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Single Layer Circular Polarized Antenna Array Based on Gap Waveguide Technology for Automotive Radar Applications

Ali Farahbakhsh[1*]

[1]Associate Professor, Electrical and Computer Engineering Department, Graduate University of Advanced Technology, Kerman, Iran

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ABSTRACT

This paper presents a single layer circularly polarized (CP) antenna array based on gap waveguide (GW) technology for automotive radar applications. The antenna element is a curved slot that is cut into the top wall of a groove gap waveguide (GGW) structure. An 8×8 slot array antenna is constructed by combining eight sub-arrays of linearly arranged slots, using an 8-way power divider as the feeding network. The power divider and the transition from WR12 to GGW are also designed based on GW technology. The proposed antenna array operates in the frequency band from 76 GHz to 81 GHz, covering the automotive radar working bandwidth. The antenna has a maximum gain of 23.8 dBi and a minimum axial ratio of 0.5 dB. The antenna performance is verified by simulation using CST Microwave Studio.

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1. Introduction

Automotive radar systems play an increasingly important role in advanced driver assistance systems (ADAS) and autonomous driving applications [1, 2]. These systems require high-performance antennas with varying antenna gain. Short-range radars use low-gain antennas, while long-range radars use high-gain antennas. Circularly polarized (CP) antennas are particularly desirable for automotive radar applications, as they are less sensitive to polarization mismatch and multipath interference and can provide more accurate radar returns [3].

There are several types of antennas that are commonly used for automotive radar applications [4-13], including microstrip antennas, substrate integrated waveguide (SIW) antennas, and hollow waveguide antennas. Each type of antenna has its own advantages and disadvantages.

Microstrip antennas are relatively easy to fabricate and have a low profile. However, they suffer from the dielectric loss. They can have a narrow bandwidth and can be susceptible to interference from other electronic components in the vehicle [6-8].

SIW antennas are less sensitive to interference than microstrip antennas. However, they still have dielectric loss and they are more complex to fabricate [9-11].

Hollow waveguide antennas offer the best performance in terms of loss. However, they are the most complex and expensive type of antenna to fabricate, especially at the millimeter-wave (mmWave) frequency bands [12, 13].

*Corresponding Author
Email Address: a.farahbakhsh@kgut.ac.ir
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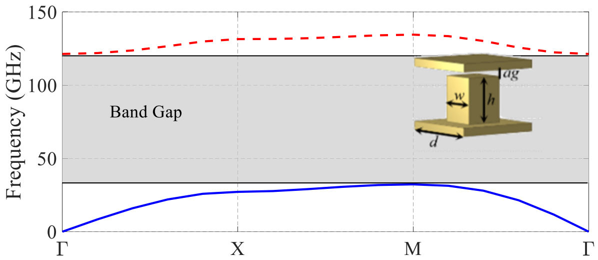

Figure 1: Simulated dispersion of the period pin structure. The pin dimensions are: w = 0.6 mm, h = 1.15 mm, ag = 40 μm, d = 1.36 mm.

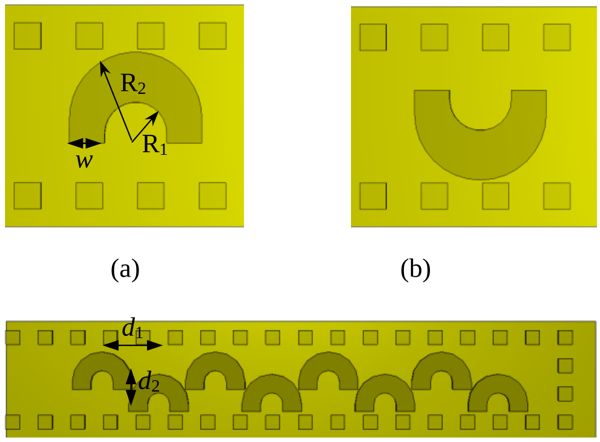

Figure 2: The geometry of the proposed slot sub-array with (a) LHCP and (b) RHCP radiations and (c) the linear array of the proposed antenna with LHCP radiation.

Gap waveguide technology was proposed by Per-Simon Kildal in 2009 as a solution to overcome the limitations of the existing technologies [14]. A gap waveguide structure is a metallic structure that confines the electromagnetic (EM) waves to a specific path by using a parallel plate perfect electric conductor (PEC) or perfect magnetic conductor (PMC) structure [15].

Gap waveguide technology is a promising approach for designing high performance CP antenna arrays for automotive radar. Gap waveguides are planar structures that can support various types of antenna elements, such as slots, dipoles, and horns, as well as microwave components [16-21]. Gap waveguide antennas have the advantages of easy fabrication and integration into a single layer, which make them suitable for automotive radar applications.

This paper presents a single layer CP antenna array based on gap waveguide technology for automotive radar. The proposed antenna array has several advantages for automotive radar applications. The single layer design makes the antenna array easy to fabricate and integrate into automotive radar systems. The CP design makes the antenna array less sensitive to multipath interference and can provide more accurate radar returns. The antenna array has a wide bandwidth and high gain, which are important for automotive radar applications.

2. Antenna Element Geometry

The proposed antenna is based on gap waveguide technology, and the first design step is to design a periodic pin structure that generates a band gap covering the desired frequency band. To achieve this, the dimensions of the periodic pins are optimized in CST Microwave Studio for the automotive radar working bandwidth which is from 76 GHz to 81 GHz [22]. The simulated dispersion diagram of the periodic pin structure is depicted in Fig. 1 whereas the optimized pin dimensions are given in the figure caption. As can be seen, the band gap covers from 40 GHz to 120 GHz which is excellent for the automotive radar applications.

The sub-array antenna element is illustrated in Fig. 2(a). The proposed antenna element is a curved slot that are placed on the top wall of a groove gap waveguide structure. By choosing the appropriate values of the slot inner and outer radiuses, two perpendicular electric field components with a 90-degree phase difference can be generated, resulting in CP radiation. The slot shown in Fig. 2(a) generates a Left Handed CP (LHCP) radiation and by mirroring the slot as shown in Fig. 2(b), a Right Handed CP (RHCP) can be achieved.

A linear array antenna of the proposed sub-array is designed and depicted in Fig. 2(c). The slots are cut into the top wall of the GGW and spaced by half a wavelength, resulting in a phase difference of 180 degrees between adjacent slots. By alternating the slots up and down, the phase difference is compensated and a broadside radiation pattern is achieved. The end of the GGW is shorted using periodic pins to suppress the unwanted radiation from the GGW end.

By tuning the distance between adjacent slots (d_1) and their offset distance (d_2), the impedance matching of the linear array antenna is obtained.

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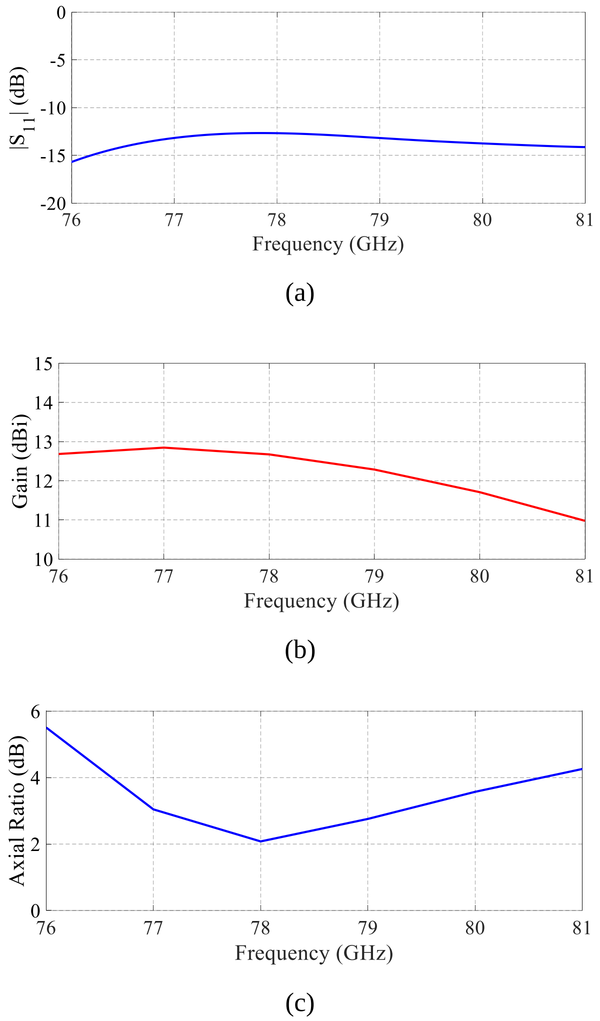

Figure 3: Simulation results of the linear array antenna. (a) the reflection coefficient, (b) the antenna gain and (c) the antenna axial ratio versus frequency.

The optimized parameters are: R_1 = 0.57 mm, R_2 = 1.25 mm, d_1 = 2.3 mm, d_2 = 0.85 mm. The simulated reflection coefficient of the antenna array is depicted in Fig. 3(a). As can be seen, the antenna S_{11} is below -12 dB from 76 GHz to 81 GHz, that shows an acceptable performance of the antenna.

The simulated gain of the linear array antenna and its axial ratio (AR) versus frequency are given in the Fig. 3(b) and (c), respectively. According to the results, the minimum AR of the antenna is about 2 dB that shows acceptable CP radiation while its maximum gain is about 12.8 dBi.

3. The Design of the Feeding Network

In order to construct a big array antenna, 8 linear antenna arrays will be combined to form an 8×8 slot array antenna. To do that, an 8-way power divider should be designed as the feeding network.

Figure 4 illustrates the geometry of the 8-way power divider. As shown, the proposed power divider comprises seven cascaded T-junctions based on GGW. The impedance matching of each T-junction is achieved by introducing two matching components in the structure which are a metallic window and the splitting pin. By optimizing the width of the matching window and the position of the splitting pin, the impedance matching is obtained. In addition, the proposed power divider includes some GGW bends. The position of the corner pin in the GGW bend is an important design parameter that affects the impedance matching of the bend. By choosing the corner pin position appropriately, an optimal bend can be designed.

The whole structure is optimized inside CST Microwave Studio in order to obtain power divider input matching. The optimized parameters of the feeding network are given in Table I. The simulated S-parameters of the feeding network are plotted in Fig. 5. According to the results, the S_{11} of the power divider is almost below -15 dB which is excellent while its transmission coefficients are around -9 dB that shows good performance of the power divider.

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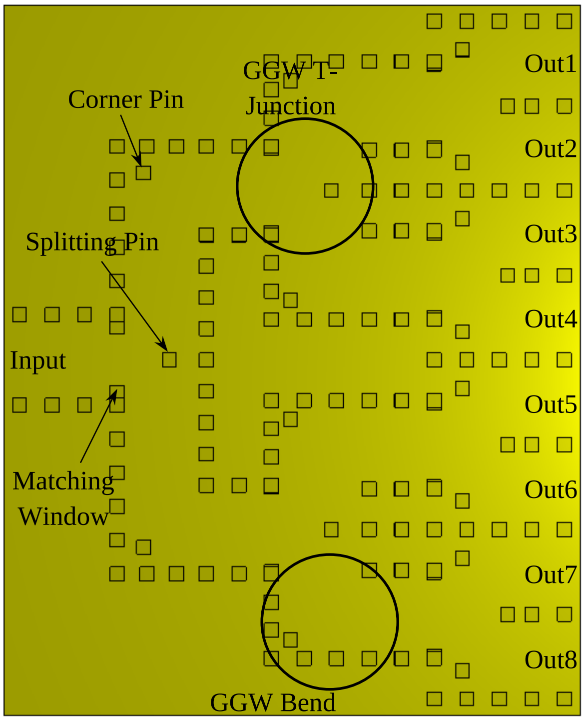

Figure 4: The geometry of the proposed 8-way GGW power divider.

Table I: The optimized design parameters of the feeding network

Parameter detail	Value (mm)
WR12 length	3.1
WR12 width	1.55
Ridge width	1.27
Ridge height	0.39
Ridge length	1.8
Window width	0.52
Splitting pin position	0.97
Corner pin position	0.74

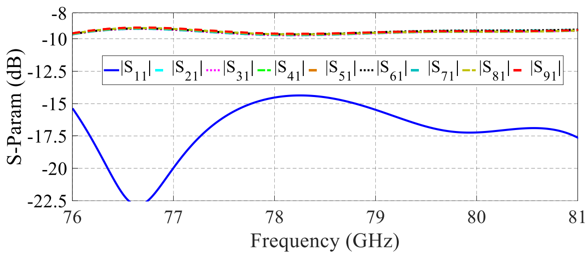

Figure 5: Simulated S-parameters of the 8-way GGW power divider.

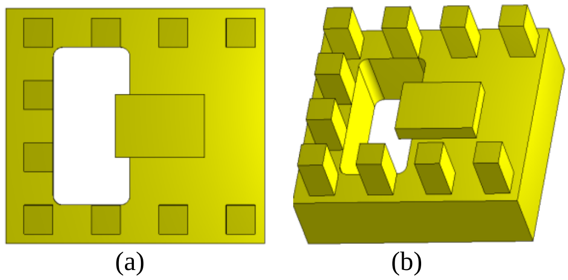

Figure 6: The geometry of the WR12 to the GGW transition. (a) top and (b) perspective views.

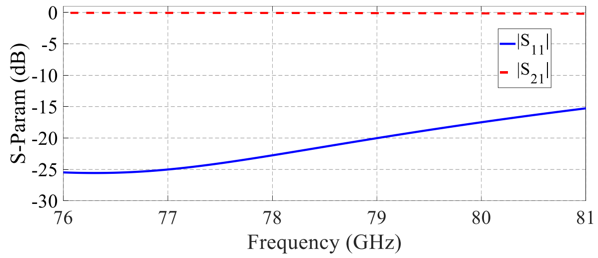

Figure 7: Simulated S-parameters of the WR12 to GGW transition.

In order to excite the proposed power divider with a standard flange waveguide, a transition from WR12 to the GGW is designed that is depicted in Fig. 6. A ridge section is employed to couple the electromagnetic (EM) waves between the WR12 and the GGW. The dimensions of the ridge block are optimized to achieve a good impedance matching of the transition.

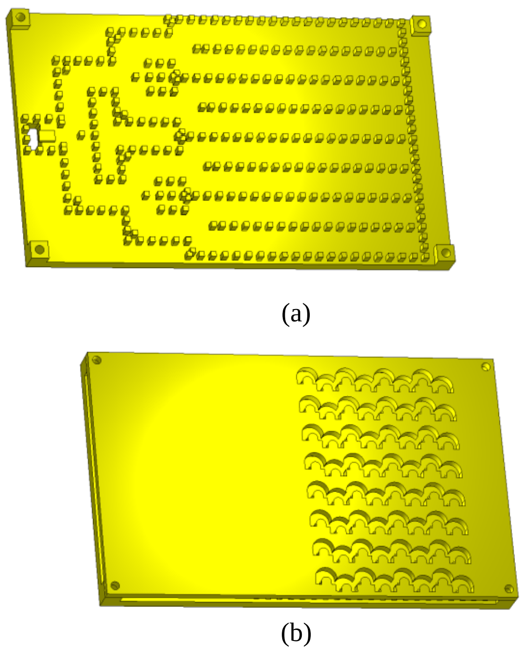

Figure 8: The geometry of the proposed slot array antenna. (a) feeding network and (b) the radiating slots.

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The optimized parameters are given in the caption of Fig. 6. The simulated S-parameters of the transition are presented in Fig. 7, which demonstrate a low S_{11} below -15 dB over the entire bandwidth.

4. 8×8 Slot Array Antenna

The complete slot array antenna is formed by arranging of eight linear array antenna and utilizing the proposed power divider to excite them in the same amplitude and phase. Figure 8 demonstrates the complete single layer array antenna. The feeding network is shown in Fig. 8(a) which includes the transition of WR12 to the GGW and the 8-way GGW power divider. Each outputs of the power divider are connected to a linear array antenna.

The array antenna was simulated using CST Microwave Studio and the electric field distribution in the feeding layer is shown in Fig. 9. The figure reveals the effective operation of the feeding network and the equal amplitude and phase power splitting.

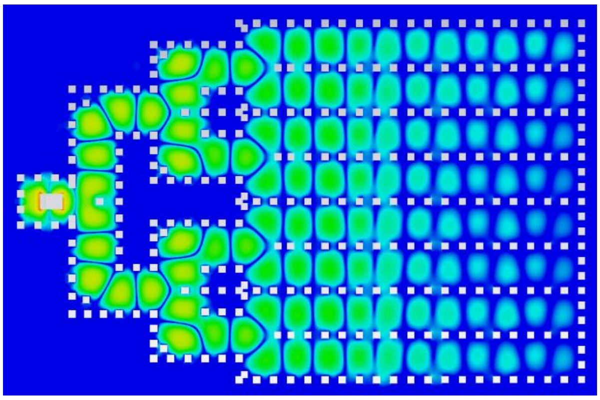
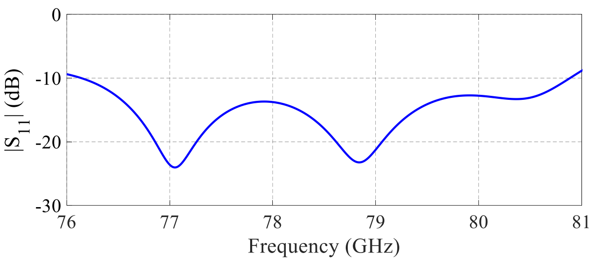
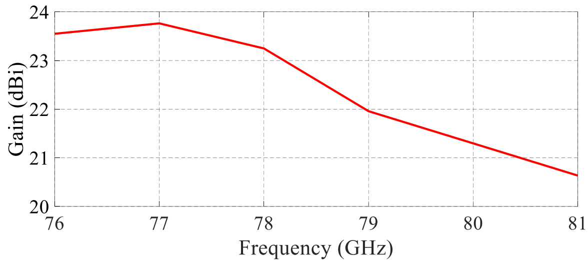


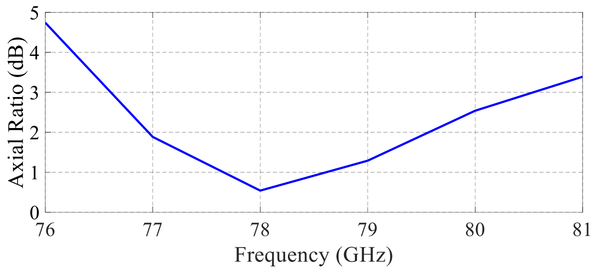
Figure 9: Simulated distribution of the E-field inside the feeding network.



(a)



(b)



(c)

Figure 10: Simulation results of the linear array antenna. (a) the reflection coefficient, (b) the antenna gain and (c) the antenna axial ratio versus frequency.

The simulated results of the antenna are plotted in Fig. 10. The reflection coefficient of the antenna is below -10 dB almost in the whole bandwidth. Fig. 10(b) shows the peak gain of the antenna versus frequency. The antenna has a maximum gain of 23.8 dBi at 77 GHz and the gain drop of the antenna in the entire bandwidth is less than 3 dBi. The antenna axial ratio is given in Fig. 10(c) which is about 0.5 dB at 78 GHz. The antenna 3 dB axial ratio bandwidth is from 76.5 GHz to 80.5 GHz which is acceptable for the automotive radar applications.

Figure 11 depicts the simulated radiation pattern of the antenna at the center frequency of 78.5 GHz in two basic planes $\varphi = 0°$ and $\varphi = 90°$. The radiation pattern in φ-90° plane is smooth that indicates the excellent performance of the power divider. In φ-0° plane, the radiation pattern has some grating lobes which are due to the nature of the travelling wave antennas. However, the grating lobe level in this plane is better than 10.5 dB which is acceptable.

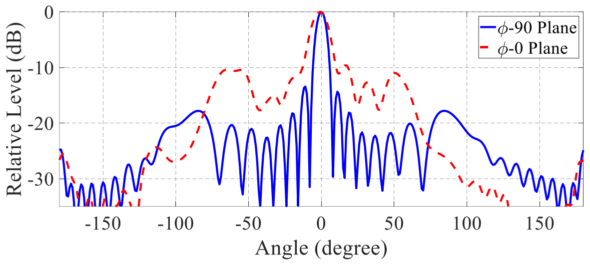


Figure 11: Simulated radiation patterns of the 8×8 slot array antenna in two basic planes.

5. Conclusions

In this paper, a single layer CP antenna array based on GW technology for automotive radar applications has been designed and simulated. The antenna element is a curved slot that is placed on the top wall of a GGW structure. The slot dimensions are optimized to achieve CP radiation with low axial ratio. An 8×8 slot array antenna is formed by arranging eight linear sub-arrays and feeding them with an 8-way power divider based on GW technology. The power divider and the transition from WR12 to GGW are also designed and optimized to achieve good impedance matching and low insertion loss. The proposed antenna array covers the frequency band from 76 GHz to 81 GHz with a high gain. The antenna performance is verified by simulation using CST Microwave Studio. The proposed antenna array has the advantages of simple structure, easy fabrication, and low cost, making it suitable for automotive radar applications.

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