IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified

Vol. 5, Issue 2, February 2017

Comparison of Two Step and Six Step Impedance Matching Techniques using Quarter Wave Transformers

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Abstract: The current paper seeks to evaluate the performance of the quarter-wave transformer-based impedance matching technique implemented by means of reduced-height waveguide structures with each section being a quarter-wavelength long electrically, with comparison between performances based on number of sections used for impedance matching. The two-step impedance matching technique has been compared to its six-step variant, by comparing the impedance variation from input to output section in both cases, to enable optimization of power transfer and reduction of standing-wave formation due to significant variation in impedance between two successive sections, which is significant in case of two-step impedance matching by two quarter-wave sections.

Keywords: Impedance Matching, Reduced-Height, Waveguide, Quarter-Wave Transformer, Impedance Variation.

I. INTRODUCTION

Microwave power propagated through waveguides is delivered effectively from source to load provided there are no significant standing waves formed in the waveguides, since the formation of standing wave leads to power loss by destructive interference of the reflected wave with the forward wave.

Hence impedance matching techniques are employed to minimize reflection of waves, and for resistive loads this is done by gradually increasing or decreasing impedance instead of directly connecting a low impedance section to a high impedance section (impedance bridging). For waveguides, the quarter-wave transformation technique is often used for impedance matching.

II. QUARTER-WAVE TRANSFORMER

A single section quarter wave transformer is considered where load resistance R_L is to be matched with a transmission line of characteristic impedance Z_0. It is assumed that a transmission line of length l and characteristic impedance Z_1 is connected between the two as shown in the following figure. Its input impedance Z_{in} is found out as given in Matthei et al [1]. The impedance transformer is shown in Figure 2.1.

$$Z_{in}=Z_1\frac{R_L+jZ_L\tan(\beta l)}{Z_L+jR_L\tan(\beta l)}$$

For $\beta l=90^0$, i.e., $l=\lambda/4$, $Z_1=(Z_0R_L)^{1/2}$ and $Z_{in}=Z_0$ hence no reflected wave appears. However for other values of βl, reflection occurs and the corresponding coefficient is determined as follows:

$$\Gamma_{in}=\frac{Z_{in}-Z_o}{Z_{in}+Z_o}=\frac{Z_1\dfrac{R_L+jZ_1\tan(\beta\ell)}{Z_1+jR_L\tan(\beta\ell)}-Z_o}{Z_1\dfrac{R_L+jZ_i\tan(\beta\ell)}{Z_1+jR_L\tan(\beta\ell)}+Z_o}$$

$$=\frac{R_L-Z_o}{R_L+Z_o+j2\sqrt{Z_oR_L}\tan(\beta\ell)}$$

$$=\rho_{in}\exp(j\varphi)$$

$$\therefore\ \rho_{in}=\frac{R_L-Z_o}{\{(R_L+Z_o)^2+4Z_oR_L\tan^2(\beta\ell)\}^{1/2}}$$

$$=\frac{1}{\left\{1+\left(\dfrac{2\sqrt{Z_oR_L}}{R_L-Z_o}\sec(\beta\ell)\right)^2\right\}^{1/2}}$$

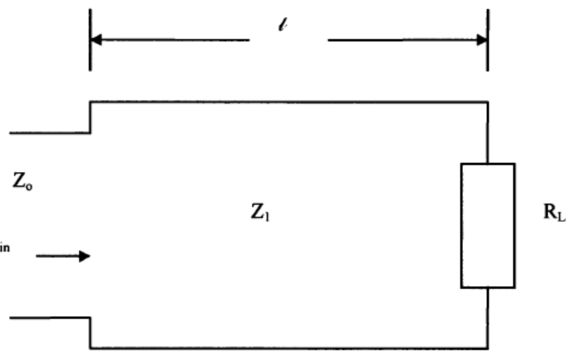

FIGURE 2.1: Single Section Quarter-Wave Transformer

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III. TWO-SECTION QUARTER-WAVE TRANSFORMER

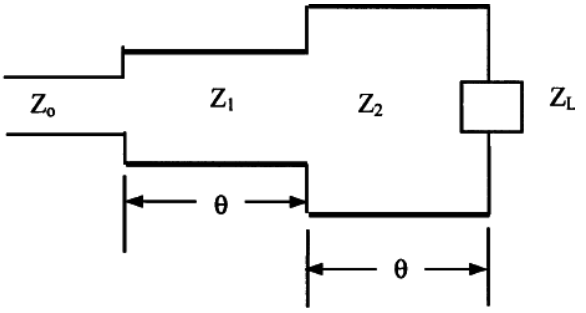

Figure 3.1: Two-Section Quarter-Wave Transformer

The two-section quarter-wave transformer is shown in figure 3.1.
For a two-section quarter-wave transformer, considering input impedance Z_{in}, impedances of the two sections $Z_1$and Z_2 respectively, and output impedance as Z_{out}, the following relation holds when the input impedance is matched to a resistive load, as shown by Chakraborty et al [2]:

$$Z_{in}/Z_1=Z_1/Z_2=Z_2/Z_{out}$$

Thus an algorithm is developed to determine the impedance values of the two sections for given input and output impedance conditions and is implemented using MATLAB.

IV. MULTI SECTION TRANSFORMER

An N-section impedance transformer as shown in Figure 4.1 is considered to be connected between a transmission line of characteristic impedance Z_0 and load R_L. The length of every section is assumed same while their characteristic impedances are different. Impedance at the input of the N-th section is determined as follows.

$$Z_{\text{in}}^{N} = Z_N \frac{\exp(j\beta\ell) + \Gamma_N \exp(-j\beta\ell)}{\exp(j\beta\ell) - \Gamma_N \exp(-j\beta\ell)}$$

Where

$$\Gamma_N = \frac{R_L - Z_N}{R_L + Z_N}$$

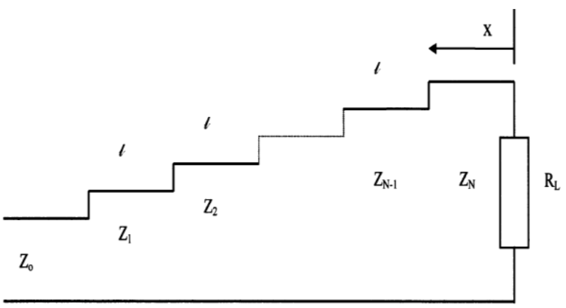

Figure 4.1: N-Section Quarter-Wave Transformer

Hence, for a six-section quarter-wave transformer, the set of equations is as follows:
$Z_{in}/Z_1= Z_1/Z_2= Z_2/Z_3= Z_3/Z_4= Z_4/Z_5= Z_5/Z_6= Z_6/Z_{out}$

V. ALGORITHM FOR OBTAINING IMPEDANCES OF QUARTER-WAVE SECTIONS

The algorithm solves for the impedances of the two quarter-wave sections in the following manner:

1. $Z_1^2=Z_{in}*Z_2$ and $Z_1*Z_2=Z_{in}Z_{out}$ together helps solve for Z_2.
2. Then by putting the value of Z_2 in the first relation, Z_1 is obtained.

For six-section quarter-wave transformer, the solution is obtained as follows:

1. $Z_1^2=Z_{in}*Z_2$, $Z_1=Z_2^2/Z_3$, $Z_2=Z_3^2/Z_4$, $Z_3=Z_4^2/Z_5$, $Z_4=Z_5^2/Z_6$, $Z_5=Z_6^2/Z_{out}$ and $Z_1Z_6=Z_{in}Z_{out}$ together helps to solve for Z_1.
2. Substituting the expression for Z_1 in $Z_1^2=Z_{in}*Z_2$, Z_2 is obtained.
3. The impedances of all other intermediate sections are determined in a similar manner.

VI. RESULTS

The results for two and six section impedance matching are shown in Table 6.1 below. The input and output impedance data correspond with the data of Williamson [3] to enable a comparison of results.

Table 6.1 Comparison of Two Section and Six Section Quarter Wave Impedance Transformer

Two Section Quarter Wave Transformer		Six Section Quarter Wave Transformer	
Section	Impedance (Ω)	Section	Impedance (Ω)
Input	69.9038	Input	69.9038
1	104.9763	1	83.2113
2	139.8879	2	99.0522
		3	117.9087
		4	140.3549
		5	167.0742
		6	198.88
Output	236.7407	Output	236.7407

The impedance variation is graphically compared in Figure 6.1 below.

Thus it can be clearly observed from the figure above that for six section impedance matching, the impedance variation has a much less steep slope compared to the two section technique. Hence it can be clearly regarded as better in terms of prevention of standing wave formation and efficiency in coupling microwave power from input to output.

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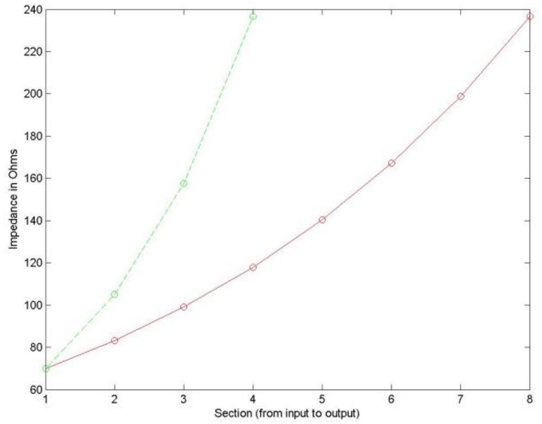

Figure 6.1 Comparative Variation of impedance from input to output in Two Section and Six Section Impedance Transformers

VI. CONCLUSION

It is found from the result obtained that six section quarter-wave transformers create a much smoother impedance profile for an electromagnetic wave travelling through a waveguide compared to two section quarter wave transformers, leading to a reduction in the possibility of standing wave formation in the waveguide. Thus future work in this area will focus on determination of power loss due to insertion of multiple quarter-wave sections for impedance matching and proposal for an optimal scheme which is expected to be frequency-dependent at microwave frequencies.

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