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MICROWAVE ANTENNAS
RETURN LOSS MEASUREMENTS
GENERAL THEORY

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1. GENERAL

1.01 This section describes the theory and method of measuring the return loss of the antenna and associated waveguide system. The method can be used to locate impedance irregularities in the antenna-waveguide system which includes the antenna, circular and rectangular waveguides, directional couplers, pressure windows, and channel networks.

1.02 It is very important that all impedance irregularities in the antenna system be kept within limits or the radio system will have excessive noise due to intermodulation products. These irregularities may be caused by damaged or improperly installed waveguide or by foreign matter in the waveguide.

2. THEORY

2.01 Consider a transmission line as in Figure 1 in which a signal generator is connected to a terminated transmission line, and a detector is connected to the line at a point near the generator. At some distance L from the detector an impedance discontinuity causes a reflection of a portion of the incident power. The following discussion presents a method of locating the point of reflection and of measuring the magnitude of the reflected power.

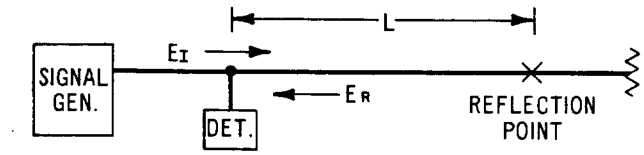


Figure 1

2.02 In Figure 1 the voltage at the detector will be the vector sum of the incident signal E_I and the reflected signal E_R. As can be seen in Figure 2 below, the vector sum E_D will depend upon the phase relationship between E_I and E_R which is a function of the length of line between the detector and the point of reflection. If, in Figure 1, L equals 1/2 wavelength at the generator frequency, the signal would shift 180° traveling to the point of reflection and 180° returning to the detector. Neglecting phase shift at the reflection, the total shift would be 360° and E_I and E_R would add to produce a voltage maximum. However, if the distance L were 1/4 wavelength the total shift would be 180° and E_I and E_R would subtract to give a voltage minimum. For other electrical lengths of line the resultant voltage E_D would be somewhere between these limits.

2.03 To locate an impedance discontinuity in a line, the arrangement of Figure 1 may be employed by varying the frequency of the generator. At a frequency near zero a wavelength is extremely long, the reflected voltage

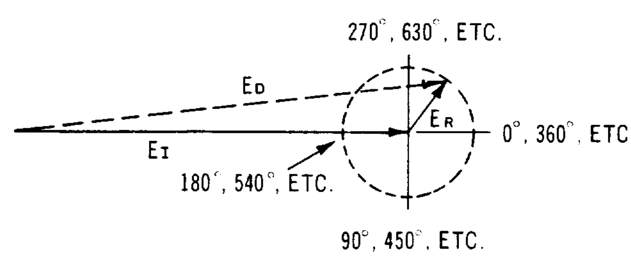


Figure 2

changes phase by a very small amount, the incident and reflected voltages are essentially in phase, and the resultant voltage is a maximum. As the generator frequency is increased the resultant voltage will decrease to a minimum when L becomes equal to 1/4 wavelength and then increase to a second maximum. This is illustrated by Figure 2 where 0° and 360° are the points of maximum voltage and 180° the voltage minimum. At f_2, the frequency of the second maximum, the distance to the point of reflection is 1/2 wavelength. The distance may be determined by the equation:

$$(1)\ L = \frac{492d}{f_2 - f_1}$$

where: f_2 and f_1 are the frequencies in megacycles per second of voltage maxima. (In the case cited above, f_1 is zero.) 492 is 1/2 wavelength in feet of a one megacycle per second wave in free space transmission.

(d) is a propagation constant and is the ratio of the velocity of transmission in the line to the velocity in free space. (See par. 2.13.)

2.04 In microwave systems employing waveguide for transmission lines, the lowest frequency that can be transmitted is determined by the cut-off frequency of the waveguide, and the wavelengths involved are fractions of a foot. Hence the procedure just described which utilized frequencies near zero for f_1 cannot be used. However a variation using the same principles may be employed and Figure 3 is a typical arrangement.

2.05 An RF sweep generator is connected to the waveguide and antenna system. The output of the detector is connected to the vertical deflection terminals of the oscilloscope. The horizontal deflection of the oscilloscope is synchronized to the sweep generator. As the frequency is swept across the band of interest the synchronization is such that the lowest frequency voltage appears at the left of the oscilloscope trace and the highest frequency voltage at the right. At any frequencies within the swept band where the phase shift traveling from the detector to the point of reflection and back is a multiple of a full wavelength, a voltage peak will appear on the oscilloscope trace and at frequencies half way between a voltage minimum will appear. As a result the trace appears as a series of ripples.

2.06 If the phase shift from the detector to the reflection and return is one wavelength further at the highest frequency than at the lowest frequency one complete ripple cycle would result and the oscilloscope presentation may appear as shown in Figure 4 which depicts voltage maxima at the ends of the trace. It should be borne in mind that the frequencies at which voltage maxima occur depends upon the phase shift (including reactive phase shift at the point of reflection) and that the ripple cycle could start at any point in the cycle.

2.07 In the above example, equation (1) may be used to determine the distance L to the point of reflection. In this case, f_1 and f_2 are any two corresponding frequencies of a complete cycle.

2.08 In the case of longer distances to the reflection point the pattern of Figure 4 would be repeated and may appear as in Figure 5. To apply equation (1), $f_2 - f_1$ would be the frequency difference between adjacent peaks. This is referred to as the ripple frequency.

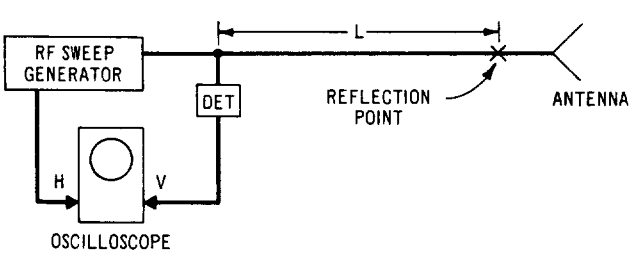


Figure 3

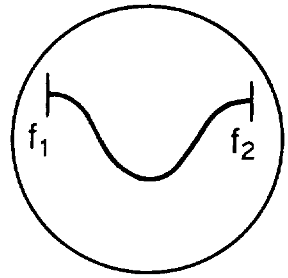


Figure 4

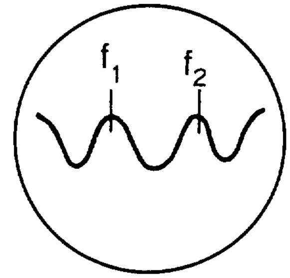


Figure 5

2.09 For distances L shorter than the case illustrated by Figure 4 less than one complete cycle would be displayed and the ripple period must be estimated.

2.10 The magnitude of the reflection may be determined from the oscilloscope presentation and the following equations:

$$\text{(2) P.P. ripple} = 20 \log \frac{E_I + E_R}{E_I - E_R}$$

$$\text{(3) RL} = 20 \log \frac{E_I}{E_R} \text{(assumes lossless waveguide)}$$

By calibrating the oscilloscope so that the peak-to-peak amplitude of the ripple can be determined in db, this value can be used with equation 2 to determine E_R (assume E_I = unity). This value of E_R can then be substituted in equation (3) to determine the return loss.

Example:

P.P. ripple = .5 db (from measurement)

$$20 \log \frac{1 + E_R}{1 - E_R} = .5 \text{ db}$$

$$E_R = .0286$$

$$\text{RL} = 20 \log \frac{1}{.0286} = 30.8 \text{ db}$$

2.11 Although dominant mode waveguide has low attenuation, the loss may become appreciable for long antenna runs. To take this loss into account, the return loss of an individual reflection point as given by equation (3) should be modified by subtracting twice the waveguide loss (round trip loss) between the detector and the point of reflection.

2.12 To eliminate the need for calculating the parameters of interest, graphs can be prepared to determine directly the distance L as a function of the ripple frequency and Return Loss as a function of the peak-to-peak ripple amplitude. However, since the propagation constant, which determines the factor (d) in equation (1), and the waveguide loss will vary with different systems and the ripple amplitude, as read from the oscilloscope, will vary with particular test arrangements, such graphs are included in the Sections dealing with specific systems. These Sections will also specify the requirements to be achieved.

2.13 In special applications, or in trouble shooting, it may be desired to compute the parameters of equation (1). The values of the propagation constant (d) for the dominant mode in waveguides used in the 4 Gc, 6 Gc, and 11 Gc systems are given below:

WAVEGUIDE TYPE	(d)
WC281 (4 Gc)	.78
WC281 (6 Gc)	.92
WC281 (11 Gc)	.98
WR229 (4 Gc)	.76
WR137 (6 Gc)	.72
WR159 (6 Gc)	.80
WR90 (11 Gc)	.81

3. ANALYZING THE TEST TRACE

3.01 Up to this point we have considered only the case where a single impedance mismatch exists in the transmission line. Unfortunately this is not the general case for a practical system where a number of components may cause appreciable reflections.

3.02 An example of a system which includes a defect in the waveguide is pictured in Figure 6. The horn reflector antenna normally has a return loss in the order of 40 db or higher. Therefore, the ripples resulting from the antenna mismatch will be small in amplitude. Because the antenna is relatively far from the sweep source, the number of ripples will be greater than those resulting from other mismatches closer to the sweep generator. Figure 7A shows the ripples resulting only from the antenna return loss.

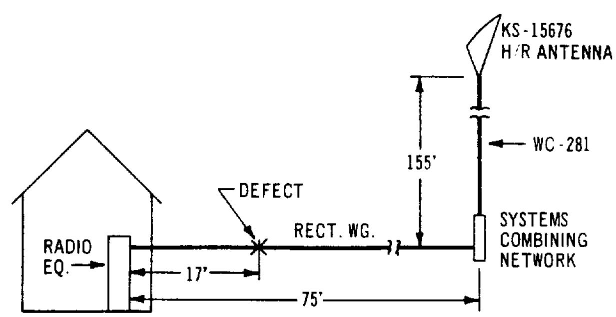


Figure 6

3.03 The systems combining network will normally have a return loss in the order of 30 db or higher. Therefore, the ripples from this source will usually be greater than those produced by the antenna. However, since the distance from the sweep generator is less there will be fewer ripples. Figure 7B shows the ripples resulting only from the combining network.

3.04 The defect pictured at 17 feet from the radio equipment represents a damaged waveguide or a foreign object within the waveguide. The purpose of including this trouble condition is to show the effect of a "close-in" irregularity upon the ripple pattern. In this case only a portion of a complete cycle of ripple will be seen on the oscilloscope trace. Figure 7C shows about three quarters of a complete cycle, which is what would be seen if no other reflections were present.

3.05 Under actual test conditions, the ripples from the three reflection points will combine to produce a complex waveform on the oscilloscope. Figure 7D is an example of the combination. The relative phase and amplitude of each reflection will determine the exact pattern of the complex wave.

3.06 In order to determine if the system will meet the objective for return loss, it is necessary to determine the individual components by eye and then to determine the peak-to-peak values of each component ripple. Once the ripples are identified and the amplitude and ripple period determined, the findings are then compared to the objectives given in the Sections for the particular radio system.

3.07 Figure 7E shows the general method of analyzing the ripple pattern. Each ripple component is identified in terms of peak-to-peak amplitude and frequency spacing between adjacent peaks. In this case the ripples resulting from the antenna and from the combining network are fairly easy to identify. The period of the lowest frequency ripple from the nearby defect usually has to be approximated by doubling the estimated 1/2 cycle frequency in the manner shown. The low frequency ripple associated with a "close-in" reflection may be only a portion of a cycle, as shown in the example, thereby making it difficult to determine accurately the amplitude or frequency spacing of the peaks.

3.08 It should be noted that when a cycle of one ripple is distorted by the slope of a larger ripple, the peak-to-peak amplitude of both sides of the smaller ripple should be averaged to approximate the correct ripple amplitude. This is illustrated in Figure 7E. The amplitude of the ripple caused by the systems combining network is determined by adding X and Y and dividing by 2. Additional accuracy will result from averaging several cycles of each ripple when possible.

4. ILLUSTRATIVE EXAMPLES

4.01 Figure 8 is included to illustrate the analysis of the test trace. The examples are from photographs of actual test traces of TD-2 antenna-waveguide systems. The oscilloscope calibration is 1 db per major vertical division and 2 mc per small horizontal division. The reference trace with frequency markers is also visible.

4.02 Figure 8A is a typical good system. The small amplitude ripple (less than 0.1 db) is from a horn reflector antenna. The frequency between peaks is approximately 2 megacycles.

4.03 Figure 8B shows a test trace with peak-to-peak ripples of 0.25 db and a frequency between peaks of about 4 megacycles. The defect in this case was a lump of putty in the waveguide.

4.04 Figure 8C shows a ripple of about a 10 megacycle period caused by a damaged flexible waveguide inside the building. The superimposed high frequency ripple is from a horn-reflector antenna.

4.05 Figure 8D shows a ripple pattern of a defective antenna feed horn superimposed on a broad ripple caused by a rubber washer in the first fifteen feet of waveguide.

5. OBJECTIVES FOR RETURN LOSS

5.01 It is not possible to set objectives for return loss that are applicable to all systems for there is a dependence upon the number of message channels transmitted and other system parameters. Such objectives are given in the Sections pertaining to specific systems. However, the need for maintaining a high order of return loss is discussed below.

5.02 An impedance discontinuity in a waveguide system will reflect a portion of the incident signal arriving at that point from either direction. Two such reflection points will, therefore, produce an echo signal which follows the main signal in time. For example, assume a transmitting antenna with a return loss of 30 db and a defective waveguide near the radio transmitter having a return loss of 15 db. The reflected signal from the antenna, 30 db down from the transmitted signal, will be re-reflected from the defective waveguide back toward the antenna. Since the defective waveguide has a return loss of 15 db the echo signal will be 45 db below the main transmitted signal (neglecting waveguide loss) and delayed by the round trip transmission time between the two points of reflection. It is such echo signals that cause delay distortion and produce intermodulation noise on the message channels.

5.03 The amount of delay distortion an echo signal will produce is dependent upon the magnitude and time delay of the echo. The requirements then must depend upon the distance between reflection points as well as the return loss of each. The amount of delay distortion that can be tolerated depends upon the particular system and the use to which the system is put.

5.04 Generally, the return losses of the radio transmitter output and the receiver input are the lowest of the waveguide system. The requirement curves for the particular systems are based upon echoes caused by reflections from these points and any other reflection point in the associated antenna and waveguide system.

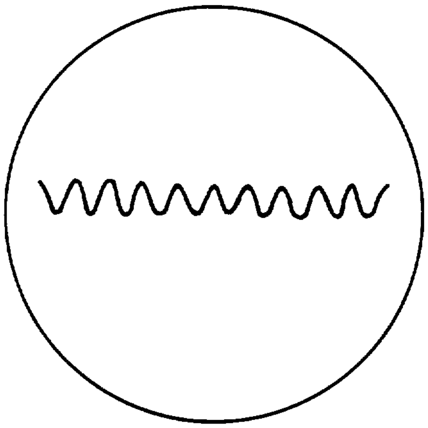
6. TROUBLE LOCATION

6.01 Failure to meet return loss requirements is frequently caused by damaged waveguide or by foreign objects in the waveguide. The defect can be located approximately by following the Sections for the particular systems. A visual inspection of the waveguide should then be made to locate any damage. If no damage is apparent, arrangements must be made to open the waveguide to inspect for foreign objects. These must be removed and any damaged waveguide replaced.

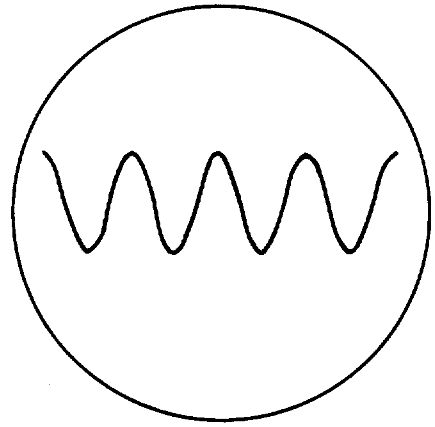
> ***WARNING: POSSIBLE RADIATION HAZARD! Do not look into a transmitting waveguide or expose any part of the head or torso to the end of, or area adjacent to an opened waveguide flange while the R.F. equipment is energized. The power density near the end of or adjacent to an opened flange of an energized transmitting waveguide can cause damage to living tissues. The eyes, internal, and reproductive organs are especially susceptible to this damage.***

6.02 Flexible waveguide may be a source of excessive reflection if it is incorrectly mounted by compressing or stretching or if it is sharply bent.

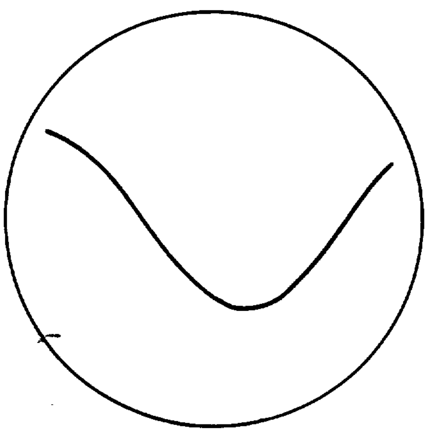
6.03 Excessive slope in the oscilloscope display is often caused by misalignment of channel filters or a reflection in the first few feet of waveguide. This slope results from the fact that only a fraction of a ripple is displayed on the oscilloscope.



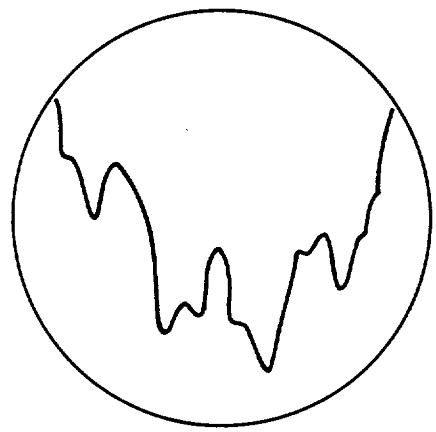
(A) Ripples from Antenna Only



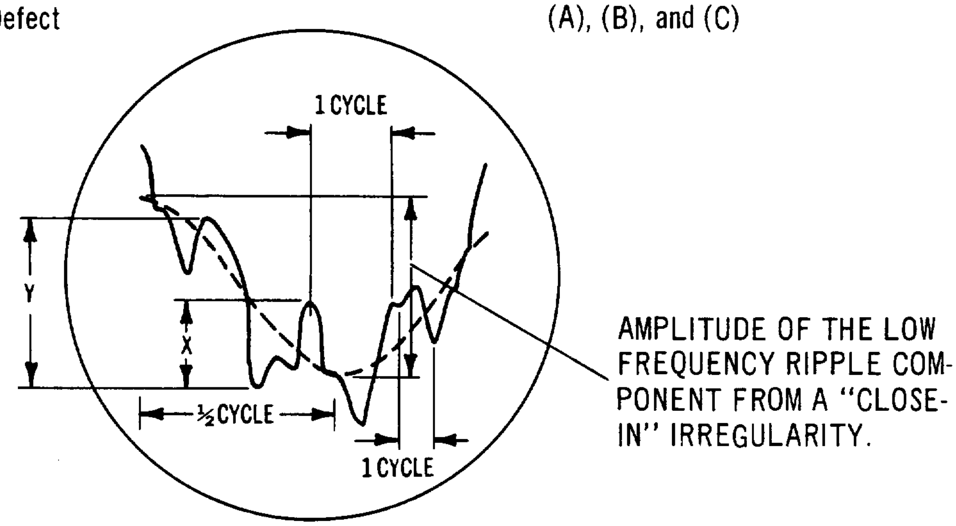
(B) Ripples fron Systems Combining Network Only



(C) Ripple from "Close In" Waveguide Defect

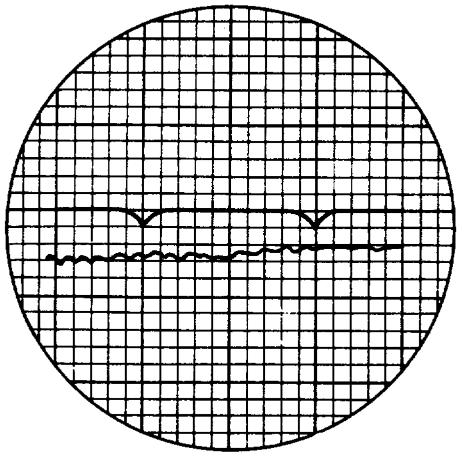


(D) Complex Wave Addition of (A), (B), and (C)

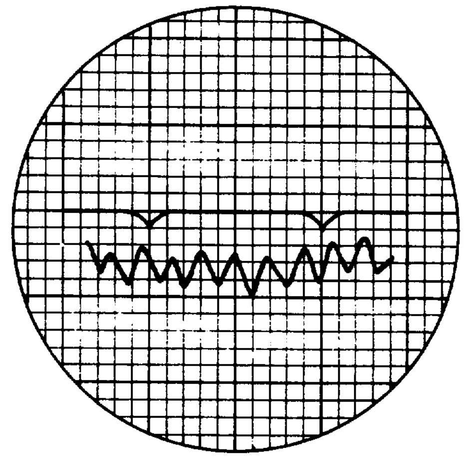


(E) Analysis by Eye of Wave Shown in (D)

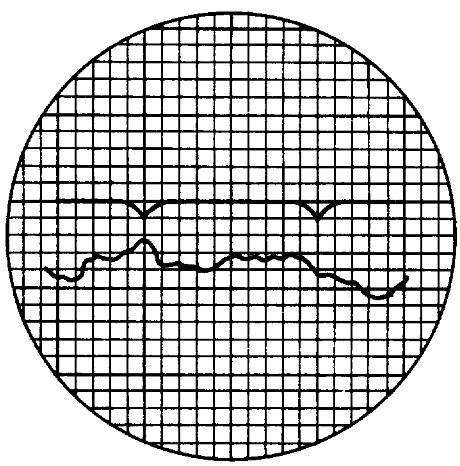
Fig. 7 – Analysis of Oscilloscope Display



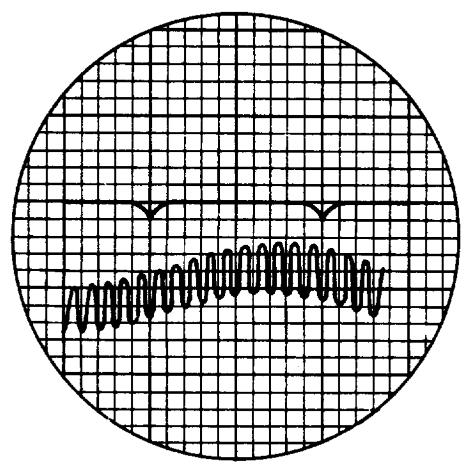
(A) HORN REFLECTOR ANTENNA – GOOD SYSTEM



(B) PUTTY IN WAVEGUIDE



(C) DAMAGED FLEXIBLE WAVEGUIDE. HIGH FREQUENCY RIPPLE IS FROM ANTENNA



(D) DEFECTIVE FEEDHORN ON 8-FOOT DISH ANTENNA (HIGH FREQUENCY RIPPLE), AND RUBBER WASHER IN WAVEGUIDE (LOW FREQUENCY RIPPLE)

Fig. 8 – Illustrative Test Traces