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Laminated Active Integrated Antenna Arrays Composed of Functional Layers for Microwave Wireless Power Transmission in Space

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1. Introduction

In order to develop power generation from a clean energy source such as the sun, the SPS2000 system has been proposed by the Institute of Space and Astronautical Science, Ministry of Education, Japan. Many working groups have been established to make develop and promote the specialized technology for SPS2000[1]. One of them has taken charge of the development of the spacetenna (the transmitting antenna of the SPS2000 system). Point of the charge of the working group involves realization of a light and multi-functional antenna and transmitter system to provide the clean and low-cost power utility.

Recent microwave and antenna engineers have intensively developed a novel technique of an active integrated antenna, which integrated a planar antenna with a planar circuit[2]. This technique can provide improvement of propagation loss between the active element and the radiator in the subsystem, and of power combining efficiency. Further, in order to achieve the size reduction of a radar system, each function of the active integrated antenna can be laminated in such a way of stacking the functional layers of oscillator, amplifier, mixer and antenna. As a result, the radar front-end made using the active integrated antenna technique became thin and light by laminating each layer coupled by a slot aperture electromagnetically[3]. Using this active integrated antenna in the laminated fashion, weight reduction and conformability are expected to be accomplished with increment of the radar functions in the SPS2000 spacetenna.

In this paper, two types of the active integrated antennas were shown with the laminated functional layer. In order to increase the transmitting power and enhance the design flexibility, the two-stage FET amplifier was adopted in the unit cell. Further, in the other case, the oscillation layer consisting of the parallel feedback oscillator for extending the function of the spacetenna was involved in the bottom of the unit cell. The fundamental operations from these arrays were confirmed and the details are discussed in the text.

2. Configuration

The basic structure of a unit cell of the laminated active integrated antenna is shown in Fig.1. It consists of the three layers; the amplification circuit layer with an FET power amplifier, the coupling layer with the two slot apertures embedded in the metal ground plane, and radiation layer by a patch antenna. The operating frequency was settled at 2.45 GHz. The main transmission lines were designed to have the characteristic impedance of 50 Ω by the microstrip line as well as by the strip line. For avoidance of degradation on the antenna performance due to unexpected radiation from the circuit, the radiation layer is separated from the circuit layer in a stratified fashion. In order to solve a heat problem from the FET, the active circuit was settled at the bottom layer which has a large metal ground plane for the radiation cooling to the direction of the dark universe.

The signal flow occurs as follows. In the circuit layer, a 2.45 GHz input signal from an external source travels through a width direction of the patch resonator which has the property of simple filtering. The FET with input and output matching networks then amplifies the filtering signal, and the amplified signal is reentered into the patch resonator in the direction of the patch length. The amplified signal resonated in the circuit layer goes up through the two slot apertures embedded in the common ground for the upper patch radiator as well as for the bottom patch resonator in the amplification layer. Then, the patch antenna in the top layer is exited by the amplified signal.

One of the two types of the array is the 2-element laminated active integrated amplifier antenna array using the two-stage FET amplifier in the amplification circuit layer. This configuration in the amplification layer is shown in Fig. 2. The two-stage FET amplifier consists of the low-noise FET amplifier and the high-power FET. In order for the patch resonator #1 and the patch resonator #2 to operate with the same amplitude, the coupling coefficient of the directional coupler was set with the same value of the gain of the low-noise FET amplifier to compensate for each other. Further, for the adjacent patch resonator to operate in the same phase, the electrical length of the transmission line between the adjacent resonators was adjusted. Hence, the input signal to each unit cell of the array can be kept with the same amplitude and phase, and it is possible to realize the periodical alignment. In addition, the high power FET amplifier was added in the microstrip transmission line as the final amplifier for increasing the radiation power. Each FET amplifier was designed with 15 dB gain at 2.45 GHz and with two open matching stubs both at an input and at output port. A chip resister was connected in parallel at the gate and drain terminal in order to obtain the stable operation for the FET amplifier.

The second example is the laminated active integrated antenna involving the oscillation layer. In order to extend the function of the laminated active integrated amplifier antenna, the oscillation layer consisting of a parallel feed back oscillator was added into the unit cell. The basic structure of the unit cell is shown in Fig. 3. The parallel feed back loop of the oscillator is electromagnatically coupled with the patch resonator in the amplification circuit layer through the two slot apertures. One of the apertures is the input slot, which is matched with the output of the FET oscillator, and other is the decoupled slot to feedback a small amount of the power resonated in the patch resonator toward the oscillator. In order to stably operate the unit cell, the injection signal from an external source is input to the patch resonator in the amplification layer.

3. Experimental Result

According to the design concept described above, the laminated active integrated antenna arrays were fabricated. The package-type FET used were the GaAs HEMT (i.e., Mitsubishi MGF4314E) as the low-noise amplifier and the GaAs FET (i.e., Fujitsu FLL107ME) as the high-power amplifier. The substrate used here was 25NG0310CSSA(i.e., ARLON dielectric constant=3.25, thickness=0.751 mm, copper thickness=0.018 mm). The measurement was carried out with a horn antenna (9.9 dBi at 2.45GHz) in an anechoic chamber. The distance between the DUTs and the horn antenna was approximately 1.7 m. The received signal was observed using a spectrum analyzer.

The laminated active integrated antenna with the two-stage FET amplifier was fabricated and operated at 2.45GHz. Bias conditions for the FET amplifiers were with V_{gs}=-1.2 v, V_{ds}=10 v, I_{ds}=150 mA for the high power amplifier and V_{gs}=-0.4 v, V_{ds}=2.0 v, I_{ds}=30 mA for the low-noise amplifier. The measured antenna patterns are shown in Fig. 4 and compared with the computed patterns. The receiving power was -5.67 dBm, when the external signal with 0 dBm was input. The antenna patterns in the E- and H-planes agreed with the theoretical patterns.

Based on findings from the data of the unit cell described above, the 2-element array of the laminated active integrated amplifier antenna aligned in the H-plane was fabricated. The fabricated array is shown in Fig. 5. The typical bias conditions for the FET amplifiers in the array were with V_{gs}=-1.2 v, V_{ds}=10 v, I_{ds}=150 mA for the high power amplifier and V_{gs}=-0.4 v, V_{ds}=2.0 v, I_{ds}=30 mA for the low-noise amplifier. The measured receiving power was -2.17 dBm and the EIRP was estimated as 32.7 dBm. The calculated and measured antenna patterns in the H-plane is shown in Fig. 6. Although the side lobes increased due to the unexpected radiation from the edge of the finite substrate, the measured antenna pattern agreed with the theoretical one around the main lobe and at the null points. Hence, the two unit patch plates are found to operate in the in-phase status.

The laminated active integrated antenna with the oscillator circuit is shown in Fig. 7 and operated at 2.449 GHz in the self-oscillating condition after adjustment. Please note that there is only one FET amplifier in the amplification layer in this case. The observed spectrum in the self-oscillation condition is shown in Fig. 8. The bias conditions for the FET oscillator and amplifier were V_{gs}=-0.2 V, V_{ds}=2.0 V, I_{ds}=20 mA and V_{gs}=-0.2 V, V_{ds}=2.0 V, I_{ds}=10 mA, and the peak receiving power was -37.5 dBm. The spectrum of the unit cell is shown in Fig. 9 when a signal of -15dBm was injected into the patch resonator in the amplification layer. The receiving power increased up to -36.67 dBm.

The reduction of the phase noise and the stability of operation were obviously observed.

4. Conclusion

In this paper, the design method and the experimental results for the two types of laminated active integrated amplifier antenna were demonstrated. The 2-element array of the laminated active integrated amplifier antenna array using the two-stage FET amplifier operated in the in-phase status and the EIRP of 32.7 dBm was observed. The laminated active integrated antenna with the oscillation layer showed performance with the stability condition by inputting the injection signal. The fundamental data for the system requirements of the spacetenna of a light-weight and multi-functions were believed to be obtained using the laminated active integrated antenna technique.

Acknowledgment

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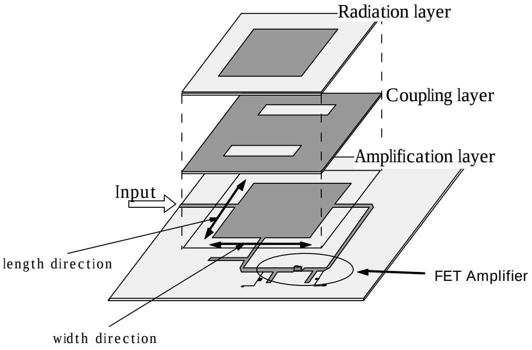


Fig. 1 Fundamental structure of the unit cell of the array

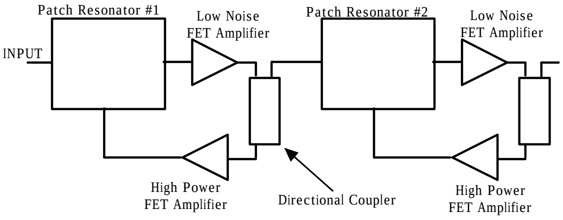


Fig. 2 Configuration of the 2-element array using two-stage FET amplifiers

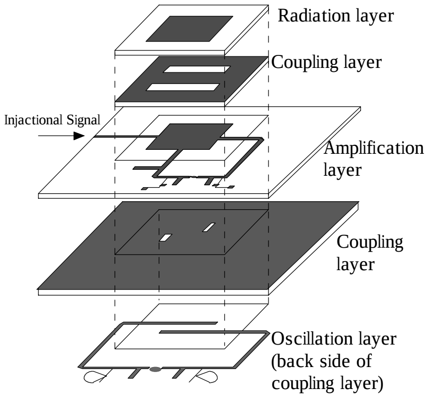
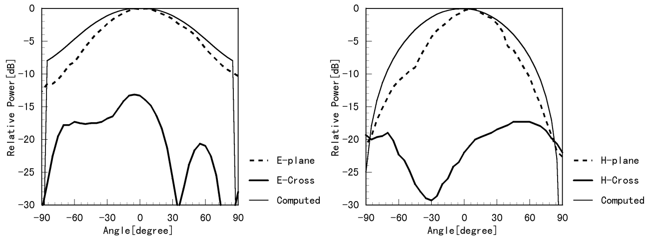


Fig. 3 Structure of the unit cell with the oscillation layer



(a) E-plane (b)H-plane

Fig. 4 Antenna pattern of the unit cell

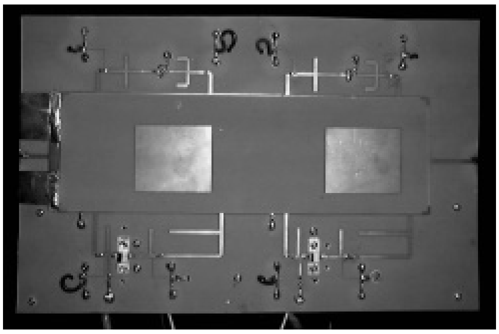


Fig. 5 Fabrication of the 2-element array

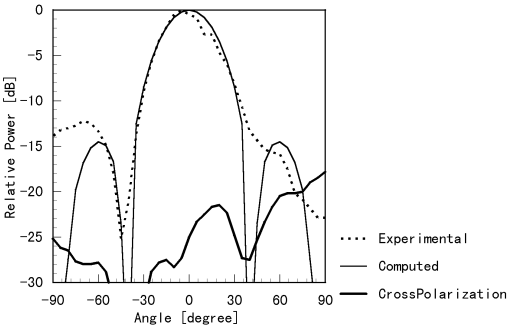
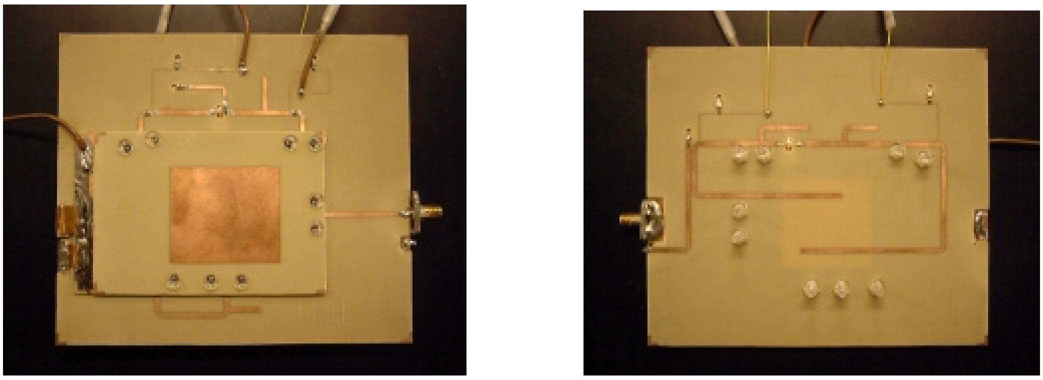


Fig. 6 Antenna pattern of the array in the H-plane



(a) Top view

(b) Bottom view

Fig. 7 Fabrication of the active integrated antenna with the oscillation layer

Fig. 8 The spectrum of the active integrated antenna with the oscillation layer (self-oscillating)

Fig. 9 The spectrum of the active integrated antenna with the oscillation layer (injection locking)