ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

BANDWIDTH ENHANCED AND SIDELOBES LEVEL REDUCED RADIAL LINE SLOT ARRAY ANTENNA AT 28 GHz FOR 5G NEXT GENERATION MOBILE COMMUNICATION

Ibrahim Maina[1, 2], Tharek Abd. Rahman[1] and Mohsen Khalily[1]
[1]Wireless Communication Center (WCC), Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Skudai, Johor Bharu, Malaysia
[2]Abubakar Tafawa Balewa University, Bauchi, Nigeria
E-Mail: imaina32@yahoo.com

ABSTRACT
Radial Line Slot Array Antenna has simple structure and exhibit good radiation characteristics. It is low cost, easy to manufacture with high gain and it found application in services like Direct Broadcast Services and Wireless LAN. Its features make it attractive for millimeter wave mobile broadband applications like the fifth generation (5G) mobile communication system. Also, it can be designed for circular, linear or elliptical polarization. But achieving a reduced sidelobes level has not been an easy task in its design. This paper presents a simple technique to improve the impedance bandwidth and reduce the sidelobes level in linearly polarized Radial Line Slot Array Antenna at 28 GHz for 5G mobile communication system. In the design, high frequency laminate RT duroid 5880 and air gap were utilized with a modified dielectric coated 50 Ω SSMA connector as the coaxial to waveguide transition. The technique was experimented via simulation on Computer Simulation Technology Microwave Studio 2014 software. The simulation result gave a return loss of -18.98 dB at 28 GHz. Gain of 23.3 dB, 10 dB impedance bandwidth of 1.28 GHz, sidelobes levels of: -16.5 dB (E-plane); -17.5 dB (H- plane) and efficiency of 96 % were also realized.

Keywords: 5G, radial line slot array antenna, sidelobes level, 28 GHz.

INTRODUCTION
Over the years, interest in mobile data have and is still experiencing an unprecedented growth. This growth is further fuelled by the emergence of new data hungry devices like e-book readers, notebooks, smartphones, tablets etc. It is envisaged that the next generation of wireless system informally called the fifth Generation (5G) will be data intensive and will support myriad of connectivity between machines, humans, devices and a lot more. In short, there will be connectivity between anything, anywhere and anytime. Hence the need for available spectrum to support these services becomes critical. The sub 3 GHz spectrum has since being exhausted while the 3 - 300 GHz remains underutilized. In the 3 - 300 GHz span, 3 - 30 GHz is called Super High Frequency (SHF) band while 30 - 300 GHz is known as Extremely High Frequency (EHF) or millimeter wave band. But according to Zhouyue and Khan [1], since they share the same propagation characteristics they can be referred collectively as millimeter wave band with wavelength ranging between 1 to 100 mm. This window, pave the way for multi gigabit data rate provision over short distance. Additionally, assessment of capacity and measurement study of millimeter wave mobile broadband presented in [2] demonstrated the suitability of 28 GHz for this technology which utilizes cell size of around 200 m with power friendly microcell or picocell base station. The technology favoured narrow beams for signal transmission and reception. Because with narrow beam, interference from neighbouring cells is suppressed and overlap among adjacent cells can be managed effectively. Therefore the design of narrow beam antenna with an appreciable reduced level of sidelobes and sufficient bandwidth is paramount for 5G operation. Hence Radial Line Slot Array (RLSA) antenna which has inherent narrow beam characteristics becomes a potential candidate antenna for this application.

The use of RLSA for microwave and millimeter wave application is not totally a recent idea as reported by Albani *et al* [3]. Research on RLSA started in the early 60’s. Its design was pioneered by Kelly in the late 1950 [4]. This antenna can radiate and receive pencil shaped beams which can be made to be linear [5], circular [6], [7] or elliptically polarized. Much attention on this antenna was seen around the year 1985 [6] focusing mainly on satellite applications [8]. Its high gain characteristics motivated its development for Wireless LAN, mobile satellite and EHF or millimeter wave band [9].

So with the development of broadband mobile technology going on, RLSA which is low cost, with ease of manufacture, installation, high gain, efficiency, and narrow beam automatically presents itself as a solution antenna. Furthermore, with the envisaged massive wireless connectivity to be offered by 5G, interference issues will become a challenge. Hence the need for not only narrow beam antenna but with reduced sidelobes level too. In the referred literatures, attention has been on achieving high gain while suppressing grating lobes by the use of cavity material with dielectric constant greater than 1 only.

ARPN Journal of Engineering and Applied Sciences

Therefore this paper presents a simple design to realize an enhanced bandwidth and a reduced sidelobes level in linearly polarized RLSA at 28 GHz for 5G mobile communication system with a caveat that the antenna must have a gain of at least 12 dB, 10 dB impedance bandwidth of 1 GHz [10]. The remaining paper is organized as follows: The conventional structure of the antenna was first highlighted followed by brief explanation on how to achieve the feed transition customization. The proposed antenna design is then explained followed by results, conclusions and acknowledgment.

The conventional RLSA structure

The theory and design of RLSA with linear polarization fed by disk ended feed probe have been succinctly dealt with in [8], [11]. Its standard or conventional form consist basically of two parallel plates spaced a distance *d*. The upper plate contains the radiating slots patterns and the lower plate acts as the ground. This is pictorially shown in Figure-1.

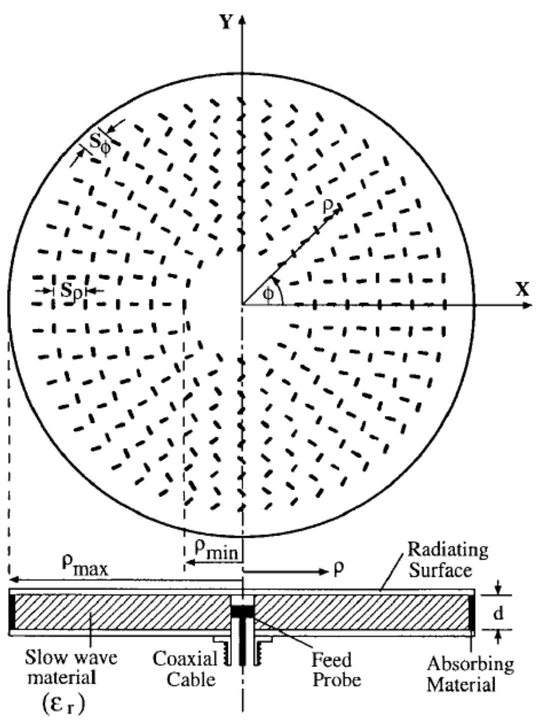


Figure-1. Standard form of RLSA [12].

The space *d* which act as the radial waveguide is usually filled with a dielectric material of suitable relative permittivity (ε_r). *d* is restricted by the relation

$$d < \frac{\lambda_g}{2} \quad (1)$$

where $\lambda_g = c / \sqrt{\mu_r \varepsilon_r}$

and

λ_g wavelength in the guide

c speed of light

μ_r relative permeability

The dielectric material create a slow wave in the guide resulting in $\lambda_g < \lambda_o$ (free space wavelength) to prevent grating lobes from appearing in the radiation pattern. It was recommended in [8] that ε_r must be greater than 1 for that to be achieved. As shown in Figure-1, a circle of radius ρ_{min} around the feed probe is left devoid of slots to allow the formation of axially symmetric traveling wave. The slots are arrayed along the radial distance ρ spaced S_ϕ and S_ρ in azimuth and radial directions respectively. The slot orientation and these separations are controlled to space the slots in a defined distribution on the radiating surface so that their radiation is added in phase in the beam direction and also yield linear polarization. The axially symmetric outward travelling wave is launched into the guide by the rear center fed disk ended dielectric coated coaxial to waveguide transition feed probe. This ensures that only TEM mode propagate in the radial cavity. And to realize uniform illumination over the radiating surface according to [12] the slot length is varied with respect to the radius ρ_{max} of the radiating surface according to the relation.

$$l_{rad} = \left(5.8678 + 6.415 \times 10^{-3} \rho\right) \frac{12 \times 10^9}{f_o} \quad (2)$$

f_o is the center frequency.

The slot then couples the wave in the desired direction at the radiating surface. The radiating surface and ground were made of copper plates.

The feed transition

The feed transition utilized in this paper is a dielectric coated 50 Ω SSMA connector modified with disk ended head. This arrangement as used in previous researches was found to effectively convert the signal from TEM coaxial mode to the desired TEM cavity mode. An amplified section of this transition in the standard form design is shown in Figure-2. The choice of SSMA (frequency handling range 100 MHz - 40 GHz) was informed by the desired center frequency which is 28 GHz. With the ceiling placed on *d* by equation (1), variables R (diameter of the disk head), *a* (height of air space above the head), *b* (height of the disk head) and *c* (height of air space below the head) need be optimized to achieve the optimum performance. More analysis on this type of transition can be found in [13].

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

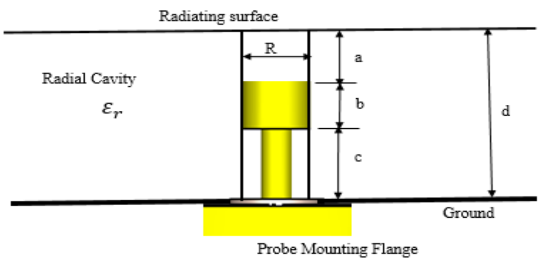
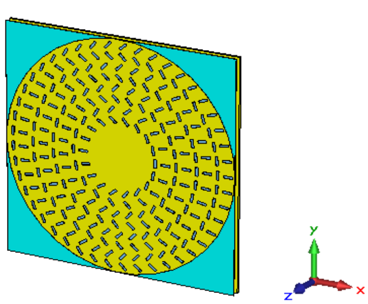


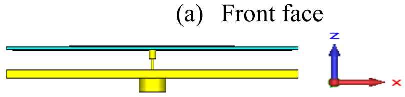
Figure-2. Disk ended coaxial to waveguide transition.

Proposed antenna structure

The frequencies of applications were RLSA was given much attention enumerated in the literatures allowed for almost a centimeter value of *d* to be used and achieving low sidelobes level has not been of major concern. But for the application in question here, the need to have low sidelobes level and the corresponding value of *d* makes it difficult to achieve an optimum and acceptable customization with the conventional design structure. To simplify the design, the concept of using air gap layer in antenna structure as presented in [14], [15] and [16] was adapted. The concept was demonstrated for RLSA with FR4 laminate utilizing none disk ended dielectric coated 50 Ω SMA connector at 26 GHz [17] and 5.8 GHz [18] with success. In this paper, the idea was extended to include a disk ended 50 Ω dielectric coated SSMA probe and RT duroid 5880 high frequency laminate. The air gap is formed between the ground and the RT duroid 5880 board all having rectangular shapes while the radiating surface with circular dimension sits on top of the board. With such arrangement, the manufacturing process was further eased. In addition, the use of rectangular shaped cavity and ground in the proposed design was to have a well aligned structure. The disk ended feed probe post was made to resides completely within the air gap. CST perspective of the design is shown in Figure-3. To achieve optimum performance, we optimize only R and *b*.



(a) Front face



(b) Side view

Figure-3. CST perspective of the modified design.

RESULTS

Both the conventional and the proposed designs were simulated. Likewise air gapped with none disk ended design was also simulated. The specifications of the parameter used are listed in Table-1. In the conventional design, polypropylene was used as the cavity material. Polypropylene was used because it was favoured for most of the RLSA designs in the literatures. R, *a*, *d* and *c* were set to be 2.6 mm, 0.3 mm, 1.5 mm and 1.2 mm respectively (the best for the arrangement). For the air gap design, RT duroid 5880 of thickness 0.254 mm with dielectric constant 2.2 was used along with air gap of 2.5 mm. The dimension for the air gap was born from the desire to achieve a low overall dielectric constant for the cavity while not violating the restriction on *d*. For the proposed design with parameters given in Table-1, the overall cavity dielectric constant was found to be 1.12. The simulation results are as shown in Figures 4 to 9.

Table-1. The specification of the simulated antennas.

Parameter	Value
Centre frequency f_o	28 GHz
Cavity thickness(Maximum) *d*	3.0 mm
Radius of antenna	50 mm
No. of slots in first ring	18
Thickness of radiating surface (copper)	0.1 mm
Thickness of ground (copper)	1.0 mm
Relative permittivity of RT duroid 5880 Polypropylene	2.2 2.4

The S-parameter results for the optimization of the proposed design is shown in Figure-4. The best performance was observed with *b* = 1.7 mm and R = 2.2 mm with S_{11} value of -18.98 dB at 28 GHz and a 10 dB impedance bandwidth of 1.28 GHz at first instance.

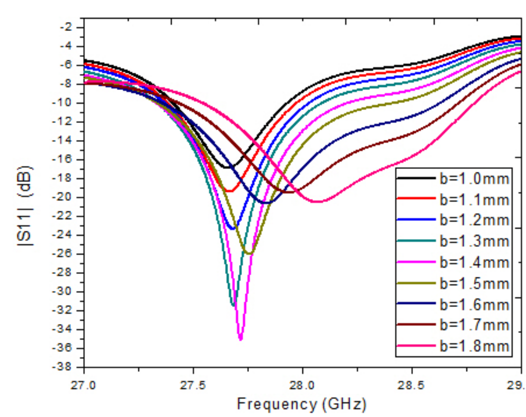


Figure-4. Simulated reflection coefficient of the proposed air gap design with R = 2.2 mm and variable *b*.

VOL. 10, NO. 14, AUGUST 2015 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

To establish the optimum design point with b = 1.7 mm, different values of R were used as in Figure-5. It was confirmed that the best performance is still with the set R = 2.2 mm and b =1.7 mm.

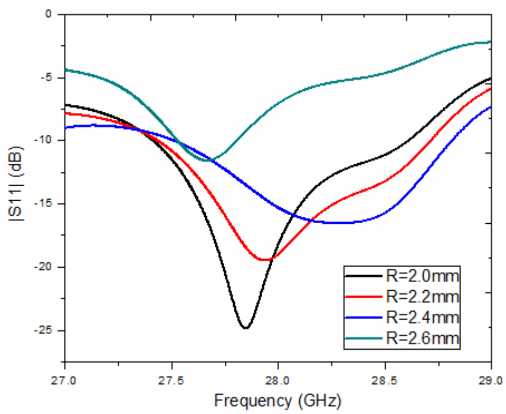


Figure-5. Simulated reflection coefficient of the proposed air gap design b = 1.7 mm with variable R.

For the conventional and the proposed designs, the S-parameter results obtained were compared as shown in Figure-6. The performance improvement both in term of S_{11} and bandwidth for the proposed design can be clearly seen. The conventional had a bandwidth of 0.92 GHz which did not fulfil the bandwidth requirements for 5G as mentioned before, while the proposed RLSA had a 10 dB bandwidth of 1.28 GHz. To further confirm the claimed improvement brought in by adding the disk head in the air gap design, a none disk ended design as earlier mentioned was simulated. Its result is depicted in Figure-7, where an impedance bandwidth of only 0.28 GHz was observed. This further reveals the suitability of the proposed design for the target frequency band and application.

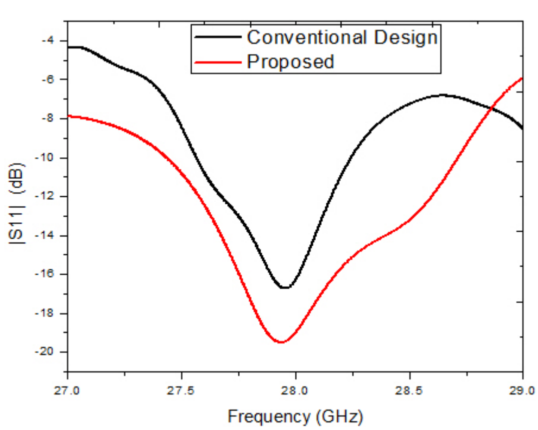


Figure-6. Simulated reflection coefficient of the proposed design compared with the conventional design.

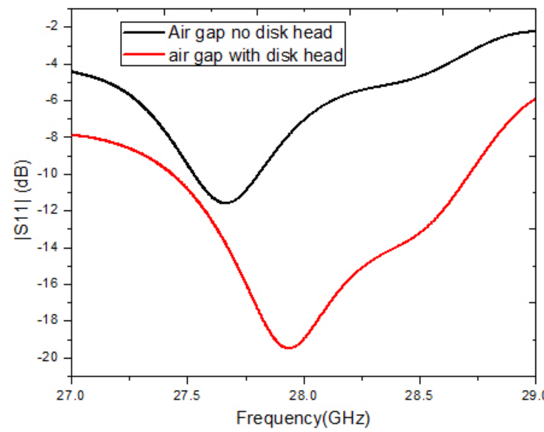


Figure-7. Simulated reflection coefficient of the proposed design and air gap none disk ended design.

The achieved reduced sidelobes levels are revealed from the E - and H - plane radiation patterns of the conventional and modified design as shown in Figures 8 and 9. Sidelobes level of -16.5 dB, 3 dB half power beam width of 7.5^o and -17.5 dB, 3 dB half power beam width of 7.5^o were achieved in the E - and H - planes respectively for the proposed as against -13.9 dB and -8.3 dB for the E - and H - planes in the conventional design. Furthermore, the CST results showed that the antenna has radiation efficiency of -0.1823 dB. Which means that the proposed antenna has an efficiency of 96 %.

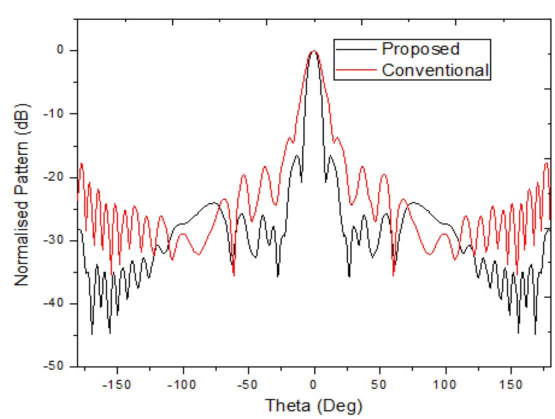


Figure-8. E -plane radiation pattern.

ARPN Journal of Engineering and Applied Sciences

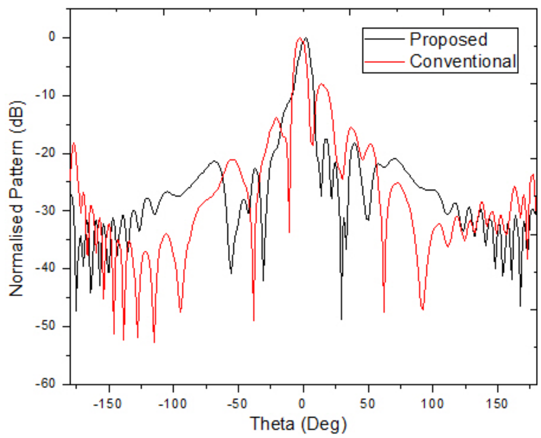


Figure-9. H -plane radiation pattern.

CONCLUSIONS

A hybrid low profile air gap disk ended probed linearly polarized RLSA was designed and simulated. The simulations were carried out on Computer Simulation Technology Microwave Studio 2014 platform. By properly adjusting the critical design parameters, a compact antenna with radius of 50 mm having enhanced impedance bandwidth and reduced sidelobes level for mobile broadband application at 28 GHz was realized meeting all the supposed requirements for 5G antennas. The air gap and the disk ended probe greatly improved the return loss, the realized bandwidth, and the achieved low sidelobes as compared to the conventional and the air gapped with none disk ended probe designs. An acceptable gain that surpass the limit set for 5G application was also achieved while sidelobes levels in both E - and H - planes were pushed down. All these suggest that the antenna can suitably be used for mobile broadband applications like the 5G.

ACKNOWLEDGEMENT

The authors are very grateful to the Malaysian Ministry of Higher Education (MOHE), the Research Management Centre (RMC), and the Wireless Communication Center (WCC), Universiti Teknologi Malaysia (UTM), under Research University Grants Vote No. 01K29, HiCOE grant for supporting this study.

REFERENCES

[1] Z. Pi and F. Khan. 2011. An introduction to millimeter-wave mobile broadband systems. Communications Magazine, IEEE. 49: 101-107.

[2] S. Rangan, T. S. Rappaport and E. Erkip. 2014. Millimeter-Wave Cellular Wireless Networks: Potentials and Challenges. Proceedings of the IEEE. 102: 366-385.

[3] M. Albani, A. Mazzinghi and A. Freni. 2012. Automatic Design of CP-RLSA Antennas. Antennas and Propagation, IEEE Transactions on. 60: 5538-5547.

[4] K. Kelly. 1957. Recent annular slot array experiments. In 1958 IRE International Convention Record. pp. 144-152.

[5] M. Ando, T. Numata, J. I. Takada and N. Goto. 1988. A linearly polarized radial line slot antenna. Antennas and Propagation, IEEE Transactions on. 36: 1675-1680.

[6] M. Ando, K. Sakurai, N. Goto, K. Arimura and Y. Ito. 1985. A radial line slot antenna for 12 GHz satellite TV reception. Antennas and Propagation, IEEE Transactions on. 33: 1347-1353.

[7] N. Goto and M. Yamamoto. 1980. Circularly Polarized Radial Line Slot Antennas. IEICE Technical Report. Vol. 57-80.

[8] P. W. Davis and M. E. Bialkowski. 1997. Experimental investigations into a linearly polarized radial slot antenna for DBS TV in Australia. Antennas and Propagation, IEEE Transactions on. 45: 1123-1129.

[9] T. Purnamirza, T. A. Rahman and M. H. Jamaluddin. 2012. The Extreme Beamsquint Technique to Minimize the Reflection Coefficient of Very Small Aperture Radial Line Slot Array Antennas. Journal of Electromagnetic Waves and Applications. 26: 2267-2276.

[10] F. Khan, P. Zhouyue and S. Rajagopal. 2012. Millimeter-wave mobile broadband with large scale spatial processing for 5G mobile communication. In Communication, Control, and Computing (Allerton), 2012 50th Annual Allerton Conference on. pp. 1517-1523.

[11] J. I. Takada, M. Ando and N. Goto. 1992. A reflection cancelling slot set in a linearly polarized radial line slot antenna. Antennas and Propagation, IEEE Transactions on. 40: 433-438.

[12] P. W. Davis and M. E. Bialkowski. 1999. Linearly polarized radial-line slot-array antennas with improved return-loss performance. Antennas and Propagation Magazine, IEEE. 41: 52-61.

[13] M. E. Bialkowski. 1991. Analysis of a coaxial-to-waveguide adaptor incorporating a dielectric coated probe. Microwave and Guided Wave Letters, IEEE. 1: 211-214.

[14] S. M. Shum and K. M. Luk. 1994. Characteristics of dielectric ring resonator antenna with an air gap. Electronics Letters. 30: 277-278.

[15] D. Guha and J. Y. Siddiqui. 2004. Resonant frequency of equilateral triangular microstrip antenna with and without air gap. Antennas and Propagation, IEEE Transactions on. 52: 2174-2178.

[16] D. Bhardwaj, Komal, D. Bhatnagar and S. Sancheti. 2008. Square patch microstrip antenna with single notch having an air gap. In Recent Advances in Microwave Theory and Applications, 2008. MICROWAVE 2008. International Conference on. pp. 910-912.

[17] I. M. Ibrahim, T. A. Rahman, M. I. Sabran, U. Kesavan and T. Purnamirza. 2013. Wide Band Open Ended Air Gap RLSA Antenna at 26 GHz Frequency Band. Progress in Electromagnetic Research Symposium Proceedings. pp. 470-473.

[18] W. A. W. Muhamad, T. A. Rahman and M. F. Jamlos. 2013. The effects of air-gap on spider radial line slot array (SRLSA) antenna for point to point application. In Wireless Technology and Applications (ISWTA), 2013 IEEE Symposium on. pp. 388-390.