A 4×4 60 GHz LTCC SIW Cavity Array Antenna

Junfeng Xu[*1], Zhining Chen[*2], Xianming Qing[*], Wei Hong[#]

[*]*Institute for Infocomm Research, Singapore*

[1]jxu@i2r.a-star.edu.sg

[2]chenzn@i2r.a-star.edu.sg

[#] *State Key Lab. of Millimeter Waves, Southeast University, China*

***Abstract*— In this paper, a 4×4 60GHz SIW cavity array antenna on multilayered LTCC is designed. The parallel-fed structures are implemented beneath radiating elements. The radiating element, power diver, broadwall coupler and SIW-RWG multilayer transition are optimized for broad bandwidth purpose. Furthermore, the arrays with 1×1, 1×2, and 2×2 elements are also simulated and compared. Verified by measured results, the 4×4 cavity array antenna possesses the merits such as compact size, wideband operation, and high efficiency.**

I. Introduction

The demand for high data-rate wireless connection for wireless personal area network (WPAN) has spurred the rapid development of low-cost millimeter-wave (mmW) systems operating in the frequency range of 30-300 GHz [1, 2]. Among them, the technology for wireless systems operating in 60-GHz unlicensed bands has been much attractive. Due to high operating frequencies, antenna design has been one of the most challenging tasks. Printed antennas as good candidates for portable devices have the unique challenges in losses caused by surface waves, dielectric and undesirable radiation, fabrication and installation tolerance, fabrication and material cost, as well as integration degree into board or package or chip [3]. As a result, it is very difficult to use conventional printed circuit board (PCB) technology to design and fabricate the mmW antennas.

Low Temperature Co-fired Ceramic (LTCC) is a multilayer technology with advantages for planar integration [4]. Laminated waveguide (LWG) [5] or substrate integrated waveguide (SIW) [6] is an enclosed planar guided-wave structure, suitable for mmW applications. Compared to open structures, such as microstrip or CPW, SIW does not suffer from radiation loss and interference at high frequencies.

Several antennas based on LTCC and LWG technologies were designed, for example, at 77GHz [7], 60GHz [8], and 94GHz with 5% bandwidth [9].

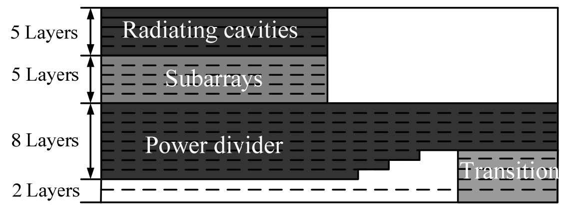
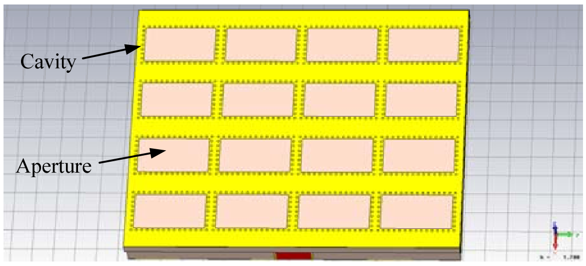
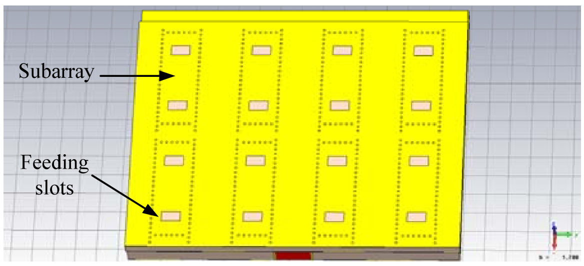


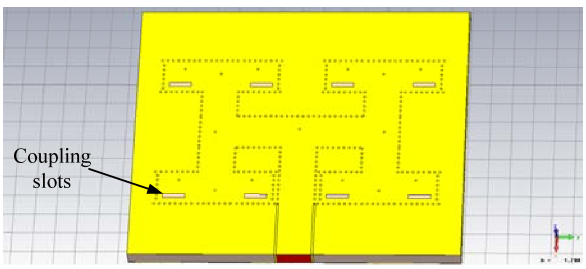
Fig. 1 Side view of the SIW antenna in LTCC



(a) radiation elements



(b) two-element subarrays



(c) power divider

Fig. 2 Top view of the SIW antenna in LTCC

LWG as a closed structure has been used for feeding a microstrip array to reduce feeding loss and improve the efficiency in [10].

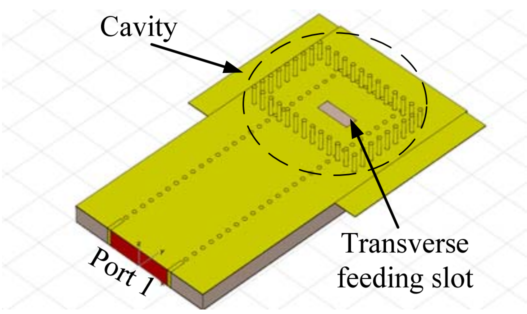
In this paper, by fully using the features of LTCC and SIW technologies, a 4×4 array antenna with a wide bandwidth is implemented. Components including a broadband multilayer SIW-RWG transition are designed and optimized. Arrays with 1×1, 1×2, and 2×2 elements are also designed and compared.

II. ANTENNA STRUCTURE

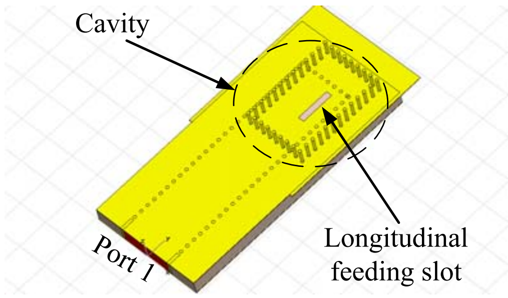
The side view of the 4×4 array antenna is shown in Fig. 1, where the portion of proposed SIW antenna is shadowed in grey. As shown in Fig. 2(a), upper 5 layers consist of array of the radiation elements. The type of the element is a slot-fed cavity [7]. The transverse and vertical spacing between adjacent elements are 3.8mm and 3mm respectively. In the middle 5 layers, there are 4×2 two-element subarrays, as shown in Fig. 2(b). The broadwall cross couplers are used for parallel feeding the two-element subarrays. The bottom 8 layers are the power divider, as shown in Fig. 2(c). For measurement purpose, a novel multilayer SIW-RWG transition is proposed. The simulation tool is the CST Microwave Studio. The LTCC material used is the Ferro A6-M, ε_r= 5.9, tan δ =0.002.

III. ANTENNA DESIGN

The radiating element is a rectangular substrate cavity with via wall. An aperture on the top layer of the cavity is for radiating while a slot on the bottom layer of the cavity is for feeding it. The cavity can serve as good transition between the substrate and the air so that wide bandwidth can be achieved. The radiating elements with transverse and longitudinal feeding slots are shown in Fig. 3. The simulated $|S_{11}|$ of them are shown in Fig. 6. It is observed that the transverse slot offers wider bandwidth than the longitudinal one. Thus, the transverse slot is used as the feeding slot for the array configuration.



(a) transverse feeding slot



(b) longitudinal feeding slot

Fig. 3 The radiating element with two feeding slots

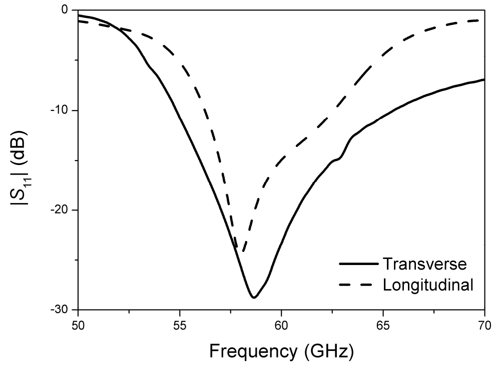
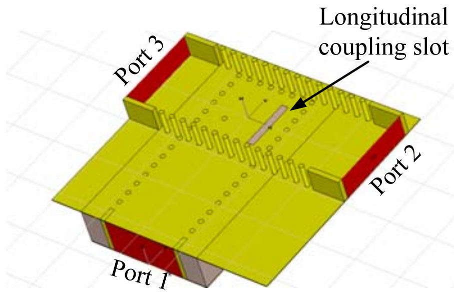
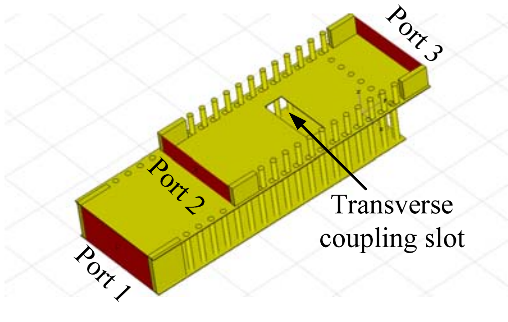


Fig. 4 $|S_{11}|$ of the radiation element with two feeding slots



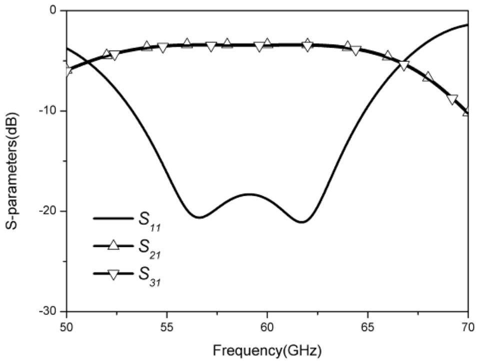
(a) cross coupler



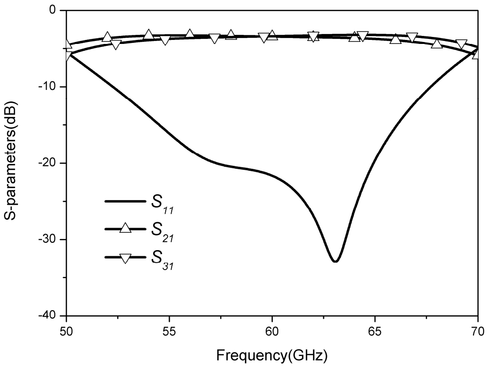
(b) parallel coupler

Fig. 5 Structure of the two couplers

The broadwall coupler is a critical component to transmit power vertically between the subarray and the power divider, as shown in Fig. 5. The simulated S-parameters of the two couplers as shown in Fig. 6 also demonstrate the wide-band feature.



(a) cross coupler



(b) parallel coupler

Fig. 6 S-parameters of the two couplers

Because the dielectric constant of the material is high, it is usually difficult to achieve wide-band transition between SIW and standard waveguide directly. A multilayer transition is proposed in Fig. 7. The substrate cavity serves as the transition between the SIW and RWG. By simulation, the 20dB return loss bandwidth is about 18% with insertion loss of less than 0.5 dB.

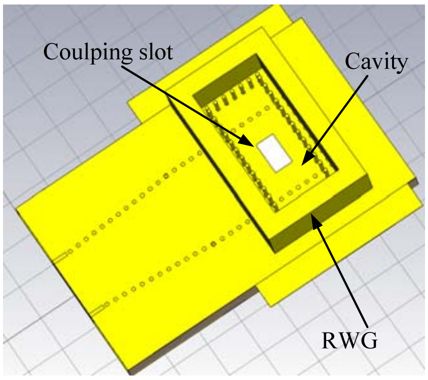


Fig. 7 Top view of the multilayer SIW-RWG vertical transition

IV. RESULTS OF THE ARRAY ANTENNA

The single subarray with the broadwall couplers can achieve broadband matching due to its symmetrical configuration. However, it is difficult to implement parallel couplers in the large array consisting of many stages of subarrays because more vertically cascaded couplers are required as the array elements increase. As a result, the required layers must increase proportionally with the increase of radiation elements. However, this causes high cost and even exceeds maximum number of layers in LTCC process.

Therefore, the cross couplers are used in array design especially for large arrays because the transverse area may increase but the thickness of the total structure are kept unchanged when the number of subarrays increases. The single subarray with the cross coupler is shown in Fig. 8.

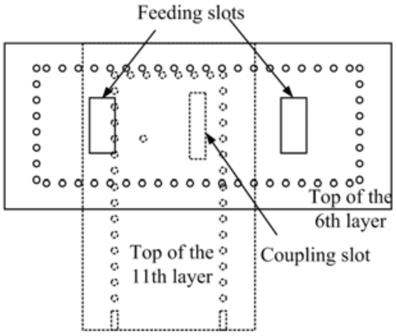


Fig. 8 Top view of the two-element subarray with cross coupler

The slot array antennas with various elements are designed and simulated. The simulation models include the SIW-RWG transition, feeding network and the radiation elements. The $|S_{11}|$ of the 4×4 array is shown in Fig. 10. The measured bandwidths for $|S_{11}|$<-10 dB is 53.5−63.8 GHz or 17.2% but it exceeds -10 dB within the range of 54.9-56.5 GHz. This degradation may be due to the fabrication tolerance and the connection of feeding RWG to the antenna. The size of the 4×4 array is 35×16mm.

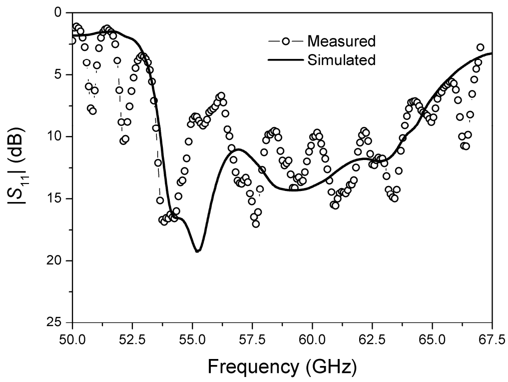
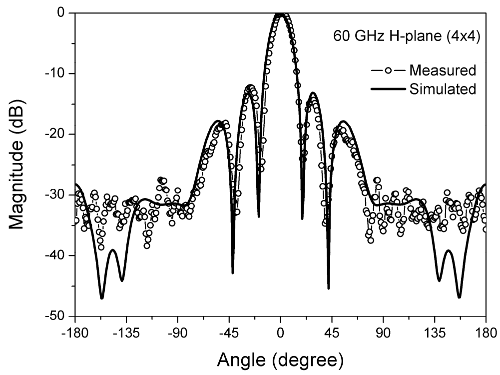
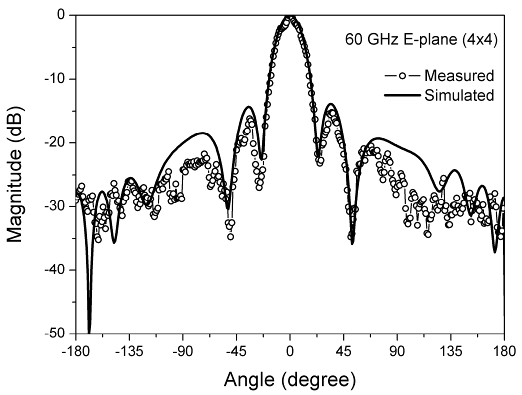


Fig. 9 $|S_{11}|$ of the 4×4 array



(a) H-plane



(b) E-plane

Fig. 10 Radiation patterns of the 4×4 array at 60 GHz

TABLE I SPECIFICATION COMPARISON

	Band-width	Gain(dBi) @60GHz	Gain ripple (dB)	Efficiency @60GHz
Single element	17.7%	6.7	0.3	90%
2-element subarray	18.5%	10.0	1.4	85%
2×2 array	17.5%	12.6	0.9	83%
4×4 array	18.2%	18.5	1.3	77%

The radiation patterns of the 4×4 array at 60 GHz are shown in Fig. 10. The measured and simulated patterns are in good agreement. The measured gain at 60 GHz is 15.8 dBi. It is also verified that the pattern characteristics are nearly unchanged throughout the whole work band. The direction of the mainlobe is kept to pint to broadside and the side lobe levels are around -13 dB. These good features are due to the symmetrically parallel-fed network. The simulated performances of single element, subarray, and various arrays are compared in Table I. Another advantage of the antenna is that the bandwidth keeps nearly constant when the array becomes larger. The small gain ripples in the work band indicate the antennas possess wide bandwidth in terms of radiation performance. The efficiencies are high for all the antennas. This may primarily attribute to the low loss feature of SIW.

V. CONCLUSIONS

A 4×4 60 GHz slot array antenna by using the advantages of both the LTCC and SIW technologies has been designed and implemented. Based on the multilayer feature of LTCC, symmetrical parallel-fed structure has been realized. Wide bandwidths of both the impedance matching and radiation have been achieved. Also, the size of the antenna has been compact because the feeding networks are under the radiation elements. Because of its close structure and low loss, the proposed SIW antenna arrays have achieved high efficiency.

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