A Compact L-Band LTCC Mixer with High Image Rejection

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Abstract **Low Temperature Cofired Ceramic (LTCC) Technology has been perceived as a potentially enabling integration technology for addressing the commercial viability of the size and performance requirements of high functionality Telecommunication equipment for Multi-Radio applications. In this paper a 1.7-1.8 GHz Multi-Layer Ceramic Technology Image Reject Mixer Module is presented. The Ball Grid Array (BGA) assembled LTCC Mixer Module achieves double balanced operation and an Image Rejection of greater than 67 dB. By virtue of its multilayer construction and high level passives integration the mixer occupies an active area of 15x13 mm2. To our knowledge this is the smallest non-IC based DBM Image Reject Mixer Module in the 1-2 GHz range.**

I. INTRODUCTION

High performance, low cost & miniature integrated circuit technologies are urgently required to built the enabling hardware platforms for future Multi-Radio terminals. To meet the above requirements a flexible integrated technology approach is needed to efficiently combine multiple ASICs/RFICs with high density inter-connects and high performance miniaturised RF passives. A range of Multi-Chip Module (MCM) technology platforms have been suggested that can potentially meet the above requirements. Among the most promising technology candidates are the ones related to the tight combination of Multilayer Ceramic Passive Circuits and Si/GaAs based ICs with this combination better termed as 'Multilayer Ceramic Integrated Circuits' (MCICs) , [2]. An illustration of such a Integrated MCIC Module scenario is given in Figure 1.

In evaluating the potential of such approach, LTCC MCIC modules with a high level of embedded passives functionality need to be demonstrated.

High Performance L-band Mixer applications for 2.5/3G Wireless Base Station applications are typically addressed using high level LO injection Balanced Diode or FET resistive type mixers [2]. Since RFIC solutions may not meet stringent linearity requirements the construction of such mixers typically relies on using discrete ferrite-bead type RF/LO/IF baluns and Si Diode/GaAs FET assembled dies to achieve balanced operation. A relatively high level of LO power is required to ensure good linearity performance.

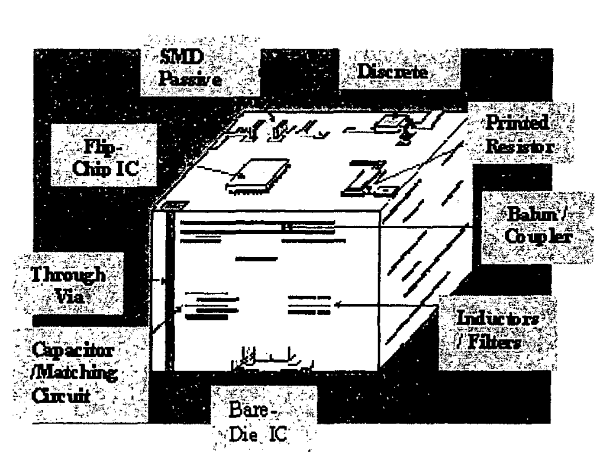

Figure 1. LTCC Module Integration Scenario

When there exists the additional requirement for high image rejection a relatively expensive discrete narrowband image reject filter may be used prior to the mixer. Alternatively an Image Reject (IR) mixer topology may be pursued. The latter solution requires an even greater number of extra passive components, namely an extra DBM Mixer, 2 RF/IF 90° hybrids and an LO signal divider. Furthermore, the typical wideband image rejection achieved with such discrete components is not likely to exceed 25dB on a production yield basis. Both aforementioned solutions would further compromise conversion loss, increase cost and need more assembly area.

Therefore a more flexible integrated design approach is needed to overcome the above limitations in size, performance and overall cost.

To this end we present a compact L-band LTCC IMR Diode Mixer. The mixer monolithically integrates 4 baluns, 2 RF/IF Hybrids, one LO signal divider and a HPF filter within the multilayer LTCC structure. Under such implementation high image rejection, low conversion loss and an small active area of 15x13 mm^2 are achieved.

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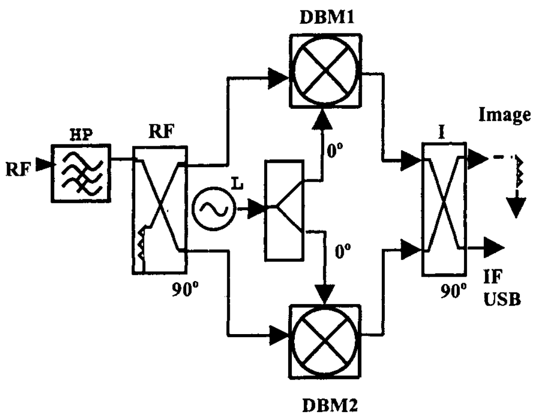
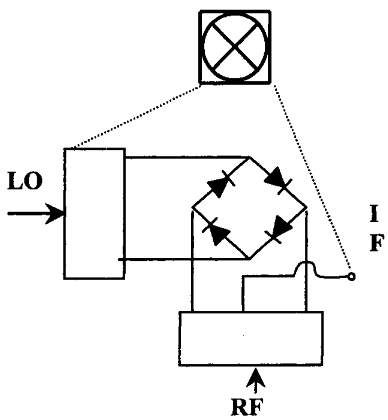
II. MIXER DESIGN DESCRIPTION

The LTCC Image Reject Mixer Block Level schematic is illustrated in Figures 2a and 2b.



(a)



(b)

Figure 2 : Image reject Mixer Module Design
(a) Block level schematic (b) DBM Mixer detail

Figure 2a illustrates the block level schematic of the designed mixer. Figure 2b illustrates the double balanced mixer design approach. The IR downconvtering mixer was designed for a RF frequency range of 1710-1785 MHz and a selected IF frequency of 500 MHz. The LO and Image frequency ranges were at 1210-1285 MHz and 710-785 MHz respectively.

The LTCC substrate used is 1.85 mm in height and comprises of ~94 um thick multi-layers with a dielectric constant of 7.8. Buried conductors are Ag, and ~10 um thick. The loss tangent of the material is ~0.0045 in the 2 GHz range. Typically for the realization of such mixers around 10 layers of LTCC tape are needed. The substrate is split in 2 main integration levels, separated by an internal ground plane. Each integration level uses transmission lines (TRLs) of the embedded microstrip configuration. Additionally, each integration level-stacked components such as inductors, parallel plate capacitors and broadside-coupled TRLs are used to realize the module's passive components. The illustrative crossection of the mixer is shown in Figure 3.

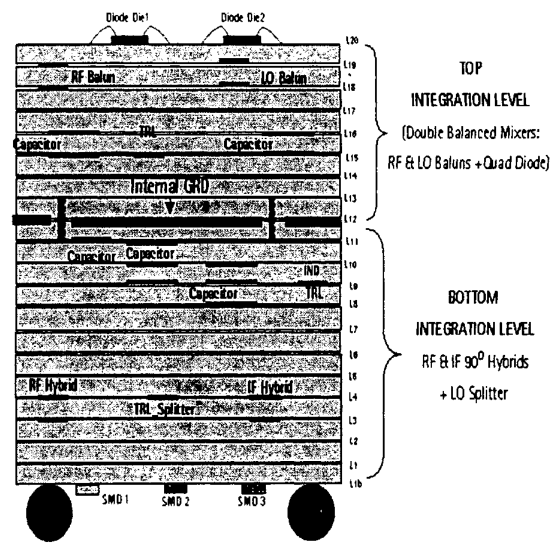


Figure 3: LTCC Mixer Substrate crossection

On the bottom integration level the HPF image reject filter, RF and IF 90 Hybrids and a Wilkinson LO splitter are realized. In such a configuration the mixer I/Os are on the bottom level of integration. BGA balls provide the interconnect method on the carrier substrate. The HPF is a 5-element series capacitor/parallel inductor type filter. It is designed to achieve at least 35 dB of extra suppression at the image frequency. The RF and IF 90° Hybrids are wiggled broadside coupled line components using even and odd mode velocity compensation, for improved phase balance [3]-[4]. The 90° hybrids and Wilkinson splitter termination resistors are realized using 0402 SMD components. The layout of the bottom integration level is shown in Figure 4.

On the top integration level, the 2 DBM mixers are implemented. Two Si diode octo-quads, one for each

DBM mixer, are wirebonded and glop-topped with a non-conductive epoxy material for environmental protection. Broadside coupled RF and LO baluns are realized. The RF Balun is of the horseshoe configuration and the IF outputs (IF1 and IF2) are extracted through its balanced center point allowing for good LO-IF isolation. The top integration level embedded layout is shown in figure 5.

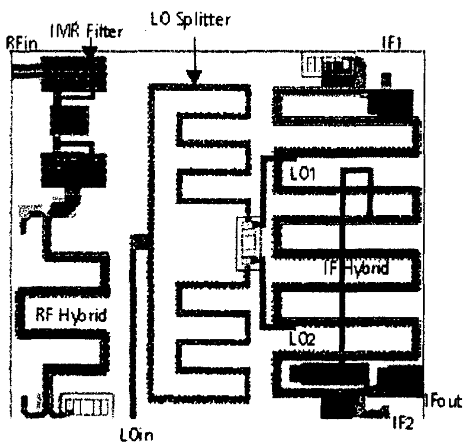


Figure 4: Bottom Integration Level of IMR Mixer

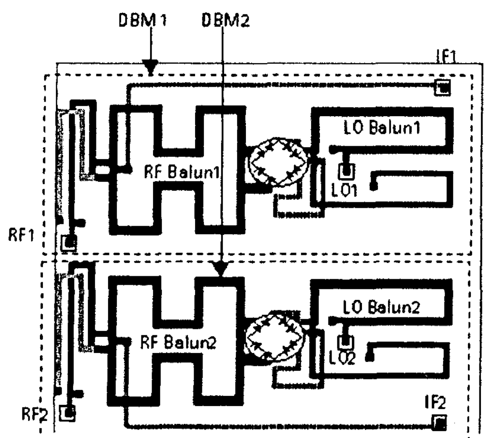


Figure 5: Top Integration Level of IMR Mixer

Each of the multilayer embedded components were designed using Electromagnetic (EM) simulation using the Agilent ADS Momentum, 2.5D EM simulator. Each passive component was simulated individually and the resulting S-parameters were used to predict the overall mixer response using the Agilent ADS Circuit simulator.

III. Results

The manufactured BGA interconnect image reject mixer as assembled on an PWB test fixture is shown in Figure 6. A BGA ball diameter of ~1.25 mm was used. The top view shows the glop-toped Si octo-quad dies. No other circuit element is visible since all other top-level integration elements are completely embedded within the ceramic.

In such a case the 'circuit' is the 'package' of the mixer module and no top metal cover cap for the module was considered necessary for added isolation and environmental protection purposes.

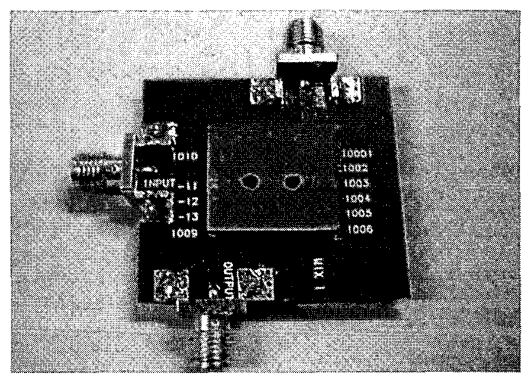


Figure 6: Photo of the manufactured LTCC IR Mixer

In order to evaluate the image rejection that was attributed to the Image reject Mixer without the HPF filter's contribution, as well as estimate the Image reject mixers' intrinsic conversion loss, an RF probeable test circuit of the HPF filter was also manufactured.

Figure 7 shows the HPF filter layout including the RF probe pads and Figure 8 the measured and Momentum EM simulated results for direct comparison.

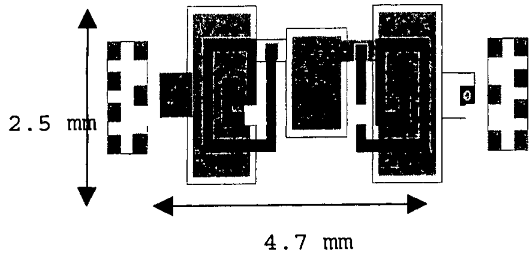
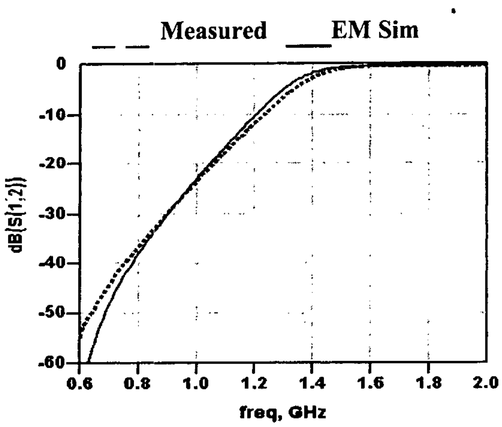
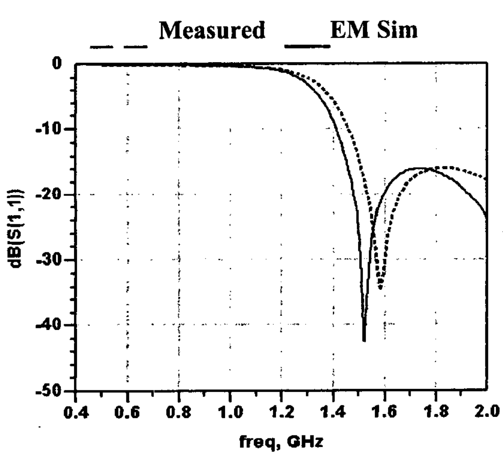


Figure 7: Layout of HPF filter with RF probe pads



(a)



(b)

Figure 8: HPF Filter (a) Insertion Loss (b) Return Loss

The good agreement between measured and simulated results illustrates sufficiently low LTCC manufacturing tolerances. Measured HPF filter suppression at the image frequency and RF band insertion loss were >38dB and < 0.6 dB respectively.

The mixer measured versus simulated results are summarized in Table 1. The measured overall Image rejection is over 67dB. This implies that the wideband image suppression due to the IR mixer only is greater than 28 dB. This illustrates the very good amplitude and phase balance of the Image reject mixer. Furthermore the extracted IR mixer intrinsic CL is < 6 dB.

Table 1

PROPERTY	SIMULATED RESULT	MEASURED RESULT
Frequency Range	RF 1.71-1.785GHz IF: 500 MHz	RF 1.71-1.785GHz IF: 500 MHz
Conversion Loss	< 6.8 dB	< 6.5 dB
Image rejection	> 66 dB	> 67 dB
LO-IF Isolation	> 45 dB	> 41 dB
LO-RF Isolation	> 31 dB	> 32 dB
RF-IF isolation	>36 dB	>34 dB
IF return loss	> 12 dB	> 14 dB
RF return loss	> 13.5 dB	> 12.5 dB

IV. CONCLUSION

A compact L-band DBM Image Reject Mixer with in excess of 67dB image rejection and excellent conversion loss properties has been demonstrated. The mixer's good performance and small size have been achieved by virtue of the dense passives' monolithic integration and inherent design flexibility that multilayer cofired ceramic technology offers.

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