Design Considerations for Single Package Radio™ (SPR) Solution for EGSM/DCS Dual Band Cellular Phones

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Abstract – **Fully integrated front end radio on SPR, that provides hybrid SOC and SIP solution, is presented. The SPR includes DCR transceiver, PA, directional coupler detector and FEM implemented on different die technologies plus discrete SAW, LPF, and diplexer in addition to embedded and discrete SMT components . The module is implemented on low cost 4-layers MCM laminate substrate and its size equals to 13x13x1.8 mm. The area saving on PCB phone boards by using the SPR is about ¼ the discrete solution implementation. Results show that the complete radio integration can be successfully integrated on SPR.**

I. INTRODUCTION

Recent advances in integration technology and device performance paved the way for higher level of System integration On Chip (SOC) or In Package (SIP). Complete front end radio for cellular systems includes several blocks, RFIC transceiver, Power Amplifier (PA), and Front End Module (FEM) blocks in addition to control circuitry and matching components. The electrical specifications for each block dictate the technology of choice to achieve the stringent system performance requirements. In present state of the art systems, Si CMOS, Si or SiGe BiCMOS, GaAs HBT, and GaAs PHEMT are used for IC implementation, while ceramic, LTCC and laminate substrates are employed for passive components and circuits plus packaging, in addition to Surface Acoustic Wave (SAW) technology necessary for filtering. So hybrid solution that blends SOC and SIP might be the only viable approach, at the present time, to achieve the desired level of integration for complete front end radio in a Single Package Radio (SPR). This SPR solution is capable of mixing and matching the different technologies based on lowest cost, smallest size, and lowest power consumption assuming the system specification is satisfied by default.

In this paper, SPR module implementation that realizes all the RF functions, from antenna to baseband analog I/Q interface, in a 13x13x1.8 mm laminate package is presented. The module is used for dual-band EGSM/DCS-based systems. SPR integrates power amplifier (PA), Direct Conversion Receiver (DCR) -based RF transceiver, directional detector, two RF SAW filters and all the discrete components for the T/R switch function that include 2 low-pass filters, 2 RF switches, one diplexer. The module supports GPRS operation. It is EDGE downlink compatible with universal analog baseband interface that is compatible with any GSM baseband solution. SPR enables low external component-count radio, just few power supply decoupling capacitors needed externally. Separate enable lines for transmit, receive, and synthesizer sections are used for power management

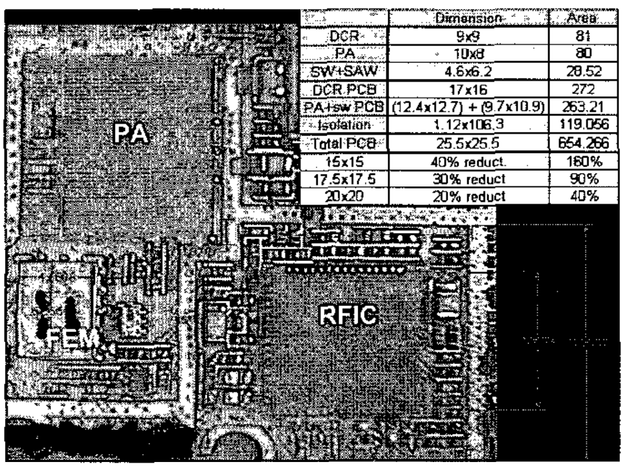
II. SPR BLOCK DIAGRAM

The SPR module is comprised of a receive path and a transmit path. The receive path consists of a diplexer which realizes a low-pass filter in the EGSM band and a high-pass filter in the DCS band, two transmit/receive (T/R) switches and SAW filters, one for each band, and the receive section of the RF transceiver which contains for each band an integrated LNA, a quadrature demodulator section performing direct down conversion, and baseband amplifier / filter circuitry with I and Q outputs and three stages of DC offset correction. On the transmit path, the module is comprised of the same diplexer and T/R switches as in the receive path, two low-pass filters, one per band, for harmonic suppression, a dual-band directional detector for the Power Amplifier Control (PAC) loop, a dual-band PA and the transmit section of the RF transceiver which consists of a vector modulator within a translation loop, or offset PLL, architecture with integrated high-power transmit oscillators for frequency up-conversion. The fully integrated synthesizer is driven by the integrated reference crystal oscillator circuitry that uses an external crystal resonator. Band selection is performed externally through the bi-directional input. Each section of the module is separately enabled via the enable signals of the transmit, receive and synthesizer sections. To control different modes of operation, 24-bit word register is programmed using the three wire input signals.

III. SPR DESIGN CONSIDERATIONS

The discrete solution for the SPR consists of 2 layers laminate LGA 9x9x1 mm DCR Transceiver including Si RF BiCMOS, laminate MCM dual band PA including GaAs HBT and CMOS controller plus matching components, Antenna/Switch (Ant/Sw) LTCC module including 2 SPDT GaAs PHEMT RF switch and CMOS decoder, 2 LPF and 1 diplexer, SC88 plastic package Directional detector coupler including GaAs HBT die, and 2 SAW filters one for each band, in addition to the discrete components required for matching, loop filter, etc. This implementation occupies more than 650 mm^2 on the phone PCB board. The size of the integrated SPR module targets about 1/3 to ¼ of the discrete solution. Example of fr nd radio PCB discrete solution implementation is shown in Fig. 2.

Several considerations should be taken into account to minimize the risk associated with the design and implementation of the SPR. The design should be transferable from discrete to integrated solution to minimize development and debugging time.



	Dimension	Area
DCR	9x9	81
PA	10x8	80
SW+SAW	4.6x6.2	28.52
DCR PCB	17x16	272
PA+sw PCB	(12.4x12.7) + (9.7x10.9)	263.21
Isolation	1.12x106.3	119.056
Total PCB	25.5x25.5	654.266
15x15	40% reduct.	160%
17.5x17.5	30% reduct	90%
20x20	20% reduct	40%

Fig.2 SPR discrete implementation on PCB board

Multilayer laminate substrate has been chosen due the availability of the infrastructure within Skyworks and maturity of the technology. PA and DCR transceiver, which are considered as the most critical subblocks, have been already implemented on laminate-based packages. The LTCC Ant/Sw could not be used, since the form factor of the module, with height greater than 1.1 mm, could not be integrated within the SPR module with total target height of 1.8 mm. All the FEM discrete components will be directly mounted on the module. Although, embedded components can be used, discrete implementation was preferred to decrease the development cycle. Another consideration is the Surface Mount Component (SMT) number and size. All the 0805 components with height of 1.35 mm can not be used on the SPR module. All these components, used mainly in the transceiver loop filter and by-pass CAP for the front end radio discrete implementation should be replaced with smaller from factor components. Finally, SPR implementation faces many challenges in electrical, thermal and mechanical design which are critical for the success of the design of the SPR module. Coupling, crosstalk, radiation, conflict requirements for insertion loss in both Rx and Tx, return loss and matching among the subblocks, ground splits strategy among RF, analog, and digital circuits to avoid ground bounces and coupling enhancement, and critical placement of shielding structures to avoid isolation degradation are some of the many electrical challenges facing SPR solution design. In addition, special considerations should be taken into account, in the mechanical design of the bottom side of the module, to improve the solder joint reliability of the large land grid array type MCM and to avoid die cracking for the large numbers of dice attached at the substrate surface. SMT components placement and pad design should be carefully optimized to avoid the creation of voids within the module after the overmolding process. Finally, thermal effects due to the coexisting of the high power PA with its thermal radiation with the rest of the blocks, especially SAW filters, could lead to severe degradation in the module electrical performance and reliability.

Two factors are critical for the implementation of the SPR module, coupling between different components and 50 ohm on long interconnects and between matching sensitive components, especially in the FEM. The isolation between different dice in the SPR and between the package substrate interconnects is crucial to avoid spurious signal coupling. Fig. 3 depicts die-to-die isolation as function of distance in the presence and in the absence of the shields, calculated using HFSS electromagnetic simulation. The isolation enhances with the VIAS shield at small distances by about 6 dB.

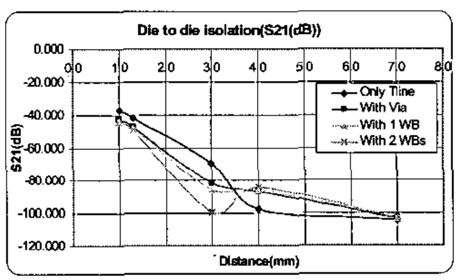


Fig.3 Die-to-Die coupling with and without isolation.

Due to the complexity of the SPR design and to minimize the need for matching components, special attention for the 50 ohm lines should be considered. Fig. 5 a,b, and c show the different option for 50 ohm line in microstrip, backed ground coplanar, and adjacent lines configuration, respectively. Two different line width/line spacing options are used on each layer to facilitate the routing and to address the different requirements for each functional subblock.

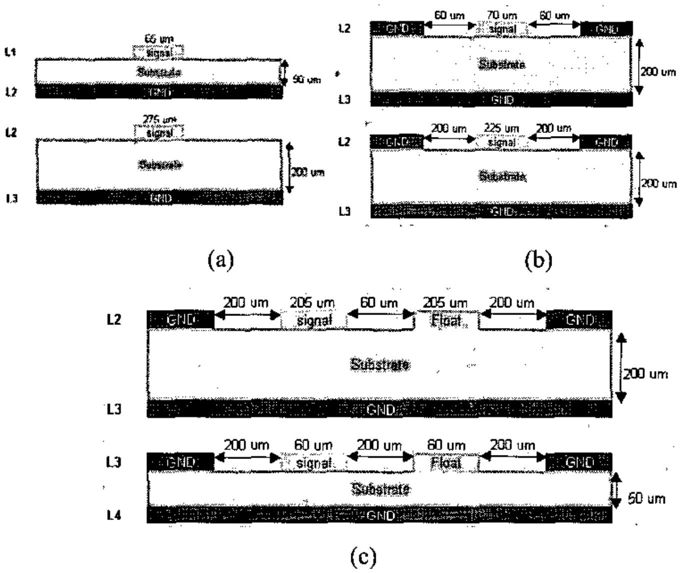


Fig.5 50 ohm lines used in the SPR on laminate substrate.

IV. SPR FLOOR PLANNING AND LAYOUT

The SPR consists of several subblocks with competing requirements. Its overall size was a direct result of the components used in the design, as shown in Fig. 8. The size of the MCM, 13x13 mm, was mostly influenced by the size of the DCR transceiver, PA and FEM. The MCM thickness, 1.8 mm, is determined by the height of the diplexer and the two LPF's (1.1 mm).

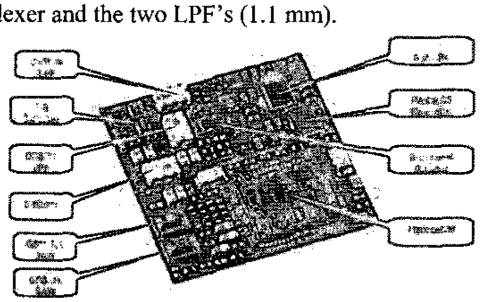


Fig.8 SPR components location and floor planning

The PA and SAW was placed in opposite locations to minimize the thermal radiation effect on the SAW performance, as previously explained. The PA and DCR transceiver are placed side by side. Hence, the integrated SPR MCM is divided into two sections, the left hand side is the transmit chain, while the right hand side is the receive chain. These two regions are separated by shielding structures to improve the isolation within the module. Also, the bottom center ground plane is optimized to avoid noise coupling between the Tx chain and the sensitive Rx chain.

V. MEASURED AND SIMULATED RESULTS

The SPR and 4 different partitions representing the transceiver, PA, Coupler detector and FEM are fabricated and assembled. The DCR transceiver, the directional detector, and the PA are tested and found performing in the SPR MCM similar to their discrete implementation. First, the results for the FEM, GSM only as example, will be presented. The FEM consist of the 2 LPF, 2 RF switches, 2 SAW filters and diplexer. Fig, 10 and 11 show comparison between the measured and simulation data of the insertion and return loss of the RX and Tx path of the FEM, respectively. Note that the evaluation board loss is not deembedded from the results and equals to 0.3 dB and 0.6 dB for the Rx and Tx path, respectively. The insertion loss for the Rx and Tx path is 2.3 dB and 1.0 dB, respectively. The measured gain, noise figure, and sensitivity for the SPR EGSM Rx chain at 942 GHz is 88.1 dB, 5.8 dB, and -109.2 dBm, respectively. Note that the sensitivity is calculated based on 6 dB baseband SNR. The measured output power for the EGSM Tx chain at 902.4 MHz equals to 33.2 dBm and is shown in Fig. 12. The measured attenuation characteristics between the Tx GSM and Rx DCS is shown in Fig. 13. The attenuation level at the second harmonic frequency of the GSM Tx which overlaps the DCS Rx band is greater than 35 dB. These results are presented as an example for the performance achieved with the SPR implementation. Detailed performance analysis is presented in [3].

VI. CONCLUSION

Fully integrated front end radio on SPR, that provides hybrid SOC and SIP solution, is presented. The SPR includes DCR transceiver, PA and FEM implemented on different die technologies. The module is implemented on low cost 4-layers MCM laminate substrate and its size equals to 13x13x1.8 mm. Results show that careful planning and rigorous analysis can lead to first time success for SPR implementation.

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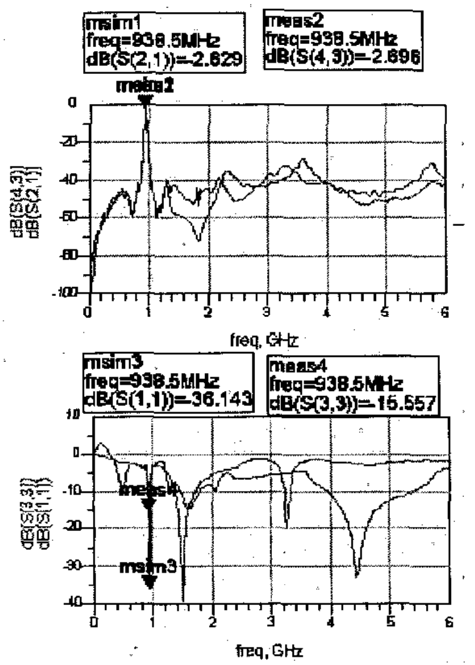

Fig.10 Comparison between measured and simulated insertion and return loss for FEM Rx path (evaluation board loss not deembedded and equals to 0.3 dB)

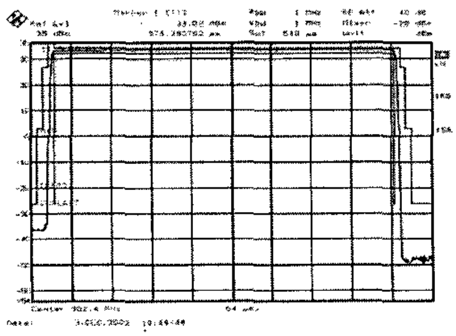

Fig.12 Measured Tx chain output power for at 902.4 MHz

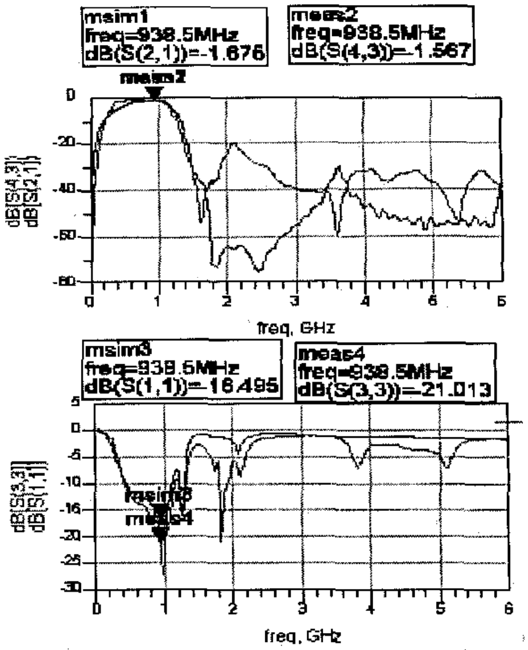

Fig.11 Comparison between measured and simulated insertion and return loss for FEM Tx path (evaluation board loss is not deembedded and equals to 0.6 dB)

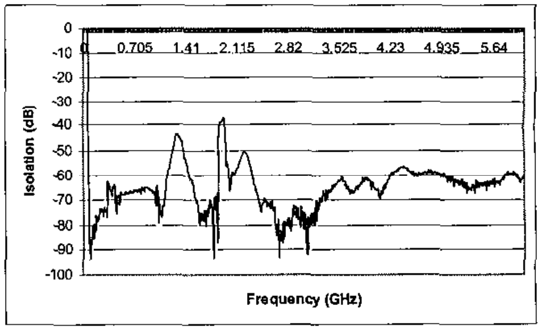

Fig.13 Measured isolation characteristics between EGSM Tx and DCS Rx

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