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# Flexible and Scalable Additively Manufactured Antenna Array Tiles for Satellite and 5G Applications Using A Novel Rugged Microstrip-to-Microstrip Transition

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***Abstract*—This paper presents a novel flexible and scalable tiled antenna array operating at Ku band, with individual patch antenna tiles and a corporate feeding network achieved by microstrip-to-microstrip transition. Both simulation and measurements for a 2 by 2 array show good matching and radiation at center frequency. The basic structure of the four tiles array can be scaled to any larger array of 2^N elements by duplicating the feeding element. The feed line is flipped to make connection to each patch antenna. This design can be applied to scalable active phased-array radars and support future demand for high volume 5G communication.**

***Keywords—Phased Array; Inkjet Printing; 5G Communication***

## I. Introduction

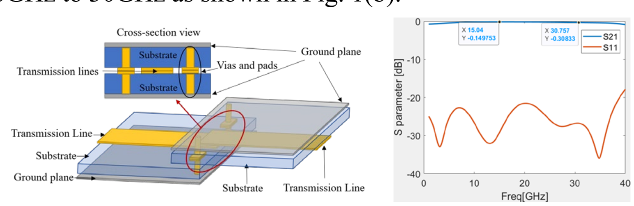
In recent years, there has been growing demand for faster data rates and greater bandwidth for 5G communication systems such as cellular networks, Internet of Things and massive MIMO [1]. Large antenna arrays are required to support these applications. However, such arrays are usually bulky and heavy, which will bring in high power assumption and more challenges in manufacture. Especially in modern SATCOM system, the battery capacity can limit the maximum size of antennas and typical phased array antennas in use are difficult to integrate on small UAVs. In order to achieve lightweight feature and maintain high gain ability, tiled array structure has been proposed and become popular in active electronically scanned radars [2]. Integrated tiled structure can reduce the cost for phased array in millimeter wave 5G communication systems to a great extent [3]. Most designs in past research have all the tiles integrated in one board with multilayer material stackup, which are difficult to assemble or scale to other frequencies. It has also been reported that the inevitable small gaps between the tiles due to manufacturing constraints can have negative impact on radiation pattern [4].

Instead of a large planar structure, the tiled array proposed in this paper consists of many small unit cells, and a specially designed feeding structure is used to connect each tile by a “flip chip” microstrip to microstrip interconnect that can be directly soldered together. This simple structure with standalone elements displays higher scalability and flexibility, that enables the array to change the dimension based on different requirements and to conformally wrapped around a curved surface such as the wings of a small UAV. The fabrication process includes inkjet printing to create the antenna pattern in a convenient and low-cost manner. These advantages largely expand the applications of this tiled structure in 5G communication. The presented tiled array is operating at 15GHz in Ku band that is widely used for satellite communication. In the following sections, the design and fabrication of this array is introduced, and the simulation and measured results of this array are compared and analyzed.

## II. Design and Fabrication

### A. Microstrip-to-Microstrip Transition

The proposed array has separate feedlines and radiation elements to achieve scalable feature. This means each tile needs to be physically connected to the feedlines. A straightforward solution is adapted by flipping over the feedlines to make physical contact to the tile, which is essentially a microstrip-to-microstrip transition, as shown in Fig. 1(a). Two vias are placed aside the transmission line to connect two grounds. Square pads are added at the top of vias to reduce difficulty in soldering and provide higher stability. The distance from the vias to each edge is simulated and optimized in CST Microwave Studio. The dimension of the vias and the pads are chosen to support a wideband transmission with insertion loss less than 0.3dB from 10GHz to 30GHz as shown in Fig. 1(b).




(a) (b)

Fig. 1 Microstrip transition structure. (a) 3D schematic and cross section view (b) Simulation result of insertion loss

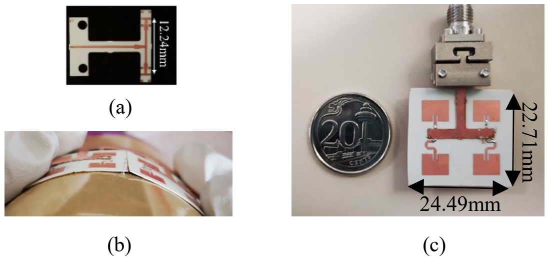



Fig. 2 Fabricated array tiles. (a) Basic feedline structure (b) Demonstration of flexibility (c) Size comparison for a 2 by 2 array

### *B. Patch Array Design*

The basic corporate feeding structure and a fully fabricated 2 by 2 element array are shown in Fig .2. Each unit tile in the array is an individual square element of an inset-fed microstrip patch antenna operating at 15 GHz. Extra transmission lines are added as 180-degree phase shifters to compensate the out-of-phase performance of two of the patches. The corporate feeding network is composed by symmetric T-junctions. The quarter wave transformer is designed to have inversed tapered shape to leave more space for soldering pads and provide equal power division to two branches. Both the feedline and the phase shifter are first optimized in Keysight ADS then integrated into the antenna model in CST to perform EM simulation. This four-element array with feedlines can be extended to any 2^N element array by simply copying the whole structure at the feeding point. Fig .2(b) shows an example of 8 element array bended over a cylinder, where separate cells share the total stress and enhance the flexibility.

### *C. Fabrication*

The patch elements are fabricated on a 0.254mm thick Rogers 4350B substrate with a relative permittivity of 3.66. First the vias and the outline of the feedline are milled out by LPKF ProtoMatS62. Then silver paste is used to fill the holes, following with 30mins bake under 160 C° in the oven. To form the antenna pattern, SU8 is inkjet printed on the copper layer of the substrate as photoresist, which is later exposed under UV light to cure. Finally, the tiles are fully emersed in ferric chloride for 30 mins to etch off the uncovered copper. Heat can be applied to expediate the process. When the etching stops, the board is washed by clean water and acetone is used to etch off the SU8 top layer. The feedline is fabricated using the same method on the same material with 0.168mm substrate thickness. Once the prototypes of both the tiles and the feedline are ready, they can be soldered together by aligning the pads.

## III. RESULTS AND DISCUSSION

The simulation and measured results are shown in Fig. 3 and Fig. 4. For the 4 tiles array, the measured S11 maintains below -10dB at center frequency but shows a frequency shift from 15GHz to 15.3GHz compared with simulation. The deviation in fabrication, especially the alignment of the pads, could be the main factor affecting the return loss. The maximum bandwidth in simulation is only 240MHz, mainly because of choosing a low dielectric constant substrate with small thickness. This can be improved by using flexible materials with higher permittivity.

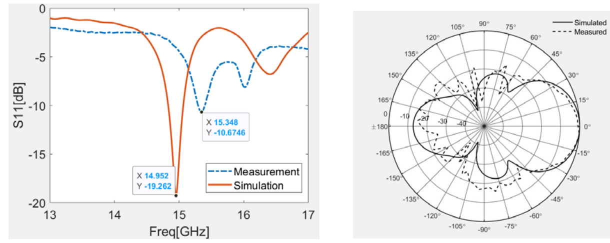



Fig. 3. Measured and simulated results of S11 and radiation pattern

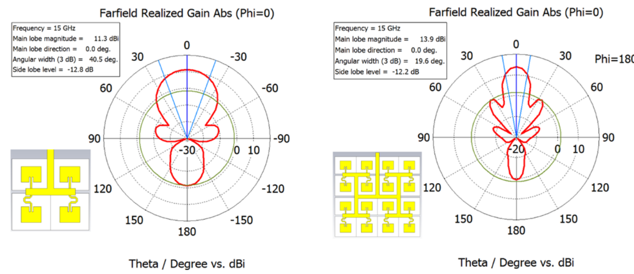



Fig. 4. Realized gain of a 4 tile array and a 16 tile array in simulation

The measured radiation pattern matches well with simulation and the maximum gain at 15GHz is 11.3dBi. The initial simulation for a 16-tile array also shows good radiation and low side lobe level. This indicates high scalability. Overall, this tiled array structure displays acceptable performance in both simulation and measurements. It also has good flexibility to be installed at a curved surface. This structure can be widely applied into phased array systems and each unit tile can be replaced by any form of sub array, so that a large array with fewer elements and smaller surface area can be constructed.

## IV. CONCLUSION

This paper presents a flexible and scalable tiled antenna array operating in Ku band. It is the first demonstration of a tiled array using microstrip to microstrip transition. The proposed structure and fabrication process can be easily adapted to higher frequencies for 5G applications by simply modifying the patch dimension. However, at a frequency higher than 60GHz, the width of the feedlines and the size of the patches can be very small and the difficulty in soldering may increase. Future work can focus on optimizing the microstrip transition and integrating this structure into larger flexible phased array systems.

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