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*Abstract***— This paper proposes an innovative circular patch antenna that resonated at 2.34 GHz using 3D printing technique. The purpose of using 3D printing is a way to reduce cost and time in fabrication of the antenna. By introducing a new material to the subject which is Acrylonitrile Butadiene Styrene (ABS) as the substrate of the antenna, the cost can be greatly reduced. Furthermore, a coaxial probe feed is used and it is said to be easy to fabricate, matched and has low spurious radiation. The feeding method that has been used in this research is a coaxial line feed where the inner conductor of the coax is connected to the patch meanwhile the conductor is connected to the ground. This antenna is designed on an ABS substrate with εr = 2.74 and it has a loss tangent of 0.007. The thickness is said to be 3.25 mm. In addition to that, it has the return loss (S11) of 24.3 dB at 2.34 GHz. The whole designation of the antenna is by using Computer Simulation Technology (CST) software. The anticipated design of a circular patch antenna can be extended to conformal antenna and therefore, the prototype will become more compact, efficient and robust.**

Keywords- Antenna; Circular patch; Patch Antenna; 3D printing; Acrylonitrile Butadiene Styrene.)

I. INTRODUCTION

As the technology of the world is globally increased, the usage of the antenna has been the important device for communication system. Most of other devices in this world have an antenna portion in it. For example, cars have the antenna for it to access the radio frequency. At home, the remote control and television both has the antenna applications on it. Not only that, antenna can also be useful during environment disaster attacking the world. However, the uses of antenna is not limited to certain areas as it is also covered other applications such as radars, telemetry, satellite communications, global positioning for remote sensing and etc. [1]. The most preferable antenna design is rectangular and circular patch antenna for it has multiple frequency operation, linear and circular polarization and feed line flexibility [1].

A microstrip antenna consists of a radiating patch on one portion of the dielectric substrate in which has a ground plane on other parts [2]. It also can be characterized by many physical parameters. It can easily designed with many types of shapes and as well as the dimension. To add, this type of antenna can be subcategorized by several types of antenna such as micro strip patch antenna, micro strip travelling-wave antenna, printed slot antenna, and lastly the micro strip dipole [3].

Over recent years, 3D printing has been a great invention in order to revolutionize the manufacturing environment. It has the ability to arbitrarily place different materials in the three dimensions come with high precision. 3D printing industry has their own target in developing even more complex structure and is able to fully function such as cars, cellphones, machines and etc. This will eventually elevates the potential of these small entrepreneurs of product customizations to get involve with manufacturing industry. However, a large scale array of different printing technologies has been developed and introduced into the global world, all comes with their own advantages and disadvantages whereby the main factors will mostly related to the cost, build speed, resolution, geometry limitation and lastly the surface finish [4][5]. Meanwhile, as for printing dielectric structures, a dominant method will be used such as fused deposition modelling and also the selective laser sintering. Whilst for the metal structures, the dominant method are an electron beam melting (EBM) and selective laser melting. The limitations of 3D might be the roughness of the surface after finish printing it out. However in EBM, powder article in a powder bed will be fused and melted by using the electron beam. Nevertheless, the roughness of the surface on the metal part will results in serious degradation of the electromagnetic performance [4][5][6].

On the other part, a new concept of technologies has been introduced to the world in order to avoid a high cost in production and a time consuming in using the old method. It is known to have an extra effort on the etching; masking and plating parts as well as it might contain some of inorganic and chemically hazard materials. However, 3D printing is introduced to overcome some of the limitations that we are facing in manufacturing industry by laying down sequential layers of materials. As nanotechnology researches are going exponentially by years, it is not surprising that a Nano particle ink can be a solution to those biohazards materials. For the past years, the ink can be only used in a planar surface. However, it also enables to print a 3D structure so that it would form another shapes of 3D antenna [7].

Apart from that, an Acrylonitrile Butadiene Styrene (ABS) will used in this research. ABS is a type of plastic that is consists of a chain of monomer Acrylonitrile, 1,3–Butadiene and Styrene. By using ABS, it will leads to many advantages such as strong in its structure and also durable at low and high temperature. Most importantly, it is easy to be fabricated into various sizes and shapes. This type of material is been chosen in 3D printing due to the limited range of choices of materials at the moment. ABS is chosen among others materials because of the strength and as well as the conductivity of the material. Not only that, ABS is being used in this research because the antenna will be fabricated in an array on top of a conformer shape. A 3D printer is enabled to print the conformer perfectly according to the desired dimension [8]. On a side note, another material called FR-4 is also being used in this research. FR-4 is a common type of material in antenna designation due to its conductivity. FR-4 is made up of woven fiberglass material with an epoxy resin binder laminate. Switches, transformers, washers and many others real-life applications are using FR-4 as their main components [9].

Therefore, in this paper works will involve comparison study of a circular patch antenna by using FR-4 and ABS as substrates. Both substrates are resonated at 2.34 GHz. The comparison is done by using Microwave Studio in Computer Simulation Technology software (CST). Thus, in Section II, the discussion will be on antenna design whereas in section III, the discussion will be about the antenna parameters. The simulation results and further analysis will be discussed in Section IV. Section V is to conclude the investigation on the design of circular antenna.

II. ANTENNA DESIGN

For circular patch antenna, a design procedure is outlined which leads to practical designs of a circular micro strip antennas for the TM_{110} mode. Firstly, some parameters are to be determined from [10]. The parameters included in these calculations such as dielectric constant of the substrate, ε_r, resonant frequency, f_r and as well as the height of the substrate, h. Note that the units for f_r is in Hz and h is in centimeters.

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

Where a is radius of the patch (in cm) and F can be obtained using (2).

$$F = \frac{8.791x10^9}{f_r\sqrt{\varepsilon_r}} \tag{2}$$

The resonant frequency can be found by using this formula:

$$(f_r)_{110} = \frac{1.8412v_o}{2\pi a_e\sqrt{\varepsilon_r}} \tag{3}$$

Where V_0 is the speed of light.

Figure 1 and 2 shows the design of circular patch antenna on ABS and FR-4 substrate respectively using CST software. Both antennas has been fed using coaxial probe feeding technique.

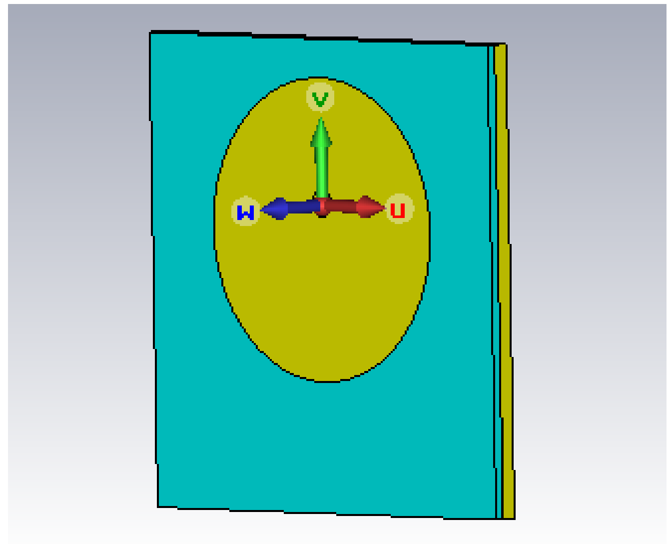

Figure 1: Structure of antenna with ABS as substrate

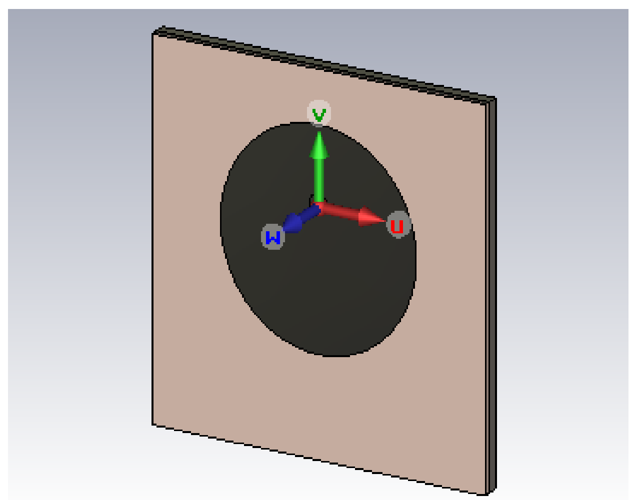

Figure 2: Structure of antenna with FR-4 as substrate

Next section presented the circular patch antenna parameters calculated from (1), (2) and (3) for both ABS and FR-4 substrates.

III. ANTENNA PARAMETERS

In designing the circular patch antenna, there are a few parameters that should be considered. A good design should consider the reflection coefficient and good impedance match in order to get the expected resonance frequency. The results will be compared with two types of substrate which are the ABS and FR-4 as the substrate. Meanwhile, as for both patch and ground, it would be the copper material.

Table 1 shows the overall dimension of the circular patch antenna for ABS and FR-4.

Table 1: Design specification of two circular patch antennas.

Parameters	ABS	FR-4
Patch Radius (mm)	21.50	17.66
Patch Height (mm)	0.45	0.07
Feed Height (mm)	3.25	3.25
Feed Radius (mm)	1.69	1.71
Ground Length (mm)	60	60
Ground Width (mm)	60	2
Ground Height (mm)	1.25	60
Substrate Length (mm)	30	60
Substrate Height (mm)	30	1.25
Substrate Width (mm)	1.25	60

IV. RESULTS AND DISCUSSION

The radius of both patch (for substrate ABS and FR-4) are calculated using (1), (2) and (3). The simulations are performed using CST Microwave Studio. Figure 3 shows return loss or S11 for both circular patch antennas on FR-4 (red curve) and ABS (green curve). It shows that S11 of ABS exhibits better return loss value compared to FR-4.

A parameterization technique has been used in determining the optimum value for probe feed. The location of probe feed must meet a requirement in order to obtain the lowest value of S11. From figure 4, S11 (1) in red show the most optimum result. Table 2 shows the radius of circular patch, r1 and position of probe feed, s1 to be optimized. The value of s1 is calculated from center of the substrate to the upper side of the substrate. Three sequences for the parameterization is being used in this procedure. Table 2 shows that the S11(1) has r1 value of 21.5 whereas s1 has the value of 1.5. Hence, based on the results shown in Figure 4, the parameters of S11(1) as shown in red will be chosen.

Figure 5 shows the Z11 parameters for both ABS and FR-4.The other results such as gain, IEEE gain, and etc. will be presented in a tabulation data.

Figure 6 shows that the polar plot pattern of ABS as substrate. The farfield pattern is being set at theta at 90 degrees in order to determine the radiation pattern. The same procedures are being implemented for FR-4 in figure 7. Meanwhile for figure 8 and 9, the patterns are shown using 3D farfield plot.

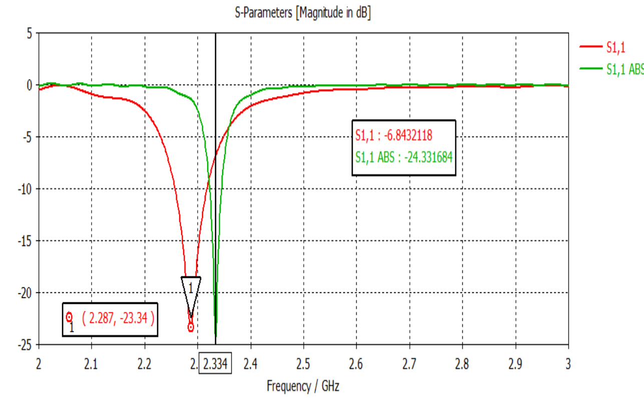

Figure 3: Graph of S11 parameters of FR-4 (red) and ABS (green) as substrate.

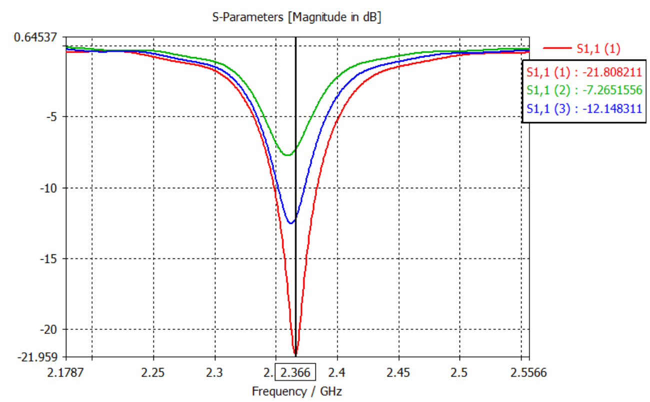

Figure 4: Parameterization of probe feed of ABS substrate

Table 2: Parameterization of radius of circular patch and probe feed location.

No. of run	r1	s1
1	21.500	1.5
2	21.492	0
3	21.492	0.75

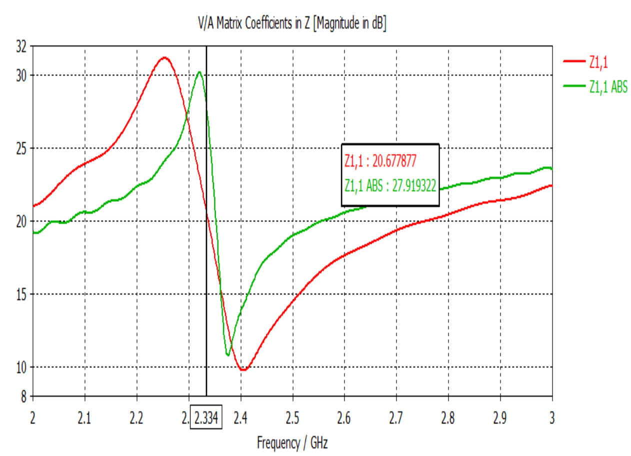

Figure 5: Graph of Z11 parameters of FR-4(red) and ABS (green) as substrate.

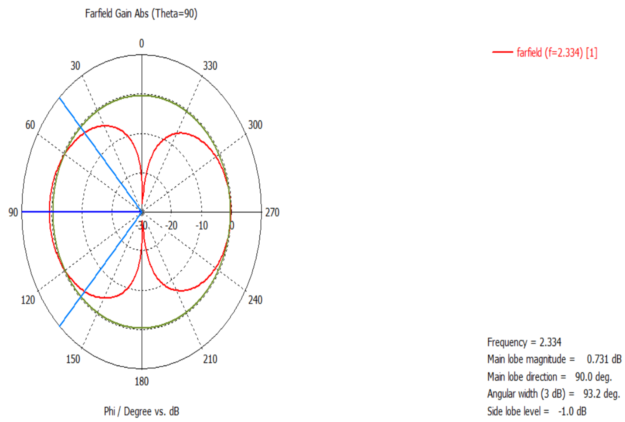

Figure 6: Graph of polar plot of ABS as substrate.

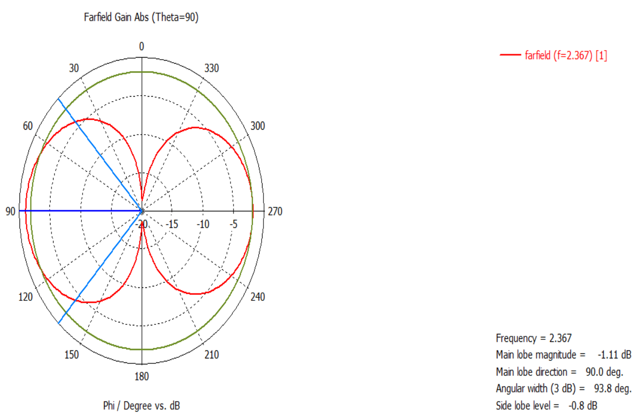

Figure 7: Graph of polar plot of FR-4 as substrate.

Table 3 shows the overall performance of the circular patch antenna for ABS and FR-4. Based on the S11, it shows that the circular patch using ABS substrate is better compared to the FR-4. Meanwhile, for the directivity and gain, ABS exhibits higher value than FR-4. Hence, for the overall parameter results also shows that ABS is more efficient in terms of performance wise.

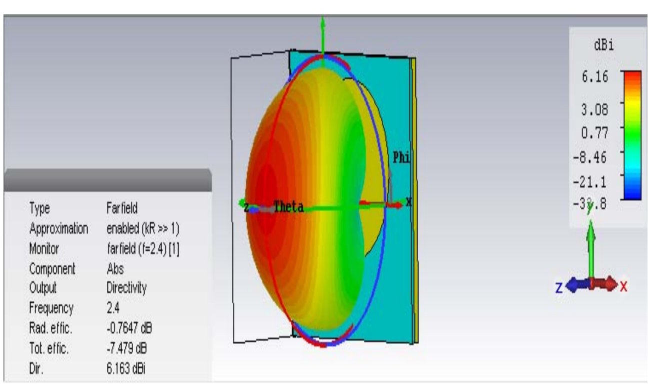

Figure 8: Far field pattern of ABS as substrate.

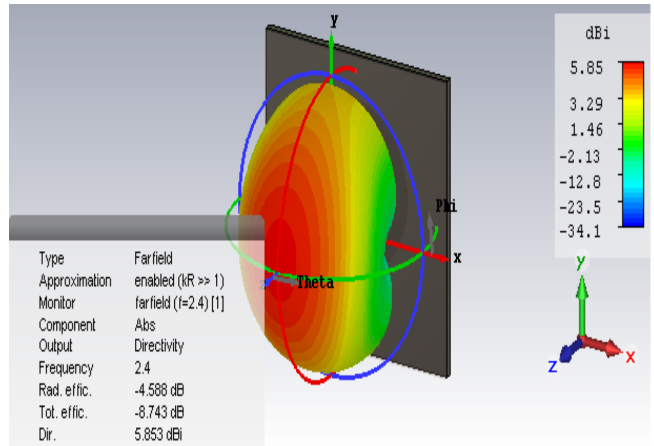

Figure 9: Far field pattern of FR-4 as substrate.

Table 3 : Comparison of Performance Parameters

Parameters	**ABS**	**FR-4**
Return Loss (dB)	24.49	23.34
VSWR	1.13	1.15
Directivity (dBi)	6.163	5.853
Gain (dB)	5.398	1.265
Radiation Efficiency (dB)	-0.765	-4.588
Total Efficiency (dB)	-7.479	-8.743
Resonant Frequency (GHz)	2.334	2.29

V. CONCLUSION

In this findings, the use of ABS type of material shows that the results produced is better than FR-4. ABS can be printed out precisely according to the dimension during simulation since it is printed by using a 3D printer machine. Thus, to reiterate the research finding is that ABS has the S11 which satisfy the condition of a resonated frequency that must be lower than -10 dB. By the appearance, this circular antenna possessed small size and thus it is suitable to be built as conformal antenna in 3D for further research.

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REFERENCES

[1] T. Hart, B. McArthur, " A revolutionary antenna concept ," Mission Critical Mgazine, Michigan, 2012.

[2] R. Garg, P. Bartia, I. Bahl, A. Ittipiboon, ''Microstrip Antenna Design Handbook'', 2001, pp 1-68, 253-316 Artech House Inc. Norwood, MA

[3] J. Mei, M. Lovell, and M. Mickle, "Formulation and processing of novel conductive solution inks in continuous inkjet printing of 3-D electric circuits," IEEE Trans. on Electronics Packaging, vol. 28, no. 3, pp. 265-

273, July 2005.

[4] C.L. Holloway, and E. F. Kuester, "Power loss associated with conducting and superconducting rough interfaces', IEEE Trans. Microw.Theory Tech., 2000, 48, (10), pp. 1601–1610

[5] H. Rajagopalan and Y. Rahmat-Samii, "On the reflection characteristics of a reflectarray element with low-loss and high-loss substrates," *IEEE Antennas Propag. Mag.*, vol. 52, no. 4, pp. 73–89, Aug. 2010.

[6] H. Lipson, and M. Kurman, "Fabricated: The New World of 3D Printing" Wiley, USA, 2013.

[7] Y. Ning, and W. Jiang, "The electromagnetic characteristics of conducting rough surfaces at millimeter wave frequencies". IEEE Int. Conf. Microwave and Millimeter Wave Technology, 2008 (ICMMT 2008), Nanjing, China, April 2008

[8] M. Mirzaee, S. Noghanian, L. Wiest, and I. Chang, "Developing Flexible 3D Printed Antenna Using Conductive ABS Materials", IEEE, North Dakota, 2015.

[9] C. H. Goh., C. K. Chakrabarty and M. H. Badjian, "Dielectric verification of FR-4 substrate using microstrip bandstop resonator and CAE tool", Communication (MICC), 2009 IEEE 9th Malaysia International Conference, Kuala Lumpur, 2009.

[10] C. A. Balanis, Antenna Theory: Analysis and Design. Canada: Wiley-Interscience, 2005.