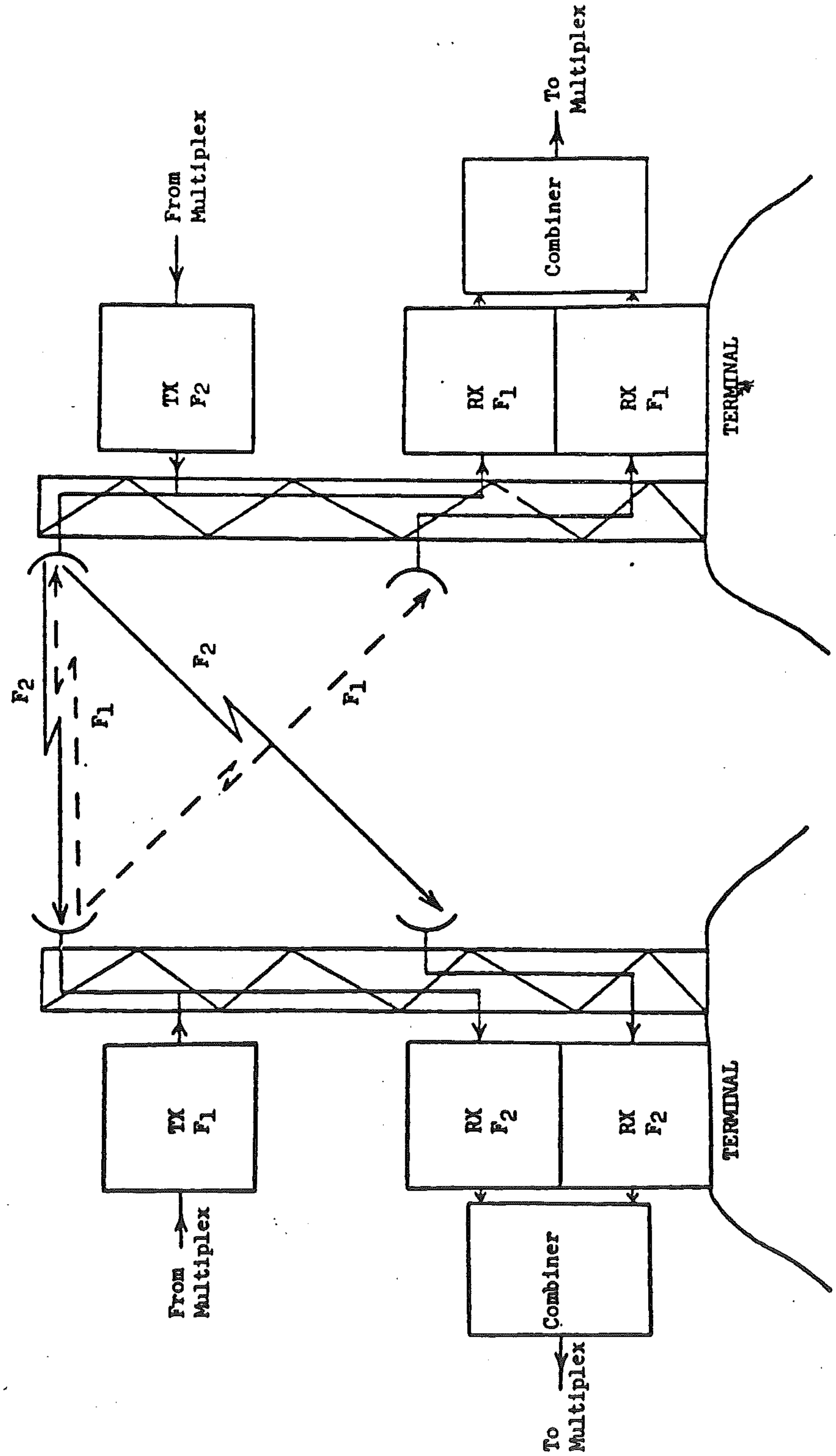
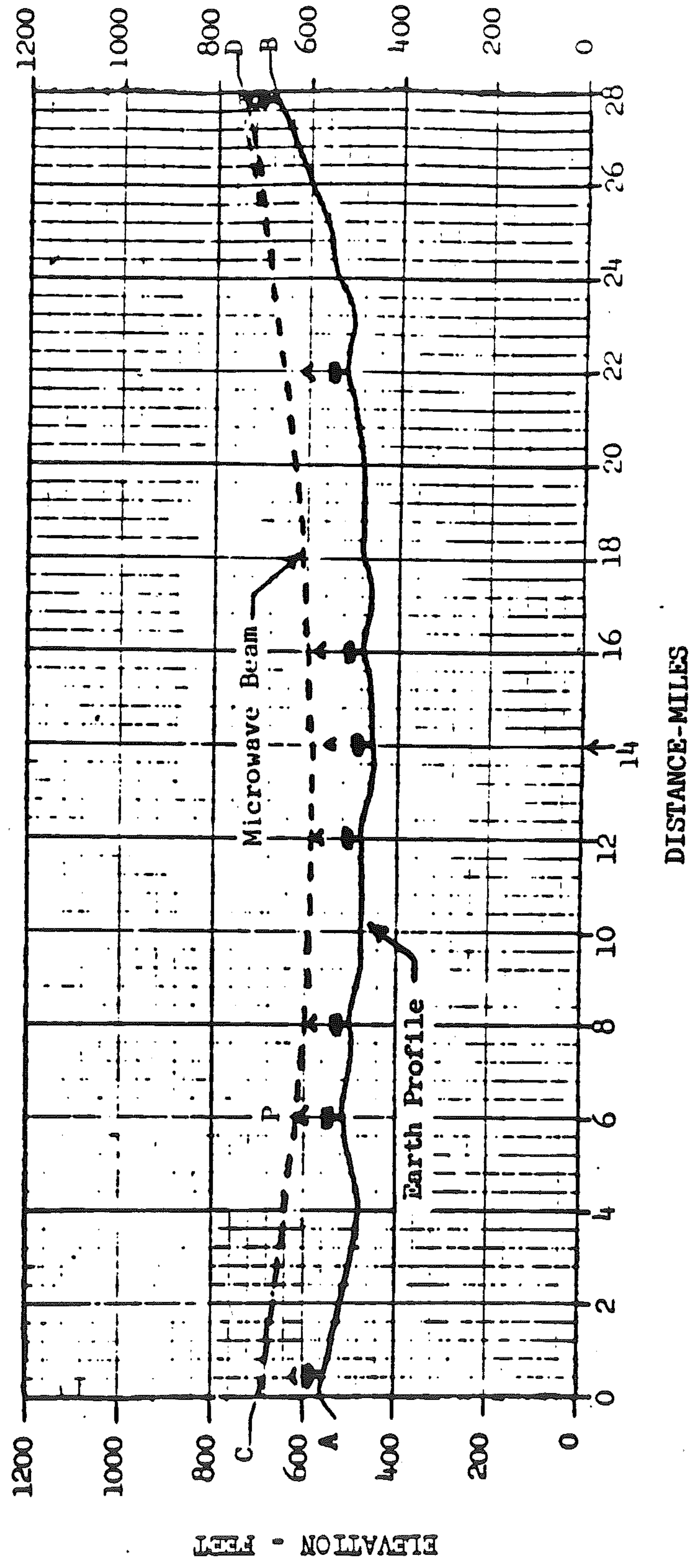


FIGURE A5

PATH PROFILE

RECTANGULAR GRAPH PAPER

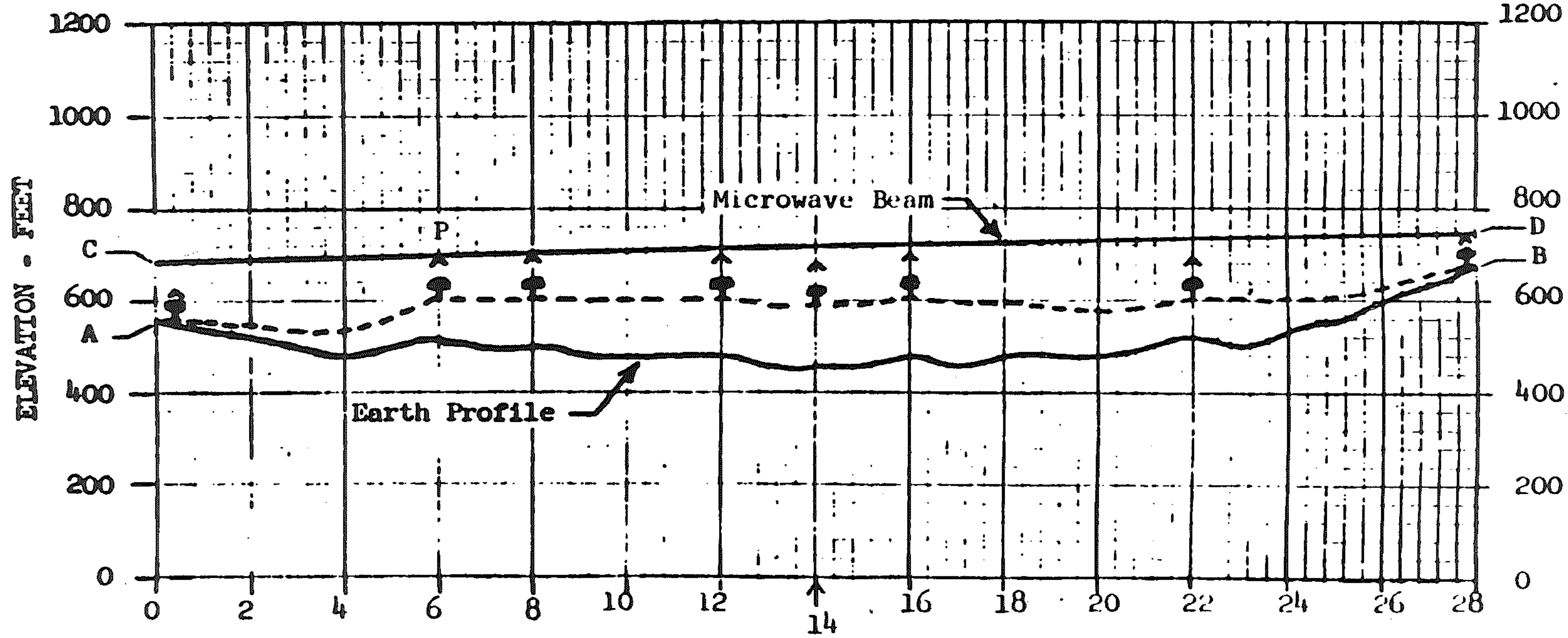
(Curved Microwave Beam)



Scale:
Path Distance: 1" = 4 miles
Elevation: 1" = 400'
K = 1
Tree (40')
.6 First Fresnel Zone
Clearance plus 10'

FIGURE B1

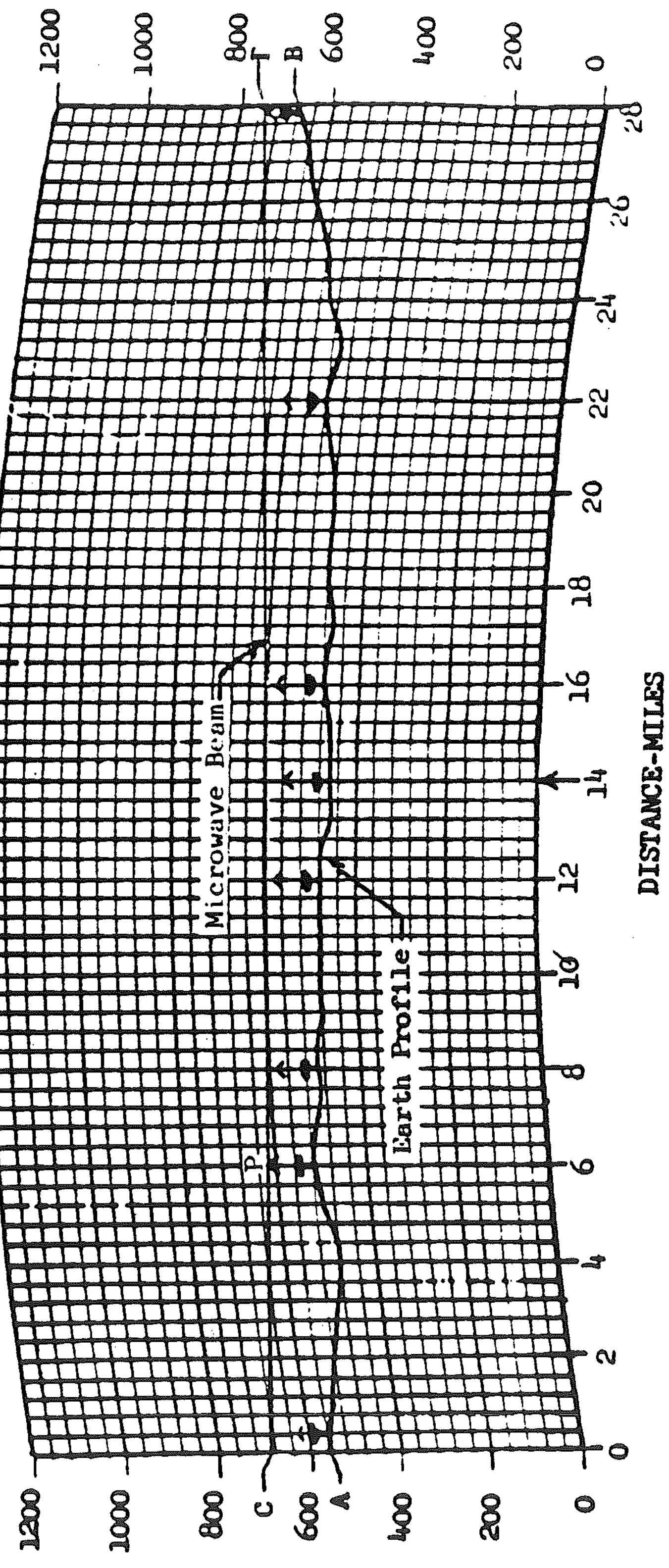
PATH PROFILE
RECTANGULAR GRAPH PAPER



Scale:
Path Distance: 1" = 4 miles
Elevation: 1" = 400'
K = 1
Tree (40')
.6 First Fresnel Zone Clearance Plus 10'

FIGURE B2

PATH PROFILE
CURVED GRAPH PAPER

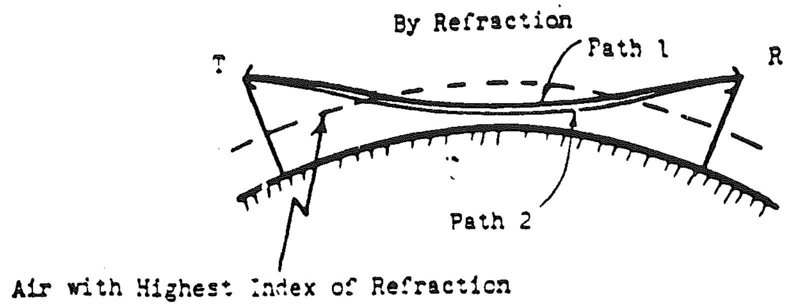


SCALE:
PATH DISTANCE: 1" = 4 miles
ELEVATION: 1" = 400'
K = 1
Tree (40')
.6 First Fresnel Zone Clearance Plus 10'

FIGURE B3

FIGURE B4

EXAMPLE OF MULTIPATH PROPAGATION BY REFRACTION



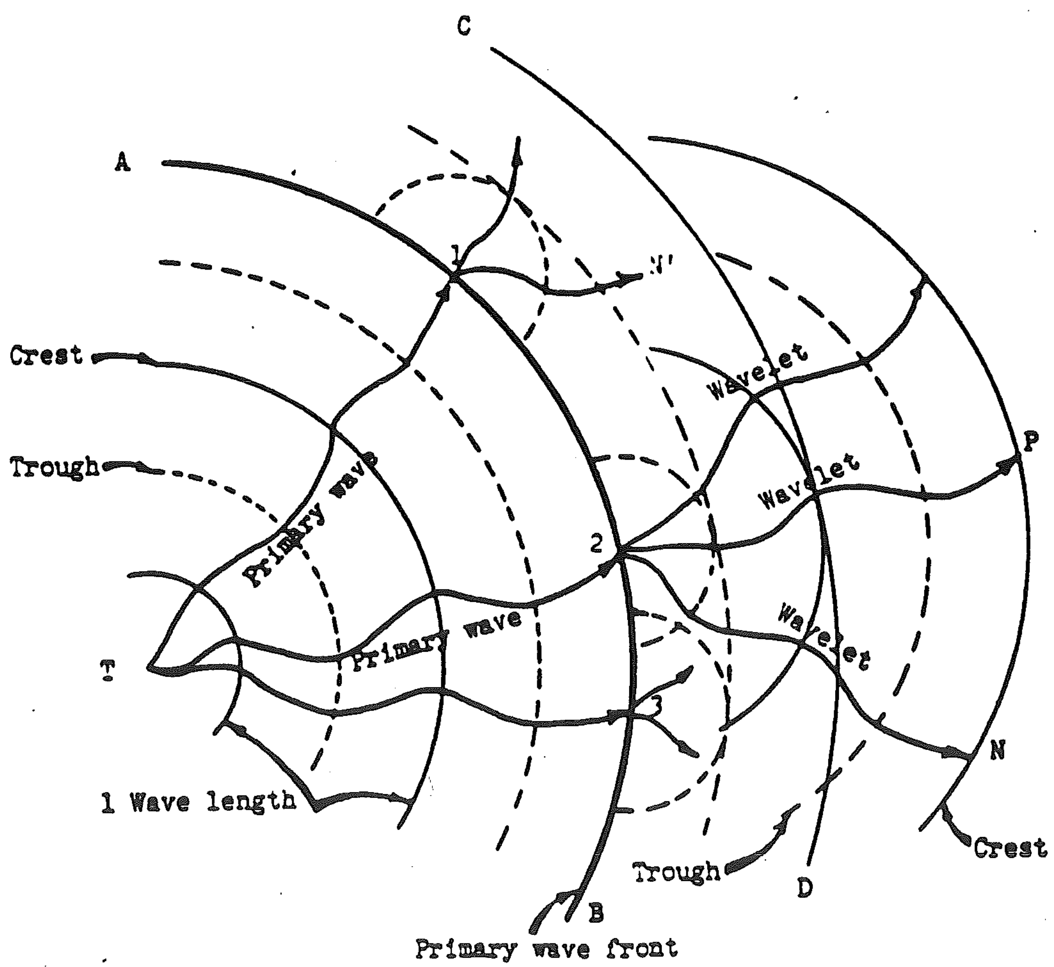
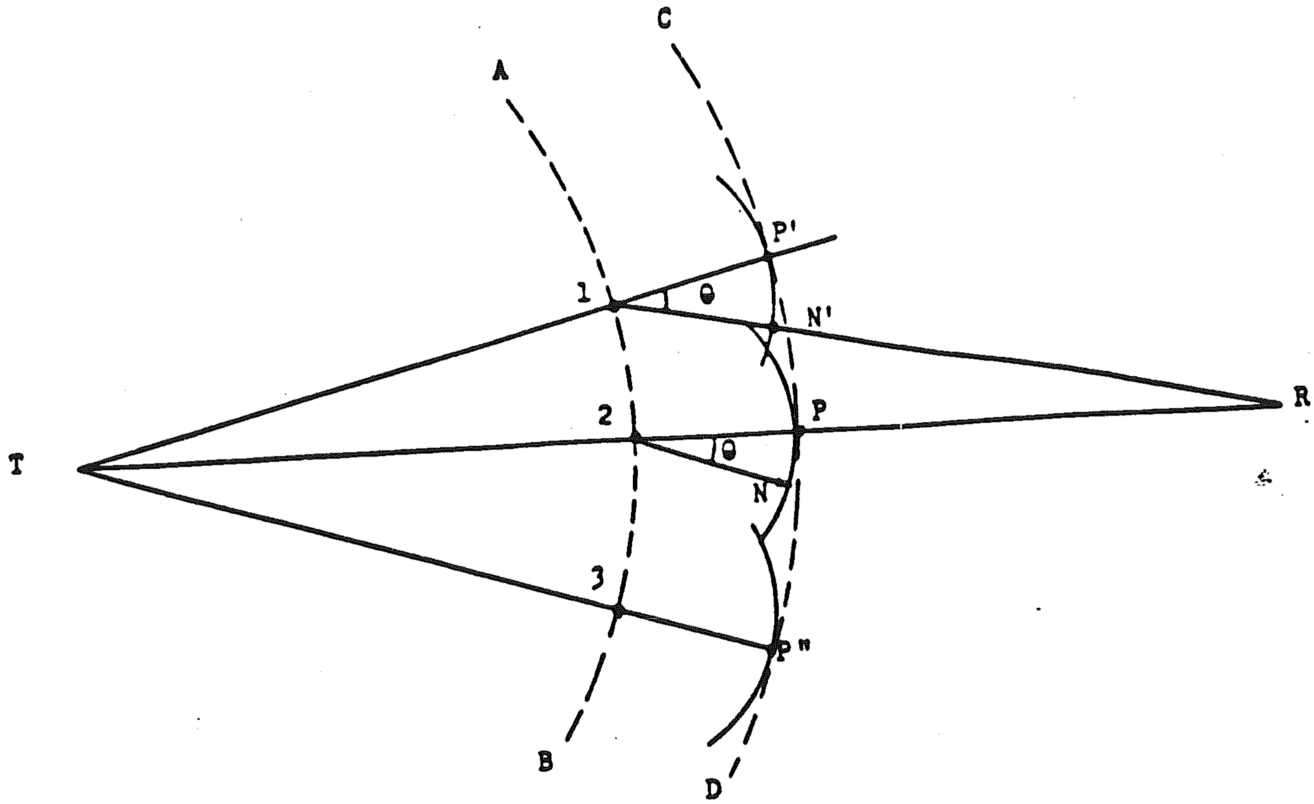


FIGURE B5

HUYGEN'S WAVELETS

FIGURE B6

DIFFRACTION



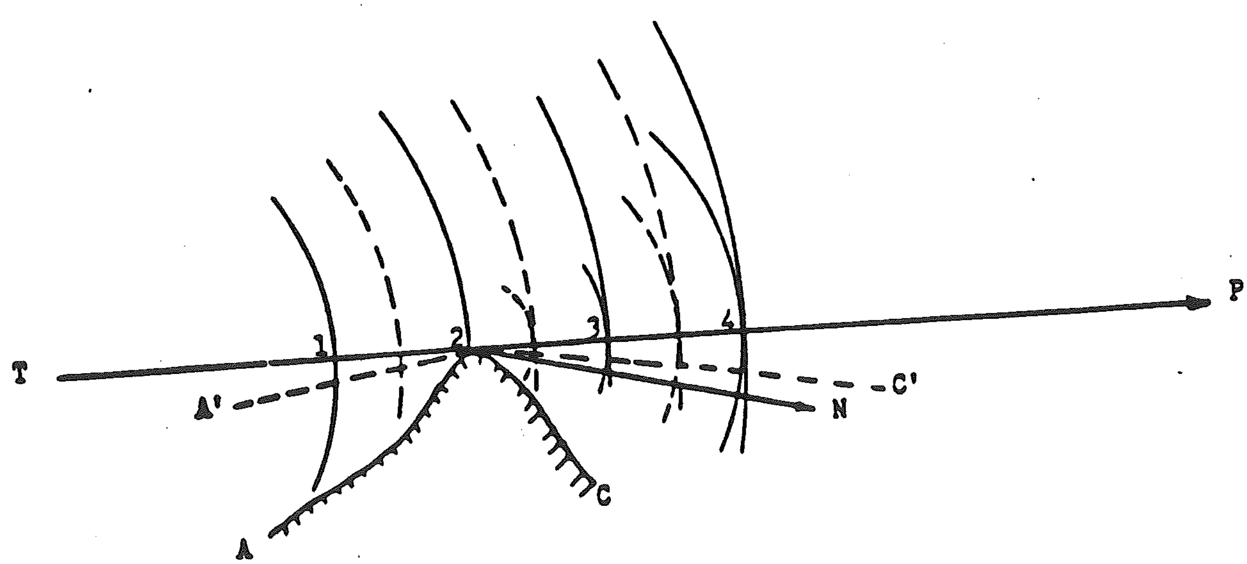


FIGURE B7

DIFFRACTION OVER A HILL

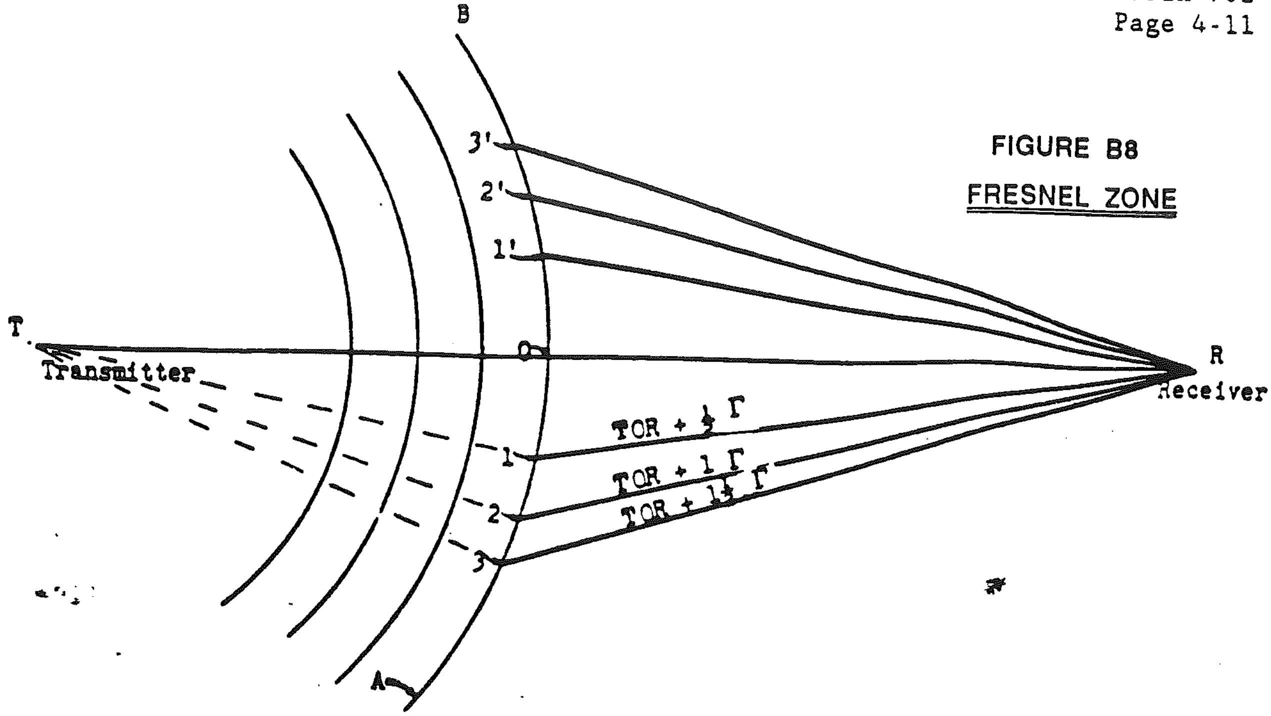


FIGURE B8

FRESNEL ZONE

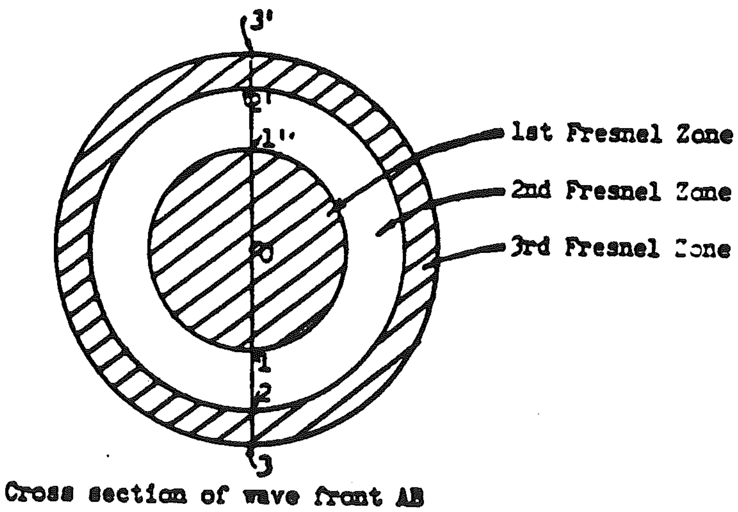


FIGURE B9

CROSS-SECTION OF FRESNEL ZONE

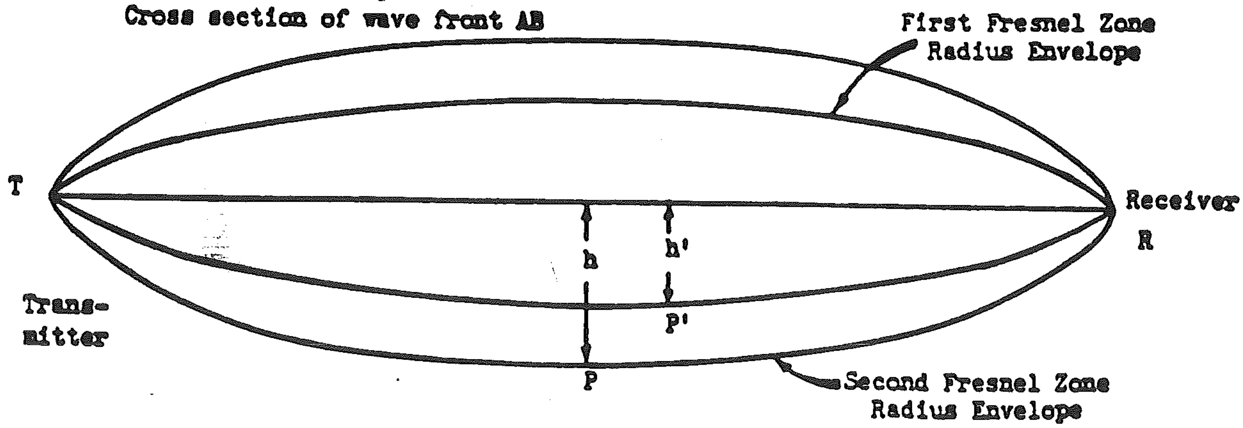


FIGURE B10

FRESNEL ZONE ENVELOPES