A Dual Band Resonant-Cavity Antenna for Satellite Communication

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***Abstract*—This paper demonstrates design of a dual-band resonant-cavity antenna (RCA) for satellite applications. The antenna can be used as base antenna for near-field meta-steering technology aimed at providing connectivity using low-earth-orbit satellite services. The notable feature of the presented RCA includes its planar profile and use of thin partially reflecting surface (PRS) for gain enhancement that can be designed for the antennas operating at any two frequencies within two operating bands. The design example presented here operates at 20 GHz and 27 GHz, where RCA peak directivity is 14 dB and 17 dB. The directivity can be increased by either using larger aperture or arraying copies of the proposed RCA.**

Keywords—Resonant Cavity Antenna (RCA), Partially Reflecting Surface (PRS), Dual band Antenna, Ka band SATCOM

I. INTRODUCTION

Shared aperture high-gain antennas are inevitable for upcoming space-based internet services using low-earth-orbit (LEO) satellite platforms. The ground receiver terminal, even those are stationary, for these satellite application needs a beam-steering antenna that is capable to track a satellite as it moves over the horizon [1]. Some of the modern low-profile antenna solutions including near-field meta-steering aimed at creating low-profile antenna for the ground receivers, covers one of the links and thus two antenna apertures are needed for the uplink and downlink frequency bands [2]. The dual-band antenna system presented in this paper can be used as a base antenna for aperture efficient beam-steering systems for satellite applications.

A dual-band planar antenna can be designed by using the working principle of resonant cavity antennas (RCAs). The RCA is also known as Fabry-Perot antenna or electromagnetic band gap antenna in the literature and is based on creating a defect that allows transmission within a stop band of a electromagnetic band gap structure. A classic RCA antenna has a partially reflecting surface (PRS) that is placed at a certain height/spacing from fully reflecting surface, which is often the ground plane of the primary feed. A cavity is formed between the PRS and the ground plane, which resonates when the PRS has high reflection magnitude and a positive gradient in the phase of reflection. Several RCA designs have been reported in literature with an aim to enhance the gain of patch antennas [3, 4]. Most of these designs either operate at a single frequency or do not allow independent design at the dual frequency bands. Some of them also incorporate greater number of metal and dielectric layers for PRS increasing the overall height of structure.

This paper demonstrates the design of a thin dual band PRS unit cell with only one metal-dielectric layer having the flexibility to tune the cavity resonance independently at the two frequencies. The overall structure is also low profile as compared to previously reported antennas operating in same band [5]. The height of the PRS above the dual band feed antenna is optimized to get directivity enhancement at the dual frequency bands. The subsequent section II of this paper discusses the overall design of the antenna and PRS. Results are discussed in section III of the paper while Section IV discusses the conclusion.

II. ANTENNA DESIGN

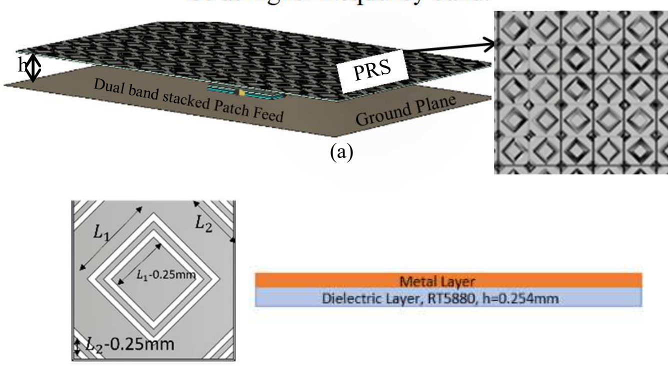
The configuration of the dual-band RCA is shown in Fig.1. It comprises of a dual-band antenna feed with an extended ground plane and a partially reflecting surface (PRS). When PRS is placed at an appropriate height $'h'$ and has a reflecting phase φ_{PRS}, the cavity formed between the PRS and the ground plane resonates. The cavity height can be calculated using [6]:

$$h(f) = \frac{c}{4\pi f}(\varphi_{PRS} + \varphi_G - 2n\pi) \qquad \text{eq-1}$$

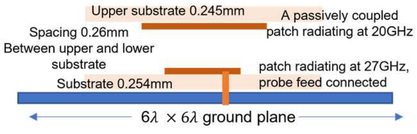
Where φ_G is the reflection phase of the ground plane and 'n' is an integer. In an ideal, broadband cavity with fixed height, the reflection phase of the PRS increases linearly with frequency. On the other hand, most practical PRSs have decreasing phase. The objective of the dual-band RCA is to create a PRS that meets ideal phase line at two frequencies so that cavity resonance condition is satisfied at two frequencies for a fixed height 'h'.

The patch antenna used in this paper has a coaxial probe feed and is shown in Fig. 1(c). There are two Rogers RT 5880 substrate with a thickness of 0.254 mm. The lower substrate has a patch of size 4.3 mm x 3.5 mm that is directly connected to the coaxial probe. The second patch is printed on the lower face of the upper substrate and is separated by a spacing of 0.26 mm. It has the size 5.5 x 4.5 mm. The two patches radiate at frequencies of 27 GHz and 20GHz, respectively. The spacing between the two patches radiating at lower and upper band was optimized to get maximum gain separately at the two operating frequencies while maintaining S_{11} below -10dB at the two bands.

The PRS is made of a fundamental cell element which has a printed metal layers on one sides of a 0.254 mm Rogers RT5880 laminate. The printed layer of the unit cell has four tilted square loop slots that are etched in the metallic layers. The two square loop slots in the middle control the lower frequency, while the two square loop slots at the corners control the resonance at higher frequency band.



(b)



(c)

Fig. 1: a). The configuration of complete antenna structure, b) Top and side view of unit cell of PRS, c) Dual-band stacked patch antenna used as primary feed.

The cell was simulated with periodic boundary conditions in CST Microwave Studio (MWS) and the reflection phase was plotted and compared with theoretical phase for an ideal cavity of height h=6 mm. By varying $L_1$the intersection between the PRS response and ideal phase line shifts as seen in fig.2. Same can be observed by varying L_2. The RCA is designed using the optimal dimensions (L_1= 4.5 mm and L_2 = 2 mm) of the PRS unit cells, which meets ideal phase curve at lower frequency 20.69 GHz and upper frequency 26.8 GHz. It is to be mentioned here that, that PRS cell should have sufficiently high reflection magnitude along with the required phase to enhance RCA gain. The magnitude of the reflection coefficient at the two operating frequencies was -1.73 dB and -2.2 dB.

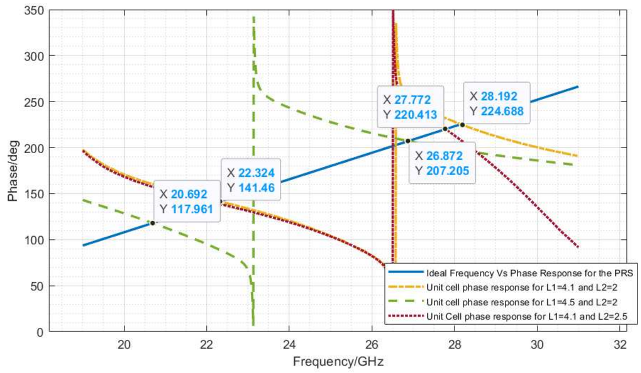


Fig. 2: Reflection phase of the PRS unit cell compared with an ideal reflection phase needed for a cavity of height 6 mm. The cells critical parameters (L_1 *and* L_2) were varied to understand effect on the reflection characteristics.

This PRS was placed above dual-band patch antenna and results were predicted using Transient solver in CST MWS.

III. SIMULATION RESULTS

The superstrate PRS structure was placed at a fixed height of 6 mm from the ground plane to predict the RCA radiation characteristics.

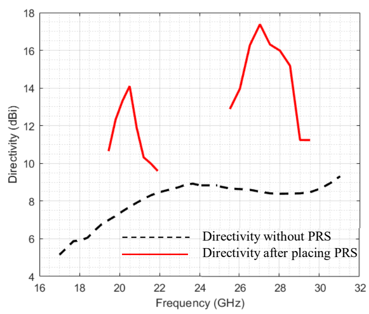


Fig. 3: Predicted directivity of the antenna in a frequency band around center operating frequencies.

The far-field directivity of the RCA in the broadside direction is shown in Fig. 3. For comparison, we have included the directivity of the patch only, i.e., without PRS. The 3-D far-field radiation pattern and directivity in E-Plane for Φ=90º are plotted in Fig. 4. Simulations results show that the RCA peak directivity in the broadside direction is 14.1 dBi and 17.4 dBi at 20 GHz and 27 GHz, respectively. The directivity is higher at upper frequency because of the larger effective aperture. The RCA gain when compared with patch antenna is increased by 6.3 dB and 8.7 dB at the two frequencies.

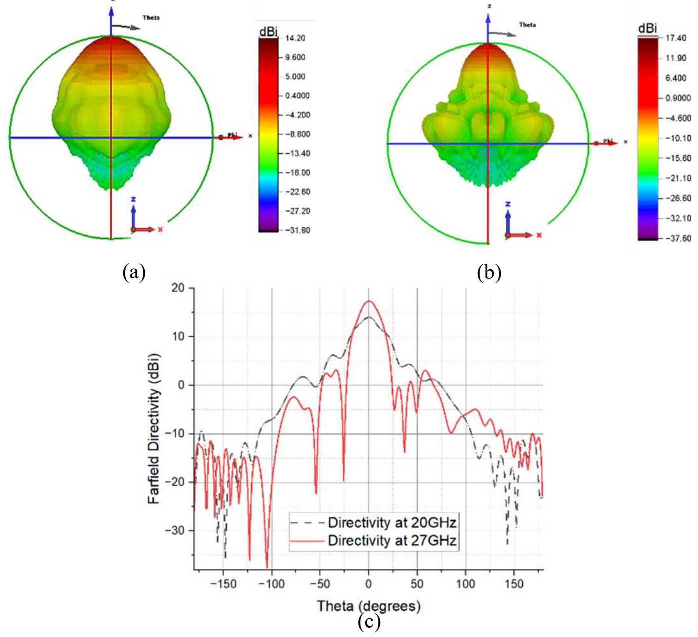


Fig. 4: a). Radiation Pattern at 20GHz, b) Radiation Pattern at 27GHz, c). Predicted pattern cuts at 20 GHz (top) and 27 GHz (bottom) for Φ=90º angle.

IV. CONCLUSION

A dual-band resonant-cavity antenna (RCA) design is presented using a printed thin partially reflecting surface (PRS). It was shown that by varying the length of square loops on the PRS unit cell element, its reflection phase can be tuned to give an ideal phase at any two operating frequencies within desired lower and upper frequency bands. An RCA can be realized if the reflection magnitude is sufficiently high at these frequencies. The PRS proposed in this paper has reflection coefficient magnitude of -1.7 dB and -2.2 dB and provides close to ideal phase at the two operating frequencies of 20 GHz and 27 GHz. The RCA has beam peak in the broadside direction and maximum directivity of 14.1 dB and 17.4 dB. The overall thickness of the antenna is 7mm.

V. REFERENCES

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