

Multilayer Substrate-Integrated-Waveguide Aperture-Coupled Antenna Array for Millimeter-Wave Handset Device

Seong-Jin Park

Dept. of Electrical Engineering
KAIST
Daejeon, Republic of Korea
pondsky@kaist.ac.kr

Dong-Hun Shin

Dept. of Electrical Engineering
KAIST
Daejeon, Republic of Korea
husido@kaist.ac.kr

Seong-Ook Park

Dept. of Electrical Engineering
KAIST
Daejeon, Republic of Korea
soparky@kaist.ac.kr

Abstract—A substrate-integrated-waveguide (SIW) aperture-coupled antenna array is presented at millimeter-wave band. The antenna design is located on the upper part of the substrate fixed with a half size of Samsung Galaxy Note 4. The antenna array has been implemented with the multilayer structure which is realized by stacking three substrates and a copper plate. The simulated results are validated with the measured one. The proposed antenna is a good candidate for millimeter wave handset device.

Keywords—Substrate integrated waveguide (SIW); 5G; antenna array; millimeter wave; handset antenna; 28 GHz

I. INTRODUCTION

A millimeter-wave antenna has lately become a subject of special interest for 5G communication. The antenna needs to be accommodated in 5G handset device and realize directional fan beam, broadband and low cross-polarization. [1]

Antenna array schemes can realize these aims. The cost and efficiency of the antenna at the millimeter-wave are significant considerations. Feeding network constituting microstrip lines have been broadened in antenna arrays design based on the advantages of low cost and simple fabrication. However, the microstrip feeding line in terms of the antenna array performance is not appropriate at millimeter wave band because not only the considerable transmission loss but also the undesired radiations from microstrip line, as increasing the operating frequency.

A substrate integrated waveguide or SIW [2] has been proposed to solve these problems. SIW has many merits such as characteristics of rectangular waveguide, simple fabrication, easy integration with other circuits, and low manufacturing cost where the conventional printed circuit board (PCB) can be used. For the above mentioned reason, SIW has considered an attractive choice for millimeter-wave applications. Various kinds of array antennas have been researched in the literature [3]-[4].

In our design, the antenna array consists of an SIW feeding network and multilayer structures containing substrates and a copper plate. The simulated and measured result demonstrate that the proposed antenna array has wide bandwidth, fan radiation beam pattern, and low cross-polarization performance. The advantages of low fabrication cost and good characteristics

show that the proposed antenna is a good candidate for future millimeter-wave handset device.

In this paper, 8 elements antenna array operating at 28 GHz is demonstrated within a half size of a cellular device. The paper is organized as follows. In Section II, analysis of the proposed antenna is described. Section III presents the simulated and measured properties of the proposed antenna which features a return loss and radiation characteristic. Lastly, the paper is concluded in Section IV.

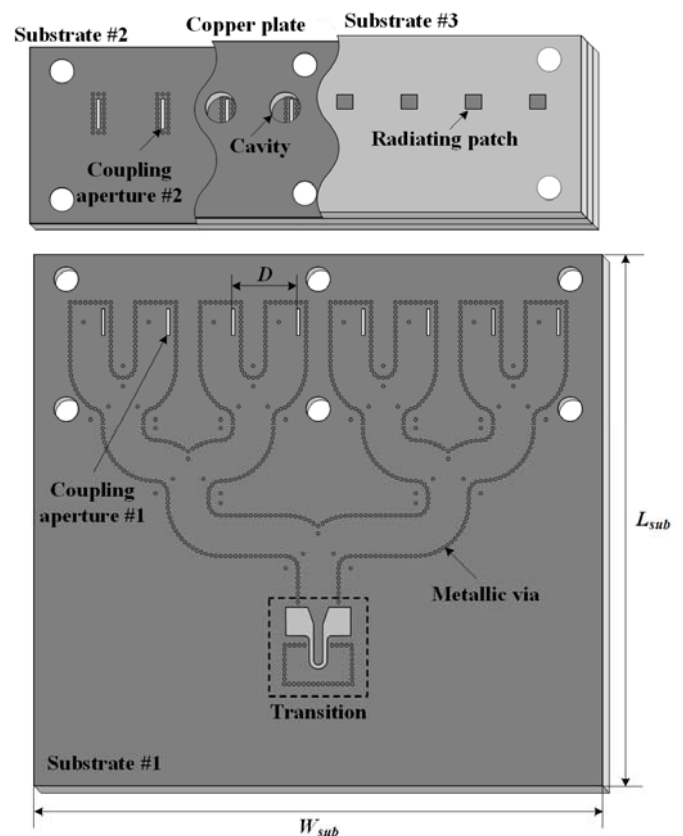


Fig. 1. Geometry of the proposed SIW aperture-coupled antenna array.

II. ANTENNA DESIGN

One of the most important factors is placement of the antenna within a handset device before designing the antenna. As shown in Fig. 1, the antenna is placed on the upper side of substrate 1 fixed with a half size of a cellular device ($W_{sub} = 70$ mm and $L_{sub} = 63.5$ mm). Maintaining the Integrity of the Specifications

The overall geometry of the antenna consists of four stacked layers which are substrate 1, substrate 2, a copper plate and substrate 3 in a row. The antenna is fed by an SIW feeding network and a waveguide to SIW transition onto substrate 1. Vertical coupling apertures 1 are slotted on the upper side of substrate 1 to propagate the wave from substrate 1 to substrate 2. The coupling apertures, the circular cavities in the copper plate, and the patches on substrate 3 consist of 8 elements cavity-backed aperture-coupled antenna array. There are six screw holes which are applied to fix substrates and the copper plate. Four screw holes on the bottom side of substrate 1 are drilled to connect WR-28 coaxial waveguide adapter.

TABLE I
DIMENSIONS OF T-JUNCTION (UNITS: mm)

Parameters	W_{siw}	d_{via}	g_{via}	a_1	a_2	a_3
Values	5	0.4	0.6	0.95	2.11	1.76

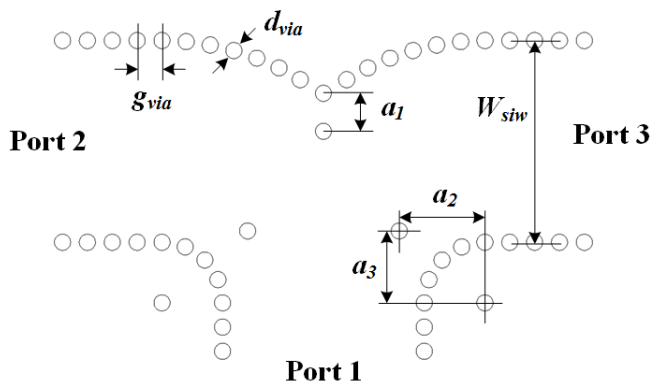


Fig. 2. Configuration of T-junction divider used in the SIW feeding network

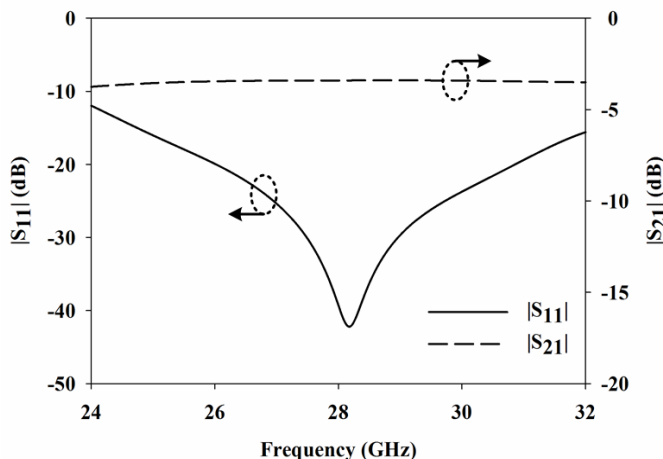


Fig. 3. Simulated S parameters of the T-junction divider.

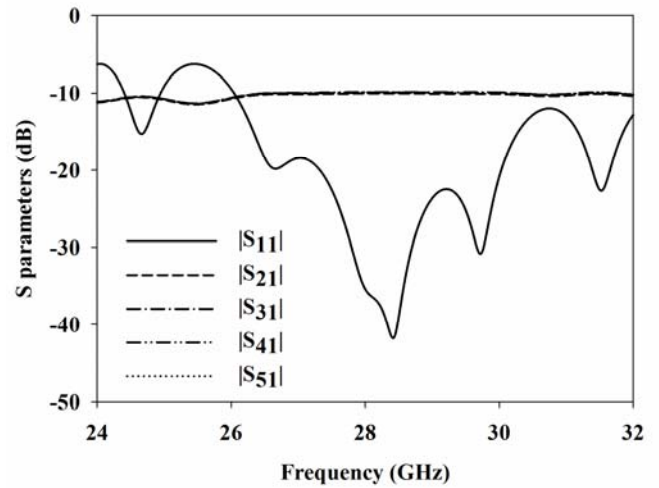


Fig. 4. Simulated S parameters of the overall SIW feeding network on substrate 1.

In our design, substrate 1, 2 and 3 are Rogers 4350B laminates with thickness of 0.508 mm and dielectric constant of 3.66. The thickness of the copper plate is 0.5 mm. The whole height of the antenna array is around 2 mm, which is in good agreement with height limitations of handset devices.

An SIW feeding network is employed to widen the bandwidth of antenna arrays. By applying this feeding network, the distance between antenna elements in the azimuth plane is 8 mm (D) which is around $0.8 \lambda_0$ at 28GHz. The SIW feeding network consists of seven T-junctions which effectively influences the bandwidth of the whole network. The specific configuration of T-junction is shown in Fig. 2. A power can be split by three vias from port1 to port 2 and 3. In addition, impedance matching of the T-junction can be realized by tuning the positions of the vias. Detailed values of the dimensions are given in Table I.

The simulated S parameters of T-junction are shown in Fig. 3, which demonstrates that T-junction has broad bandwidth from 26 to 31 GHz for $|S_{11}| < -20$ dB. As shown in Fig. 4, the simulated $|S_{11}|$ of the overall SIW feeding network on substrate 1 is less than -20 dB from 27 to 30 GHz. Also, the graph shows that the output powers are around -10 dB, which is equally distributed in the frequency range above.

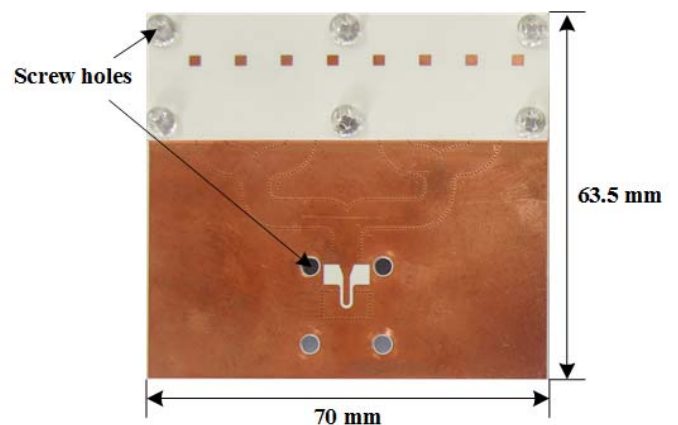


Fig. 5. Photograph of the fabricated antenna.

III. MEASUREMENT AND RESULT

In order to verify the proposed design, the SIW aperture-coupled antenna array was fabricated and measured. The photograph of the fabricated antenna is exhibited in Fig. 5. The measured return loss and radiation pattern of the proposed antenna array are using Agilent R281A coaxial waveguide adapter. The measured return loss of the antenna array was performed with Agilent Network Analyzer E8364. The far-field pattern of the antenna array was measured in a millimeter wave anechoic chamber.

The simulated and measured $|S_{11}|$ of the fabricated SIW aperture-coupled antenna array is shown in Fig. 6. The simulated and measured bandwidths of the antenna array are 1.05 GHz from 27.7 to 28.75 GHz and 1.56 GHz from 27.29 to 28.85 GHz for $|S_{11}| < -10$ dB, respectively. The difference between the simulation and the measurement is due to fabrication errors and unwanted reflection inside the waveguide adapter.

The measured radiation pattern of the antenna array is shown in Fig. 7, which demonstrates a sharp beam pattern with 8.86 degree beam-width in the azimuth plane and a broad beam pattern with 79.63 degree beam-width in the elevation plane. The peak antenna gain at the central frequency is 13.7 dBi based on our measurement. The simulated and measured cross-polarization in the elevation plane is lower than -20 dB, which are good polarization property. The side-lobe level of radiation patterns are around -15 dB, which are in good agreement with the theoretical value of a uniform array antenna.

IV. CONCLUSION

A SIW aperture-coupled antenna array has been investigated at 28 GHz band. The overall antenna can be realized by stacking the substrates and the copper plate. By designing the SIW feeding network, the broadband and high isolation are simultaneously achieved. The proposed antenna array was fabricated and measured to verify the design. The proposed antenna performance can be achieved with a gain up to 14 dBi,

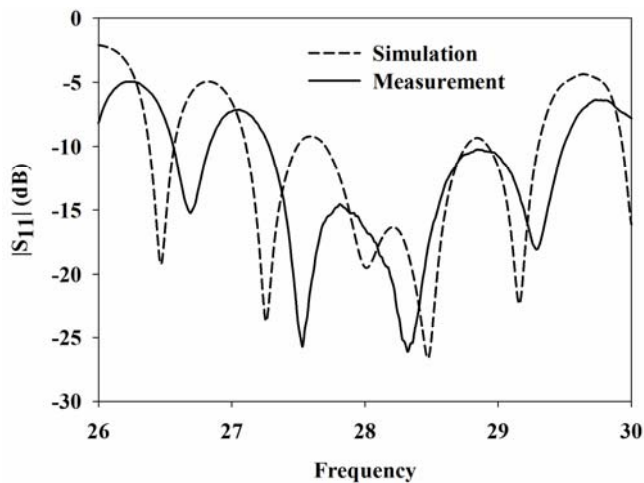


Fig. 6. Simulated and measured $|S_{11}|$ of the proposed antenna array.

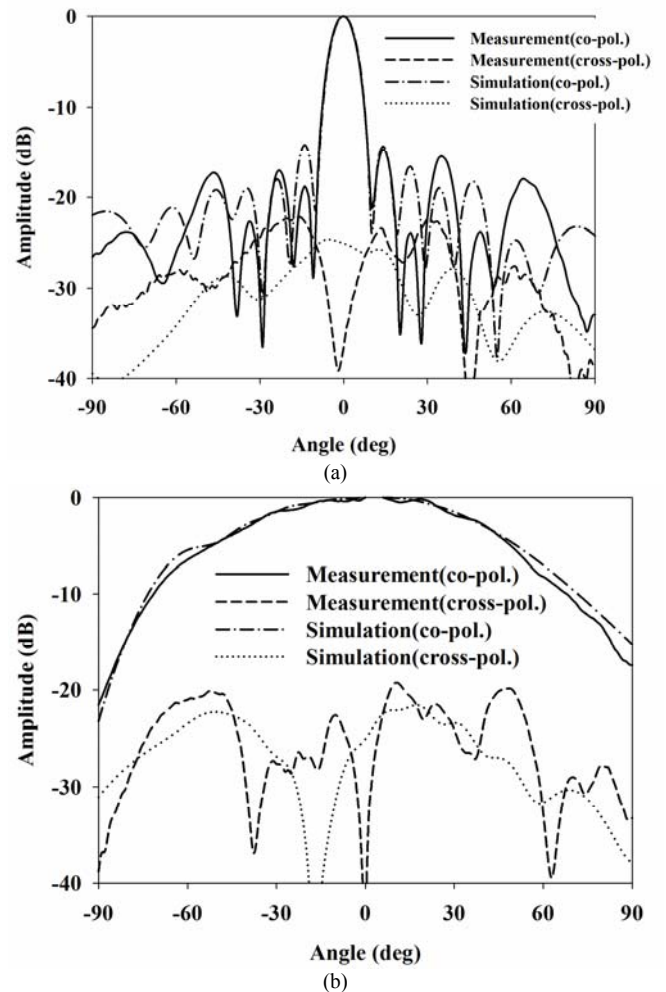


Fig. 7. Measured radiation pattern of the proposed antenna array at 28.25 GHz: (a) in the azimuth plane; and (b) in the elevation plane.

a bandwidth of 1.56 GHz and fan radiation beam patterns with low cross-polarizations.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded the Korea government (MSIP, No. 2013R1A2A1A01014518).

REFERENCES

- [1] W. Hong, K. H. Baek, Y. Lee, Y. Kim and S. T. Ko, "Study and prototyping of practically large scale mmWave antenna systems for 5G cellular devices," *Communications Magazine, IEEE*, 52(9), pp. 63-69, 2014.
- [2] D. Deslandes and K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwave and Wireless Compon. Lett.*, vol. 11, no. 2, pp. 68-70, Feb. 2001
- [3] X. P. Chen, K. Wu, L. Han, and F. He, "Low-cost high gain planar antenna array for 60-GHz band applications," *IEEE Trans. Antennas and Propagat.*, vol. 58, no. 6, pp. 2126-2129, Jun. 2010.
- [4] Y. J. Li and K. M. Luk, "Low-cost high-gain and broadband substrate integrated waveguide fed patch antenna array for 60-GHz band," *IEEE Trans. Antennas and Propagat.*, vol. 62, no. 11, pp. 5531-5538, Nov. 2014.