60 GHz Band 2×4 Dipole Array Antenna Using Multi Stacked Organic Substrates Structure

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1. Introduction

Wireless systems using license-free 60 GHz band have been focused as Gbps ultra-high speed data rate short range communication. Beamforming techniques based on array antennas have been employed to obtain high directional antenna gain [1]. In order to realize an array antenna in millimeter-wave frequency range, the accuracy of positioning of the antenna elements becomes considerably important. Conventional 60 GHz band beamforming antennas have used a patch array antenna configuration [1], [2] . Since the patch antenna is patterned on a substrate, high accuracy of the positioning is obtained. These patch array antennas realize a main beam in the vertical direction of the substrate. In order to realize a main beam in the horizontal direction of the substrate, 1×4 dipole array antenna was developed and beam scanning in the azimuth plane was possible [3]. For 2-dimensional (azimuth/elevation) beam scanning, 3×2 vivaldi array antenna using multi-layered substrate was reported [4]. It showed the 2-dimensional beam scanning function, but a high antenna gain could not be obtained. Since the antenna elements were fabricated in a multi-layered substrate, the antenna elements were placed very close (nearly 1/25 λ_0) in elevation direction and it caused relatively low antenna gain.

In this paper, a novel 2×4 dipole array antenna is proposed which enables 2-dimensional (azimuth/elevation) beam scanning in the horizontal direction of the substrate. The copper ball interconnection technology is employed to stack several organic substrates and secure an appropriate element distance (nearly 1/2 λ_0) in the elevation direction. This technology has been widely used in ball grid array (BGA) package. Planar dipole antennas are employed to form a beam in the horizontal direction of the substrate. To show that the proposed array antenna configuration is valid for beamforming in the horizontal direction of the substrate, 6 sets of fixed beam dipole array antennas are designed, fabricated, and evaluated. The proposed antenna shows that multi stacked organic substrates structure can be repeatedly fabricated with sufficient accuracy.

2. Antenna Configuration

Figure 1 shows a configuration of 2×4 dipole array antenna using multi stacked organic substrates structure. MEGTRON6 which is provided by Panasonic Electric Industry Co., is employed as multi-layered organic substrate. Value of relative permittivity of 3.5 and dielectric loss tangent of 0.002 at 2 GHz are used. Multi-layered substrates S1, S2, S3, S4, and S5 are stacked along the z axis by the copper ball interconnection technology to keep flat and stable spaces between the substrates. Also copper balls serve as the signal transmission line of 60 GHz band [5]. In modern technology, copper ball and multi-layered substrate can be manufactured with sufficient accuracy. Specifically, the accuracy for both copper ball and multi-layered substrate is approximately ±10μm. Therefore, multi stacked organic substrates structure can also be fabricated with sufficient accuracy. The common RF input port is set at the left end of the substrate S3 in Fig. 1. The length of the substrate S3 is longer than substrates S2 and S4 so that the 1.85 mm coaxial connector can be connected. Grounded co-planar waveguide (GCPW) was selected as an feed circuit. 2×4 planar array is constituted in xz plane by placing 4 elements on each multi-layered substrate S1 and S5. Since ground exists behind elements, main beam is radiated to the opposite direction

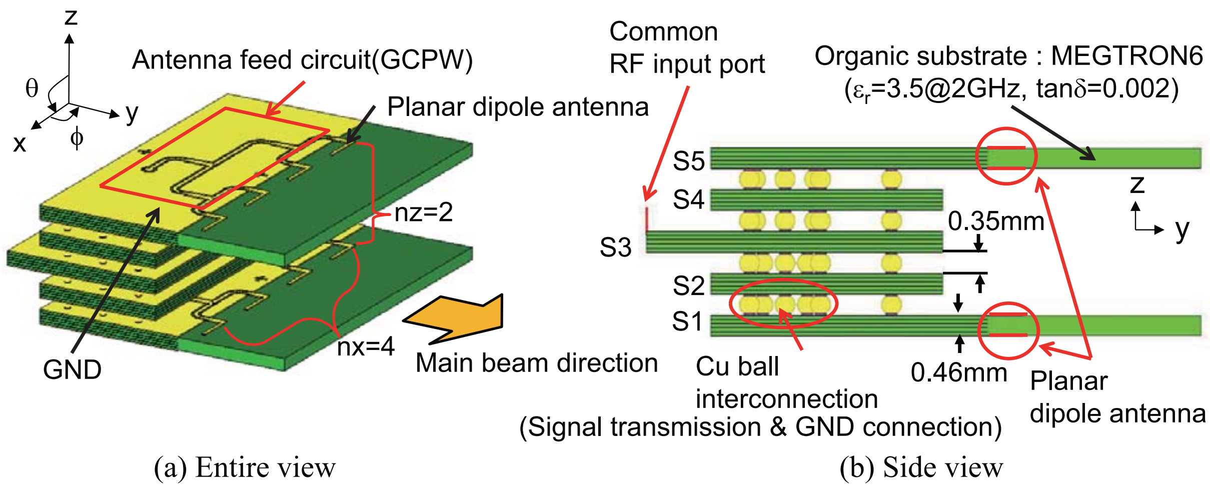


Figure 1: Configuration of 2×4 dipole array antenna using multi stacked organic substrates structure

of the ground; it is radiated in the +y direction as in Fig. 1. The center-to-center element distance in the x direction and z direction are defined as dx and dz, respectively. dx must be more than the length of a planar dipole antenna physically. Since the element length was 0.48 λ_0 [6], dx is set to 0.50 λ_0. λ_0 is defined as free-space wavelength at 60 GHz. We assume the diameter of a copper ball and the thickness of the multi-layered substrate to be 0.35 mm and 0.46 mm, respectively. Hence, we decided to use 5 multilayer substrates so that dz may approach 0.5 λ_0 which is the same value as dx. As a result, dz is set to 0.35 mm (copper ball diameter) ×4+0.46 mm (substrate thickness) ×4=3.24 mm=0.65 λ_0.

3. Antenna Design for Beam Steering Experiments

To verify beam steering, proposed dipole array antennas with fixed beam are designed. Generally, some phase shifters are needed for beam steering. For simplicity, in this work, a fixed phase difference feed is realized by varying the feed line length to each element. Therefore, several designs of fixed beam dipole array antennas are required for verifying beam steering. In this paper, 6 sets of dipole array antennas with fixed beam are designed. Specifically, (px, pz)=(0°, 0°), (180°, 0°), (225°, 0°), (225°, 135°), (135°, 0°), (135°, 225°). px and pz are defined as the phase difference between adjacent elements in the x and z direction, respectively.

4. Fabrication and Evaluation

6 sets of dipole array antenna with fixed beam are fabricated and evaluated. The distance between the elements in the vertical direction (dz) of fabricated array antenna depends on the manufacturing accuracy of multi stacked organic substrates structure. Confirming the manufacturing accuracy of multi stacked organic substrates structure is essential for proposed array antenna configuration. In addition, to confirm the validity of proposed array antenna for phased array beamforming applications, radiation patterns of fabricated dipole array antennas with fixed beam are simulated and measured.

Figure 2 shows a photograph of a fabricated dipole array antenna. Figure 2(a) is an entire view. Figure 2(b) is a side view. dz of 6 samples are measured to confirm the manufacturing accuracy of dz in multi stacked organic substrates structure. Table 1 shows the measurement results of dz for 6 samples. The variation in dz is smaller than approximately 30 μm. The measurement results show that multi stacked organic substrates structure can be fabricated with sufficient accuracy at millimeter-wave band. Figure 3 shows a CT scan image of a fabricated dipole array antenna. Figure 3(a) is an entire view and Fig. 3(b) is an enlargement view of the copper ball interconnection part, marked in (a). By CT scan, it is confirmed clearly that the signal line and ground between substrates are properly soldered to the copper balls. Figure 4 shows simulation and measurement results of radiation pattern

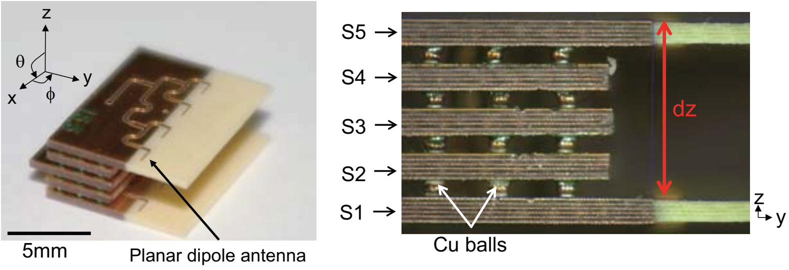
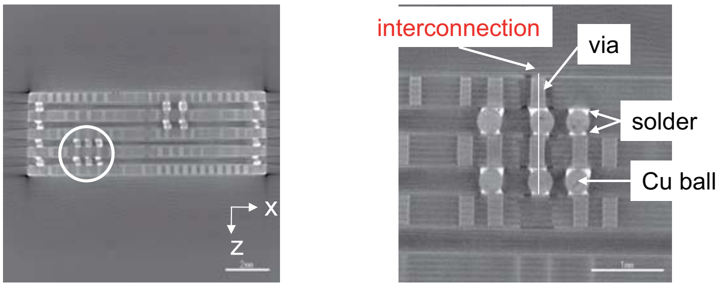


Figure 2: Photograph of fabricated dipole array antenna : (a) entire view and (b) side view

Table 1: Measurement results of element distance dz for 6 samples

	dz (Measurement)	dz (Design)
Sample 1	3.23mm	3.24mm
Sample 2	3.24mm	
Sample 3	3.24mm	
Sample 4	3.26mm	
Sample 5	3.25mm	
Sample 6	3.23mm	



(a) (b)

Figure 3: CT scan image of fabricated dipole array antenna : (a) entire view and (b) enlargement view of the copper ball interconnection, marked in (a)

for 6 sets of phase difference at 60 GHz. Radiation pattern as θ is varied from 0° to 360° for specific ϕ. Each ϕ is the maximum radiated direction. The measurement results agree with simulation results. These simulation and measurement gains include the loss of the feed circuit (approximately 1.6 dB). Therefore, the measured gain of un-scanned array which excepted the feed circuit loss is 14 dBi. Also the measured gains of scanned arrays are more than 8 dBi. The measurement results show that beam scan with relatively high directivity compared to the gain of the single element (7.6 dBi) [6] is possible in relatively wide range for both the azimuth plane and the elevation plane.

5. Conclusion

In this paper, we propose a 60 GHz band planar array antenna configuration which enables 2-dimensional (azimuth/elevation) beam scanning in the horizontal direction of the substrate for beam-forming application. Proposed array antenna is fabricated using copper ball interconnection technology. The variation in the element distance in the vertical direction is smaller than approximately 30 μm. By CT scan, it is confirmed that the signal line and ground between substrates are properly soldered to the copper balls. These results show that the array antenna using multi stacked organic substrates structure can be repeatedly fabricated with sufficient accuracy. Radiation patterns for 6 sets of dipole array antenna with fixed beam are simulated and measured. The measurement results agree with simulation results and show that beam scan with relatively high directivity is possible with relatively wide range for both the azimuth plane and the elevation plane. Therefore, the array antenna using multi stacked organic substrates structure is valid for beamforming in the horizontal direction of the substrate.

Acknowledgments

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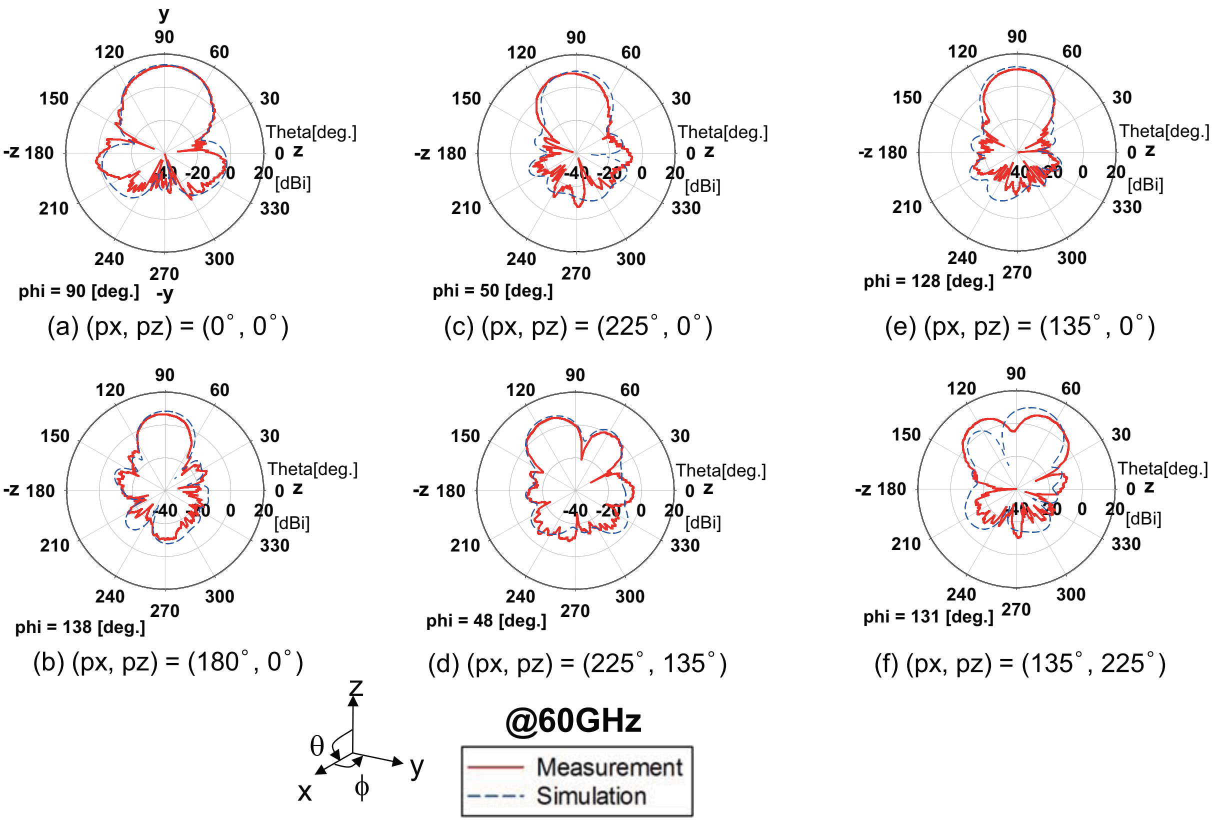

Figure 4: Simulation and measurement results of radiation pattern in 6 sets of phase difference (include the loss of the feed circuit)

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