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Development of a Millimeter Wave Eight-Element Phased Array Antenna for 5G Mobile Communications

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Abstract

The fifth generation (5G) mobile communications systems demand millimeter wave (mmWave) bands of the electromagnetic spectrum beside the current sub-6 GHz frequencies. Allocation of mmWave frequencies for the cellular systems will ensure more capacity and higher speed links. For the last few years wireless communications societies in industry and academia have put significant research effort to develop novel and efficient antenna architectures. We need brand-new antenna structures that can overcome the challenges of 5G communications environment such as high propagation loss of mmWaves and the large bandwidth demand of the planned networks. In this paper, a microstrip mmWave antenna array for 5G mobile phone terminals is introduced. First, the single antenna element with the rectangular patch radiator is investigated. The numerical investigation is carried out with a full-wave electromagnetic solver. The single antenna design operates between 27.1 GHz – 28.95 GHz frequencies. The proposed antenna based on microstrip approach shows low profile characteristics without compromising performance. A maximum gain of ~7.7 dBi is achieved within the operation band. Then eight-element phased array implementation of the proposed antenna is analyzed. Uniformly spaced linear array method is used with $\sim\lambda/2$ spacing in the configuration. The eight-element array boosts the maximum total gain value up to ~15 dBi, and yields beam steering at broadside up to $\pm 50^\circ$ with low side lobe levels (SLL). Furthermore, the proposed phased array design is compact with the dimensions of 10 mm×48.6 mm×0.51 mm, and therefore it is compatible with the mmWave band radio frequency integrated circuit (RFIC) transceivers.

Keywords: Phased Array, Millimeter-Wave Antenna, Fifth Generation, 5G.

5G Mobil Haberleşme için Milimetre Dalga Sekiz Elemanlı Faz Dizisi Anten Geliştirilmesi

Öz

Beşinci nesil (5G) mobil iletişim sistemleri, mevcut 6 GHz altı frekans bölgesinin yanı sıra spektrumun milimetre dalga (mmDalga) bantlarını da talep ediyor. Hücresel sistemlere mmDalga frekanslarının tahsisi, daha fazla kapasite ve daha hızlı bağlantılar sağlayacaktır. Son birkaç yıldır endüstri ve akademideki kablosuz iletişim toplulukları, yeni ve verimli anten mimarileri geliştirmek için önemli bir araştırma çabası içine girdiler. Yüksek mmDalga yayılma kaybı ve planlanan ağların büyük band genişliği talebi gibi 5G iletişim ortamının zorluklarının üstesinden gelebilecek yepyeni anten yapılarına ihtiyacımız olduğu açık. Bu çalışmada, 5G cep telefonu terminalleri için bir mikroşerit mmDalga anten dizisi geliştirilmiştir. İlk olarak, dikdörtgen yama yapıdaki tek anten elemanı incelenmiştir. Benzetim çalışmaları tam dalga elektromanyetik çözücü ile gerçekleştirilmiştir. Tek anten tasarımı 27.1 GHz – 28.95 GHz frekansları arasında çalışmaktadır. Mikroşerit yaklaşım ile geliştirilen önerilen anten, performanstan ödün vermeden düşük boyut profil özelliği göstermektedir. Anten, haberleşme bandında maksimum ~7.7 dBi kazanç elde etmektedir. Daha sonra, önerilen antenin 8 elemanlı faz dizisi uygulaması analiz edilmiştir. Tasarımda $\sim\lambda/2$ boşluk bırakılarak düzgün aralıklı lineer dizi yöntemi kullanılmaktadır. Sekiz elemanlı dizi, maksimum toplam kazancı ~15 dBi'ye kadar artırmakta, düşük yan lob seviyeleri (YLS) ile $\pm 50^\circ$ 'ye kadar huzme yönlendirme sağlamaktadır. Ayrıca, önerilen faz dizi tasarımı, 10 mm×48.6 mm×0.51 mm boyutlarında, kompakt ve bu nedenle mmDalga band radyo frekansı entegre devre (RFIC) alıcı-vericileri ile uyumludur.

Anahtar Kelimeler: Faz Dizisi, Milimetre Dalga Anten, Beşinci Nesil, 5G.

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1. Introduction

Millimeter wave (mmWave) antennas have garnered significant attention to meet the requirements of the fifth generation (5G) communication systems. The origin of 5G is based on the increasing demand of people for fast and higher capacity wireless communications. mmWave bands above 24 GHz promise huge signal bandwidth to overcome the expected high-data transmission capacity up to the theoretical peak speed 10 Gbps at fast mobile communication environment (IMT Vision, 2015). mmWave 5G New Radio (NR) pushes the boundaries of different bands in the spectrum. In 2016 the 28 GHz band was allocated as licensed by the Federal Communications Commission (FCC) for 5G mobile radio services (FCC Report, 2016). 37-39 GHz and 64-71 GHz frequencies are other allocated bands.

Multiple-input multiple-output (MIMO) technology is fundamental to the fourth generation (4G) long term evaluation (LTE) cellular networks. Almost all mobile 4G/LTE devices carry multi-antenna configurations to utilize the superiorities of MIMO, and this approach is now being adapted in the next generation 5G networks (Boccardi et al, 2014; Lota et al, 2017). Various mmWave antenna architectures have been proposed in the last few years (Lota et al, 2017; Ozpinar&Aksimsek, 2021). Park et al. proposed a 28 GHz band antenna posing a tilted radiation pattern on an elevation plane (Park et al, 2016). Better isolation between resonator antennas enabling more efficient 5G MIMO performance was reported by Zhang et al (2019). Lima de Paula et al proposed air filled SIW 1x4 antenna array operating between 24.25-29.5 GHz bands based on dual layer printed circuit board (PCB) technology (2021). The array implementation of mmWave antennas is the major technique to maximize the gain and counter the path loss in mmWave propagation (Fakharzadeh et al, 2010; Lota et al, 2017). In particular, various array antennas capable of beamforming have been developed to provide full-spherical coverage for the future mobile handsets (Yang et al, 2016; Yu et al, 2018; Ozpinar et al, 2020). Beamforming, i.e., multibeam systems, have already been used in the current wireless communications systems. To achieve multiple beams with high quality 5G coverage zone, the phased arrays are adopted.

In this article, mmWave eight-element phased array antenna for 5G mobile phones is numerically investigated. The top layer of the single element antenna consists of a rectangular patch and tapered fed line. Eight-element phased array antenna is excited with Dolph-Chebyshev coefficients to suppress the side lobe levels in radiation pattern. The proposed array poses the horizontal beamforming capability up to $\pm 50^\circ$ with a maximum gain of 14.8 dBi. The proposed design is compact with the surface area of $10 \times 48.6 \text{ mm}^2$. The simulation outcomes prove that the presented eight-element phased array can be used in the future 5G mobile handsets.

2. Antenna Design and Parameters

The future 5G mobile phone terminals need low profile antennas without compromising performance. In this work, the microstrip approach is selected for high gain and compact phased array design. Fig. 1 shows the structure of the proposed antenna with the antenna parameters. The proposed design consists of the radiating rectangular patch and microstrip fed line. The bottom layer is fully grounded with copper. The

proposed antenna is compatible with PCB fabrication. The antenna element is designed on Rogers RT5880 substrate with the dielectric constant of $\epsilon_r = 2.2$, and loss tangent of $\tan\delta = 0.0009$. The height of the dielectric layer is 0.51 mm. The overall dimension is $10 \times 10 \text{ mm}^2$.

The optimized dimensions of the proposed antenna are as follows: The total width W_s and length L_s 10 mm. The width of the fed line X_1 is 1.47 mm. The interconnection distance X_2 is 0.5 mm. The width of the rectangular patch X_3 is 5.33 mm. The length of the patch Y_2 is 3.13 mm. The distance between the patch and the fed point Y_1 is 4.15 mm. $t = 0.035 \text{ mm}$, and $h = 0.51 \text{ mm}$. t and h represent the thickness of the metal and dielectric layer, respectively.

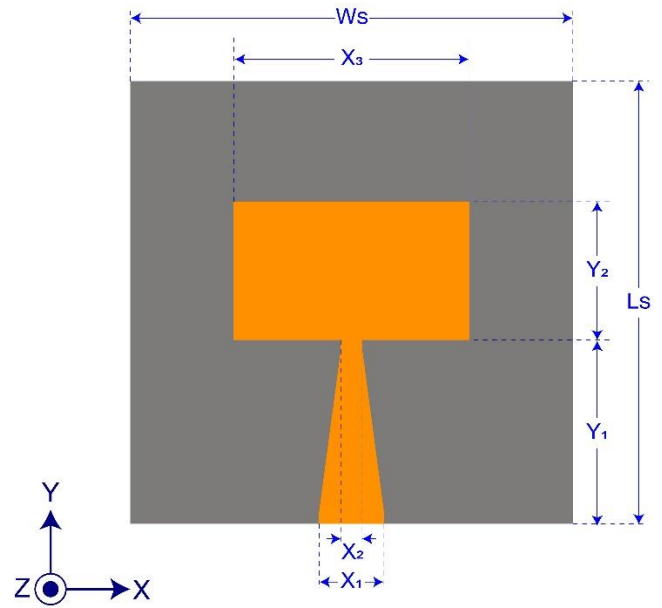
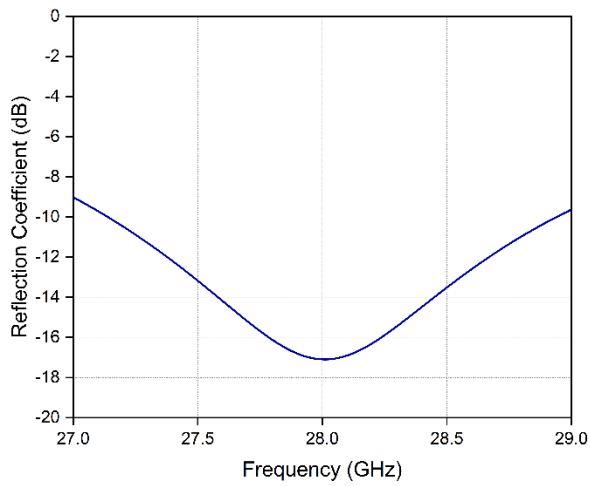


Figure 1. The geometry of mmWave antenna: Top view

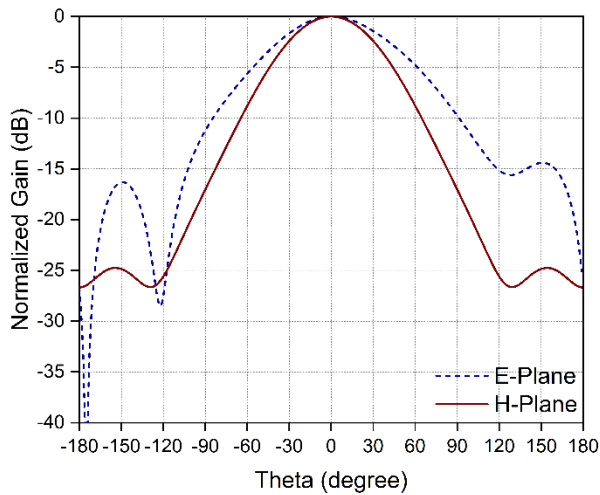
3. Results

3.1. mmWave Single Element Antenna

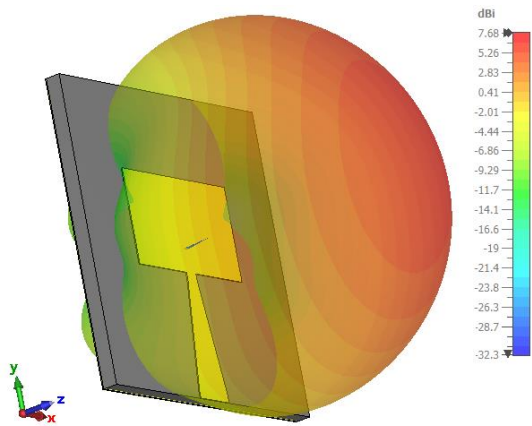
This section investigates the radiation skills of the single element antenna at 28 GHz band of 5G spectrum.



(a)



(b)

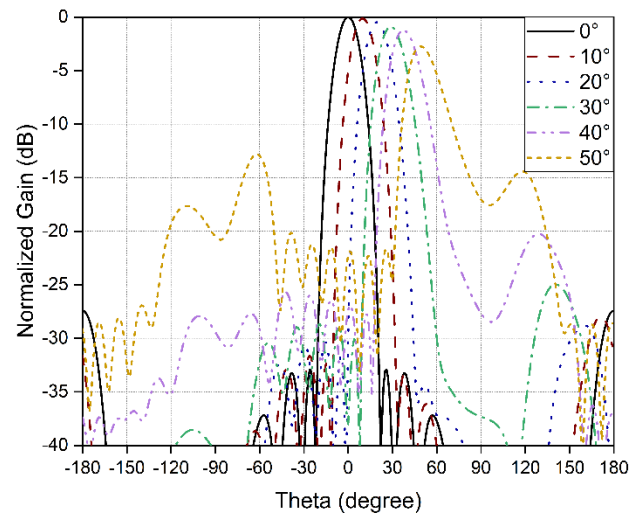


(c)

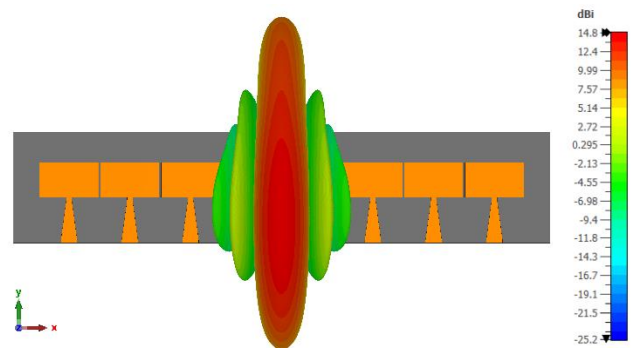
in Fig.2(b), the antenna radiates in the broadside direction with the low side lobe levels below -14.4 dB and -24.7 dB for E- and H-plane, respectively. Fig.3(b) illustrates the 3D radiation pattern of the antenna. As shown in Fig.3(b) ~7.7 dBi maximum gain is achieved.

3.2. 8-Element Phased Array Antenna

Smartphones will be used in 5G mobile communications need highly skilled antenna architectures that can steer the beam in high performance in order to achieve the required coverage. Eight-element phased array is designed to verify the beamforming capability of the proposed antenna for typical 5G mobile devices. The overall dimension of the array is 10 mm×48.6 mm×0.51 mm. The spacing distance between each element is $\sim\lambda/2$ at the center frequency.



(a)



(b)

Figure 3. (a) Simulated normalized 2-D E-plane gain patterns of the 8-element linear array in different scanning angles at 28 GHz. (b) 3D radiation pattern for 0°.

The simulations are carried out using three dimensional full-wave electromagnetic solver CST Microwave Studio 2021. Fig. 2(a) shows the reflection coefficient (S11) characteristics of the antenna. The center frequency is 28 GHz. The proposed antenna provides - 10 dB bandwidth of 1.85 GHz between 27.1 GHz – 28.95 GHz (1:1.06 BW). S11 shows its deep around - 17.1 dB. Fig.2(b) plots the co-polarized far-field gain patterns of the single element antenna in E- and H-planes at 28 GHz. As shown

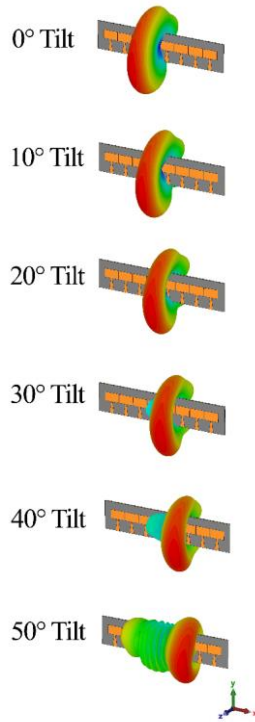


Figure 4. 3D tilted radiation pattern up to 50° at 28 GHz.

Dolph-Chebyshev coefficients are used to excite the array (Yu et al, 2018). The used coefficients are 0.2622, 0.5187, 0.812 and 1 for the first 4 antenna elements from the left edge to the center of the antenna, respectively. Fig.3(a) compares the simulated normalized E-plane gain patterns of the 8-element linear array in different scanning angles from 0° to 50° with 10° step at the operation frequency of 28 GHz. As shown in Fig.3(a), the normalized gain reduces to -3dB level when the beam angle exceeds $\pm 50^\circ$. Furthermore, 8-element linear array limits the side lobe levels around -15dB. Fig.3(b) shows the 3D radiation pattern of the 8-element phased array at 28 GHz with a 0 degree phase difference between the ports. Fig.4 illustrates the 3D radiation pattern in different beam scanning angle up to 50°. The 8-element array gain varies between 11.4-14.8 dBi with the scanning angle. Table 1 summarizes the maximum gain of the array in different scanning angles. As shown in Table 1, the maximum gain of the proposed array decreases with the scanning angle.

Table 1. Maximum gain of the array in different scanning angles.

Scanning Angle	Maximum Gain (dBi)
0°	14.8
10°	13.6
20°	13.2
30°	12.8
40°	12.5
50°	11.4

4. Conclusion

A mmWave eight-element phased array antenna is successfully presented in this paper. The proposed array poses good radiation skills such as beam steering coverage up to 50°
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with a maximum gain of 14.9 dBi. The proposed array is compact, and can be easily integrated to the mmWave RFIC transceivers. Furthermore, the single element antenna indicates -10 dB bandwidth of 27.1 GHz – 28.95 GHz frequencies. The presented outcomes prove that the single element antenna can be adopted, and used in various array configurations for 5G mobile communication systems.

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