# Comparative Analysis of Three Types of VHF/UHF Antennas for GPR Array

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***Abstract*—This article presents the comparative analysis of antennas for Ground Penetration Radars (GPR) that operate in the VHF/UHF band around 200 MHz. Three types of antennas are optimized to improve bandwidth, obtain a gain greater than 5 dB while analyzing their Half Power Beam Width-HPBW, and front to back levels. These antennas are candidates to be implemented on a 2x2 array for a double polarized GPR to improve its resolution and range. This radar conducts non-invasive explorations to obtain data from Caral's archaeological center in the city of Lima, Peru. The geometry design, simulation results, and optimization of the antennas were calculated using the ANSYS-HFSS software. The simulation results have indicated that the Antipodal Vivaldi antenna showed better results than the Log Periodic Dipole Arrays and the DGS Vivaldi antennas.**

**Keywords: GRP, DGS Vivaldi Antenna, LPDA, Antipodal Vivaldi Antenna, and ANSYS-HFSS.**

## I. INTRODUCTION

In Peru, there is still a great diversity of archaeological centers that need to be explored, one of these is the Archaeological site of Caral in Lima. Caral is the oldest city in America, where the first Andean civilization was established [1]. Archaeologists and researchers are in need of means to perform explorations without damaging archaeological remains. The original cemetery of the city needs to be found, and it is probable that is buried more than 12 meters away, which explains the use of large wavelengths or low operating bands for this radar. Thus, technological tools are required to perform explorations in ranges over 12 meters without compromising image resolution. Accordingly, a double polarized ground penetrating radar operating at 220 MHz has been implemented, with 20 MHz of bandwidth. Many figures of merit in the radar require more bandwidth and gain in the prototype antennas. Since a radar with these characteristics is not commercially accessible, developing a Georadar for lower frequencies implies designing an antenna with good radiation characteristics, small, portable, and compact to be moved throughout the archaeological center.

Several antennas have been tested and implemented for GPR such as Vivaldi Antennas with modifications [2], [3], [4] and improvements such as the use of Defected Ground Structure (DGS) [5] or metasufaces [6]. Other interesting candidate antenna for the GPR is the Log-Periodic Dipole Antenna (LPDA) [7], since its dimensions can be kept small for low frequency bands. The original design of a Vivaldi antenna with DGS [8], a Vivaldi Antipodal antenna [9], and a flat LPDA are compared in this paper. Then, the parameters are optimized to improve the bandwidth, radiation pattern, and gain in each one of the antennas to fulfill the requirements of the GPR. Finally, a comparative study of the results were carried out with the ANSYS HFSS simulator in order to obtain one or more optimal antennas for use in the final GPR subsystem.

## II. ANTENNA DESIGN

Our proposed antennas for Georadar of terrestrial penetration applications are shown below. Our comparison metrics include bandwidth, gain, front-to-back ratio, and HPBW- Half Power Beam Width.

### A. DGS Vivaldi Antenna

The original Vivaldi antenna was developed back in 1979 to produce a symmetrical beam at the exit, and small side lobes. This antenna is formed by a metal plate with an exponential aperture followed by an uniform slot terminated in a cavity, on an FR4 substrate. A Vivaldi antenna using DGS in the shape of 8 T-resonators on each edge was optimized to obtain bandwidth in the 200 MHz.

The antenna is powered by micro-strip/slot-line transition. It uses FR4 as substrate ($\varepsilon_r$= 4.4 and $tan\delta_e = 0.025$) with a thickness of $h$= 3.2 mm. The geometric extension of the Vivaldi antenna are $W_{sub}$= 525 mm wide by $L_{sub}$= 750 mm long. Other dimensions include: $Lr_0$= 50 mm, $Lr_1$= 600 mm, $Wr_1$ = 82 mm, $D_s$= 88 mm, $R_{sub}$= 69 mm, $D_{fd}$= 50 mm, $L_s$= 94 mm, $W_1$= 6 mm, $W_{stripline}$= 3 mm, $L_{dgs}$= 90 mm, $G_{dgs}$= 30 mm, $G_{dgs}$= 32 mm, $D_{gs}$= 236 mm, $P$= 13 mm and $theta$= 110°, where $theta$ represents the angle (degrees) of the circumference section for the microstrip.

As one of the main features of the radar is its portability, and complying with the specifications of the GPR subsystem, we added $T$-shaped structures to the original Vivaldi design to increase the current path and reduce the size of the antenna. Fig. 1 shows its basic structure and geometric parameters. $R_1$ and $R_2$ correspond to the exponential factors, defined

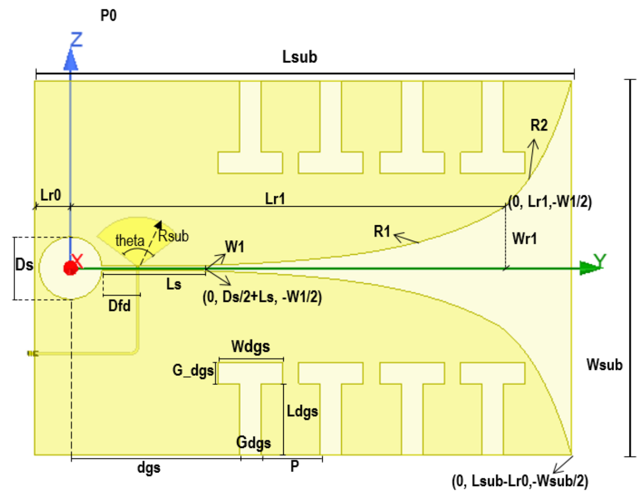

Fig. 1: Geometry of DGS Vivaldi antenna with dimensions.

by coordinates $(0, D_s/2 + L_s, -W_1/2)$, $(0, Lr_1, -W_1/2)$ and $(0, L_{sub} - Lr_0, -W_{sub}/2)$.

### *B. Log-Periodic Dipole Antenna (LPDA)*

The LPDA is formed by a set of dipoles of different sizes, arranged in descending order in the direction of the maximum radiation from the antenna [10]. The input impedance, gain and radiation pattern of the LPDA is repeated periodically. Specifically, the antenna presents a periodic logarithmic relationship between elements, which depends on the separation factor ($\tau$) and the spacing factor ($\delta$) [11].

LPDA's bandwidth is directly proportional to its size, i.e., the larger the antenna the wider the bandwidth. This creates known limitations [10] in the antenna design. Optimizing antenna parameters are set to $\tau$= 0.78 and $\delta$= 0.14 to improve bandwidth without sacrificing size.

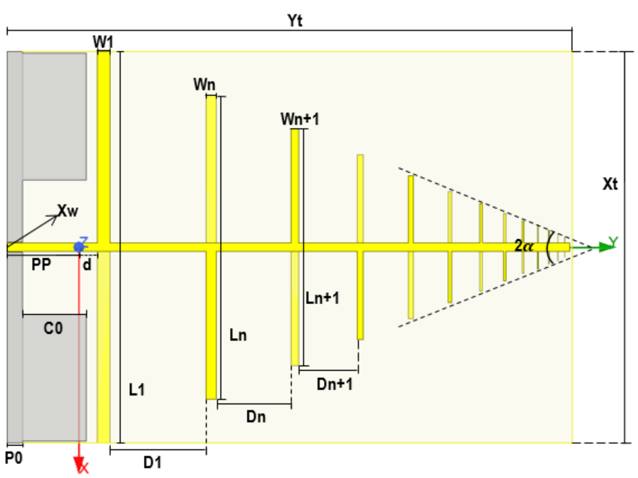

Fig. 2: Geometry and dimensions of LPDA.

A 3.2-mm thick FR4 is used as a substrate. The final dimensions of the LPDA are $Y_t$= 750.34 mm long by $X_t$= 525 mm wide. The geomtric distribution of the antenna is depicted in Fig. 2. Other important parameters asociated our design are $P_0$= 20 mm, $P_p$= 119 mm, $D_1$= 127 mm, $L_1$= 525 mm, $W_1$= 17.8 mm, $C_0$= 85 mm, $X_w$= 8.3 mm, $\alpha$= 21.5°.

### *C. Antipodal Vivaldi Antenna*

The Antipodal Vivaldi antenna is usually better suited for wideband applications. The difference between the previously proposed DGS Vivaldi antenna and the one proposed here is that we added the tapers on the frontal and the antipodean side of the dielectric. The feeding structure is a microstrip line whose ground plane gradually narrows to form a composite transmission line for a couple of striplines [12].

A Multiobjective Genetic Algorithm-MOGA [9] was used to optimize the performance of the antenna to comply with the GPR requirements. This algorithm optimizes the edges of the geometry to improve the bandwidth of the antenna. In addition, two reflectors were added parallel to the tapers to improve the radiation pattern, as illustrated in Fig. 3 in grey color.

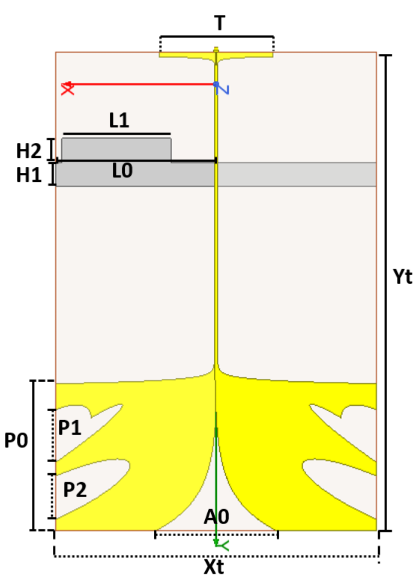

Fig. 3: Geometry and dimensions of Antipodal Vivaldi antenna.

This antenna design uses FR4 substrate with a thickness of $h$= 3.2mm. The overall size of the antenna is $X_t$= 530 mm by $Y_t$= 793.3 mm long. Other important parameters include $P_0$= 243.57 mm, $P_1$= 87.14 mm, $P_2$= 72 mm, $L_0$= 262.34 mm, $L_1$= 180 mm, $H_1$= 40 mm, $H_2$= 40 mm, $A_0$= 200 mm, and $T$= 188.57 mm.

## III. RESULTS AND ANALYSIS

In this section, the bandwidth (BW), Front to Back (F/B), gain (G), and HPBW of the antennas are compared and analyzed.

### *A. Bandwidth*

To comply with the GPR scope and subsequent processing of radargram profiles, a bandwidth greater than 20MHz was considered over frequencies from 200MHz to 550MHz. Furthermore, the overall GPR prototype operates on this range.

The DGS Vivaldi antenna works in a range that goes from 239 MHz to 255 MHz with (BW=16 MHz) a reflection coefficient of -11.5dB at 247 MHz. In the case of the Antipodal Vivaldi antenna, it works from 253 MHz to 513 MHz (BW=260 MHz) with the lowest reflection coefficient of -21.38 dB at 469 MHz. Finally, the LPDA works from 294 MHz to 535 MHz (BW=241 MHz) with a return loss of -21.84 dB at 312 MHz. Fig. 4. shows simulation results for S11 parameters, where the bandwidth can be obtained.

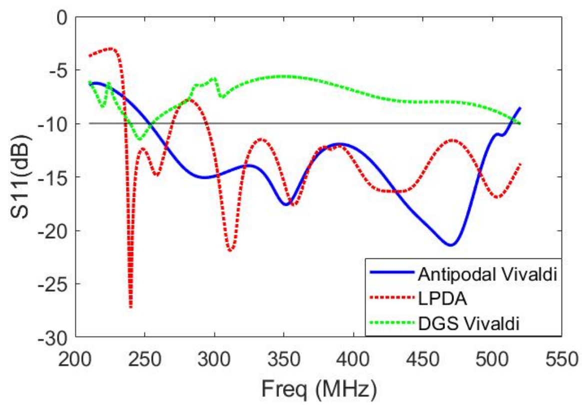


Fig. 4: Comparison of return losses $|S_{11}|$(dB) for three proposed antennas

### B. Gain

Antenna gain is an important feature for the GPR, since it can increase or decrease the radar range. Higher antenna gain provides a bigger range and better signal quality. It also can produce undesired first rebound of the power back to the radar. Accordingly, in response to such trade-off, the DGS Vivaldi antenna presents a maximum gain of 4.2 dB at a frequency of 247 MHz, the LPDA presents a maximum gain of 5.13 dB at a frequency of 312 MHz. Finally, the Antipodal Vivaldi antenna presents maximum gain of 6.6 dB at a frequency of 469 MHz. The gain of the LPDA is higher among these antennas. In terms of gain, the LPDA provides a better performance as shown in Fig. 5.

Fig. 6 shows a comparison between the gain of the three antennas, ranging from 200 MHz to 550MHz. From the radiation pattern, $\theta = 90°$ and $\phi = 90°$ are taken as fixed values since it is the direction of maximal gain. It is observed that the DGS Vivaldi antenna presents gain values above 5 dB in the frequency ranges from 251 MHz to 277 MHz and 286 MHz to 550 MHz. At 246 MHz, the DGS Vivaldi antenna is exhibits the highest return loss value; however, with an average gain of 4.2 dB. In the same way, the LPDA has >5 dB gain in the frequency range from 293 MHz to 377 MHz, and from 448 MHz to 528 MHz. Moreover, note that the Vivaldi antipodal antenna presents values above 5 dB in frequency ranges from 406 MHz to 550 MHz.

### C. HPBW

HPBW is the angular region in which the radiation pattern of a beam takes a value of 3dB below the maximum gain [13],

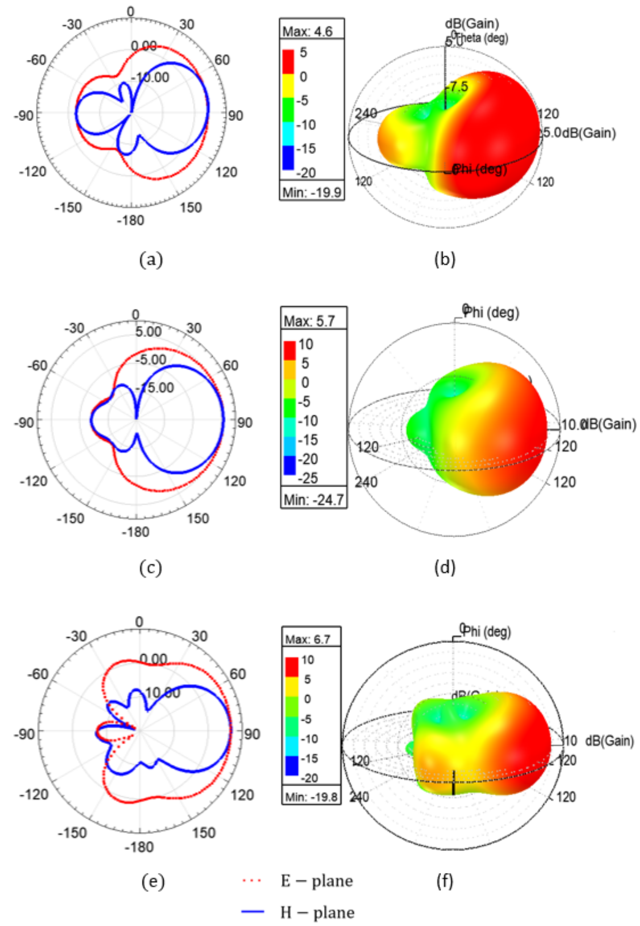


Fig. 5: Radiation pattern, solid plot represents E-plane and plot H-plane. (a) DGS Vivaldi Antenna, E- and H-plane of radiation pattern at 247MHz. (b) 3D plot of Vivaldi Antenna at 247MHz. (c) LPDA, E and H-plane of radiation pattern at 294MHz. (d) 3D plot of LPDA at 294MHz. (e) Antipodal Vivaldi Antenna, E- and H-plane of radiation pattern at 469MHz. (f) 3D plot of Antipodal Vivaldi Antenna at 469MHz.

which defines the footprint of the radar. In this case, the values presented by the DGS Vivaldi, LPDA, and Antipodal Vivaldi antennas are 72.6°, 68°, 61°, respectively. The minimum values are considered the best because they represent better directivity.

### D. Front to Back Level

The ratio between the maximum radiated power in front direction and the radiated power in the opposite direction, F/B, indicates how good the antenna is at rejecting signals from the rear. For our specific GPR subsystems, this feature is important since these antennas are supposed to operate with the electronic prototype in the back. High levels of front to back are desired in this case. The DGS Vivaldi antenna provides 6.7 dB, the LPDA features 11.83 dB, and the Antipodal Vivaldi antenna features 13.76 dB. Table I shows a summary of the results for the main required antenna parameters for the GPR. On the other hand, no similar analysis investigations were found.

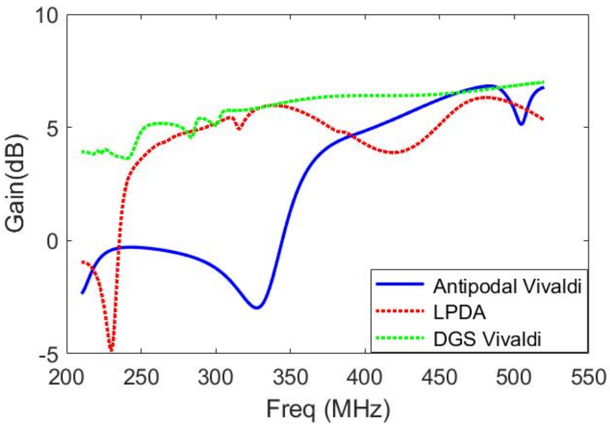


Fig. 6: Gain in dB vs. frequency for all three proposed antennas

TABLE I: Comparison of antenna parameters between DGS Vivaldi, LPDA, and Antipodal Vivaldi.

| | DGS Vivaldi | LPDA | Antipodal Vivaldi |
|---|---|---|---|
| Operating BW (MHz) | 239-255 | 294-535 | 253-513 |
| Peak Gain Main Lobe (dB) | 4.2 | 5.13 | 6.6 |
| Peak Gain Back Lobe (dB) | -2.5 | -6.7 | -7.16 |
| Front to Back (dB) | 6.7 | 11.83 | 13.76 |
| Bandwidth (MHz) | 40 | 241 | 260 |
| HPBW | 72.6° | 68° | 61° |

## IV. Conclusion

Three types of antennas for GRP were studied and evaluated in this work. After the simulation and analysis of the parameters of each antenna in light of our GPR operation, it was observed that the LPDA and the Vivaldi Antipodal antenna are the ones with the best results. The Antipodal Vivaldi antenna presents a gain of 6.6 dB, with a bandwidth of 260 MHz and F/B level of 13.76 dB. On the other hand, the LPDA that presents a gain of 5.13 dB, with a wide 241 MHz band and 11.83 dB of F/B. Both antennas are optimal to be used in the manufacture of dual-polarization Georadars because both present good F/B with values above 10 dB.

Contrary to what was expected, the DGS Vivaldi antenna does not have a wide bandwidth, limiting itself to only 16 MHz, with a gain of less than 5 dB. Accordingly, the Vivaldi antenna cannot be chosen for the implementation of this specific GPR application when compared to the other two.

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