Optimized Circular Polarized Antenna with Small Aperture for Satellite Communications

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In this paper, three element Planar Inverted F antenna is studied for IoT communication from Low Earth Orbit Satellite. Apparent advantages of planar inverted-F antennas for satellite communication makes this topology a strong candidate for small aperture satellite antennas. These advantages can be listed as wide beamwidth, circular polarization on zenith direction and possibility to use as a gateway antenna simultaneously. The antenna consist of two part. One of them is placed at the top as radiating elements and this part consists of tree inverted F elements placed circularly at 120 degree intervals. A serial power divider circuit, placed on the bottom of the structure. The aim of serial power divider is deliver equal amplitude to each antenna element. The RF signal is transmitted with sequential 120 degree phase shift to the antenna elements to provide circular polarization. The antenna has simulated on CST and both layers are produced with low cost FR4 material.

Key Words: PIFA, Sat-Com, IoT, UHF, RHCP

1. Overview

Satellite communications(Sat-Com) are used for many applications for decades and their progress has nearly never stopped. Along with satellite communications, IoT applications and services became one of the influential areas with the emergence of 5G and LPWAN concepts. Recently, satellite-based communication came out as a perfect choice for Internet of Things (IoT) applications. These applications use the agility of Sat-Com and diversity of IoT, however it has serious drawbacks, such as sustaining link budgets with simple and low gain components. This paper proposes a simple antenna design providing circular polarization and some gain with small size, both of which relieves the link budget.

2. General Design

A current method based on a quadri-fillar design has produced encouraging results. The tri-fillar model has been examined and compared with this structure in [1]. The 3-element feeding network will be easier to use and have a lower loss with the same delay lines concept because of the shorter line length. The primary goal of this work is to simplify and reduce feeding circuit losses that result in the low-cost but high-loss substrate material by concentrating on a tri-fillar design.

Three identical Planar inverted-F antennas (PIFAs) are used as radiating elements in the suggested antenna. The antenna offers a more compact form than other antennas because of its structure. Each element rotates physically 0°, 120°, and 240° around the substrate's center, correspondingly. Inverted-F shape travels along the top substrate's edge and turns into the center at the end to maximize the length of the elements. Each element has a feeding line and a ground short at the start, which, as depicted in Fig. 1, link to the feeding network at the bottom PCB through copper wires.

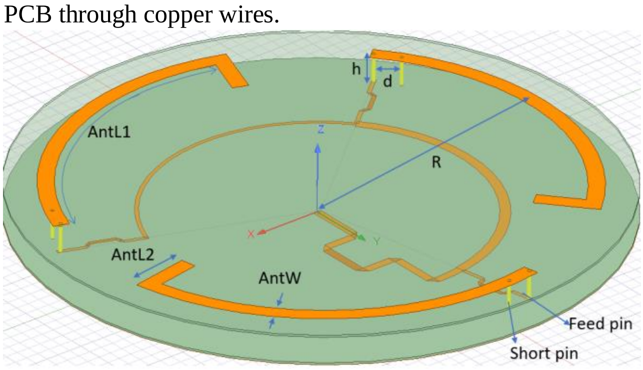

Fig 1. Overview of proposed antenna.

The feeding network, which is located on the lower substrate, is the antenna's second component. The series-feed power divider structure is shown in Fig 2. This layer is for dividing the RF signals into equal-sized segments at each port with the proper phase shift of 120°. In this proposed design, a conventional series-feed power divider (SFPD) is employed to meet these needs. Circularly polarized antenna designs frequently use the SFPD, which is a highly straightforward and effective construction [2–6]. An FR4 Epoxy substrate is used to concentrate on low-cost application (ε_r = 4.4, tan δ = 0.02). The permittivity of FR-4 is in a good choice to produce a 120° phase shift between the ports while having larger losses than RF substrate, such as Roger RO4003 or RT5880.

Each port's phase shift is affected by the parameter R_{in}. The power distribution property is affected by w1 to w3 of the transmission lines. A quarter-wave line that connects to the antenna primary port also functions as an impedance matching

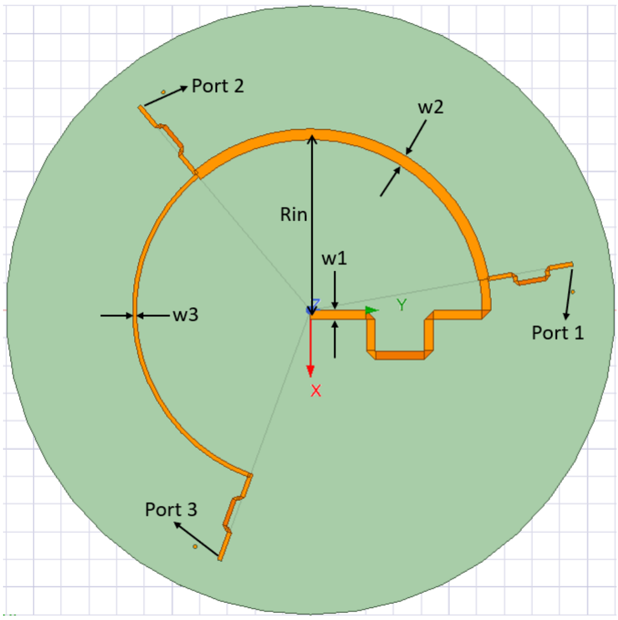

Fig. 2. The serial power divider structure.

circuit and a phase shifter. The feeding network's line dimensions can be determined using the equation in [6]. The corresponding circuit is shown in Fig. 3 with Z_{in}, Z_1, Z_2, and Z_3 representing the input, port 1, port 2, and port 3, respectively, in terms of impedance. These values at this structure are 50 Ohm. The proposed 3-way power divider delivers three equal powers to the circuit's outputs, satisfying the condition that

$$P_1 = P_2 = P_3 = P_{in}/3 \quad (1)$$

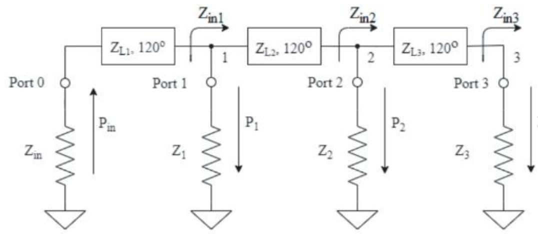

Fig. 3. Equivalent circuit of serial power divider.

Three one-third wave impedance transformers connect the three output ports. These lines have 120^0 phases and an impedance of Z_{L1}, Z_{L2} and Z_{L3}. Eq. (2) can be used to determine the input impedances Z_{in1}, Z_{in2} and Z_{in3} at points 1, 2, and 3.

$$\begin{aligned} Z_{in1} &= Z_1(P_1/P_{in}) \\ Z_{in2} &= Z_2(P_2/P_{in} - P_1) \\ Z_{in3} &= Z_3 \end{aligned} \quad (2)$$

The input impedance at each position can be calculated using Eqs. (1) and (2).

$$Z_{in1} = Z_1/3\,, Z_{in2} = Z_2/2\,, Z_{in3} = Z_3 \quad (3)$$

Finally, the transformer lines' characteristic impedance can be described as

$$\begin{aligned} Z_{L1} &= \sqrt{Z_{in}Z_{in1}} \\ Z_{L2} &= \sqrt{(Z_{in1}Z_{in2}Z_1)/(Z_1 - Z_{in1})} \\ Z_{L3} &= \sqrt{(Z_{in2}Z_{in3}Z_2)/(Z_2 - Z_{in2})} \end{aligned} \quad (4)$$

The impedances of the ports in the suggested design are the same as Z0 = 50. Consequently, the following equations can be found by applying Eqs. (3) and (4).

$$\begin{aligned} Z_{L1} &= Z_0/\sqrt{3} = 28.86\Omega \\ Z_{L2} &= Z_0/2 = 25\Omega \\ Z_{L3} &= Z_0 = 50\Omega \end{aligned} \quad (5)$$

The feeding circuit that satisfies the impedance in Eq. (5) is simulated using the 3D EM solver. The insertion loss simulation result of the power divider is shown in Fig. 4. The return loss simulation of the antenna is shown in Fig. 5. Each port's power is displayed near to a value of -5 dB, or one-third of the input power. These findings demonstrate that the power divider performs as predicted by the equations above. The phase difference between the ports also has a value that is quite close to 120.

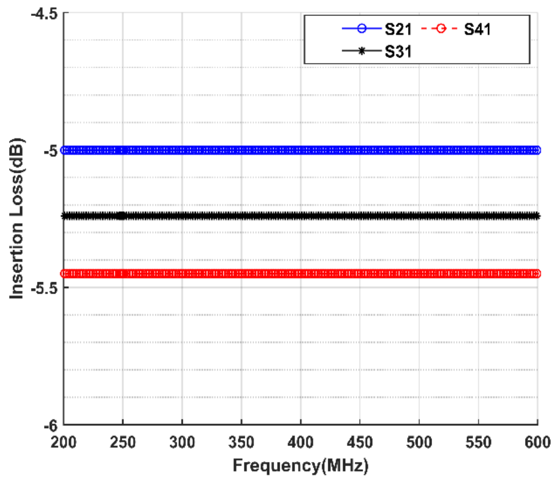

Fig. 4. Insertion losses of power divider ports.

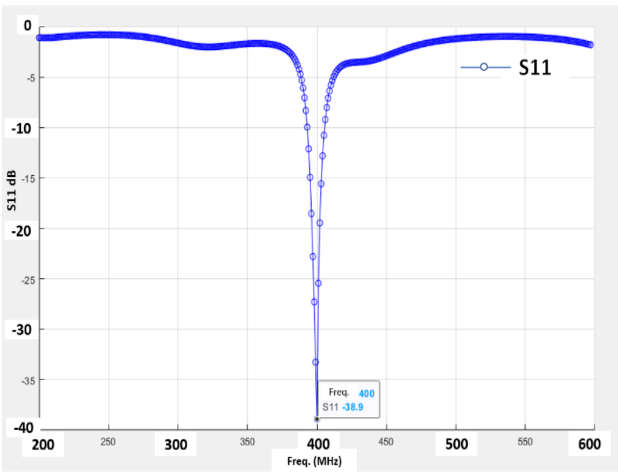

Fig 5. Return loss of proposed antenna.

3.Antenna Implementation, Simulation and Measurement Results

With ε_r = 4.4 and tan δ = 0.02, the suggested antenna is fabricated on a 1 mm thick FR4 Epoxy substrate. A 3D EM solver was used to optimize the antenna parameters, which are displayed in Table 1. Additionally, copper wires are soldered together to connect the top and bottom boards. These wires are 12 mm long to guarantee a precise 10 mm gap between the boards. Finally, port 1 of the feeding circuit is soldered with a typical female SMA.

Table 1. Optimize parameters of the proposed antenna.

W1	w2	w3	AntL1	AntL2
4.34 mm	5.24 mm	1.8 mm	155 mm	16.1 mm

AntW	h	d	R	Rin
7.44 mm	10 mm	12.6 mm	94.2 mm	64 mm

The implemented antenna is shown in Fig. 6.

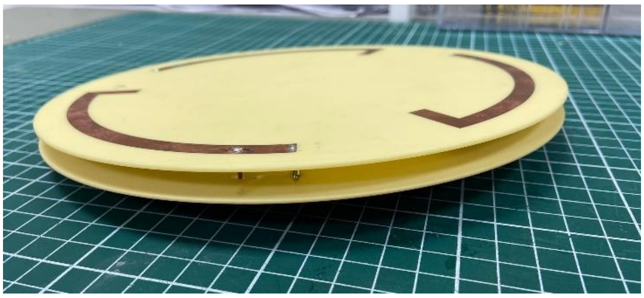

Fig. 6. The implemented antenna.

Axial ratio vs elevation(theta) degree simulation result of the antenna is shown in Fig. 7.

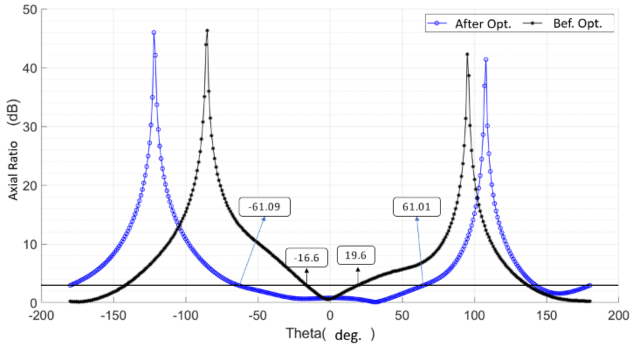

Fig. 7. Axial ratio vs elevation(theta) degree simulation result.

According to Fig. 7. the antenna showed circular polarized feature along 123° in main beam of antenna. 3D radiation pattern of the antenna is shown in Fig. 8 and 2D radiation pattern is shown in Fig 9.

As shown in Fig. 9 main beam width of the antenna is 111° and antenna max gain is 1 dBi.

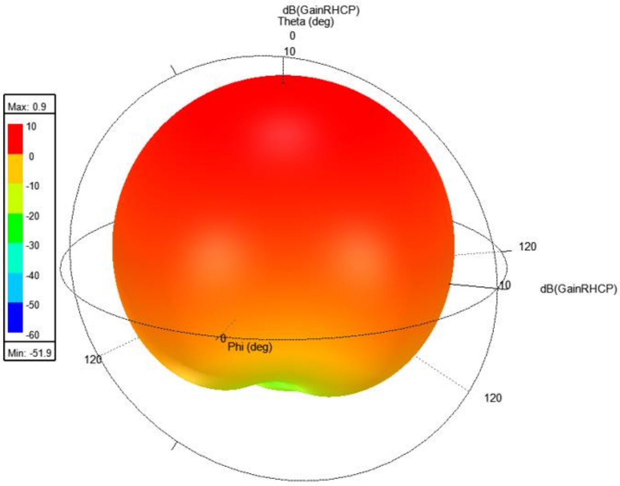

Fig. 8. 3D radiation pattern of the antenna.

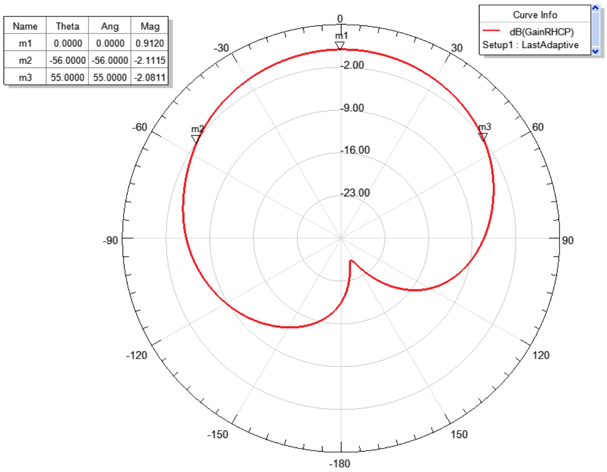

Fig. 9. 2D gain pattern of the antenna.

Simulated and measured return loss (S11) of the antenna is shown in Fig. 10.

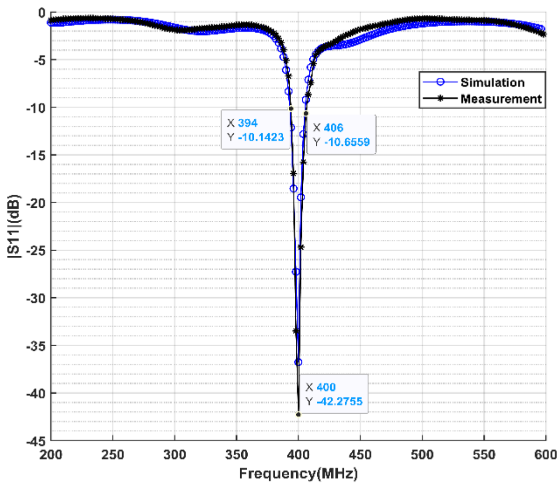

Fig. 10. Simulated and measured return loss of the antenna.

As shown above the antenna operate at 394 MHz to 406 MHz, so it has 12 MHz band width.

4. Conclusion

IoT applications require very small and very cheap components to provide abundant devices for many varying applications. Proposed antenna design enables satellite communications using very small devices. Using with the device shown in Fig. 11, containing the signal processing and RF blocks, this antenna enables satellite IoT communication employing LoRa modulation. 150 dB link budget for 1200 bps data rate could be achieved with this design.

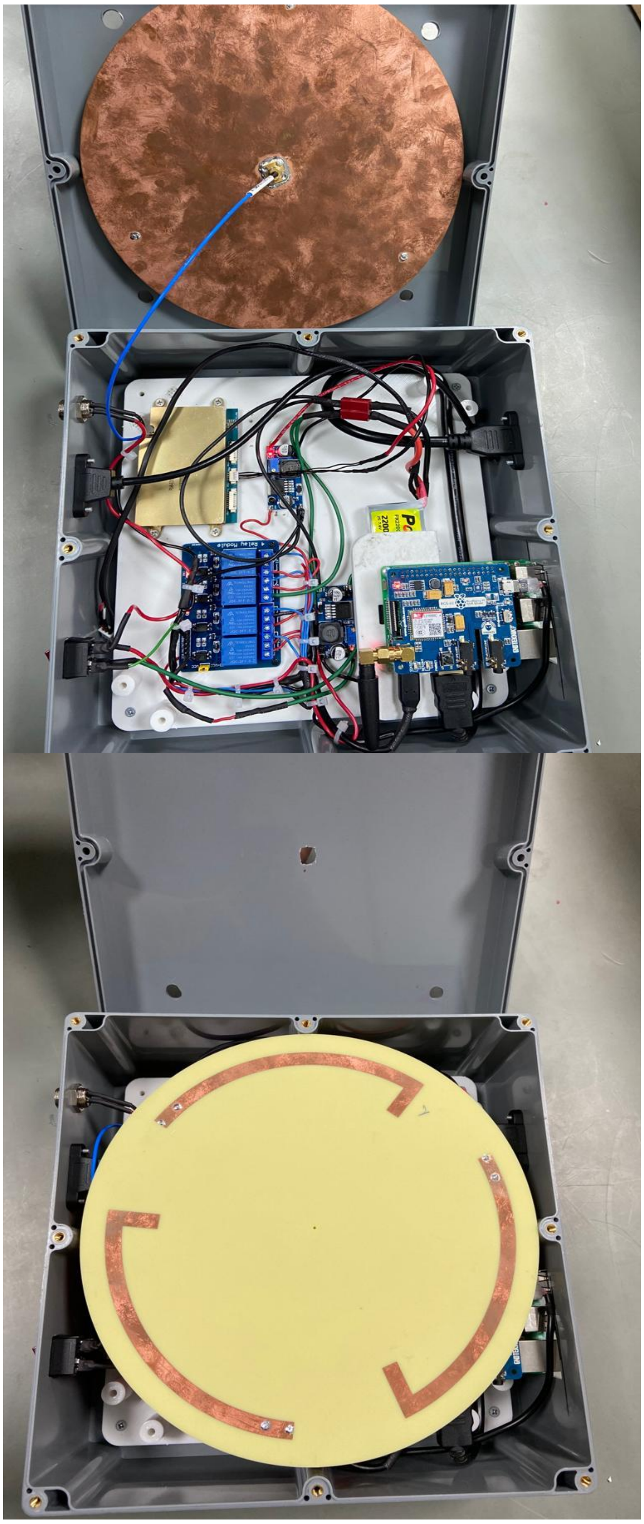

Fig. 11. IoT ground terminal device.

Acknowledgments

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References

1. Ferrero, F., L. H. Trinh, T. Telkamp, and R. Spurett, "Low cost compact terrestrial antenna for space LPWAN communication," 40th ESA Antenna Workshop Antenna Developments for Terrestrial and Small-Space Platforms (ESA-ESTEC 2019), Noordwijk, Netherlands, ESA, Oct. 2019.
2. Xu, P., Z.-H. Yan, T.-L. Zhang, and X.-Q. Yang, "Broadband circularly polarized slot antenna array using a compact sequential-phase feeding network," Progress In Electromagnetics Research C, Vol. 47, 173–179, 2014.
3. Chen, X., L. Yang, J. Zhao, and G. Fu, "High-efficiency compact circularly polarized microstrip antenna with wide beamwidth for airborne communication," IEEE Antennas and Wireless Propagation Letters, Vol. 15, 1518–1521, 2016.
4. Inserra, D., W. Hu, and G. Wen, "Design of a microstrip series power divider for sequentially rotated nonuniform antenna array," International Journal of Antennas and Propagation, 1–8, 2017.
5. Piroutiniya, A., M. H. Rasekhmanesh, and P. Mohammadi, "Wide-band circularly polarised antenna array using sequential phase feed structure and reinforced square radiating patch element," IET Microwaves, Antennas and Propagation, Vol. 12, No. 8, 1395–1399, Apr. 7, 2018.
6. Reddy Sura, P. and S. N. Reddy, "Broad band CP antenna array for X-band applications using sequential phase rotation technique," Optik, Vol. 203, 163547, 2020.