MILLIMETER-WAVE ACTIVE INTEGRATED ANTENNA ARRAY UTILIZING HARMONIC INJECTION FOR AN MMIC OSCILLATOR WITH PHOTONIC BAND GAP STRUCTURE

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1. INTRODUCTION

In information and telecommunication systems, the demand for the millimeter wave technology has been growing rapidly. Among them, the satellite communication system for the broadcast and mobile communication, Intelligent Transport System (ITS) and the indoor wireless LAN system have been progressed[1].

As one of the technologies to realize these systems with low cost, the quasi-optical and active integrated antenna technique has been proposed and developed, and many demonstrations have been published[2]-[4]. By incorporating a Monolithic Microwave Integrated Circuit (MMIC) into the active integrated antenna, the small-sized and low-cost millimeter-wave subsystems can be accomplished[5].

However, the FET and its integrated circuit operating at a millimeter-wave frequency are expensive and complicated. To fabricate the low-cost millimeter-wave subsystems, use of the second harmonic generated by the nonlinear operation of FET is useful for obtaining a higher operating frequency with a simple structure[6]. In addition, for stable operation, use of the techniques such as injection locking is considered to apply. Furthermore, utilization of the technology with a photonic band gap (PBG) structure may be suitable for increasing the effective radiation from the planar antenna.

In this paper, a design method and experimental data of the millimeter-wave active integrated antenna arrays using the harmonics and the injection locking were described. In order to increase the radiation efficiency, the photonic band gap structure in the ground plane of the circuit was etched out for easy fabrication and suppression of degradation on the characteristics due to the surface wave at the high frequencies.

2. CONFIGURATION and DESIGN

As the design policy for the active integrated antenna array demonstrated in this paper, the active integrated antenna gives two types of antenna radiation pattern. The differential antenna pattern is allotted for radiation at the fundamental frequency from the antenna, while the radiation at the second harmonic creates the sum pattern to accomplish harmonic space diversity.

The structure of the active integrated antenna array is shown in Fig. 1. It consists of the four parts; an MMIC oscillator for the fundamental and second harmonic generation, a CPW-fed slot antenna with an open-ended matching stub, a strong coupling line for control of the locking mode and a directional coupler for the harmonic injection locking from an extend source. The MMIC oscillator is composed of a series feedback FET oscillator with a microstrip line on a GaAs substrate. It operates around 23GHz as the fundamental operating frequency.

On the design of the slot antenna, the feed line and strong coupling line, commercially available simulators (HP-EEsof ADS and Momentum) were used. In order to design the proposed active integrated antenna, it is important to distinguish the part dealt at the fundamental frequency from that at the second harmonic. The antenna part was with the input impedance of 50Ω at the second harmonic of 46GHz to give the impedance matching to the circuit part. Therefore, the dimension of the slot antenna with the CPW feed line is $0.94\lambda_g$ by $0.062\lambda_g$ (λ_g: guided wavelength).

The other part except the slot antenna was designed at 23GHz, the fundamental frequency. At this frequency, the unit cell of the array was designed to operate with the anti-phase mode with respect to the adjacent unit cells. This can be achieved by designing the unit cell with the RF short circuit at the middle point of the coupling line between the adjacent unit cells. In order to enhance the short status at the center of the coupling line, the quarter wavelength stub was attached. In order to change the length of the open-ended tuning stub easily, the short-length CPW is etched with a small gap. These are shown in Fig. 1. The feed line and the MMIC Oscillator is connected by bonding wires. The directional coupler was designed at 10.5GHz, which is the half harmonic of the operating frequency of the MMIC oscillator.

Furthermore, in order to increase the radiation efficiency and to avoid the characteristic degradation due to the surface wave, the photonic band gap (PBG) structure was fabricated by etching in periphery of the antenna. The PBG structure was designed using the program coded with the FDTD method. In this paper, the photonic band gap structure is periodic pattern of the etched circular hole around the slot antennas. Radius of circle was 1.116mm and distance of the circles was 2.48mm. The calculated band diagram is indicated in Fig. 2. As the result, the photonic band gap was observed at 44.70GHz to 46.46GHz for the TE mode.

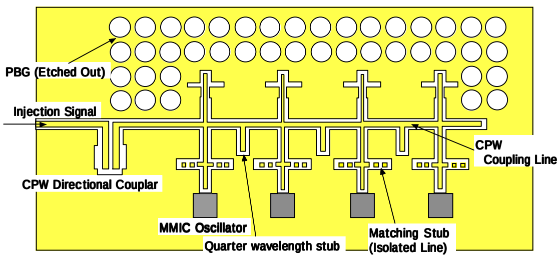


Fig. 1 The configuration of the active integrated antenna array

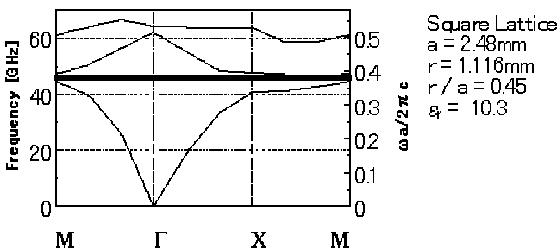


Fig.2 The calculated band diagram

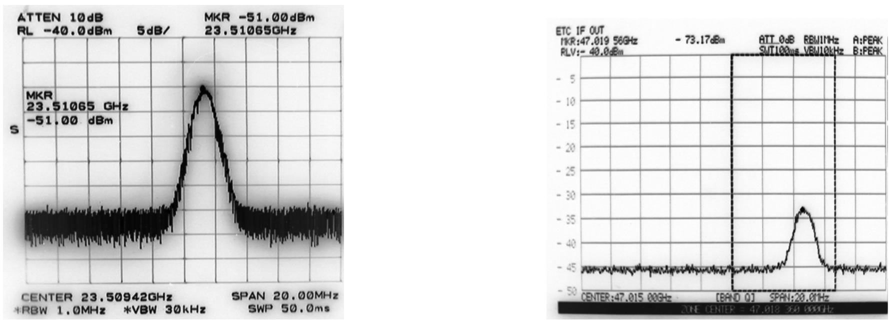
According to the design concept described above, the two types of 4-element active integrated antennas with PBG or without PBG were fabricated. The array was designed by way of periodic alignment of the unit cell. The distance of the antenna elements was $0.469\lambda_0$ at the fundamental frequency and 0.938λ_0 at the second harmonic (λ_0: the wavelength in free space).

3. EXPERIMENTAL RESULTS

Based on the design concept mentioned above, the active integrated antenna arrays were fabricated. The dielectric substrate used was an alumina ceramic substrate with a relative dielectric constant of 10.3, the thickness of 0.635mm, the conductor thickness of 5μm.

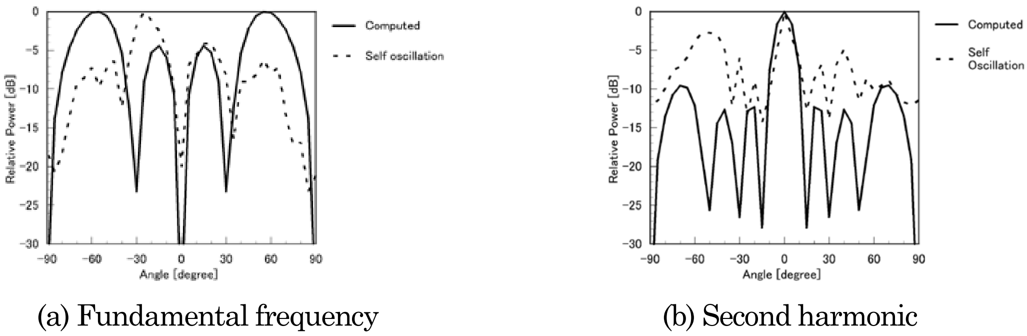
The observed spectrum from the active integrated antenna array is shown in Fig. 3. The active integrated antenna oscillated at 23.51GHz as the fundamental frequency, and 47.02GHz as the second harmonic. The bias conditions were Vgs1=-0.488V, Vgs2=-0.451V, Vgs3=-0.139V, Vgs4=-0.728V, Vds=2.11V (common) and Ids=73mA (total). The measurement distance was about 1m using the standard gain horn with 30dBi. The maximum receiving powers were −51.00dBm as the fundamental frequency and -70.73dBm as the second harmonic. The measured antenna patterns for the active integrated antenna array is shown in Fig. 4. It is obvious that the active integrated antenna operated in the anti-phase status at the fundamental frequency and operated with the in-phase mode at the second harmonic frequency, since Fig. 4 showed that the fundamental frequency exhibited a difference pattern while the second harmonic showed the sun pattern. The good agreement between the experimental data and the calculated patterns around the main lobe and null points was observed.

For the stable operation, half harmonic microwave signal was input through the directional coupler. The maximum receiving power was increased upto -50.92dBm and -70.42dBm, respectively, when the injected power was 17dBm at 11.75GHz which was a half of the self-oscillating frequency of the MMIC oscillator. The measured locked spectrum is shown in Fig. 5. From this measurement, it was observed the active integrated antenna array was externally locked by the half harmonic microwave signal with respect to the MMIC fundamental operating frequency. In addition, the stable operation was also obtained.



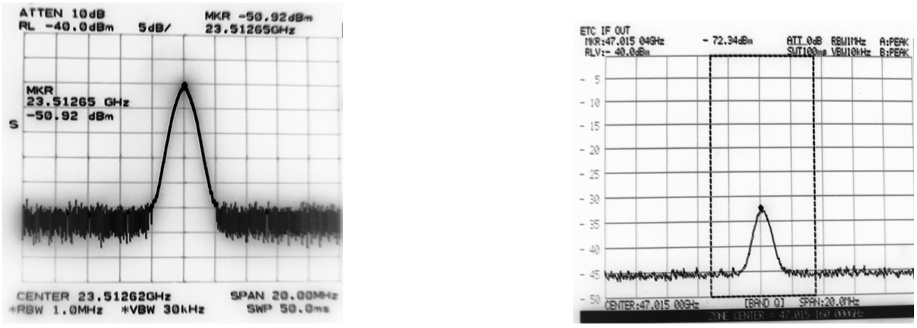
(a) Fundamental frequency (b) Second harmonic

Fig. 3 The spectrum of the active integrated antenna array with photonic band gap structure (self-oscillation)



(a) Fundamental frequency (b) Second harmonic

Fig. 4 The Radiation patterns of the active integrated antenna array with photonic band gap structure



(a) Fundamental frequency (b) Second harmonic

Fig. 5 The spectrum of the active integrated antenna array with photonic band gap structure (Injection locking)

4. CONCLUSION

In this paper, the design method and the experimental results of the active integrated antenna array with photonic band gap structure utilizing harmonic injection were demonstrated. The active integrated antenna array was externally locked by the external signal at the half frequency with respect to the fundamental operating frequency of the MMIC oscillator. In addition, the differential antenna pattern was obtained at the fundamental frequency and sum antenna pattern was at the second harmonic. From these results, it is believed that the fundamental data for the small-sized and low-cost millimeter wave active integrated antenna using the MMIC oscillator were obtained.

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