# Millimeter-Wave Metallic Bull's–Eye Antenna with Wideband Broadside Radiation Characteristics

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***Abstract*—This work presents a low-profile metallic Bull's-Eye antenna with high broadside gain and a wide bandwidth. The antenna was designed for a center frequency of 37.5 GHz and showcases 6 periodic corrugations plus a soft electromagnetic surface at its outer edge with 5 corrugations. Simulation results reveal a broadside gain greater than 15 dBi over a 6.5 GHz bandwidth (17.3%). The antenna has a peak gain of 18.9 dBi at 36.1 GHz with a return loss below –15 dB throughout its operational bandwidth. An input-matching bandwidth greater than 10 GHz (26.7%) was achieved using a tapered waveguide feeding structure. The soft electromagnetic surface is used to achieve a sidelobe level of –12 dB at 36.1 GHz and better than –9.5 dB throughout the bandwidth.**

***Index Terms*—Bull's-Eye, leaky-wave antenna, wideband antenna, soft surface, tapered aperture, metallic grating.**

## I. Introduction

Over the past two decades, Bull's-Eye leaky-wave antennas have attracted much interest due to their structural simplicity and ability to realize highly directive beams while maintaining a compact profile [1]. To date, these antennas face the drawback of a narrow operational bandwidth around the design frequency imposed by the periodic perturbations, making it challenging to achieve broadside radiation over a large bandwidth. This paper presents a Bull's-Eye antenna design that addresses the bandwidth limitations of previous designs by using two sets of corrugations and a tapered waveguide feed.

## II. Antenna Design

The proposed antenna was designed for an operational center frequency of 37.5 GHz and a cross-sectional view along its diameter is depicted in Fig. 1. Starting dimensions used in the design were based on those described in [2]. Narrow corrugations supporting the $TE_{11}$ waveguide mode were selected for the design based on parametric analyses carried out in [3] that resulted in large gain enhancement and possessed the least sensitivity to the corrugation depth and width. The antenna is fed by a standard WR-28 waveguide. A tapered waveguide feed was employed as in [4] to extend the input-matching bandwidth and enable greater degrees of freedom in selecting the dimensions of the corrugated structure. An electromagnetic soft surface (SS) comprising of 5 periodic corrugations was also employed at the aperture edge as in [5]. The SS reduces edge diffraction effects and rising sidelobe levels at higher frequencies that are caused by the beam-scanning behaviour

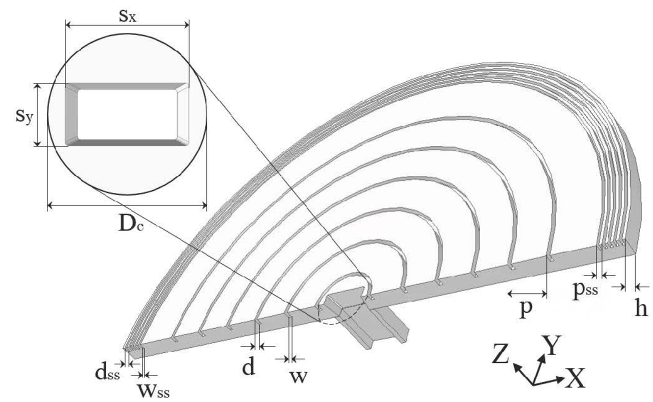


Fig. 1. Cross-sectional cut of the proposed Bull's-Eye antenna geometry with inset illustrating the tapered waveguide feed. The antenna $E$–plane and $H$–plane lie along the $yz$–plane and $xz$–plane respectively.

of the excited $n = -2$ harmonic at and past the design frequency [1].

The antenna dimensions can be found in Table I. The corrugation period $p$, width $w$, depth $d$, antenna thickness $h$ and SS ($p_{ss}$, $w_{ss}$, $d_{ss}$) were designed using approximate analytical methods and parametric studies, leaving the tapered slot width $s_x$ and height $s_y$, as well as the distance between the feed and first corrugation $D_c$ to be chosen via optimization processes. A transition region denoted $T$ was necessary between the most

TABLE I
Bull's-Eye Antenna Dimensions

| Parameter | Description | Dimensions (mm / $\lambda$*) |
|---|---|---|
| $s_x$ | Flared slot width | 8.81 / 1.10 |
| $s_y$ | Flared slot height | 4.41 / 0.55 |
| $h$ | Flared slot depth | 3.74 / 0.47 |
| $D_c$ | Bull's-Eye diameter | 11.39 / 1.42 |
| $p$ | Groove period | 7.48 / 0.94 |
| $w$ | Groove width | 0.75 / 0.10** |
| $d$ | Groove depth | 1.37 / 0.17 |
| $T$ | Transition region | 1.92 / 0.24 |
| $p_{ss}$ | SS groove period | 1.04 / 0.13 |
| $w_{ss}$ | SS groove width | 0.51 / 0.06 |
| $d_{ss}$ | SS groove depth | 1.15 / 0.14 |
| $D_a$ | Aperture diameter | 115.37 / 14.4 |

*$\lambda$ = 8 mm
**(mm / $p$)

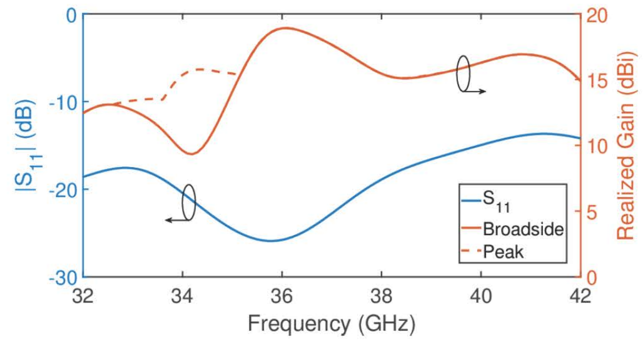


Fig. 2. Simulated return loss and far-field realized gain of the proposed antenna over frequency. The solid and dashed gain plots illustrate the peak gain at broadside ($\theta = 0^\circ$, $\phi = 0^\circ$) and the peak gain over all elevation angles ($\theta$, $\phi = 0^\circ$) respectively. The intersection of the solid and dashed lines at 35.2 GHz marks the frequency at which the broadside beam splits.

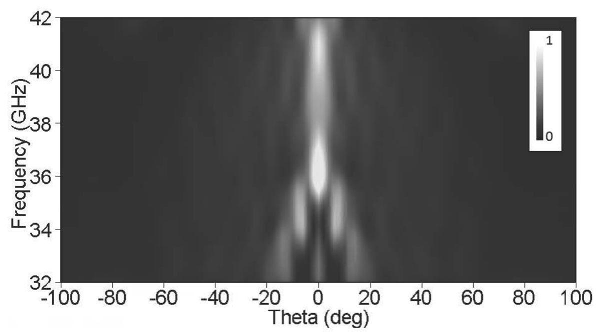


Fig. 3. Simulated normalized magnitude of the absolute value of the far-field gain as a function of elevation angle and frequency. A single broadside beam is maintained over a 6.5 GHz bandwidth (17.3%) from 35.3 GHz to 41.8 GHz.

outward radiating corrugation period and the first corrugation of the SS that was also described in [5]. Electric and magnetic symmetry planes were used along the $E$–plane and $H$–plane of the antenna due to its circular symmetry to decrease the simulation time.

## III. Simulation Results

The antenna was simulated using the Ansys HFSS full-wave solver. A return loss of –20.7 dB was achieved at the design frequency of 37.5 GHz with a minimum of –26.1 dB at 35.9 GHz and better than –15 dB over the simulation bandwidth from 32 GHz to 42 GHz (26.7%) as can be seen in Fig. 2. The spectral behaviour of the far-field realized gain is also presented, exhibiting 16 dBi of gain at the design frequency of 37.5 GHz, with 18.9 dBi peak gain at 36.1 GHz. The frequency response of the Bull's-Eye antenna showcases the broadside beam-splitting effect that can be seen at 35.2 GHz. The gain plots in Fig. 2 and Fig. 3 illustrate the broadside beam undergoing discrete step changes in the radiation angle below the beam-splitting frequency.

As expected for leaky-wave structures, the antenna's radiation angle changes and splits the main beam, however broadside radiation is maintained even below the design frequency of 37.5 GHz at the cost of reduced gain. Indeed, the

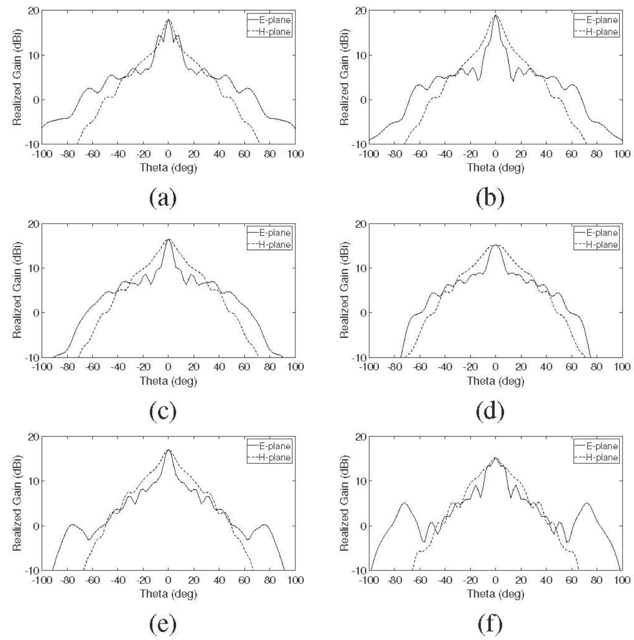


Fig. 4. Simulated far-field radiation patterns of the proposed antenna at different frequencies. The solid lines represent the $E$–plane cuts and the dashed lines represent the $H$–plane cuts at: (a) 35.3 GHz, (b) 36.1 GHz, (c) 37.5 GHz, (d) 38.4 GHz, (e) 40.9 GHz, and (f) 41.8 GHz.

antenna's gain reaches a minimum of 10 dBi at 34.2 GHz. The three beams can also be viewed in Fig. 4 (a), where the gain peaks are more clear. Fig. 4 shows the $E$–plane and $H$–plane radiation patterns over the broadside gain bandwidth of the antenna, giving insights into the sidelobe behaviour. Here it is seen that the SS is effective in reducing sidelobes introduced by the $n = -2$ harmonic from about 36.1 GHz to 38.4 GHz.

## IV. Conclusion

A wideband low-profile Bull's-Eye antenna with improved bandwidth and wideband radiation capabilities has been presented and examined. A peak gain of 18.9 dBi has been achieved at 36.1 GHz with frequency-stable broadside radiation from 35.3 GHz to 41.8 GHz, resulting in a gain bandwidth of 6.5 GHz (17.3%). With these results, the proposed antenna can find uses in high-gain wideband applications.

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