

Comparison of 60 GHz Planar Array Antenna on LTCC and Rogers Substrates for 5G applications

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Abstract- The spectrum currently allocated for mobile service is fragmented into different frequency bands (800, 900, 1800, 2100, 2600 MHz). However, those bands are getting congested and they are unable to satisfy the increasing user demand. The use of millimeter-wave bands appears as an opportunity to implement short range 5G data networks. The principal advantage of using millimeter-wave bands is the large amount of contiguous spectrum that can be used, which allows the delivery of high data rates. However, the technology is not yet so mature as in microwave frequencies. This paper presents array antennas using different materials: low-temperature cofired ceramics (LTCC) and Rogers substrates of a single radiating element, 1x2 and 2x2 array. The 2x2 array antenna achieves a -10 dB bandwidth from 58 to 65 GHz with a peak gain of 10.8 dBi at 60 GHz.

Keywords- Aperture-coupled patch antenna, LTCC, 5G, Antenna array, 60 GHz.

I. INTRODUCTION

Nowadays, consumer device bandwidth requirements are increasing at rapid rates. Historical bands below 3 GHz become crowded, which pushes the development of 5G. At millimeter-wave bands, atmospheric propagation effects can be ignored within around 1 km and antenna size is small enough to be used both in user terminal equipment and base stations [1]. The large band of 7-9 GHz of unlicensed spectrum at 60 GHz appeals with multi-gigabit per second data rates [2]. However, the signal propagation path loss and high packaging integration loss are normally higher than 20 dB [3], which challenge the design of high-gain antennas.

Low Temperature Cofired Ceramic (LTCC) Microstrip patch antennas have been widely used in recent years because of their good characteristics; they are electrically thin, lightweight, low cost, conformable and they possess wider bandwidth compared to conventional patch antennas [4-6]. The first step in designing a microstrip patch antenna is to choose a suitable dielectric substrate. However, microstrip patch antennas have been traditionally fabricated on substrates such as FR4, Rogers and Taconic which typically exhibit permittivities no greater than 10.

LTCC has been regarded as a promising technology for its flexibility in realizing a number of layers and its highly compact vertical integration [7]. LTCC materials also have low permittivity and provide low loss in millimetre-wave band. Since the conductor layers in LTCC materials are screen-printed, aperture coupled microstrip slot antennas [8]

are a good choice to reduce back radiation, which is an inconvenience in mobile communication. At 60 GHz band, microstrip slot antenna is very small and lightweight.

In this paper, we designed some prototypes on Rogers substrates to compare with the results of LTCC at 60 GHz for 5G applications. Six of them with 1x1, 1x2 and 2x2 patches are realized on LTCC. Obtained bandwidths are up to 10% and gains up to 11.1 dBi. Another six are fabricated on substrate, achieving a wide bandwidth of up to 5.2%, with a superior gain of 11 dBi.

II. ANTENNA DESIGN

A. Radiating Element

Fig.1 presents the structure of the proposed aperture-coupled patch antenna using LTCC. The top substrate is a 0.336 mm-thick layer of DuPont 9V7k, the bottom substrate is a 0.112 mm-thick layer of the same material. The relative permittivity ϵ_r of multilayer LTCC substrate is 7.1 and the loss tangent $\tan \delta$ is 0.0009. Fig.2 presents the proposed aperture-coupled patch antenna on Rogers substrates. The top substrate is a 0.127 mm-Rogers 5880, whose relative permittivity ϵ_r is 2.2 and the dissipation factor $\tan \delta$ is 0.0009. It is followed by a 0.050 mm-thick Rogers 2929, whose relative permittivity ϵ_r is 2.94 and the dissipation factor $\tan \delta$ is 0.003. The stacked layers below the Rogers 2929 are respectively a 0.018 mm-thick groundplane with an aperture of 0.4 mm x 0.65 mm and a 0.254 mm-thick Rogers 6010 with high relative permittivity ϵ_r 10.2 to reduce the size of the feeding network, thereby mitigate the back radiation and the losses of the conductor.

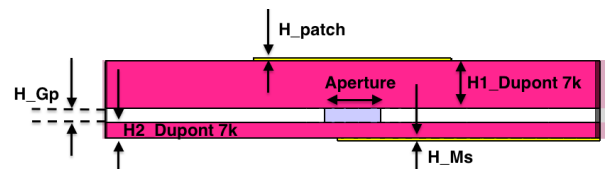


Fig.1. Stack-up of Aperture-coupled patch using LTCC.

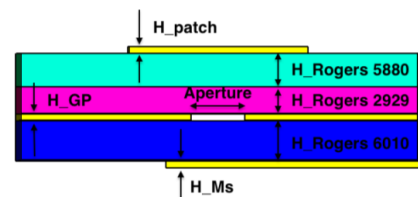


Fig.2. Stack-up of Aperture-coupled patch using Rogers substrate.

B. Antenna Array

To achieve greater directivity and gain, 1x2 and 2x2 array antennas of the previous basic design are proposed. The sizes of each element remain the same. The quarter-wave transformer strip line is used to maintain a 50Ω impedance. However, the discontinuity of the power divider increases the back radiation. To reduce back lobe of radiation pattern, Fig.3 presents the T-junction power divider. The junction angle is optimized in order to distribute the equal power to each radiating element. To reduce the mutual coupling between radiating elements, the optimized value of the inter-element spacing is chosen to be $0.6\lambda_0$.

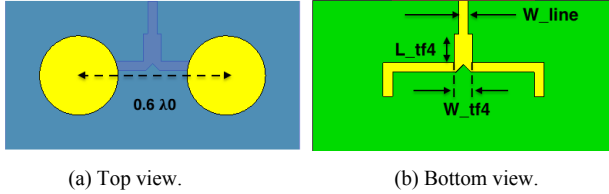


Fig.3. 1x2 array antenna.

Fig.4 presents the feed network of 2x2 array antenna designed to avoid discontinuities. The upper two patches are given 180-degree phase rotation with respect to the pair below, instead of using an equal feeding phase approach.

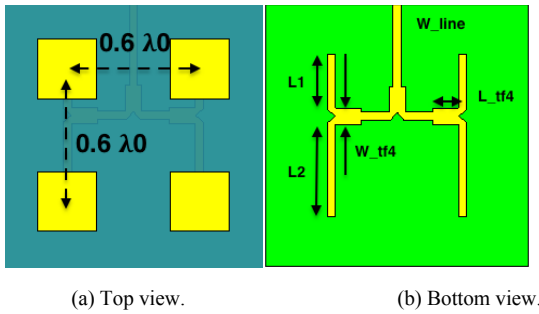


Fig.4. 2x2 array antenna.

Fig.5 presents the phase distribution of the feeding network shown in the Fig.4.

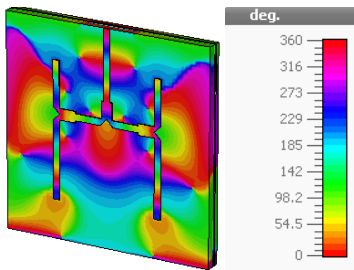


Fig.5. Phase distribution for the feeding network.

Table I presents the optimized dimensions of the proposed array using CST MWS.

Param(mm)	LTCC	Rogers	Param(mm)	LTCC	Rogers
W_line	0.13	0.19	L_tf4	0.65	0.56
L1	0.92	1.25	Aperture	0.4x0.65	0.4x0.65
L2	2.02	2.15	L_patch	0.64	1.34
W_tf4	0.34	0.36	R_patch	0.31	0.79

TABLE I. OPTIMIZED ANTENNA DIMENSIONS.

III. COMPARISON BETWEEN LTCC AND ROGERS

A. Gain

Table II presents a summary of the gain results that have been obtained using Rogers substrates and LTCC approaches. The 2x2 array antenna with circular patches using LTCC and Rogers substrates can achieve a gain of 11 dB at 60 GHz.

Gain (dB)		Circular			Square		
		Ix1	Ix2	2x2	Ix1	Ix2	2x2
LTCC	f=59 GHz	5.36	7.84	10.5	5.45	7.92	10.4
	f=60 GHz	5.43	8.0	10.7	5.41	7.88	10.8
	f=61 GHz	5.46	8.1	11.1	5.36	7.82	10.9
Rogers	f=59 GHz	6.56	7.69	11	6.55	7.8	10.8
	f=60 GHz	6.54	7.36	11.1	6.49	7.6	10.8
	f=61 GHz	6.43	6.89	11	6.34	7.19	10.6

TABLE II. GAIN OF ROGERS SUBSTRATES AND LTCC.

B. Directivity

Table III presents a summary of the directivity results that have been obtained using Rogers substrates and LTCC approaches. The 2x2 element array with circular patches using Rogers substrates can achieve a directivity of 11.6 dB at 60 GHz.

Directivity (dB)		Circular			Square		
		Ix1	Ix2	2x2	Ix1	Ix2	2x2
LTCC	f=59 GHz	5.56	8.25	10.9	5.61	8.14	10.8
	f=60 GHz	5.62	8.32	11.2	5.59	8.1	11
	f=61 GHz	5.65	8.38	11.3	5.55	8.05	11.2
Rogers	f=59 GHz	6.84	8.25	11.5	6.86	8.34	11.4
	f=60 GHz	6.85	7.9	11.6	6.82	8.14	11.4
	f=61 GHz	6.8	7.39	11.6	6.77	7.7	11.2

TABLE III. DIRECTIVITY OF ROGERS SUBSTRATES AND LTCC.

C. Beamwidth

Table IV presents a summary of the beamwidth results that have been obtained using Rogers substrates and LTCC approaches at $\varphi=0^\circ$ and $\varphi=90^\circ$. The 2x2 element array using LTCC achieves narrow beamwidth.

Beamwidth($^\circ$)		Circular			Square		
		Ix1	Ix2	2x2	Ix1	Ix2	2x2
LTCC	$\varphi=0^\circ$	96.1	46.3	42	84.7	46.3	41.7
	$\varphi=90^\circ$	86.2	84.4	33.1	109.4	101.9	32.9
Rogers	$\varphi=0^\circ$	81.2	48.4	45.8	81.0	48.7	46.1
	$\varphi=90^\circ$	86.8	81.7	43.8	89.4	80.7	43.5

TABLE IV. COMPARISON BEAMWIDTH AT 60 GHZ.

D. Side lobe Level

Table V presents a summary of the side lobe level results that have been obtained using Rogers substrates and LTCC approaches at $\varphi=0^\circ$ and $\varphi=90^\circ$. The 2x2 element array using Rogers substrates has lower side lobe level.

SLL at 60 GHz (dB)		Circular			Square		
		Ix1	Ix2	2x2	Ix1	Ix2	2x2
LTCC	$\varphi=0^\circ$	-9.6	-4.3	-6.5	-18.8	-11.9	-6.3
	$\varphi=90^\circ$	-9.6	-4.3	-6.4	-18.9	-11.9	-6.3
Rogers	$\varphi=0^\circ$	-15.5	-7.1	-10.5	-16.2	-8.2	-10.0
	$\varphi=90^\circ$	-11.7	-7.1	-10.5	-11.2	-8.1	-10.0

TABLE V. COMPARISON SIDE LOBE LEVEL AT 60 GHZ.

E. Efficiency

Table VI presents comparison of radiation efficiency that have been obtained using Rogers substrates and LTCC. We can observe that LTCC designs are more efficient.

Radiation Efficiency at 60 GHz(%)	Circular			Square		
	1x1	1x2	2x2	1x1	1x2	2x2
LTCC	95.4	92.9	91.6	96.1	95.0	91.9
Rogers	93.7	88.9	88.0	92.4	88.5	87.0

TABLE VI. COMPARISON RADIATION EFFICIENCY AT 60 GHZ.

F. Reflection coefficient S_{11}

Fig.6 presents the S_{11} curves of 2x2 antenna arrays of circular or square patches using Rogers substrates and LTCC.

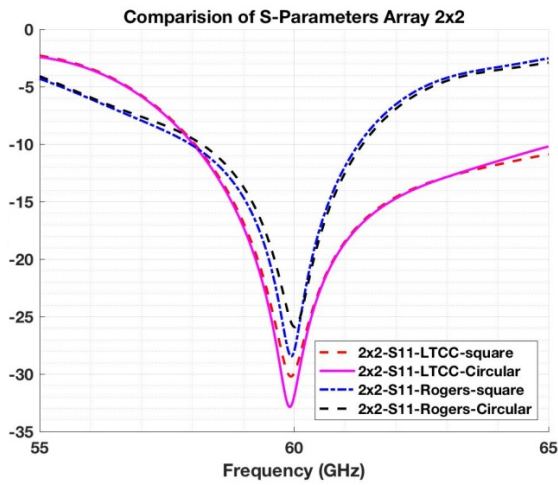


Fig.6 . 2x2 Array Comparison of S_{11} .

Table VII presents a summary of bandwidth results that have been obtained using Rogers substrates and LTCC approaches. The 2x2 element array with square patches using LTCC can achieve -10dB bandwidth from 58 to 65 GHz.

$S_{11} < -10$ dB (GHz)	Circular			Square		
	1x1	1x2	2x2	1x1	1x2	2x2
LTCC	58.1 - 62.1	58.6 - 65	58 - 65	57.2 - 62.6	57.0 - 62.4	58 - 65
Rogers	58.3 - 61.3	58.1 - 61.9	58.1 - 61.4	58.4 - 61.2	58.7 - 62.4	58.0 - 61.3

TABLE VII. COMPARISON BANDWIDTH AT 60 GHZ.

G. Comparison of Radiation Pattern

Fig.7 and Fig.8 present the gain comparison of 1x2 radiation pattern array antenna of square and circular patches at 60 GHz using Rogers substrates and LTCC respectively. The crosspolar component using Rogers substrates are higher than using LTCC.

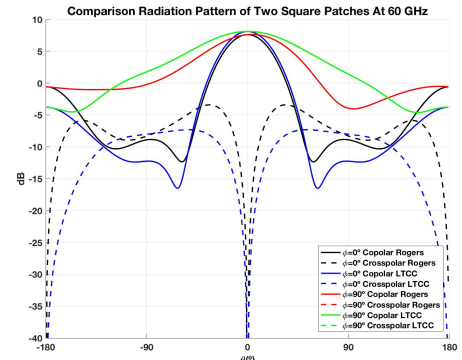


Fig.7 . Comparison of 1x2 radiation pattern array antenna of square patches at 60 GHz.

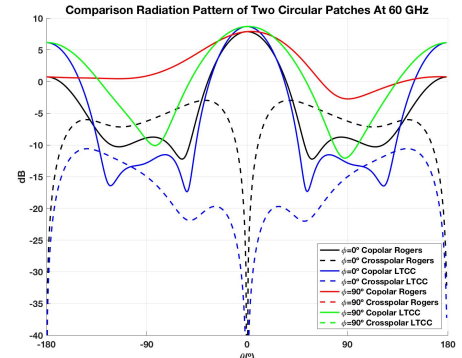


Fig.8 . Comparison of 1x2 radiation pattern array antenna of circular patches at 60 GHz.

Fig.9 and Fig.10 present the gain comparison of 2x2 radiation pattern array antenna of square and circular patches at 60 GHz using Rogers substrates and LTCC respectively. The radiation pattern is very similar. However, the crosspolar component using Rogers substrates are higher than using LTCC.

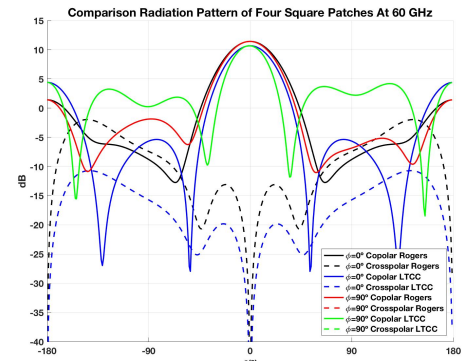


Fig.9 . Comparison of 2x2 radiation pattern array antenna of square patches at 60 GHz.

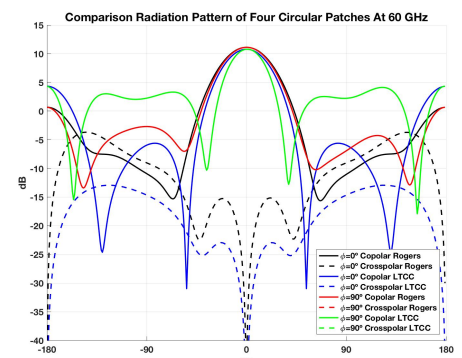


Fig.10 . Comparison of 2x2 radiation pattern array antenna of circular patches at 60 GHz.

H. Radiation Pattern en 3D of 2x2 Planar Array.

Fig.11 and Fig.12 present the 2x2 radiation pattern array antenna of square and circular patches at 60 GHz using Rogers substrates.

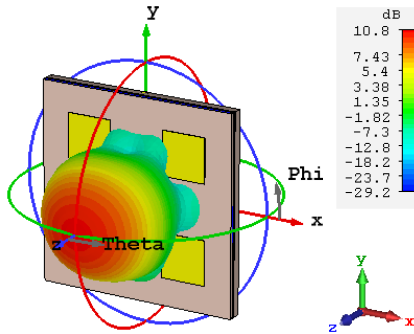


Fig.11. 3D Radiation pattern of 2x2 array antenna of square patches at 60 GHz.

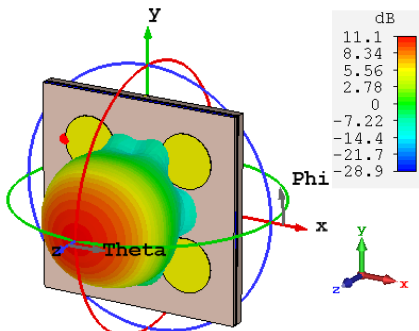


Fig.12. 3D Radiation pattern of 2x2 array antenna of circular patches at 60 GHz.

Fig.13 and Fig.14 present the 2x2 radiation pattern array antenna of square and circular patches at 60 GHz using LTCC.

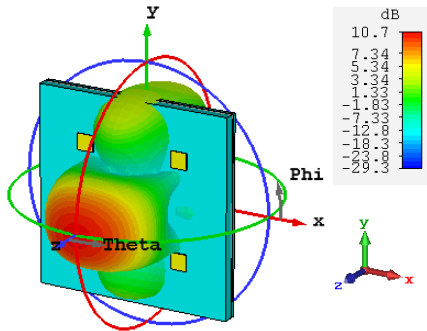


Fig.13. 3D Radiation pattern of 2x2 array antenna of square patches at 60 GHz.

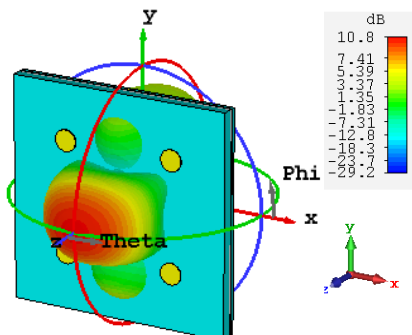


Fig.14. 3D Radiation pattern of 2x2 array antenna of circular patches at 60 GHz.

IV. CONCLUSION

Planar antenna arrays are presented at 60 GHz with two different materials: LTCC and Rogers substrates. From the results of simulation, we can find that LTCC has a better performance at 60 GHz band in comparison to Rogers substrates in the aspects of S-parameter, bandwidth, losses, radiation efficiency and crosspolar. However, the Rogers substrates can achieve higher gain and directivity. The 2x2 element array with circular patch using Rogers substrate can achieve a maximum gain of 11.1 dB at 60 GHz. Prototype measurement results will be presented in URSI 2017.

V. ACKNOWLEDGMENT

The simulations done in this work have been carried out using CST Studio Suite under a cooperation agreement between Computer Simulation Technology and Universidad Politécnica de Madrid. This work has been supported by the project ENABLING5G, “Enabling Innovative Radio Technologies for 5G networks” (TEC2014-55735-C3-1-R) of the Spanish Research and Development National Program and by the project S2013/ICE-3000 SPADERADAR-CM of the Madrid Region Government.

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