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SIGNIFICANCE OF SMITH CHART IN ANTENNA TECHNOLOGY

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ABSTRACT

This paper presents Smith Chart as a graph based method of simplifying the complex math needed to describe the characteristics of microwave components. Smith Chart can look imposing; it's nothing more than a special type of 2-D graph, much as polar and semilog log-log scales constitute special types of 2-D graphs. We have shown the utility of Smith Chart with the help of different graphs and figures.

Keywords: Smith Chart spectral simulation antenna parameters, Characteristics impedance, Quarter wave antenna.

I. INTRODUCTION

The Smith Chart[1][2] is a graphical aid or monogram designed for electrical and electronics engineers specializing in radio frequency to assist in solving problems with transmission lines and matching circuits[3]. It is an alternative to using tabular information. The Smith Chart can be used to represent many parameters including impedances, admittances, reflection coefficients, S_n scattering parameters, noise figure circles, constant gain contours and regions for unconditional stability[4][5].

The Smith Chart is plotted on the complex reflection coefficient plane in two dimensions and is scaled in normalized impedance (the most common), normalized admittance or both, using different colors to distinguish between them. These are often known as the Z, Y and YZ Smith Charts respectively. Normalized scaling allows the Smith Chart to be used for problems involving any characteristics impedance or system impedance, although by far the most commonly used is 50 ohms. With relatively simple graphical construction it is straightforward to convert between normalized impedance (or normalized admittance) and the corresponding complex voltage reflection coefficient. The purpose of this paper is to give the basic idea of Smith Chart and to show its importance in antenna technology.

II. MATHEMATICAL BASIS

Transmission line as shown

$$\Gamma_e = \frac{Z_e - Z_0}{Z_e + Z_0} = |\Gamma_e| e^{j\theta e} = \Gamma_y + j\Gamma_i \quad (1)$$

Since $|\Gamma_e| \leq 1$, the value of Γ_e must lie on or within the unity circle with a radius of 1. The reflection coefficient at any other location along a line is shown in below.

$$\Gamma_d = \Gamma e^{e^{-2ad}} e^{-j2\beta d} = |\Gamma_e| e^{-2ad} e^{j(\theta_\varepsilon - 2\beta d)} \quad (2)$$

which is also on or within the unity circle. Figure 1 shows circles for a constant reflection coefficient Γ and constant electrical-length radials βd .

The normalized impedance along a line is given by

$$z = \frac{Z}{Z_0} = \frac{1+\Gamma e^{e^{-2\gamma d}}}{1-\Gamma e^{e^{-2\gamma d}}} \quad (3)$$

With no loss in generality, it is assumed that $d = 0;$ then

$$z = \frac{1+\Gamma e}{1-\Gamma e} = \frac{Z_e}{Z_0} = \frac{R_e + jX_e}{Z_0} = r + jx \quad (4)$$

and
$$\Gamma_e = \frac{z-1}{z+1} = \Gamma_r + j\Gamma_i \quad (5)$$

Substitution of Eq. [5] into Eq. [4] yields

$$r = \frac{1-\Gamma_r^2 - \Gamma_i^2}{(1-\Gamma_r)^2 + \Gamma_i^2}$$

and
$$x = \frac{2\Gamma_i^2}{(1-\Gamma_r)^2 + \Gamma_i^2} \quad (7)$$

Equations (6) and (7) can be rearranged as

$$\left(\Gamma_r - \frac{r}{1+r}\right)^2 + \Gamma^2 = \left(\frac{1}{1+r}\right)^2 \quad (8)$$

and
$$\left(\Gamma_r - 1\right)^2 + \left(\Gamma_i - \frac{1}{x}\right)^2 = \left(\frac{1}{x}\right)^2 \quad (9)$$

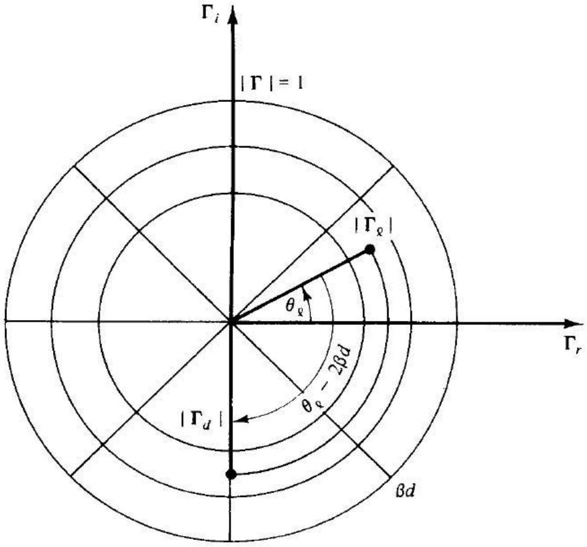

Fig. 1. Constant Γ circles and electrical-length radials βd.

Equation (8) represents a family of circles in which each circle has a constant resistance (r). The radius of any circle is 1/(1+r), and the center of any circle is r/(1+r) along the real axis in the unity circle, where r varies from zero to infinity. All constant resistance circles are plotted in Fig. 2 according to Eq. (8).

Equation (9) also describes a family of circles, but each of these circles specifies a constant reactance (x). The radius of any circle is (1/x), and the center of any circle is at

$$\Gamma_r = 1 \quad \Gamma_i = \frac{1}{x} \quad (where - \infty \le x \le \infty)$$

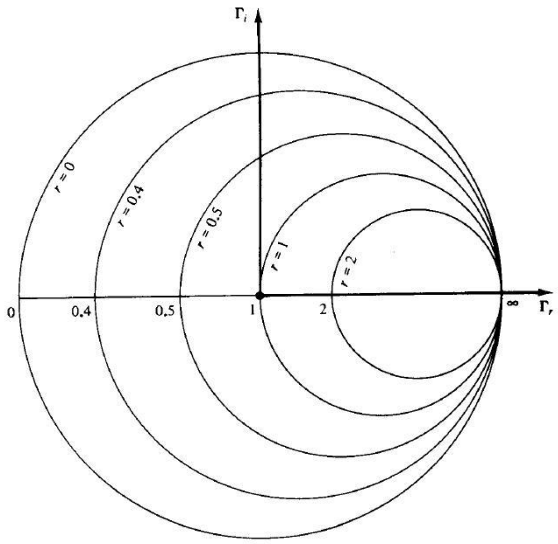

Fig. 2. Constant resistance (r) circles

There are relative distance scales in wavelength along the circumference of the Smith chart. Also, there is a phase scale specifying the angle of the reflection coefficient. When a normalized impedance z is located on the chart, the normalized impedance of any other location along the line can be found by use of Eq. (3).

$$z = \frac{1+\Gamma e^{e^{-2\gamma d}}}{1-\Gamma e^{e^{-2\gamma d}}} \quad (10)$$

$$\Gamma e^{e^{-2\gamma d}} = |\Gamma_e| e^{-2\alpha d} e^{j(\theta_\varepsilon} - 2\beta d) \quad (11)$$

The Smith chart may also be used for normalized admittance. This is evident since

$$Y_0 = \frac{1}{Z_0} = G_0 + jB_0 \quad \text{and} \quad Y_0 = \frac{1}{Z} = G + jB \quad (12)$$

Then the normalized admittance is

$$y = \frac{Y}{Y_0} = \frac{Z_0}{Z} = \frac{1}{z} = g + jb \quad (13)$$

A Smith chart or slotted line can be used to measure a standing-wave pattern directly and then the magnitudes of the reflection coefficient, reflected power, transmitted power, and the load impedance can be calculated from it. The following points are considered about the Smith chart.

(i) At extreme left on the chart r = 0, x = 0 i.e. $Z_L = 0 + j0$, represents a short circuit on the transmission line. At extreme right on the chart r = ∞, x = ∞ i.e. $Z_L = \infty + j\infty$, represents an open circuit on the line.

(ii) A complete revolution (360°) around the Smith chart represents a distance of ƛ / 2 on the line. Clockwise movement on the chart is considered as moving toward the generator (or away from the load), indicated in figure. Similarly, counter clockwise (anticlockwise) movement on the chart corresponds to moving toward the load (or away from the generator), indicated in figure.

(iii) The outermost scale is used to determine the distance on the line from the generator end in terms of wavelengths and the next scale determines the distance from the load end in terms of wavelengths.

(iv) The centre on the Smith chart is indicated by a digit 1.The left side from the centre line gives the value of V_{min} , I_{max} , Z_{min} , 1/SWR and the right side from the centre line gives the value of V_{max} , I_{min} , Z_{max} , SWR .

(v) The circle around the horizontal line which passes through the centre indicates the resistive part whereas the circle away from the centre indicates reactive part.

The upper circle away from the centre line indicates inductive part whereas the lower circle away from the centre line indicates capacitive part.

(vi) The Smith chart is also used as admittance chart (as Y = 1/ Z).

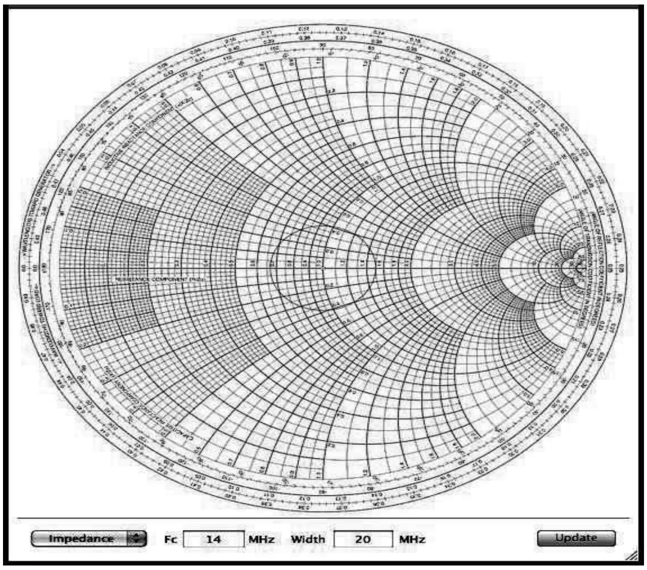

Fig. 3. Smith Chart

III. USE OF SMITH CHART IN ANTENNA TECHNOLOGY:

Smith Chart can be used as

1. Quarter Wave Antenna
2. Single Stub Impedance Matching
3. Double Stub Impedance Matching

In this paper only Quarter wave antenna is considered.

Quarter Wave Antenna

The quarter wave antenna is the simplest model of antenna: it only requires a rigid wire and a ground plane.

The quarter wave antenna (λ/4 length) must radiate with respect to a ground plane. The ground plane can be either the PC board itself, or the metal case of the outlet. In both cases make sure the wire is vertical to get the highest impedance. Anyhow, the impedance value will remain under 50 Ω. If the antenna is tilted parallel to the ground, the impedance value will decrease significantly.

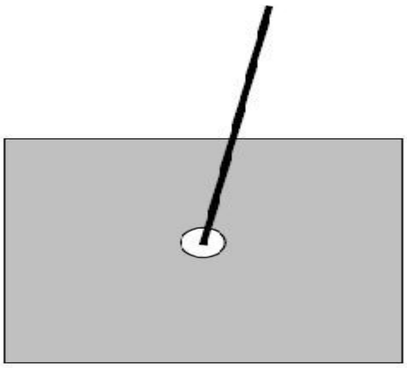

Fig. 4. Tilted Antenna

The λ/4 length is purely theoretical. Depending on the nature of the wire and the geometry of the ground plane, consider the length as (k = λ/4) with k comprised between 0.93 and 0.98 . Wire size should be at least 0.34 mm^2 (AWG 22).

In case the antenna is to be set outside the case, the radiating length to be considered is only the part outside the case. However, the connection from inside the case to the PC board must be done with an adapted coaxial cable. Thus the Smith Chart plays an important role in Antenna Technology.

IV. CONCLUSION

Smith Chart keeps the chart relevant for today's instrumentation and design automation applications. It is nothing more than a special type of 2-D graph. The coexistence of complex-impedance and complex reflection coefficient information on has single graph allows us to easily determine how values of one affect the other. Typically we might want to know that complex reflection coefficient would result from connecting particular road impedance to a system having given characteristic impedance.

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