Checked 4/29/81 L S.

RADIO ENGINEERING
MICROWAVE RADIO
GENERAL PLANNING

CONTENTS PAGE

1. INTRODUCTION

A. Purpose of Practice

1.01 This section is the first in a series of practices which discuss the considerations involved in planning and engineering microwave relay systems. This first section is intended as a general guide to engineers who are responsible for the selection of microwave routes and equipment, or the construction of mierowave systems. It will also be of help to others who are engaged in making studies to determine the methods by which new or additional facilities for service are to be provided.

1.02 The intent is to first discuss those general considerations that apply to all microwave systems, including heterodyne types which are normally used to satisfy "long haul" requirements, and baseband types which are used for "short haul" requirements. Separate sections discuss in more detail the somewhat different considerations involved when engineering routes that utilize one or the other of these types of equipment.

1.03 This section will not give a theoretical explanation of microwave propagation, nor will it outline the detailed computations and considerations involved in calculating expected transmission performance of a microwave system.

B. Extent of Use and Advantages of Microwave

1.04 Microwave technology, stimulated by radar development work during World War II, was timely because of its ability to provide the broadband facilities needed for the transmission of television signals that developed shortly thereafter. Early use of portable type microwave equipment to fill the need for short or temporary television links, where it was not practical or economical to do this by other means, has continued. Microwave has also made long haul network facilities for television service practical, as was demonstrated by the use of the TD-2 system for the first transcontinental transmission of television signals in September, 1951, and the subsequent rapid growth of this service.

1.05 The broadband capabilities of microwave make it ideal for use in transmitting multiplexed telephone signals, such as those generated by the L and other types of carrier systems which had been developed earlier for use over broadband coaxial or paired cable transmission systems. The economic and other advantages of microwave, including flexibility and reliability, are such that by the end of 1963 about 45% of all intertoll circuit mileage was composed of carrier derived circuits transmitted over microwave. The development of reliable and economical short haul type microwave systems has resulted in an increased use of this type of facility in recent years. As existing cable and wire plant which can be multiplexed with carrier is exhausted, the use of short haul microwave facilities to economically provide new and diversified routes is increasing.

1.06 An important factor which will contribute to the expanded use of microwave is an increased need for facilities to transmit services such as broadband data, TELPAK, the various TV requirements, or any other services which require broadband channels. Once a route has been established for any of these requirements, the cost of adding extra broadband channels for message service is very inexpensive. By the same token, once a route is established for regular message service the additional cost to provide for these special services is minimal. Another factor which has led to selection of microwave, rather than expanding existing types of facilities, is the requirement to provide for alternate routes such as "Terminal Area Protection" circuits.

C. Frequency Bands Available to Common Carriers

1.07 The term "microwave radio" is usually shortened to simply "microwave" as though it were not radio at all, but some altogether different method of transmission. Microwave, however, generally refers to radio systems which operate at frequencies in the order of 1,000 megacycles (Mc/s) or above. Existing literature will also refer to 1,000 megacycles as one kilomegacycle (Kmc/s) or more recently, as one gigacycle (Gc/s). At this frequency and above, the distance occupied by one cycle of the radio wave, as it propagates in space, is relatively short (about one foot at 1 Gc/s and one inch at 11 Gc/s), hence the designation — "microwave". By comparison, frequencies in the 150 Mc/s band, widely used in Bell System Mobile Radio Service, have wavelengths that are in the order of 6-1/2 feet.

1.08 The Bell System has made substantial use of microwave frequency bands, which are available to Communications Common Carriers, in the vicinity of 2, 4, 6, and 11 Gc/s. These are outlined in the following table.

FREQUENCY (Gc/s)	APPROXIMATE WAVELENGTH (inches)	EQUIPMENT USED BY BELL SYSTEM
2.110-2.130 +2.160-2.180	5.6-5.4	Non-W.E. Co.
3.700-4.200	3.2-2.8	TE, TD-2
5.925-6.425	2.0-1.8	TH, TM-1, Non-W.E. Co.
10.700-11.700	1.1-1.0	TJ, TL, TL-2

The very short wavelengths involved at these high frequencies allow the output energy from a radio transmitter to be focused into a very narrow beam, much as light from a searchlight, by the use of parabolic shaped reflectors. The high concentration of energy achieved by these parabolic antenna structures, which are usually from about five to ten feet in diameter, make practical the use of radio frequency generating and amplifying devices that produce only relatively small amounts of power output. This is a very important factor in the design of microwave because of its effect on system cost and reliability. This narrow beam also provides discrimination between systems so that several systems may be operated in the same general vicinity without interfering with each other. Another characteristic at these frequencies is that very little of the radiated energy is reflected or bent around the curvature of the earth or around other large obstructions in the path between the transmitting and receiving antennas. Therefore, with the exception of a very few systems that employ extremely high transmitter power and very large antennas, it is necessary to limit separation between transmitting and receiving antennas so that there is a direct optical path between them. Usually these "line-of-sight" paths average from about 20 to 30 miles in length. Some may be much shorter, or considerably longer, depending upon factors such as the relatively fixed location of circuit terminals, and the character of intervening topography which may limit the engineer's choice when locating intermediate repeater stations.

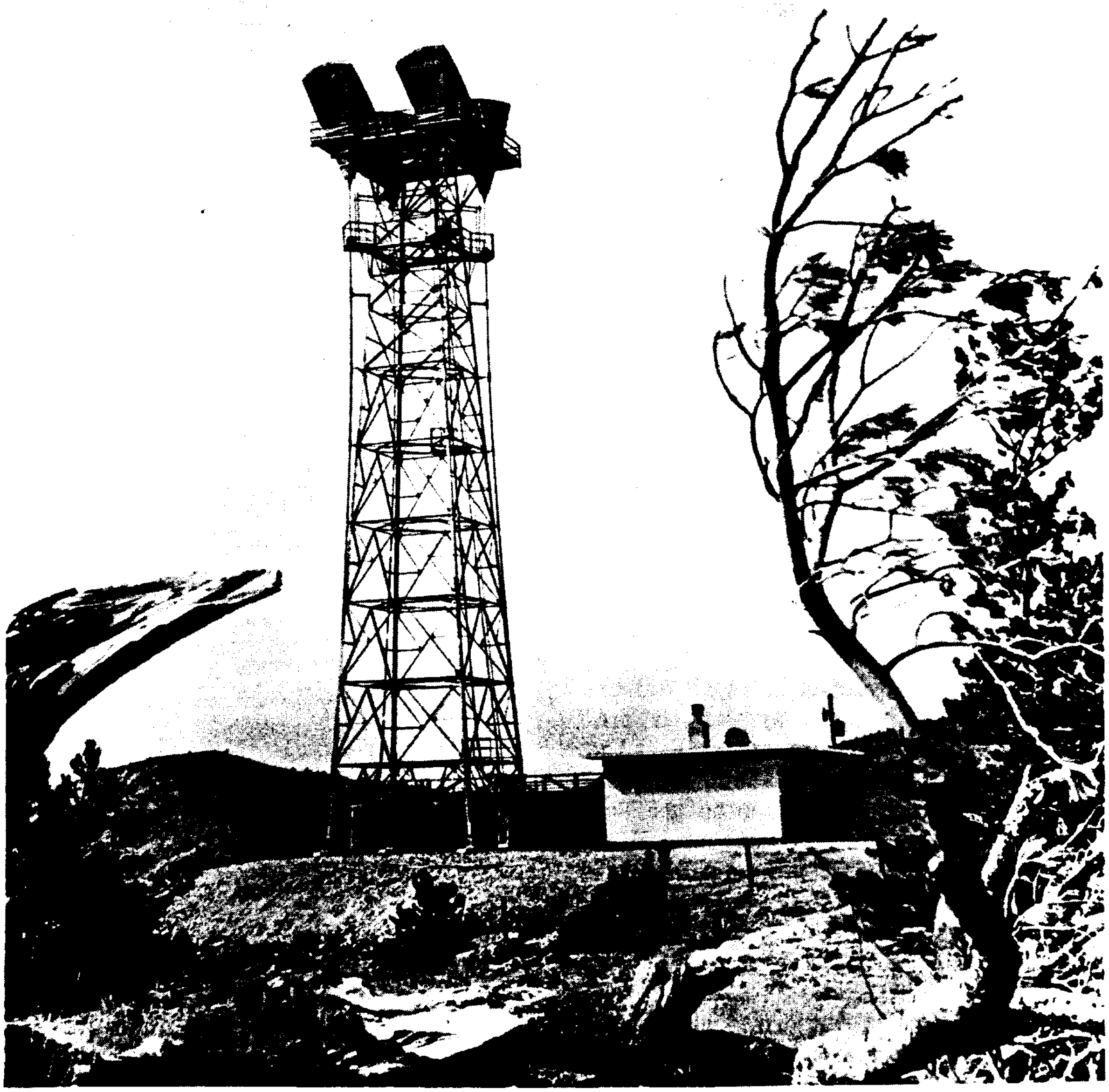

Fig. 1 – A TYPICAL LONG HAUL MICROWAVE REPEATER STATION — The highly directive horn-reflector type antennas shown may be used for operation in the 4, 6 and 11 Gc/s frequency bands.

D. Types of Microwave Equipment

1.09 Microwave systems now in general use are classified into two broad categories, IF heterodyne and baseband remodulation types. These classifications refer to the specific type of microwave equipment that is utilized.

1.10 In IF heterodyne systems a received radio frequency (RF) signal is converted (heterodyned) to a lower or intermediate frequency (IF), usually in the range of 70 Mc/s, where it is amplified and then converted back to a frequency in the RF range, for transmission to the next station.

1.11 In a baseband remodulation system the received RF signal is also converted to an IF signal for amplification, but this time the signal goes through an additional step, called detection or demodulation, to produce a baseband signal which is in the same form as the original multiplex, video or other basic signal source that was introduced for transmission over the system. This baseband signal is then again used to modulate an RF signal of the proper frequency for transmission to the next station — hence, the name baseband remodulation system.

1.12 IF heterodyne systems require additional equipment at terminal stations called frequency modulation terminals (FM terminals) to convert baseband signals to IF and IF signals to baseband, so that the basic signal source may be introduced or recovered.

1.13 The type of modulation almost universally employed in both systems is frequency modulation (FM), which means that the transmitter frequency is varied about its basic frequency assignment in proportion to the amplitude of the impressed modulating signal. At any one station, a frequency, higher or lower than the one that was received, is assigned to the transmitter, in conformance with a standard frequency plan, so that the transmitted signal will not interfere with the relatively low-level received signal, a situation familiar to those acquainted with carrier system crosstalk problems.

1.14 The advantage of the IF heterodyne system is that a minimum of distortion and noise is contributed at each repeater station, thus allowing good performance over long multihop systems. To take maximum advantage of

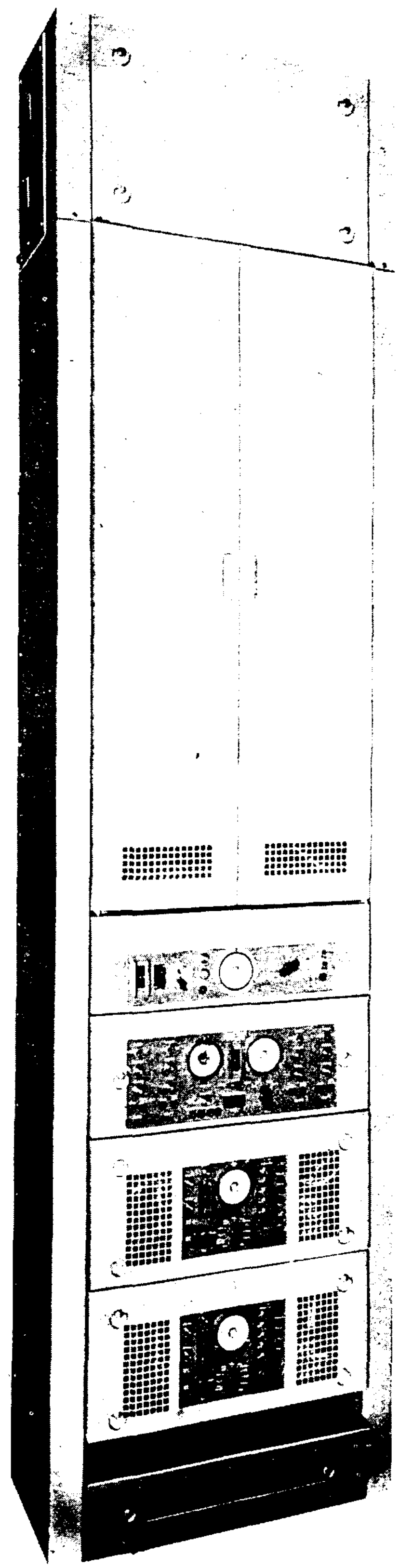

Fig. 2 – TD-2 MICROWAVE REPEATER EQUIPMENT — The bay shown here contains one transmitter-receiver unit and associated control panels. This long haul IF heterodyne system has been used extensively to provide all types of Bell System services

Fig. 3 – A TYPICAL SHORT HAUL MICROWAVE REPEATER STATION — Parabolic type antennas, covered with radomes for protection against snow and debris, are aimed toward reflectors at the top of the tower for transmission of signals to adjacent stations.

this feature, however, requires well designed and well built equipment, including the antenna system. It therefore does not necessarily result in a less expensive system, as might be implied by the above discussion. It is necessary with such systems to limit the number of terminal points where the IF signal is converted to baseband by FM terminal equipment, otherwise transmission objectives for circuits in the order of 4,000 miles in length cannot be met.

1.15 An advantage of baseband remodulation systems, when transmitting multiplexed carrier signals, is that the original baseband signal is readily available at each station along a route to allow for dropping and inserting groups of voice circuits. This also usually includes facilities for an order circuit, and for remote alarm and control of the radio system itself. Due to the additional degradation suffered at each station in the detection, and again in the remodulation

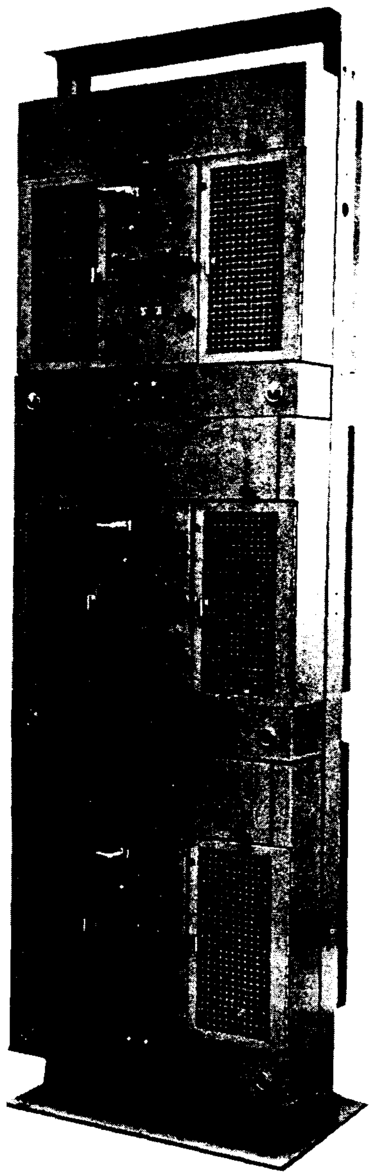

Fig. 4 – TM-1/TL-2 MICROWAVE REPEATER EQUIPMENT — The bay shown here contains three transmitter-receiver units along with associated alarm and order-wire equipment. This transistorized, short haul, baseband type equipment uses a small battery plant as a source of emergency power.

process, these systems are generally limited to about 9 repeaters in tandem (or 10 hops total) in order to meet overall transmission and noise objectives. They may take advantage of relatively inexpensive frequency generation and modulation schemes. For these reasons they have found particular use in the shorter applications where it is necessary initially, or in the future to drop and reinsert channels at frequent intervals along a route.

1.16 IF heterodyne systems are generally referred to as "long haul" or "heavy route" systems, because of the ability to carry large numbers of circuits over long distances. Baseband remodulation systems, in the past, were generally referred to as "light route" systems but since the circuit carrying capacity of most newer systems has been increased, from the range of 120 or 240 circuits up to 600 or more circuits, the term "short haul" is now more generally applicable. The 10 hop requirement usually limits these systems from about 200 to 300 miles in length.

1.17 At present, the 2 Gc/s band is used almost exclusively for short haul (and light route) types of service, the 4 Gc/s band for long haul, the 6 Gc/s for both long and short haul, and the 11 Gc/s for short haul only.

1.18 Special tubes are necessary for generating and amplifying signals at the high frequencies used in the microwave region. In addition to the specially designed triodes which are used at the lower microwave frequencies, klystrons and traveling wave tubes (TWTs) are widely used to generate and amplify the higher frequencies. Klystrons which are in general use for microwave systems develop output power in the range of 0.1 to 1.0 watt of RF energy, while TWTs used in these systems result in outputs in the order of 5 watts of RF power. More recently, solid state varactor diodes, which act as frequency multipliers to produce useful amounts of power in the microwave region, have been developed. Solid state devices offer the promise of simple power supplies and ease of maintenance. Therefore, it is expected that solid state devices and circuitry will continue to be developed to a point where they can be widely used for all microwave applications. In many of the newer systems, or of those currently under development, the klystrons or TWTs are the only active elements in the microwave system which are not solid state devices.

E. Regulatory Requirements

1.19 All transmitters must be licensed by the Federal Communications Commission (FCC) before being placed in operation. Construction permits or other authority must be obtained from the FCC before a system can be constructed or tested. Anyone making adjustments on transmitters must hold an FCC commercial 2nd class or higher operator's license. All concerned with the planning and engineering of microwave systems, therefore, must be thoroughly familiar with, and adhere to, the requirements of the FCC.

1.20 The FCC will not issue construction permits or licenses for a system unless it has been assured by the applicant that the safety reguirements of the Federal Aviation Agency (FAA), concerning antennas and their supporting structures, have been met. This involves such factors as antenna or tower heights, warning lights, and obstruction marking. These requirements must be understood and adhered to by those responsible for the engineering, construction, and operation of microwave systems.

2. DETERMINING CIRCUIT AND ROUTE REQUIREMENTS

A. Knowledge of the General Switching Plan

2.01 Before the Direct Distance Dialing (DDD) plan was introduced it was necessary to establish a definite switching and routing pattern for the interconnection of toll offices. Radio engineers should be familiar with the DDD plan, particularly as it applies in their area, and the purpose of any new circuits they proposed via microwave, for inclusion in this network.

2.02 The transmission objectives to be met over voice circuits in the toll network depend upon their particular use. Long intertoll trunks in general will have more restrictive requirements than the shorter end links or toll connecting trunks. When provided by microwave, the most controlling requirement to meet is usually the noise objective. With any particular type of microwave equipment the noise introduced by the system will increase as either the length or the number of circuits carried over the system is increased. It is these factors, primarily, that determine whether baseband remodulation or IF heterodyne type equipment should be used. Net loss stability of the voice channels carried over a system is also a function of the type of equipment. Stability requirements are more easily met on the longer circuits with IF heterodyne type equipment. In many cases some of the circuits being carried over a proposed microwave system will be extended beyond one or both terminals of the system under consideration by means of wire line or by another microwave facility. Care must be exercised to ensure that the overall requirements of these circuits will be met. Reliability objectives, which prescribe the degree of circuit continuity, are usually quite high but may vary somewhat, depending upon the size of any circuit group, the importance of the individual services over it, and the extent to which alternate facilities or routes are available. The degree of reliability that can be obtained is affected considerably by the choice of equipment and protection or standby arrangements that are provided.

B. Circuit Requirements

2.03 Since system design will depend to a great extent upon the number of circuits to be transmitted over the system, it is necessary to have a realistic estimate of this figure, not only of the initial circuit load, but of the load expected in the future as well. These estimates depend upon traffic studies of calling rates and also upon a forecast of the additional requirements needed for special services such as private lines and foreign exchange lines. Any known or expected TV or other broadband requirements should be carefully considered for their effect on the type and amount of equipment required or on the route the system is to follow. Another factor that must be considered in determining circuit requirements is the long range view of the switching plan. Changes contemplated in the future, such as new offices, may result in sudden changes in the number of circuits over a particular route and thereby affect the choice of microwave equipment.

C. Determining the Route

2.04 The most difficult task in designing a microwave system is that of selecting the repeater sites, or in other words, the exact route the system will follow. The two ends of the system will generally be fixed by central office terminals, but wide latitude may exist in the choice of intermediate repeater locations. If it is necessary, for instance, to drop or insert circuits at an intermediate office along a route for local traffic, this may be accomplished by a spur route off the main route or by establishing the main route repeater at the intermediate office itself. In some cases it may be desirable to deliberately locate the main route at some distance from major cities and then, by means of spur routes, provide more than one access to these terminal areas for alternate route or "Terminal Area Protection" purposes.

2.05 The engineers who select microwave sites must be thoroughly familiar with microwave propagation in order to preclude the choice of sites which will not provide the expected performance after the system is constructed. An error here can be expensive. Preliminary choices of station locations are usually made by a detailed map study, with the prime considerations being: optimum path lengths, proper path clearance, easy access to roads and sources of commercial power, and reasonable tower heights. Final path selection is done by field survey, and in many cases by actual propagation testing, using temporary towers and portable microwave equipment. This is necessary to verify adequate path clearance, as well as freedom from harmful ground reflection conditions, and to choose optimum antenna heights.

2.06 In making route and site selection it may be advantageous in many cases, for economy reasons, to temporarily or permanently utilize sites of existing systems for a portion of the route, or to plan new sites so that they may also be used for other future routes. In doing this, or in building routes which cross or pass near existing routes, the interference considerations between systems which may degrade performance or ultimately limit maximum use of either route must be carefully considered. As an aid in frequency coordination efforts it is highly desirable to prepare a map which indicates possible future microwave routes, along with frequency plans that are to be used. This map should be kept up to date and can serve as a fundamental microwave plan. It will allow for maximum utilization of existing available frequencies and will also help to avoid the need for future frequency or equipment changes which can be very costly.

3. ECONOMICS

A. Repeater Spacing

3.01 The cost per circuit mile of circuits on microwave can be very low compared to other types of transmission media. This is particularly true when many circuits are required between any two points or where the rate of circuit growth is rapid. One of the first tasks in designing a route is to make a preliminary choice of sites for repeater stations. The objective, of course, is to minimize the number of repeaters between fixed terminal locations, since the ultimate investment at each repeater station may be quite large, and every repeater point that is eliminated will thus result in a considerable cost saving.

3.02 There is a practical upper limit to the distance between repeater stations. In some cases favorable mountainous terrain may theoretically allow for exceptionally long line-of-sight radio paths, but even with some available options, including higher powered transmitters or larger antennas, a point is reached where transmission performance, notably noise and reliability, will suffer. In other cases the excessive cost for high towers, or the cost to build extensive roads or commercial power line extensions to remote locations, may preclude use of some sites which would otherwise be desirable in order to reduce the total number of repeaters.

3.03 In some cases the terrain may be such that the use of a very short path is made necessary. Where this is the case, or where two relatively short adjoining paths are necessary, it may be possible to use a "passive" repeater. A passive repeater consists of a large flat metallic reflector, resembling a billboard or drive-in movie screen, which is placed so that it will reflect the signal around or over an obstruction. It results in a substantial saving over the cost of building and maintaining an active repeater in those cases where it can be applied.

3.04 Paths which are shorter than optimum for the particular combination of equipment used will result in transmission degradation, since it results in the use of additional repeaters, and some amount of distortion will always be introduced at each of these additional repeaters. It will be remembered that baseband repeating systems are usually limited, in length, to about ten hops total. Reliability of the system may also suffer, since statistically there is a greater probability of equipment failure when there are larger numbers of transmitters and receivers in the total transmission path of a given length.

3.05 In practice, the engineer in his map study selects several possible routes and alternate repeater sites for each route under study. It is then necessary to make calculations to determine transmission quality, estimates of reliability and costs for each plan. From these he must make a decision as to which best meets the needs. In some cases the choice may be easily made, in others there may be no ***one*** right answer, and tentative judgment must be relied upon in choosing the most acceptable sites. Later field surveys or actual transmission tests may rule out a site or sites which might appear to be a good choice from a map study, and the alternate sites must then be considered in turn.

B. Repeater Station Costs

3.06 The total cost of a repeater is made up of many items, all of which must be determined or estimated to some degree in advance, in order to help make economic decisions. Among the first encountered is the cost of land acquisition, along with access roads — if any, commercial power, site grading, fencing and possibly path testing. It may be necessary in many cases to obtain an option on the land before path testing is started. Next, in addition to the cost of the building or shelter which is to house the equipment, is the cost of the microwave equipment itself. Once the type of microwave equipment is chosen, the cost of the transmitters and receivers may be easily determined, but other items may, in some cases, be subject to a choice of several options and therefore decisions must be made. This is especially true in the short haul field. What kind and amount of redundant equipment is necessary to protect against outage due to fading or equipment failure? Is frequency diversity necessary, or will nondiversity or standby equipment suffice? How much and what kind of switching equipment is necessary for this purpose and where will it be located? What kind of an emergency power system is to be provided — batteries, engine-alternators? Will they care for immediate as well as future needs? What type order wire, alarm and control system is necessary; will separate wire line or radio facilities to care for these be necessary? Other items that will be necessary include test equipment and spare parts or replacement units. Some of these items may be purchased for shared use at several sites, while others will be required at every station. The amount and location of this equipment will affect the time required to perform routine maintenance and to make repairs in case of failure. Thus initial savings in test equipment or spare parts costs may result in extra maintenance costs or poor performance.

3.07 Tower height will be determined by path clearance requirements which in turn are dependent upon the site selected. Its cost will be determined by the type of tower and antenna chosen. The tower may be self-supported or guyed. The antenna may be of the direct radiator type, such as a horn-reflector or parabolic dish type, or it may be of the periscope type consisting of a roof-mounted dish aimed at a reflector located on the tower. The type and size of antenna or reflector chosen will have a direct effect on tower strength and stability requirements.

3.08 Finally, an estimate must be made of construction and installation costs where this is not included with the material price estimates or bids.

3.09 Fortunately, many cost items except for land, access roads, towers and antennas may be common to the several alternative sites chosen, so that cost estimating is simplified to some extent, but all items must be carefully considered to get a realistic cost estimate.

3.10 Many of the above items such as land, buildings and towers are one-time charges, in that they are not required to be duplicated as additional microwave channels are added over the route. This is the reason for the earlier statement that costs for circuits via microwave can be very low especially when the circuit requirements are high or the growth rate is rapid. However, when growth is slow or ultimate requirements are low, minimum cost microwave equipment arrangements are available which still may make microwave economically attractive. Despite these one-time or initial costs microwave will usually compare favorably with other means. This is particularly true when other plans require a substantial amount of cable or conduit construction or rearrangement, a factor which may be easily overlooked when broad-gauge cost estimates are being used. In many cases the additional benefits of alternate routes or alternate means of providing service between points are justified where the cost differential is not too great. Not to be overlooked in any particular circumstance is the flexibility provided by microwave, with its capability to transmit most of the various multichannel carrier systems. This broadband capability also allows transmission of television signals or, alternately, may be divided up into various bandwidths to provide for special requirements.

3.11 In the final analysis every method that is available to provide for new or increased service requirements must be investigated and a realistic cost comparison made. These costs then must be used in conjunction with a comparison of expected performance and other service objectives, in order to make an overall judgment of which method to use.