Analysis of transmission lines matching using quarter-wave transformer

RUZHDI SEFA, ALIDA SHATRI MARAJ, ARIANIT MARAJ
Faculty of Electrical and Computer Engineering,
University of Prishtina
REPUBLIC OF KOSOVA
ruzhdi.sefa@fiek.uni-pr.edu, alida.shatri@art-ks.org, arianit.maraj@ptkonline.com

Abstract - Due to conformal capability, research on transmission lines has received much attention lately. Many studies have been reported in the last decade in which transmission lines have been analyzed extensively using various techniques. It is well known that transmission lines are used for transmission of information, but in this case the main aim is to deliver information from generator to receiver with low attenuation. To achieve this, the load should be matched to the characteristic impedance of the line, meaning that the wave coefficient should be near 1 (one). One of the most important methods for line matching is through quarter-wavelength line (quarter-wave transformer). Analysis of transmission lines using numerical methods is difficult because of any possible error that can occur. Therefore, the best solution in this case would be the use of any software package which is designed for analysis of transmission lines. In this paper we will use Sonet software which is generally used for the analysis of planar lines.

Key words: Transmission line, scattering parameters, quarter-wave transformer, matching, Sonet.

1 Introduction

Electromagnetic energy is transmitted through the electromagnetic field. This field from generator to the load is spread in the form of electromagnetic waves. The most important system for transmission of electromagnetic waves is transmission lines. Transmission lines consist of two or more conductors (e.g. coaxial lines, microstrip lines etc). Transmission lines are used in many disciplines, e.g. they pass a state carrying telephone signals and electric power [1]. Microwaves today are used also in astrophysics for star observation, microwave ovens, measuring the speed of vehicles etc. The development of microwave technology is directly connected to the development of radar systems that started from 1940. After that, microwaves began to be used in telecommunication fields [1].

Methods for analysis of transmission lines are usually numerical methods. In this paper we will use SONET software for analyzing these transmission lines. Two specific types of transmission lines for communication, which have a considerable interest, are coaxial lines and microstrip lines. Coaxial lines are flexible and are used especially to connect two electronic instruments together. Mictrostrip lines are used in integrated circuits to connect for example two circuits together. In this paper we will describe shortly transmission lines, scattering parameters, quarter-wave transformer and at the end we have analyzed one example regarding to line matching using quarter-wave transformer; simulations are made using Sonet software.

2 Transmission lines

For point to point transmission of information and power, the source energy must be directed or guided. This can be achieved by using transmission lines. A transmission line is no more than a physical connection between two locations through two conductors. Any transmission of energy through conducting or non conducting media may be considered a transmission line [2].

A transmission line is characterized by three main parameters [2] [4]

- Dimensional parameters: includes length, dimensions of each conductor, thickness of insulation etc
- Material parameters: conductivity, permittivity and permeability
- Electrical parameters: resistance, capacitance, inductance etc

The term transmission line has to do with material that is used for connecting two points together and for transmission of information between these two points. Transmission lines in addition to signal transmission are used also for other purposes, such as transforming of complex resistances, building synchronized microwave circuits etc. The transmission of microwave signal must be with weakening as small as possible.

Transmission lines used in microwave technology are classified as follow:

- Lines that have two or more insulated conductors- wireless transmission of signal that have electric and magnetic fields perpendicular to the direction of wave transmission. These waves are so called transversal waves.

- Waveguides-can be cylindrical, elliptical or rectangular
- Dielectric lines – in this group are microstrip lines

Transmission lines also can be classified in:
Low frequency lines-these lines are used for transmission of electrical power, such as AC or DC at large distances.
High frequency lines–these lines can be defined as lines that are designed to carry electromagnetic waves, whose wavelengths are shorter than the length of the line. Under these conditions, the electrical behavior of the line is more complex than for low frequency lines. For purpose of analysis, one transmission line can be modeled as network with two entries as shown in figure below:

Figure 1. Network model with two ports

If transmission line is uniform due its length, then its behavior is described by characteristic impedance Z_0. This ratio is between voltage and power at any point of the line. Because of line resistance, due the process of power transmission through line, a part of this power will be lost. This effect is called Omic or resistive loss. In high frequencies, will occur another effect called dielectric loss. Dielectric loss is caused when the conductive material within transmission line absorbs energy from alternative electric field and transforms it into heat. Total power loss on the line often is specified in decibel per meter, and usually depends from frequency of signal.

3 Scattering parameters (S parameters)

As we know, voltages and currents hardly can be measured in microwave structures because they are dependent on the length of transmission line and vary depending from their position in the line.
In microwave circuits, the waves are measured easily. One of the methods for this reason is using incident and reflected waves. This method is known as scattering parameters or S parameters. This method (S parameters) avoids many problems with voltage and current, especially in transmission lines.

The S-parameters of a network provide a clear physical interpretation of the transmission and reflection performance of the device. The S-parameters for a two-port network are defined using the reflected or emanating waves, b_1 and b_2, as the dependent variables, and the incident waves, a_1 and a_2, as the independent variables. The general equations for these waves as a function of the S-parameters are shown below [2] [3]:

$$b_1 = S_{11}a_1 + S_{12}a_2 \qquad (1)$$

$$b_2 = S_{21}a_1 + S_{22}a_2 \qquad (2)$$

S_{11} - Forward Reflection Coefficient
S_{21} - Forward Transmission Coefficient
S_{12} - Reverse Transmission Coefficient
S_{22} - Reverse Reflection Coefficient

Using these equations, the individual S-parameters can be determined by taking the ratio of the reflected or transmitted wave to the incident wave with a perfect termination placed at the output.

$$S_{11} = \frac{b_1}{a_1} \, |a_2 = 0 \qquad (3)$$

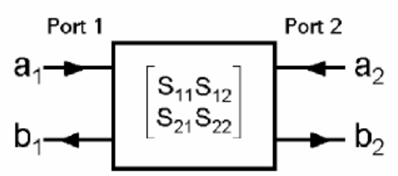
$$S_{12} = \frac{b_1}{a_2} \, |a_1 = 0 \qquad (4)$$

$$S_{21} = \frac{b_2}{a_1} \, |a_1 = 0 \qquad (5)$$

$$S_{22} = \frac{b_2}{a_2} \, |a_1 = 0 \qquad (6)$$

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \qquad (7)$$

These four S-parameters completely define the two-port network characteristics. All modern vector network analyzers can easily measure the S-parameters of a two-port device [2].



$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

Figure 2.4 Definition of two-port S-Parameter network.

S-parameters have been widely used in combining Electromagnetic (EM) analysis of transmission line networks with circuits involving of linear/nonlinear loads.

4 Line impedance matching

As we know, transmission lines are used for signal transmission, but the main aim is to deliver information from generator to receiver with low attenuation. To achieve this, the load should be matched to the characteristic impedance of the line. There are a lot of methods for line impedance matching. One of the most important methods for matching is through quarter-wave transformer. In this paper we will explain this method and at the end we will simulate with SONET software one example in which we will see the results for impedance line matching with quarter-wave transformer.

4.1 Quarter-wave transformer line matching method

If the end of a transmission line with characteristic impedance Z_{01} is terminated with a resistive load Z_L. We typically would like all power traveling down the line to be absorbed by the load Z_L. But if Z_L is not equal to Z_{01}, in this case we say that the line is unmatched and some of the incident power will be reflected. The aim is to deliver all the power to the resistive load (Z_L). To do this, we will use a matching network between transmission line and the load [6], [7], [8]. The aim of the matching network is to transform the load (Z_L) into Z_{01}. Or, say with another word, we don't want to have reflection. Since none of the incident power is reflected, and none of this power is absorbed by the lossless matching network, it all must be absorbed by the load Z_L. In this case, we don't have loss, but the problem is how to construct these networks in order to not have losses [5]. There are a lot of methods for doing impedance matching, but one of the easiest ways is using quarter-wave transformer. With this method is inserted a transmission line with characteristic impedance Z_{02} and length $\lambda/4$ (quarter-wave line) between the load and transmission line with impedance Z_{01}. This can be shown in the figure 3:

Reflection coefficient R is calculated using expression below:

$$R = \frac{Z_L - Z_{02}}{Z_L + Z_{02}} \qquad (8)$$

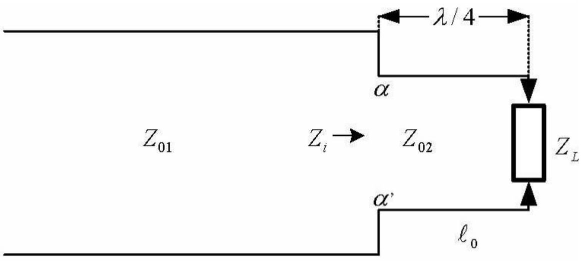


Figure 3. Quarter-wave transformer

The impedance Zt in the point of connection of two lines is:

$$Z_t = Z_{02}\frac{1+\mathrm{Re}^{j\pi}}{1-\mathrm{Re}^{j\pi}} = Z_{02}\frac{1-R}{1+R} = \frac{Z^2{}_{02}}{Z_L} \qquad (9)$$

In order to have impedance line matching, should have Z_i=$Z_{01,.}$ From where the line with length $\ell_0 = \lambda/4$ must have wave impedance like below:

$$Z_{02} = \sqrt{Z_L Z_{01}} \qquad (10)$$

5 Using SONET software for analysing transmission lines matching

Transmission line analysis through numerical methods is difficult. Therefore, in this case, the best solution is analysis of transmission lines using software packages. In this paper we have used SONET software for analyzing these transmission lines.

This software uses a modified method of moments for analysis of one project based on Maxwell's equations, enabling thus accurate calculation of three dimensional planar structures. Through this software can be calculated S, Y or Z parameters, parameters of transmission lines (Z_0, e_{eff}, etc.). In this paper, with Sonet Software we will calculate S parameters. Also, after these calculations it's possible to represent these analysis graphically, such is power density, presentation of the field in the remote area etc.

Completing a project using SONET means building a line geometry which than can be analyzed. Its well known that for designing transmission lines, there are many data given in tabular form and these data are used in some cases. Some of the main concepts in which rely the synthesis and analysis of transmission lines using Sonet software are given as below:

- Regulating the size of working box
- Determining the size of cells
- Determining the dielectric layers

- Analysis of circuit
- Graphical representation

However, in this paper we will use Sonet software to analyze the improvement of power and signal amplification. As example we have taken the range of antennas, while for line matching we will use quarter-wave transformer. In the figure below, this example is explained graphically. Also the parameters are given in this figure (figure 4)

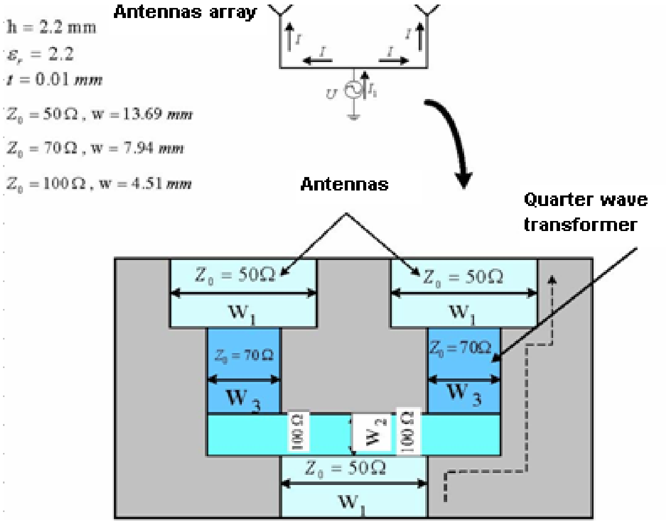


Figure 4. Antennas and quarter-wave transformer for line matching

In this case, the matching between antennas and the lines is done through quarter-wave transformer. The 3 D of this project realized in Sonet software is shown in figure 5:

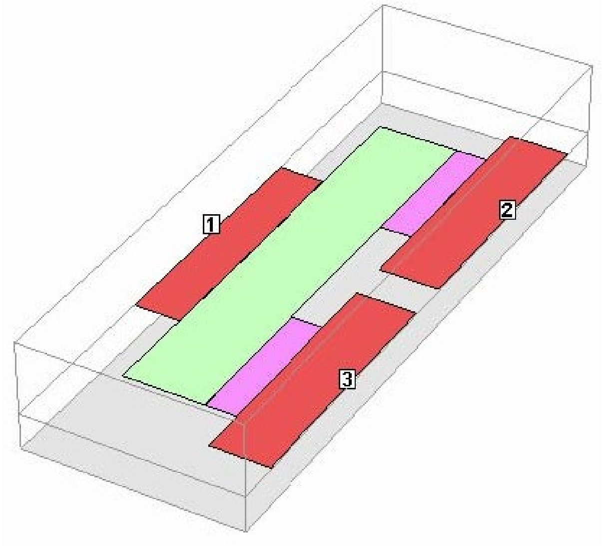


Figure 5. 3D view of project analyzed with Sonet

The main condition for microstrip line matching is that S_{11} parameter near 6 *MHz* frequency should falls below 10 *dB* value. This indicates that this line under these conditions is suitable for transmission of wave with maximum power.

Graphically with Sonet, its able to see the S parameters like below:

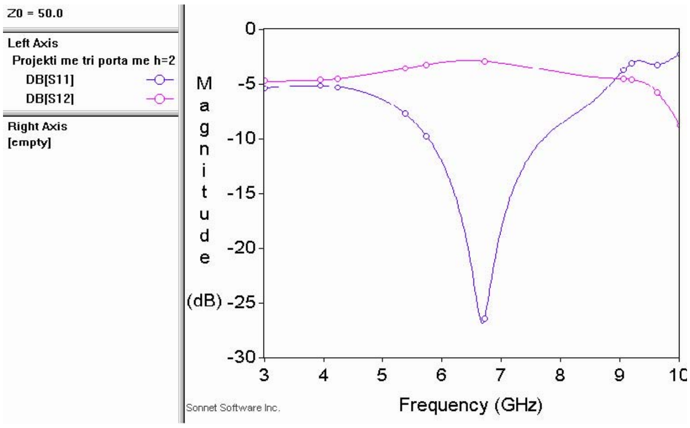


Figure 6. Scattering parameters

From the figure above, it’s clearly seen that we have matching between line and quarter-wave transformer is very suitable for such a thing.

6 Conclusion

In this paper we have don a short description of transmission lines theory. Recognizing the importance of S parameters for line matching, we have explained shortly these parameters too. A special importance we have dedicate to line matching. The reason why we want to match the line is that we would like all power traveling down the line to be absorbed by the load at the end of line. As we have seen in this paper, a matching network is a lossless 2 port device. Said in other words, we want the input impedance of the matching network to be equal with impedance in the input of transmission line. In this paper we have done the matching between antennas and lines with quarter-wave transformesrs. Based on the results, we can conclude that Sonte software is adequate for analysing transmission lines, especially S parameters. Through these analysis with Sonet software we can see graphycally an improvement of power transmission and improvement in signal amplification when we use quarter-wave transformer for line matching. Also, we have seen with this example that the method of quarter-wave transformer is very appropriate method for line matching.

References

[1] M. Sadiku, Numerical Techniques Electromagnetics, New York 2000.

[2] Rashmi Pathak, Characterizing losses in microstrip transmission lines, Summer 2005

[3] Yakup Bayram ,Hybrid S-Parameters for Transmission Line Networks with Linear/Nonlinear Load Terminations Subject to Arbitrary Excitations, IEEE,

[4] Jensen & Warnick, Transmission Lines and S-Parameters, chapter 1, October 27, ECEn 464: Wireless Communications Circuits

[5] Design of Nonplanar Microstrip Antennas and Transmission Lines Kin-Lu Wong Copyright, 1999 John Wiley & Sons, Inc. Print ISBN 0-471-18244-3 Online ISBN 0-471-20066-2

[6] Transmission Line Matching, ECE 450 Lecture from Logan Liu, ECE department, University of Illinois

[7] The quarter-wave transformer, Jim Stiles, Department of EECS, University of Kansas 2005

[8] Fundamental Transmission Line Theory and S-Parameters, Omar X. Avelar, Omar de la Mora & Diego I. Romero, march 2010