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MILITARY STANDARDIZATION HANDBOOK

EVALUATION OF HIGH FREQUENCY ANTENNAS IN AN OPERATIONAL ENVIRONMENT

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DEPARTMENT OF THE AIR FORCE
ROME AIR DEVELOPMENT CENTER
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IN AN OPERATIONAL ENVIRONMENT

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1. This standardization handbook has been approved by the U.S. Air Force.

2. This document provides valuable information concerning maintenance evaluation procedures of the antenna-transmission line systems of High Frequency antennas. The handbook presents the results of evaluation-analysis of various test methods, procedures and test equipment used in several operational environments in the form of detailed test methods, procedures and test equipment. To enhance the use of these tests, applicable antenna and transmission line concepts, and the Smith Chart are discussed in detail. The application of these tests and procedures should be very beneficial in maintaining the required system performance particularly in cases where the antenna transmission line or other parts of the antenna system have been damaged.

3. This handbook was prepared by Gordon R. Weatherup of the Rome Air Development Center. Users of this document are encouraged to report any errors or recommendations for changes or additions to the preparing activity. (See Defense Standardization Directory SD-1 for mailing address).

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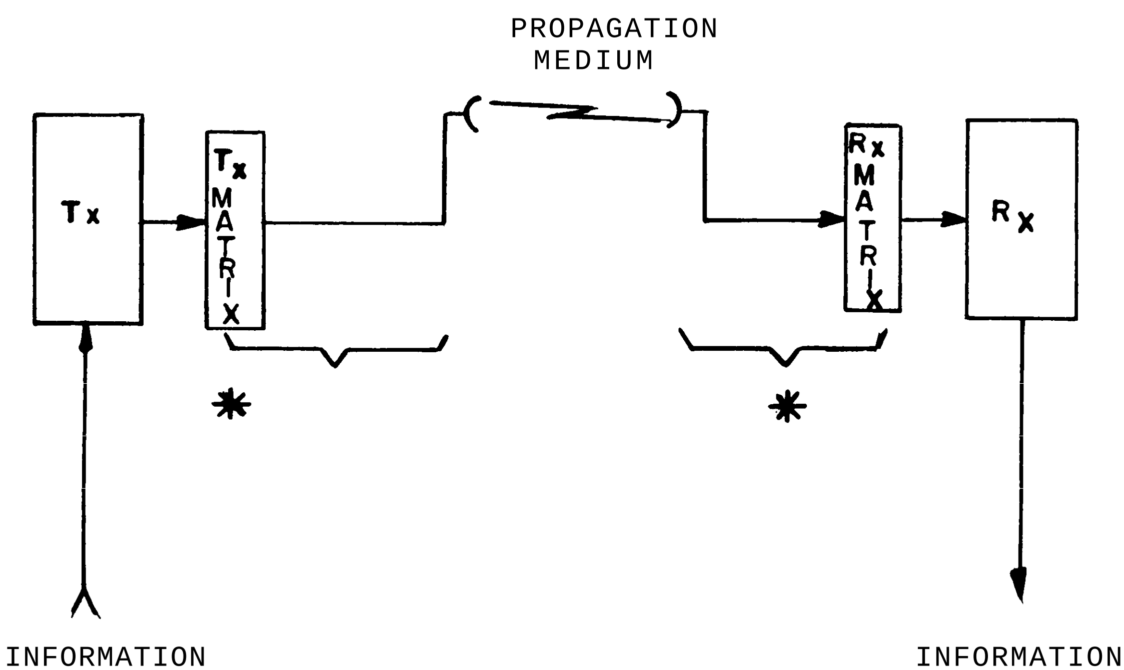
INTRODUCTION

1. General

A radio link may be used as a subsystem in a typical communication system to transfer information from user to user. The radio link will consist of transmitter(s), receiver(s), antenna-transmission line sub-sub-systems and associated equipment such as RF matrices, multicouplers, filters, etc. The simplified radio link is as follows:



* Antenna - Transmission Line system is a sub-sub-system of the radio link; however, in this report, it is called a system.

FIGURE 1. RADIO LINK

2. Current Maintenance Procedures

The current Antenna-Transmission Line system maintenance will normally consist of mechanical maintenance, i.e. tower alignment, tower painting, replacement/repair of broken antenna parts and of transmission lines that have been cut by a trench digger or damaged by lightning. The electrical maintenance, if accomplished, is usually limited to continuity checks or DC resistance measurements.

The present maintenance procedures for a typical antenna-transmission line system(s) have resulted in radio links being routinely operated in a degraded condition. This degraded condition will vary from slight, in a best case situation, to severe. Substandard electrical performance of the antenna-transmission line systems results in the loss of the communication system margin for reliability and in turn, a marginal circuit with low reliability and excessive outage time. Unfortunately, this low reliability and excessive outage time has been normally charged against propagation outage rather than antenna-transmission line deficiencies.

3. Electrical Performance Concepts

Without oversimplifying the functions of the Antenna-Transmission Line system, the prime purpose of any such system is to transfer RF power with maximum efficiency (minimum loss) from Radio transmitters to the propagation media or from the propagation media to the Radio receivers. Impedance matching is an important factor. A secondary, but important, function of an antenna is to focus or concentrate its transmitted energy or its reception or capture area in accordance with system or operational requirements. This pattern may be omnidirectional or directional. However, from a maintenance viewpoint, if the pattern and/or performance characteristics are significantly changed, then the effect should also be detected by a change in the input impedance values. The input impedance values are also affected by the loss in the Antenna-Transmission Line system.

It is recognized that the measurement of impedances (Standing Wave Ratio - SWR) of an antenna is normally accomplished at the base of the antenna. From a practical standpoint this method, while technically desireable, is not always feasible on a weekly or scheduled monitoring basis, because of the number of antennas involved at a typical antenna farm, the accessibility of these antennas in bad weather conditions, the availability of prime power to operate the test equipment, etc. Further, the transmitter/receiver is connected to the antenna-transmission line system, therefore input impedance/SWR to the system is also important.

The transmission line, when terminated in an impedance other than its characteristic impedance, may cause the input impedance of the transmission line to be quite different from either the characteristic impedance or the impedance in which the line is terminated. In such a case, the line acts like an impedance transformer, and the impedance presented to the transmitter may be a value that the transmitter can not match. It should be noted that the SWR, in this case, remains a constant value (assuming no attenuation in the line) but there are infinite number of corresponding impedance values. Because of this, it is considered essential to measure the actual impedance values and then determine the SWR. These calculations and other transmission line or antenna calculations are usually not accomplished by carrying out the laborous, repeated calculations implied. In practice, solutions are quickly found graphically on the SMITH CHART.

Although the Smith Chart may, at first appear to be somewhat formidable, the use of the Smith Chart is quite similar to the use of a graph. In fact, the chart might be considered as a specialized type of graph, with curved, rather than rectangular, coordinate lines.

4. Electrical Maintenance Procedures

It is in this area of electrical maintenance that improvements are required. It is recognized that the lack of test methods, test procedures, and adequate test equipment has resulted in the unsatisfactory electrical maintenance of antenna-transmission line systems. This was identified during the Dynamic Grasp evaluation. As part of the evaluation, various test methods, test procedures, and test equipment were evaluated in great depth.

Before discussing in detail the proposed test methods, test procedures, and test equipment, it is considered essential to discuss applicable antenna concepts (Section II), transmission line concepts (Section III) and the SMITH TRANSMISSION LINE CALCULATOR OR CHART (Section IV).

A brief outline of the proposed electrical maintenance tests is as follows:

a. Antenna-Transmission Line System

(1) Impedance measurements.

(2) Determination of SWR.

(3) Impedance Discontinuities.

b. Transmission Line (by itself)

(1) Attenuation Loss.

(2) Impedance Discontinuities.

(3) Line Length.

(4) Dielectric Strength (Higlh Potential Test).

c. Antenna (by itself)

(1) Impedance Measurements.

(2) Determination of SWR.

(3) Impedance Discontinuities

SECTION II

ANTENNA CONCEPTS

1. General

An antenna can be a transmitting or a receiving device. It can be extremely simple, such as a piece of wire hanging out of a window or a connection to a piece of pipe in a plumbing system. It can also be extremely complex, such as a surface-variable, parabolic dish, a hundred feet wide. Whatever the antenna size or configuration is; the antenna has one basic purpose, and the theory underlying the accomplishment of that purpose is applicable to all antennas.

An antenna is used to couple electromagnetic devices to the air, free space, or other media to permit the transfer of information or signals from one site to another without employing hard-wire circuits. Antennas are used in conjunction with transmitters and receivers in several modes of operation:

- Multiplexed radio circuits
- Simplex/duplex radio circuits
- Surreptitious monitoring
- Radio detection and ranging (radar)
- Navigational beacons
- Navigational sensors
- Etc.

2. Background

The electrical maintenance of an Antenna-Transmission Line system can be improved by having an understanding of their basic functions and properties.

It is believed desirable to first review some of the basic concepts of wavelength, frequency, period, and velocity of a wave.

a. Wavelength and Frequency.

The wave shown in Figure 2 is a sine wave of either current or voltage. This wave is a periodic type of wave, meaning that the current changes its direction of flow at regular time intervals, and that the voltage assumes equal alternate positive and negative values. The length of a wave (or the wavelength) is the distance from the beginning of a single wave to its end. The symbol for wavelength is "Lambda" or "λ".

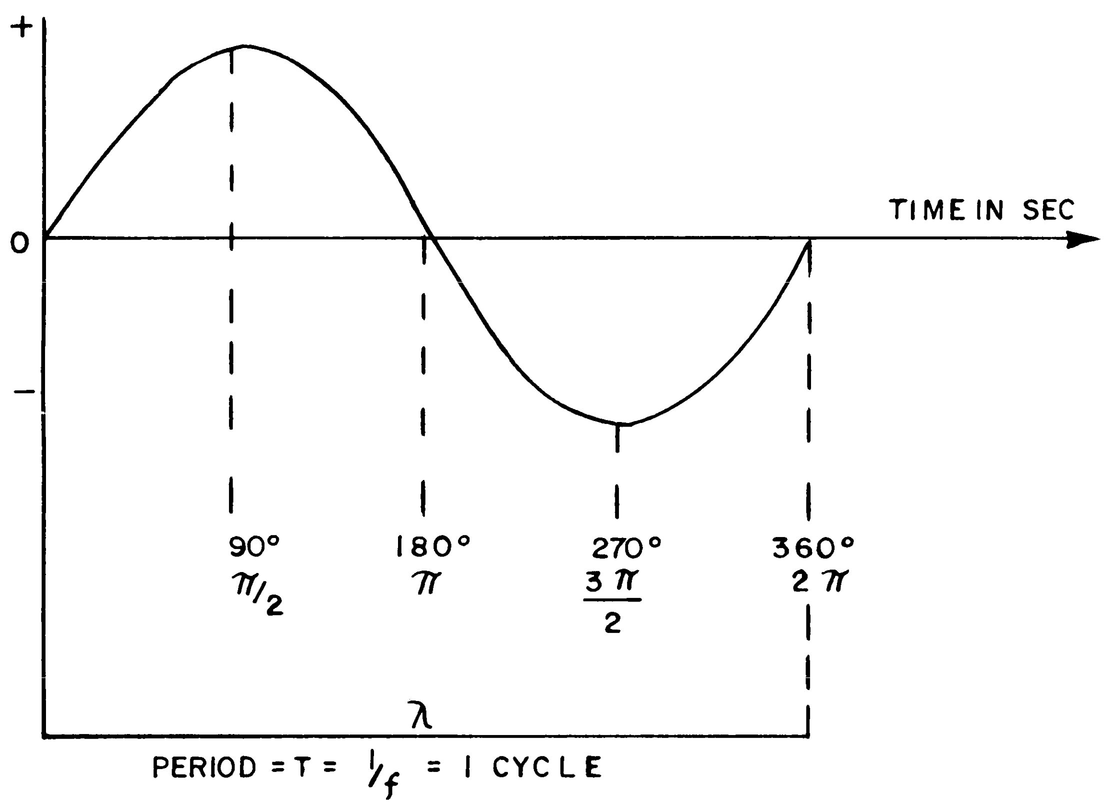


FIGURE 2. WAVELENGTH-FREQUENCY REPRESENTATION

The frequency of a period wave is the number of wavelengths per unit of time generally taken as one second. One cycle per second is defined as one Hertz (Hz). As the number of Hertz increases, the length of the wave decreases. This can be expressed as an inverse relationship:

$$f = 1/\lambda \quad \text{or} \quad \lambda =$$

Where f = frequency in Hertz

and λ = wavelength

We can convert frequency to wavelength or wavelength to frequency by using these formulas:

To change wavelength to frequency:

f in KiloHertz = $3 \times 10^5/\lambda$ (in meters)

f in MegaHertz = $3 \times 10^4/\lambda$ (in centimeters)

f in MegaHertz = $984/\lambda$ (in feet)

To change frequency to wavelength:

(in meters) = $3 \times 10^5/f$ (in KiloHertz)

(in centimeters) = $3 \times 10^4/f$ (in Megahertz)

(in feet) = 984/f (in MegaHertz)

b. Period,

Frequency may also be regarded as the time duration of a number of sine waves. A sine wave having a frequency of 30 Hz has 30 complete sine waves in one second. The time duration of a single cycle, or period, would be 1/30 second. In terms of a formula, the period would be:

$$T = I/f$$

where T = Time in seconds

f = frequency in Hertz

c. Velocity of a Wave.

The distance covered by a sine wave in a certain amount of time is known as its velocity. That is:

Velocity = Distance/Time or V = D/T

Defining the period as the time it takes a sine wave to travel a distance equal to its wave length (A), then

$$v = \lambda/T$$

Substituting l/f forT,

$$v = \lambda/(1/f) = \lambda f$$

The velocity of a radio wave (or a light wave) in free space is approximately 300,000,000 meters per second (3×10^8) or 186,000 miles per second or 984 feet per microsecond.

3. Functions of an Antenna

The real function of electromagnetic antennas is that of coupling hard circuits to a medium so as to transfer power with maximum efficiency (minimum loss). Impedance matching is thus an important factor. A secondary, but nonetheless important, function of an antenna is to focus or concentrate its transmitted energy, or its reception or capture area, according to some desired pattern which is specified or determined from system or operational requirements, This pattern may be omnidirectional or directional. This report will not dwell on the directional/omnidirectional characteristics of an antenna. However, if the pattern and/or performance characteristics are significantly changed due to degradation of the antenna, then the effect should also be detected by a change in the input impedance values.

4. Standing Wave Radio (SWR)

It is recognized that the antenna input parameters are specified in terms of a characteristic input impedance and the maximum allowable standing wave ratio (SWR) across the useful bandwidth of the antenna.

The SWf of an antenna is a good indicator of the effectiveness of the impedance match between the antenna and the propagation medium. The SWR is also the ratio of the maximum to the minimum voltage or the ratio of the maximum to the minimum current. When the medium is absolutely matched, the SWR is unity. The greater the number representing SWR, the larger is the impedance mismatch.

The SWR of an antenna will also vary, across the useful bandwidth of the antenna, from low values, approaching unity, to the maximum values allowed by specifications. This variation will follow a definite pattern and can be used in evaluating the performance of the antenna. This is particularly true relative to maintenance aspects. The current practice of considering <u>only</u> the maximum SWR's of an antenna is not acceptable; rather the entire SWR profile and the impedance plot must be considered in evaluating the antenna.

5. SWR Relationship To Impedance

For a <u>purely resistive load,</u> The SWR is equal to:

$$SWR = {}^{Z_r}/{}_{Z_o}$$

where Z_r = impedance of the load

and Z_o = characteristic impedance of the antenna.

Note: SWR is always greater than unity. Therefore, if Z_r is less than Z_o, use Z_o/Z_r.

The input impedance of a resonant antenna will be predominately resistive, but at other frequencies, it will also have reactive components. When the input impedance contains reactive components, it is called a complex impedance.

For a complex impedance load, the SWR is equal to:

$$SWR = \frac{(Z_L + Z_o) + (Z_L - Z_o)}{(Z_L + Z_o) - (Z_L - Z_o)}$$

where Z_L = complex impedance of the load

and Z_o = characteristic impedance of the antenna

Note: The product of $(Z_L + Z_o)$ or $(Z_L - Z_o)$ can be determined by right triangle relationships. A much easier method is the use of a SMITH CHART, which was designed for antenna/transmission line calculations. The use of the SMITH CHART is discussed in Section IV and as required in appropriate sections.

6. Impedance

The understanding of and use of impedance plots in evaluating an antenna is actually considered to be more useful than a SWR profile. It is helpful to examine the impedance characteristics of certain standard or basic antennas, such as a half wave dipole, a logarithmic periodic system (LPS) array, a monopole antenna and a discone antenna.

a. Half Wave Dipole Antenna.

A standard half wave dipole antenna will consist of a single wire having an electrical length equal to one-half of the length of the wave being transmitted/received. The physical length is a little less than the electrical length because of the capacitance effects between the ends of the antenna and the ground. With reference to the basic antenna, the following relationship between the current and the voltage exists along the length of a half-wave antenna:

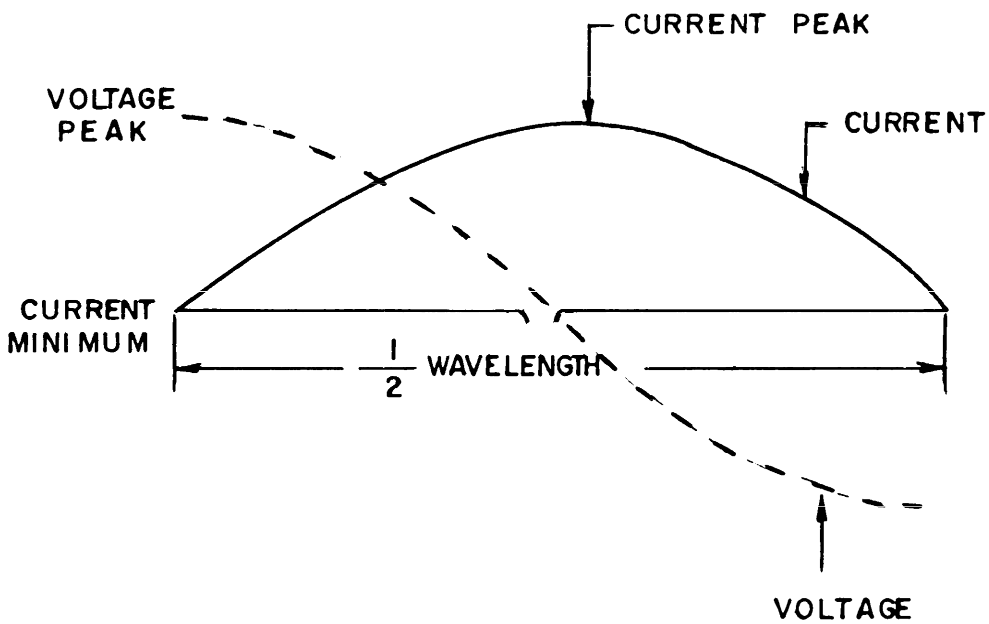
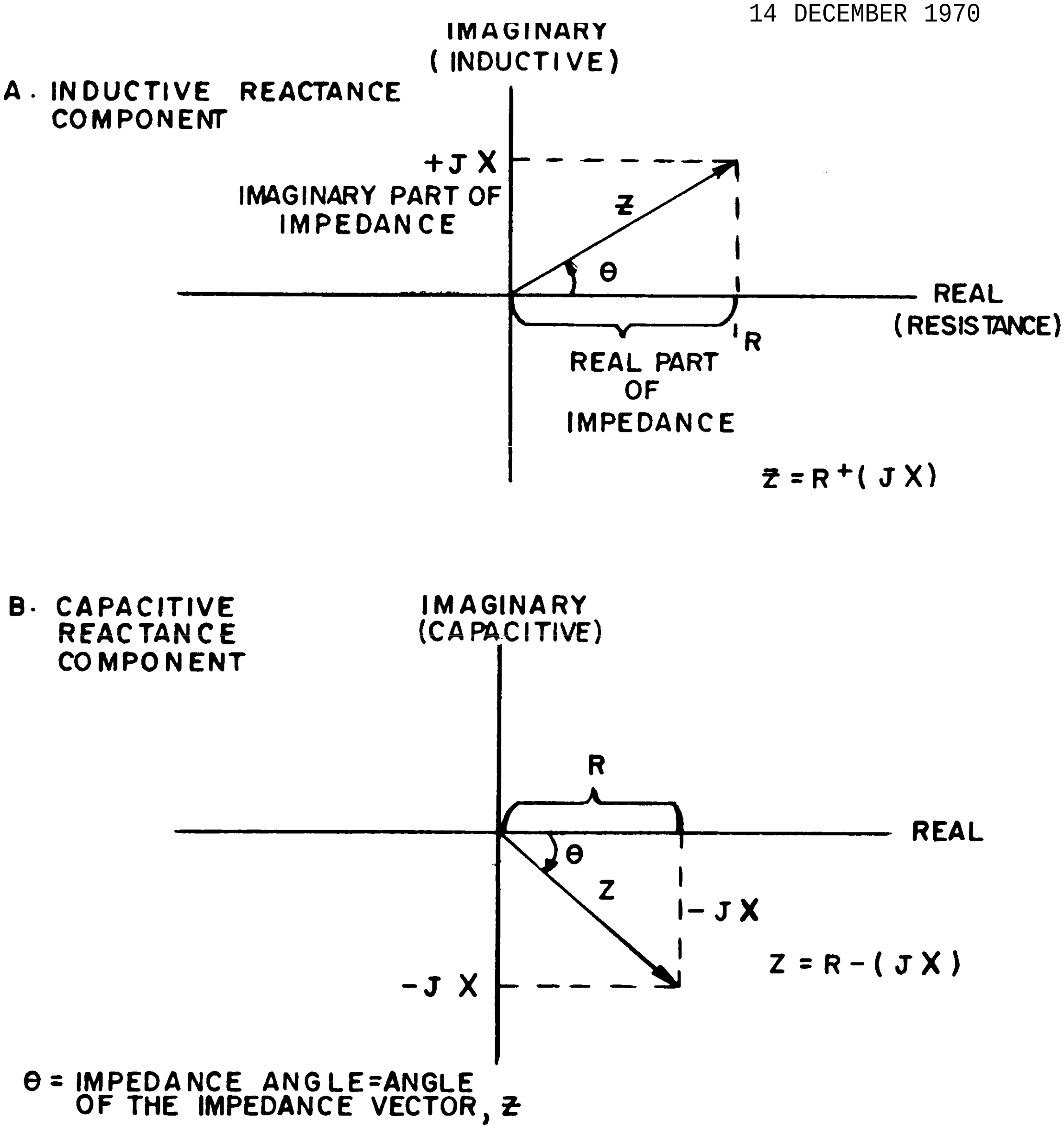


FIGURE 3. VOLTAGE AND CURRENT DISTRIBUTION along the length of a resonant HALF WAVE DIPOLE, CENTER FED

The current is maximum at the center and zero or minimum at the ends. The voltage is zero or minimum at the center and maximum at the ends. The impedance (Z) will be the ratio of the RF voltage (E) to the RF current (I) --- that is, $Z = E/I$. This means that the impedance is not constant along the length of antenna but varies from a maximum at the ends (maximum voltage, minimum current) to a minimum at the center. The above figure shows that the impedance, at the center, should be zero ohms. Practically, the impedance is 72 ohms. This impedance of a resonant half wavelength antenna is resistive R ± OjX ohms that is, it contains no reactive components such as inductance or capacitance. The ohmic or dc resistance of the antenna should be very small in comparison with the impedance and may be disregarded. Ignoring the ohmic resistance, then this impedance may be regarded as the radiation resistance of the antenna.

The input impedance of a half wave length antenna will, as the input frequency is changed from the resonant frequency, have a reactive component in addition to the resistive component. The resistive component is real and identified by “R ohms”. The reactive component is considered to be imaginary and is identified by "± jX ohms". Plus jX ohms is inductive reactance while minus jX ohms is capacitive reactance. (The j factor denotes the imaginary term and is equal to the square root of -l). Because the antenna impedance contains a reactive component (± jZ), the impedance is considered to be complex (even when the ± jZ term is zero.)

The input impedance can be represented vectorially in Figure 4. θ = impedance angle = angle of the impedance vector $\bar{Z}$ with respect to the resistance vector. Resonance of the antenna is defined when the impedance angle equals zero degrees and the antenna impedance is all resistive.



It should be noted that the importance of the real part of the antenna impedance is that the radiated/received RF power is equal to I^2R_{Real}.

FIGURE 4. VECTOR REPRESENTATION OF COMPLEX IMPEDANCE, Z

The input impedance of the halfwave dipole antenna, as the frequency is varied, can also be plotted as follows:

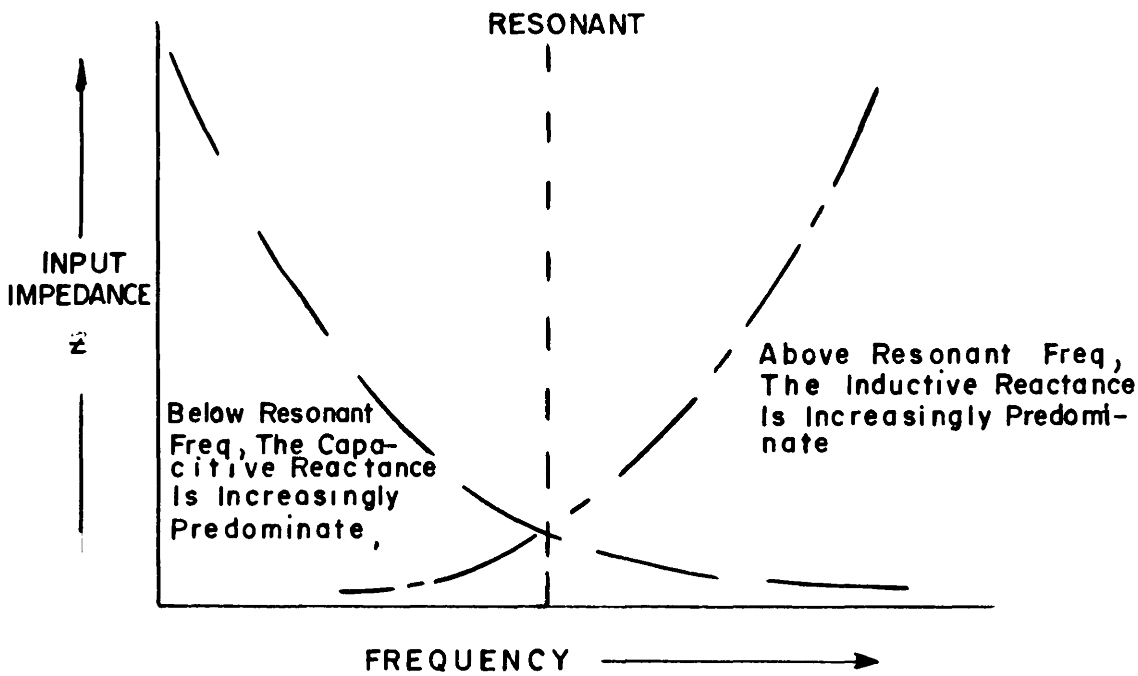


FIGURE 5. HALF WAVE DIPOLE- IMPEDANCE VS FREQUENCY

b. Logarithmic Periodic System (LPS) Antenna.

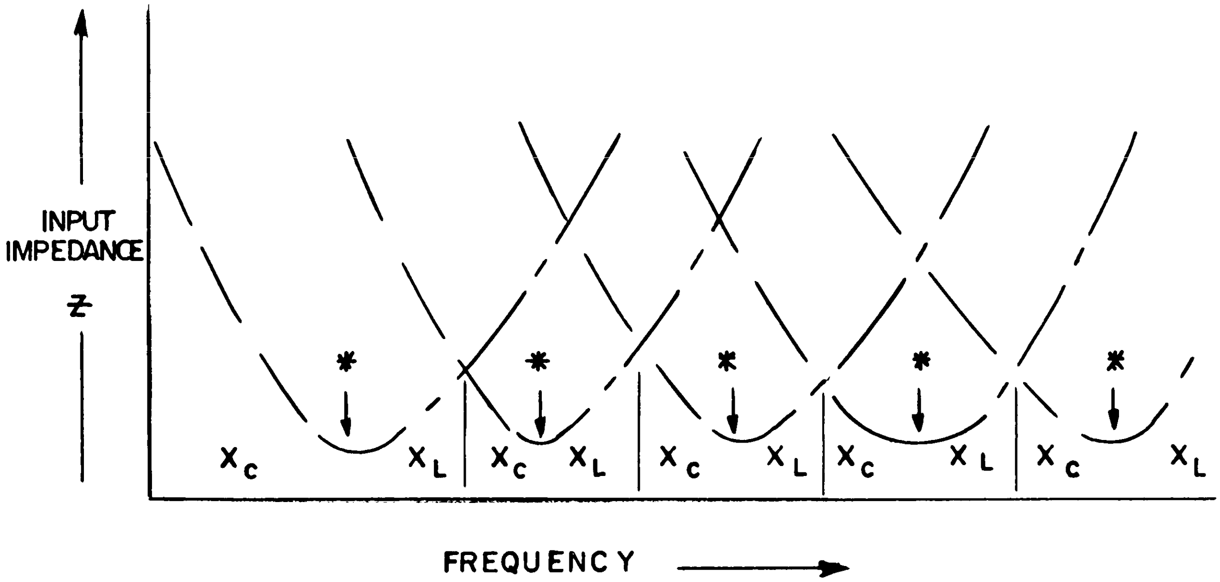
The operational use of a half wave dipole antenna is restricted to a narrow band of frequencies, where the input impedance results in a vswr of less than 2:1. However, this band of frequencies is normally inadequate to support the communication system because of the wide variations in the propagation media or because of multiple communication channel requirements.

One possible answer to cover a larger band of frequencies has been the use of a series of individual dipole antennas, each one cut for/resonant at the various operational frequencies. This answer is not too acceptable because of the large land area required.

A more acceptable answer is the use of a Logarithmic Periodic System (LPS) antenna. This antenna consists of a series of paralleled halfwave dipoles, arranged side by side in a single plane or array. This antenna is energized so as to generate a directional beam in the direction of the shorter elements. The LPS antenna may be horizontally polarized (parallel with the ground), vertically polarized (perpendicular with the ground), or circularly polarized (electrically combined horizontal polarized array and a vertical polarized array, mounted at right angles to each other on a common support structure).

The horizontal polarized array is normally supported above the ground on a tower or towers. If the antenna is rotatable, a single tower or support point is used. The vertical polarized array is normally supported between two towers. The lower half of the dipole array may be replaced with a ground screen. In this case, the feedline will be just above the ground screen. The primary advantage of this approach is the height reduction of the vertical LPS antenna.

The input impedance of an LPS antenna, will be a cyclic function over the frequency range and can be plotted as shown on Figure 6.



* resonant frequencies at the individual dipole antennas of the LPS antenna.

FIGURE 6. LPS-IMPEDANCE VS FREQUENCY

It should be noted that the capactive-inductive reactance cycle is the same for each individual dipole antenna as it was for a single halfwave dipole. As the frequency is increased, the measured X_L or X_C will actually be the smaller of the two values, i.e. - in the frequency band between the adjacent resonant dipole frequencies. In actual measurements, perfect symmetry may not be measured because of the length to diameter (L/D) ratio of the dipole elements, feedlines, other antenna elements, support towers, ground effects, etc. However the cyclic pattern should be measurable and consistent across the frequency band of the antenna.

c. Monopole Antenna.

A standard Monopole Antenna consists of a single wire having an electrical length equal to one-quarter of the length of the wave being transmitted/received. The radiating element is perpendicular to the ground and normally imaged above a ground screen. The ground screen consists of a series of radials, each extending at least one-quarter wave length long, from the base of the radiating element. The physical length of the radiating element is a little less than the electrical length because of the capacitance effects between the radiating element and the ground.

With reference to the basic antenna, the following relationship, between the current and the voltage, exists along the radiating element:

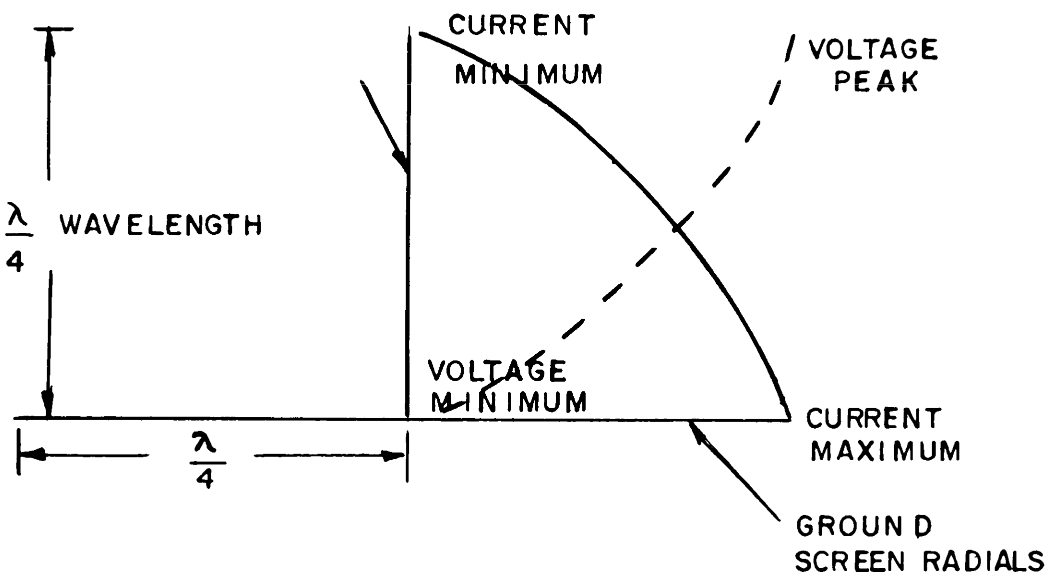
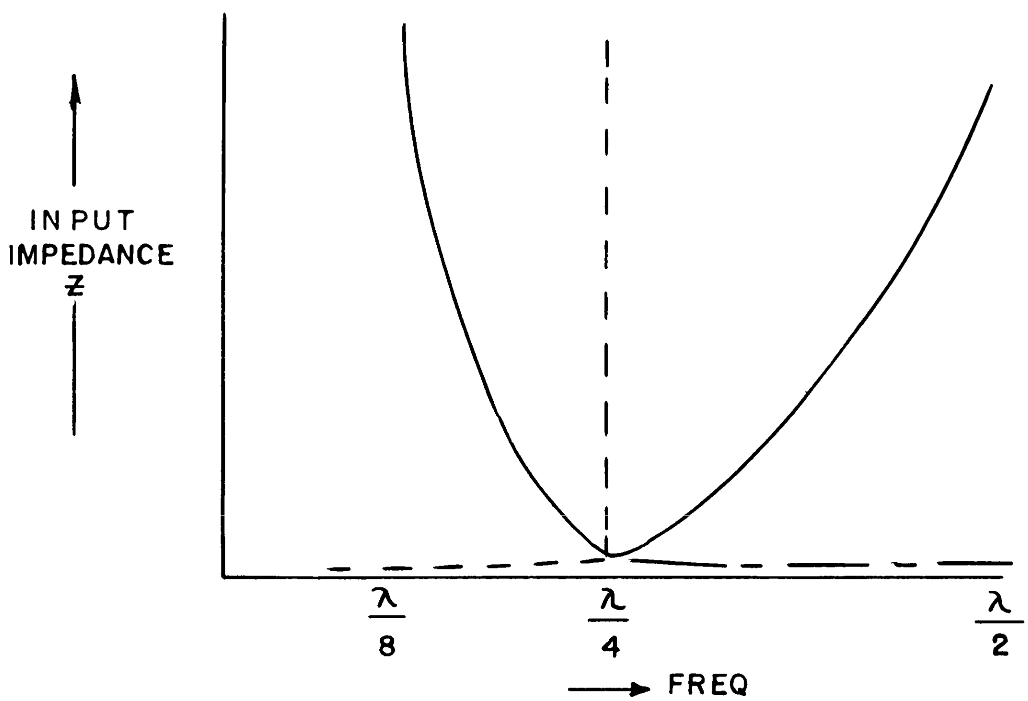


FIGURE 7. Voltage and Current Distribution
Along the Length of a Resonant
QUARTER WAVELENGTH MONOPOLE, BASE FED

The antenna current is a maximum value at the base and decreases to a minimum value at the top end of the radiating element. The RF voltage is a minimum value at the base and increases to a maximum value at the top end of the radiating element. Thus the impedance will be a minimum value at the base and increases to a maximum value at the top end so as to match the impedance of the propagation medium.

The input impedance of a monopole antenna, as the frequency is varied, can be plotted as follows:

FIGURE 8. QUARTER WAVELENGTH MONOPOLE - IMPEDANCE VS FREQUENCY



d. Discone Antenna, Base Fed.

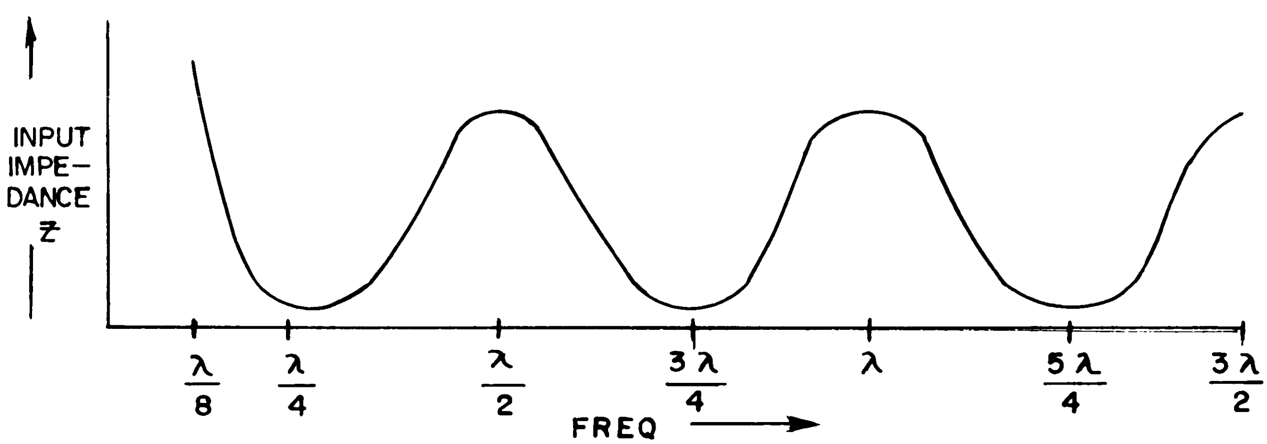
The operational use of a monopole antenna is restricted to a narrow band of frequencies where the input impedance results in a SWR of less than 2:1. However, this band of frequencies is normally inadequate to support the communication system.

One possible answer to cover a larger band of frequencies has been the use of a series of individual monopole antennas, each one cut for/ resonant at the various operational frequencies. This answer is not too acceptable because of the large land area required.

A more acceptable answer is the use of a Discone Antenna, base fed. This antenna consists of a radiating cone imaged over a ground screen. The slant height of the radiating cone should be approximately equal to a quarter wavelength at the lowest operating frequency. The antenna should have a useful frequency range of at least 8 to 1. The SWR increases as the frequency is lowered until, at approximately one-eight wavelength, the SWR climbs very rapidly. This is called the cutoff frequency of the antenna.

The discone antenna may be considered as a cross between a monopole antenna and an electromagnetic horn.

The impedance plot of a discone antenna will cycle with increasing frequency, as the slant height of the radiating cone becomes equal to multiple quarter wavelengths. The imput impedance will be low at odd number (1,3,5, etc) of quarter wavelengths and high at even number (2,4,6 etc.) of quarter wave-lengths and can be plotted as follows:



FTGURE 9. DISCONE ANTENNA-IMPEDANCE VS FREQUENCY

SECTION III

TRANSMISSION LINE CONCEPTS

1. General

A transmission line or cable is used to couple electromagnetic devices, such as transmitters and receivers, to an antenna and to transfer RF power with maximum efficiency (minimum loss). Impedance matching is thus an important factor.

Any definite length of transmission line will have a characteristic impedance (that of the cable), will cause a phase shift, and will attenuate the signal.

2. Characteristic Impedance

The working definition of the characteristic impedance of a transmission line is that value of non inductive resistance which, when connected as the load to the transmission line, results in no reflected waves, a SWR of 1:1, and a phase angle of zero degrees at the input to the transmission line. When the transmission line is terminated in its characteristic impedance, the length of the transmission line and/or the frequency is not important (except for line attenuation) and, if the generator or transmitter internal impedance is also equal to the characteristic impedance of the line, then there will be the maximum transfer of power.

When the load impedance is not equal to the characteristic impedance, then the incident wave (also called "forward" wave) from the generator or transmitter will be partially reflected at the load, giving rise to a "reflected" wave traveling back toward the generator. These two waves, the "incident" and "reflected" waves, will alternately suffer addition and subtraction of their associated voltages (and currents) creating a new single wave pattern of voltage (or current) amplitude along the transmission line length.

3. Voltage Reflection Coefficient

The ratio of the reflected voltage (or current) to the foward voltage (or current) at the point of measurement is called the voltage reflection coefficient and denoted by "rho" or " ρ " Thus

$$\rho = E_r/E_f = - I_r/I_f$$

where E_r = reflected voltage

E_f = forvard voltage

I_r = reflected current

I_f = forward current

4. Standing Wave Ratio

The peak to valley ratio of the resultant single wave pattern of voltage (or current) amplitude along the transmission line is called the Standing Wave Ratio (SWR). This ratio is a figure of merit of the impedance match at the load; ideal is 1.0, since there is no reflected wave for the matched condition. It is important to note that this single wave pattern will be repeated for each and every wave length along the transmission line. The electrical wavelength is denoted by "Lambda" or "λ".

Thus $\lambda_{ft} = \dfrac{984}{f \text{ in megahertz}}$, in terms of feet

or $\lambda_m = \dfrac{300}{f \text{ in megahertz}}$, in terms of meters

The relative voltage (or current) amplitudes and shapes of the standing waves, along one wavelength of the transmission line are shown in Figure 10. It should be noted that the SWR pattern repeats every half wave length.

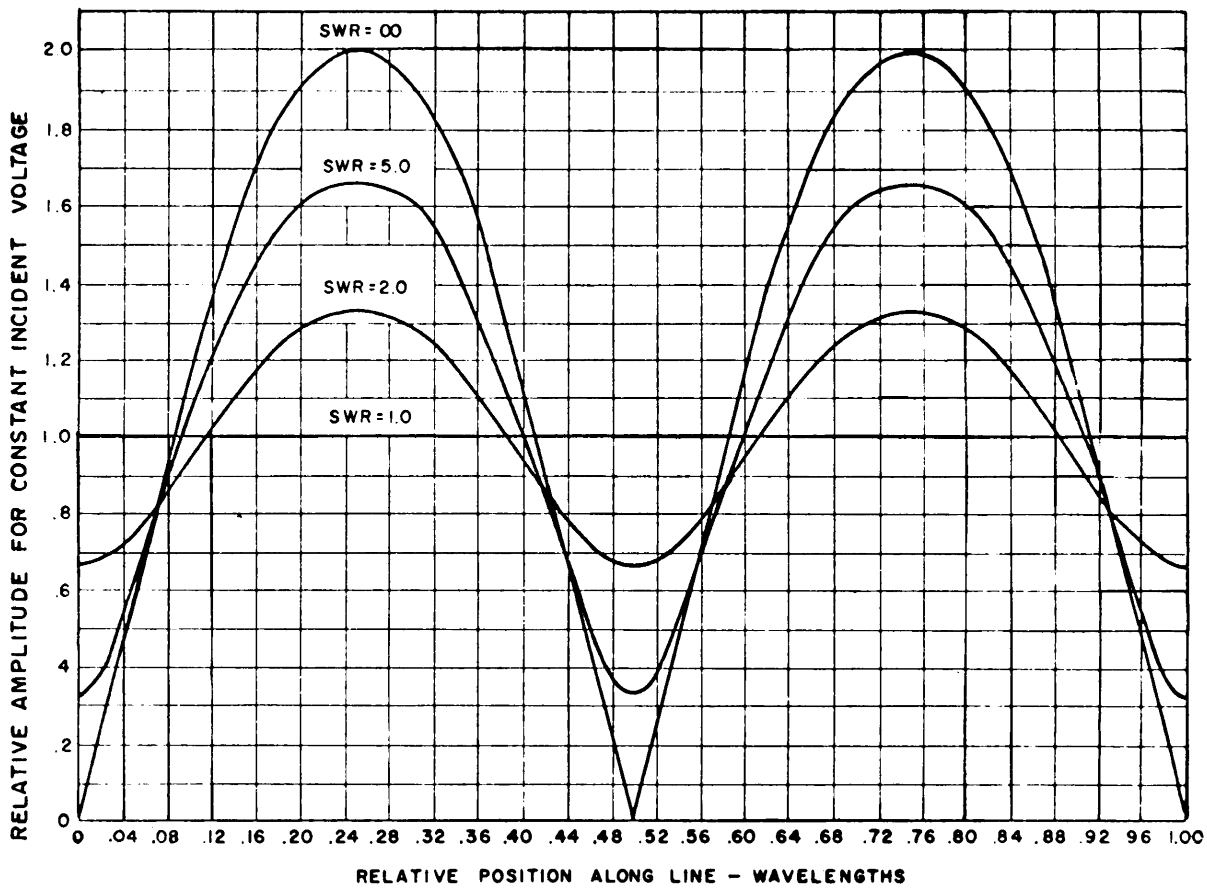
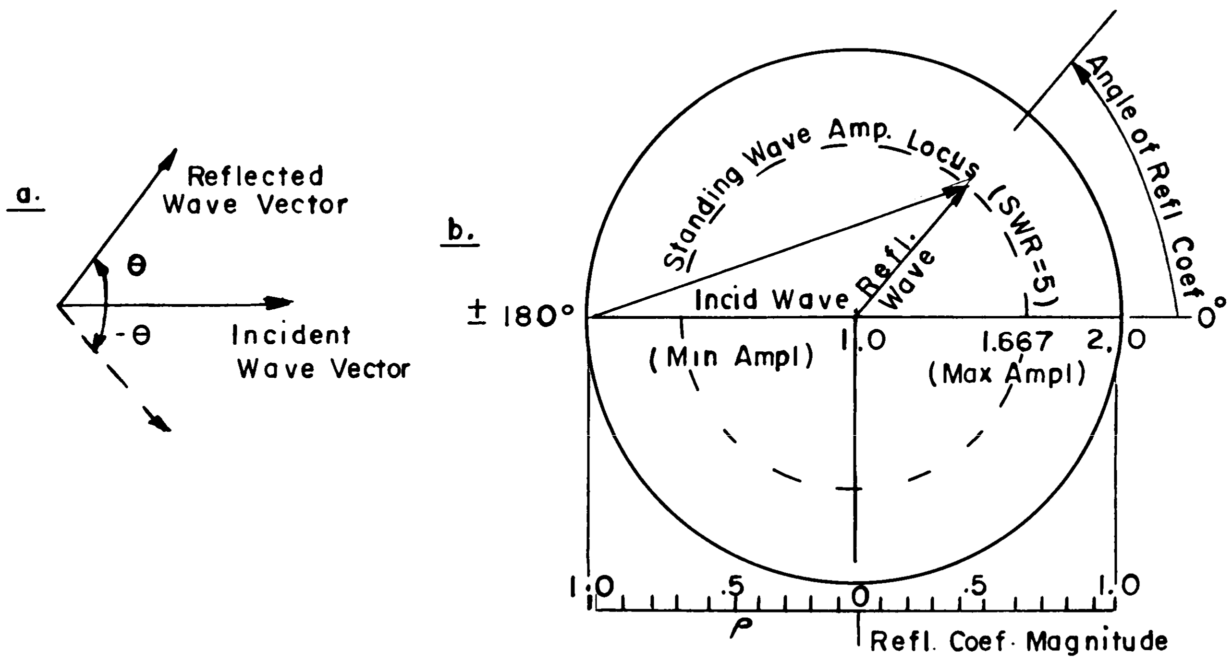


FIGURE 10. RELATIVE VOLTAGE AMPLITUDES AND SHAPES VS SWR

These relationships may also be expressed graphically using vectors as shown in Figure 11. It should be noted that the figure is only for a SWR of 5.0 and represents only one half wave length along the transmission line. Any additional half wave lengths would result in the amplitude vector rotating around the circle, one rotation for each additional half wave length. It should also be noted that the incident wave vector is equal to a value of 1.0 on the horizontal plane. The reflected wave vector is equal to 0.667 (SWR = 5) and it rotates around the incident wave vector.



θ Is The Angle That The Reflected Wave Leads (+) Or Lag (−) The Incident Wave.

Note: The incident wave is set equal to a value of 1. The reflected wave will be depending on the SWR and thus may be any value from O (SWR 1 to 1) to 1 (SWR is infinite).

FIGURE 11. GRAPHICAL REPRESENTATION OF INCIDENT AND REFLECTED TRAVELING WAVE VECTORS

The relationships between the load impedance (Z_L), the characteristic impedance of the transmission line (Z_o), the voltage reflection coefficient (ρ), and the Standing Wave Ratio (SWR) are as fol1ows:

$$\text{where } \rho = (Z_L - Z_o)/(Z_L + Z_o)$$

$$\text{and SWR} = (1 + |\rho|)/(1 - |\rho|)$$

$$\text{or SWR} = \frac{(Z_L + Z_o) + (Z_L - Z_o)}{(Z_L + Z_o) - (Z_L - Z_o)}$$

The above relationships are usually not made by carrying out the laborious, repeated calculations. In practice, solutions are quickly found graphically on a "SMITH CHART". This chart is highly useful for antenna - transmission line work. The use of this chart is covered in Section IV.

5. Phase Shift

It has been assumed in the foregoing illustrations that the electrical length of the transmission line has been exactly equal to one half wave length of the RF frequency (or multiples of the half wavelength). This implies correctly that a section of transmission line, that is one half wavelength long, will cause a phase shift of ± 180°. Similarly, a transmission line that is not one half wavelength long (or multiples of half wavelength plus part of a wavelength) will cause a phase shift in degrees that is <u>proportional</u> to the actual electrical length of the transmission line with reference to the length of the wavelength at the test frequency. This allows the use of the concept of phase shift per unit length of transmission line. The phase shift is denoted by Beta or β. The phase shift is a function of the velocity factor (v). The velocity of a wave along a conductor, such as a transmission line, is less than the velocity of that wave in free space. The ratio of the two (actual velocity versus velocity in free space) is known as the velocity factor. Obviously, the velocity factor must always be less than 1, and, in typical lines varies from 0.6 to 0.97. The velocity factor, v, causes the electrical length of a transmission line to be greater than the mechanical length. The Velocity factor is also considered, when building a resonant antenna, because the physical length is slightly less than the electrical length.

The velocity factor of a transmission line is a function of the dielectric constant K

where $$V_K = \frac{3 \times 10^8}{K} \text{ meters/second}$$

V_K = velocity of propagation for lines filled with a dielectric of dielectric constant K

3×10^8 = velocity of propagation in free space

K = dielectric constant

The velocity factor (v), for various types of transmission lines, are as follows:

Type of Line	Velocity Factor (v)
Two-wire open line (wire with air dielectric)	0.975
Parallel tubing (air dielectric)	0.95
Coaxial Line (air dielectric)	0.91
Coaxial Line (foam dielectric)	0.79
Coaxial Line (solid polyethylene dielectric)	0.667

A comparison of electrical to mechanical (actual) lengths for these types of transmission lines is as follows:

Type of Line	Length Electrical*	Length Mechanical
Two-wire open line	100 feet	97.5 feet
Parallel Tubing	100 feet	95.0 feet
Coaxial line (air dielectric), such as Heliax, etc.	100 feet	91.0 feet
Coaxial line (foam dielectric), such as Foam flex	100 feet	79.0 feet
Coaxial line, (solid polyethylene dielectric), such as RG-58 RG-213, etc.	100 feet	66.7 feet

* 100 feet, electrical length, of transmission line is used in determining line length measurements. See Section on line length measurements.

6. Angle Of Reflection Coefficient

The angle of the reflection coefficient is the angle that the reflected wave leads (+) or lags (-) the incident wave.

The angle of the reflection coefficient is also equal to the number of degrees of phase shift that the signal incurs as a result of the transmission line length. It must be carefully noted that the angle of reflection coefficient can not identify the total number of half wave lengths (electrical) in the transmission line but only that portion of the transmission line that exceeds the half wavelength(s).

7. Transmission Line Attenuation

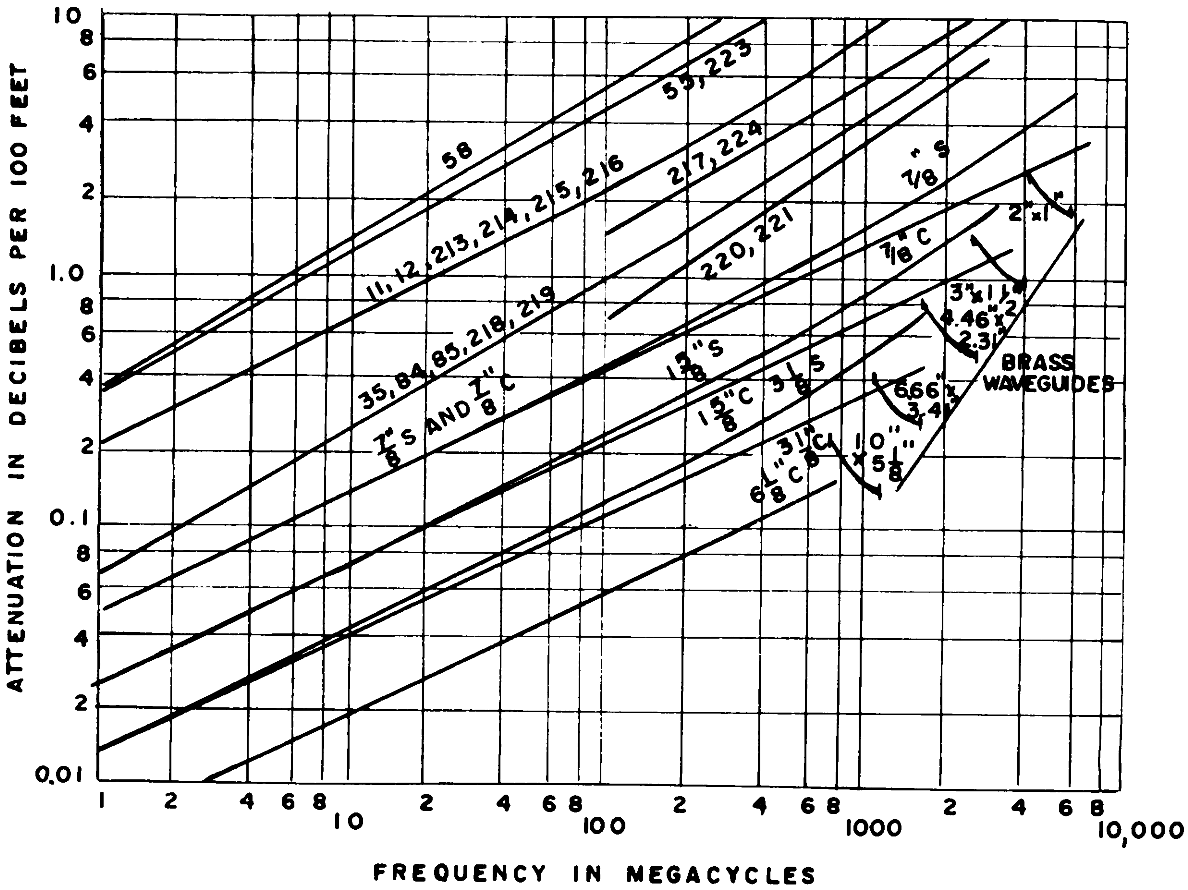
The transmission line will attenuate or reduce the magnitude of the signals as they pass along the line. As the operational frequency is increased or raised, the attenuation, for a given length of transmission line, will also increase. This loss is made up of conductor losses, due to current concentration near the surfaces of the conductors (skin effects), and dielectric losses, (leakage loss), due to the increase of dielectric volume resistivity, as the frequency is raised.

Also, at any given frequency, the smaller the overall diameter of the cable, the greater will be the cable loss.

From an antenna-transmission line system standpoint, the total allowable attenuation is normally specified. Figure 12 shows the approximate comparisons of the attenuation of general purpose RF lines and cables, up to their practical upper frequency limit. Knowing the type of and the length of the transmission line, one can compute the line loss over a specified frequency range. This attenuation figure, when increased by connector(s) loss, can be used in evaluating the condition of the installed transmission line.

8. Effect of Attenuation on SWR

The attenuation of the transmission line will reduce the apparent SWR to the antenna, when measured at the input to the antenna-transmission line system. Figure 13 is a nomograph which shows the relationship between input SWR, output SWR and line loss (attenuation in db). Examples: (a) for a known antenna SWR of 2.0 to 1 and a known line loss of 2 db; the input SWR can be determined by drawing a straight line from 2.0 to 1; on the right hand scale through 2 db on the center scale. Extend the line through to the



NOTES:

1. For RG-type cables, only the number is listed. (For instance the curve for RG-58/U is labled 58.
2. Some approximation was used in order to simplify the figure. Thus where a single curve is labled with several type numbers, the actual attenuation of each individual type may be slightly different from the curve.
3. The curves for rigid copper are labeled with the diameter of the line only, as for 7/8″C.
4. The curves for 50-ohm semirigid cables, such as Heliax, Styroflex, etc. are labeled by size in inches, as 7/8″S.
5. For comparison; curves for brass waveguides are included.

FIGURE 12. ATTENUATION OF RF TRANSMISSION LINES

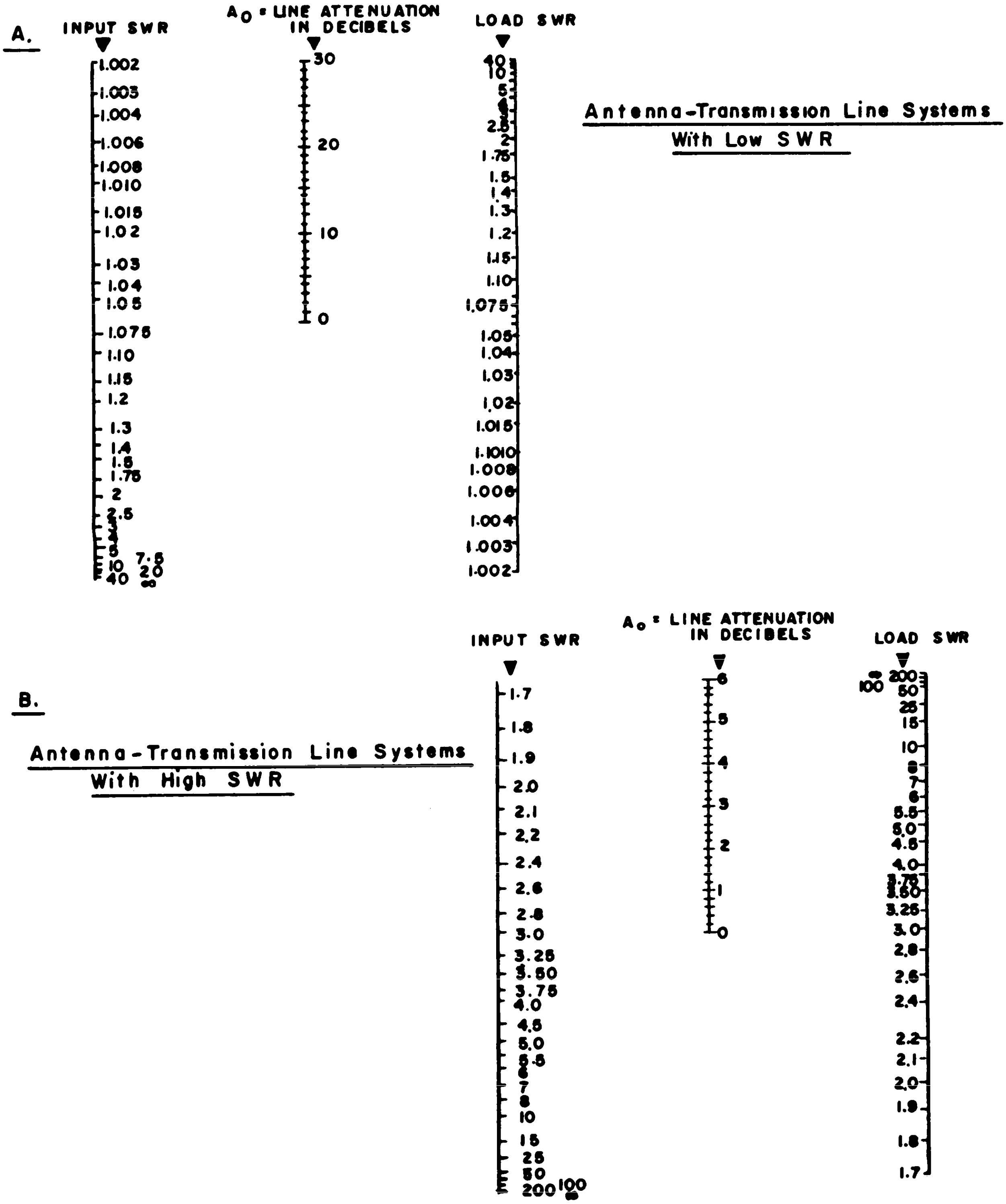


Figure 13 EFFECT OF CABLE ATTENUATION ON INDICATED SWR

left hand scale. The point of interception on the left hand scale will give a reading of 1.5 to 1 input SWR.

(b) Certain transmitters have a high VSWR protection circuitry. Assume that the protection circuit is activated when the SWR, at the transmitter, exceeds 3 to 1 and that the line loss is 2 db, what is the actual SWR at the antenna? The load or antenna SWR can be determined by drawing a straight line from 3 to 1, on the left hand scale, through 2 db on the center scale. Extend the line through to the right hand scale. The point of interception on the right hand scale will give an approximate reading of 8.5 to 1. It is obvious that the transmitter SWR protection circuitry will not provide timely warning that the antenna SWR has exceeded its specified value (nominally specified at 2 to 1).

(c) With reference to b, assume that we desire to use the high VSWR protection circuitry to indicate excessive SWR at the antenna. While the typical antenna should easily meet 2 to 1, lets set the activation of the VSWR protection at an antenna SWR of 3 to 1. Again assuming 2 db transmission line loss, what is the SWR at the transmitter, when the circuitry is activated. The input SWR or transmitter SWR can be determined by drawing a straight line from 3 to 1, on the right hand scale, through 2 db on the center scale. Extend the line through to the left hand scale. The point of interception, on the left hand scale will give an approximate reading of 1.92 to 1.

Assuming a transmitter power of 10 KW forward, a VSWR of 1.92 to 1 results in 1.1 KW reflected. With reference to b, a VSWR of 3 to 1 results in 2.6 KW reflected.

The normal maximum SWR for a transmitter is 2:1 which would be consistent with c and the suggested high VSWR circuitry activation point.

SECTION IV

SMITH TRAMSMISSION LINE CALCULATOR OR CHART

1. General

The Smith Radio Transmission-Line Calculator or Chart is named after its inventor, Phillip H. Smith. It was originally presented in Electronics, January 1939 as a Radio Transmission-Line Calculator. Its acceptance has been universal because it has proven itself extremely useful in radio work because it eliminates the need for complex mathematical calculations in solving most transmission-line problems. Because of the universal usage, they are often referred to as SMITH CALCULATOR or SMITH CHART.

The SMITH CALCULATOR is fundamentally a special kind of impedance coordinate system, mechanically arranged with respect to a set of movable scales, to show the relationship of impedance at any point along a uniform open-wire or coaxial transmission line to the impedance at any other point, and to several other electrical characteristics. The calculator assumes a form simular in appearance to a circular slide rule, but with different scales. The calculator is available from AMPHENOL RF DIVISION. An order blank form is in Appendix A.

The SMITH CHART is a printed copy of the calculator coordinate system and its various scales. The fact that the scales are not moveable on the printed charts offers only slight inconvenience over the calculator. An advantage of the printed chart is that actual calculations can be kept for a record, a data base, and for performance comparisons - a feat which is impossible with the calculator. SMITH CHARTS are available from Kay Electric Company as well as other sources.

When a transmission line is not terminated in its characteristic impedance, standing waves will result, and the input impedance will be dependent on the line's length. If the terminating impedance is known, it is a simple matter to determine the input impedance of the line for any length by means of the Smith Chart or Calculator. Conversely, with a given line length, and a known (or measured) input impedance, the load impedance may be determined by means of the chart or calculator --- a convenient method of remotely determining an antenna impedance, for example.

The understanding and use of a SMITH CHART can be improved by reviewing some of the basic concepts of AC circuitry; relative to resistive, inductive, and capacitive components and the use of a phase angle.

2. Background

a. Phase Angle.

A pair of voltages, a voltage and a current, or a pair of currents need not necessarily be in step with each other. These voltages and currents are of course all AC. Assuming that the sine waves are periodic waveforms (constant frequency) their relationships can be measured between the points at which they cross the X-axis. One voltage (or current) may lead or lag another voltage (or current). The amount of lead (or lag) is measured in degrees along the X-axis and is referred to as the phase angle. It is most usually designated by the Greek letter Theta or "θ". Whether a voltage (or current) will lead or lag a voltage (or current) will depend upon the amount of capacitance and/or inductance in the circuit. Out of phase voltages (or out of phase currents) can be added vectorially to produce a resultant voltage (or current).

(1) Phase Angle in Resistive Circuits.

For a resistive circuit consisting solely of resistance (whether in series, parallel or series-parallel) the voltage and current are always in step, (rise and fall at the same time) and are said to be in phase. Thus $\theta = 0^{0}$.

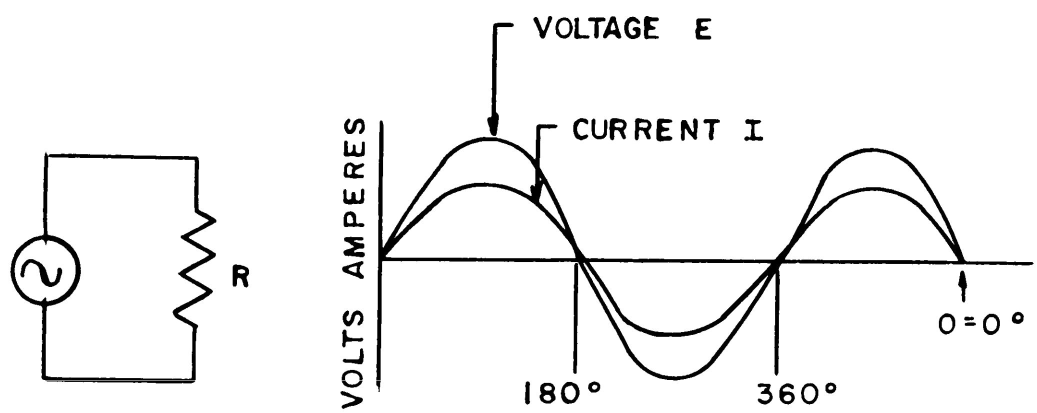


FIGURE 14. PHASE ANGLE IN RESISTIVE CIRCUITS

(2) Phase Angle in Inductive Circuits.

For an inductive circuit, consisting solely of inductors, the current lags the voltage by a maximum of 90°. Thus $\theta = +90°$. If the inductor contains resistance, and in a practical sense it always does, then the phase angle is less than 90°, depending upon the amount of resistance compared to inductive reactance.

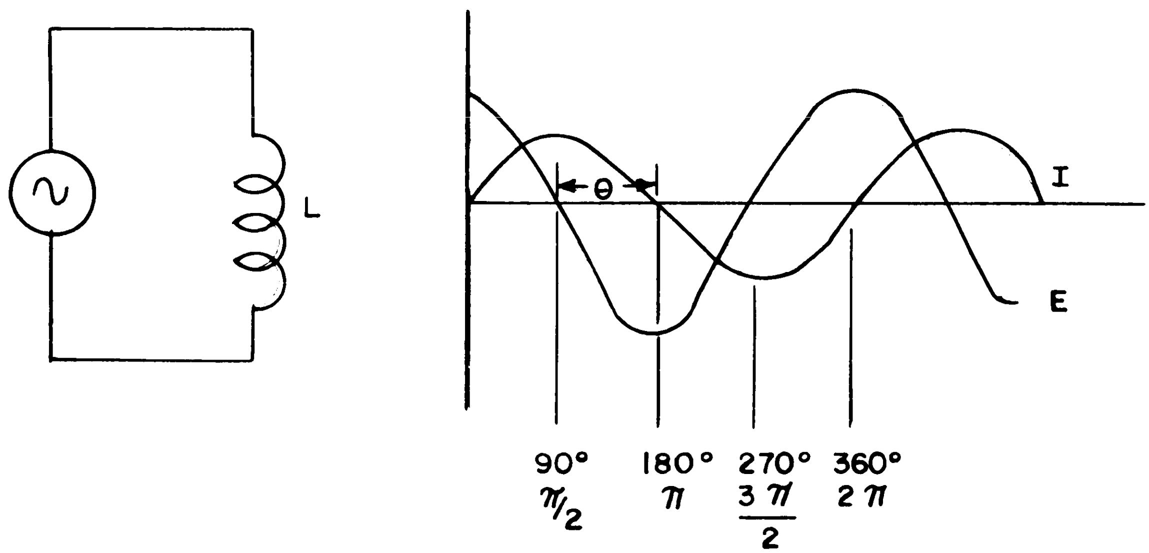


FIGURE 15. PHASE ANGLE IN INDUCTIVE CIRCUITS

(3) Phase Angle in Capacitive Circuits.

For a capacitive circuit, consisting solely of capacitors, the current leads the voltage by a maximum of 90°. The plus and minus signs preceding the phase angles are convenient reminders that inductors and capacitors have directly opposite effects in AC circuits.

(4) Phase Angle Of a Series R-L Circuit.

For a circuit consisting of an inductor in series with a resistor, the phase angle $\theta = \text{arc tan} \left(X_L / R \right)$ (read as: Theta is the angle whose tangent is X_L divided by R.).

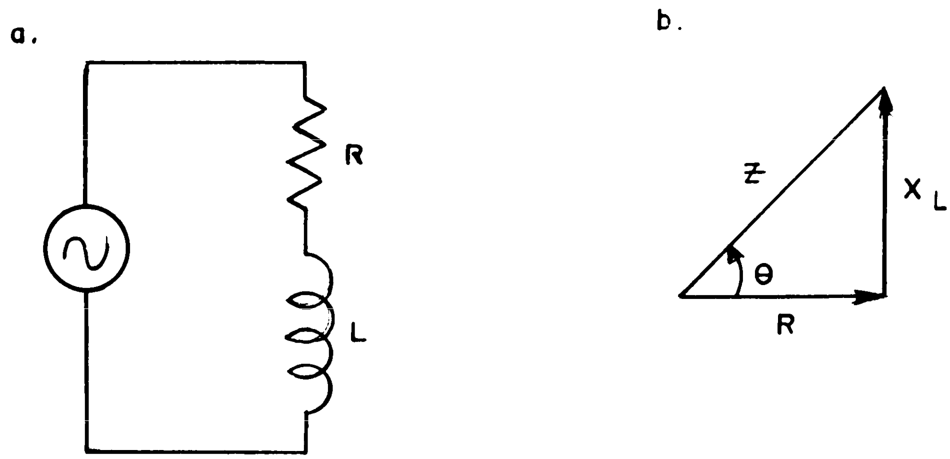
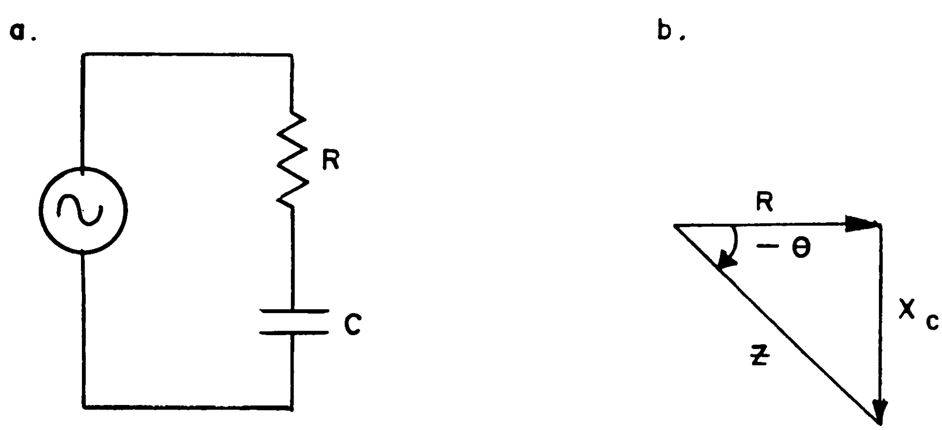


FIGURE 16. PHASE ANGLE OF A SERIES R-L CIRCUIT

The impedance $Z = \sqrt{R^2 + X_L^2}$ where Z, R and X_L are expressed in ohms.

(5) Phase Angle of a Series R-C Circuit.

For a circuit consisting of a capacitor in series with a resistor, the phase angle θ = arc tan$\left(X_C / R\right)$



NOTE: The X_L and X_C vectors are drawn in opposite directions to show the opposite effects.

FIGURE 17. PHASE ANGLE OF A SERIES R-C CIRCUIT

The impedance $Z = \sqrt{R^2 + X_C^2}$.

(6) Impedance and Phase Angle Of A Series R-L-C Circuit.

For a circuit consisting of resistance, inductance, and capacitance, and where X_L is larger than X_C. then

$$\theta = \text{arc tan}\left[(X_L - X_C)/R\right]$$

and $$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

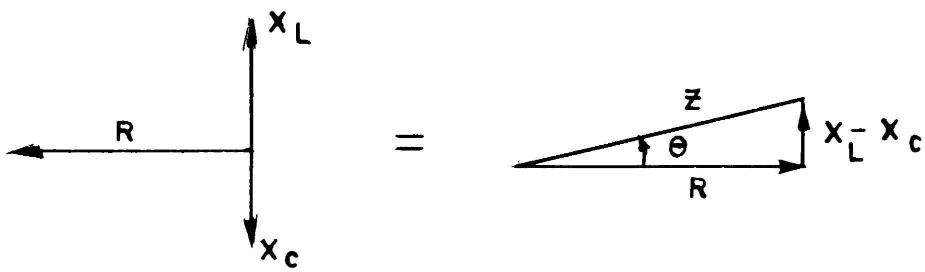
If X_C is larger than X_L, then

$$\theta = \text{arc tan } X_C - X_L /R$$

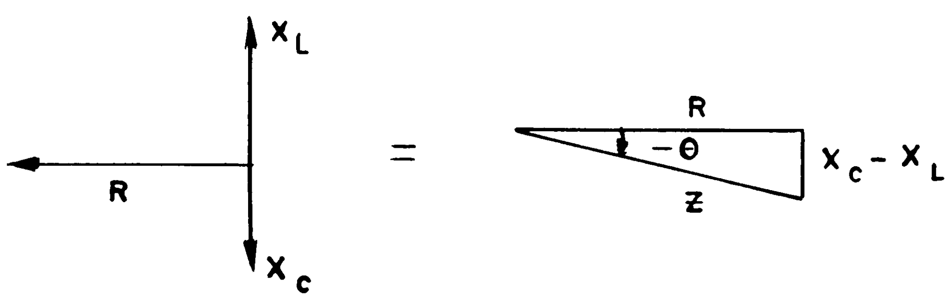
and $$Z = \sqrt{R^2 + (X_C - X_L)^2}$$

FIGURE 18. PHASE ANGLE OF A SERIES R-L-C CIRCUIT

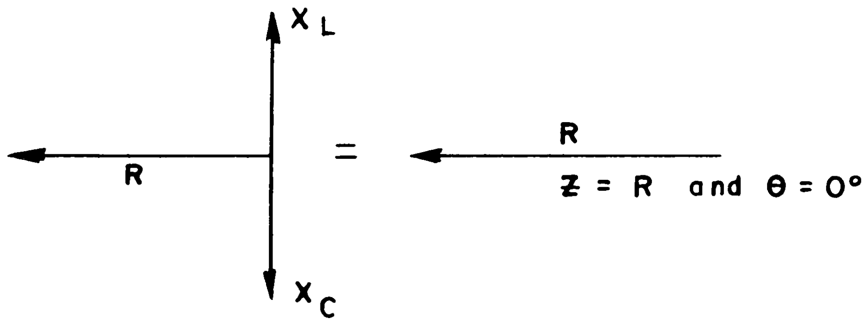
(a) (Where X_L is larger than X_C)



(b) (Where X_C is larger than X_L)



(c) (Where $X_L = X_c$).



If the inductive and capacitive reactance are equal, we have a condition of resonance and $Z = R$ and $\theta = 0^{\circ}$.

3. SMITH CHART.

After a brief review of phase angles and the effects of resistance, inductive reactance (X_L); and capacitive reactance (X_c) on the impedance (Z) of a circuit, the concepts of the SMITH CHART are easier to understand.

The Smith Chart Coordinate System consists simply of two families of circles --- the resistance family and the reactance family and external scales provided at the base of the chart. Recalling the vector relationships of a series R-L-C circuit as illustrated in Figure 19.

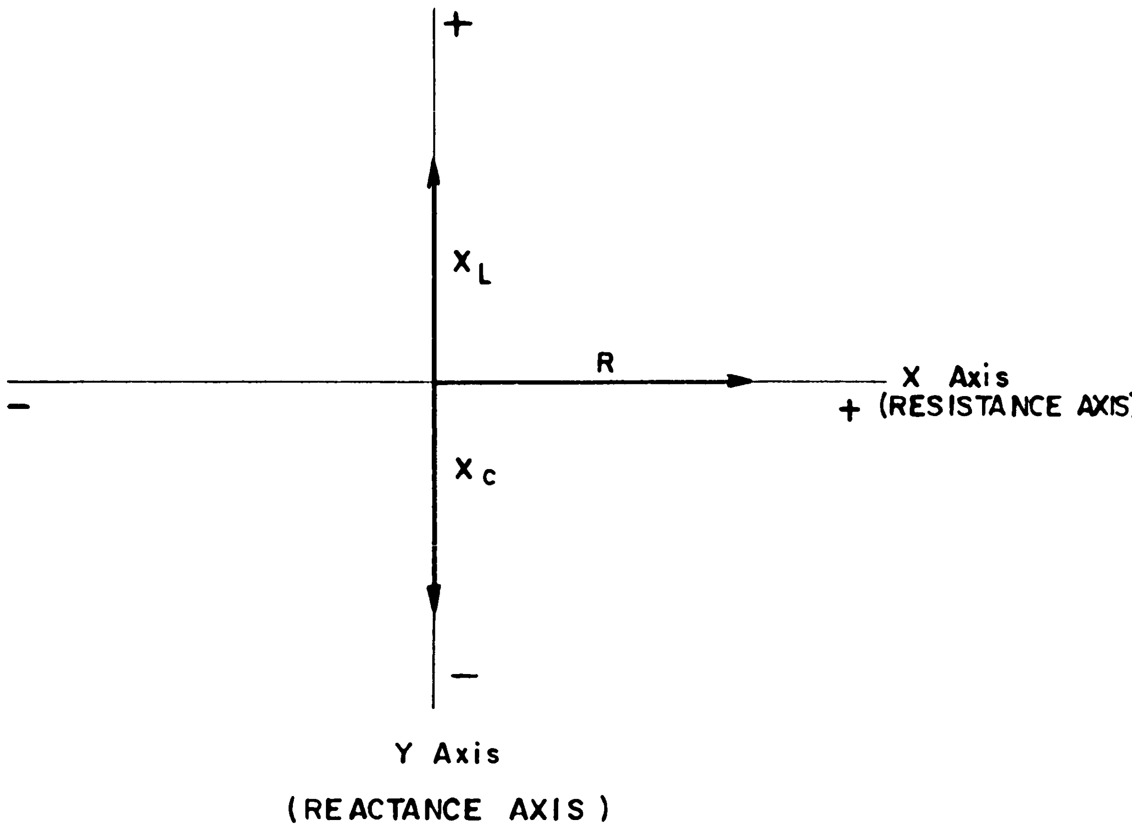


FIGURE 19. VECTOR RELATIONSHIP OF A SERIES R-L-C CIRCUIT

Because the true power or useful power in an AC circuit is equal to I^2/R, the Resistance axis is also called the "Real axis". Also, because the apparent power of an AC circuit is equal to I^2/Z, the reactance axis is called the "imaginery axis". The imaginery axis is represented by "j", which mathematically is equal to $\sqrt{-1}$. The only time when the true power is equal to the apparent power is when the circuit is all resistive or when $X_L = X_C$, - a resonant circuit.

The impedance of an AC circuit is a function of both the resistance (R) and the reactance (± jX) and can be defined by the intersection of a resistance circle and an impedance circle. (In reality the impedance vector resulting from the resistance vector and the reactance vector).

a. Resistance Family of Circles.

The resistance circles (Figure 20) are centered on the resistance axis and are tangent to the outer circle at the right center of the chart. Each circle is assigned a value of resistance, which is indicated at the point where the circle crosses the resistance axis. All points along any one circle will have the same resistance value. The values assigned to these circles will vary from zero ohms, at the left-center of the chart, to infinity at the right center of the chart. The midpoint on the chart between zero ohms and infinity is called the prime center and represents the impedance value assigned to the center of the chart. It is indicated as 1.0, during construction of the chart. A circle is then drawn around the prime center which includes both zero ohms and infinite (∞) ohms. The radius of each subsequent circle is equal to:

$$\text{Radius} = \frac{1}{1 + R/Z_o} \quad \text{units}$$

where R = resistance value

and Z_o = Normallized resistance value (value assigned to the prime center - normally the characteristic impedance of the transmission line.)

If the prime center is assigned a value of 100 ohms, then 200 ohms is represented by the 2.0 circle, 50 ohms by the 0.5 circle, 20 ohms by the 0.2 circle, and so on. If a value of 50 ohms is assigned to the prime center, the 2.0 circle now represents 100 ohms, the 0.5 circle 25

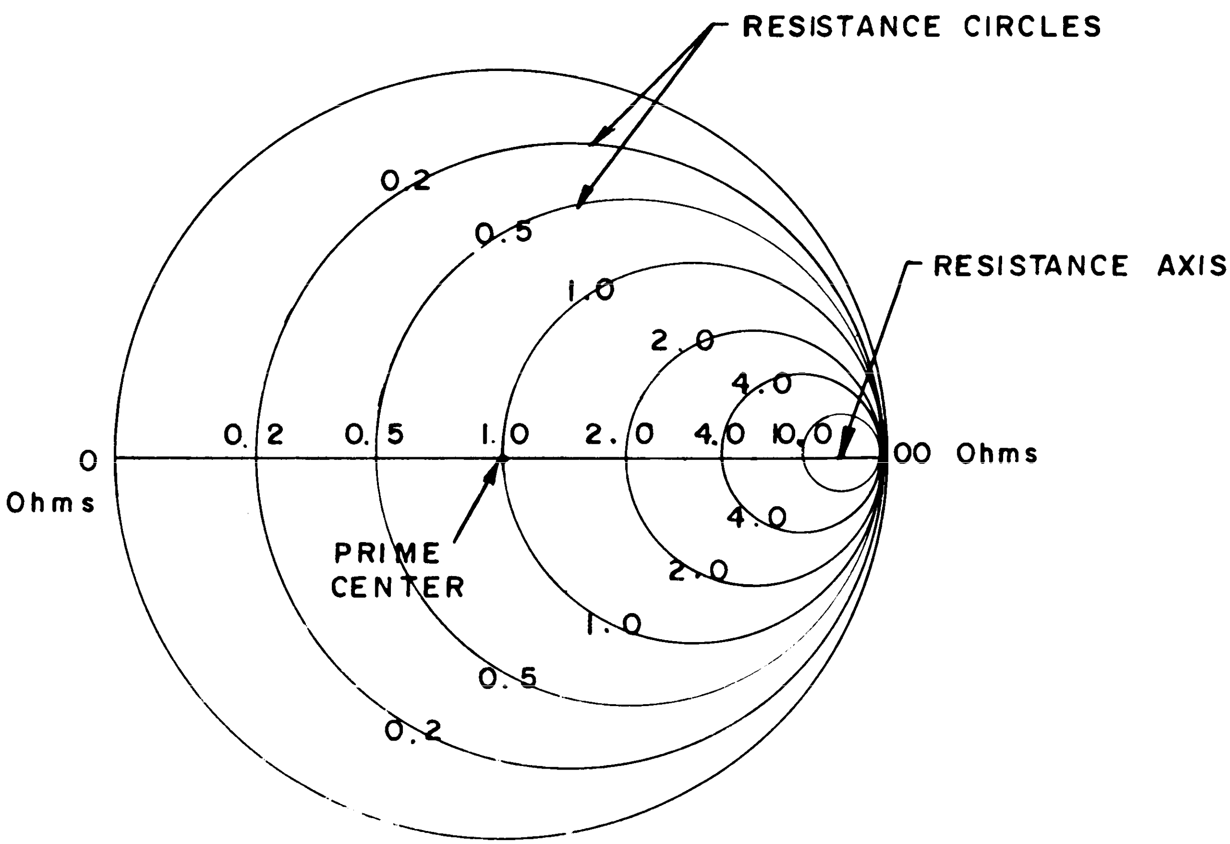


FIGURE 20. RESISTANCE FAMILY OF CIRCLES

ohms, and the 0.2 circle 10 ohms. In each case, it may be seen that the value on the chart is determined by dividing the actual resistance by the number assigned to the prime center. This process is called normalizing. Conversely, values from the chart are converted hack to actual resistance values by multiplying the chart value times the values assigned to prime center. This feature permits the use of the SMITH CHART for any impedance values, and therefore with any type of uniform transmission line, whatever its impedance. Specialized versions of the SMITH CHART are available with a value of 50 or 75 at prime center. These are intended primarily for use with 50- and 75- ohm transmission lines, respectively. 50 Ohm SMITH CHARTS are included in Appendix B.

b. Reactance Family of Curves.

The reactance circles are centered on the reactance axis and are tangent to the infinity point on the resistance axis. See Figure 21. This is consistent with and follows the reactance-resistance axis described previously. However, only those portions or segments of the complete circles, that are contained within the resistance circle centered on the prime center, are shown.

Each reactance circle segment is assigned a value of reactance, indicated near the point where the circle touches the referenced resistance circle. All points along any one segment have the same reactance value. As with the resistance circles, the values assigned to each reactance circle are normalized with respect to the value assigned to the prime center. Values above the resistance axis are positive (inductive reactance) and those below the resistance axis are negative (capacitive reactance). The radius of each circle is equal to:

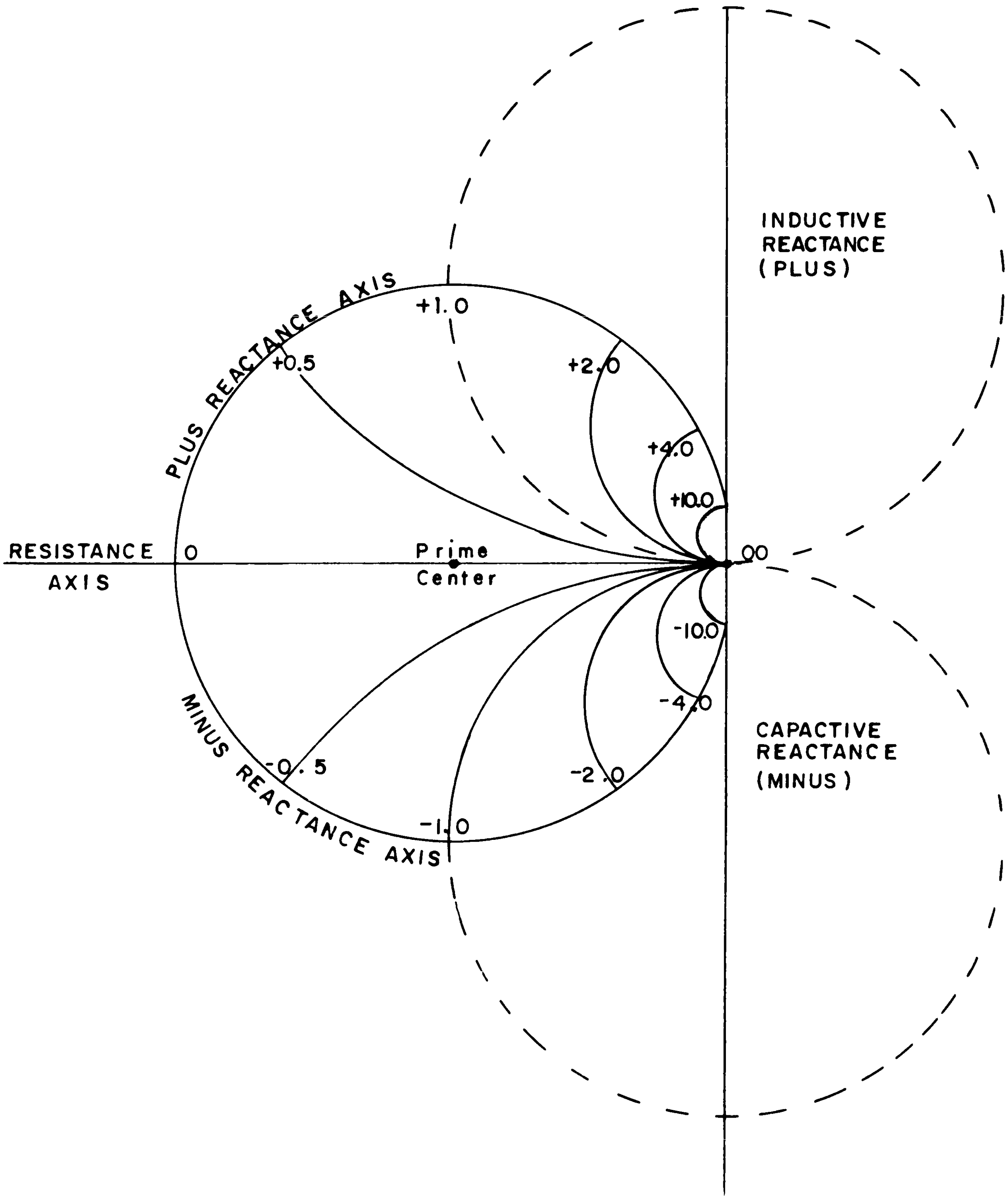


Figure 21 REACTANCE FAMILY OF CIRCLES (SEGMENTS)

$$\text{Radius} = \frac{1}{+ jX/Z}$$

Where X = reactance value (+, if inductive, -, if capacitive).

and Z_o = Normalized resistance value (Value assigned to the prime center --- normally the characteristic impedance of the transmission line).

co Coordinate System - SMITH CHART.

When the resistance family and the reactance family of circles are combined, the coordinate system of the SMITH CHART results, as shown in Figure 22. Complex series impedances (R ± jX ohms) can be plotted on this coordinate system.

4. Impedance Plotting

The plotting of complex impedances on a SMITH CHART is easily accomplished. Assume that we have an impedance consisting of 50 ohms resistance and 100 ohms inductive reactance (Z = 50 + j100 ohms). If we assign a value of 50 ohms to the prime center, we normalize the impedance by dividing each component of the impedance by 50. The normallized impedance would then be 50/50 + j (100/50) or 1.0 + j2. This impedance value would be plotted on the SMITH CHART at the intersection of the 1.0 resistance circle and the + 2.0 reactance circle (segment), as indicated in Figure 22. If a value of 100 ohms had been assigned to the prime center, the same impedance would be normalized by dividing each component of the impedance by 100. The normalized impedance would then be 50/100 + j (100/100) or 0.5 + jl. This impedance value would be plotted on the SMITH CHART at the intersection of the 0.5 resistance circle and the +1.0 reactance cicle (segment), as indicated in Figure 22. It should be noted that this intersection point of the two circles is comparable to the resultant obtained with the resistance and reactance vectors.

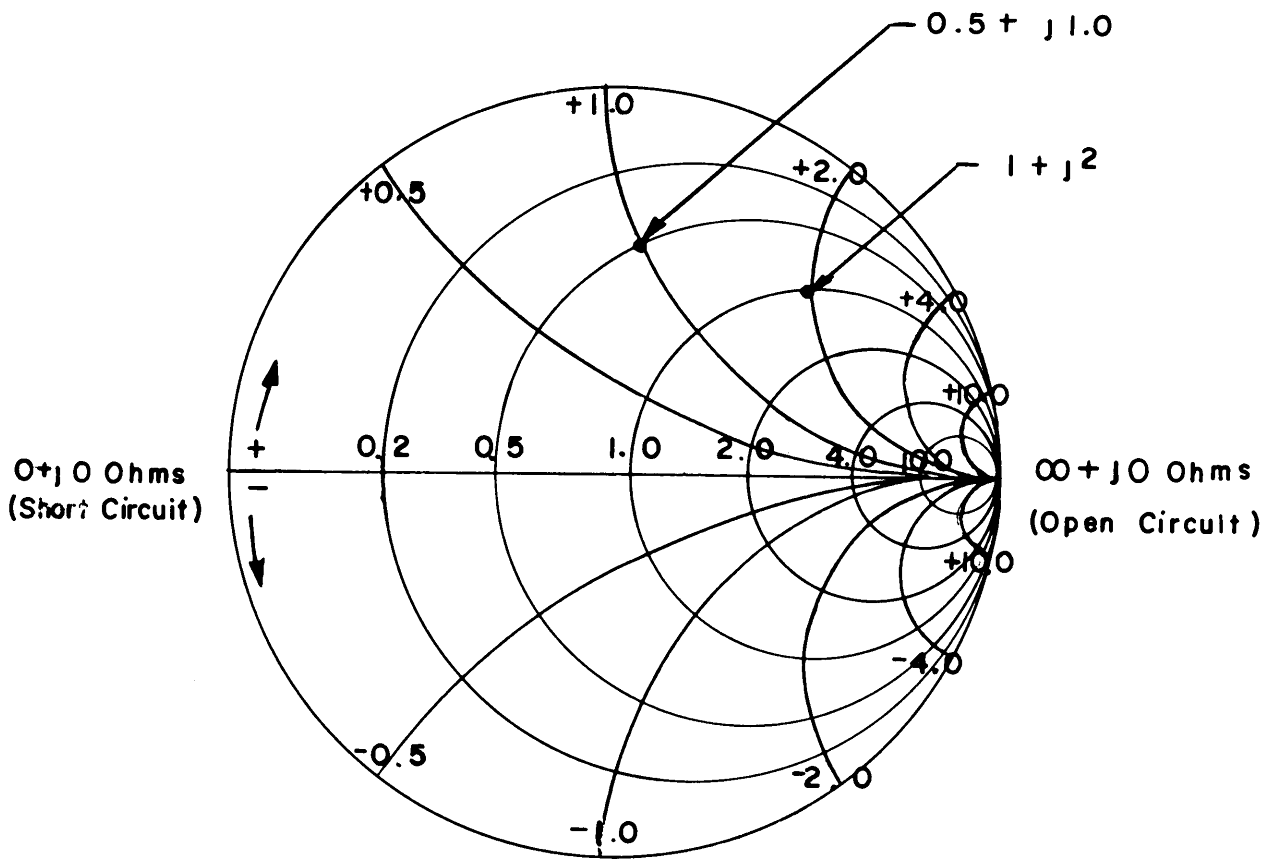


FIGURE 22. COORDINATE SYSTEM - SMITH CHART

From these examples, it may be seen that the same impedance may be plotted at different points on the chart, depending upon the value assigned to the prime center. It is customary when solving transmission-line problems to assign to the prime center a value equal to the characteristic impedance or Z_0, of the line being used. This value should always be recorded at the start of calculations, to avoid possible confusion later.

In using the specialized charts with the value of 50 at prime center, it is, of course, not necessary to normalize impedances when working with a 50 ohm line. The resistance and reactance values may be plotted directly.

a. Short and Open Circuits.

With reference to the plotting of impedances, two special cases deserve consideration. These are short circuits and open circuits. A true short circuit has zero resistance and zero reactance, or 0 + jO. This impedance would be plotted at the extreme left - center of the chart, at the intersection of the resistance and the reactance axes. An open circuit has infinite resistance, and would therefore be plotted at the extreme right - center of the chart, at the intersection of the resistance and reactance axes. These two special cases are discussed later in their use in determining transmission line lengths and losses.

b. Standing-Wave Ratio Circles.

There is a third family of circles, which are not printed on the chart but which are added during the process of solving problems. This family of circles are standing-wave ratio or SWR circles. See Figure 23. This family is centered on the prime center, and appears as concentric circles inside the reactance axis. During calculations, one or more of these circles may be added with a drawing compass. Each circle represents a value of SWR, every point on a given circle representing the same SWR. The SWR value for a given circle may be determined directly from the chart coordinate system, by reading the normalized resistance value where the SWR circle crosses the resistance axis, to the right of the prime center. (The reading where the circle crosses the resistance axis, to the left of the prime center, indicates the inverse ratio.)

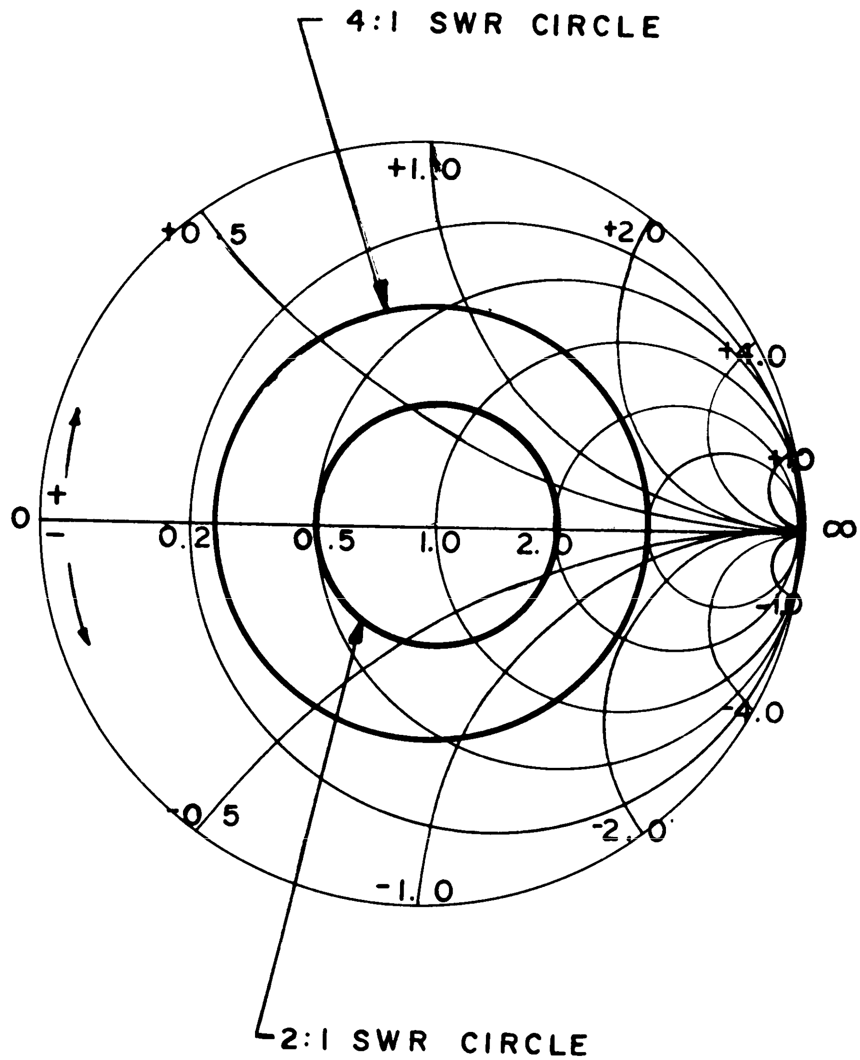


FIGURE 23. SWR CIRCLES

c. SWR of Any Impedance Point.

A variation in the use of the SWR circles is to find the SWR of an impedance point or points without drawing the circle (s). After plotting the impedance point, use a set of dividers or a compass to measure the distance from the prime center to the impedance point. Now, measure the same distance along the resistance axis, to the right of the prime center. As before, read the SWR value.

d. Wavelength Scales.

Consider the situation where a load mismatch at the end of a transmission line causes a 4 to 1 SWR to exist. If we temporarily disregard the transmission line losses, the SWR will remain constant throughout the entire length of the line. This is represented on the SMITH CHART by drawing a 4:1 constant SWR circle (a circle with a radius of 4 on the resistance axis), as in Figure 24. The design of the chart is such that any impedance encountered anywhere along the length of the mismatched line will fall on the SWR circle, and may be read from the coordinates merely by progressing around the SWR circle by an amount corresponding to the length of the line involved.

This brings into use the "wavelength scales", which are shown on Figure 24, near the reactance axis or the outer perimeter of the SMITH CHART. These scales are calibrated in terms of portions of an electrical wavelength along a transmission line. One scale, running <u>counterclockwise,</u> starts at 0 + j0 ohms, which is also at the generator or input to the transmission line and progresses toward the load. This scale is marked "wave lengths toward load". The other scale, running <u>clockwise,</u> also starts at 0 + j0 ohms, which is now considered to be the

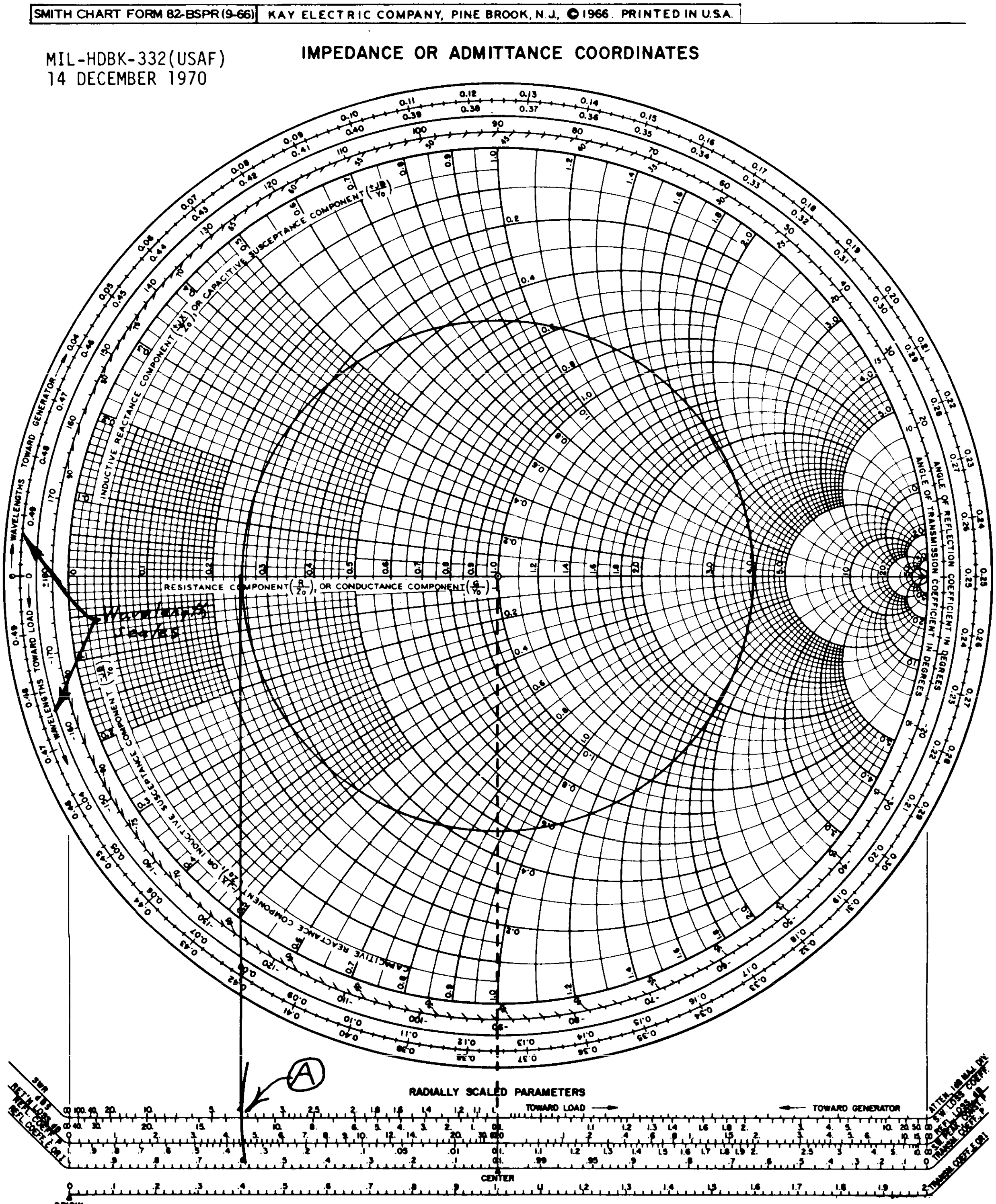


FIGURE 24. IMPEDANCE PLOT - 4:1 SWR CIRCLE

load or the end of the transmission line and progresses toward the generator. The complete circle (in either direction) represents one half wavelength. Progressing once around the perimeter of those scales corresponds to the progressing along a transmission line for a half wavelength. Because the impedance values will repeat themselves every half wavelength along the transmission line, the chart may be used for any length of line. This is done by subtracting all the integral, or whole number, of half wavelengths, from the total length of the line.

e. External SWR Scale.

At the bottom of the SMITH CHART, there are several external scales to facilitate the use of the chart. The top scale, left hand side and identified by “SWR” can also be used to determine the SWR of a SWR circle. As shown in Figure 24, the intersection of the SWR circle with the resistance axis (at the left of the prime center) is transferred to the external SWR scale by drawing a line that is tangent to the circle (perpendicular to the resistance axis). Or, the radius of the SWR circle may be simply transferred to the external scale by placing the point of a drawing compass at the center, or 1.0, on the external SWR scale, and inscribing a short arc across the appropriate scale. It will be noted that when this is done in Figure 24, the external SWR scale (E_{max}/E_{min}) indicates the SWR to be 4.O (at A) - our condition for initially drawing the circle on the chart (and the same as the SWR reading on the resistance axis).

On the same SWR scale, the ratio of the E_{max} to E_{min} is also presented in dBS. For a SWR of 4, the dB relationship is 12 dB.

This is not a loss but only the ratio of the E_{max}, on the transmission line, to the E_{min}, on the transmission line. (See Figure 10).

5. Using The SMITH CHART

The use of the SMITH CHART will be demonstrated in the following sample transmission line problems. It will be more useful if the reader has available SMITH CHART forms, a drawing compass, a set of dividers, and a straight edge or ruler to do the sample problems along with the examples.

a. Determining the input impedance of a transmission line with a known load impedance.

Assume that we have a transmission line with a characteristic impedance of 50 ohms, and an electrical length of 0.3 wavelength. Further, assume we terminate this line with an impedance having a resistive component of 25 ohms and an inductive reactance of 25 ohms (Z = 25 + j25), and now desire to determine the input impedance to the line.

Because the line is not terminated in its characteristics impedance, we know that standing waves will be present on the line, and that, therefore the input impedance to the line will not be exactly 50 ohms. We proceed as follows:

First, normalize the load impedance by dividing both the resistive and reactive components by 50 (the Z_O of the line being used). The normalized impedances in this case is 0.5 + j0.5.

Next, plot this impedance point on the chart at the intersection of the 0.5 resistance and + 0.5 reactance circles. See Figure 25.

Next, draw a SWR circle that passes through the plotted impedance point. The radius of this circle may then be transferred to the external scales with the drawing compass. The prime center of the SWR circle is transferred to the external scales center and an arc, equal to the radius of the SWR circle, is drawn on the external scales.

From the external SWR Scale, it may be seen (at A), that the voltage ratio (E_{min}/E_{max}) of 2.6 corresponds to this radius, indicating that the line has a SWR of 2.6 to 1 at the termination of the line. Note, that one can also read a SWR of 2.6 to 1 on the resistance axis (at B). Returning to the external SWR scale, the SWR of 2.6 to 1 can be converted to decibels on the dBs scale, where 8.4 dB may be read (at C), indicating that the ratio of the voltage maximum to the voltage minimum is 8.4 dB.

Next, with a straight edge or ruler, draw a radial line from the prime center through the plotted impedance point to intersect the wavelengths scale (at D). Because we are starting from the load, we will use the "wave lengths toward the generator" or outermost scale. Thus the reference wavelength position at the load is 0.088 wavelengths.

Next, to obtain the line input impedance, we merely find the point on the SWR circle that is 0.3 wavelengths toward the generator from the plotted load impedance. This is accomplished by <u>adding</u> 0.3 wavelength (the length of the line in wavelengths) to the reference or starting point, 0.088; 0.3 + 0.088 = 0.388. Locate 0.388 on the "Wavelength Toward Generator" scale (at E) and draw a second radial line from this point to the prime center. In essence, this means that radial line through the impedance point plotted for the load has been rotated <u>clockwise</u> to the radial line through the impedance point of the input to the line or at the generator.

Now, the intersection of the new radial line with the SWR circle represents the line input impedance, in this case 0.6 - j0.65. To find

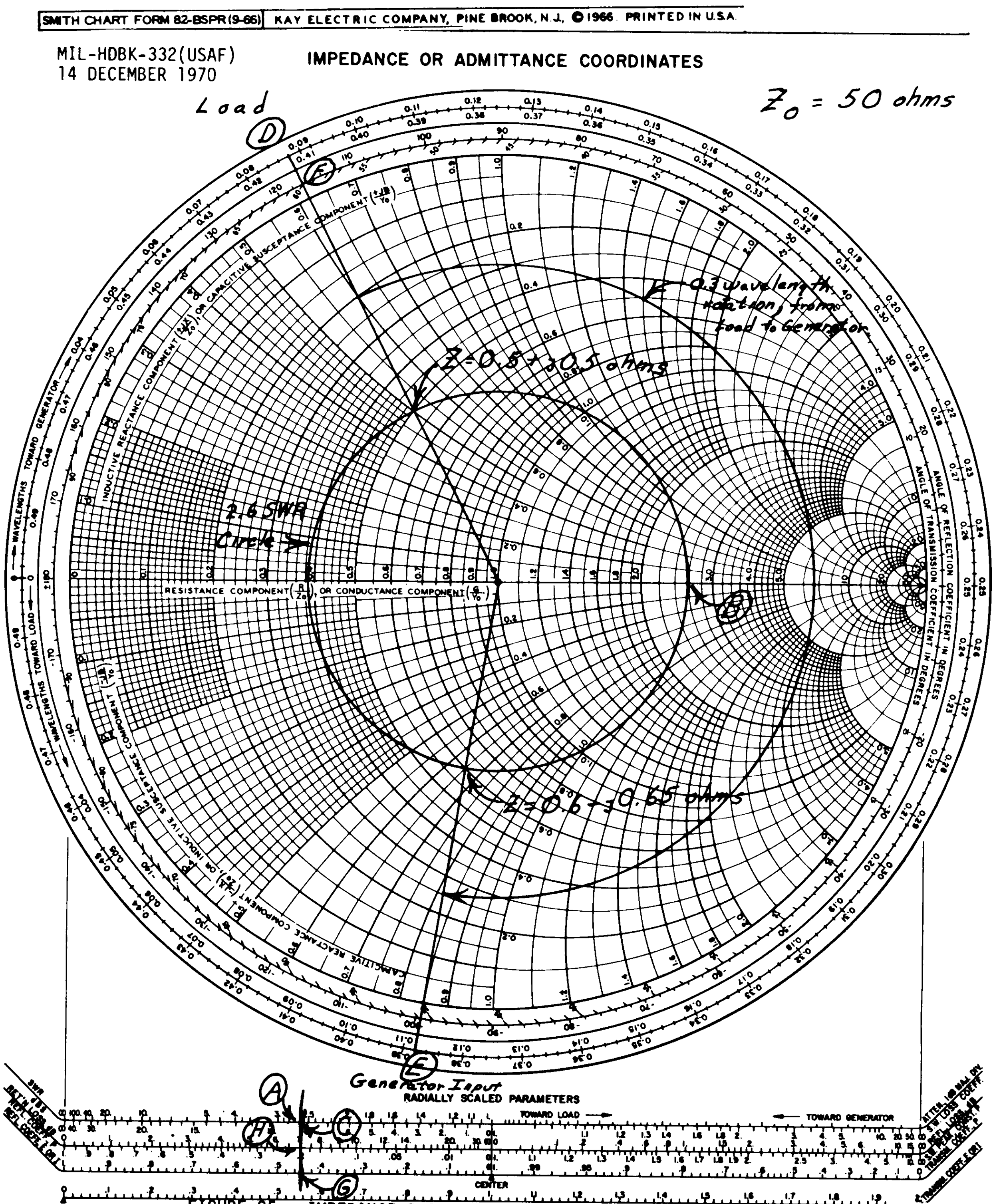


FIGURE 25. IMPEDANCE PLOT - DETERMINATION OF INPUT IMPEDANCE

the actual line impedance, multiply by 50 --- the value assigned to the prime center, which equals 30 - j32.5 ohms. This is 30 ohms resistive and 32.5 ohms capacitive reactance. This is the impedance which a transmitter must match if such an antenna-transmission line system was used or would be the impedance which would be measured on an impedance bridge, if the measurement were taken at the line input.

Additional characteristics of the antenna-transmission line system can also be determined from the chart. For example, the voltage reflection coefficient, both magnitude and phase angle is given. The phase angle is read on the "Angle of Reflection Coefficient in Degrees" scale which is just inside the "Wavelengths Toward Generator" and "Wavelengths Toward LOAD" Scales. The actual angle is read at the point where the radial line, drawn through the plot of the load impedance, intersects the angle of reflection coefficient scale (at F). The angle is about 116.5 degrees. This indicates the angle by which the reflected voltage wave lags the incident at the load. It should be noted that the angles on the bottom, or capacitive-reactance side, of the chart are negative angles, a "negative" lag indicates that the reflected voltage wave actually <u>leads</u> the incident wave.

The magnitude of the voltage-reflection coefficient may be read on the external "Refl. Coeff., E or I" scale. The voltage reflection coefficient is equal to ratio of the reflected voltage to the forward voltage and is designated by Greek letter "Rho" or " ρ ".

$$\rho = E_{Reflected} / E_{Forward} = -I_{Reflected} / I_{Forward}$$

Examination of the voltage reflection coefficient scale shows a range of values of O at the Center (SWR = 1, because there is no reflected power) to 1 at the top of the scale (SWR = ∞ , because all the forward power is reflected). The voltage reflection coefficient, Rho, is a function of the SWR circle - so the scale is symetrical with the center. A special RF bridge - detector circuit, called a "Rho Detector", is used to determine the measurement frequencies of an Antenna-Transmission Line system. The use of a Rho Detector is discussed in the test procedures.

The voltage reflection coefficient, for this example, is approximately 0.448 (at G). This means that ρ = 0.448 and that 44.8 per cent of the incident voltage is reflected. Adjacent to this scale, on the "Refl. Coeff., o " Scale, (at H), the power reflection coefficient is 0.20, indicating that 20 per cent of the incident power is reflected. Recalling that: Power = E^2/Z_o

where E = the voltage

and Z_o = characteristic impedance

Because power is proprotional to E^2, then the power reflection coefficient (in percentage) is also proportional to the percentage of (voltage reflection)^2 or $(0.448)^2$ which, of course, equals 20 per cent.

b. Determining the Load (Antenna) Impedance of an Antenna-Transmission Line System; When the Input Impedance is Known.

The determination of an actual antenna impedance from a SMITH CHART is similar to the determination of the input impedance.

The electrical length of the transmission line must be known as well as the impedance values at the input to the antenna-transmission line system. In this case, the antenna is connected to the far end of the transmission line and is the load for transmission line. Whether the antenna is used for transmission or for reception, it will make no difference. The antenna is still the terminating or load impedance for the line. The input or the generator end of the line would be that end connected to the RF impedance bridge. In this problem, the measured impedance is plotted on the SMITH CHART, and the "Wavelengths Toward Load" scale is used in conjunction with the electrical length of the transmission line to determine the actual antenna impedance.

Assume that we have measured the input impedance to the 50 ohm transmission line and found it to be 70 ohms - j25 ohms. Also we know that the electrical length of the line is 2.35 wavelengths long and that the terminating load is an antenna.

To determine the antenna input impedance, proceed as follows:

First, normalize the input impedance with reference to 50 ohms, which is 1.4 - j0.5.

Next, plot this impedance point on the chart at the intersection of the 1.4 resistance and the -0.5 reactance circles. Mark down the normalized impedance -50 ohms. See Figure 26.

Next, draw a SWR circle that passes through the plotted impedance point. The SWR of 1.7 may be read on the resistance axis (at A) or transfer the radius of the SWR circle to the external "SWR" scale, which also is read as 1.7 (at B).

Next, draw a radial line from the prime center through the plotted impedance point to intersect the wavelengths scale (at C). Because we are starting from the "generator", we will use the "Wavelengths Toward The

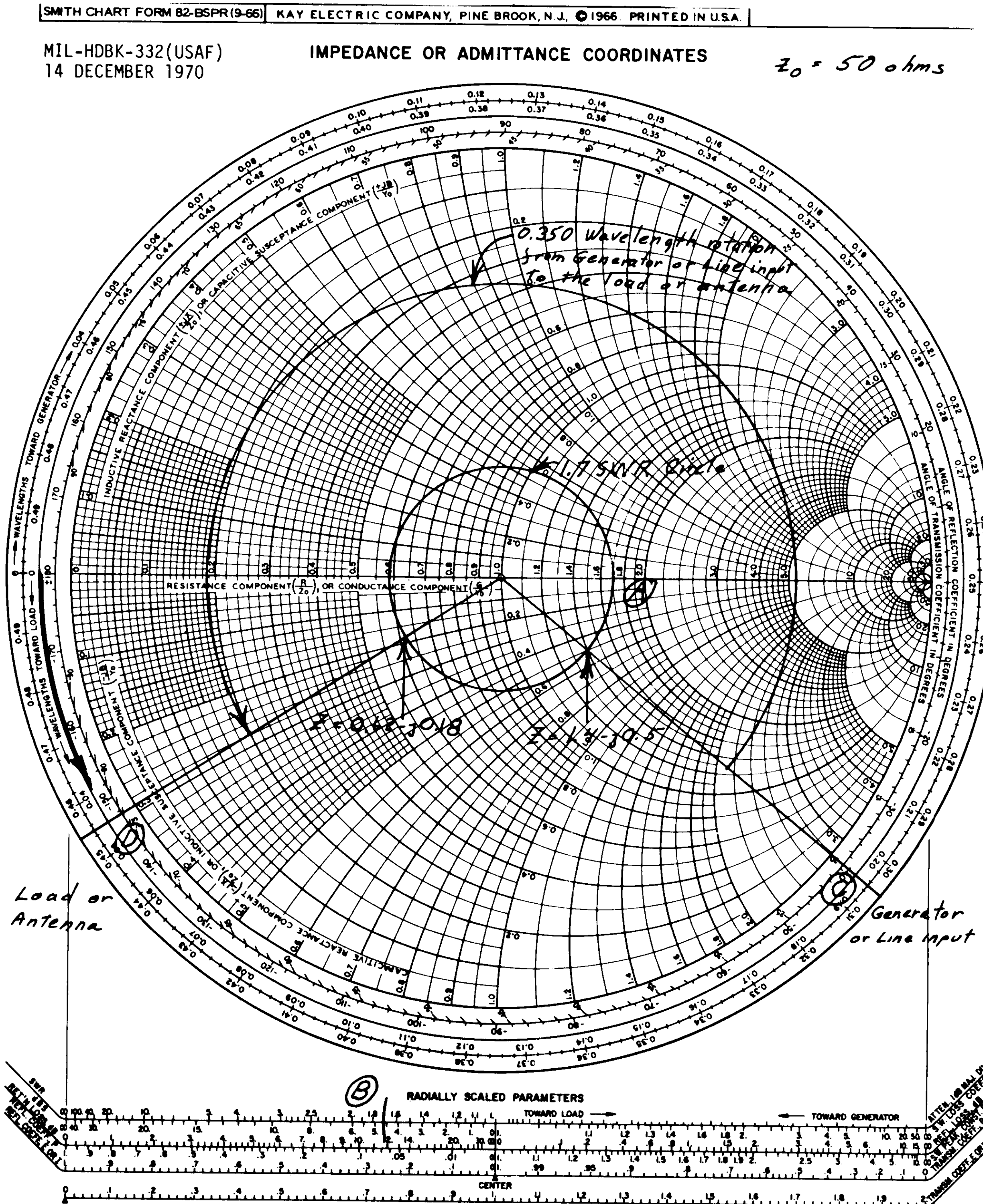


FIGURE 26. IMPEDANCE PLOT - DETERMINATION OF LOAD IMPEDANCE

Load" or the inner scale. Thus the reference wavelength position, at the input, is 0.195 wavelengths (at C).

Next, to obtain the load impedance, we find the point on the SWR circle that is 2.35 wavelengths toward the load from the plotted input impedance. 0.195 wavelengths (input) + 2.35 (transmission line electrical length) = 2.545 wave lengths. However, the calibration scales only extend from 0.0 to 0.5 wavelengths. This is permissible because the impedance values, along a transmission line, repeat every half wave length. (This factor is very important and is used to determine the transmission line length and the measurement frequencies at which the input impedances should be made.) See Section on measurements. Thus, we can subtract the whole number of half wavelengths from the 2.545 wavelength value. In this case, the largest integral number of half wavelengths that can be subtracted is 5, or 2.5 wavelengths. Therefore, 2.545 - 2.5 = 0.045 wavelengths. Locate 0.045 on the "Wavelength Toward LOAD" scale (at D) and draw a second radial line from this point to the prime center. In essence, this means that the radial line through the input impedance point has been rotated counterclockwise 2.0 wavelengths (four complete rotations of the radial line) plus 0.35 wavelengths to stop at 0.045 wavelengths (0.195 + 0.35 + 0.545, and in turn, 0.545 - 0.5 = 0.045 wavelengths).

Next, the coordinates of the intersection of the second radial line with the SWR circle represents the load impedance. To read this value, some interpolation between the printed coordinate lines must be made, and the value of 0.62 - j0.18 is read. Multiplying by 50, the load or load impedance is 31 - j9 ohms, or 31 ohms resistance with 9 ohms capacitive reactance.

C. Effect of Transmission Line Loss.

The problems presented so far have ignored the transmission line loss or attenuation. Quite frequently, it is not even necessary to consider losses when making calculations; any differences in readings obtained would be almost imperceptible on the SMITH CHART. When the line losses are appreciable because of:

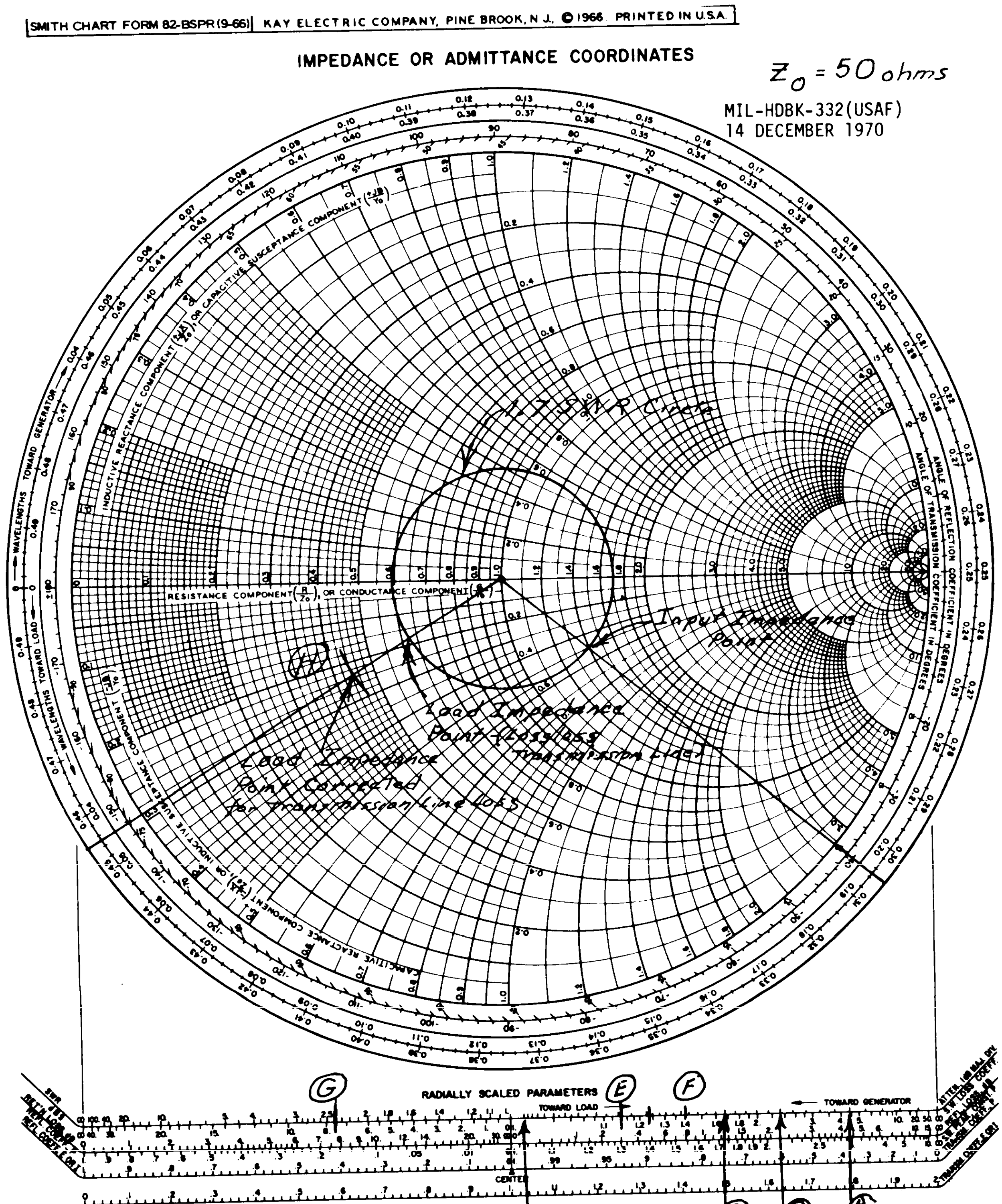
very long lines, in terms of wavelengths

or with high SWR values,

then, line attenuation should be included in the calculations. This involves only one additional step, in addition to the procedures previously presented.

The SWR will not remain constant, throughout the length of the transmission line, because of the line attenuation. The reflected power is attenuated as the RF wave travels toward the generator. As a result, there is a decrease in SWR as the incident or reflected wave progresses away from the load toward the generator. While the forward power is also attenuated as the RF wave travels toward the load, we are concerned with the reduction in SWR due to the attenuation of the reflected power.

To correctly represent this attenuation on the WITH CHART, it would be necessary to draw a curve spiraling inward and clockwise from the load impedance toward the generator. The rate at which the curve spirals inward toward the prime center would be directly related to the transmission line attenuation. Rather than drawing spiral curves, a simpler method is used in solving line-loss problems, by means of the external scale “Attn., 1 dB Maj. Div.”. See Figure 27. The dB steps are not numbered because this scale is only a relative scale.



201 FIGURE 27. IMPEDANCE PLOT - TRANSMISSION LINE LOSS CALCULATION

If we start at the top of the external scale (right hand end) and proceed in the direction indicated "toward generator", the first dB step is seen to occur at a radius from center corresponding to a SWR of about 9 (at A); the second dB step occurs at an SWR of about 4.5 (at B), the third at 3.0 (at C) ant! so forth, until the 15th dB step which occurs at a SWR of about 1.05 to l(at D). This means that a transmission line terminated in either a short or open circuit (infinite SWR) and having an attenuation of 15 dB, would measure a SWR of only 1.05 at the input. It should be noted that the dB steps near the left hand end of the scale (low SWR systems) are very close together, and a line attenuation at 1 or 2 dB, in this area will have only a slight effect on the SWR. But if at the right hand end of the scale (high SWR systems), a 1 or 2 dB loss will have considerable effect on the SWR.

The 1 dB transmission loss scale can also be used in the reverse manner by using the "toward load" direction. The measured SWR, at the generator (or input), can be corrected, by the transmission loss, to result in the SWR at the load.

In solving a problem using transmission line data, it is only necessary to modify the radius of the SWR circle by the line attenuation indicated on the "Atten., 1 dB Maj. Div." scale. This is accomplished by drawing a second SWR circle, of either greater (toward the LOAD) or lesser (toward the generator) radius than the first SWR circle. In lieu of drawing the second SWR circle, it may result in less confusion if only an arc is drawn on the radial line through the impedance point that is to be corrected for line loss.

Assume that in the previous problem (Figure 26), we have determined that the transmission line loss is 2 dB and that we want to correct for this loss. (Figure 27). To account for this line loss, transfer the radius of the SWR circle to the external "Attn., 1 dB Mag. Div" scale. This radius will cross the external scale at E. Since the line loss was determined to be 2 dB, we strike a new radius (at F), 2 dB higher (toward LOAD) on the same scale. Now transfer this new radius back to the main chart, and scribe a new SWR arc across the radial through the load impedance point. This new radius represents the SWR at the load, and is read as about 2.4 on the external SWVR scale (at G). At the intersection of the arc and the load radial line, we read 0.44 - j0.24 (at H) as the normalized load impedance. Multiplying by 50, the actual load impedance is 22 - j12 ohms. The SWR in this problem was seen to increase from 1.7 at the input to the antenna-transmission line system to 2.4 at the input to the load or antenna, when the 2 dB line loss was taken into consideration.

In the example above, use of the minor divisions at the 1 dB steps and interpolation between these marks was required. Actually, this is a simple matter to maintain the relative distance between marks, for each dB step, while counting off the proper number of steps.

The total line losses, in a given antenna-transmission line system, are dependent upon several factors, primarily frequency, line length, and SWR. Transmission line data tables show "matched line" losses for various types of transmission lines at various frequencies, usually expressed in decibels per 100 feet. RG-213, for example, has an attenuation of 0.3 dB per hundred feet at 2.0 MHz, 0.65 dB at 10 MHz, and 1.2 dB at 30 MHz. Transmission line loss tables are given in the Section on transmission lines. A more complete data source, if required, would be the "Reference Data for Radio Engineers", Fifth Edition, by ITT,[1] the MIL-HDBK-216,[2] titled "RF Transmission Lines and Fittings" or "Solid Dielectric Transmission Lines"[3], Electronic Industries Association Standard RS-199, December 1957. Attenuation for a given length of transmission line at specific frequencies may be computed from the table data; the attenuation in dB is directly proportional to the transmission line length.

(1) Transmission Line Loss Coefficient.

Adjacent to the "Atten., 1 dB Maj. Div." scale is a "S.W. Loss Coeff." scale. This scale provides a factor by which the matched-line loss in dB (of the transmission line) should be multiplied to account for the increased losses in the line when standing waves are present. These added losses do not affect the SWR or impedance calculations; they are merely the additional dielectric and copper losses of the line caused by the fact that the transmission line conducts more average current and must withstand more average voltage in the presence of standing waves. In the previous example, and in Figure 27, the loss coefficient at the transmission line input is seen to be 1.14 (at E), and 1.41 (at F) at the load. As a good approximation, the loss coefficient may be averaged over the length of the line in the example. In this case the average is 1.285. This means that the total losses in the line are 1.285 times the matched loss of the line (2 db) or 2.57 db.

d. Return and Reflection Loss In dB Scales.

Two additional external scales may find use in maintenance applications. These are the "Return and Reflection Loss in dB" scales. Both of these scales are related to the "Refl. Coeff., ρ " scale, but express values in dB, rather than in a power ratio. The "Pet'n Loss, dB" scale expresses the ratio of total forward power to reflected power in dB. This scale can be used in conjunction with the SWR Scale to determine the Input SWR to an Antenna - Transmission Line System when the forward and reflected powers are known, i.e. - at a transmitter. The "Refl. Loss, dB" scale expresses the ratio of total forward power to nonreflected power in dB. This would represent the power consumed in the load or power radiated by an antenna, plus the ohmic losses; referenced to the total forward power in the transmission line.

e. Other External Scales.

The other external scales, "S.W. Peak, Const., P", "Transm. Coeff., P", and "Transm. Coeff., E or I" are of limited use in maintenance applications. However, for the interested reader, reference is made to "Electronic P,ppli-cations of the Smith Chart"[4] by Philip H. Smith.

f. Transmission Line Length Determination.

In the problems presented sc far, the transmission line length has been conveniently stated in wavelengths. The electrical length in wavelengths of a transmission line depends upon its physical length, the radio frequency under consideration, and the velocity of propagation.

One method of determining the electrical length, in terms of wave lengths, is to measure the physical length and then determine the electrical length by use of a formula. (Reference is made to the sub-section on Phase Shift in the Transmission Line Section). The formula is:

$$\lambda_n = (L/V)\ (f/984)$$

where λ_n = number of electrical wavelengths in the transmission line.

L = physical length of the transmission line in feet.

f = Frequency in megahertz.

V = Velocity or propagation factor of the transmission line.

The velocity factor, V, is given on page 27 for different types of cables.

An alternate method of determining the electrical length, in terms of wavelengths, and then the physical length, is through measurements of the input impedances, with the transmission line terminated in either a short or open. This method requires impedance measurements at two distinct and uniquely defined frequencies. Consider the case of the line terminated in a short.

First, determine a frequency, where the input impedance, Z = 0 + j0 ohms. The actual value of the resistance will be a function of the line losses --- however, it should be of very low value on the resistance axis. (See previous paragraph on Transmission Line Loss Measurements). This frequency is such that the transmission line electrical length is exactly equal to an even number of half wavelengths. See Figure 28 which shows that a half wavelength, $\lambda/2$, at a frequency, f_1, is equal to the electrical length of the transmission line. Expressed as a formula:

$$f_1 = 984/\lambda \text{ feet}$$

where λ feet = wavelength in feet (electrical)

and f_1 = frequency in megahertz

and by definition:

$$\lambda \text{ feet} = 2L/V$$

where L = physical length of the line in feet

and V = Velocity factor

so $f_1 = 984/(2L/V) = 984(V)/2L$

The next step will be to increase the frequency until the electrical length of the transmission line is again equal to an even number of half wavelengths or one wavelength at f_2 and $Z = 0 + j0$, as before. See Figure 28. This change in frequency is equivalent to one rotation around the SMITH CHART .

and again by definition:

$$\lambda \text{ feet} = L/V$$

so $f_2 = 984/(L/V) = 984(V)/L$

Again, increase the frequency until the electrical length of the transmission is again equal to an even number of half wavelengths or one and one half wavelength at f_3 and $Z = 0 + j0$, as before, See Figure 28.

and again by definition:

$$\lambda \text{ feet} = 2/3L/V$$

$$\text{So } f_3 = \frac{984}{2/3L/V} = \frac{3\ (984)\ V}{2L}$$

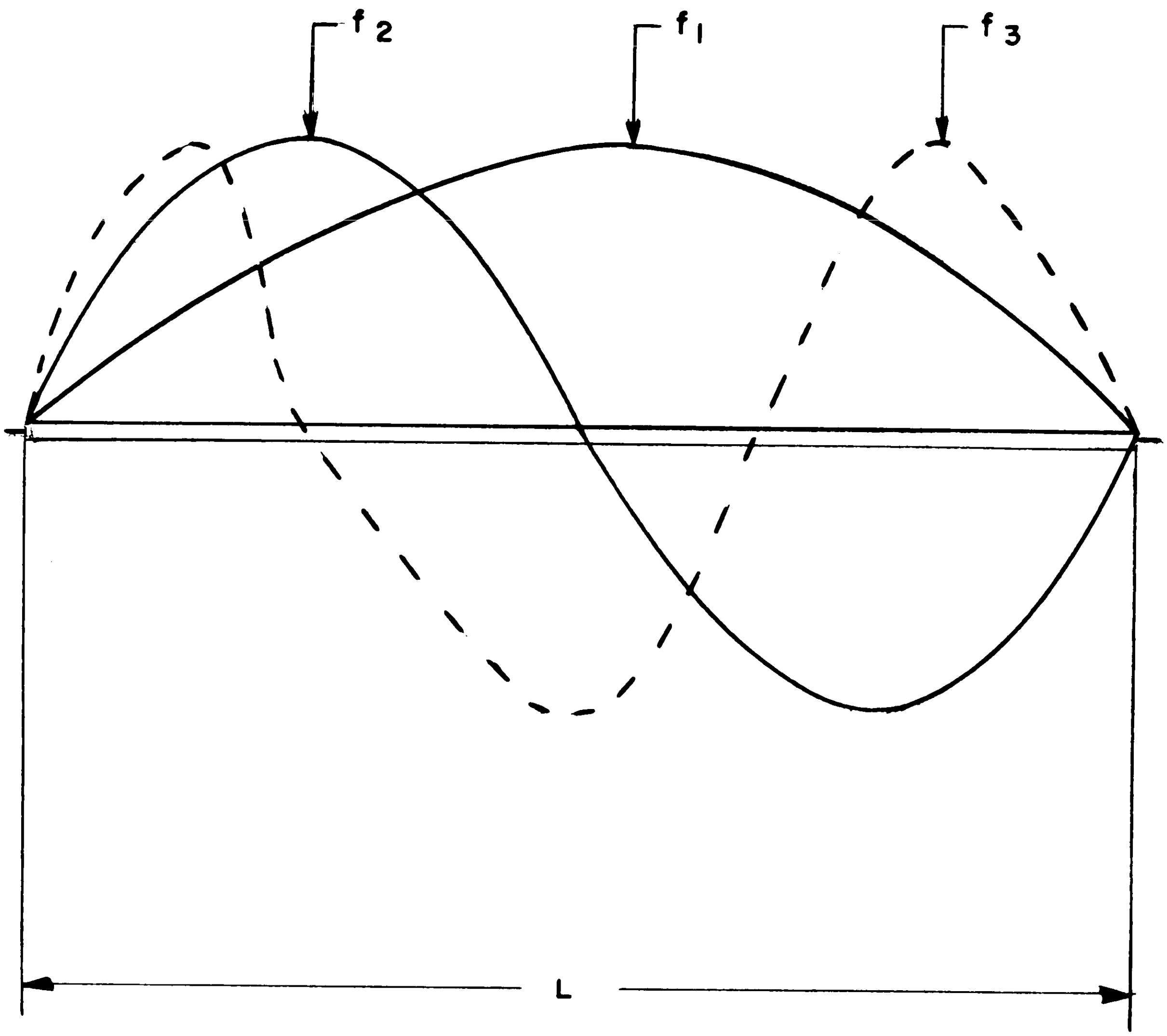


FIGURE 28. TRANSMISSION LINE - EVEN HALF WAVE LENGTHS

Let $\Delta f = f_2 - f_1 = \frac{984(V)}{L} - \frac{984(V)}{2L} = \frac{984(V)}{2L}$

or $\Delta f = f_3 - f_2 = \frac{3(984)V}{2L} - \frac{984(V)}{L} = \frac{984(V)}{2L}$

This process can be repeated for any number of frequencies - however Δf, for any two adjacent frequencies, f_n and f_{n+1}, will always be equal.

The formula can be revised to provide the length of a transmission line as follows:

Mechanical:

$$L = \frac{984(V)}{2(f_2 - f_1)} \quad \text{or} = \frac{492(V)}{f_2 - f_1}$$

Electrical:

$$L = \frac{984}{2(f_2 - f_1)} \quad \text{or} = \frac{492}{f_2 - f_1}$$

For solid polyethylene dielectric cables, such as RG-58, RG-213, etc., V = 0.667. The formula for mechanical length simplifies to:

$$L = \frac{328}{f_2 - f_1}$$

For air dielectric cables, such as Heliax, V = 0.91. The formula simplifies to:

$$L - \frac{448}{f_2 - f_1}$$

It is recognized that the "cut and try" method to identify the frequencies, f_n and f_{n+1}, would be a tedious effort. Fortunately, there is a "Rho Detector" that greatly simplifies the procedure when the transmission line has a high SWR (i.e. - open or shorted line). The Rho Detector is a form of an RF bridge, with a detector circuit, that provides a DC output that is proportional to Rho. Recalling that Rho is equal to $E_{reflected}/E_{incident}$, then the minimum Rho values occur at the frequency(s) where the input impedance, Z_{in}, matches the load impedance, Z_{load}. This determines one of the desired frequencies, f_n. The other desired frequency, f_{n+1}, is determined by either increasing or decreasing the frequency until a minimum Rho value is again obtained. The use of the "Rho Detector" is described further in the Section on Electrical Maintenance Procedures.

SECTION V

ELECTRICAL MAINTENANCE PROCEDURES

1. General

The following electrical tests and procedures are discussed in this section.

a. Antenna - Transmission Line System.

(1) Input Impedance measurements.

(a) Determine discrete frequencies for impedance measurements (use the Rho detector procedure).

(b) Make impedance measurements (use RF bridge procedure).

(2) Determination of input SWR.

(a) From Impedance Measurements (use SMITH CHART)

(b) From Swept Frequency Measurements (Use Return Loss, dB measurement procedures).

(c) Correct for transmission line loss (use SMITH CHART or SWR - attenuation charts).

(3) Impedance Discontinuities.

(a) Use Time Domain Reflectometer (TDR) measurements.

1. Use Low Power TDR procedure.

2. Use High Power TDR procedure.

b. Transmission Line (by itself)

(1) Attenuation Loss.

(a) Compute from cable loss chart.

(b) Measure the input to-output RF voltage attenuation.

(c) Make impedance measurements with line terminated in a short (or open). (Use Rho detector procedures, RF bridging procedures, and the SMITH CHART.)

(2) Impedance Discontinuities with the line terminated in its characteristic impedance. (Use low power Till or High Power TDR procedures).

(3) Line Length.

(a) Use Low Power TDR or High Power TDR procedures.

(b) Use Rho detector (2 frequency method).

(4) Dielectric Strength. Use High Voltage Megger.

(a) Use Low Voltage Insulation resistance (IR) method.

c. Antenna (by itself).

(1) Impedance measurements (same as for Antenna-Transmission Line System).

(2) Determination of SWR (same as for Antenna-Transmission Line System).

d. Antenna Baluns, Matching Units or RF Transformers,

(1) Impedance measurements (same as for Antenna-Transmission Line System).

(2) Determination of SWR (same as for Antenna-Transmission Line System).

A review of the electrical tests shows that certain tests are repeated, with some slight variations, for each category of tests. These basic tests are Rho detector measurements, RF bridge measurements, return loss measurements, and TDR measurements.

2. Rho Detector Measurements Procedures.

Rho detector measurements can determine the correct frequencies where the input impedance/SWR of an antenna-transmission line system should be measured. A Rho detector can also be used to determine the length of a transmission line by the two frequency (Δf) technique. (See detailed discussion in Section IV, on SMITH CHARTS, Rho (P), and Δf measurements).

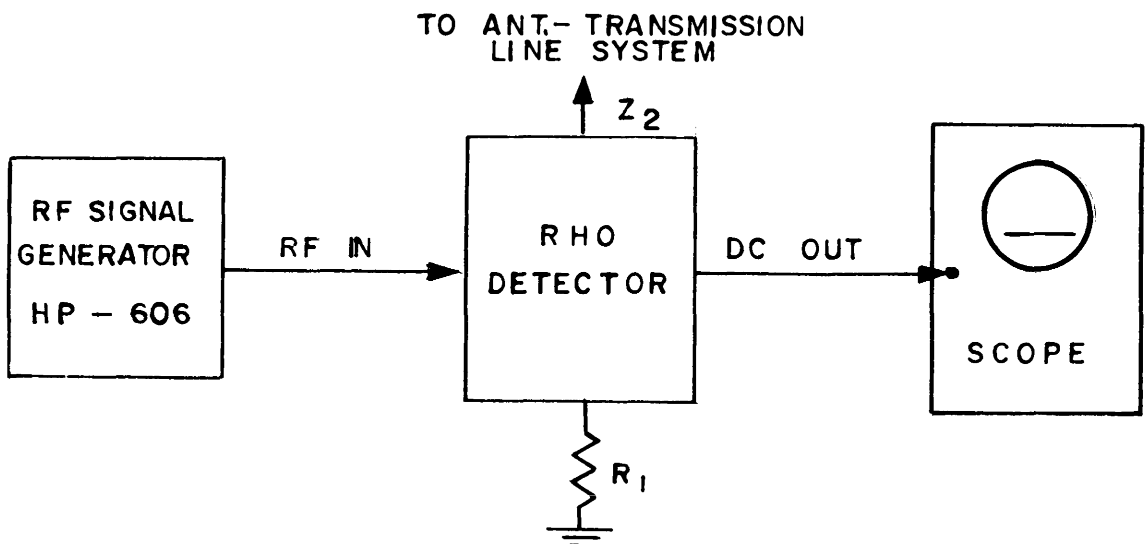
The electrical length of the transmission line, as the frequency is swept (either manually or automatically) across an RF frequency band, will change from odd multiples of quarter-wavelengths to even multiples to odd multiples and so on. One cycle, from odd to even to odd, or from even to odd to even, will correspond to one rotation around the SMITH CHART.

This variation in electrical length will affect the antenna impedance/ SWR versus frequency curve by causing a cyclic pattern to be superimposed. It should be noted that, when the quarter wave length multiples are even, the input impedance is independent of the transmission line impedance and is modified by the line attenuation. However, if the quarter wavelength multiples are odd, then the input impedance is modified both by the line impedance and attenuation. If the electrical length can not be determined with sufficient accuracy to determine the wavelength of the peak-null cycle, then the peaks should be used, inasmuch as the VSWR will not be less than the true value. The effect of transmission line attenuation on impedance/SWR is discussed in the appropriate test procedures.

The amplitude of the cyclic pattern is a function of the mismatch between the transmission line and the antenna or termination. If the termination and the transmission line are of the same value impedance, the mismatch is at a minimum value, and the amplitude would also be at minimum. Conversely, as the mismatch increases, the amplitude will also increase.

To summarize, the frequency of the cyclic period is a function of the length of the transmission line while the amplitude is a function of the mismatch between the transmission line and the termination.

The test set up would be as follows: (See Figures 29 and 30).



R_1 = Characteristic impedance of the antenna-transmission line system.

FIGURE 29. RHO DETECTOR SET UP

The initial set-up/calibration method would be as follows:

SET-UP:

a. Connect the RF Signal Generator to the "RF IN" Connector on the Rho detector. Set the RF Signal Generator Output to 1 Volt, RMS.

b. Connect R_1, a noninductive resistor, to Z_1 connector on the Rho Detector.

c. Connect the Rho Detector output to the input of the Scope.

d. Set the oscilloscope controls as follows:

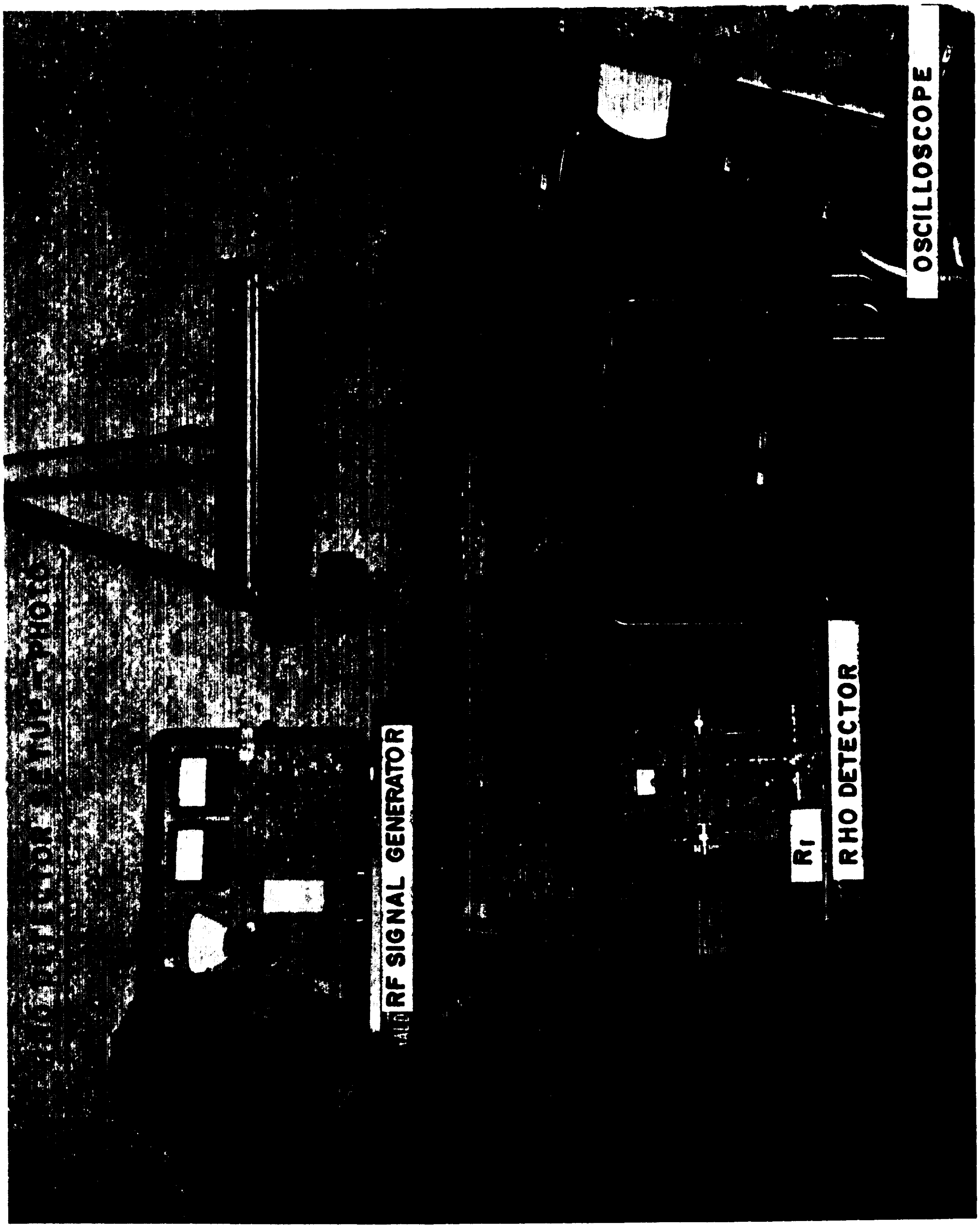


FIGURE 30. RHO DETECTOR SET UP-PHOTOGRAPH

(1) Input AC-DC switch in DC position.

(2) Input Amplitude switch in 0.1 Volt/CM Switch position.

(3) Polarity switch-in Inverted position.

AMPLITUDE CALIBRATION:

e. Short the line site (Z_2) of the Rho Detector. Adjust the scope gain controls and vertical position so that the "horizontal" trace line on the scope is on the bottom grid line.

f. Open the line side (Z_2) of the Rho Detector, adjust the scope gain controls and vertical position so that the "horizontal" trace lines on the scope is on the top grid line.

g* Repeat steps "e" and "f" until no adjustments to the scope controls are required.

IMPEDANCE MEASUREMENT FREQUENCIES:

h. Connect the antenna-transmission line system to Z_2 connector on the Rho Detector.

i. Set the RF Signal Generator to a frequency in the middle of the Antenna Frequency Range.

j. Manually sweep the RF signal generator in frequency. Observe the "horizontal" trace line on the scope. The vertical displacement (up and down movement) of the trace will trace out the SWR pattern of the antenna. Also superimposed upon this pattern will be another cyclic pattern due to the electrical length of the transmission line. After identifying the two separate patterns, determine the maximum peaks and the minimum peaks of the display. (See Figure 31)

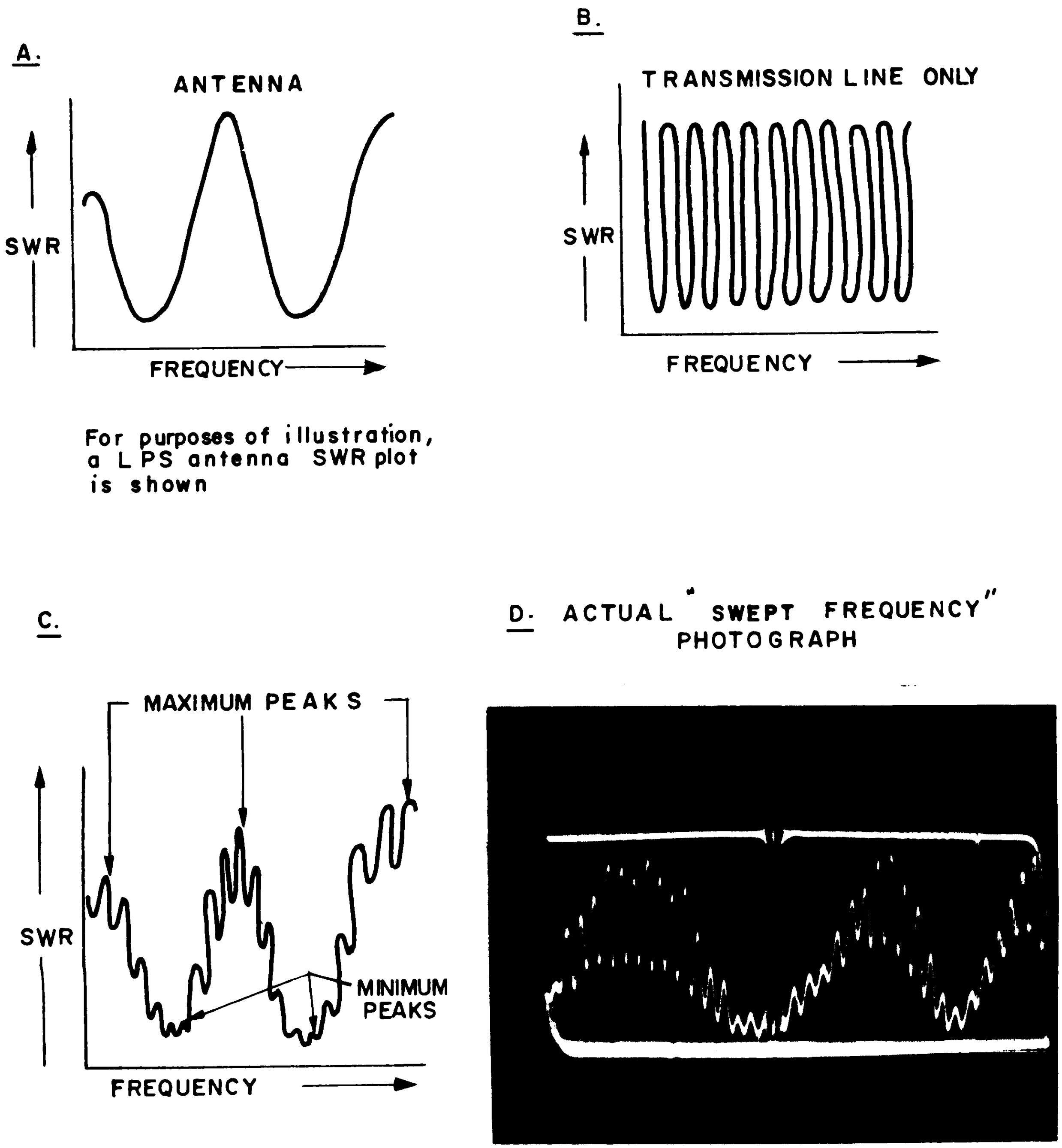


Figure 31 SWR PATTERN VS FREQUENCY

k. Tune the signal generator for maximum peak or minimum peak display on the scope. Determine this frequency with the use of a frequency counter. If no frequency counter is available, then a R-390 Receiver can be used to determine the frequency.

Proceed as follows:

(1) Reduce RF output of the signal generator to 1 Millivolt.

(2) Without changing the frequency of the signal generator, connect the RF generator directly to the receiver.

(3) Set the RF gain of the receiver to mid position. Turn the BFO on to facilitate the identification of the signal generator frequency.

(4) Tune the receiver for maximum indication on the carrier level meter. Reduce RF gain accordingly. Record the dial frequency on the receiver.

(5) Reconnect the RF Signal Generator to the Rho Detector. Return the level to 1 volt.

1. Repeat Step k, until all maximum peak and minimum peak frequencies are identified.

m. The resulting list of minimum peak - maximum peak frequencies are those frequencies where impedance of the antenna-transmission line system should be measured.

DETERMINATION OF LINE LENGTH - (Two Frequency or Δf Method):

n. Determine the frequencies of the adjacent nulls of the cyclic pattern due to the transmission line length. The line should be terminated with either a short or open; although the same adjacent nulls, where the antenna SWR is high, can also be used. In the case of an elevated antenna (rotatable LPS, Rhombic, etc.) this method is physically easier to accomplish than the use of a short or open at the antenna input.

o. Determine Δf, or $f_2 - f_1$ from adjacent RF null frequencies (step n). The mechanical length is given by:

$$L = \frac{328}{\Delta f}$$, for Polyethelyene dielectric transmission lines, i.e. RG-58, -59, -8, -9, etc.

$$L = \frac{448}{\Delta f}$$, for air dielectric transmission lines, i.e. Heliax.

where L = Physical length of line in feet.

Note: For other type of Transmission Lines, refer to Section on Transmission Lines.

p. To increase the measurement accuracy, several Δf's should be determined and then averaged to determine the final answer.

3. RF Bridging Procedures.

The Input Impedance measurements of an antenna or an antenna-transmission line system can be easily measured with the Delta Electronics RF Bridge, Model O1B-2. This bridge is easy to operate and suitable for use in an operational environment, i.e. portable, can be inserted, as required, into an operational antenna-transmission line system, enclosed in a rugged case, lightweight, etc. The bridge also has the capability of handling up to 1 KW power for use in high RF noise environments or where the antenna-transmission line system characteristics change under power.

a. RF Bridging - Low Power.

The test set up would be as shown in Figures 32 and 33.

The initial set-up/calibration method would be as follows: For ease in presenting the steps to obtain a “null” of the bridge-detector, the calibration procedure is listed last (Steps t and u). However, after the procedures have been practiced a few times, the calibration should always be done after step j.

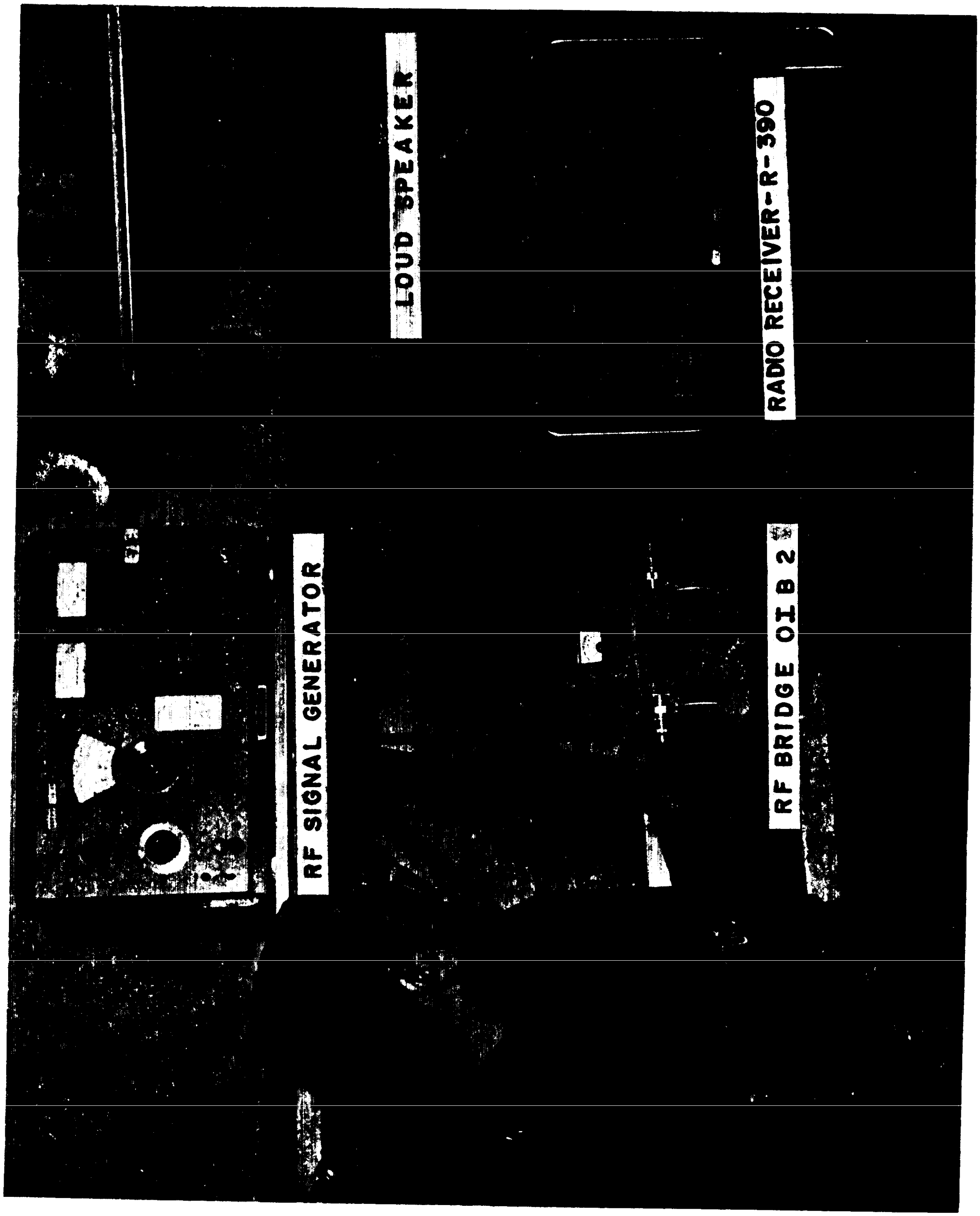


FIGURE 32. RF BRIDGING SET UP

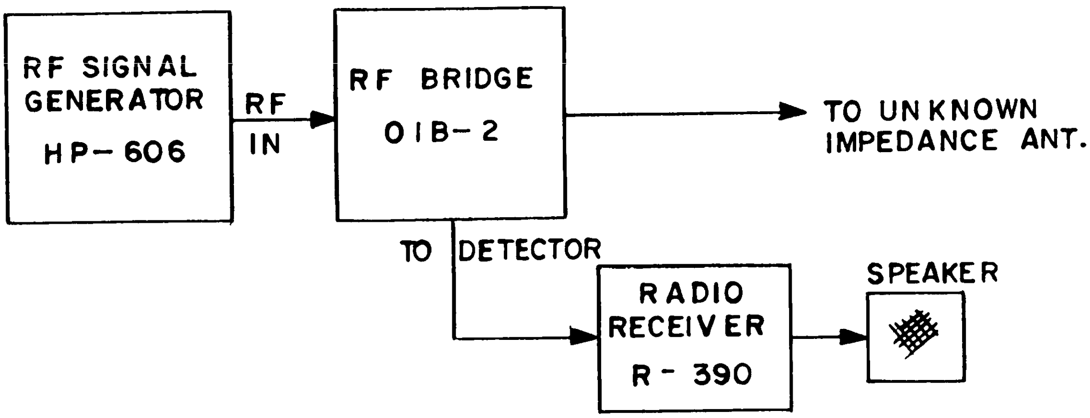


FIGURE 33. RF BRIDGE SET UP

SET UP:

a. Connect the output of the RF Signal Generator to the "RF In" port of the RF bridge.

b. Connect the "detector output" of the RF bridge to the Radio Receiver.

c. Connect a 600 ohm resistor on the line audio output of the R-390 receiver. Also connect a speaker to the phone jack of the R-390 receiver.

d. Connect the unknown impedance or antenna to the antenna terminal on the RF bridge.

BRIDGING PROCEDURES:

e. Set the RF Signal Generator to the lowest operating frequency of the antenna. Set the RF output to 1 Volt RMS, internal modulation to either 1 kHz or 400 Hz, 30 percent modulated.

f. Set the "For-Rev" Switch to "Rev" position. (Mandatory position so as to remove the high power circuitry from the circuit.)

g. Set the RF gain control on the R-390 receiver to mid scale. Coarse tune the R-390 for maximum indication on the carrier level meter or AGC voltmeter.

h. Reduce the RF gain until the AGC voltage is readable on the carrier level meter. Adjust the antenna trim fur maximum carrier level. Reduce the RF gain, if required.

i. Fine tune the receiver for maximum carrier level. Adjust Line Meter Switch and Line Gain Control for reading on the line level meter. NOTE: The maximum carrier level does not correspond to the audio output maximum.

j. Set the "R" arm and the "L-C" arm to Zero value readings. Switch the 100 ohm and 200 ohm resistors (R arm) out of the circuit. Switch the 200 ohm and 400 ohm impedance (L-C arm) out of the circuit.

NULLING OF THE RF BRIDGE:

k. Change the L-C switch position on the RF bridge. Leave on switch position that results in the lowest carrier level on the receiver. If no change, proceed to next step.

l. Coarse adjust the "R" arm on the bridge for minimum carrier level. The 100 ohm and/or the 200 ohm resistor may have to be switched in to the circuit to obtain a null. If there is no indication of a null, set the "R" arm to the nominal characteristic impedance - usually 50 ohms or 70 ohms. Proceed to the next step.

m. Coarse adjust the "L" or "C" arm for minimum carrier level. (Position of the L-C switch determines which arm is being adjusted). The 200 ohm and/or the 400 ohm Impedance may have to be switched in to the circuit to obtain a null. If there is no indication of a null, switch the “L-C” switch to the other position and again try to null the carrier level reading.

n. Tune the “R” arm and the “C” or “L” arm for minimum carrier level indication. It should be possible to null the RF signal so that there is no indication on the carrier level meter. At this time readjust the line level for a mid-scale wading. Note. - If no null can be obtained, verify the performance of the bridge and the set up by calibrating - steps t and u. If the calibration is successful, verify that there is an actual antenna - transmission line system being bridged. If there is still no null, measure the broadband noise pickup on the antenna-transmission line system. Use an RF Voltmeter. If the RF pick up is excessive for the RF bridge - detector (receiver), then use the high power (up to 1 KW) circuitry of the bridge.

o. Use the Line Level meter to fine tune the “R” arm and “C” or “L” arm for minimum null or audio output.

p. Increase the RF gain. Repeat step m. Repeat this step until the RF gain is between 7 and 8 on the RF gain control.

q. Read the “R” value on the “R” arm. Add in the additional R value, if either/both of the 100/200 ohm resistors are switched in. Read the “L” value or “C” on the “L-C” arm. The position of the “L-C” switch denotes which was measured. Add in the additional values, if either/both of the 200/400 ohm impedances are switched in.

r. While the “R” value of the complex impedance is read directly, the X_L or X_C value must be calculated from the L or C value read on the RF bridge.

For X_L, $X_L = f\ L/10$ where

f = frequency of measurement in megahertz and

L = reading on the RF bridge.

For X_c, $X_c = f\ C/10$

where f = frequency of measurement in megahertz

and C = Reading on the RF bridge.

After this calculation, the complex impedance is read as: R ohms ± jX ohms. + jX, if the impedance is Inductive (L) and - jX, if the impedance is capacitive (C).

s. Repeat steps e through p for each RF frequency where the complex impedance is required. If a frequency counter is not available to set the frequency of the RF signal generator, then the dial frequency on the receiver can be used. Set the dial frequency to the correct frequency then coarse tune the RF signal generator for the maximum carrier level. The fine tuning may be done with the receiver without affecting the accuracy of the measurements (± 0.5 kHz dial change).

CALIBRATION:

t. The set-up should be calibrated with known non-inductive resistors covering the VSWR range of 1:1, 1.5:1, 2:1, 3:1. They should be, in turn, connected to the antenna terminal of the RF bridge. The test frequencies should be, with reference to the antenna, at low, mid- and high band frequencies.

u. Determine the complex impedance for the non-inductive resistors. It should be R ohms ± j0 ohms.

The data sheet headings are as follows:

FREQUENCY	R	L_x	C_x	± jX

b. RF Bridging - High Power (UP to 1 KW RF power).

The Test set up would be as follows:

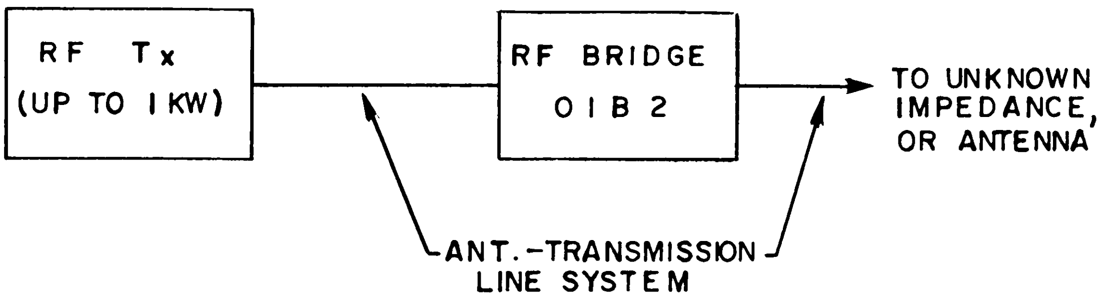


FIGURE 34. HIGH POWER RF BRIDGE SET UP

The initial set up/calibration method would be as follows:

SET UP:

a. Insert the RF bridge in the antenna-transmission line system.

b. Set the band switch know indicator to the frequency band that includes the test frequency.

c. Set the "FWD-REV" switch to "Forward".

d. Set the Amplifier Knob to the "OUT" position.

CALIBRATION:

e. Carefully bring up the transmitter power to a convenient power level (do not exceed 1 KW).

f. Tune the tune knob for maximum indicator in SWR meter. Adjust the gain knob for full scale indication on the SWR meter. If a full scale indication can not be obtained because of low power, reduce the gain to minimum; then switch in the "Amplifier" and adjust the gain for full scale deflection.

FWD - REV POWER:

g. With the FWD reading at full scale, switch the "FWD-REV" switch to read the reverse power. Note and record the relative forward and reflected power. The ratio of the reflected to the forward power can be read as a SWR value on a SMITH CHART, using the "Refl. Coeff., ρ " external scale and the "SWR" external scale. A convenient monogram is also included as Figure 35.

4. Return Loss Measurement Procedure.

The SWR of an antenna or an antenna - transmission line system can be easily determined from return loss, dB measurements. The return loss, dB can be read as a SWR value on a SMITH CHART, using the "Ret'n Loss, dB" external scale and the "SWR" external scale.

Away of determining the return loss, dB versus frequency using swept frequency techniques, is possible with the Hewlett Packard Spectrum Analyzer, Model 8552B/8553B, the Display Section, Model 141T, the Tracking Generator - Counter, Model 8443A, and a directional coupler unit Model 8721A, Option HO1. The high dynamic range of this equipment permits valid measurements of an antenna, even in the presence of 10 volts of broadband RF noise. The presence of strong, discrete signals is easily recognized in the SWR versus frequency plot and does not detract from the usefulness of the plot.

The frequencies of the maximum and minimum values of return loss, dB can be quickly identified by the Tracking Generator - Counter. These frequencies are the frequencies at which impedance measurements should be taken. The discussion of the Rho Detector is also equally applicable here.

This nomograph permits rapid calculation of the VSWR of a transmission line after the incident power (P_f) and reflected power (p_r) have been measured.

Determine the VSWR of a antenna-transmission line system for reflected power, P_r, of 1 KW, and forward power, P_f, of 10 KW.

Solution:
Align a straightedge through points P_r = l.O and P_f = 10. The straightedge intersects the center scale at 1.88, which is the input VSWR of the system.

Determine the VSWR when the reflected power, P_r, is 3.3 KW and the forward power, P_f, is 10 KW.

Solution:
Align a straightedge through points P_r = 3.3 and P_f = 10. The VSWR is 3.75.

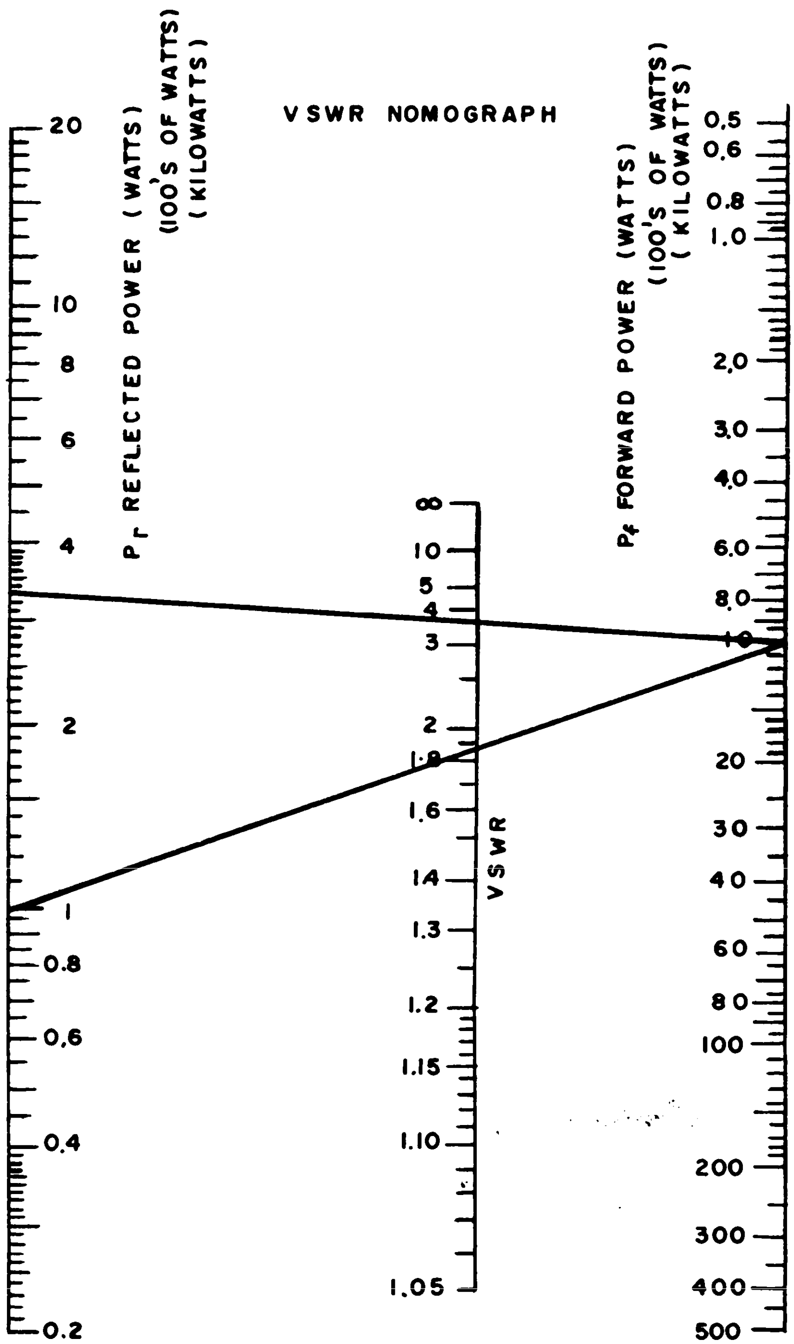


Figure 35 VSWR NOMOGRAPH

The test set up would be as follows: (See Figure 37)

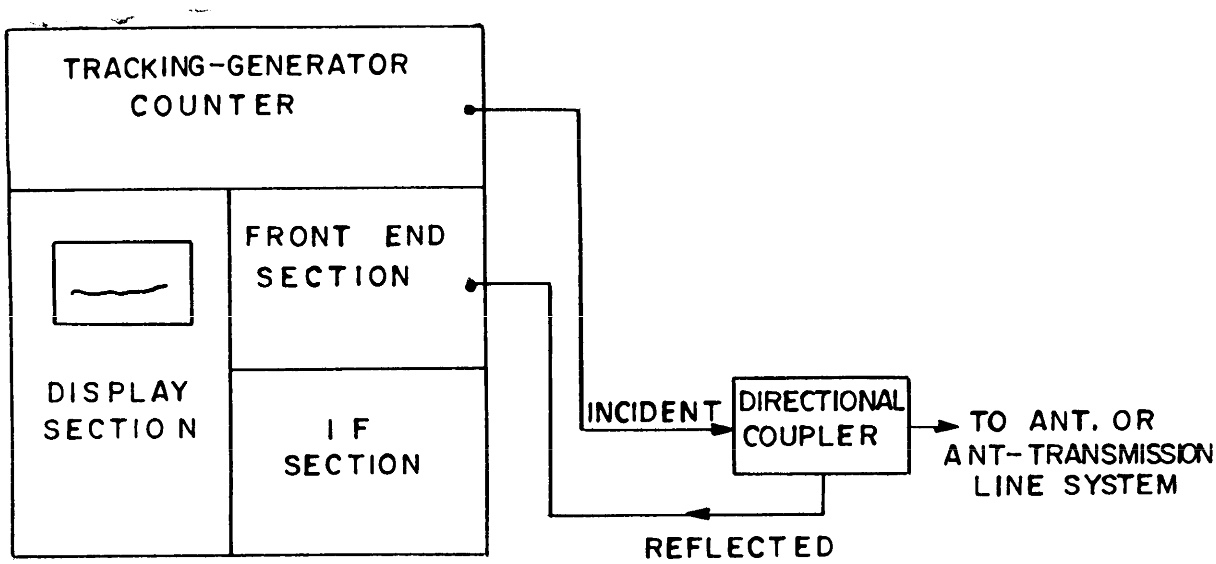


FIGURE 36, RETURN LOSS SET UP - SWEPT FREQUENCY

SET UP:

a. Connect the equipment as shown in Figures 36 and 37.

NOTE: The Directional Bridge, 8721A can be connected to provide either "Incident" or "Reflected" power - In this test only the "Reflected" terminal is used.

b. The following levels, control settings and ranges are recommended for use in a typical operational environment. However, variations are acceptable, and may be desirable in unusual cases.

c. Set the Tracking Generator output to 0 dBm. A lower output may be used where the broadband RF interference power levels are less than 0 dBm, i.e. a receiving site. If the output is decreased, then either the input attenuator or the IF gain of the spectrum analyzer must be increased.

d. Determine the frequency range(s) over which the return loss (SWR) is to be determined. If this frequency range exceeds 20 MHz, 2 or more separate measurements may be required.

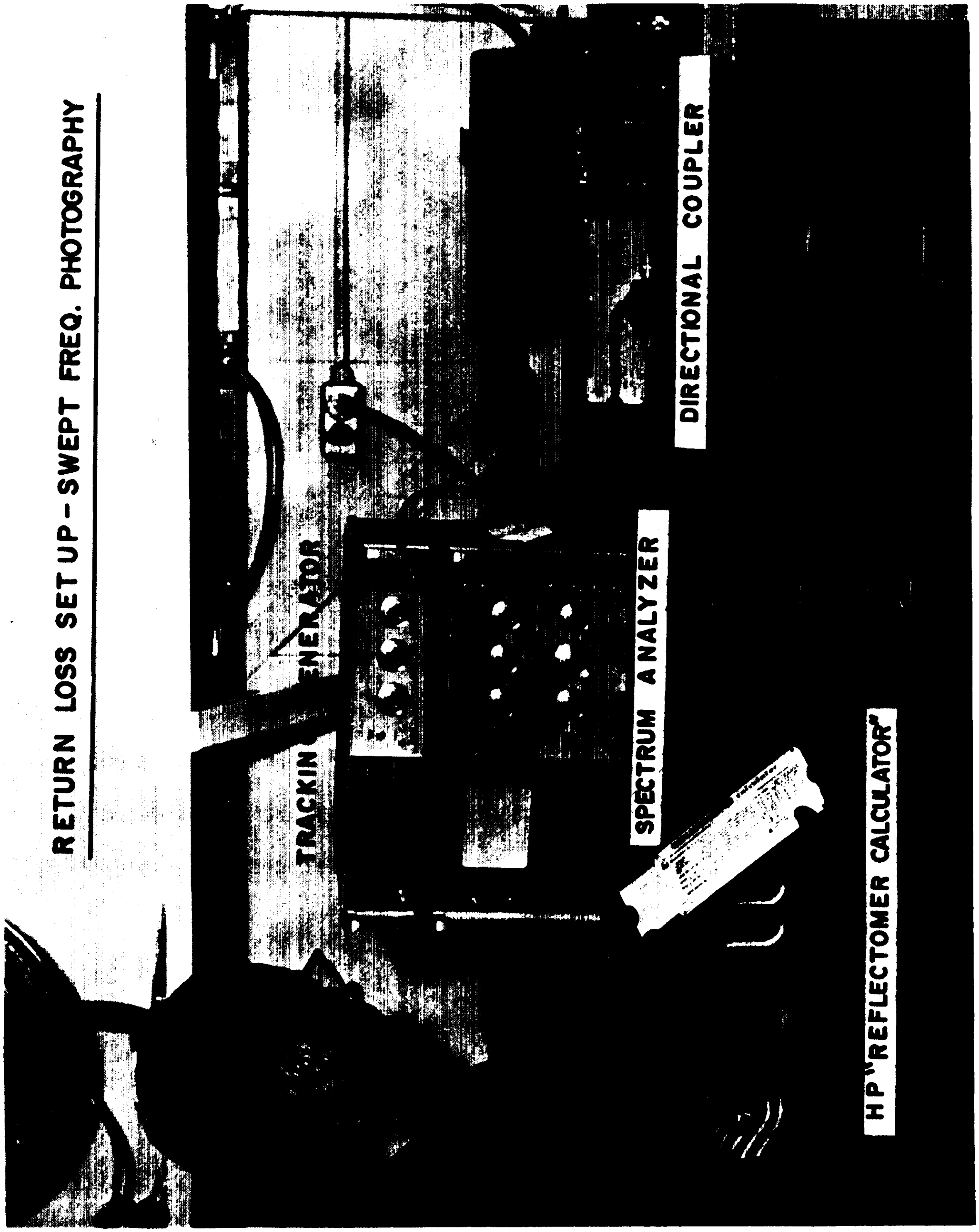


FIGURE 37. RETURN LOSS SET UP - SWEPT FREQUENCY PHOTOGRAPHY

e. Set the center frequency of the tracking generator to the center of the selected frequency range. This is accomplished by pulling the "Marker Position" knob to the "out" position and tuning the frequency tune knob until the displayed frequency on the tracking generator is the desired frequency. The frequency is also read on the frequency dial indicator of the spectrum analyzer.

f. Set the "Scan width/per Division", on the Spectrum Analyzer to result in the required sweep range, step d. For example, the following is a guide:

Scan Width/Division	Swept Range
10 MHz	100 MHz
5 MHz	50 MHz
2 MHz	20 MHz *
1 MHz	10 MHz
0.5 MHz	5 MHz
0.2 MHz	2 MHz
0.1 MHz	1 MHz

* Probably the most useful range for general display of antenna cyclic return loss versus frequency.

g. Set the "bandwidth" on the Spectrum Analyzer to 10 kHz position. Set the "Scan Time Per Division" on the Spectrum Analyzer to 1 Sec. Set the "Log-Linear" switch to 2 dB position. Set the input attenuator position to "40 dB".

h. To set the "Log Ref Level", it is desirable to first measure the RF interference level on the antenna-transmission line with a broadband RF voltmeter, i.e. Boonton 91CH Voltmeter. If the broadband RF noise is 0 dBm, (0.24 Volts/50 ohms), or less, then set the "Log Ref Level" to "0 dB".

Adjust the vernier or display adjust, to full scale deflection. See Step j. If the broadband RF noise is between OC/Bm and 20 dBm (0.24V/50 ohms to 2.35V/50 ohms), insert a 50 ohm attenuator between the detector output of the Directional Coupler and the input to the Spectrum Analyzer. The attenuator should be set for either 14 dB attenuation (maximum attenuation for a 3:1 SWR Full Scale Display) or 20 dB attenuation (maximum attenuation for a full scale display, infinite SWR). If the broadband noise is between + 20 dBm and + 30 dBm (2.35 Volts/50 Ohms and 7.07 Volts/50 ohms) measurements are possible but the display will be compressed by 1 to 2.5 dB. If the broadband noise exceeds + 30 dBm, this method will not work. The only other solution is to shut down the transmitter(s) or if possible, reorientate the antenna(s). The following chart presents the initial settings of the "Log ref level" and "display adjust" positions:

External Attenuator	Full Scale Display Return Loss	SWR	Log Ref Level	Display Adjust
0 dB	0 dB	∞:1	0 dBm	-2 dB
0 dB	6 dB	3:1	- 0 dBm	-8 dB
14 dB	6 dB	3:1	- 10 dBm	- 12 dB*
20 dB	0 dB	∞:1	- 10 dBm	- 12 dB*

* Maximum sensitivity of equipment.

i. Display Section Control. Initially the "writing speed" should be on "STD". The intensity control should always be at the lowest value to present a trace on the display. The display time of the trace may be increased by advancing the "persistence" control. If multiple traces are to be examined or stored, then the persistence control can be advanced full clockwise. Displayed traces can be stored for long term storage for purposes of photography or sketching by pushing the "STORE" button. Brillance of the stored display is controlled by the "TIME" knob.

j. With the Display Section in "STD" writing position, persistence and , intensity controls set for a visible trace, adjust the DISPLAY ADJUST for full scale deflection. Readjust intensity control for minimum width of trace.

CALIBRATION:

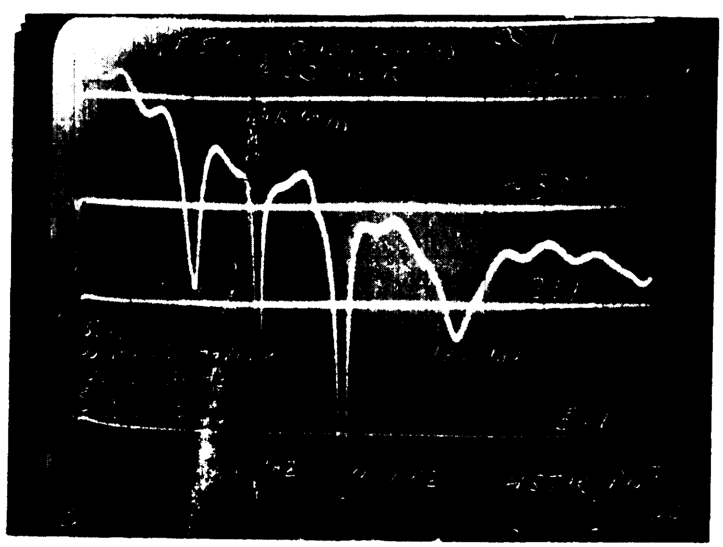
k. Connect known mismatches to the directional coupler. Verify "return. loss" versus SWR versus the known mismatch SWR'S. A Hewlett-Packard "Reflectometer Calculator" or the SMITH CHART external scales may be used.

MEASUREMENTS:

1. connect antenna to the directional coupler. Observe pattern.

m. If a permanent record (photograph is desired), then put "scan mode" switch into single sweep position. Push sweep button and advance intensity control until display is visible and of desired width. Advance persistence control to maximum. Push sweep button again. It is desirable to replace the antenna with each of the known mismatched loads, in turn, and then push the sweep button for each load. Transfer the displayed information into "STORE" where it can be photographed or sketched. See Figure 38.

A. Return Loss,
Full Scale = 0 dB
SWR = ∞
(20 dB external attenuation)



B. Return Loss
Full Scale = 6 dB
SWR = 3
(14 dB external
attenuation)

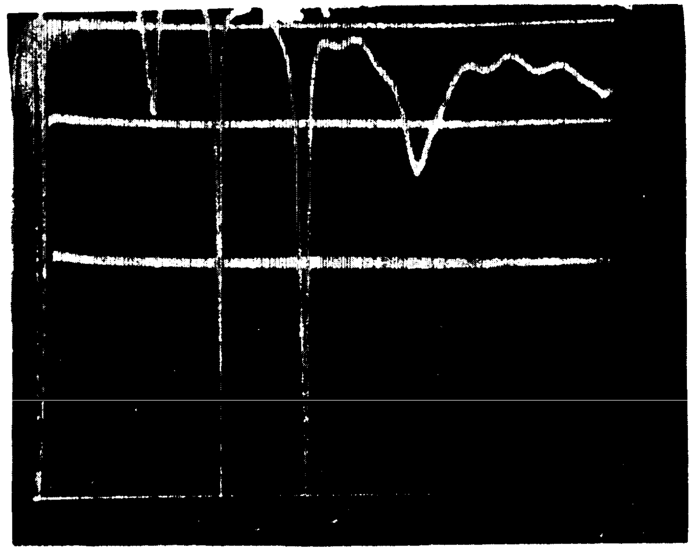


FIGURE 38. RETURN LOSS DISPLAYS

5. TDR Measurement Procedures

The use of a TDR measurement can quickly determine the location of each resistive or reactive discontinuity in a coaxial transmission line-antenna system. These discontinuities may be shorts, opens, loose connectors, defective splices, wrong impedance sections, etc. which can be easily identified. The requirement for maintenance can also be identified by comparing the current TDR display to the baseline record for the transmission line antenna system.

a. Low Power TDR Measurements.

The low power TDR measurements is a modified method in that a pulse gate, whose length is equal to the time base sweep of the oscilloscope, is used rather than the conventional use of a pulse of very short duration. This approach is used because of equipment availability.

This method should work at a majority of the receiving sites and for a few of the transmitting site antennas, i.e. Rotatable Antennas that can be rotated away from the antenna farm.

The test set up would be as follows. (See Figure 40).

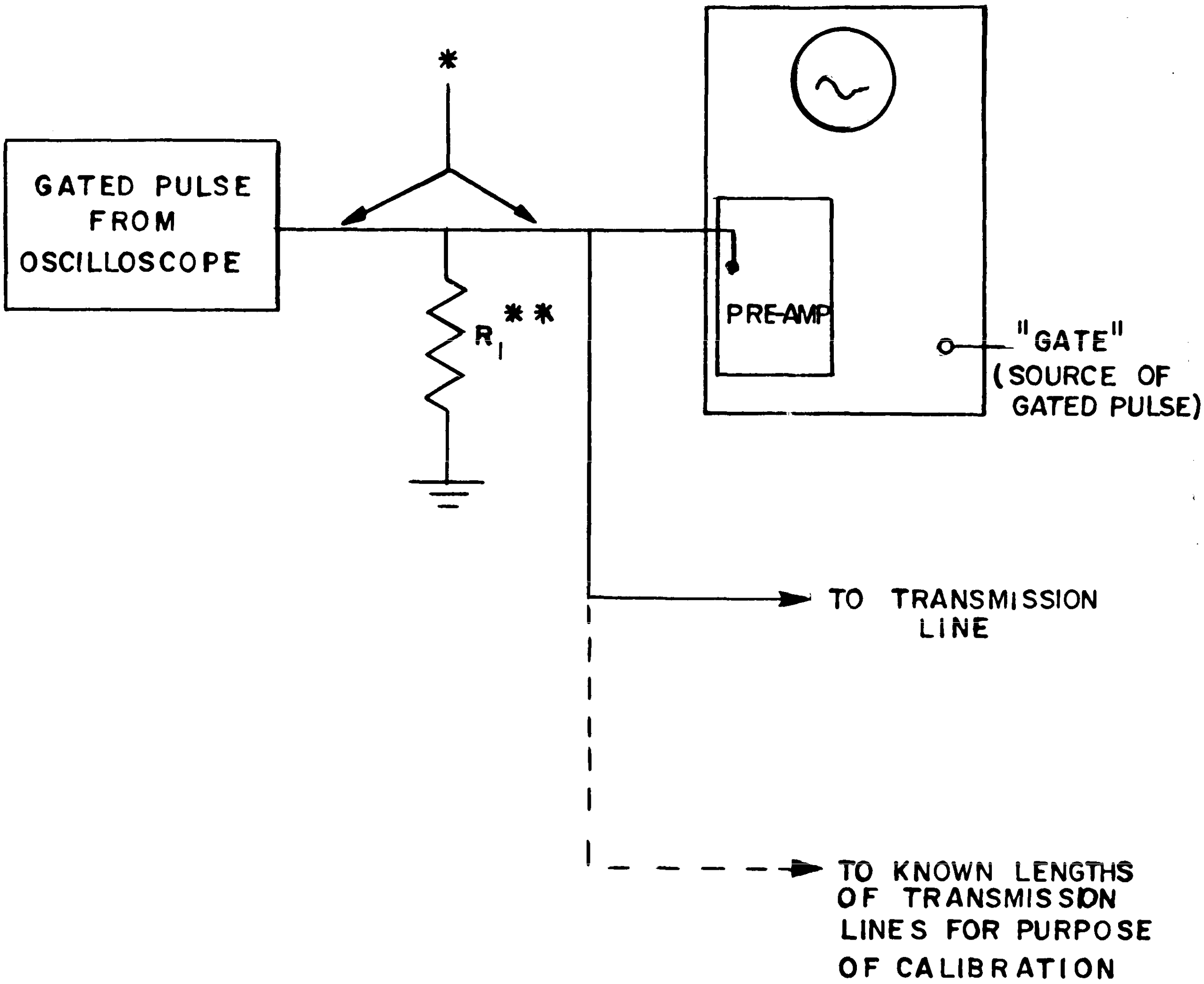


FIGURE 39. TDR SET UP USING AN OSCILLOSCOPE

* These cables must be kept as short as possible for best test results.

** R_1 = Characteristic impedance of the transmission line, usually either 50 ohms or 70 ohms.

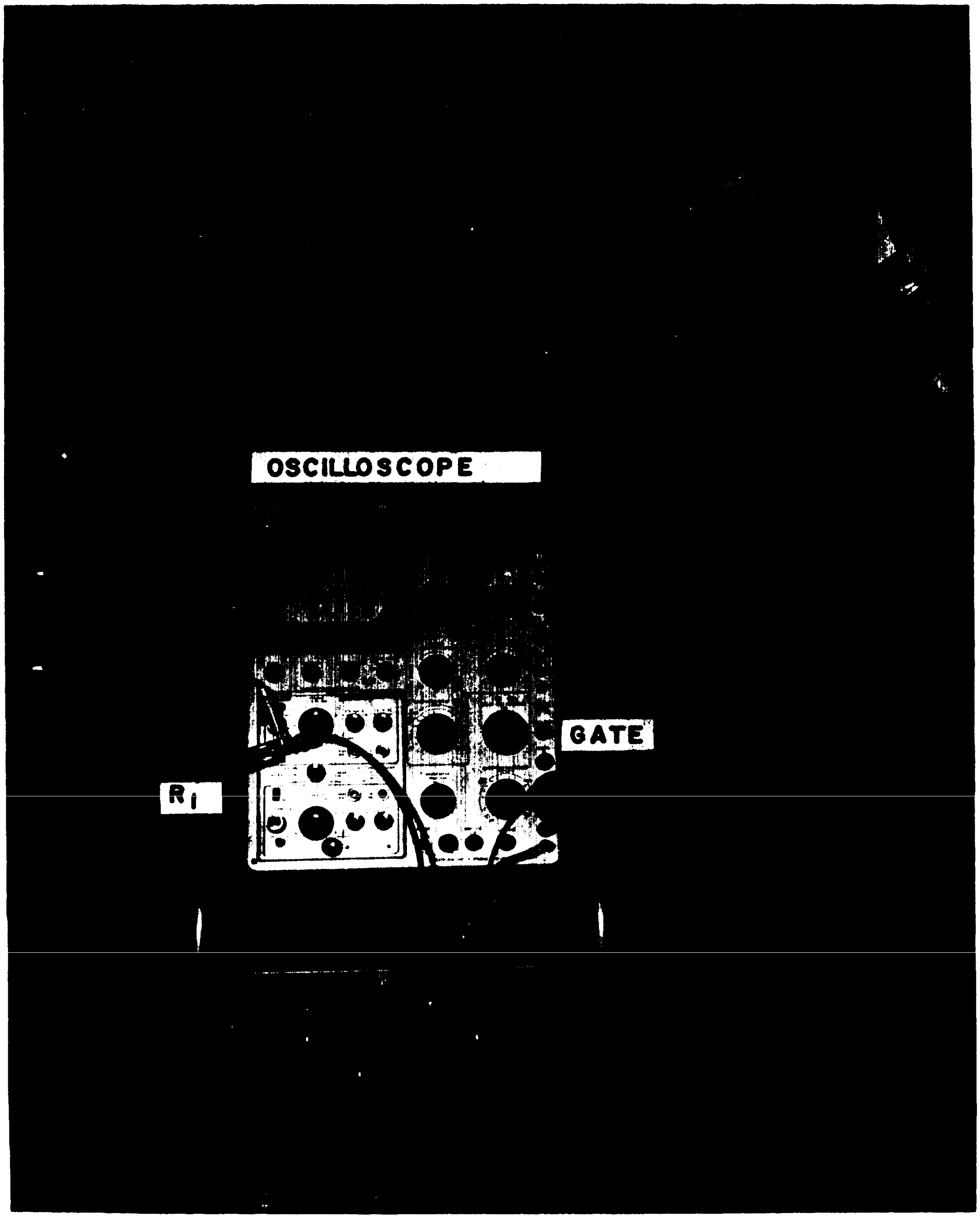


FIGURE 40. TDR SET UP

The initial set-up/calibration method would be as follows:

SET UP:

a. Using a BNC Tee, connect the "Gate" output to the input of the SCOPE vertical pre-amplifier and attach another BNC Tee to the other connection.

b. Connect RI, a noninductive resistor, to one of the Tee connections. R_1 must be of the same value as the characteristic impedance of the transmission line.

c. Set the oscilloscope controls as follows:

(1) Pre Amp voltage range to 0.5 volts, initially.

(2) AC-DC input switch in DC position.

(3) Set Variable Time/CM switch to 1 microsecond, initally. Set 5X Magnifier to off, initially.

AMPLITUDE-IMPEDANCE MISMATCH CALIBRATION:

d. Short the remaining BNC connector (used later to connect to the reference transmission line or the unknown transmission line. This simulates a shorted transmission line.

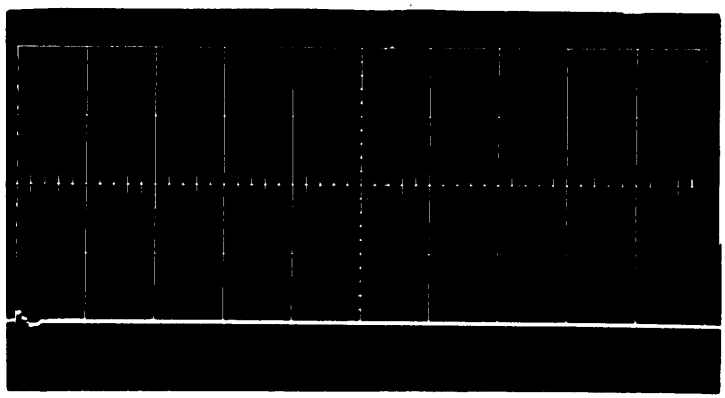
e. Adjust the Preamplifier controls, volts/CM and vertical position, until the scope display trace is on the base line. See Figure 41a.

f. Remove the short. The input now corresponds to an open transmission line.

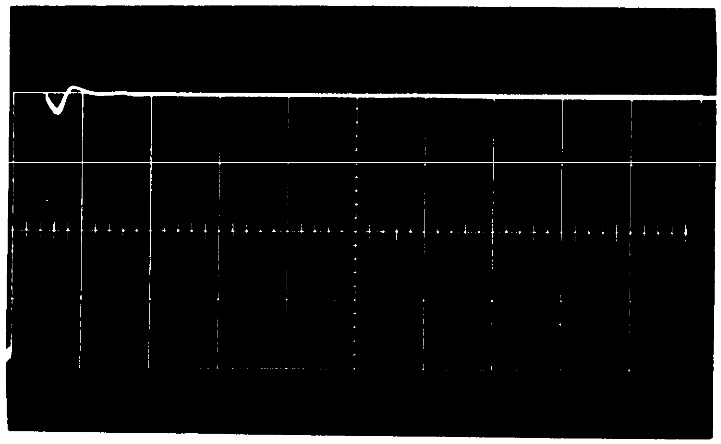
g. Adjust the preamplifier controls, Volts/CM and vertical position, until the scope display trace is on the top line. See Figure 41b.

h. Repeat steps d through g, until the simulated open - short transmission line conditions are shown as top line - base line. This calibrates the amplitude or Impedance mismatch portion. For verification connect another non-inductive resistor, of the same value as the characteristic

a. TDR -
Line Shorted



b. TDR -
Line Open



c. TDR -
Line Terminated
in its characteristic
impedance

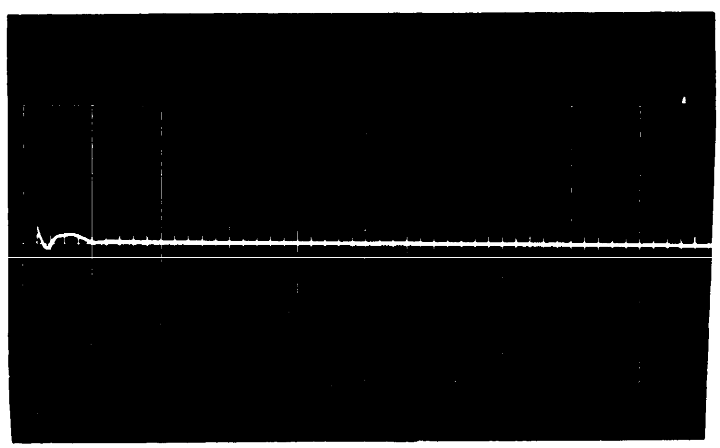


FIGURE 41. TDR - AMPLITUDE CALIBRATION

impedance of the transmission line. The scope display trace should now be on the center line. See Figure 41c.

DISTANCE - TIME BASE CALIBRATION:

i. Connect a known length of transmission line to the scope input. The use of a 100 foot or equivalent 100 foot transmission line is recommended. If the known line has a different dielectric than the line to be measured (air versus polyethylene or styroflex versus RG-8), then the equivalent length must be used. Thus, 74.1 feet of polyethylene dielectric transmission line (RG-58, RG-59, RG-8, RG-9, etc.) is equal <u>physically</u> to 100 feet of air dielectric transmission line (styroflex).

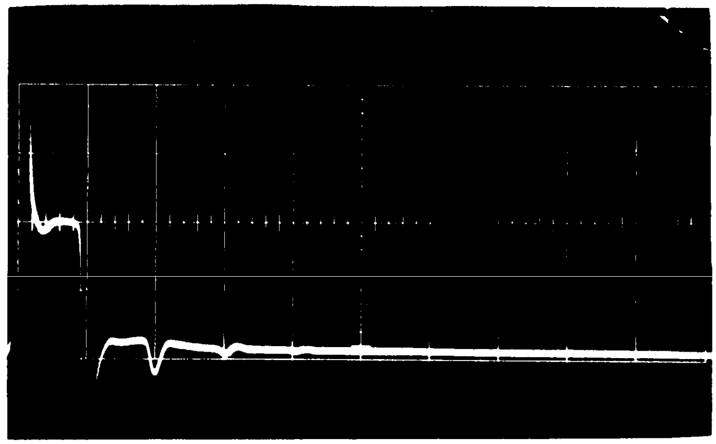
j. Adjust the horizontal position of the scope trace, so that the initial rise time of the gate pulse is on the extreme left vertical line. See Figure 42a.

k. Short the far end of the known transmission line. Adjust the variable time base switch and vernier so that the scope trace returns to the base line at the first vertical line (100 feet per centimeter calibration). See Figure 42a. Note that multiple reflections of the basic 100 foot transmission line are seen at the second and third vertical lines. Vernier adjustment can also be made by use of these reflections.

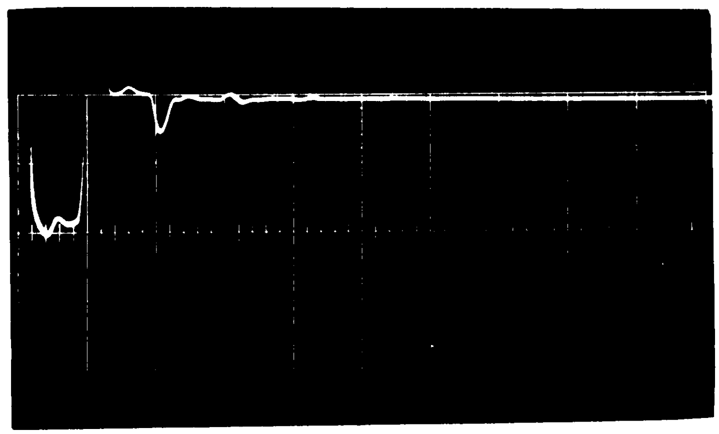
1. Open the far end of the known transmission line. The scope trace should go to the top line at the first vertical line. See Figure 42b.

m. Repeat steps k and 1 until the scope trace changes position at the first line or centimeter. This gives the capability of 1000 feet display (100 feet per centimeter times 10 centimeters.) It can be increased by changing the variable time switch. Verify by observing the reduction of the nominal impedance line, from 1 centimeter to l/2 centimeter (2000

a. TDR -
100 foot line
Terminated
with a short



b. TDR -
100 foot line
Terminated
with an open



c. TDR -
100 foot line
Terminated as a
1.5 to 1 mismatch

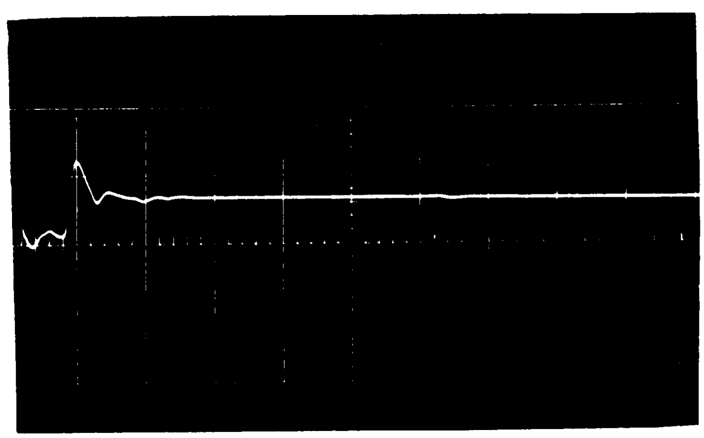


FIGURE 42. TDR - DISTANCE CALIBRATION

feet total) to 1/5 centimeter (5000 feet total). The distance can be decreased similarly by the use of the “5X magnifier”.

n. Connect a mismatched load (non inductive resistor) to the far end of the line. See Figure 42c. for a 100 foot line terminated in a 1.5:1 mismatch. Other value terminations can be used for calibration purposes. Note the discontinuity at the termination of the line.

o. Disconnect the known transmission line. For ease of calibration, it is recommended that the reference standard (known length and impedance) transmission line be permanently installed and connected to an unused RF jack on the antenna matrix. A reference line should be installed for each different characteristic Impedance transmission line - antenna system.

p. Connect the unknown transmission line. Adjust the range (Variable time/centimeter function) until the entire transmission line can be seen. See Figure 43 a, b, c for typical scope presentations of various transmission line - antenna displays. If it is desired, the sensitivity (Amplitude - Impedance Mismatch) can be increased by decreasing the voltage range switch and recalibrating with the desired known terminations.

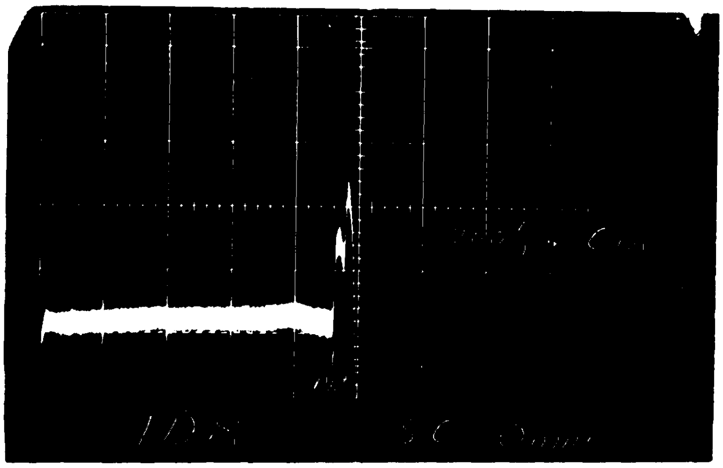
q. Make a record of the scope display for future comparison and reference. This record can be a photograph or a sketch of the display. Note and record all settings of the scope controls.

b. High Power TDR Measurements.

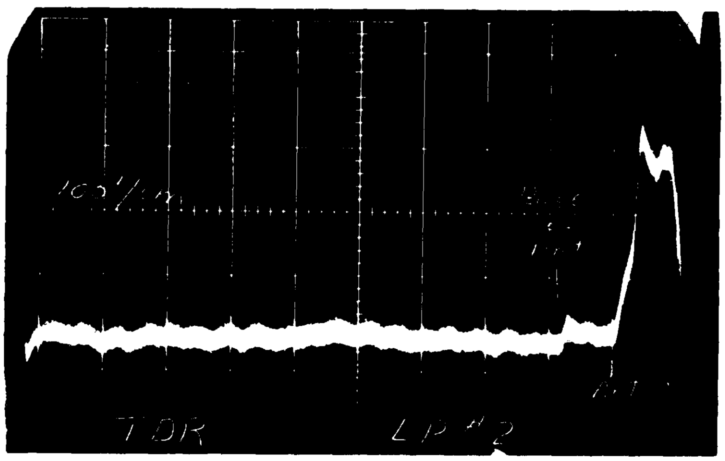
The high power TDR Measurements are accomplished by using DELTA ELECTRONICS HIGH POWER PULSE REFLECTOMETER, MODEL PRH-1.

The high peak pulse power of the PRH-1 permits TDR line measurements in the presence of high induced voltages from adjacent operating antenna systems. Highly useful data has been obtained on the middle curtain of

a. Granger Associates Model 794-20 Omnidirectional Antenna



b. Collins Model 237B-3 Directional Antenna



c. Rhombic Antenna

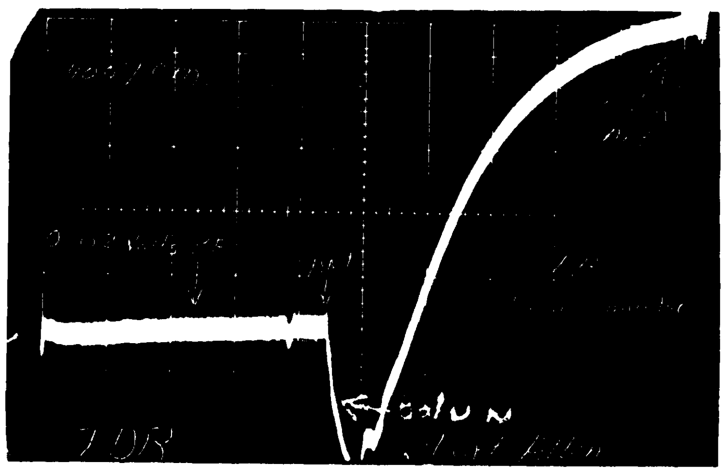


FIGURE 43. TDR DISPLAYS

a tri-nested rhombic installation, with 40 KW transmitters operating on both the top and bottom curtains.

The PRH-1 generates high voltage, short duration gaussian shaped pulses and provides, through a divider network, an output to observe these pulses along with their ethos on an oscilloscope. The pulse voltage (and the pulse peak power) is readily adjustable.

The test set-up would be as follows:

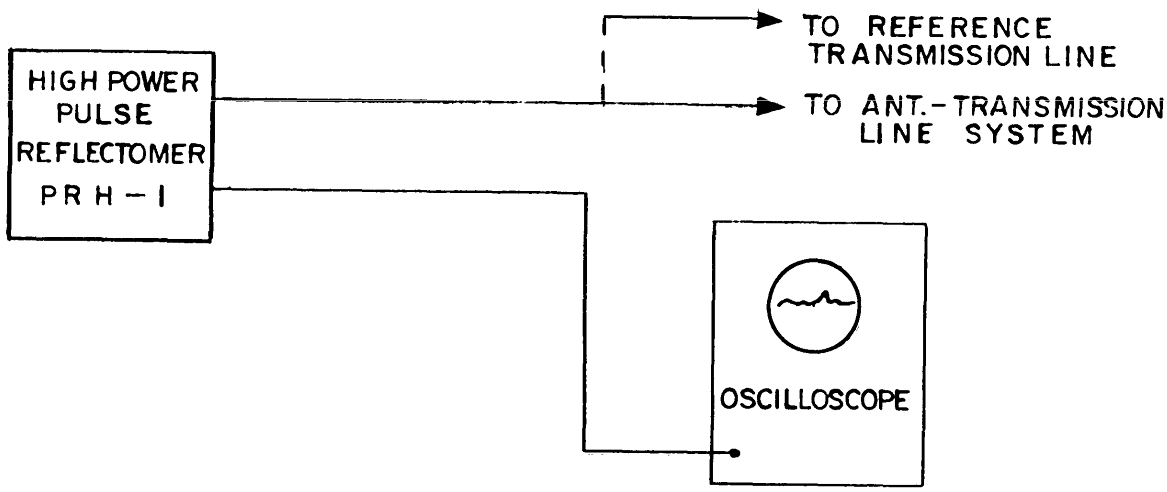


FIGURE 44. HIGH POWER TDR SET UP

The Initial set up/calibration method would be as follows:

SET UP:

a. Connect the PRH-1 to the primary power.

b. Connect the PRH-1 "pulse output" to the reference transmission line (100 feet - electrical).

c. Connect the PRH-1 "scope output" to an oscilloscope.

d. Set the horizontal sweep on the oscilloscope to 0.2 microsecond/ cm. (initially).

e. Set the vertical sensitivity to 2 volts/cm (initially).

CALIBRATION:

f. The "pulse height" adjustment knob (rear of the instrument) is first turned to the maximum counter-clockwise position.

g. Adjust the "height control" knob to give the desired reading on the front panel voltmeter. (1 kilovolt could be used).

h. Adjust the "pulse height" knob until the pulse trace appears on the oscilloscope. If the trace is too dim, increase the "height control" knob until a display of acceptable intensity appears on the oscilloscope. The pulse height will not be changed by his second adjustment.

i. The display range is adjusted by selecting the proper horizontal deflection rate or sweep rate on the oscilloscope. With a sweep rate of 0.1 microseconds per centimeter, the range scale will be approximately 50' per centimeter of display for an air insulated line or 33' per centimeter for a polyethylene insulated line. Assuming for the moment that we want to measure a polyethylene dielectric antenna-transmission line system, and the reference transmission line is also of the same type; we would adjust the vernier on the scope display so that 100 feet of reference line is equal to 2 centimeters on the scope display.

If the antenna - transmission line system and the reference line are of different dielectrics, then a conversion factor or a special length of reference line is required. The conversion factor is as follows:

$$L_1 = L_2 V_1 / V_2$$

where L_1 = length of the reference line

L_2 = length of the antenna - transmission line, usually 100 feet for calibration purposes

V_1 = Velocity factor for reference line

V_2 = Velocity factor for antenna - transmission line.

The table below gives the velocity factor for various types of transmission lines. It should be noted that the velocity factor, for each type of cable, will vary slightly as the cable size and the characteristic impedance is changed.

Type of Line	Velocity Factor
Air Dielectric Line (Rigid)	0.998
Heliax Line	0.91
Styroflex Line	0.90
Foam Dielectric Line	0.79
Teflon Dielectric Line	0.69
Polyethelyne Dielectric Line	0.667

OPERATION:

j. Connect the antenna - transmission line to the reflectometer, in place of the reference line.

k. Oscilloscope display. When the oscilloscope is adjusted properly, the initial pulse will be seen on the left stale of the display and the echo pulses will be seen along the horizontal axis. The range is determined by measuring the distance in centimeters (with the oscilloscope graticule) from the leading edge of the initial pulse to the leading edge of the echo pulse and using the scale length calibration. The characteristics of the individual echo shapes can be used to determine the nature of the line faults. A large positive - going pulse indicates an open circuit. A large negative - going pulse indicates a short circuit. A small S-shaped echo going first negative and then positive indicates a line disturbance equivalent to a shunt capacity. An S-shaped echo of opposite polarity indicates an inductive disturbance.

By adjustment of the range, the complete antenna - transmission line system can be displayed and the individual elements of the entire system can be identified, i.e. - connectors, baluns, patch panels, antenna, etc.

It is desirable to take a photograph or make a sketch for each antenna - transmission line system when it is known to be in proper operating condition. Notations should be made of the pulse height settings and oscilloscope settings for each photograph. It is often found that each antenna will have a characteristic signature. By comparing the echo returned, during inspection periods, to the original or data base, the status of the antenna - transmission line system can be determined. Typical plots are shown on Figure 68a, b and c.

6. Antenna - Transmission Line System Measurements

It should be carefully noted that actual measurements of “as-found” antenna-transmission line systems were used to illustrate the test methods and procedures. Nonconformance with system specifications, i.e. SWR of 2:1, only means that the current SWR of the antenna is out of specification. It does not mean the antenna, when originally installed, was out of specification.

a. Input Impedance Measurements.

The RHO detector procedure and the RF bridge procedure are used to determine the input impedance values at the minimum-maximum SWR points in the SWR versus frequency plot. The use of these procedures will result in the determination of the following:

RF Test Frequency

R in ohms

L_x or C_x

$\pm$ jx

normalized R (R/Z_0)

normalized $\pm$ j X $(\pm jX/Z_0)$

A completed data sheet for the input impedance measurements, of a Collins 237B3 LPS antenna, is shown as Figure 45. Figures 46a and b show the actual impedance plots on SMITH CHARTS.

b. Determination of input SWR.

1. From impedance measurements.

(a) The normallized impedance points, $Z = R/Z_0 \pm jX/Z_0$ were plotted on a SMITH CHART. The radius of the SWR circle, or the distance from the prime center to the plotted impedance point was then swung in an arc to the resistance axis (Prime Center to infinity ohms) and the resultant SWR was noted on the data sheet. (See Fiqure 45).

(b) Various types of omnidirectional antennas from different antenna manufacturers are used in the Dynamic Grasp Communication System.

INPUT IMPEDANCE
for
Collins 237B-3 Antenna
Tx Bldg - # 1

Fort Allen
20 Jan 70

RF Frequency	R in ohms	L_x	C_x	± jX in ohms	NORMALIZED R/Z_o	± jX/Z_o	SWR
6.000	72	40		24.0	1.44	0.48	1.7
6.694	55	10	4	6.69	1.1	0.134	1.18
7.537	95			-3.01	1.9	-0.06	1.9
8.183	62	8		6.5	1.24	0.13	1.28
8.942	95		4	-3.57	1.9	0.072	1.9
9.979	42	Ø	Ø	Ø	0.84	Ø	1.19
10.957	105	5		5.5	2.1	0.11	2.1 *
11.361	44	10		11.4	0.88	0.23	1.3
12.395	108		5	-6.2	2.16	-0.124	2.2 *
14.047	47	Ø	Ø	Ø	0.94	Ø	1.06
15.043	90		10	-15.1	1.80	-0.30	1.85
16.867	44	Ø	Ø	Ø	0.88	Ø	1.14
18.584	78		10	-18.5	1.51	-0.37	1.65
20.283	41	Ø	Ø	Ø	0.82	Ø	1.22
21.854	54	12		26.2	1.08	0.52	1.65
24.180	46		2	-4.82	0.92	-0.097	1.1
26.587	46	9		23.8	0.92	0.475	1.64
29.164	47	Ø	Ø	Ø	0.94	Ø	1.06
30.000	37	1		3.0	0.74	0.06	1.35

* SWR is out of specification.- even before allowing for the transmission line attenuation. Suspect that radiating element #4 may need maintenance.

FIGURE 45. DATA SHEET FOR INPUT IMPEDANCE

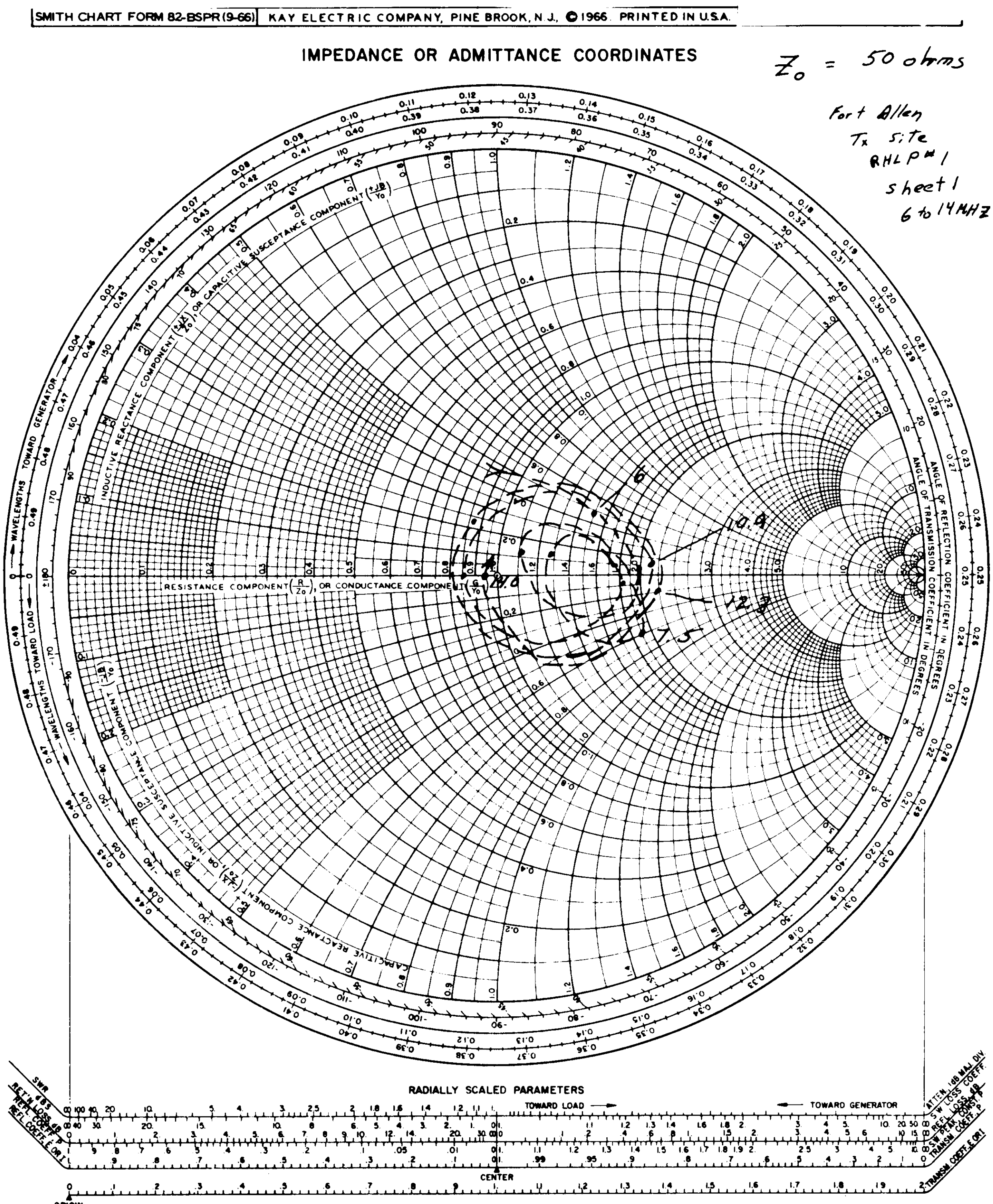


FIGURE 46a. IMPEDANCE PLOT - HLPS ANTENNA, 237B-3 (6-14 MHz)

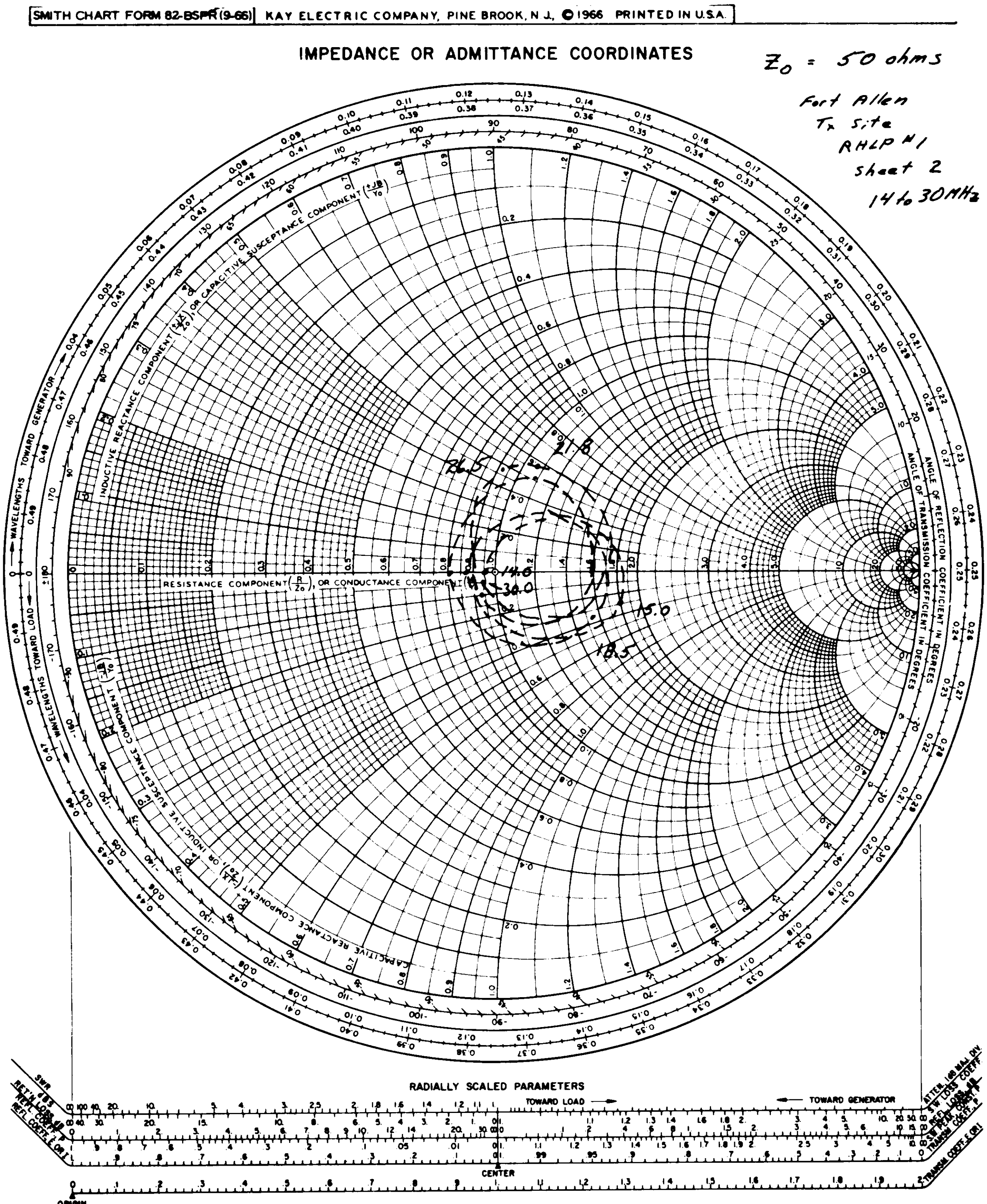


FIGURE 46b. IMPEDANCE PLOT - HLPS ANTENNA, 237B-3 (14 to 30 MHz)

The following SWR-frequency profiles are presented for purposes of illustrating SWR-frequency profiles, certain SMITH CHART plots, antenna-wavelength relationships, etc. (plotted from measured data). The $\lambda/4$ wavelength versus SWR (impedance) is discussed in Section II, Antenna Concepts.

(1) COLLINS MODEL 437 C-( )A Antenna.

The Collins 437C-( )A series of broadband monopoles consists of three wideband, vertically polarized, omnidirectional antennas each covering a 10:1 frequency range. The antenna is formed by two truncated cones connected base to base and supported through the center by a steel tower. The antenna operates as a base fed monopole imaged above - ground screen. In the lower frequencies, both cones radiate; in the higher frequencies the top cone is decoupled by a crossover network, and only the lower cone radiates. The SWR and impedance plots for Model 437C-lA are presented on Figures 47 and 48. Note that a special form of SMITH CHART was used - This chart is expanded and covers those cases where the SWR is less than 3 to 1. The SWR and impedance plots for Model 437C-2A are presented on Figures 49 and 50 a, b and c. The SWR plot for Model 437C-3A is also presented on Figure 49.

(2) GRANGER ASSOCIATES MODEL 794-20 Antenna.

The Granger Associates Model 794-20 antenna is a wideband, vertically polarized omnidirectional antenna. The antenna is a base fed-discone antenna imaged above a ground screen. The antenna uses a matching unit to provide additional capacitive reactance (Xc), at the lower frequencies, to effect a proper impedance match. The SWR and Impedance plots are presented on Figures 51 and 52-a and -b.

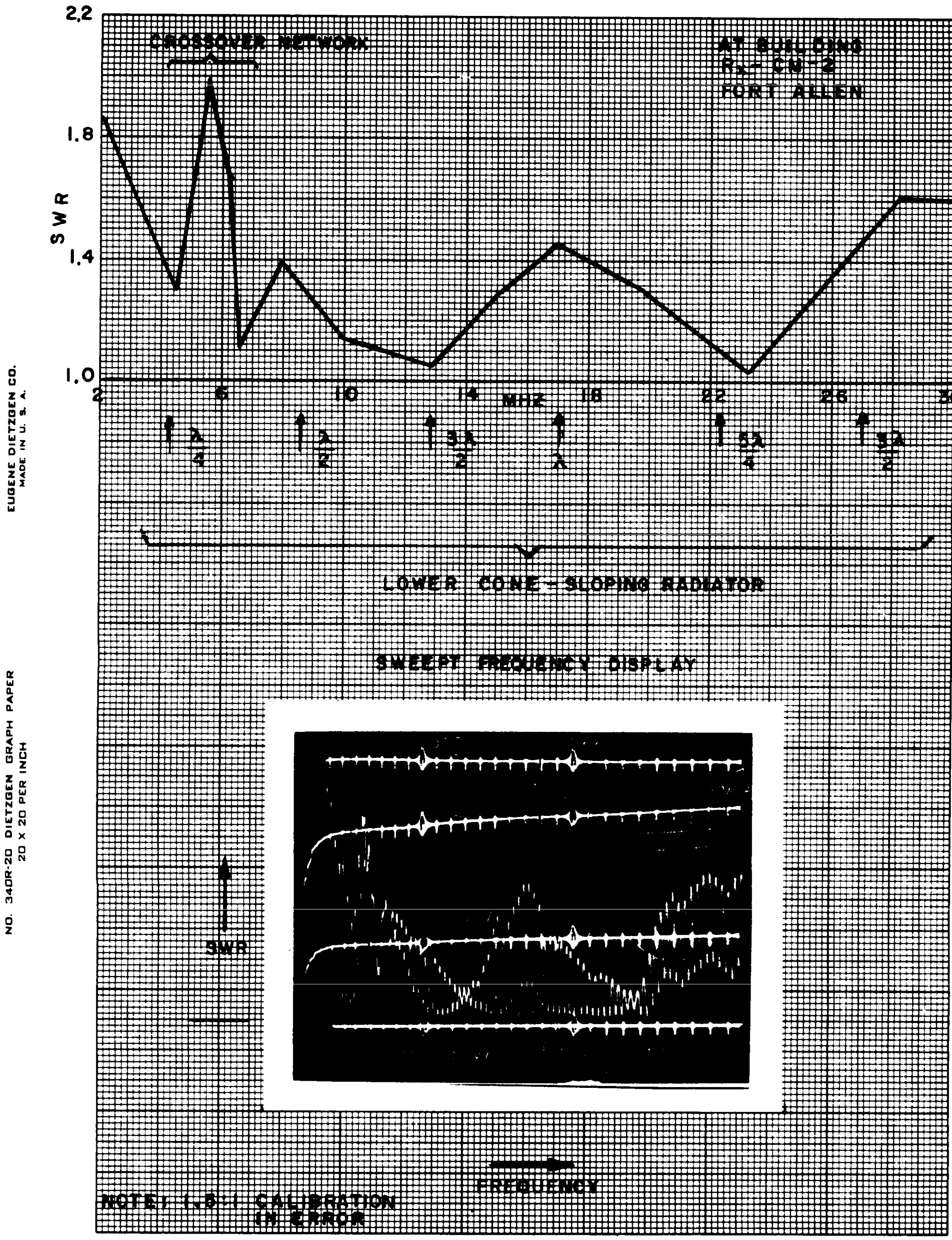
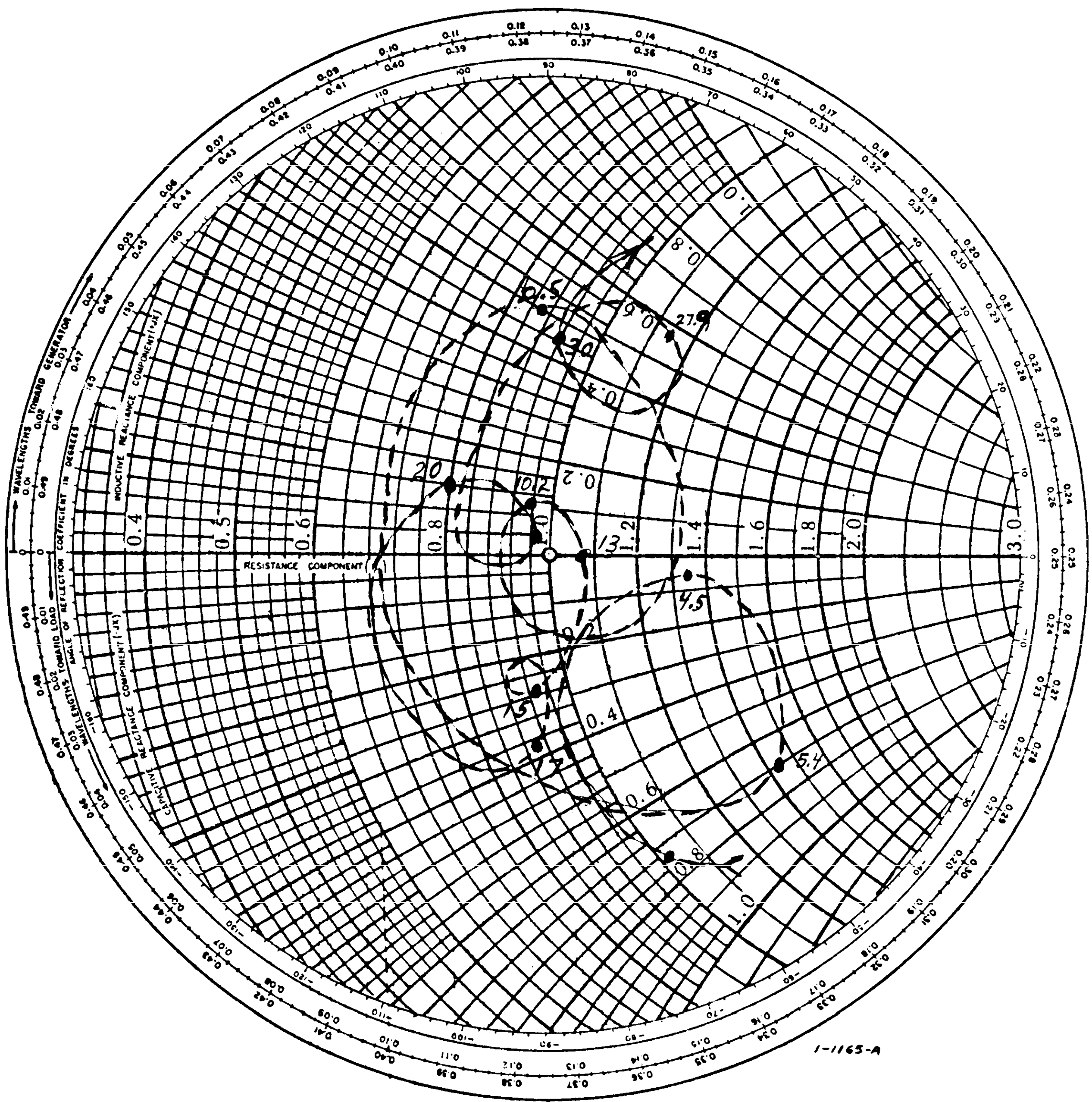


FIGURE 47 SWR- COLLINS MODEL 437C-IA ANTENNA

NORMALIZED IMPEDANCE COORDINATES -- CHARACTERISTIC IMPEDANCE Z_0 = 50 ohms



Electronics - VOL. 17, NO. 1, PP.-130-133, 318-325, JAN. 1944

FIGURE 48. IMPEDANCE PLOT - OMNIDIRECTIONAL ANTENNA 437C-1A

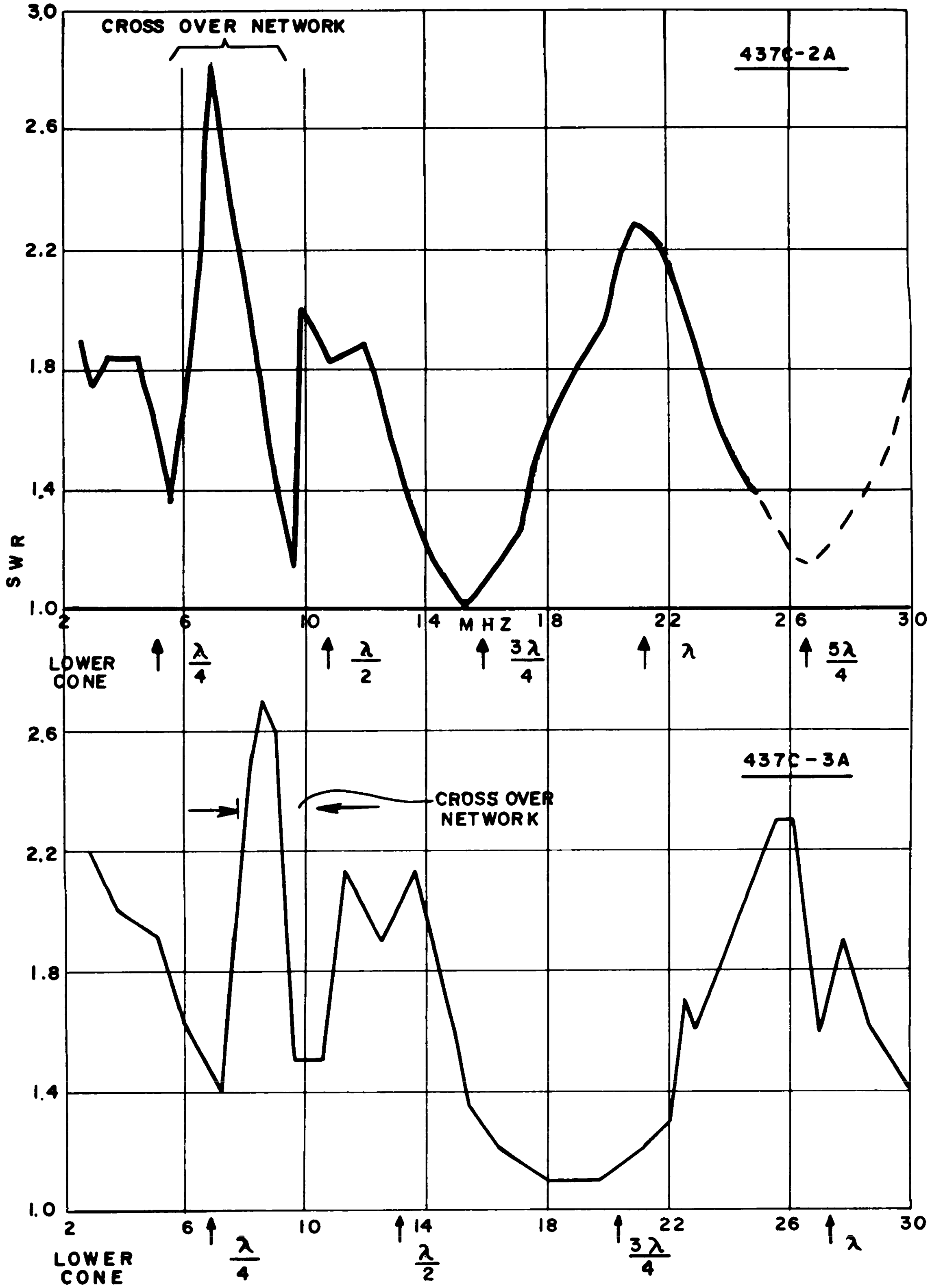


Figure 49 SWR-COLLINS MODEL 437 C-( ) ANTENNA

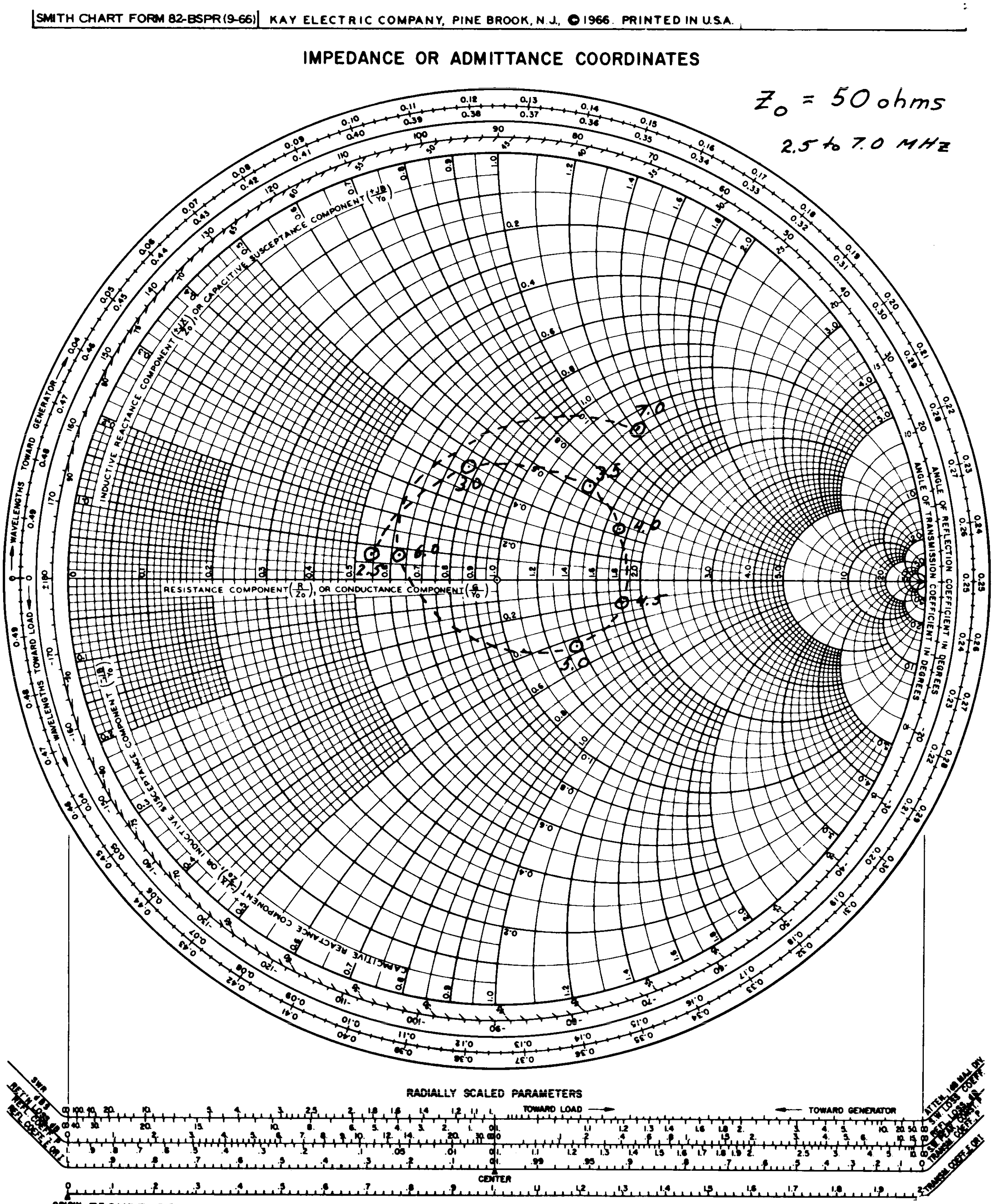


FIGURE 50a. IMPEDANCE PLOT - OMNIDIRECTIONAL ANTENNA 437C-2A, (2.5 to 7.0 MHz)

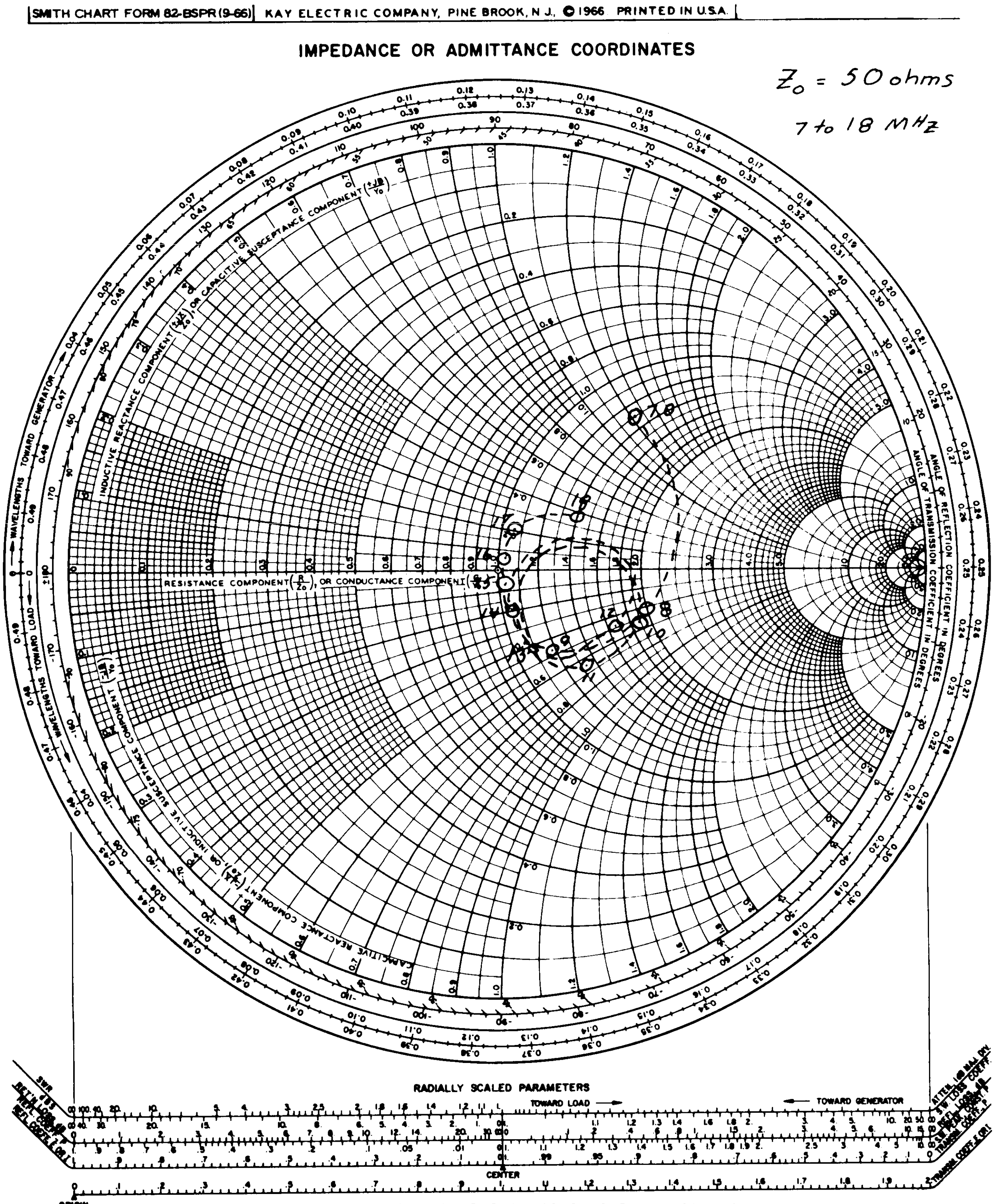


FIGURE 50b. IMPEDANCE PLOT - OMNIDIRECTIONAL ANTENNA 437C-2A (7 to 18 MHz)

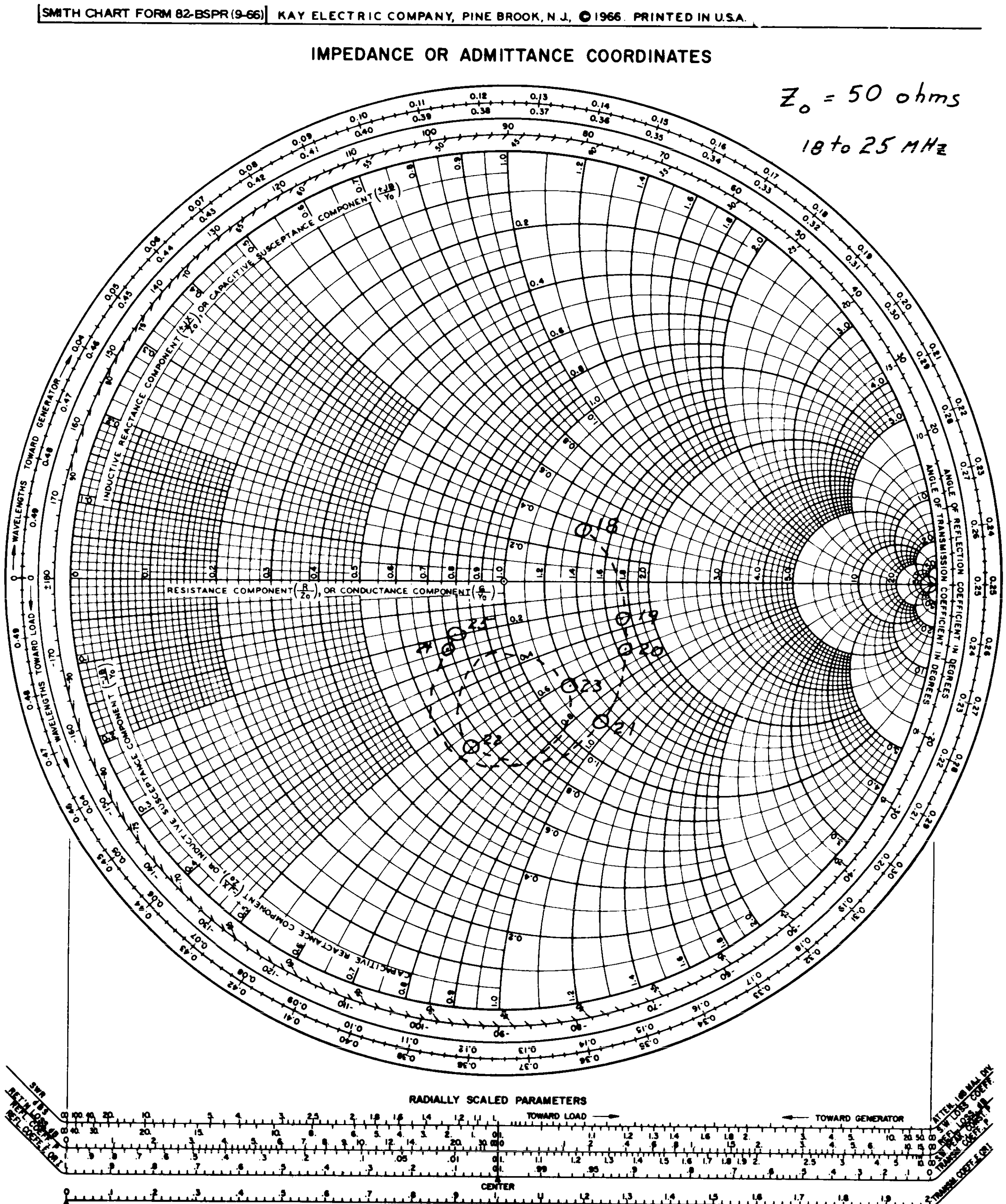


FIGURE 50c. IMPEDANCE PLOT-OMNIDIRECTIONAL ANTENNA 437C-2A
(18 to 25 MHz)

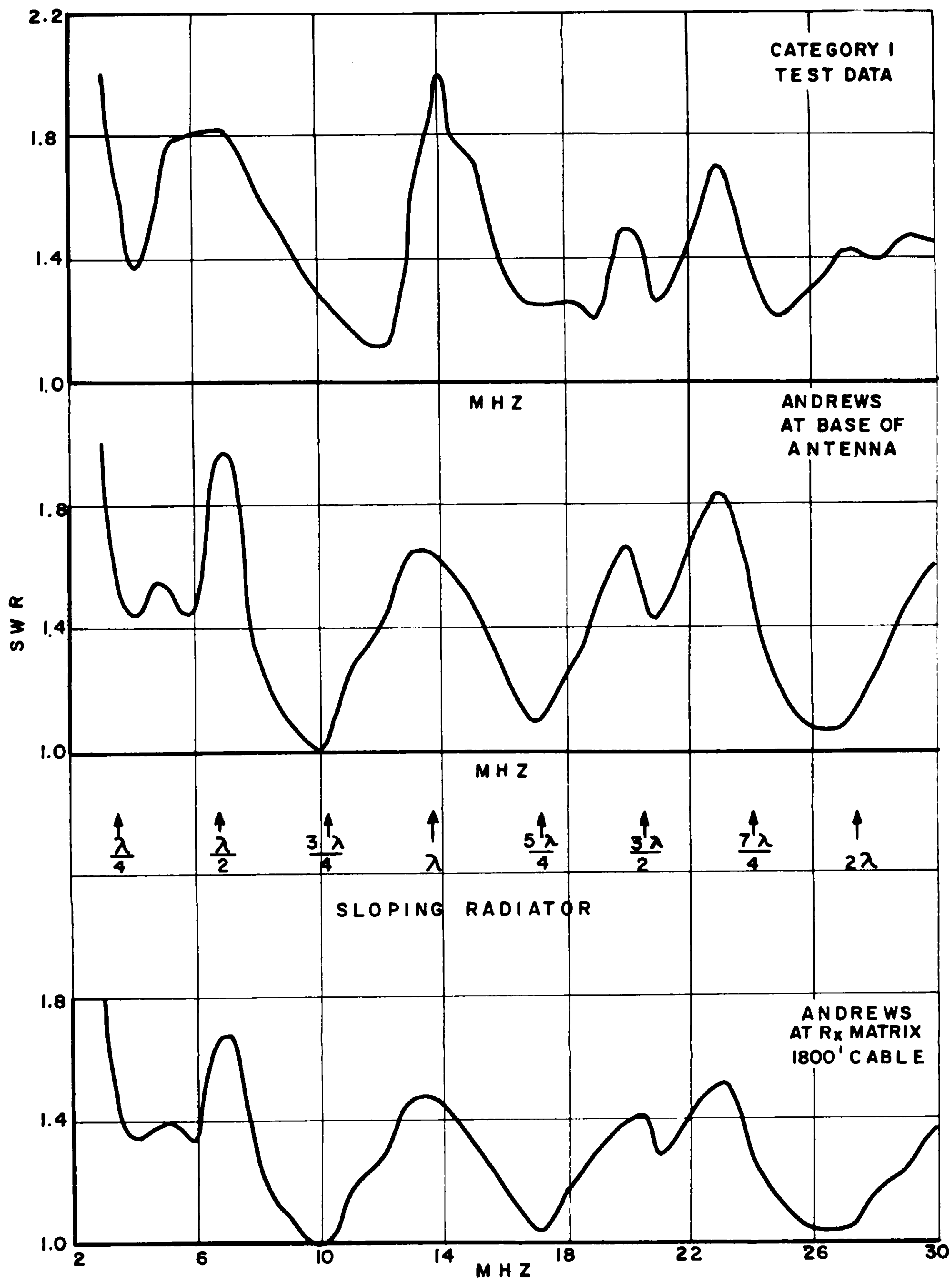


Figure 51 SWR - GRANGER ASSOC. MODEL 794 - 20

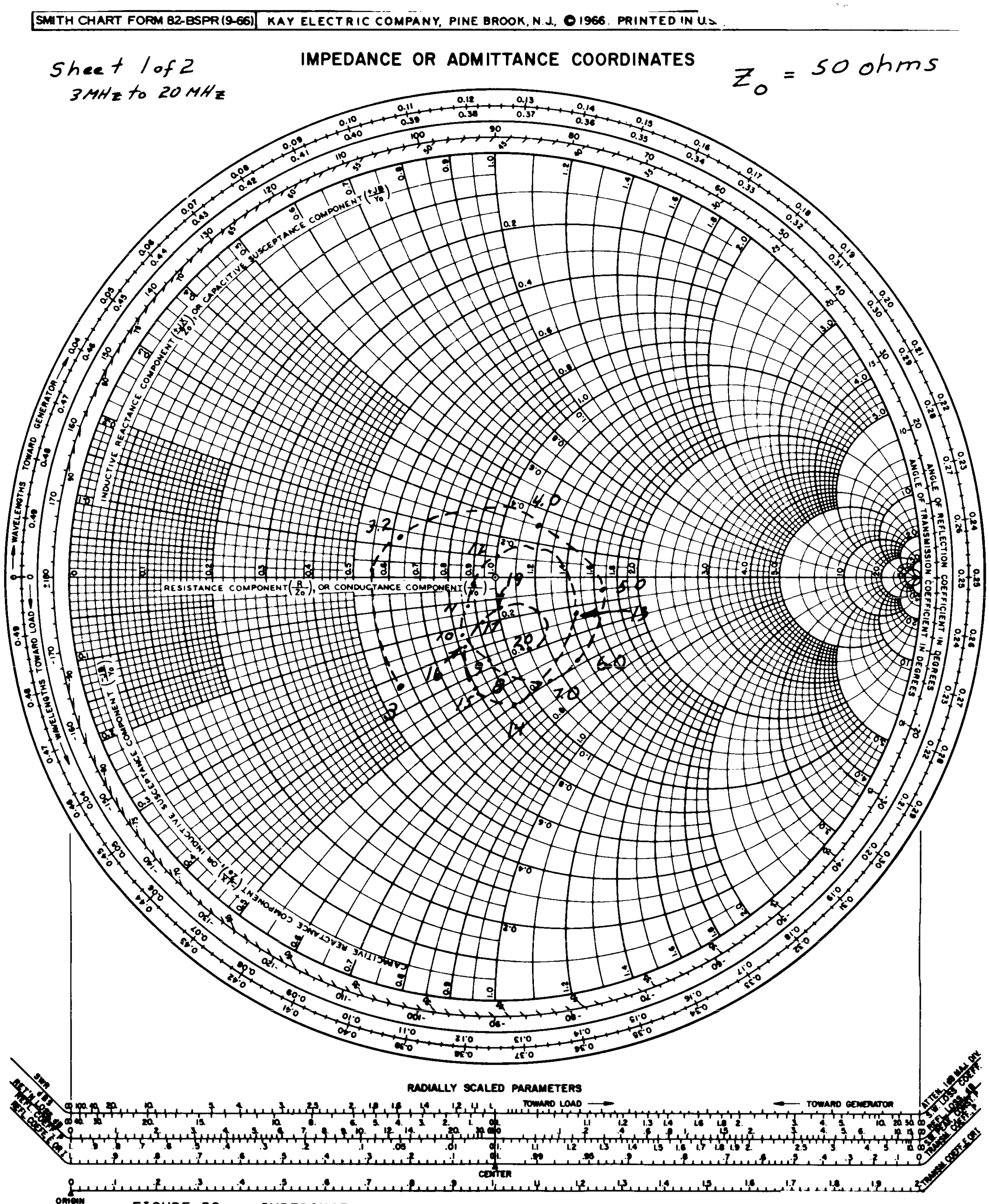


FIGURE 52a. IMPEDANCE PLOT-OMNIDIRECTIONAL ANTENNA 794-20
(3 to 20 MHz)

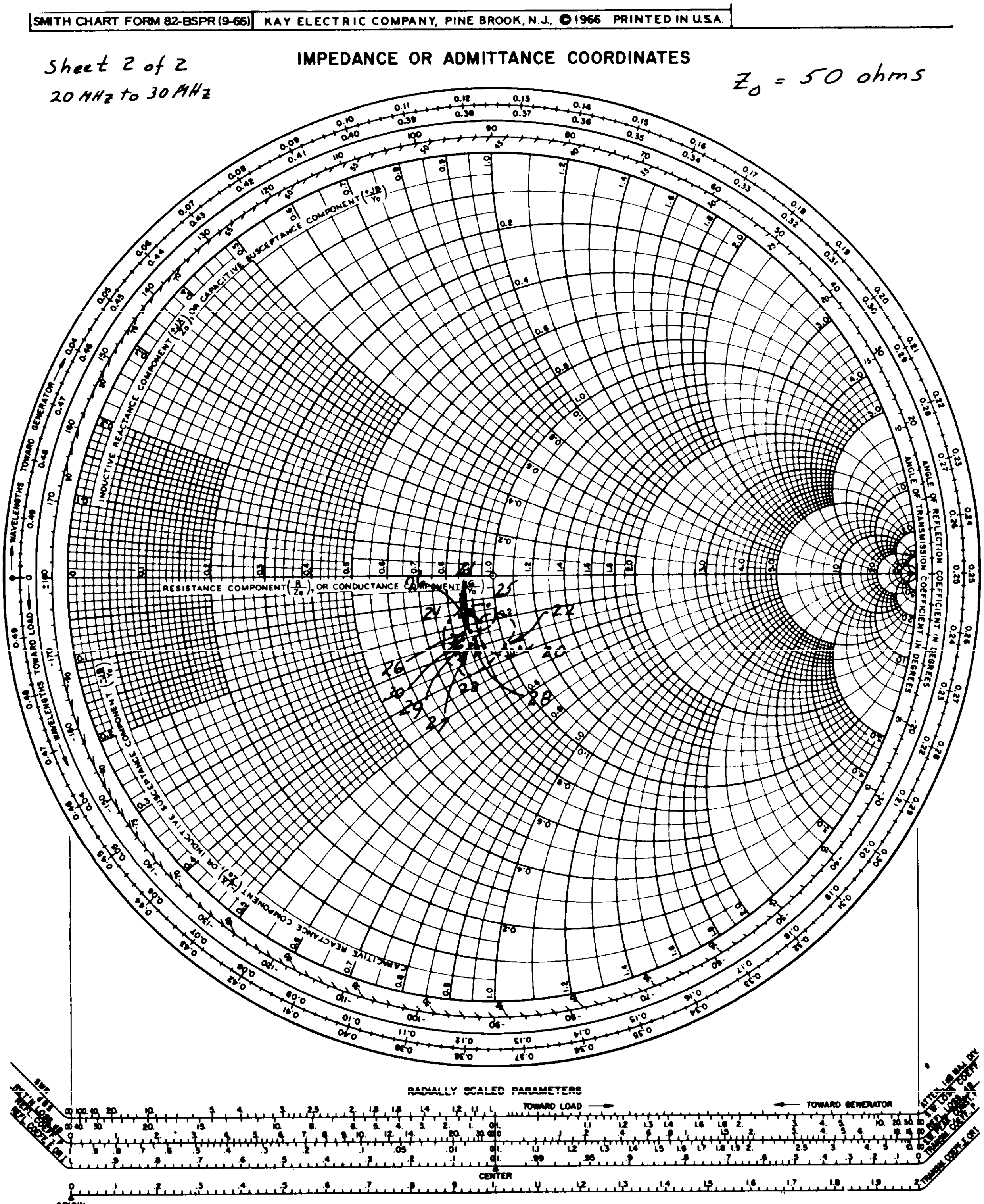


FIGURE 52b. IMPEDANCE PLOT-OMNIDIRECTIONAL ANTENNA 794-20
(20 to 30 MHz)

(c) Various types of directional LPS antennas from different antenna manufacturers are also used in the Dynamic Grasp Communication System. The following SWR-frequency profiles are presented for the purposes of illustrating SWR-frequency profiles, antenna-wavelength relationships, etc. (plotted from measured data).

(1) APC INDUSTRIES MODEL LPH-9 ANTENNA.

The APC LPH-9 Antenna is a single planar array, horizontally polarized, that is mounted on two towers. The antenna array consists of 16 elements and is capable of being rotated, in 30 degree steps, for azmuthal coverage. The SWR-frequency profile is presented on Figure 53.

(2) COLLINS MODEL 237A-1 ANTENNA.

The Collins 237A-1 Antenna consists of two arrayed planar arrays, horizontally polarized, that are mounted on two towers. Each antenna array consists of 13 elements. The array assembly is capable of being rotated, in 30 degree steps, to provide azmuthal coverage. The SWR-frequency profile is presented on Figure 54.

(3) COLLINS MODEL 237B-1 , -3 ANTENNA.

The Collins 237B-( ) antenna is a single planar array, horizontally polarized, that is mounted on either a single tower (-3) or two towers (-1). The antenna array consists of 13 elements and is capable of being rotated, in 30 degree steps, for azmuthal coverage. The SWR-frequency profile is presented on Figure 55.

(4) GRANGER ASSOCIATES MODEL 757 ROSETTE ANTENNA.

The Granger Associates Model 757 antenna consists of four each vertical polarized Logarithmic Periodic arrays, arranged in a rosette, using a common center tower and another tower for the high

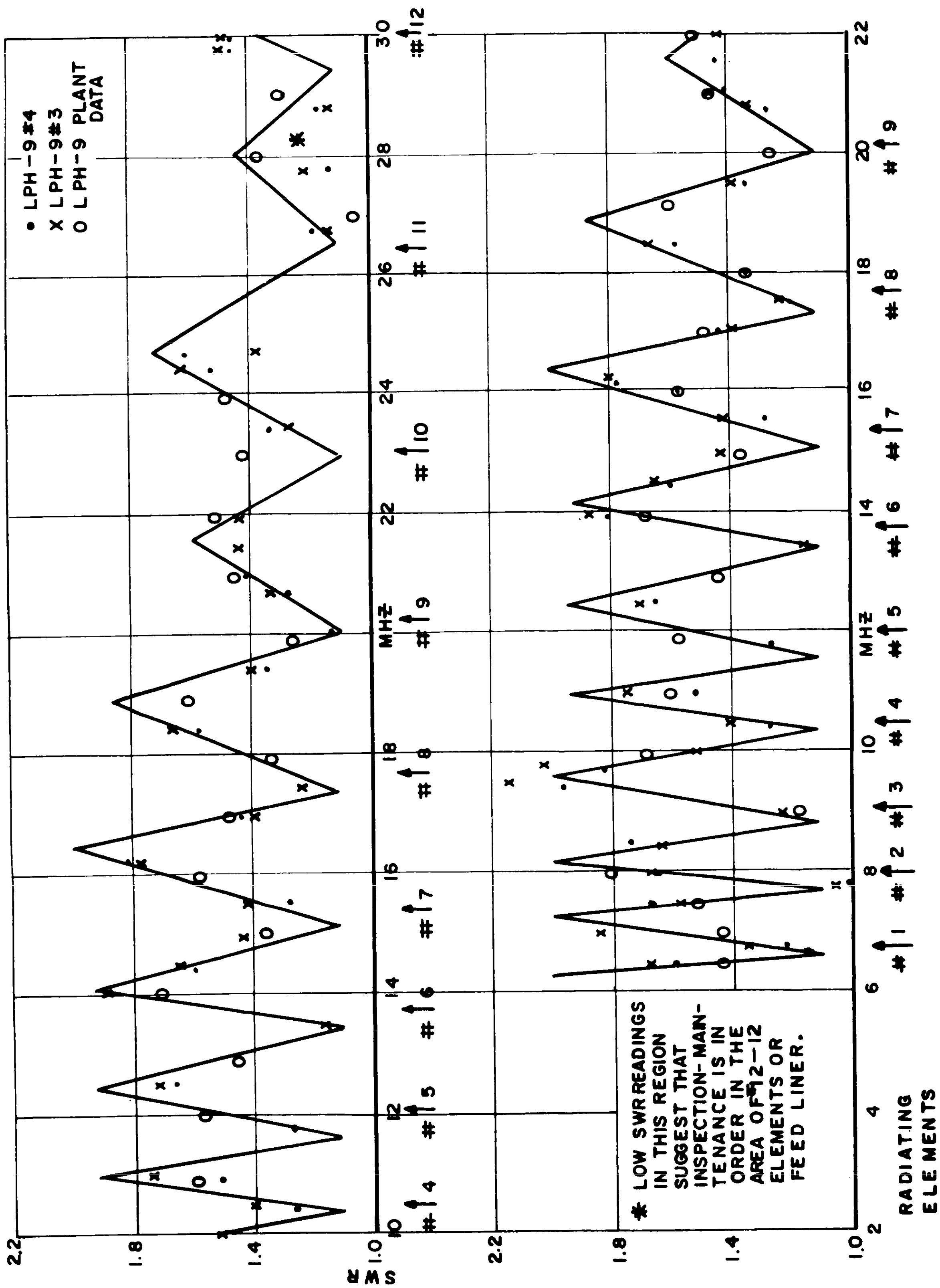


Figure 53 SWR - APC INDUSTRIES MODEL LPH-9 ANTENNA

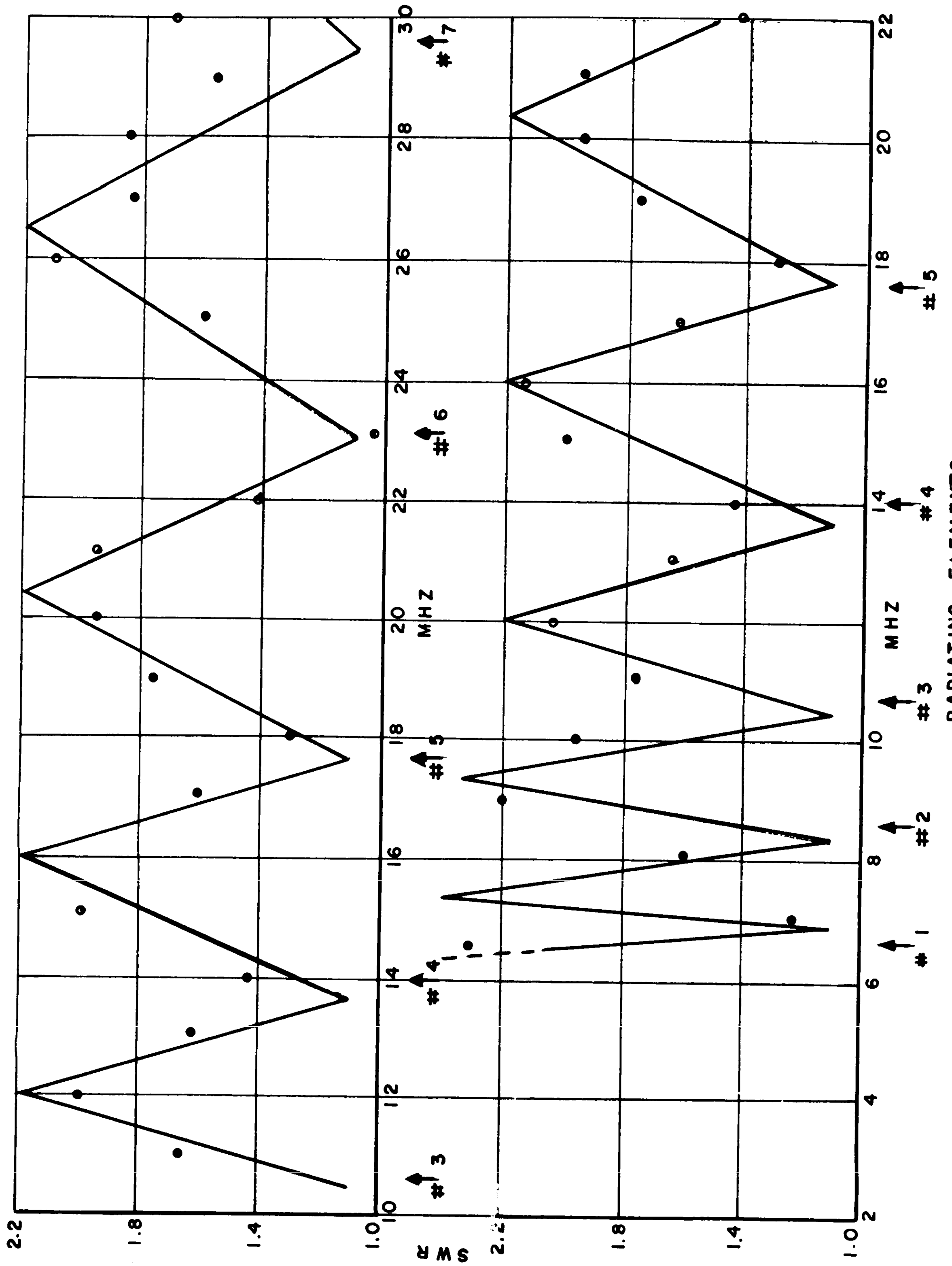


Figure 54 SWR - COLLINS MODEL 237A-1 ANTENNA

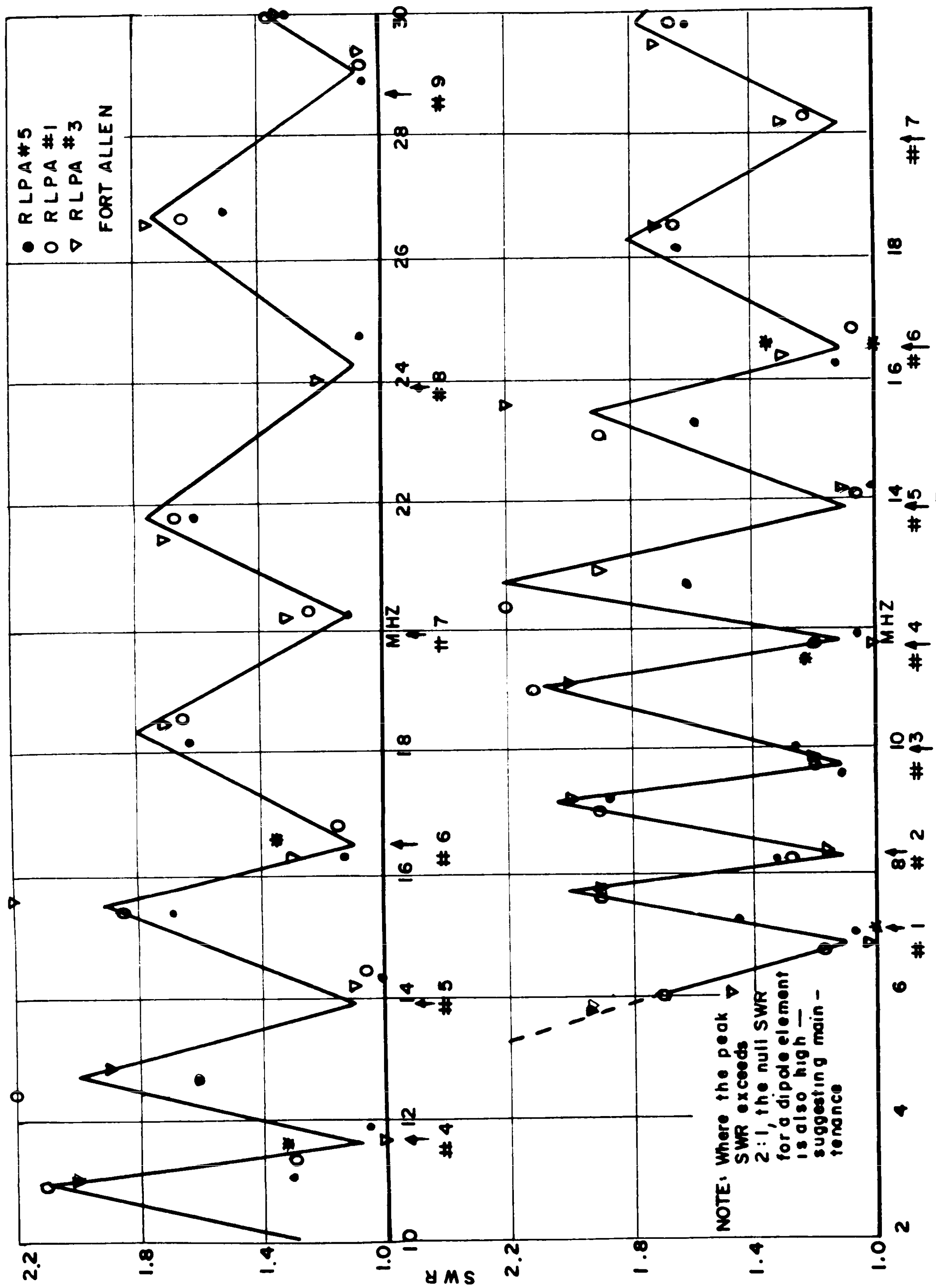


Figure 55 SWR — COLLINS MODEL 237 B-1,3 LPS ANTENNA

frequency end of each array. The arrays are imaged above a ground screen. Azmuthal coverage, in 90 degree steps, is provided by selection of each of the arrays in turn. The SWR-frequency plot is presented on Figure 56.

(5) HY-GAIN MODEL 6-40 ANTENNA.

The Hy-Gain 6-40 antenna is a single planar array, horizontally polarized, that is mounted on a single tower. The antenna array consists of 14 elements and is capable of being rotated, in 30 degree steps, for azmuthal coverage. The SWR-frequency profile is presented on Figure 57.

(6) TRYLON MODEL AN/FRA-88 ANTENNA.

The Trylon AN/FRA-88 antenna is a single planar array, horizontally polarized, that is mounted on two towers. The antenna array consists of 14 elements and is capable of being rotated, in 30 degree steps, for azmuthal coverage. The SWR-frequency profile is presented on Figure 58.

(2) From Swept Frequency Measurements.

The return loss, swept frequency measurement procedures were used to identify those frequencies of minimum and maximum return loss. The frequencies and the associated return loss are listed on a data sheet. The SWR, for each return loss, was then determined from a SMITH CHART. An alternate way would be to calibrate the oscilloscope display with known mismatches. Then, assuming the use of an Oscilloscope Camera, multiple exposures, on a single film shot, can be made that would show several known SWR mismatches (calibration) and the actual antenna return loss profile. This multiple exposure photograph is an excellent data base for maintenance purposes. See Figure 38 for antenna SWR-Frequency profiles.

(3) Correction for transmission Line Loss.

The determination of the transmission line loss is discussed

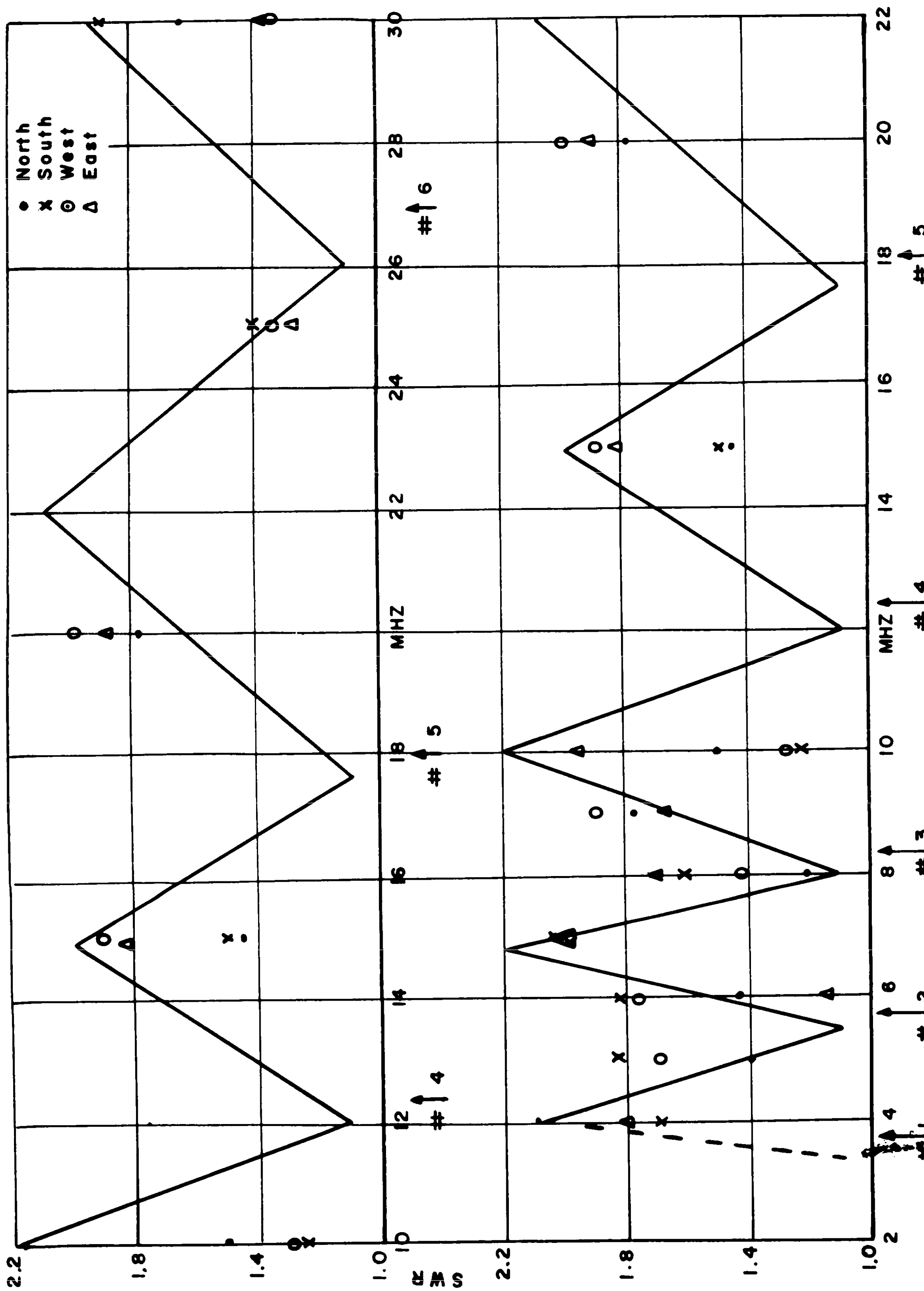


Figure 56 SWR - GRANGER ASSOC. MODEL 757 ROSETTE ANTENNA

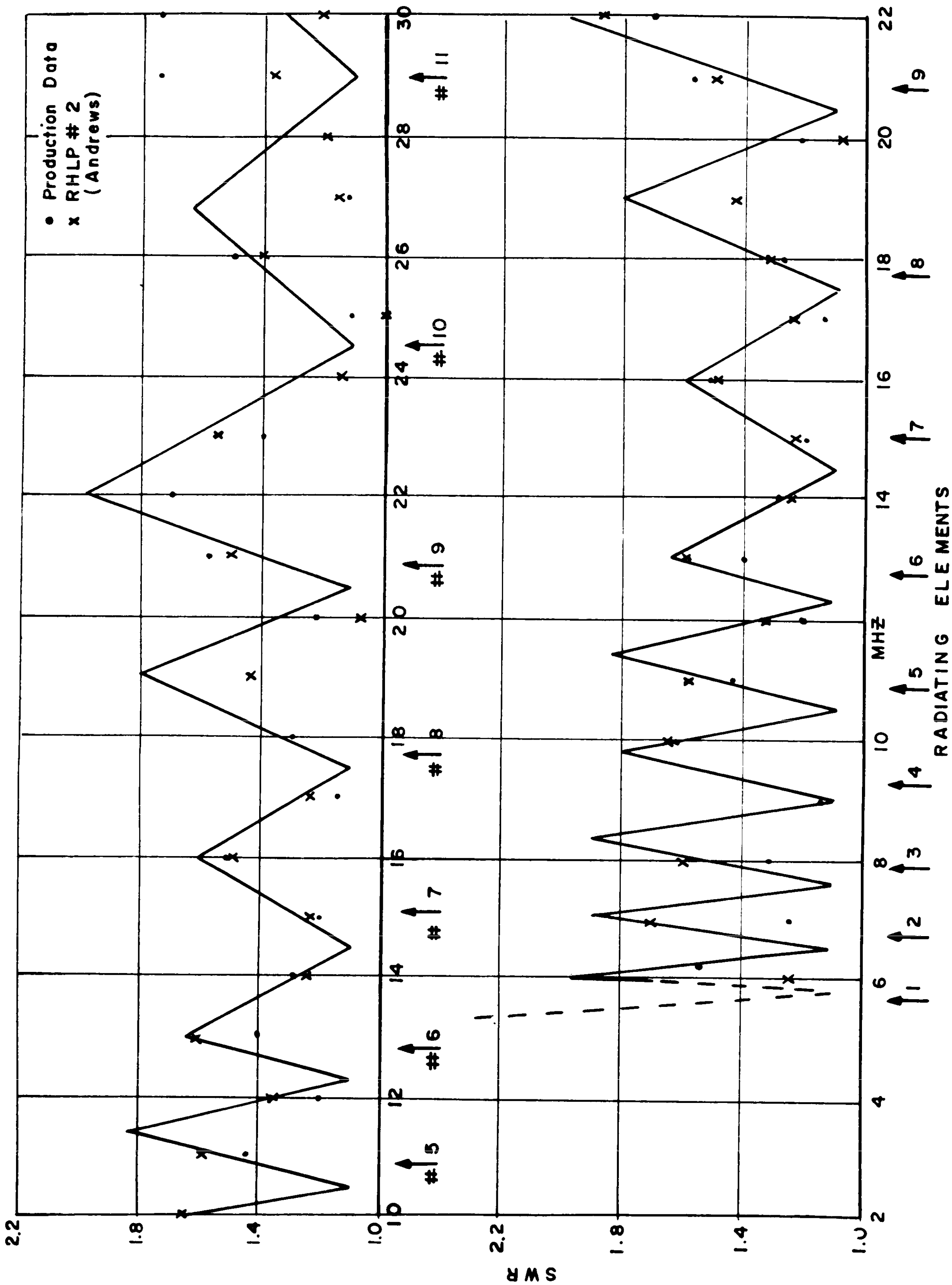


Figure 57 SWR - HY-GAIN MODEL 640 LPS ANTENNA

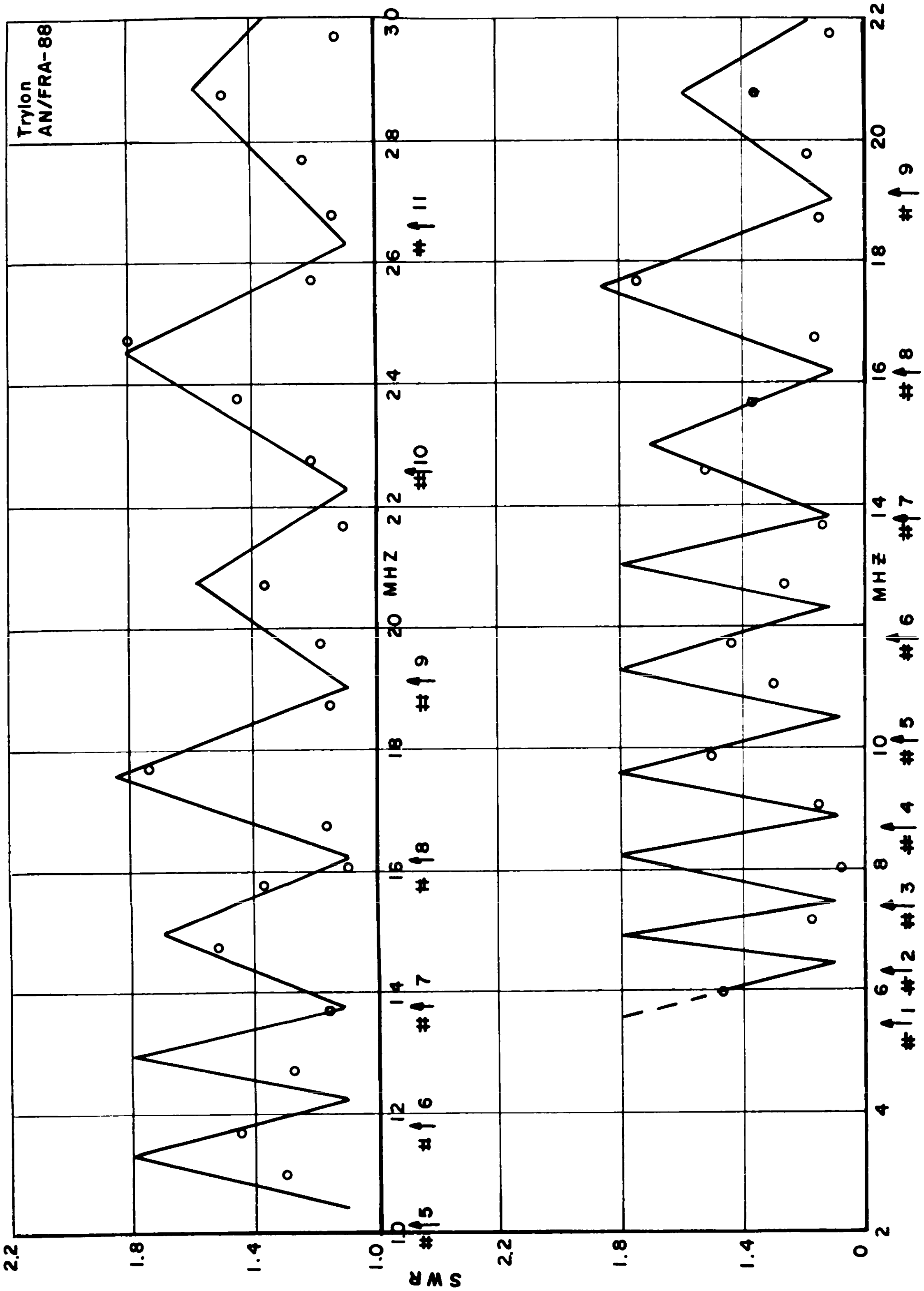


Figure 58 SWR - TRYLON MODEL AN/FRA-88 ANTENNA

under Transmission Line Tests and Procedures.

Having determined the line loss versus frequencies, the SWR, at the input to the antenna-transmission line system, can be corrected to the SWR at the input to antenna.

(a) SMITH CHART.

The radius of each SWR circle, for the input to the antenna-transmission line system, is increased by the attenuation of the transmission line 1oss. The increased radius is determined by the external scale, trans. loss - 1 dB steps, on the SMITH CHART. The resultant radius now determines the SWR (on the SWR scale) at the input to the antenna.

(b) ATTENUATION - SWR CHARTS.

The Input SWR or the Load (antenna) SWR can also be determined with suitable nomoqraphs. See Figure 10. The SWR correction method is similar to that using the SMITH CHART.

(c) A typical SWR correction, from input of an Antenna - Transmission Line System to the input to the antenna is presented on Figure 59. Arbitrarily selected frequencies may be used to supplement the frequencies determined by the “Rho Detector” method.

c. Impedance Discontinuities.

The TDR measurement procedures are used to determine the impedance discontinuities of the transmission line portion of the antenna - transmission line system. With reference to the Low Power TDR, displays, Figure 43, the presence of RF is also an indicator of the antenna performance. With reference to High Power TDR displays, typical antenna performance is shown on Figures 68a, b and c.

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FREQUENCY in MHz	INPUT SWR	Transmission Line Loss in dB	SWR at Input to Antenna	
4.437	1.30	1.06	1.40	
5.756	1.95	1.2	2.4	
10.192	1.08	1.7	1.1	PEAK-NULL
10.355	1.18	1.7	1.3	SWR's
14.269	1.04	1.95	1.06	RHO DETECTOR
17.468	1.41	2.2	1.75	FREQUENCIES
24.108	1.10	2.7	1.18	
28.162	1.55	2.9	2.4	
2.0	2:00	0.9	2.4	
3.0	1.55	1.0	1.75	
4.0	1.40	1.05	1.5	
5.0	1.60	1.1	1.75	
7.0	1.68	1.3	2.05	
8.0	1.40	1.45	1.55	
9.0	1.25	1.55	1.3	Arbitrary
11.0	1.30	1.75	1.45	frequencies
12.0	1.20	1.80	1.30	
13.0	1.04	1.85	1.05	
15.0	1.28	2.0	1.48	
20.0	1.20	2.45	1.4	
22.0	1.14	2.6	1.24	
26.0	1.40	2.8	1.75	
29.0	1.12	2.95	1.26	
30.0	1.48	3.0	2.0	

FIGURE 59. SWR CORRECTION SHEET (Rx Site - CM-2 Antenna)

7. Transmission Line Measurements.

a. Attenuation Loss.

(1) Compute from Cable Loss Chart.

The computed attenuation loss is determined from Figure 9, Attenuation of RF Transmission Lines. The attenuation, for the specific type of transmission line versus test frequencies, is given in dB per hundred feet. The line attenuation, for each frequency, is equal to the dB per hundred feet times the line length divided by 100. This line attenuation should be increased by the connector loss. This loss will vary from 0.1 db to 0.25 db, per connector. It is recommended that the total attenuation be plotted on log-loo graph paper. A typical data sheet for transmission line loss calculations is shown on Figures 59 and 60.

(2) Measurement of input to output RF Voltage Attenuation.

The attenuation can be determined by measuring the input voltage, the output voltage and then converting the ratio of the two values to loss in dB.

The test set up would be as shown in Figure 61.

The initial set up/calibration method would be as follows:

SET UP/CALIBRATION.

(a) Terminate the RF Signal Generator with R_1, a noninductive resistor equal to the characteristic impedance of the transmission line.

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15 Jan 70

F MHz	TYPE OF CABLE RG-213/U	7/8" S		Loss in 60' of RG-213/U	Loss in 798' of 7/8" S	Connector Loss	Total Calculated Loss
	Loss/100 ft	from chart *					
2 MHz	0.29 dB	0.06 dB		0.6(0.29) +	7.98(0.06) +	0.3 =	0.95 dB
6 MHz	0.51 dB	0.11 dB		0.6(0.51) +	7.98 (0.11) +	0.3 =	1.48 dB
10 MHz	0.68 dB	0.14 dB		0.6(0.68) +	7.98(0.14) +	0.3 =	1.83 dB
14 MHz	0.80 dB	0.16 dB		0.6(0.80) +	7.98(0.16) +	0.3 =	2.00 dB
18 MHz	0.91 dB	0.19 dB		0.6(0.91) +	7.98(0.19) +	0.3 =	2.36 dB
22 MHz	1.00 dB	0.21 dB		0.6(1.0) +	7.98(0.21) +	0.3 =	2.57 dB
26 MHz	1.10 dB	0.23 dB		0.6(1.1) +	7.98(0.23) +	0.3 =	2.79 dB
30 MHz	1.20 dB	0.25 dB		0.6(1.2) +	7.98(0.25) +	0.3 =	3.01 dB

* See figure 12, "Attenuation of RF transmission Lines"

FIGURE 60a. TRANSMISSION LINE LOSS CALCULATIONS for CM-2 Antenna

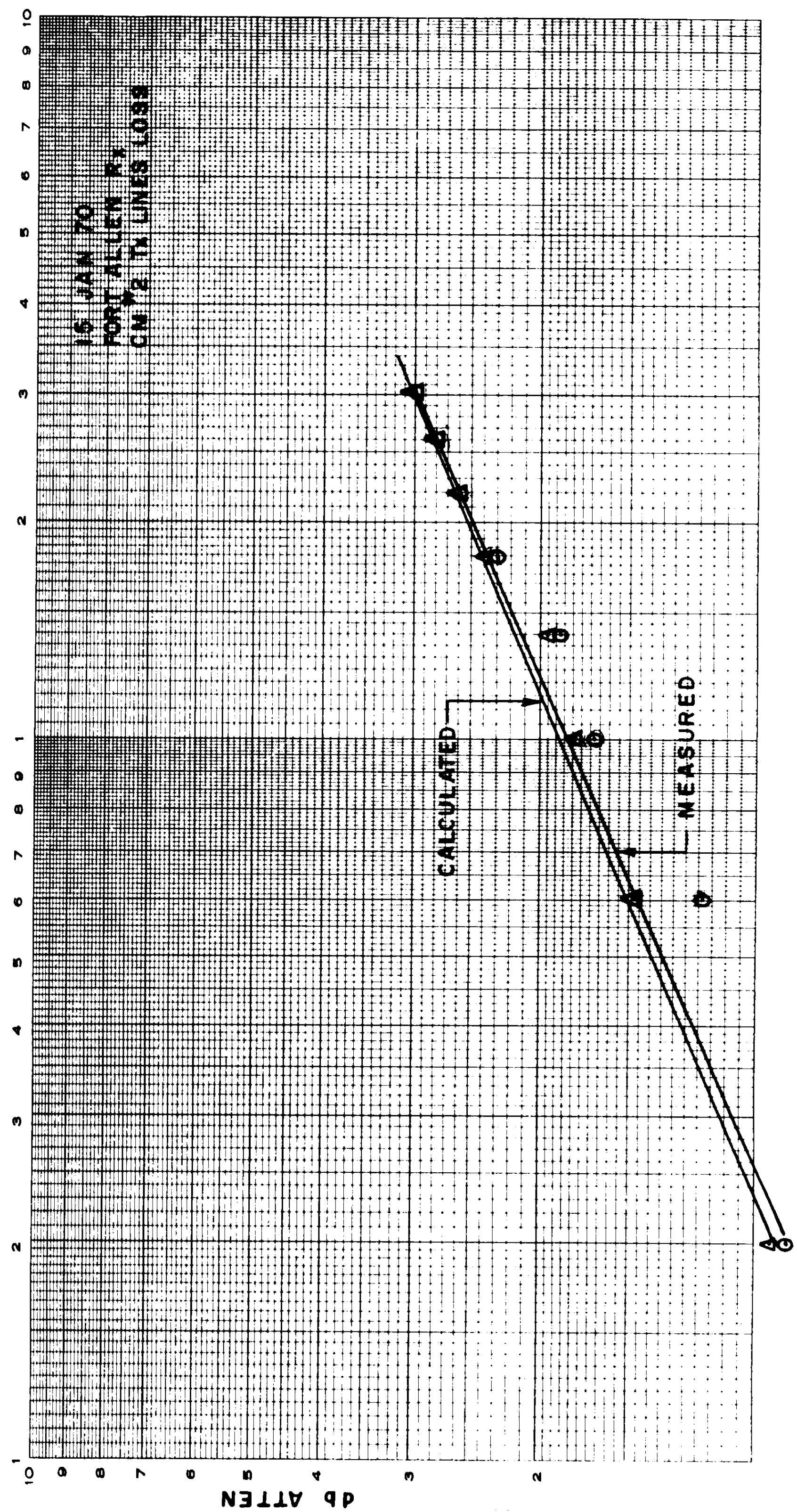


Figure 60b TRANSMISSION LINE LOSS - CALCULATIONS

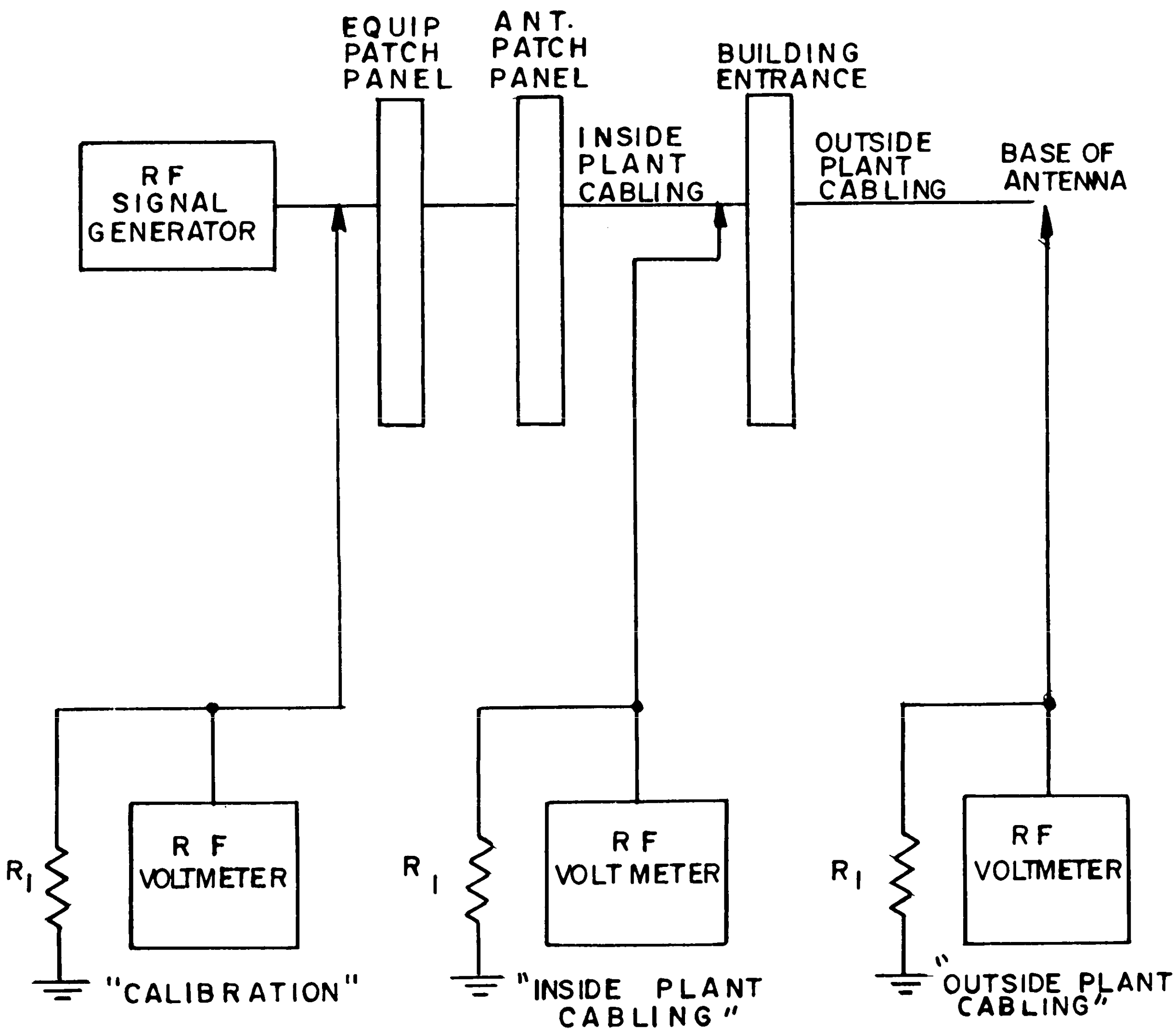


FIGURE 61. LINE ATTENUATION - E_{in}/E_{out} MEASUREMENTS

(b) Connect the RF Voltmeter to measure the voltage across R_1.

(c) Set the RF signal generator to the lowest frequency of the antenna - transmission line system. Adjust the output of the RF signal generator output level meter. Measure and record the voltage, as read on the RF voltmeter. Any differences should be noted for voltage corrections in the following steps.

(d) Repeat Step c but doubling the RF frequency for each reading in turn, until the highest frequency of the Antenna-Transmission Line is reached.

(e) If a Boonton Model 91CA or Hewlett Packard Model 411A RF Voltmeter is used, the readings can be taken directed in dB. This will greatly simplify the calculations. The RF signal generator should then be set to give a convenient reading on the RF voltmeter, say + 1.0 dBm (0.707 volts, 50 ohms). Calibration of the RF signal generator output meter versus frequency is now accomplished.

ATTENUATION MEASUREMENTS

(f) Connect the RF signal generator to the antenna side of the equipment patch panel or of the antenna matrix.

(g) Move the Termination (R,) and the RF Voltmeter to measure the RF voltage on the associated cable at the “building wall” antenna entrance.

(h) Disconnect the inside plant cable and connect to RI.

(i) Read and record voltage or dB m levels for each frequency of steps c-d.

(j) Reconnect the inside plant cables after each set of readings.

(k) This completes the test measurements of the “inside plant” transmission line(s).

(l) To convert the voltage readings to dB loss, one must convert the input RF voltage and the output or measured RF voltage into a ratio.

$$\frac{\text{RF Voltage in}}{\text{RF Voltage out}} = \text{ratio of voltage loss or attenuation}$$

To convert the voltage ratio to dB, refer to Figure 62 and read the dB loss for that ratio.

Voltage Ratio		Decibels (dB)
Gain	Loss	
1.01	0.989	0.1
1.02	0.977	0.2
1.04	0.966	0.3
1.04	0.955	0.4
1.06	0.944	0.5
1.07	0.933	0.6
1.08	0.923	0.7
1.10	0.912	0.8
1.11	0.902	0.9
1.12	0.891	1.0
1.15	0.863	1.2
1.18	0.851	1.4
1.20	0.832	1.6
1.23	0.813	1.8
1.26	0.788	2.0
1.29	0.776	2.2
1.37	0.759	2.4
1.35	0.741	2.6
1.38	0.724	2.8
1.41	0.707	3.0
1.50	0.668	3.5
1.58	0.633	4.0
1.68	0.600	4.5
1.78	0.562	5.0
1.88	0.531	5.5
2.00	0.501	6.0
2.24	0.447	7.0
2.51	0.398	8.0
2.82	0.355	9.0
3.16	0.316	10.0

FIGURE 62. VOLTAGE RATIO/dB CONVERSION TABLE

(m) The next step is the addition of the "outside" plant transmission lines, from the building wall to the base of the respective antennas, to the "inside" plant transmission lines.

(n) Move the termination (R_l) and the RF Voltmeter to the base of the associated antenna. Disconnect the transmission line at the base of or at the input feed point of the antenna. Connect the termination (R_l) and the RF voltmeter to the transmission line.

(o) Read and record voltage or dBmW levels for each frequency of steps c-d.

(p) Reconnect the transmission line to the antenna.

(q) Repeat for all appropriate antennas.

(r) Determine the total transmission line loss or attenuation in dB as set forth previously. See Figure 63.

(s) It is recommended that the measured loss be also plotted on the same graph paper as the computed loss. See Figure 60.

(3) Make impedance measurements with line terminated in a short (or open).

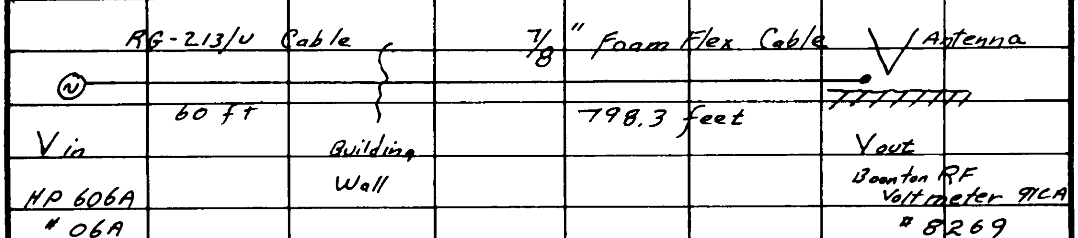
(a) Use the Rho Detector procedure to determine the frequencies where the magnitude of the reflection coefficient is at a minimum. The frequencies where Rho is at a minimum, indicates that phase angle, **θ,** is 180° (for a short) or 0° (for an open).

(b) Measure the impedance of the transmission line at each frequency using the RF Bridging procedure. Note: If the line is of such length where **Δf** (see discussion on determination of line length) is less than 2 Megahertz, then the measurement frequencies should be spaced across the frequency band of the antenna.

R_x Matrix to 437C-1A Antenna, 858.3 ft. — FT. Allen, 15 Jan 70

Frequency in MHz	Voltage in	Voltage Correction (RF Voltmeter)	Voltage out (as read)	Voltage out (corrected)	Vout/Vin	dB meas	dB Calculated
2	1.00 V	+0.030	0.870	0.900	0.900	0.9	0.95
6	1.00 V	+0.025	0.835	0.860	0.860	1.2	1.5
10	1.00 V	+0.025	0.795	0.820	0.820	1.7	1.8
14	1.00 V	+0.020	0.775	0.795	0.795	1.9	2.0
18	1.00 V	+0.020	0.745	0.765	0.765	2.3	2.4
22	1.00 V	+0.030	0.700	0.730	0.730	2.6	2.6
26	1.00 V	+0.030	0.682	0.712	0.712	2.8	2.8
30	1.00 V	+0.030	0.670	0.700	0.700	3.0	3.0

SET-UP:



Note: Voltage measurements were not made at the building wall.

FIGURE 63. TRANSMISSION LINE LOSS MEASUREMENT-VOLTAGE

(c) Plot the Impedance points on a SMITH CHART. The points should be on or very near the Resistance Axis.

(d) Determine the SWR for each plotted impedance point.

(e) Determine the attenuation of the transmission line by transferring the radius of the SWR circle to the external scale, transmission loss - 1 dB steps. See Figure 64.

(f) It is recommended that the measured loss be also plotted on the same graph paper as the computed loss.

b. Impedance Discontinuities With the Line Terminated in its Characteristic Impedance.

(1) The TDR measurement procedures are used to determine the impedance discontinuities of the transmission line. It may be helpful to terminate the line in a mismatch so that the end of the transmission line can be positively identified. This will also aid in the determination of the line length. (See Figures 42 and 43.

c. Line Length.

The determination of the line length can be accomplished by either the use of the TDR procedures or the RHO detector, Δf measurements, See Figure 43 (TDR) and Figure 65 (Δf).

d. Dielectric Strength.

The determination of the Dielectric Strength or Insulation Resistance (IR) values of a Transmission Line can also determine the ability of the line to withstand application of RF Voltage. The requirement for maintenance can also be identified by comparing the current IR readings to the baseline readings of the transmssion line.

98.5 feet of RG-58 Cable					
FREQUENCY MHZ	"SHORTED" Cable 1/SWR	SWR	ATTENUATION IN DB	"OPEN" Cable SWR	ATTENUATION IN DB
3.25	0.08	12.5	0.7	13.0	0.6
6.50	0.14	7.15	1.25	6.8	1.35
9.75	0.20	5.0	1.75	5.8	1.50
13.00	0.23	4.35	2.075	4.4	2.05
16.25	0.25	4.0	2.25	4.1	2.15
19.50	0.26	3.84	2.35	3.9	2.30
22.75	0.29	3.45	2.6	3.8	2.50
26.00	0.32	3.12	2.95	3.3	2.75

FIGURE 64. TRANSMISSION LINE LOSS MEASUREMENT-IMPEDANCE

Physical length of RG-58 cable = 100.0 feet

f_2	f_1	"Δf" $f_2 - f_1$		length $L = \frac{328}{\Delta f}$			
Cable Terminated with a "Short"							
4.893	1.592	3.301		99.5			
8.161	4.893	3.268		100.1			
11.436	8.161	3.275		100.1			
14.726	11.436	3.290		99.6			
18.033	14.726	3.307		99.5	average =		99.7 feet
21.303	18.033	3.270		100.1			
24.584	21.303	3.281		100.0			
27.900	24.584	3.316		99.0			
31.213	27.900	3.313		99.0			
Cable terminated with an "Open"							
6.489	3.233	3.256		100.8			
9.819	6.489	3.330		98.5			
13.079	9.819	3.260		100.7			
16.378	13.079	3.300		99.5			
19.699	16.378	3.321		98.7	average =		99.5 feet
22.972	19.699	3.273		100.1			
26.292	22.972	3.320		98.7			
29.612	26.292	3.320		98.7			

FIGURE 65. TRANSMISSION LINE LENGTH DETERMINATION-Δf METHOD

The DC potential should be greater than the applied RF Voltage, peak to peak, with a SWR of 2:1.

The following chart presents the voltage relationship:

T_x Power	RF Voltage$_{RMS}$ 2:1 SWR	RF Voltage Peak to Peak	Recommended -0 DC Voltage for IR Test
1 KW	316 volts	950 volts	1.5 KV
10 KW	1,000 volts	2,828 volts	4.0 KV
40 KW	2,000 volts	5,656 volts	10.0 KV

For receiving systems, it is customary to use a DC Voltage of 500 volts.

(1) Low Voltage IR Measurements (500 Volts DC)

The Low Voltage IR measurements are applicable to receiving antenna-transmission line systems.

The test set up would be as follows:

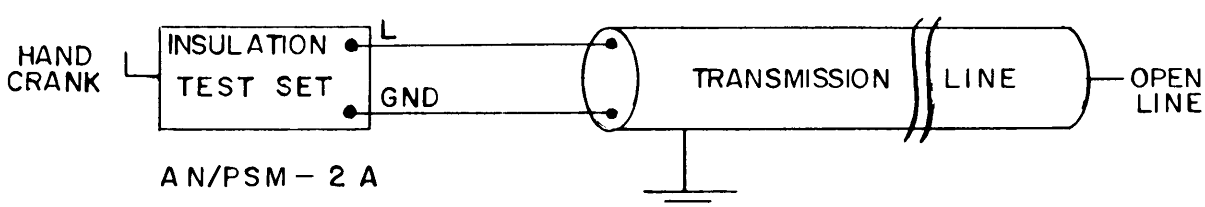


FIGURE 66. IR SET UP FOR LOW VOLTAGE MEASUREMENTS

The initial set up/calibration method would be as follows:

SET UP:

(a) The meter point should read infinite resistance (∞) when there are no external connections to the output binding posts "L" and "GND". If the meter does not read ∞, refer to the instruction manual.

(b) Place a direct short between binding posts "L" and "GND" - use one of the test leads.

(c) Turn the crank in either direction at operating speed which is indicated when the indicator buttons or bulbs glow steadily.

(d) Read the meter. The meter pointer should be over the zero mark. If not, refer to the instruction manual.

(e) Remove the connection from Terminals “L” to “GND”.

CALIBRATION:

(f) Alternately connect noninductive resistors, of 0.5, 7.5, 5.0, 10.0 and 100 megohm values, between the binding posts “L” and “GND”. Proceed as in “c” above.

(g) The meter readings should correspond to the value of the resistor being tested, ± 2 1/2 %.

IR MEASUREMENTS:

(h) Be sure that the transmission line is disconnected at the antenna input or balun input.

(i) Connect the black lead spade type terminal lug to the “GND” binding post on the ohmmeter.

(j) Connect the black lead alligator clip to the ground side of the transmission line.

(k) Connect the red lead spade type terminal lug to the “L” binding post on the ohmmeter.

(l) Connect the red lead alligator clip to the center conductor of the transmission line.

(m) Turn crank in either direction at the minimum speed reaquired to provide steady illumination of the indicator lamps.

(n) Read and record the megohms of the insulation resistance of the transmission line. If the resistance is more than 1000 megohms, the meter pointer will stay at rest over the infinity mark.

(2) High Voltage IR Measurements (up to 10,000 Volts DC).

The high voltage IR measurements are applicable to transmitting antenna-transmission line systems.

The test set up would be as follows:

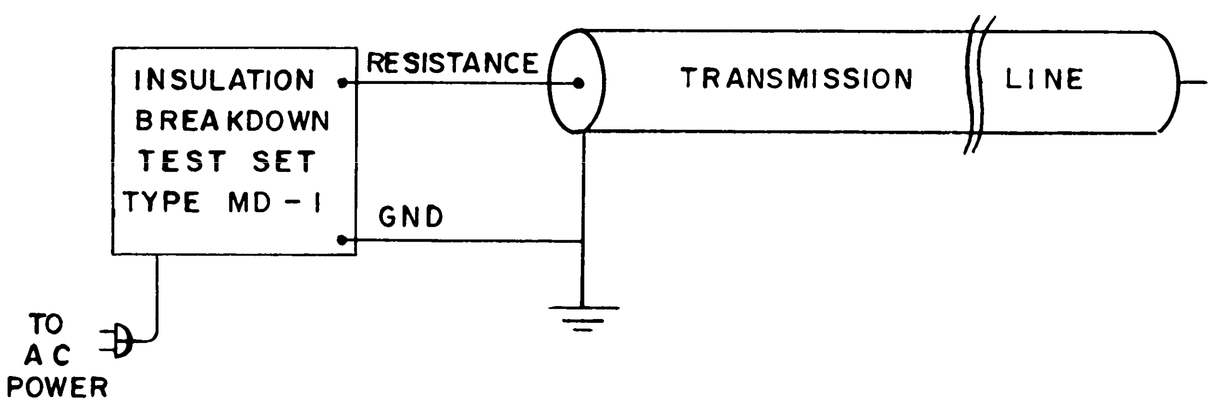


FIGURE 67. IR SET UP FOR HIGH VOLTAGE MEASUREMENTS

The initial set up/calibration method would be as follows:

SET UP:

(a) Connect the qround cable assembly to the ground binding post and to the ground portion of the transmission line.

(b) Check the zeroing of both meters. Adjust if necessary by rotating the zero adjust screws on the face of the meters.

(c) Set “On-Off” switch (Hi Voltage) and Voltage Control (Level) to Of f.

(d) Connect the test set to the prime power. The input power pilot lamp should be lit.

(e) Set current range switch to shunt (off). Set voltage range switch to “lot Kilovolts”. Turn “ON-OFF” Hi voltage switch to ON. Turn voltage control clockwise and the “kilo volt meter” should read up scale. Do not turn the voltage control be.vend full scale reading. Return voltage control to off position.

(f) Set voltage range switch to 15 KV. Rotate voltage control clockwise and observe the kilovoltmeter; full scale deflection should be obtained. As the voltage is increased beyond this point, the self protect spark gap will fire (can also be heard) and the voltage will drop to between 12 and 16 kilovolts. Return voltage control to off position.

CALIBRATION:

(g) Connect high voltage cable assembly to "resistance jack" and to ground of the case. Rotate voltage control clockwise until the kilo voltmeter reads 10 KV (red line). Turn microammeter range switch from shunt to 500. The reading should be 100 microamperes on the current meter. If this is satisfactory, turn meter range to 100 microampere and the meter should now read full scale. Return voltage control to zero.

IR MEASUREMENTS:

(h) Make sure the high voltage switch is off and voltage control is fully counterclockwise at the “off” position before connecting the Resistance lead to the center conductor of the transmission line.

(i) Set current range switch to off (shunt) position. Set voltage range switch to "1.5 KV" for low voltage test or to "15 KV" for high voltage test. Slowly rotate the voltage control clockwise until the desired voltage is reached. If there is no indication of breakdown, then rotate microammeter range switch to 500 (if the reacting is less than 100 microamperes, to 100 range).

(j) Note and record the voltage setting and the current. The IR value may be calculated by ohms law. (Note: On the resistance jack, it is impossible to obtain more than 150 microampere due to the internal resistance in the test set). After the resistance is calculated:

$$\text{Resistance} = \frac{\text{Volts}}{\text{Current}} \quad \text{or Megohms} = \frac{\text{Volts}}{\text{Microamperes}}$$

Deduct 100 megohms from the calculated value to obtain the IR of the transmission line.

(k) To facilitate the resistance measurements, the chart in the lid of the test set is calibrated to give the resistance directly when 10 KV is applied to the line. To use this chart: 1. Increase the voltage to 10 KV, 2. Read the current, 3. Enter the chart with this value of current, and 4. Read the resistance of the test specimen in megohms. On this chart, the internal resistance has already been deducted from the total resistance.

8. Antenna Only Measurements.

a. Impedance Measurements.

The RHO Detector procedure and the RF Bridqe procedures are used to determine the input impedance values at the minimum - maximum SWR points in the SWR versus frequency plot. See Antenna - Transmission Line System, Impedance measurements, Paragraph 6, for actual impedance plots of typical antenna.

b. Determination of SWR.

The SWR of an antenna can be determined from impedance measurements or from swept frequency measurements. See Antenna - Transmission Line System, Determination of input SWR measurements.

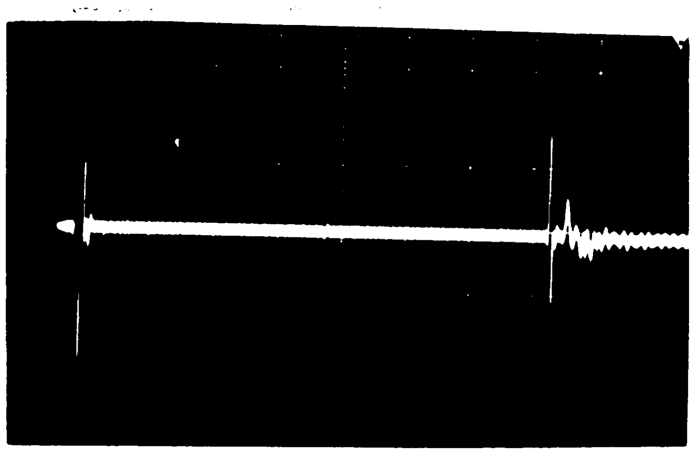
c. Impedance Discontinuities.

The impedance discontinuities of an antenna may also be shown by the use of TDR measurements. Different types of antennas will have a characteristic signature. For Low Power TDR displays, see Figure 43. For High Power TDR displays, see Figures 68a, b and c.

1. Grangers Associates Model 794-20 Omnidirectional Antenna with balun input

* Note Cable Splice

** Note large inductive display because of input coil for D.C. Continuity (in balun)



2. Above antenna, display expanded at antenna

* Note capacitive display because of coupling capacitor in the balun.

** Note the inductive Nature of the antenna, itself at low frequencies.

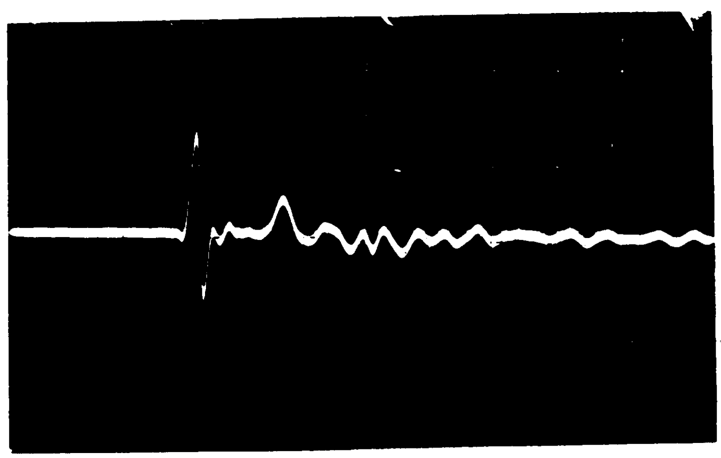
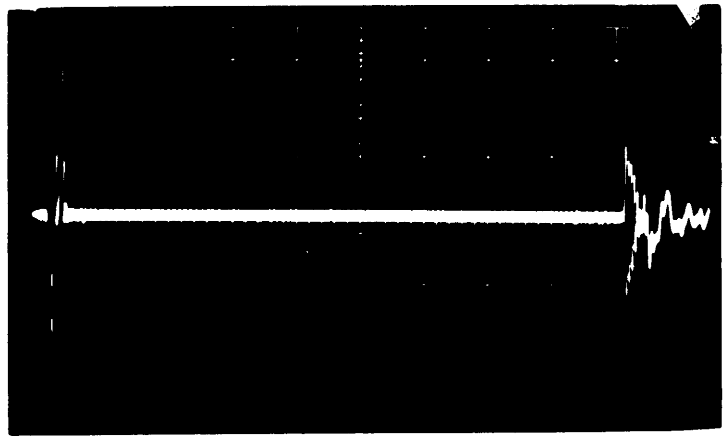


FIGURE 68A. HIGH POWER TDR DISPLAYS

1. Collins Model 237B-3 Directional Antenna

* Good Transmission Line Splice

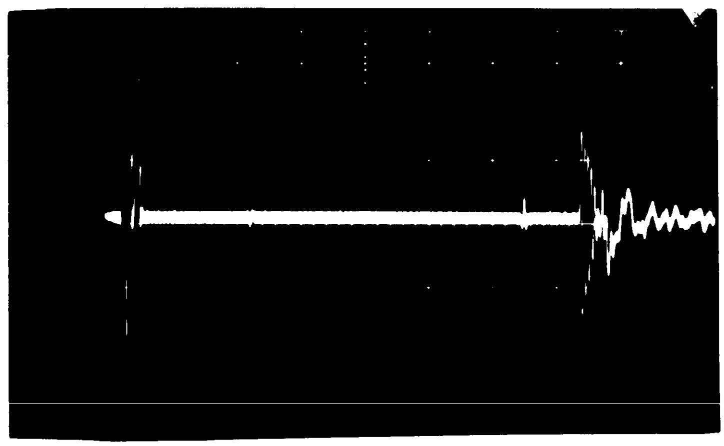


*

2. 237B-3 Antenna

* Splice

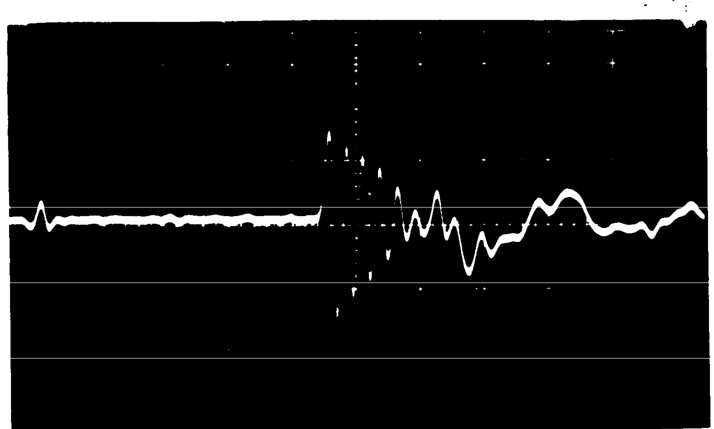
** Poor Splice



* **

3. 237B-3 Antenna, display expanded at antenna

1. Poor Splice (see2.)
2. Base of Towers (rotator)
3. Top of Tower - elbow
4. Input to balun
5. Input to array (note inductive)

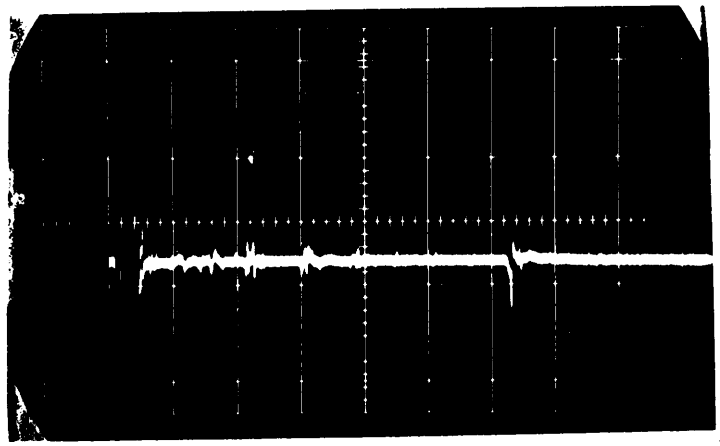


1 2 3 4 5

FIGURE 68B. HIGH POWER TDR DISPLAYS

a. Rhombic Antenna

1. Dissipation line
Termination (short)



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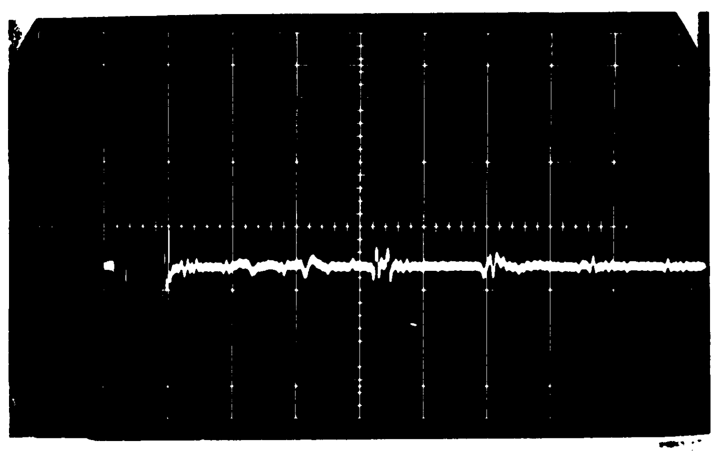
b. Rhombic Antenna
display expanded
to identify details

1. 600 Ω line supports
2. Turn in the 600 Ω line
3. Input to balun
4. Input to antenna
5. Side towers & support insulators
6. End of rhombic antenna
7. Input to dissipation line
8. Dissipation line, fold back



111 2 3 4 5 6 7 8

FIGURE 68C. HIGH POWER TDR DISPLAYS

SECTION VI

TEST EQUIPMENT

The present test equipment complement is inadecuate, both in quantity and quality, to maintain the required performance of the antenna - transmission line systems. Everything else being equal, the performance/maintenance of an antenna - transmission system is dependent upon the supporting test equipment. If the supporting test equipment is of low quality or inadequate to do the required maintenance, then the performance of the antenna - transmission system must of necessity be of low quality. The low performance of a critical system in the communication circuit, will be evidenced by low reliability of the communication circuit.

It is recommended that the test equipment complement (unit authorization list - UAL) be increased to include the following:

1. RHO Detector - Telonic VSWR Kit: Model TRB-1. (This model is recommended because it will handle up to 1 watt of RF power - 7.07 volts).

2. HF Bridge - Delta Electronics; Model OIB-2. (This Model is recommended because it is simple to operate and can either be operated as a normal bridge or as a high power bridge - up to 1 KW of power).

3. Return Loss Measurements - Hewlett Packard Spectrum Analyzer and Directional Bridge; consisting of Display Section, Model 141T; RF Section, Model 8553B, IF Section, Model 8552B, Tracking Generator - Counter, Model 8443A, and Directional Bridge, Model 8721A. (This model is recommended because of its ability to handle high levels of RF pick up on the antenna - transmission line system - up to 5 volts, is simple to operate, and can be used for many other functions).

4. TDR Measurements Low Power	- Tektronix Scope 545 or equal. (This item should be available or on the UAL).
5. TDR Measurements High Power	- Delta Electronics; Model PRH-1. (This model is recommended because of the high voltage pulse output - up to 5 KV).
6. IR Measurements (Low Power)	- Holtzer Cabot; ohmmeter Model ZM-14A/ PSM-2A, Stock No. 6625-643-2250.
7. IR Measurements (High Power)	- General Meters, Inc.; Insulation Breakdown Test Set Model MD-1, Stock No. 6625-575-4625.
8. Line Attenuation Measurements	- Hewlett Packard RF Signal Generator, Model 606A (This item should be on the UAL) and Hewlett Packard RF Voltmeter Model 411A.

SECTION VII

SUMMARY

The current maintenance - evaluation procedures of the antenna - transmission line systems are inadequate to maintain the required system performance. Actual evaluation and analysis of communication circuit performance confirms the inadequacy of the system maintenance. The substandard electrical performance of the antenna - transmission line system results in the loss of the communication system margin for reliability and in turn, a marginal circuit with low reliability and excessive outage time. Unfortunately, this low reliability and excessive outage time has been normally charged against propagation outage rather than antenna - transmission line deficiencies.

Various test methods, procedures, and test equipment were used and evaluated in several operational environments. This report presents the results of the evaluation - analysis in the form of detailed test methods, procedures and test equipment. To enhance the use of the recommended tests and subsequent evaluation, applicable antenna concepts, transmission line concepts, and the SMITH CHART are discussed in detail.

It is recommended that the proposed test procedures and methods be incorporated into the current antenna - transmission line maintenance procedures.

REFERENCES

1. “Reference Data for Radio Engineers”, Fifth Edition, ITT.

2. Mil-Hdbk-216, titled “RF Transmission Lines and Fittings”.

3. “Solid Dielectric Transmission Lines”, Electronic Industries Association Standard RS-199, Dec. 1957.

4. “Electronic Applications of the Smith Chart” by Philip H. Smith.

ACKNOWLEDGMENTS

Appreciation is gratefully acknowledged for the technical support and background data on antenna measurements offered by Mr. J. Dylis - Hewlett Packard, Mr. K. Owens - Delta Electronics, Mr. R. Bell - Collins Radio Co., Mr. F. Davis - Antenna Products Co., Mr. F. Phillips - Granger Associates, and Mr. J. Walsh - Hy - Gain Electronics Corp.. In addition appreciation is acknowledged for the excellent support of Hq AFCS personnel , in particular SMSgt R. White, and of the 2045th Communications Group, particularly 1st Lt. John Ausen and 1st Lt. Ken Barbi.

Custodian	Preparing Activity
Air Force - 17	Air Force - 17

APPENDIX A

Order Blank For Smith Calculator

The Amphenol RF Calculator is a valuable "tool" the modern engineer wants and needs. The nine-inch diameter plastic device has six moving parts, accurately imprinted and in precise alignment. One side is equivalent to a 28¼ inch long slide rule with nine common scales. The Smith Chart side relates the series components of impedance at any position along open-wire or coaxial transmission line to the impedance at any other point, standing wave amplitude ratio, and attenuation. Detailed instructions and a handy carrying case are included.

We pay postage and handling charges so unit price is only $3.00. To obtain your copy, complete order form and enclose in envelope with check or money order and send to:

AMPHENOL RF DIVISION
33 East Franklin Street
Danbury, Connecticut 06810
Attn: Ninon de Zara

AMPHENOL RF CALCULATOR

TM

RADIO TRANSMISSION LINE CALCULATOR (SMITH CHART) & CIRCULAR SLIDE RULE

Please RUSH (   ) Calculators by return mail @ $3.00/unit.

Enclosed is my ☐ check ☐ M.O. payable to AMPHENOL RF DIVISION in the amount of $____________.

NAME ______________________ TITLE ______________________

COMPANY ______________________

COMPLETE ADDRESS ______________________

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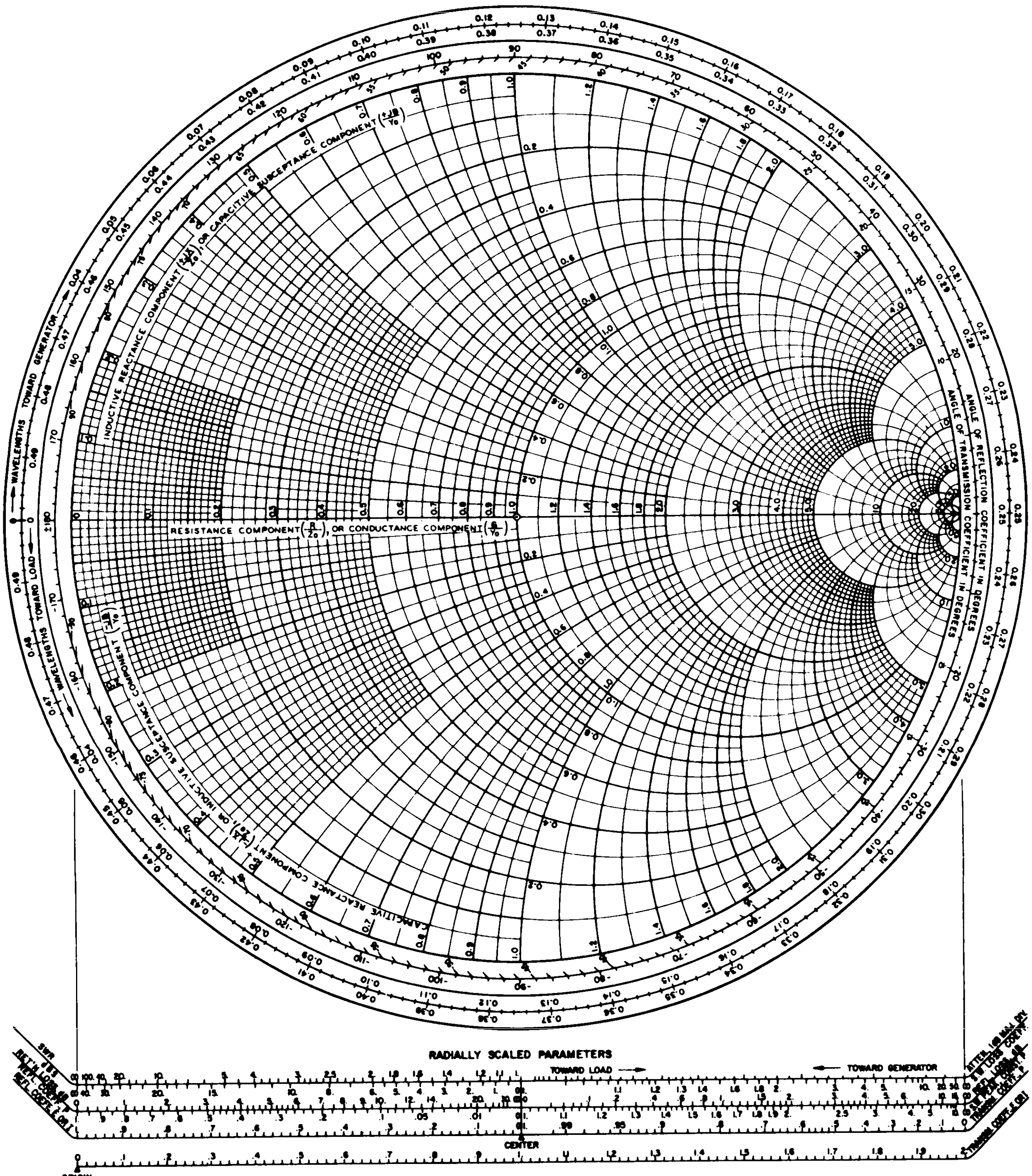
DATE ______________________ SIGNATURE ______________________

APPENDIX B

Samples of Smith Charts

NAME	TITLE	DWG. NO.
		DATE
SMITH CHART FORM 82-BSPR (9-66)	KAY ELECTRIC COMPANY, PINE BROOK, N.J. © 1966 PRINTED IN U.S.A.	

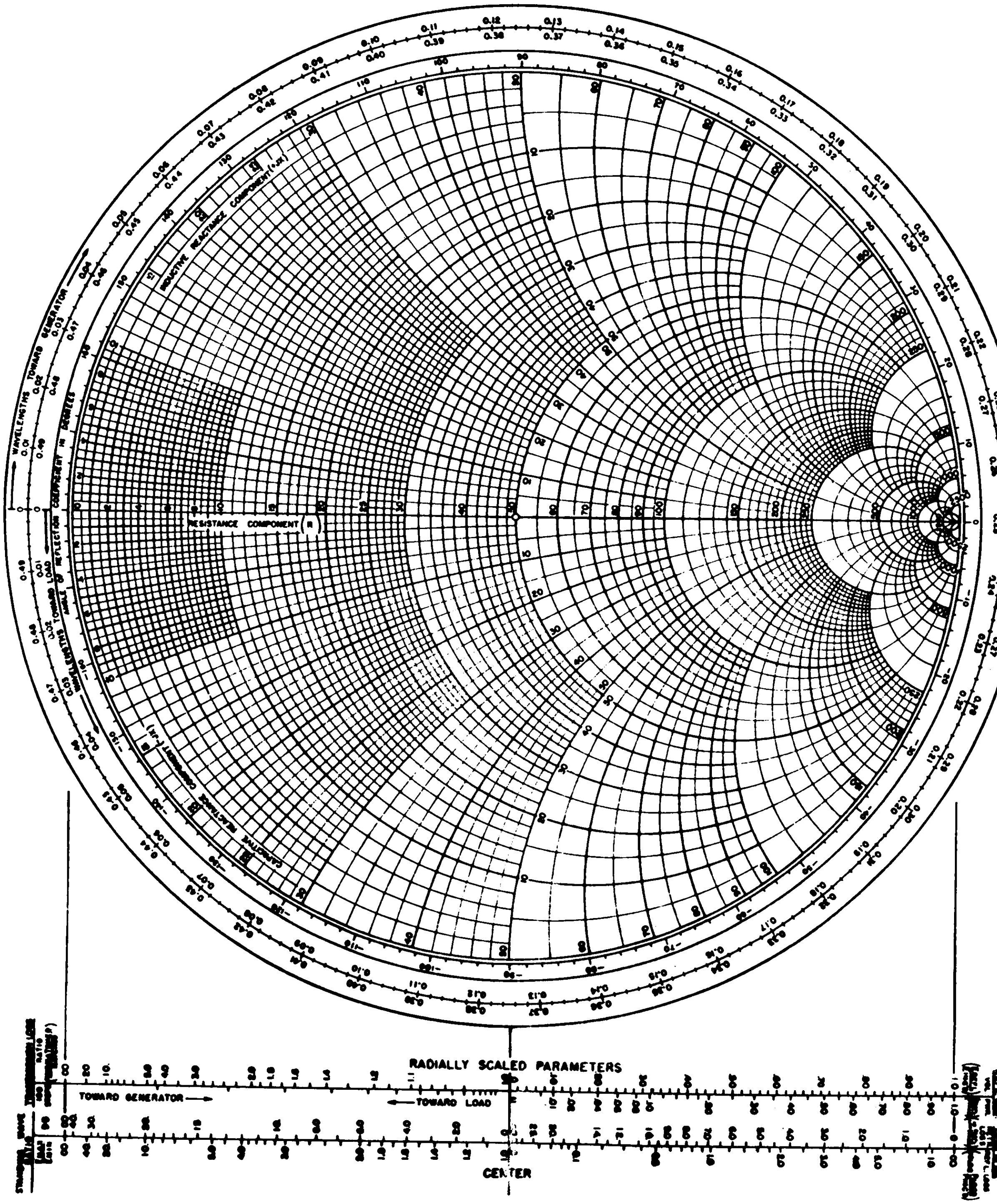
IMPEDANCE OR ADMITTANCE COORDINATES



TITLE

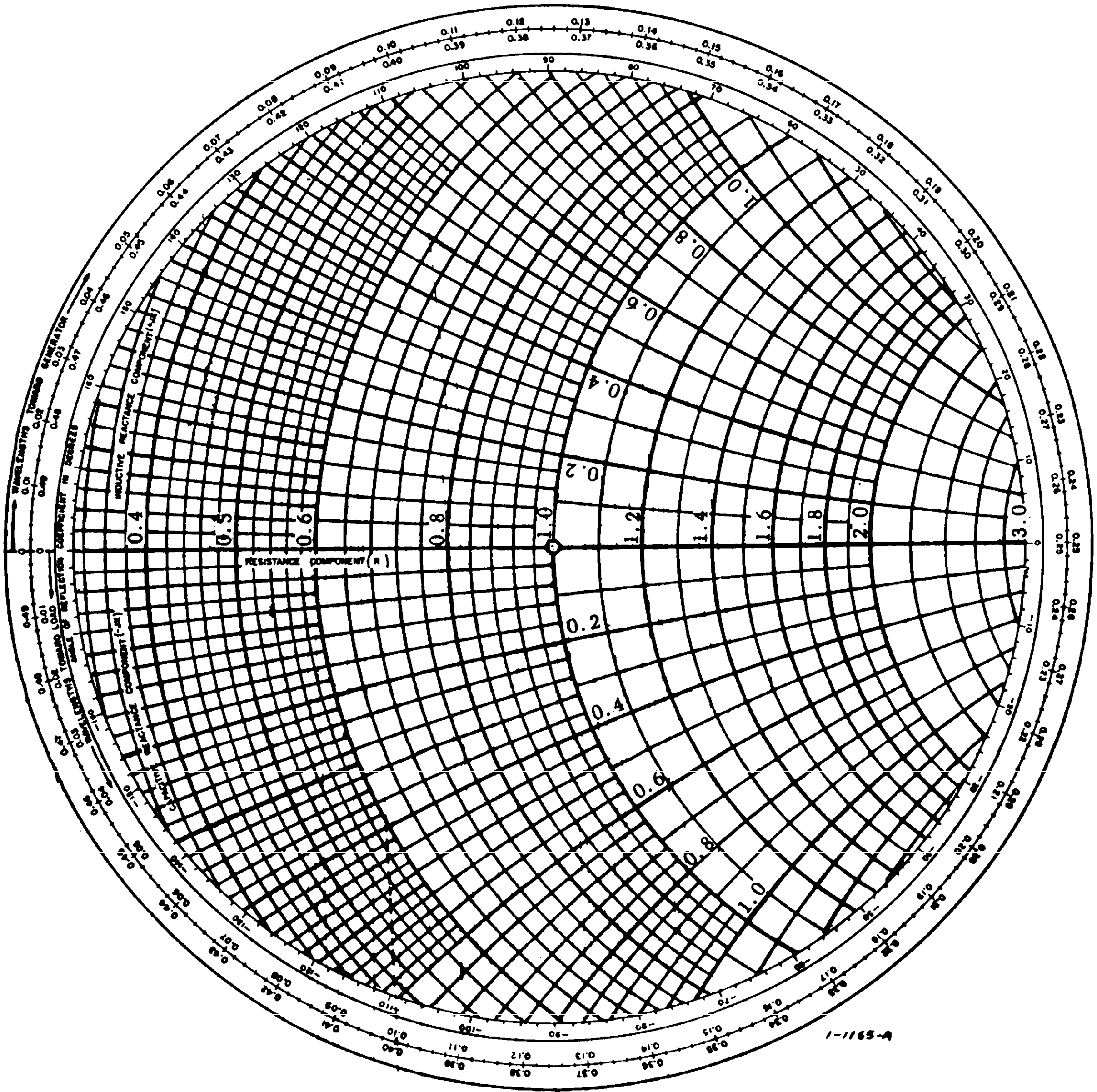
DATE

IMPEDANCE COORDINATES—50-OHM CHARACTERISTIC IMPEDANCE



NAME ____________________ TITLE ____________________ DATE ____________

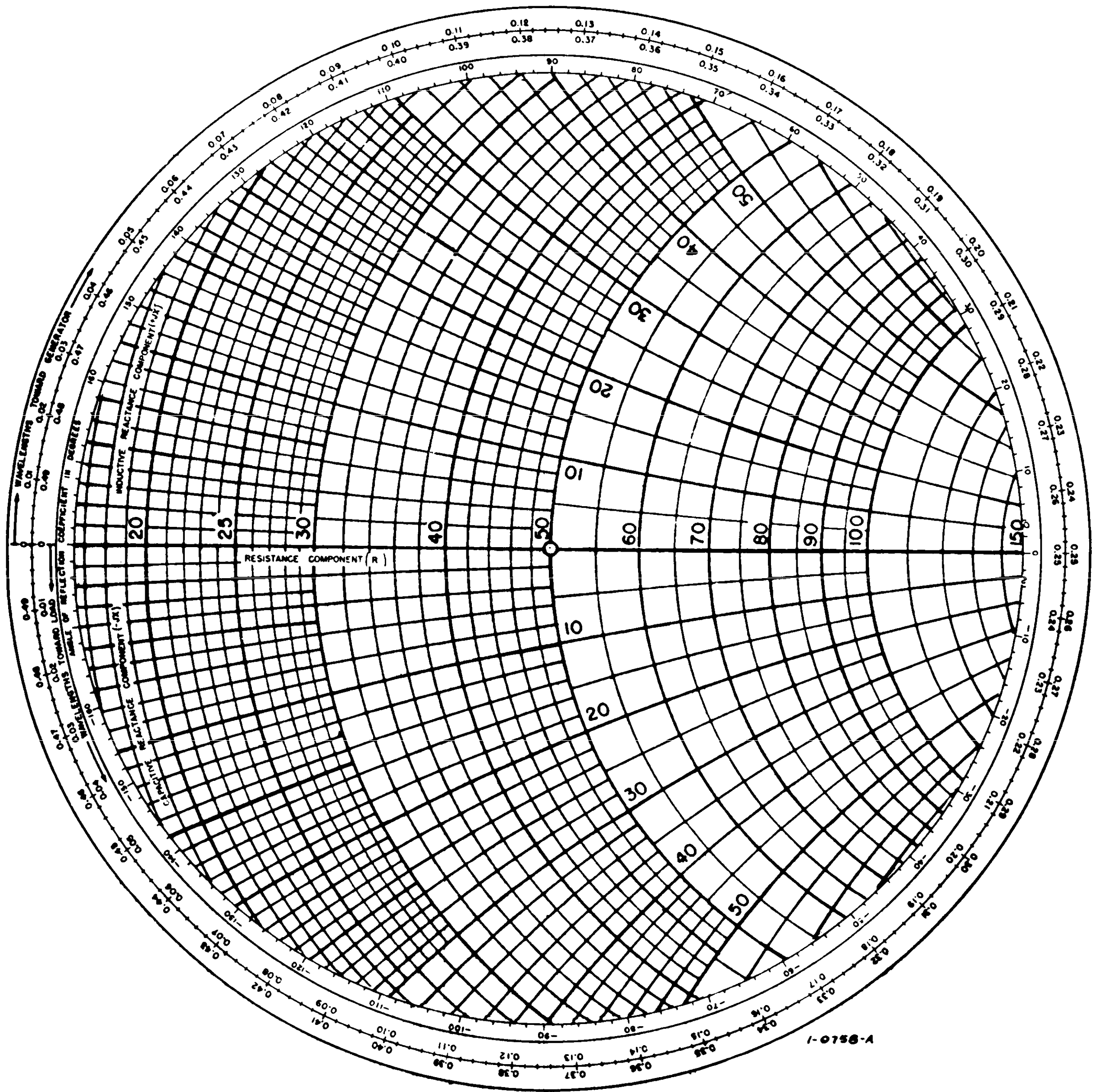
NORMALIZED IMPEDANCE COORDINATES -- CHARACTERISTIC IMPEDANCE ________



Electronics - VOL 17, NO. 1, PP.-130-133, 318-325, JAN. 1944

NAME ____________ TITLE ____________ DATE ____________

IMPEDANCE COORDINATES — 50 OHM CHARACTERISTIC IMPEDANCE



Electronics - VOL 17, NO. 1, PP-130-133, 318-325, JAN 1944