A Highly Integrated Transceiver Module for 5.8 GHz OFDM Communication System using Multi-layer Packaging Technology

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***ABSTRACT* — A highly integrated transceiver module for 5.8 GHz OFDM communication system is presented. The antenna and filter are directly fabricated on the module using multi-layer packaging technology in order to reduce size and interconnection losses. A cavity backed patch antenna with a vertical feed and an embedded 3-D filter have been designed and integrated on the package using a low-temperature co-fired ceramic (LTCC) process. RF functional blocks including PA, LNA, Mixers and VCO are developed using GaAs-based MMICs and are attached on the surface of the LTCC board. RF blocks are vertically stacked and connected through via structures. The specifications of the functional blocks have been determined and verified through system simulations based on the IEEE 802.11a standard. The total size of the module is 14 X 19 X 2 mm^3. Measurement and simulation results of the components and the module are also presented.**

I. Introduction

Wireless data communication standards in the 5-6 GHz frequency band has attracted a great deal of attention as they provide higher data rates in the unlicensed ISM band. Orthogonal frequency division multiplexing (OFDM) has been selected for both IEEE 802.11a and HIPERLAN/2 standards, due to its robustness over the multi-path fading channel environment [1]. Hence, the next generation of wireless communication products will demand a compact and cost effective OFDM solution. The integration of the antenna and the RF front end in a compact module is quite attractive and challenging. Several works on modules in which the antenna has been integrated have been presented for mm-wave wireless applications [2], [3]. These techniques are difficult to adopt in C-band, due to the larger relative size of the antenna at the frequency of interest.

Low temperature co-fired ceramic (LTCC) is quite attractive for RF applications since low loss transmission line and high Q passives can be realized [4]. Recent studies on the suitability of LTCC for development of passives, filters, baluns and modules have been presented [5]-[10]. Due to the high dielectric constant of the substrate, the bandwidth of an antenna fabricated in LTCC is very narrow and its efficiency is low [11]. In spite of such limitations, integrating an antenna in a LTCC module is still an attractive solution to realizing a complete system-on-a-package (SOP) module.

In this paper, a system-on-a-package (SOP) solution to the RF module for OFDM is presented. In order to reduce the size and interconnection loss of the module, the antenna and filter have been fabricated directly on the package and integrated with MMIC components. The specifications for RF components have been determined by system simulations. A cavity-backed patch antenna (CBPA) has been developed and fabricated on the top of the module and a band-pass filter is embedded inside the package. RF building blocks consisting of power amplifier (PA), low noise amplifier (LNA), mixers and voltage controlled oscillator (VCO) are developed using GaAs MESFET and HBT processes and attached on the bottom side of the module. Antenna, filter and RF blocks are connected using via structures. Performance of the receiver and transmitter are measured and the results are presented.

II. OFDM System Configuration

The block diagram of the OFDM transceiver is shown in Fig. 1. System simulations including IF and baseband blocks have been performed to determine and verify the specification of RF components. A super heterodyne architecture has been chosen for the transceiver module. The module consists of up and down converting mixers, VCO, PA, LNA, band select filter, antenna and a switch for the time division duplex (TDD) mode of operation. To make the module compact, we shared the VCO and band select filter between the transmitter and receiver.

The baseband signal processing consists of a bit generator, quadrature amplitude modulator (QAM), symbol mapper, inverse fast fourier transform (IFFT) and guard insertion blocks. Bits generated from the random bit generator are mapped using 4-QAM that maps the input bits to a four-symbol constellation. These symbols are then fed to the serial to parallel converter and subsequently to the IFFT block. Following the IFFT, a guard interval is added between successive OFDM symbols to protect the transmitted data against time dispersion and multi-path

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characteristics of the channel. An uncoded data rate of 67 Mbps was used as the input to the 4-QAM block. The number of carriers and IFFT points were chosen to be 48 and 64 respectively. An IF frequency of 1 GHz has been assumed and the IF bandpass signal has been realized by the I-Q modulator block in HP-ADS.

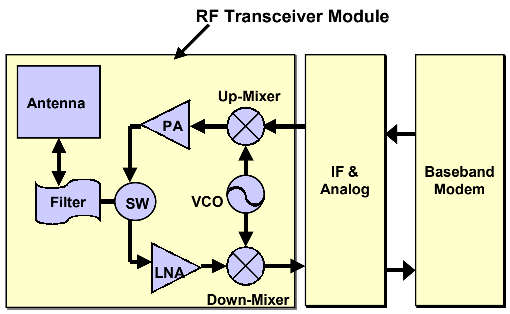

Fig. 1. OFDM system configuration

III. PACKAGE MODULE DESIGN

A. LTCC Layout Design

The structure of the packaging module is shown in Fig. 2. The module has been designed based on 20 layers of Dupont 951 tape (dielectric constant is 7.8 and loss tangent is 0.0026). The thickness of each layer is 3.6 mil and the via diameter is 5.2 mil.

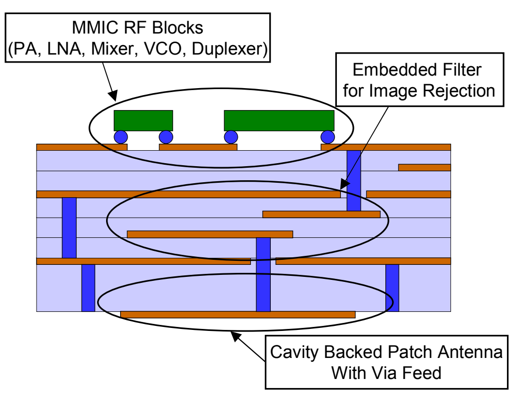

Fig. 2. Integrated RF module including antenna, filter and RF transceiver block.

Before designing the package, the layers are properly assigned, the antenna, filter and transceiver utilize 8, 10 and 2 layers respectively. The total size of the module is 14 X 19 X 2 mm^3 including all the RF blocks. The grounds are connected efficiently to suppress the unwanted parasitic modes.

B. Antenna on a Package

A CBPA has been designed based on LTCC design rules and is shown in Fig. 3. The antenna has advantages over the conventional patch in terms of larger bandwidth, smaller size and less interference with other components [12]. The cavity structure has been constructed by surrounding the ground plane of the antenna with rows of vias. The patch is made on the top surface and is connected with the embedded filter through a via. The location of the via feed on the patch radiator has been optimized to get impedance matching between the antenna and the filter. The gap between the edge of the patch and the cavity wall is determined carefully, since it affects the bandwidth and radiation efficiency of the antenna.

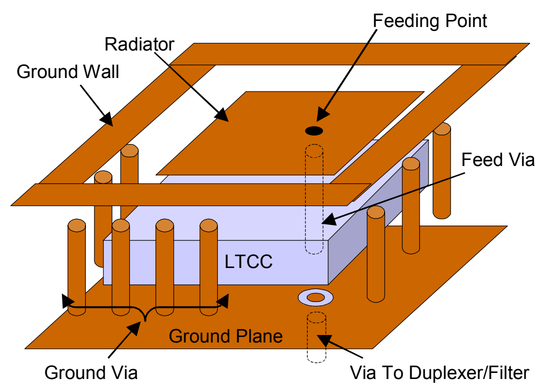

Fig. 3. Cavity-backed patch antenna on LTCC.

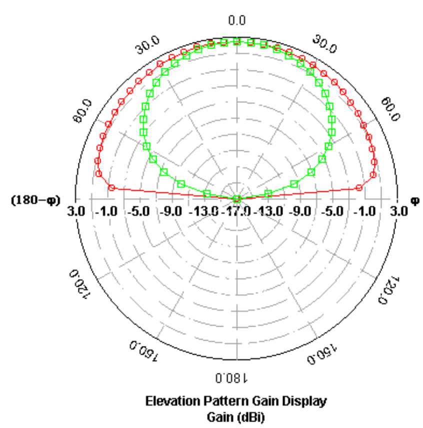

Fig. 4. Radiation pattern of the cavity-backed patch antenna

The CBPA was designed using the method of moment software, IE3D [12]. Fig. 4 shows the simulated radiation pattern of the CBPA. The radiation efficiency and the bandwidth of the antenna are 48 % and 1.2 %, respectively.

C. Embedded Filter

An embedded coupled stripline filter has been developed for the module. The configuration of the filter is shown in Fig. 5. Stripline has been used for the embedded structure to improve insertion loss. The input and output ports are connected to the antenna and the duplexer switch through vias. The two ground planes for the filter are connected to each other using multiple vias to eliminate the parallel plate modes. Fig. 6 shows the measured performance of the embedded filter. It shows -3.5 dB insertion loss and -20 dB image rejection.

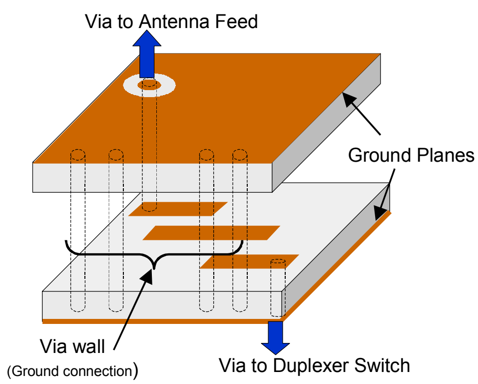

Fig.5 Configuration of embedded coupled stripline filter

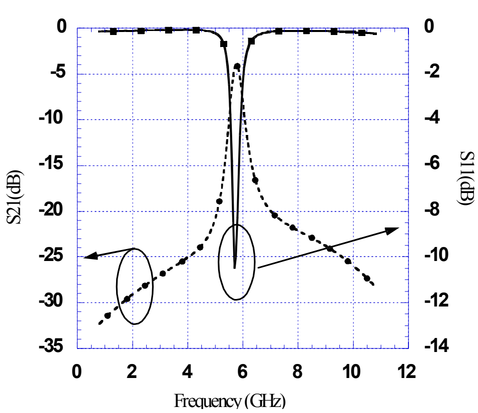

Fig.6 Measured performance of the filter

IV. MMIC AND MODULE DEVELOPMENT

The chipset for OFDM was developed with the help of two different foundries, RFMD GaAs HBT and TriQuint GaAs MESFET processes. A 3-stage class-A type PA and Gilbert-cell type active mixer are developed using HBT. Simulated performance of the PA is shown in Fig. 7. Gain, and output power of the PA are 21 dB and 29dBm respectively. Fig.8 shows the simulated performance of the mixer. Conversion gain, noise figure and IIP3 of the mixer are 2 dB, 15.5 and 9 dBm, respectively. The VCO and the LNA have been designed in the MESFET process. The simulated performance of the VCO is shown in Fig. 9. Tuning range is from 4.6 to 5 GHz (400 MHz) and output power is 7.5dBm. The noise figure of the LNA is 2.1 and its gain is 13 dB [13]. To verify the performance of the packaging module, commercially available GaAs MMIC components have been used.

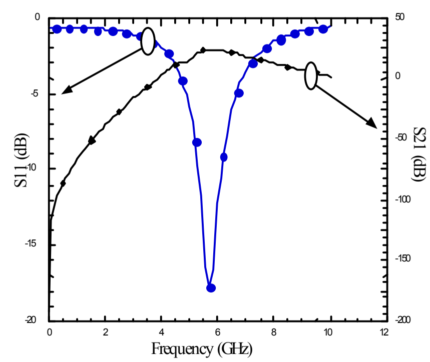

Fig. 7 Characteristics of the HBT power amplifier

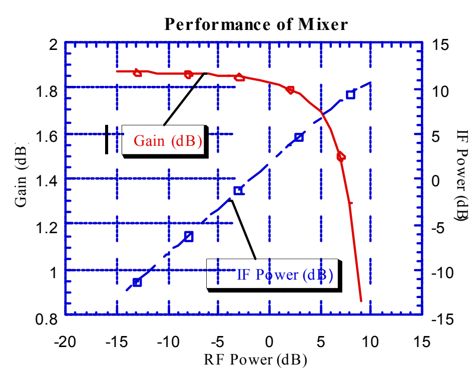

Fig. 8 Harmonic performance of HBT mixers

For verification, the receiver and transmitter including the embedded filter have been fabricated using National Semiconductor LTCC foundry as shown in Fig. 10.

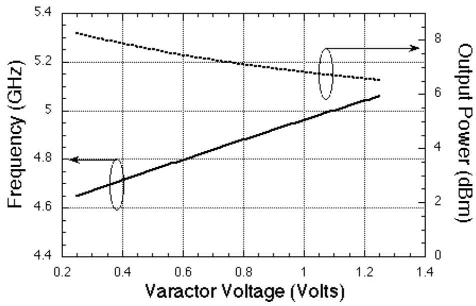

Fig. 9 Output frequency versus control voltage of VCO

RF and DC probe pads have been created on the surface of the ceramic package using wire bondable gold metallization. Since the filter is embedded, and the chips are being wire-bonded to the surface of the package, the interconnection between the chips and filter has been accomplished by connecting the signal line from the filter using a via, to the surface of the package. The stripline topology used for the filter placed one of its ground planes on the top of the package. These are also wire-bonded to the chips on either side of the signal bond. The mixer is then directly bonded to the PA/LNA with its LO and IF ports being bonded to RF pads on the package. The on-wafer measurements are on going for the transmitter and receiver. The complete module, which includes antenna and filter, has been designed and is being fabricated.

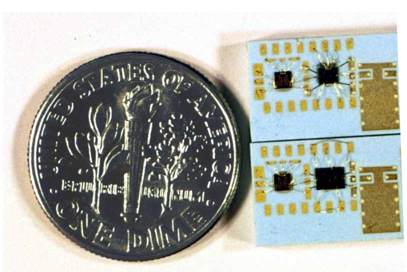

Fig.10 First prototype of transmitter and receiver modules

V. CONCLUSION

SOP solution for OFDM module using LTCC has been presented. To reduce the size of the module and transmission loss, antenna, filter and RF components have been integrated vertically. The specification of each component has been determined and verified using system simulations. A novel CBPA and embedded filter have been developed for the module. In addition, MMIC components have been developed using GaAs processes. Future works include development of wider bandwidth antennas on high dielectric constant substrates and analysis of coupling between RF blocks on the same package.

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