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40GHz Cavity-Backed Slot Array Antenna

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1. Introduction

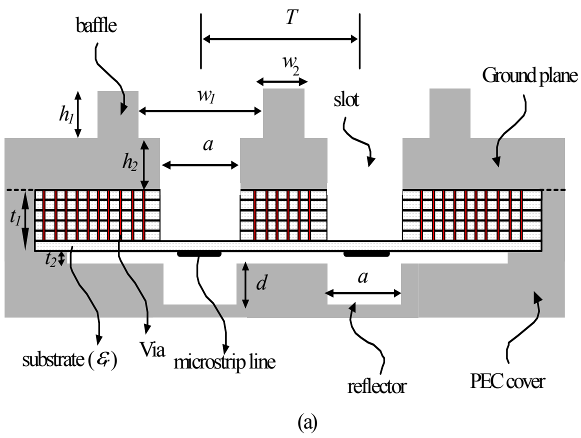
Based on the basic functions (oscillation, amplification and frequency conversion functions) of active circuits, Active Integrated Antenna (AIA) technology can be largely divided into the oscillator & amplifier type and the frequency conversion & simple transmission type. In order to integrate active circuits, planar antennas are commonly used [1].

Implementation technologies of AIA include an oscillator-integrated antenna [2], transmission transposition AIA [3] and direct conversion receiver [4] as a result of diverse types of research. The oscillator-integrated antenna comes in a smaller size than previous ones, and operates at low costs and with low losses thanks to the loading function for active elements on top of the basic radiation function.

We designed the antenna structure by changing all of the design parameters. In addition, we also propose a multi-layer antenna using Low Temperature Co-fired Ceramic (LTCC) technology to integrate active circuits. Widely applied to high-frequency passive elements, LTCC technology literally corresponds to a co-fired processing technology that simultaneously produces metals and their ceramic boards at low temperature, and its results.

2. 2x2 Array Antenna Design

Based on design parameters of the microstrip line, we designed the structure of the cavity-backed 2x2 slot array antenna by applying the design method of 2-slot cavity-backed single-slot antennas to the feed line on the LTCC board.



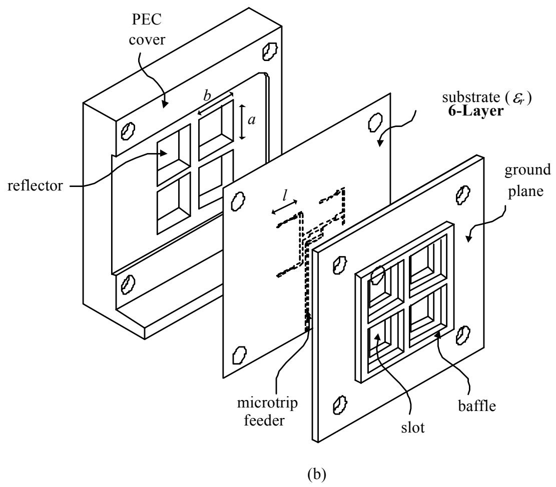


Figure 1 : Geometry of a cavity-backed 2x2 slot array antenna with LTCC substrate : (a) side view of a 2x2 slot array antenna and (b) perspective of a 2x2 slot array antenna

In addition, we designed array antennas by using such design parameters and various types of antenna by adjusting the height of baffles and depth of reflectors, and described characteristics by comparing them with fundamentally designed antenna.

ISBN: 978-4-88552-223-9 C3055©IEICE

Fig. 1. shows the structure of a cavity-backed 2x2 slot array antenna. We added transformers for an array antenna, and selected appropriate design parameters to design the antenna.

Table 1. outlines parameters of the designed cavity-backed 2x2 slot array antenna. Similar to the design of a single antenna, we designed the antenna with the initial design values, and obtained the optimal design values by simultaneously changing parameters of the antenna and running the simulation.

Table 1 : Design parameters of the cavity-backed 2x2 slot array antenna with LTCC

parameters	Design values(mm)	Initial values
a	3.49	$\approx \lambda_0/2$
b	5	$\approx \lambda_0/2$
d	0.082	$\approx \lambda_g/4$
t1	0.63	-
t2	0.5	-
h1	2	-
h2	1	-
w1	6	$\approx \lambda_0$
w2	1	-
l	1.95	$\approx 0.6\lambda_g$

3. Fabrication and Measurement of the 2x2 Slot Array Antenna

For this thesis, we produced an antenna with a different baffle height and different reflector depth from the optimally designed antenna in order to measure the characteristics of the cavity-backed 2x2 slot array antenna with the new structure.

(a) (b) (c) (d)

Figure 2 : Fabricated cavity-backed 2x2 slot array antenna with LTCC : (a) top side LTCC substrate, (b) baffle with LTCC substrate, (c) reflector with v-type connector and (d) finished 2x2 array antenna

Since the frequency of the cavity-backed 2x2 slot array antenna is at 40GHz, the precision process is required to manufacture the antenna. Fig. 2. illustrate the LTCC-applied cavity-backed 2x2 slot array antenna that we manufactured.

Fig. 3. shows the return loss of the cavity-backed 2x2 slot array antenna. The impedance bandwidth reached approximately 28.6% (31.3～43.3GHz) in the simulation, and 32.3% (34.5～48.1GHz) in the measurement. In the graph, the measurement moved downward as a whole, compared with the simulation, as a result of losses on the LTCC substrate.

Table 2. summarizes the simulation and measurement results of the impedance bandwidth when the height of baffles (h1) and depth of reflectors (d) were changed for the cavity-backed 2x2 slot array antenna using the LTCC board.

The simulation and measurement results demonstrated movement of the resonance frequency. This is attributable to several reasons. First of all, it is difficult to create a structure that accurately follows the design measurements during the antenna production process like the production of a Teflon applied antenna[5]. Namely, it is extremely difficult to accurately carve a rectangle while making reflectors on the PEC cover, and slots and baffles in the ground plane. In addition, errors stem from mounting boards during the LTCC process since aerial substances are generated due to various problems arising from connection of the connector and the air gap between the inductive board and the metal conductor, as the inductive board, ground plane, PEC cover and connector must be manually assembled.

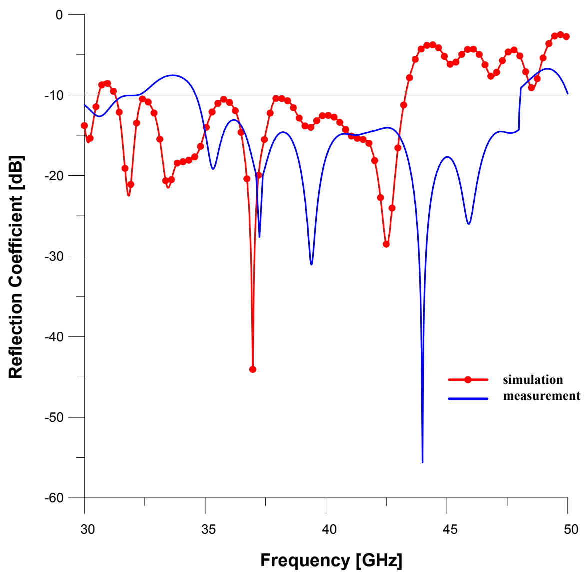


Figure 3 : Simulated and measured -10dB return loss results of the cavity-backed 2x2 slot array antenna

Table 2 : Comparison of the impedance bandwidths of the cavity-backed 2x2 slot array antenna

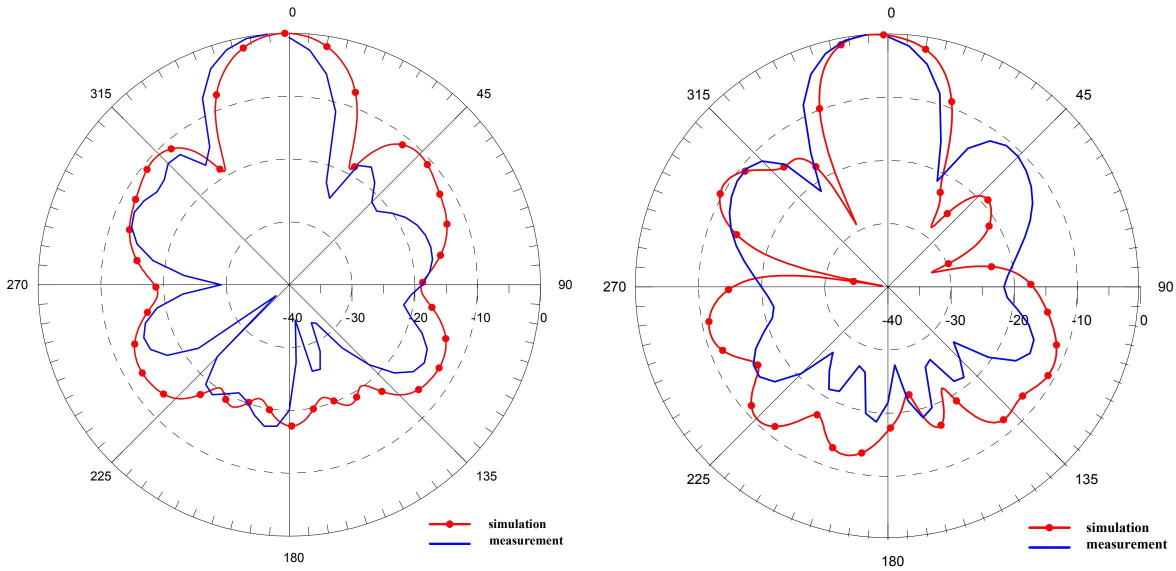
Antenna Type	Return loss bandwidth	
	Simulation	Measurement
h1=0mm, *d*=0.882mm	31.3～43.3GHz (28.6%)	31.3～41.3GHz (23.8%)
h1=1mm, *d*=0.882mm	31.2～43.3GHz (28.6%)	31.4～41.5GHz (24%)
h1=2mm, without PEC cover	38.6～43.3GHz (11.3%)	31.2～50GHz (44.8%)
h1=2mm, *d*=0.882mm	31.3～43.3GHz (28.6%)	34.5～48.1GHz (32.3%)
h1=3mm, *d*=0.882mm	31.3～43.3GHz (28.6%)	33.2～48.6GHz (36.7%)
h1=2mm, *d*=1.5mm	38.6～43.2GHz (10.9%)	38.7～43.2GHz (10.7%)

Fig. 4. shows simulated and measured radiation pattern results of the 2x2 cavity-backed slot array antenna. And LTCC applied cavity-backed 2x2 slot array antenna compared the simulation results with the measurement results on the gain obtained by changing the height of the baffles and depth of reflectors.

Comparing the case at h1=0mm and d=0.882mm with the case at h1=1mm and d=0.882mm, the gain of the antenna recorded approximately 11.48dBi and 14.31dBi, respectively. At h1=0mm (without a baffle), the side lobe increased compared to the case with h1=1mm (the baffle has a height of 1mm) because the gain diminished due to the electromagnetic coupling caused between the slots when radiation occurred at the antenna, and the side lobe increased. The back radiation remained almost the same in both cases.

The gain of the antenna reached 10.74dBi in the case of h1=2mm without a PEC cover, and 15.23dBi in the case of h1=2mm and d=0.882mm. When there was no PEC cover, there was considerable back radiation, reducing the gain.

The gain at h1=3mm and d=0.082mm posted 14.34dBi and 14.87dBi at h1=2mm and d=1.5mm. Comparing these measurement results with the initially designed antenna (h1=2mm and d=0.882mm), the optimal antenna gain was attained when the depth of reflectors was $d \approx \lambda_g/4$ since waves appeared open during the process whereas the gain slightly decreased at d=3mm. In addition, the side lobe decreased and the antenna displayed optimal gain when the height of baffles was h≈λ_0/4.



(a) (b)

Figure 4 : Simulated and measured radiation pattern results of the 2x2 cavity-backed slot array antenna : (a) E-plane and (b) H-plane

4. Conclusion

In this thesis, we designed a cavity-backed slot antenna with a new structure holding broadband characteristics which is a precedent in the production of AIA to display the largest bandwidth and gain by changing the design parameters of the LTCC board (Dupont 943) through simulation. In addition, we conducted comparative analysis on the interpreted results and the actual production and measurements, and verified validity.

This antenna structure resolved the problem of narrow impedance bandwidth, which is the largest weakness of microstrip antennas, and boosted its practicality by increasing the gain. Moreover, its spurious radiation is quite small thanks to the very low cross polarization, which we believe to be a quite excellent achievement and we can improve it even further through more accurate production and testing of the antenna structures. Furthermore, it can be applied to the production of AIA, and contribute to the development of antenna technologies at the millimeter frequency level, including broadband antennas with a new structure and combination-type antennas integrating active and passive elements for broadband services provided by broadband Internet, broadcasting, telecom and fusion.

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