Multibeam Metal-Only Groove Gap Waveguide-Based Slot Array in E-Band

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***Abstract*— Radar technology, particularly at the 76-81 GHz band, plays a central role in ADAS (Advanced Driver Assistance Systems) development, offering precise measurements and robustness in obstacle detection. This work presents a gap waveguide-based, metal-only antenna, combining low transmission losses with scalable design. The proposed 1×8 slotted array antenna, fed through groove gap waveguide technology, provides multi-channel and multibeam operation. Its metal-only construction ensures seamless integration into vehicle chassis while maintaining efficiency in automotive frequency bands. The proposed structure behavior has been validated through full-wave simulations in CST Microwave Studio. The results present a potential candidate for antennas with multibeam performance in E-band.**

***Index Terms*— slot antennas, automotive applications, groove gap waveguide, E-band.**

I. Introduction

Enhancing safety and convenience on the road has remained a main objective for each successive generation of vehicles over the past three decades. The goal is to relieve drivers from repetitive tasks and split-second decisions in complex traffic scenarios, improving safety and comfort. This suite of features is commonly referred to as a driver assistance system. These driver assistance systems rely on sensors capable of discerning the traffic environment surrounding the vehicle. These systems are becoming crucial due to the increasing interest in new reliable autonomous vehicles. To bring these features to society, the integration of sensors designed to recognize the traffic scenario surrounding the vehicle is imperative [1].

Radar technology excels at providing highly accurate measurements of the distance and velocity of distant objects. By utilizing multiple receive or transmit channels, it can further extract valuable angular information [2]. Additionally, radar systems exhibit robustness in the face of environmental factors, including extreme temperatures and adverse lighting, weather conditions, or dust [3].

Radar automotive applications work in the 76-81 GHz frequency band [1], [4]. This band allows for the use of small sensor sizes compatible with high gain narrow beam width antenna requirements. However, the small size of the sensors/antennas arises problems related to the manufacturing processes. In addition, the use of dielectric substrate at those frequencies notably increases the losses, decreasing the overall efficiency.

In this work, we propose a metal-only solution based on waveguide. It is widely acknowledged that waveguides exhibit exceptionally low transmission losses. Particularly in the E-band, these losses can be remarkably low [5]. This represents a significant advantage compared to the losses experienced along printed transmission lines [6]. Employing waveguide technology affords considerable flexibility in antenna selection and design, encompassing options such as open-ended waveguide radiators, horn antennas [7], or slotted arrays as in the present work [8]. Additionally, waveguides provide broad bandwidth and excel in isolation properties.

The proposed antenna configuration is a 1×8 slotted array, and its feeding network is designed employing groove gap waveguide technology [10]. This feeding network comprises of two primary components: a transition module to facilitate the transition from WR10 to the groove waveguide and an integrated -3 dB power splitter within the groove. It is worth highlighting that this design inherently lends itself to scalability for operation. The desired radiation behavior of the device is achieving a beam scanning in the 76-81 GHz band. The intended radiation behavior aims at achieving beam scanning in the 76-81 GHz band. The multiport feeding capability enables the realization of three distinct beams without the need for amplitude or phase control at the ports.

II. Antenna Design

The design of the proposed antenna is divided into two different subsystems: the corporate feeding network, developed using gap waveguide technology (Fig. 1), and the array based on radiating slots, designed to achieve the desired radiation pattern which aims to achieve at least $\pm$ 8º beam scanning (Fig. 2).

The bandwidth of the structure will be limited by the radiating slots which will be designed to work in the 76-81GHz range. On the other hand, the feeding network is intended to work in the whole E-band.

A. Groove Gap Waveguide designs

The feeding network seamlessly incorporates a -3dB power splitter, leveraging groove gap waveguide technology [10]. This approach employs a parallel plate waveguide design, utilizing engineered metamaterials, including both hard and soft surfaces [11].

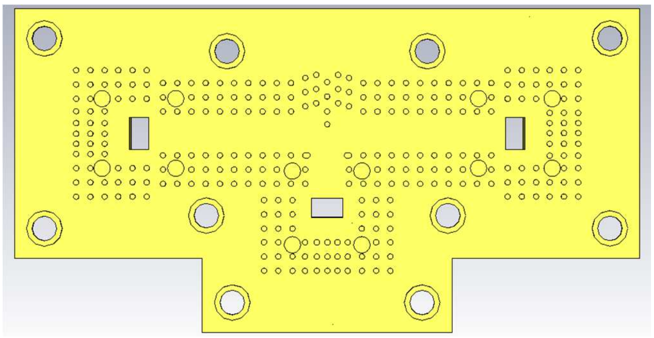


Fig. 1. Proposed antenna feeding network composed of a -3dB power splitter and three WR10 to groove gap waveguide transitions.

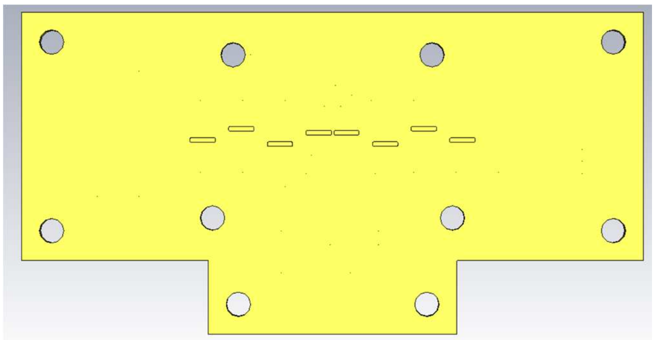


Fig. 2. Proposed 1×8 slot array designed to obtain a radiation pattern.

In the initial stages of the design process, we set out to define the parameters controlling the stop band needed for the groove gap waveguide to work. Our first critical step involves precise adjustments to both the height (h_c) and width (d) of the corrugations, alongside fine-tuning the height of the gap (h_g) and the periodicity of the elements (p), shown in Fig. 3. Subsequently, our focus shifts to configuring the system for the generation of a quasi-TE propagating mode within the central section of the structure, illustrated in Fig. 4.

Our initial design step aims to establish a high-impedance condition, ideally resembling a perfect magnetic conductor (PMC), by employing a periodic surface including corrugations. This choice is guided by the compelling advantages unearthed in previous research. Notably, this structure offers practical benefits, as it can be crafted exclusively of metal, requiring just a trio of pins [9]. In practical terms, this condition finds fulfillment when the gap height (h_g) is less than $\lambda/4$, effectively setting the lower frequency boundary for the gap waveguide. The upper cutoff frequency is limited by the generation of higher-order modes when the condition $h_g + h_c = \lambda/2$ is satisfied.

In so doing, our attention turns to the selection of groove width. Here, we intentionally choose a horizontal configuration to minimize the structure volume [10]. In this specific case, the width (W) is thoughtfully set to be approximately $\lambda/2$ at the lower cutoff frequency of the stopband.

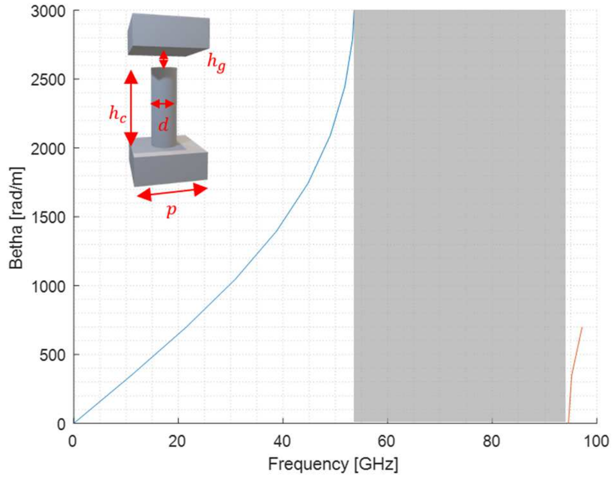


Fig. 3. Dispersion diagram of a single corrugation extracted from CST Microwave Studio © Eigen Mode solver using periodic boundaries. The grey square shows the band stop region of the structure. The parameters used for the simulation are $p = 1$; $h_c = 1.1$; $h_g = 0.4$ and $d = 0.4$ all the units expressed in millimeters.

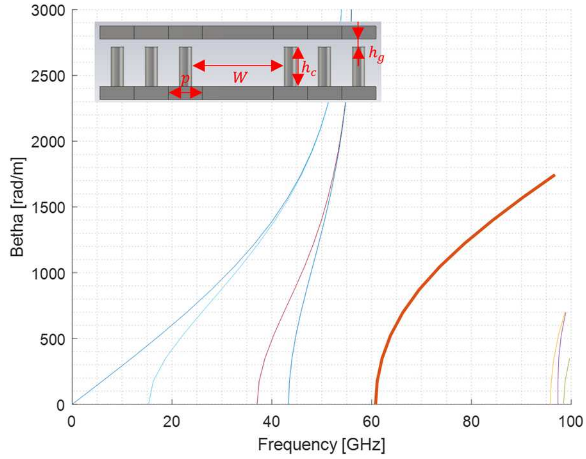
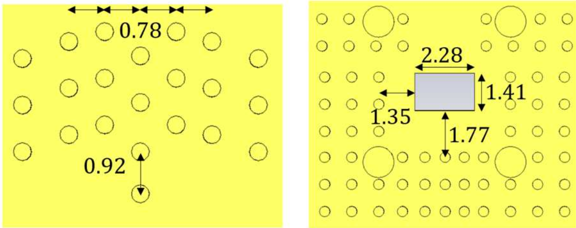


Fig. 4. Dispersion diagram of the proposed groove gap waveguide structure extracted from CST Microwave Studio © Eigen Mode solver. The red solid line represents the desired quasi-TE mode. The parameters are selected as: $p = 1$; $h_c = 1.1$; $h_g = 0.4$ and $W = 3.15$ all the units expressed in millimeters

Once the parameters of the groove gap waveguide are fixed, two independent structures are needed to complete the -3dB power splitter: a transition from WR10 to the groove gap waveguide and the power divider structure itself.

Both designs are achieved following the existing state of the art. The power divider (Fig. 5 (a)) is designed using the method discussed in [12] as the propagating mode inside the groove is a quasi-TE mode. The transition (Fig. 5 (b)) is designed similarly to the one presented in [13].

Figures 3 and 4 show that the structure is properly propagating a single mode in the E-band (60-90 GHz) where the corrugated structure is designed to behave ideally as a PMC.



(a) *(b)*

Fig. 5.(a) Proposed -3dB power splitter structure. (b) Proposed transition from W10 to the groove gap waveguide. Units in mm.

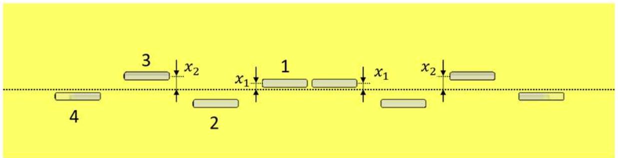


Fig. 6. 1x8 slot array. The left and right sides are symmetrical and the offsets of the slots denominated 1 and 4 are identical ($x_1 = 0.26$ mm) as well as 2 and 3 ($x_2 = 0.55$ mm).

B. *1x8 Slot Array Design*

The structure of the feeding network allows for the propagation of the quasi TE_{10} mode as in a conventional rectangular waveguide. Thus, the same methodology can be followed in other to design the slot array. In this work, the analysis presented in [8] by Elliot is used. Due to the configuration of the feeding network, the design of the 1x8 array was divided into two mirrored 1x4 arrays that achieves a beam pointing broadside direction.

Following [8] it is possible to obtain both the size of the slots and the offset with respect to the center of the waveguide. This second parameter will be the main responsible for the amplitude feeding law of the slots. In this work, we have selected a 1:2:2:1 amplitude distribution for which the offsets obtained are shown in Fig. 6. While the length of the slots is selected to be approximately $\lambda_g/2$ and the width is selected to be $\lambda_g/10$ (being λ_g the guided wavelength), which is associated with the TE_{10} mode propagating inside the groove gap waveguide.

III. SIMULATED ANTENNA PROPERTIES

The antenna designed in the previous section is now simulated using a commercial full-wave analysis tool in order to obtain both the scattering parameters and the radiation patterns. Fig. 7 shows the main structure in CST Microwave Studio ©.

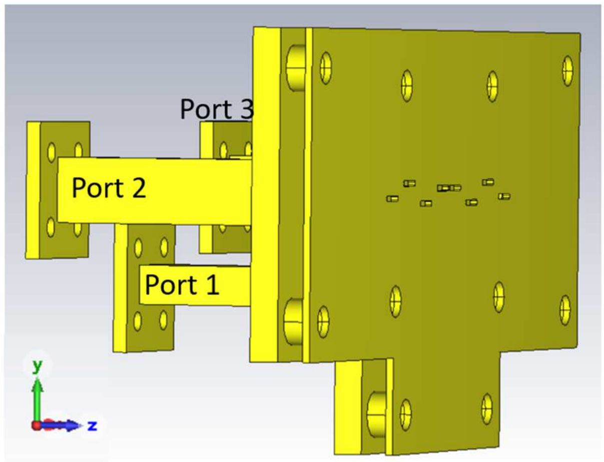


Fig. 7. Structure simulated in CST using Aluminium for all the components considered and a superficial roughness of 0.001 mm.

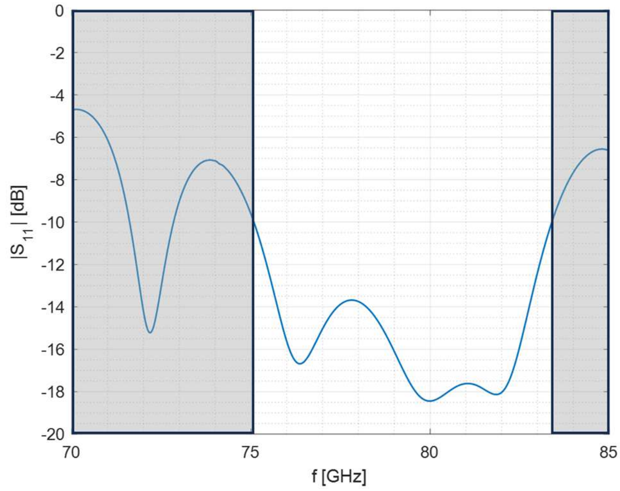


Fig. 8. S_{11} parameter of the structure. The structure is adapted to work from 75 to 83 GHz.

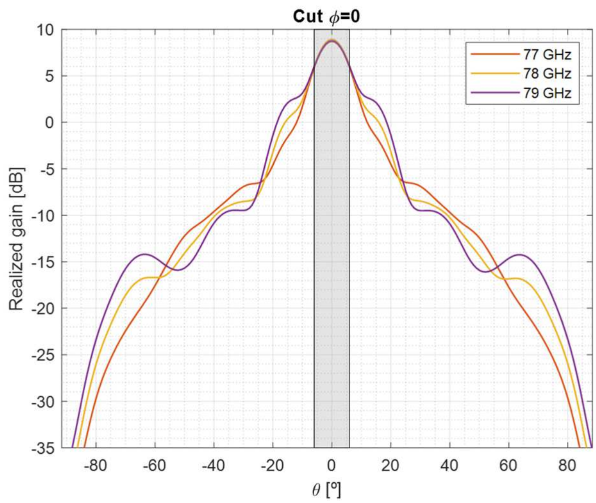


Fig. 9. Realized gain pattern of the structure at different frequencies when fed through port 1. The -3dB bandwidth is approximately 10º.

A. Central port behavior

A priori, the antenna is designed to be fed through port 1 (Fig. 7), so that we define this response as main behavior. The s_{11} parameter shows suitable matching within the commonly utilized radar automotive frequency band (76-81 GHz) as shown in Fig. 8, Within this 5 GHz bandwidth the S_{11} is nearly lower than -12 dB, only being -10 dB at the edge of the band. Then, the realized gain of the antenna is shown in Fig. 9. The main cuts show an almost 10 dB gain with approximately 10º beamwidth.

B. Lateral ports behavior

As above mentioned, the antenna was designed to be fed by port 1 (main behavior However, the feeding network, designed as a -3dB splitter, enables multi-feeding capability and the generation of three distinct beams. This configuration also facilitates an easy intermediate test during the manufacturing process. Consequently, two additional ports are available for feeding the structure, resulting in tilted beams. Hence, the response of feeding the antenna using port 2 or port 3 is also evaluated. The S_{22} and S_{33} parameters and the generated realized gain pattern when feeding through ports 2 and 3 are shown in Fig. 10 and Fig. 11.

The $S_{22,33}$ parameters show suitable matching within the commonly utilized radar automotive frequency band (76-81 GHz) as shown in Fig. 10.

It is easy to extract from the radiation patterns that when the structure is fed through different ports beam scanning is obtained. The main lobe tilts from -9º (port 2) to 9º (port 3) passing through 0º (port 1). This behavior is significantly useful when dealing with automotive applications as it is convenient to have at least three different beams [14] in order to achieve the needed beam scanning range maintaining the intersecting around their -3dB point [15].

IV. Conclusion

This work introduces a metal-only slotted antenna built upon groove gap waveguide technology. Its metal-only design not only facilitates seamless integration into vehicle chassis but also ensures minimal losses within the automotive frequency bands. The fully integrated feeding network, featuring a -3dB power splitter, offers the flexibility of multi-port feeding. This adaptability has been proven particularly valuable in achieving beam scanning, as changing the feeding port enables this capability. Furthermore, the multiport configuration has the potential to support multiple input/output channels, enhancing the extraction of additional angular information for a wide range of applications.

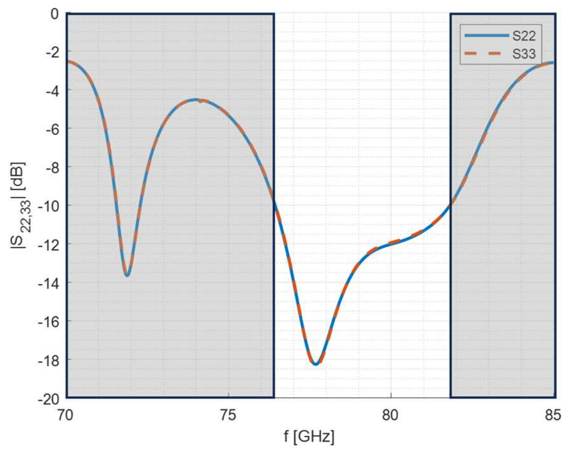


Fig. 10. S_{22} and S_{33} parameters of the structure. The structure is adapted to work from 75 to 83 GHz.

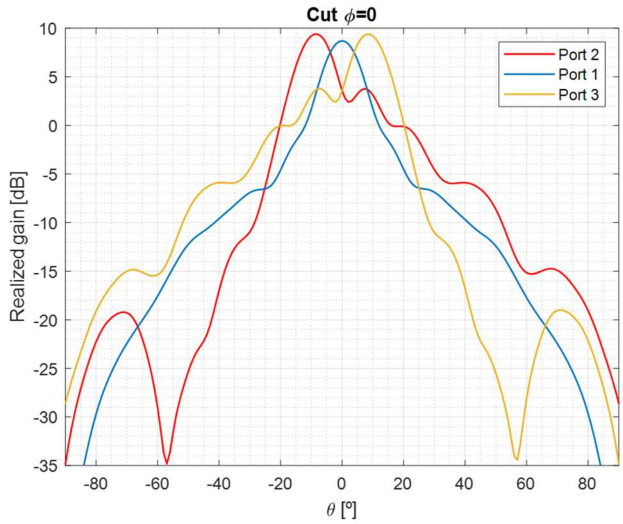


Fig. 11. Realized gain pattern of the structure as a function of the theta angle (θ) when fed through ports 1, 2, and 3 at 79 GHz.

Acknowledgment

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