Microstrip patch antenna for wireless and RFID applications at 2.45 GHz

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Microstrip patch antennas have become very popular and common due to their small size form factor, light weight and low cost. These microstrip antennas fitted suitable for wireless applications such as RFID applications which normally come in small and light structure. As of today there are many different types of RFID antenna designs with different shapes and dimensions, but most of them have an overall antenna size of around 100mm x 100m. In this paper, a novel optimized compact microstrip antenna design is introduced. The design operates in frequency of 2.45 GHz with circular polarization. The proposed design aims to reduce the overall microstrip patch size as much as possible while maintaining the antenna performances. Computer Simulation Tool (CST) software will be used to model and design the microstrip antenna to obtain optimized results.

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1. Introduction

In the present world, wireless application has become very common in the lives of people. A wireless system is able to provide the flexibility and mobility characteristics which allow a system to function more conveniently in many situations. Take a common example such as the wireless local area network (WLAN), it provides everyone in an area the connection through an access point to the wider Internet without any wires needed. This gives users the mobility and convenience to do anything through the internet. In this project, we will take a look at another wireless system which is the Radio-frequency identification RFID systems. The RFID system is a wireless system which uses radio-frequency electromagnetic fields to transfer data, which is for the purpose of identification. The system has similar characteristic that is mentioned above which is the mobility and convenience characteristics. RFID is emerging as a revolutionary technology for a wide range of applications, including supply-chain management, retail sales, access management, healthcare and etc. [1], [2] Normally a microstrip antenna is more suitable for these systems because the components of the RFID system – tags and readers – have become smaller and cheaper and the technology has been used in a variety of different areas.

There are increasing efforts to the design of microstrip patch structures for antenna arrays. This is because the microstrip patches have several main advantages such as they are light weight and low cost, they are also planar and able to integrate with electronic or signal processing circuitry [3]. Day by day there are increasing numbers of RFID antenna design which uses a different approach for different RFID frequencies. But the problem statement here is to address the size of the microstrip antenna and the polarization of the antenna. Normally microwave RFID microstrip antenna designs have size approximate the length and width of 100mm or above and the polarization is linear polarized which is not so ideal for RFID applications.

This paper proposes a novel microstrip patch antenna which aims to have good performance with a more compact antenna size, so that it provides the flexibility to fit in various situations. Additional to that, the proposed design is also a circular polarized design. Hence the antenna is able to receive horizontally polarized signal equally as well as a vertically polarized antenna. Therefore there is far less fading and flutter when circular polarization is used. The operating frequency of the design is at 2.45GHz which is the ISM band for fast and multiple detections at the same time. In this project, several designs of circular polarized patch antenna were proposed. These designs incorporate the combination of truncated corners and various slots to achieve design goals. The symmetric-corner truncation which is introduced in [4] produces circularly polarized radiation and the addition of slits and slots further reduced the overall size of the antenna. The overall size of the proposed antenna is reduced in length of 57mm and width of 37mm., which is a huge reduction of 40% compared to the reference designs.

2. Methodology

The CST Microwave Studio software is one of the best known tools used for modelling and simulating antenna designs. The software provides convenience of setting up dimensions of the antenna which can be modify or optimized anytime, this allows the flexibility to experiment with different designs. The software also provides practical environment settings to setup the antenna model. The CST design flow chart is shown in Fig. 1.

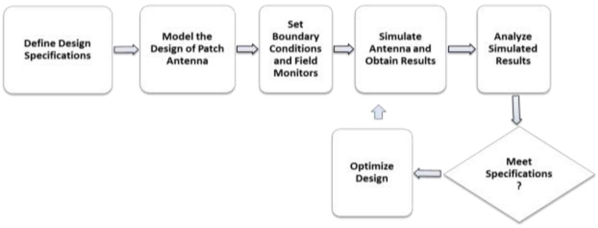


Fig. 1. CST Design Flow Chart.

Design specifications should be defined before the start of modeling in CST. The specifications are based on the antenna applications. After setting all the parameter values, the patch antenna can be modeled. With the help of the mesh grid and local coordinate system, CST software is able to inform the user on the whole structure of the design clearly. The local coordinate system is very important for designing a microstrip patch antenna as it is informing the XYZ plane of an antenna which is useful during examination of the radiation pattern as well as other field monitor. With the parameter list, the CST software also provides bricks of various shapes which are able to model from square brick to circular brick as well as other shapes. The CST software is able to calculate the impedance of an antenna feed, in this case is the thin microstrip feed line. The software uses the inputs of substrate material permittivity, and the height of the substrate to calculate the width of the feed line based on the input impedance, which is 50Ω in most cases. Boundary Condition is set to "open" so that the design is assumed to be simulated in an open area. Other boundaries such as conductive walls or magnetic can be set as well. As for field monitor, a broadband far-field monitor is set from frequency 2 GHz to 3 GHz. The center frequency is set to the operating frequency 2.45 GHz. Other field monitors including current density field, E-fields, H-fields, etc. Before the simulation, a waveguide port is set up at the end of the microstrip transmission line. A waveguide port has the boundary condition of the calculation domain, enabling the stimulation as well as the absorption of energy. The height of the waveguide port is normally five times the height of the substrate plus the ground plane thickness and the width of the port is normally six times the width of the feedline, as shown in Fig. 2. For a microstrip patch antenna, only 1 port is needed. After the port is set, the microstrip antenna design is simulated using time domain solver.

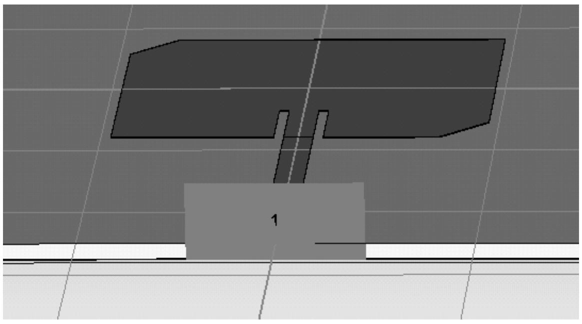


Fig. 2. Waveguide Port Model.

Simulated results are analyzed by plotting return loss S_{11}, realized gain, and axial ratio plot. Current density can be seen in the results folder too. The CST software provides a template based post processing setup for users to set and evaluate specific results which includes S-parameter results and far-field results. Optimizing the design is a complicated and time consuming task. It revolves around experimenting with different dimensions, sweeping of variable values, different substrate materials, different feeding methods as well as different design altogether. It is a process to produce the best performance which matched with most of the specifications if not all. Design optimization is the most important part of design a patch antenna as it will require critical analysis for each of the possibilities rather than just experimenting blindly.

3. Results and discussion

3.1. Rectangular Patch Antenna Design

The substrate and ground plane size in this design shown in Fig. 3 is optimized to 100mm x 100mm with a thickness of 1.59mm.

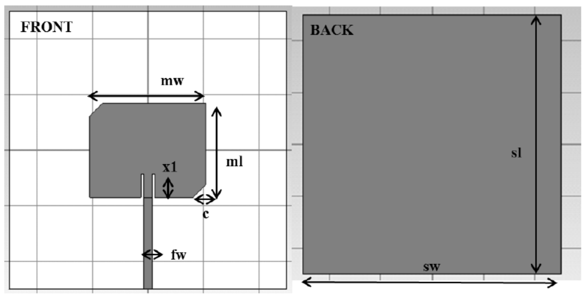
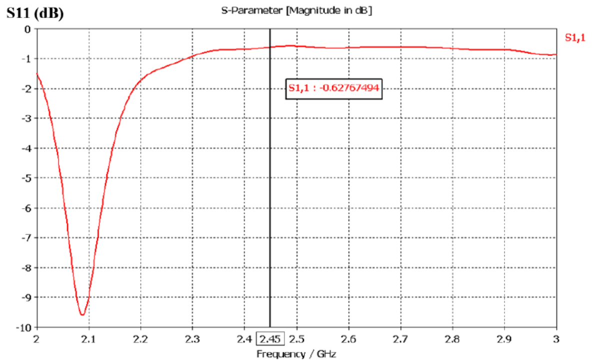
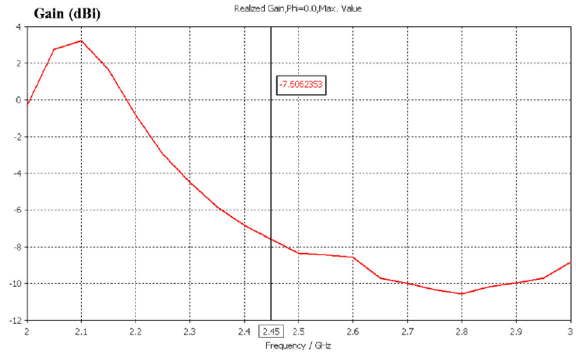


Fig. 3. Rectangular Patch Antenna Design.

The design shows a poor performance in Fig. 4 with a return loss, S_{11} of -0.6276 dB at frequency of 2.45 GHz. This is because the resonant frequency is at 2.1 GHz instead of 2.45GHz. The realised gain is -7.6 dBi at 2.45 GHz which is actually at loss. The gain is fairly high at 2.1 GHz due the resonant frequency peak. The axial ratio of 40dB in XZ-plane, phi = 0° shows that it is linear polarized. Overall the design is a failure to meet the specifications.



(a)



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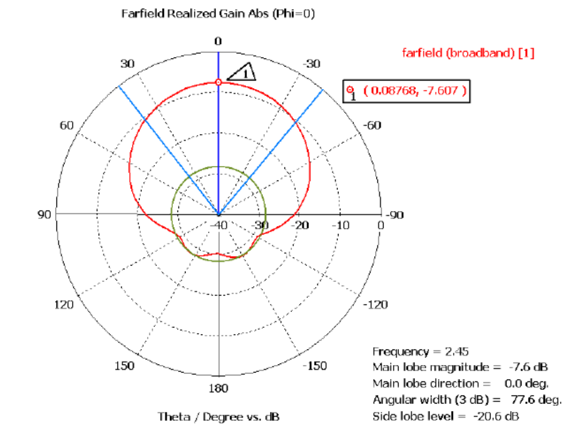


(c)

Fig. 4. Initial Design (a) Return Loss, S_{11} (dB), (b) Gain (c) Radiation pattern.

3.2. Improved Rectangular Patch Antenna with Slots

Modifications have been made to the design to add in cross slots in the center of the patch. By adding in slots, this allows to shrink down the patch size to 21 mm x 22 mm (Length x Width). The substrate and ground plane size have shrank down to 70 mm x 70 mm to save some space. The dimensions of the truncate corners are set to 3.5mm because the patch size is now smaller. The inset feed is shifted to the right by 3.7mm from the center and cross slots are added in to help to spread the distribution of current.

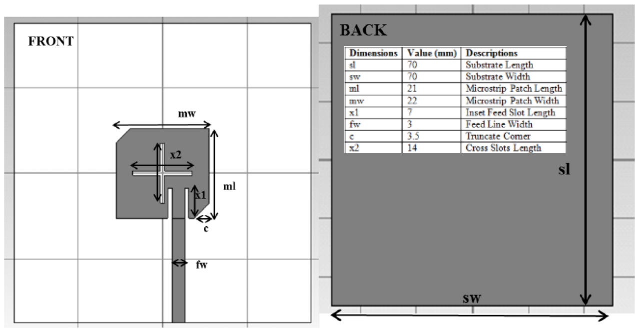
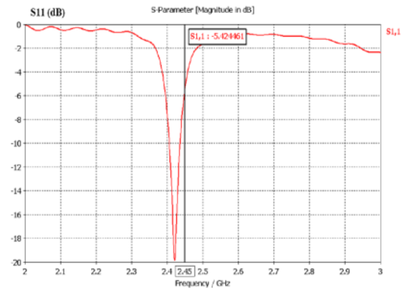
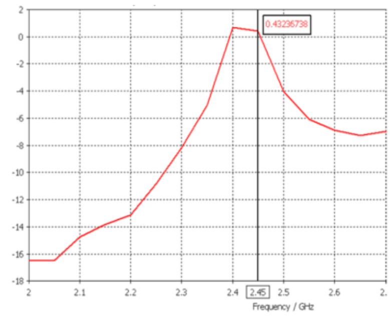


Fig. 5. Improved Rectangular Patch Antenna with Slots.

Return loss, S_{11} in Fig. 6 shows a -5.42 dB at resonant frequency of 2.45 GHz which is poor because the resonant frequency is slightly shifted to the left which is around 2.42 GHz. Compared to the previous design, improvements can be seen such as a realized gain of 0.42 dBi at 2.45 GHz as well as lower axial ratio value, 18.65 dB.



(a)



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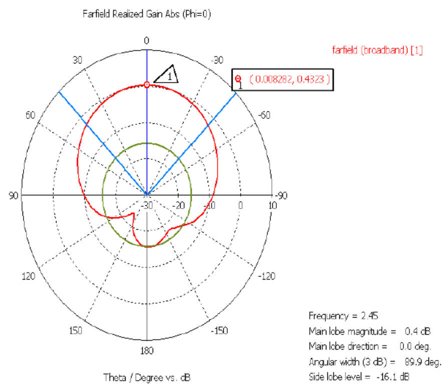


(c)

Fig. 6. Improved Rectangular Patch Antenna (a) Return Loss, S_{11} (dB), (b) Gain (c) Radiation pattern.

3.3. Slotted Patch Antenna

The third design in Fig. 7 has taken further steps to add in more slits and slots including adding slots on the ground plane. The slotted patch antenna design test the effectiveness of the number of slots on the patch. Practically, by adding more slots to the design, the fundamental frequency will be lower than a similar antenna without slots. Therefore for the same resonant frequency the size of the patch can be smaller compared to other designs. In this case, the patch size is 20 mm x 20 mm. The reason for adding slots in the ground plane is because when the patch is getting compact, there is not much space left for inserting slots.

Dimensions	Value (mm)	Descriptions
sl	80	Substrate Length
sw	80	Substrate Width
ml	20	Microstrip Patch Length
mw	20	Microstrip Patch Width
x1	5.5	Inset Feed Slot Length
fw	3	Feed Line Width
c	2	Truncate Corner
x2	7	Cross Slots Length
x3	16	Ground Plane Slot
x4	8	Side Slot

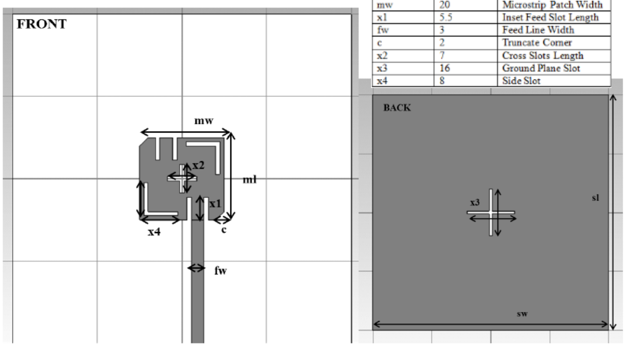


Fig. 7. Slotted Patch Antenna.

The simulated results of this design show that the resonant frequency is at 2.45GHz (Fig. 8) which is the desired frequency with return loss, S11 of -21.8 dB (Fig. 4.6(a)) and realized gain of 2.6dBi (Fig. 4.6(b)). This shows overall that the return loss have met the specifications while the gain is still 2.5dBi away from specifications. The axial ratio in this design is 16 dB in the XZ - plane, phi = 0°.

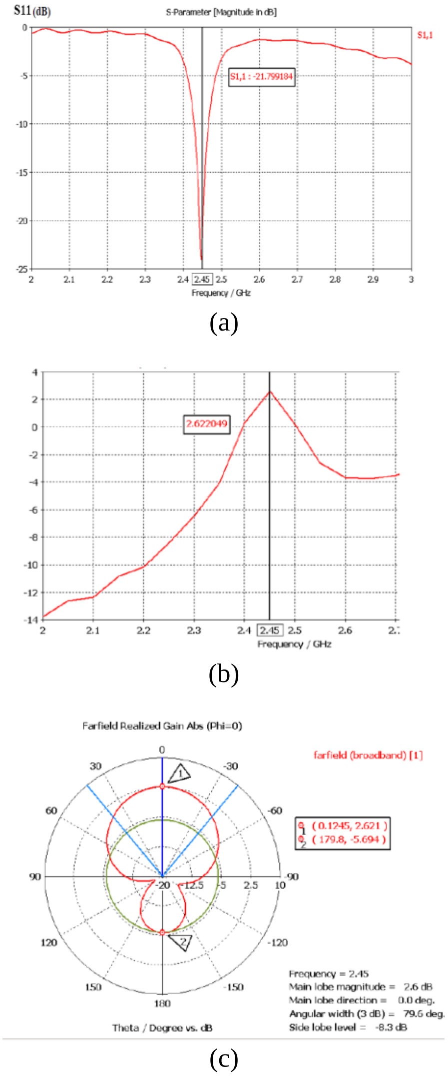
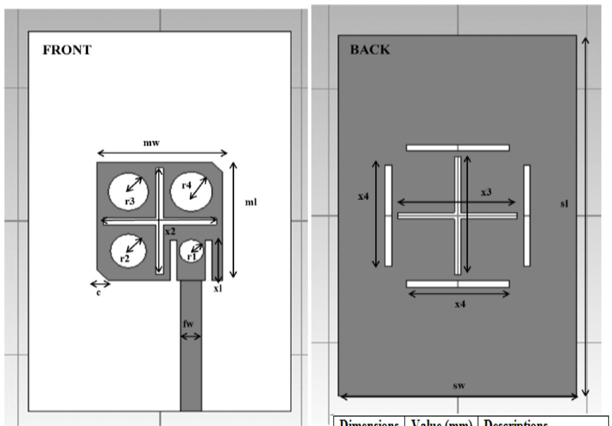


Fig. 8. Slotted Patch Antenna (a) Return Loss, S_{11} (dB), (b) Gain (c) Radiation pattern.

3.4. Circular Slotted Patch Antenna

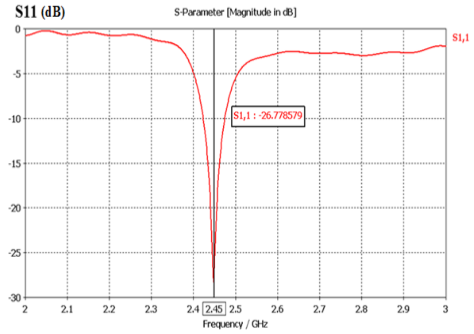
The proposed circular slotted patch antenna design shown in Fig. 9 has achieved overall best performance compared to other designs. Therefore it is optimized to use as the final design for this project. The design is also based on slots, but instead of just normal slits and slots, the design includes circular slots. Each of the circular slots can be optimized individually by modifying their radius, and this gives better customization compared to normal slots. More slots are also added to the ground plane to enable shrinking of the patch size to only 17.8mm x 17.8mm, whereas the ground plane size is 57mm x 37mm (Length x Width) which is also the smallest overall antenna size out of all designs. The inset feed I shifted 4.4 mm away from the center, this is to cater some space for circular slot *r*.



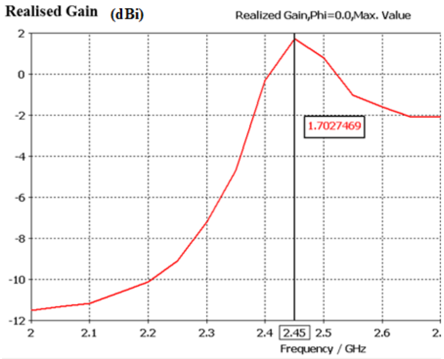
Dimensions	Value (mm)	Descriptions
sl	57	Substrate Length
sw	37	Substrate Width
ml	17.8	Microstrip Patch Length
mw	17.8	Microstrip Patch Width
x1	6.1	Inset Feed Slot Length
fw	3	Feed Line Width
c	1.62	Truncate Corner
x2	16	Cross Slots Length
x3	18.5	Ground Plane Slot
x4	16	Side Slot
r1	1.7	Circular Slot Radius 1
r2	2.5	Circular Slot Radius 2
r3	2.8	Circular Slot Radius 3
r4	2.95	Circular Slot Radius 4

Fig. 9. Circular Slotted Patch Antenna.

Most of the results in this design meet the desired specifications. The return loss, S_{11} obtained is -26.78 dB at 2.45 GHz which is shown in Fig. 10 (a). However the realized gain (Fig. 10 (b)) is only 1.7 dBi which is quite low, this is because the FR-4 material has a high loss tangent of 0.025 compared to other materials.



(a)



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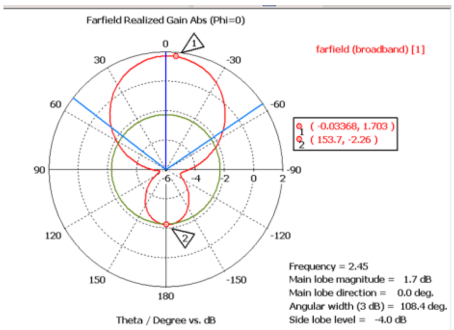

(c)

Fig. 10. Circular Slotted Patch Antenna Design (a) Return Loss, S11 (dB), (b) Gain (c) Radiation pattern.

From Fig 10 (c), the far field radiation shows that from theta = 90° to -90°, the radiation is almost omnidirectional but in this design, the gain is higher which is better. At mark ‘2’, the back-fire radiation is -2.26 dB which is considered acceptable. Achieving smaller back-fire of the radiation, larger gain will be obtained at the right plane.

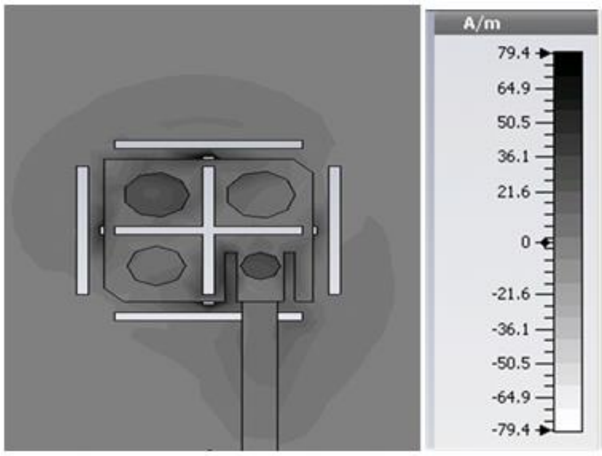

Fig. 11. Circular Slotted Patch Antenna Surface Current.

The current distribution results Fig 11 is also acceptable as the strongest currents are around the end of the slots and this shows that the surface current path is effectively lengthened by the slot and slits resulting in lower resonance frequency. This is the comparison table for the different designs modelled throughout the project.

To test out other materials for substrate, the Rogers RO4350 material is used with a loss tangent of only 0.004 which is much lower compared to FR-4 (0.025). After simulation, Fig. 12 results show a realised gain of 3.64dB which is almost double of the gain obtained by using FR-4 material. However the axial ratio and return loss have slightly poorer performance due to the design has not yet been fully optimized.

Table 1. Comparison Table of Different Designs.

Antenna Design	**Gain**	**Return Loss**	**Mechanical Specifications Dimensions L x W x H (mm^3)**	**Axial Ratio (Polarization)**
Initial Rectangular Patch Antenna Design	-7.606dBi	-0.627dBi	100 x 100 x 1.59	40dB (Linear)
Improved Rectangular Patch Antenna with Slots	0.43dBi	-5.42dBi	70 x 70 x 1.59	18dB (Not Circular)
Slotted Patch Antenna	2.6dBi	-21.8dBi	80 x 80 x 1.59	16.24dB (Not Circular)
Optimized Circular Slotted Patch Antenna	1.7dB	-26.78dBi	57 x 37 x 1.59 (Smallest)	3.1dB (Circular)

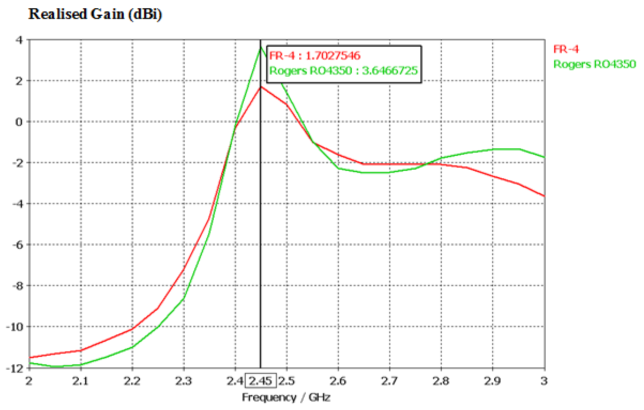

Fig. 12. Gain (dB) Comparison Between Different Substrate Material.

4. Conclusion

Overall antenna performance from the proposed design is considered successful by meeting most of the specifications. The antenna design is able to achieve circular polarized which is one of the most challenging goals to meet and the return loss, S_{11} obtained is -26.78dB at 2.45GHz. However the realized gain of the antenna is considerably low which is 1.7dBi if FR-4 substrate is used, it is increased to 3.64dBi with a Rogers RO4350 substrate. This shows that there is a need to put more efforts in experimenting with different substrate materials. Other achievements of the project can be considered very successful.

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