A New Small Size Wideband Impedance Transformer

Aleksandar Nesic, Sinisa Jovanovic

Abstract – **This paper presents a new microstrip transformer for the frequency range from 600 MHz up to 8 GHz, and for up to 3.5 GHz for meandered version. Overall dimensions of the meandered transformer are as low as 50x10mm. The circuit is designed for 100 to 50 Ohm impedance transformation. Two different concepts of meandered impedance transformer are presented. All types of the presented transformers achieve the reflection coefficient better than -20 dB in pass-band.**

Keywords - **Microstrip, Impedance matching**

I. Introduction

Impedance transformers are one of the most important components in microwave circuits. In most cases they are realized as a quarter-wavelength conventional transformers with a relatively narrow frequency range. Broader bandwidths can be achieved basically as a multiple-section transformer [1, 2] or as a coupled-line transformer [3-5].

The overall size of the impedance transformer is significant for its practical implementation. The existing wideband multi-section impedance transformers are relatively long. The meandered multi-section transformer exhibits a smaller bandwidth compared to the un-meandered version with the same number of sections and the same length [1].

The broad-band small size impedance transformer covering frequency range from 0.6 to 1.6 GHz is recently reported [6]. However, the configuration proposed in this paper is realized using 50mm long striplines coupled by gaps as narrow as 30μm. Such structure is less suitable for integration with surrounding components than microstrip and it could be difficult for fabrication due to very narrow yet lengthy gaps.

In this paper, two new ultra-broadband microstrip impedance transformers are presented. In the first case we introduce a tapered transformer designed by applying the Klopfenstein method for optimal tapering of an ideal transmission line [7] on tapered microstrip line design.

In the second case the dimensions of the tapered transformer are obtained through optimization in a program for circuit simulation against the return loss requirements in specified frequency range. In both cases it employs meandered tapered microstrip lines. Also, we obtain much broader bandwidth with same size compared to the impedance transformer presented recently on ref. [6].

II. Design Using The Klopfenstein Method

General theory of tapered impedance transformer for an ideal transmission line is presented in [7]. It gives a segmented change of an ideal transmission line's characteristic impedance over the length of a transformer for several levels of required maximums of equirippled return loss, as shown in Fig.1.

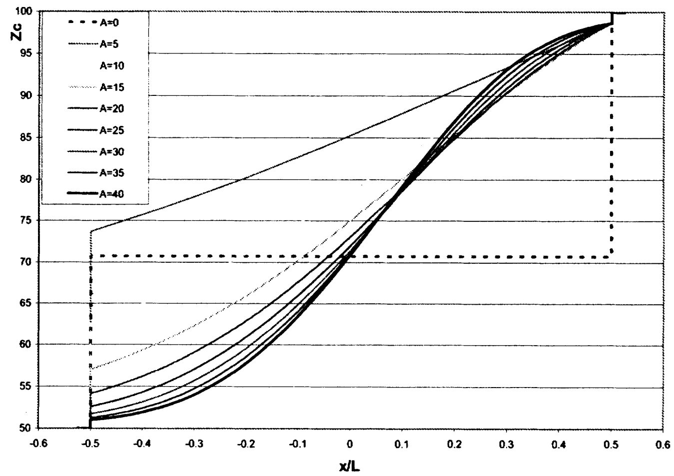

Fig.1 Characteristic impedance change of an ideal transmission line for different required levels of return loss

One interesting aspect of this design is that the taper has abrupt change of characteristic impedance at each ends and continuous change along the length of the taper.

In the first step of the design process, we obtain from [7] characteristic impedances in 41 points for a 50 to 100Ω transformer in a form of an ideal transmission line divided in 40 segments for the lowest reflection coefficient of -50dB (40dB below the reflection coefficient without a transformer). Based on these characteristic impedances, the corresponding widths of a microstrip line taper are calculated. The obtained layout of the microstrip taper is shown in Fig.2 with length reduction for better visibility of the width change.

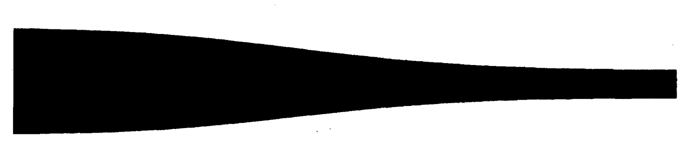

Fig.2 Layout of the microstrip line tapered transformer obtained using Klopfenstein metod (the length is reduced 20×)

The next step was to test the obtained design with a circuit analyzer program to adjust the overall length of the taper based on required lower pass-band frequency. The circuit simulator results obtained for the port impedances of ZP1=50Ω and ZP2=100Ω are shown on Fig 3.

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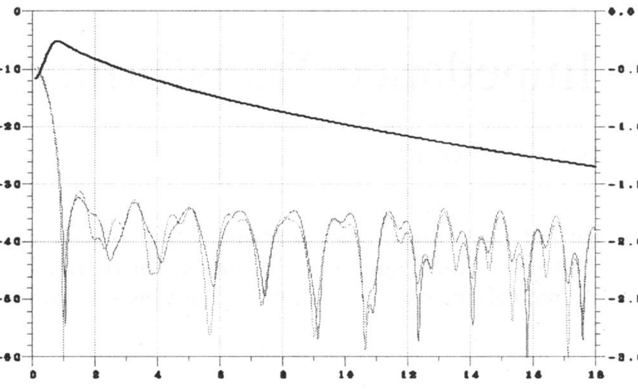

Fig.3. Circuit simulator results for return loss and insertion loss (right Y axis) of tapered microstrip impedance transformer

Fig. 3 shows the worst case reflection coefficients in the pass-band of about -32dB, which deviate from theoretical value for an ideal transmission line of -50dB by about 18dB. This discrepancy is caused by using of two different programs in the design process: Linecalc for synthesis of microstrip line segments having required characteristic impedances, and a circuit simulator for analysis of the obtained design. The tapered line with a length of 220mm has the reflection coefficients better than -32dB for all frequencies above 750MHz.

In the next step we tested the microstrip transformer with full-wave EM simulator (IE3D). Obtained results presented in Fig.4, when compared with the results obtained by a circuit simulator from Fig. 3, show further degradation of the reflection coefficient by about 6dB achieving the maximum values in the passband of -26dB.

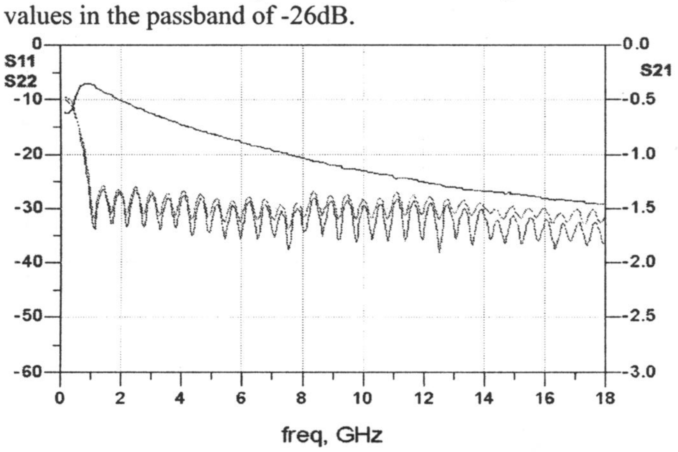

Fig.4. EM analyzer (IE3D) results for return losses and insertion loss (right Y axis) of tapered microstrip impedance transformer

In the next step the achieved design is meandered by inserting "band" elements between suitable segments, in order to minimize the overall dimensions while preserving the dimensions of each segment (Fig.5).

Finally, obtained meandered design is analyzed with an EM simulator before realization. Results are presented in Fig.6. Degradation of reflection coefficient is evidently due to inserted bends (even they are compensated) of meandered tapered microstrip line which increase on higher frequency.

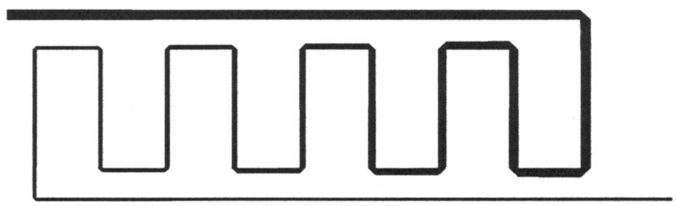
Fig.5. The meandered microstrip tapered impedance transformer obtained by implementation of Klopfenstein method (Ver.1)

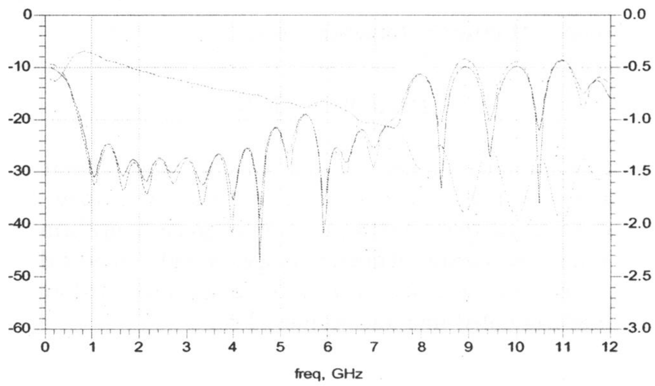

Fig.6. EM analyzer results for return loss and insertion loss (right Y axis) of tapered and meandered microstrip impedance transformer

III. Design With Circuit Simulator Optimization

Another meandered microstrip impedance transformer is designed using different approach. A tapered microstrip transmission line is composed from the start as a meandered tapering line consisting of 26 linear microstrip taper elements connected with "90° bend" elements. The tapers' dimensions were optimized to achieve requested reflection coefficient within specified frequency range. In order to minimize the number of variables for optimization, the tapers orthogonal to the input and output line have the same length (except the first and the last of them), while the lengths of the tapers parallel to input and output line are proportional to their widths.

Starting from a meandered segmented linear taper the segments' widths are optimized in circuit simulator against the return loss requirements better than -30dB over the frequency range from 500MHz to 15.5GHz. The total length of the optimized transformer is maintained to be equal to the Ver. 1 transformer. The design obtained from the described simulation is shown in Fig.7, while Fig.8 shows its frequency characteristics according to the circuit simulator.

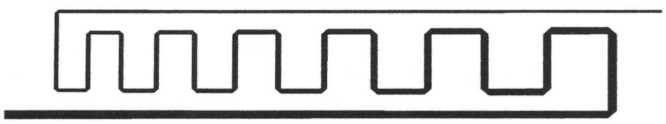

Fig.7 The meandered microstrip tapered impedance transformer obtained by optimization in circuit simulator (Ver.2)

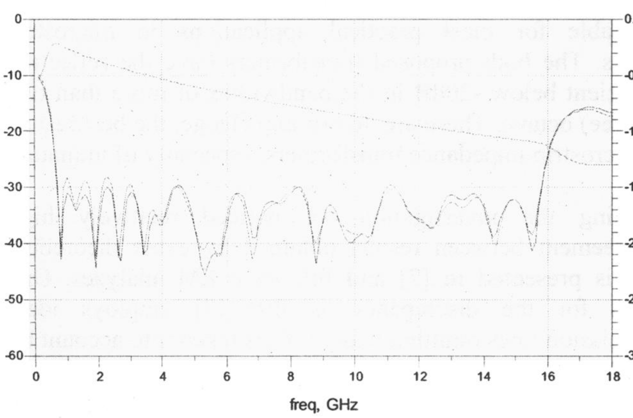

Fig.8. Results for return loss and insertion loss (right Y axis) of the tapered microstrip impedance transformer obtained from optimizations in ciruit simulator.

The designed impedance transformer is analyzed in the next step with a program for full-wave EM analysis (IE3D). The obtained results are presented in Fig. 9.

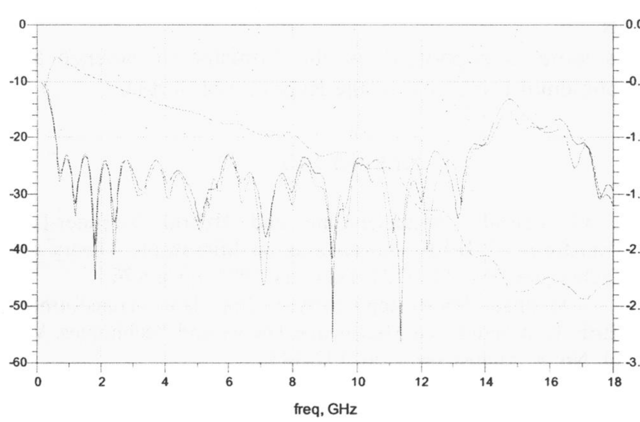

Fig.9. Results for return loss and insertion loss (right Y axis) of the tapered microstrip impedance transformer obtained from analysis in EM simulator.

IV. Realization And Measured Results

The tapered microstrip transmission line and both versions of meandered impedance transformers were realized on dielectric substrate with $\varepsilon r=2.1$, h=0.254mm, tgδ=0.0004, and metallization thickness t=11μm.

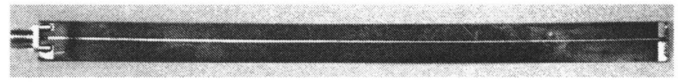

Fig.10. Photo of tapered microstrip transformer obtained by implementation of the Klopfenstein method

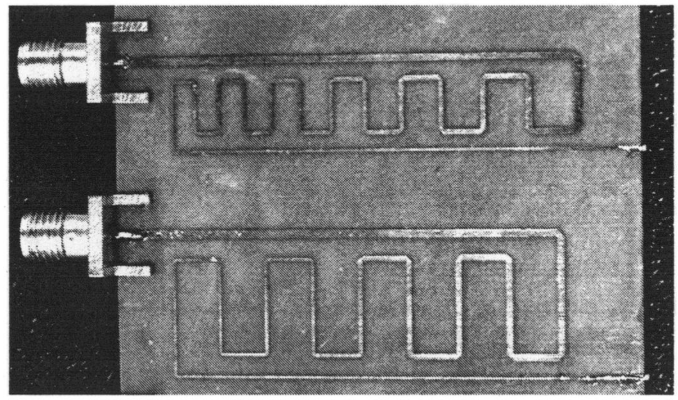

Fig.11. Meandered microstrip tapered impedance transformer:
a) obtained by optimization in circuit simulator (up)
b)obtaind by implementation of Klopfenstein method (down)

The realized transformers were measured on Agilent's E8364A Network Analyzer. Since we had only 50Ω measuring equipment, we performed only S11 measurement with 100Ω port of the transformers being terminated with subminiature 100Ω resistors (IMS SG1000J with 5% tolerances).

The measured S11 reflection coefficient for the tapered microstrip transformer from Fig. 10 is shown in Fig. 12, while the corresponding results for the meandered transformer Ver. 1 and Ver. 2 are shown in Fig. 13 and Fig. 14, respectively.

Simulated and measured return losses differ probably due to: tolerances in fabrication of tapered line, tolerances of terminating 100Ohm resistor as well as the discontinuity at the connection of the microstrip line and the terminating resistor (especially at higher frequencies).

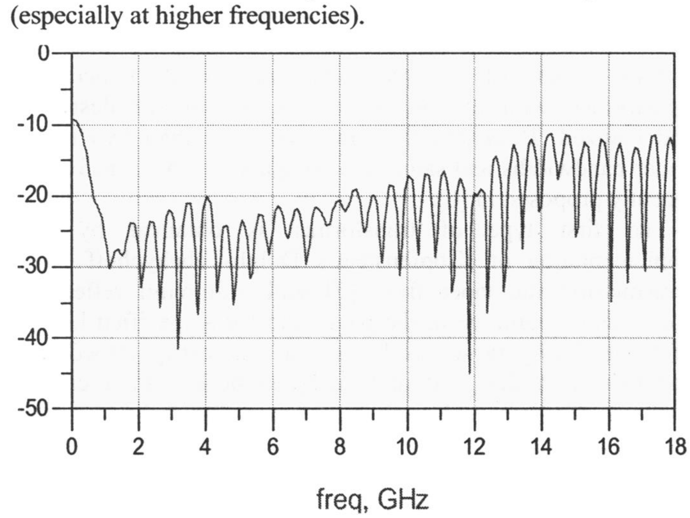

Fig.12. Measured results for return losses for tapered microstrip impedance transformer from Fig. 10.

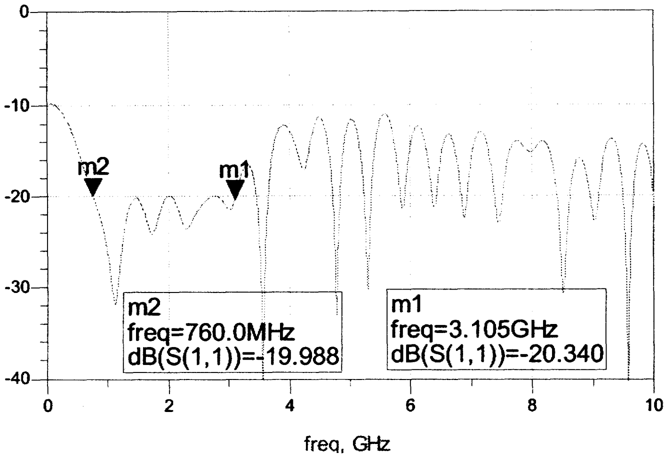

Fig.13. Measured S11 return loss for meandered microstrip tapered impedance transformer obtained by the Klopfenstein method

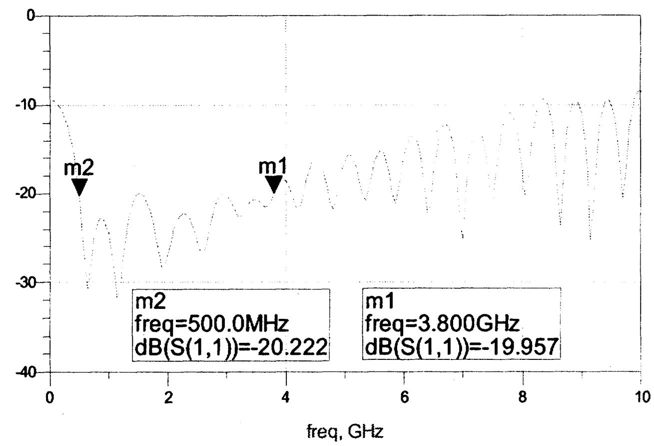

Fig.14. Measured S11 return loss for meandered microstrip tapered impedance transformer obtained by optimization in a circuit simulator

V. CONCLUSION

Two types of tapered and meandered impedance transformers with minimized sizes are investigated, designed and realized. Both transformers have more than two times wider bandwidths and same size compared to the transformer recently proposed in [6].

The first type of transformer is obtained by the implementation of Klopfenstein's Dolph-Tchebycheff ideal transmission-line taper from [7] with minimum reflection coefficient magnitude in the pass-band for a specified length of taper. Using these results, a real microstrip impedance transformer is designed and analyzed both with a circuit analyzer program and with a program for full-wave EM analyzes. After that, this structure is meandered to obtain minimal size.

The second transformer is obtained through optimisation of a meandered microstrip line of similar size.

The measured bandwidths for reflection coefficient better than -20 dB for the microstrip tapered and meandered impedance transformer designed using Klopfenstein method is between 0.76 GHz and 3.105 GHz. For the transformer designed using circuit optimization by computer, bandwidth for the same reflection coefficient is obtained in the frequency range between 0.5 GHz and 3.8 GHz.

Obtained reflection coefficient, lower than -20 dB, is quite acceptable for most practical applications in microstrip circuits. The both proposed transformers have the reflection coefficient below -20dB in the bandwidths of more than two (or three) octave. These are, to our knowledge, the best results for microstrip impedance transformers, especially of miniature size.

During the investigation we noticed relatively high disagreement between results obtained by exact theoretical analysis presented in [7] and full-wave EM analyzes. One reason for the discrepancy is that [7] employs ideal transmission lines omitting many effects taken into account by an EM program. Another reason could be insufficient accuracy of an EM program. Structures like these, having very low reflection coefficient could be a good benchmark for testing the accuracy of various programs for EM analysis.

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REFERENCES

[1] E. G. Cristal: "Meander-Line and Hybrid Meander-Line Transformers" IEEE Transactions on Microwave Theory and Techniques, Vol. MTT-21, February 1973, pp. 69-76.

[2] G. L. Matthaei: Short-Step Chebyshv Impedance Transformers, IEEE Transactions on Microwave Theory and Techniques, Vol. 14, No. 8, August 1966, pp. 372-383.

[3] A. Podcameni: "Symmetrical and asymmetrical edge-coupled-line impedance transformers with a prescribed insertion loss design", IEEE Trans. Microwave Theory Tech., Vol. MTT-34, pp. 1-7, Jan. 1986.

[4] S. P. Liu: "Planar transmission line transformer using coupled micrstrip lines", IEEE-S IMS Digest 1998, pp. 789-792 .

[5] K. S. Ang, C. H. Lee and Y. C. Leong: "Analysis and design of coupled line impedance transformers", IEEE MTT-S Int. Microwave Symp. Dig., 2004, pp. 1951-1954..

[6] K. S. Ang, C. H. Lee and Y. C. Leong: "A Broadband Quarter-Wavelength Impedance Transformer With Three Reflection Zeros Within Passband", IEEE Trans...

[7] R. W. Klopfenstein: "A Transmission Line Taper of Improved Design", Proc. of the IRE, January 1956, pp. 31-35.

[8] IE3D USER'S MANUAL, Zeland Software Inc.