Millimeter-Wave (mmW) Antenna Design for 5G Massive MIMO applications

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***Abstract*—**The EM simulator, HFSS, was used to simulate two types of antenna design for 5G 38 GHz band application. Two identical mmW LTCC microstrip antenna arrays were built for experimental validation. The results demonstrated a return loss better than 15 dB and a peak gain higher than 6.5 dBi at frequencies of interest, which verified the feasibility of the design concept.

Keywords— low-temperature cofired ceramic (LTCC), microstip patch antenn, tapered-slot antenna.

I. Introduction

5G cellular networks applying massive MIMO technology promise revolutionary improvements in network capacity, data rates and latency, with greatly increased network flexibility and efficiency[1]. Systems operating at mmW regime is now being considered to fully realize the 5G version with much additional spectrum. The frequency bands around 28GHz and 39 GHz, which are driving much of today's 5G NR development. Consequently, the trend poses the challenges in designing and testing the mmW antenna array. In this paper, two type antenna designs are investigated numerically and the 64-element microstrip massive MIMO is built by using LTCC for experimental study, showing very impressed performance.

II. Design

In this study, both microstrip patch and taper-slot antenna design are investigated for 5G applications.

II.1 Microstrip Patch Antenna Design

A perpendicular coaxial transition is most suitable for mmW applications, because this method's measurements indicate a return loss better than 14 dB and an insertion loss better than 0.4 dB from DC to 40 GHz [2]. Therefore, the coaxial-fed microstrip patch printed on the LTCC substrate was applied to the MIMO design. The design concept are verified using HFSS, as shown in Fig. 1.

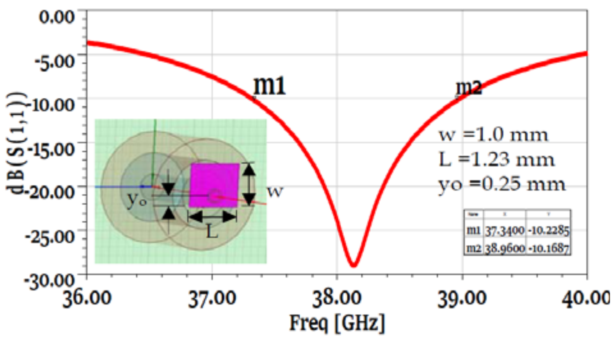
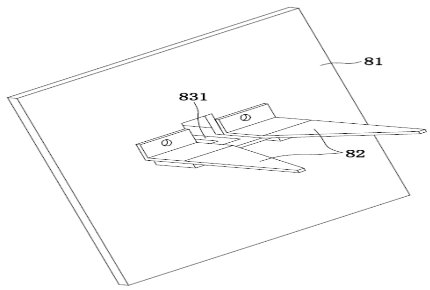


Fig1. The simulated S_{11} of a single microstrip antenna patch; the inset shows the simulation layout.

II.2 Tapered-Slot Antenna Design

The proposed microstrip line fed tapered-slot antenna design (Fig.2a) was simulated and plotted in Fig.2b, showing the magnitude of S11 (dB) less than -16dB over frequency regime from 35GHz to 41 GHz.



(a)

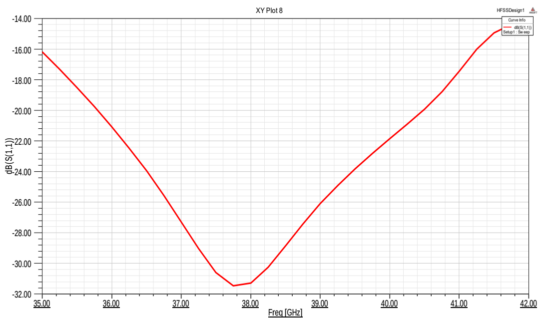


Fig. 2. (a) The layout of the tapered-slot antenna design; (b) the simulated result of the proposed tapered-slot antenna design.

From the numerical study results of two antenna design, one can observe that the tapered-slot antenna design shows well return loss performance but more difficulty in manufacture. Thus, we decide to use microstrip patch antenna for experimental study of the mmW massive MIMO.

III. Experimental Study

The mmW MIMO antenna comprising 64-element perpendicular coax-fed microstrip patch antennas that resonate at 38 GHz (Fig. 3) is integrated with eight subarrays, each comprising eight microstrip patches printed on the RF substrate with a thickness of 15 mil. The element spacing of the array is arranged in a triangular lattice (dx = 5.5 mm; dy = 8.5 mm) to obtain a beam scanning azimuth angle of $\pm$ 25° when maintaining maximum room to allocate the modified k-connector.

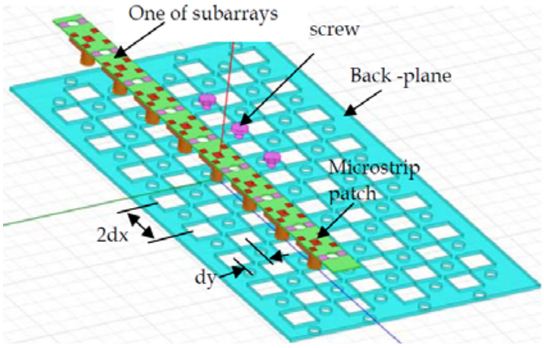


Fig. 3 Design concept of the proposed mmW microstrip antenna array.

A key parasitic of perpendicular transition is the inductance triggered by ground currents that must flow around the circumference of the coax outer conductor to reach the underside of the microstrip section. Therefore, the substrates with the printed microstrip patches were soldered on a modified k-connector with four ground pins on the four corners of the connector base to secure the antenna (Fig.4a) .

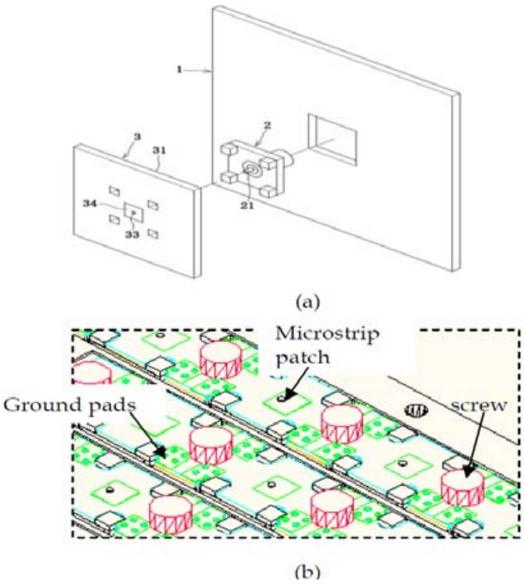


Fig. 4. (a) Design of a single mircostrip patch. (b) Closed look of the assembled array

After all of the subarrays were integrated, nine screws were used to fix the RF substrate of each subarray onto the back-plane of the array (Fig. 4.b). Subsequently, the array was placed in a tin stove for wave soldering reflow. After all subarrays were soldered on the back-plane of the array, all of the screws were removed.

To experimentally verify this design approach, two identical mmW microstrip patch antenna arrays were built for testing. The measurement setup was established by connecting one patch with two mmW microstrip patch arrays, which were placed face-to-face 19.5 cm apart (Fig. 5).

Fig. 5. Measurement setup established by connecting one patch to two arrays.

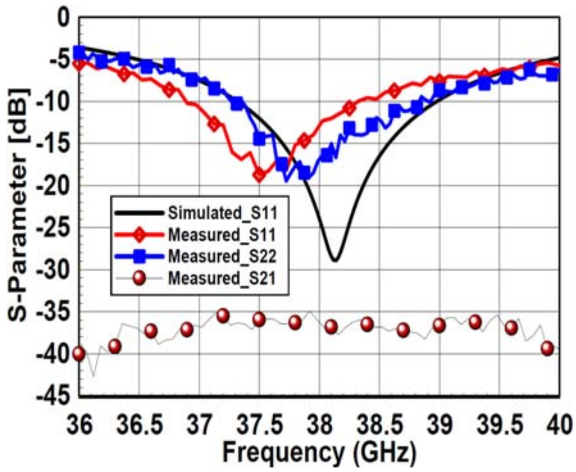


Fig. 6. Measured S-parameters of the test setup (Fig. 4).

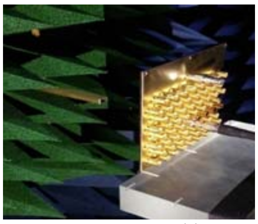
Two-port S-parameters were measured using the Rohde & Schwarz ZVA40 vector network analyzer (Fig. 5). The simulated S_{11} (solid line in Fig. 6) was computed using a single microstrip patch to reduce computing time but the measured S_{11} (the solid line with diamond shapes) and S_{22} (the solid line with rectangular shapes) corresponded to the center element of two microstrip antenna arrays (Fig. 3).

Next, the Friis power transmission formula [3] was used to calculate the maximum antenna power gain (in the central forward direction of the antenna)

$$\boldsymbol{G_r G_t} = \boldsymbol{G}^2 = \left(\frac{\boldsymbol{P_r}}{\boldsymbol{P_t}}\right)\left(\frac{4\pi \boldsymbol{R}}{\lambda_0}\right)^2 = |\boldsymbol{S}_{21}|^2\left(\frac{4\pi \boldsymbol{R}}{\lambda_0}\right)^2, \qquad (1)$$

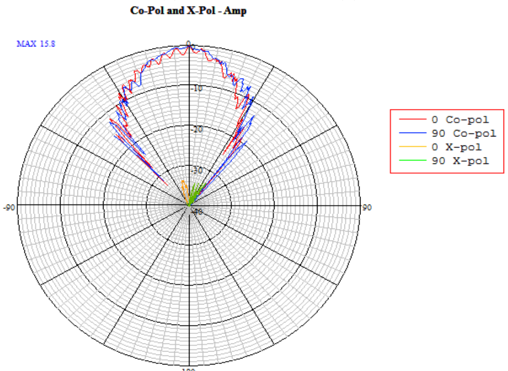
where G_r and G_t are the power gains of the receiving and transmitting antennas, respectively, and P_t and P_r are the transmitted and received powers, respectively. Because the two antennas are identical, $G_t = G_r = G$, and the power ratio P_r/P_t is the measured direct transmission coefficient $|S_{21}|^2$, which was obtained using the vector network analyzer. By substituting the measured $|S_{21}|$ into (10), the measured maximum antenna power gain was about 6±1.2 dBi against frequencies ranging from 36.0 to 40 GHz.

Finally, the radiation pattern at the center element of the prototype mmW array was measured at OIT near- and far-field test ranges.Figs. 7(a) and (b) display photographs of the tested setup, and Fig. 7(c) illustrates plots of the measured co-pol and cross-pol for the 2D radiation pattern cuts in the x-y and x-z planes at 37.75 GHz.



(a)

(b)



(c)

Fig. 7 Amplitude(a) and phase (b)photographs of the tested setup of the LTCC massive MIMO antenna array; (c) Measured 2D co-/cross-pol radiation patterns

I. CONCLUSION

In this paper, a millimeter wave 64-element LTCC microstrip antenna array with high gain and well return loss is presented. The experimental study confirms that a microstrip patch antenna array with a high radiation gain performance in an mmW range is feasible for future 5G applications

References

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