PRACTICAL ASPECTS OF THE TRANSMISSION LINE STUB MATCHING IN MICROSTRIP

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Abstract

While designing microwave circuits with microstrip lines using open or shorted stubs for matching or realization of filters, the actual circuit can be substantially mismatched when the length of the open stub is below 30 degrees of electrical length, or shorted stub is over 60 degrees of electrical length. Realization of such stubs could lead to practical difficulties because the normal etching accuracy does not support the exact lengths required for such stubs.

Keywords

Transmission lines, stub matching, stub filters, production problems

1. Introduction

When matching complex impedance to the standard real impedance of 50 ohm (or any other value), using transmission line and stub configuration, we have to observe certain precautions regarding the length of the stub used for the final match. Considering only the case of stubs, the use of either open or shorted configuration, is often determined by the overall circuit requirement, such as easy biasing and circuit realization. Typical configuration for amplifier matching is presented in Fig.1.

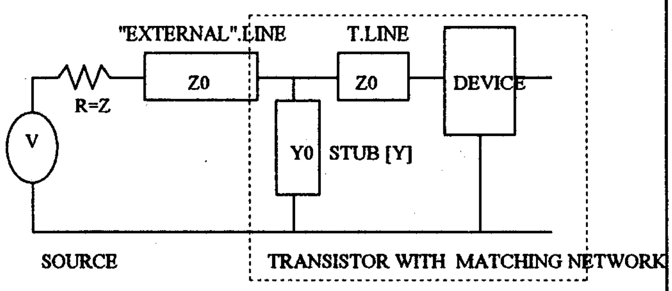

Fig.1. Configuration for transmission line-stub matching

The selection of the stub type is usually important, since one configuration may yield a shorter stub than the other. Unfortunately, another **additional** condition must be also taken into consideration when selecting the stub for the length. Note here, that adding a quarter wavelength to the calculated length of stub, will change an open stub to a shorted stub and vice versa. The short BASIC program was written for the purpose of the stub length evaluation. Program calculates only the **shortest** appropriate lengths of stubs (i.e., less than 90 degrees of electrical length or .25 λ).

2. The stub impedance calculations

For a short sections of the transmission line, in this case a stub, we could assume that the losses will be small and therefore can be neglected. Hence we could use the results from the analysis of lossless transmission lines. For such cases, analyzing parallel stub elements, which are for all practical considerations at one end open or shorted lengths of a common transmission line, the admittance of the open lossless stub is given by

$$Y_{OS} = j.Y_0 . \tan \vartheta \quad (1)$$

and for the **shorted lossless stub** we obtain,

$$Y_{SS} = -j.Y_0 \cot \vartheta \quad (2)$$

In these equations suffixes "os" and "ss" refers to the open and shorted stub respectively, and the admittance $Y_o = 1/Z_o$ is the characteristic admittance of the used transmission line. Exact meaning of the angle ϑ is defined later in the text. The resulting values are obviously pure susceptances.

Examining the presented equations, we could see, that the only difference between the tan and the -cot functions is 90 degrees or $\pi/2$ radians. This fact can be mathematically presented for the degrees notation as

$$\tan(90^o + \vartheta) = - \cot \vartheta \quad (3)$$

From that, a very important simplification for the calculation of stub values can be concluded. If an open, i.e. capacitive, stub shorter than 90 degrees, with a positive sign for the susceptance B is desired, and a negative value for ϑ is obtained from the equations, we need to add 90 degrees to the result to obtain the desired solution.

If in the case of a shorted, i.e. inductive, stub, we obtain a positive susceptance value, 90 degree's length of line must be added to ϑ, to obtain shorter than 90 degree stub, if desired. The graphic representation of the relationship between the functions for an open (tan), and shorted stubs (-cot) is shown in Fig.2.

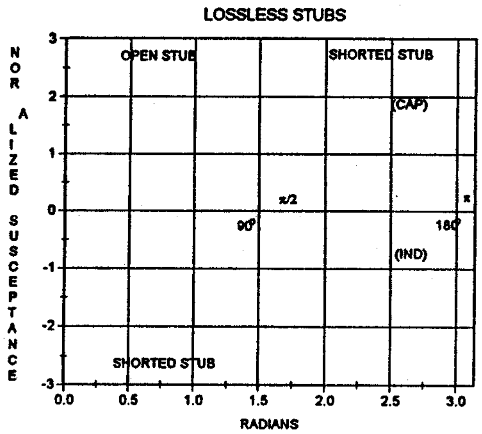

Fig.2.Electrical lenght vs. susceptance

The above conclusions are obviously applicable to any other stub configurations, because they have general validity. Therefore when designing for example filters using stubs, the same precautions must be made like in the case of stub matching.

From the Fig.2 we could conclude that the usable, practical length for the realization of the shorted stub is actually below 60 degrees of the electrical length (at the design frequency), or below $\pi/3$ radians. Stub impedance's above this value changes too rapidly for reliable realization of such lines. In case of open stubs the line lengths below 30 degrees may become from the same reason difficult to realize. This practical limit should be taken as a guidance, when determining which computed value is suitable for realization of the actual matching network or filter.

The angle ϑ in the equations actually represents the following relationship,

$$\vartheta = \beta.L = 2\pi.L/\lambda \quad \text{[radians]}$$

or

$$\vartheta = \beta.L = 360.L/\lambda \quad \text{[degrees]} \tag{4}$$

where L is the length of the stub (transmission line). From this relationship, for the calculated, desired susceptance B, the corresponding length L can be calculated by using (1) and (2) respectively.

Considering that for the shorted stubs, having length less than 90 degrees, the susceptance is negative, we obtain from (2)

$$Y_{ss} = -j.B_{ss} = -j.Y_o \cot \vartheta \tag{5}$$

or

$$\tan \vartheta = Y_o/B_{ss} \tag{6}$$

from which

$$\beta.L_{ss} = \vartheta = \tan^{-1}(Y_o/B_{ss}) \tag{7}$$

From the equation (7) the length of the shorted stub becomes

$$L_{ss} = (\lambda/2\pi).\tan^{-1}(Y_o/B_{ss}) \tag{8}$$

Note that (7) gives the value of β.L in degrees or radians, depending on the used conversion.

For the open stub shorter than 90 degrees the value of susceptance needs to be positive and,

$$Y_{os} = j.B_{os} = j.Y_o \tan \vartheta \tag{9}$$

or

$$\tan \vartheta = B_{os}/Y_o \tag{10}$$

leading to

$$\beta.L_{os} = \tan^{-1}(B_{os}/Y_o) \tag{11}$$

and from the equation (11) we obtain for the open stub length

$$L_{os} = (\lambda/2\pi).\tan^{-1}(B_{os}/Y_o) \tag{12}$$

The wavelength is obtained from the design frequency f as

$$\lambda = 3.10^8/f \tag{13}$$

which, if substituted into the equations (8) and (12) gives the equivalent stub lengths in the free space.

To calculate the actual lengths of the microstrip lines, selected for realization of the amplifier or filter we need to calculate the effective dielectric constant of the microstrip lines and then correct the free space wavelengths calculated before. This is done in the last part of the program by using the relation

$$L_m = L/\sqrt{\varepsilon_f} \tag{14}$$

The value of effective dielectric constant ε_f is calculated from permitivity for various microstrip configurations and given in Wheeler article [1]. Results for the actual lengths of lines can be subsequently calculated. This concludes the transmission line-stub analysis and design.

3. Practical engineering results

Having reviewed the theory, we could proceed to make microstrip stub calculations for the real design case. Selecting frequency of 1000 MHz and assuming characteristic impedance of all lines to be 50 ohms, we could, using a simple computer program calculate the open and shorted stub impedances for various electrical lengths and express them in millimeters. The evaluation is done for few widely used substrate permitivities and plotted in all graphs. The actual results are presented in Fig. 3.

To evaluate the differences between subsequent stub lengths, which will give better insight into the problem, we could plot this parameter for each 10 ohm increase in the stub impedance. The resulting values are presented in Fig.4.

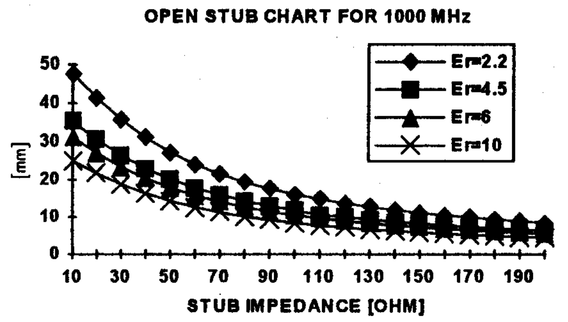

Fig.3. Open stub lengths as function of its impedance for 50 ohm lines.

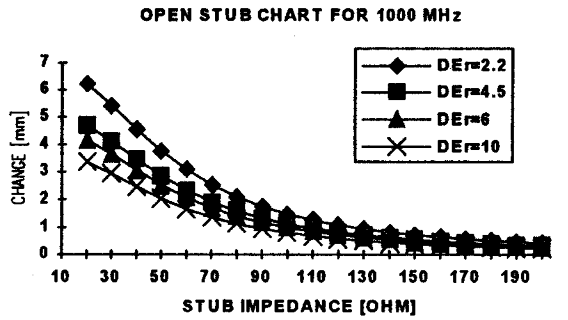

Fig.4. Open stub length differences for 10 ohm impedance steps for 50 ohm lines

From the chart we could see that the difference for each subsequent change of 10 ohms in the line impedance is decreasing with increase of the stub impedance. Note that values above 90 ohm stub impedance correspond to the open stub electrical lengths of 30 degrees and below. For these values the change in a length of the stub for each 10 ohm impedance change is in order of 0.5 mm and less. To realize (etch) on microstrip substrate such exact line lengths may present practical problems. Any marginal change in the line length due to imperfect etching therefore results in a large change in the stub impedance and in the end in subsequent undesired mismatch. Therefore using open stubs with impedances above 90 ohms, (i.e., electrical lengths below 30 degrees) will result in practical fabrication difficulties, while attempting to realize (etch) exact lengths of such stubs. Consequently, we should avoid using open stubs with electrical lengths below 30 degrees to avoid potential mismatch, because the exact lengths of such stubs will be difficult to manufacture.

Similar, and more convincing conclusion could be drawn from the examination of the graph for the equivalent capacity of the open stub with particular impedance. Plot of the equivalent capacity for selected open stub impedances is presented in Fig.5.

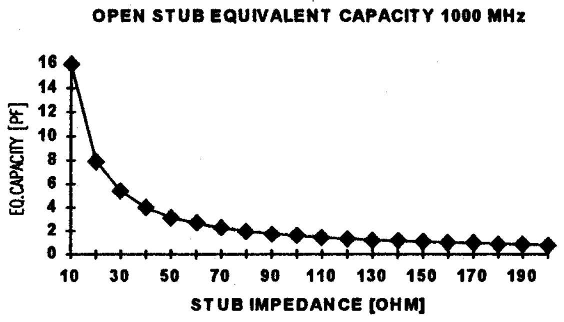

Fig.5. Equivalent capacity for various open stub impedances (Chart valid for any ε_r).

From the plot we could clearly see that the equivalent capacity variations for stubs with impedances above 90 ohms results in the capacity change about 0.1 pF. Therefore

to replace stub with impedance above 90 ohms by its equivalent lumped capacity will present very difficult problem indeed, because tolerances of capacitors in this range do not allow for selection of the exact value capacitor needed to replace the open stub [2].

Keeping the permitivity constant we could also examine the influence of the characteristic impedance Zo on the open stub length. From the plotted results in Fig.6. we could see that any change in the stub characteristic impedance will result in a change in the stub length. The lower the characteristic impedance, the shorter the stub.

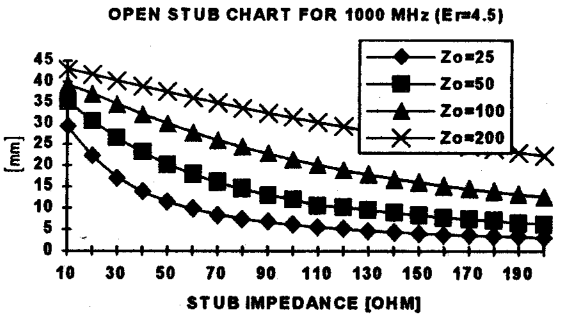

Fig.6. Open stub lengths plotted against its impedance for few values of Zo..

In the above calculations we did not take into the consideration the effect of an imperfect open circuit at he end of the open stub. Existence of open end does not provide for ideal open circuit, and various authors derived formulas for correction of this effect. One such formula for open ended microstrip line was published by Hammerstad and Bekkadal [3]. They derived empirical result for negative correction of open end microstrip in the form

$$\frac{l}{h} = 0.412\left(\frac{\varepsilon_r + 0.3}{\varepsilon_r - 0.258}\right)\left(\frac{W/h + 0.262}{W/h + 0.813}\right) \qquad (15)$$

where l is the negative length correction, h substrate thickness and W microstrip width. The l/h ratio varies for substrate effective dielectric constant and stub-line impedance. For substrates from ε_r =2 to 10 is having values between .5 to .3 for line-stub impedance 50 ohms and .3 to .15 for line impedance of 150 ohms. This value is much bigger than the difference for each 10 ohm step in the line impedance and therefore results in an additional error, particularly when the length of the stub is longer than 60 degrees (i.e., impedance larger then 90 ohms).

From Fig. 7. we could see that the necessary negative length correction for the open stub, when plotted from (15) for practical values of permitivity, is also experiencing saturation, and for permitivities above 4 changes very little.

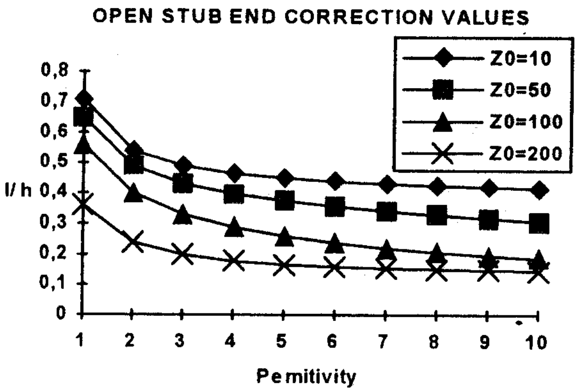

Fig.7. Open stub end length correction for ratio l/h against permitivity (Eq.(15)

In the case of the shorted stub we could come to similar conclusions, because the difference between two functions is 90 degrees. Therefore plotting similar graph like for the open stub will result in Fig.8.

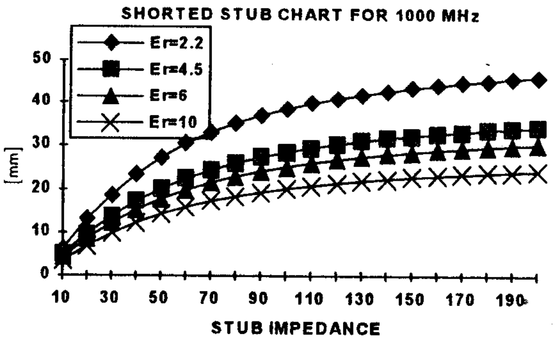

Fig.8. Shorted stub lengths plotted against its impedance for 50 ohm lines.

Considering that the functions for open and shorted stubs are similar, the difference chart will be the same like for the open stub. The relation between open and shorted (SHT) stub impedances and their electrical lengths is presented in Fig.9. For the open stub are plotted few values of characteristic impedance Zo. Values for shorted stub are for 50 ohm lines only. Graph is for ε_r= 4.5 and is independent of frequency because is plotted for electrical degrees.

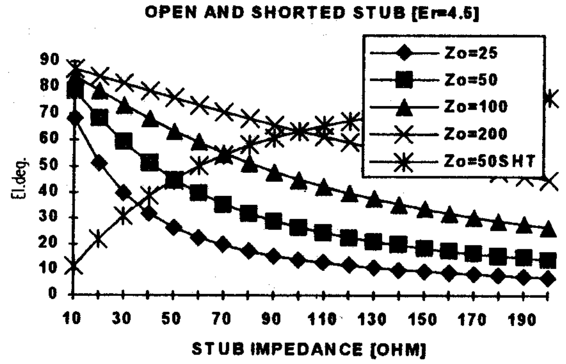

Fig.9. Stubs electrical lengths plotted for few characteristic line impedances.

4. Conclusions

References From the presented results for the frequency of 1000 MHz, is obvious that there exist practical manufacturing limits to the use of stubs for matching or in filters. When the functions of tan or cot start changing too rapidly, influencing the actual stub length, it is difficult to achieve the necessary accuracy in etching equivalent open or shorted stubs. In such cases some manual adjustment of stub length is always needed. Because the actual length of the stubs is directly related to the wavelength (i.e. frequency), the situation will be even more critical at higher microwave frequencies. The characteristic impedance of the lines is also having influence on the stub lengths. In case of the open stub the compensation for the open end of the stub will play an important role and realization of such stubs must take this effect into consideration, otherwise the actual etching of such stubs could lead to large errors.

References

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About authors...

Stanislav NOVAK was born in Prague in 1932. He received M.Sc. degree in 1959 and Ph.D. degree in 1968, both from Slovak Technical University, in Bratislava, Slovakia.