Development of Highly Integrated 3D Microwave - Millimeter Wave Radio Front-End System-on-Package (SOP)

M.Tentzeris, J.Laskar, A.Sutono, C.–H. Lee, M.F. Davis, A.Obatoyinbo, K. Lim

Packaging Research Center, School of ECE, Georgia Institute of Technology
Yamacraw Design Center, Atlanta, GA 30332, U.S.A.;

Abstract **— We present the development, implementation and measurement of a 3D-deployed RF front-end System-on-Package (SOP) topology in a standard low-loss multi-layer ceramic (LTCC) technology. A compact 14 GHz GaAs MESFET-based satellite transmitter integrated with a low-loss embedded filter for outdoor units were built on a 400 × 310 × 35.2 mil^3 943AT tapes. The LTCC stripline filter exhibits a measured maximum insertion loss of 1.8 dB while the entire transmitter chain yields a 32-34 dB of gain in the 13.5 to 14.5 GHz range. These results suggest the feasibility of building highly SOP integrated microwave and millimeter wave radio front ends. In addition, a highly integrated transceiver module for OFDM Communication System using Multilayer Packaging technology as well as Multilayer Integrated Passives using Fully Organic SOP technology demonstrate the capabilities of SOP for other applications such as the OFDM Wireless LAN and LMDS.**

I. INTRODUCTION

The current drawbacks of most commercially available microwave and millimeter wave front-ends, such as the Ku-band satellite transceivers for outdoor units, are their relatively large size, heavy weight primarily caused by discrete components such as the filters, and separately located modules [1]. Multi-layer ceramic and organic-based SOP implementation are capable of overcoming this limitation by integrating components as part of the module package that would have otherwise been acquired in discrete form. 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. LTCC-based modules demonstrated so far [2-4] were dedicated for phased-array applications. In this paper, we demonstrate an example of a compact functional 14 GHz LTCC-based transmitter module suitable for outdoor satellite transmitter units. The module features an integrated stripline filter similar to [5] and MMIC chipsets fabricated in a commercial Triquint's GaAs MESFET foundry. Experimental results demonstrate low-loss filter and transmitter gain performance that meet the system specification derived from a system-level study. In addition, the 3D radio front-end architecture is also applied to build an OFDM transceiver in LTCC and Georgia Tech's PRC multi-layer fully organic-based SOP technology.

II. 3D 14-GHZ LTCC MODULE IMPLEMENTATION

Two MMICs consisting of VCO-mixer and power amplifier have been integrated on a multi-layer LTCC substrate where a stripline front-end transmitter filter was integrated. The module consisting of ten stacked Dupont 943AT tapes where each layer is 4.4 mils thick, was fabricated by National Semiconductor. Fig.1 illustrates the three-dimensional view of the LTCC module where the MMIC chips were wire-bonded on the surface. The stripline filter was designed in a "Z"-shaped edge-coupled line topology to minimize the area where the middle segment was deployed perpendicular to the first and third segments. This filter requires eight 943AT tapes and is buried two layers below the surface so the MMICs can be directly attached on top of it. The filter ground planes were carefully connected to the MMIC grounds wirebonded to the ground pads on the surface layer through via interconnects as indicated in Fig.1. The filter input was transitioned to the CPW line wire-bonded to the RF port of the mixer while the output transition to CPW was wire-bonded to the input of the driver amplifier. Such configuration where the filter is integrated between the mixer and PA

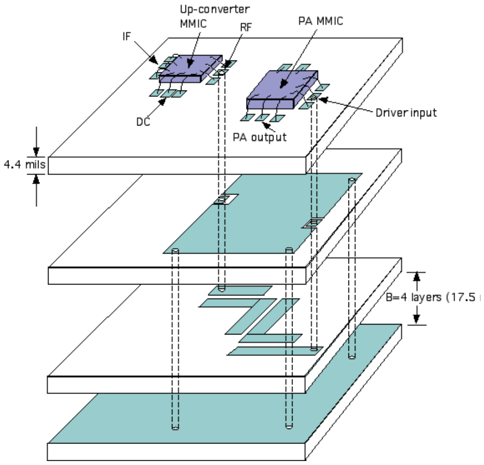

Fig. 1. 3D view of the LTCC Ku-band transmitter module with integrated stripline filter

was chosen to eliminate the mixer harmonics and thereby, improving the linearity of the transmitter. The transition to CPW also enables separate measurement of the filter whose measured results indicate a maximum insertion loss of 1.8 dB from 13.5 to 14.5 GHz. The entire module occupies an area of 400 × 310 × 35.2 mil^3 as shown in Fig. 2. The entire transmitter chain exhibits a total gain of 32 dB incorporating the wirebond loss from 13.5 GHz to 14.5 GHz and image rejection of more than 30 dBc at 12 GHz as shown in Fig. 3.

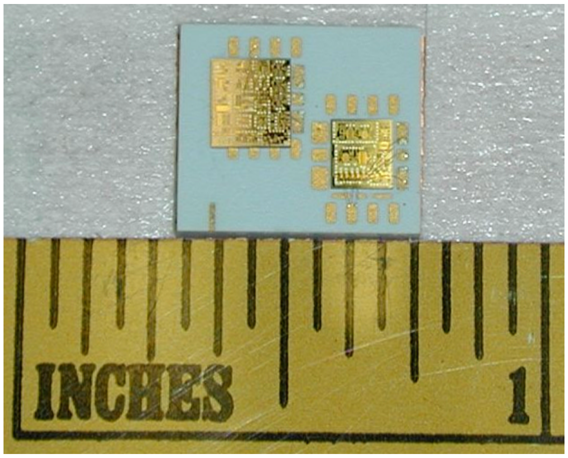

Fig.2. Photograph of the fabricated LTCC transmitter module.

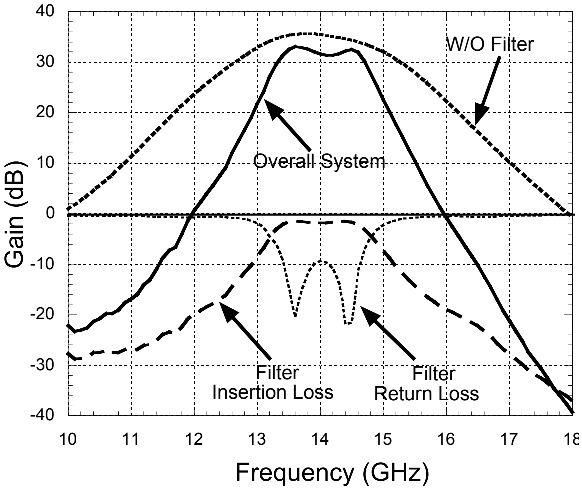

Fig. 3. Overall system gain performance with filter characteristics.

III. INTEGRATED LTCC TRANSCEIVER MODULE FOR 5.8GHz OFDM COMMUNICATION SYSTEM

In Fig.4 a test coupon of high-density, fully organic multi-layer interconnects, and integrated passives for RF and microwave front-ends (PRC-SOP) [6] is presented. Fig 5 shows the system block diagram for a 5.8GHz OFDM system, also built according to the 3D topology in Fig. 6 using LTCC and PRC-SOP. The antenna and filter are integrated on-package for miniaturization and loss minimization. A cavity backed patch antenna with a vertical feed and an embedded 3-D stripline folded coupled-line filter have been built in both LTCC and PRC-SOP processes. RF functional blocks including PA, LNA, Mixers and VCO have been 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.

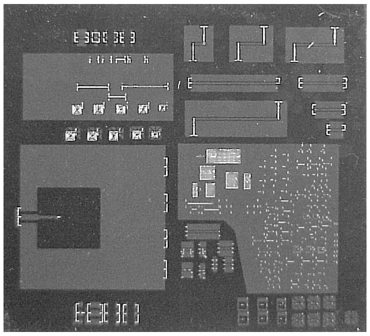

Fig. 4. Multi-layer organic test coupon showing integrated passives, LSA, and MS-to-CPW interconnections.

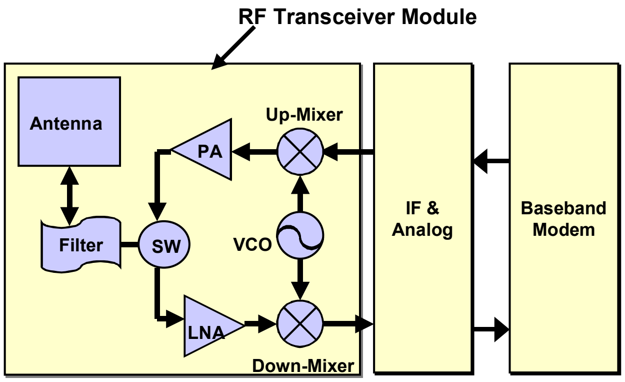

Fig. 5. OFDM system block diagram.

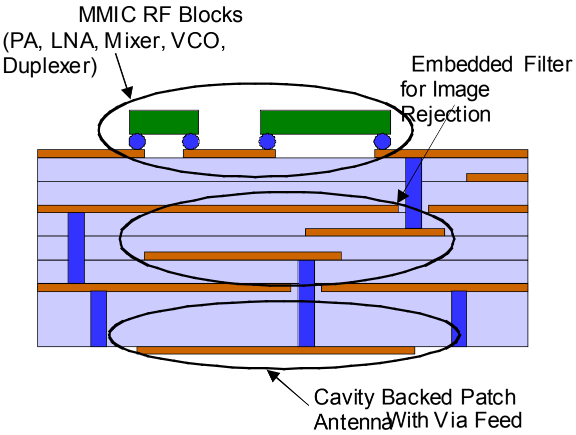

Fig. 6. Integrated RF module including antenna, filter and MMICs.

III. CONCLUSION

We have presented the development and characterization of two compact highly integrated SOP-based radio front-end modules; for Ku-band applications suitable for satellite outdoor units and for 5.8 GHz OFDM Wireless LAN including the antenna. Three-dimensional transmitter architecture in multi-layer ceramic and organic technology has been incorporated and yields more than 40 % savings of real estate for the LTCC-based Ku-band transmitter. This development suggests the feasibility of building highly SOP integrated microwave and millimeter-wave radio front ends.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support of the NSF Packaging Research Center at Georgia Tech, the Yamacraw Design Center and the NSF Career Award. We also would like to thank Ray Brown and Mike Ehlert from National Semiconductor for fabricating the LTCC prototypes, as well as TriQuint Semiconductor for MMIC fabrication.

REFERENCES

[1] Ge Zhiqiang, "A downsized and integrated C-band transceiver for VSAT," *1995 IEEE Microwave and Optoelectronics Conference*, vol. 1, pp. 33-36, 1995.

[2] W. Simon, R. Kulke; A. Wien, M. Rittweger, L. Wolff, A. Girard, and J.-P. Bertinet, “Interconnects and transitions in multilayer LTCC multichip modules for 24 GHz ISM-band applications,” *2000 IEEE IMS Digest*, vol.2, pp. 1047-1050, Boston, MA.

[3] K. Fujii, Y. Hara, Y. Shibuya, T. Sakai, and Y. Takano, “Highly integrated T/R module for active phased array antennas,” *1998 IEEE RFIC Digest*, pp. 77-80, Baltimore, MD.

[4] J.W. Gipprich, L.E. Dickens, J.A. Faulkner, “Power amplifier yields 10 watts over 8-14 GHz using GaAs MMICs in an LTCC serial combiner/divider network,” *1993 IEEE IMS Digest*, vol. 3 pp. 1369-1372, Atlanta, GA.

[5] A. Sutono, J. Laskar, and W.R. Smith, "Development of three dimensional integrated bluetooth image reject filter,"*IEEE-IMS Digest*, vol.1, pp. 339-342, Boston, MA, June 2000.

[6] M.F. Davis, A. Sutono, K Lim, J. Laskar, and R. Tumamala, “Multi-layer fully organic based System on Package (SOP) technology for RF applications”, Presented at the 2000 IEEE EPEP Topical Meeting, Scottsdale, AZ, October 23-25, pp103-106