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Design and Analysis of Compact Antenna for 5G Communication Devices

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***Abstract*—A novel slotted rectangular patch antenna for E and W band, which resonates at the frequency of 67 GHz and has impedance bandwidth of 13.2 GHz, is used for resolving the issues of compactness, gain and efficiency of antenna designs for future generation 5G devices such as watches, and dongles. The single element antenna, having a dimension of $5.5 \times 4.7 \times 0.381$ mm3, with a realized gain of 8.9 dBi was achieved. A rectangular slot was placed in the ground plane, just under the feed line of a microstrip patch antenna (MSPA), and this works as a defected ground structure (DGS): this improved the gain by up to 2 dB in the proposed design. The partial ground is used for tuning the impedance bandwidth. The rationale for the DGS, the partial ground, and the effect of the slot technique are discussed and implemented in this paper.**

Keywords—5G, Slot Antenna; Ultra-wideband; DGS; Partial Ground Plane

I. INTRODUCTION

In the late 20th century, communication through the wireless network system became publically accessible. The first handheld devices provided two features: calling and texting. For this purpose initially, a MHz bandwidth was quite enough to fulfil the requirement of users. After that, with the growth of telecommunication technology, people felt facilitated by the smart devices which exponentially not only increased the rate of mobile usage but also introduced high definition applications, which need much higher data rates. At the start of the 21st century, a lot of new higher frequency bands, 3G and 4G, were developed to cover the deficiency present in the system, but these were not enough for consumer needs [1]. The allocation of higher frequency bands for public use opens new doors in wireless communication, having advantages of higher bandwidth and miniaturizing of the antenna. Use of electronic devices through wireless communication is becoming more and more popular in recent times, such as the internet of things (IoT). The most used bands for the Internet of Things are Ka and W band [2]. The advantage of using the W band over Ka and other lower frequency bands is their potentially higher gain, compact size, and lighter weight [2].

The drawback in designing patch antennas for higher frequencies is due to its miniaturized size as it is known that the patch is a near-perfect radiator when a half-wavelength in size, so when a mm-wave antenna is designed, its size is so compact that it may increase conduction and reflection losses. As a patch radiator is a cavity resonator, to cover a larger bandwidth, it becomes necessary to use a thicker substrate which boosts the leakage power due to surface wave propagation [3]. Substrate integrated waveguide (SIW) and slotted waveguide provide a waveguide structure to create an array antenna and this is currently a hot topic providing up to 30 dBi of gain and narrow beamwidth, but to achieve this excellent result it is necessary to trade off the low impedance bandwidth against the large size of an antenna [4]. Some of the appropriate designs for a single patch antenna have been done, but the material used in the structure is relatively expensive and complicated [5]-[7].

In the literature, different shapes of UWB antennas, such as rectangular, square, circular, triangular, and E-shaped as elements for an array have been discussed, giving bandwidths from 3 GHz to 10 GHz [2]. By making an array of antennas, it is possible to minimize the sidelobes and receive directional radiation patterns with high gain, which is very suitable for use in a base station, radar applications, and satellite communications. In recent studies, an important techniques to solve the drawbacks of the patch is the use of metamaterials: Electromagnetic Band Gap (EBG), Artificial Metallic Conductors (AMC), High Impedance Surfaces (HIS), Frequency Selective Surface (FSS) are used in this context. The addition of slots in the ground patch, which allow the designer to control the bandwidth of the antenna by selecting patch size and thickness of the substrate [8]-[10].

Meta-materials contain periodic structures used to simulate the dielectric material. In this method, much complex calculation and analysis are required to make the artificial properties of the natural dielectric materials. Different types of meta-materials are available and are classified as Negative Index Meta-material (NIM), Single Negative Index Meta-material (SNG), Epsilon Negative Media (ENG) and Mu-Negative Index (MNG), depending upon the value of permittivity and permeability of the material [11]. The photonic bandgap (PBG) and EBG are advanced methods used to improve the results of antenna design, but the drawback of this method is its periodicity and complex nature. PBG can control the propagation of the electromagnetic wave, and its structures are periodic structures etched on the ground plane. In EBG, regular or periodic slots are introduced in the ground plane. Its structural complexity and size are less complicated than PBG, but both are very difficult to fabricate [10]-[14].

The most straightforward technique, with regard to the size, complexity, and periodicity in the etched ground structure is DGS (Defected Ground Structure), for which complex

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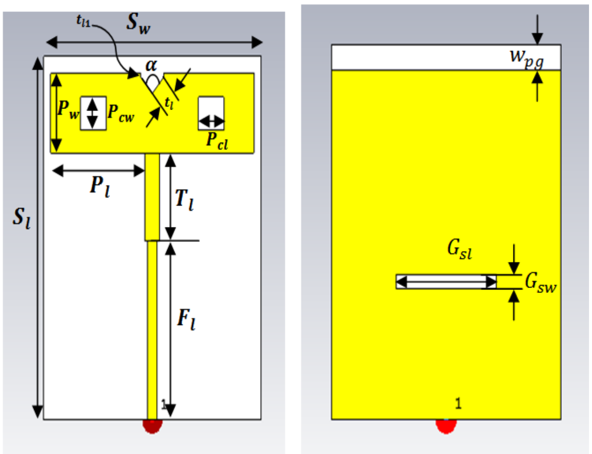
calculations and architecture are not needed; slots of any shape are only put in the ground plane to achieve the desired results for the antenna system. In the design proposed here, a partial ground plane is used to set the impedance bandwidth at the desired frequency. To improve the gain of the antenna, DGS was used and slots were made in the patch to fulfil a requirement for smartwatches, dongles, and RFID tags. The in-depth analysis for changing the flow of the current direction and producing a fringing field to improve the gain and efficiency of the antenna has been done and the length of the ground plane was changed to enable tuning and broadening of the bandwidth of the design.

II. ANTENNA DESIGN

The final design of the proposed antenna is shown in Fig. 1.



(a) Front view (b) back view

Fig. 1. The geometry of the final antenna design.

TABLE I. ANTENNA PARAMETERS

Length	Values (mm)	Length	Values (mm)
S_l	5.5	α	90°
S_w	4.7	T_l	1.34
P_w	1.2	P_l	2.05
P_{cw}	0.5	F_l	2.7
P_{cl}	0.55	w_{pg}	0.38
t_l	0.36	G_{sl}	2.06
t_{l1}	0.05	G_{sw}	0.2

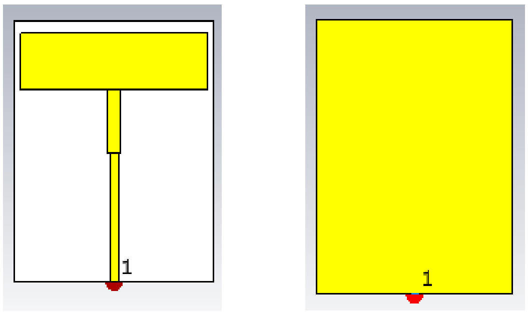
The antenna was designed on a thin rectangular layer of low-cost material (Rogers Corp. RT5880) having a substrate size of 5.5 × 4.7 × 0.381 mm^3 with relative permittivity of 2.2 and a loss tangent of 0.0009. On the front view, the rectangular radiating patch of size 1.2 × 4.4 × 0.035 mm^3 is fed by a 50 Ω feed line (0.2 mm width). Due to the need for impedance matching the proposed antenna feed line is divided into two parts, the upper part, which is slightly thicker than the lower part, which works as a quarter-wave transformer (0.3 mm width). To improve the gain, two rectangular slots were introduced, and a cut appears in the middle of the patch is for increasing the efficiency and removing the reflection effect on the feed line. The antenna geometry parameters are shown below in Table I.

III. PARAMETRIC ANALYSIS

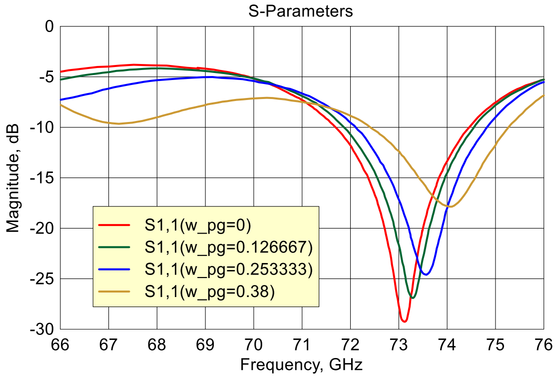
A. Effect of Partial Ground Plane

A basic patch antenna (front and back view) is presented in Fig 2. The impedance bandwidth of the patch is widened by changing the length of the ground plane. S11 was studied for different values of ground plane dimensions.

In Fig. 3, the behaviour of the S-parameters when using a slot in the front of the patch is shown. The solution found covers approximately 8 GHz impedance bandwidth for S11 better than −6 dB with a 74 GHz resonance frequency. Slots performed a pivotal role to improve the gain of the antenna: the two rectangular slots in the front have improved the gain by 1 dB in the design. The v-shaped cut in the middle of the patch is placed to remove reflection effects.



(a) Front (b) back

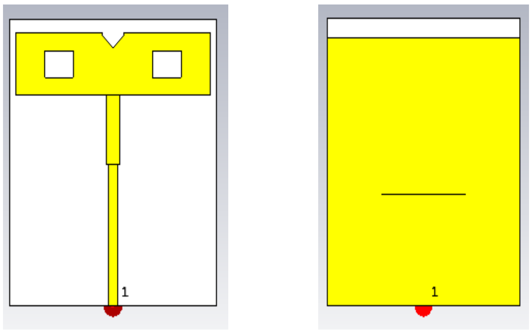


(c) Reflection coefficient

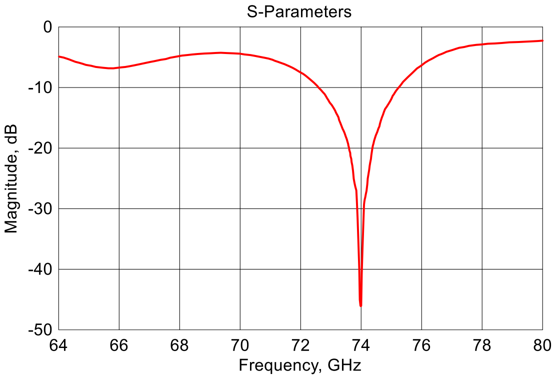
Fig. 2. The geometry of the proposed antenna (Step I).

B. Effect of Defected Ground Structure

DGS is a popular emerging technique in antenna design. It makes the design more flexible due to its simple non-periodic structure. In the present design, we get 2 dB more gain and enhance 2 GHz of impedance bandwidth by simply putting a rectangular slot having a dimension of 2.06 × 0.2 mm at 3 mm above the lower edge of the ground plane, as shown in Fig. 4.

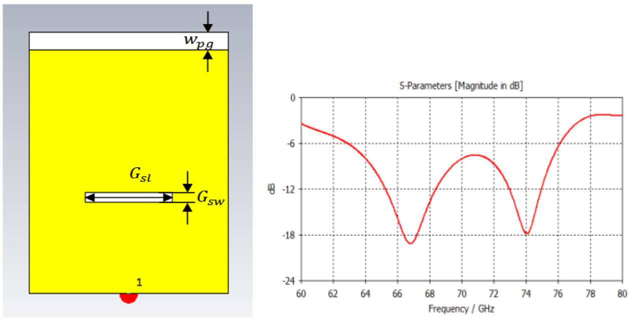


(a) Front (b) back



(c) Reflection coefficient

Fig. 3. The geometry of the proposed antenna (Step II).



(a) Back view (b) S-parameter

Fig. 4. The geometry of the proposed antenna (Step III).

IV. SIMULATION RESULTS

To simulate the antenna, Computer Simulation Technology (CST) Studio 2018 was used. By using the above-mentioned techniques, a suitable antenna for 5G devices like watches dongles and RFID tags, working in the W and E bands was designed, covering 100% allocated bandwidth for W Band with S11 under −6 dB: the gain was 9 dBi and the total radiated efficiency was 96% at the resonant frequency and above 75% for the whole band. From the simulated results a 13.3 GHz impedance bandwidth was attained (62.7 to 76 GHz) considering $S11 < -6$ dB as a reference and two bands were obtained where S11 was under −10 dB: these covered 64.8 to 69 GHz and 72.5 to 75.1 GHz, with impedance bandwidths of 4.2 GHz and 3.1 GHz for W and E bands respectively. The return loss and realized gain of the proposed antenna are depicted in Fig. 5 and Fig. 6, respectively.

The overall gain of the antenna is above 5.9 dBi for the whole band, and a maximum of 8.9 dB is obtained by using the DGS technique. The total radiated efficiency is greater than 76% throughout the band, and maximum efficiency is 96%, as shown in Fig. 7. This antenna has radiation patterns that are acceptable for mobile applications at different frequencies, as shown in Fig. 8.

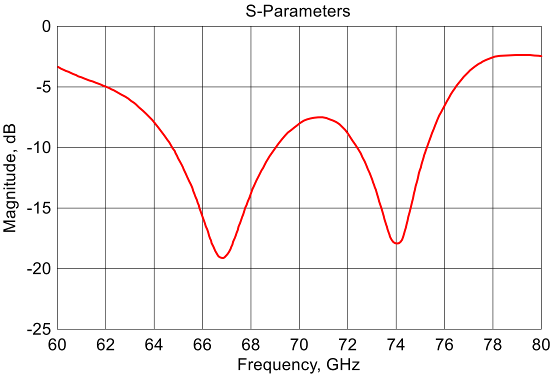


Fig. 5. Reflection coefficient.

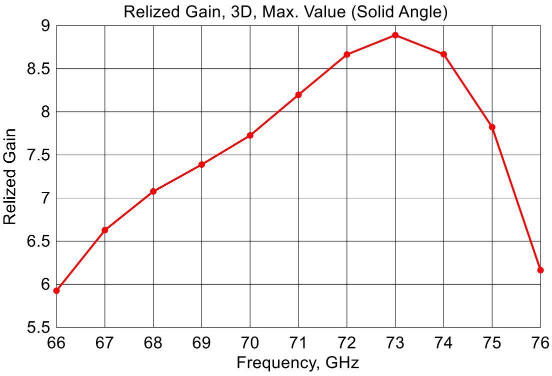


Fig. 6. Realized gain of the antenna.

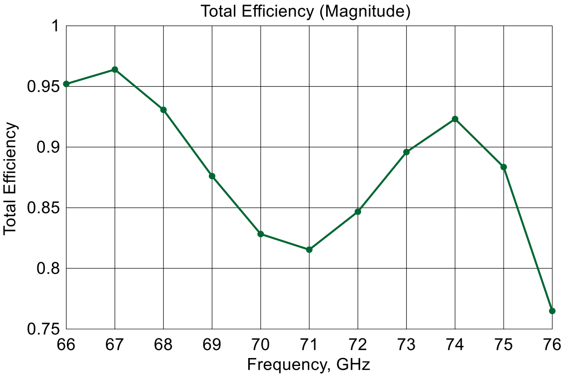
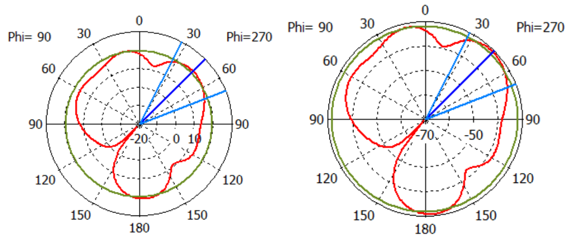
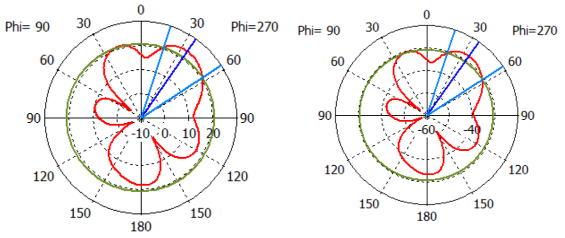


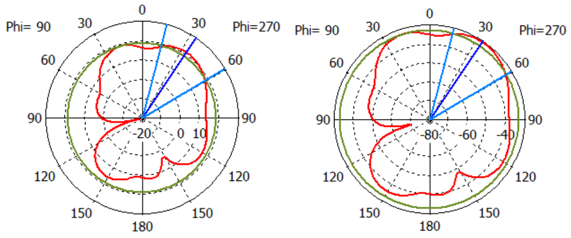
Fig. 7. The total efficiency of the designed antenna.



(a) E-field at 66 GHz (b) H-field at 66 GHz



(c) E-field at 73 GHz (d) H-field at 73 GHz



(e) E-field at 76 GHz (f) H-field at 76 GHz

Fig. 8. Radiation plots at different frequencies.

The voltage standing wave ratio (VSWR) is less than 3.5 for −6 dB return loss, and there are two bands where the return loss is better than −10 dB, centred around 67 and 74 GHz: Fig. 9 shows the VSWR, from which return loss can be derived. The radiation patterns in the E and H planes are shown in Fig. 8 at different frequencies in order to determine the beam width, beam shape, directivity, and radiated power of the proposed design.

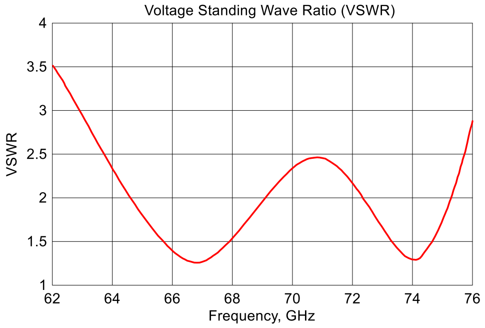


Fig. 9. VSWR of the proposed antenna.

V. CONCLUSION

An in-depth analysis of the introduction of slots on a patch antenna has been undertaken, to change the current density and direction of fringing fields. In this paper, the design constraints on a W and E band patch antenna for 5G communication devices such as smartwatches and dongles has been attempted, by introducing slots on the patch, which give a good result covering a wide bandwidth of 66 to 76 GHz, having a maximum realized gain of 8.9 dBi and total radiation efficiency of 76%, requiring only a single patch of compact size.

REFERENCES

[1] D.C. Cox, “Fundamental limitations on increasing data rate in wireless systems,” *IEEE Communications Magazine*, vol. 46, no. 12, pp. 16-17, Dec. 2008.

[2] Y. Niu, and B. Hu, “A Dual-Polarized Full-Corporate Waveguide Slot Array Antenna on W-Band,” in *Proc. 2018 12th International Symposium on Antennas, Propagation and EM Theory (ISAPE)*, 2018, pp. 1-3.

[3] C. Locker, T. Vaupel, and T.F. Eibert, “Radiation efficient unidirectional low-profile slot antenna elements for X-band application,” *IEEE transactions on antennas and propagation*, vol. 53, no. 8, pp. 2765-2768, Aug. 2005.

[4] H. Luo, W. Tan, L. Gen, Y. Xiao, and H. Sun, “Design and implementation of a W-band 16 × 16 slot array antenna with Low Sidelobe Level,” *IEEE Antennas and Wireless Propagation Letters*, 2019.

[5] Y. J. Cheng, Y. X. Guo, and Z. G. Liu, “W-band large-scale high-gain planar integrated antenna array,” *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 6, pp. 3370-3373, June 2014.

[6] A. Deshmukh, and K. P. Ray, “Analysis of broadband variations of U-slot cut rectangular microstrip antennas,” *IEEE Antennas and Propagation Magazine*, vol. 57, no. 2, pp. 181-193, April 2015.

[7] Kin-Lu Wong, and Wen-Hsis Hsu, “A broad-band rectangular patch antenna with a pair of wide slits,” *IEEE Transactions on Antennas and Propagation*, vol. 49, no. 9, pp. 1345-1347, Sept. 2001.

[8] X. Zhang, L. Jin, Y. Ji, and L. Che, “Design of a novel broadband flaps antenna for W-band application,” in *Proc 2016 IEEE 13th International Conference on Signal Processing (ICSP)*, Chengdu, 2016, pp. 1795-1798.

[9] F. Ren, W. Hong, and K. Wu, “W-band series-connected patches antenna for multibeam application based on SIW butler matrix,” in *Proc. 2017 11th European Conference on Antennas and Propagation (EUCAP)*, Paris, 2017, pp. 198-201.

[10] A. A. Deshmukh, A. A. Desai, P. Kadam, and K. P. Ray, “Ultra-wide band E-shaped patch antenna,” in *Proc. 2016 IEEE Annual India Conference (INDICON)*, Bangalore, 2016, pp. 1-5.

[11] Krishnananda, and T. S. Rukmini, “EBG antennas: Their design and performance analysis for wireless applications,” *International Journal of Computer Applications*, vol. 48, no. 23, pp. 20-27, June, 2012.

[12] A. Deshmukh, and K. P. Ray, “Analysis of broadband variations of U-slot cut rectangular microstrip antennas,” *IEEE Antennas and Propagation Magazine*, vol. 57, no. 2, pp. 181-193, April 2015.

[13] Q. Li, Y. Wei, M. Tan, X. Lei, G. Wu, M. Huang, Y. Gong, “Flexibly extensible planar self-isolated wideband MIMO antenna for 5G communications,” *Electronics*, vol. 8, no. 9, article 994, Sept. 2019.

[14] M. Young, *The Technical Writer’s Handbook*. Mill Valley, CA: University Science, 1989.