J Korea Industr Inf Syst Res Vol.19 No.1, 2014
http://dx.doi.org/10.9723/jksiis.2014.19.1.019

밀리미터파 SoP 응용을 위해 광대역 수직천이를 집적한 초소형 LTCC 팻치안테나

(Compact LTCC Patch Antenna Integrating a Wideband Vertical Transition for millimeter-wave SoP Applications)

이 영 철*
(Young Chul Lee)

Abstract In this work, a compact patch antenna based on a low temperature cofired ceramic (LTCC) has been presented for V-band system-on-package (SoP) applications. In order to integrate it with transceiver block, a waveguide (W/G) to embedded microstrip line (eMSL) vertical transition was designed using slot-fed double stacked patch antennas for easy assembly and wide bandwidth. The 2 x 2 patch antenna integrating the transition was designed and fabricated in the 5-layer LTCC dielectrics. The whole size of the fabricated antenna including the 2 x 2 patches, transition and W/G was 20 x 24 x 5.39 mm^3. The fabricated antenna has achieved a 10 dB impedance bandwidth of 2.45 GHz from 61 to 63.45 GHz.

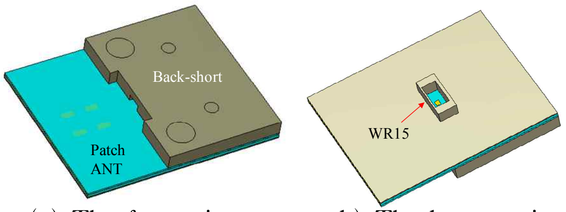
Key Words : Millimeter wave, V-band, Vertical Transition

1. Introduction

Recently, various wireless communication systems has been proposed and developed [1~3] widely and rapidly using 60 GHz or above bands, which lead to a great demand for compact and low-cost radio systems. The low temperature cofired ceramic (LTCC) based ystem-on-package (SoP) approach [1~3] is one of the most promising solutions for integration of the radio system due to its multi-layer integration capability, excellent metal conductivity, low-loss characteristics, and a temperature coefficient of expansion (TCE) close to semiconductors.

Antenna designs for radio systems using 60 GHz or above bands have been tried to integrate it into chip [4] and package [1, 2]. The antenna integrated into the silicon-based chip showed poor radiation efficiency due to the low resistivity and high permittivity [4]. Now several approaches have been tried for reduction of the silicon substrate loss [5, 6]. In this work, a 2 x 2 patch antenna integrating a transition (waveguide to embedded microstrip line) using a low temperature co-fired ceramic (LTCC) is presented for 60 GHz s SoP applications.

* 목포해양대학교 전자학과, 제1저자 및 교신저자 (leeyc@mmu.ac.kr)



(a) The front view b) The bottom view

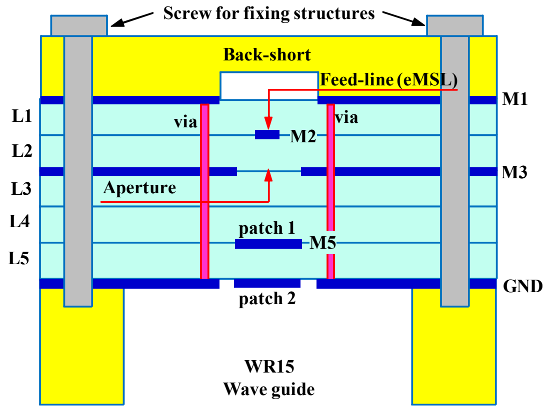
<Fig 1> 60 GHz LTCC patch antenna (ANT) with a waveguide-to-eMSL transition

2. Design of a LTCC Patch Antenna

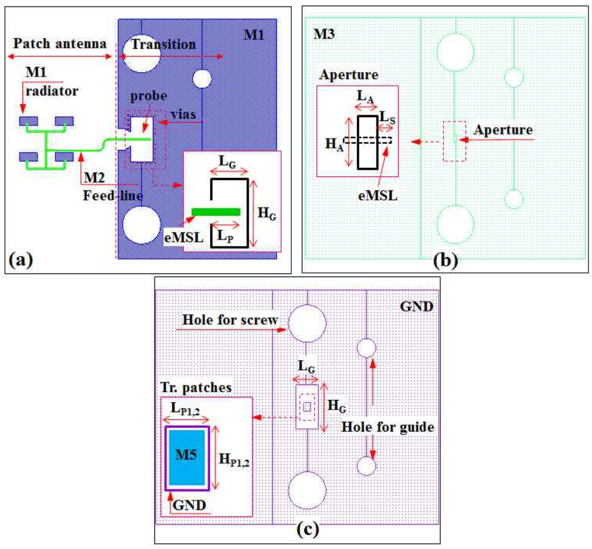
A 60 GHz LTCC patch antenna with a waveguide (W/G) to embedded microstrip line (eMSL) transition is shown in <Fig 1>. This antenna consists of a 2 x 2 patch antenna, transition, back-short structure, and waveguide (WR15). The transition should be designed for interconnecting the patch to the W/G. The antenna and transition are designed using the LTCC dielectric substrate with a relative permittivity and a loss tangent of 6.6 and 0.001, respectively. The thickness of each LTCC layer is 114 μm. The conductor materials are 10 μm thick gold and silver for a outer and inner metal, respectively. The five LTCC layers are used to design the antenna and transition.

2.1 Waveguide Transition

The transition configuration is presented in <Fig 2>. In order to interconnect the compact LTCC patch antenna with the waveguide (W/G)-type ports of the wireless communication equipments. A waveguide-to- microstrip line transition is required. Several types of waveguide-to- microstrip transitions have been researched using probe [7], ridged [8], and slot-coupled type [9]. In this work, considering an easy integration with an eMSL structured feed-line coupler and available wide bandwidth at a 60 GHz band, a waveguide-to-eMSL transition is designed using slot-fed double stacked patch antennas [10].



<Fig 2> Structure of a waveguide to eMSL transition (L_x: the number of the LTCC sheet layer and M_x: the number of the metal layer)

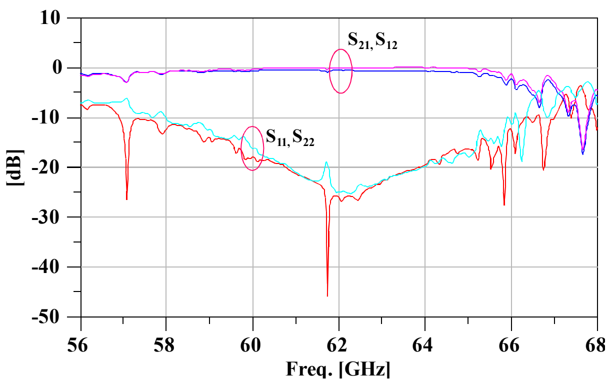


<Fig 3> Conductor layouts on the LTCC sheets for a 2x2 patch antenna [(a) the 1st(M1)- and 2nd (M2) - layer pattern (inset: an inserted eMSL probe), (b) the 3rd (M3) layer (inset: an aperture dimensions), (c) the 5th (M5) - and ground (GND) - layer pattern (inset: transition (Tr.) patches)].

The transition consists of the eMSL, coupling aperture, and double patches. <Fig 3> shows layouts of the eMSL-to-W/G [WR15, 1.88 (L_G) x 3.67 (H_G) mm^2] transition and microstrip patch antenna. A probe at the end of the eMSL coupler is inserted into the W/G and its end is short-circuited using a back-short structure as shown in <Fig 2> and <Fig 3(a)>. The optimized length of the back-short is 800 μm which is almost the same as a quarter-wave length at the center frequency. The W/G in the LTCC substrate is surrounded by vias for interconnecting GND planes and reducing parallel-plate leakage in the substrate. The critical parameters of the transition are the probe length (L_P), stub length (L_S), the size of the aperture (L_A x H_A) and patch antennas (L_{P1} x H_{P1} and L_{P2} x H_{P2} for M5 and GND, respectively). These parameters are numerically optimized and summarized in <Table1>.

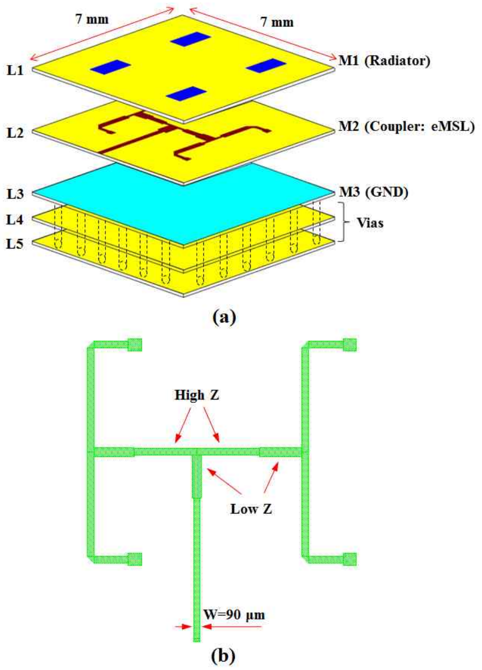
<Table 1> Optimized parameters [mm]

Parameters	Description	Dimension
L_P	Length of the probe	1.28
L_S	Length of the stub	0.227
H_AxL_A	Size of the aperture	0.696 x 0.225
H_{P1}xL_{P1}	Size of patch 1	0.690 x 0.545
H_{P2}xL_{P2}	Size of patch 2	0.725 x 0.573



<Fig 4> Simulated results of the eMSL- to - W/G transition

Transmission characteristics of the designed eMSL-to-W/G transition are calculated by using a commercial electromagnetic simulator [11]. The simulated results of the eMSL-to-W/G transition are shown in <Fig 4>. The bandwidth for reflection below -10 dB is 8.08 GHz (13%) from 57.98 to 66.06 GHz.



<Fig 5> Structure of the LTCC patch antenna (a) and an eMSL power divider (3dB-coupler) for a 4-way (b)

2.2 Patch Antenna

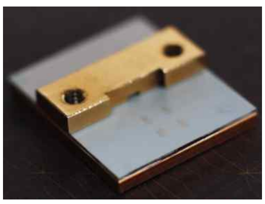
The 2x2 array patch antenna is designed with a LTCC microstrip (MSL) structure. <Fig 5> shows the schematic structure of the LTCC antenna and an eMSL power divider. 3 layers from L1 to L3 are for the antenna and additional 2 layers (L4 and L5) are used for internal and outer ground planes. Total 5 layers are used because of LTCC design rule of the Foundry Company [12]. Therefore, they are interconnected for ground planes. The radiating patches are placed on the 1stlayer (L1) and their size is the same as 1.5 x 0.71 mm^2. Thee MSL structured feeding network is designed on the 2nd

layer (L2) using a T-divider (power divider). In this structure, 70.7Ω-quarter-wavelength ($\lambda_g/4$) transformers are required. However, it is impossible to implement them because limitation of a line width is 90 μm in the LTCC design rule. Therefore, the additional $\lambda_g/4$ transformers with low impedance (Z) are designed at the common port as shown in <Fig 5 (b)>. The width of high Z lines is 90 μm and their impedance is 47 Ω. For the low Z lines, their width and length are optimized considering overall characteristics. The optimized width and its impedance are 130 μm and 40 Ω, respectively. The ground plane is on the front side of the 3^{rd} layer and is interconnected with L4 and L5 using vias. The antenna size is as small as 7 x 7 x 0.57 mm^3.

3. Fabrication and Measurement

3.1 Fabrication

The designed LTCC 2x2 patch antenna with the eMSL-to-W/G transition was implemented in 5-LTCC dielectric layers using a standard LTCC process. A thickness between the metal layers is 114 μm. A relative dielectric constant and loss tangent of the LTCC dielectric are 6.6 and 0.009, respectively, at 60 GHz. Ag and Ag/Pd conductors were screen-printed on the unfired layers as internal and external conductors, respectively. <Fig 6> shows a photograph of the fabricated antenna integrating the transition. The bottom view presents the WR15 waveguide and holes for screw and

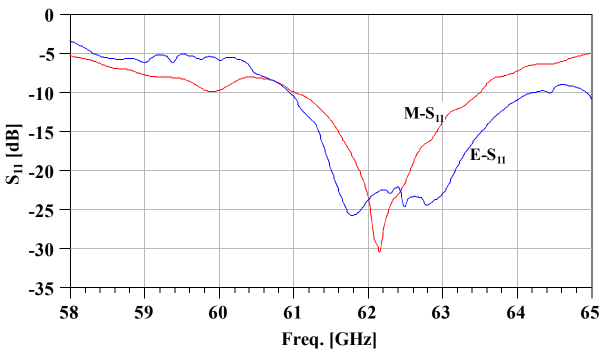


<Fig 6> Fabricated LTCC patch antenna with the transition

guiding. The whole size of the antenna including the waveguide and back-short structure is as small as 20 x 24 x 5.39 mm^3.

3.2 Measurement

The fabricated LTCC antenna was mounted on the waveguide (WR15) and the back-short structure was assembled using a conductive paste. <Fig 7> shows the measured return-loss characteristic compared to the simulated one. The simulated return loss shows a -10 dB bandwidth of 3.2 GHz (61 ~ 64.2 GHz). The 10 dB impedance bandwidth of the measured one is 2.45 GHz from 61 ~ 63.45 GHz which is lower value of 750 MHz than the simulated one. The parasitic resistance, inductance, and capacitance, which came from assembly process and misalignment among the LTCC patch antenna, WR15 W/G, and back-short structure, result in shorter bandwidth than the simulated one.



<Fig 7> Measured return loss of the fabricated LTCC patch antenna compared to the simulated one [M: measurement and E: Simulation]

4. Conclusion

A LTCC 2 x 2 patch antenna integrating a waveguide (W/G) to embedded microstrip line (eMSL) transition was reported for 60 GHz wireless communication applications. A W/G-to-eMSL transition using slot-fed double stacked patch antennas was designed for easy integration with the antenna and wide available bandwidth of the transition. The designed 2 x 2 patch antenna was fabricated using the 5-layer LTCC dielectrics. The whole size of the fabricated antenna including 2 x 2 patches, transition, and W/G was 20 x 24 x 5.39 mm^3. The antenna achieves a 10 dB impedance bandwidth of 2.45 GHz from 61 to 63.45 GHz.

Acknowledgement

I would like to thank Mr. Azzemi and Salizul in TMRND, Malaysia for their helps in this project from TMRND.

References

[1] Young Chul Lee, Won-il Chang, and Chul Soon Park, "Monolithic LTCC SiP Transmitter for 60GHZ Wireless Communication Terminals," *IEEE MTT-S Int. Microwave Symposium Digest*, June 2005.

[2] Dong Yun Jung, Won-il Chang, Ki Chan Eun, and Chul Soon Park, "60-GHz System-on-Package Transmitter Integrating Sub-Harmonic Frequency Amplitude Shift-Keying Modulator," *IEEE Trans. on Microwave Theory and Techniques*, Vol.55, No.8, 1786-1793, 2007.

[3] Y. C. Lee, "CPW-to-Stripline Vertical via Transitions for 60 GHz Ltcc Sop Applications," Progress In Electromagnetics Research Letters, Vol. 2, pp.37-44, 2008.

[4] Y. P. Zhang, L. H. Guo, and M. Sun, "On-chip antennas for 60-GHz radios in silicon technology," *IEEE Trans. on Electron Devices*, Vol. 52, pp.1664-1668, 2005.

[5] K. T. Chan, A. Chin, Y. P. Chen, Y. D. Lin, T. S. Duh, and W. J. Lin, "Integrated antenna on Si, proton-implanted Si and Si-on-quartz," *IEDM Tech. Digest*, 2001, pp.903-906.

[6] J. G. Kim, et al., "60-GHz CPW-FED post-supported patch antenna using micromachining technology," *IEEE Microw. Wireless Compon. Lett.*, Vol. 15, No. 10, pp.635-637, 2005.

[7] K. W. Kim, C. H. Na, and D. S. Woo, "New Dielectric-Covered Waveguide-to-Microstrip Transitions for Ka-Band Transceivers," *IEEE MTT-S In. Microwave Symposium Digest*, vol.2, 2003, pp.1115-1118.

[8] H. W. Yao, A. Abdelmonem, J. F. Liang, and K. A. Zaki, "Analysis and Design of Microstrip-to-Waveguide Transitions," *IEEE Trans. on Microwave Theory and Techniques*, Vol.42, No.12, pp.2371-2380, 1994.

[9] W. Grabherr, B. Huder, and W. Menzel, "Microstrip to Waveguide Transition Compatible with MM-Wave Integrated Circuits," *IEEE Trans. on Microwave Theory and Techniques*, Vol.42, No.9, pp.1842-1843, 1994.

[10] J. H. Choi, K. Tokuda, H. Ogawa, and Y. H. Kim, "Gap-Coupled Patch-Type Waveguide-to-Microstrip Transition on Single-Layer Dielectric Substrate at V-Band," *Electron. Lett.,* Vol.40, No.17, pp.1067-1068, 2004.

[11] CST MICROWAVE STUDIO, CST Inc., [Online] Available: http://www.cst.com

[12] RN2 Technologies, [Online] Available: http://www.RN2LTCC.com.

이 영 철 (Young Chul Lee)

- 정회원
- 영남대학교 전자공학과 공학학사
- 영남대학교 전자공학과 공학석사
- 한국정보통신대학교 (Information and Communications University, ICU) 공학부 공학박사
- 목포해양대학교 해양공과대학 전자공학과 부교수
- 관심분야 : 밀리미터파 회로 및 시스템

논 문 접 수 일 : 2014년 01월 13일
1차수정완료일 : 2014년 02월 12일
2차수정완료일 : 2014년 02월 19일
게 재 확 정 일 : 2014년 02월 19일