



High-Gain Three-Element Series-Fed Antenna for Millimeter-Wave 5G Applications

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Abstract—Millimeter wave frequencies have become a key element for the development of the 5th (5G) and 6th (6G) generations of wireless communications. These bands provide wide bandwidth and high-speed data transfer. Antennas for these frequency ranges should attain high gain in order to compensate for atmospheric losses, and should be easily manufacturable and of low cost. In this article we present the design, manufacture and measurement of a three-element series-fed antenna that achieves a wide bandwidth covering the n259 and n260 bands, from 36.05 GHz to 45 GHz, gain better than 10 dBi, and a reduced size of 15 mm X 31.835 mm. This antenna has the dimensions and properties to be successfully incorporated in wireless devices, especially for 5G applications. To the best of our knowledge, no other antenna with these characteristics has been reported.

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Index Terms—Millimeter wave, high gain antenna, FR2 band, 5G antenna, n259, n260

I. INTRODUCTION

WIRELESS technology has rapidly evolved due to the development of 5G and 6G communication generations. One of the main advantages brought by this evolution is the exploitation of frequencies corresponding to the millimeter wave range (mm-wave), such as the n259 (39-43.5 GHz) and n260 (37-40 GHz) bands, since they can provide a large enough bandwidth to alleviate the spectrum cramming at low microwave frequencies (sub-6 GHz), besides improving the rate of data transmission. A fundamental part of this evolution centers on the design and manufacture of different types of antennas, and different operating principles, such as single input, single output (SISO) and multiple input, multiple output (MIMO) antennas.

There have been several published reports on SISO and MIMO antennas and arrays which cover the n259 and n260 bands [1]-[9]. Based on SISO, a dual-polarized Vivaldi antenna

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was presented in [1]. This design achieved a bandwidth from 22.5 to 45 GHz, covering the n257-n261 bands with an average gain of 5 dBi over the entire bandwidth, but presenting a large size due to the integration of an elliptical lens above it to increase the gain.

This increase, however, is not significant when compared to the increase in size. Similarly, a broadband magnetolectric dipole SISO antenna, operating from 27.42 to 48.42 GHz, covering the n259, n260 and n261 bands with a gain of 6 dBi was presented in [2]. A 16-element antenna array attaining an impedance bandwidth from 28.44 to 59 GHz and a maximum gain of 17.9 dBi was reported in [3]. A wideband dual-polarized 4-element antenna array was reported in [4]. This array has a bandwidth from 24 to 44 GHz, covering the n257-n261 bands with a gain ranging from 8.4 to 10 dBi. An aperture-fed dual-polarized antenna array has also been reported [5], which has an impedance bandwidth from 36.7 to 43.6 GHz covering the bands of interest with a 5 dBi gain. MIMO antennas and arrays for these frequency bands have also been reported. The simulation of an antenna achieving a bandwidth covering 24.5-41.675 GHz, with a maximum gain of 4.5 dBi, was reported in [6], and even though the authors claim that it covers the n257-n261 bands, it fails to cover the n258 band, which starts at 24.5 GHz, as well as the n259 band, which should cover up to 43.50 GHz, according to “*The 3rd Generation Partnership Project (3GPP)*” [10]. A triple band MIMO antenna that covers the Ku, Ku-K, n259 and n260 bands was reported in [7]. Although the article claims to cover the latter two bands, it presents an impedance bandwidth of 37.78-43.61 GHz, therefore not covering the n260 band in its entirety. In addition, it presents a maximum gain of 5 dBi at 40.62 GHz. Similarly, the development of a 2 x 2 dual-band MIMO antenna (27 and 38 GHz) covering a bandwidth from 36.1 to 44.6 GHz in the second band has been reported, achieving a maximum gain of 18.59 dBi at 38.1 GHz [8]. Moreover, an ultra-wideband MIMO antenna from 4.3 to 60 GHz fed by a coplanar waveguide (CPW) was reported in [9], obtaining an average gain over the entire bandwidth of 5 dBi.

Although the operating frequencies of the n259 and n260 bands overlap, many researchers have reported efforts to cover only one of them. It is noteworthy mentioning that there have been numerous publications for the n260 band [11]-[25], whereas there have been only very few reports dedicated to the n259 band, such as [26]. Hence, a device able to cover both

chloride). The manufactured structure, a photograph of which is shown in Fig. 4, was then measured using a VNA previously calibrated using the SOLT routine. Fig. 5 shows the experimental setup, which consisted of the VNA, cables and two rotating towers where antennas were placed, one on each port.

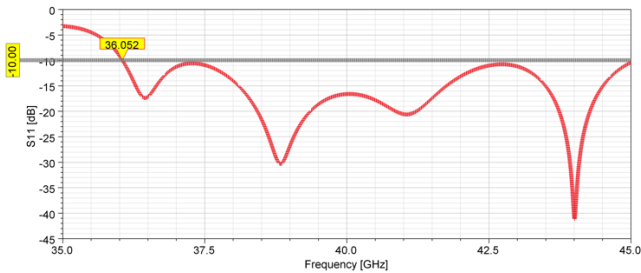


Fig. 2. Simulated return loss showing the attained bandwidth.

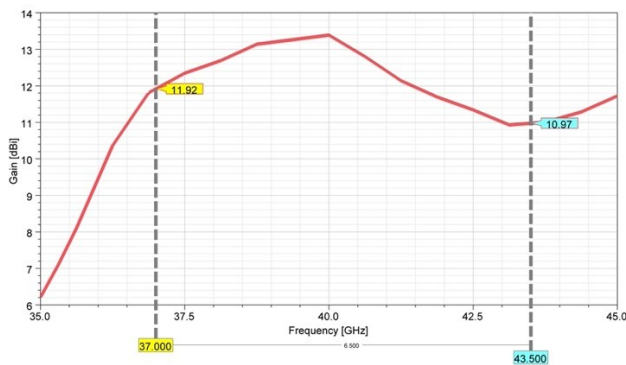


Fig. 3. Simulated gain for the antenna, above 10 dBi from 37 GHz to 43.5 GHz.

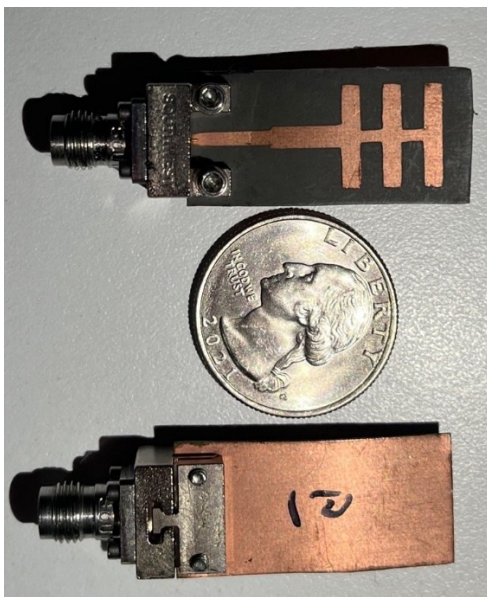


Fig. 4. Photograph Of The Manufactured Antenna Including The Connector.

As Fig. 4 shows, the antenna was reliably manufactured with the used technique. It is important to note, however, that several devices were manufactured and tested, and the best were the ones selected for this study.



Fig. 5. Experimental setup showing the VNA and an antenna connected to each port.

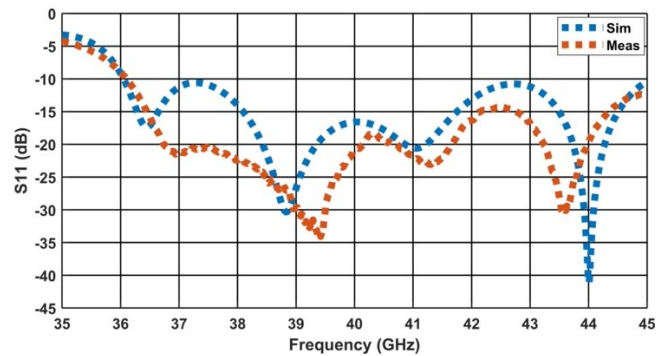


Fig. 6. Comparison of simulated and experimental return loss.

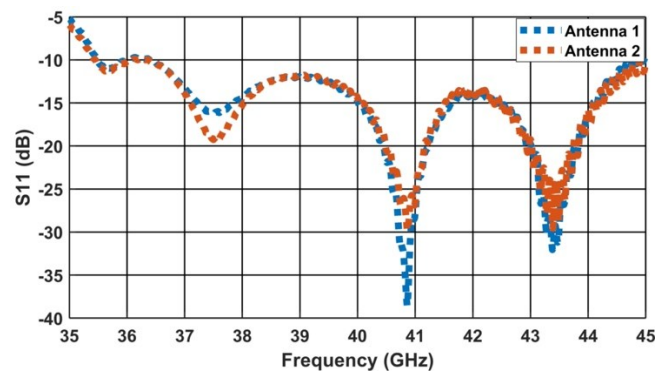


Fig. 7. Comparison of the measurements of two identical antennas.

Fig. 6 presents the comparison of the simulated and measured results for the return loss (S_{11}). To measure gain, the technique outlined in [28] was used. This method is based on having two antennas with an almost identical response, so that their gain is the same. The measurements of two such devices are presented in Fig. 7, with which the gain, shown in Fig. 8, was determined. The reference also provides the minimum distance between antennas, depending on the frequency of interest, to determine the far-field region. In our case, this distance was calculated to be close to 27 cm, and all measurements were made considering antenna separation of 30 cm, as can be observed in Fig. 5.

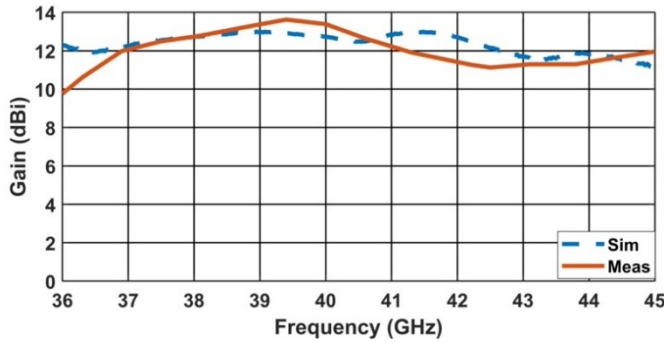


Fig. 8. Comparison of simulated and measured gain.

Since the antenna has a wide bandwidth, the pattern was measured for three different frequencies within the bandwidth; lower (37 GHz), central (40 GHz) and upper (43 GHz). The change in the pattern is evident as the frequency increases.

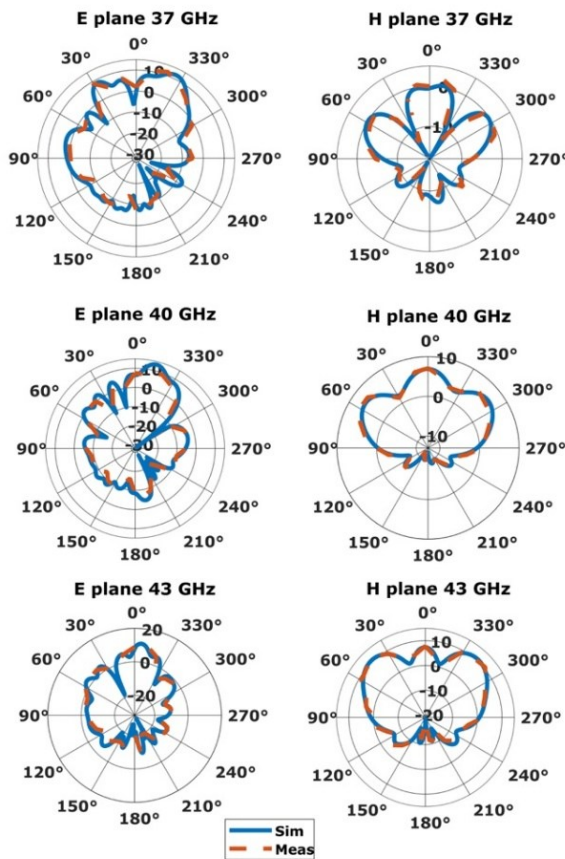


Fig. 9. Measured and simulated radiation patterns at different frequencies. Both the Electric Plane ($f=p/2$) and the Magnetic Plane ($f=0$) are shown.

Using the same experimental setup, the radiation pattern of the antenna was measured by rotating one of these while the other one was kept stationary. This was done for both the polar (θ) and azimuthal (ϕ) angles, at positions measured with a protractor. A graph of the radiation patterns at different frequencies is shown in Fig. 9.

IV. DISCUSSION

As can be seen from Fig. 6, the return loss is below -10 dB in the range from 36 GHz to 45 GHz, indicating a 9 GHz bandwidth which completely covers the n259 and n260 communication bands. It is interesting to note that the experimental results are better than the simulated ones. Furthermore, as can be seen in Fig. 8, the gain is above 10 dBi within the bandwidth, making this a high-gain antenna. The efficiency of the device, from simulation, attained an average value of 85%. Some loss is attributed to the ohmic resistance of the device, which is less the 3 ohms since the copper layer was 35 microns thick (one ounce substrate).

The radiation pattern in the E-plane presents its main lobe at approximately 330° for the lower frequency, and it moves counterclockwise as frequency increases, reaching 345° at 43 GHz. The pattern measured on the H-plane shows a greater change with increasing frequency; it is observed that at the lower frequency, the antenna has a main lobe at 0° with two secondary lobes at 60° and 300°. The main-lobe shift in orientation can be understood if the antenna is seen as a three-element array; as the frequency changes, the phase between elements also changes, and the main lobe shifts in direction as it does for a scanning array. This fact is also responsible for the asymmetry of the fields. And even though the magnitude and orientation of the grating lobes also changes, the overall difference minimally affects the gain of the main lobe, as can be seen in figures 3 and 8.

TABLE II
COMPARISON BETWEEN THE PROPOSED DESIGN AND OTHER REFERENCES

Reference	Bandwidth (GHz)	Peak gain (dBi)	MIMO	Number of elements	Size (mm ³)
[1]	22.5-45	8.5	No	1	12 x 5.5 x 0.254
[2]	27.42-48.42	6	No	1	5 x 5 x 1.6
[3]	28.44-59	17.9	No	16	30x30x1.2
[4]	24-44	10	No	4	22.6 x 5 x 1.6
[5]	36.7-43.6	5	No	8	Not reported
[6]	24.5-41.675	4.5	Yes	1 x 1	24 x 15 x 0.787
[7]	12.81-13.96-14.90-19.355-37.78-43.61	5	Yes	2 x 2	16 x 16 x 0.254
[8]	22-30.4-36.1-44.6	8.75-18.59	Yes	2 x 2	32.4 x 32.8 x 0.8
[9]	4.3-60	9	Yes	1 x 1	20 x 41.5 x 1.6
This work	36.1-45.0	12.98	No	1	15 x 31.835 x 0.508

Table II shows the comparison of the proposed three-section antenna with different published works. As can be seen, there are few antennas reported which cover the bandwidth of 37-43.5 GHz. We can notice that in [6], [7], [8] and [9] the designed antenna is MIMO; however, only [3] and [8] have satisfactory gain since they are antenna arrays. Furthermore, the antennas in [6] and [7] claim to cover both bands, but the reported frequency range does not show that this is accurate. The antenna reported in this work provides an ample bandwidth covering the n259 and n260 bands while providing a gain above 10 dBi over the entire bandwidth, in addition to being low cost and of simple manufacture.

V. CONCLUSIONS

The antenna presented here was designed and validated based on theory, extensive electro-magnetic simulations and high frequency measurements. It presents a 9 GHz covering the n259 and n260 5G communication bands, a satisfactory gain of over 10 dBi across the bandwidth, and a reasonable efficiency above 85%. Furthermore, it is a low-cost, simple to manufacture device, which can be used for a host of applications for 5G wireless devices operating in this frequency range.

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