Vehicular mm-Wave Array for Smart Handover

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***Abstract*- The emergence of new technologies such as autonomous vehicles and high data rate 5G networks requires advanced antenna types that are capable of fulfilling requirements for highly demanding wireless communication links. The array of microstrip-fed slot-coupled patches is one such type of antenna that provides low return loss and good transient behaviour for broadband applications. A compact size slot-coupled patch antenna subarray and its phased array is proposed in this paper. Two different substrates Rogers TMM4 and Green Tape™ 951 Low Temperature Co-Fired Ceramic (LTCC) are considered for the fabrication of microstrip feedline. The feedline is fabricated on the respective substrates and then mounted on a Rogers RT/duroid 5880 laminate. Ground planes are used on both the front and backside of the antenna array. The antenna is operating in a range of 24.25 GHz - 29.5 GHz. A Smart Array is proposed in this paper which has a good performance in terms of antenna gain and scanning property for 5G application in Smart handovers.**

I. INTRODUCTION

The demand for efficient antenna performance has increased rapidly due to the rise in user density and high data rate requirements. Modern communication technologies now-a-days require wideband antennas that are capable of achieving stable radiation pattern and beam steering capabilities with high gain. Millimetre wave spectrum provides a promising solution for the increasing user traffic [1]. Because of the high free-space propagation losses of millimetre wave propagation, antenna array, which can increase the antenna gain and provide beam steering capabilities needs to be used. Since the antenna array behaves as a directional antenna, to establish point-to-point communication between mobile terminals and base stations, the phased array antenna should be adopted. On the other hand, the compact size of the array element is a growing demand to increase the isolation of adjacent elements. Hence, the Low Temperature Co-fired Ceramic (LTCC) technology is proposed as an attractive way to realize compactness. However, the LTCC material exhibits high dielectric permittivity, which will make antenna bandwidth narrower [2].

In this work, the antenna is designed to cover the potential 5G bands reserved by the World Radiocommunication Conference (WRC) organized by ITU [3] that are in Europe, in China (24.25-27.5 GHz) and in the USA, Japan, and others (27.5-28.5 GHz). Further, a compact size LTCC-based couple-fed slot antenna element and its phased array antenna are proposed for smart handover applications.

II. SINGLE ELEMENT DESIGN AND ANALYSIS

The first part of the design deals with the radiating element and its corresponding feeding. Two options are considered for fabricating the microstrip feeding, the first one is etching on a Rogers TMM4 substrate ($\varepsilon_r = 4.5$, thickness of 0.27 mm), while the second one the feedline is fabricated on LTCC made of Green Tape™ 951 ($\varepsilon_r = 7.7$, thickness of 0.2 mm). In both cases the feedline is mounted on a Rogers RT/duroid 5880 laminate ($\varepsilon_r = 2.2$, thicknesses of 0.84 and 0.8 mm respectively) where the microstrip patch is printed. The proposed broadband antennas are designed in three main steps. First, the microstrip feedline is optimized for 50 Ω for both substrates. As a second step, the antenna patch is also optimized at the required impedance, and both the optimized feedline and the patch are put together to form a final single element. Layout and dimensions of the single antenna element for both the substrates are depicted in Fig.1 and Table I.

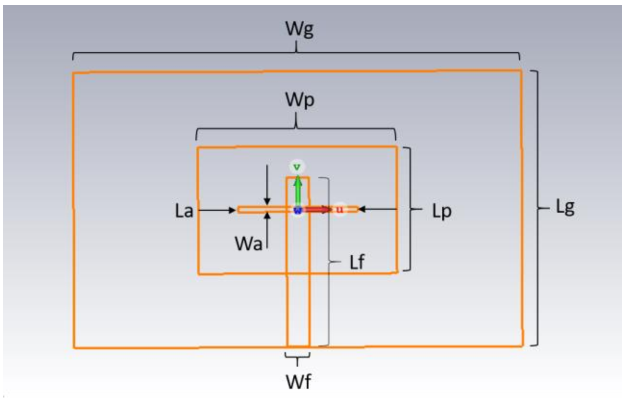

Fig. 1. Single element layout

TABLE I

Lengths	Values (Rogers TMM4)	Values (LTCC)
Patch length (Lp)	2.76 mm	2.8 mm
Patch width (Wp)	4.3 mm	4.4 mm
Slot length (La)	2.65 mm	2.19 mm
Slot width (Wa)	0.11 mm	0.11 mm
Feed length (Lf)	3.75 mm	2.87 mm
Feed width (Wf)	0.5 mm	0.24 mm
Ground Length(Lg)	8.36 mm	8.36 mm
Ground Width(Wg)	9.8 mm	9.9 mm

The return loss of a single element in both designs is offering an impedance bandwidth from 24.25 GHz to 29.5 GHz, as depicted in Fig. 2(a), 2(b).

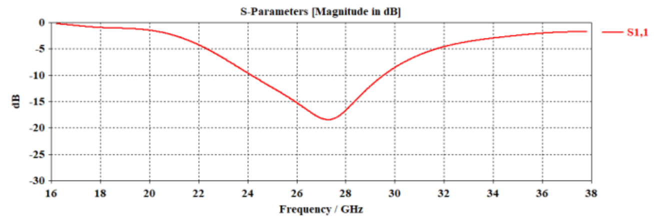

Fig. 2(a). S_{11} for a single element with Rogers TMM4 Substrate layer

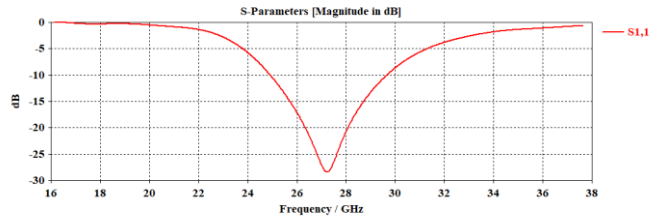

Fig. 2(b). S_{11} for a single element with LTCC Substrate layer

Hence, it can be seen that the antenna elements are properly matched at the proposed frequency bands. The three-dimensional Gain plots of the single antenna elements at the central frequency are illustrated in Fig.3 (a), (b).

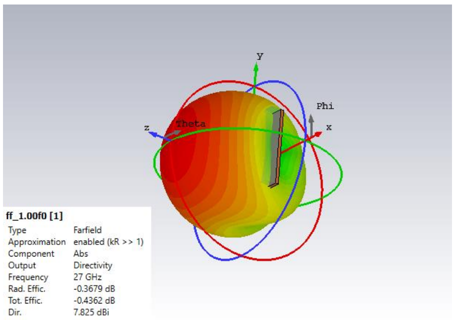

Fig. 3(a). Gain for a single element with Rogers TMM4 Substrate layer

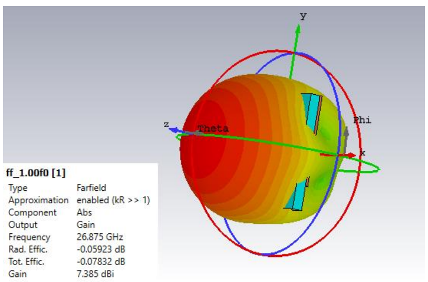

Fig. 3(b). Gain for a single element with LTCC Substrate layer

III. ANTENNA ARRAY DESIGN AND ANALYSIS

A first corporate subarray antenna was designed using four antenna elements. The inter element distance between any two adjacent elements of the array is $\sim 0.6\,\lambda_0$ (λ_0, being the free space wavelength at the central frequency of 27 GHz), that provides enough reduction of the mutual coupling between elements. In order to improve the matching conditions through all the frequency bands T junctions, miter bendings [4] and quarter-wave transformers have been introduced. The dimensions for the corporate feed layout is presented in Fig.4 and Table II.

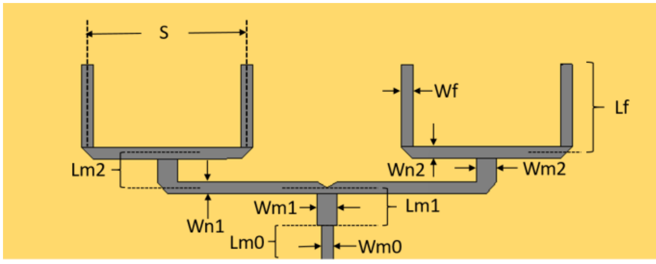

Fig. 4. Corporate feed layout

TABLE II

Lengths	Values for Rogers TMM4	Values for LTCC
S	6.84 mm	5.8 mm
Lf	3.75 mm	2.87 mm
Wf	0.5 mm	0.24 mm
Lm0	1.53 mm	1.19 mm
Wm0	0.5 mm	0.24 mm
Lm1	1.48 mm	1.16 mm
Wm1	0.85 mm	0.44 mm
Lm2	1.48 mm	1.16 mm
Wm2	0.85 mm	0.44 mm
Wn2	0.5 mm	0.24 mm
Wn1	0.5 mm	0.24 mm

This compact structure is designed to be mounted on the PCB of a mobile device. The S-parameters of the proposed antenna arrays for both substrates is shown in Fig.5 (a), (b).

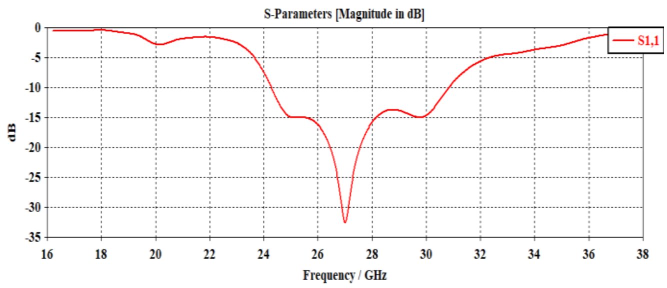

Fig. 5(a). S_{11} for array element with Rogers TMM4 Substrate layer

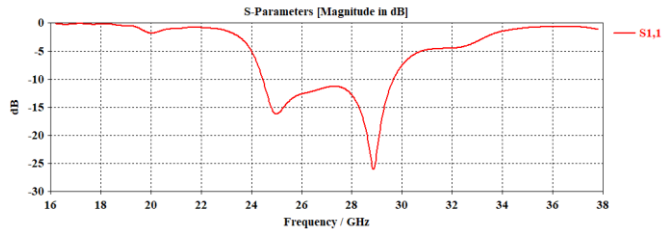

Fig. 5(b). S_{11} for array element with LTCC Substrate layer

It can be seen from Fig.5 that the antenna array has good performance within the entire frequency range of 24.25 GHz to 29.50 GHz. The three-dimensional Gain plots of the antenna arrays at the central frequency is illustrated in Fig.6 (a), (b).

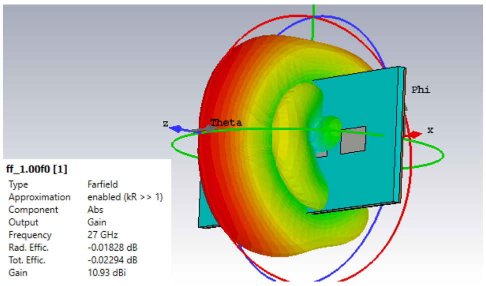

Fig.6 (a) Radiation Pattern for the array element with Rogers TMM4 substrate layer

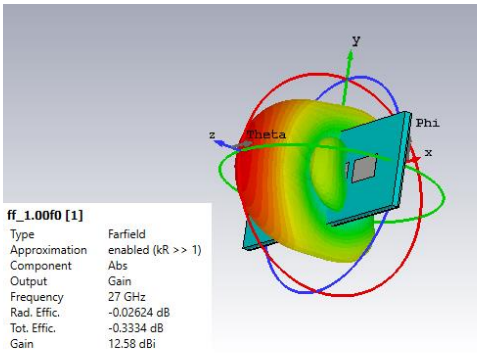

Fig.6 (b) Radiation Pattern for the array element with LTCC substrate layer

Hence, the base-antenna of the array behaves as a moderate directional antenna that could eventually be improved into the final array adding a back ground reflector. A very important criterion for evaluating the scanning property of the antenna array is to see if the side lobes of the 3D radiation patterns are small for bigger scanning angle. A scanning angle close to $\pm 20°$ has been obtained. Both designs (Rogers and LTCC substrates exhibit good S_{11} plots in the desired frequency range. But, when it comes to fabrication, the LTCC technique may be easier for fabrication. Moreover, it significantly cuts down the material and manufacturing costs.

IV. SMART ARRAY BEAMFORMING

One of the requirements of the 5G communication system is that the antenna array can realize beam forming and scanning so the point-to-point communication between a base station and mobile terminal could be optimized.

There are several factors to consider when designing an antenna array composed of fixed subarrays. Typically an antenna array design includes parameters such as array dimensions, single element spacing, the spatial arrangement of the elements, element tapering, and finally the effects of mutual coupling between the elements are important to characterize before the final design is implemented. In addition to this, when dealing with subarrays proper tilings and feeding becomes an additional issue. Once an initial configuration of the array design is complete, architectural partitioning can be iteratively evaluated against the overall system performance goals.

In this paper, a Smart array antenna is proposed. The design consists of 4x1 subarrays and each subarray is a corporate array antenna implemented in the previous section. Beamforming techniques based on complex weighting vectors can be applied on the signals that feed each subarray. Beamforming allows control of the signal for both amplitude and phase evaluated at the subarray level. An Integrated Device Technology (IDT) chip [5] will be used to apply the necessary subarray weights and perform the required beamforming through the chip's inbuilt SPI module which includes registers for each channel to control phase and gain biases. This chip is also integrated with On-chip Wilkinson combiners and a 5-bit DAC outputs to drive an (optional) external LNA or PA. Smart array architecture is presented in Fig.7.

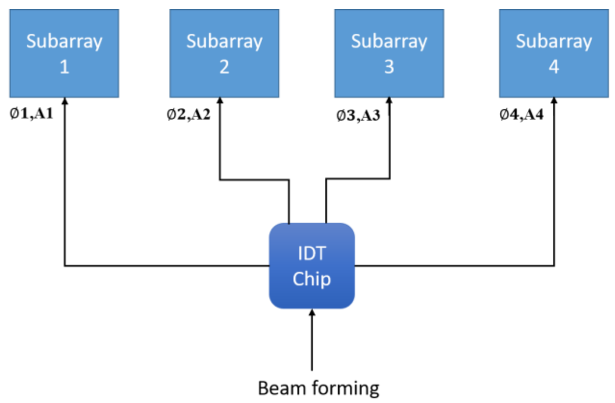

Fig.7 Smart array architecture

The distance between the sub arrays centers is ~2.4 λ_0 (borders of the sub-arrays is kept at ~0.6 λ_0) that provides enough reduction of the mutual coupling between subarrays. The three-dimensional radiation pattern plots of the total array considering that all the subarrays are excited with equal amplitudes (1,1,1,1) and phases (0°,0°,0°,0°) respectively at the central frequency is illustrated in Fig.8.

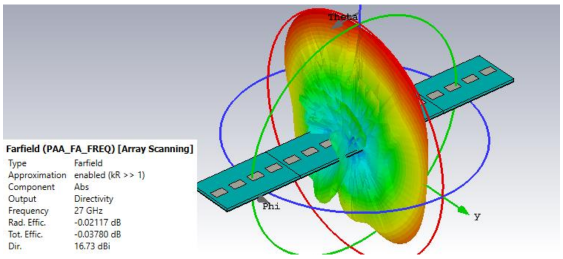

Fig.8 Gain for Smart array

The above plot in Fig.8 is highly directive and has a narrow angular beamwidth (3dB) of 5º. For the Smart handover application a wide angular beamwidth is required. Hence, we perform beamshaping by modifying amplitudes and phases as presented in Table III.

TABLE III

Modified weights	Amplitudes	Phases
Subarray1	1	0º
Subarray2	2	60º
Subarray3	2	60º
Subarray4	1	0º

The angular beamwidth (3dB) for the subarray, unmodified Smart array and the modified Smart array according weights in table 3 is 20º, 5º, 13º respectively and is represented through gain vs elevation angle plots in Fig.9 (a), (b), (c).

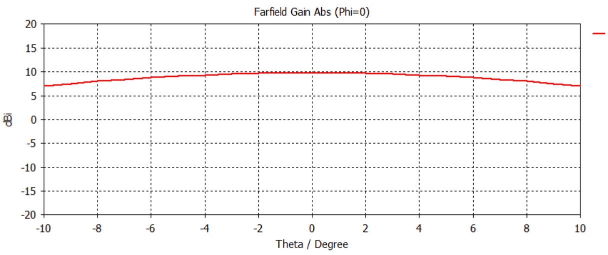

Fig.9 (a) Gain vs Elevation angle plot for Subarray

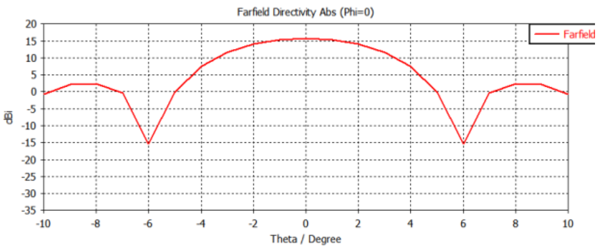

Fig.9 (b) Gain vs Elevation angle plot for Unmodified Smart Array

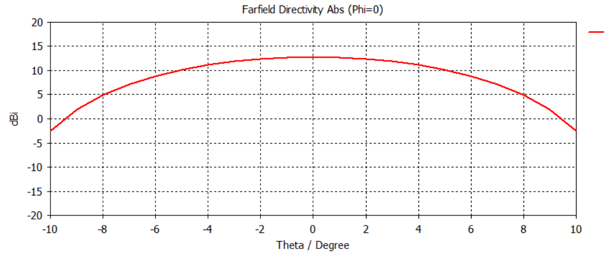

Fig.9 (c) Gain vs Elevation angle plot for Modified Smart Array

This Smart array model can be extended to support various beam patterns using Fourier Synthesis technique. The weights are updated adaptively to reshape the radiation pattern depending on the user velocity and distance to the base station. The technique uses Machine Learning algorithms such as Kalman filter algorithm [6] to track the user velocity and use the data to switch between narrow beams for pedestrian users and wide beams for users moving at high speeds (trains/buses) in order to handle handovers efficiently in extreme Doppler shift conditions.

V. CONCLUSIONS

A compact size LTCC-based millimetre-wave phased array antenna system with good radiation performance within the frequency range from 24.25 GHz to 29.50 GHz is presented. The antenna array is based on the microstrip slot-fed antenna element. And the proposed Smart array has good performance in terms of antenna gain and scanning property within a wide frequency range, it is a good candidate for 5G millimetre wave application in Smart handovers.

ACKNOWLEDGEMENTS

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REFERENCES

[1] T. S. Rappaport, F. Gutierrez, E. Ben-Dor, J. N. Murdock, Y. Qiao and J. I. Tamir, "Broadband Millimeter-Wave Propagation Measurements and Models Using Adaptive-Beam Antennas for Outdoor Urban Cellular Communications," in IEEE Transactions on Antennas and Propagation, vol. 61, no. 4, pp. 1850-1859, April 2013.

[2] U. Ullah, N. Mahyuddin, Z. Arifin, M. Abdullah, A. Marzuki, "Antenna in LTCC technologies: a review and the current state of the art", *IEEE Antennas Propag. Mag.*, vol. 57, no. 2, pp. 241-260, Apr. 2015.

[3] Mobile broadband: the patch to 5G.ITU/SPBPU seminar for CIS and Europe. "Development of the modern radiocommunication ecosystem". 6-8 June 2018 st.petersburg.

[4] G. Matthaei, L. Young and E.M.T. Jones, Microwave Filters, Impedance-Matching Networks and Coupling Structures, Artech House, 1080, pp. 203, 206.

[5] https://www.idt.com/us/en/products/rf-products/phased-array-beamformers/f5280-transmitreceive-half-duplex-ic-25ghz-31ghz

[6] Kalman, R. E. (1960). A New Approach to Linear Filtering and Prediction Problems. Transaction of the ASME - Journal of Basic Engineering, 35-45.