Compact Stripline Lowpass Filters with Very Wide Stopband

Raphael Ruf, Wolfgang Menzel

Institute of Microwave Techniques, University of Ulm
D-89081 Ulm, Germany
raphael.ruf@uni-ulm.de
wolfgang.menzel@uni-ulm.de

***Abstract* — This paper presents two new approaches for extending the stopband performance of planar quasi-lumped stripline lowpass filters. First, a countermeasure is introduced against rectangular waveguide modes which are able to propagate in a fully shielded planar filter assembly. Incorporating this technique in the traditional high-low-impedance filter, a better stopband performance can be achieved, at the expense of only slightly increased complexity of the filter geometry. The second part of the paper proposes a trade-off for the capacitance-to-inductance ratio that has to be realized by a certain lowpass specification. By changing the terminating impedances of the filter, this ratio can be shifted in favor of the type of element which is more easily realized in a certain design technology.**

***Index Terms* — Lowpass filter, SIW, Wide stopband.**

I. Introduction

There is a high demand for lowpass filters exhibiting a wide stopband. Examples comprise mixers and oscillators, both of which are key components in modern communication systems. Due to their non-linear nature, these devices produce multiple harmonics, often spreading interfering signals over a large spectrum. To fulfill the requirements of a broad stopband, lowpass filters for suppressing these unwanted signals are usually designed using quasi-lumped elements [1].

However, as frequency is increasing, the behavior of these lumped elements is deteriorating. Once a signal wavelength is in the order of the dimensions of the elements, these start acting as transmission lines or even resonators, seriously degrading the stopband performance of the filter. So the most promising approach in obtaining a broad stopband is to keep the dimensions of the elements small. There are many proposals in the literature to accomplish this goal, for example by the usage of multilayer structures [2] or DGS (defected ground structure) [3]. In this paper, a method of changing the terminating impedance of the filters is presented.

Other ubiquitous design goals of microwave filters are low insertion loss and reduced interference between neighboring components, both of which can be attained by using a shielded assembly. Thanks to the availability of multilayer PCB's (printed circuit board) and the development of the SIW (substrate integrated waveguide) [4] fully shielded filter configurations are possible. However, by adding such an enclosure, filter behavior can be affected by waveguide modes. Often their cutoff-frequency is within the stopband of the lowpass filter and the propagating mode deteriorates the stopband performance, frequently leading to sharp peaks in the transmission coefficient S_{21}. This paper presents a novel approach for suppressing these unwanted waveguide modes without exerting too much influence on the filter circuit.

II. Suppression of Waveguide Modes in Stripline Filters

The complete shielding of a planar filter circuit can be accomplished by using a multilayer PCB setup like the one shown in Fig. 1, consisting of two sheets of Rogers RO4003 substrate bonded together by a RO4450 prepreg. Layers L1 and L4 are completely metallized to achieve top and bottom shielding. Lateral shielding is done by via-rows.

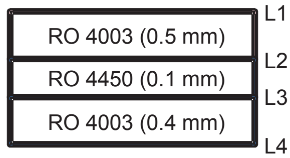

Fig. 1. Multilayer setup with designation of layer thicknesses and metallization layers.

The resulting structure constitutes a closed channel equivalent to a SIW [4], which is capable of supporting part of the modes of a rectangular waveguide, except those modes having surface currents perpendicular to the vias. Unlike the rectangular waveguide, the height of the SIW is usually much smaller than its width.

For these reasons, predominantly TE_{m0} modes are supported by the SIW, with the TE_{10} mode having the lowest cutoff-frequency, which is therefore most likely to cause trouble in lowpass filters. This mode has a sinusoidal variation of the electric field along the width of the guide, exhibiting a maximum in the center.

The proposal of this work is to provide a via at this position for short-circuiting the electric field and thereby greatly suppressing the propagation of the TE_{10} mode. The longitudinal position of these vias should be chosen in a way to have minimal influence on the filter behavior. Fig. 2 shows a perspective view of a typical high-low impedance filter.

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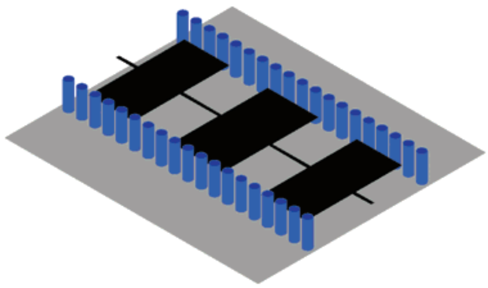

Fig. 2. Isometric view of a high-low impedance lowpass filter.

At first glance, the inductive sections seem to be good candidates for the via positions, yet this is a poor choice for two reasons. First, positioning the vias strictly in the channel center is not possible, so the maximum of the electric field of the TE_{10} mode will not be hit by the via. Second, a via in close proximity to an inductive section will reduce its inductance. Since it is anyway difficult to realize efficient inductors in planar circuits (Section III), this is a prohibitive approach.

Placing the vias within the capacitive sections has proven to be the better choice. Some of the metallization of the capacitive patches is etched away, lowering the capacitance of the patches. This loss is relieved to some extent, and, in some cases, may even be overcompensated by the additional capacitance formed between the penetrated patches and the vias. Fig. 3 shows a modified version of the high-low-impedance filter including the proposed vias.

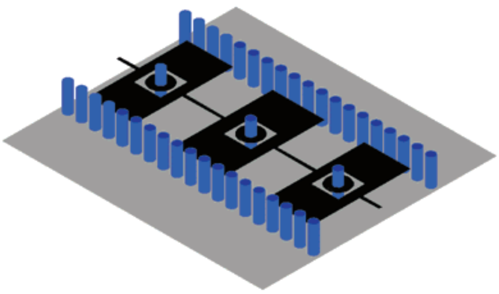

Fig. 3. Isometric view of a high-low impedance lowpass filter with proposed vias for suppression of waveguide modes.

To validate this approach, two filters have been designed using a fullwave simulator [5]. Both filters share exactly the same layout as in Fig. 2 and Fig. 3, the only difference being the additional vias in the second filter. The simulated scattering parameters of the traditional filter are shown in Fig. 4, which clearly shows a spurious response centered around 14 GHz, limiting the stopband of the filter to approximately 3.5 times the cutoff-frequency.

Considering the dimensions of the simulation box, this frequency spur can be attributed to the TE_{101} waveguide resonance. Placing an additional, highly dissipative thin dielectric layer directly beneath the cover of the simulation box for evaluation purposes attenuates this spur to a large extent, suggesting it is of waveguide nature. The response of the filter with the additional vias, displayed in Fig. 5, shows the first spur at 24 GHz, indicating the suppression of the waveguide resonance. A further investigation of this spur with the help of current-density plots generated by [5] revealed a resonance of the middle capacitive section.

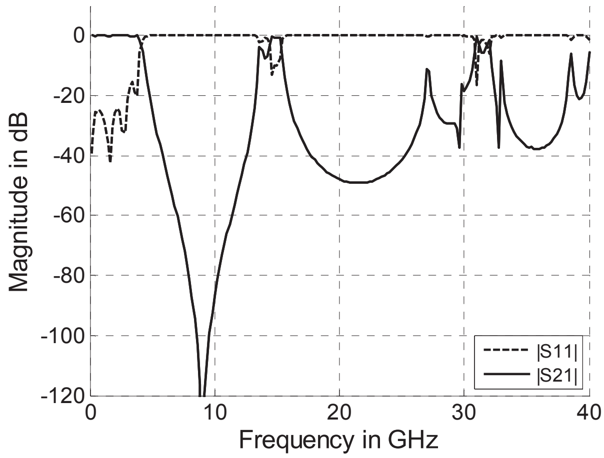

Fig. 4. Simulated scattering parameters response of the filter geometry depicted in Fig. 2.

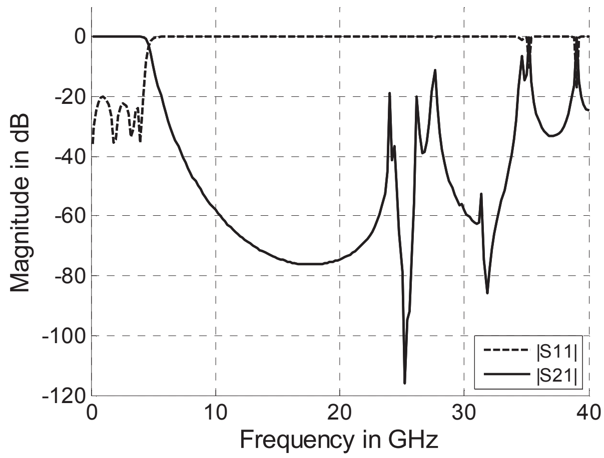

Fig. 5. Simulated scattering parameters response of the filter geometry depicted in Fig. 3.

III. Filters With Arbitrary Terminating Impedances

Regarding planar filter structures, it turns out, that usually the inductors are the critical elements. If designed as shown in Fig. 2 the resulting inductor lengths are usually bigger than those for the capacitors. Their length can be decreased by narrowing the strip, yet limitations due to insertion loss and fabrication are soon reached. Another popular approach to decrease the inductor size is the usage of DGS [3]. However, the resulting notches either require additional shielding channels; otherwise they increase insertion loss due to radiation and also promote crosstalk to nearby components.

On the other hand, the size of the capacitive sections can be kept small by using substrates with a high dielectric constant. Another approach is to use thin substrates with a back-metallization. Therefore, a trade-off between inductance and capacitance would help to both reduce the size and the insertion loss of a planar filter. As a further consequence of size reduction, parasitic resonances of the quasi-lumped elements are shifted towards higher frequencies yielding an improved stopband.

The element values for realizing a lowpass filter are obtained from the filter coefficients g_i by scaling these both in terms of cutoff-frequency f_c and terminating impedance Z, equations (1) and (2) being valid for the inductance and capacitance values [1, 6]. Inspection of these equations shows that the respective inductances are proportional to the terminating impedance, while capacitances are inversely proportional to that quantity. By deviating from the usual system impedance of 50 Ohms, the element values of inductances and capacitances can be adjusted. In the case of planar filters, a reduction of the terminating impedance is alleviating the design of inductors by lowering their values. On the other hand, the values of the capacitances are increasing.

$$L_i = \frac{Z}{2\pi \cdot f_c} \cdot g_i \tag{1}$$

$$C_i = \frac{1}{Z \cdot 2\pi \cdot f_c} \cdot g_i \tag{2}$$

To demonstrate the feasibility of this concept, three different filters have been designed and fabricated, all of which are using the waveguide-mode blocking vias introduced in Section II. All filters are designed for a cutoff-frequency of 5 GHz and a minimum return loss of 20 dB within the passband. The first (conventional) filter is of the type shown in Fig. 3, while the second one (Fig. 9) uses DGS of a rectangular shape to decrease the size of the inductive sections. The third filter is designed for operation in a Z=20 Ohms environment which reduces the values of the inductors by a factor of 2.5, whereas capacitances are increased by the same factor. For that purpose an additional metallization layer is provided just beneath the capacitive sections (on Layer L3 in Fig. 1). The measured scattering parameters of these filters are shown in Fig. 6 – Fig. 8 respectively.

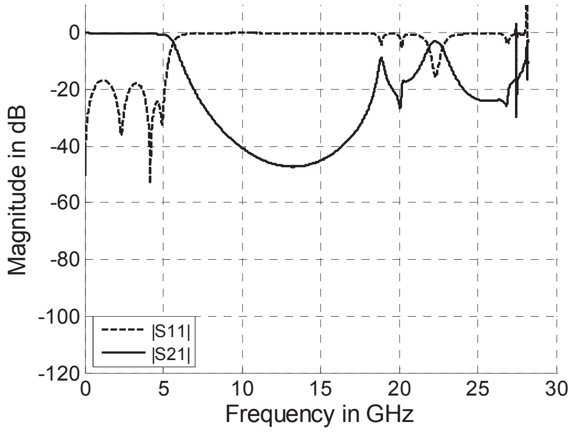

Fig. 6. Measured scattering parameters response of the high-low impedance filter using waveguide-mode suppression vias.

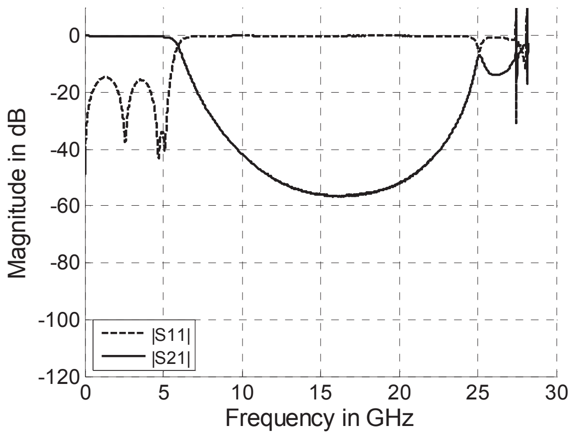

Fig. 7. Measured scattering parameters response of the high-low impedance filter using waveguide-mode suppression vias and DGS.

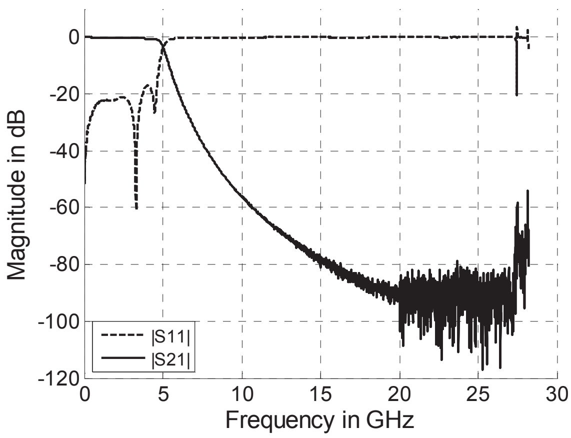

Fig. 8. Measured scattering parameters response of the high-low impedance filter using waveguide-mode suppression vias, working in a 20 Ohm environment.

Measurements have been performed in a 3.5 mm coaxial test environment; results above 27 GHz therefore are affected by higher order modes in the coaxial system.

The conventional filter shows a first spur at 19 GHz, which is due to a resonance of the middle inductor having the biggest size of all elements (Fig. 6). For the filter with DGS, an improvement in terms of spurs can be noticed, with the first spur located at 25 GHz (Fig. 7). The filter with 20 Ohms terminating impedances shows a superior behavior compared to the other two, in fact no spurs are observed within the measurement range (Fig. 8). Much greater attenuation values in the stopband are obtained, reaching down to the noise floor of the measuring equipment.

However, this filter shows a slightly lower cutoff-frequency, which is attributed to shrinking of the RO4450 prepreg during the lamination process. Based on prior experiences with this material, shrinkage has been accounted for in the design process of the filter, yet precise predictions are difficult. For future developments a non shrinking layer (RO4003) shall be used for implementing the capacitances.

Deviating from the usual system impedance adds the need for some post processing steps after the measurement, the first being the conversion of the scattering parameters, which are referenced to 50 Ohm, to Z- or Y-Parameters. These can be easily scaled to the desired impedance level of 20 Ohm, followed by a reconversion to scattering parameters. Integrating such filters in a 50 Ohm environment may be a difficult task, however a whole system operating in a 20 Ohm environment is conceivable.

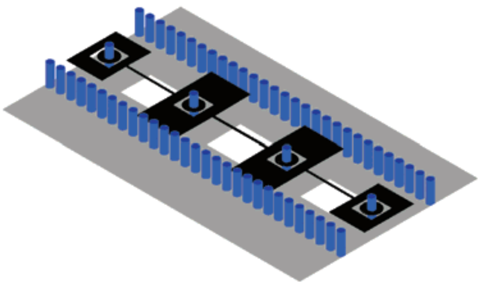

Fig. 9. Isometric view of a high-low impedance lowpass filter with vias for suppression of waveguide modes and DGS.

IV. Conclusion

Two methods for enhancing the stopband performance of planar microwave lowpass filters have been presented in this paper. Waveguide resonances based on the TE_{10} mode excitation can effectively be suppressed by placing vias within the capacitive patches of a high-low impedance filter. The method has been shown to be both versatile and easily applicable, adding only minor complexity to the filter layout.

The second proposal is a trade-off between the inductance and capacitance to be realized for a certain filter. Changing the termination impedance of the filter to lower values than the usual 50 Ohms, the construction of inductive sections can be alleviated. An example filter has been designed and manufactured, showing superior stopband performance in contrast to conventional filters.

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