SMD-type 42 GHz waveguide filter

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Abstract — **A novel concept for the transition between a microstrip line and a rectangular waveguide is presented and applied to a 42 GHz waveguide filter. Measurement results are presented which are in very good agreement to simulations. The waveguide is formed by soldering a U-shaped metallic filter part onto a RF-PCB (printed circuit board) using the board metalization as the last remaining waveguide wall. This technology is potentially enabling a fully automated SMD-assembly (surface mounted device) of waveguide components integrated into planar circuits.**

I. Introduction

Despite all the discussions around communication market situation a steady growing demand for high performance millimeter-wave radio systems available at low cost is obvious.

Typical applications are VSAT modules with uplink at 30 GHz, Point-to-Point radios within 20-38-64 GHz and Point-to-Multipoint radios with spectrum allocations at 26, 28, 31, 32 and 42 GHz.

In order to drive down production cost for volume-manufacturing of millimeter-wave transceiver modules, new manufacturing technologies are currently going to be established [1]. The conventional manufacturing approach of using "patchwork technology" consisting of alumina based thin film technology, dispensing, pick&place and chip&wire assembly in metal packages under clean room conditions will be replaced by new technologies such as using fully automated SMD-assembly of packaged and standardized MMICs (box-of-bricks concept) together with DC-components on a less costly PTFE-FR4-based multilayer RF-PCB.

Stringent ETSI- and customer-specifications combined with module architectures targeted for low overall GaAs chip area and the use of broadband MMIC building blocks impose heavy constraints on the filtering technology to be used in order to provide spurious free operation at mm-wave frequencies.

Waveguide filters featuring high stopband attenuation, low insertion loss and sharp skirt because of their high resonator quality factor Q are the ideal candidates for such applications from a technical point of view. However waveguide filters fabricated in conventional milling technology are expensive, bulky and unfavorable to the connection with planar circuits. Various concepts to circumvent these difficulties have been presented in recent literature. Dielectric filled and substrate integrated waveguide filters are presented in [2]-[5] which are partly easy to fabricate however at the expense of higher tolerance requirements because of the shrinkage in dimensions proportional to a scaling factor s of

$$s = \left(\sqrt{\varepsilon_r}\right)^{-1} \tag{1}$$

and lower Q factor due to dielectric losses. A concept for the integration of an air filled waveguide filter is presented in [6] where the waveguide filter is aperture coupled to the connecting MSLs (microstrip lines) and mounted below the substrate ground plane which simultaneously acts as the top wall of the waveguide.

In this paper an approach is presented where an air filled waveguide filter is formed by conductive attachment of a component further called "filter part" on top of a PCB substrate. This can be done cost effectively using standard SMD-assembly process side by side with other SMD components as packaged MMICs and electronic circuitry. Replacing the metal typically used for waveguide filters by a filter part consisting of injection molded metalized plastics [8] additionally helps to lower production costs for high volumes.

II. Principle Of The Filter

The filter part (Fig. 1) provides three of the four waveguide walls. The waveguide is closed by using the top metalization of the RF-PCB as the last remaining waveguide wall. Metalization and filter part are connected by soldering. Self alignment of the filter part occurs during soldering.

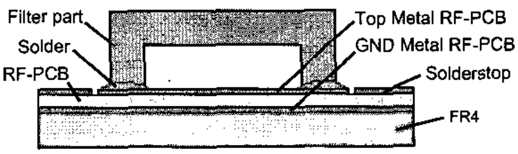

Fig. 1. Principle cross section of the assembled SMD-Filter.

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The RF connections to the input/output feeding MSLs are done by coupling regions integrated at both ends of the filter part and corresponding landing structures on the PCB side. The design and stand alone measurement results of this transition are presented in section III.

The combination of transitions with waveguide filter region is discussed in section IV together with technology related aspects of using metalized plastic material for the filter part. Section V will conclude and give an outlook on further work planned.

III. Microstrip To Waveguide Transition

For the microstrip to waveguide transition the principle of "ridged waveguide transition" [7] is modified to be suitable for the belongs of milling / injection molding and SMD attachment.

The functionality of the transition is explained by subdividing into several regions. A 3D-sketch for the transition region of the filter part and a photograph of the PCB layout are shown in Fig. 2 and Fig. 3.

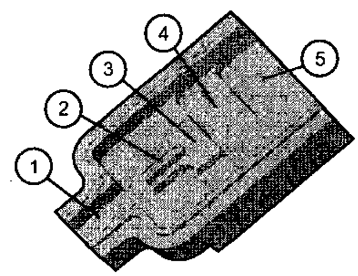

Fig. 2. Transition region of the filter part (different regions are denoted from *1* to *5*).

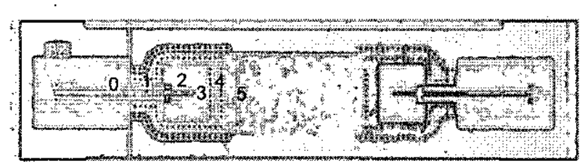

Fig. 3. RF-PCB structure for back-to-back testing of microstrip to waveguide transition (different regions are denoted from *0* to *5*).

Region *0* denotes the 50 Ω feeding MSL outside the transition. A Rogers RO4003□ substrate (thickness 203μm) laminated to an FR4 core was selected for the RF-PCB.

To avoid backward radiation of RF energy a cutoff-channel (region *1*) is designed. Microstrip mode is the only propagating mode for the frequency range of interest.

The MSL is connected to the ridge in region *2* by soldering. High aspect ratios (ridge height to ridge width in Fig. 2) being unfavorable for fabrication are avoided. The width of the ridge is chosen to be matched to the MSL.

Since the impedance level in rectangular waveguide region *5* is considerably higher than 50 Ω, impedance transforming steps in height (region *3* and region *4* in Fig.2) are used to obtain broadband matching for the desired frequency range.

Simultaneously the field pattern of region *1* being concentrated mainly in the substrate beneath the ridge is first transformed to a field pattern in region *3* with maximum energy in the airgap between ridge and substrate and further to the desired TE10 mode pattern of standard waveguide (region *5*). Via holes connecting the sidewalls of the filter part to the ground metal of the RF substrate are used to form a completely closed waveguide structure in regions *1* to *3*. Via holes arranged transversal to the direction of wave propagation (transition from region *3* to *4*) manage the transition from partially dielectric filled to air filled waveguide.

Design of the transition is done with the commercially available tool CST Microwave Studio□. A return loss better than –20 dB from 36.5 GHz to 47.7 GHz is predicted in simulation of a single transition.

Transition design is validated using a back-to-back configuration of two transitions connected by a straight waveguide (Fig. 3). Measurements are performed via probe-tips using TRL calibration. The measurement results of this configuration are shown in Fig. 4. Measured return loss is better than -17 dB over a bandwidth larger than 9.9 GHz (relative bandwidth about 25%). Insertion loss is lower than -1.8 dB within the same frequency range. Correcting this value for the loss which partly is caused by the connecting MSLs yields lower than 0.7 dB insertion loss for the single transition.

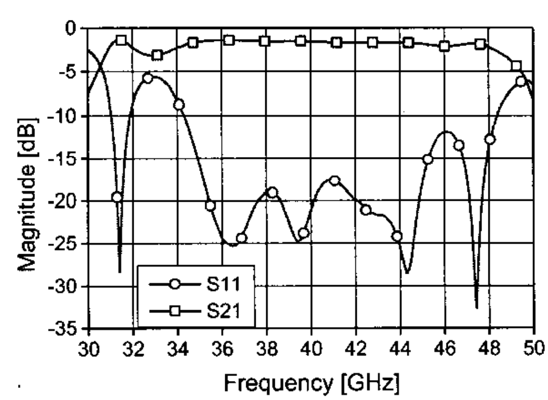

Fig. 4. Measured return and insertion loss of the microstrip to waveguide transition (back-to-back configuration).

IV. FILTER DESIGN AND MEASUREMENT

An H-plane type design using symmetrical inductive irises of equal thickness is selected for the filter. Design procedure described in [9] is done using CST Microwave Studio□ and a linear circuit simulator. Design parameters for the prototype milled metal version shown in Fig. 5 (upper structure) and Fig. 6 are: Tschebyscheff design, filter order n=7, 0.1 dB ripple, center frequency f_0 = 42 GHz and bandwidth bw = 4 GHz. Reduced waveguide height is used for the filter corresponding to the height of the waveguide in region *5* (Fig. 2). This results in a slight degradation of resonator Q factor but aids a broadband matching for the transition to MSL.

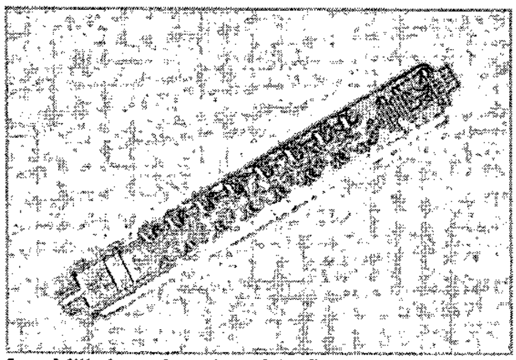

Fig. 5. Milled metal version of the filter part.

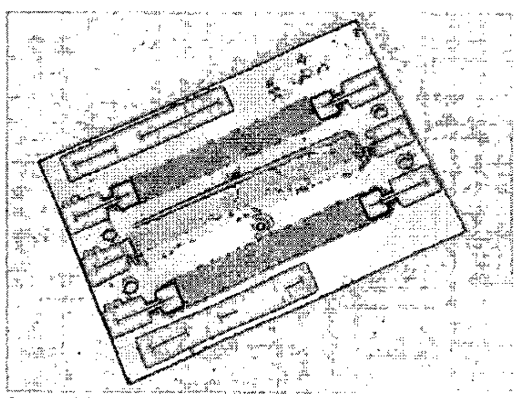

Fig. 6. Milled metal version filter part assembled on testboard.

Measurement results of the assembled filter are given in Fig. 7. Passband characteristics are slightly shifted to lower frequencies when compared to simulation. This is due to the effects of surface roughness not considered in design. Passband insertion loss amounts to -2.0 dB at f_0. Lower stopband attenuation for frequencies below 38.6 GHz is limited by parasitic coupling effects to approximately -56 dB down to 30 GHz. By putting some absorbing material on top of the substrate besides the MSL and close to the testports, stopband attenuation can further be improved. These results are plotted in Fig. 8 in comparison to data without placement of absorbing material.

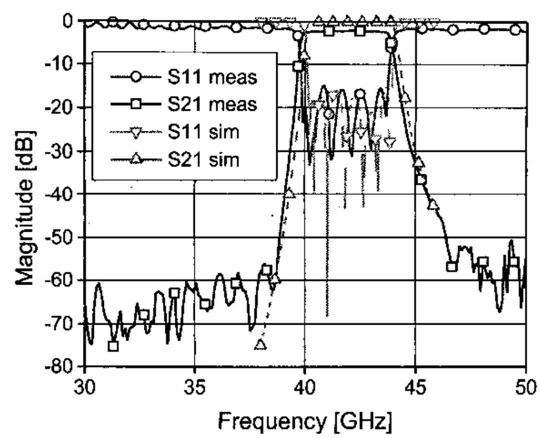

Fig. 7. Simulated and measured return and insertion loss of the 42 GHz SMD-filter.

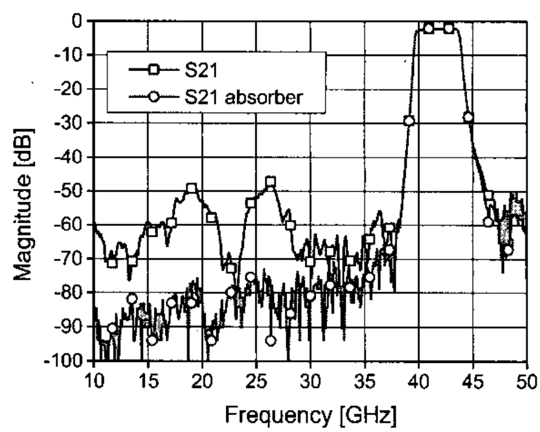

Fig. 8. Comparison: broadband measured insertion loss of 42 GHz SMD-filter with and without absorbing material placed beside the testports and the connecting lines.

For low cost and high volume production the milled metal version of the filter part may be replaced by a metalized plastic version.

Tolerance analysis yields that maximum tolerances of 10μm have to be met for some critical dimensions (e.g. width of iris openings) in order to achieve the goal of better than -15 dB return loss response in passband. Mechanical measurement of metalized plastic parts indicates that this is possible to achieve in production using state of the art plastics design, mold form tooling and reproducible injection molding process. Appropriate plastic material is selected to withstand temperatures of 270°C occurring in lead-free soldering. The CTE-match (coefficient of thermal expansion) between plastics material and PCB is very well. Same is true also for the milled metal version. Plastic parts are plated using a chemical / galvanic plating process [10] providing a high electrical conductivity metal finish suitable for low RF losses.

V. Conclusion

Design and results of a surface-mountable 42 GHz transition from microstrip to air filled waveguide are presented. The transition is based on a combination of "ridged waveguide transition" and waveguide impedance transformer. Transition concept was applied to mount a classical airfilled waveguide filter onto a PCB circuit with microstrip input / output connection. High stopband attenuation, low insertion loss, sharp transition from stopband to passband and compact design have been demonstrated using this filter. Such a filter therefore is a solution to overcome the limited performance of planar filters at mm-wave frequencies (high insertion loss, poor reproducibility due to etching tolerance and low isolation due to surface waves and radiation).

Realization of the filters in plastic molding technology for mass markets seems to be feasible and therefore is under development.

The transition presented in section III will also be useful for waveguide input / output to be realized on next generation RF-PCB e.g. for antenna connection. A low-cost waveguide junction can be formed to connect waveguide components to the PCB backside.

Acknowledgement

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References

[1] M. Oppermann, "LMDS Applications and RF Radio Links go for SMD based module technology – reality, experience and future trends," *IMAPS 2002 Proceedings*, pp. 273-278, September 2002.

[2] N. Kinayman, C. Eswarappa, N. Jain and A. Buckle, "A novel Surface-Mountable Millimeter-Wave Bandpass Filter," *IEEE Microwave and Wireless Components Letters*, vol. 12, no. 3, March 2002.

[3] M. S. Aftanasar, P. R. Young and I. D. Robertson, "Rectangular Waveguide Filters Using Photoimageable Thick-film Processing,", *32nd European Microwave Conference Proceedings*, vol. 1, pp. 29-32, September 2002.

[4] M. Ito, K. Maruhashi, K. Ikuina, T. Hashiguchi, S. Iwanaga and K. Ohata,, "60-GHz-band Dielectric Waveguide Filters with Cross-coupling for Flip-Chip Modules," *2002 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1789-1792, June 2002.

[5] C.-Y. Chang and W.C. Hsu, "Photonic Bandgap Dielectric Waveguide Filter," *IEEE Microwave and Wireless Components Letters*, vol. 12, no. 4, April 2002.

[6] W. Menzel and M. Wetzel, "Waveguide Filter integrated into a planar Circuit," *32nd European Microwave Conference Proceedings*, vol. 3, pp. 957-960, September 2002.

[7] W. Menzel and A. Klaassen, "On the Transition from Ridged Waveguide to Microstrip," *19th European Microwave Conference Proceedings*, pp. 1265-1269, September 1989.

[8] W. Menzel, J. Kassner and U. Goebel, "Innovative Packaging and Fabrication Concept for a 28 GHz Communication Front-End," (Invited Paper), *IEICE Transactions on Electronics - C*, Japan, Special Issue on "High Frequency/High Speed Devices for Information and Communication Systems to support 2K Society", vol. E82-C, no. 11, pp. 2021-2028, November 1999.

[9] G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks and Coupling Structures*. Norwood, MA: Artech House, 1980

[10] R. Dolp, W. Mayer, W. Grabherr, "Industrialization of a 58 GHz High Gain Flat Panel Antenna Design using Injection Molding Technique," *29th European Microwave Conference Proceedings*, vol. 3, pp. 13-15, September 1999.