E-band reconfigurable polarizer for waveguide fed antennas

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A new design for a reconfigurable polarizer integrated E band horn antenna is proposed in this paper. The reconfigurable polarizer consists of two septum based waveguides which can be arranged in different configurations. Depending on the orientation of the waveguides relative to each other the desired polarization can be achieved among Linear, Right-handed circular and Left-handed circular polarization. The polarizer is integrated with a horn antenna and optimized to work from 60 to 90 GHz. This antenna is fabricated, and measured for different frequencies. The proposed design has a line of sight Axial Ratio (AR) around 1 dB and a 3 dB AR beamwidth of 56° at the center frequency.

1 Introduction

Polarization reconfigurability is a desirable trait in most modern communication systems (Balanis, 2005; Choudhury, 2023). However, there are many different applications where the antenna choice is fixed, such as using a horn antenna or any other waveguide-fed transmitter. In such cases, including a reconfigurable waveguide polarizer to the antenna would be necessary to attain polarization diversity. As modern communication systems move towards millimeter wave technologies to make use of their higher data rates and lower latencies, there is an imperative need to attain polarization diversity in these bands to provide robust solutions (Xiao et al., 2017).

The oldest approach in literature dealing with an agile polarizer in E band would be the meandering line polarizer (Zürcher, 1998). Other approaches include using periodic structures such as equally spaced dielectric gaps, circular cavities, cross slots, *etc.*,; but these do not cover all polarizations in the same device (Ayoub et al., 2022; Dietlein et al., 2007). Using a lens to change the polarization is a very attractive alternative (Poyanco et al., 2023; Melendro-Jimenez et al., 2023), however these designs may affect the efficiency and directivity of the antenna. Also, these ideas require an additional structure to be mounted on top of the antenna, which may not always be possible. Polarization flexibility at lower frequencies can easily be achieved with the use of pin diodes, varactors, MEMS switches, or even mechanical methods in the antenna design/feeding circuit to have it radiate in circular or linear polarization (Patriotis et al., 2021; Cheng and Dong, 2021; Chen et al., 2019). However, these approaches cannot be implemented at higher frequencies. At these frequencies there has been one recent demonstration to electronically attain polarization change using Liquid Crystals (LC) (Doumanis et al., 2014). However, LC devices may not always be practical and can be difficult to implement.
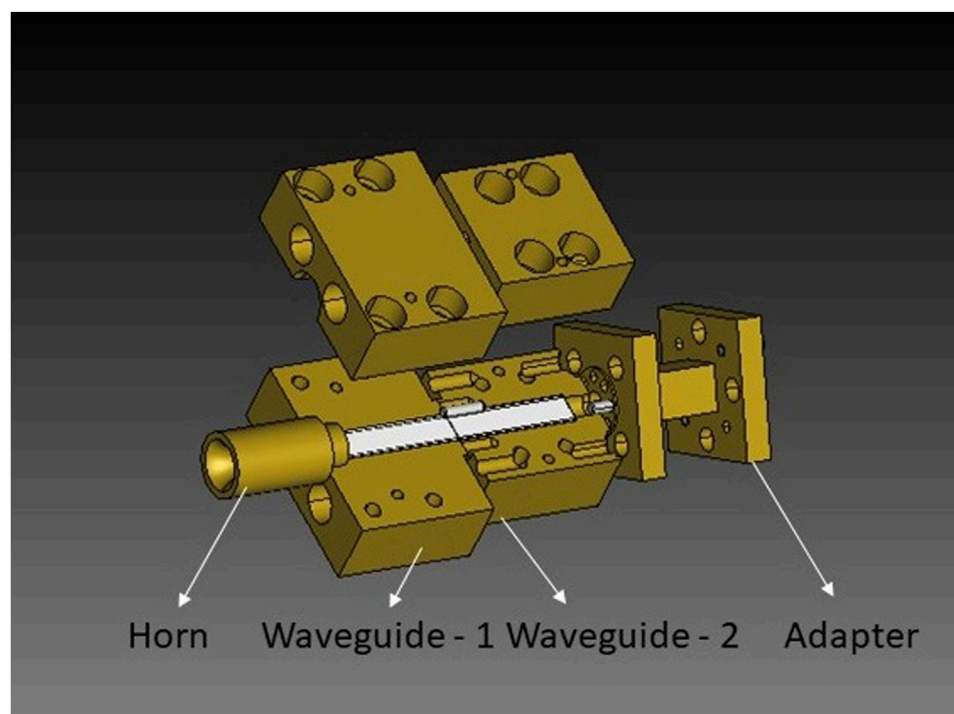
FIGURE 1
The different components of the proposed polarizer integrated horn antenna. The upper half of the polarizer has been removed to display the dielectric septum inside it.

In this paper, we propose a novel waveguide polarizer which can be reconfigured before application to attain one out of three polarizations for each test case - linear polarization (LP), Right handed circular polarization (RHCP), or Left handed circular polarization (LHCP). To demonstrate the functioning of this reconfigurable polarizer we integrate it to the feed of an E-band horn antenna and characterize it. The different components of the polarizer are shown in Figure 1.

To attain the polarization conversion one can use a septum based partition in the waveguide. Dielectric loading using a septum has already been shown to induce CP in (Wang et al., 2004). Using the same principle, a stepped septum polarizer was developed in (Chen and Tsandoulas, 1973), and later used to polarize a horn (Franco, 2011), and even used to create a duplexer at 225 GHz (Leal-Sevillano et al., 2013). We expand on this approach by adding another similar dielectric film in the feeding waveguide. Thus, depending on how the two dielectric films are arranged, we can have six different orientations, as seen in Figure 2. By using smart fabrication techniques, we integrate a low-gain horn antenna to this design so that the dielectric films forming the septum can be arranged in multiple ways to generate reconfigurablity in terms of the polarization of the horn. The key advantage offered by our work is that the working principle of this design can be extended and applied to any waveguide-fed antenna. It would also be possible to include elliptical polarization by creating new alignment positions of the septum within the waveguide structure. A similar advantage is offered in (Farzami et al., 2018), but uses pin diodes and hence

can only operate in lower frequencies. Since our design makes use of a septum to control the polarization of the transmitted wave, it constrained at the higher frequencies by the smallest dimensions at which the septum can be created. Thus, in this way, we introduce a novel reconfigurable horn antenna which depending on how it is assembled, can radiate with LP, RHCP, or LHCP.

2 Materials and methods

The antenna has four parts; the horn antenna, two waveguides consisting of a septum in the middle forming the polarizer, and an adapter. These are all assembled as shown in Figure 1.

2.1 Polarizer

The septum is created by a thin film of Polytetrafluoroethylene (PTFE) inserted in two of the slots of thickness pt which can be seen from the cross sectional view shown in Figure 3. To maintain symmetry, two additional slots of thickness cw are also created perpendicular to the septum. For ease of fabrication, the waveguides were designed with a partition in between so that the septum can be locked in place during assembly. This allows both waveguides to be independently removed and rotated in steps of 45° before
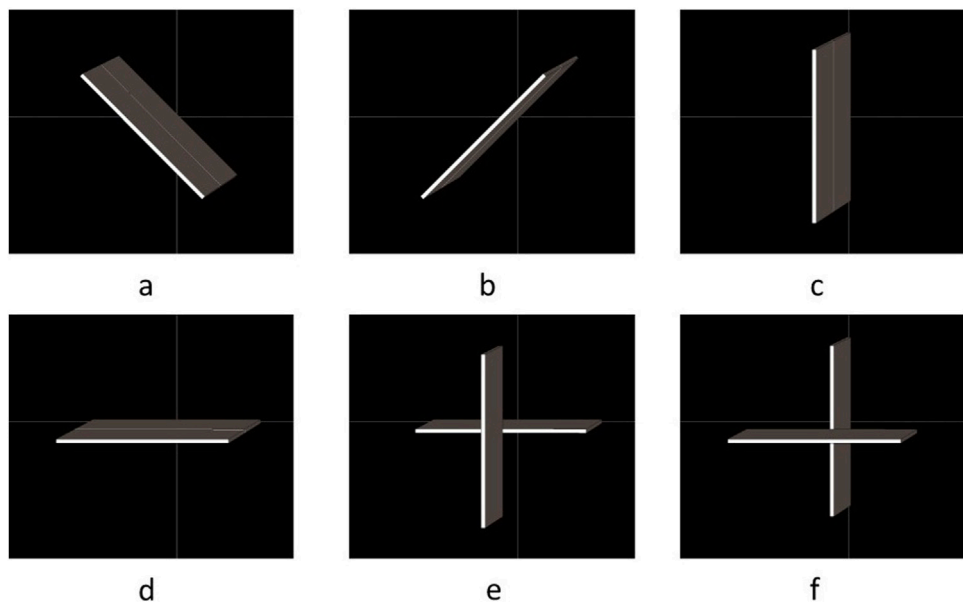
FIGURE 2
All six possible different configurations of the proposed polarizer. Configuration **(a)** results in a RHCP wave, and **(b)** results in a LHCP wave. Rest of the configurations **(c–f)** result in a linear wave.
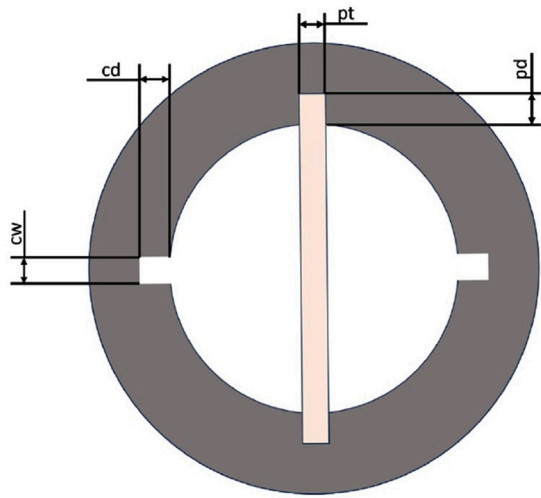

FIGURE 3
Cross sectional view of the polarizer.

reassembly. The adapter is necessary so the rotation of both waveguides can occur independently of the feed. The waveguides can be removed and fitted in any other orientation depending on the need, forming the different configurations shown in Figure 2. The polarizer is tapered at both ends by a value of *tl* The dimensions of all the parameters involved in the design are shown in Table 1.

The default configuration of the polarizer is shown in Figure 2a, where both septums are making an angle of 45° to the horizontal plane of the waveguide. This results in the horn getting fed with a RHCP wave. Similarly, if they are aligned at an angle of −45° (Figure 2b), it results in a LHCP wave. If they are both parallel to the waveguide, or perpendicular to each other, as in Figure 2c–f, then the linearly polarized wave continues to propagate and is fed to the horn. The septum controlling the orthogonalization of the E fields is well studied and has already been described in (Wang et al., 2004). The length of the septum changes the phase difference between the orthogonal modes, and thus this parameter (*pl*) is optimized to obtain minimum axial ratio (AR) throughout the bandwidth. To verify the polarization, the electric field distribution is observed as the wave propagates, as shown in Figure 4. In this figure, we can see how the electric fields which are fed to the input port are separated into the fields of about equal amplitude on the septum, and on the inner walls of the waveguide. The electric fields propagating through the septum has a phase different from the rest of the fields propagated through the waveguide. Finally, at the end of both septums, these orthogonal degenerate TE11 fields combine with a phase difference of 90° to create circular polarization. This can be made RHCP or LHCP by changing the orientation of the septum. In the case of linear polarization, the phase shifts are either canceled out by each other of the opposing septums (since they are of the same length) or do not add up constructively with a difference of 90° for configurations (c-d).

TABLE 1 Dimensions involved in the polarizer (in mm).

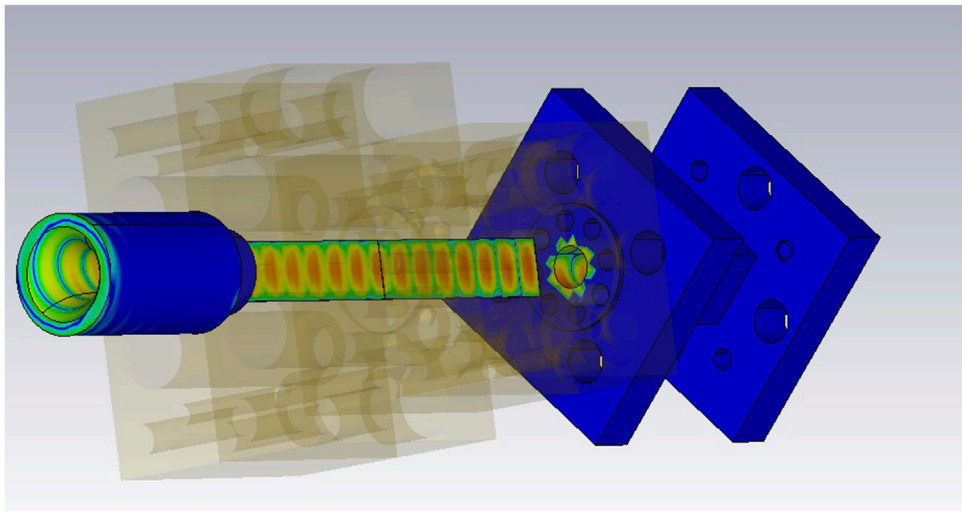| d1	hl	tl	pl	cw	cd	pt	pd	c1	c2
3.18	15	3	36.48	0.55	0.101	0.1	0.39	0.0001	0.656

FIGURE 4
Electric field distribution on the septum. These fields combine with the remaining fields within the waveguide to create the CP pattern for the attached horn.
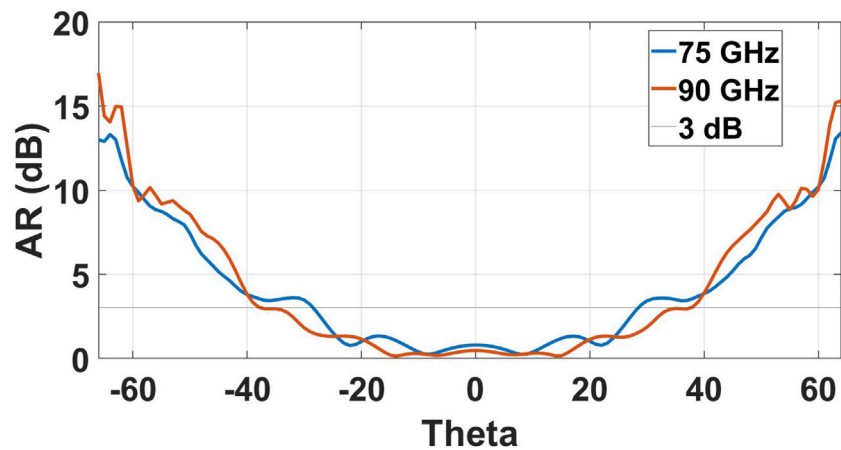

FIGURE 5
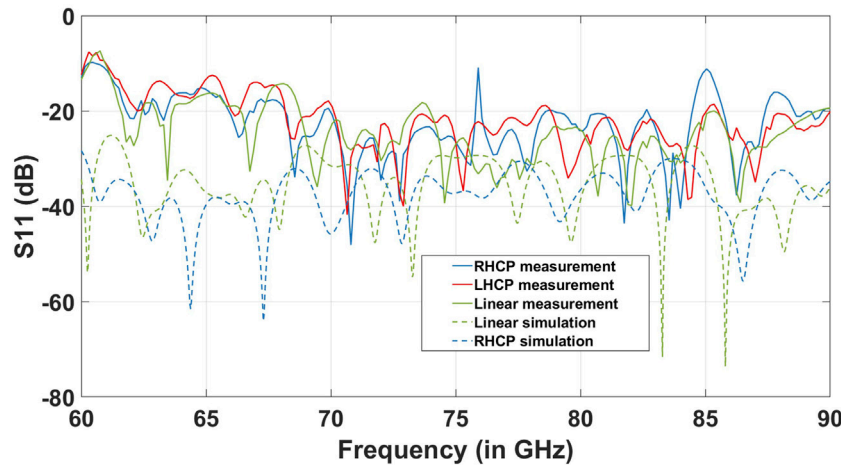Axial ratio simulations as a function of theta for $\phi = 0°$. This is done for RHCP configuration.

FIGURE 6
$S11$ measurements and simulation of the antenna under different configurations.

FIGURE 7
Measurment setup of the antenna. The polarizer is set to operate in the RHCP mode here.

2.2 Horn antenna

A horn antenna is selected to be included with the polarizer. The horn antenna is created by designing an exponential taper between the diameter of the polarizer (d_1) to the aperture diameter with coefficients c_1 and c_2. The length of the horn is denoted by hl. The curve of the horn can be described using the Equation 1

$$c_1\left(e^{c_2 l} - 1\right) + \frac{d_1}{2} \tag{1}$$

The adapter is a standard WR-12 circular waveguide that has UG-387 flanges on both sides. The antenna is fabricated on a CNC machine and assembled for experimental verification.

To verify the polarization of the proposed antenna system, the Axial Ratio (AR) was also calculated for the waveguide along with

the horn antenna. Figure 5 shows the AR at 75 and 90 GHz as a function of theta. We here see that there exists an AR ≤ 3 dB beamwidth of 56° at 75 GHz. At 90 GHz we see that that this increases to 69°. Here we also observe that the line of sight AR is 0.8 dB at 75 GHz, and 0.4 dB at 90 GHz. Thus, this way the polarization beamwidth of our proposed antenna system was verified.

3 Results

We first test for the S11 of our fabricated antenna. Figure 6 shows the measured S11 data. We can see in this figure that there is good matching of the antenna throughout the entire E band. There is a small aberration for the RHCP S11 around 76 GHz but this can be attributed to a small loss caused by errors during fabrication or assembly of the setup. We tested for all configurations but here only display results of configurations (a-c) from Figure 2 for convenience. We see that the impedance matching is maintained as we try different configurations.

Next, the radiation pattern of the polarizer integrated horn antenna is measured using a spherical near field measurement chamber. The measurement setup is shown in Figure 7. The radiation pattern for config-a is shown in Figure 8 for 75 and 90 GHz. We see here that there is one main lobe for the RHCP configurations, keeping an isolation of around 10 dB with the cross-polarization measurements. We also plot the simulations and see good similarities for the co-pol measurement. The cross polarization beam measurements seem to differ from the simulations, especially in terms of a significant decrease in the backlobe. The cross polarization measurements also indicate a narrow main lobe as compared to the simulations.

The radiation patterns for the linear configuration are shown in Figure 9. Again, the co pol measurements are in good agreement with the simulations. There is isolation of 20 dB at 75 GHz and 10 dB at 90 GHz, but the cross pol pattern is slightly different from the simulations. While the cross polarization measurement is narrower than the simulation at 75 GHz, it becomes wider at 90 GHz. This consistent anomaly for the cross polarization measurement could indicate that certain small bends in the septum while fabricating and assembling might be causing these differences. More precise fabrication and assembling of the polarizer may
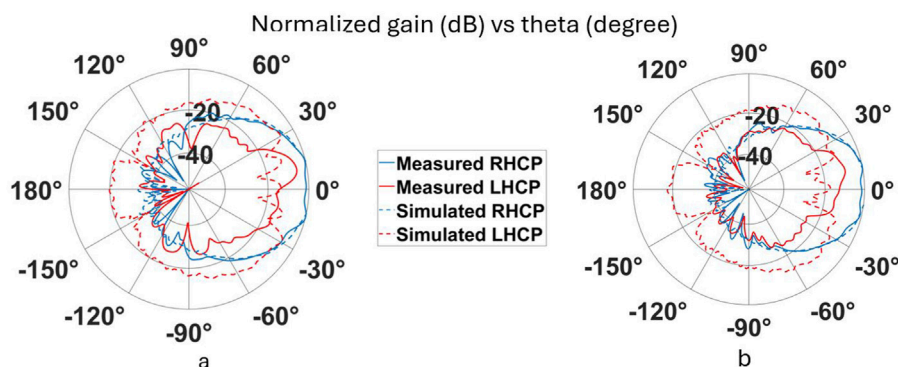

FIGURE 8
Radiation pattern measurements (normalized gain (dB) v/s theta (degree)) for RHCP configuration. The planes are for $\phi = 0$ and are taken at 75 GHz **(a)** and 90 GHz **(b)**.
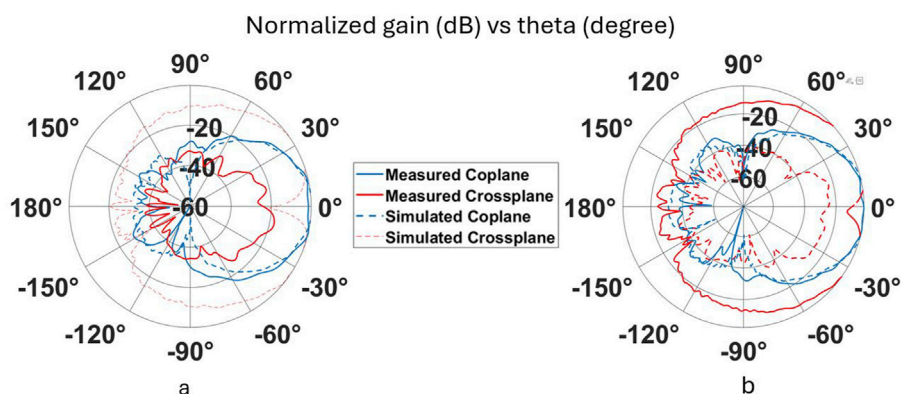
FIGURE 9
Radiation pattern measurements (normalized gain (dB) v/s theta (degree)) for linear configuration. The planes are for $\phi = 0$ and are taken at **(a)** 75 GHz, and **(b)** 90 GHz..

improve the cross polarization pattern. A more suitable choice of dielectric material for a sturdy septum may also improve the accuracy of assembly.

All the configurations generate a dominant main lobe with a half power beamwidth around 48˚ at 75 GHz. This value steadily declines to around 36˚ at 90 GHz. Small sidelobes exist in certain patterns but these are around 25–30 dB below the mainlobe.

4 Conclusion

A novel reconfigurable polarizer integrated horn antenna is proposed in this paper. The polarizer works on the principle of a septum made of two dielectric films causing a phase shift in the propagating orthogonal E fields. The design is made in such a way that the two waveguides containing the septum can be oriented in multiple ways. Depending on the orientation of the adjoining waveguides a linear wave can be kept the same, or converted to LHCP or RHCP. A possible drawback of the proposed antenna would be the difficulty in the waveguide assembly. The septum is very delicate and the antenna performance is sensitive to imprecise manufacturing. The proposed antenna can easily be included in any waveguide fed design and can also be scaled to radiate the desired polarization at any frequency.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JC: Data curation, Conceptualization, Visualization, Formal Analysis, Investigation, Writing – review and editing, Methodology, Software. JV: Investigation, Validation, Visualization, Supervision, Formal Analysis, Writing – original draft. EA: Resources, Writing – review and editing, Methodology, Project administration, Supervision. SL: Validation, Resources, Project administration, Writing – review and editing, Supervision, Funding acquisition. CC: Visualization, Formal Analysis, Resources, Funding acquisition, Conceptualization, Project administration, Writing – review and editing, Supervision, Validation.

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Conflict of interest

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