DESIGN OF AN LTCC SWITCH DIPLEXER FRONT-END MODULE FOR GSM/DCS/PCS APPLICATIONS

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***Abstract*—This paper presents the results of an antenna switch/filter module integrating GSM/DCS/PCS diplexer functions and Rx/Tx antenna switching on a low temperature co-fired ceramic (LTCC) substrate. Although the RF front-end module (FEM) was configured for dual band (GSM/DCS) applications, the high pass filter function was designed to operate in the PCS band as well. Harmonic filtering was included in the diplexer design, which reduced the filtering requirements for the power amplifier. The 50-ohm in/out FEM utilized GaAs PHEMT switches and associated bias passives surface mounted on the LTCC substrate. S-parameter characterization of the FEM demonstrated excellent insertion and return loss characteristics. For GSM, the return and insertion losses measured at 912 MHz were better than 28 dB and less than 1.7 dB, respectively. Similarly, for DCS applications, the return and insertion losses at 1.77 GHz were better than 19 dB and less than 1.5 dB, respectively. In both cases, the design approach yielded excellent agreement between measured and simulated results.**

I. INTRODUCTION

There is an interest in developing miniature microwave frequency FEMs for use in handset transmit and receive applications. In these applications, the FEM must possess narrow pass-bands and have sharp signal rejection out of band. In addition, the FEM must have low insertion loss and reasonable return loss in order to be used with commercially available P.A. modules. These diplexers must be of compact size in order to be compatible with broadband monolithic circuitry presently used in transmit/receive modules.

In most radio applications, in order to meet size requirements, a large part of the radio circuit is usually integrated in Si or GaAs technology. The switches and filter functions form an exception however, due to the power levels involved and the requirement for low signal losses [1]. The losses in transmit and receive chains directly influence the power consumption and receiver sensitivity [1]. Miniaturization of those functions requires a substrate technology such as LTCC for integration of accurate, high quality, passive components. Attributes of LTCC, which enhanced integration, included a low loss dielectric and a relative dielectric constant of 9.1, which enabled low loss stripline designs and geometries realizable with standard screen-printing techniques. Also, the use of thick-film silver metalization enabled lower conductor loss than circuits on Si, or GaAs, which utilize thin film metal systems. The loss tangent (on the order of 0.001 at 10 GHz) of the material used in this work was lower than other substrates readily used for MMIC and MIC circuits [2]. Furthermore, the ability to design circuits in a stripline environment minimized radiation and the ability to integrate vertically reduced size. LTCC fabrication advantages included the mitigation of design risk via multiple prototype builds of increased complexity. This was possible through the quick prototype cycle time (typically one week) available in-house. Also, screens used to define geometries were obtained at a fraction of the cost of expensive photo masks used in thin film processing enabling the investigation of multiple design options.

This paper describes the design approach, which was used to realize the LTCC FEM, and includes a summary of results for two different prototypes designed and fabricated. The first prototype investigated basic filter functions. The second added complexity and increased the level of integration. Both prototypes included the same Diplexer initially designed using lumped elements with *Agilent Technologies Advanced Design System (ADS)*. Passive elements from the lumped element model were then designed in LTCC and optimized using *Sonnet Software's* EM solver.

II. PROTOTYPE OVERVIEW

A block diagram of the basic RF functions contained in both prototypes is shown in Figure 1. All elements of the diplexer and low-pass filter functions were realized in the LTCC substrate, as well as the control lines for the GaAs PHEMT switches. GaAs switches were selected instead of PIN diodes because of their low current, single supply, and low control voltage characteristics. Also, no additional passive components were required to resonate device parasitics when using these switches as frequently needed when using PIN diodes. Switches were selected to provide at least 20 dB isolation between Tx and Rx paths at the expense of slightly higher insertion loss.

The diplexer was realized using low-pass and high-pass filters, each with 50-ohm characteristic impedance at the input and output terminals. Figure 2 shows the lumped element model for the diplexer.

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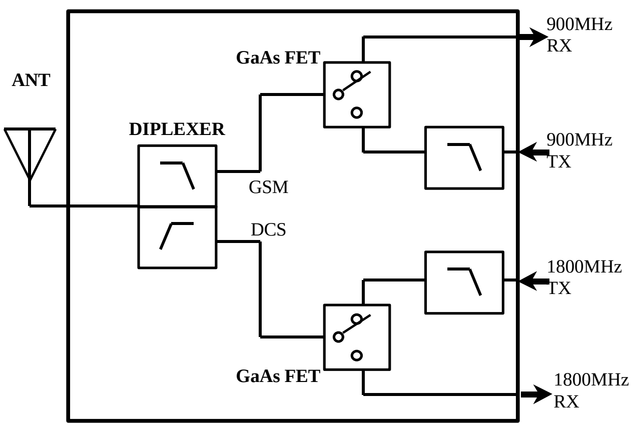

Figure 1: Block diagram of the antenna switch/filter Front-End Module for Prototype I.

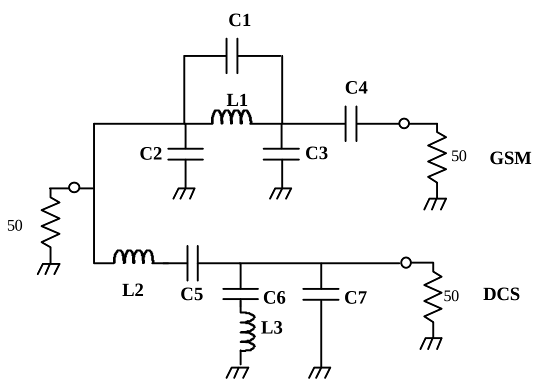

Figure 2: Diplexer circuit schematic used in Prototype I and Prototype II.

The GSM portion of the diplexer shown in Figure 2 was designed to produce a parallel resonance at 1.8 GHz by selection of L1 and C1. Said resonance provided greater than 30 dB of attenuation for the second harmonic. The resonant frequency is given by:

$$\omega_{\circ GSM} = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{1.07\times10^{-12}\times7.348\times10^{-9}}}$$

$$\omega_{\circ GSM} = 1.79GHz$$

The DCS portion of the Diplexer was realized using elements L2 and C5 which were designed to produce a series resonance in the center of the passband at 1747 MHz. Elements L3 and C6 were designed to produce a series resonance at GSM frequencies and yielded greater than 26 dB signal rejection at 900 MHz.

III. Modeling Approach

Since there exists very little room to tune circuits fabricated on LTCC substrates, modeling must be rigorous in order to obtain first pass design success. The basic modeling approach used in this work is outlined in Figure 3.

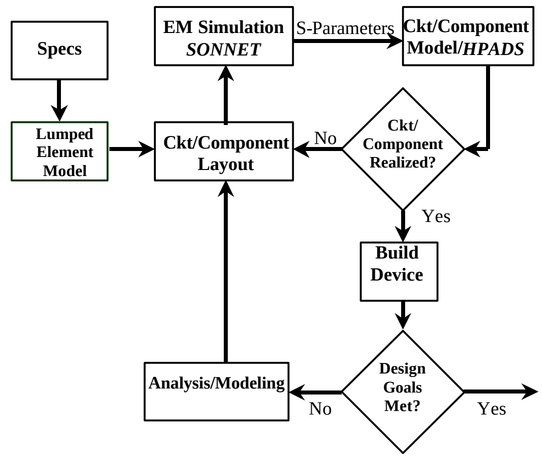

Figure 3: Modeling flow for LTCC design.

Initially, a lumped element equivalent circuit was used to obtain the response required by the system specification. Then, filter elements obtained from the equivalent circuit were realized in LTCC using basic parallel plate capacitance estimates corrected for fringing and inductance curves developed in-house. Individual components were then simulated using Sonnet software's EM solver and the s-parameters generated from these computations were then used in ADS to simulate the circuit response. Each component's layout in Sonnet was then independently modified if needed and re-simulated. After a few iterations, the desired response was obtained. The final step was to simulate the entire circuit in Sonnet to check for possible coupling between the integrated components. If coupling had an adverse effect on the response, the physical separation between components was increased or a ground wall was inserted between them.

IV. FEM Prototype I Results

Figure 1 shows the block diagram for the first prototype. This design focused on the diplexer and included GaAs FET switches mounted in a cavity. The DC blocking capacitors required by the GaAs FET switches were mounted on the test board. Figure 4 and Figure 5 plot measured and simulated insertion loss characteristics for the GSM and DCS cases, respectively. As can been seen by the data shown in Figure 4 and Figure 5, excellent agreement between measured and simulated results were obtained. Table 1 summarized the insertion loss, return loss, and harmonic attenuation obtained for the first prototype.

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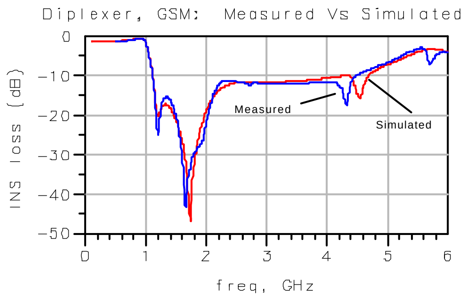

Figure 4: Simulated & measured insertion loss for GSM Prototype I.

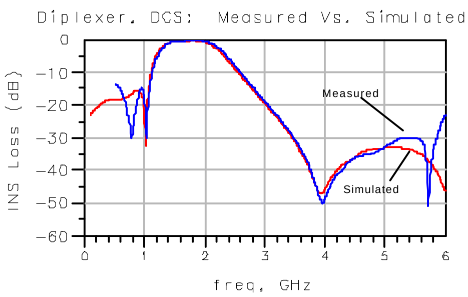

Figure 5: Simulated & measured insertion loss for DCS prototype I

	Freq . MHz	Insertion Loss	Return Loss	Attenuation 2Tx	Attenuation 3Tx
GSM	920	0.5 dB	26.7 dB	26.7 dB	11.8 dB
DCS	1770	0.9 dB	27.9 dB	28.5 dB	27.3 dB

Table 1: Prototype I insertion loss and harmonic attenuation summary.

In order to simulate a mismatch case at the antenna port, which can happen if the antenna is disturbed during handset operation, a 6:1 VSWR, at all phase angles, was presented to the module and the corresponding isolation measured between DCS and GSM portions of the design. Table 2 summarizes these load pull results.

	Freq. MHz	Antenna Matched	Antenna Mismatch
GSM			
	920	17.7 dB	15.4 dB
	2Tx	26.4 dB	26.3 dB
	3Tx	22.1 dB	22.1 dB
DCS	1770	34.3 dB	32.4 dB
	2Tx	27.2 dB	27.3 dB
	3Tx	37.0 dB	33.4 dB

Table 2: Prototype I isolation data summary

The data shown in Table 2 indicates that adequate isolation was obtained independent of antenna load. Excellent R.F. performance was obtained from the first prototype. Less than 1 dB insertion loss and better than 20 dB return loss was obtained for both bands. No tuning or board level components were required in order to achieve these results.

V. FEM PROTOTYPE II RESULTS

The second prototype increased the complexity of the design by adding bi-directional 20 dB couplers to monitor the RF energy at the Tx port of the module. Also, blocking capacitors mounted to the PC test board in prototype I were surface mounted on top of the second prototype. A block diagram for the second prototype is given in Figure 6.

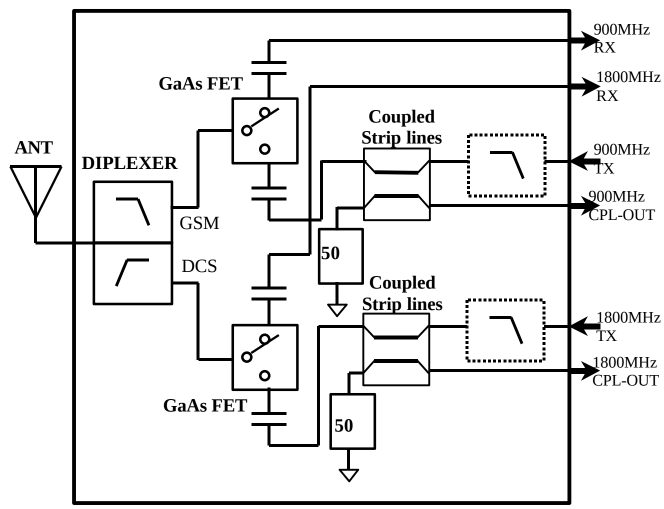

Figure 6. Block diagram of the second prototype.

The broadside couplers were designed in a strip-line configuration with L=210mils (5.33mm) and θ_e=17.38° and L=188mils (4.77mm) and θ_e=31.1° for GSM and DCS bands, respectively. Measured and simulated results for the GSM coupler are shown in Figure 7, similar results were obtained for the DCS band.

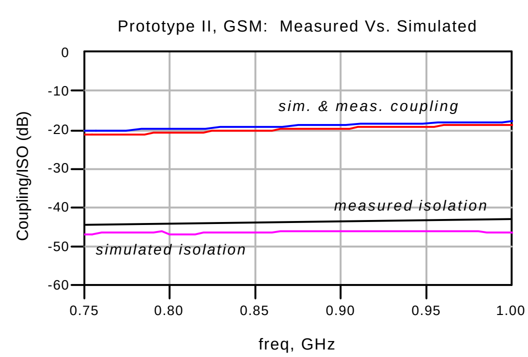

Figure 7: Measured and simulated GSM coupler performance.

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Hence, better than 20 dB Directivity was obtained for this prototype. The slight discrepancy between the measured and simulated isolation was due to the variation in the non-precision surface mount resistor used to terminate the unused port of the coupler. Figure 8 is a photograph of the second FEM prototype taken on an in-house designed PC Board. Again, measured and simulated results were in good agreement as shown in Figures 9 and 10.

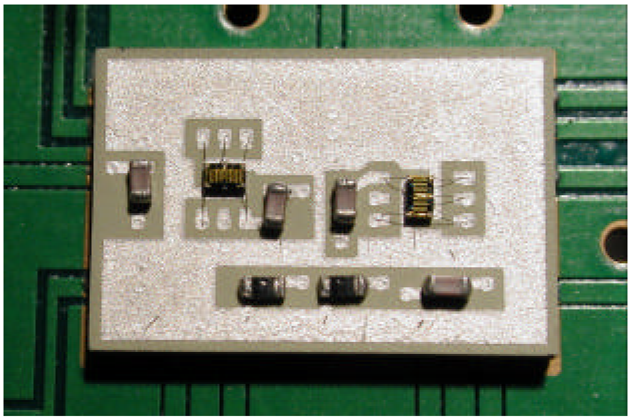

Figure 8: Top view of the second prototype.

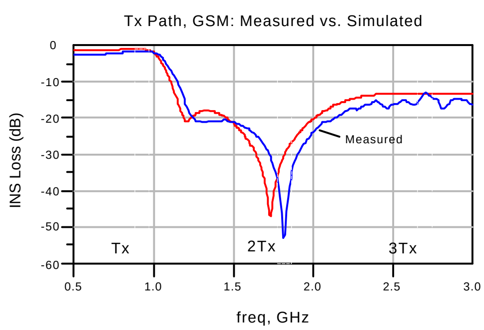

Figure 9: Meas. & simulated insertion loss -GSM Prototype II.

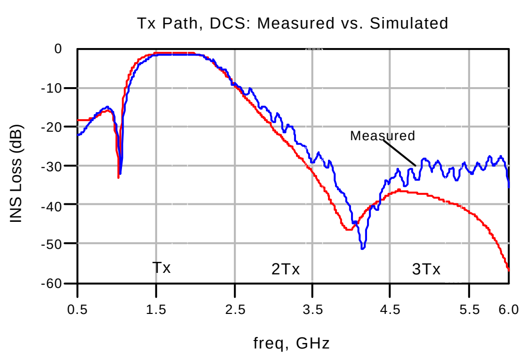

Figure 10: Meas. & simulated insertion loss –DCS Prototype II.

Figure 11 and Figure 12 summarizes typical measured results for the second prototype. Insertion loss and isolation trade-offs could be made by the type of GaAs FET switch used in the design.

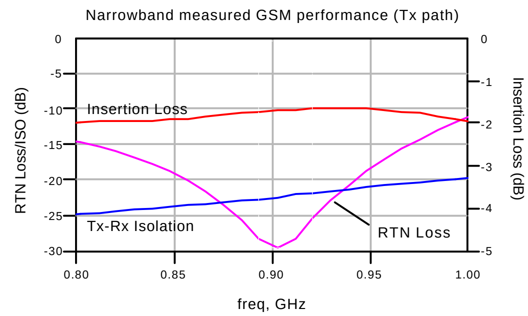

Figure 11: Measured results for the GSM band of Prototype II.

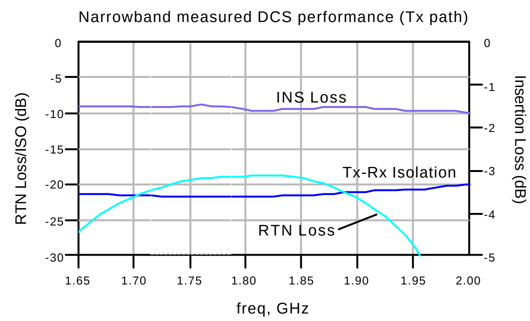

Figure 12: Measured results for the DCS band of Prototype II.

VI. Summary

Switch/diplexer front-end modules for GSM and DCS/PCS bands were designed and fabricated on LTCC substrates. Excellent performance was obtained for both prototypes reviewed in this work. Diplexer design reduced the filtering requirements for the P.A. output while maintaining low insertion loss characteristics in the pass band. The modeling approach used yielded first pass design success in both cases and excellent prediction of the measured performance was obtained.

VII. References

[1] A. De Graauw, “A new Thin Film Passive Integration Technology for Miniaturization of Mobile Phone Front-End Modules”, *IEEE MTT-S Digest*, pp.1925-28, 2000.
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