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# Miniaturized and Out-of-Band Improved Bandpass Filter in Si-BCB Technology.

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**Abstract** — This paper reports on the design of a 24 GHz bandpass filter. This device is developed in a multilayer BCB-Si technology to ensure the development of the system on a unique chip. Moreover the technique of integration of semi-lumped lowpass filters in bandpass filter is used to reduce the global size and eliminate spurious response of the filter. The general method to design this kind of filters is described and experimental results are presented.

**Index Terms** — Si-BCB technology, bandpass filter, lowpass filter.

## I. INTRODUCTION

In the last few years, the great expansion of telecommunication has lead to develop microwave circuit on a unique chip to improve cost and performances. However, passive components realized directly on the silicon substrate present high-level losses because of its resistivity. To avoid this problem, some technologies based on the use of thick polymer layers have been investigated [1-2]. In the same time, some techniques to miniaturize passive components have been developed [3]-[5]. One of them consists in integrating semi-lumped lowpass filters in a distributed bandpass filter [6].

This particular technique presents two advantages:

- The first one concerns the control of the attenuated band. In fact, by inserting lowpass structures, we control the attenuated band while keeping the in-band performances in term of central frequency, bandwidth, return and insertion losses. This improvement of the attenuated band can also be performed by adding lowpass filters but increases inevitably the size of the device.
- The second one is induced by the topology of the chosen lowpass filter. In fact, the semi-lumped lowpass filter can be smaller than a quarter wavelength inverter according to the technology in

use. In this paper, we show the two concepts are well suited one to the other. Thus, we propose miniaturized filter which presents low spurious electrical responses by taking advantages of multilayer Si-BCB technology.

In a first part, we briefly present the technology to highlight its advantages. Then, we show the simulation procedure to design this kind of filter on Si-BCB technology. Finally, we propose experimental results.

## II. TECHNOLOGY

The technology is based on the use of a high resistivity silicon substrate combined to thick polymer layers. 10- $\mu\text{m}$  thick organic layers realized in Benzocyclobutene (BCB) are stacked with alternated 4- $\mu\text{m}$  thick conductive gold layers.

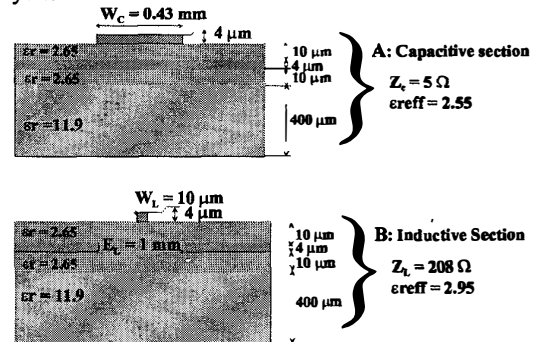


Fig. 1. Technology Si-BCB; capacitive and inductive sections.

This technology presents many advantages in term of losses, and achievable characteristic impedances. Fig. 1 describes the two basic technological configurations for both capacitive and inductive lines. In fact, we can obtain low characteristic impedance (5 Ohms) by using a TFMS configuration in one hand, and high characteristic

impedance (208 Ohms) by using defected ground plane in the other hand. Moreover, in this last case the BCB layer placed under the ground plane maintains the isolation in view of the silicon substrate. So, we obtain a low loss technology which allows, in the same time, very high and very low characteristic impedance. This induces the miniaturization of the semi-lumped lowpass filters and then of the bandpass filter.

The technology is composed of five main steps:

- First, a  $10\mu\text{m}$  **thick polymer layer** is spun on the silicon wafer after a cleaning step. The BCB layer is then partially polymerized during one hour at  $210^\circ\text{C}$  under a nitrogen flow. In order to favorite the next layers adhesion, a light  $\text{CF}_4/\text{O}_2$  plasma is achieved.
- Next, the **elaboration of the ground metal level** is performed with first the evaporation of a Ti/Au seed layer and then a  $3\mu\text{m}$  gold electroplating into a thick photoresist mould. The plating is followed by gold and titanium etchings.
- The next step consists in the **formation of metallic vias**, which are required to link the ground plane to the stub-ends and the coplanar ground probe access. These vias are obtained through the same technological steps of the ground plane. It only differs in term of thickness.
- A **second BCB layer** is then spun on and patterned to achieve openings on top of the vias. Next, the polymer is hard-cured at  $250^\circ\text{C}$  for one hour under nitrogen flow. To avoid any problem of bad contact; a light BCB etching is performed.
- Finally, the last metal level is realized with the same techniques as for the ground plane.

Next part is dedicated to the simulation of a band-pass filter centered at 24 GHz, using this technology.

### III. SIMULATION

At first, we have to fix the dimensions of the two configurations according to the working frequency. Here the chosen dimensions are ones described in Fig. 1.

To design this kind of filters, three steps are carried out.

The first one consists in a 2D simulation to obtain the characteristic impedance and the effective permittivity of the equivalent transmission line.

Then, a circuit simulation is performed by considering ideal transmission lines (on ADS<sup>TM</sup> for instance). Each

element of the circuit, *i. e.* resonators and inverters, are replaced by C-L-C semi-lumped lowpass filters (Fig. 2). This step allows the optimization of the cut-off frequencies of the integrated lowpass filters and leads to obtain the desired electrical response in the in-band. As it is explained in [6], the harmonic responses are automatically attenuated.

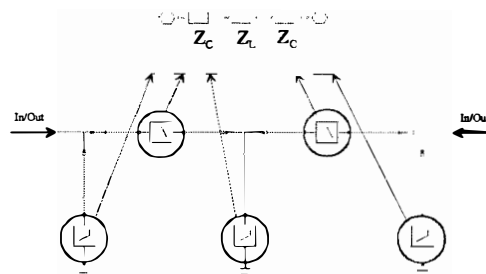


Fig. 2. Ideal transmission line schematic.

Fig. 3 presents the comparison between the electrical response of a classical quarter-wavelength stubs (dotted line) and of the one obtained after the optimization process (line). The harmonic responses are suppressed while keeping the bandpass at 24 GHz.

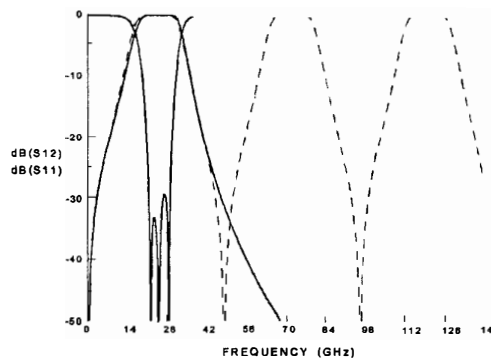


Fig. 3. Simulated electrical response of the third order bandpass filter with the multilayer BCB-Si technology.

Fig. 4 depicts a wide-band simulation of this third order bandpass filter. It shows that the spurious harmonics may be rejected up to 210 GHz by considering metallic and dielectric losses.

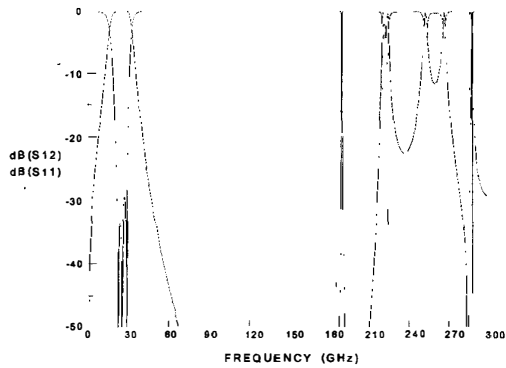


Fig. 4. Wide-band simulated electrical response of the third order bandpass filter with the multilayer BCB-Si technology.

Moreover, one should note that the size of the filter does not exceed  $2.25 \times 1.2 \text{ mm}^2$  instead of about  $3.9 \times 1.3 \text{ mm}^2$  for a classical filter on an alumina substrate.

Finally, the complete structure is simulated on HFSS<sup>TM</sup> [6] to consider the losses and the discontinuities effect. The figure 5 presents the simulated scheme with capacitive TFMS section and inductive 3D-CPW section.

As depicted in Fig. 6, in spite of a frequency shift induced by the discontinuities effect, the technique appears as quite good by considering the bandwidth and the return losses. Thus, to verify the electromagnetic results, this filter was realized.

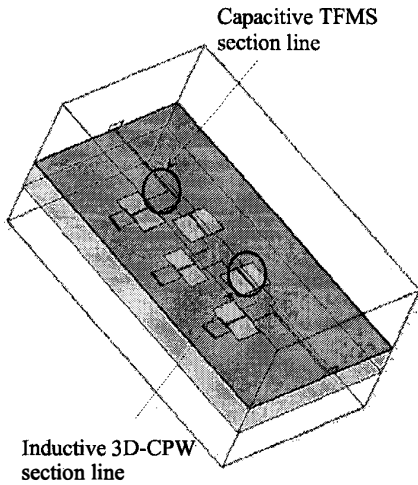


Fig. 5. Scheme on HFSS V9.0<sup>TM</sup>.

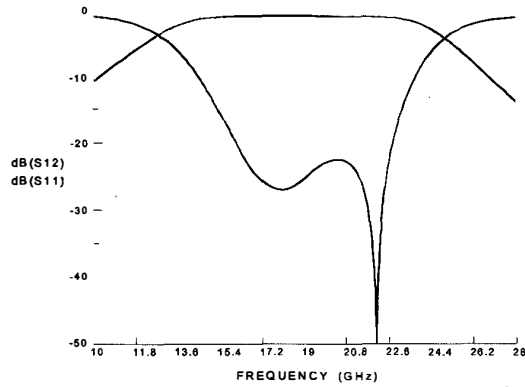


Fig. 6. Simulated electrical response in the in-band of the bandpass filter with the multilayer BCB-Si technology.

## VI. EXPERIMENTAL RESULTS

TRL access lines

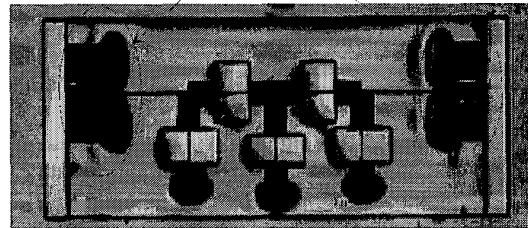


Fig. 7. Photograph of the third-order filter.

Fig. 7 presents the photograph of the circuit. One should note the coplanar access lines to permit on wafer measurements. Thus, TRL calibration kit has been used to de-embed the transitions.

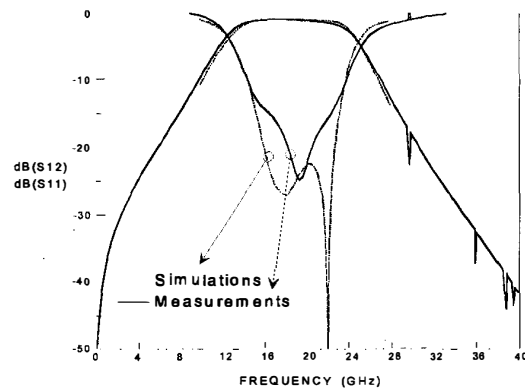


Fig. 8. Experimental and simulated responses in the in-band.

Figure 8 shows measurements are in a quite good agreement with the electromagnetic response. Insertion losses are about 1.1 dB, the 3dB-bandwidth is 12.5-25 GHz and return losses are better than 15 dB.

#### VII. Conclusion

In this paper, we proposed a bandpass filter at 24 GHz. This filter presents low spurious response and its size is minimized thanks to the use of a multilayer Si-BCB technology. Moreover, this technology allows the development of microwave system on a unique chip. This induces a great improvement by considering cost and performances.

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