Log-Periodic Dipole Antennas in Printed Circuit Technology

Guilherme Conde Vieira
guilhermeconde.v@gmail.com

Instituto Superior Técnico, Lisboa, Portugal

June 2018

Abstract

The traffic of information nowadays is becoming larger than ever before. Devices and connections are growing faster than both the population and Internet users. By the year of 2021, it is expected for the Smartphone traffic to exceed the PC traffic. With new communication systems being developed every year, it is essential to have good measurement antennas to test and validate them. The Log Periodic Dipole Antenna (LPDA) is one of the most used frequency independent antennas, with applications ranging from HF (or even MF) to microwave. This is a broadband, multi-element and directional antenna. Combining this antenna with Printed Circuit Technology, which is a low cost, easy fabrication and installation technology that stands for low profile, compact, light weight and robust antennas, the application possibilities are tremendously extended. This thesis proposes the study, design, optimization and fabrication of a pair of printed LPDA antennas, designed to work in the frequency range 500-1750 MHz, with an input impedance of 50 Ω, a reflection coefficient below -10 dB and a gain as high as possible, for application as standard antenna for low frequency far-field anechoic chamber measurements. The design procedure has to deal with size restriction imposed by the PCB technology fabrication laboratory. Another LPDA to be fabricated using not PCB technology, and therefore free from size limitations is also designed. The experimental input reflection coefficient and radiation pattern results show a good agreement with numerical simulation (CST) results providing validation of the design procedure and proof of the proposed antenna concept.

Keywords: Log-periodic dipole antenna, Printed antennas, Miniaturization techniques, Standard antennas, Antenna measurements, Broadband antenna.

1. Introduction

Today, sharing information is easy, fast and cheap. This ability to share information has made it possible for people and industries to collaborate more, develop new solutions and combine different areas of expertise, overturning the old and traditional business models. The traffic of information nowadays is becoming larger than ever before. Devices and connections are growing faster than both the population and Internet users. In 2016, computers were responsible for almost 46 percent of the total IP traffic, with Smartphones only taking a smaller part, 13 percent. By the year of 2021, it is expected for the Smartphone traffic to exceed the PC traffic, with the first one having 33 percent of the total IP traffic, where Computers will decrease to 25 percent. Also, the majority of IP traffic will be Wireless, with 63 percent.

With new Wireless communication systems being developed and with Wireless IP traffic increasing substantially every year, it is essential to have good measurement systems and techniques to validate the requirements. To test those systems, the antenna research and development (RD) community has a lot of computational electromagnetic (CEM) tools at their disposal. Tools that minimize the financial resources for the design of new antennas by allowing to simulate a virtual environment but in order to validate the simulated results there is a strong need for new measuring antennas. Despite the fact that the software available is now accurate enough to achieve a point of convergence with the measured results, only by putting the antenna under test (AUT) to a real environment can provide enough confidence for a total validation and final characterization of the antenna. To do that, an anechoic chamber seems the ideal place. It is a room designed to suppress contributions from the surrounding environment during the experimental tests, by providing protection from weather and by absorbing the reflections of the electromagnetic waves. Ideally, since the chamber can isolate electromagnetic (EM) waves from the exterior, the receiving antenna would only receive the EM waves directly from the emitting antenna, since the chamber walls (ideally) absorb the waves inciding on
them. The measuring process of either radiation pattern or antenna gain in the chamber is quite simple. The antenna in the receiving position is placed in the far field of the source antenna and by measuring the received power and comparing it with the gain of the standard antenna one can obtain the gain of the AUT. That is why standard gain antennas are very important, as they are commonly used for gain reference and antenna measurements. These are antennas that are able to operate in a specific range of frequencies with a reasonable gain and with their characteristics well-known.

The LPDA is one of the most used frequency independent antennas, ranging from HF (or even MF) to microwave applications. This antenna is known for its wide bandwidth and its simple design. It is a broadband, multi-element, directional antenna with radiation and impedance characteristics that ideally repeat themselves regularly as a logarithmic function of the excitation frequency. This characteristic and the fact that at Instituto Superior Técnico and at Instituto de Telecomunicações there are no standard antennas able to cover frequencies below 1.72 GHz (IT/IST has antennas that cover a frequency spectrum from 1.72 GHz to 75.8 GHz), makes the LPDA antenna a perfect candidate to provide a solution to fill this gap. With the development of large scale integrated circuit and printed circuit board (PCB) technology, printed antennas have drawn a lot of attention in the antenna community. Their light weight, low cost, easy fabrication and installation and good performance has attracted a lot of interest. These antennas are low profile, robust and not expensive to manufacture using modern printed-circuit technology, and they are very versatile in terms of resonant frequency, radiation pattern, polarization and impedance. Moreover, they are very easy to integrate with electronic components and arrays and they offer the possibility of being printed on curved surfaces to accomplish the creation of conformal antennas. With this technology being cheaper than the traditional antennas and since IT/IST has requested an antenna able to work at low frequencies for application as standard antenna for low frequency far-field anechoic chamber measurements.

This paper proposes to contribute with a step-by-step design procedure and simulated performance analysis of a printed log-periodic dipole antenna (LPDA) that is able to operate over a wide frequency range 500-2400 MHz. It contributes with the development of an expertise in the antenna field. The work carried out goes through all the important stages of an EM engineering process, namely, analysis, design (with optimization), fabrication and test. Initially it has been necessary to obtain know how on the LPDA antenna working principles and get acquainted with the software simulation tool (CST). It was then possible to develop a well sustained activity that has allowed the following original contributions: detailed parametric analysis of LPDA printed antenna. All the relevant parameters such as: dipole’s size, number of dipoles, feeding line, feeding coaxial cable, termination, dipole width and substrate shape, have been studied; design (with optimization), fabrication and test of a printed LPDA antenna with strict maximum size restrictions, large bandwidth and gain control; design and optimization of a non-printed LPDA antenna supported in foam and providing not only large bandwidth but also gain improvement; enhancement of the IT/IST set of standard gain antennas with a pair of printed LPDA antennas that can be used in the frequency range [500-2400] MHz and therefore extending the measurement capabilities lower to 500 MHz.

2. Antenna Characteristics

2.1. Geometry Description

With a rather simple design, the antenna is composed by a sequence of linear dipoles, displaced side-by-side, forming a coplanar array. The dipoles differ from sizes and are fed alternately by a common transmission line. The geometrical dimensions of the elements in the LPDA follow a very specific pattern. For the following analysis, the notation below will be used:

- \( d_n \) or \( D_n \) - distance between elements \( n \) and \( n+1 \);
- \( a_n \) - radius of the element \( n \);
- \( l_n \) - half the length of the element \( n \) (\( n = 1,2,...,N \));
- \( L_N \) - length of the element \( n \) (\( n = 1,2,...,N \));
- \( X_n \) - distance of element \( n \) to the antenna (virtual) apex;
- \( L_a \) - Total length of the antenna;
- \( L_N \) - Length of the shortest dipole;
- \( L_1 \) - Length of the longest dipole;
- \( 2 \alpha \) - Apex angle;
- \( B \) - Usable band;
- \( K_1 \) and \( K_2 \) - Upper and lower truncation coefficients.

Figure 1: LPDA configuration [1].
These parameters are related through a spacing factor ($\sigma$) and a scaling factor ($\tau$) and the antenna array increases logarithmically as defined by the scaling factor presented in equation 1.

$$\tau = \frac{l_{n+1}}{l_n} = \frac{X_{n+1}}{X_n} = \frac{d_{n+1}}{d_n} = \frac{a_{n+1}}{a_n}, \quad 1 \leq n \leq N$$

(Figure 1)

Frequently the radius of the dipoles do not respect entirely the geometric progression. Usually dipoles have the same radius.

Also, the spacing factor ($\sigma$) is defined by:

$$\sigma = \frac{d_n}{2L_n}$$

The angle $2\alpha$ is a characteristic of frequency independent structures. It is called the apex angle and it relates with $\tau$ and $\sigma$.

$$\tan\alpha = \frac{L_n}{2X_n} = \frac{L_n - L_{n+1}}{2d_n} = \frac{1 - \tau}{4\sigma}$$

Constant dimensions are used because it is very hard to obtain wires of different diameters and to maintain tolerances of very little gap spacings. Contrary to the Yagi-Uda antenna, where only one element of the array is directly empowered by the feed line, while all the others remain operating as parasitics, in the log-periodic array all the elements work connected to each other [pp.619-635]Balánis. The antenna configuration is described mostly in terms of the design parameters $\sigma$, $\tau$ and $\alpha$ and they relate to each other as presented in equation 2.3.

There is an important relation between the values of $\alpha$ and $\tau$. If the value of $\alpha$ increases then the value of $\tau$ decreases and vice-versa. Furthermore, along with the decrease of $\alpha$ or the increase of $\tau$, the number of dipoles that are closer to each other increases, increasing the number of elements in the active region which are approximately $\frac{\lambda}{2}$. Nonetheless, the variations of impedance and other characteristics as a function of frequency are smaller, due to the smoother transition between the elements. Also, if $\alpha$ decreases then the gain increases and vice-verse [pp.619-635]Balánis.

The original study of Carrel allowed to obtain the dependence of the LPDA directivity with the parameters $\sigma$ and $\tau$, for antennas with $Z_0$ equal to 100 Ohm and $\frac{\lambda}{2} = 177$. It shows that dependence, along with the relative space between the dipole elements ($\sigma$), called Optimum $\sigma$, which maximizes the directivity for a specific value of $\tau$ sebentacomplementosantenas. However, the original directivity curves are incorrect due to an error in the expression for the E-plane field pattern, so the values are very optimistic, being 1-2 dB higher than what it is supposed.

According to Peixeiro1988, the corrected directivity contour curves are represented in figure 2 below. The corrected curves (not the dashed ones) indicate that in order to achieve only 1dB additional gain, a larger spacing factor $\sigma$ and a bigger scaling factor $\tau$ are needed, which require the an-

$\sigma \leq \frac{1}{\sqrt{\tau}} \leq \frac{N}{2}$

\[1\]

$\sigma \leq \frac{1}{\sqrt{\tau}} \leq \frac{N}{2}$

\[2.3\]

$\sigma \leq \frac{1}{\sqrt{\tau}} \leq \frac{N}{2}$

\[3\]
tenna to extend its length by having more radiating elements.

The first step regarding the LPDA design is to choose the desired directivity, $D_0$. That will determine the scale ($\tau$) and space factors ($\sigma$) using Carrel’s design contours presented in the figures above, $D(\tau, \sigma)$. The operation frequency range and the truncation coefficients ($K_1, K_2$) allow to obtain the length of the longest ($L_1$) and shortest ($L_N$) elements Peixeiro1988.

Figure 3 shows a corrected diagram of the truncation coefficients Peixeiro1988, corresponding to the case $Z_0 = 100 \ \Omega$ and $\frac{L_{n_1}}{L_{n_2}} = 177$.

![Figure 3: Truncation coefficients for optimum ($\tau$, $\sigma$) pairs [2].](image)

In figures 2 and 3 the solid curves correspond to Carrel results Carrele while the dashed curve were proposed in Peixeiro1988.

The following expressions are used:

$$L_1 \geq K_1 \lambda_{\text{max}}$$  \hspace{1cm} (4)

$$L_N \leq K_2 \lambda_{\text{min}}$$  \hspace{1cm} (5)

The number of dipoles is given by:

$$N = 1 + \frac{\log(L_1/L_N)}{\log(1/\tau)}$$  \hspace{1cm} (6)

Where the operational band ratio is represented by:

$$B = \frac{f_{\text{max}}}{f_{\text{min}}} = \frac{\lambda_{\text{max}}}{\lambda_{\text{min}}}$$  \hspace{1cm} (7)

The active region bandwidth is:

$$B_{ar} = \frac{K_1}{K_2}$$  \hspace{1cm} (8)

After obtaining $B_{ar}$ and $B$ it is possible to obtain the lengths of the shortest and longest dipoles.

Length of the longest dipole:

$$L_1 = k_1 \lambda_{\text{max}} = L_N B_{ar}$$  \hspace{1cm} (9)

Length of the shortest dipole:

$$L_N = k_2 \lambda_{\text{min}} = \tau^{N-1} L_1$$  \hspace{1cm} (10)

$X_n$ represents the spacing between elements and it can be obtained by:

$$X_n = \frac{2\sigma L_n}{1 - \tau}$$  \hspace{1cm} (11)

The total length of the antenna ($L_A$) corresponds to the distance between the shortest and the longest dipoles:

$$L_A = X_1 - X_N = \frac{L_1 L_N}{2\tau_{max}} = \frac{2\sigma(L_1 L_N)}{1 - \tau}$$  \hspace{1cm} (12)

Also, the dipoles thickness is represented by the ratio:

$$\frac{L_{n_1}}{L_{n_2}}$$  \hspace{1cm} (13)

Having in mind the desired input impedance, the voltage standing wave ratio (VSWR) allowed, the power-handling capability and some practical construction limitations, the characteristic impedance of the feeder transmission line can be obtained by the following expression:

$$Z_0 = \frac{Z_{\pi \arccosh e^{2a}}}{2a} \approx \frac{Z_{\pi L_n e^a}}{2a} \quad (e \gg a)$$  \hspace{1cm} (14)

Where the transmission line conductors radius is represented by "a" and spacing between wires by "e" (for further analysis sebentacomplementosantenas). For high power emission antennas it is necessary to have transmission lines with high characteristic impedances, which means more space between the conductors to hold the voltages without disruption sebentacomplementosantenas.

2.3. Feeding Technique

![Figure 4: Balun implementation [3].](image)

The antenna feeding is made using a copper semi-rigid coaxial cable directly soldered to the LPDA...
feeder point and by having a SMA connector on the other end, the balun is implemented by soldering the outer conductor of the coaxial cable along the feeding line of the LPDA and the inner conductor soldered directly to the other feeding line through a via, as it can be seen in figure 4. Strictly speaking, this configuration is in essence composed by two antenna feeder lines each on the opposite side of the PCB that provide a 180 degree phase shift and an array of dipole elements connecting alternately to the one on the upper and to the other on the bottom side of the PCB [4].

2.4. Gain Measurement

There are two simple methods that can be used to measure the antenna gain: the absolute gain and the gain comparison techniques (or gain-transfer method) gain measurements. The absolute gain method does not require previous knowledge of the transmitting (T) or receiving (R) antenna gain. If the antennas (T and R) are identical, one measurement and use of the Friis transmission formula is sufficient to determine the gain Balanis.

On the other hand, the gain-transfer technique needs to be used in parallel with standard gain antennas to obtain the absolute gain of the AUT. Every technique has its own advantages and disadvantages, in terms of accuracy, time consumption and cost.

For example, the gain transfer method produces a simple and accurate solution for measuring the antenna gain. It uses a standard antenna with its characteristics well-known, such as the reflection coefficient and gain to determine the gain of an AUT in conjunction with equation 15 (below).

$$G_{AUT} = \frac{P_{R_{AUT}}G_{SGH}}{P_{T_{SGH}}(1 - |\tau|_{AUT})} \left(\frac{d_{AUT}}{d_{SGH}}\right)^2$$

(15)

$G_{AUT}$, $d_{AUT}$, $P_{R_{AUT}}$, and $|\tau|_{AUT}$ represent the unknown gain, the distance between the AUT and the transmitting antenna, the received power and the reflection coefficient related with the AUT, respectively. Further, $d_{SGH}$, $P_{T_{SGH}}$ and $G_{SGH}$ are the distance between the standard gain antenna and the transmitting antenna, the received power associated with the standard gain antenna and standard antenna gain, respectively. It is also important to say that pyramidal horn antennas are universally accepted and used as standard gain antennas Simulating measurements.

In the anechoic chamber of IT/IST, the two antennas (AUT and standard antenna) are 5 m apart. This means that the far-field distance needs to be less than 5 m.

3. Antenna Design and Optimization

3.1. Design Considerations

When designing an antenna, certain limitations are taken under consideration. Every antenna is different and for every purpose, different requirements are set. For the simulation procedure, the author used the CST MWS software, which allowed the simulation of the antenna under a controlled environment, in order to understand how the antenna performs by studying its radiation characteristics and each parameter influence on the antenna’s behaviour.

During the simulation process, some important characteristics were monitored and taken under consideration, such as the antenna realized gain, that takes into account all the losses (like the loss of mismatching), the bandwidth, the cross-polarization, the reflection coefficient ($S_{11}$), the efficiency, the directivity, the antenna’s radiation patterns and some other important characteristics. It is imperative to say that during the optimization process the antenna was simulated using 1 coaxial cable since it was known from the start that the prototypes would be fed that way. The feeding method depends on the type of device and the required characteristics one intends to use the antennas for.

In order for the prototype antenna to meet its specific requirements, the gain should be the highest possible, since the antenna will be used as a standard antenna for gain measurements. As for the reflection coefficient, this is one of the parameters that better describes how well matched to the feeding coaxial cable is the antenna for each working frequency, by measuring and comparing the power of the reflected electromagnetic wave versus the power of the incident wave. The lower the power of the reflected wave, the better matched the antenna is. The input reflection coefficient, or $S_{11}$, is a very important parameter since it defines the frequency band in which the antenna operates. In other words, for this specific project one important requirement is for the antenna to cover frequencies ranging from 500 MHz to 1750 MHz, so this condition must be satisfied $|S_{11}| \leq -10$ dB within that frequency range.

This criteria is used as a rigorous reference and is suitable for this specific project, not always considered as such for every antenna (different values such as -6 dB i.e. for mobile communications, or -15 dB are used, depending on the antenna application). Moreover, despite CST being a tremendous tool in the simulation of a variety of antennas, not always the simulation and the experimental results are exactly the same.

The choice of FR4 was simple. It is a relatively cheaper material that is easy to get access to and that has high fabrication tolerances. Sure it is not
the most suitable solution if one wants a low loss board, but since this project requires for the antenna to operate mostly at lower frequencies, this limitation is certainly not a drawback, since this is a lossy substrate that exhibits poor performance with the increase in frequency. Moreover, the choice of this substrate was not only to provide robustness but also to help decrease the antenna overall size.

For this project, the maximum production size for the PCB board is 420x350mm and it is imposed by the UV machine, used in the production process. This represents a huge problem, since the lower the frequency of operation the bigger the antenna needs to be. Moreover, the antenna will be used has a standard antenna for low frequency far-field measurements in the anechoic chamber and so in order to minimize the reflections from the walls of the chamber, the antenna has to have a gain as high as possible.

To reach the best compromise possible, a lot of simulations were performed. In terms of polarization, it will have linear polarization, which is common in antennas with dipoles. It will also have an input impedance of 50 Ω and a reflection coefficient below -10 dB for the required bandwidth.

4. Optimized antenna in FR4

4.1. Configuration

From figure 5 it is noticeable that the designed antenna has a trapezoidal design that meets the size limit requirement of 420 x 350 mm, with a size of 417.07 x 325 mm. This includes a 1 mm margin between the largest dipole (L1) and the limit of the board to prevent future production problems like damage L1 when cutting the dielectric. The dielectric (represented in yellow) used is a FR-4 lossy material with a relative permittivity ($\epsilon_r$) of 4.3, loss tangent (tan$\delta$) of 0.025 @ 10GHz, thermal conductivity (k) of 0.3 W/k/m and a thickness of 1.6 mm. Regarding the feeding technique, conclusions from section ?? and also tests realized on this configuration dictated that the antenna would be fed thought a semi-rigid UT-086 coaxial cable positioned straight along the antenna feed line. The cable has a length of 419 mm and was excited with a wave guide port at first and then tested with an SMA connector.

The antenna has the following configuration ($\tau$ 0.89 and $\sigma$ 0.11):

4.2. Mounting structure interface and fabricated prototype

After the antenna was fabricated, an interface to connect it to the positioner of the anechoic chamber had to be made specific for this LPDA antenna. The structure is made of acrylic material to not interfere with the antenna’s radiation characteristics and had to be strong enough to hold the antenna in vertical and horizontal alignments.

The disc has an external diameter of 190 mm with four holes of 8.1 mm of diameter, distributed uniformly over a circumference of 170 mm of diameter.

Figure 6 below shows the mounting structure made in the IT/IST workshop with the antenna attached. Figure 7 shows the fabricated prototype

<table>
<thead>
<tr>
<th>Dipole element (n)</th>
<th>Length $L_n$ (mm)</th>
<th>Spacing $a_n$ (mm)</th>
<th>Width $W_n$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>245.00</td>
<td>22.50</td>
<td>6.40</td>
</tr>
<tr>
<td>2</td>
<td>218.00</td>
<td>27.97</td>
<td>5.70</td>
</tr>
<tr>
<td>3</td>
<td>194.00</td>
<td>27.60</td>
<td>5.97</td>
</tr>
<tr>
<td>4</td>
<td>172.71</td>
<td>35.00</td>
<td>4.51</td>
</tr>
<tr>
<td>5</td>
<td>153.71</td>
<td>35.81</td>
<td>4.82</td>
</tr>
<tr>
<td>6</td>
<td>135.00</td>
<td>30.10</td>
<td>3.57</td>
</tr>
<tr>
<td>7</td>
<td>127.76</td>
<td>26.70</td>
<td>3.18</td>
</tr>
<tr>
<td>8</td>
<td>108.86</td>
<td>23.83</td>
<td>2.83</td>
</tr>
<tr>
<td>9</td>
<td>94.64</td>
<td>21.23</td>
<td>2.52</td>
</tr>
<tr>
<td>10</td>
<td>85.83</td>
<td>18.88</td>
<td>2.24</td>
</tr>
<tr>
<td>11</td>
<td>76.39</td>
<td>16.81</td>
<td>2.00</td>
</tr>
<tr>
<td>12</td>
<td>67.99</td>
<td>14.96</td>
<td>1.78</td>
</tr>
<tr>
<td>13</td>
<td>60.51</td>
<td>13.31</td>
<td>1.58</td>
</tr>
<tr>
<td>14</td>
<td>53.84</td>
<td>11.85</td>
<td>1.43</td>
</tr>
<tr>
<td>15</td>
<td>47.93</td>
<td>10.54</td>
<td>1.25</td>
</tr>
<tr>
<td>16</td>
<td>42.56</td>
<td>9.33</td>
<td>1.12</td>
</tr>
<tr>
<td>17</td>
<td>37.96</td>
<td>-</td>
<td>1.00</td>
</tr>
</tbody>
</table>
(with a coin of 1 euro on its side for reference).

Figure 6: Mounting structure with the LPDA on it.

Figure 7: Fabricated prototype.

4.3. Input Reflection Coefficient Results

Figure 8 contains the $S_{11}$ simulation (CST) and the two measurement results. Measurement 1 (in blue) correspond to the first measurement where the antenna was placed on top of a foam, whereas measurement 2 (represented by red) correspond to the second measurement where the antenna was mounted on the structure.

The simulated and measured results have very good agreement between each other and match the requirement of being below -10 dB for the entire bandwidth of interest. Furthermore, the antenna is able to operate in a wider band than the required one, being able to operate from 500 MHz up to almost 2.5 GHz, which is 650 MHz more than the initial required band.

Aside from the average magnitude of $|S_{11}|$ being 6 dB difference between the simulated and measured results, which can be caused by the simulator itself (accuracy and mesh used) and the non-anechoic laboratory environment where $|S_{11}|$ was measured, there are always other factors that happen during the fabrication process that can cause this little discrepancies such as fabrication tolerances, the way the antenna was cut, the soldering and connection of the cable that introduce losses and even the materials used, specially FR4 which is not a high quality substrate.

4.4. Simulated Radiation Pattern Results

From figure 9 it is possible to identify that the X axis positive is set toward the apex of the antenna (after a coordinate transformation), where the shortest dipoles are. Below are represented the radiation pattern cuts for both E and H planes for some specific frequencies of $f = (500, 600, 800, 950, 1100, 1400, 1750, 2000, 2300, 2400, 2500)$ MHz, which were carefully chosen to show how the radiated fields change with frequency. As expected, the lower frequency (500 and 600 MHz) provide much higher back radiation. The front-to-back ratio is about 10 dB.

- **E-plane: Constant Theta, Theta = 90°**

- **H-plane: Constant Phi, Phi = 0°**
4.5. Measured Radiation Patterns
This section presents the radiation patterns measured in the two anechoic chambers previously indicated. As explained before, the chamber of IT/IST is certified for frequencies above 2 GHz. To overcome this, and because it was imperative to measure and test the antenna performance in the lower frequencies (500 MHz), the author went to IT at the Department of Electronics, Telecommunication and Informatics (DETI) of University of Aveiro (UA) to test the prototypes in their chamber. The main difference between their chamber and the one in the IT/IST is that they have standard gain horn antennas down to 700 MHz.

The results presented below show both patterns, E-plane and H-plane, with their correspondent vertical and horizontal polarizations. Each figure corresponds to a certain frequency and includes the simulated patterns, the patterns measured in the IT/IST anechoic chamber and the ones measured at IT/UA.

The measured frequencies in Aveiro were: 500 MHz, 700 MHz, 900 MHz, 1100 MHz, 1300 MHz, 1500 MHz and 1750 MHz. For each frequency, 4 different angular sweeps were made. Measurements at 500 MHz were made using the standard antenna IMC: IWH-560 and for every other frequency the antenna A-INFO LB-7180 was used. Also, for a future comparison between more than one transmitting antenna, measurements at 1750 MHz were also made using the horn SGH1726. In sum, the total azimuthal sweeps were 32 using three antennas in total (4 sweeps with IMC: IWH-560, 24 sweeps with A-INFO LB-7180 and 4 sweeps with the horn SGH1726).

Regarding the anechoic chamber of IT/IST, the measurements were: radiation pattern for the frequencies 1100 MHz, 1300 MHz, 1500 MHz and 1700 MHz using the horn FMI 06240-10 and the radiation pattern and gain for frequencies 1750 MHz, 2000 MHz and 2300 MHz using a horn FMI 08240-10. (Note: the Horn FMI 08240-10 plus the transition 08093-NF10 plus the transition N-SMA width 6.1 KG.)

For more radiation pattern representation see this Thesis.
4.6. Gain

The summary of the gain results of both FR4 and foam antennas are included in tables 2 and 3. There is a good agreement between CST simulation and the experimental IT/IST results. One can see from table 2 that for example for the frequency 1750 MHz the difference is negligible. However there is a significant difference concerning the IT/UA experimental results. At the moment there is not a consolidated explanation for this difference, despite the amount of reflections from the walls of the chamber when operating at lower frequencies.

Table 2: Comparison of gain results for the FR4 antenna.

<table>
<thead>
<tr>
<th>Frequency [MHz]</th>
<th>500</th>
<th>600</th>
<th>1100</th>
<th>1200</th>
<th>1350</th>
<th>1500</th>
<th>1750</th>
<th>2000</th>
<th>2800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain [dB]</td>
<td>5.03</td>
<td>5.08</td>
<td>5.04</td>
<td>5.07</td>
<td>5.03</td>
<td>5.02</td>
<td>5.01</td>
<td>5.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Measured IT/IST</td>
<td>7.1</td>
<td>7.3</td>
<td>8.1</td>
<td>8.1</td>
<td>7.1</td>
<td>7.2</td>
<td>8.0</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Measured IT/UA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

Table 3: Simulation gain results for the foam antenna.

<table>
<thead>
<tr>
<th>Frequency [MHz]</th>
<th>500</th>
<th>600</th>
<th>1100</th>
<th>1200</th>
<th>1350</th>
<th>1500</th>
<th>1750</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain [dB]</td>
<td>5.58</td>
<td>5.56</td>
<td>5.54</td>
<td>5.43</td>
<td>5.11</td>
<td>5.64</td>
<td>5.35</td>
<td>5.35</td>
</tr>
</tbody>
</table>

5. Conclusions

This paper describes the study, design, optimization, and fabrication of a LPDA antenna in printed circuit technology. The design and optimization of a non-printed LPDA antenna is also presented.
the same bandwidth as the FR4 antenna. This was also true because since it did not require any use of the printed technology, there was no size restriction and so the antenna has almost 1 meter of total boom length, compared to the 43 cm of total length of the FR4 LPDA. The dimensions and characteristics of the two optimized antennas are listed below. Both antennas provide a 50 Ω input impedance and linear polarization.

Figure 16: LPDA in FR4 prototype dimensions.

- **Printed LPDA**
  
  Size [cm]: ZZ = 32.5, YY = 41.70, XX = 11.79; Thickness [mm]: 1.6; Weight (without sma): 273.8 g; Bandwidth (|S11| ≤ -10 dB): 4.8-1 (500-2400 MHz); Average gain: 6.5 dB;

- **LPDA in foam**
  
  Size [cm]: ZZ = 38, YY = 98.99, XX = 13.55; Thickness [mm]: 5.35; Bandwidth (|S11| ≤ -10 dB): 4.2-1 (500-2100 MHz); Average gain: 9.5 dB;

5.1. Future Work

First of all, it is necessary to find a good explanation for the significant difference obtained in gain between experimental IT/UA and IT/IST results. Secondly, he optimized LPDA antenna in foam should be produced, tested and its results compared to the simulated ones, with the same thing for the second LPDA antenna printed in FR4. Further, every optimization process is very unique and has specific requirements that need to be addressed. Despite the fact that the proposed objectives for this project have been achieved, the author considers there is always room for improvement. One interesting suggestion for future work would be to continue the optimization process of the LPDA antenna in foam, which was not concluded in this thesis due to the unavailable materials and the short time frame of this project. Also, since the antenna in FR4 was tested in two anechoic chambers, one in the IT/IST and other in IT/UA, it would be interesting to realize new measurements in a low frequency certified chamber such as the one in the Polytechnic University of Madrid. As future work, it would also be interesting to refine the mesh structure in the CST simulator and to use the maximum number of accuracy and cells to obtain more accurate simulation results. This would be particularly relevant for gain results at low frequency. Finally, one interesting project would be to design and simulate a log-yagi antenna with the same project requirements, which is a combination of a Log-Periodic antenna with a Yagi-Uda antenna logyagi, that provides an excellent wideband pattern with a very high gain, specially when bending some of its elements. This would be very interesting to compare with the printed LPDA antenna, since they are very similar in terms of configuration and operation.

**Acknowledgements**

Firstly, the author would like to express his sincere gratitude to Professor Custdio Peixeiro for the continuous support during this thesis, for his patience, dedication, knowledge and guidance. To Mr. Carlos Brito and Eng. Antonio Almeida, for their knowledge, experience and participation in the fabrication and test of the prototypes. Also, to Mr. Faria, for his time and effort helping manufacture the mounting structure to hold the antenna onto the positioner of the anechoic chamber. Further, a special thanks to the author’s parents, brother and friends, for their unconditional encouragement and support during this journey. To Instituto Superior Tecnico (IST), a school filled with science and knowledge, where the author completed his studies. To IT/UA (DETI), Prof. Nuno Borges de Carvalho and Eng. Hugo Mostardinha, for their help, knowledge, sympathy and availability in the execution of the prototype anechoic chamber measurements. Finally, a very special thanks to Instituto de Telecomunicacions (IT), the institution that sponsored and hosted this thesis.

**References**


