The Study of Design Features of CPW-FED Asymmetrical Slot Array for K-Band Applications

Marija Milijic[1], Branka Jokanovic[2]
[1]University of Niš, 18000 Nis, Serbia
{marija.milijic@elfak.ni.ac.rs}
[2]Institute of Physics
University of Belgrade, Pregrevica 118
11080 Pregrevica, Serbia
{brankaj@ipb.ac.rs}

ABSTRACT: *We in this work discussed the design features of antenna array that consists rectangular slots positioned asymmetrically relative to CPW feeding line. The designed asymmetrical slots offer greater flexibility in antenna design and easier control of crucial antenna parameters such as gain, side lobe suppression and bandwidth. Besides we designed it to be useful for frequency range 24.25-27.5 GHz and therefore it is suitable for future great capacity broadband 5G technologies.*

Keywords: Antenna Array, Asymmetrical Slot Antennas, CPW-fed Antennas, CPW T-junction

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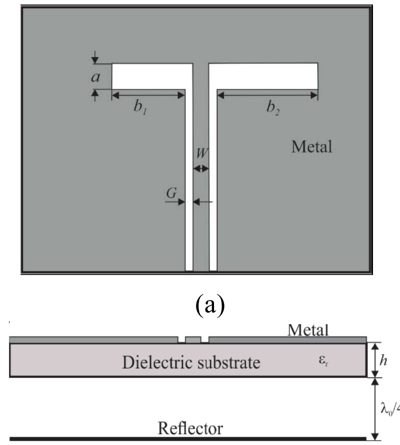
1. Introduction

With the rapid growth of the wireless communication system, sub-6 GHz frequency range has become overcrowded. Therefore, the operation bandwidth of the upcoming 5G networks will be at higher frequencies compared with previous generations of mobile communication networks [1]. Several promising millimetre-wave bands have been released by the International Telecommunication Union (ITU) for the 5G wireless communication system that include the 24.25 – 27.5 GHz, 37 – 40.5 GHz, 66 – 76 GHz bands [2]. Meanwhile, the Federal Communications Commission (FCC) has considered the spectrum of approximately 11 GHz above 24GHz for flexible, mobile and fixed wireless broadband for the next-generation 5G networks and technologies in the United States [3]. Among the available millimetre wave spectrum, frequency around K band is extensively highlighted for 5G because of lower atmospheric absorptions and relatively lesser attenuations while these effects become more prominent at higher frequencies [4].

Furthermore, 5G generation of mobile networks are intended to connect hundreds different devices creating crucial demands for services of great broadband capacities and transmission speeds [1]. Consequently, new challenges to design of millimetre-band antennas have come out requiring antennas composed of dozens of radiating elements. Antenna arrays feature better radiation characteristics, combined with the reduced sizes and higher gains. CPW (coplanar waveguide) - fed antennas have received much attention for finding applications in 5G mobile communication systems due to their wide bandwidth, low cost, light weight, small size, and ease of fabrication [5-7].



(a)

(b)

Figure 1. CPW-fed asymmetrical rectangular slot: a) top view b) side view

This paper presents a centrally offset fed rectangular slot array designed for wide-band applications in 5G frequency range 24.25-27.5 GHz. The slots are located asymmetrically relative to CPW feeding line in order to easier control of crucial antenna parameters such as gain, side lobe suppression and bandwidth. Aside from planar structure and inexpensive fabrication, given simulated results report that the proposed antenna array has 1.85 GHz bandwidth in terms of radiation pattern and 1.2 GHz bandwidth in terms of S_{11} parameter with 16 dBi average gain that make this class of antennas a good candidate for a variety of 5G communication applications.

2. CPW-Fed Asymmetrical Slot Antenna

Geometrical view of the proposed CPW-fed asymmetrical slot antenna is shown in Fig. 1. It is modelled using a substrate with thickness of h = 0.508 mm and relative permittivity of ε_r = 2.54. The rectangular slot is with width a and arms of different length b_1 and b_2 causing that the CPW feed line is not positioned in the middle of slot. The widths of the strip and gap (W and G) of the CPW feed line, whose impedance is around 120Ω, are 0.3 mm and 0.375 mm, respectively. The antenna's metal surface is of size 15 x 14 mm^2. At the distance $\lambda_0/4$ =2.89 mm from the slot antenna there is a reflector plate whose dimension are the same as the antenna's dimensions (λ_0 is wavelength in vacuum at the centre frequency f_c=25.875 GHz).

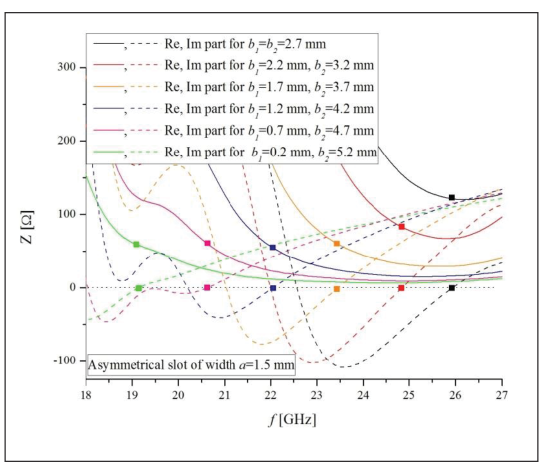


Figure 2. De-embedded impedance of the CPW-fed asymmetrical slot antenna versus frequency. The slot width, a and its overall length, $b=b1+b2$ are fixed

$\Delta b=b_2-b_1[mm]$	2^{nd} resonance[GHz]	Impedance [Ω]
0	25.9	120
1	24.85	80
2	23.45	60
3	22.05	55
4	20.6	60
5	19.15	55

Table 1. Second Resonance and Impedance of CPW-fed Asymmetrical Slot Antenna Versus Difference Δb between Its Arms Lengths

To estimate the performance of the proposed CPW-fed slot antenna, it is simulated using the WIPL-D software [8]. Its impedance is determined by its de-embedded S_{11} and S_{21} parameters using formulas [9]:

$$Z = -\frac{1}{Y_{21}(S_{11}, S_{21})} \quad (1)$$

$$Y_{21}(S_{11}, S_{21}) = -\frac{2S_{21}}{(1+S_{11})^2 - S_{21}^{\ 2}} \frac{1}{Z_0} \quad (2)$$

where Z_0=120Ω is impedance of CPW feed line. The simulation results of impedance for asymmetrical slot with width a =1.5 mm is presented in Figure 2. It can be observed that with constant slot length only by changing the arms' length it can cover entire *K*-band within impedance range 55-120Ω. The asymmetrical slot, whose total length and arm's lengths are both changeable, offers a bigger opportunity to fit impedance at desired frequency than rectangular or bow-tie slot whose length can be only adjusted [10,11]. The numerical values from Figure 2 are presented in Table 1 together with the second resonance and slot impedance at second resonance for all considered difference Δb between slot arms, length b_2 and b_1.

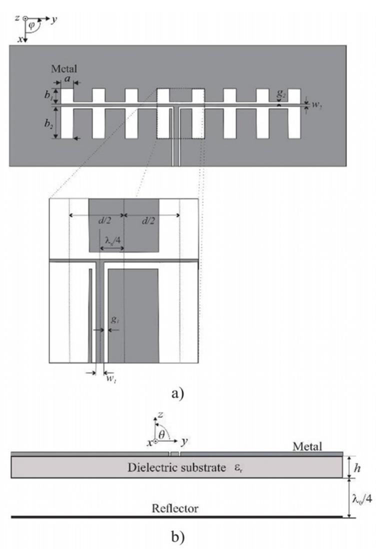


Figure 3. CPW-fed asymmetrical slot array: a) Top view b) Side view

3. The Array of CPW-fed Asymmetrical Slots

The configuration of the proposed CPW-fed asymmetrical slot array is depicted in Figure 3. A dielectric substrate of constant ε_r=2.54 and thickness h = 0.508 mm is used. The centre frequency f_c = 25.875 GHz is calculated as the central value of range 24.25 – 27.5 GHz, recommended by ITU [2]. The antenna array is at the distance $\lambda_0/4$ =2.89 mm from the reflector plate whose dimension are the same as the array's dimensions. Unlike the microstrip antennas with a backside ground plane, slot antennas require the reflector plane to be at a distance equal to the quarter of the free space wave-length. It should ensure that the antenna radiates only in half the space. The array is split into two identical four-slot subarrays placed at the different distances from the CPW T-junction. In order to provide the in-phase feeding of both subarrays, the CPW T-junction is moved off the symmetry axes (see Fig. 3) for $\lambda_g/4$, where λ_g=9 mm is CPW line wavelength at the centre frequency f_c. The difference between lengths of CPW lines between T-junction and sub-arrays results in shift between their S-parameters in Smith chart (Fig. 4). The 60Ω CPW line (featuring the strip w_1= 0.9mm and gap g_1= 0.1mm) is used to enable feeding for both sub-arrays dividing power into two 120Ω CPW feed lines featuring the strip w_2= 0.3mm and gap g_2= 0.375 mm for feeding every four slots sub-array.

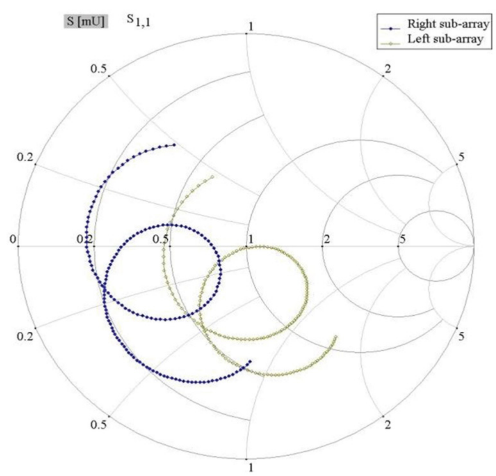


Figure 4. The S-parameter Smith chart for four-element sub-arrays calculated at the CPW-T junction. S-parameters are normalized to the impedance of CPW feeding line (120 ©)

The dimensions of metal plate are 77mm x 25mm x 0.508 mm. Each slot has a rectangular shape with a = 2 mm width and arms of different length b_1=2 mm and b_2 = 4.35 mm. Also, the slots are positioned at mutual distance d = 9 mm. The antenna array is designed, simulated and analysed using WIPL-D software [8].

4. Simulation Results and Discussion

The radiation patterns for lower, central and upper frequency are presented in Figs. 5 - 6 resulting in the range from 25.48 GHz to 27.23 GHz. The obtained simulation results point out that arrays with centrally feeding feature more wideband characteristics than the series-fed arrays [12] which is one of the crucial demands for 5G communication systems. The investigated frequency domain has the maximum gain fluctuation 1.6 dB from the gain at the central frequency which is 16.85 dBi. Side lobe suppression varies from 10 dB at the edge frequencies to 13 dB at the central frequency, which is expected for an uniform antenna array. Furthermore, the comparisons between E-plane co-polar and cross-polar radiation patterns as well as H- plane radiation pattern for φ =0° for three considered frequencies are shown in Fig. 5.

Further presented result is S_{11} parameter versus frequency in Fig. 7. It can be observed that S_{11} is below -10 dB for frequencies between 25.475 GHz and 26.65 GHz. Bandwidth which is quoted in terms of return loss, is less than bandwidth determined by radiation pattern.

The Table II presents the review of the overall characteristics of examined array with asymmetrical slot antennas fed by CPW transmission line at three considered frequencies.

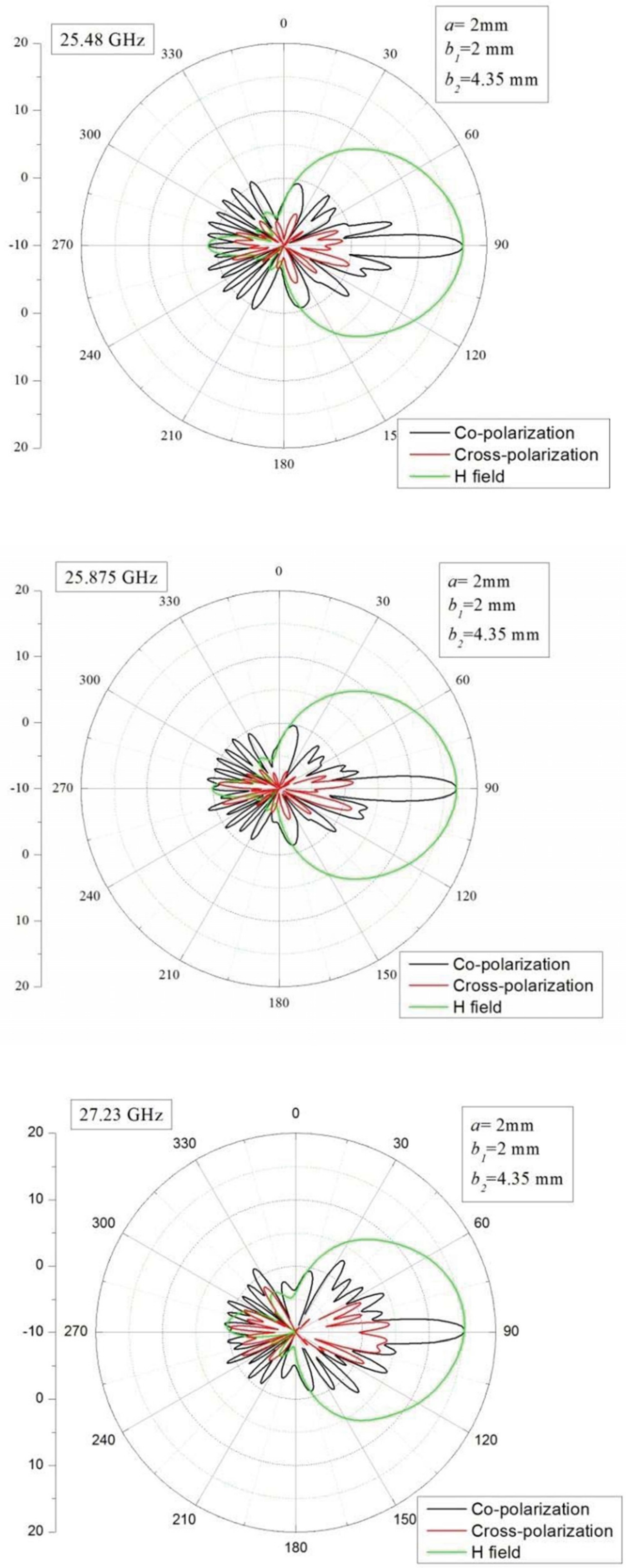


Figure 5. E-plane co- and cross-polar and H-plane radiation pattern for the CPW-fed asymmetrical slot array at: a) 25.48 GHz b) 25.875 GHz c) 27.23 GHz

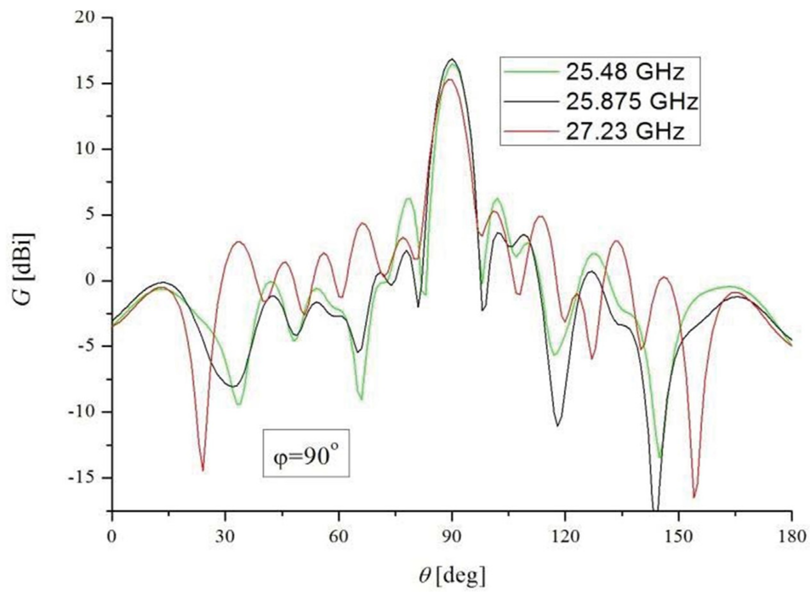


Figure 6. Radiation pattern in the E-plane for the CPW-fed asymmetrical slot array at 25.48 GHz, 25.875 GHz and 27.23 GHz (φ=90°)

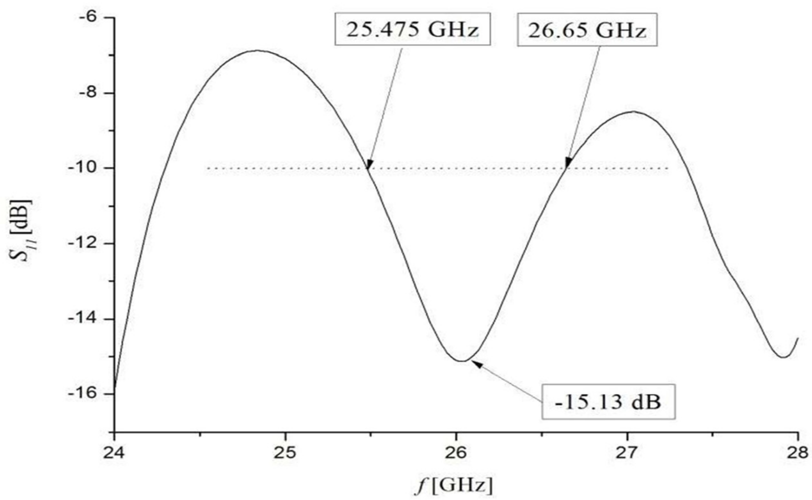


Figure 7. S_{11} parameter of the CPW-fed asymmetrical slot array versus frequency

5. Conclusion

An antenna design is one of the major considerations to realise mm-wave based 5G applications. Modern wireless communication system requires low profile, light weight, high gain, ease of installation, high efficiency and simple in structure antennas. The design of a wideband compact antenna is a challenging task especially at the operating higher frequencies around 28-GHz. The key features of a CPW-fed antenna are low profile, relative ease of construction, low weight, comfortable to planar and non-planar surfaces, low cost, simple and inexpensive manufacturing. These advantages make them popular in many wireless communication applications.

In this paper, a wideband compact array of CPW-fed asymmetrical rectangular slots is proposed. The centrally feeding provides a wide bandwidth from 25.48 to 27.23 GHz. Furthermore, the simulation results show excellent characteristics of the proposed antenna array, concerning average gain of 16.2 dBi and very symmetrical radiation pattern.

Characteristics / *Frequency* [GHz]	25.48	25.875	27.23
Gain [dBi]	16.48	16.85	15.25
SLS [dB]	10	13	10
Co/cross-polar ratio [dB]	> 18	> 18	> 13.5
3dB-beamwidth [°]-E plane	6.5	51	7
3dB-beamwidth[°]-H plane	53	7.5	45

Table 2. The Characteristics of the Asymmetrical Slot Antenna Array FED by CPW Transmission Line

Further research will be conducted by introducing a rat-race CPW coupler and its comparison with CPW T-junction, presented in this paper. The antenna with better simulated results is intended to be fabricated and measured.

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