Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 7 Issue 4, April - 2020

Design Procedure of Single Shunt (Short Circuited) Stubs Impedance Matching Networks Using the Smith Chart

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***Abstract*— The design of single shunt (short circuited) stubs impedance matching networks using the Smith chart is presented in this paper. The single shunt stub matching network is designed by the graphical method using the Smith chart. The results showed that using the designed stubs obtained using designed procedure presented in this paper gives excellent matching networks. Microwave engineers and designers of stubs should apply the design procedure presented in this paper in the analysis and design of stubs.**

Keywords: Single Shunt Stubs, Impedance Matching, Smith Chart, Transmission Line

I. INTRODUCTION

Impedance matching or tuning is very desirable with radio frequency (RF) and microwave transmission lines connected to sources and loads [1, 2]. In transmission line problems, impedance matching simply means terminating a transmission line in its characteristic impedance, symbolized by Z_0. When a transmission line is not terminated by its characteristic impedance, maximum power is not transferred to the load, and power will be wasted due to reflections from the load. This reduces the efficiency of transmission [3, 4].

The basic idea of impedance matching is illustrated in Figure 1, which shows an impedance matching network placed between a load impedance and a transmission line [1]. The matching network usually uses lossless components like reactive lumped elements (inductors and capacitors), transmission line and impedance transformers.

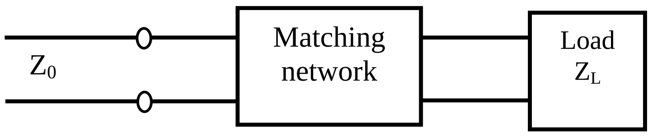


Figure 1: An impedance matching network matching an arbitrary load impedance to a transmission line

Impedance matching is needed according to [1, 5] for the following reasons:

i. Maximum power is delivered to a load when the transmission line is matched at both the load and source ends.

ii. Some equipment such as amplifiers can be damaged when too much power is reflected back to the source.

iii. Impedance matching in a power distribution network (such as an antenna array feed network) may reduce amplitude and phase errors.

Factors used for selecting a matching network in [1, 5] are:

i. **Complexity:** A simpler impedance transformation network is usually cheaper, more reliable, and less lossy than a more complex design.

ii. **Adjustability:** In some applications the matching network may require adjustment to match a variable load impedance

iii. **Bandwidth:** Any type of matching network can ideally give a perfect match at a single frequency. In many applications, however, it is desirable to match a load over a band of frequencies.

The major impedance matching networks are: L-section networks, Stubs, Quarter wave transformers (QWTs), Half-wave transmission lines, and Tapered transmission lines. The design of shunt stubs matching network is treated in this paper.

II REVIEW OF RELATED WORKS

As of the time of publishing this work, the design procedure of single shunt stubs impedance matching networks using the Smith chart by researchers is not reported in journal papers. The only related journal article to this work is published by [5]. The detailed and comprehensive design procedure of stubs using the Smith chart was not presented in the paper [5].

The published works of [1, 3, 4, 6, 7, 8, 9, 10] show how stub matching networks are designed. Their design procedures on stub designs are complex, not comprehensive and straightforward for implementation by designers. These limitations on stub designs are addressed in this work.

A Stub Matching Networks

Impedance matching networks using lumped elements like inductors and capacitors are suitable for low-frequency electronics. At higher frequencies, majority of impedance matching networks using distributed elements (or transmission line sections) because the physical dimensions of the components become comparable with the wavelength of transmitted signals, and lumped components behave in unexpected ways [10].

A stub is a piece (or section) of transmission line which is normally short circuited or open circuited at the far end. Stubs are connected in series or shunt (parallel) across the main transmission lines to introduce, at the point of attachment, a reactance whose value depends on the length (l) and distance (d) of termination of stubs from a complex load [1, 7, 10]. Stubs are categorized into single stub tuning, double stub tuning and triple stub tuning [10]. A single shunt stub impedance matching network is shown in Figure 2.

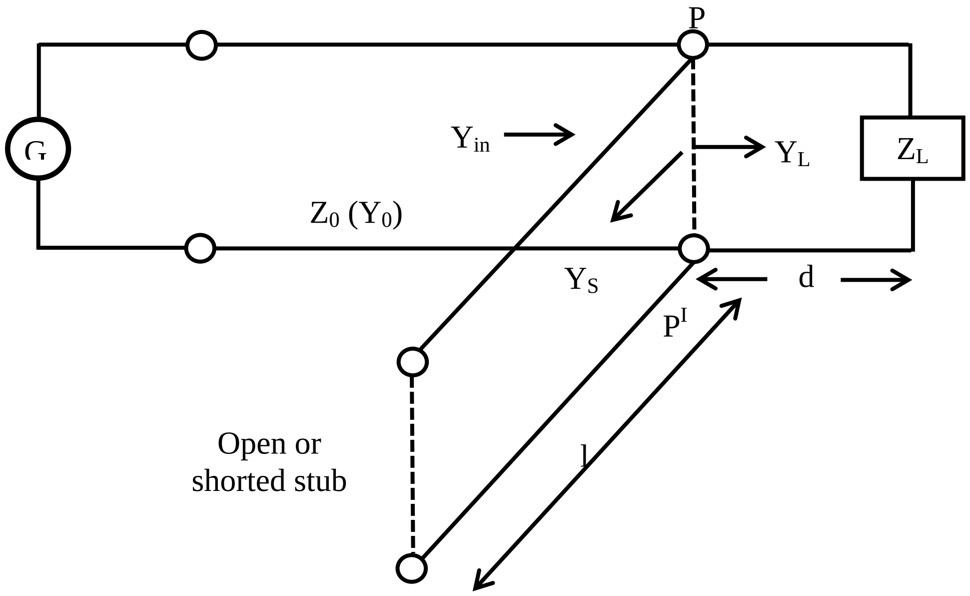


Figure 2: A single shunt stub matching network.

By adjusting of the position of the stub at PP[1]and by varying the length of the short circuited stub, standing waves can be eliminated left of PP[1]. According to [7], if the input admittance at PP[1]is Y_{in}, that of the load Y_L and that of the lossless stub Y_S, then:

$$Y_{in} = Y_s + Y_L \quad (1)$$

$$\text{where } Y_L = \frac{1}{Z_L} = G_L \pm jB_L \quad (2)$$

$$\text{and} \quad Y_S = \frac{1}{Z_S} = G_L \pm jB_S \quad (3)$$

The distance(d) is found by adjustment such that

$$G_L = G_0 = \frac{1}{Z_0} \quad (4)$$

Hence, Equation (1) becomes:

$$Y_{in} = G_s \pm jB_L \pm jB_S \quad (5)$$

The length (l) of the stub is varied until $|B_L| = |B_S|$, while their angles are opposite, for then the succeptances cancel out, leaving a pure conductance G_O. Hence Equation (5) simplifies to Equation (6).

$$Y_{in} = G_0 \quad (6)$$

or

$$Z_{in} = Z_0 \quad (7)$$

Usually the short circuited stub is about $\lambda/4$ long since it can be made inductive or capacitive by varying its length near l = λ/4.

Impedance matching networks can be designed either analytically (using hand calculations or computers) and graphically using the Smith chart [10]. In order to avoid complicated analytical solutions, graphical solution using the Smith charts are widely used in the design of stubs [7].

3. METHODOLOGY

In this paper, the design procedure for designing single shunt stubs matching networks using the Smith chart is presented for transmission engineers to apply in their design works. The following procedure (or steps) should be used by designers in the design of single shunt stubs with the Smith chart.

Step 1: Normalize the load impedance with respect to the transmission line, and plot the point on the Smith chart.

Step 2: Draw a VSWR circle through the normalized load impedance point with centre of the chart as the origin. Now construct the load admittance, which is the point diametrically opposite to the normalized impedance point (or travel around the VSWR circle from the normalized load impedance through a distance λ/4). Draw a line from the centre through the normalized load admittance point to intersect the WTG scale. Since the stub impedance is connected in parallel to the load impedance, it is always better to work with admittances when making stub calculation connected in parallel.

Step 3: For the remaining steps, we use the Smith chart as an admittance chart. Starting from the normalized load admittance point, find the point nearest to the load in which the normalized admittance (y) is 1 ±jb. These points are the intersection of the drawn (impedance/admittance) circle with the circle g(or r) = 1. These are the points in which stubs designed to tune out the excess susceptance±jb will be placed. Read off the distances travelled around the circumference of the chart to the point g = 1. These are the distances(d) from the load to the stub.

Step 4: To find the lengths (l) of the short circuited stubs, move along the circumference clockwise from the point $(\infty, j\infty)$ which is the normalized admittance (y) of the short circuit (or along the VSWR = ∞ circle or g = 0 circle) at which the susceptance±jb tunes out.

Step 5: Read off the distances in wavelengths from the starting point $(\infty, j\infty)$ to the tuned out susceptances (±jb) point by moving around the perimeter of the chart. These are the required lengths of the stubs.

Numerical Problem For a load impedance $Z_L = 60 - j80\Omega$, design two single stub (short circuit) shunt tuning networks to match the load to a 50Ω line. Assume that the load is matched at 2GH_Z and that the load consist of a resistor and capacitor in series [1].

The steps outlines in the procedure for designing single shunt (short circuited) stubs are as applied.

Step 1: $z_l = Z_L/Z_O = (60 - j80)/50 = 1.2 - j1.6\ \Omega$. Point z_L is plotted on the Smith chartas shown in Figure 3, under Results and Discussion section.

IV RESULTS AND DISCUSSION

The Smith chart plots for single shunt (short circuited) stub design are shown in Figure 3.

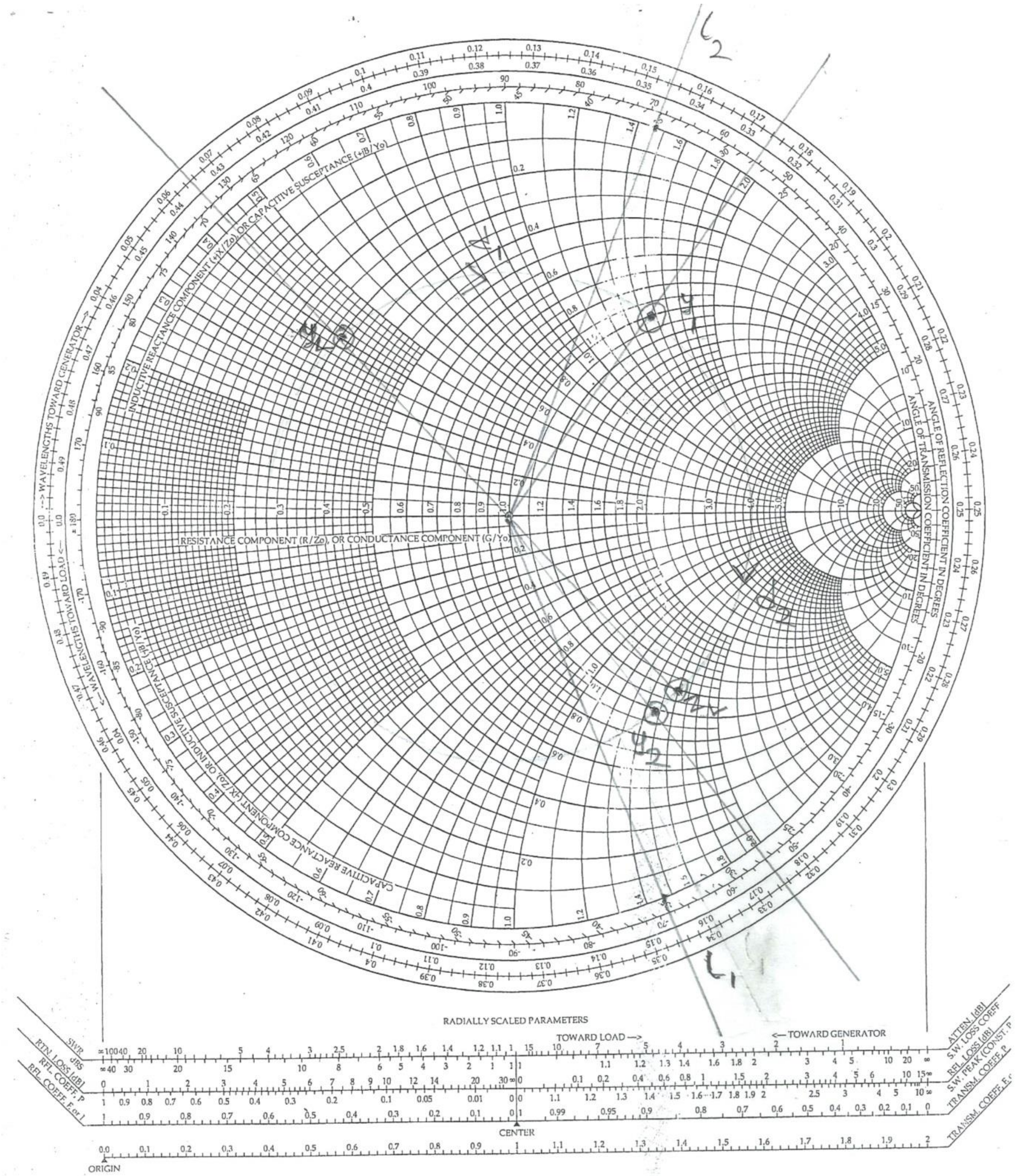


Figure 3: Smith chart for single shunts (short circuited) stub design.

Step 2: Circle plotted has VSWR = 4.0.Load admittance y_L is plotted as shown in Figure 3.

Step 3: VSWR circle intersects the 1±jb circle at two points,y_1 and y_2 in Figure 3. Thus the distance (d) from the load to the stub is given by either of these two intersections. Reading the WTG scale, we obtain:

$$d_1 = 0.174 - 0.065 = 0.109\lambda$$

$$d_2 = 0.325 - 0.065 = 0.260\lambda$$

:. The stub distances from the load are 0.110λ and 0.260λ respectively.

From the graph, at the two intersection points, the normalized admittances are:

$$y_1 = 1.00 + j1.47, \text{and}$$

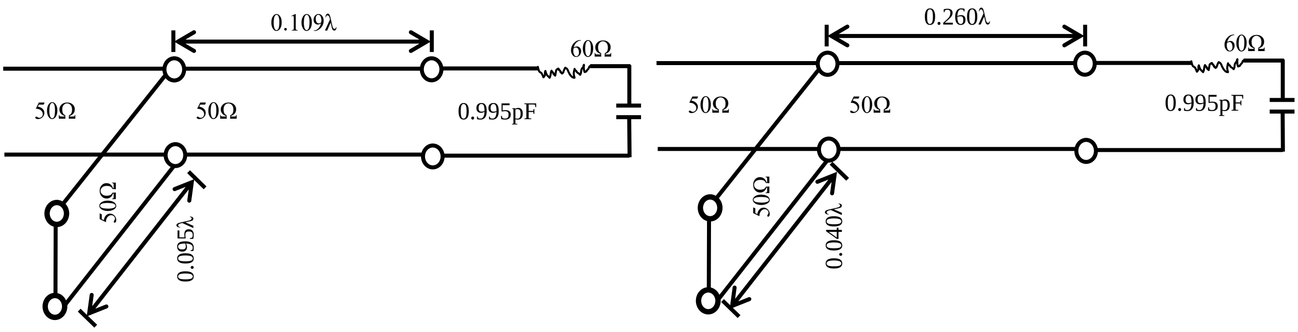
$$y_2 = 1.00 - j1.45.$$

Steps 4 and 5: The first tuning solution requires a stub with a susceptance (b) of –j1.47. The length of the short circuited stub that gives this susceptance is found on the Smith chart by starting at y = ∞ (the short circuit), and moving along the outer edge of the chart (g = 0) toward the generator to the – j1.47 point. The stub length (l_1) is then

$l_1 = 0.345 - 0.250 = 0.095\lambda$

Similarly, the required short circuit stub length for the second solution is: $L_2 = 0.404\lambda$

The series RC load impedance is $Z_L = 60 – j80\Omega$ at 2GHz, so $R = 60\Omega$ and $C = 0.995$ pF. The designed two single stub shunt tuning short circuits are shown in Figure 4.



Solution #1 Solution #2

Figure 4: The designed two shunt (short circuited) stub matching networks.

The design two shunt (short circuited) stub matching networks obtained by applying the design procedure of this paper, gives the same two shunt stub matching networks by [1].

V. CONCLUSION

In this paper, the design of single shunt (short circuited) stubs impedance matching networks using the Smith chart is presented. From the results of the design, there are always a minimum of two stub matching solutions for any given matching problem. The design specifications for single shunt stub matching networks can be determined by analytical and graphical approaches. The graphical approach using the Smith chart is fast, intuitive, and usually accurate enough in practice.

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