Design and Analysis of LPDA antenna for through the wall detection TTWD applications

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Abstract -*In this paper we present the design and simulation and implementation of a directional UWB logarithmic periodic dipole antenna (LPDA) for through the wall detection applications. The antenna operates at the range [0.5-3] GHz, with linear polarization and more than 6 dB gain, and VSWR less than 2.2.*

Key Words: LPDA, UWB, TTWI, Gain, SSL, VSWR.

1. INTRODUCTION

Through the wall imaging has been a very interesting subject since it can help policemen and soldiers operations. Studies found that the ultra-wide band UWB signals are suitable for TTWI. The importance of UWB in such technology comes from the need of wide bandwidth for better range resolution [1], [2]. Signals must penetrate the walls and detect the human behind it, and since losses increases with frequency, a lower bandwidth is desired to satisfy better penetration. Thus the selection of a frequency range of 0.5-3 GHz is appropriate for assuring both fine range resolution and good penetration through the walls even with big thickness.

As in any radar system, antennas are considered the most critical element, and the importance of antennas designs increases in TTWI where signals from the hidden target is weak, thus most of the power radiated by radar must be focused toward the wall and targets we aim to detect.

Antennas used in such application must satisfy a good impedance matching across the desired wide bandwidth and good radiation properties such as narrow beam width which means high gain in order to detect targets behind walls.

As mentioned above, the need of wide bandwidth is very important in TTWRI to get better range resolution. This characteristic imposes the use of UWB antenna. L.P.Ligthart et al used slot antennas to get a UWB bidirectional one to use detection of objects under the interface [3]. Horn and helix are both unidirectional antennas with adequate gain but they have no wide beams [4]. Many of these wideband antennas are not widely used in practical applications due to their unstable radiation pattern, or large gain variations [5]. A large improvement in the beamwidth and radiation pattern was achieved by adding either shielding plane behind antenna or cavity, or by using absorbing materials [6-8]. F.Fioranelli et al used an optimized Patch-Like antenna with a reduced size and low back loop [9]. In [10], a wideband magneto-electric antenna was developed for through-the-wall imaging radar (TTWIR) applications, where a rectangular cavity is introduced to improve the total gain and the front-to-back ratio (FBR) of the antenna. finally, Wang Zhuopeng et al introduce A new type of magneto-electric dipole antenna with wide beam over the operating bandwidth used in Ultra-wideband Through-the-wall radar [11]. However these methods lead to decreased efficiency or cannot handle high power for TTWRI.

In this paper we propose an optimized directional UWB logarithmic periodic dipole antenna (LPDA) in the frequency range [0.5-3] GHz, with overall gain more than $6dB$ over the studied bandwidth. some modification of this antenna was done using stripes dipoles for ease of fabrication instead of circular ones in the tradition antenna, and In order to decrease the length of the tallest dipole which operate at the lowest frequency, we add a substitution element at the both ends of this dipole for substituting the length, we also use an elliptical metallic reflector for increasing the directivity. The simulation of the antenna is done using the commercial software CST in order to study and optimize the antenna and its radiation properties.

2. Antenna Design Methodology

This kind of antennas consist of an array of dipoles with different lengths and spacing, where the change of these dimensions lead to a change in the operating frequency, and it satisfy equation (1).[12]

$$\frac{1}{\tau}=\frac{l_2}{l_1}=\frac{l_{n+1}}{l_n}=\frac{R_2}{R_1}=\frac{R_{n+1}}{R_n}=\frac{d_2}{d_1}=\frac{d_{n+1}}{d_n}=\frac{s_2}{s_1}=\frac{s_{n+1}}{s_n} \quad (1)$$

Where τ is a geometric ratio, l is dipole length, d is dipole diameter, R is the distance between two consecutive antennas, and s is spacing between the poles of the single dipole, with can be defined as in equation (2). The LPDA structure is shown in figure (1).

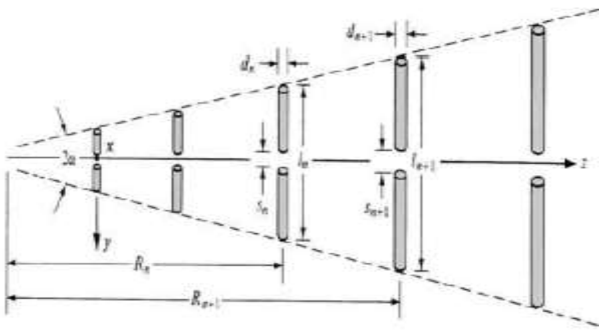


Fig-1: LPDA antenna Structure [12].

The first step is determining the dimensions of the parameters τ, α, σ using monograph in figure(1) and equation (2).

$$\alpha = \arctan\left(\frac{1-\tau}{4\sigma}\right) \qquad (2)$$

Where α is half the dipole spacing angle. Then active region bandwidth B_{ar} is calculated using equation (3).

$$B_{ar} = 1.1 + 7.7(1-\tau)^2 \cot\alpha \qquad (3)$$

Then the designed bandwidth B_s can be calculated by multiplying the active region bandwidth and the desired bandwidth B as in equation (4).

$$B_s = B.B_{ar} = B(1.1 + 7.7(1-\tau)^2 \cot\alpha) \qquad (4)$$

The total length of the antenna Lis represented by the difference between the tallest dipole l_{max} and the smallest one l_{min} and given in (5).

$$L = \frac{\lambda_{max}}{4}\left(1 - \frac{1}{B_s}\right) cot\alpha \qquad (5)$$

Where λ_{max} is the maximum wavelength which equals $2l_{max}$.

The number of dipoles N is then calculated using the equation (6).

$$N = 1 + \frac{\ln(B_s)}{\ln(1/\tau)} \qquad (6)$$

The proposed antenna operates on the frequency $[0.5-3]GHz$ with directivity more than 6 dB and input impedance of 50 Ω.

Antenna's dipoles diameters are summarized in table (1).

Table-1: Antenna's Dipoles dimensions

Element No.	Dipole Diameter (d) in mm	Dipole Length (l)in mm	Distance (s) in mm
1	0.99	31.2	1.19
2	1.15	36.3	1.38
3	1.34	42.2	1.61
4	1.55	49.1	1.86
5	1.8	57.1	2.16
6	2.1	66.4	2.52
7	2.44	77.2	2.93
8	2.84	89.8	3.41
9	3.3	104.4	3.97
10	3.84	121.4	4.61
11	4.47	141.1	5.37
12	5.2	164.1	6.25
13	6.04	190.8	7.26
14	7.03	221.9	8.45
15	8.17	258	9.82
16	9.5	300	11.42

3. Simulation and results

We analysis the performance of the designed antenna using the commercial software CST Microwave Studio and optimize the dimensions until having the best performance. We need the VSWR of the antenna to be less than 3 over the desired bandwidth. We accept the value of 3 because of the ultra-wide band, which implies a good matching between the antenna and the transmission line, so more power delivered to the antenna to be radiated towards wall and targets. The second requirement of the desired antenna is to be directive, so we need a high gain antenna, thus we study the far-field properties of this antenna and find results.

We modify the traditional LPDA antenna by making the distance between the two rods of dipole constant, and we use simplified striped shape of dipoles which is equivalent to the cylindered shape, this substitution is done for the ease of manufacturing. We also use an elliptical metallic reflector for increasing the directivity.

The LPDA we designed have Number of elements is 16, length L=370mm, distance between dipoles is 10 mm, thickness of striped dipole elements is 2 mm.

In order to decrease the length of the tallest dipole which operates at the lowest frequency, we add a substitution element at both ends of this dipole for substituting the length as shown in figure (2).

Using CST Microwave Studio for antenna simulation we get

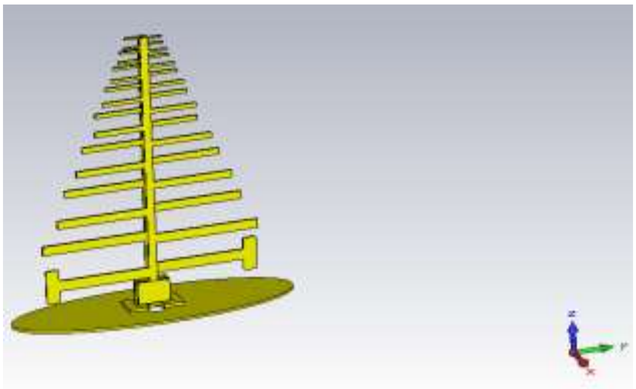


Fig-2: Proposed LPDA antenna model in CST

The Voltage Standing Wave Ratio VSWR of the simulated antenna is shown in figure (3).

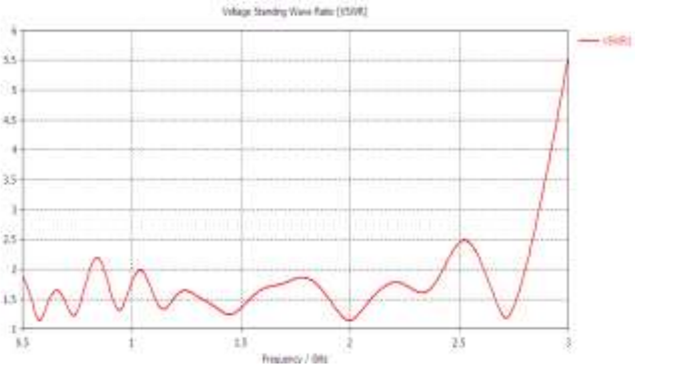
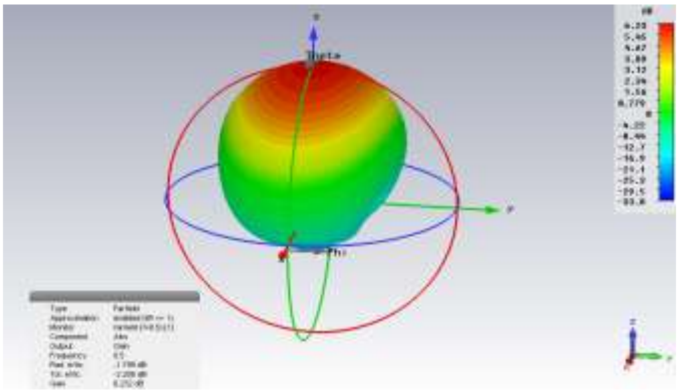


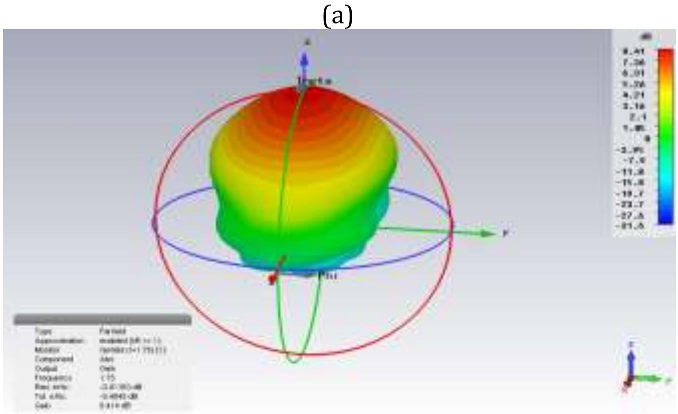
Fig-3: VSWR of the antenna versus frequency

As we see in figure (3), VSWR is below 2.5 over the frequency range [0.5-2.5]GHz, this means that the maximum reflected power is about 18.4%.

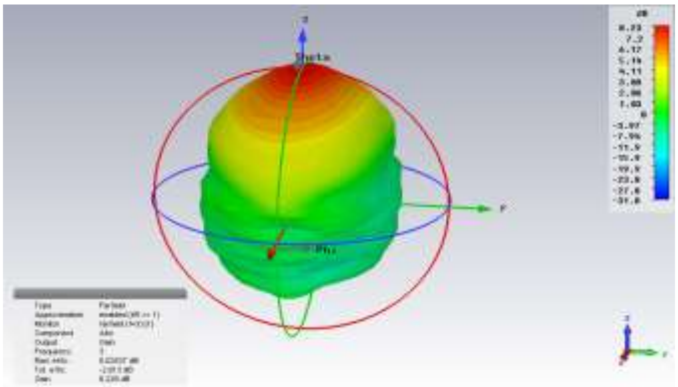
Another important problem faces the TTWRI antennas is the two-lobes pattern, this leads to two problems: the first one is that the radiated power by one lobe may not focused well in the target direction, and the second one is that the second lobe may receive undesired signal or clutter form wall in case of monostatic radar, where both the transmitter and receiver use one antenna. In order to compete this problem, we must use a low frequency as we noticed from far field simulation result. The far fields at frequencies 0.5GHz, 1.75 GHz, and 3 GHz was simulated using CST an a comparison between the 3D radiation pattern is shown in figure (4).



(a)



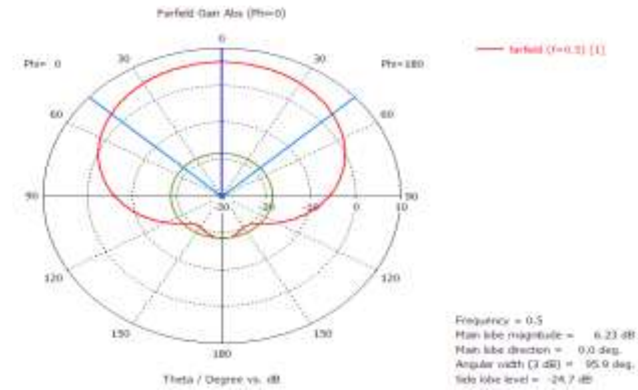
(b)



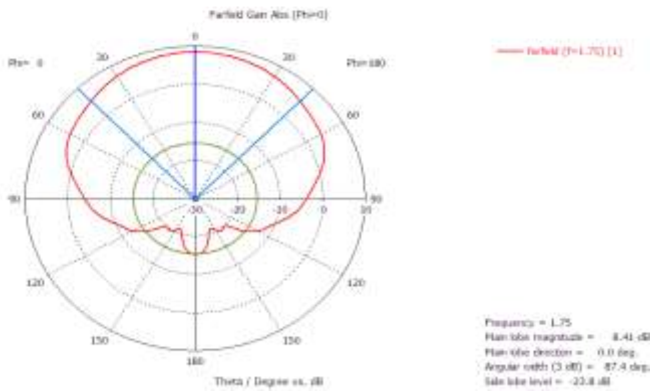
(c)

Fig-4: 3D far-field of the antenna at frequencies (a) f=0.5 GHz, (b) f=1.75 GHz, (c) f=3 GHz

Another comparison between far fields was done in the H plan ($\emptyset = 0$) at at frequencies 0.5GHz, 1.75 GHz, and 3 GHz and the plot results are shown in figure (5).



(a)

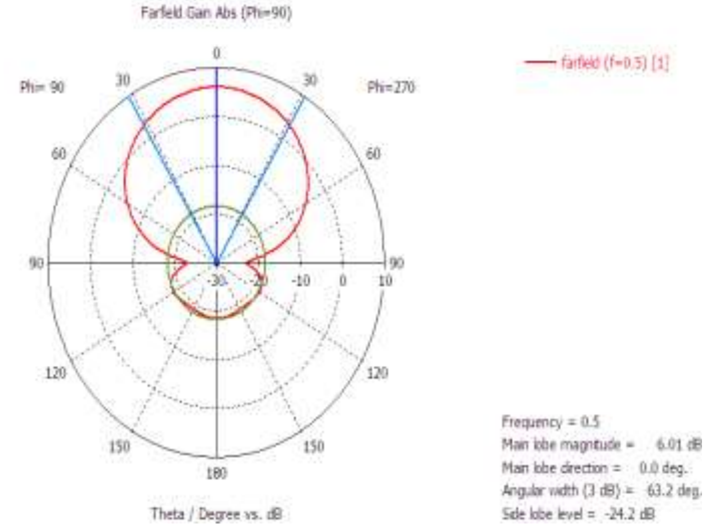


(b)

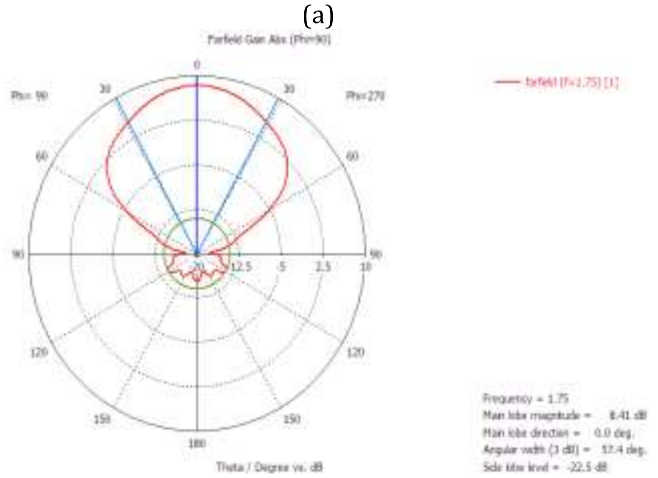
(c)

Fig-5: Polar far field of the antenna in plane H(ϕ=0) at frequencies (a) f=0.5 GHz, (b) f=1.75 GHz, (c) f=3 GHz

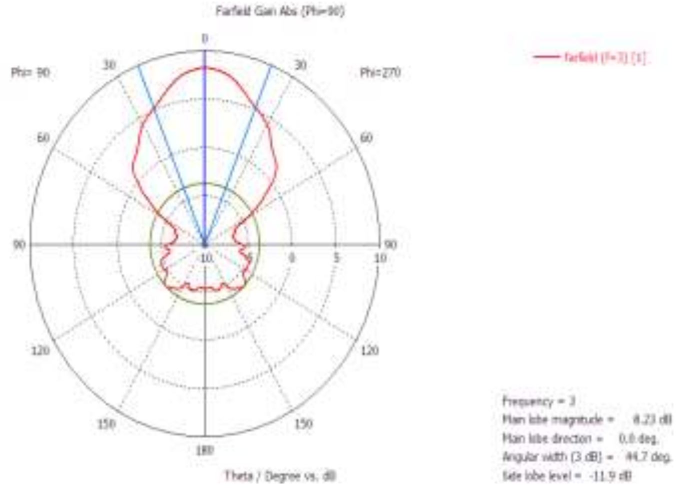
Finally we show far field comparison in the E plane at frequencies 0.5GHz, 1.75 GHz, and 3 GHz and the results are shown in figure (6).



(a)



(b)



(C)

Fig-6: Polar far-field of the antenna in plane E(ϕ=90) at frequencies (a) f=0.5 GHz, (b) f=1.75 GHz, (c) f=3 GHz.

As we notice from far field simulation, the lower frequency has lower side lobes and thus it's better in TTWRI applications.

In order to find the maximum gain over the entire bandwidth, we use the post-processing tool in CST and monitor the maximum gain over frequencies as shown in figure (7). It shows that total gain is more than 6 dB, and becomes more than 7.5 dB in the frequency range [0.7-3] GHz.

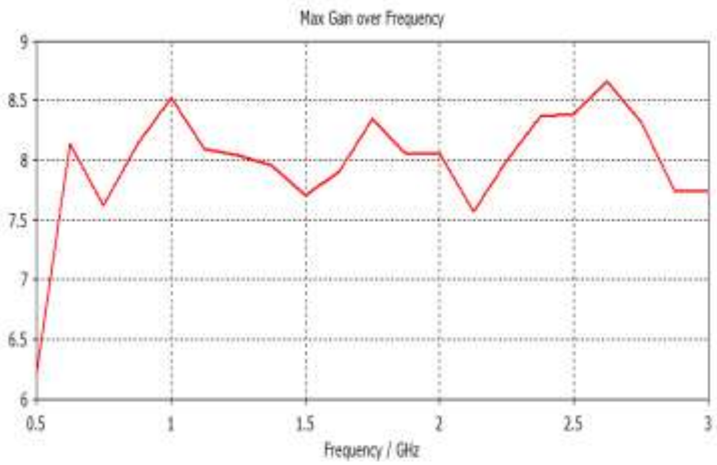


Fig-7: maximum gain vs frequency

3. CONCLUSIONS

In this paper we presented the design and simulation of an LPDA antenna for TTWRI applications in the 0.5-3 GHz frequency range. A modified antenna has been done by making the distance between the two rods of dipole constant, and using simplified striped shape of dipoles for the ease of manufacturing. We also use an elliptical metallic reflector for increasing the directivity. The proposed antenna operates in the range 0.5 – 3 GHz with good matching and convenient beamwidth for the TTWRI applications.

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