Design LTCC Antenna for Bluetooth Application

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***Abstract*—A miniaturized compact antenna is in demand due to the rapid progression of the Radio Frequency (RF) and also wireless of the telecommunication systems. By developing a compact and portable antenna will provides many advantages to the humankind. Designing a multilayer antenna by using the Low Temperature Co-Fired Ceramic (LTCC) provides the superiority of producing a compact, low profile and high performance antenna. A design of a compact novel Low Temperature Co-fired Ceramic (LTCC) antenna for the integrated Bluetooth application is presented in this paper. There are three types of novel antenna designed in this paper which are aperture coupler LTCC antenna, microstrip feed LTCC antenna and microstrip feed FR4 antenna. The specifications for the LTCC antenna designed to operate at a frequency of 2.45 GHz. Ferro A6S material type is used with the dielectric, ε_r 5.9, a substrate thickness, h of 0.096 mm and the copper thickness, t of 0.01 mm. The FR4 antenna is designed to operate at 2.45 GHz with a dielectric, ε_r of 4.7, a substrate thickness, h of 0.8 mm and the copper thickness, t of 0.035 mm. The simulation was done using the CST Studio Suite version 2011 software. The aperture coupler LTCC antenna was first designed to operate at 2.45 GHz. Each aperture coupler antenna performances have been analyzed by layer and also by placement of the ground to obtain the best design for this feeding method. The microstrip feed LTCC antenna and FR4 antenna were designed and optimized to get the best performance for these designs. These three types of antenna with different materials and feeding method are compared in terms of their sizes, return loss, and gains. The simulation results for the proposed aperture coupler LTCC antenna and microstrip feed LTCC antenna having a compact size of 25.6 mm x 22.0 mm and 32.5 mm x 23.5 mm. The microstrip feed FR4 antenna has the size of 38.4 mm x 28.18 mm. The aperture coupler LTCC antenna has a return loss of -17.883 dB and a maximum gain of 3.326 dB meanwhile the microstrip feed LTCC antenna has a return loss of -14.995 dB and a maximum gain of 2.614 dB. The results obtained for the microstrip feed FR4 antenna are -10.179 dB return loss, and a maximum gain of 2.692 dB.**

***Keywordss*—Multilayer, LTCC, CST CAD Package, return loss and maximum gain.**

I. INTRODUCTION

Bluetooth is a boost popular technology that allows short-range wireless communication between several electronic devices. Its most significant feature is that it allows devices to transfer and synchronize data wirelessly with one another, eliminating the need of cables, cords, and adapters necessary for a lot of today's technology. Since this technology uses wireless control and communication (for an example mobile headset), it requires a novel size so that it can be embedded in the mobile headset.

Antennas are implemented in a telecommunications field widely. There are omnidirectional antenna, directional antenna, 30 degree sectorization antenna, 60 degree sectorization antenna and etc. Those antennas are applied to the field according to its compatibility and working efficiency. For an example, omnidirectional antenna radiates its wave uniformly in all directions and produces a “doughnut shape” radiation pattern. It can be used for many IEEE 802.11 b, g, a applications at 2.4 - 2.5 GHz and 5.15 - 5.35 GHz [1].

Recently in the market, the in-built PIFA (Planar Inverted-F Antenna) is used as the Bluetooth antenna in mobile phones since it provides many advantages. This type of antenna acquires a definite space of the mobile phones for it to work at a specific frequency. However, nowadays the size trends of the mobile phones are limited. Therefore, the size of the Bluetooth antenna is requested to be miniaturized and it still operates at its top performance [2].

At present, designing a multilayer antenna by using the Low Temperature Co-Fired Ceramic (LTCC) is the latest technology that provides the superiority of producing a compact, low profile, light weight, low manufacturing cost, ease of manufacture, portability and good performance RF and wireless systems of an antenna. This ceramic chip’s high relative permittivity will make the designed ceramic antenna as a promising choice since it results in a large decrease of the antenna’s size for the operating frequency [3-5].

There are two feeding methods proposed in this paper which are aperture coupled antenna and also microstrip feedline antenna. These types of feeding method are compared in terms of the antennas performances. Microstrip feedline is an easier method to fabricate as compared to aperture coupled antenna in which it is a just conducting strip connected to the patch but it has a problem back radiation due to the power loss occurred. Aperture coupled microstrip slot antenna is a feeding method that can reduce the back lobe size and hence increases the antenna's bandwidth [6. 7]. Aperture coupled microstrip slot antenna couples the patch antenna with microstripline through an aperture.

So, three antenna designs are proposed for the integrated Bluetooth application operates at 2.45GHz. The designs are eight layers aperture coupler LTCC antenna, eight layers LTCC microstrip feedline antenna, and eight layers FR4 microstrip microstrip feedline antenna.

II. METHODOLOGY

The flow chart shown in Figure 1 shows the steps need to be taken into account in order to ensure the designed antenna is a successful design. Steps of designing are important in order to plan the desired antenna. This flow chat was implemented for all the antenna designs.

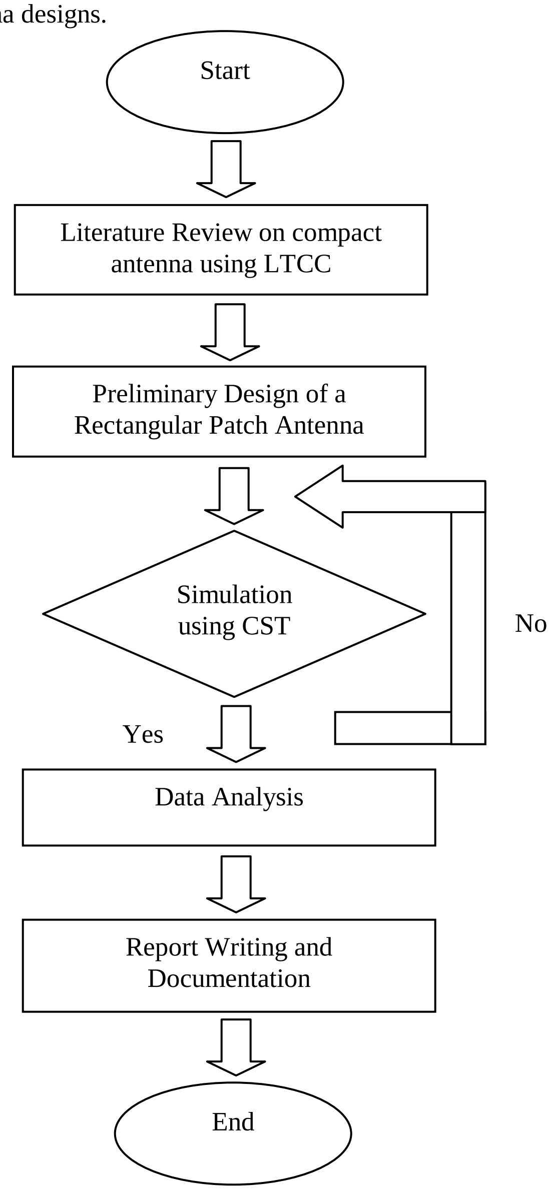

Figure 1: Flow chart of the methodology.

For a preliminary design, the operating frequency and also material's dielectric and height plays an important role in order to determine the initial values for width and length of the patch. The width and length of the patch can be calculated by using the formula (1) to (4);

Formula for patch's width;

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \qquad \ldots (1)$$

Formula for patch's length;

$$L = \frac{\lambda_0}{2} . 2\Delta L \qquad \ldots (2)$$

Where;

$$\acute{\varepsilon}ff = \frac{\acute{\varepsilon} + 1}{2} - \frac{\acute{\varepsilon} - 1}{2}[1 + 12\frac{h}{w}]^{-1/2} \qquad \ldots (3)$$

$$\Delta L = 0.412(h)\frac{(\acute{\varepsilon}ff + 0.3)\ \left(\frac{W}{h} + 0.264\right)}{(\acute{\varepsilon}ff - 0.258)\ \left(\frac{W}{h} + 0.8\right)} \qquad \ldots (4)$$

The sizes for the width and also length of the substrate are determined by;

$$W_{substrate} = W + \ 12.7\ mm \qquad \ldots (5)$$
$$L_{substrate} = L + \ 12.7\ mm \qquad \ldots (6)$$

The preliminary design obtained from the calculations for the patch's width and length for both LTCC antennas are 33.2 mm and 25.43 mm. The initial size of the substrate is 45.9 mm and 38.13 mm in length. The antenna was simulated by using these preliminary sizes of patch and substrate to obtain the results. In order to gain the optimum performance at the optimum operating frequency for the antenna, both sizes of the patch and substrate are altered and reduced. The designs that give then best results operates at 2.45 GHz will be chosen.

The ground placement analysis also has been done for the aperture coupler LTCC antenna. This analysis has been done by layer. The ground was placed from layer one to layer eight, meanwhile the feed line is fixed at the bottom of the layer one. This analysis has been done to determine the best ground placement for aperture coupler antenna at its operating frequency. The chosen aperture coupler LTCC antenna provides the best results for the design in terms of return loss and gain.

The width obtained from the calculations for the FR4 antenna is 36.26 mm and a length of 28.14 mm. These sizes were used to simulate the performance of this antenna. In order to gain the optimum performance for this antenna at the operating frequency, the sizes of the patch and substrate were altered. The design that gives the best performance will be chosen.

The first design is the aperture coupler LTCC antenna for the integrated Bluetooth application that operates at 2.45GHz. The second design is the microstrip feed LTCC antenna operates at 2.45GHz for the integrated Bluetooth applications. The last designed antenna is a microstrip feed FR4 antenna operates at 2.45 GHz for the Bluetooth applications.

III. RESULTS AND DISCUSSION

A. *Simulation Results*

All the antenna designs were investigated by using CST Studio Suite version 2011. There are two types of feeding methods designed for the antennas discussed in this paper which are aperture coupler and also microstrip feedline. These two feeding methods were employed in the design of the LTCC antennas and the performance for each design is compared meanwhile the performance of the microstrip feedline FR4 antenna is also compared with the microstrip feedline LTCC antenna.

1. Aperture coupler LTCC antenna.

Figure 2 shows the design of the multilayer aperture coupler antenna. The ground and aperture slot of this antenna are placed at the first layer (bottom layer) of the antenna. The initial values for the width and length for the antenna from the calculations are 33.2 mm and 25.43 mm.

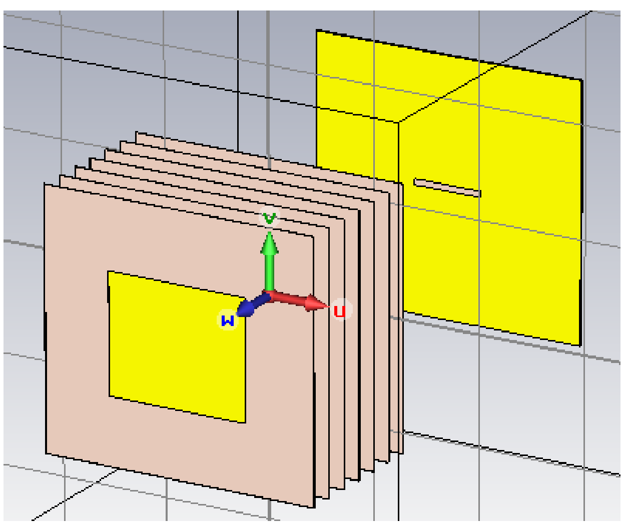

Figure 2: Multilayer aperture coupler LTCC antenna.

This design was being analyzed layer by layer, from one layer to eight layers LTCC antenna. The simulation results were compared in terms of the size of the patch (width and length), the return loss, its gain and also directivity. This research was done to determine the best multilayer design for the aperture coupler LTCC antenna. The results obtained are showed in the Table 3;

Table 3: The results for each design antenna.

No. of layer	Width, w (mm)	Length, l (mm)	Return loss, S_{11} (dB)	Gain (dB)	Dir. (dBi)
1	18.0	24.7	-28.376	-13.92	3.541
2	31.0	19.92	-11.52	-6.103	5.908
3	25.8	21.2	-18.3414	-2.537	5.856
4	23.0	22.03	-13.178	-1.096	5.822
5	27.5	21.28	-12.169	-1.496	5.771
6	24.7	22.0	-25.624	1.721	5.890
7	24.5	22.0	-20.863	2.507	5.885
8	25.6	22.0	-17.883	3.326	5.935

Based on the Table 3, it is observed that the best multilayer aperture coupler LTCC antenna design for the integrated Bluetooth application is the eight layers LTCC antenna since it provides the highest gain as compared to the other design which is 3.326 dB and directivity of 5.935 dBi. The gain represents the performance of the designed antenna. High gain provides a better performance for an antenna.

Figures 4 show the simulation results for the return loss, S_{11} for the one layer until eight layers aperture coupler LTCC antenna.

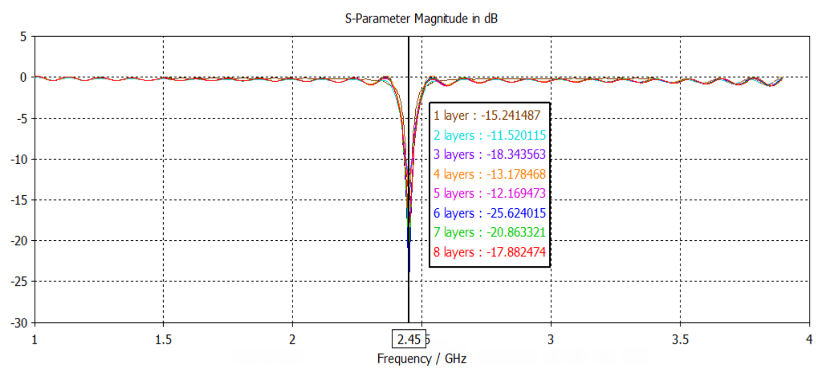

Figure 4: Shows the S-parameter for all antenna designs.

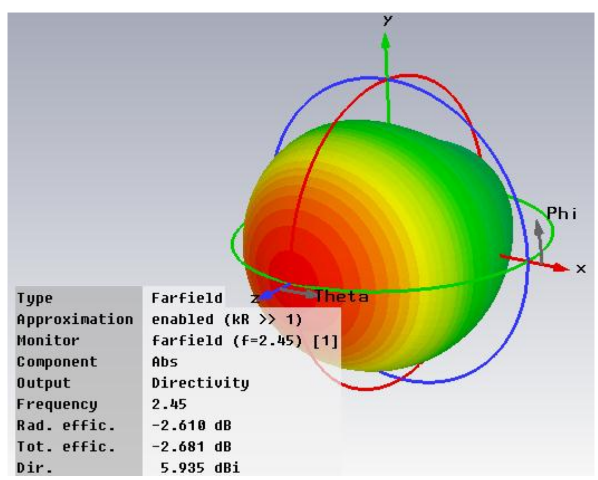

Figure 5: Shows the directivity of the eight layer aperture coupler antenna.

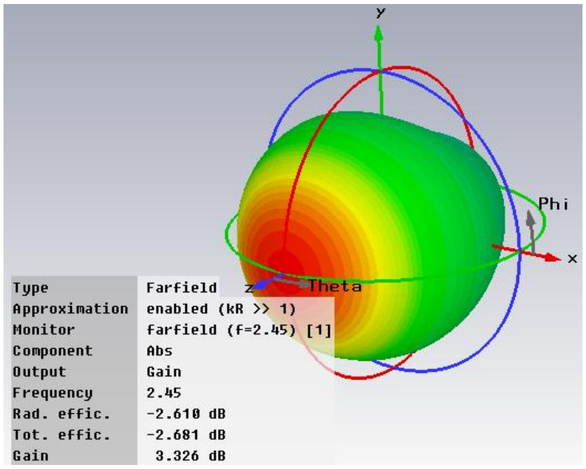

Figure 6: Gain of the eight layers aperture coupler antenna.

The performance of the eight layers LTCC aperture coupler antenna is also affected by the placement of the ground. It is observed that by placing the ground at a different layer will gives a different performance results. The performance results are shown in the Table 7;

Table 7: Shows the results observed by placing the ground at a different layer.

Ground Placement	Feed line Width, w_0 (mm)	Width, w (mm)	Length, l (mm)	Return loss, S_{11} (dB)	Gain, (dB)
Layer 1	0.181	25.6	22.0	-17.883	3.326
Layer 2	0.357	25.0	21.73	-14.588	2.534
Layer 3	0.518	22.5	22.0	-21.787	1.241
Layer 4	0.743	27.9	21.0	-18.359	1.182
Layer 5	0.895	22.0	20.0	-11.628	0.582
Layer 6	1.095	31.15	20.0	-16.925	-2.122
Layer 7	1.272	37.5	18.0	-12.812	-6.3

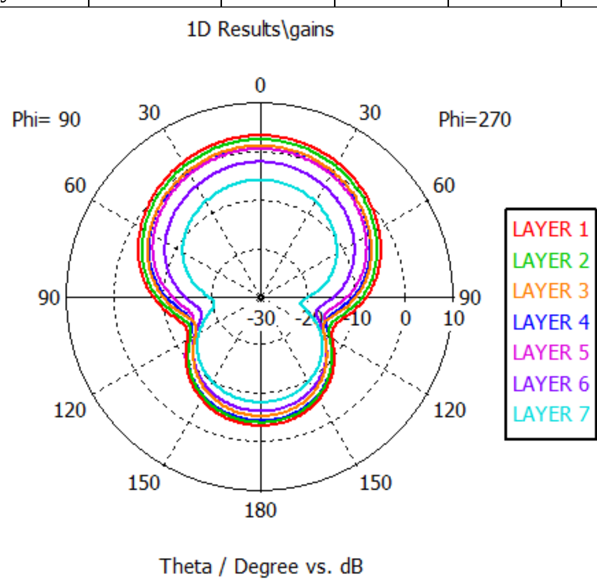

Figure 8: Shows the value of gains that were affected by ground placement.

Based on the results obtained, it is observed that by placing the ground at the first layer (bottom layer) of the antenna gave the best performance as compared to the other layer. As the ground is placed farther than the feed line, it will caused higher losses and less efficient. The gain is also decreased as the ground is placed farther than the feed line. Thus, the antenna will not give a good performance.

2. Microstrip feedline LTCC antenna.

Figure 9 shows the design of the microstrip feedline LTCC antenna.

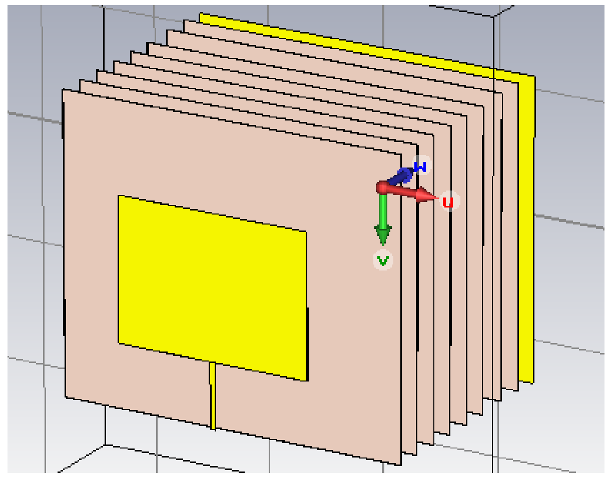

Figure 9:Microstrip feed LTCC antenna design.

It is observed that the antenna's performance for this design is less compared to aperture coupler antenna. The results for this design are shown as follows;

Table 10: Shows the results obtained for microstrip feedline LTCC antenna.

Width, w (mm)	Length, l (mm)	Return loss, S_{11} (dB)	Gain (dB)	Dir. (dBi)
32.5	23.5	-14.995	2.614	6.341

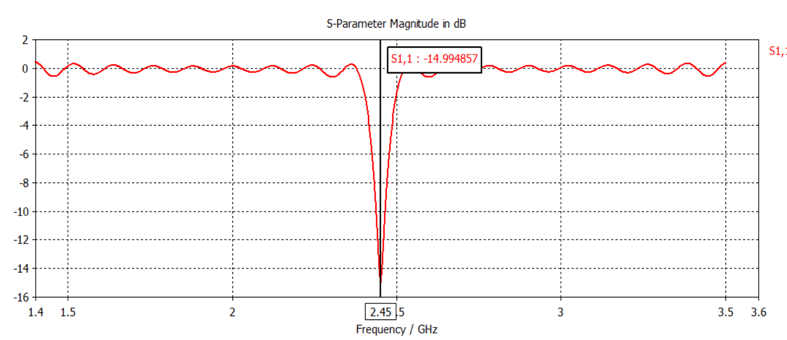

Figure 11: The S-parameter of the antenna.

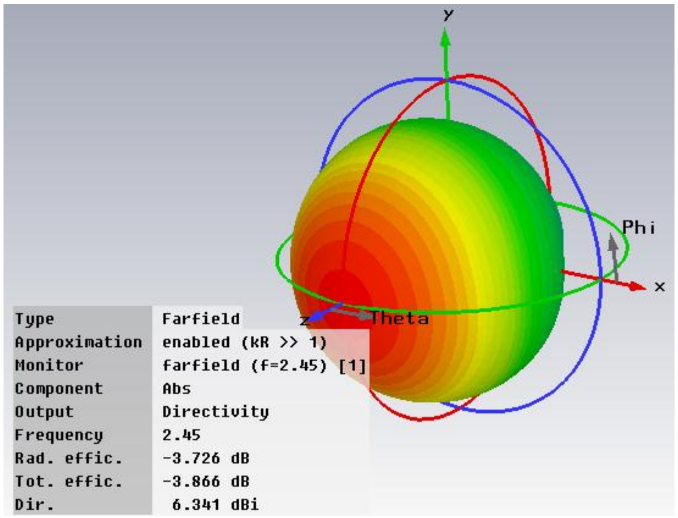

Figure 12: Directivity pattern of the antenna.

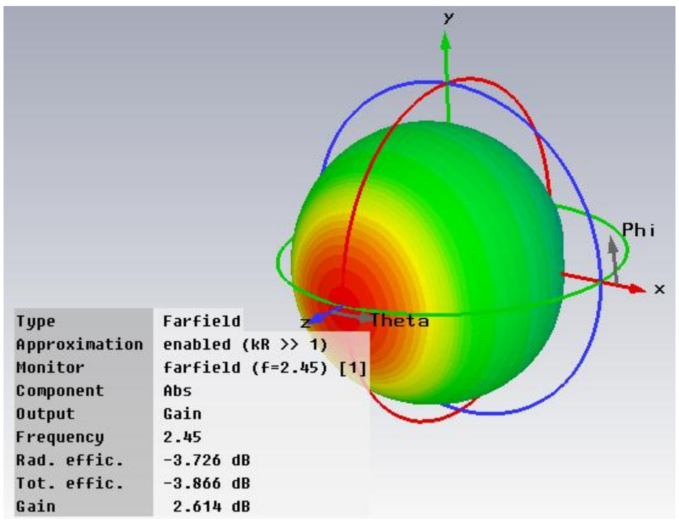

Figure 13: Gain of the antenna.

3. Comparison between aperture coupler LTCC antenna and microstrip feedline antenna performance.

Table 14: Shows the results obtained for both antenna designs.

	Aperture coupler LTCC antenna	Microstrip feed LTCC antenna
Operating frequency	2.45 GHz	2.45 GHz
Return loss, S_{11}	-17.883	-14.995
VSWR	1.433	1.292
Gain	3.326	2.614
Directivity	5.935	6.341

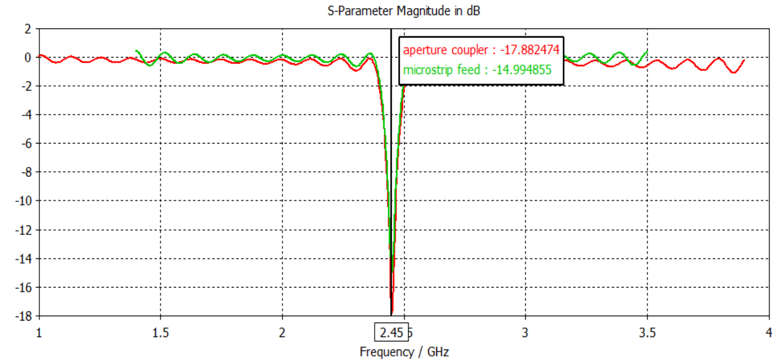

Figure 15: Shows the comparison between the return loss values for different feeding method

From the comparison, it is found that the aperture coupler LTCC antenna provides a better performance as compared to the microstrip feedline LTCC antenna. The return loss, S_{11} for aperture coupler antenna is better than the microstrip feedline antenna which is -17.883 dB and the gain of the aperture coupler LTCC antenna is also better as compared to the gain of the microstrip feedline antenna which is 3.326 as compared to the return loss for the microstrip feed antenna which is -14.995 dB with a maximum gain of 2.614 dB.

4. Microstrip feed FR4 antenna.

Figure 16 shows the design of the microstrip feedline FR4 antenna.

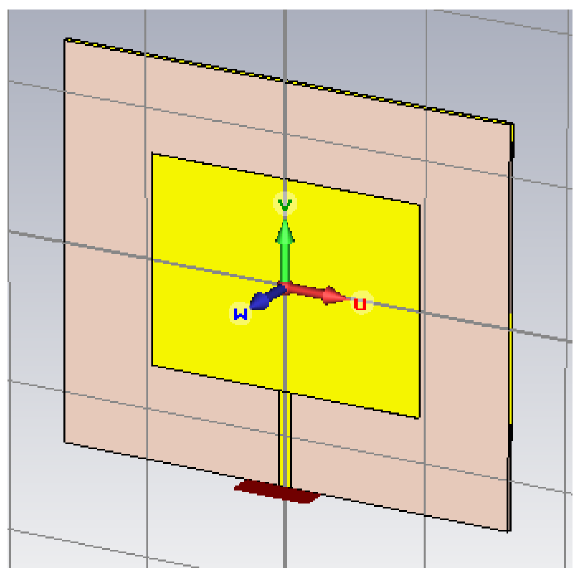

Figure 16: Microstrip feed FR4 antenna.

Table 17: Shows the results obtained for microstrip feedline FR4 antenna.

Width, w (mm)	Length, l (mm)	Return loss, S_{11} (dB)	Gain (dB)	Dir. (dBi)
38.0	28.17	-10.179	2.692	6.790

From the calculations, the initial values for the patch's width and length of this antenna are 36.26 mm and 28.18 mm. The size of the patch and substrate are both reduced in order to get the best result at the optimum frequency for this design which is 2.45 GHz. The width and length of the patch are found to be 38.0 mm and 28.17 mm. The results obtained for this design are shown as follows;

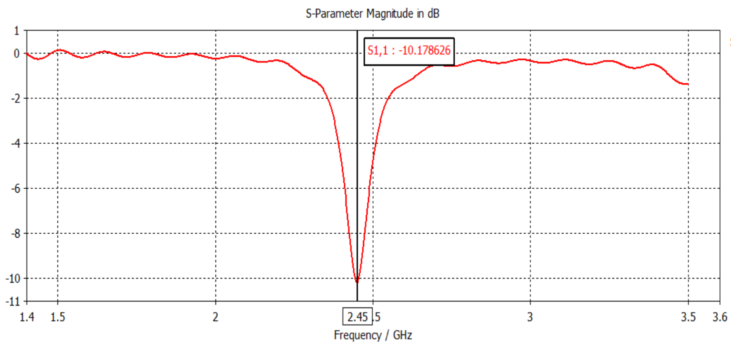

Figure 18: Return loss for the designed antenna.

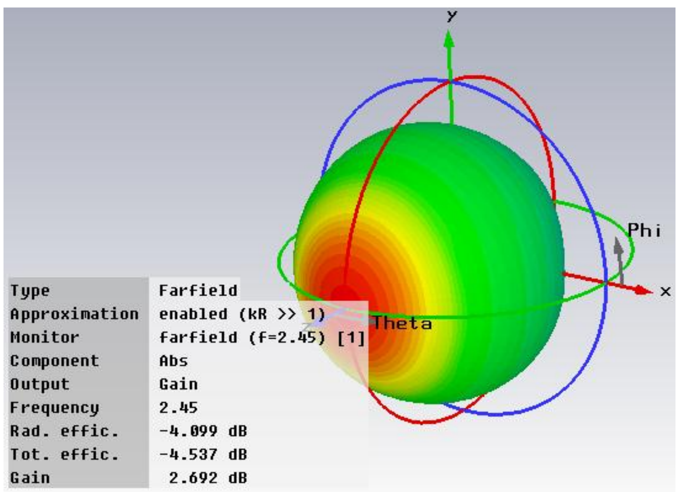

Figure 19: Gain of the microstrip feedline FR4 antenna.

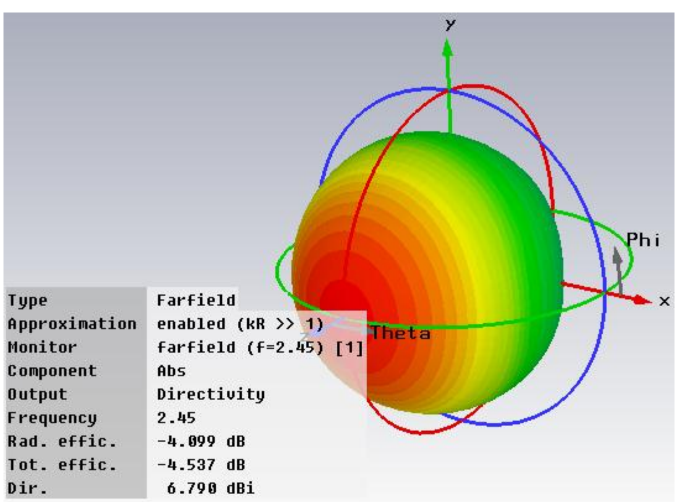

Figure 20: The directivity of the designed antenna.

5. Comparison between the performance of the microstrip feedline LTCC antenna and microstrip feedline FR4 antenna.

Table 21: Shows the results obtained for both antenna designs.

	LTCC antenna	FR4 antenna
Operating frequency	2.45 GHz	2.45 GHz
Return loss, S_{11}	14.995	-10.179
VSWR	1.292	1.897
Gain	2.614	2.692
Directivity	6.341	6.790

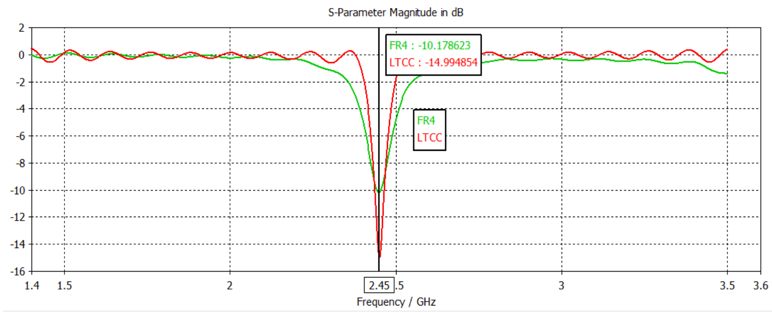

Figure 22: Return loss comparison.

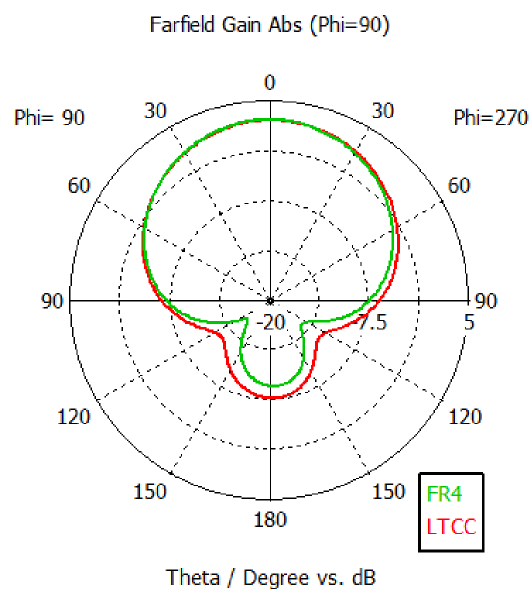

Figure 23: Gain comparison for both antenna.

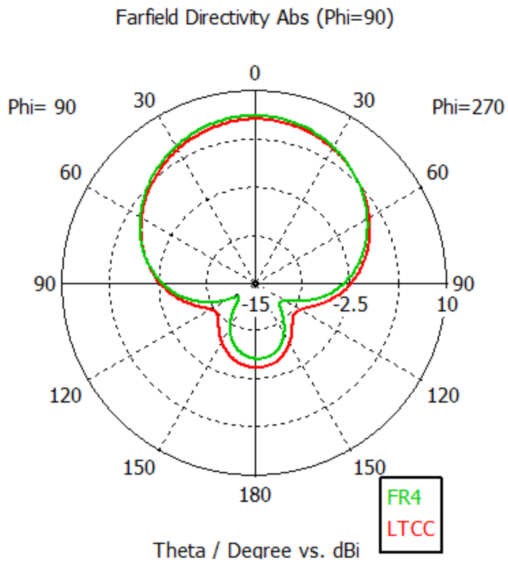

Figure 24: Directivity comparison for both antennas.

From the observation from the results obtained, it is proved that LTCC is a technology that can be applied in order to miniaturize the antenna size while maintaining the antenna performance in terms of its return loss, gain and also directivity.

IV. CONCLUSION

Compact LTCC technology antennas are proposed and simulated for the Bluetooth applications. This novel LTCC antenna can be controlled easily by wireless system. In order to reduce the antenna size, this antenna is designed as a multilayer antenna. Two types of multilayer antenna with different feeding method are proposed and simulated by CST Studio Suite which is aperture coupler antenna and microstrip feedline antenna. The results observed for the 25.6 mm x 22.0 mm aperture coupler LTCC antenna has a return loss of -17.883 dB and a maximum gain of 3.326 dB meanwhile for microstrip feedline LTCC antenna has a dimension of 32.5 mm x 23.5 mm with a return loss of -14.995 dB and a maximum gain of 2.614. A microstrip feedline FR4 antenna is also designed and compared with the microstrip feedline LTCC antenna. The size of the FR4 antenna is found to be 38.0 mm x 28.17 mm with a maximum gain of 2.692 dB and a directivity of 6.790 dB. As a conclusion, from the observations it is proven that LTCC is a technology that can be applied in order to reduce the size of any antenna design while maintaining the antenna's performance and aperture coupler antenna gives a better performance as compared to the microstrip feedline antenna.

V. FUTURE RECOMMENDATION

These two proposed LTCC patch antennas are a narrow bandwidth antenna. It is well-known that a patch antenna is a narrow band antenna. An antenna will provide a better performance if it has a broad bandwidth. So, after doing some research, I come with a conclusion that for a good performance of an antenna, a broad bandwidth antenna is needed.

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