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Empty Substrate Integrated Waveguide Slot Antenna Array for 5G Applications

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***Abstract*—This paper introduces a linear slot antenna array based on an empty substrate integrated waveguide at 28 GHz. The proposed antenna offers the advantages of reduced weight and fabrication cost as well as facilitates relatively easier integration with planar electronic components as compared to conventional slotted waveguide antenna arrays. A high gain and efficiency and low losses are major considerations which can be achieved by the proposed design when compared to the substrate integrated waveguide slot antenna array. The proposed antenna geometry suggests an operating bandwidth of 10.4% (i.e. 26.5-29.4 GHz) suitable to fulfil 5G demands with high gain performance of 11.6 dBi at 28GHz.**

***Index Terms*—5G, antenna, millimetre-wave, Empty Substrate Integrated Waveguide.**

I. INTRODUCTION

The tremendous progress and advancement of wireless communication networks have augmented the demands of available bandwidth to provide high data rates for the ever-increasing number of wireless users and applications. This trend has encouraged the researchers to look beyond lower frequency spectrum for future upgradation. Millimetre-wave (MMW) frequencies are anticipated as highly promising for the realization of next generation mobile networks (i.e. 5G) in order to deliver high data throughput and better coverage [1, 2]. However, there are several challenges involved in the development of such a system based on a number of factors. For instance, atmospheric attenuation and path losses become critically higher at these frequencies [3]. Also, the received signal power reduces at MMW frequencies as compared to lower frequency bands due to smaller effective aperture size of single element antenna. Therefore, in order to compensate these losses, the MMW communication systems are required to incorporate high gain antenna arrays.

The slotted waveguide antenna array could be a potential candidate due to a number of reasons such as, high gain profile, high efficiency, lesser complexity of feed system, simplicity of the structure and accurate control over the radiation pattern characteristics [4, 5]. Metallic rectangular waveguide (RWG) are extensively investigated in this regard, though limited due to its increased weight and fabrication cost. In order to deal with such issues substrate integrated waveguide (SIW) structure is developed, which depict the advantages of an ease of fabrication and high level of integration for slot antenna array [6, 7]. However, the key limitation in this scenario is the presence of dielectric which increases the losses as compare to conventional RWG, especially at higher frequencies [8]. The desired outcome would be to retain the advantages of RWG without compromising the low profile structural characteristics and low-cost fabrication suggested by SIW structures. In order to achieve this objective, a simple and low-cost structure is proposed in [9], referred as an Empty Substrate Integrated Waveguide (ESIW). ESIW structure is constructed by creating a void or aperture of rectangular shape in the geometry of a planar substrate. Moreover, the upper and lower surfaces as well as the lateral walls are metallized to create an empty-waveguide-like geometry. The results suggest much lower losses and improved *Q*-factor could be achieved in the devices integrated with this novel technique as compared to the equivalent designs in SIW [9].

In this paper, a linear antenna array with four radiating slots is designed. The purpose of this research is to designed an integrated waveguide slot antenna array and improve the radiation efficiency as compared to SIW based slot antenna array. The proposed design is evaluated based on numerical simulation. Detail about the measurement results will be presented in the final paper.

II. PROPOSED ANTENNA DESIGN

The proposed geometry of empty substrate integrated waveguide slot antenna array at designed frequency of 28 GHz is presented in Fig. 1. Longitudinal slots etched on the broadside of the ESIW structure interrupt the transverse current flow that excite these slots and give rise to radiation. The ESIW structure is employed on Rogers 4003 substrate ($h_{ESIW} = 0.508$ mm, permittivity $\varepsilon_r = 3.55$, and cladding thickness $t = 35$ μm). The design procedure for the proposed ESIW structure is thoroughly demonstrated in [10] and same parameters for K_a-band referred in [10] are implemented in this work as well. The ESIW structure has the microstrip-to-empty-waveguide transition at one end, and terminated by short-circuit at the opposite end to keep the standing waves inside, shown in Fig. 1. Hence, standing wave slotted waveguide antenna array configuration has been achieved by this design. In order to excite the slots to maximum, these are positioned at the peaks of the standing wave current inside the guide. To achieve this, the end slot is placed at a distance of $\lambda_g/4$ from the short-circuit waveguide termination. To get broadside beam to the waveguide, the spacing between two consecutive slots was set to $\lambda_g/2$ and placed in an alternative order around the centreline of the waveguide so that all slots are fed in phase. The detailed dimensions of the 1×4 linear array are given in TABLE I. The proposed slot antenna array is designed based on the Elliot procedure [4, 5]. As it is a uniform array so all the slots are kept at a constant offset distance from the centreline of the waveguide (shown as dotted line) in Fig. 1, resulting maximum side lobe level (SLL) of about -10 dB. Reduced levels of side lobes could be attained by adopting a non-uniform positioning of slots on either side of centreline of the waveguide.

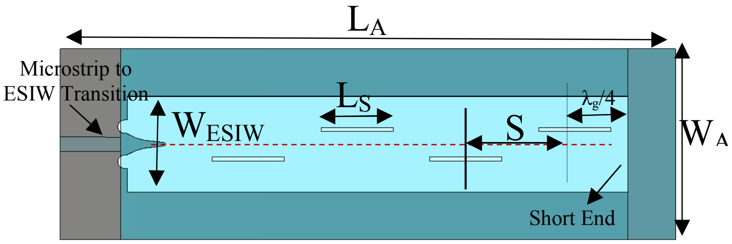


Fig. 1. Proposed ESIW Slot Antenna Array

TABLE I. DIMENSIONS OF PROPOSED ESIW SLOT ANTENNA ARRAY

Parameters	(mm)
Length of Antenna (L_A)	43.54
Width of Antenna W_A	14.22
Guided Wavelength (λ_g)	7.8
Slot Length, L_s	5.4
Slot Width, w_s	0.5
Off-Center Distance of Slots, d	0.464
ESIW width, W_{ESIW}	7.112
Spacing between two consecutive slots, s = $\lambda_g/2$	3.9

III. RESULTS AND DISCUSSION

The proposed antenna is designed, modelled and numerically evaluated using CST Microwave Studio software to inspect the suggested concept of introducing ESIW structure in order to introduce a new integrated slot antenna array at 28 GHz. The performance of antenna is inspected based on the S-parameters, radiation pattern, realized gain and efficiency. The obtained results based on simulations are discussed in detail in this section.

A. S-Paramters

The S_{11} plot of the proposed ESIW slot antenna array is provided in the Fig 2. The results show that the designed antenna offers an impedance bandwidth of 10.4% (i.e. 26.5-29.4 GHz) which is sufficient to fulfil the demands of 5G.

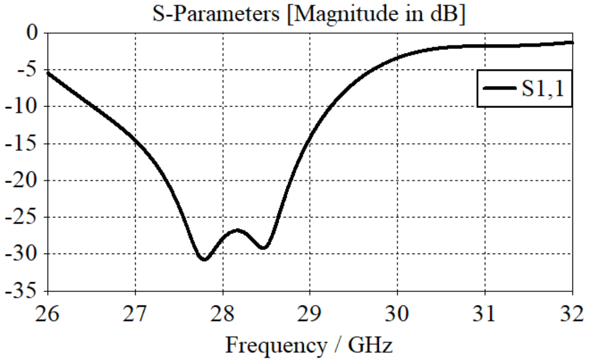
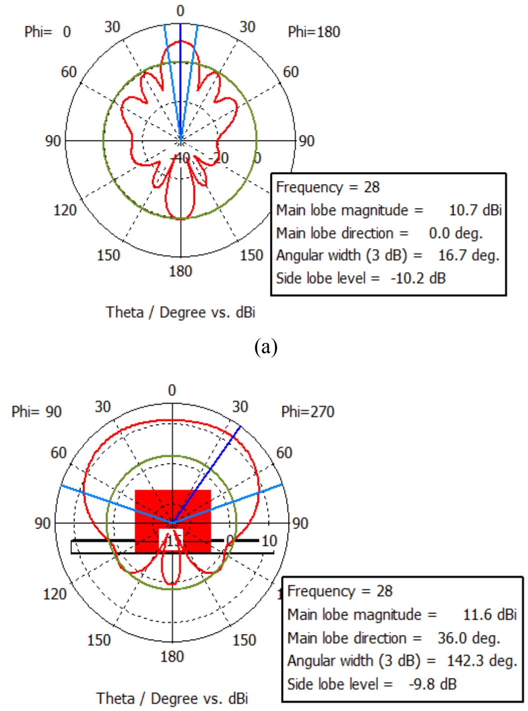


Fig. 2. S_{11} of the proposed Empty Substrate Integrated Waveguide slot antenna array.

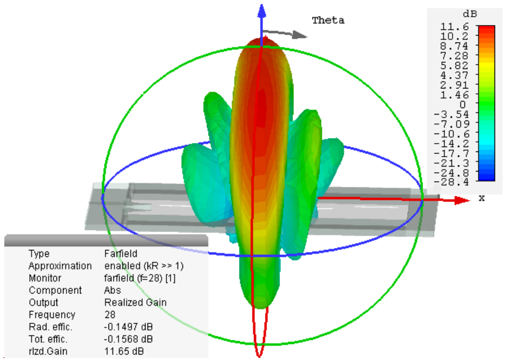
B. Radiation Pattern

The simulated E- and H-plane patterns computed at 28 GHz are presented in Fig. 3 (a and b). It is observed that the radiation profile of antenna is directed along broadside direction in both of the configurations. Also, 3D radiation pattern of the antenna array is depicted in Fig. 3 (c).



(a)

(b)



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=28) [1]
Component Abs
Output Realized Gain
Frequency 28
Rad. effic. -0.1497 dB
Tot. effic. -0.1568 dB
rlzd.Gain 11.65 dB

(c)

Fig. 3. Radiation pattern of the proposed ESIW slot Antenna Array at 28 GHz: (a) H-Plane at Phi=0º, (b) E-Plane at Phi=90º, (c) 3D radiation pattern of antenna array.

C. *Realised Gain and Efficiency*

The realised gain plot vs. frequency are provided in Fig. 4. The results depict that the realised gain for the proposed slot antenna array is about 11.6 dBi at 28 GHz. The gain performance is consistent in the proposed range of operation. Additionally, the numerically computed radiation efficiency of the designed antenna at 28 GHz is approx. 94% which shows high matching characteristics.

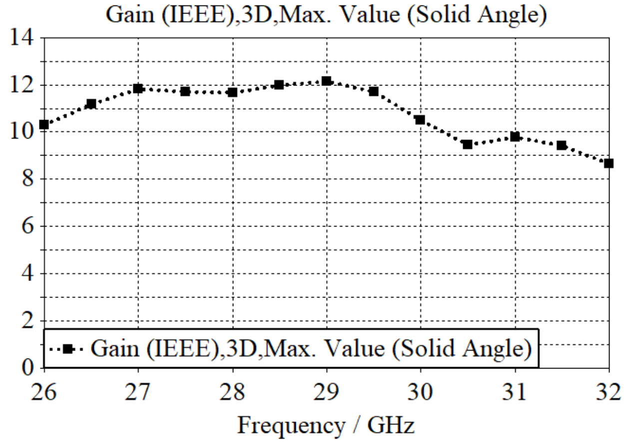


Fig. 4: Gain of the proposed ESIW slot antenna array

IV. CONLUSION

In this paper, a slot antenna array has been introduced based on a novel structure of ESIW. The antenna design is presented to deliver a low-loss and highly efficient performance at 28 GHz and also enhances the feasibility of practical implementation in a cost-effective way with relatively lesser complexity involved in the planar design modelling and integration. The designed antenna suggests an operating bandwidth of 10.4% (i.e. 26.5-29.4 GHz) with high gain of 11.6 dBi at 28 GHz. Based on these features the antenna is recommended as potential candidate to be incorporated in future 5G applications.

REFERENCES

[1] J. G. Andrews *et al.*, “What will 5G be?” IEEE J. Sel. Areas Commun., vol. 32, no. 6, pp. 1065–1082, Jun. 2014.

[2] T. S. Rappaport *et al.*, “Millimeter-wave mobile Communications for 5G cellular: It will work!,” IEEE Access, pp. 335–349, 2013.

[3] L. Wei, R. Q. Hu, Y. Qian, G. Wu, “Key elements to enable millimeter wave communications for 5G wireless systems,” *IEEE Wireless Commun*, vol. 21, no. 6, pp. 136-143, Dec. 2014.

[4] Elliott, R. S., “An improved design procedure for small arrays of shunt slots,” IEEE Trans. Antennas Propagat., Vol. 31, 48–53, Jan. 1983.

[5] 8. Elliott, R. S. andW. R. O’Loughlin, “The design of slot arrays including internal mutual coupling,” IEEE Trans. Antennas Propagat., Vol. 34, 1149–1154, September 1986.

[6] M. Ando *et al.*, “Novel single-layer waveguides for high-efficiency millimeter-wave arrays,” IEEE Trans. Microw. Theory Techn., vol. 46, no. 6, pp. 792–799, Jun. 1998.

[7] D. Deslandes and K.Wu, “Integrated microstrip and rectangular waveguide in planar form,” IEEE Microw. Wireless Compon. Lett., vol. 11, no. 2, pp. 68–70, Feb. 2001.

[8] Y. Li, W. Hong, G. Hua, J. X. Chen, K. Wu, T. J. Cui, “Simulation and experiment on SIW slot array antennas,” *IEEE Microw. Wireless Compon. Lett.*, vol. 14, no. 9, pp. 446-448, Sep. 2004.

[9] A. Belenguer, H. Esteban, and V. E. Boria, “Novel empty substrate integrated waveguide for high-performance microwave integrated circuits,” IEEE Trans. Microw. Theory Techn., vol. 62, no. 4, pp. 832–839, Apr. 2014.

[10] H. Esteban *et al.*, “Improved Low Reflection Transition From Microstrip Line to Empty Substrate-Integrated Waveguide,” IEEE Microw. Wireless Compon. Lett., vol. 27, no. 8, pp. 685–687, 2017.