Parasitic Circular Polarized Vertical Antennas

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Abstract—In the space communications field it is well known that a circular polarized ground station antenna is desirable. The polarization rotation due to the Faraday Effect and the satellite attitude variation translates into a fluctuating received signal, especially in a situation in which a linear polarized antenna is used on-board a satellite, as is the case with almost all LEO (Low Earth Orbit) CubeSAT educational satellites. The use of omnidirectional vertical antennas fitted with passive, parasitic, circular polarizers for VHF/UHF bands is presented. The goal is to minimize the signal fading at low and medium elevation angles.

Keywords—vertical antennas; circular polarization; parasitic element; passive polarizer; end fed dipole

I. INTRODUCTION

LEO (Low Earth Orbit = 160 - 2000 km) satellite communications are subject to some constraints that impose a particular approach. Considering a LEO satellite on a near circular orbit, the following facts are taken into account. Due to the high orbital speed (~ 7 km/s) the satellite stays above the horizon at a given location for only a short period of time, up to 15 minutes, and that in the most favorable case when the satellite passes overhead, near the zenith. During the pass, the satellite remains at high elevation angles (80 - 90°) only for a brief period of time, the period in which the Doppler Effect is also the most pronounced. Moreover, for most locations on Earth, the percentage of high elevation passes is low. For the greater part of the pass, the satellite remains at low elevation angle (0 - 20°), farther away from the ground station, with high radio signal path loss. In many actual ground station installations, the true horizon is obstructed at those low elevation angles, rendering such operational regions less accessible. In the Table I, Fig.1 and Fig.2, the pass time and path loss at 435MHz versus elevation angle are shown for a real case study (Delfi-C3 CubeSat: high elevation pass, range 617 km at maximum elevation of 87.5°).

For an entry level online SDR (Software Defined Radio) satellite ground station network that makes use of omnidirectional fixed antennas installed near the receiver, the medium elevation angles are of interest. The satellite is in this region for about one third of the pass time, with less path loss and in the line of sight. Thus an antenna with a favorable radiation pattern especially at medium elevation angles is called for. The variation in attitude of a satellite, often fitted with linear polarized antennas, and the polarization rotation due to the Faraday Effect, still present in the UHF band, result in signal fading, unless a circular polarized antenna is used.

<table>
<thead>
<tr>
<th>Elevation [°]</th>
<th>Range [km]</th>
<th>Relative path loss [dB]</th>
<th>Pass time [s]</th>
<th>Pass duration</th>
</tr>
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<tr>
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<td>2900</td>
<td>13.44</td>
<td>420</td>
<td>54%</td>
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<td>1966</td>
<td>10.07</td>
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<td></td>
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<tr>
<td>20</td>
<td>1461</td>
<td>7.49</td>
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<td>38%</td>
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</tr>
<tr>
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<td>0.59</td>
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<tr>
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<tr>
<td>90</td>
<td>617</td>
<td>0.00</td>
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</table>

Fig. 1. Pass duration vs. elevation angle.

Fig. 2. Relative path loss at 435 MHz vs. elevation angle.
Various circular polarized omnidirectional fixed antenna designs are available, most of them using crossed radiators and phase shifters (e.g. turnstile, eggbeater, QHA Quadrifilar Helix Antenna, TPM Texas Potato Masher) or multiple phased radiators (e.g. double cross, Lindenblad), these being approaches that requires careful impedance and phase matching. As an alternative solution, a passive, parasitic, circular polarizer can be used in conjunction with a single driven element, of which several designs are available: using sleeve dipoles [1,3,8], biconical dipole [4], slot array antenna [5,6], dielectric resonator antenna [7]. The use of a circular parasitic polarizer for an UHF satellite band antenna was first proposed in [8].

II. ANTENNA STRUCTURE

The same principle of using a passive parasitic polarizer applied to long end fed vertical antennas, at least half wavelength tall (i.e. 3/4 wavelength ground plane, 5/8 wavelength ground plane, J-pole, end fed half wave and full wave dipoles), is investigated. These vertical antennas can be seen as EFHW (End Feed Half Wave) dipoles followed by matching networks, as shown in Fig. 3. The total radiation patterns differ according to the design of the matching networks. The passive parasitic polarizer shown in Fig. 4, consisting of an array of tilted parasitic elements, positioned symmetrically around the driven element, is placed in the voltage node (about quarter wavelength from the top end).

For a full wave end fed antenna, two such passive polarizers should be used, placed in each of the two planes of the voltage nodes. The 3/4 wave, 5/8 wave and J-pole antennas can be fed by design with regular low impedance coaxial cable. The end fed half and full wave dipoles are fed in the voltage antinodes and consequently they have high input impedance, requiring separate impedance matching networks.

III. PRINCIPLE OF GENERATION OF CIRCULAR POLARIZATION

It is known that a pair of 45° tilted dipole antennas with a λ/4 spacing, which are orthogonally crossed, radiate circular polarization in both directions on the array axis, when each dipole is excited in phase with a current of equal amplitude (Fig. 5) [1,2].

The principle of generation of circular polarization by means of parasitic elements, used for the presented antenna, is described in [1].

“A model antenna, for explaining the parasitic polarization principle, consists of a vertical dipole and a pair of +45° tilted parasitic elements, set on the same axis with the spacing of about a λ/4 between the dipole and the element, as shown in Fig. 6. Since the radiation field from the vertical dipole can be divided into two orthogonally crossed electric fields, each tilted elements is excited by the parallel component of the field. Thus, it can be considered that the antenna is equivalent to a pair of orthogonally crossed two element arrays on the same axis, and the phase center of each array is shifted to a half distance of the spacing between the dipole and the parasitic element, which results in a spatial phase difference between two arrays of about 90°. In this case, each array should have the radiation pattern with the maximum and the equal amplitude in both directions on the array axis.

Ideally, assuming that the current on the parasitic element has equal amplitude and opposite phase compared with the parallel component of the current on the dipole, the radiation pattern of the array satisfies the above condition “[3].
IV. SIMULATIONS RESULTS

Preliminary design and simulations of these vertical antennas fitted with passive polarizer were made using the antenna analyzer software MMANA-GAL [9]. A four 45° tilted parasitic elements 0.425λ long was used, spaced one-quarter wavelength from the driven element. This preliminary simulation shows as expected that by using a passive polarizer, horizontal gain can be obtained. The amount of gain is highly dependent on the length, tilt angle and position of the parasitic elements. Further optimization is required in order to make the gain in the vertical and horizontal fields as close as possible, while keeping a good impedance match.

Fig. 6. Principle of circularly parasitic polarized antenna - dipole antenna and two tilted parasitic elements.

Fig. 7. Parasitic 3/4 wavelength antenna 2D elevation far field plot (vertical field – red, horizontal field – blue).

Fig. 8. Parasitic J-pole antenna 2D elevation far field plot (vertical field – red, horizontal field – blue).

Fig. 9. Parasitic 5/8 wavelength antenna 2D elevation far field plot (vertical field – red, horizontal field – blue).

Fig. 10. Parasitic end fed half wavelength dipole antenna 2D elevation far field plot (vertical field – red, horizontal field – blue).

Fig. 11. Parasitic end fed full wavelength dipole antenna 2D elevation far field plot (vertical field – red, horizontal field – blue).

V. EXPERIMENTAL RESULTS

A prototype of a vertical circular polarized antenna for the 70cm satellite band was built (Fig.15), based on a three-quarter wavelength ground plane antenna design that exhibits intrinsic unbalanced feed, impedance close to 50 ohms and has a favorable radiation pattern at medium elevation angles (up to 4.4 dBi of gain over 20 - 70° of elevation). After initial tuning, antenna analyzer measurements showed a low SWR better than 1.2:1 (Fig.13), over the whole 70 cm satellite band (435 – 438 MHz).
Fig. 12. Parasitic polarized 3/4 wavelength vertical antenna geometry with currents distribution plotted.

Fig. 13. Circular polarized 3/4 wavelength antenna 3D total far field plot.

Fig. 14. Parasitic 3/4 wavelength antenna SWR measurement.

Fig. 15. The parasitic polarized 70cm vertical antenna prototype.

Fig. 16. The parasitic circular polarizer.
In order to test the polarization of this antenna prototype, a basic outdoor measurement setup was made, with the antenna under test (AUT) in receiving mode [13-16]. The measurement setup consists of a reference radio transmitter fitted with a linear polarized (half wave dipole) antenna and a spectrum analyzer, based on a software defined radio (SDR) receiver, connected to the antenna under test.

A 434MHz reference CW (Continuous Wave) radio beacon was built for this purpose (Fig.17). The Aurel RTX-MID-3V radio transceiver module was used as transmitter, providing 10dBm output power on 433.92MHz [10]. The module is battery powered through a 3.3V voltage regulator of type 78L33A [11]. A 70cm dipole was used as reference antenna, center fed with RG174 coaxial cable, one meter long. A choke balun (two turns of coax on a ferrite core TDK ZCAT 2035[12]) was placed on the cable, close to the antenna, in order to avoid the radiation of the coaxial cable shield and the ground traces. The electronics, including the battery, was shielded in a metal box.

![Fig. 17. Reference radio transmitter electronic schematic diagram.](image1)

The layout of the components of the radio beacon is shown in Fig.18. The arrangement of the beacon components was chosen to render the radiation pattern of the reference dipole antenna as clean as possible.

![Fig. 18. Reference radio beacon components arrangement.](image2)

The signal from AUT is applied to the input of a software defined radio receiver USB dongle (improved version of RTL-SDR: TCXO, tuner chip RS20T2). The control of the SDR receiver and the power level measurement was made with a software application [20], implemented in the graphical tool GNU Radio Companion (GRC), under Pentoo Linux distribution.

![Fig. 19. SDR receiver based spectrum analyzer and power meter.](image3)

The GRC flowcart of the power meter is shown in Fig. 20. The minimum possible sampling rate of the RTL-SDR receiver is 0.25MSPS (250kHz baseband span).

The complex baseband input signal from the RTL-SDR Source block is plotted by the FFT Sink block and filtered by the FIR Filter block (bandwidth BW=2kHz). The filtered complex signal (I+iQ) is displayed by the Waterfall Sink block, being converted to float data type. After averaging, the signal is applied to a decimal logarithm block, the resulting logarithmic power value 10log10(I^2+Q^2) being displayed by the Number Sink block.

![Fig. 20. GRC spectrum analyzer and power meter flow chart.](image4)

The linearity test and calibration of the SDR power meter was made using a Agilent N5183A professional signal generator. This measurement showed that there is a good linearity of the power meter readings, between about - 30dBm and - 80dBm input power, for a RF gain of 6.3dB, confirming the theoretical 48dB dynamic range of the RTL-SDR receiver.

![Fig. 21. SDR power meter linearity test.](image5)
Measurements of the polarization of the vertical circular parasitic polarized antenna prototype were made in real environment, with antenna mounted outside, on a roof top.

The reference beacon was placed on a non-conducting structure at a convenient distance and height from the antenna under test (AUT), in the far field region (>10λ). For practical reasons, the distance and the view angle between the reference radio transmitter and AUT has been chosen as in Fig. 23.

Two sets of measurements were made for vertical and horizontal reference antenna position (i.e. polarization), in the absence of the polarizer (NO) and for different position angle of the polarizer’s elements: vertical (V), horizontal (H) and tilted (45°).

These preliminary results are summarized in Table II. The errors due to the unwanted reflections, losses, mismatches and misalignments were neglected.

The effect of the passive parasitic polarizer can be clearly seen, a relative horizontal antenna gain of 10dB being obtained, for an incident horizontal polarized wave, when the parasitic elements are tilted. On the contrary, when the incident wave is vertically polarized, the effect of the position angle of the parasitic elements is less pronounced, within the error margins. Errors of 1-2 dB are common for this type of measurements.

VI. Conclusions

Vertical, end feed, parasitic polarized omnidirectional antennas were preliminarily investigated. The measurements confirmed the role of a passive parasitic polarizer in receiving horizontally polarized waves with vertical antennas. The gain in the horizontal field, that minimizes signal fading, makes these antennas a good choice for space and terrestrial communications.

The advantages of the circularly polarized 3/4 wavelength antenna prototype, for space applications, over other fixed omnidirectional circular polarized antenna designs, can be summarized as follows:

- The radiation pattern is favorable at low and medium elevation angles, region in which the low earth orbiting LEO satellites are most of the time. The overhead passes, with high elevations, are much rare and, when available, the satellites stay in this region for a much shorter time. Concentrating the gain at those low and medium elevations, increases the link margin or BER (Bit Error Rate) of the radio downlink, for the greater part of the pass. The radiation pattern is also of interest in the radio astronomy field, for the forward scatter radio meteor detection technique.

- The end fed design makes this antenna prototype easier to build and tune, with less electrical connections subjected to failure. Furthermore, being asymmetrical end fed and having intrinsic low impedance, it is easy to match and feed with common unbalanced coaxial lines.

Further measurements, at different elevation angles and for various tilt angles of the parasitic elements are necessary. The outdoor type of measurements has the disadvantages of being time consuming and weather dependent. A more accurate and complete radiation pattern characterization can be obtained in an anechoic chamber, using reduced scale antennas.

Comparative receiving sessions and statistical analysis of the LEO CubeSat satellites transmissions are considered further, using as reference a classical circular polarized turnstile antenna.
REFERENCES


