A Microstrip Patch Antenna by Using LTCC for X-Band Applications

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Abstract— A design, model and simulation of a 2×1 array microstrip rectangular patch antenna with Low Temperature Co-fired Ceramic substrate is presented in this paper. The specifications for the proposed antenna is it has a frequency of 10GHz, Ferro A6S LTCC substrate, an epsilon 5.9, a substrate thickness of 0.096mm and copper thickness of 0.01mm. Parametric study was done with different conducting material, height of antenna by multilayer substrate and distance between radiating patch. The simulation was done using CST Microwave Studio Software. Results of the design were analyzed in terms of gain, directivity, return loss and Voltage Standing Wave Ratio.

Keywords— Array, Microstrip Patch Antenna, Low Temperature Co-fired Ceramic, CST Microwave Studio, Voltage Standing Wave Ratio.

I. INTRODUCTION

THE microstrip patch antenna is a metallic strip or patch mounted on a dielectric layer or substrate which is supported by a ground plane. Microstrip antennas are attractive due to their light weight, conformability and low cost. The characteristics of microstrip antenna are low profile,conformable to planar and no planar surface, and also that will be simple to manufacture. Major operatioal disadvantages of microstrip antenna are their low efficincy, low power, poor polarization purity, poor scan performance, spurious feed radiation and very narrow fequency bandwidth[1]. Rectangular patch antenna is simplifies the analysis and prediction on the performance.

Low Temperature Co-fired Ceramic (LTCC) is a multilayer platform technology that have benefits are high packaging density, dielectric constant, high thermal conductivity, reliability and stability[5]. Using the method will be reducing the size of antenna and also functionality for the portable electronic devices. LTCC large scale array antenna an attracted some attention due its flexibility in manufacturing, the capability of passive integration and the low production cost [4]. Array use quarterwave transform technique on the feed. That be consider as a power divider of designing the antenna.

Main an objective for these design are to reducing the size of antenna and an investigate the parametric study for designing the LTCC. When changing the parameter in each layer an effect their performance of antenna.

In this paper, a microstip patch antenna operating at 10GHz frequency using LTCC technology is designed and simulated using material substrate is Ferro A6S. The design of single patch and array of simulated and measured data are compared.

II. METHODOLOGY

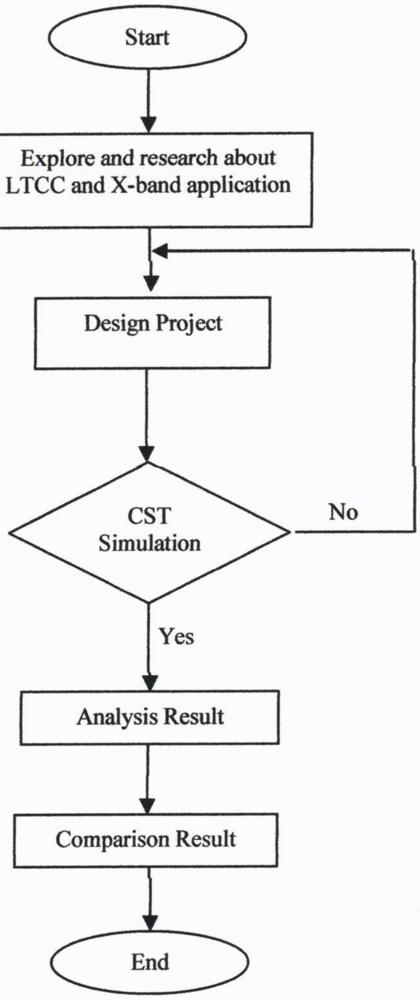


Figure 1: Flow chart of methodology

The flow of tasks performed to complete the design of this project show in the figure above. At the beginning are doing more detailed research and multilayer LTCC antenna. The theory of the matter must be studied and understood.

The second step is to design the patch antenna based on the frequency of X-Band, 10GHz. Manually calculations would be done to make the antenna design in CST. The design to operate at 10GHz frequency using Ferro A6S dielectric material, the dielectric constant ε_r, 5.9 and the height of substrate h, 0.096 mm. After that, the design will be simulated using CST software to be in a multilayer antenna. Several design that analyzed are single patch, an array with different gap size of patch either at λ_4 , λ_2 and λ also the change of performance of the conventional patch antenna with different material. During the simulation, return loss for the simulation results are expected to meet the specifications -10 dB cut. However, if the design is not successful, the process must be repeated patch antenna design.

Next is to analyze data of antenna in CST. Data obtained from measurements will be analyzed. All data of the simulated design will be comparing to get the good performance of antenna by using LTCC method. Results of the analyzed also prove the objective of this project.

A. *Single Microstrip Patch Antenna*

The calculation must be done before to design the microstrip patch antenna on the Computer Simulation Technology (CST). The calculation of rectangular microstrip patch antenna and the circular microstrip patch antenna are different.
The rectangular patch antenna design procedures of calculation are:

First, to obtained the practical width of rectangular patch antenna. The expression for W is given by Balanis as:

$$W = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \qquad (1)$$

Second an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of $\varepsilon_{reff}$is slightly less then εr because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air. The expression for ε_{reff} is given by Balanis as:

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \qquad (2)$$

Third was obtained the length expansion of rectangular patch antenna. The equation is:

$$\Delta L = 0.42h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3)$$

Hence, the effective lengths for the TM010 mode are:

$$L_{eff} = L + 2\Delta L \qquad (4)$$

Where:

$$L_{eff} = \frac{\lambda}{2}$$

$$\lambda = \frac{\frac{c}{f}}{2\sqrt{\varepsilon_{reff}}}$$

So,

$$L = \frac{c}{2fr\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (5)$$

After all calculation that would be done, another part is to design the rectangular patch antenna on the Computer Simulation Technology.

The calculations of the two rectangular patch antenna using different dielectric materials are FR4 and Ferro A6S prove that the reducing size of antenna when use the LTCC. For an antenna the dielectric material FR4, ε_r 4.54 with height of substrate 1.5 mm although the dielectric material Ferro A6S, ε_r 5.9 with height of substrate 0.096 mm proven that will reducing the size antenna. Using the Ferro A6S for LTCC give a good performance than FR4 because the height of substrate increased but thin so the radiation will be radiated well.

From the calculation of rectangular patch antenna, design it by Computer Simulation Technology. The transmission line model is applicable to infinite ground planes only. However, for practical considerations, it is essential to have a finite ground plane. To find the ground plane specific measure that used equation are:

$$Lg = \frac{\lambda_g}{2} + L \quad (6)$$

$$Wg = \frac{\lambda_g}{2} + W \quad (7)$$

Another part that must considered it on the feed line part. The feed line must be located on the patch, where the input impedance is 50 ohms for the resonant frequency. Beside that the width of the feed line, calculated automatically by using the calculated line impedance from the CST design software. There is some procedure process to determine the feed line on the patch antenna:

$$Z_\alpha = 90\left(\frac{{\varepsilon_r}^2}{\varepsilon_r - 1}\right)\left(\frac{L}{W}\right)^2 \quad (8)$$

Then:

$$Z_T = \sqrt{50 \times Z_\alpha} \quad (9)$$

Therefore

$$y_0 = \frac{L}{\pi}\cos^{-1}\sqrt{\frac{50}{Z_T}} \quad (10)$$

The physical notch and its corresponding junction capacitance influence slightly the resonance frequency. The maximum value occurs at the edge of the slot ($y_0 = 0$) where the voltage is maximum and the current is minimum. The minimum value (zero) occurs at the center of the patch ($y_0 = L/2$) where the voltage is zero and the current is maximum[1].

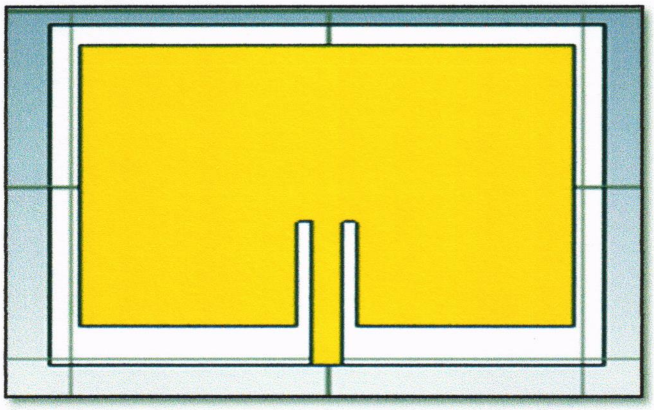


Figure 2: Conventional patch antenna.

The Figure 2 above is the completely rectangular patch antenna by drawn in the Computer Simulation Technology software. That would be completely design, so the design can be simulated by apply the E-field, H-field and also the far-field to define the return loss of the rectangular patch antenna.

B. 2×1 Patch Antenna

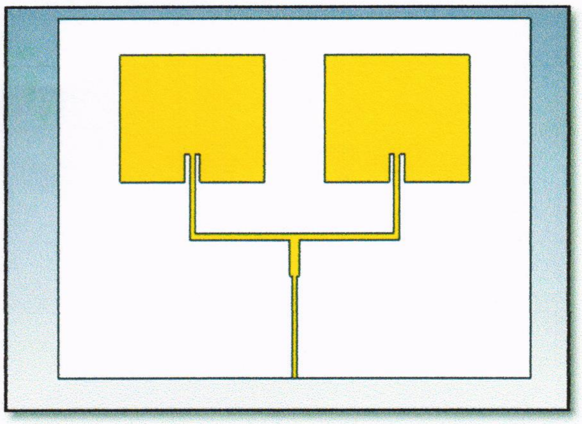


Figure 3: Array microstrip patch antenna.

The structure an array of the designing the antenna in the Computer Simulation Technology software shows in Figure 3. The measurement that be consider also same with single patch antenna. Consider measurement of S-parameter, Voltage Standing Wave Ratio (VSWR), bandwidth, gain and directivity. In additionally of design array is calculated the power divider. For this design by using the quarter wave transforms method that must equal to 35.36Ω by equation:

$$Z_{in} = \frac{50}{\sqrt{2}} \quad (11)$$

III. RESULTS AND DISCUSSION

The design of antenna investigated on comparison of patch antenna with different material, an increase the multilayer will be effect the performance of gain and bandwidth. Also comparison between conventional and 2×1 rectangular patch array antenna and the performance of 2×1 rectangular patch array antenna by compare between 2 element array based on distance. Results were analyzed in terms of scattering parameter, voltage standing wave ratio (VSWR), bandwidth, gain and the directivity.

Table1: Design parameter specification of microstrip patch antenna.

Material Substrate	Ferro A6S
Dielectric constant	5.9
Substrate Height (h)	96um
Center Frequency	10GHz
Copper Thickness	0.035mm

A. Single and multilayer substrate of antenna.

In this section, the conventional antenna designed to analyze the performance of the antenna when increasing the height of substrate. Below was discussion of single and multilayer substrate of conventional antenna.

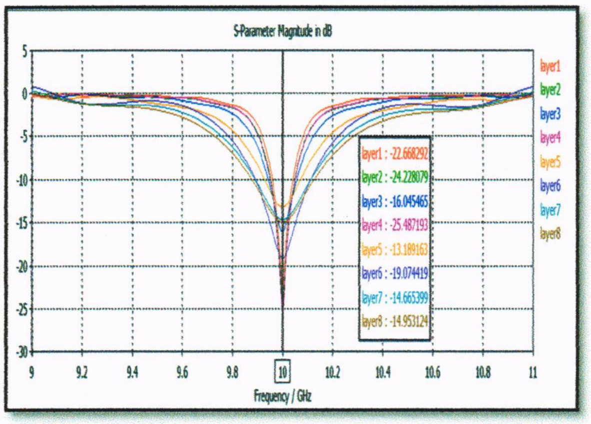


Figure 4: S-parameter of conventional antenna.

Figure 4 is the conventional of 1 layer till 8 layers scattering parameter when optimize the size of patch and the width of feedline. The line impedance equals to 50 ohms. The value of return loss was below -10dB at the center frequency 10GHz.

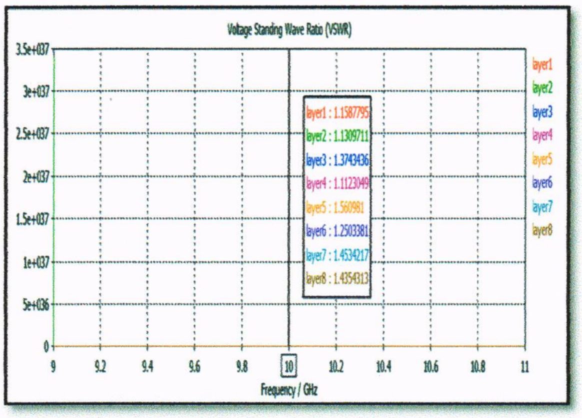
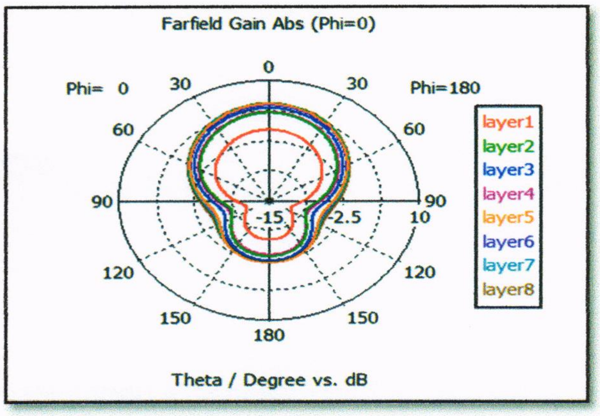
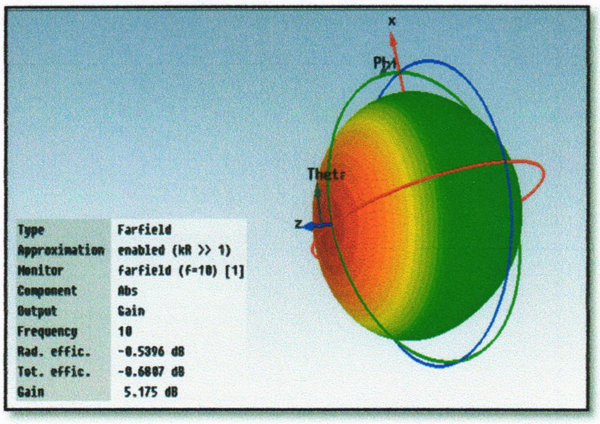


Figure 5: VSWR of conventional antenna.

The value of VSWR depends on the result of scattering parameter for each design.



(a)



(b)

Figure 6: Gain of conventional antenna.

The radiation pattern of gain at the resonant frequency 10GHz show in the Figure 6. In Figure 6(a) was the polar plot for multilayer. Figure 6(b) the best performs of gain at layer 8 of multilayer conventional antenna. The radiation efficiency of the patch antenna is affected not only by conductor and dielectric losses, but also by surface-wave excitation. As the substrate thickness decreases, the effect of the conductor and dielectric losses becomes more severe of limiting the efficiency. On the other hand, as the substrate thickness increases, the surface-wave power increases, thus limiting the efficiency.

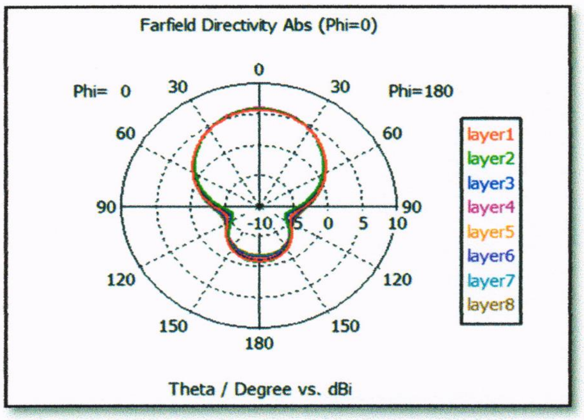


Figure 7: Farfield Directivity at Phi = 0.

Directivity of an antenna is equal to the ratio of the maximum power density to its average value over a sphere as observed in the far field of an antenna. Above directivity of the conventional patch antenna at phase was 0.

Table 2: Comparison between single layer and multilayer substrate.

LAYER	S_{11} (dB)	VSWR	Bandwidth (GHz)	Gain (dB)	Directivity(dBi)
1	-22.6683	1.15878	0.07571	-0.2906	5.610
2	-24.2281	1.13097	0.09350	3.220	5.764
3	-16.0455	1.37430	0.10910	4.2660	5.763
4	-25.4872	1.11230	0.10180	3.3460	5.835
5	-13.1892	1.56098	0.14182	4.9990	5.751
6	-19.0744	1.25030	0.22545	4.7780	5.727
7	-14.6654	1.45320	0.22909	5.0690	5.739
8	-14.9531	1.43540	0.26545	5.1750	5.714

Table 2 show the comparison result of the single and multilayer of the microstrip antenna using Ferro A6S materials of substrate.

B. Rectangular patch antenna with different material.

In the conventional patch antenna, the material of patch and ground is copper (annealed). But this result to investigate the comparison between conventional antenna using the silver for patch and the ground. Silver material which it the good conductor compare with copper (annealed). The cost using the silver an expensive than copper (annealed). Investigate of the single and multilayer of antenna for the silver material.

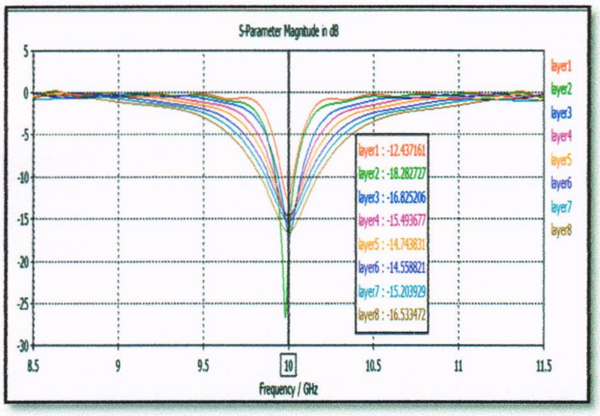


Figure 8: S-parameter of patch antenna (silver).

Scattering parameter lowest than -10dB will be the good performance because the return loss reflected back the signal is lower. For this design, the value of scattering increasing at targeted frequency 10GHz.

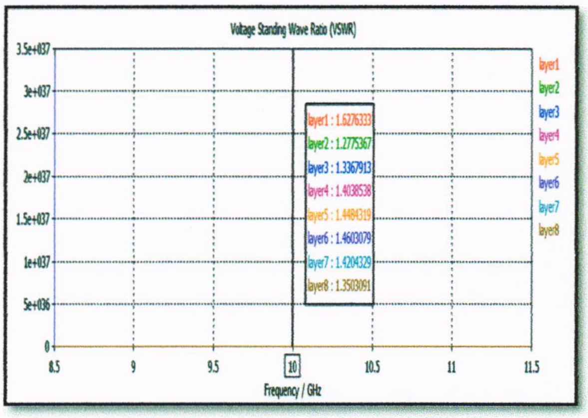
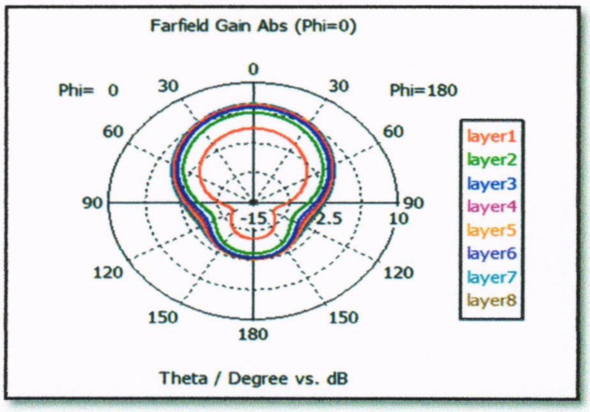
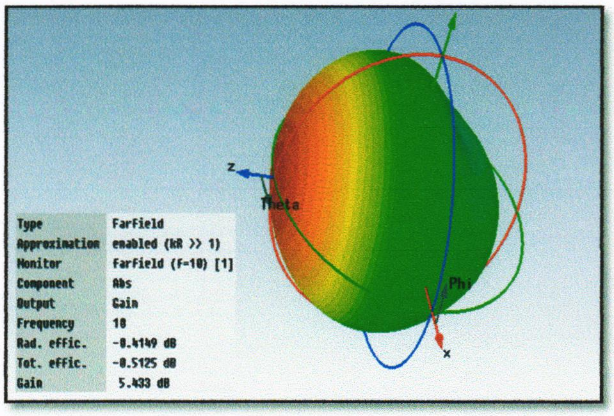


Figure 9: VSWR of patch antenna (silver).

Impact of the result on Figure 8, the VSWR become decreasing an approximate to the unity. The result of VSWR above was acceptable when designing the antenna. If VSWR result more high than 2.0 it will damage the antenna.



(a)



(b) Farfield at layer 8.

Figure 10: Gain of patch antenna (silver) at f = 10GHz.

Figure 10 show the plotting of single and multilayer of the conventional patch antenna that patch and ground used silver material and the best gain performs of multilayer at layer 8. Compare with the conventional patch antenna copper (annealed) result that the silver get increasing frequently when the layer increase. For the copper (annealed) the gain increasing when increasing the layer but some part of the layer the gain become decreasing.

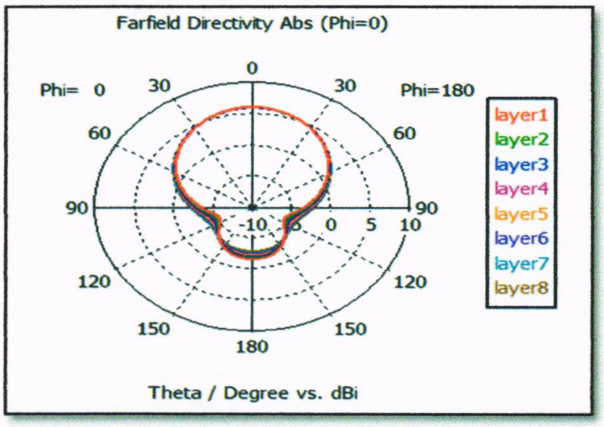


Figure 11: Farfield Directivity at Phi = 0.

Polar plot of the directivity at phase 0 was show in Figure 11. The result plot of the major lobe of antenna an approximate to unity comparing with the polar plot of directivity copper (annealed).

Table 3: Result patch antenna with different material.

TYPE OF ANTENNA	LAYER	S_{11} (dB)	VSWR	Bandwidth (GHz)	Gain (dB)	Directivity(dBi)
Conventional antenna (copper)	1	-22.6683	1.15878	0.07571	-0.2906	5.610
	2	-24.2281	1.13097	0.09350	3.220	5.764
	3	-16.0455	1.37430	0.10910	4.2660	5.763
	4	-25.4872	1.11230	0.10180	3.3460	5.835
	5	-13.1892	1.56098	0.14182	4.9990	5.751
	6	-19.0744	1.25030	0.22545	4.7780	5.727
	7	-14.6654	1.45320	0.22909	5.0690	5.739
	8	-14.9531	1.43540	0.26545	5.1750	5.714
Conventional antenna (silver)	1	-12.5796	1.6143	0.06309	0.373	5.909
	2	-18.2829	1.2775	0.11356	3.595	5.889
	3	-16.8252	1.3368	0.12934	4.630	5.883
	4	-15.4937	1.4034	0.16404	5.015	5.874
	5	-14.7438	1.4484	0.18927	5.264	5.862
	6	-14.5588	1.4603	0.22397	5.360	5.850
	7	-15.2039	1.4204	0.27445	5.425	5.841
	8	-16.5335	1.3503	0.32808	5.433	5.848

C. Compare between Conventional Antenna and Array Antenna (λ/4).

This section will discuss about the comparing design between conventional patch antenna and the rectangular patch array between 2 elements that distance (λ/4).

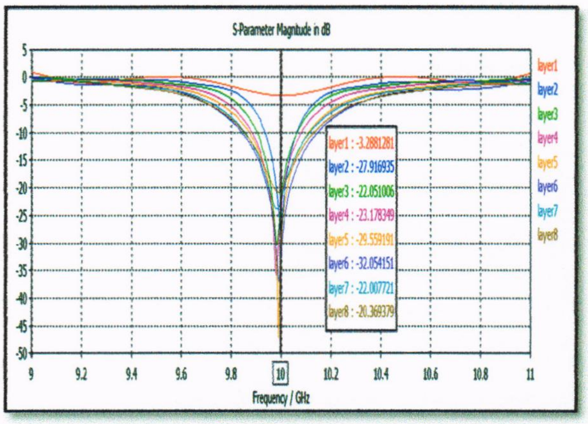


Figure 12: S-parameter of array antenna (λ/4).

Above the result of 2×1 element array antenna with the distance is λ/4. This result compare it with conventional antenna for analyze different performance. Scattering parameter of array more high than conventional patch. At layer 7 the value of scattering parameter conventional antenna and array antenna was -14.6654 dB and -22.0077 dB.

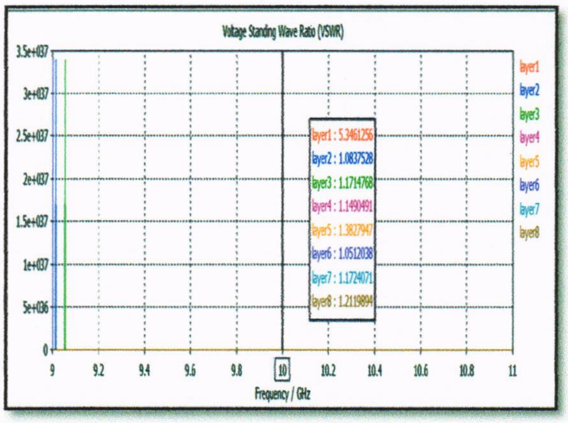
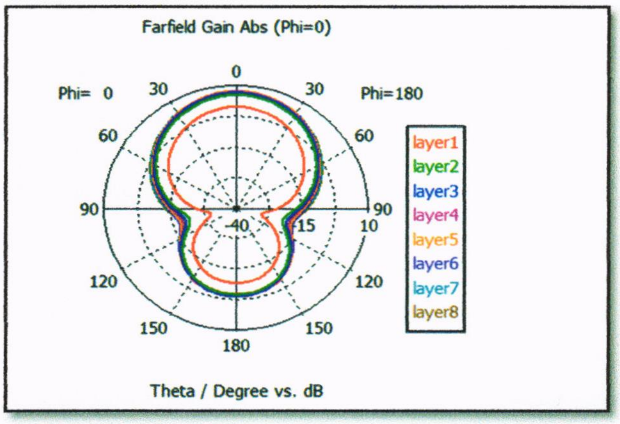
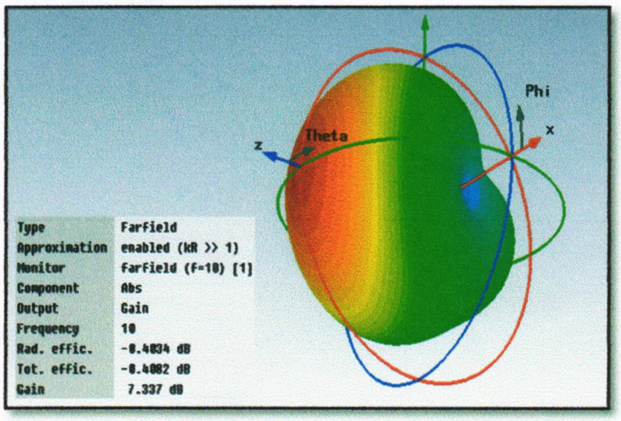


Figure 13: VSWR of array antenna (λ/4).

Figure 13 shown VSWR from layer 1 to layer 8 of array antenna and the result in range 2 to 1.



(a)



(b) Farfield at layer 5.

Figure 14: Gain of array antenna (λ/4).

The gain of array antenna was increase compare with the conventional antenna design. Polar plot result the array antenna radiated very well in performs.

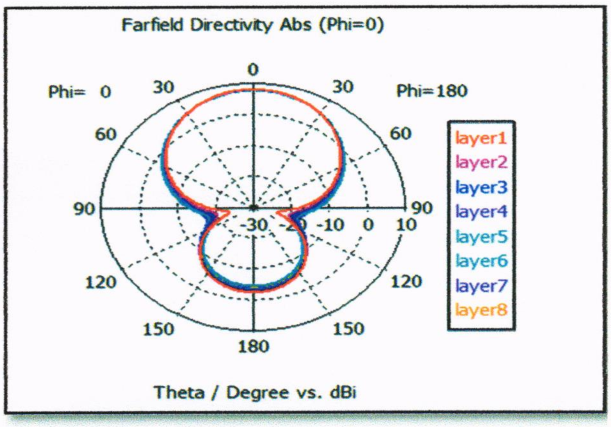


Figure 15: Directivity of array antenna (λ/4).

Above directivity of two elements patch array antenna with distance λ/4 at phase 0.

Table 4: Compare between conventional patch antenna and array antenna (λ/4).

TYPE OF ANTENNA	LAYER	S_{11} (dB)	VSWR	Bandwidth (GHz)	Gain (dB)	Directivity(dBi)
Conventional patch antenna (copper)	1	-22.6683	1.15878	0.07571	-0.2906	5.610
	2	-24.2281	1.13097	0.09350	3.220	5.764
	3	-16.0455	1.37430	0.10910	4.2660	5.763
	4	-25.4872	1.11230	0.10180	3.3460	5.835
	5	-13.1892	1.56098	0.14182	4.9990	5.751
	6	-19.0744	1.25030	0.22545	4.7780	5.727
	7	-14.6654	1.45320	0.22909	5.0690	5.739
	8	-14.9531	1.43540	0.26545	5.1750	5.714
Array antenna (λ/4)	1	-3.2881	5.3461	-	1.056	7.816
	2	-27.9169	1.0837	0.12618	5.969	7.778
	3	-22.0510	1.1715	0.15983	6.744	7.767
	4	-23.1783	1.1491	0.19558	7.126	7.753
	5	-29.5591	1.3828	0.23764	7.337	7.741
	6	-32.0532	1.0512	0.30541	7.310	7.716
	7	-22.0077	1.1724	0.25287	7.223	7.574
	8	-20.3694	1.2119	0.28004	7.247	7.574

D. *Performance Comparison between Distance of Two Element Patch Antenna Array ((λ/4), (λ/2), λ)*

As on section C of this paper show the result of two element rectangular patch antenna array distances was λ/4. Other comparing between distances (λ/2) and λ would be discussed below.

i. *2×1 Element Patch Antenna Array (λ/2).*

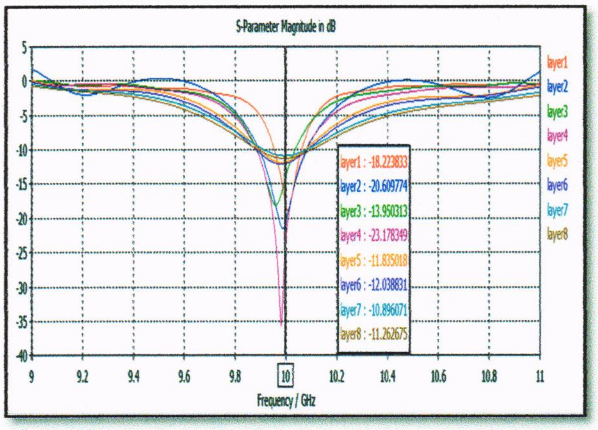


Figure 16: S-parameter of array antenna (λ/2).

By comparing the array antenna between the distances, the return loss on λ/2 was the good performs because the value of bandwidth would increase.

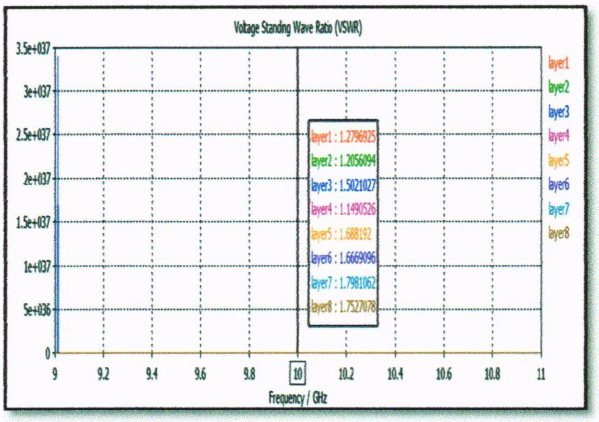


Figure 17: VSWR of array antenna (λ/2).

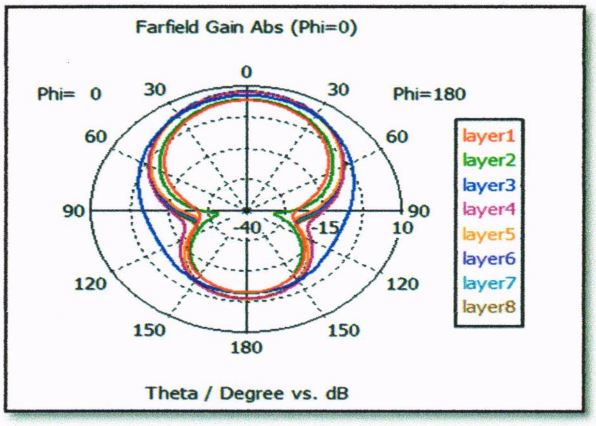


Figure 18: Gain of array antenna (λ/2).

The different of array between the distance would effect that the gain performance. The major lobe of the gain was an accurate to the 0.

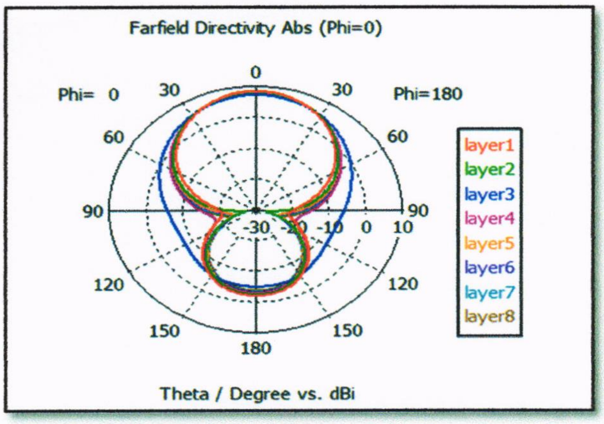


Figure 19: Directivity at Phi = 0 of array antenna (λ/2).

ii. 2×1 Element Patch Antenna Array λ.

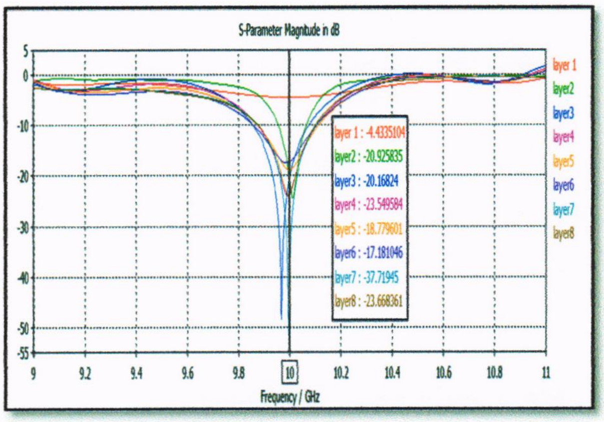


Figure 20: S-parameter of array antenna λ.

Return loss of the array antenna distance λ plotted as above. By comparing of three condition of distance, the λ/4 and λ at layer 1 have result less than -10dB. The multilayer of designing array gets a more increasing result.

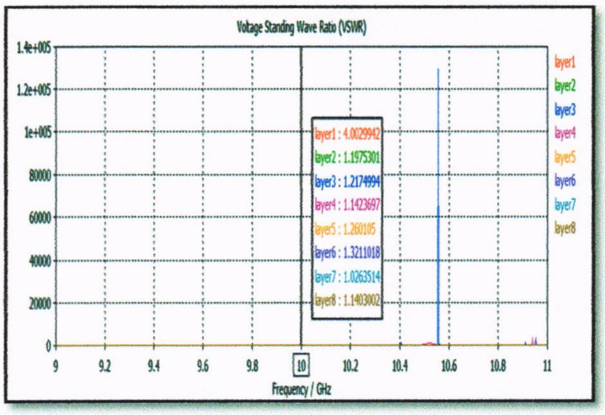


Figure 21: VSWR of array antenna λ.

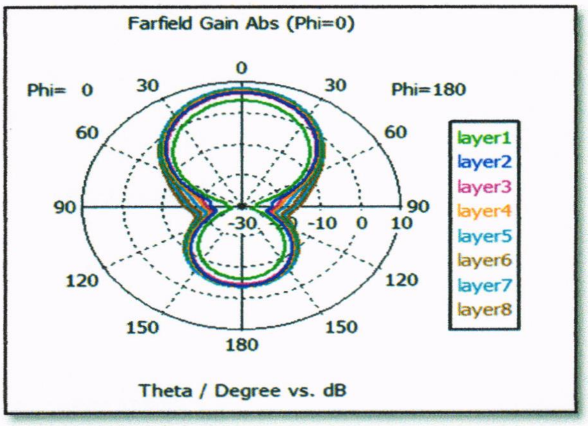


Figure 22: Gain of array antenna λ.

Designing the array antenna was a good selection for increasing the gain and bandwidth of the antenna. When the distance of two elements was increase the gain more approach to the 0 likely the result above.

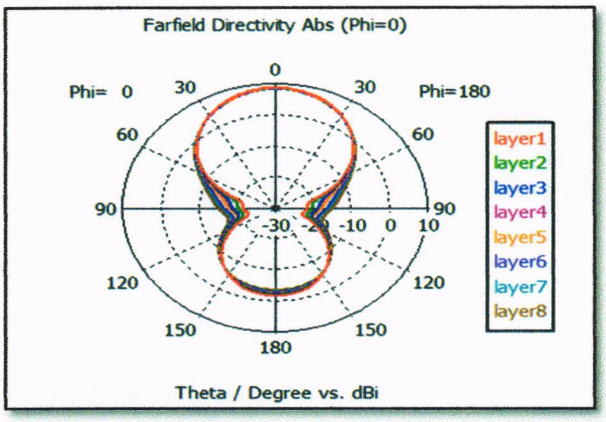


Figure 23: Directivity at Phi = 90 and 0 of array antenna λ.

Result of directivity of two element array antenna on the phase of 0 was shown above.

Table 5: Compare between distance of two element patch antenna array.

TYPE OF ANTENNA	LAYER	S_{11} (dB)	VSWR	Bandwidth (GHz)	Gain (dB)	Directivity(dBi)
Antenna array (λ/4)	1	-3.2881	5.3461	-	1.056	7.816
	2	-27.9169	1.0837	0.12618	5.969	7.778
	3	-22.0510	1.1715	0.15983	6.744	7.767
	4	-23.1783	1.1491	0.19558	7.126	7.753
	5	-29.5591	1.3828	0.23764	7.337	7.741
	6	-32.0532	1.0512	0.30541	7.310	7.716
	7	-22.0077	1.1724	0.25287	7.223	7.574
	8	-20.3694	1.2119	0.28004	7.247	7.574
Antenna array (λ/2)	1	-18.2238	1.2797	0.10729	3.990	8.183
	2	-20.6098	1.2056	0.18717	4.280	7.919
	3	-13.9503	1.5021	0.15352	5.960	7.075
	4	-23.1783	1.1491	0.19769	7.126	7.753
	5	-11.8350	1.6882	0.17935	7.279	7.898
	6	-12.0388	1.6669	0.20021	7.442	7.876
	7	-10.8961	1.7981	0.17310	7.536	7.841
	8	-11.2627	1.7527	0.22732	7.539	7.814
Antenna array (λ)	1	-4.4335	4.0029	-	3.833	8.515
	2	-20.926	1.1975	0.10845	6.449	8.481
	3	-20.168	1.2175	0.21272	6.143	8.473
	4	-23.549	1.1424	0.23358	6.953	8.428
	5	-18.779	1.2601	0.24249	7.322	8.364
	6	-17.181	1.3211	0.24818	7.397	8.267
	7	-37.718	1.0263	0.23149	7.751	8.220
	8	-23.668	1.1403	0.22591	7.694	8.138

IV. CONCLUSION

The aim of this project was to design microstrip patch antenna in conventional and two element patch array antenna for incorporation in the X-band frequency at 10GHz by using the Low Temperature Co-Fired Ceramic (LTCC) technologies. The results obtained proved that be successfully designed.

Another that proved by using the LTCC would be reduced size of antenna. In term of calculation results obtained by comparing the antenna between using Ferro A6S and FR-4 would be reduced size of antenna.

By the results that investigated the changing of the parameter an effected with the output of simulation and their parametric of design. An analyzed the design takes it more time during simulated to get the expectation of frequency and resonant impedance at part of design. It also give more information by the practically when to design it.

V. FUTURE RECOMMENDATION

This project design firstly must know the parameter specification that given would be to apply on the part the designing. The thick of substrate with the dielectric constant have are more different whether a lower dielectric constant or higher dielectric constant. Using the higher of height substrate would be effect the radiated and sometimes unsuccessfully propagate the design. By choose the right of dielectric material to design is an important. By using the parasitic element method will be upgrade the result in term of gain. Also the design can be simulated using another software for more efficient in high frequency design of antenna.

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