



RESEARCH ARTICLE

Single and Double Stub Tuner Impedance Matching of Microwave Circuits Using Mathcad Software

Husham J. Ahmad, Firas M. Z. Mahmood

Department of Communication and Computer Engineering, Cihan University-Erbil, Kurdistan Region, Iraq

ABSTRACT

In this paper impedance matching, using tuning stubs of different types and forms are designed and analyzed using Mathcad Software. The aim of this paper is impedance matching, which is to connect an arbitrary complex-valued load impedance to a source with a given resistive internal impedance (Intrinsic Impedance Z_0) without causing input reflection and to ensure the transfer of maximum power from source to load (Z_L). Smith chart is designed in this paper with Mathcad software. This tool is considered a very powerful tool to show the results on the Smith chart. Single and double stub tuners are designed and analyzed with examples. The designed software is used in this paper for different cases, such as single stub and double stub tuners (open-ended and short-ended) for matching capacitive and inductive loads. The software designed in this paper is useful for designers working in this field as well as in the education process.

Keywords: Microwave circuits, impedance matching, transmission lines

INTRODUCTION

Impedance matching is one of the most important aspects of microwave circuit design.^[1] The main purpose of impedance matching is to connect complex values of load impedance with a source that has a specific resistive inner impedance Z_0 to avoid input reflection and to maximize power transfer from source to load.^[2] In real-world situations, load impedance often has to be matched with a transmission line that has a particular characteristic impedance Z_0 as shown in Figure 1.1.

One way of impedance matching is using tuning stubs. Tuning stubs are segments of transmission lines that are used for distributed impedance match.^[3] They can be used for both open and short transmission lines.^[4] Transmission line theory states that an open and short transmission line has an imaginary input impedance connected to a transmission line that can be connected in series or parallel. Depending on the complexity of the circuit, there are different designs for matching networks. Single-stub is the most common type of matching network, and two stubs are also available.^[5,6] It is always possible to detect a matching network if the load impedance (Z_L) is positive real. However, there are many different types of matching networks available, and in this article, we will discuss and analyze how they are designed and how they perform in practice. The choice of a matching network will depend on a number of factors, such as ease of use, bandwidth, performance, and adaptability.

In engineering solutions, simplicity is often favored, and the most optimal choice is typically the simplest design that fulfills the necessary specifications. A less intricate matching

network tends to be more economical, space-efficient, dependable, and exhibits lower loss in comparison to a more elaborate design.

When it comes to bandwidth, the goal is to achieve a perfect match at a specific frequency. However, in real-world scenarios, it is often necessary to match a load across a range of frequencies. This can be accomplished through various methods, although it usually entails added intricacy. In engineering, there is a strong preference for simplicity when it comes to finding solutions. Generally, the best choice is the design that is the simplest while still meeting all the necessary specifications. Opting for a simpler matching network has several advantages. It is more cost-effective, takes up less space, offers increased reliability, and has lower levels of loss compared to a more intricate design.

When it comes to bandwidth, the goal is to achieve a perfect match at a specific frequency. However, in real-world scenarios, it is often necessary to match a load across a range of

Corresponding Author:

Husham J. Ahmad, Department of Communication and Computer Engineering, Cihan University-Erbil, Kurdistan Region, Iraq.
E-mail: husham.jawad@cihanuniversity.edu.iq

Received: April 19, 2024

Accepted: June 01, 2024

Published: July 08, 2024

DOI: 10.24086/cuesj.v8n2y2024.pp1-8

Copyright © 2024 Husham J. Ahmad, Firas M. Z. Mahmood. This is an open-access article distributed under the Creative Commons Attribution License.

frequencies. This can be accomplished using various methods, although it usually results in increased complexity.

Single-Stub Tuning

Figure 1.2 illustrates a commonly employed method for achieving matching, which involves the use of a stub – a single segment of the transmission line. This stub can be either short-circuited or open-circuited and is connected to feed line transmission with a specific space from load. The advantage of the single-Stub tuning circuit is its seamless integration into the transmission line medium, eliminating the need for discrete components. Shunt stubs are typically used in micro-strip line or strip-line configurations, nevertheless series of stubs are better to use in slot-line and coplanar waveguide setups.^[7,8]

When fabricating transmission line media like micro-strip or strip-line, open-circuited stubs are more convenient as they do not require creating a slot in the substrate to the ground plane. Conversely, for transmission lines such as coaxial cable or waveguide, short-circuited stubs will be preferred. This is due to the potential for radiation from the large cross-sectional area of an open-circuited line, causing the stub not reactive along. This paper will use both of Smith chart and analytic solutions to achieve shunt-stub tuning. A Smith chart will be utilized solely for presenting computer solutions and results, which are typically accurate enough for practical applications. On the other hand, analytic expressions provide more accurate information and are more valuable in computer-aided design.

Double-Stub Design

In section (1.1), the single-Stub tuner does matching between load impedance and a transmission line but requires adjustable length of transmission line between the stub and load. That may be not an issue for a stable matching circuit but could give difficulties if a variable tuner is desired. In such cases, the double-Stub tuner, using two tuning stubs in known positions and is often constructed using a coaxial line with modified stubs connected in parallel with the main coaxial line, can be utilized. However, it is important to note that a double-Stub tuner is unable to be matching with all of the load impedances.

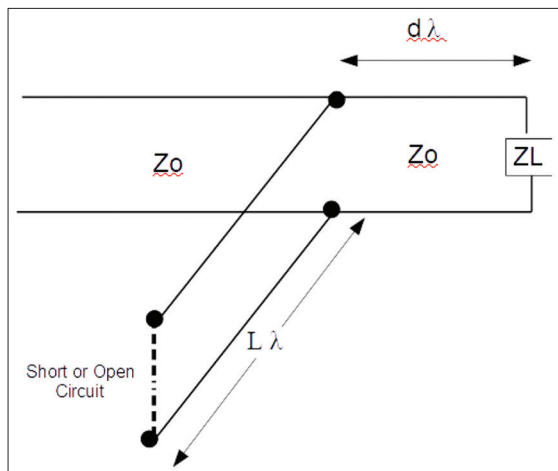


Figure 1.1: Single stub tuner

Figure 1.2 shows the double-Stub tuner circuit, allowing the load to be placed at various distances from the first stub. This setup is considered too closely resemble real-world situations. The shunt stubs in Figure 1.2 can be readily added for specific transmission line types, while series stubs are more suitable for other line variations. In both cases, the stubs can be either short-circuited or open-circuited.^[9,10]

Smith Chart Solutions

Figure 1.3 shows the Smith chart, outlining the essential steps for using the double-Stub tuner. When dealing with the single-Stub tuner, there are two potential solutions. The susceptance of the first stub, b_1 (or b_1' for the second solution), adjusts the load admittance to y_1 (or y_1'). These points are located on the rotated circle $1 + jb$, with a rotation length of d wavelengths ($d\lambda/2$) toward the load. Here, $d\lambda/2$ represents the electrical length between two stubs. Subsequently, by transforming y_1

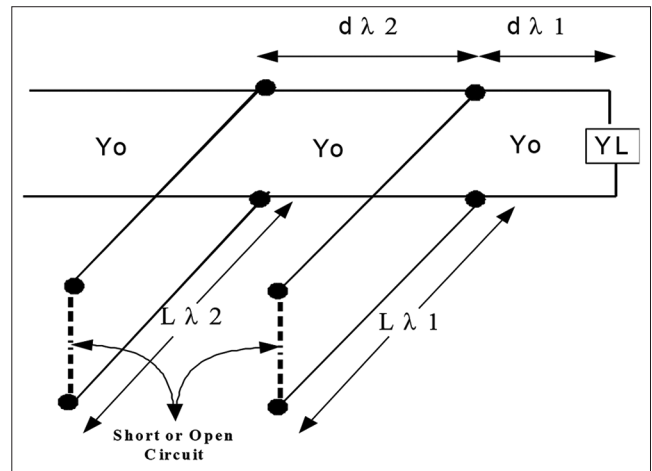


Figure 1.2: Double stub tuner

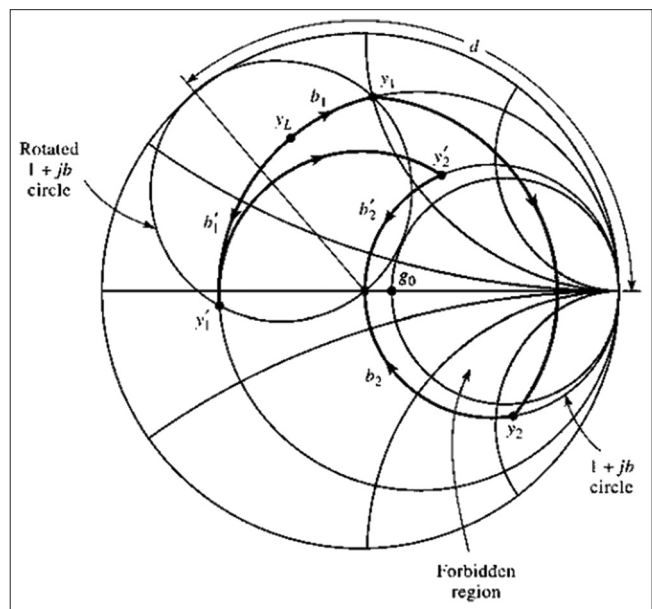


Figure 1.3: The Smith chart structure illustrates the double-Stub tuner operation

(or y_1') toward the generator through a length of the line of d , we arrive at the point y_2 (or y_2'), which must pose on the circle $1+jb$. The second stub will introduce a susceptance of b_2 (or b_2'), aligning the point with the center of the Smith chart and thereby completing the matching process. In certain practical designs, it may be necessary to connect the first stub at a specific distance $d\lambda_2$ from the load, as illustrated in Figure 1.2. In all cases, the aforementioned procedure will be followed, albeit with a modified y_L .^[11]

Computer-Aided Design of Combining Smith Chart with Mathcad

In this paper, a complete Smith chart has been designed using Mathcad software. The code can be seen in Appendix 1. Figure 2.1 shows a typical plot of the Smith chart in Mathcad software.

The Smith chart constructed in Appendix 1 is used in this paper as a tool to show the calculated results. This in fact will help designers to get clear pictures about their results and reduce the time for analyzing the validity of their design.^[12]

SINGLE AND DOUBLE MATCHING DESIGN WITH MATHCAD CODES

Single Stub Tuner

Referring to Figure 1.1, a Mathcad code is built in this paper and is given in Appendix 2. The application of this built software is worked through two examples, namely for capacitive and inductive loads. The results are shown in Figures 2.1 and 2.2 for the two solutions, solution (1) and (2) for short and long stub lengths.

Double Stub Tuner

Referring to Figure 2.2, which shows a double stub tuner diagram, we design a computer program using Mathcad software. This program can be seen in Appendix 3. The application of this designed program is used for a number of examples for a variety of cases. Results are shown in Figure 2.3a-f for the case of capacitive load and a variety of auxiliary (q_{aux}) angles.

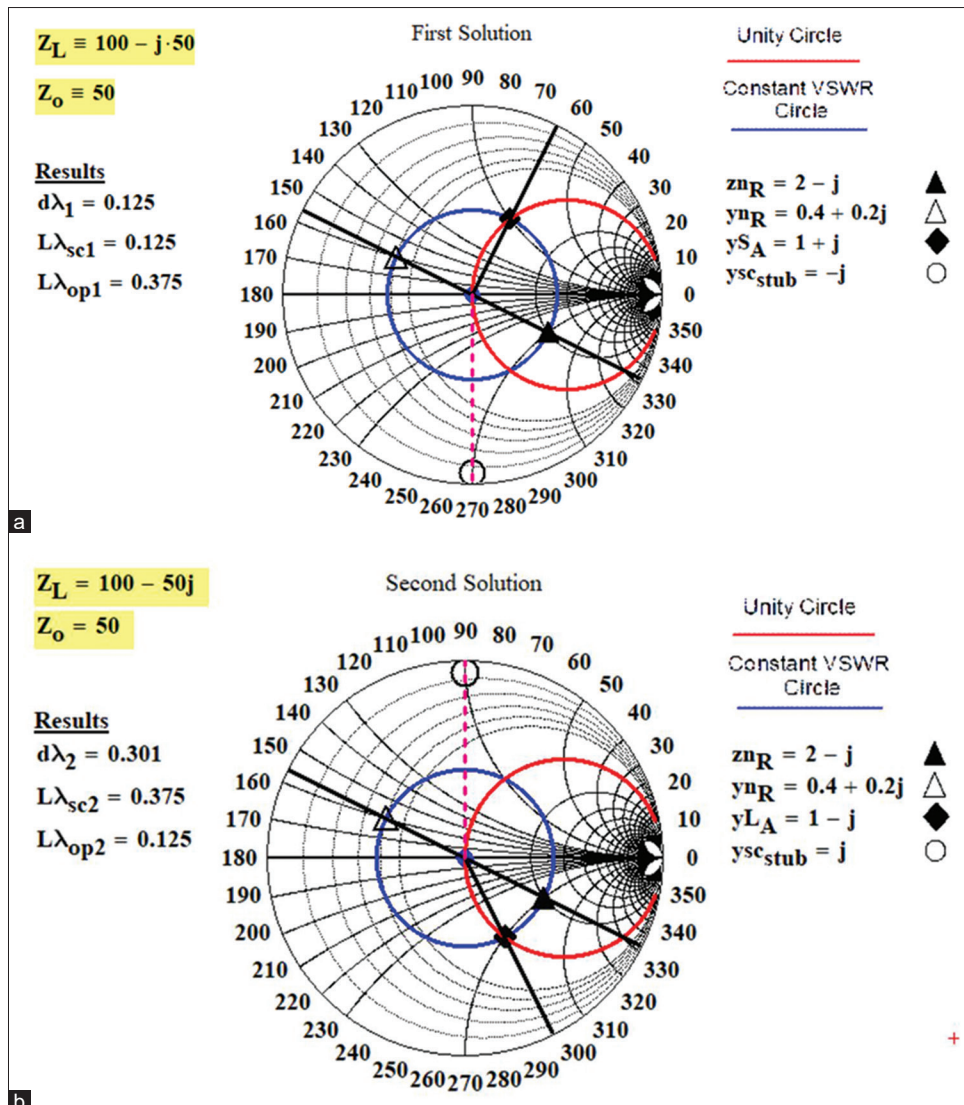


Figure 2.1: Capacitive impedance load single stub matching results. (a) Capacitive load, solution (1), (b) Capacitive load, solution (2)

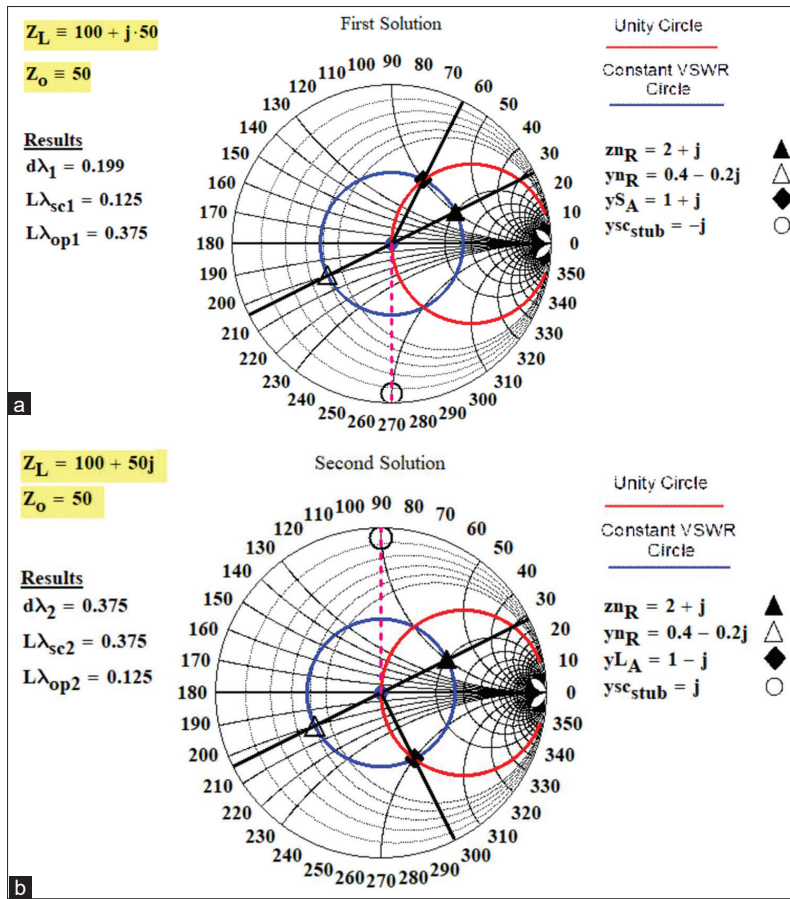


Figure 2.2: Inductive impedance load single stub matching results. (a) Inductive load, solution (1), (b) Inductive load, solution (2)

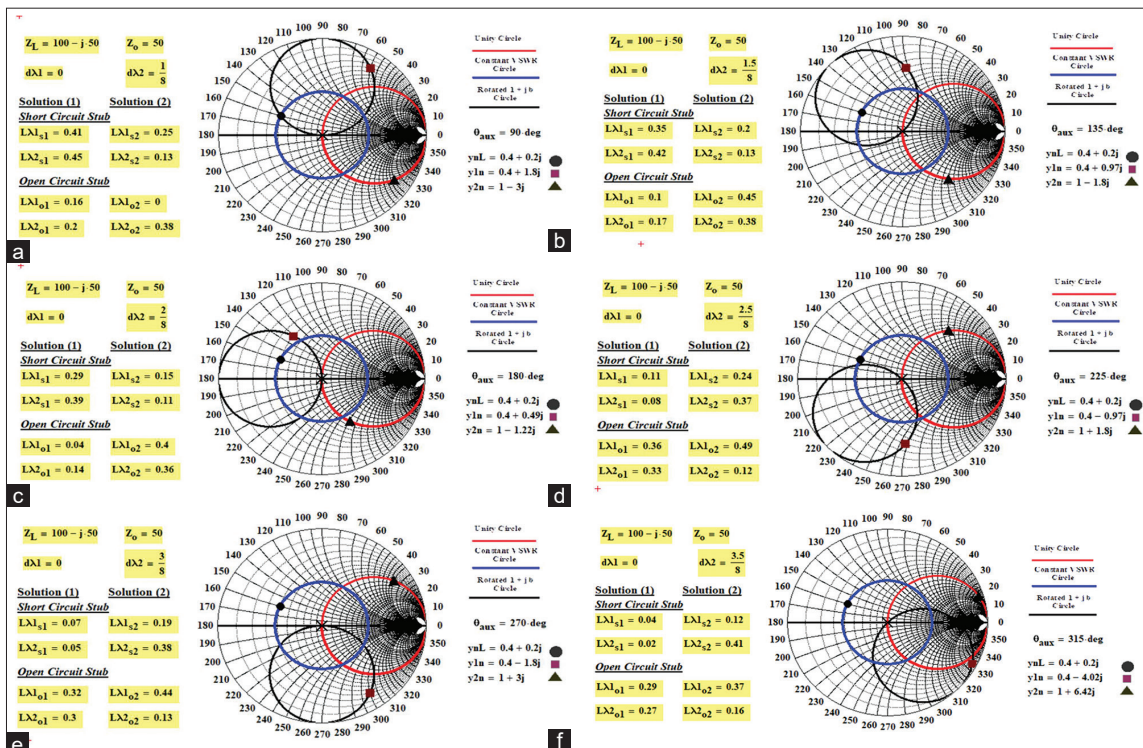


Figure 2.3: Results of applying the designed program for designing a double stub tuning microwave circuit for capacitive load (Case $d_{11} = 0$). (a) Auxiliary angle 90°, (b) Auxiliary angle 135°, (c) Auxiliary angle 180°, (d) Auxiliary angle 225°, (e) Auxiliary angle 225°, (f) Auxiliary angle 315°

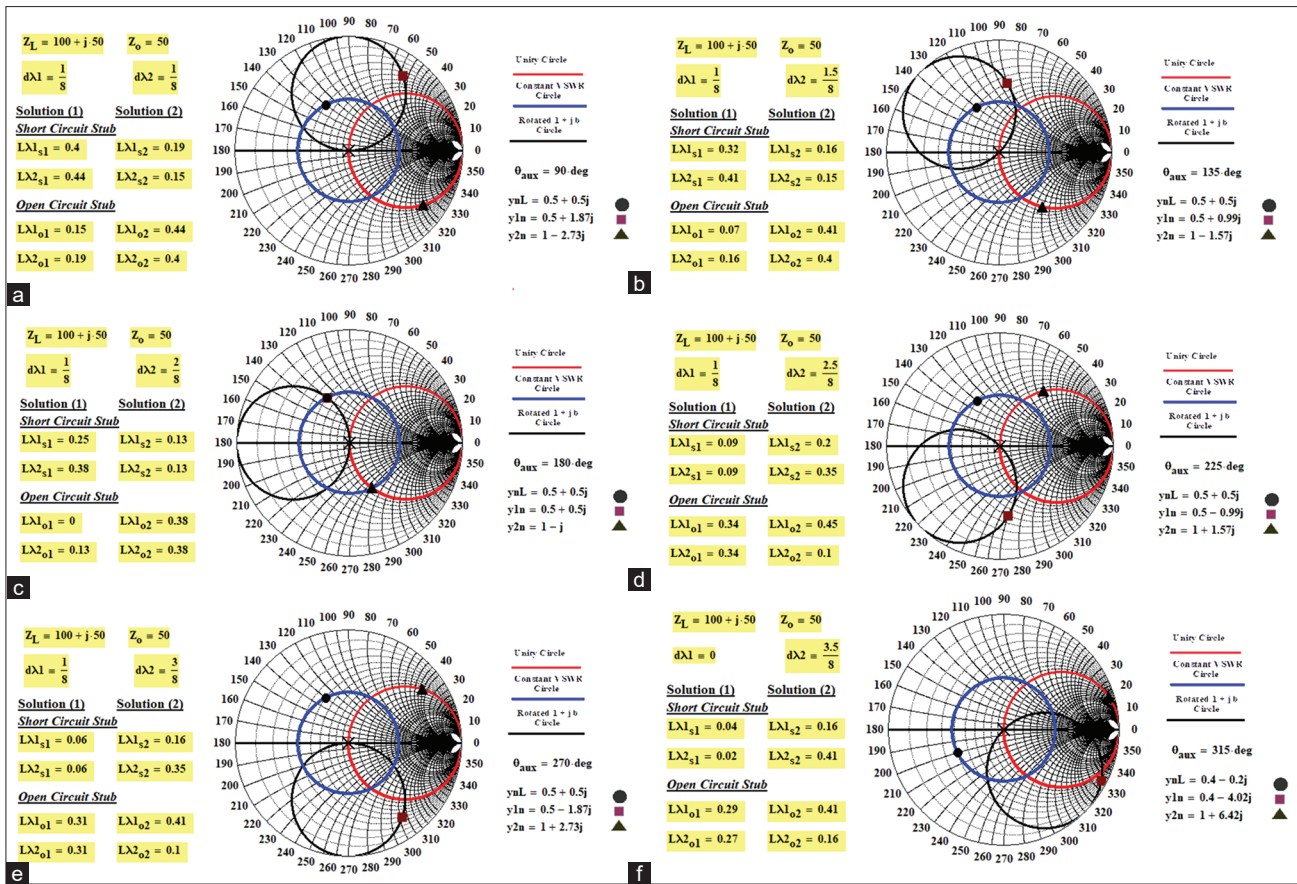


Figure 2.4: Results of applying the designed program for designing double stub tuning microwave circuit for capacitive load (Case $dl_1 = 1/8$). (a) Auxiliary angle 90°, (b) Auxiliary angle 135°, (c) Auxiliary angle 180°, (d) Auxiliary angle 225°, (e) Auxiliary angle 270°, (f) Auxiliary angle 325°

The results shown in Figure 2.3 above are for the case $dl_1 = 0$ and variable lengths of dl_2 . The designed software is applied for another case in which dl_1 is set to $1/8$ and for different rotation angles and results are presented in Figure 2.4.

DISCUSSIONS AND CONCLUSIONS

Two software are designed in this paper, namely, single and double stub tuners for matching loads in microwave circuits. These two software were examined by solving selected examples. Examples were selected to evaluate the performance of the designed software for capacitive and inductive load impedances.

The results are presented in the forms of numerical as well as graphical (on Smith chart). Designers in this field need some time, to project their results on the Smith chart to help them to visualize whether their approach in the right direction. The designed software in this paper is to shorten the time required and to obtain accurate solutions. Figures 2.2 and 2.3 show the results of the designed software.

These results show the capability of the designed software to deal with a variety of cases of different load impedances and various conditions. The big achievement of using the designed software in this paper is time-saving and high accuracy. This software may be used by researchers as well as undergraduate studies.

REFERENCES

1. R. J. Weber. *Introduction to Microwave Circuits: Radio Frequency and Design Applications*. Vol. 1. John Wiley and Sons, United States, 2001.
2. G. A. QasMarrogy. Performance analysis of adaptive noise canceller using (NLMS) algorithm for speech communication systems. *Al-Mansour Journal*, vol. 29, no. 1, pp.103-116, 2018.
3. G. A. QasMarrogy and H. J. Ahmad. Simulation of moving target indication radar system based on VisSim/comm application. *Cihan University-Erbil Scientific Journal*, vol. 5, no. 2, pp.38-45, 2021.
4. J. Ahmad and A. QasMarrogy, A. Modeling of an airport traffic control (ATC) radars using mathcad. In: *Proceedings of the 4th International Conference on Communication Engineering and Computer Science, Coimbatore, India*, pp. 15-16.
5. C. E. Free and C. S. Aitchison, C.S. *RF and Microwave Circuit Design: Theory and Applications*. John Wiley and Sons, United States, 2021.
6. S. Babic and C. Akyel. *Impedance Matching by Tuner Stubs (Single, Double and Triple) Analytical Method*. Authorea Preprints, 2023
7. A. Jain and R. P. Yadav. Design and development of rigid coaxial line based variable stub tuner. *Frequenz*, vol. 75, no. 5-6, pp.153-158, 2021.
8. A. B. Obot. Design procedure of single shunt (short circuited) stubs impedance matching networks using the smith chart. *Dimensions*, vol. 7, no. 4, p.12344-12348, 2020.
9. A. A. Muller, V. Asavei, A. Moldoveanu, E. Sanabria-Codesal, R. A. Khadar, C. Popescu, D. Dascalu and A. M. Ionescu. The 3D

- Smith chart: From theory to experimental reality. *IEEE Microwave Magazine*, vol. 21, no. 11, pp.22-35, 2020.
10. S. Aiswarya and S. K. Menon. Design of Open and Short-Circuit Stubs for Filter Applications. In: *Intelligent Data Communication Technologies and Internet of Things: Proceedings of ICICI 2020*. Singapore: Springer Singapore, pp. 663-672, 2021.
 11. B. P. Smyth and A. K. Iyer. Design of a Compact Dual-Band Double-Stub Matching Network Using MTM-EBGs. In: *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*. United States, IEEE, pp. 89-90, 2020.
 12. F. M. Mahmood. Design and Implementation of Microstrip Directional Coupler for Satellite Communication Application. In: *Cihan University-Erbil Conferences, 4th International Conference on Communication Engineering and Computer Science*, pp. 144-150, 2022.

APPENDIX 1

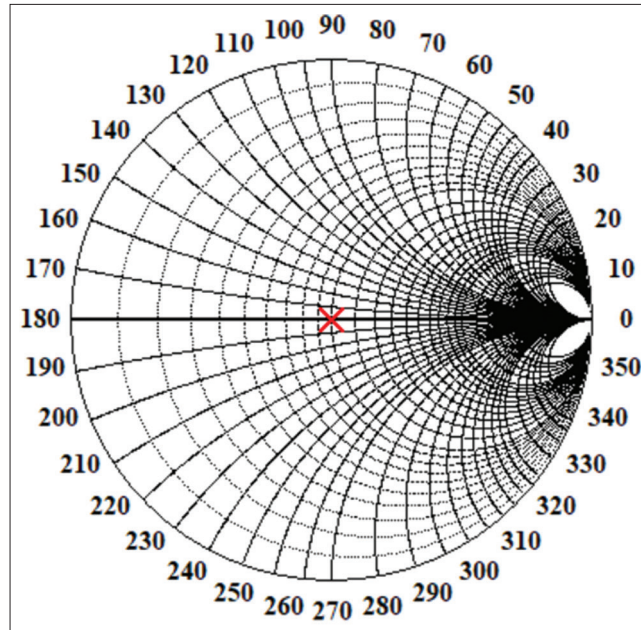


Figure A1: Smith chart plot using Mathcad

APPENDIX 2

$$Z_L = R_L + jX_L = \text{Re}(Z_L) + j \text{Im}(Z_L) \quad G = \text{Re}(Y_L) + j \text{Im}(Y_L)$$

$$t1 := \begin{cases} X_L \sqrt{\frac{R_L(Z_o - R_L)^2 + X_L^2}{Z_o}} \\ R_L - Z_o \end{cases} \text{ if } R_L \neq Z_o \quad t2 := \begin{cases} X_L \sqrt{\frac{R_L(Z_o - R_L)^2 + X_L^2}{Z_o}} \\ -X_L \end{cases} \text{ if } R_L = Z_o$$

$$d\lambda(t) := \begin{cases} \frac{1}{2\pi} \arctan\left(\frac{t}{Z_o}\right) & \geq 0 \\ \frac{1}{2\pi} \arctan\left(\frac{t}{Z_o}\right) + 0.5 & < 0 \end{cases}$$

$$d\lambda_1 := d\lambda(t1) \quad d\lambda_2 := d\lambda(t2)$$

$$GG(t) := \frac{R_L t^2}{R_L^2 + (X_L + Z_o \cdot t)^2} \quad BB(t) := \frac{R_L^2 t - Z_o - X_L \cdot t \cdot X_L + Z_o \cdot t}{Z_o [R_L^2 + (X_L + Z_o \cdot t)^2]}$$

$$L\lambda_{sc}(t) := \begin{cases} \frac{-1}{2\pi} a \tan\left(\frac{Y_o}{BB(t)}\right) \text{ if } \frac{-1}{\pi} a \tan\left(\frac{Y_o}{BB(t)}\right) \geq 0 \\ \frac{-1}{2\pi} a \tan\left(\frac{Y_o}{BB(t)}\right) + 0.5 \text{ otherwise} \end{cases}$$

