A System-in-Package (SiP) Integration of a 62GHz Transmitter for MM-wave Communication Terminals Applications

Young Chul Lee and Chul Soon Park

Abstract—**We demonstrate a 2.1 X 1.0 X 0.1cm^3 sized compact transmitter using LTCC System-in-Package (SiP) technology for 60GHz-band wireless communication applications. For low-attenuation characteristics and resonance suppression of the SiP, we have proposed and demonstrated a coplanar double wire-bond transition and novel CPW-to-stripline transition integrating air-cavities as well as novel air-cavities embedded CPW line. The fabricated transmitter achieves an output of 13dBm at a RF frequency of 62GHz, an IF frequency of 2.4GHz, and a LO frequency of 59.6GHz. The up-conversion gain is 11dB, while the LO signal is suppressed with the image rejection mixer below -21.4dBc, and the image and spurious signals are also suppressed below –31dBc.**

Index terms—**mm-wave, System-in-Package, SiP, LTCC**

I. INTRODUCTION

With the expanding needs for multimedia data services in wireless communications, millimeter waves (mmW) have recently evolved as a carrier frequency. Notable topics of research include the radio over fiber targeted as an infra for the mmW mobile communication network; mmW fixed broadband wireless access (BWA) systems [1, 2]; and wireless local area networks (W-LAN). In order to implement the terminals for mobile communications or W-LAN, a small size and lightweight radio transceiver is indispensable. Multi-layer LTCC based System-in-Package (SiP) technology [3, 4, 5] integrating MMICs is one of the best candidates for mmW radio integration due to its effective attenuation performance, integration capability, similar temperature coefficient of expansion (TCE) value to MMICs, and cost effectiveness [6].

In this work, we demonstrate a 62GHz radio transmitter integrating MMICs on the LTCC multi-layer circuit for wireless communication terminal applications. We have clarified the possible problems in the three dimensional (3D) integration of the mmW circuits in respect to attenuation, resonance, and isolation. Several methods used to solve the problems are introduced with electromagnetic (EM) simulation and measurements, and have been implemented in a compact radio transmitter as small as 2.0 x 1.0 x 0.1 cm^3. The measured transmitter performance, including the overall gain and output power, is presented.

II. MM-WAVE RADIO INTEGRATING MMICS ON LTCC MULTILAYER CIRCUIT

The single chip radio is the eventual target of research for mobile communication terminals. However, the chip must still be integrated within a package. Moreover, to integrate the components, which cannot be implemented with semiconductor devices such as high Q filters and antennas for mmW radio, SiP is inevitable especially for mmW radio integration. Fig. 1 shows the schematic concept of an mmW radio that integrates MMICs on a

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LTCC multilayer circuit. All passive and functional circuits will be embedded within the LTCC multilayer circuits, and each layer of the LTCC circuits will be integrated together through the via hole interconnection. The compact radio, if it can be miniaturized to a reasonable size, can be embodied in WLAN and mobile terminals.

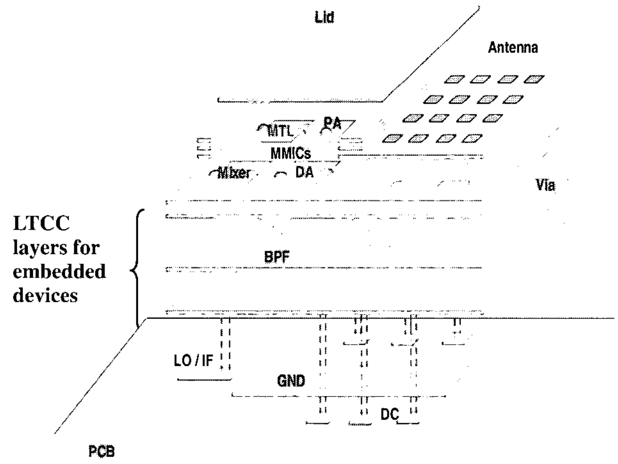


Fig. 1. The 3D schematic concept of mm-w radio SiP

III. REDUCTION OF ATTENUATION

Attenuation along transmission lines and circuit structures should be minimized for power efficiency and noise performance of the mmW transceiver. Particularly in 3D integrated radios, discontinuities such as wire-bond transition [7, 8, 9] for a chip–to–LTCC board interconnection and a CPW-to-stripline (SL) via transition of embedded passive device integration [10] generates a significant amount of reflection and radiation. Low loss structures for chip-to-LTCC board interconnection and CPW-to-stripline transition are proposed and demonstrated.

1. Coplanar double wire-bond transition

The MMIC chip–to–LTCC board interconnections have been optimized in order to reduce radiation and parasitic inductance along the 60GHz RF path. An angled bonding wire connection to reduce radiation and mutual inductance [9] and coplanar-type wire interconnection with two ground wires to confine the radiated EM fields within the ground wires have been adopted.

The chip–to–LTCC board interconnection has been evaluated with a 0.1μm gate-length PHEMT power amplifier. The scattering parameters of the power amplifier with the optimized wiring structure are described in Fig. 2 in comparison to those of conventional wiring. The insertion loss and return loss are improved by 0.5dB and 10dB, respectively, compared to the conventional one at 60GHz.

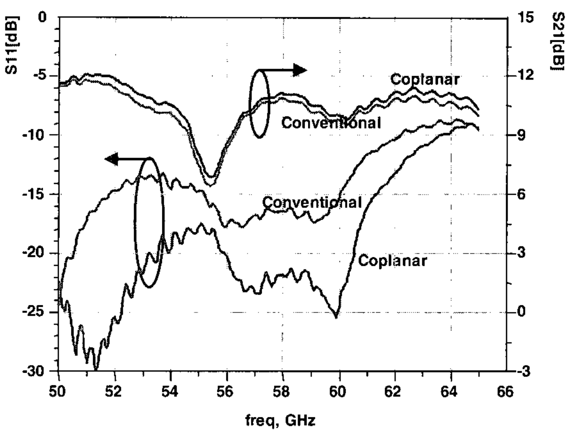


Fig. 2. Measured insertion and return loss of a fabricated 60GHz power amplifier module

2. CPW-to-Stripline Transition

The attenuations caused by impedance mismatch along the vias and radiations around the discontinuities are remedied, in general, by placing ground vias around the transitions [10]. However, leak through the parasitic capacitance between the via and the bottom ground of the stripline is inevitable.

We propose a CPW-to-SL transition with a stagger via and air cavity [11, 12] below it to minimize both the abrupt via discontinuity and the shunt capacitance as shown in Fig. 3. The LTCC transition is designed with six stacked layers and the total thickness is 600μm. CPWs are placed on the top layer and the signal line of a SL is placed on the 3rd layer. The nominal dielectric constant of each layer is 7.8. The stagger via consists of two-stacked vias through the 4th and 5th layer and one via in the 6th layer. These two via blocks are connected through a line, and the width and length are 120μm and 100μm, respectively. The diameter of vias is 150μm. The air cavities [11, 12] of 170μm in diameter are embedded through the 1st to 3rd layer below the 6th layer via. The characteristic impedance of 50Ω is maintained for both the CPW and the SL, and the width and gap of the CPW are 244μm and 95μm, respectively. The width of the SL is 135μm and the lengths of the CPW and the SL are 1,125μm and 630μm, respectively.

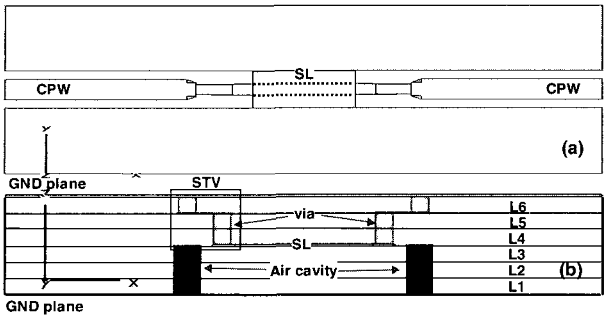


Fig. 3. The novel CPW-to-SL transition (a) the top view, and (b) the cross sectional view (GND: the ground plane, STV: the stagger via block, Lx: the number of layers)

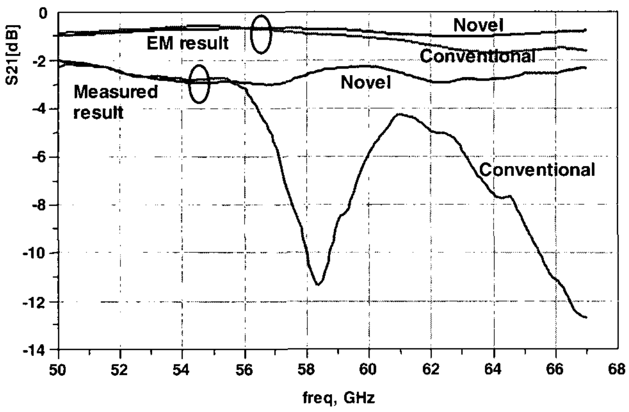


Fig. 4. Comparison of designed and measured results between the novel CPW-to-SL transition and the conventional one

Fig. 4 presents the absolute value of the transmission coefficients of the proposed CPW-to-SL transitions in comparison with the conventional one. The fabricated novel transition shows -2.2 dB insertion loss compared to the –6dB of the conventional one at 60GHz. These values represent the losses along the three-segment transmission lines of 2,880μm and two CPW-to-SL via transitions.

IV. SUPPRESSION OF UNWANTED RESONANCES

The conductor-backed coplanar waveguide (CBCPW) causes undesired resonance modes such as parasitic rectangular waveguide modes and parasitic patch antennas modes [13, 14]. The resonant frequency of the parasitic rectangular waveguide is given by [15],

$$f_{cr} = \frac{1}{2D\sqrt{\mu_0 \varepsilon_0 \varepsilon_r}} \quad \text{[GHz]} \qquad (1)$$

where, D is the spacing between vias, ε_o is the permittivity of free-space, μ_o is the permeability of free-space, and ε_r is the relative dielectric constant of the substrate.

The surface ground planes of the CBCPW behave like patch antennas generating parallel plate modes. Therefore, energy is coupled into the two ground plane patches through the electric field in the gap of the CPW along the entire length [13], and their resonant frequencies [16] are similar to those of the simple patch antenna [13, 14],

$$f_r = \frac{c}{2 \cdot W_g}\left(\frac{\varepsilon_r + 1}{2}\right)^{-1/2} \quad \text{[GHz]} \qquad (2)$$

where, Wg is the width of the rectangular patch, and c is the speed of light.

Fig. 5 and inset present the insertion loss of a typical 50Ω CBCPW line and its layout, respectively, with a width of 300μm, a gap of 150μm, and a length of 3,260μm; the height of the substrate is 400μm. Vias of 150μm in diameter to short the lower and upper ground planes are placed at the both sides with a distance (D) of 1,620μm; corresponding to the parasitic rectangular waveguide mode at 34GHz. Resonances at 19.5GHz and 39GHz are due to the patch antenna mode and the harmonic, respectively.

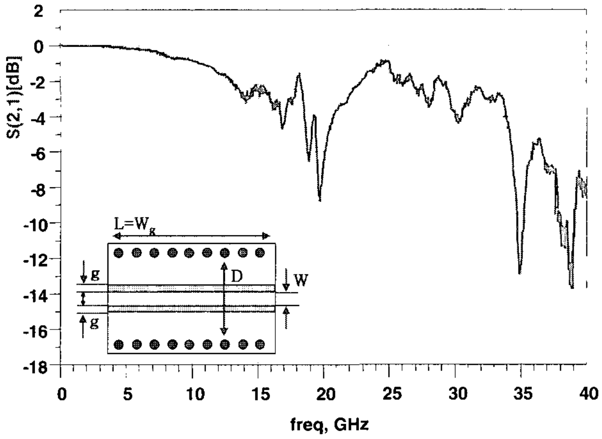
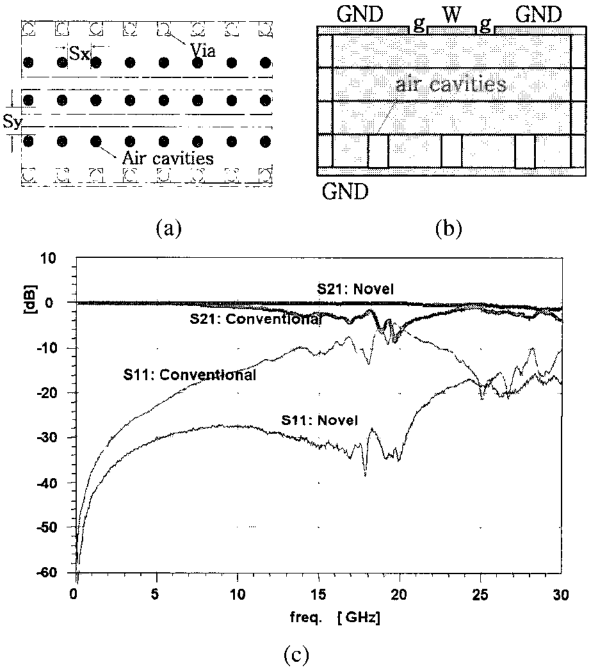


Fig. 5. Unwanted resonance modes due to the wide ground plane and embedded vias (the inset: the top view of the CBCPW; L=the length, g=the gap, and W=the width)

The rectangular waveguide modes have been successfully suppressed by placing the vias within shorter distance than the calculated value from Eq. (1).

The parasitic patch antennas modes have been excluded inserting air cavities [11, 12], the low dielectric constant layer, under the surface ground planes of the CBCPW as described in (a) and (b) of Fig. 6. Embedded air cavities can confine the electromagnetic (EM) fields around the signal line (W). Therefore, parasitic modes are suppressed. Fig. 6(c) reveals that the resonance at 19.5GHz is effectively suppressed.



(a) (b)

(c)

Fig. 6. Unwanted resonance suppression using embedded air cavities, (a) and (b): the layout and the cross section of the novel CBCPW with embedded air cavities; (c): measured result (Sx/y: the x/y-directional spacing; Sx=300μm and Sy=315μm, GND: the ground plane)

V. ISOLATION

Planar mmW circuits may suffer from parasitic modes due to power leakages from transmission lines [13] and unexpected radiation at discontinuities [17, 18, 19]. These parasitic modes can propagate to other parts of the circuits through the DC bias feed lines, IF path or the signal lines, and finally result in unexpected crosstalk and feedback. These internal cross talk and feedback effects have a distinct influence on circuit stability. In order to save the stability the DC feed lines and long IF feed lines are shielded with isolating ground planes and vias as will be shown in Fig. 8. The high frequency noise from bias has been effectively bypassed only next to the RF circuitry that employs appropriate resistors and capacitors.

VI. A 62GHZ TRANSMITTER SIP

1. A 62GHz Heterodyne Transmitter

Fig. 7 shows a block diagram of the transmitter for 62GHz wireless communications applications. The transmitter consists of a 60GHz-band HBT up-converting mixer and four 0.15μm GaAs PHEMT MMICs: two frequency multipliers (MTLs), a drive amplifier and a power amplifier. In order to save module size, a local oscillator (LO) rejection filter has been eliminated through the adoption of the image rejection mixer. The LO signal of the transmitter is supplied by multiplying the external LO source of 14.9GHz by 4 to the GaAs HBT image rejection mixer.

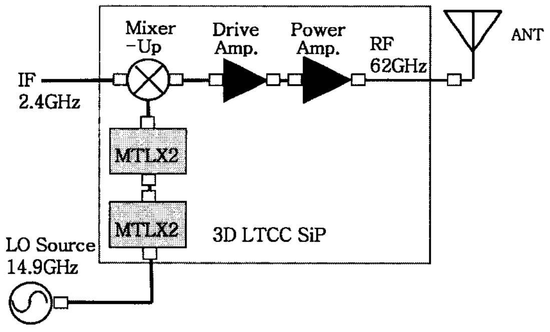


Fig.7. Block diagram of the 62GHz transmitter

2. Design and Fabrication of the Transmitter SiP

A schematic cross-sectional view of the 62GHz transmitter SiP is shown in Fig. 8. The bias and IF feeds are embodied in the 5-layer LTCC circuit while MMICs and the off-chip component are placed on top of the 500μm thick LTCC block. CPWs and SLs were used for signal transmission, and vias were embedded for interconnection between layers or internal grounds. MMICs were mounted in the 100μm deep cavities to minimize the length of wire or ribbon bonding.

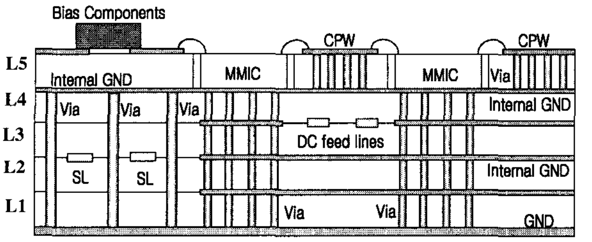


Fig. 8. Schematic cross-sectional view of the transmitter SiP (SL: the IF feed line)

Fig. 9. shows a photograph of the fabricated 62GHz radio transmitter integrating five MMIC chips and off-chip components on the LTCC multilayer circuit. The total size of the transmitter SiP is as small as 2.1 X 1.0 X 0.1cm^3.

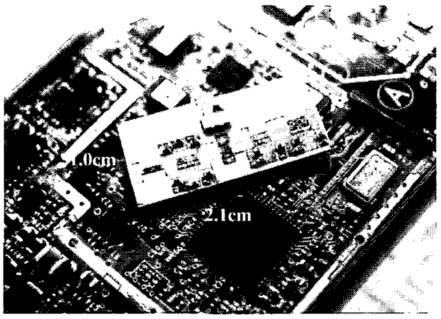


Fig. 9. The fabricated 62 GHz radio transmitter(2.1 X 1.0 X 0.1cm^3)

3. Measured Results

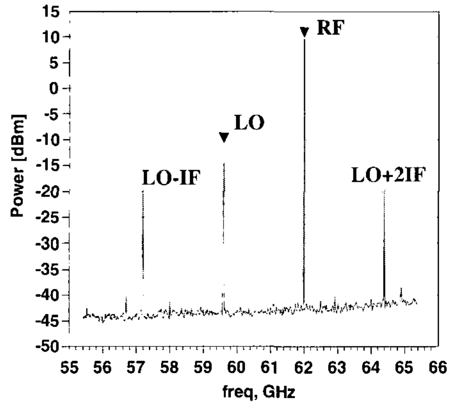


Fig. 10. Frequency spectrum at the transmitter output

Fig. 10 shows the measured frequency spectrum of the LO, RF, image (LO-IF), and spurious (LO+2IF) signals at the output port of the transmitter. The isolation level between the LO and RF signal is less than -20.6dBc and the image and spurious levels are less than -29.6dBc.

Fig. 11 demonstrates the RF output power and the power gain as a function of 2.4GHz IF input power for the transmitter. With an IF power of 2.9dBm, the 62GHz RF power at a 1-dB gain compression point is 13dBm while the up-conversion gain of the transmitter is 11dB.

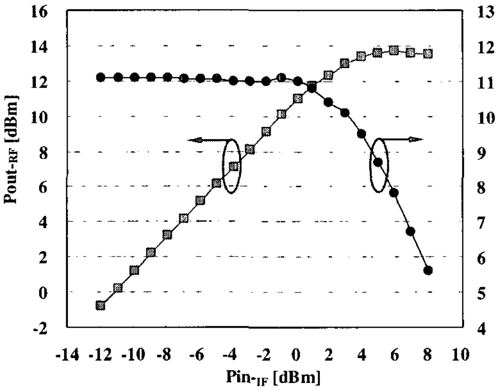


Fig. 11. Output power and gain of the fabricated transmitter (RF freq.=62GHz, IF freq.=2.4GHz, and LO freq.=59.6GHz)

VII. CONCLUSION

We present a compact transmitter as small as 2.1 X 1.0 X 0.1cm^3 using LTCC System-in-Package (SiP) technology for 60GHz-band wireless communications applications. The attenuation, resonance, and isolation issues associated with the three-dimensional mmW structure have been successfully controlled. The fabricated transmitter achieves a 62GHz output of 13dBm with an IF frequency of 2.4GHz and a LO frequency of 59.6GHz. The LO signal is suppressed with the image rejection mixer below -21.4dBc and the up-conversion gain is 11dB.

ACKNOWLEDGMENT

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