A 40 GHz LTCC Receiver Module Using a Novel Submerged Balancing Filter Structure

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Abstract **A SMT compatible 40 GHz discrete mixer in LTCC is proposed. A novel filter structure was implemented in a buried layer which serves as a balun for a discrete balanced mixer at the same time. The design approach scales very well with frequency and stopband specification and allows the design of compact low cost modules.**

I. INTRODUCTION

The availability of low loss material systems created the interest in designing microwave modules on Low Temperature Cofired Ceramic (LTCC) up to several tens of GHz. At 40 GHz for example multifunctional communication submodules can be advantageously manufactured with this technology [1]. Instead of just forming the carrier for relatively expensive Monolithic Microwace Integrated Circuits (MMIC) this multilayer ceramic allows one to integrate compact passive triplate waveguide structures inside the ceramic. Thus the design of discrete microwave circuits is possible especially in combination with Flip Chip (FC) mounted components on the top layer. A demonstration of the technical valence of this approach is shown by a receiver module comprising an amplifier, a filter and a mixer.

By using a novel triplate line structure the function of a bandpass filter and a balun is performed by one component. On one hand the bandpass rejects the image frequency, on the other hand the balun and a FC double diode form a balanced mixer as a downconverter. This filtering balun is buried in the LTCC in order to save top layer area for the amplifier MMIC, the diode and auxillary functions. The buried design furthermore minimizes coupling to neighbouring circuitry, resulting in a better LO RF rejection.

II. THEORETICAL ANALYSIS OF THE PRESENTED STRUCTURE

The mixer structure implemented in the multilayered ceramics is presented in Fig. 1. The triplate filtering balun consists of a series of four elements of the basic type shown in Fig. 2.

A theoretical insight into the behaviour of the structure can be achived on the basis of odd- and even mode analysis of this single filter element as displayed in Fig. 2. The function of a basic element is best described by an excitation with an odd and even mode at port 1a and 1b. Odd mode operation is defined as an excitation of port 1a and 1b with waves of equal amplitude which are 180° out of phase whereas in even mode operation both waves are in phase. For symmetry reasons the same phase condition as for the input ports result for the output signals at port 2a and 2b. Both modes are decoupled and no mode conversion takes place.

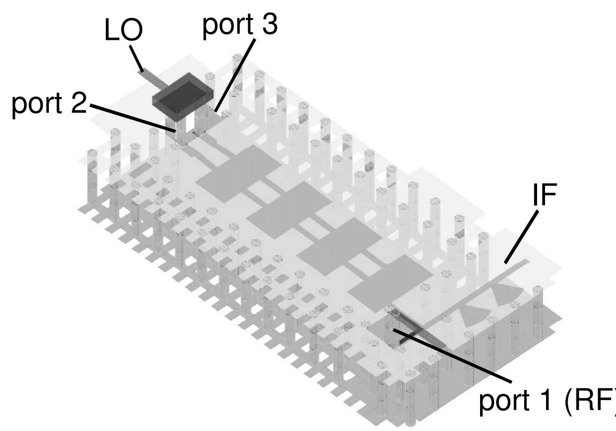

Figure 1: The proposed filter structure with FC-diode

For odd mode operation the structure forms a $\lambda/2$ resonator in the transverse direction of the patch. The four transmission lines are roughly $\lambda/4$ long and present an impedance inverter. The frequency response of the patch for the odd mode as well as for the equivalent lumped resonator is illustrated in Fig. 3. By putting several resonators in a chain a higher order filter

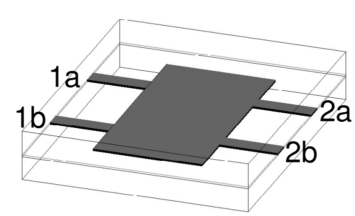

Figure 2: Basic filter element

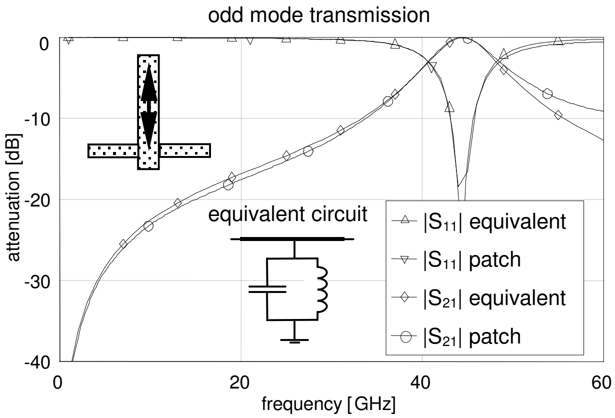

Figure 3: Response of odd mode and equivalent circuit

can be designed using the well known design procedures as described in [2] and others.

The transverse resonance described above cannot occur in even mode operation due to the symmetry. Instead, the pair of input transmission lines have the same potential as a function of the longitudinal position and can be treated as one effective line. Hence the equivalent circuit depicted as inlay in Fig. 4 is valid. The equivalent response of the patch in even mode operation and the equivalent lumped model is sketched in Fig. 4. The proposed filter network is considered as an extension of the work of Knoechel [3].

III. Balancing Filter Operation And Measurement

Based on the equivalent circuits gained in the previous section, it is now possible to describe the structure as two filters, one for odd and one for even excitation. The topology of the first filter is well known and used for wide band stop applications. Hence this filter only suppresses the even mode and determines the amplitude and phase symmetry in the resulting balun. The odd mode experiences a narrow bandpass filtering which is responsible for the desired image frequency suppression of the structure.

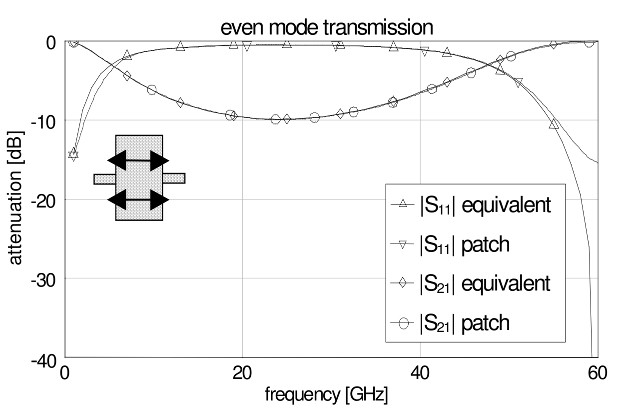

Figure 4: Response of even mode and equivalent circuit

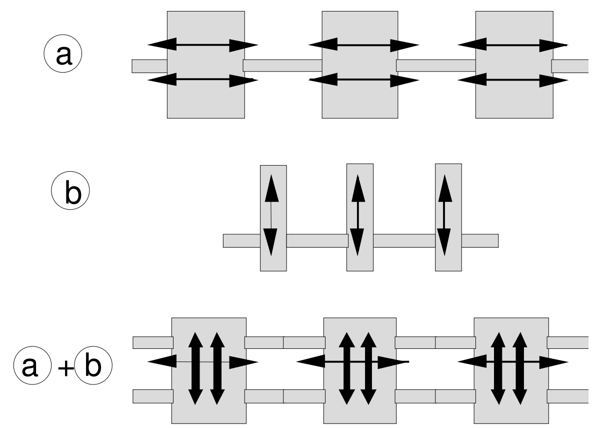

Figure 5: Even (a) and odd mode (b) equivalent filters and proposed structure (a) + (b)

In general unbalanced excitation is applied to the structure which is the linear superposition of an even and an odd mode. Excitation only at terminal 1a (Fig. 2) and canceling waves at terminal 1b represent the operation of the structure in Fig. 1. Properly designed, the structure suppresses the even mode component and guides the odd mode component, which is preferred when its frequency is in the passband.

Measured results are given in Fig. 6. The bandstop behaviour described increases quickly above 25 GHz. The passband transmission applies almost only for the odd mode, as desired for balanced mixing in the double diode. The triplate structure is buried in the third layer of the ceramic and almost fully shielded by ground planes and via fences. This is advantageous with respect to isolation and package modes. In

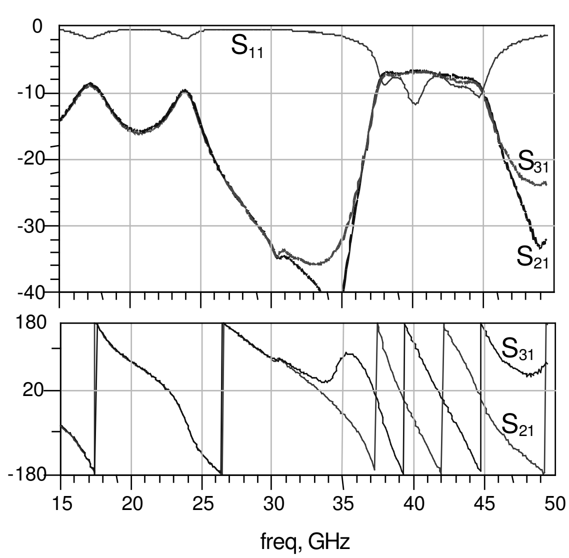

Figure 6: Balancing filter measured response

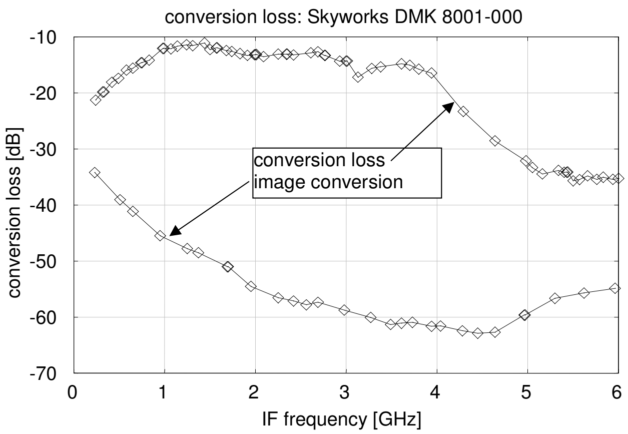

Figure 7: Measured conversion performance at 39 GHz LO

particular the via fence around the filter suppresses the parallel plate mode.

IV. MIXER OPERATION

For mixer operation the structure has to be optimized for the particular diodes to be used. The impedance of the balun can be easily tuned for optimum diode operation by adjusting the length of the balanced output transmission lines at port 2 and 3 in Fig. 1 [4]. Varying their length tunes even mode reflection phase and their width tunes the amplitude of the reflection.

A downconverter has been designed for a receiver application in the 42 GHz bands using a LO frequency of 39 GHz and an IF frequency at 3 GHz. A Skyworks DMK 8001-000 diode was applied as nonlinear device. The mixers RF bandwidth is 3 GHz, reaching from 40 to 43 GHz. The corresponding conversion loss and image rejection is shown in Fig. 7 is about 12 dB at a LO level of 11 dBm. The conversion loss of the mixer is about 4 dB higher than the loss of typical MMIC mixers due to the insertion loss of the balancing filter. The insertion loss could be greatly reduced by using low loss

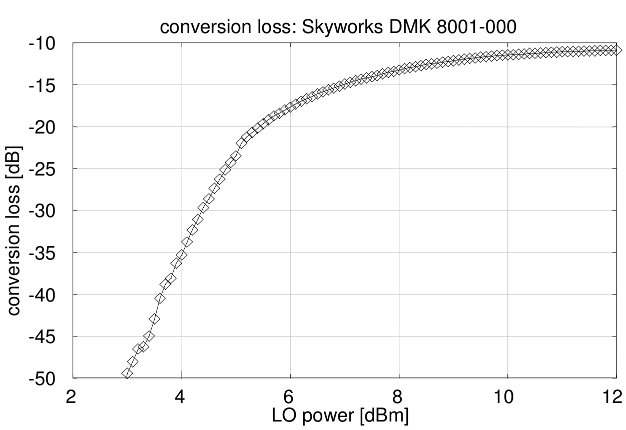

Figure 8: Conversion loss vs. LO power

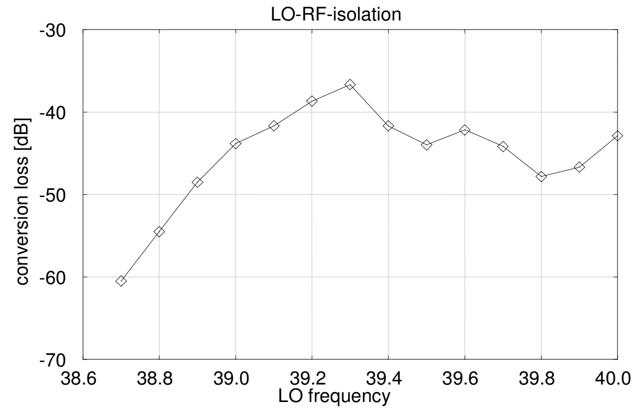

Figure 9: isolation vs. LO-frequency

tapes such as DuPont 943. This would also enable one to increase the filter order and to further improve the image suppression which is already better than 30 dB at present. The conversion loss vs. LO power is shown in Fig. 9. It can be seen that mixer saturation sets in at roughly 10 dBm. This value strongly depends on the diode used. For the applied diode proper operation starts at 6 dBm. of LO power. The isolation depicted in Fig. 9 is greater than 40 dB.

V. THE SUBSYSTEM AND MODULE LAYOUT

The device proposed in the previous section is intended for use in a 40 GHz receiver chain. Fig. 10 shows the context of the proposed module as subsystem in the Rx chain of a 40 GHz link. The dashed line points out the components which can advantageously be integrated in one physical module. The low noise amplifier is a bare die which is flip chip assembled on top of the module. It takes advantage of the LTCC substrate as carrier and of the decoupling circuitry integrated inside the module.

The filter and balun performance depends strongly on the low dielectric loss tangent. Furthermore it can be implemented cheaply using just a double diode at a fraction of GaAs area and price of MMIC Mixers. The triplate structure relaxes the LO-leakage known from microstrip filters through inherent shielding.

The subsystem described above has been integrated into a multifunctional module who's layer configuration is shown in Fig. 11. A Ball Grid Array (BGA) on the bottom side is used

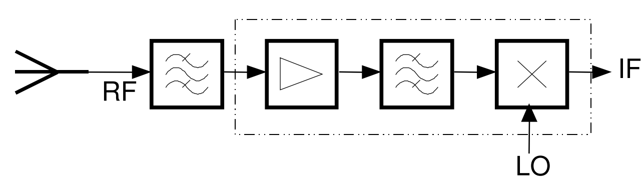

Figure 10: The submodule as part of a receiver

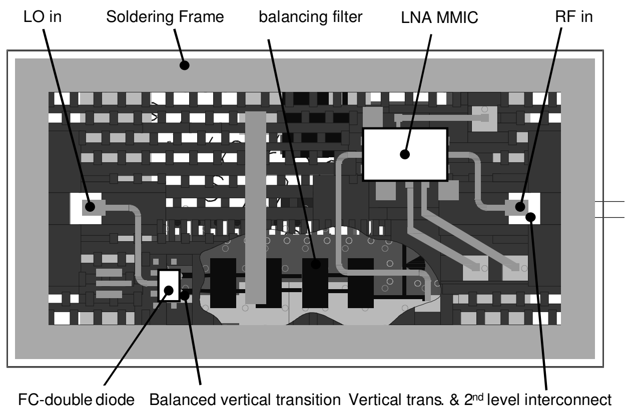

Figure 11: The RF part of the module layout

for SMT compatibel interconnect. The module with mounted devices and its BGA footprint can be seen in the photo Fig. 12. After FC assembly, the module can be closed with a deep-drawn lid on top for shielding and protection of the bare dies. Other sealing concepts can be applied as well with minor design modifications. Finally the module can be mounted on a PCB using standard SMT processes.

Besides the balancing filter, the bias capacitors for the MMIC amplifier have been integrated into the ceramic, which helps to reduce assembly cost further. A con-siderable advantage in LTCC technique is the ease of obtaining bias decoupling and filtering due to high quality passives and easy shielding between neighbouring circuitry using via cages and intermediate groundplanes. This is certainly the case for the proposed application.

VI. CONCLUSION

A SMT compatible module in LTCC is presented. The design is based on a novel balancing filter structure for the mixer. It uses low cost double diodes in flip chip assembly. A conversion gain comparable with existing solutions has been reported [5]. The paper demonstrates the feasibility of the System-in-a-Package approach for particular RF-functionality in the 40 GHz band and shows a way to low cost module design using submerged microwave passives and advanced LTCC technology.

In this example the submerged filter avoids coupling to neighbouring circuitry as well as package moding and allows the application of new packaging concepts. Furthermore it saves top layer space for additional component assembly.

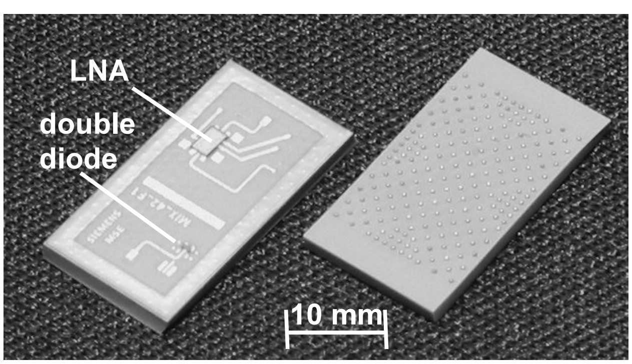

Figure 12: FC assembled LTCC module and BGA footprint

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