

# Microwave System Engineering Using Large Passive Reflectors\*

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**Summary**—This paper will provide the microwave engineer with the basic techniques of microwave system engineering using large passive reflectors and will outline the many advantages of their use. Small passive reflectors of the "periscope type" have been used for many years on microwave systems. Large passive reflectors have also been used but to a much lesser degree. Large passives may be used at intermediate points on long (200 miles or more) microwave links in lieu of active repeaters. Most microwave engineers have little knowledge of system engineering using these reflectors. This paper describes their use in both the "near" and "far fields" in line-of-sight systems and describes how they may be used on non-line-of-sight systems (tropospheric scatter and diffraction systems). Formulas are developed and graphs provided which will enable the microwave engineer to determine the path loss of multihop passive reflector systems. Large passive reflectors should be considered as another tool which can be used by the microwave engineer for planning and engineering communications systems. When used effectively with line-of-sight, diffraction and tropospheric scatter modes of propagation, communication systems may be engineered more economically, with more reliability and with a decrease in the operating and maintenance problems.

## INTRODUCTION

FOR MANY YEARS microwave systems have used passive reflectors of the "periscope type" operating in the "near field" of the antenna (Fig. 1(a)). These small passive reflectors may introduce a slight gain or loss in the microwave system. The use of these reflectors in the "near field" has been adequately described.<sup>1-6</sup> Passive reflectors may be used in microwave systems in both the "near field" and the "far field." Even as early as 1945 while microwave systems were still in their infancy, pioneering experimentation and testing of passive reflectors in both the "near field" and "far field" was being conducted by the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, N. J., (formerly the Signal Corps Engineering Laboratories).<sup>1</sup> Large reflectors may be used in this manner to extend the distance

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<sup>1</sup> L. G. Fobes, "Multichannel radio communications within the army," IRE TRANS. ON MILITARY ELECTRONICS, vol. MIL-4, pp. 511-512; October, 1960.

<sup>2</sup> W. C. Jakes, Jr., "A theoretical study of an antenna-reflector problem," Proc. IRE, vol. 41, pp. 272-274; February, 1953.

<sup>3</sup> D. R. Crosby, "Theoretical gain of flat microwave reflectors," 1954 IRE CONVENTION RECORD, pt. 1, pp. 71-75.

<sup>4</sup> R. E. Greenquist and A. J. Orlando, "An analysis of passive reflector antenna systems," Proc. IRE, vol. 42, pp. 1173-1178; July, 1954.

<sup>5</sup> J. Drexler, "An experimental study of a microwave periscope," Proc. IRE (Correspondence), vol. 42, p. 1022; June, 1954.

<sup>6</sup> I. Takasu, "The Passive Antenna of Reflect Plane," Japan Telecomm. Rev., Nippon Telegraph and Telephone Public Corp.; Autumn, 1959.

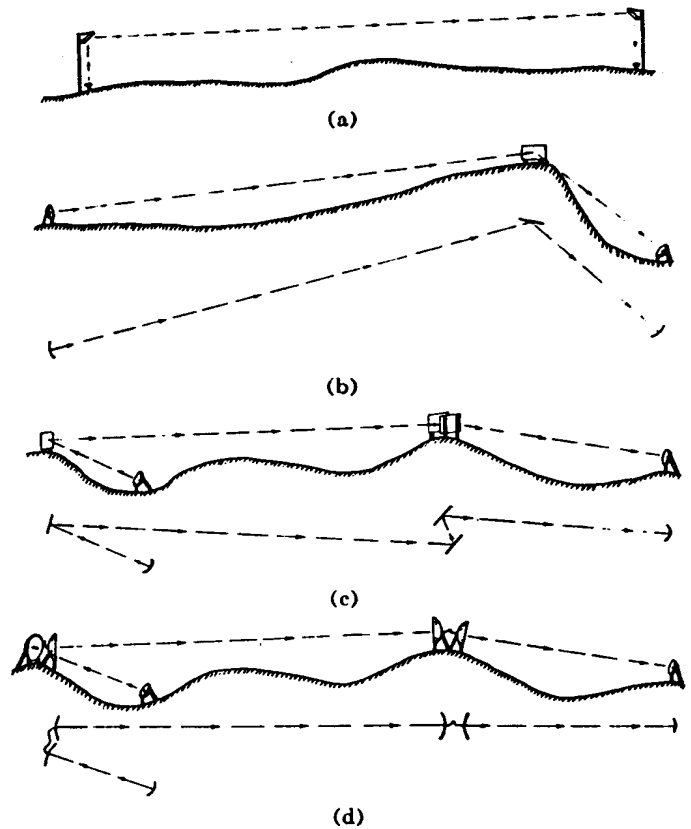


Fig. 1—Types of passive antenna systems. (a) Periscope type. (b) Two hop system using single passive reflector. (c) Three hop system using single and double passive reflectors. (d) Three hop system using back-to-back antennas.

between two active microwave terminals or in lieu of active microwave repeaters. A few articles have been published on the use of large passive reflectors operating in the "far field."<sup>6-12</sup>

Most microwave engineers have very little knowledge of system engineering using large passive reflectors even though these reflectors have been widely used in hundreds of different locations primarily in mountainous areas. It is commonly believed that large passive reflectors are

<sup>7</sup> H. Mugniski and T. F. Koch, "Passive repeater bands microwave beam," Electronics, vol. 26, p. 134; February, 1953.

<sup>8</sup> R. F. H. Yang, "Passive repeater using double flat reflectors," 1957 IRE NATIONAL CONVENTION RECORD, pt. 1, pp. 36-41.

<sup>9</sup> F. Cappuccini and F. Casparini, "Passive repeater using double flat reflectors," Proc. IRE, vol. 46, pp. 784-785; April, 1958.

<sup>10</sup> R. Aschden, "Passive relay by microwave mirror," TSF et TV, vol. 33, pp. 5-7; January, 1958.

<sup>11</sup> R. Aschden, "Passive TV relay and its practical possibilities," TSF et TV, vol. 33, pp. 329-330; November, 1957.

<sup>12</sup> I.T.T., "Reference Data for Radio Engineers," Stratford Press, New York, N. Y., 4th ed., p. 757; 1957.

practical only if they are used on microwave systems where the reflector is located near one end of the path. They are more efficient if located near one end of the microwave path; however, they may also be used on paths of 200 or more miles (Fig. 1(b) and 1(c)) including diffraction and tropospheric scatter paths. The use of tropospheric scatter type equipment (high power transmitters and very sensitive receivers) greatly increases the versatility of large passive reflectors. Two antennas connected back-to-back by a short transmission line may also be used as a passive repeater (Fig. 1(d)). However, they are more expensive and less efficient.

Formulas are developed and graphs are provided which will enable the microwave engineer to determine the path loss of multihop passive reflector systems using reflectors in both the "near" and "far" fields. This paper augments that information previously published and will attempt to acquaint the microwave engineer with the basic techniques of microwave system engineering using large passive reflectors and to outline many advantages of their use.

NEAR FIELD—FAR FIELD

In order to calculate the loss of a microwave system using large passive reflectors it must be determined whether the reflectors are in the "near field" or "far field" of the terminal antenna. An antenna is normally considered a point source and transmits a spherical wave. If this wave front varies from a plane wave by a small amount  $\Delta r$  (Fig. 2(a)) then the wave front may be considered as a plane wave. The most commonly accepted definition of the "far field" is that space in the field of an antenna where, over a given area, the spherical wave varies from a plane wave by less than  $\lambda/16$  (Fig. 2(b)).<sup>13</sup> If this variation is more than  $\lambda/16$  the given area is normally considered to be in the "near field." Therefore the radius  $r$  of the "near field" is

$$r = \frac{2D^2}{\lambda} \text{ or } \frac{2a^2}{\lambda} \tag{1}$$

where antenna diameter  $D$  or reflector side  $a$  and  $\lambda$  are in the same units. Expressing  $r$ ,  $D$  and  $a$  in feet and converting  $\lambda$  to megacycles we have

$$r = \frac{D^2 f}{492} \text{ or } \frac{a^2 f}{492} \tag{2}$$

The radius of the "near field" for different antenna and passive reflector sizes is plotted in Fig. 3.

Two different methods are described in this paper for determining the systems loss when passive reflectors are used. These methods may be referred to as the "far field" and "near field" methods.

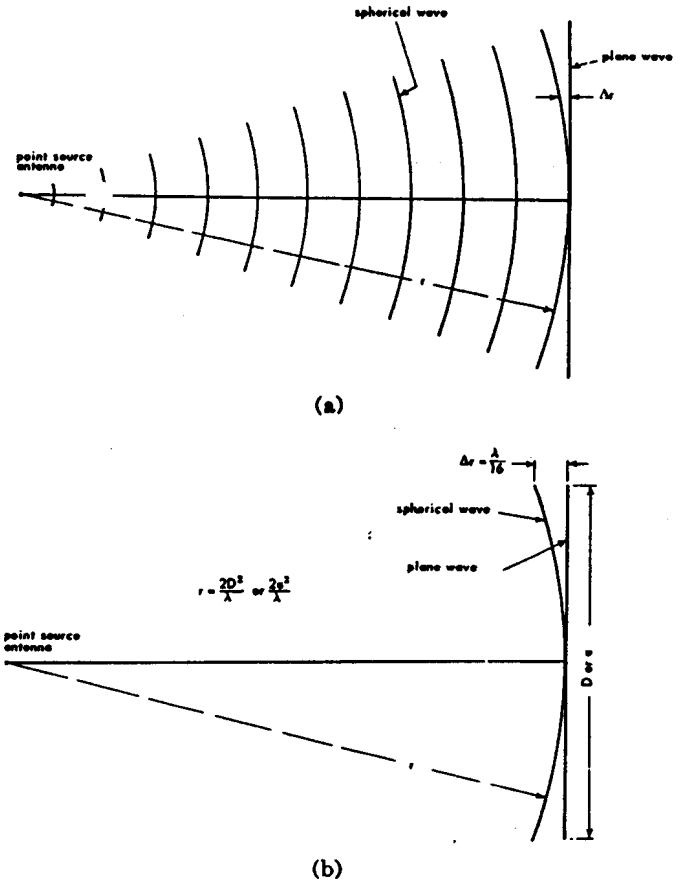


Fig. 2—Determination of the "near field."

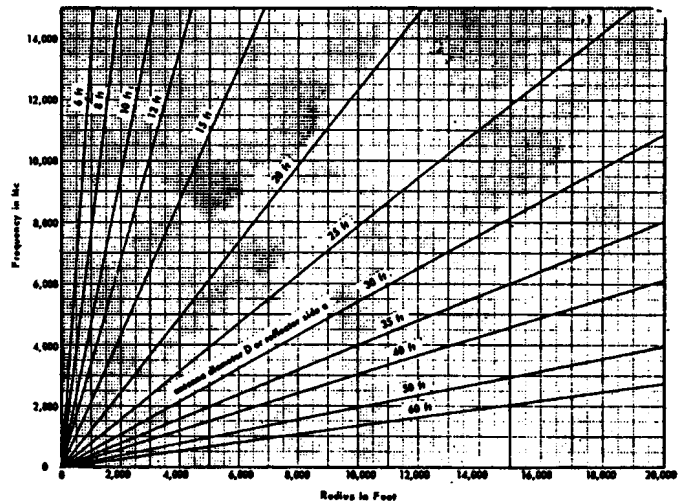


Fig. 3—Radius of the "near field."

TWO HOP SYSTEM USING A PASSIVE REFLECTOR IN THE "FAR FIELD"

Consider a passive reflector of projected area  $a^2$  located in the "far field" of the terminal antennas (Figs. 1(b) and 4). A passive reflector has the gain of two back-to-back aperture antennas. The gain  $G_r$  of an aperture antenna is

$$G_r = \frac{4\pi a^2}{\lambda^2} \tag{3}$$

<sup>13</sup> S. Silver, "Microwave Antenna Theory and Design," M.I.T. Rad. Lab. Ser., McGraw-Hill Book Co., Inc., New York, N. Y., vol. 12, pp. 196-199; 1949.



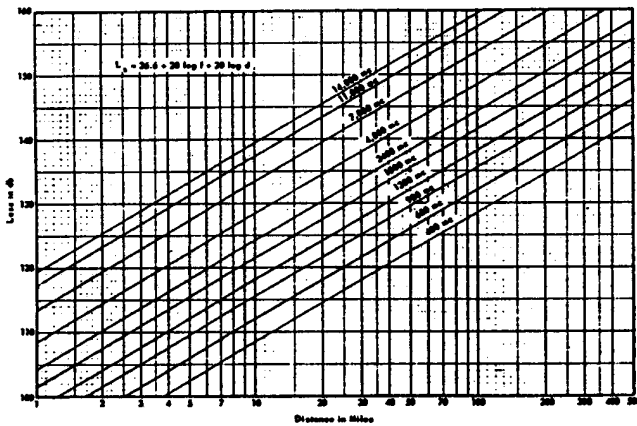


Fig. 6—Free space loss.

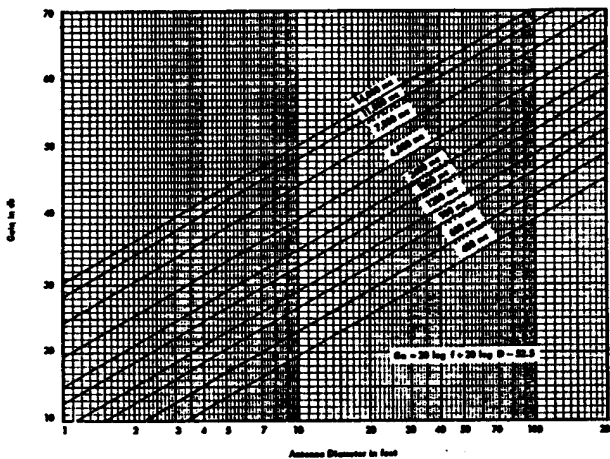


Fig. 7—Gain of parabolic antenna.

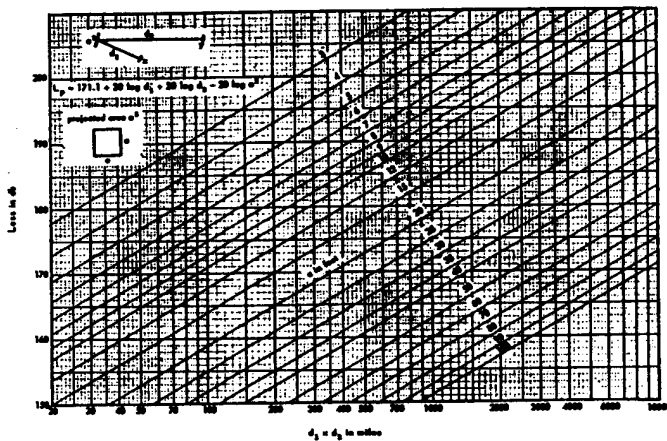


Fig. 8—Space loss on a two hop passive reflector system.

where

- $d_1$  = distance from Terminal A to Passive Reflector 1 in miles,
- $d_2$  = distance from Passive Reflector 1 to Passive Reflector 2 in miles,
- $d_3$  = distance from Passive Reflector 2 to Terminal B in miles,
- $a_1^2$  = projected area of Passive Reflector 1 in square feet,
- $a_2^2$  = projected area of Passive Reflector 2 in square feet.

It should be noted that for a three hop microwave system using two passive reflectors in the "far field" the total space loss between isotropic antennas is *dependent on frequency* with the loss *inversely* proportional to the square of the frequency. Therefore the *higher the frequency, the less the total space loss between isotropic terminal antennas on a three hop system.*

USE OF PASSIVE REFLECTORS IN THE "NEAR FIELD"

There is very little difference in the use of large passive reflectors in the "near field" and the use of the more common "periscope type." The only difference is in the size of antennas and reflectors and the spacing between them. As can be seen from Fig. 3 the radius of the "near field" can be quite large. A 7000 Mc, 60-foot antenna has a "near field" radius of approximately 10 miles. Passive reflector efficiencies are plotted in Fig. 9. These reflector efficiencies are the gains and losses of the antenna-reflector combination as compared to the antenna alone.

Consider a 7000 Mc, 30-foot antenna with a passive reflector of projected area of 1200 square feet (approximately 35-foot projected square) located one mile away. From Fig. 9,  $l$  is approximately 0.8,  $1/k$  is approximately 0.5 and there is no additional loss. Therefore the system has the same loss as if the terminal antenna was in the passive reflector location. In effect we have moved the terminal antenna one mile with no additional loss.

USE OF DOUBLE PASSIVE RELECTORS IN THE "NEAR FIELD"

Single passive reflectors as previously described can be efficiently used when the deflection angle at a repeater site is greater than approximately 40° or 50°. When the required deflection angle is less than 40° or 50° double passive reflectors will normally be more efficient. The efficiency of double passive reflectors as compared with a single passive reflector is a function of the wave length, projected area of the two reflectors and spacing. The use of double passive reflectors has been adequately described.<sup>6</sup> Double passives have a gain or loss over the gain of a single passive of projected area equal to the projected area of the smaller of the double passives. These gains or losses are plotted in Fig. 10.

The most efficient arrangement of double passives is two reflectors with equal projected areas located close to each

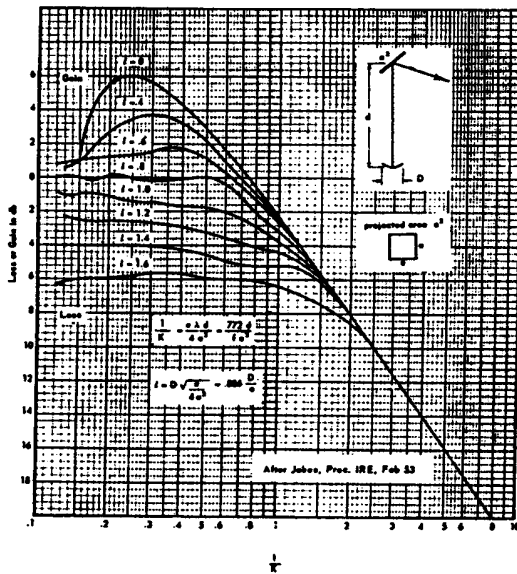


Fig. 9—Efficiency of passive reflectors in the “near field.”

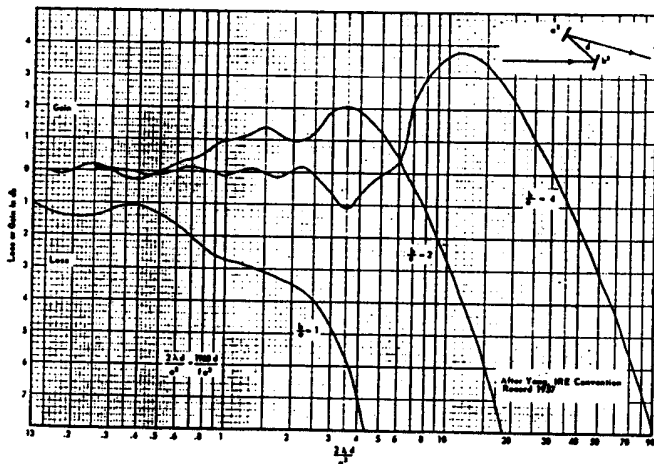


Fig. 10—Efficiency of double passive reflectors.

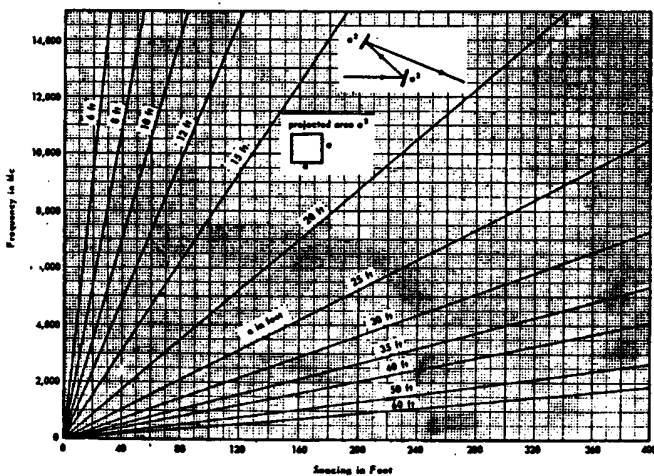


Fig. 11—Maximum spacing of double passive reflectors for loss < 1 db.

other. The additional loss can be kept below 1 db (Fig. 10), if

$$\frac{2\lambda d}{a^2} \leq 0.13, \tag{13}$$

where

- $\lambda$  = wave length,
- $d$  = spacing between reflectors,
- $a^2$  = projected area of reflector.

The maximum reflector spacings in which the additional loss can be kept below 1 db are plotted in Fig. 11. As can be seen on the higher frequencies the spacing can be several hundred feet.

INSTALLATION CONSIDERATIONS

The same installation practices used for large parabolic antennas should be used for large passive reflectors. In order for the path loss equations used in this paper to be accurate the passive reflectors must be installed using good microwave system engineering practices. First fresnel zone clearance should be maintained on all paths. If first fresnel zone clearance is not maintained then the additional loss due to grazing, diffraction or tropospheric scattering must be considered.

There are additional considerations required when double passive reflectors are utilized. Consider double passive reflector installations as shown in Fig. 12. That portion of the wave front that is reflected by each reflector must clear the other reflector by several wavelengths. From the experience gained from the installation of many double passive reflectors it has been determined the clearance should be at least 15 wavelengths which is only approximately 2 feet at 7000 Mc.

Double passive reflectors may be arranged in a symmetrical or asymmetrical configuration as shown in Fig. 12. The minimum spacing between reflectors is determined by symmetry and the required 15 wavelengths clearance. The smaller the deflection angle the greater the required spacing between reflectors. Consider two installations requiring 50° and 24° deflection angles. At 7000 Mc the minimum spacings are 67 feet and 146 feet (Fig. 12(a) and (b)). Although an asymmetrical configuration requires much less space (Fig. 12(c)) wider reflectors are required in order to maintain the desired projected width. In Fig. 12 all reflectors have a projected width of 30 feet.

An interference problem may develop when the required deflection angle is zero or very small. The direct wave may be propagated to the distant terminal due to diffraction, scattering, ducting or other means. This direct wave may be out of phase with the wave from the passive reflector and cause fading or cancellation. To prevent this type of problem will require careful investigation of the possible field strengths of the direct wave. If interference seems probable one possible solution is the use of two cross

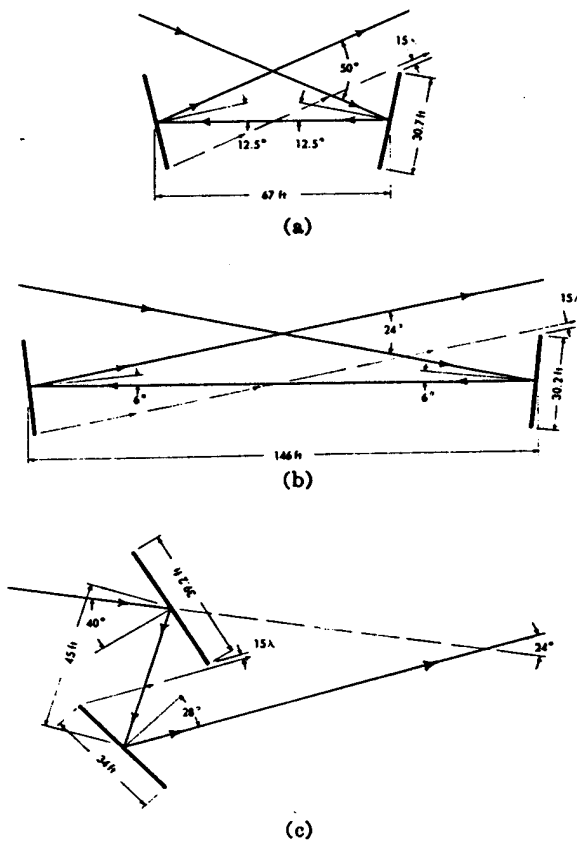


Fig. 12—Installation of double passive reflectors.

polarized back-to-back parabolic reflector antennas. This will minimize the interference between the direct and reflected waves. However, the parabolic reflectors may be more economical than either tropospheric scatter or line-of-sight *active repeater* systems. If back-to-back parabolic reflector antennas are used they will have to have a diameter 50 per cent greater than the width of passive reflectors (assuming square projected area) in order to have the same gain (see Figs. 5 and 7).

SYSTEM PLANNING

If a requirement exists between two non-line-of-sight locations in which there are one or two intermediate points which are in line-of-sight of each other and the terminal locations, then the use of a two or three hop passive reflector system will normally provide less loss than tropospheric scatter and may be more economical than either tropospheric scatter or a line-of-sight system. Plotted in Fig. 13 are the terminal-to-terminal losses of a typical 100 mile line-of-sight, passive reflector and tropospheric scatter systems with 30-foot parabolic terminal antennas. The tropospheric scatter losses include "antenna-to-medium" coupling loss.

For example a 100-mile tropospheric scatter system with 0° take off angles will have a terminal-to-terminal loss of

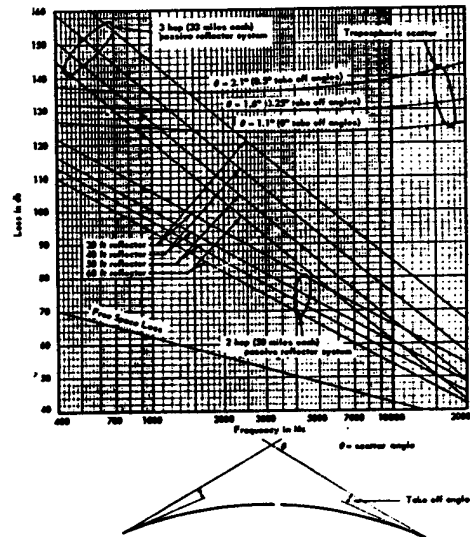


Fig. 13—Comparison of terminal to terminal loss of a typical 100 mile line-of-sight, tropospheric scatter and passive reflector systems, each with 30 foot parabolic terminal antennas.

from 123 to 127 db. In contrast a 7000-Mc three-hop system with 30-foot passive reflectors will have a terminal-to-terminal loss of 95 db and a two hop system with a 30-foot passive reflectors will have a terminal-to-terminal loss of only 72 db. This is an improvement of 29 db for a three hop system and 51 db for a two hop system. These improvements would be much greater if there were positive take off angles on the tropospheric scatter system or if larger reflectors were used on the passive reflector systems. Since the path loss on a passive reflector system is proportional to the product of the path distances, any reduction in this product by proper site selection will also reduce the path loss and give an additional improvement over a tropospheric scatter system.

A 120-channel military microwave system using active repeaters is routed as shown in Fig. 14. These active repeaters could be eliminated by increasing the 6-foot terminal antennas on the A-B link to a diameter of 20 feet, increasing the 4-foot terminal antennas on the B-C link to a diameter at 30 feet, and installing 30 foot square (projected area) double passive reflectors at relays 1, 2 and 3. The receive signal levels would be approximately 30 db above the receiver threshold. The use of tropospheric scatter would be extremely difficult and costly. The scatter angle between Terminal A and Terminal B is 1.9° and between Terminal B and Terminal C is 3.8°. These two links would require 60 foot or larger antennas in space diversity with transmitter powers of 1 kw or greater on the A-B link and 10 kw or greater on the B-C link.

A military tropospheric scatter system efficiently uses large passive reflectors in the "near field" (Fig. 15). Double 52.5 foot (projected area) reflectors are located 1.4 miles from the 33-foot terminal antenna. The scatter

ECONOMIC CONSIDERATIONS

There are many factors involved in the planning and designing of microwave systems. Economic considerations may determine if a communication requirement will be met by a line-of-sight active repeater system, line-of-sight passive repeater system, tropospheric scatter system or diffraction system.

An active microwave repeater requires buildings, primary and emergency power, microwave equipment, access roads, frequent maintenance, and in some cases, full time operating personnel. In contrast passive repeaters may be installed in a normally inaccessible location. There are no requirements for buildings, power, microwave equipment, access roads or operational personnel. The passive reflector and all installation materials may be delivered by any means, even by helicopter. When passive reflectors are used in lieu of active repeaters normally an antenna of higher gain will be required at the terminal sites. A completely new active repeater site costs approximately \$260,000.<sup>14</sup> In contrast a passive repeater using double passive reflectors and high gain antennas at the terminals (30-foot terminal antennas and 30-foot double passive reflectors) will only cost approximately \$80,000.

Tropospheric scatter systems normally require high power transmitters, very sensitive receivers in dual, quadruple and in some cases octuple diversity. The cost of tropospheric scatter terminals in the typical 100-mile system previously mentioned would normally be much greater than that of the passive reflector system due to the higher system losses. In many cases the use of passive reflector systems can provide the same grade of service much more economically.

In addition to the reduction in the initial cost of microwave systems using large passive reflectors there is also a great reduction in operational cost. Elimination of active repeaters or a reduction in the power requirements and complexity of the terminals results in a reduction in the number of operating and maintenance personnel, reduces the quantity of spare parts, reduces the cost for commercial and emergency power and reduces site operation and maintenance cost.

RELIABILITY

There are many factors which determine the reliability of a communication system. Reliability is proportional to the complexity and quantity of the electronic equipment and to the quantity and quality of operating personnel. The use of large passive reflectors will in many instances reduce both the quantity and complexity of the electronic equipment and reduce the quantity of operating personnel. These reductions will cause a corresponding increase in the reliability of the communication system.

<sup>14</sup> R. D. Chipp and T. Cosgrove, "Economic analysis of communication systems," presented at 7TH NAT'L COMMUNICATIONS SYMP., Utica, N. Y.; October 2-4, 1961.

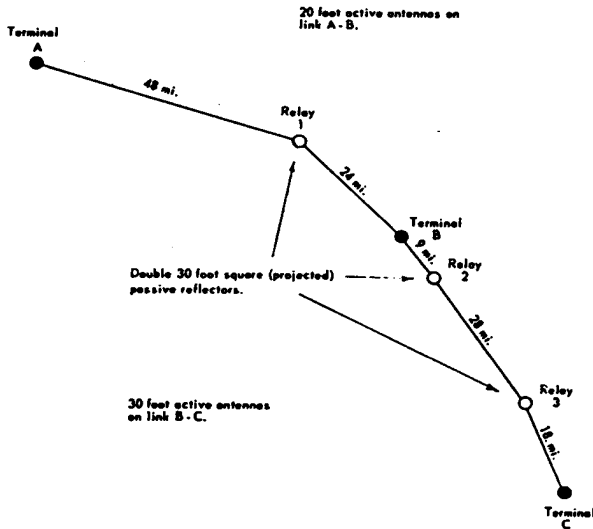


Fig. 14—Military microwave system which could efficiently use large passive reflectors.

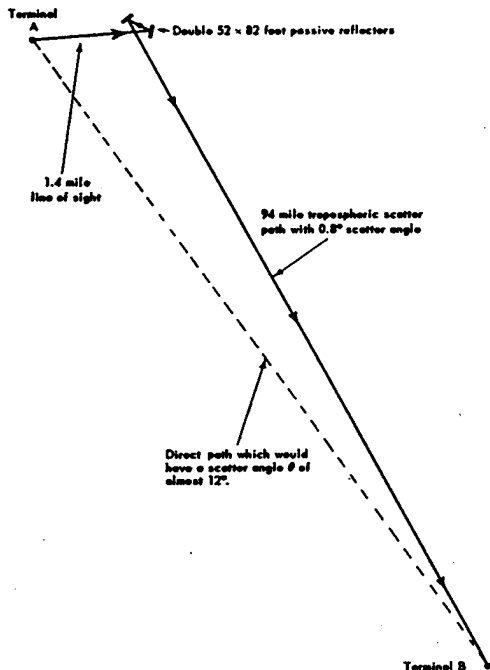


Fig. 15—Military tropospheric scatter system which uses large passive reflectors.

path from the passive reflectors to the distant terminal is 94 miles with a scatter angle of 0.8°. Communication between the two terminals via tropospheric scatter without the passive reflectors would be impossible since the scatter angle between the two terminals would be almost 12°. From Figs. 9 and 10 it can be determined that the additional loss introduced by the passive reflectors is approximately 4 db more than the loss from the passive reflectors to the distant terminal. The transmitter power used on this link is only 100 w at 1800 Mc.

## CONCLUSIONS

Large passive reflectors are extremely practical. They can be used to replace active repeaters on line-of-sight microwave systems and can also be used on diffraction and tropospheric scatter systems. By the use of high power transmitters and very sensitive receivers long, two or more hop systems may be effectively utilized. The space loss on a two hop system is *independent* of frequency and on a three or more hop system is *dependent* on frequency with *less* loss at the *higher* frequencies. By the use of frequencies of several gigacycles with their higher gain antennas, the system losses can be quite low. Large terminal antennas and passive reflectors may be sited and installed using the same engineering and installation practices normally used for tropospheric scatter systems.

Large passive reflectors are also economical. When used to replace active microwave repeaters or to extend a tropospheric scatter or diffraction system considerable savings in initial and operating cost can be realized. The reliability of communication systems using large passive reflectors will be considerably higher due to a reduction of the quantity and/or complexity of the electronic equipment.

Large passive reflectors should be considered as another tool which can be used by the microwave engineer for planning and engineering communication systems. When used effectively with line-of-sight, diffraction and the tropospheric scatter modes of propagation, communication systems may be engineered more economically, with more reliability and with a decrease in the operating and maintenance problems.