CPW Circular Patch Antenna for Ground Penetrating Radar Applications

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Abstract A Co-planar Waveguide (CPW) Circular patch antenna for Ground Penetrating Radar (GPR) applications is presented in this paper. The antenna is designed on Rogers substrate RO 3010 with dielectric constant of 10.2 with a thickness, h = 1.22 mm and tangent loss = 0.0022 operates from 1.1 to 5.5 GHz with the overall size is 140 mm × 140 mm. CPW was used as an input method for the antenna with 50 Ω impedance matching and Computer Simulation Technology (CST 2013) has been used as simulation tools to observe the antenna performances. In order to produce antenna with high gain performance, a reflector is located at the back of the antenna. The antenna parameters such as simulated return loss, gain, radiation pattern and current distribution of the antenna is presented.

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H.A. Sulaiman et al. (eds.), *Theory and Applications of Applied Electromagnetics*, Lecture Notes in Electrical Engineering 344,
DOI 10.1007/978-3-319-17269-9_7

1 Introduction

Ground Penetrating Radar (GPR) is one of the radar application which transmits a radio wave signal, typically from tens of MHz to some GHz frequency range. The main task of GPR is to map structures and features buried in the ground. The GPR system can work at different frequencies depending on the required resolution and depths detection, which can be used for different applications such as detecting buried objects likes pipes, underground cables, land mines, gold and metal rod inside concrete wall, archaeological digs, etc. In other words, the term ground in GPR does not necessarily means soil, but it could be concrete, wood or any non-metallic materials (man-made structures).

The concept of applying radio wave to the internal structure of the ground is not a new concept. This works have been applied to map the thickness of ice sheets in the Arctic and Antarctic and sound the glaciers. However, in the early 1970s, peoples start using GPR to the non-ice environments [1–3].

GPR is basically working with the same principle with classical radar or space radar. However, GPR works in more complicated scenario as compared to free space radar. This is because in GPR enviroment, GPR signal has to travel throughout the medium which can have losses and exhibit dependent electromagnetic properties, thus introducing dispersive effects [4].

In GPR system, the needs for good penetrating depth and fine resolution are always enticing researcher to develop a good transmitter and receiver system. One of the important components of this system is the antenna which has good features such as high gain, wide-bandwidth, compact in size, good matching and directional radiation pattern. There are many GPR antennas have been developed over the past few years and the most popular are the horn antenna, bow-tie and monopole antenna. Out of these antennas options, planar antenna are the most preferred one since it is easy to integrate with other GPR components.

In this paper, the Co-Planar Waveguide (CPW) Circular patch structure is presented. The proposed antenna is designed on Rogers substrate RO 3010 ($\varepsilon_r = 10.2$ and tangent loss = 0.0022). It features wide operational bandwidth covering across 1.1–5.5 GHz frequency band. By having this feature, the antenna is suitable for GPR system for buried objects detection including the measurement of thickness pavement and the detection of steel rod inside concrete wall, pipeline, archaeologies and etc. The design methodology of circular patch antenna with CPW as the feeding line method is elaborated in this paper. The simulated results, such as, return loss, gain, radiation pattern and current distribution of the proposed antenna are presented.

1.1 Ground Penetrating Radar

In a GPR system, there are few types of radar architecture which are commonly used such as mono-static, bi-static and multi-static architecture. In mono-static radar architecture, the transmitting and receiving radar pulse signal are accomplished by a single antenna. In turn, two separated antennas are required in bi-static radar architecture, with one antenna used for transmitting and one antenna used for receiving. In a multi-static radar system, the transmitting signal is performed by a single antenna while multiple receiving antennas in an array configuration are required for the receiving part [5, 6]. Each of these architectures has their own advantages and disadvantages. In a nutshell, there are many factors or parameters has to be considered in a GPR system which bring many researchers to get involved in this area. Nowadays, GPR is being used in various areas, such locating buried utilities, searching for buried object, forensic investigation and etc. Thus different specification of GPR may be considered for different applications.

Many people think GPR performance is only limited by the instrumentation. This is true in some cases, but another factor such as the depth of penetration is primarily governed material itself. Lossy materials will limit the penetration depth. The selection of the operating frequency, transmitted power and the gain of the antenna, may affect the GPR performance. Lower frequencies will improve the depth of penetration because attenuation primarily increases with frequency. However, lowering the frequency results in loss of resolution and it is not suitable for imaging system. The basic GPR working principal will be elaborated in Sect. 1.2 and the antenna design methodology will be discussed in Sect. 2.

1.2 GPR Working Principles

Figure 1 shows the bi-static radar architecture to detect buried objects under the earth's surface.

Basically, the working principle of a GPR similar to a space radar as mentioned in the previous section, but in GPR, it involves materials that introduce signal loss and clutter. GPR uses radio frequency signal that emits by a transmitter. The signal propagates through a host materials and hit an object, reflection occurred and the

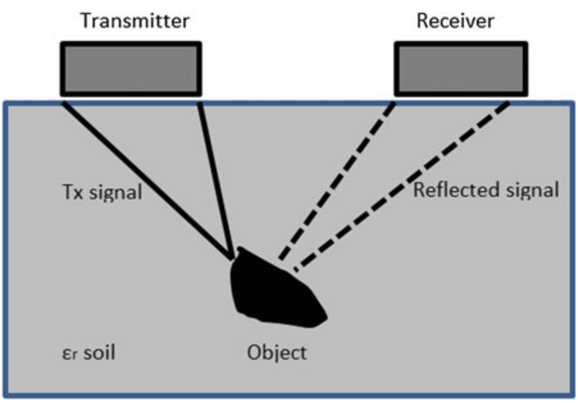

Fig. 1 GPR principal for Bi-static radar architecture

reflected signal is captured by a receiver. The image will be plotted based on the received signal in the receiver. In lossy host materials, the signal can penetrate to a limited depth before being absorbed by the materials. Therefore, penetration is always an issue for lossy materials.

2 The Antenna Design Methodology

The design for circular patch antennas can be found in various antenna design handbook and papers [5–7] and the designed structure is accomplished using commercial electromagnetic software Computer Simulation Technology (CST 2013). The antenna is designed using Rogers substrate RO 3010 which has a thickness, $h = 1.22$ mm, $\varepsilon_r = 10.2$ and tangent loss = 0.0022. The initial dimension of the radius of the circular patch antenna, a is calculated using expression (1) and (2) [7].

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}}} \tag{1}$$

where,

$$F = \frac{8.791 \times 10^9}{f_r\sqrt{\varepsilon_r}} \tag{2}$$

In expression (1) and (2), one has to note that, the resonant frequency, f_r must be in Hz and thickness of the substrate, h must be in cm. In this expression, the fringing fields effect is neglected. In usual case, fringing fields make the size of patch electrically large. By considering the fringing fields effect, expression (3) is used to determine the effective radius, a_e of the circular patch antenna.

$$a_e = a\left\{1 + \frac{2h}{\pi a\varepsilon_r}\left[ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{\frac{1}{2}} \tag{3}$$

The coplanar waveguide technique (CPW) is chosen as the feeding method of the proposed antenna. Easy in fabrication and less complex impedance matching are the advantages of this feeding technique. These are some of the reasons why CPW feeding method is mostly preferred mainly in the design of planar antennas [8].

The design structure of the proposed antenna is depicted in Fig. 2.

Because of the used of high dielectric constant substrate, the overall dimension of the patch is very small which is 140 × 140 mm^2. To achieve high gain antenna and directional radiation pattern, the reflector is located 60 mm away from patch antenna. The radius, r for the circular patch is 27.5 mm with the length, l_2 CPW is 22 mm. The gap for the CPW feed slot is 1.0 mm. The overall optimized dimensions of the proposed antenna are shown in Table 1.

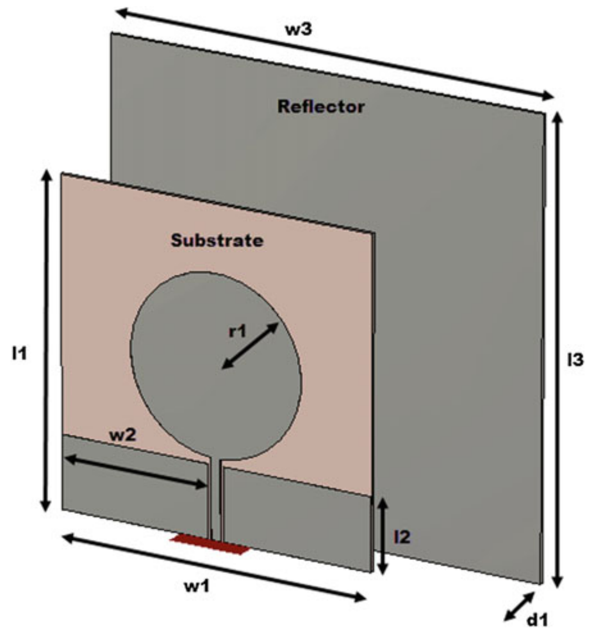

Fig. 2 Proposed antenna structure

Table 1 Dimensions of proposed antenna

Antenna parameters	Size (mm)
Width substrate, w_1	100
Length substrate, l_1	100
Length ground plane, l_2	22
Width of ground plane, w_2	47.5
Length of the reflector, l_3	140
The width of the reflector, w_3	140
Radius patch, r_1	27.5
Gap between patch and reflector, d_1	60

3 Result and Discussion

In this section, the simulated results of reflection coefficient, radiation pattern, gain and the effect of the reflector are discussed. Current distribution on the CPW circular patch antenna is also presented in this section.

3.1 Simulated Reflection Coefficient

The simulated reflection coefficient of the proposed antenna with reflector and without reflector are shown in Fig. 3. By considering return loss better than 10 dB,

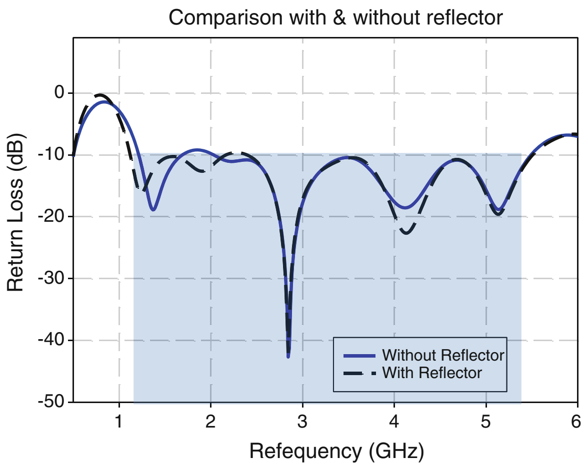

Fig. 3 Simulated reflection coefficient (dB) of the proposed antenna

the operational bandwidth of the antenna covers from 1.2 to 5.5 GHz without the presence of the reflector. When the reflector is placed behind the antenna, the operational bandwidth increased about 0.1 GHz at the lower frequency, which results to 1.1–5.5 GHz operational bandwidth. The proposed antenna in this paper has fulfill one of the requirement of the GPR antenna, which require a wide operational bandwidth. As explained in Sect. 1, wider bandwidth is demanded because of the need of higher resolution when plotting the image. As a results, the proposed antenna is suitable for GPR application such as to detect object inside concrete wall, to detect pavement thickness, forensic investigations, archaeologies etc. At present, researcher in various research fields are still looking for the best transmitter such as antenna part and good processing part (depending on their application) for image processing.

3.2 Radiation Pattern and Gain

The simulated 3D far-field radiation pattern for the proposed antenna are depicted in Fig. 4. Three different frequencies such as at 1.5, 2.0 and 2.5 GHz has been selected and analysed in this paper. Figure 4a, b shows the comparison radiation pattern of the proposed antenna at 1.5 GHz for with and without reflector. As can be seen in Fig. 4a, the antenna radiates omnidirectional with gain 2.25 dB. When the reflector is placed at the back of the antenna, the gain is increased to 4.3 dB and the radiation pattern is more directive. From this finding, it can be concluded that by placing the reflector at the back of the antenna, the antenna performance improved in terms of gain and radiation pattern as well as the bandwidth as discussed in Sect. 3.1. As illustrated in Fig. 4b, c, the gain increase from 2.5 to 5.5 dB and the pattern is still directive toward the front antenna. However, the radiation pattern split into two

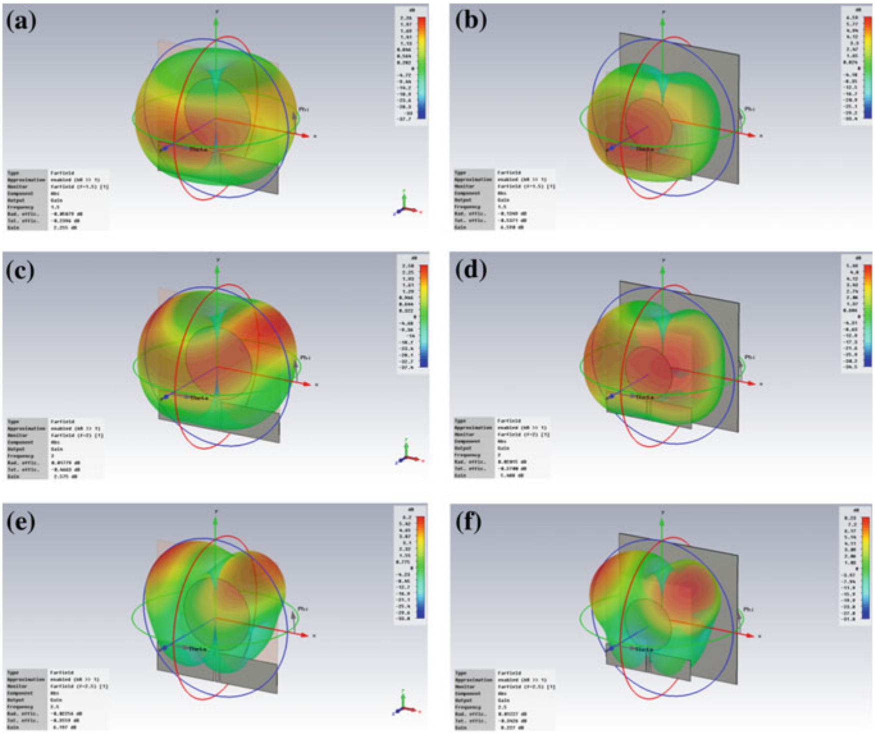

Fig. 4 Simulated Radiation Pattern. **a** Radiation pattern at 1.5 GHz without reflector. **b** Radiation pattern at 1.5 GHz with reflector. **c** Radiation pattern at 2.0 GHz without reflector. **d** Radiation pattern at 2.0 GHz without reflector. **e** Radiation pattern at 2.5 GHz without reflector. **f** Radiation pattern at 2.5 GHz without reflector

main directives at frequency 2.5 GHz for both with reflector and without reflector as depicted in Fig. 4e, f. The gain of the proposed antenna for 1.5 GHz until 5.5 GHz is tabulated in Table 2.

Table 2 shows the gain in dB for the CPW circular patch antenna from 1.5 to 5.5 GHz. According to the results, it clearly shows that the gain is increased when the reflector is located to the antenna. The peak gain occurs at frequency 4.5 GHz, which is about 9.24 dB with a reflector and the gain of the antenna is maintained across the frequencies 2.5–4.0 GHz where the value is about 8.0 dB.

3.3 *Current Distribution*

The current distribution of the proposed antenna is shown in Fig. 5. Current distribution normally gives an insight view the physical behaviour of the antenna. For consistent observation, the current distribution of CPW circular patch antenna with

Table 2 Simulated gain of CPW Circular patch antenna for with and without reflector

Frequency (GHz)	Gain (dB)	
	Without reflector	With reflector
1.5	2.55	6.59
2.0	2.57	5.48
2.5	6.19	8.23
3.0	6.12	8.76
3.5	6.05	8.16
4.0	6.91	8.70
4.5	6.96	9.24
5.0	5.50	6.54
5.5	6.47	7.31

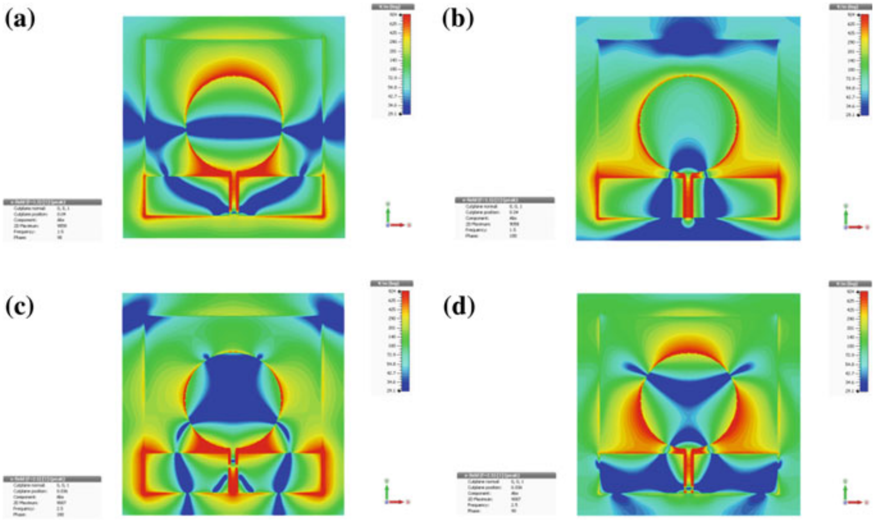

Fig. 5 Current distribution at 1.5–2.5 GHz. **a** Current distribution at 1.5 GHz (0/180°). **b** Current distribution at 1.5 GHz (90/270°). **c** Current distribution at 2.5 GHz (0/180°). **d** Current distribution at 2.5 GHz (90/270°)

reflector is demonstrated at phase 0/180° and 90/270° for both 1.5 and 2.5 GHz respectively. Figure 5a, b shows a top view of the current distribution for the proposed antenna at 1.5 GHz (0/180°). As can be seen, the red colour on the patch antenna indicates strong current density the blue colour present less density. The current distribution only can be viewed in the simulation tools and it is importance, particularly to analyse the performance of the antenna when different types of materials are considered.

4 Conclusion

In conclusion, the coplanar waveguide (CPW) circular patch antenna for Ground Penetrating Radar (GPR) applications has been designed using Rogers RO3010 operates from 1.1 to 5.5 GHz is presented in this paper. The investigation of the antenna has been extended by adding a metallic reflector at the back of the antenna and the performances of the antenna are observed. The performance of the antenna in term of return loss, radiation pattern, gain and current distribution has been discussed and analysed. The reflector helps the antenna to be more directive and increase gain from 2.25 to 6.59 dB at 1.5 GHz, 6.12–8.76 dB at and 6.96–9.24 dB at 4.5 GHz. These are significant benefits of the proposed antenna which make it suitable for GPR applications, especially when wide bandwidth and high resolution is considered.

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