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A Compact and Wide Beam Radiating Element for Electronically Steered Array Antenna

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ABSTRACT

This paper discusses the design, simulation, optimization, and development of a wide-beam, rugged radiating antenna element at L-band frequencies. The antenna has been designed in radial horn configuration. The antenna consists of an L-shaped radiating element with two flared metallic walls to obtain a wide beamwidth. The half-power beamwidth of the designed antenna is approximately 117° in the E-plane- and 320° in the H-plane, respectively. The measured VSWR of the antenna over the frequency band of 1040 MHz to 1240 MHz is 1.85:1. The measured gain of the designed antenna is 1.88 dBi at 1100 MHz. The designed antenna has a size reduction of ~50 % compared to the conventional antenna. Owing to wide beamwidth, the designed radiating element can be used for the realization of the electronically steered antenna with ± 55° beam steering with a scan loss of 3 dB.

Keywords: Wide beam; L-band; Radial horn configuration; L-probe; VSWR

1. INTRODUCTION

High-gain directional antennas are required for long-distance point-to-point communication systems. Realization of these antennas may be done either in a reflector-based configuration or array-based configuration. At lower frequencies, the realization of the antenna in a reflector-based configuration has several limitations in terms of size and volume. Array configuration can be used to mitigate the size and volume limitations of reflector-based configuration, but this also requires the mechanical positioning system which can be used to orient the beam in the desired direction. One of the solutions to avoid these limitations would be the use of an electronically steered antenna.

Due to the multifold advantages of electronically steered antenna(ESA), all mechanically steered antennas are being replaced by it. ESA not only removes the positioning system from the mechanically steered antenna but also makes the system to steer the radiated beam faster. Other advantages of an electronically steered antenna include low profile, low RCS, no periodic maintenance etc.

One of the important components of the electronically steered antenna is the radiating element. It plays a very vital role in deciding the performance of ESA. For wide-angle scanning, using electronically steered antennas, the beamwidth of the radiating element should be as large as possible as this will help in reducing the scan loss of the antenna at a maximum steered angle.

Conventional horn antennas are a very popular directional antenna, where the sides of waveguides are flared in the E and H planes to obtain directional radiation patterns. It is a very rugged antenna. Nos. of literature have been published on horn antennas[1-7].

One of the limitations of the horn antenna is that the size of the horn antenna is governed by the size of the waveguide. It cannot be smaller than the waveguide, as it is the feeding guide. Further, horn antenna is a directive antenna having a narrow beamwidth (≤ 70°). To mitigate this, we have designed a compact L-shaped monopole antenna fed by an SMA connector and the directional pattern of the antenna has been obtained by flaring it using the metallic wall. Using this technique, we achieved large beamwidth in the E and H planes but with lower gain. Several configurations/ methods have been reported by several authors[8-12] for the realization of compact antenna with wideband and wide beam performance. Multiple ways have been reported to increase the impedance bandwidth of helical antennas[13-15]. Impedance bandwidth of the order of 7 % has been achieved by Louvière & Sharaiha[13], *et al.* at L-band frequency. Sainati[14], *et al.* achieved 7.7 % bandwidth in quadrifilar antenna at S-band frequency with dual-band operation. A printed quadrifilar antenna with 6 % bandwidth has been realized by Lamensdorf & Smolinski[15].

The meander line technique has been utilized by Ibambe[16], *et al.* to reduce the size of the antenna with enhanced efficiency. A sectoral conformal circular patch antenna with a shorted wall has been realized by Rao[17], *et al.* to minimize the overall size and increase the beamwidth of the antenna. The paper also discusses the study of the antenna's radiation performance degradation when mounted on an aerial platform. Joong Nam, *et al.* in their paper[18], discusses the wide beam antenna for a 5G wireless communication system. Single-fed wide beam dual-band L-probe fed antenna has been discussed by Yuanquin

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Chen[19], *et al.* This configuration of the antenna is very complex and for a large phased array, realization of radiating elements becomes very complex and difficult. Zhiming Xiao[20], *et al.* details a wideband magneto-electric dipole antenna with wide beamwidth for MM wave applications. Again, the configuration of the antenna does not allow it to be used as a radiating element for the large electronically steered antenna. In all the above-mentioned literature, radiating elements have either small beamwidth or are complex to be realized for large arrays for ESA.

The present paper describes a novel compact, rugged and simple wide beam and wideband antenna that can be used as a radiating element for an L-band electronically steered antenna with wide beam scanning. The antenna possesses more than 18 % impedance bandwidth at L-band frequency, and it has a beamwidth of the order of 117° & 320° in the E- and H- planes respectively. This makes the designed radiating element, suitable for beam steering of more than 55° with a scan loss of 3 dB.

2. DESIGN CONSIDERATION, METHODOLOGY & SIMULATION

The requirement of broadband operation and wide beamwidth for radiating elements can be met through many antenna configurations such as cross dipole, microstrip patch, helix and quadrifilar helix antenna etc. Cross dipole requires a large volume at the L-band. Microstrip patch antenna are low profile but require a larger size. Further, microstrip antennas are inherently narrowband antenna and hence cannot be selected for wideband operation. Helical antenna and printed quadrifilar antenna provide circularly polarized radiation, but in this case, maintaining the axial ratio over the wide radiated beam is very difficult.

One of the methods to design a wideband antenna is in waveguide configuration. The conventional horn antenna is fed by a rectangular/ circular waveguide and it is flared in E and H plane. The beamwidth of a conventional waveguide is of the order of 70° with a gain of 5-6 dBi. When it is flared in E and H plane, the beamwidth of the antenna decreases further and gain increases. Hence, the objective of a wide beam radiation pattern (beamwidth > 100°) cannot be met through a conventional horn antenna.

To overcome this, a quarter wavelength L-shaped capacitively loaded monopole has been used in the present work for wideband operation. To obtain the required wide beamwidth, two metallic walls have been utilized. It also helps in shaping the radiated beam. This configuration of antenna has been termed as radial horn antenna. In this configuration, an L-shaped metallic radiating element has been integrated with the input SMA connector. The gap between the input connector and the radiating element has been optimized to obtain the required antenna performance. The other end of the radiating element has been isolated from the flared wall using Teflon material. The antenna has been made compact by using L-shaped radiating geometry as well as capacitive loading. A curved dielectric radome has been designed, which protects the designed antenna from the outer environment.

Size of conventional monopole antenna: $\frac{wavelength}{4}$ (1)

At 1 GHz the wavelength is 300 mm and the size of the conventional antenna would be 75 mm. By using capacitive loading, the size of the antenna (L-shaped radiating element) has been reduced to 40 mm. In this way, we obtain a size reduction of about 50 % using this design.

All the dimensions of the radial horn antenna have been calculated theoretically and the antenna was modelled on High Frequency Structure Simulator (HFSS) software. After EM simulation, optimization of the antenna has been carried out to meet the coverage and gain requirement. Performance optimization of the antenna has been carried out at 1.1 GHz. The 3D CAD model of the designed antenna is shown in Fig. 1. Figure 2-3 shows the simulated VSWR and simulated 3D-radiation pattern of the designed antenna. Simulated

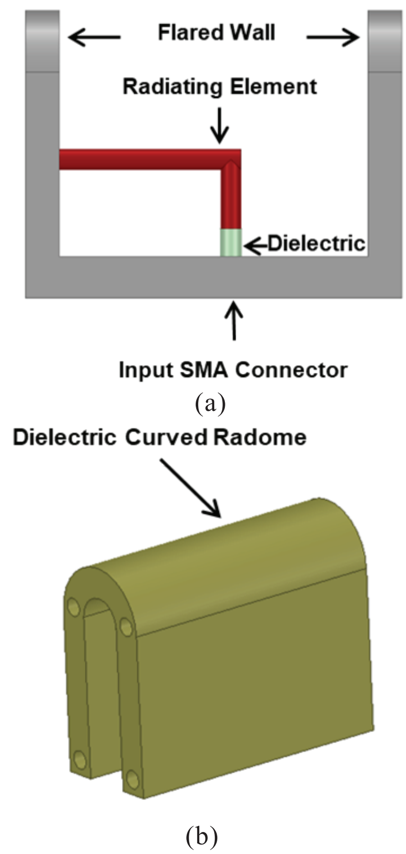

Figure 1. (a) 3D CAD model of the antenna element; and (b) 3D CAD model of radome.

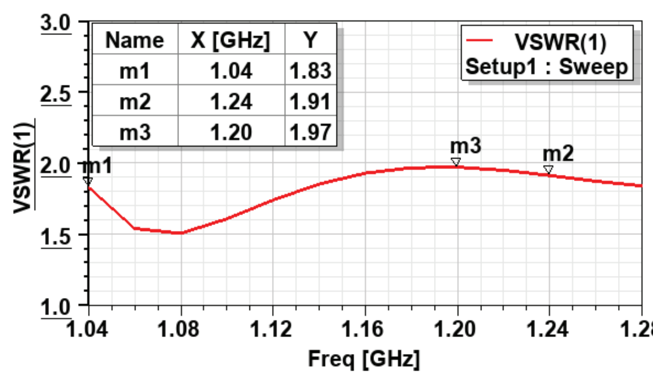

Figure 2. Simulated VSWR of the designed antenna.

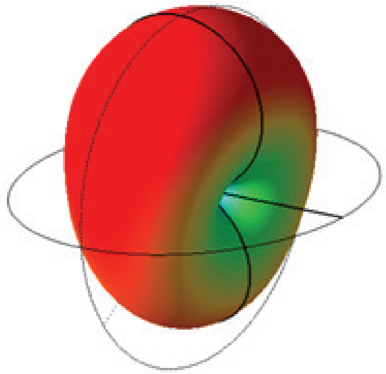

Figure 3. The simulated 3D radiation pattern of the designed antenna.

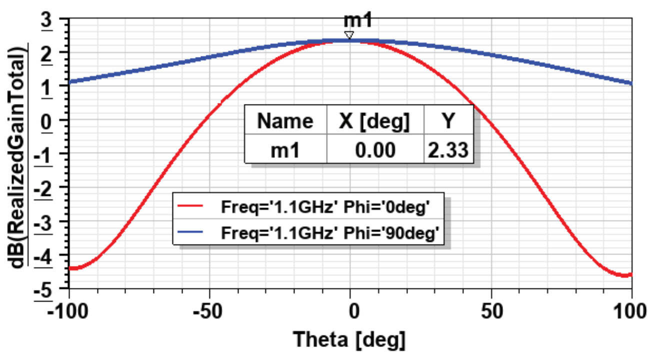

Figure 4. The Simulated 2D radiation pattern of the designed antenna in the E and H plane @ 1.1 GHz

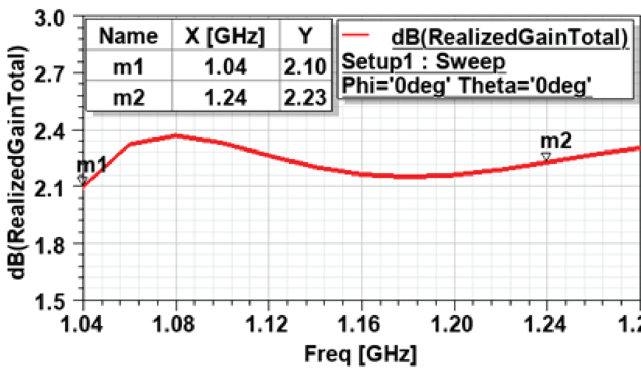

Figure 5. Gain variation of the antenna over the operating frequency band.

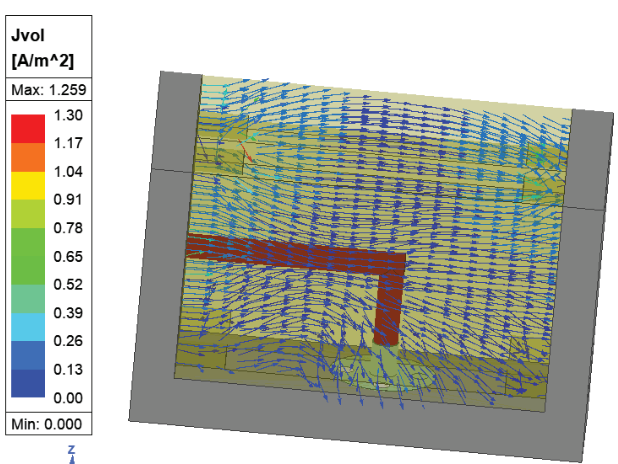

Figure 6. Current distribution of the radiating element as well as the radiation over the radiating area.

Table 1. Finalized dimensions of the designed radial horn antenna

Parameters	Dimensions
Vertical length of the radiating element (l_v)	0.07 λ
Horizontal length of the radiating element (l_h)	0.11 λ
The Diameter of the radiating element	0.01 λ
Length of radial horn (l)	0.20 λ
Width of radial horn (w)	0.06 λ
Height of radial horn (h)	0.15 λ
Dielectric material used	Teflon
Input connector	SMA (F)
Where λ is the wavelength at the frequency of operation.	

Figure 7. The photograph of the developed antenna.

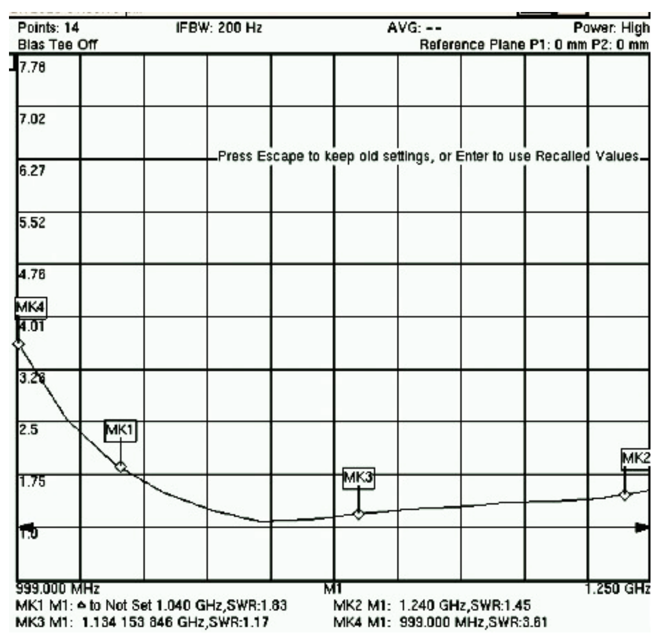

Figure 8. Measured VSWR of developed radial horn antenna.

2D-radiation patterns in the E and H plane @ 1.1 GHz and gain variation of the antenna over the operating frequency band are shown in Fig. 4 & Fig. 5 respectively. From the simulation results, it is seen that simulated VSWR over 1040 to 1240 MHz is less than 2. The Simulated beamwidth of the antenna in E- and

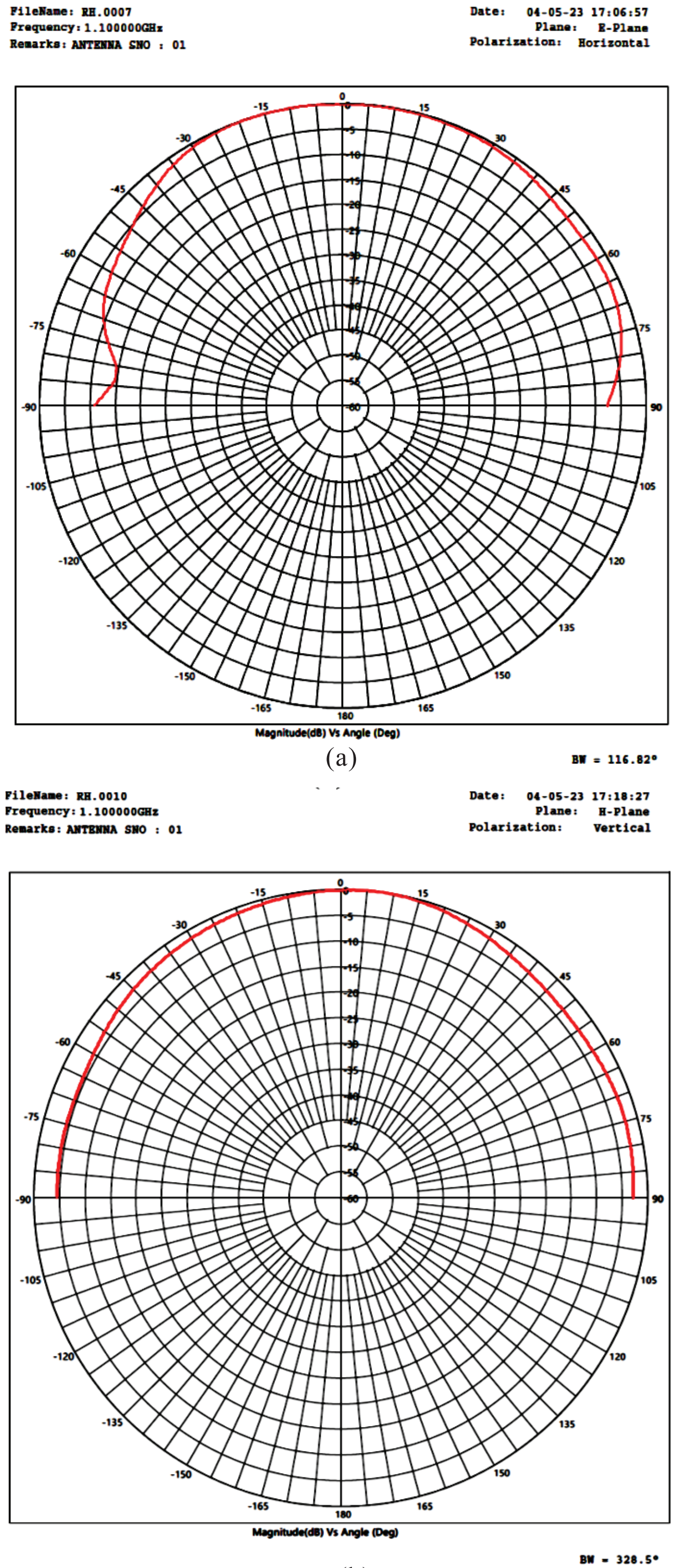

Figure 9. Measured E- & H- plane radiation pattern of developed radial horn antenna.

H-plane are 120° and 320°, respectively. The simulated gain of the antenna @ 1.1 GHz is 2.33 dBi. The current distribution of the radiating element as well as the radiation over the radiating area is shown in Fig. 6. Table 1 shows the finalized dimensions of the designed antenna in terms of wavelength.

After rigorous optimization of the antenna, the antenna was fabricated in the Centre for Advanced Mechanical Engineering (CAME) facility of DEAL using the CNC machine with a fabrication tolerance of ±50 micron. The radiating element (circular cylinder) was fabricated in two parts and later it was joined in an L-shape. The outer wall and base of the antenna were developed in an integrated manner and the radome for the antenna was developed using Teflon material. All the parts of the antenna were integrated and a SMA connector was integrated with the radiating element to feed the antenna. The photograph of the developed antenna is shown in Fig. 7.

3. EXPERIMENTAL RESULTS

VSWR measurement of the developed antenna was carried out using the vector network analyser. Figure 8 depicts the measured VSWR of the antenna. The measured VSWR of the antenna is in excellent agreement with the simulated values. 1.85:1 VSWR has been achieved over 1.04 GHz to 1.28 GHz. The realized antenna was evaluated for its radiation pattern in the Antenna Test Range Facility. The antenna was mounted in an anechoic chamber in such a manner that its polarization matches with that of the transmitting antenna. Figure 9 shows the measured radiation pattern of the developed antenna. The measured beamwidth of the antenna over the E- and H-plane are 117° & 320°, respectively. The Standard Gain Horn (SGH) method has been used to measure the gain of the realized antenna. The gain measurement of the antenna is shown in Fig. 10. The measured gain of the antenna is 1.88 dBi.

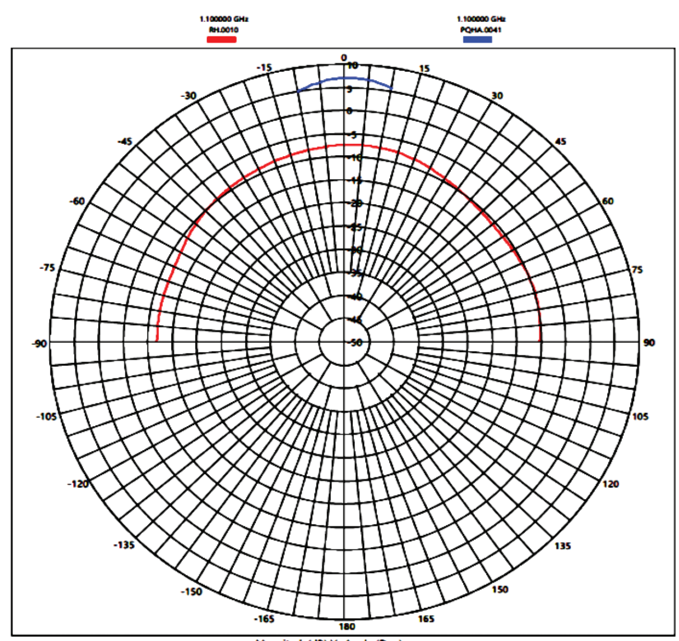

Figure 10. Gain measurement of developed radial horn antenna.

5. CONCLUSION

A wide beam compact, rugged and wideband radial horn antenna has been designed, simulated and developed using an L-shaped capacitively loaded monopole with flared wall. The developed Antenna shows measured impedance bandwidth of 18 % (1040MHz –1240MHz). The peak gain of the developed antenna is 1.88 dBi at 1.1 GHz. The measured radiation pattern of the antenna shows E- and H- plane beamwidth of 117° & 320° which makes it a suitable radiating element for an Electronically Steered Antenna for +/- 55° beam steering with a scan loss of 3 dB. There is approximately a 50 % size reduction at the L-band using the above configuration of the antenna. Deviation in the gain of the antenna may be attributed to fabrication tolerances and measurement inaccuracies of antenna test range instruments. The realized antenna is the most suitable radiating element for a wide scan electronically steered antenna.

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In the current study he contributed to the design, simulation, development and measurement of the antenna.

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In the current study he contributed to the design review of the antenna.