Smith-Chart Calculations for the Radio Amateur

Graphical Solutions of Transmission-Line Problems

PART I

BY GERALD L. HALL,* K1PLP, EX-KH6EGL

An earlier *QST* article by K6CRT [1] has created considerable interest among amateurs in the use of the Smith Chart. Now that the measurement of the resistive and reactive components of a complex impedance has been brought into the realm of possibility, even for an amateur with a limited budget,[2] still greater amateur interest in the Chart will undoubtedly develop.

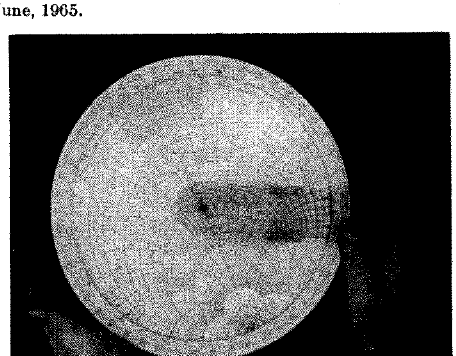
The Smith Radio Transmission-Line Calculator is named after its inventor, Phillip H. Smith, and was originally described in *Electronics* for January, 1939, where it was presented in cutout form. Radio development, during and since the war, has promoted considerable interest in this calculator among engineers and research workers, particularly in the field of u.h.f. where electrical measurements must be made indirectly. The Calculator has also proven itself useful in h.f. and v.h.f. work, because it eliminates the need for complex mathematical calculations in solving most transmission-line problems. Although its appearance may at first seem 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.

When a transmission line is not terminated in its characteristic impedance, standing waves will result, and the input impedance of the line will vary depending 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.

* Hopkins St., Wilmington, Mass. 01887.

[1] Cholewski, "Some Amateur Applications of the Smith Chart," *QST*, January, 1960.

[2] Strandlund, "Amateur Measurement of $R + jX$," *QST*, June, 1965.



The Smith Transmission-Line Calculator.

This article reviews the basic use of the Smith Chart and, in addition, discusses the external scales now provided on most versions of the Chart. These scales greatly simplify the calculations involved in line-loss considerations.

Because of the length of the article, it is divided into two parts. The second part will appear in an early issue.

Impedance Coordinate System

The 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 true Calculator assumes a form similar in appearance to a circular slide rule, but with different scales, of course. The Smith Calculator is available in durable plastic for a few dollars from the Emeloid Company, 1239 Central Ave., Hillside, N. J.

A perhaps more common form of the Calculator is the Smith Transmission-Line Chart, or merely Smith Chart, which is a printed copy of the Calculator coordinate system and its various scales. The fact that the scales are not movable on the printed charts offers only slight inconvenience over the true Calculator. An advantage of the printed Chart is that actual calculations may be kept for record or later checking — a feat which is impossible with the Calculator version. Smith Charts are available at most college bookstores for a few cents each, or from General Radio Company, West Concord, Mass.

The Smith Chart coordinate system consists simply of two families of circles — the resistance family and the reactance family. The *resistance circles* (Fig. 1) are centered on the *resistance axis* (the only straight line on the Chart), and are tangent to the outer circle at the bottom 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 have the same resistance value.

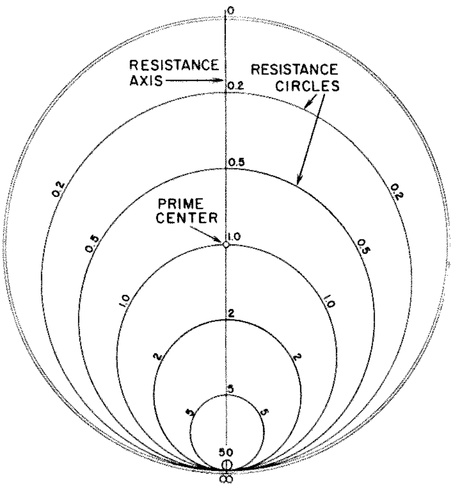


Fig. 1.

The values assigned to these circles vary from zero at the top of the chart to infinity at the bottom, and actually represent a ratio with respect to the impedance value assigned to the center point of the Chart, indicated 1.0. This center point is called *prime center.* If prime center is assigned a value of 100 ohms, then 200 ohms resistance 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 is assigned to prime center, the 2.0 circle now represents 100 ohms, the 0.5 circle 25 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 prime center. This process is called *normalizing.* Conversely, values from the Chart are converted back to actual resistance values by multiplying the Chart value times the value 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 may be. Specialized versions of the Smith Chart may be found with a value of 50 or 75 at prime center. These are intended primarily for use with 50- and 75-ohm lines, respectively.

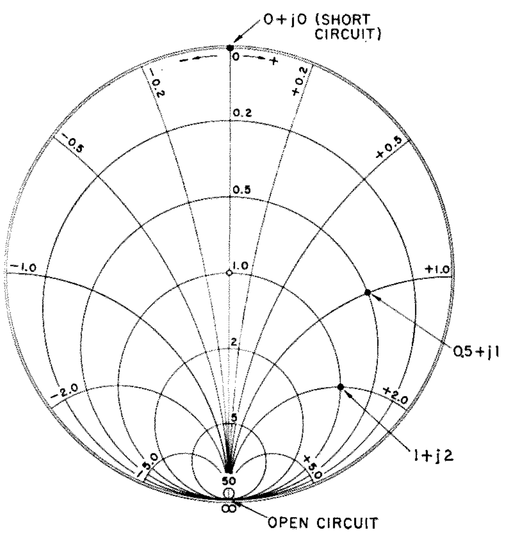


Fig. 3.

Now consider the *reactance circles* (Fig. 2) which appear as curved lines on the Chart because only segments of the complete circles are drawn. These circles are tangent to the resistance axis, which itself is a member of the reactance family (with a radius of infinity). The centers are displaced to the right or left on a line tangent to the bottom of the chart. The large outer circle bounding the coordinate portion of the Chart is the reactance axis.

Each reactance circle segment is assigned a value of reactance, indicated near the point where the circle touches the reactance axis. 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 prime center. Values to the right of the resistance axis are positive (inductive), and those to the left of the reactance axis are negative (capacitive).

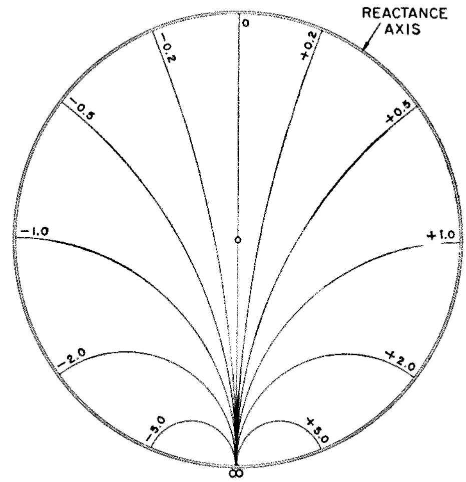


Fig. 2.

When the resistance family and the reactance family of circles are combined, the coordinate system of the Smith Chart results, as shown in Fig. 3. Complex series impedances can be plotted on this coordinate system.

Impedance Plotting

Suppose we have an impedance consisting of 50 ohms resistance and 100 ohms inductive reactance ($Z = 50 + j100$). If we assign a value of 100 ohms to prime center, we normalize the above impedance by dividing each component of the impedance by 100. The normalized impedance would then be $\frac{50}{100} + j\frac{100}{100} = 0.5 + j1.0$. This impedance would be plotted on the Smith Chart

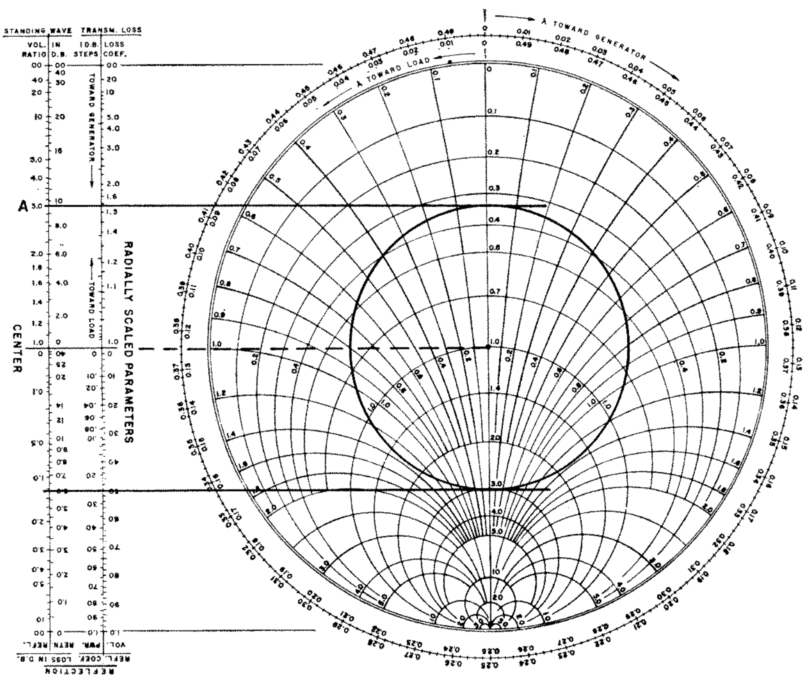


Fig. 5.

at the intersection of the 0.5 resistance circle and the +1.0 reactance circle, as indicated in Fig. 3. If a value of 50 ohms had been assigned to prime center, as for 50-ohm coaxial line, the same impedance would be plotted at the intersection of the $\frac{50}{50} = 1.0$ resistance circle, and the $\frac{100}{50} = 2.0$ positive reactance circle, or at $1 + j2$ (also indicated in Fig. 3). 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 prime center. It is customary when solving transmission-line problems to assign to 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 50-ohm line. The resistance and reactance values may be plotted directly.

Short and Open Circuits

While on the subject of plotting impedances, two special cases deserve consideration. These are short circuits and open circuits. A true short circuit has zero resistance and zero reactance, or $0 + j0$. This impedance would be plotted at the top 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 bottom of the Chart, at the intersection of the resistance and reactance axes. These two special cases are sometimes used in determining line lengths, line losses, and line impedances.

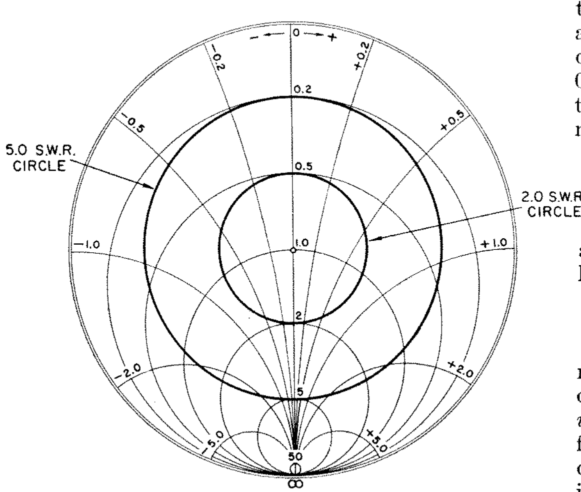


Fig. 4.

Standing-Wave Ratio Circles

Members of a third family of circles, which are not printed on the chart but which are added during the process of solving problems, are *standing-wave-ratio*, or *s.w.r., circles*. See Fig. 4. This family is centered on 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

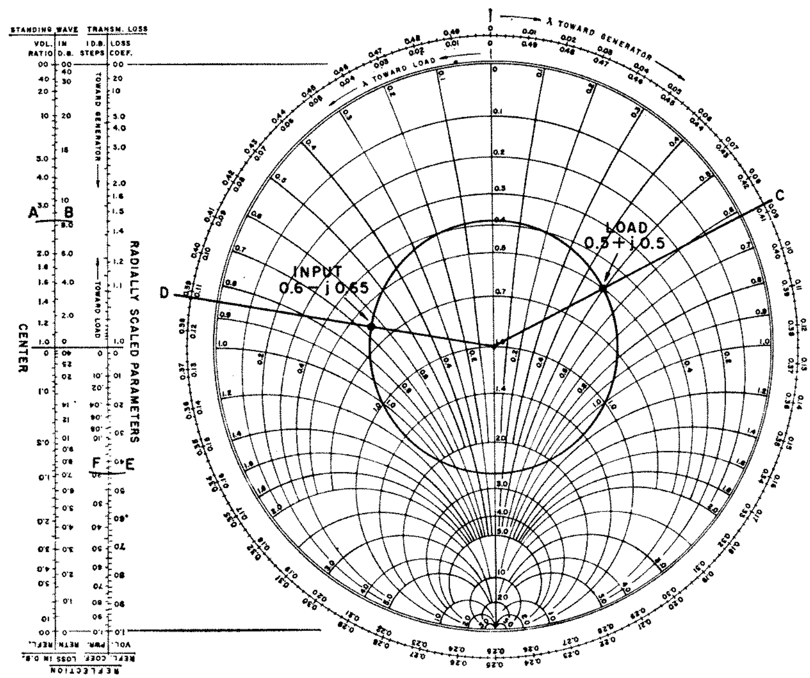


Fig. 6.

represents a value of s.w.r., every point on a given circle representing the same s.w.r. The s.w.r. value for a given circle may be determined directly from the chart coordinate system, by reading the resistance value where the s.w.r. circle crosses the resistance axis, below prime center. (The reading where the circle crosses the resistance axis above prime center indicates the inverse ratio.)

Consider the situation where a load mismatch in a length of line causes a 3-to-1 standing-wave ratio to exist. If we temporarily disregard line losses, we may state that the s.w.r. remains constant throughout the entire length of this line. This is represented on the Smith Chart by drawing a 3:1 constant-s.w.r. circle (a circle with a radius of 3 on the resistance axis), as in Fig. 5. The design of the Chart is such that any impedance encountered anywhere along the length of this mismatched line will fall on the s.w.r. circle, and may be read from the coordinates merely by progressing around the s.w.r. circle by an amount corresponding to the length of the line involved.

This brings into use the *wavelength scales*, which appear, in Fig. 5, near 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 counterclockwise, starts at the generator or input end of the line and progresses toward the load, while the other scale starts at the load and proceeds toward the generator in a clockwise direction. The complete circle represents one half wavelength. Progressing once around the perimeter of these scales corresponds to progressing along a transmission line for a half wavelength. Because impedances will repeat themselves every half wavelength along a piece of line, the Chart may be used for any length of line by disregarding or subtracting from the line's total length an integral, or whole number, of half wavelengths.

Also shown in Fig. 5 is a means of transferring the radius of the s.w.r. circle to the external scales of the chart, by drawing lines tangent to the circle. Or, the radius of the s.w.r. circle may be simply transferred to the external scale by placing the point of a drawing compass at the center, or 0, line and inscribing a short arc across the appropriate scale. It will be noted that when this is done in Fig. 5, the external STANDING-WAVE VOLTAGE-RATIO scale indicates the s.w.r. to be 3.0 (at A) — our condition for intially drawing the circle on the Chart (and the same as the s.w.r. reading on the resistance axis).

Solving Problems with the Smith Chart

Suppose we have a transmission line with a characteristic impedance of 50 ohms, and an electrical length of 0.3 wavelength. Also, suppose 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 desire to determine the input impedance to the line. Because the line is not terminated in its characteristic 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 (Z_0 of the line being used). The normalized impedance in this case is $0.5 + j0.5$. This is plotted on the Chart at the intersection of the 0.5 resistance and +0.5 reactance circles, as in Fig. 6. Then draw a constant-s.w.r. circle passing through this plotted point. The radius of this circle may then be transferred to the external scales with the drawing compass. From the external S.W.V.R. scale, it may be seen (at A), that the voltage ratio of 2.6 exists for this radius, indicating that our line is operating with an s.w.r. of 2.6 to 1. This figure is converted to decibels in the adjacent scale, where 8.4 db. may be read (at B), indicating that the ratio of the voltage maximum to the voltage minimum along the line is 8.4 db.

Next, with a straightedge, draw a radial line from prime center through the plotted point to intersect the wavelengths scale, and read a value from the wavelengths scale. Because we are starting from the load, we use the TOWARD-GENERATOR or outermost calibration, and read 0.088 wavelength (at C). To obtain the line input impedance, we merely find the point on the s.w.r. circle which is 0.3 wavelengths toward the generator from the plotted load impedance. This is accomplished by adding 0.3 (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 TOWARD-GENERATOR scale (at D), and draw a second radial line from this point to prime center. The intersection of the new radial line with the s.w.r. circle represents the line input impedance, in this case $0.6 - j0.65$. To find the actual line input impedance, multiply by 50 — the value assigned to prime center, which equals $30 - j32.5$, or 30 ohms resistance and 32.5 ohms capacitive reactance. This is the impedance which a transmitter must match if such a system were a combination of antenna and transmission line, or is the impedance which would be measured on an impedance bridge if the measurement were taken at the line input.

In addition to the line input impedance and the s.w.r., the Chart reveals several other operating characteristics of the above system of line and load, if a closer look is desired. For example, the voltage reflection coefficient, both magnitude and phase angle, for this particular load is given. The phase angle is read under the radial line draw through the plot of the load impedance where the line intersects the ANGLE-OF-REFLECTION-COEFFICIENT scale. This scale is not included in Fig. 6, but will be found on the Smith Chart, just inside the wavelengths scales. In this example, the reading would be about 116.5 degrees. This indicates the angle by which the reflected voltage wave lags the incident wave at the load. It will be noted that angles on the left half, or capacitive-reactance side, of the Chart are negative angles, a "negative" lag indicating that the reflected voltage wave actually leads the incident wave.

The magnitude of the voltage-reflection-coefficient may be read from the external REFLECTION-COEFFICIENT-VOLTAGE scale, and is seen to be approximately 0.44 (at E) for this example, meaning 44 per cent of the incident voltage is reflected. Adjacent to this scale on the POWER calibration, it is noted (at F) that the power reflection coefficient is 0.20, indicating that 20 per cent of the incident power would be reflected. QST

Smith-Chart Calculations for the Radio Amateur - Part 2

QST February 1966, pp. 30-33

Part 1 appears in QST January 1966, pp. 22-26 (http://www.arrl.org/tis/info/pdf/16622.pdf)
Part 2 appears in QST February 1966, pp. 30-33 (http://www.arrl.org/tis/info/pdf/26630.pdf)

Smith-Chart Calculations for the Radio Amateur

PART II[1]

BY GERALD L. HALL,* K1PLP, EX-KH6EGL

Determining Actual Antenna Impedances

To determine an actual antenna impedance from the Smith Chart, the procedure is similar. The electrical length of the feed line must be known, and the impedance value at the input end of the line must be determined through measurement. In this case, the antenna is connected to the far end of the line and becomes the load for the line. Whether the antenna is intended purely for transmission of energy, or purely for reception makes no difference; the antenna is still the terminating or load impedance on the line as far as these measurements are concerned. The *input* or *generator* end of the line would be that end connected to the device for measurement of the impedance. In this type of problem, the measured impedance is plotted on the Chart, and the TOWARD-LOAD wavelengths scale is used in conjunction with the electrical line length to determine the actual antenna impedance.

For example, assume we have a measured input impedance to a 50-ohm line of $70 - j25$ ohms. The line is 2.35 wavelengths long, and is terminated in an antenna. We desire to determine the actual antenna impedance. Normalize the input impedance with respect to 50 ohms, which comes out $1.4 - j0.5$, and plot this value on the Chart. See Fig. 7. Draw a constant-s.w.r. circle through the point, and transfer the radius to the external scales. The s.w.r. of 1.7 may be read from the S.W.V.R. scale (at A). Now draw a radial line from prime center through this plotted point to the wavelengths scale, and read a reference value, which is 0.195 (at B), on the TOWARD-LOAD scale. Remember, we are starting at the *generator* end of the transmission line.

To locate the load impedance on the s.w.r. circle, we add the line length, 2.35 wavelengths, to the reference value from the wavelengths scale, and locate the new value on the TOWARD-LOAD scale; $2.35 + 0.195 = 2.545$. However, the calibrations extend only from 0 to 0.5, so we must subtract a whole number of half wavelengths from this value and use only the remaining value. In this situation, the largest integral number of half wavelengths that can be subtracted is 5, or 2.5 wavelengths. Thus, $2.545 - 2.5 = 0.045$, and the 0.045 value is located on the TOWARD-LOAD scale (at C). A radial line is then drawn from this value to prime center, and the coordinates at the intersection of the second radial line and the s.w.r. circle represent the load impedance. To read this value closely, some interpolation between the printed coordinate lines must be made, and the value of $0.62 - j0.18$ is read. Multiplying by 50, the actual load or antenna impedance is $31 - j9$ ohms, or 31 ohms resistance with 9 ohms capacitive reactance.

Problems may be entered on the chart in yet another manner. Suppose we have a length of 50-ohm line feeding a resonant quarter-wave vertical ground-plane antenna. Further, suppose we have an s.w.r. monitor in the line, and that it indicates an s.w.r. of 1.7 to 1. The line is known to be 0.95 wavelength long. We desire to know both the input and the antenna impedances.

From the data given, we have no impedances to enter onto the chart. We may, however, draw a circle representing the 1.7 s.w.r. See Fig. 8. We also know, from the definition of resonance, that the antenna presents a purely-resistive load to the line; i.e., no reactive component. Thus, the antenna impedance must lie on the resistance axis. By observing the Chart with only the s.w.r. circle drawn, we see two points which satisfy this requirement in Fig. 8. These points are $0.59 + j0$ and $1.7 + j0$. Multiplying by 50, these values represent 29.5 and 85 ohms resistance. This may sound familiar, because the *ARRL Handbook* tells us that when a line is terminated in a pure resistance, the s.w.r. in the line equals Z_R/Z_0 or Z_0/Z_R, where Z_R = load resistance and Z_0 = line impedance.

If we consider antenna fundamentals, we know that the theoretical impedance of the ground-plane antenna is approximately 36 ohms. We therefore can quite logically discard the 85-ohm impedance figure in favor of the 29.5-ohm value. This is then taken as the actual load-impedance value for the Smith Chart calculations. The line input impedance is found to be $0.64 - j0.21$, or $32 - j10.5$ ohms, after subtracting 0.5 wavelength from 0.95, and finding 0.45 wavelength on the TOWARD-GENERATOR scale. (The wavelength reference in this case is 0.)

Determination of Line Length

In the example problems given so far, the line length has conveniently been stated in wavelengths. The electrical length of a piece of line depends upon its physical length, the radio frequency under consideration, and the velocity of propagation in the line. If an impedance-measurement bridge is capable of quite reliable readings at high line-s.w.r. values, the line length may be determined through line input-impedance measurements with short- or open-circuit terminations. A more direct method is to measure the line's physical length and apply the value to a formula. The formula is:

* Hopkins St., Wilmington, Mass. 01887

[1] Part I of this article appeared in the January issue.

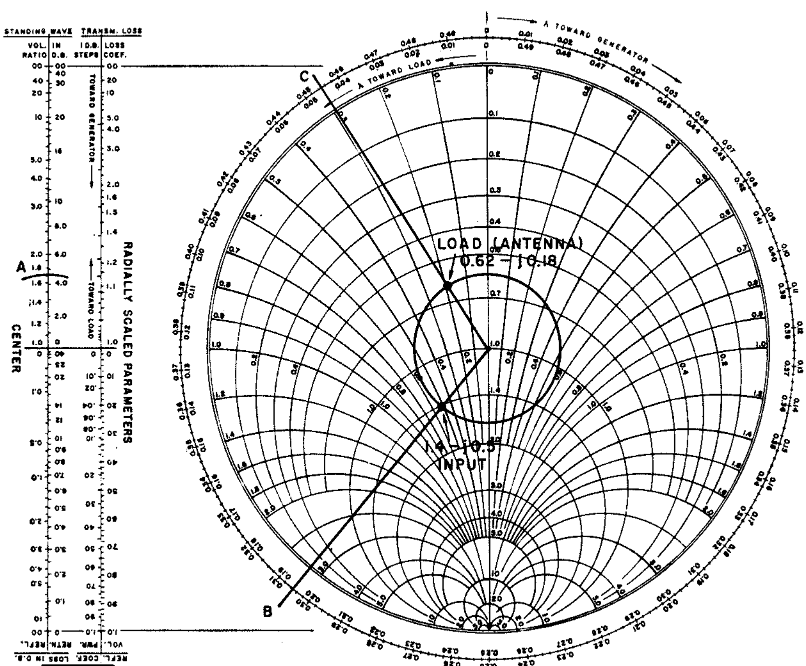


Fig. 7.

$$N = \frac{LF}{984K}$$

where

N = Number of electrical wavelengths in the line,

L = Line length in feet,

F = Frequency in megacycles, and

K = Velocity or propagation factor of the line.

The factor K may be obtained from transmission-line-data tables, such as appear in the *Handbook* in the chapter on transmission lines. Common coaxial cables with solid dielectric, such as RG-8, 9, 11, 17, 19, 58, 59 and 83 have a velocity or K factor of 66.9 per cent. Teflon-dielectric, or combination solid- and air-dielectric lines, have a higher velocity factor — up to 93 per cent for some special types of coaxial line. Most 300-ohm receiving-type balanced Twin-Lead has a velocity factor of 82 per cent; 75-ohm receiving-type ribbon line 68 per cent, transmitting type 71 per cent. Open-wire lines and ladder-type TV lines will exhibit a velocity factor of 97 to 97.5 per cent. All types of line having a solid dielectric can vary in velocity factor from the values given here, depending on the age and condition of the dielectric material. As the dielectric deteriorates, the velocity factor will become lower, and usually the associated dielectric losses will become higher. This is especially true of ribbon-type lines, where the dielectric material is exposed directly to the weather in most installations. In applying the velocity factor to the formula, the percentages must be converted to their decimal equivalent.

Line-Loss Considerations

The problems presented so far have ignored attenuation, or line losses. Quite frequently it is not even necessary to consider losses when making calculations; any difference in readings obtained would be almost imperceptible on the Smith Chart. When the line losses become appreciable, as with very long lines in terms of wavelengths, or with high s.w.r. values, loss considerations may be warranted. This involves only one simple step, in addition to the procedures previously presented.

Because of line losses, the s.w.r. does not remain constant throughout the length of the line. Power reflected from a mismatched load is attenuated as the wave travels toward the generator. As a result, there is a decrease in s.w.r. as one progresses away from the load. To truly represent this situation on the Smith Chart, instead of drawing a constant s.w.r. circle, it would be necessary to draw a spiral inward and clockwise from the load impedance toward the generator. The rate at which the curve spirals toward prime center is related to the attenuation in the line. Rather than drawing spiral curves, a simpler method is used in solving line-loss problems, by means of the external scale TRANSMISSION-LOSS, 1-DB. STEPS in Fig. 9. Because this is only a relative scale, the db. steps are not numbered.

If we start at the top end of this external scale and proceed in the direction indicated toward generator, the first db. step is seen to occur at a radius from center corresponding to an s.w.r. of about 9 (at A); the second db. step falls at an s.w.r. of about 4.5 (at B), the third at 3.0 (at C), and so forth, until the 15th db. step falls at an s.w.r. of about 1.05 to 1. This means that a line terminated in a short or open circuit (infinite s.w.r.) and having an attenuation of 15 db., would exhibit an s.w.r. of only 1.05 at its input.

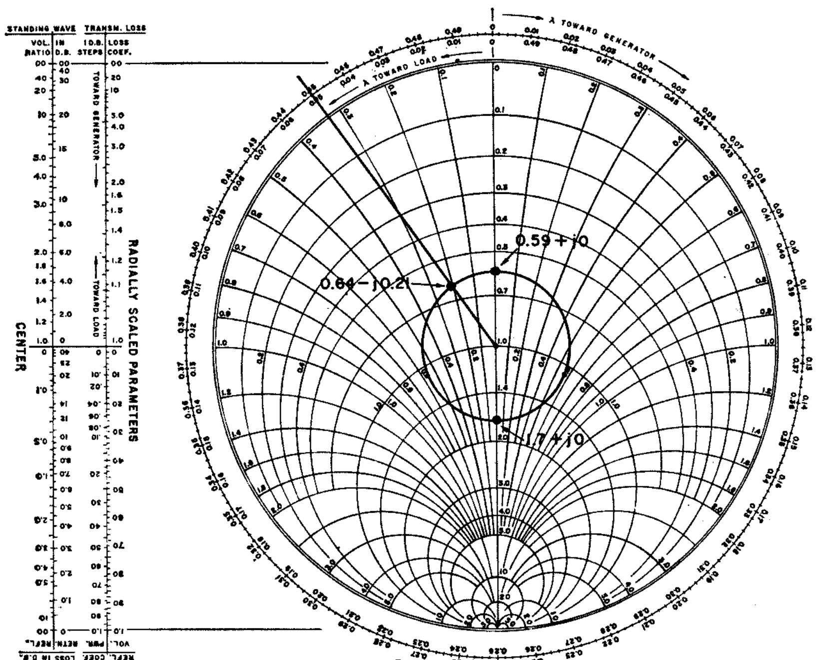


Fig. 8.

It will be noted that the db. steps near the lower end of the scale are very close together, and a line attenuation of 1 or 2 db. in this area will have only slight effect on the s.w.r. But near the upper end of the scale, 1- or 2-db. loss has considerable effect on the s.w.r.

In solving a problem utilizing line-loss information, it is necessary only to modify the radius of the s.w.r. circle by an amount indicated on the TRANSMISSION-LOSS, 1-DB.-STEPS scale. This is accomplished by drawing a second s.w.r. circle, of either greater or lesser radius than the first, as the case may be.

Assume that we have a 50-ohm line 0.282 wavelength long, with 1-db. inherent attenuation. The line input impedance is measured as $60+j35$ ohms. We desire to know the s.w.r. at the input and at the load, and the load impedance. As before, we normalize the $60+j35$-ohm impedance, plot it on the Chart, and draw a constant-s.w.r. circle and a radial line through the point. In this case, the normalized impedance is $1.2+j0.7$. From Fig. 9, the s.w.r. at the line input is seen to be 1.9 (at D), and the radial line is seen to cross the TOWARD-LOAD scale at 0.328 (at E). To the 0.328 we add the line length, 0.282, and arrive at a value of 0.610. To locate this point on the TOWARD-LOAD scale, first subtract 0.500, and locate 0.110 (at F); then draw a radial line from this point to prime center.

To account for line losses, transfer the radius of the s.w.r. circle to the external 1-DB.-STEPS scale. This radius will cross the external scale at G, the fifth db. mark from the top. Since the line loss was given as 1 db., we strike a new radius (at H), one "tick mark" higher (toward load) on the same scale. (This will be the fourth db. tick mark from the top of the scale.) Now transfer this new radius back to the main chart, and scribe a new s.w.r. circle of this radius. This new radius represents the s.w.r. at the load, and is read as about 2.3 on the external S.W.V.R. scale. At the intersection of the new circle and the load radial line, we read $0.65-j0.6$ as the normalized load impedance. Multiplying by 50, the actual load impedance is $32.5-j30$ ohms. The s.w.r. in this problem was seen to increase from 1.9 at the line input to 2.3 (at I) at the load, with the 1-db. line loss taken into consideration.

In the example above, values were chosen to fall conveniently on or very near the "tick marks" on the 1-DB. scale. Actually, it is a simple matter to interpolate between these marks when making a radius correction. When this is necessary, the relative distance between marks for each db. step should be maintained while counting off the proper number of steps.

The total losses in a given piece of transmission line are dependent upon several factors, primarily frequency, line length, and s.w.r. Transmission-line data tables show "matched-line" losses for various types of lines at various frequencies, usually expressed in decibels per hundred feet. RG-8/U, for example, has an attenuation of 0.28 db. per hundred feet at 3.5 Mc., 0.65 db. at 14 Mc., 0.98 db. at 28 Mc., 2.65 db. at 150 Mc., and so on. The *A.R.R.L. Antenna Book* has quite complete tables of common transmission-line data. Attenuation for a given piece of line may be computed from table data; the attenuation in db. is directly proportional to the line length.

Adjacent to the 1-DB.-STEPS scale lies a LOSS-COEFFICIENT scale. This scale provides a factor

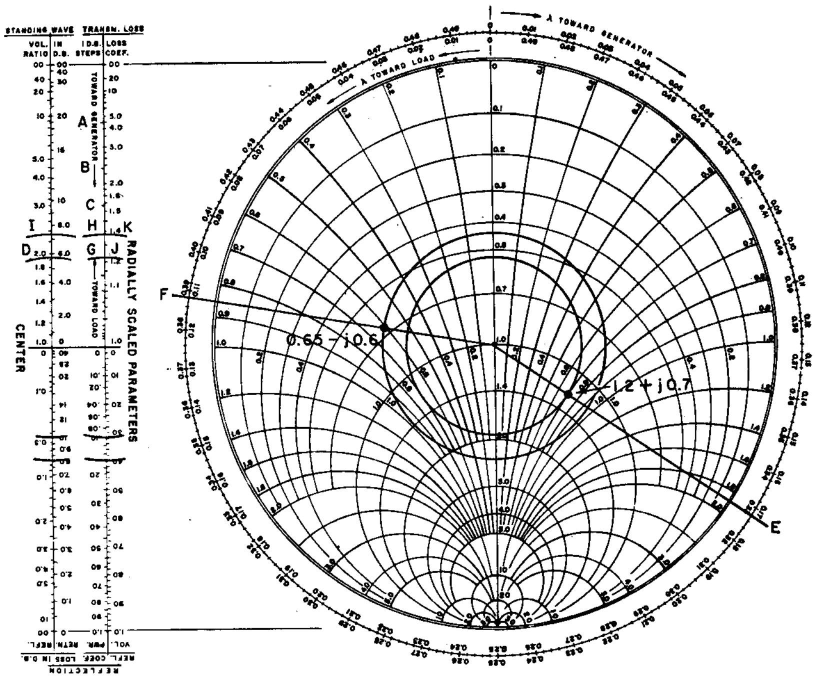


Fig. 9.

by which the matched-line loss in db. should be multiplied to account for the increased losses in the line when standing waves are present. These added losses do not affect the standing-wave ratio or impedance calculations; they are merely the additional dielectric and copper losses of the line caused by the fact that the line conducts more average current and must withstand more average voltage in the presence of standing waves. In the above example and in Fig. 9, the loss coefficient at the input end is seen to be 1.21 (at J), and 1.39 (at K) at the load. As a good approximation, the loss coefficient may be averaged over the length of line under consideration; in this case, the average is 1.3. This means that the total losses in the line are 1.3 times the matched loss of the line (1 db.), or 1.3 db.

Two additional external scales may find limited use in amateur applications. These are the REFLECTION-LOSS IN DB. scales. Both of these scales are related to the REFLECTION COEFFICIENT OF POWER scale, but express values in db., rather than in a power ratio. The RETURN scale expresses the ratio of total forward power to reflected power in db. This is sometimes called the *reflection loss,* although it does not necessarily represent an actual loss of power. If an impedance match is made at the sending end of the transmission line with a generator or a transmitter, a "reflection gain" takes place which neutralizes the "loss" at the load end. The REFLECTED 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 ohmic losses), referenced to the total forward power in the line.

Summary

To summarize briefly, any calculations made on the Smith Chart are performed in four basic steps, although not necessarily in the order listed.

1) Normalizing and plotting a line input (or load) impedance, and constructing a constant s.w.r. circle.

2) Applying the line length to the wavelengths scales.

3) Determining attenuation or loss, if required, by means of a second s.w.r. circle.

4) Reading normalized load (or input) impedance, and converting to impedance in ohms.

The Smith Chart may be used for many types of problems other than those presented as examples. The transformer action of a length of line — to transform a high impedance (with perhaps high reactance) to a purely resistive impedance of low value — was not mentioned. This is known as "tuning the line," for which the Chart is very helpful, eliminating the need for cut-and-try procedures. The Chart may also be used to calculate lengths for shorted or open matching stubs in a system. In fact, in any application where a transmission line is not perfectly matched, the Smith Chart can be of value.

The Chart can also be used in solving other types of problems which were not brought into the scope of this article. Such problems include the use of the Chart for admittance, conductance, and susceptance calculations, or the computation of equivalent series or parallel components of an impedance or admittance. In short, the Smith Transmission Line Calculator or Chart is a very versatile tool for either amateur or professional use. QST