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Fabrication of a Proto-Type Active Integrated Antenna for a Compact and High-Power Phased Array System

#Shigeaki Kawai [1], Shigeo Kawasaki [1], Takeshi Yamamoto [1], Yasuyuki Sakurai [1],
Harunobu Seita [1], Katsutoshi Nakajima[1], Kyoji Kanazawa [1],
Masaya Tamura [2], Toshio Ishizaki [2], Tamotsu Suda [3]
[1] Research Institute for Sustainable Humanosphere, Kyoto university
Gokasho, Uji, Kyoto 611-0011, Japan, {k-shige, kawasaki, t-yamamo, seita}@rish.kyoto-u.ac.jp
[2] Panasonic Electronic Devices Co., Ltd.
Oazakadoma, Kadoma, Osaka, 571-8506, Japan,
{ishizaki.toshio, tamura.masaya}@jp.panasonic.com
[3]Japan Radio Company
5-1-1,Shimorenjyaku, Mitaka, Tokyo 181-8510 Japan, suda.tamotssu@jrc.co.jp

1. Introduction

Recent progress on telecommunication systems enables us to realize a high performance active phased array antenna (APAA) with low cost and compactness in a field of a mobile communication system. In order to make the high-performance APAA system prevail, there are many technical items to overcome in terms of antennas as well as microwave circuits such as small size, light weight, low loss, high power and high efficiency [1], [2].

In addition to the progress on the telecommunication systems, energy crisis and global warming have been closed-up as important problems from various social standing-points. As one of the good solutions, Space Solar Power System (SSPS) using microwave frequencies has been proposed to utilize plentiful supply of solar energy in space[3-6]. In this case, the high-performance APAA system is also strongly requested to realize.

As one of the promising technologies to reply requirements for these systems, an active integrated antenna (AIA) technique can be applied[7],[8]. From the good nature of AIA, it can provide improvement of loss between the circuit and the antenna, and its integration leads to reduction of the size[9]. In this paper, design and test results of a prototype of AIA array for a compact and high power phased array antenna are demonstrated. The circular polarized patch antenna with high power semiconductor devices in the AIA was used and the small-sized phase shifter by the LTCC technology was adopted. Fundamental data for the high performance APAA were obtained.

2. Configuration

The AIA array consists of an antenna part and a circuit part (the phase shifter and driver / power amplifier circuits). In order to obtain stable operation condition as well as compactness, a ceased circuit substrate method was developed for the multi-stage high power amplifier. The operating frequency of the AIA is 5.8GHz.

2.1 Antenna

Microstrip patch antennas are thin and light in weight. Circular polarized antennas are useful when the polarization of antennas is variable such as mobile communication. Therefore, circular polarized patch antennas are suitable for the AIA. The structure of the circular-polarized patch antennas designed at 5.8GHz is shown in Fig. 1. It shows that the polarization of the antenna

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is right circular polarization. An antenna pattern for single element calculated by HFSS (High Frequency Structure Simulator) is shown in Fig. 2. It is predicted that this antenna works as a right circularly polarized antenna.

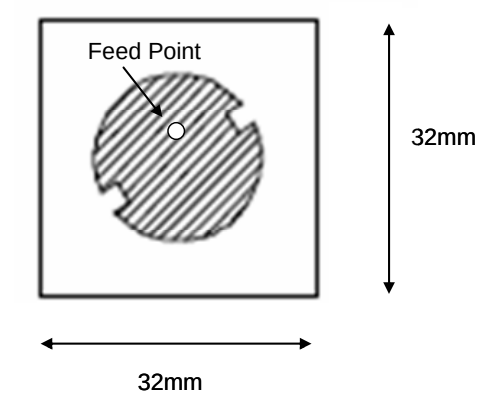


Figure 1 the structure of the antenna

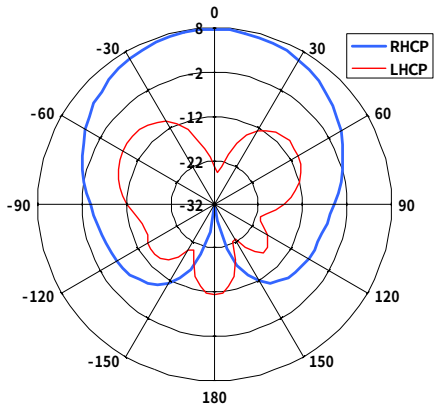


Figure 2 the calculated antenna patterns

2.2 Circuits

(1) Amplifier

In order to obtain high gain, the multi-stage amplifier was proposed. A high power two-stage amplifier circuit for AIA was designed with FLC167WF, high power GaAs FET provided by Eudyna Co. For the purpose of miniaturization of the circuit, high dielectric substrate of CGC-500 provided by Tyukokasei Co. is utilized. The characteristics of the FET were simulated with a small signal model which assumes the FET is utilized in class A operation. Fig. 3 is the layout of the designed two stage amplifier. The gain of the circuit calculated by ADS (Advanced Design system) is predicted as 19dB.

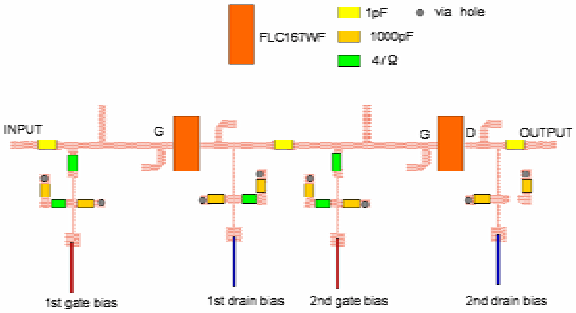


Figure 3 the layout of amplifier

(2) Phase Shifter

Generally speaking, the phase shifter which controls the phase of signals is said to be expensive and occupy large circuit area. From the system requirements, the design policy of compactness was also applied to the phase shifter. For this purpose, the LTCC technology was chosen. Using the LTCC circuit substrate, the microstrip lines of the phase shifter are stratified in thin layers.

As the first step for the compact phase shifter, the 3-bit phase shifter with the loaded-type and the hybrid-type combination was designed. In Fig. 4, the structure of the 3- bit phase shifter is indicated. High-Frequency Structure Simulator (HFSS) is chosen to design the LTCC phase shifter. Simulation results for 45 degree are as follows. The return and insertion loss from FET ON status were obtained as -13.19dB and -1.13dB at 5.8GHz, respectively. Further, those from FET OFF were -13.00dB and -0.79dB at 5.8GHz, respectively. The total phase shift from this phase shifter was about 49 degree.

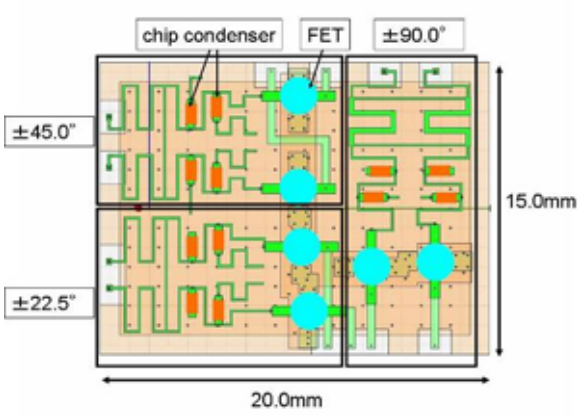


Figure 4 a structure of 3-bit phase shifter

(3) Circuit by creased substrate

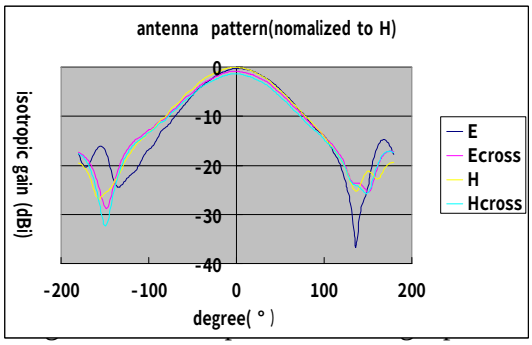
An example of a creased circuit substrate was shown in Fig. 5. Creased circuits enable us to bend a microwave circuit without connectors. This method can be applied to realize compact AIA circuit with little loss. In case of the creased circuit shown in Fig 5, insertion loss is 0.8dB at 5.8GHz. Creased circuits also enable us to integrate thermal discharging system such as a fin and an air duct into the AIA.

Figure 5 a circuit by creased substrate

3. Fabrication

3.1 Antenna

The circular patch antenna is fabricated. Its return loss was measured with -18dB at 5.8 GHz. The single antenna pattern measured is also shown in Fig. 6. The gain of the antenna is 5.7dB and axial ratio is 1.5dB. It is proved that the antenna works as a circular polarized antenna.



antenna

3.2 Amplifier

The output and gain characteristic of the fabricated amplifier are shown in Fig 7. The maximum output power of the amplifier is 24.8dBm (1.3W) at 5.8GHz with gain of 12dB. The reason the gain measured is smaller than calculated gain is considered as manufacturing error and deterioration of FET by heat.

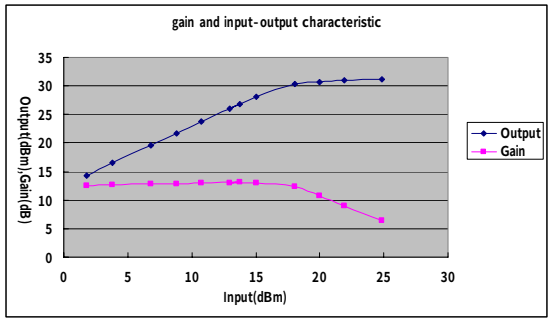


Figure 7 Gain and Input / Output characteristic of the two-stage amplifier

3.3 Phase Shifter

The main theme of this fabrication of phase shifter by LTCC technology is to realize the small-sized phase shifter. The size of this phase shifter shown in Fig. 4, 15mm x 20mm x 0.5mm. Measured characteristics of the phase shifter are shown in Table 1. The best insertion loss from each bit was -3.1dB, the typical return losses was -15dB and the phase errors of the phase shifters with 45, 90, 180 degrees were 5.8, 2.0 and 10 degrees, respectively. From these results, improvement of losses is needed by changing a capacity of chip condensers.

Table 1 Measurement results about characteristics of 3-bit phase shifter with LTCC substrate

volume of phase shift	45 °		90 °		180 °	
a state of FET	ON	OFF	ON	OFF	ON	OFF
return loss (dB)	-18.9	-19.6	-12.1	-10.3	-12.1	-6.6
insertion loss (dB)	-4.6	-3.1	-4.1	-8.4	-6.4	-17.4
volume of phase shift (a measurement result)	51 °		88 °		170 °	

3.4 AIA

The fabricated proto-type AIA shown in Fig. 8 composed of the amplifier circuit and antennas demonstrated above. As you can easily observe, the creased circuit substrate for compactness of AIA is adopted is adopted between the first-stage amplifier and the second stage amplifier. The circular polarized patch antennas are connected to the output of the amplifier block. The saturation level of EIRP(Effective Isotropic Radiated Power) of the AIA was 43.3dBm. From the observation, it was found that gain of the two-element array antenna is 8.7dBi, the output of the amplifier on AIA is 31.6dBm.(1.45W) Phased array is composed by connecting the AIA and the

phase shifter. The future task is downsizing the amplifier and the phase shifter utilizing MMIC and LTCC technology and developing compact active phased array antennas.

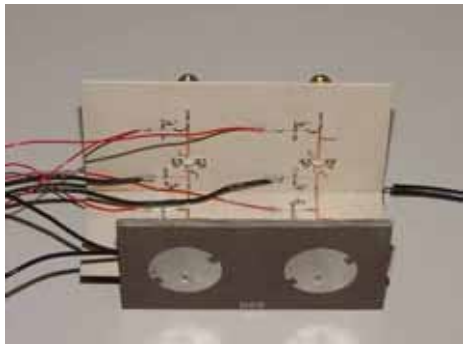


Figure 8 the two-element AIA array

4. Conclusion

The high power circular polarized AIA array and phase shifter are fabricated. The maximum output of the AIA is 1.45W per one element. The phase difference of phase shifter is 51~ 170 degree and the minimum loss of the phase shifter is -3.1dB. Future task is downsizing the circuit, reducing a loss of phase shifter, and developing APAA.

Acknowledgments

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