Binomial multi-section matching network with very low reflection coefficient.

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Abstract: - In this article, the methodology for the design of broadband impedance transformers is presented. The design of a set of Binomial impedance transformers with different operating frequency and dielectric characteristics is performed. These impedance transformers operate over frequency range from 1 to 2.8 GHz with a reflection coefficient $\Gamma_m = 0.05$. The dielectric materials used were Duroid substrate and FR4 substrate, Duroid substrate has dielectric constant ε_r = 2.2 and thickness of substrate 1.27 mm and for FR4 substrate dielectric constant is ε_r = 4.4 and thickness of substrate 1.544 mm. The matching networks were simulated by ADS. Proposed matching networks can be used for UWB communication applications.

Key-Words: - Binomial matching network, fractional bandwidth FBW, maximum reflection coefficient.

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1 Introduction

Impedance matching is necessary to present maximum power transfer, because if this does not exist, a reflected signal is generated at the input of the receiving block. The reflected signal represents losses.

The matching networks present between the blocks that are intended to be coupled, the conjugated complex impedances to comply with a maximum power transfer. There are narrowband and broadband coupling networks.

Within narrowband coupling networks we can mention L-type networks, stub-type networks and quarter-wavelength transformer networks. Two types are presented for broadband coupling networks: Binomial type and Chebyshev type [1].

The Binomial-type network is based on the quarter-wavelength matching network, so it is used for real impedance matching.

The Binomial matching network is made up of several sections of transmission lines of length lambda quarters (figure 1), where each one has a different impedance and those values are included within the range of impedances that are to be coupled.

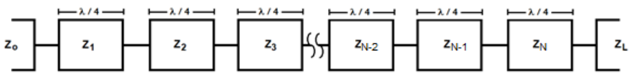

Fig. 3 Binomial Matching Network.

For the calculation of the Binomial matching network, it is important to obtain the fractional bandwidth (FBW) as a function of the number of sections of the matching network.

The fractional bandwidth determines the percentage of the central frequency that can be matched and it depends on the maximum allowed reflection coefficient Γ_m, the sections number of matching network and the values of the impedances to be coupled. Let us remember that for a transfer of at least 90% of the power, it is necessary that it be coupled, that is, its maximum reflection coefficient should be less than -10 dB or 0.31 (magnitude) [3].

In this paper, the design of a set of Binomial-type broadband matching networks is presented.

This work helps to the reader to understand the design process of Binomial broadband matching networks and also can be used for educational purposes.

2 Matching network Design.

The calculation of broadband matching networks begins by determining the value of some constants, a number of coupling network transmission line sections are proposed. The constants are A (equation 1) and the binomial coefficients are C_n^N (equation 2).

$$A = \frac{1}{2^{N+1}} ln \frac{Z_L}{Z_o} \quad \text{(Eq. 1)}$$

$$C_n^N = \frac{N!}{(N-n)!n!} \quad \text{(Eq. 2)}$$

In equation 2, the Binomial coefficients are calculated for the different values based on the number of sections.

As the number of sections increases, the fractional bandwidth of the matching network also increases (equation 3). The maximum reflection coefficient determines and limits the maximum bandwidth, since if this value is exceeded, then it cannot be considered coupled (only with values less than Γ_m, depending on the application).

$$FBW = 2 - \frac{4}{\pi} arccos \left[\frac{1}{2} \left(\frac{\Gamma_m}{|A|} \right)^{\frac{1}{N}} \right] \quad \text{(Eq. 3)}$$

Now, the impedances of each section of the Binomial matching network (equation 4) will be determined.

$$lnZ_{n+1} lnZ_n + 2^{-N} C_n^N ln \frac{Z_L}{Z_o} \quad \text{(Eq. 4)}$$

Once the impedance of each section is obtained, the dimensions W and d are determined by calculating transmission lines at the operation frequency and characteristics of the substrate using the effective permittivity (equation 5).

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(\frac{1}{\sqrt{1 + 12\frac{d}{W}}} \right) \quad \text{(Eq. 5)}$$

The width (W) of the microstrip is calculated according to equation 6.

$$\frac{W}{d} = \begin{cases} \frac{8e^A}{e^{2A} - 2}, \wedge \frac{W}{d} < 2 \\ \frac{2}{\pi} \left[B - 1 - ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left\{ ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right\} \right], \wedge x \geq 0 \end{cases}$$

(Eq. 6)

Where:

$$A = \frac{Z_o}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1} \left(0.23 + \frac{0.11}{\varepsilon_r} \right) \quad \text{(Eq. 7)}$$

$$B = \frac{377\pi}{2Z_o\sqrt{\varepsilon_r}} \quad \text{(Eq. 8)}$$

Once the above has been calculated, the value W and ε_e are obtained because the thickness of the substrate is obtained. The wavelength is obtained by equation 9.

$$\lambda = \frac{C}{f\sqrt{\varepsilon_e}} \quad \text{(Eq. 9)}$$

And thus, the length of the transmission line section (l) is determined. The above calculation is performed for each transmission line section given the previously calculated impedances to complete the Binomial matching network.

3 Results.

The calculation and simulation of Binomial matching networks were performed.

The design of a three-segment Binomial matching network at a frequency of 2 GHz with transmission line elements using the Duroid substrate is shown, which has a dielectric constant $\varepsilon_r = 2.2$ and thickness of substrate 1.27 mm. The maximum reflection coefficient is proposed to be

$$\Gamma_m = 0.05$$

Obtaining A and FBW from equations 1 and 3:

$$A = 0.02534$$

$$FBW = 86.31\%$$

Determining the values of the impedances of the 3 sections.

$$Z_1 = 52.5994\Omega$$

$$Z_2 = 61.2372\Omega$$

$$Z_3 = 71.2934\Omega$$

Subsequently, the physical dimensions of the transmission lines are calculated to present the same electrical length according to their values of impedances.

Table 1. Physical dimensions of the Binomial matching network.

Impedance	W (mm)	l (mm)
Z_1	3.62	27.45
Z_2	2.85	27.63
Z_3	2.21	27.82

Once the calculations have been made and using the Advanced Design System (ADS), the Source and load impedances are configured, as well as the parameters of the transmission line sections of the Binomial impedance transformer, as shown in figure 2.

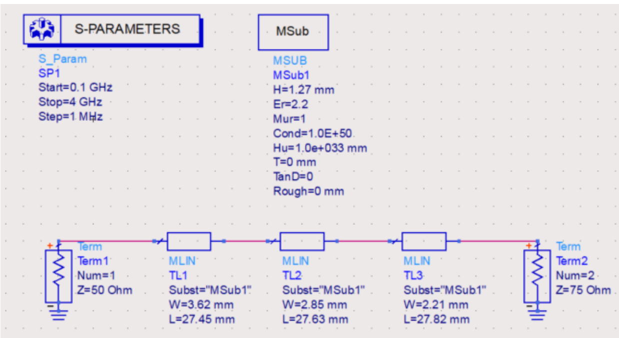

Fig. 2 Binomial matching network in ADS.

Figure 3 shows the frequency response of the 3-section Binomial matching network.

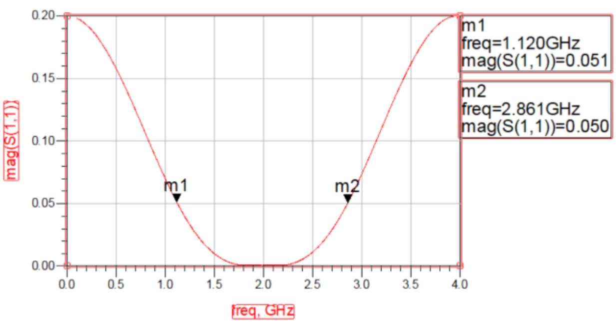

Fig. 3 Scattering parameter S_{11}using Duroid substrate.

The scattering parameter S_{11} allows observing the required reflection coefficient (0.05).

From here, it can be seen that since FBW=86.31%, therefore at a frequency of 2 GHz, there will be a theoretical bandwidth of 1.7262 GHz and from the simulation, a bandwidth of 1.741 GHz is obtained with the coefficient maximum reflection of 0.05.
For the FR4 substrate the return losses S_{11} is shown in figure 4.

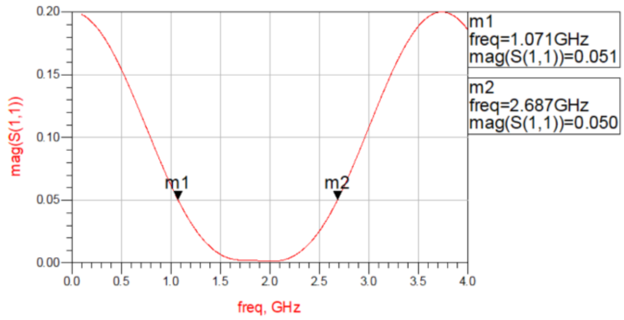

Fig. 4 Scattering parameter S_{11}using FR4 substrate.

Hence, the bandwidth is 1.616 GHz with a maximum reflection coefficient of 0.05.

The calculation was performed for 16 different types of Binomial coupling networks at different frequencies as shown in table 2.

Table 2. Binomial matching networks for different operation conditions.

	F (GHz)	$Z_0(\Omega)$	$Z_L(\Omega)$	Γ_m	ε_r	H(mm)
1	1	50	100	0.05	2.2	1.27
2	1.5	50	100	0.05	2.2	1.27
3	2	50	100	0.05	2.2	1.27
4	2.5	50	100	0.05	2.2	1.27
5	1	50	100	0.05	4.4	1.544
6	1.5	50	100	0.05	4.4	1.544
7	2	50	100	0.05	4.4	1.544
8	2.5	50	100	0.05	4.4	1.544
9	1	50	75	0.05	2.2	1.27
10	1.5	50	75	0.05	2.2	1.27
11	2	50	75	0.05	2.2	1.27
12	2.5	50	75	0.05	2.2	1.27
13	1	50	75	0.05	4.4	1.544
14	1.5	50	75	0.05	4.4	1.544
15	2	50	75	0.05	4.4	1.544
16	2.5	50	75	0.05	4.4	1.544

4 Conclusion

Despite having only made matching networks with three sections, as the number of sections of the Binomial transformer increases, the bandwidth increases. The frequency response of the Binomial matching network turns out to be flat in the bandwidth shown.

Bandwidth is increased by employing substrates with low dielectric constant. A very small reflection coefficient was chosen, but for an acceptable value (less than 0.3), the bandwidth of the coupling network is several gigahertz.

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References:

[1]. Pozar, D. M. (2012). Microwave engineering, 4to ed. Hoboken, NJ: J. WileyR. S. Kshetrimayun, "An Introduction to UWB Communication Systems," IEEE Potentials, Vol. 28, No. 2, pp. 9-13, April, 2009.

[2]. J.M. Drozd; W.T. Joines, "Using the binomial transformer to approximate the Q distribution for maximally flat quarter-wavelength-coupled filters," IEEE Transactions on Microwave Theory and Techniques, Vol. 46, No. 10, october, 1998.

[3]. I. De Coster, E. Van Lil & A. Van de Capelle, "Comparison of Design Methods for Binomial Matching Transformers," Journal of Electromagnetic Waves and Applications, 14:9, 1229-1239, DOI: 10.1163/156939300X01139 (2000).