POS1-36

Wideband Complex Impedance Matching Using Unequal-Length Multi-Section Transformers

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Abstract

In this paper, the Multi-Section Transformers (MSTs), the lengths of whose sections are not the same, are proposed and considered as matchers between two complex and frequency dependent impedances in a wide frequency range. The optimum values of the MST parameters are obtained through optimization approach. The usefulness of the proposed structure is verified using some examples.

1. Introduction

Impedance matching is a very important concept in RF and Microwave engineering. There is a significant interest to design matchers for efficient matching between two real or complex frequency dependent impedances in a wideband or multi-band frequency range. For example, to design wideband amplifiers we need to transform the impedances of a region of the Smith chart to another region [1-2]. Using uniform transmission lines and stubs is the most straightforward approach for matching between two complex impedances but in a narrow frequency band [3-4]. Also, using multi-section quarter-wave transformer is the most straightforward method for matching in a wide frequency band [3-4]. However, the multi-section quarter-wave transformers are usually used only for matching between two real and constant impedances. In the author's work reported in [5], microstrip nonuniform transmission lines have been used for matching between two complex impedances in a wide or multi- band frequency range. In this paper, we propose Multi-Section Transformers (MSTs), the lengths of whose sections are not the same, as matchers between two complex and frequency dependent impedances in a wide frequency range. The optimum values of the MST parameters are obtained through optimization approach. The usefulness of the proposed structure is verified using some examples.

2. Analysis of MSTs

In this section the analysis of MSTs is reviewed. Figure 1 depicts a typical unequal-length MST with N sections as a matcher between two complex impedances. The characteristic impedance and the length of each section is Z_n and d_n, respectively. Also, total length of MST has been considered d.

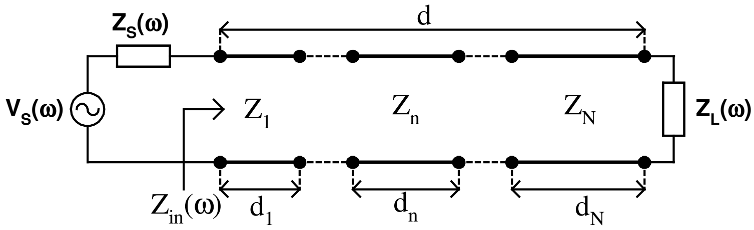

Figure 1. The unequal-length MSTL as a matcher between two complex impedances

The *ABCD* parameters of the whole of MST are obtained from those of the sections as follows

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$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \cdots \begin{bmatrix} A_n & B_n \\ C_n & D_n \end{bmatrix} \cdots \begin{bmatrix} A_N & B_N \\ C_N & D_N \end{bmatrix} \quad (1)$$

where the *ABCD* parameters of the *n*-th section are as follows

$$A_n = D_n = \cos(2\pi f d_n / c) \quad (2)$$

$$B_n = Z_n^2 C_n = jZ_n \sin(2\pi f d_n / c) \quad (3)$$

in which c is the velocity of the light. Finally, the input reflection coefficient of MST at frequency f is determined as follows

$$\Gamma_{in}(f) = \frac{Z_{in}(f) - Z_S^*(f)}{Z_{in}(f) + Z_S(f)} \quad (4)$$

where

$$Z_{in}(f) = \frac{AZ_L(f) + B}{CZ_L(f) + D} \quad (5)$$

is the input impedance of MST at frequency f.

3. Synthesis of Impedance Matchers

In this section a general method is proposed to design optimally the impedance matchers. An optimum designed matcher has to have the input reflection coefficient as small as possible in a desired frequency range. Therefore, the optimum values of the characteristic impedances and the length of sections, Z_n and d_n, can be obtained through minimizing the following error function related to M frequencies $f_1 < f_2 < \ldots < f_M$ inside the desired matching bandwidth.

$$\text{Error} = \sqrt{\frac{1}{M} \sum_{m=1}^{M} |\Gamma_{in}(f_m)|^2} \quad (6)$$

Moreover, defined error function should be restricted by some constraints such as having fixed length and weak discontinuities, given by

$$\sum_{n=1}^{N} d_n = d \quad (7)$$

$$\alpha \le \frac{Z_n}{Z_{n+1}} \le \alpha^{-1}, \qquad \forall n = 1, 2, ..., N-1 \quad (8)$$

where α is a coefficient less than and close to one.

4. Examples and Results

We would like to design an MST as an impedance matcher in a frequency range of 2.0 to 4.0 GHz (an octave bandwidth). Two cases as the following are considered for the load and source impedances.

Case 1: Real loads; Z_L = 100 Ω resistor and Z_S = 50 Ω resistor.

Case 2: Complex loads; Z_L = (100 Ω resistor parallel with 0.53 pF capacitor) and Z_S = (50 Ω resistor series with 1.06 pF capacitor).

It is assumed that $\alpha = 0.8$. Figure 2 illustrates the input reflection coefficient in case 1 for d = 5, 10, 12.5, 18 and 22 cm, considering N = 5 sections. Tables 1 and 2 show the optimum values of the parameters in this case, also. It is seen that the best matching is for d = 12.5 cm (five quarter wavelength). Furthermore, Figure 3 illustrates the input reflection coefficient in case 2 for d = 3, 5 and 7 cm, considering N = 7 sections. Tables 3 and 4 show the optimum values of the parameters in this case, also. It is seen that the best matching is for d = 5 cm. Moreover, Figure 4 illustrates the input reflection coefficient in case 2 for d = 3, 5 and 7 cm, considering N so that having the same matching. Finally, Figure 5 illustrates the input reflection coefficient in case 2 for N = 5, 7, 10 and 15 sections, considering d = 5 cm. From Figures 2-5, the following results are concluded:

1. For an assumed length of the matcher d, as the number of sections N is increased the impedance matching becomes better.
2. For an assumed number of sections N, the best impedance matching occurs for a specified length of the matcher d.
3. If the length of the matcher d is increased or decreased with respect to its optimum value, more sections N will be required not to decrease the matching performance.
4. The matching in the case of complex loads is less than that of in the case of real loads, which is due to the Bode-Fano criteria [3].

Table 1. The optimum values of the characteristic impedances of transmission lines in case 1, considering $N = 5$ sections

Z_n [Ω]	n=1	n=2	n=3	n=4	n=5
d=5 cm	70.8727	56.6982	70.8727	88.5909	70.8727
d=10 cm	52.7457	61.9062	73.4012	81.5782	94.9251
d=12.5 cm	51.5321	57.7974	70.6912	86.4754	97.0129
d=18 cm	52.4104	60.6743	75.8429	91.7580	99.0602
d=22 cm	58.9083	73.6353	63.2210	71.3672	85.0248

Table 2. The optimum values of the length of transmission lines in case 1, considering $N = 5$ sections

d_n [mm]	n=1	n=2	n=3	n=4	n=5
d=5 cm	2.3680	14.2109	17.1956	13.6825	2.5431
d=10 cm	24.0419	21.9512	11.8313	18.5000	23.6756
d=12.5 cm	25.0002	25.0009	24.9989	24.9998	25.0002
d=18 cm	26.2078	26.0371	25.8370	25.6274	76.2907
d=22 cm	24.0486	49.1129	49.3534	73.3266	24.1586

Table 3. The optimum values of the characteristic impedances of transmission lines in case 2, considering $N = 7$ sections

Z_n [Ω]	N=1	n=2	n=3	n=4	n=5	n=6	n=7
d=3 cm	100.2415	80.1932	64.1545	51.3236	64.1545	80.1932	100.2415
d=5 cm	80.0901	64.0721	51.2577	41.0061	51.2577	64.0721	80.0901
d=7 cm	58.8394	47.0715	37.6572	39.6766	49.5957	61.9946	77.4933

Table 4. The optimum values of the length of transmission lines in case 2, considering $N = 7$ sections

d_n [mm]	n=1	n=2	n=3	n=4	n=5	n=6	n=7
D=3 cm	6.9559	0.4286	1.1689	12.8571	1.3160	0.4286	6.8449
D=5 cm	9.6357	0.7143	5.7205	21.4286	3.6437	0.7143	8.1430
D=7 cm	12.4345	1.0000	30.0000	15.5000	1.0000	1.0000	9.0654

5. Conclusion

The Multi-Section Transformers (MST), the lengths of whose sections are not the same, were proposed and considered as matchers between two complex and frequency dependent impedances in a wide frequency range. The optimum values of the MST parameters are obtained through optimization approach. The usefulness of the proposed structure was verified using some examples. It was seen that for an assumed length of the matcher, as the number of sections N is increased the impedance matching becomes better and for an assumed number of sections, the best impedance matching occurs for a specified length of the matcher. Also, if the length of the matcher is increased or decreased with respect to its optimum value, more sections will be required not to decrease the matching performance.

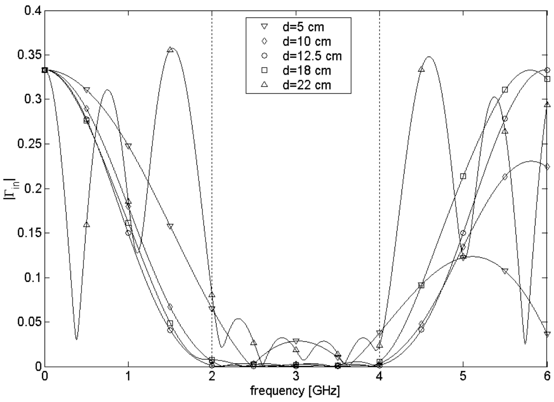

Figure 2. The input reflection coefficient for impedance matcher in case 1, considering $N = 5$ sections

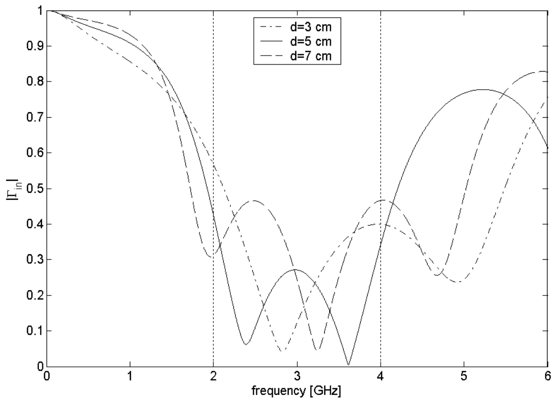

Figure 3. The input reflection coefficient for impedance matcher in case 2, considering $N = 7$ sections

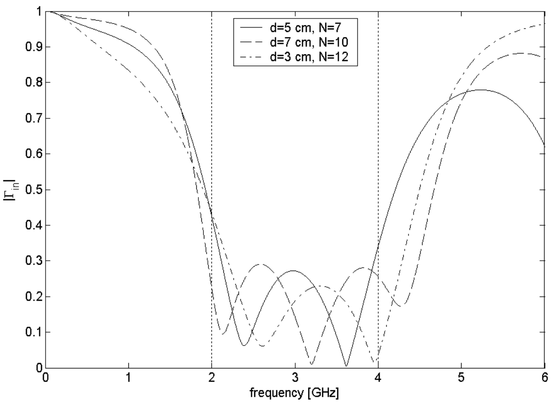

Figure 4. The input reflection coefficient for impedance matcher in case 2

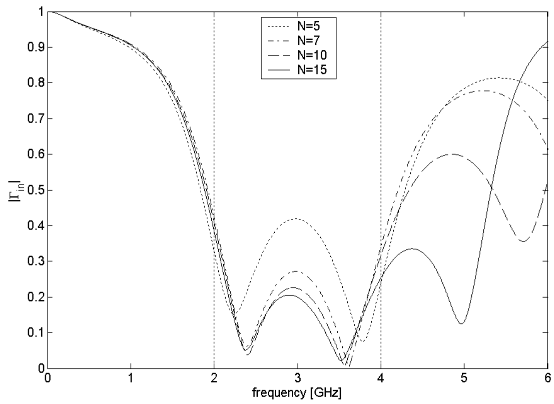

Figure 5. The input reflection coefficient for impedance matcher in case 2, considering $d = 5$ cm

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