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DESIGN OF COMPACT RF COMPONENTS FOR LOW-COST HIGH-PERFORMANCE WIRELESS FRONT-ENDS

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Abstract: This paper presents the design and fabrication of RF components for compact and low cost wireless radio front-end systems. The system-on-package (SOP) concept has been applied to the design of an integrated C-Band transceiver and results are presented for a high performance LTCC band-pass filter and a via-fed stacked cavity-backed patch antenna. Multi-layer organic packaging development is also reported for very high Q-factor inductors and embedded filters. In addition, simulations and experimental data for an RF-MEMS '2bit x 2bit' tuner and a micromachined filter demonstrate the benefits of the integration of micromachined structures.

I. INTRODUCTION

Multilayer integrated components and micromachining structures are critical to meet the cost and performance requirement of highly integrated wireless systems. The current drawbacks of most commercially available microwave, millimeter wave, and high-speed optoelectronics transceiver front-ends include the relatively large size and heavy weight primarily caused by discrete components and separately located modules. Multi-layer ceramic and organic-based SOP implementation is capable of overcoming this limitation by integrating components that would have otherwise been acquired in discrete form, and MMICs in a single package, hence the term System-on-Package (SOP). On-package components not only miniaturize the module, but also eliminate or minimize the need for discrete components and thereby reduce the assembly time and cost as well. In addition, less discrete components improve reliability because of the reduced solder joint failures. In this paper, we present highly miniaturized LTCC and fully-organic-based radio front-end packaging designs including a high performance second order narrow-band band-pass filter design with two cascaded coupled line sections for C-band, a via-fed stacked cavity-backed patch antenna designed to fully cover the required band (5.725-5.825 GHz), embedded in multiplayer LTCC substrate and multiplayer organic-based very high Q-factor inductors (up to 180) and embedded filter. Results for a reconfigurable wideband tuner with MEMS switches and a micromachined silicon waveguide filter at Q-band based on a periodic structure are presented as well.

II. 3D INTEGRATED WIRELESS MODULE DEVELOPMENT

We have developed a high performance second order narrow-band band-pass filter with two cascaded coupled line sections embedded in strip-line configuration to improve insertion loss. This design is based on a 10 layers LTCC process [1]. A schematic view is presented in Figure 1. Filter performance has been measured and exhibits a –2.9dB insertion loss, – 20.8dB return loss, about 200 MHz bandwidth and image rejection greater than –20 dB as shown in Figure 2.

A via-fed stacked cavity-backed patch antenna [2] has been designed (based on a 10 layers LTCC process) for WLAN IEEE 802.11a 5.8 GHz band as shown in Figure 3. The input impedance characteristic of the stacked-patch antenna is shown in Figure 4. The 10-dB return-loss bandwidth of the antenna is about 4%, fully covering the required band (5.725-5.825 GHz). The radiation pattern at 5.8 GHz shows that this antenna has a desirable gain (near 6 dBi) and very low cross-polarization (less than –35 dBi).

III. MULTI-LAYER ORGANIC BASED PACKAGE

A multi-layer packaging process using a organic material developed by Georgia Institute of Technology's NSF Packaging Research Center offers the potential as the next generation technology of choice for SOP for

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RF-wireless, high speed digital and RF-optical applications. The current SOP configuration is shown in Figure 5. It incorporates low cost materials and processes consisting of a core substrate (FR-4 for example) laminated with two thin organic layers. The thickness of the core substrate is 40 mils while the thickness of the laminate layers are 2.46 mils each. CPW-microstrip transition shows that it can be used up to 20 GHz. CPW inductors and HGP inductors using multilayer organic technology demonstrate a Q of 182, SRF 20GHz, L_{eff} 1.97 nH [3]. The bandpass filter design for C band applications consisting of a square patch resonator with inset feed lines, as shown in Figure 6, shows measured bandwidth of 1.5 GHz and a minimum insertion loss of 3 dB at the center frequency of 5.8 GHz. Lifted slot antenna has been successfully implemented in the package.

IV. RF MEMS COMPONENTS

The key benefits of RF-MEMS switches are their low power requirements and low insertion loss while maintaining compatibility with conventional semiconductor processing techniques. The design goal behind the designed '2bit x 2bit' RF-MEMS tuner is to match many impedances over a wide band [4]. This is accomplished through the use of MEMS capacitive switches to connect the stubs of a double stub tuner to a bank of fixed capacitors. A diagram of the design structure is presented in Figure 7. The dual stub configuration is commonly used to match impedances over a wide band. Each stub is terminated with a T junction into two one-port capacitors. Effectively, these capacitors add in parallel. By modifying the capacitance of each individual capacitor, the total capacitance seen by the stub can be varied. The RF-MEMS switch can be used to provide either a low capacitance, where the membrane is in the up (off) position, or a high capacitance in the down (on) position. The switch capacitance adds in series to the capacitance of the stub. The tuner uses four tunable capacitive stubs, each with a different configuration, providing a total of sixteen configurations, and thus sixteen impedances, that can be matched , as it can easily be seen in Figure 8.

V. MICROMACHINED BANDPASS FILTER

The last compact structure that is presented in this paper is the geometry of a 2-pole high-Q bandpass filter (Figure 9) that has been designed for a silicon substrate and demonstrates very low insertion loss (better than –2.5dB) and high Q with 2.5% equiripple bandwidth. The periodic structures typically consist of periodic arrangements of metallic or dielectric elements with different shapes and they exhibit different frequency regions in which electromagnetic waves cannot propagate. In our case, the structure was created by etching the holes periodically in the silicon substrate. Then the resonant elements are defined by locally disturbing the periodicity of the structure and used to design microwave filters at 45GHz[6]. A laser micromaching technique is applied to fabricate the experimental devices. This technique allows for high mechanical tolerances and is suitable for mass production. Simulation results for this filter are shown in Figure 10 and measurements after the wafer-bonding will be available at the conference.

VI. CONCLUSION

We have presented very compact LTCC-packaged components for low-cost high-performance wireless front-ends. A C-band second order narrow-band band-pass filter with two cascaded coupled line sections has been presented and a via-fed stacked cavity-backed patch antenna has been designed to fully cover the required band (5.725-5.825 GHz) and implemented in multilayer LTCC substrate. Multi-layer organic packaging developed for SOP is reported as well. Very high Q-factor inductors (up to 180) and embedded filter have been presented as an example of the high performances of multi-layer organic package. Results for a 2bitx2bit wideband MEMS tuner and a micromachined bandpass filter with high quality factor demonstrate the potential benefits of the combination of SOP with MEMS technology.

ACKNOWLEDGEMENT

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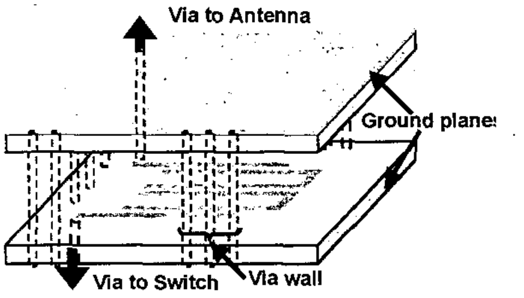

Fig. 1. Design schematic of a band-pass filter.

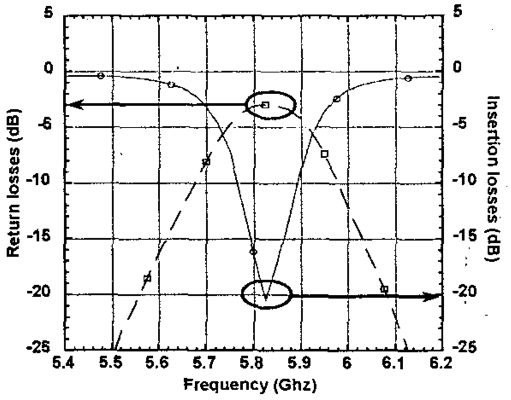

Fig. 2. Performances of the band-pass filter.

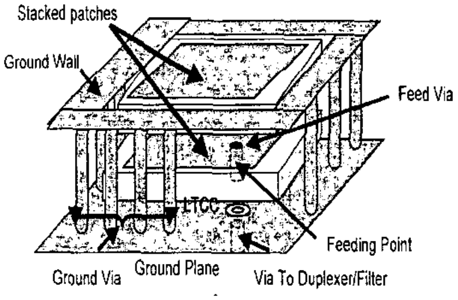

Fig. 3. Stacked patch antenna.

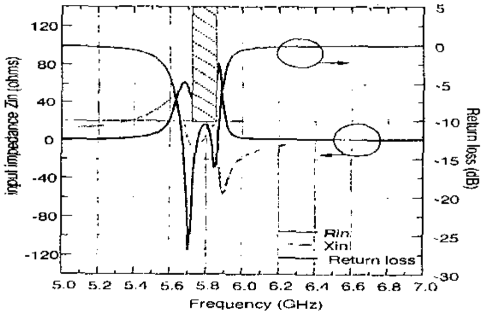

Fig. 4. Input impedance characteristic of the stacked patch antenna.

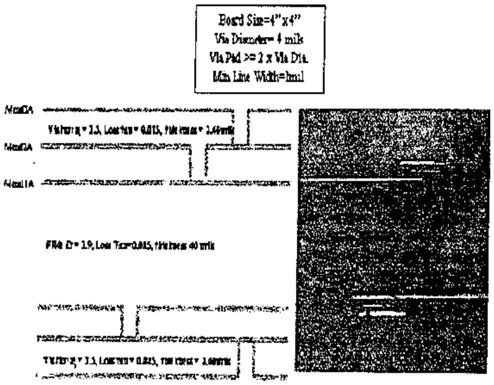

Fig. 5. Cross view of multiplayer organic based package.

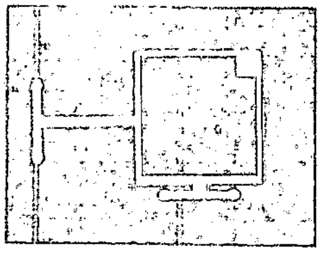

Fig. 6. Photo of band-pass filter for 5.8 GHz and measurement results.

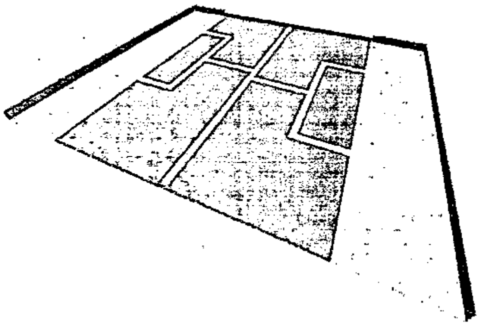

Fig.7 MEMS 2bitx2bit tuner

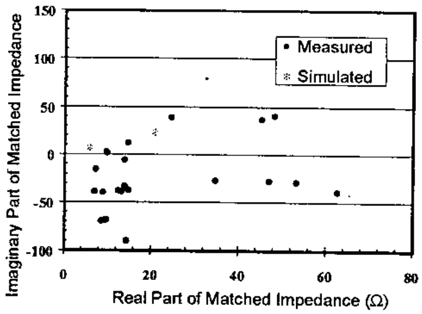

Fig. 8 Plot of measured and simulated matched impedances20GHz

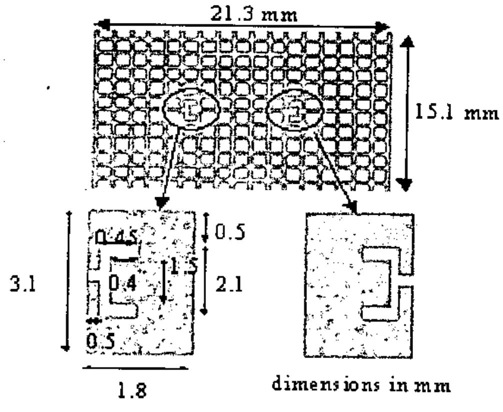

Fig. 9 Two pole filter with periodic structure

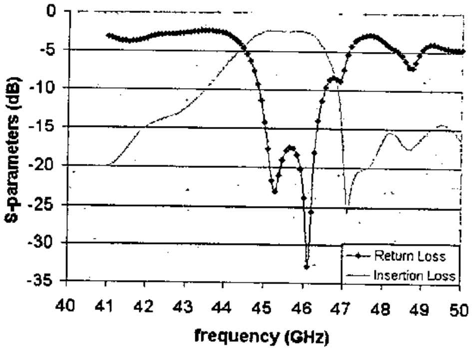

Fig. 10 Simulated performance of micromachined filter