Design of Microstrip Patch Antenna with LTCC Substrate for K-band Application

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Abstract- **This paper presents the design model and simulation of 2×1 microstrip patch antenna with multilayer LTCC substrate for K-band application. The specification for the proposed array antenna is it has a frequency of 22GHz, Ferro A6S LTCC substrate, an epsilon 5.9, a substrate thickness of 0.096mm and copper thickness of 0.01mm. The design was simulated using Computer Simulation Tool Microwave Environment Software. LTCC Ferro A6S was chosen as substrate compares to other because it has high relative permittivity and multilayer structure which result in a compact size antenna. The performance of the antenna was evaluated in terms of bandwidth, gain, directivity, return loss, and Voltage Standing Ratio (VSWR).**

Keywords- Circular patch antenna, Low-Temperature Co-fired Ceramic (LTCC)

I. INTRODUCTION

In this paper K-band application frequency was used. The range frequency for K-band it's between 18GHz – 26GHz. The K-band is used primarily for radar and satellite communication. Microstrip antenna widely used for various applications such as satellite communication, wireless communication, GPS and radar communication. [1] A microstrip patch antenna is commonly used in communication device due to its small size, thin profile configurations, conformity and low cost. However their disadvantages by using microstrip patch antenna it is limited bandwidth of antenna. The bandwidth can be increased but at the cost of size of the patch making it large and bulky.[2] There are ways to increase the bandwidth without increase size of patch antenna its array. Antenna array it is often convenient, simpler and more practical. [3] Based on work done by Sanghamitra Dasgupta [4], prove that the design antenna array can increase the gain of antenna. To overcome this problem of microstrip patch antenna, the LTCC technique with array has been used to improve bandwidth of antenna.

Low temperature co-fired ceramic is widely used in wireless communication for next wireless communication because in wireless application are requiring low loss at high frequency and good characteristic comparative to cost. [5] Advantages of LTCC such as its high temperature resistance, high thermal conductivity, low dielectric loss and excellent characteristics for high-frequency. [6] LTCC also high-speed and functionality for portable electronic device in rapidly expanding mobile network system, so it's suited to the material of small antenna. [7] Their several typical methods used to improve the bandwidth using LTCC technique such as E-shape microstrip patch antenna [8] ,H-type microstrip slot antenna.[9] and multilayer air gap.[10] In this paper, single and 2×1 circular microstrip patch antenna was design with multilayer substrate material Ferror A6S. Ferror A6S as material substrate because of size patch of antenna was proved by calculation. This antenna was investigates on increases of multilayer can increase the bandwidth and gain, the performance comparison between circular microstrip patch antenna and 2×1 circular microstrip patch array antenna, effect of performance based on the distance between

2 element array for 2×1 circular microstrip patch array antenna and also performance circular microstrip patch antenna with different conductor .

II. METHODOLOGY

The microstrip patch antenna with multilayer substrate was designed and optimized using Computer Simulation Tool to get the result of return loss, VSWR, gain, and bandwidth

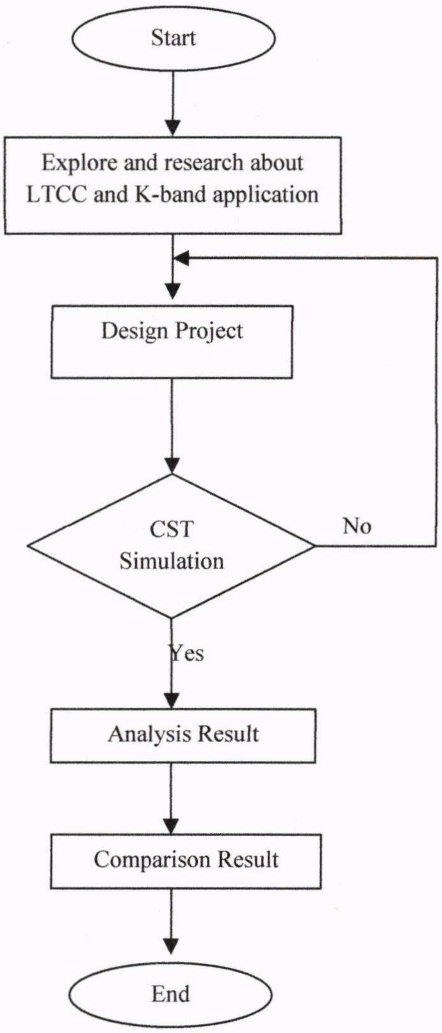

Figure 1: Project Methodology

Figure 1 show the flow chart of methodology. Project activities are start with research and explore about LTCC (Low temperature co-fired ceramic) and K-band application. The microstrip patch antenna was design and analyzed by using CST software. The design specifications are used listed in Table 1. Finally the result of microstrip patch antenna was compared and analyzed in tern of return loss, gain, bandwidth, and VSWR.

Table 1: Design Specification for Circular Patch Antenna

Material Substrate	Ferro A6S
Dielectric costant	5.9
Loss Tangent δ	0.002
Substrate Height (h)	96um
Center Frequency	22GHz
Copper Thickness	0.01mm

A. Single Microstrip Patch Antenna Design

The calculation for circular microstrip patch antenna using equation 1 and 2,

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

$$F = \frac{8.791\times10^9}{f_r\sqrt{\epsilon_r}} \quad (2)$$

Dimension of width

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r}} \quad (3)$$

Where;
c = speed of EM wave in vacuum 3×10^8 m/s
f = operational frequency
ε_r = substrate permittivity

Effective dielectric constant

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \quad (4)$$

Where;
h = thickness of substrate
w = width of patch antenna

Length extension

$$\Delta L = 0.412h\frac{(\epsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\epsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (5)$$

$$L = \frac{c}{2f\sqrt{\epsilon_{reff}}} - 2\Delta L \quad (6)$$

Ground Substrate

$$L_s = L + 6h \quad (7)$$

$$W_s = W + 6h \quad (8)$$

Figure 2 shows the top of single circular patch antenna. The dimension of the value a is 1.619 mm and W_o is a 0.14665 mm.

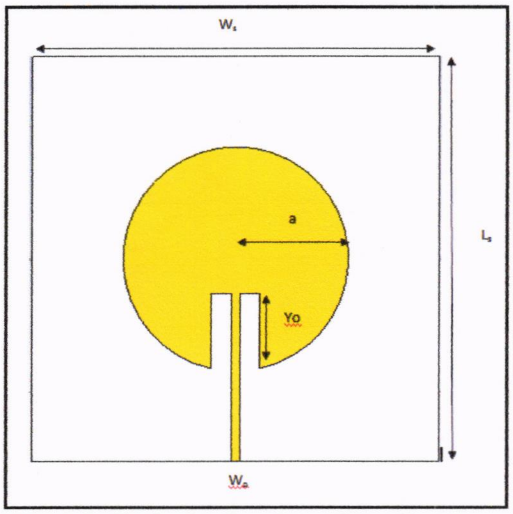

Figure 2: Single circular microstrip patch antenna

B. Circular Microstrip Patch Array Antenna

The antenna is integrated in multilayer LTCC substrate with 2×1patch array antenna. Figure 3 show the top of circular patch array antenna.

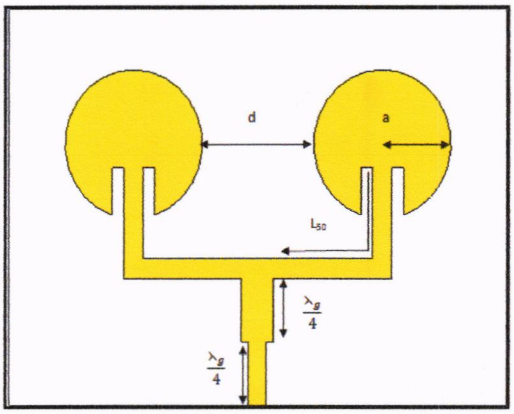

Figure 3: Structure of the two element antenna array

The design as show in figure 3 is design of two element circular microstrip patch antenna such as single element antenna as show in figure 2. The input impedance of the microstrip feed line is 50Ω. Quarterwave transformers technique is used to match the 50Ω microstrip line where, L_{50} is the length of 50Ω microstrip line. In between both are connected by 35.36Ω microstrip line with length is λg/4. The parameters (d) of between 2 element show in table 2.

Table 2: Spacing Between 2 Element

λg	5.7535mm
λg/2	2.8768mm
λg/4	1.4384mm

C. Multilayer Substrate

Figure 3 shows the multilayer design for 8 LTCC layer. The antenna is designed to operate at 22GHz frequency, using Ferror A6S dielectric material, the specification of design antenna shows at table 1.

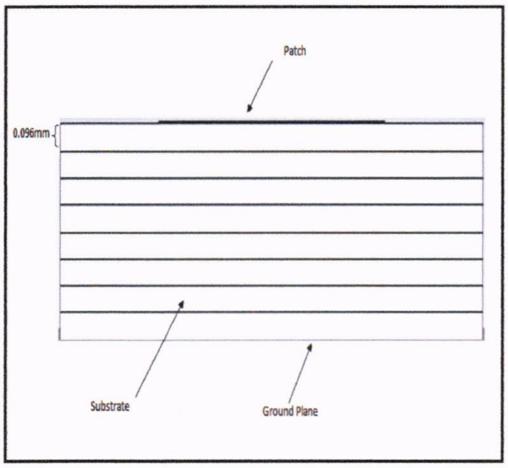

Figure 3: Multilayer substrate

III. RESULT AND DISCUSSION

This project of antenna was investigate on increases of multilayer can increase the bandwidth and gain, the performance comparison between circular microstrip patch antenna and 2×1 circular microstrip patch array antenna, effect of performance based on the distance between 2 element array for 2×1 circular microstrip patch array antenna, performance circular microstrip patch antenna with different conductor and also performance antenna with parasitic element with multilayer substrate.

A. Single layer and Multilayer Substrate

The simulated antenna S-parameter (S_{11}) versus frequency is shown in figure 4 for 8 layers which show the return loss is below -10dB is follow the standard IEEE for design antenna. To get the better performance for return loss the patch of antenna was optimize until the value of return loss was below -10dB follow the IEEE standard.

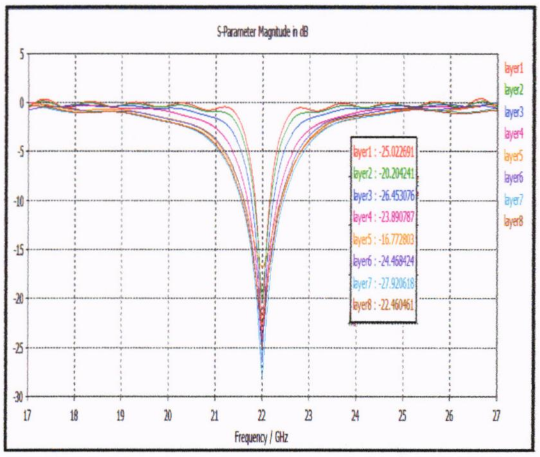

Figure 4: Return Loss single Circular Microstrip patch antenna

The result voltage standing wave ratio of the circular microstrip patch antenna with LTCC technology at center frequency of 22GHz shown in figure 5. At the center of 22GHz, the simulated result VSWR value is below 2. Low value of VSWR indicates the antenna have a small value of reflection coefficient.

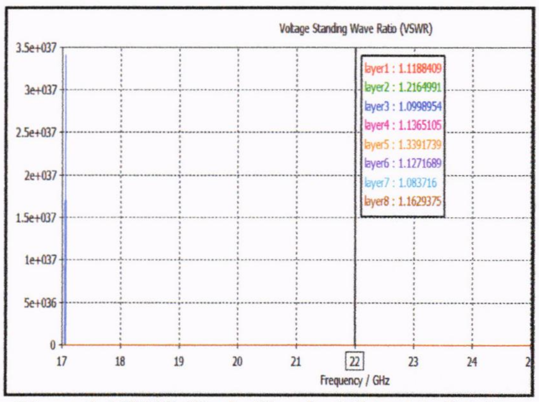

Figure 5: VSWR Single Circular Microstrip Patch Antenna

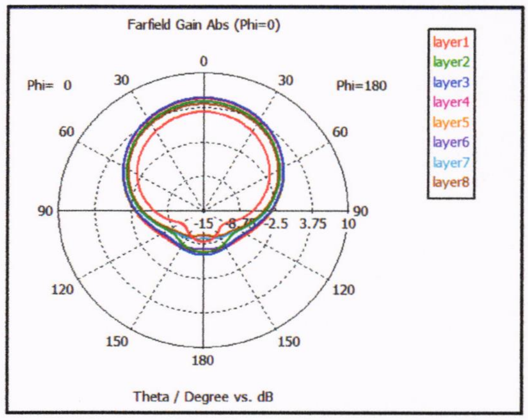

Figure 6: Simulated radiation pattern gain for single circular microstrip patch antenna

Figure 6 shows the radiation pattern gain at 22GHz for single layer and multilayer substrate. By Increases of substrate can be affected the radiation pattern gain.. The best value of antenna gain is 5.57dB at the layer 3. The best result of radiation pattern (3D) of the microstrip patch antenna at layer 3 shown at figure 7.

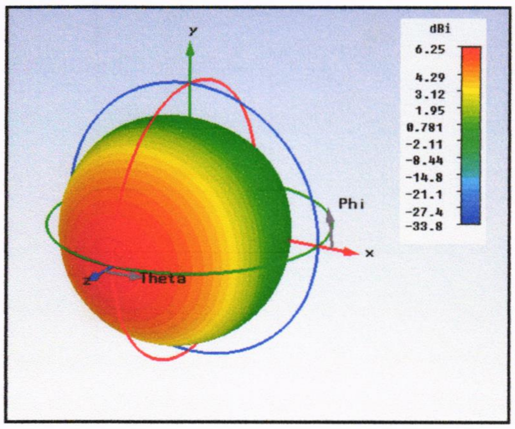

Figure 7: The radiation pattern (3D) for single circular microstrip patch antenna at layer 3

Table 3: Comparison between Single Layer and Multilayer Substrate

Types of antenna	layer	S11 (dB)	Fr (GHz)	BW (MHz)	VSWR	Zin	Gain (dB)	Directivity (dB)
Single Layer	1	-25.02	22	324	1.11	50	2.93	6.36
Multilayer Substrate	2	-20.20	22	366	1.22	50	4.89	6.31
	3	-26.45	22	439	1.10	50	5.57	6.25
	4	-23.89	22	659	1.14	50	5.36	6.16
	5	-16.77	22	764	1.34	50	5.46	6.13
	6	-24.47	22	785	1.13	50	5.37	6.08
	7	-27.92	22	899	1.03	50	4.81	5.99
	8	-22.46	22	899	1.16	50	4.43	5.88

The comparison result between single layer and multilayer shown in figure 3. The entire circular microstrip patch antenna with multilayer substrate proves that by using LTCC technology can increase gain and bandwidth performance. When compare between layer 1 and layer 8 the antenna bandwidth increase 63.95% while gain of antenna increase 33.86% at center frequency 22GHz.

B. Simulation for Conventional Circular Patch Antenna Circular Array Patch Antenna with LTCC Technology

This antenna was design circular patch array antenna with distance between 2 elements its λ/4. This antenna design is investigate the performance of array antenna with multilayer substrate at resonant frequency 22GHz.

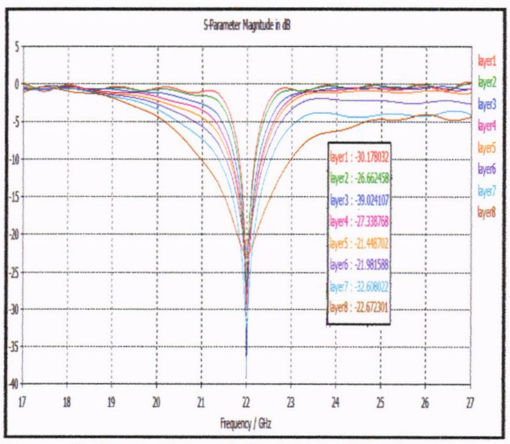

Figure 8: Return loss of circular patch array antenna (λ/4)

The simulated -10dB return loss of the antenna array shown in figure 8. The simulation result gives a return loss of below -10dB at operating frequency 22GHz. For IEEE standard the ideal value for S-parameter is below -10dB.

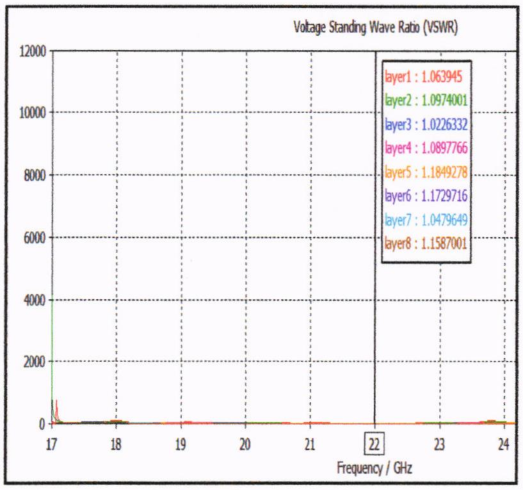

Figure 9: VSWR for circular patch array antenna (λ/4)

Based on paper [11] increases the radius of patch can be affected result of VSWR. The best result VSWR at frequency 22GHz frequency after radius of patch antenna was optimizing shown in figure 9.

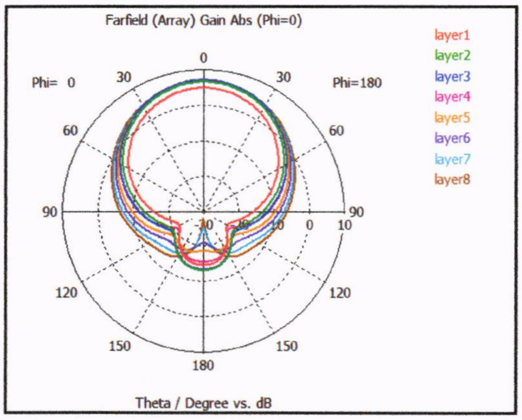

Figure 10: Simulated radiation pattern gain of circular patch array microstrip patch antenna (λ/4)

The simulated of radiation pattern gain for circular microstrip patch antenna shown in figure 10. Main lobe magnitude of circular antenna array for each layer is closely to 0 dB at center frequency 22GHz. Figure 11 show the simulated gain for the circular patch antenna array at 22 GHz. The best result simulated gain for this design is 7.71dB was at layer 3. The performance result between circular patch antennas with circular patch array antenna in table 4 proved that using LTCC substrate for circular patch array antenna can be improve performance of gain and bandwidth antenna design.

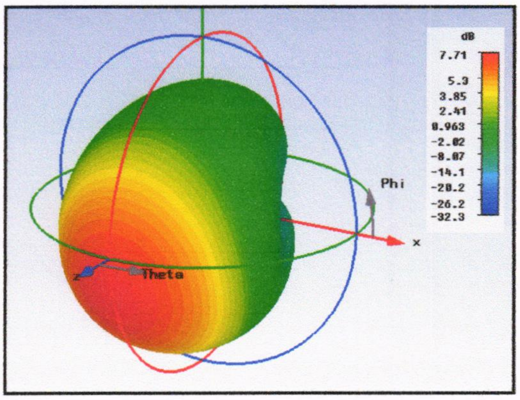

Figure 10: 3D Simulation radiation pattern gain of circular patch array antenna (λ/4)

Table 4: Performance between Conventional Circular Patch Antenna and Circular Patch Array Antenna

Types of antenna	layer	S11 (dB)	Fr (GHz)	BW (MHz)	VSWR	Zin	Gain (dB)	Directivity (dB)
Conventional Circular Patch Antenna	1	-25.02	22	324	1.11	50	2.93	6.36
	2	-20.20	22	366	1.22	50	4.89	6.31
	3	-26.45	22	439	1.10	50	5.57	6.25
	4	-23.89	22	659	1.14	50	5.36	6.16
	5	-16.77	22	764	1.34	50	5.46	6.13
	6	-24.47	22	785	1.13	50	5.37	6.08
	7	-27.92	22	899	1.03	50	4.81	5.99
	8	-22.46	22	899	1.16	50	4.43	5.88
Circular Patch Antenna Array	1	-30.18	22	356	1.06	50	5.31	8.58
	2	-26.66	22	397	1.10	50	7.13	8.49
	3	-39.02	22	533	1.02	50	7.71	8.39
	4	-27.34	22	644	1.09	50	7.61	8.26
	5	-21.45	22	748	1.18	50	7.47	8.01
	6	-21.98	22	868	1.17	50	7.34	7.79
	7	-32.61	22	1193	1.05	50	7.13	7.51
	8	-22.67	22	1998	1.16	50	6.87	7.24

C. Performance Comparison Between Distance of Two Element Circular Patch Antenna Array((λ/4), (λ/2), λ)

The design of two element array consists of two circular microstrip patch antenna. The input impedance of the feeding network is 50Ω. This design to investigate the performance of antenna with multilayer substrate based on the spacing between 2 element circular patch antennas. Parameters of spacing between two elements as shown at table 2. However this design only done until layer 6, because at layer 7 and 8 the size of patch became larger. So its no suitable for this design.

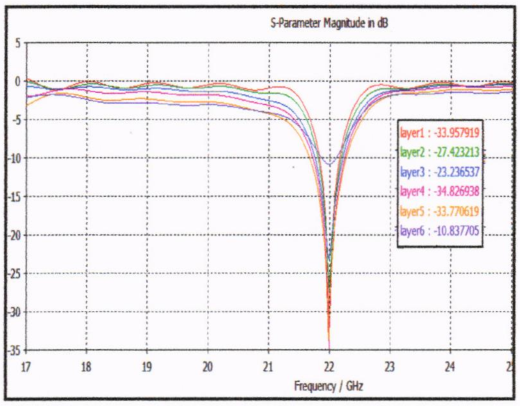

Figure 11: Return loss of circular patch array antenna (λ/2)

Figure 11 shows the frequency versus return loss for the antenna at frequency 22GHz after optimize size patch of antenna. From figure 11 shows the return loss at frequency 22GHz is below than -10 dB for each layer substrate. VSWR also been affected when the patch radius optimize, the result of VSWR after optimize shown figure 12. The ideal VSWR value for design antenna is equal to one.

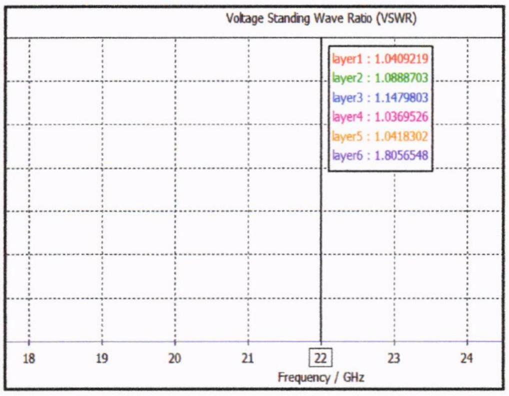

Figure12: VSWR for circular patch array antenna (λ/2)

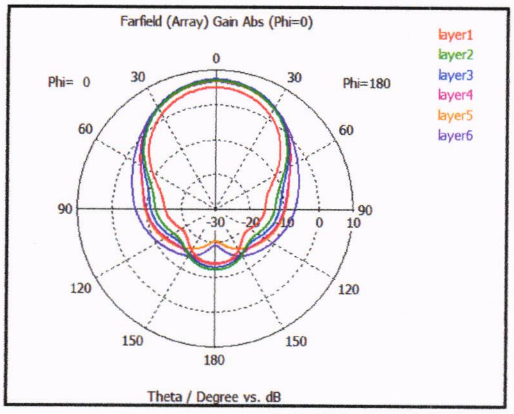

Figure 13: Simulated radiation pattern for gain of circular patch array antenna

The simulation result of radiation pattern for gain for each layer shown in figure 13. The higher main lobe magnitude for the gain obtained is 7.4 dB was at layer 3.

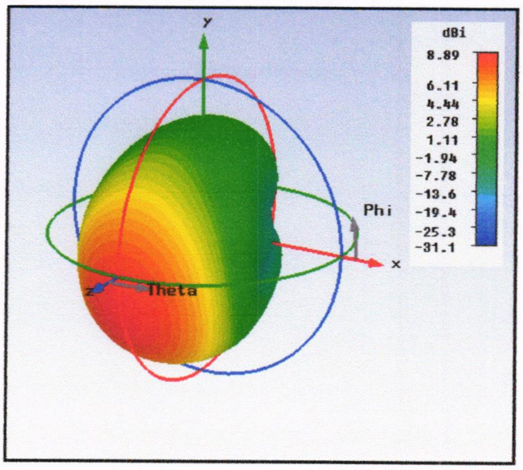

Figure 14: 3D Simulation radiation pattern gain of circular patch array antenna (λ/2)

Figure 14 is best result of simulated radiation pattern of circular patch array antenna at layer 3 with directivity 8.89 dB and gain 8.05 dB.

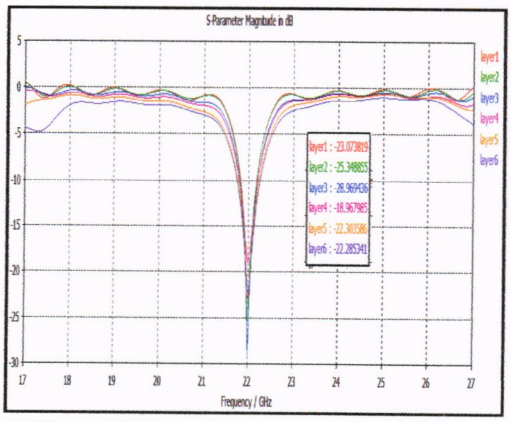

Figure 15: Return loss of circular patch array antenna (λ)

The simulated -10dB return loss of the proposed circular patch array antenna at the distance between two elements is λ shown in figure 15. The higher bandwidth of -10dB return loss obtained at the layer 6 was 513 MHz (from 21.733GHz to 22.246GHz).

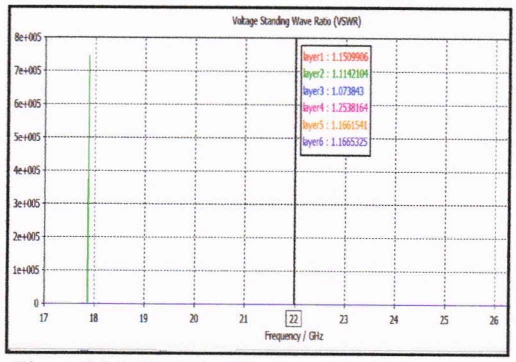

Figure 16: VSWR for circular patch array antenna (λ)

Result voltage standing wave ratio of the array antenna (λ) with multilayer substrate shown in figure 16. At the center frequency 22GHz the best result of VSWR value is 1.07 at layer 3.

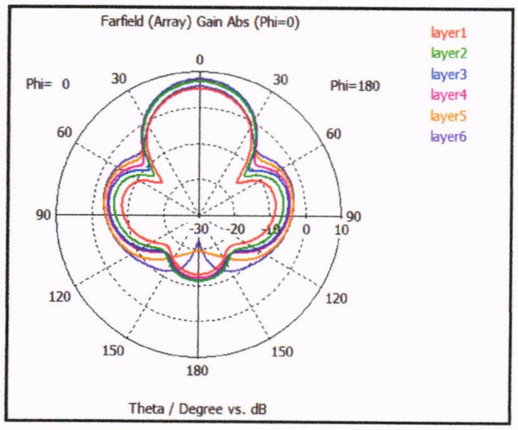

Figure 17: Simulated radiation pattern gain of circular patch array antenna (λ)

The radiation pattern gain result of circular patch array antenna for each layer shown in figure 17. The higher main lobe magnitude (gain) can be obtained at layer 4 is 8.0dB.

Figure 18 show the radiation pattern at 22GHz for layer 4. The simulated radiation pattern gain of 2 by 1 at layer 4 is 8.99dB. According paper [13], the array design antenna generates more intensity and focus at more of radiation.

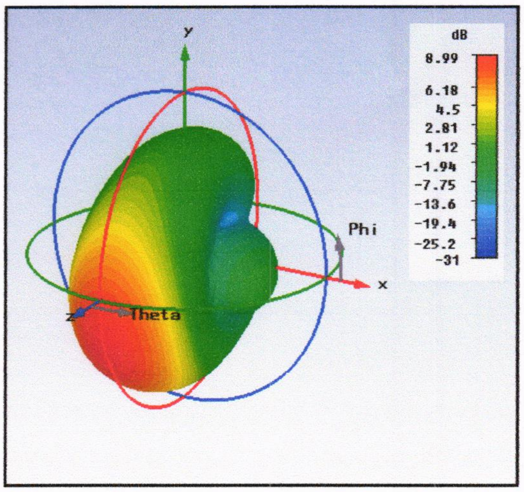

Figure 18: 3D Simulation radiation pattern gain of circular patch array antenna (λ)

Table 5 shows the result of circular patch antenna. It can be conclude that increases the distance of two of element array can increase the value of gain. However, to design antenna array with multilayer substrate must be consider the range frequency for K-band application. [13]

Table 5: Result of Circular Patch Antenna Array

Types of antenna	layer	S11 (dB)	Fr (GHz)	BW (MHz)	VSWR	Zin	Gain (dB)	Directivity (dB)
2×1 Array (λ/4)	1	-30.18	22	356	1.06	50	5.31	8.58
	2	-26.66	22	397	1.10	50	7.13	8.49
	3	-39.02	22	533	1.02	50	7.71	8.39
	4	-27.34	22	644	1.09	50	7.61	8.26
	5	-21.45	22	748	1.18	50	7.47	8.01
	6	-21.98	22	868	1.17	50	7.34	7.79
2×1 Array (λ/2)	1	-33.96	22	353	1.04	50	5.47	9.15
	2	-27.42	22	387	1.09	50	7.53	9.04
	3	-23.24	22	439	1.15	50	8.05	8.89
	4	-34.83	22	523	1.04	50	7.95	8.59
	5	-33.77	22	586	1.04	50	7.47	8.14
	6	-10.84	22	274	1.8	50	6.77	7.30
2×1 Array (λ)	1	-23.07	22	345	1.15	50	5.86	10.28
	2	-25.35	22	356	1.11	50	8.04	10.26
	3	-28.97	22	439	1.07	50	8.87	10.06
	4	-18.97	22	449	1.25	50	8.99	9.85
	5	-22.30	22	502	1.17	50	8.55	9.29
	6	-22.29	22	513	1.17	50	7.47	8.18

D. Design Circular Patch Antenna Using Silver Conductor

The design of antenna with material silver was investigated.

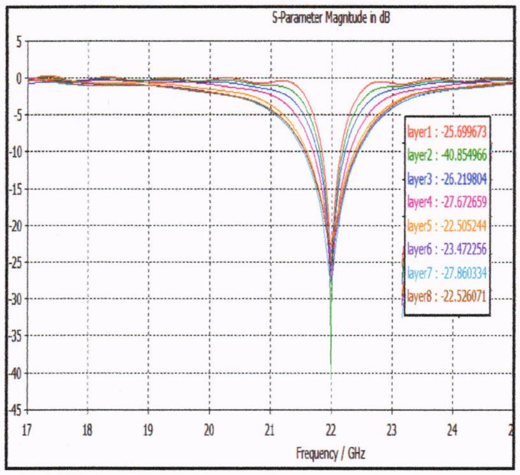

Figure 19: Return loss of circular patch antenna (Silver)

Analysis result of return loss for multilayer substrate microstrip patch antenna with material silver shown in figure 19. After adjusting the radius of patch antenna the return loss results for single layer is -25.70dB and layer 8 is -22.53dB at resonant frequency 22GHz.

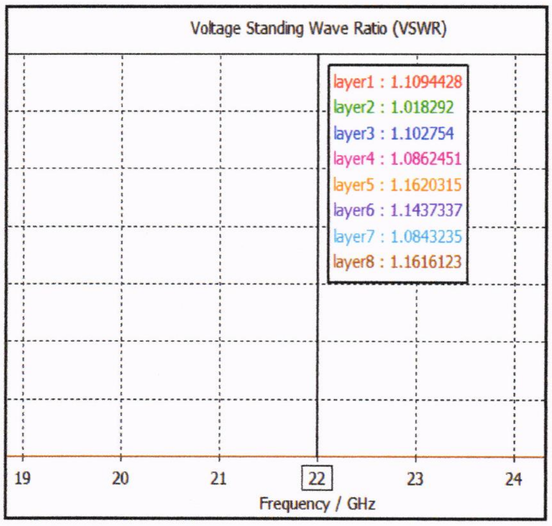

Figure 20: VSWR of circular patch antenna (Silver)

Result of voltage standing wave ratio shown in figure 20. The value VSWR for single layer is 1.11 and 8 layer is 1.16. The ideal VSWR result for antenna design is equal to 1.

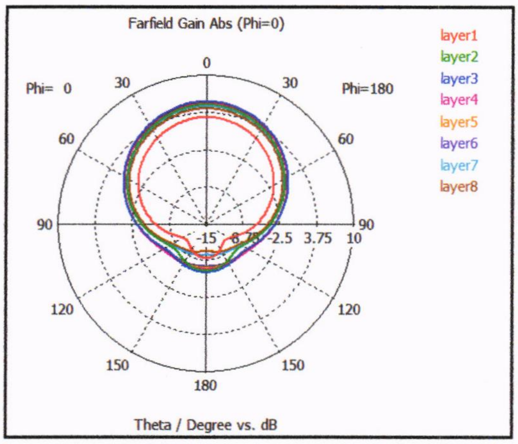

Figure 21: Simulated radiation pattern gain of circular patch antenna (Silver)

A figure 21 shows comparing the each layer for silver conductor, the radiation pattern performs the best result main lobe magnitude at layer 3 was 5.6 dB.

Farfield 3-dimensianal plot for layer 3 is shown in figure 22. It shows that the best result gain for multilayer substrate of the antenna is 5.59 dB at layer 3.

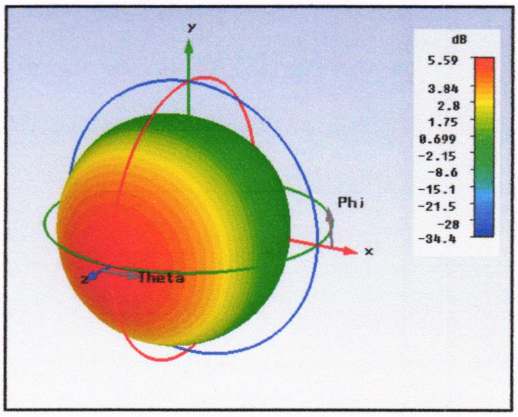

Figure 22: 3D simulated radiation pattern gain of circular patch antenna (Silver)

Table 6 shows comparison result between material copper and silver patch of antenna with LTCC substrate. From this table, the better material to use for patch and ground is silver because the value of gain performance is higher than copper material.

Table 6: Result of Circular Patch Antenna with Different Conductor

Types of antenna	layer	S11 (dB)	Fr (GHz)	BW (MHz)	VSWR	Zin	Gain (dB)	Directivity (dB)
Circular Patch Antenna (Copper)	1	-25.02	22	324	1.11	50	2.93	6.36
	2	-20.20	22	366	1.22	50	4.89	6.31
	3	-26.45	22	439	1.10	50	5.57	6.25
	4	-23.89	22	659	1.14	50	5.36	6.16
	5	-16.77	22	764	1.34	50	5.46	6.13
	6	-24.47	22	785	1.13	50	5.37	6.08
	7	-27.92	22	899	1.03	50	4.81	5.99
	8	-22.46	22	899	1.16	50	4.43	5.88
Circular Patch Antenna (Silver)	1	-25.70	22	313	1.11	50	2.97	6.36
	2	-40.85	22	396	1.02	50	5.04	6.30
	3	-26.22	22	459	1.10	50	5.59	6.24
	4	-27.67	22	615	1.09	50	5.30	6.15
	5	-22.51	22	761	1.16	50	5.41	6.14
	6	-23.47	22	860	1.14	50	5.44	6.10
	7	-27.86	22	928	1.08	50	4.81	5.99
	8	-22.53	22	834	1.16	50	4.43	5.88

E. Design Microstrip Patch Antenna with Parasitic Patch in K-band with LTCC Technology

In paper [15] Tomohiro Seki using parasitic method can be increase the bandwidth of antenna. From his paper, design the 3 layer with 2×2 parasitic array for each layer. In this paper the circular microstrip patch antenna with parasitic patch design for K-band application is presented.

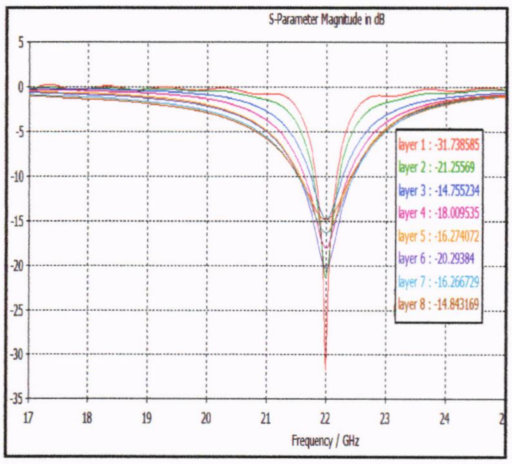

Figure 23: Return loss of circular patch antenna (Parasitic)

The simulated -10dB return loss of the antenna shows in figure 23. From simulation the better result S-parameter obtains is -31.739 dB at 22GHz.

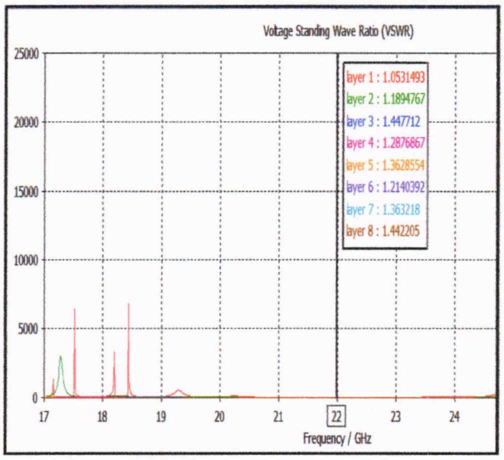

Figure 24: VSWR of circular patch antenna (Parasitic)

Figure 24 shows the voltage standing wave ratio for each layer substrate. From simulation result the best result was obtained is 1.05 at layer 1. A perfect antenna design would have VSWR is equal to 1.

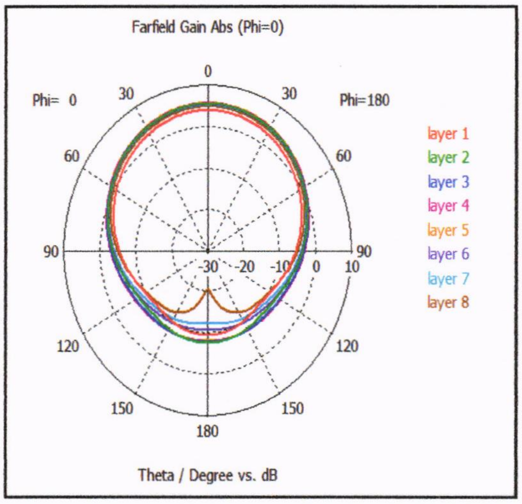

Figure 25: Radiation pattern of circular patch antenna (Parasitic)

The radiation patterns of the antenna from layer 1 until layer 8 are shown in figure 25 at resonant frequency is 22GHz.

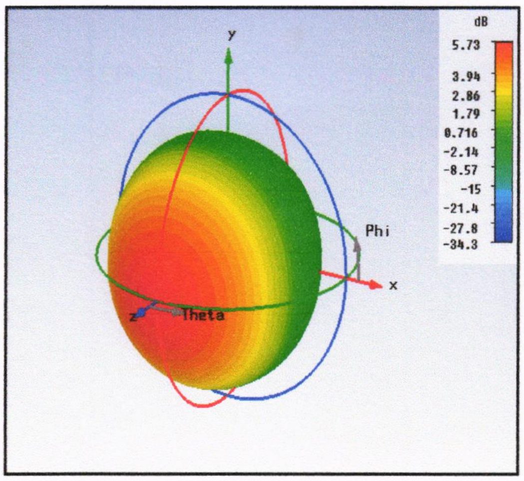

Figure 26: (3D) Radiation pattern of circular patch antenna (Parasitic)

The radiation pattern (3D) for circular patch antenna with parasitic patch shows in figure 26. The figure shows the best result of gain at layer 5 which 5.730 dB when compare with other layer.

Table 7 shows the comparison between with parasitic and without parasitic patch with LTCC technology.

Table 7: Comparison result between with Parasitic and without Parasitic

Types of antenna	layer	S11 (dB)	Fr (GHz)	BW (MHz)	VSWR	Zin	Gain (dB)	Directivity (dB)
Conventional Circular Patch Antenna	1	-25.02	22	324	1.11	50	2.926	6.357
	2	-20.20	22	366	1.22	50	4.891	6.305
	3	-26.45	22	439	1.10	50	5.573	6.247
	4	-23.89	22	659	1.14	50	5.355	6.156
	5	-16.77	22	764	1.34	50	5.463	6.132
	6	-24.47	22	785	1.13	50	5.367	6.083
	7	-27.92	22	899	1.03	50	4.807	5.989
	8	-22.46	22	899	1.16	50	4.429	5.881
Circular Patch Antenna with Parasitic Patch	1	-31.74	22	379	1.05	50	3.969	6.481
	2	-21.26	22	421	1.19	50	5.583	6.411
	3	-14.76	22	537	1.44	50	5.580	6.261
	4	-18.01	22	747	1.29	50	5.678	6.251
	5	-16.27	22	896	1.36	50	5.730	6.242
	6	-20.29	22	926	1.21	50	5.391	6.138
	7	-16.27	22	949	1.36	50	5.278	6.132
	8	-14.84	22	926	1.44	50	5.024	6.143

IV. CONCLUSION

The objective of this project is to investigate microstrip patch antenna with LTCC technology at frequency 22GHz can increase the gain and bandwidth of antenna with different technique for the case study multilayer structure design can increase 33.86% gain and bandwidth 63.95%. The performance for patch array antenna with LTCC technology increases gain 39.88% and 55% bandwidth. All the case was done its effect the result of gain and bandwidth. However, some of the technique the value of gain increases until 3 layer of substrate. That means the best layer to choose this design antenna with this specification as shows at table 1 was layer 3.

V. RECOMMENDATION STUDY AND EFFECT

The performance antenna with LTCC technology can be upgrade by uses several methods to improve performance gain and bandwidth of antenna such as slotted patch antenna with parasitic in K-band application. This type of design it's more suitable for 8 layer LTCC substrate at higher frequency.

VI. ACKNOWLEDGMENT

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VII. REFERENCES

[1] Jayesh V. Gohil and Deepak Bhatia, "Design of 2×1 Circularly Polarized Microstrip Patch Antenna Array for 5.8 GHz ISM Band Applications", *2012 Nirma University International Conference on Engineering,* Nuicone 2012, 06-08 December, 2012.

[2] Neeraj Rao and Dinesh Kumar V., "Gain and Bandwidth Enchancement of a Microstrip Antenna Using Partial Substrate Removal in Multiple-layer Dielectric Substrate", *Progress In Electromagnetics Research Symposium Proceedings, Suzhou, China,* Sept 12-16,2011

[3] Constantine A. Ballanis, *Antenna Theory,* third edition, A John Wiley & Son, Inc, 2005

[4] Sanghamitra Dasgupta, Bhaskar Gupta and Hiranmoy Saha, "Development of Circular Microstrip Patch Antenna Array for Rectenna Application", *IEEE INDICON,* 2010, Kolkata, India December 17-19, 2010

[5] Assia Abdeslam Hanzaz, "LTCC System for High Frequency Application", *Proceedings of the International Multi Conference of Engineers and Computer Scienties,* vol 12, 2012

[6] Wei Quan, Bo Yan, Zhigang Wang, and Jinhong Wang, "An E-type Microstrip Slot Antenna with Parasitic Patches in Ka-band with LTCC Technology", IEEE 2010

[7] Xiaofei, S., W. Zhihong, et al. (2011). "A H-type microstrip slot antenna in Ku-band using LTCC technology with multiple layer substrates", *Mechanic Automation and Control Engineering (MACE),* 2011 Second International Conference on.

[8] Ahmed T. Hussein and Saad Luhaib, " Designing E-shape Microstrip Patch Antenna in Multilayer Structure for WiFi 5GHz Network", *20th Telecommunications forum TELFOR 2013,* Serbia, Belgrade, November 20- 22, 2012

[9] Xiaofei Shi, Zhihong Wang, Hua Su, and Yun Zhao, " A H-type Microstrip Slot Antenna in Ku-band Using LTCC Technology with Multilayer Substrate", 2011 IEEE

[10] Khairi Budayawan, Maryam Isa, Alyani Ismail and Raja Syamsul Azmir, "Implementation Model of Rectangular Microstrip Antenna with Multilayer Air Gap", *2011 IEEE International RF and Microwave Conference,* 12-14 December 2011, Seremban, Malaysia

[11] N. A. Zakaria, A. A. Sulaiman and M. A. A. Latip, " Design of Circular Microstrip Antenna",*2008 IEEE International RF and Microwave Conference Proceedings,* December 2-4, 2008, Kuala Lumpur.

[12] Rina Abdullah, M.T Ali, N. Ismail, S. Omar, N. N. S. N. Dzulkefli, " Multilayer Parasitic Microstrip Antenna Array for WiMAX Application", *2012 IEEE Asia-Pacific Conference on Applied Electromagnetics,* December 2012

[13] S.Holzwarth, J.Kassner, R.Kulke, and D.Heberling, "Planar Antenna Arrays On LTCC-Multilayer Technology",

[14] O.Hazila, S.A. Aljunid, Fareq Malik and A. Sahadah."Performance Comparison between Rectangular and Circular Patch Antenna Array", *Proceedings of 2010 IEEE Student Conference on Research and Development,* 2010

[15] Tomohiro Seki, Naoki Honma, Kenjiro Nishikawa, and Kouichi Tsunekawa, " A 60 GHz Multilayer Parasitic Microstrip Array Antenna on LTCC Substrate for Syestem-on-Package", *IEEE microwave and wireless compronents letters,* Vol. 15, No.5, May 2005