DESIGN AND SIMULATION OF BROADBAND MATCHING NETWORK USING BINOMIAL (EMPIRICAL) TRANSFORMER TECHNIQUE

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ABSTRACT

This paper discusses the design and simulation of broadband matching network using Binomial (Empirical) Technique. The realization of 4-section impedance matching network using coaxial lines is carried out. MATLAB and AWR software were used for the implementation.

Keywords: Bandwidth, Binomial, Broadband matching, coaxial lines, impedance,

I INTRODUCTION

In many cases, loads and termination for transmission lines in practical application do not have impedance equal to the characteristic impedance of the transmission line. This result in high reflection of wave transverse in the transmission lines and correspondingly a high VSWR due to standing wave formation[1-3], one method to overcome this is to introduce an arrangement of transmission line sections or lumped elements between the mismatched transmission line and its termination/load to eliminate standing wave reflection. This is called an impedance matching. Matching the source and load to the transmission line or waveguide in a general microwave network is necessary to deliver maximum power from the source to the load. In many cases, it is not possible to choose all impedances such that overall matched conditions result [4]. These situations require that matching networks be used to eliminate reflections. Depending on the application, matching may be required over a band of frequencies such that the bandwidth of the matching network is an important design parameter [6].

Impedance matching networks at a single frequency can be designed without much difficulty to provide a reflection coefficient of zero at the desired frequency [5, 7]. However, in many applications it is desirable to match impedances over a range of frequencies. One way of designing broadband matching networks is to use multiple sections of transmission line rather than just one section as in the case of the quarter wave transformer [8]. In order to simplify the analysis of these multiple section matching networks, the theory of small reflections is utilized. A Binomial (Empirical) multi-section matching transformer can provide larger bandwidth for a given number of transmission line sections. The Binomial (Empirical) transformer technique exploits the characteristics of Pascal's Triangle [7].

No. of sections	**Coefficients**

0	1
1	1 1
2	1 2 1
3	1 3 3 1
4	1 4 6 4 1

This trend continues for N number of sections.

The aim of this paper is to design and simulate four sections broadband impedance matching using binomial (Empirical) algorithm with load impedance, Z_L = 100Ω and characteristic impedance, Z_0 = 50Ω.

The objectives are:

(i) Calculation by hand and MATLAB implementation (Approximate solution)

(ii) Verification of the design with MATLAB simulation (Exact solution) and

(iii) Implementation of the design on Advancing the Wireless Revolution (AWR) software (Engineering solution).

II PROPOSED METHODOLOGY

The methodology to be adopted in this paper includes

(a) Determination of the required impedances, Z_1, Z_2, Z_3, and Z_4 of the sections to match the load using approximation.

(b) Determination of the reflection coefficients Γ_0, Γ_1, Γ_2, Γ_3 and Γ_4 using the theory of reflections.

(c) Determination of the section length, $l = \lambda/4$.

(d) Computation of the required Bandwidth and Percentage bandwidth for $\rho_m = |\Gamma_m| = 0.1$ from the graph obtained.

III THEORY AND CALCULATIONS

Here the design and implementation of the broadband matching network are carried out and it consists of three main phases.

3.1 First Phase: Approximate Solution

Theory of small reflections and binomial (empirical) formulae are used to determine total reflection, characteristic impedance and reflection coefficient of each section.

Given that, $|\Gamma_m| = 0.1$, $Z_L = 100\Omega$, $Z_0 = 50\Omega$, f = 2GHz, N = 4, and $\varepsilon r=1$

We can determine the length of each section by using, $l=\lambda/4$

But $\lambda = \frac{C}{f\sqrt{\varepsilon r}} = \frac{3\times10^8}{2\times10^9}$ = 0.15m or 150mm, therefore, $l=\lambda/4$ = 150mm/4 = 37.5mm

The required characteristic Impedances of the sections are:

$$Z_1 = (\sqrt[16]{Z_O})^{15} \times (\sqrt[16]{Z_L}) = (\sqrt[16]{50})^{15} \times (\sqrt[16]{100}) = 52.2\Omega$$

$$Z_2 = (\sqrt[16]{Z_O})^{11} \times (\sqrt[16]{Z_L})^{5} = (\sqrt[16]{50})^{11} \times (\sqrt[16]{100})^{5} = 62.1\Omega$$

$Z_3 = (\sqrt[16]{Z_O})^5 \times (\sqrt[16]{Z_L})^{11} = (\sqrt[16]{50})^5 \times (\sqrt[16]{100})^{11} = 80.5\Omega$

$Z_4 = (\sqrt[16]{Z_O}) \times (\sqrt[16]{Z_L})^{15} = (\sqrt[16]{50}) \times (\sqrt[16]{100})^{15} = 95.8\Omega$

The reflection coefficients of the sections are:

$\Gamma_O = \frac{Z_1-Z_o}{Z_1+Z_o} = \frac{52.2-50}{52.2+50} = 0.022$, $\Gamma_1 = \frac{Z_2-Z_1}{Z_2+Z_1} = \frac{62.1-52.2}{62.1+52.2} = 0.087$, $\Gamma_2 = \frac{Z_3-Z_2}{Z_3+Z_2} = \frac{80.5-62.1}{80.5+62.1} = 0.129$

$\Gamma_3 = \frac{Z_4-Z_3}{Z_4+Z_3} = \frac{95.8-80.5}{95.8+80.5} = 0.087$, $\Gamma_4 = \frac{Z_L-Z_4}{Z_L+Z_4} = \frac{100-95.8}{100+95.8} = 0.022$

From the theory of small reflection, we have

$\Gamma_{total} = 2e^{-jN\theta}\,[\Gamma_O \cos(N\theta) + \Gamma_1 \cos(\{N-2\}\theta + \frac{1}{2}\Gamma_{N/2}]$ for N = 4,

$\therefore \Gamma_{total} = 2e^{-j4\theta}\,[\Gamma_O \cos(4\theta) + \Gamma_1 \cos(2\theta) + \frac{1}{2}\Gamma_2]$

But we know, the electrical length of each section is given by, $\theta = \beta l = \frac{2\pi f l}{c}$

Computing the equations in matlab yield the following result/graph:

```
Zo=50; ZL=100;
Z1=((Zo)^(15/16))*((ZL)^(1/16)); % Calculate the %values of  Z1, Z2, Z3 and Z4
Z2=((Zo)^(11/16))*((ZL)^(5/16));
Z3=((Zo)^(5/16))*((ZL)^(11/16));
Z4=((Zo)^(1/16))*((ZL)^(15/16));
rho_0=(Z1-Zo)./(Z1+Zo);          % Calculate the values of %reflection coefficient of each section
rho_1=(Z2-Z1)./(Z2+Z1);
rho_2=(Z3-Z2)./(Z3+Z2);
rho_3=(Z4-Z3)./(Z4+Z3);
rho_4=(ZL-Z4)./(ZL+Z4);
f_centre=2e9;                    % Cut off frequency
length= (3e8/f_centre)/4;        % Calculate the length of %each section
f=0:10e6:4e9;
beta_l =(2*pi*f*length)./3e8;    % Calculate the electrical %length of each section

N=4;                             % Number of sections
rho_total=(2*exp(-j*N*beta_l)).*(rho_0*cos(4*beta_l)+rho_1*cos(2*beta_l)+0.5*rho_2); % Calculate the Total reflection
plot(f,abs(rho_total));
grid on
xlabel('Frequency GHz')
ylabel('|Total Reflection|')
title('The graph of |Total Reflection| Vs Frequency')
```

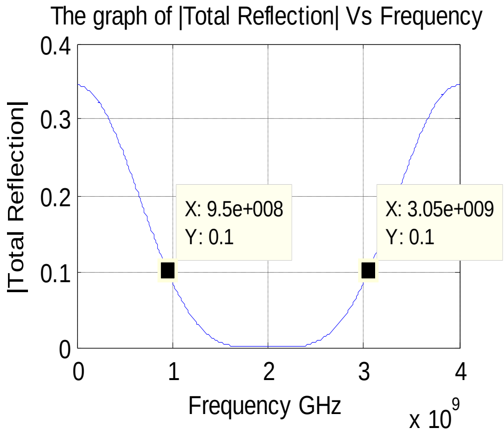

Figure1, magnitude of the total reflection vs frequency

3.2 Second Phase: Exact Solution

In the second phase, MATLAB is used to calculate the exact total reflection, Γ_{total}, for the values of characteristics impedances and lengths that were computed in the first phase and then $|\Gamma_{total}|$ vs. Frequency was plotted in MATLAB by using the formula $|\Gamma_{total}| = \frac{Z_{in,total} - Z_0}{Z_{in,total} + Z_0}$, where $Z_{in,total}$, is the impedance seen at the input side of overall microwave circuit and it depends on frequency. Recursive operations are used to determine the total impedance seen at the input side of each section which acts as the load to the next transmission line section.

Frequency range of 0 to 4GHz in step of 10MHz was used.

```
Zo=50; ZL=100; Z1=52.2; Z2=62.1; Z3=80.5; Z4=95.8;
f_centre=2e9;
length= (3e8/f_centre)/4;
f=0:10e6:4e9;
beta_l=(2*pi*f*length)./3e8; Zin_total1=Z4*(ZL+j*Z4*tan(beta_l))./(Z4+j*ZL.*tan(beta_l));
Zin_total2=Z3*(Zin_total1+j*Z3*tan(beta_l))./(Z3+j*(Zin_total1).*tan(beta_l));
Zin_total3=Z2*(Zin_total2+j*Z2*tan(beta_l))./(Z2+j*(Zin_total2).*tan(beta_l));
Zin_total4=Z1*(Zin_total3+j*Z1*tan(beta_l))./(Z1+j*(Zin_total3).*tan(beta_l));
total_reflection=(Zin_total4-Zo)./(Zin_total4+Zo);  plot(f,abs(total_reflection));
grid on
xlabel('Frequency Hz')
ylabel('|Total Reflection|')
title('The graph of Total Reflection Vs Frequency')
```

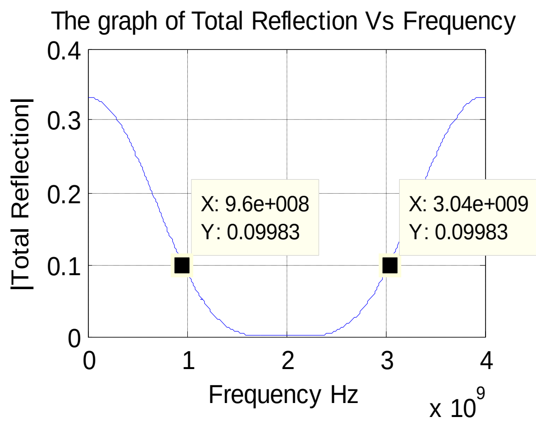

Figure2. magnitude of the total reflection vs frequency for the exact solution

3.3 Third Phase: Engineering Solution

AWR Microwave Design Environment software is used to implement and simulate the binomial (Empirical) transformer designed in the previous sections. The lengths of the transmission lines are physical lengths (not electrical lengths).

As in second phase, the frequency range of 0 to 4GHz in step of 10MHz is used. Fig.3a and 3b below show the AWR implementation and simulation respectively.

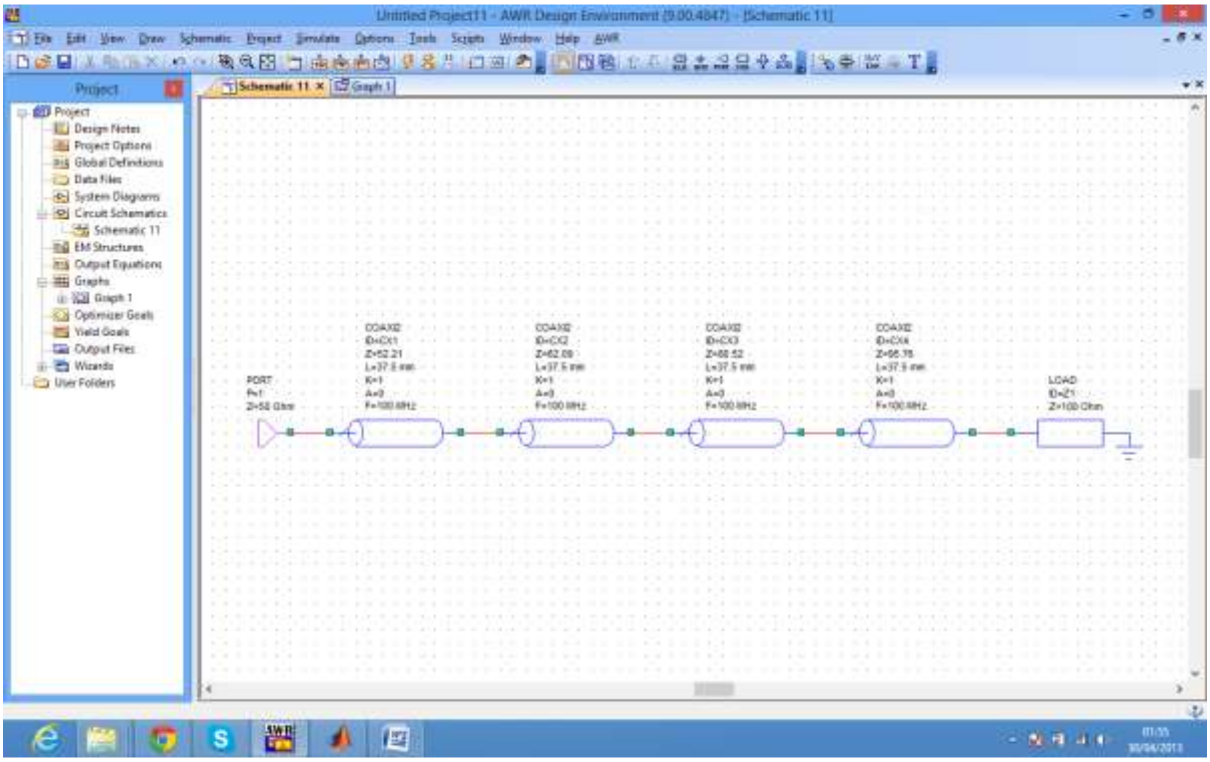

Figure3a, Implementation of the design using AWR software

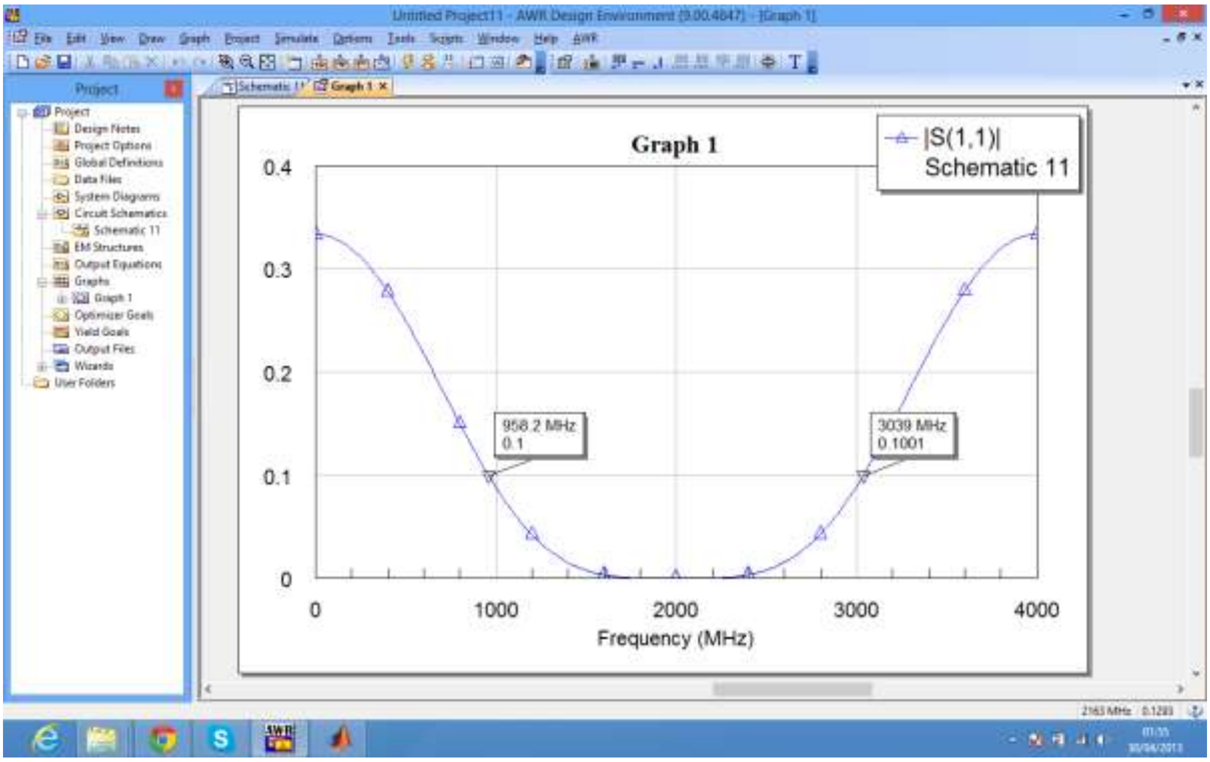

Figure3b, AWR Simulation of the design

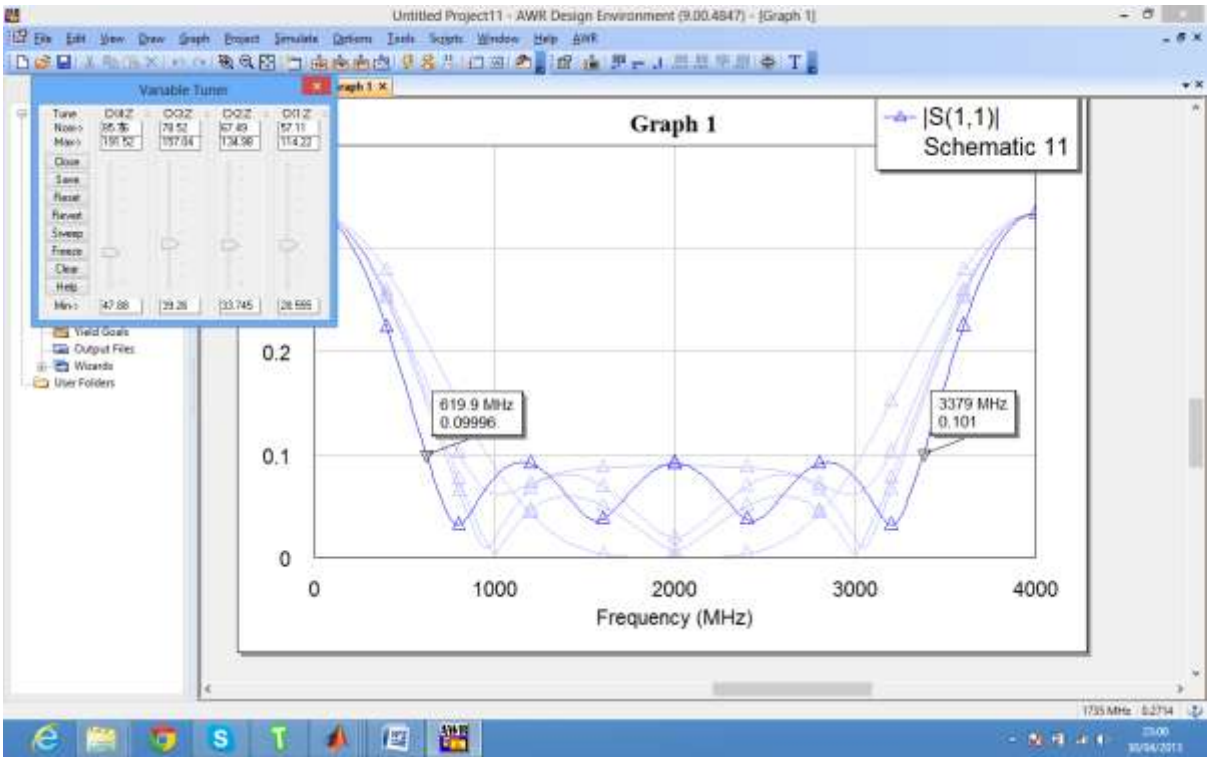

Figure3c AWR simulation after tuning

IV RESULTS AND DISCUSSION

The table1 below gives the desired impedances and reflection coefficients obtained in the first phase of the project for the given $Z_L = 100\ \Omega$ and $Z_0 = 50\ \Omega$.

Table1: values of desired impedances and reflection coefficients

Characteristics Impedances (Ω)		Reflection coefficients	
Z_1	52.2137	Γ_0	0.0217
Z_2	62.0929	Γ_1	0.0864
Z_3	80.5245	Γ_2	0.1292
Z_4	95.7603	Γ_3	0.0864

The three main phases of the design were analysed using the above values of the impedances and reflection coefficients and the result obtained in figure1, 2 and 3 for $|\Gamma_m| = 0.1$, are as follows:

(a) For the approximate solution, the frequency bandwidth is $(3.05\text{x}10^9 – 9.5\text{x}10^8)$ = 2.1GHz. Percentage bandwidth = (2.1/2) x 100% = 105%.

(b) For the exact solution, the frequency bandwidth is $(3.04\text{x}10^9 – 9.6\text{x}10^8)$ = 2.08GHz. Percentage bandwidth = (2.08/2) x 100% = 104%.

(c) For the Engineering solution, the frequency bandwidth is (3039– 958.2) = 2080.8GHz. Percentage bandwidth = (2080.8/2000) x 100% = 104.04%.

After using the tune and tune tool to adjust the characteristic impedances, an appreciable increase in the bandwidth is noticed. New Band width after tuning is (3379 – 619.9) MHz = 2759.1 MHz and % Bandwidth = 2759.1/2000 = 137.96% an increase of about 33.91%. Table 2 below shows the new values of the characteristic impedances

Table 2: new values of the characteristic impedances

Characteristics Impedances (Ω)		Reflection coefficients	
Z_1	57.11	Γ_0	0.0217
Z_2	67.49	Γ_1	0.0864
Z_3	78.52	Γ_2	0.1292
Z_4	85.76	Γ_3	0.0864

IV CONCLUSION

In this paper, a 4- section Binomial (Empirical) matching transformer was designed and simulated using three different phases, Calculation by hand and MATLAB implementation (Approximate solution), verification of the design with MATLAB simulation (Exact solution) and implementation of the design on Advancing the Wireless Revolution (AWR) software (Engineering solution).

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