Design of Compact UWB Multilayered Microstrip Filter with Wide Stopband

N. Azadi-Tinat, H. Oraizi

***Abstract*—**Design of compact UWB multilayered microstrip filter with E-shape resonator is presented, which provides wide stopband up to 20 GHz and arbitrary impedance matching. The design procedure is developed based on the method of least squares and theory of N-coupled transmission lines. The dimensions of designed filter are about 11 mm × 11 mm and the three E-shape resonators are placed among four dielectric layers. The average insertion loss in the passband is less than 1 dB and in the stopband is about 30 dB up to 20 GHz. Its group delay in the UWB region is about 0.5 ns. The performance of the optimized filter design perfectly agrees with the microwave simulation softwares.

***Keywords*—**Ultra-wideband, method of least square, multilayer microstrip filter, n-coupled transmission lines.

I. INTRODUCTION

IN 2002, the USA Federal Communications Commission (FCC) allocated the frequency band 3.1-10.6 GHz to the UWB commercial applications [1]. The UWB technology has since been applied to various communication and radar systems and many efforts have been made in the development and realization of various UWB configurations and structures [2], [3].

Microstrip filters due to low weight and cost and ease of manufacture are suitable choices to use in many microwave circuits. Many planar microstrip filters use coupled lines to achieve a desired coupling, such as combline, interdigital and hairpin filters [4], [5]. But the planar structure of these types of filters in the wideband and UWB applications make the edges of microstrip lines too close and in some cases they may not be realizable by the available technology, such as photolithography. In such cases, multilayered structures of microstrip filters are preferable, because they provide additional degrees of freedom for the filter design.

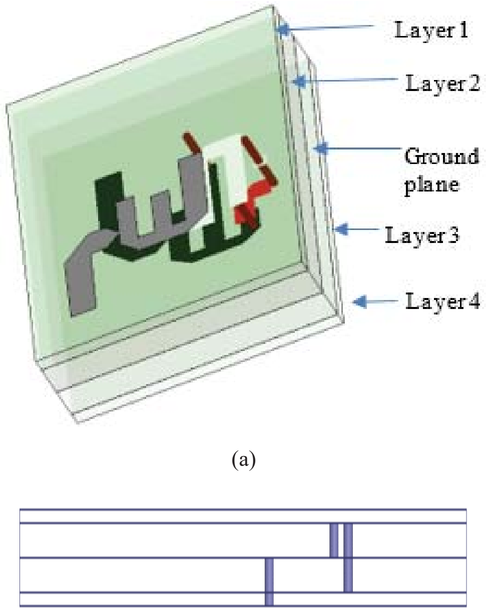
In this paper, a four layered E-shape microstrip filter for UWB applications is introduced. Fig. 1 (a) shows the configuration of proposed filter and for a better view, the heights of layers are scaled. Fig. 1 (b) shows the side view of filter and the location of vias. Fig. 1 (c) shows each layer separately and shows that layers 2 and 3 have been connected with one via passing through the ground plane. Such a structure is actually the advantage of this design, which provides for the precise location of resonators above each other for miniaturization. The E-shaped structure of resonators provides the required coupling to obtain the UWB bandwidth. Fig. 2 shows the effect of height on the two coupled lines. The ratio of h1/h2 is chosen less than one in the follow-up design to achieve better couplings. The short and open stubs in the middle of resonators could produce transmission zeroes to suppress the spurious responses and obtain a very wide stopband up to 20 GHz. Use of the short circuit stubs for the lower degree filters to provide transmission zeros in the lower stopband is necessary, but it has the disadvantage of greater lengths of stubs compared to open circuit stubs (Fig. 3)

The design procedure is based on the method of least squares and the theory of N-coupled transmission lines which determines the optimum filter geometrical dimensions.

II. DESIGN PROCEDURE

The four-layer-three-E-shape resonator microstrip filter configuration is depicted in Fig. 1. Its equivalent circuit is shown in Fig. 4, which is composed of straight strips, bends, T-junctions and coupled lines. For each section the transmission matrix is developed [6] and used to obtain overall transmission matrix

$$[T]=[T_{s2}][T_{s1}][T_{m1}][T_{c1}][T_{m2}][T_{c2}][T_{m3}][T_{t1}][T_{t2}] \qquad (1)$$



(a)

(b)

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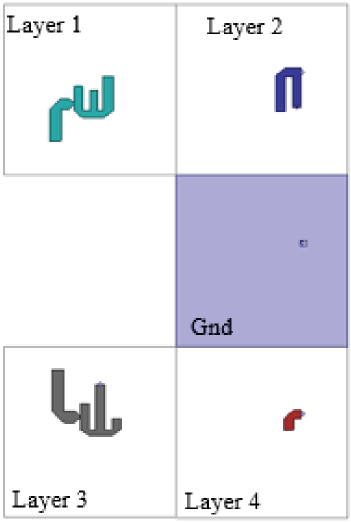

(c)

Fig. 1 Schematic diagram of proposed multilayer microstrip filter: (a) 3-D view, (b) side views, (c) schematic of each layer separately

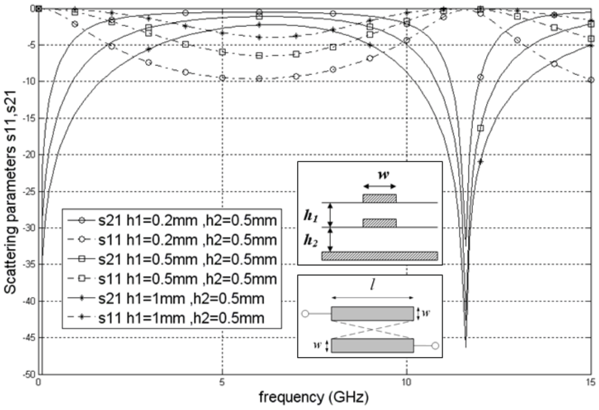

Fig. 2 Effect of height of layers on frequency response of two parallel coupled lines

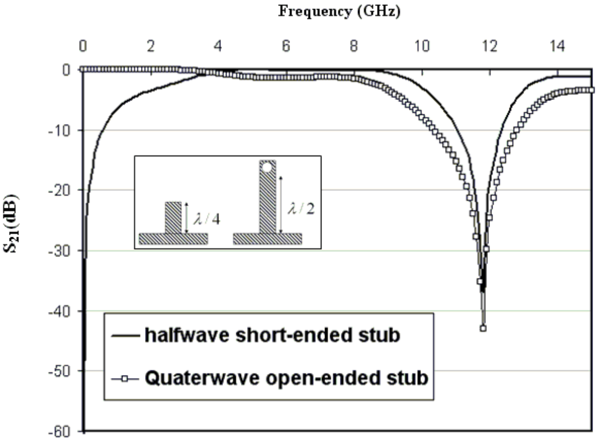

Fig. 3 Comparison between the frequency responses of short and open stubs

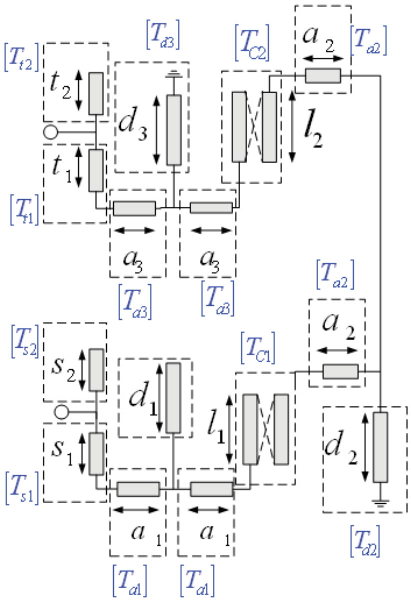

Fig. 4 The equivalent circuit of proposed multilayer microstrip filter

Finally, the overall transmission matrix of filter is used to determine its scattering parameters including the insertion loss (s21) and return loss (s11):

$$s_{21,k}=\frac{2}{A_k+B_kY_{l,k}+CZ_{s,k}+D_kZ_{s,k}Y_{l,k}} \tag{2}$$

$$s_{11,k}=\frac{A_k-B_kY_{l,k}+CZ_{s,k}-D_kZ_{s,k}Y_{l,k}}{A_k+B_kY_{l,k}+CZ_{s,k}+D_kZ_{s,k}Y_{l,k}} \tag{3}$$

Therefore, the insertion and return losses of the proposed filter may be expressed as:

$$IL_k=-20\log\left(\left|s_{21,k}\right|\right) \tag{4}$$

$$RL_k=-20\log\left(\left|s_{11,k}\right|\right) \tag{5}$$

where subscript k indicates the k_{th} frequency in the specified frequency bandwidth and Z_S and Y_L are the source impedance and load admittance, respectively. The desired frequency response of the filter is shown in Fig. 5, which is indicates the lower stop and transition bands, passband, and upper transition band and stopbands.

An error function is then constructed as

$$\begin{aligned}e&=wt_1\sum_{k=1}^{n_{SL}}(IL_k-ILSB_{lk})^2+wt_2\sum_{k=n_{SL}}^{n_{PL}}(IL_k-g_{TL}(f_k))^2\\&+wt_3\sum_{k=n_{PL}}^{n_{PU}}(IL_k-ILPB_k)^2+wt_4\sum_{k=n_{PU}}^{n_{SU1}}(IL_k-g_{TU}(f_k))^2\\&+wt_5\sum_{k=n_{SU1}}^{n_{su2}}(IL_k-ILSB_{u1k})^2+wt_6\sum_{k=n_{SU2}}^{K}(IL_k-ILSB_{u2k})^2\end{aligned} \tag{6}$$

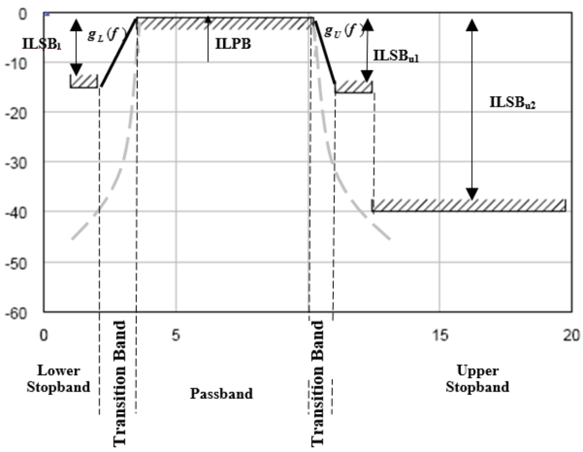

Fig. 5 Specified frequency response of the bandpass filter

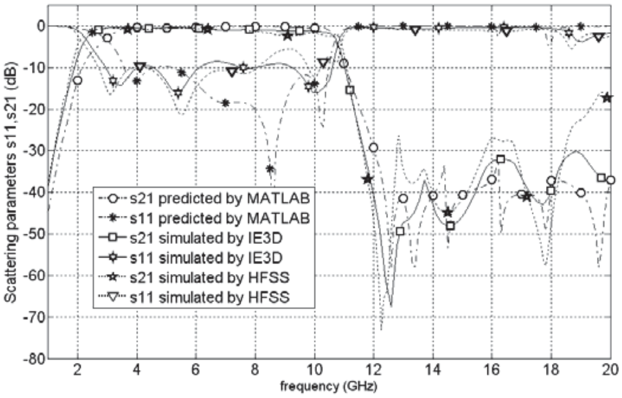

Fig. 6 Comparison of the frequency responses of proposed multilayered microstrip filter as obtained by the simulation softwares (IE3D & HFSS) and predicted by MATLAB

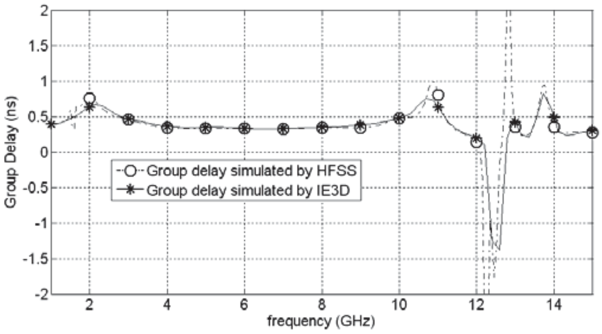

Fig. 7 Group delayed of proposed multilayered microstrip filter.

The specified frequency band is divided into K discrete frequencies, ILSB and ILPB are the desired insertion losses in the stop and pass bands, and *gTL* (*f k*) and *gTU* (*f k*) are the linear functions in the lower and upper transition bands, respectively which join the stop and pass bands, and wti are the weighting functions which enhance the effect of different bands relative to each other. The minimization of the error function gives the physical dimensions of the filter.

A computer program was written in MATLAB [7] for the optimum design of multilayered E-shaped microstrip filter based on the minimization of error function in (6). Its input parameters are: filter bandwidth, the design specifications on the insertion losses in the passband, stopbands and transition bands, number of discrete frequencies in the bandwidth and other appropriate parameters required in the error function.

The initial values of the geometrical dimensions of the filter, such as the widths, lengths and spacings of the strip line sections, are selected as follows: The width of all the strip lines are taken equal to 1 mm. They may also be selected equal to the total height of substrates. The displacement or the offset between coupled lines is taken equal to zero and remain zero in the design procedure. The initial lengths of open and short stubs may be taken equal to a quarter and half wavelengths at the center frequency, respectively.

III. DESIGN EXAMPLE

Consider four substrate layers with three E-shaped resonators. The layers one and four are made of substrates RO4003 with height of 8 mil and the layers two and three are made of RO5880 with height of 20 mil. The aforementioned related parameters and design data are given in Table I. The frequency responses of the filter (as s11 and s21) obtained by the computer simulation results and full-wave software such as IE3D and HFSS [8], [9] are shown in Fig. 7. Observe that the suppression of spurious harmonics is about 30 dB. The group delay of filter is shown in Fig. 7, which is quite constant in the specified bandwidth 3.1-10.6 GHz and is less than 0.5 ns. For the proof of concept, a prototype model is fabricated and its photograph is shown in Fig. 8.

TABLE I
PARAMETERS OF DESIGNED MULTILAYERED MICROSTRIP FILTER

parameters of substrates

$substrate\ 1: RO4003, 8mil$

$substrate\ 2: RO5880, 20mil$

$substrate\ 3: RO5880, 20mil$

$substrate\ 4: RO4003, 8mil$

Widths of input and output 50 Ω feedline 2 mm

Dimension of resonators (all mm) (Fig .4)

$Input: s2 = 2.95, s1 = 1.06, w_s = 1.4$

$Output: t2 = 2.13, t1 = 2.18, w_t = 1.6$

Other dimensions:

$a_1 = 1.27, w_{a1} = 1.3, d_1 = 3.52, w_{d1} = 2.56$

$l_1 = 11.92, w_{l1} = 1.98$

$a_2 = 1.2, w_{a2} = 1.5, d_2 = 5.4, w_{d2} = 1.4$

$l_2 = 1.9, w_{l2} = 1.6$

$a_3 = 1.27, w_{a3} = 1, d_3 = 7.9, w_{d3} = 1.6$

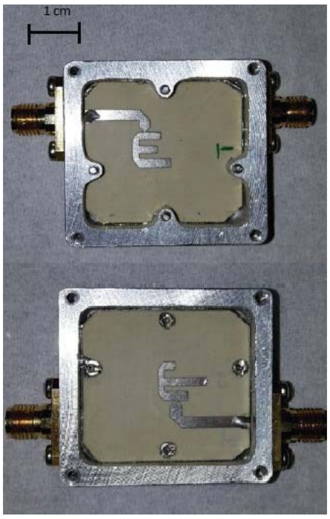

Fig. 8 The photograph of fabricated multilayered microstrip filter

IV. CONCLUSION

A compact multilayered E-shaped resonator microstrip bandpass filter with wide stopband is presented together with an optimum design procedure based on the theory of N-coupled transmission lines and method of least squares. The resonators are well-placed above each other in four layers providing a compact the size for the filter. The open and short stubs in the E-shaped resonators provide transmission zeroes in the upper and lower stopbands to create a wide stopband up to 20 GHz. The full-wave simulation and prototype fabrication of proposed filter has verified the results of proposed design method.

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