

# Design of a Circular Patch Antenna with a reflector for GPR applications

Ouboudrar Ismail, Lagmich Youssef, Oulhaj Otman and Amina Aghanim

Laboratory of Sciences and Advanced Technologies (LSTA), Polydisciplinary Faculty of Larache (FPL), Abdelmalek Essaadi University, Tetouan, Morocco.

**Abstract.** In this paper, a structure of a patch antenna operating at 0.5 GHz is proposed for ground-penetrating radar (GPR) applications, with an optimized performance at low frequencies. The structure was designed using FR4 substrate, with a 4.4 permittivity value, and a tangent loss equivalent to 0.021. The prototype design is backed by an optimized rectangular reflector, which has improved the antenna gain and directivity. The performance of the antenna is evaluated in terms of the return loss, gain, and the radiation pattern for two cases, with and without a reflector. When using the reflector, a good radiation pattern is obtained, a wide operational bandwidth ranging from 0.4GHz and 1.25 GHz is achieved, and an increased gain from 4.3 to 7.43dB was realized.

**Keywords:** Antenna, Patch, GPR, reflector

## 1 Introduction

Microstrip antennas are one of the most popular antennas in the wireless communication market. We can find applications of microstrip antenna in various fields of technology like in mobile communication systems[1], satellite communications[2], spacecraft, radars[3], wireless phones and wireless computer networks[4]

This type of antenna received a considerable attention starting in 1970 in a paper written by R.Munson (1974)[5], although the idea of a microstrip antenna can be traced back to G.A.Deschamps 1953 [6]. A microstrip Patch Antenna, in its simplest form consists of a radiating patch on one side of a dielectric substrate, and ground plane on the other side of the substrate.[7]

The major advantage which makes the antenna so popular is their low profile, lightweight, easy fabrication, and low-cost solution and can be integrated with other microstrip components in monolithic applications like RFIC or MMIC [8]. However they have also some drawbacks such as the low frequency bandwidth, the radiation efficiency deterioration as frequency and antenna array size increases due to an augmentation in the feeding network losses and limited to relatively low power levels.[7]

Few words about feeding methods since the microstrip antenna is some sort of a resonator we need to excite the fields in this generator in this resonator and there is various ways to feed the antenna. Some of the most common feeding techniques are Microstrip-Line feed, Microstrip Inset Line Feed, Co-axial Line Feed, Aperture Coupled Line Feed, Proximity Coupling Feed.[9]-[7]

The Ground-penetrating radar (GPR) technique consists of employing radio waves and detecting the reflected signal to show the denoted structure [10]. Given the advantages of superior agility, high data density, and short survey time in large non-accessible areas of interest, it has been widely investigated and applied to glaciology, archeology, avalanche rescue, mineral exploration, and landmine detection.[10]

In this paper, a design patch circular antenna operating in the frequency of 0.5 GHz, with a reflector to compensate the gain is presented. The organization of this work is the following: The second section elaborates the principle of working and the different types of ground penetrating radar systems, while the third section was dedicated to the conception of the circular patch antenna. The fourth section consists of illustrating and discussing the simulated results of the structure with and without the reflector using CST environment and finally a conclusion with an opening to some short incoming perspectives.

## 2 Ground penetration radar

### 2.1 Working principle

Much previous research has concerned ground-penetrating Radar (GPR), which refers to an electromagnetic (EM) technique mapping conditions below the ground level and the building materials [11]. This system aims to transmit a radio wave signal, into the probed material and receive the reflected pulses after contacting and detecting the discontinuity [12]. It should be mentioned that the discontinuity could be at the level of the boundary or even at the interface level of the material with different dielectrics or even at the level of a subsurface object contact such as delimitation. The range of the transmitted wave signal

goes from the range of some megahertz to some gigahertz [13]. The fig.1 shows clearly this process.

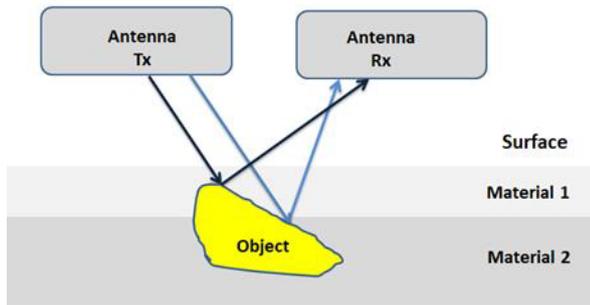


Fig 1. Working principle of GPR

## 2.2 Types of GPR architecture

In the literature, three commonly used types of radar architecture are studied in the GPR system, a mono-static GPR where the transmitting and the receiving radar pulse are accomplished by the same antenna. Also, a second type named bi-static GPR, where the transmitting and receiving process are established by an antenna each one. A single antenna performs the third type, called multi- static, here the transmitting signal while multiple receiving antennas in an array configuration are required for the receiving part[14].

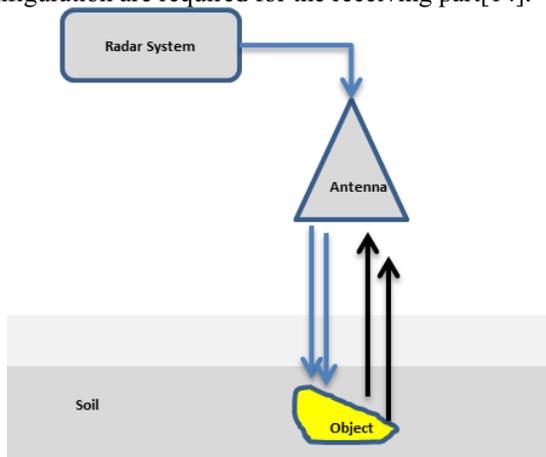


Fig 2. Mono-static architecture radar

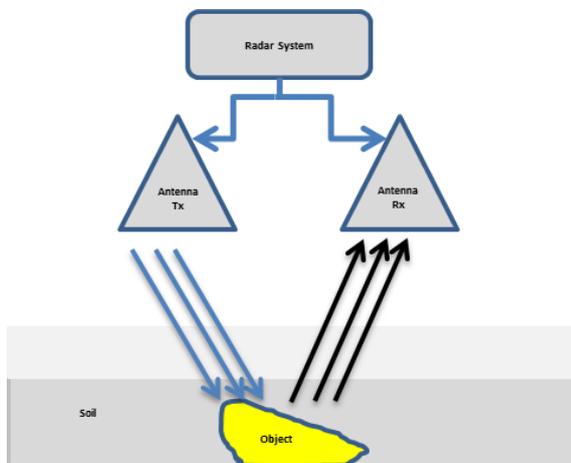


Fig 3. Bi-static architecture radar

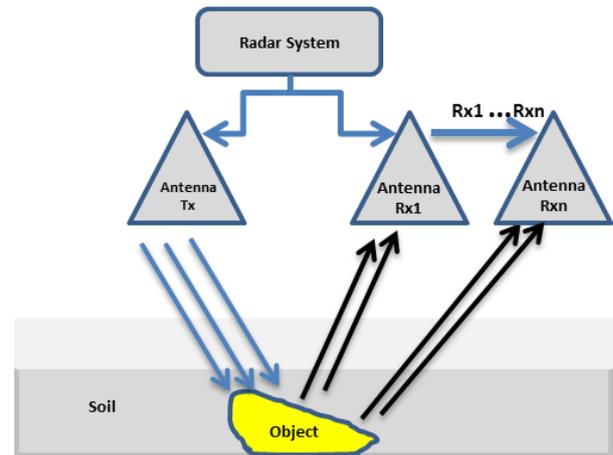


Fig 4. Multi-static architecture radar

## 3 Patch antenna Design

The antenna under consideration is generally used in GPR systems. This structure has been designed using a FR4 substrate [15], the choice was performed based on the low cost and easiness of fabrication of the concerned material. The dimensions of this substrate are  $h_s=1.57$  mm, the dielectric constant is  $\epsilon_r=4.3$  and the tangent of losses is equivalent to 0.021 [15].

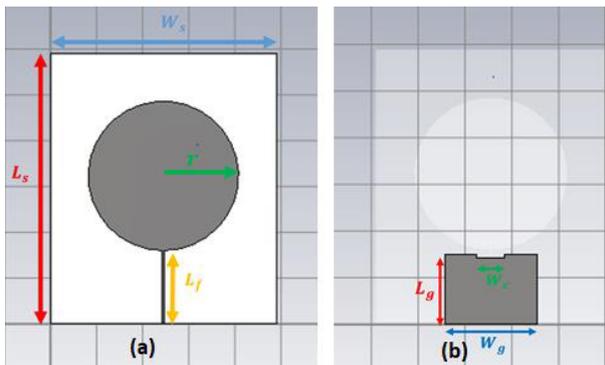
The topology of the patch antenna was designed under CST environment, where the dimensions of the substrate are 200 mm x 250 mm. The micro-strip line fed of  $50\Omega$  is characterized with dimensions of 17 mm x 35 mm. It should be noted that the ground plane length is the same as the feeding line length [16].

In order to obtain a wide operational bandwidth, the modification and reduction of the ground plane was performed based on two parameters [17][19], which are  $W_g$  and  $L_g$  respectively referring to the width and the length of the ground plane. The carried out modification was performed at the punctual contact between the feeding line and the patch antenna. The radius circle size was established using (1) [5] and gave the value  $r=81$  mm. Both figures Fig.3 show the dimensions of the concerned structure.

$$r = \frac{F}{\sqrt{\left\{1 + \frac{2h}{\pi\epsilon_r F} \left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}}} \quad (1)$$

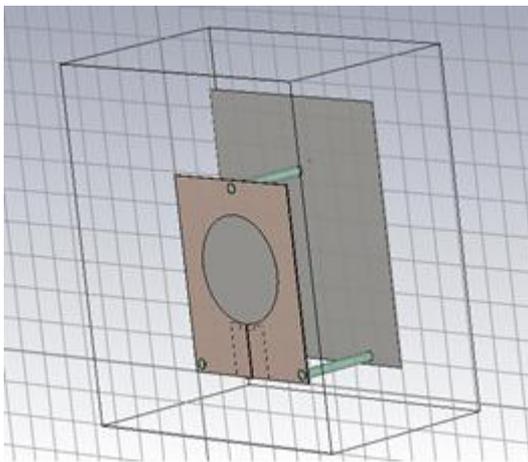
$$\text{Where } F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \quad (2)$$

- $h$  : The thickness of the substrate in cm.
- $f_r$  : The resonant frequency.
- $\epsilon_r$ : The dielectric constant of the substrate.



**Fig 5.** (a)Upper face of the antenna (b) Lower face of the antenna

In order to achieve a directional radiation pattern, we have used a structure in form of a reflector connected to the antenna with four plastic cylinders, their length is  $d=130\text{mm}$ , in the beginning the value of this length was  $d=10\text{mm}$  then we has optimized this parameters, until we got an optimized result with the value of  $d=130\text{mm}$ . The geometry is showed in Fig.5.



**Fig 6.** Antenna and reflector system

The overall optimized dimensions of the proposed antenna are showed in Table 1.

**Table 1.** Geometry Parameters

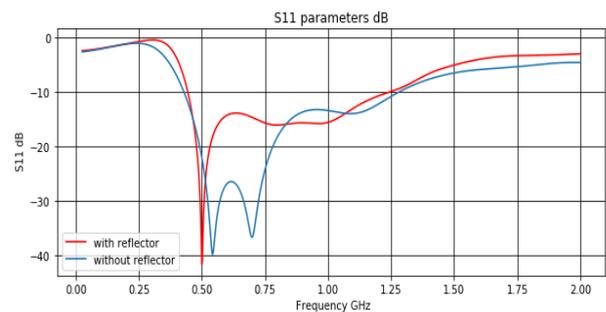
Parameters	Size (mm)
Substrate Width ( $W_s$ )	245
Substrate Length ( $L_s$ )	295
Ground plane Length( $L_g$ )	80
Ground plane Width( $W_g$ )	70
Feed line Width ( $W_f$ )	1.9
Feed line Length( $L_f$ )	80
Reflector with a spacing( $d$ )	130
Width of slot ( $W_c$ )	30

## 4 Results and Discussing

In this section, a discussion of the obtained results is presented in terms of the return loss, the bandwidth (MHz), the directivity (dBi) and the gain (dB) for the considered structure with and without reflector in order to establish the directional radiation radiation pat-tern.

### 4.1 Reflection Coefficient

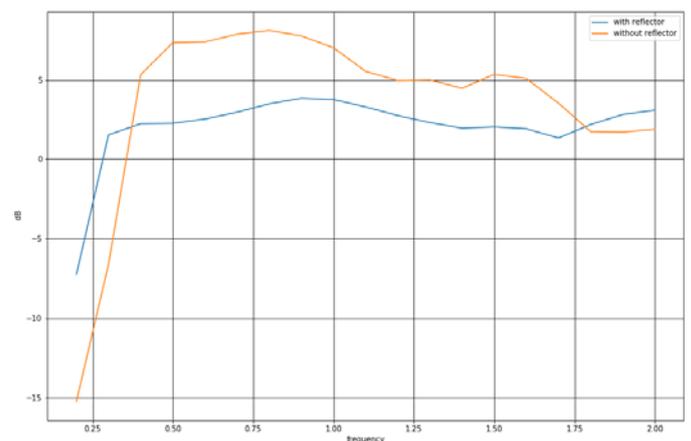
The carried out results of the reflexion coefficient of our structure is shown in fig.5 where it depicts  $S_{11}$  of the antenna with and without reflector at an operating frequency of 0.5 GHz. The blue plot of the reflexion coefficient of the structure without reflector has a return loss of 39.90 dB, and a bandwidth at -10 dB ranging from 0.45 GHz to 1.32 GHz. While we can clearly see that the  $S_{11}$  results has been optimized when the reflector was added. The red plot has showed a return loss of 41.1 dB and a bandwidth at -10 dB ranging from 0.44 GHz to 1.25 GHz.



**Fig 7.** Simulated S11 with and without reflector

### 4.2 Radiation Pattern and Gain

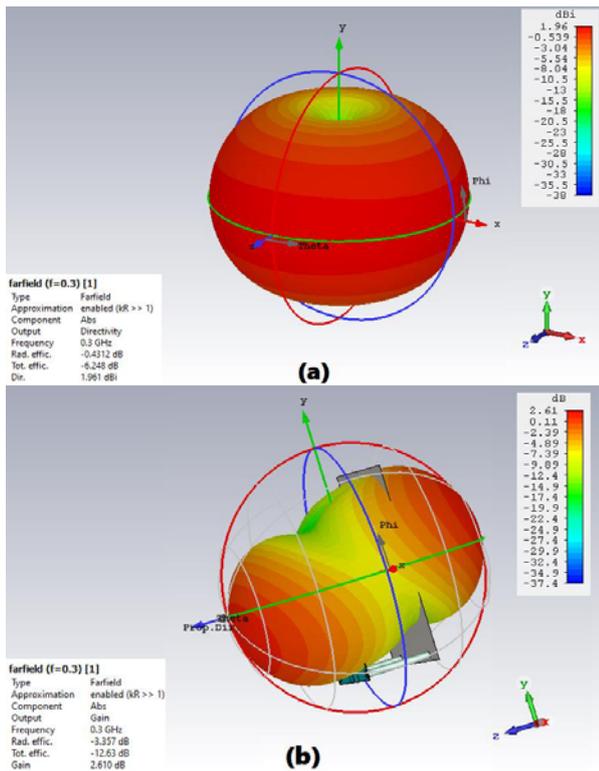
The simulated 3D far-field radiation pattern for the patch antenna has been elaborated in this section. The comparison radiation pattern of the proposed antenna at 0.5 GHz with and without reflector has been presented in Fig.8. The performance of the proposed antenna is compared with preexisting antennas, and analysis is presented in Table 2.



**Fig 8.**Gain of the structure with and without reflector

**Table 2.** Compared results

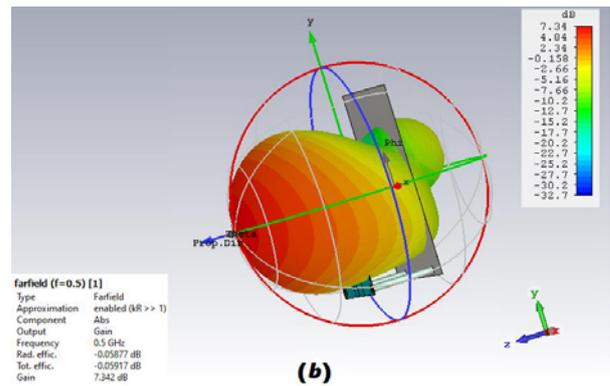
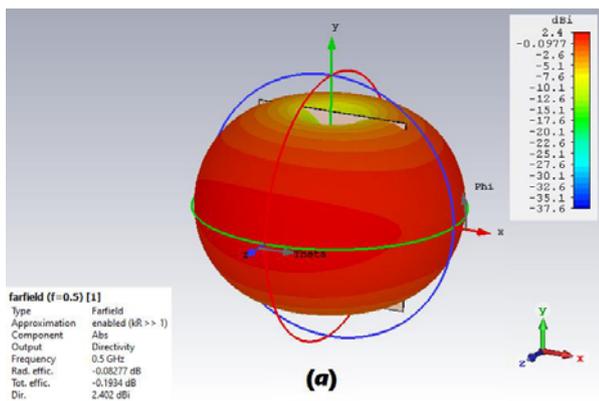
Reference	[18]	[14]	Proposed design
Antenna dimensions (cm <sup>2</sup> )	18x22	10x10	24.5x29.5
Frequency (GHz)	0.6- 4.6	1.1-5.5	0.45-1.32
Peak gain (dB)	5.01	4.3	7.43
Reflector type	Planner	Planner	Planner



**Fig 9.**(a) Radiation pattern at 0.3 GHz without reflector.(b) Radiation pattern at 0.3 GHz with reflector.

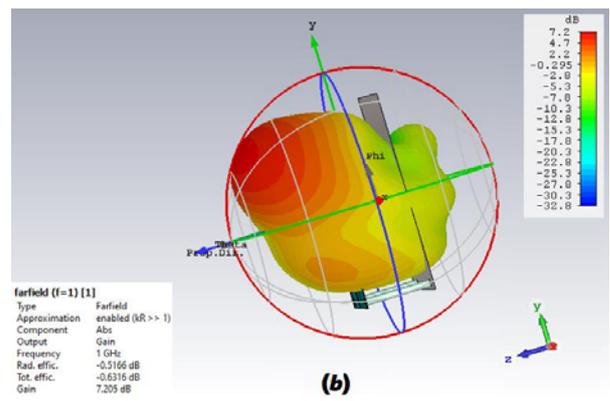
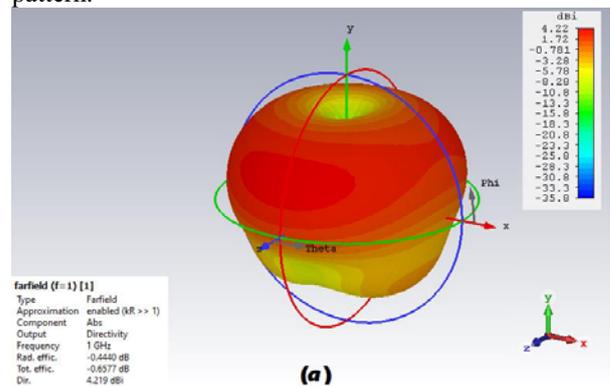
Adding the reflector to the structure adopter we could have seen that the directivity and gain had increased in the three different previous frequencies.

For example Fig.9 depicts comparative performances illustrating of the gain, where it has increased by an amount of 1.07 dB going from 1.53 to 2.6 also Fig.9 shows the appearance of the directivity



**Fig10.**(a) Radiation pattern at 0.5 GHz without reflector. (b) Radiation pattern at 0.5 GHz with reflector.

The antenna has radiated omnidirectional with gain 2.8 dB. When the reflector was positioned at the back of the antenna, the gain has increased to 7.43 dB and the radiation pattern is more directive. In this regard, it is clear that the fact of including the reflector at the back of our antenna has highly improved the performances in terms of gain as well as the radiation pattern.



**Fig11.**(a) Radiation pattern at 1GHz without reflector.(b) Radiation pattern at 1 GHz with reflector.

At the third frequency we can clearly say the performances of the antenna has decreased in term of directivity as well as change in the gain going from 4.21dB to 7.20 dB .

## Conclusion

In this work, we had presented and proved the efficiency of a reflector in increasing and improving the directivity of the radiation. This was effectuated by comparing the structure with and without reflector in terms of the following properties: the return loss, the gain, the radiation pattern of patch circular antenna operating in the frequency 0.5 GHz, with a large bandwidth ranging from 0.43 to 1.25 GHz. By this, we can clearly say that this type of antenna is suitable for GPR applications. In this regard, we are expecting to develop our structure and bring an antenna array to see if the reflector will prove again its efficiency in improving the radiation directivity in terms of gain and polarization.

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