Comparison of Surface Mounted High Quality Filters for Combination of Substrate Integrated and Waveguide Technology

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Abstract — **A comparison of substrate integrated waveguide (SIW) and substrate mounted waveguide (SMW) filters with focus on the quality factor Q is presented. Two differently coupled K-band SMW filters are compared to stand-alone SIW and waveguide filters, all comprised of five resonators. The SIW and waveguide filters are directly coupled through H-plane discontinuities. The first SMW filter is coupled using an iris while the second one is coupled via a microstrip stub. They are simulated using numerical field solvers and compared to simulated and measured responses of a SIW prototype filter. This comparison shows a Q factor improvement of a factor 3.7 for the SMW filters over the SIW filters.**

Index Terms — **Substrate integrated waveguide (SIW), surface mounted waveguide (SMW), waveguide filters, filter design.**

I. INTRODUCTION

Modern wireless communication systems demand high-performance and highly integrated RF/microwave filters of compact size and easy manufacturability. Recently evolving technologies, such as substrate integrated waveguide (SIW) circuits [1], meet these requirements. However, passive filters built in this technology lack performance regarding their quality factors [2]-[4] when compared to waveguide filters [5]. Waveguide technology provides very low-loss, high-Q resonators but is heavy and space consuming, and the integration and interfacing with printed-circuit boards causes additional expenses. Approaches to combine planar transmission line structures with the advantages of high quality waveguide cavities have been made by feeding a cavity with microstrip lines [6]-[8]. However, these setups do not provide a fully shielded environment for the transmission lines. Other structures involving surface mounted waveguide components have been published: in [9], a transformer to mount a waveguide horn on top of an open SIW is presented; in [4], shorted SIW stubs, mounted on top of SIWs are used to create resonator filters. Substrate mounted waveguide (SMW) is a promising attempt to combine the high Q-factor of waveguide technology with the advantages of SIW circuitry. Those are small foot-print fabrication, low-cost integration, fully electromagnetic shielded signal environment. Moreover, SMW agrees well with system-on-substrate technology [10].

II. DESIGN OF FILTERS

The basic design of microwave filters in waveguide technology is well known, e.g. [11]. In this paper, the mode-matching technique (MMT) is used to obtain initial dimensions for the investigated filters [12]. Based on the initial designs, SIW and SMW filters are simulated and optimized using CST Microwave Studio and ANSYS HFSS. Additionally, the SIW filter is prototyped and measured. For access with a test fixture, a microstrip (50Ω) to SIW taper is designed [13]. For the SIW and the iris coupled SMW filter, Rogers RT/Duroid 6002 substrate with relative permittivity of 2.94 and height of 508 μm is used. The microstrip coupled SMW filter employs RT/Duroid 5880 with relative permittivity of 2.2 and height 389 μm. The loss tangent for both substrates is 0.0012. All four filters are designed for a center frequency of 19.05GHz with a bandwidth of 2.62 percent (500MHz). The SIW dimensions are designed using formulas presented in [14]. The diameter of the via holes is 0.65 mm and the center-to-center spacing 1 mm. The resonators for the SMW and waveguide filters are simulated using surrounding copper (σ=5.96x10^7 S/m) walls. Silver plated aluminum is also an option.

A. SIW Filter

Fig. 1 shows the dimensions of the iris-coupled five-resonator SIW filter. For the measurements, the coaxial-to-microstrip-to-SIW transitions are deembeded using TRL calibration standards.

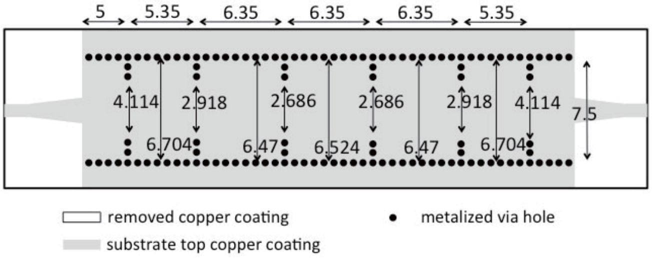

Fig. 1. Schematic top view of the H-plane iris-coupled five resonator SIW filter with dimensions in millimeters.

Fig. 2 presents the results of the initial MMT design, CST and HFSS simulations as well as measured data. When comparing the initial MMT design with simulations, a good agreement is observed. The return loss is below 28 dB for the passband. Suppression is better than 30 dB in the stopband. In the passband, $|S_{21}|$ shows insertion losses between 2 dB and 3 dB, as expected for planar SIW filters. However, differences in the measured data are observed with at least one resonator being detuned. Therefore, the $|S_{11}|$ parameter of the measurement lacks steepness at the upper cutoff frequency, and the minimum return loss is approximately 17 dB. This is likely caused by imprecise manufacturing and/or not fully metalized via holes.

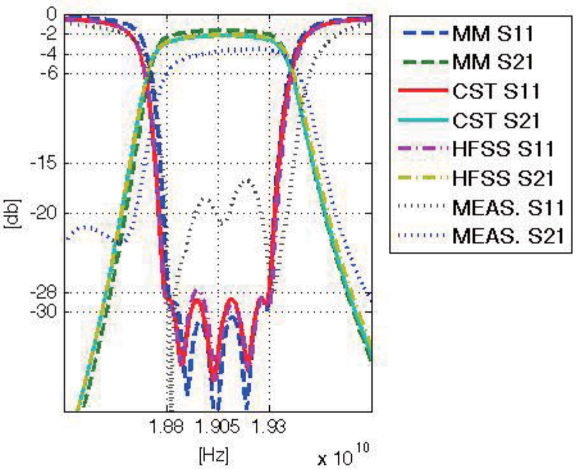

Fig. 2. Comparison of responses for the SIW filter by MMT, CST, HFSS, and measurements.

B. SMW Filter with Iris Coupling

Fig. 3 shows the dimensions of the iris coupled SMW filter. The incoming and outgoing SIW has a taper extending to the width of the SMW. This transformer allows better control of the dimensions of the coupling slots. This coupling section acts as iris (inverter) to the first resonator. Figure 5 presents the results for this filter. A good match between the SIW and the filter is achieved. The maximum insertion loss is 1 dB, the return loss is better than 20 dB, and the stopband attenuation is 30 dB.

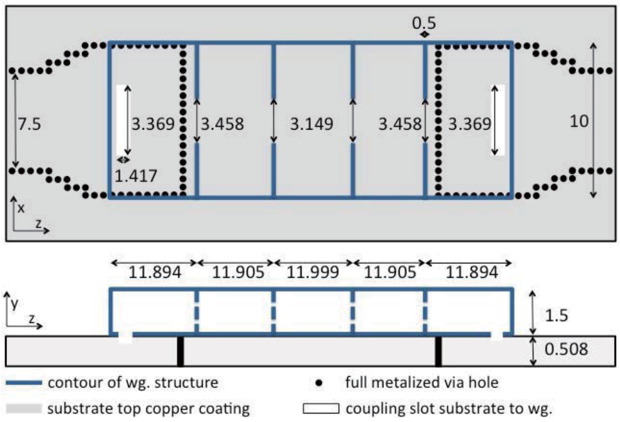

Fig. 3. Schematic top and side view of the H- and E-plane iris-coupled five resonator SMW filter with dimensions in millimeters.

C. SMW Filter with Microstrip Stub Coupling

Fig. 4 shows the dimensions of the microstrip-stub-coupled SMW filter. Again the coupling section acts as inverter to the first resonator. In this design, the taper allows for a larger (unmetallized) coupling area when compared to that in Fig. 3. The results are also presented in Fig. 5 with matching responses from CST and HFSS. The return and insertion losses are better than 17 dB and 1 dB, respectively.

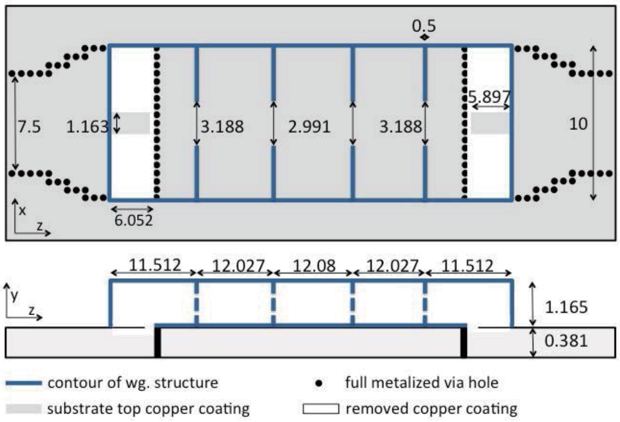

Fig. 4. Schematic top and side view of the H- and E-plane microstrip-stub-coupled five resonator SMW filter with dimensions in millimeters.

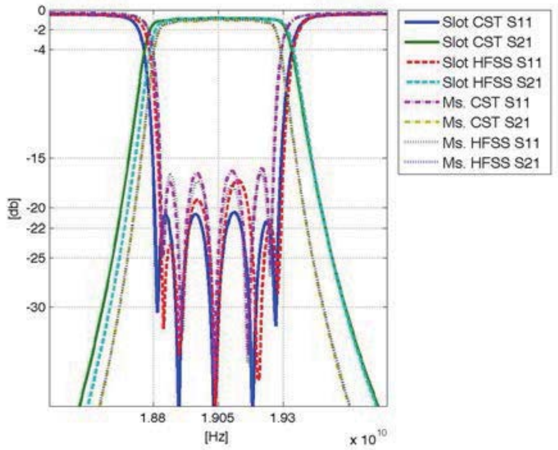

Fig. 5. Comparison between iris-coupled and microstrip-stub-coupled SMW filter.

D. Waveguide Filter with Iris Coupling

Fig. 6 shows the H-plane iris-coupled waveguide filter along with its dimensions. The response for this filter (c.f. Fig. 7) shows 20 dB return loss and 1 dB insertion loss for the specified bandwidth of 500 MHz at midband frequency of 19.05 GHz.

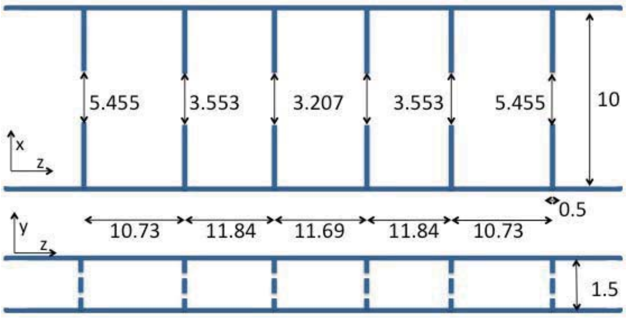

Fig. 6. Schematic top and side view of the H-plane iris-coupled five resonator conventional waveguide filter with dimensions in millimeters.

III. COMPARISON OF RESULTS

Fig. 7 shows the scattering parameters of all four filters. It can be observed that the passband for the iris- and microstrip-coupled SMW filter is narrower than that of the waveguide and SIW filter. (Note that the major difference of the SIW filter selectivity from the other responses can be attributed to the filter characteristic with 28 dB return loss.) The decrease in bandwidth for the iris-coupled SMW filter is approximately 20 MHz, that for the microstrip-stub-coupled one is 60 MHz. Observing the insertion loss, the SMW filters are almost matching the waveguide filter at 1 dB. The SIW filter is falling short at about 2 dB to 3 dB. This result translates directly to better Q values for the SMW filter compared to those of the SIW. The Q factor of the SMW filter is 1600. It is superior to that of the SIW filter by a factor of 3.7 and achieves about 67 percent of the Q value available with the conventional waveguide filter. Investigations on the SMW coupling interfaces have identified the dielectric loss to cause the Q difference between SMW and waveguide. The Q-factor results are summarized in Table I.

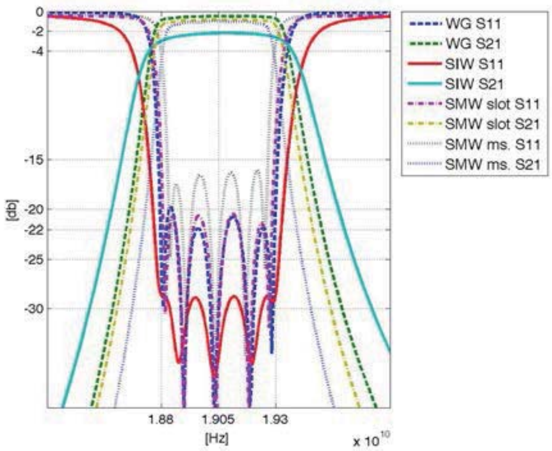

Fig. 7. Comparison of responses of investigated filters.

TABLE I COMPARISON OF QUALITY FACTORS (CST)

	SIW	SMW, iris	SMW, m. s.	Waveguide
Q	430	1600	1600	2360

IV. CONCLUSION

A comparison between filters in SIW, conventional waveguide and SMW technologies is presented. By mounting inline air cavities on top of SIW structures, a significant enhancement of the quality factor can be achieved. The Q value of SMW filters improves by a factor of 3.7 compared to filters in SIW technology. Two different ways to couple the signal into the SMW are presented. The first is realized by coupling via an iris. The second one transforms the field using a microstrip stub. Simulations using CST and HFSS as well as measurement data of the SIW filter prove the consistency of the design. With a height of only a few millimeters, the SMW filters provide a low-cost, highly integrative solution for passive, low-loss, high-quality microwave and millimeter-wave filters with high signal integrity capabilities due to a fully shielded environment.

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