A MILLIMETER-WAVE ACTIVE INTEGRATED ANTENNA ARRAY WITH A 3D PRINTED PBG STRUCTURE

Hideyuki ISHIDA, Shigeo KAWASAKI and Ryuta SONODA
Tokai University
Department of Electrical and Electronic Engineering
1117 Kita-Kaname, Hiratsuka, Kanagawa 259-1292, Japan
TEL: +81-463-58-1211 (Ext. 4061), FAX: +81-463-59-4014
E-mail: kawasaki@keyaki.cc.u-tokai.ac.jp

ABSTRACT

Application of the printed PBG to the active integrated antenna was demonstrated in this paper. The stratified two dimensional printed PBG plates work as a bulk-like three dimensional PBG and as a band elimination filter. The active integrated antenna array operated at millimeter-wave frequency by making use of the second harmonic generation from the MMIC oscillator in the active integrated antenna array. Due to attaching the three dimensional PBG to the antenna substrate, the leakage of the fundamental power of the MMIC oscillator was confirmed to reduce.

1. INTRODUCTION

In information and telecommunication systems, importance for development of microwave and millimeter-wave technologies have been increasing rapidly. In order to realize these systems with small-size, multi-functions and low cost, the quasi-optical and active integrated antenna has been proposed[1],[2]. By incorporating a Monolithic Microwave Integrated Circuit (MMIC) into the active integrated antenna, the small-sized millimeter-wave subsystems with potentially low cost can be made[3].

However, the FET and its integrated circuit operating at the millimeter-wave frequency are still expensive. Therefore, in order to realize the low-cost millimeter-wave subsystem, use of the second harmonic generated by a nonlinear active device such as an FET with a simple structure is considered[4],[5]. In addition, small power generation and large propagation loss at the millimeter-wave frequency have been one of big problems. To improve the radiation efficiency and to avoid the characteristic degradation due to the surface wave, a Photonic Band-Gap (PBG) technology has been developed. The PBG structure is realized with a periodic alignment of a dielectric material and/of a metal. In this structure, wave propagation is totally prohibited in the certain frequency band. The variety in the PBG applications has been extended in the microwave and millimeter-wave engineering. Recently, the novel method of etching in the ground plane has been proposed for the microwave PBG structure[6]. It is called as a printed PBG (PPBG) and is fabricated in 2D and 3D fashions.

In this paper, a design method and experimental data of the millimeter-wave active integrated antenna arrays utilizing the second harmonic with the 3D printed PBG (3D PPBG) structure are described. Further, one example of the 3D PPBG applications to the antenna substrate is shown here.

2. DESIGN

2.1 Millimeter-wave active integrated antenna utilizing harmonics

The active integrated antenna demonstrated here consists of the GaAs MMIC oscillator and the CPW-fed planar slot antenna and was designed with the strong coupling method[7],[8]. Utilizing the second harmonic generation from nonlinear operation of the MMIC oscillator, the millimeter-wave power is effectively combined in accordance with the suitable mode control between the adjacent oscillators[9]. A configuration of the 4-element active integrated antenna array is shown in Fig.1. It consists of the four parts; an MMIC oscillator for the fundamental and the second harmonic generation, a CPW-fed slot antenna with an open-ended matching stub a strong coupling line for the mode control, and a directional coupler for the injection locking with an external source. The MMIC oscillator is composed of the series feedback FET oscillator with the microstrip line on the GaAs substrate. It operates around 21.6GHz as the fundamental operating frequency.

For the design of the slot antenna, the feed line and the strong coupling line, commercially available simulators (Agilent-EEsof ADS and Momentum) were used. The slot antenna has an input impedance of 50Ω at the second harmonic of 43.2GHz to give the impedance matching to the MMIC oscillator. The dimension of the slot antenna with the CPW feed line is 0.94 l_g by 0.062 l_g (l_g: the guided wavelength) at 43.2GHz and the distance between the adjacent slots is 0.47 l_0 (l_0: the free space wavelength) at 21.6GHz.

The other circuits except the slot antenna and the MMIC oscillator were designed at 21.6GHz, the fundamental frequency. At this frequency, the unit cell of the array was designed to operate with the anti-phase mode to the adjacent unit cell. This can be achieved by designing the unit cell with the RF short circuit at the middle point of the coupling line. In order to enhance the short status at the center of the coupling line, the quarter wavelength open stub was attached in parallel. The directional coupler for the injection signal was designed at 10.8GHz, which is half of the operating frequency of the MMIC oscillator.

2.2 3D PPBG structure

In order to increase radiation efficiency and to avoid characteristic degradation due to the leaked fundamental microwave power, the PPBG structure was made by etching. To suppress the leaked fundamental power from the slot antenna, the PPBG substrate was stacked and attached at the back side of the planar antenna substrate shown in Fig.2. The design of the PBG structure was carried out by a computer simulation program, which is based on the Finite Different Time Domain (FDTD) analysis using direct solution of the Maxwell's equations.

The 3D PPBG structure was made by stratifying the dielectric substrate with the net-metal-line pattern as shown in Fig.2. A unit cell of the periodic structure is used for the computational domain and for enforcement of periodic boundary conditions as indicated in Fig.3. Parameters for the calculation are indicated in Table 1. The Bloch's boundary conditions at four faces of a periphery in the unit cell and the perfectly matched absorbing boundary condition (PML) with 4 layers at the top and bottom faces are applied.

Using these boundary conditions, the Maxwell's equations are solved. Then, the field can be obtained at a meshed point in the computational domain. The results are indicated in Fig.4. The band gap for both the TE and TM modes was observed in the frequency range of 21.2 to 22.0GHz. By attaching the 4-layered 3D PPBG on the back side of the slot antenna in the substrate, attempt for the suppression of the leaked fundamental power radiation can be done.

3. EXPERIMENTAL RESULTS

The dielectric substrates used were the alumina ceramic substrate for the active integrated antenna array and the Teflon substrate for the PPBG with a relative dielectric constant of 10.3 and 3.25, respectively, and the tangent delta of 0.0025, and the thickness of 0.635mm and 0.787mm (ARLON:25N).

The measured and calculated antenna patterns from active integrated antenna array at the fundamental and the second harmonic without and with the 3D PPBG are shown in Fig.5. The typical bias conditions were Vgs1=-0.61[V], Vgs2=-0.1[V], Vgs3=-0.3[V], Vgs4=-0.06[V], Vds=3.0[V] (common) and Ids=40[mA] (total). The measurement distance between DUT and the receiving antenna was about 1m. Standard gain horns with about 30dBi for both 21.6GHz and 43.2GHz were used as the receiving antenna. The measured antenna patterns were compared with the calculated ones. The good agreement between the experimental data and the calculated data around the main lobe and at null points was observed. Therefore, it was confirmed that the active integrated antenna array operated in the anti-phase mode at the fundamental and in the in-phase mode at the second harmonic as expected.

From the observation of Fig.5, the effect of attaching the laminated 3D PPBG was confirmed as decrease of the fundamental receiving power with a little change in the second harmonic receiving power.

4. CONCLUSION

The design method and the experimental data from the millimeter-wave active integrated antenna arrays utilizing the harmonics with the 3D PPBG structure are demonstrated. The 3D PPBG was made by stacking the 2D PPBG plates. The 3D PPBG combining with the active integrated antenna plays a role to reduce the leakage from the slot antenna at the fundamental operating frequency of 21.6GHz of the MMIC oscillator.

5. ACKNOWLEDGEMEMTS

This project is partially supported by Tokai University Rainbow 21 project.

REFERENCES

[1] Z. Popovic, R. Weikle, M. Kim and D. Rutledge, "A 100-MESFET Planar Grid Oscillator", IEEE Trans. Microwave Theory Tech., 39, 2, Feb. 1991, pp. 193-200.

[2] J. Bae, T. Unou, T. Fujii and K. Mizuno, "Spatial power combining of Gunn diode using an overmoded-waveguide resonator at millimeter wavelengths, IEEE Trans. Microwave Theory Tech., 46, 12, Dec. 1998, pp. 2289-2294.

[3] T.Adachi, J.Kobayashi, S.Kawasaki, H.Urabe and K.Iwasaki, "Millimeter-Wave Harmonic

Space Diversity Active Integrated Antenna with Microwave Injection Locking", APMC2000, Australia, pp.1506-1509, Dec. 2000.

[4] S. Kawasaki and T. Itoh, "Millimeter-Wave Active Integrated Antennas Utilizing Harmonics", 1995 Electronics and Communication in Japan, 78, 1, Jan. 1995, pp. 90-100.

[5] T. Tokumitsu, K. Kamogawa, I. Toyoda and M. Aikawa, “A Novel Injection-Locked Oscillator MMIC with Combined Ultrawide-Band Active Combiner/Divider and Amplifiers”, IEEE Trans. Microwave Theory Tech., 42, 12, Dec. 1994, pp. 2572-2578.

[6] V. Radisic, Y. Qian, R. Coccioli, and T. Itoh, "Novel 2-D Photinc Band Structure for Microstrip Lines", IEEE Microwave and Guided Wave Lett., vol. 8, no. 2, pp. 69-71, Feb. 1998.

[7] S. Nogi, J. Lin and T. Itoh, "Mode Analysis and Stabilization of a Spatial Power Combining Array with Strongly Coupled Oscillators”, IEEE Trans. Microwave Theory Tech., 41, 10, Oct. 1993, pp. 1827-1837.

[8] S. Kawasaki and T. Itoh, "Quasi-Optical Planar Arrays with FET's and Slots", IEEE Trans. Microwave Theory Tech., 41, 10, Oct. 1993, pp. 1838-1844.

[9] S. Kawasaki, "High Efficient Spatial Power Combining Utilizing Active Integrated Antenna Technique", IEICE Trans. Electron., Vol. E80-C, No. 6, June 1997, pp. 800-805.

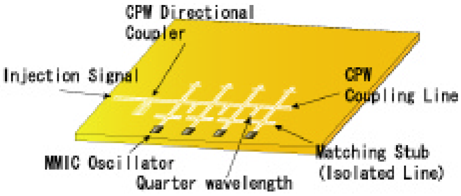


Fig.1 Configuration of the active integrated antenna array

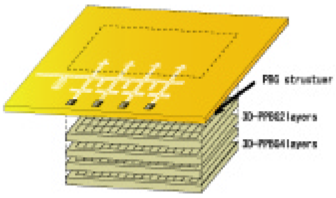


Fig.2 Configuration of the active integrated antenna array with 3D PPB

Table 1 Calculation conditions for analysis

The analysis condition		
Pitch a=3.15[mm], radius r=1.5[mm]		
Dielectric constant ε_r=3.25		
Step size [mm]		
⊿x	⊿y	⊿z
0.05	0.05	0.05
Number of cell		
IX	JY	KZ
63	63	60

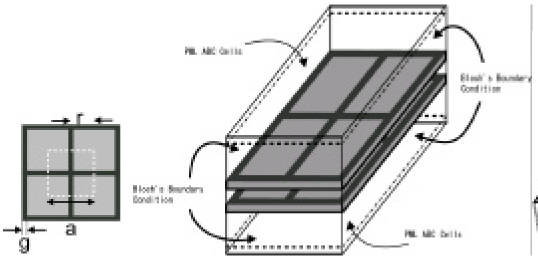


Fig.3 Structure and unit cell of 3D-PPBG

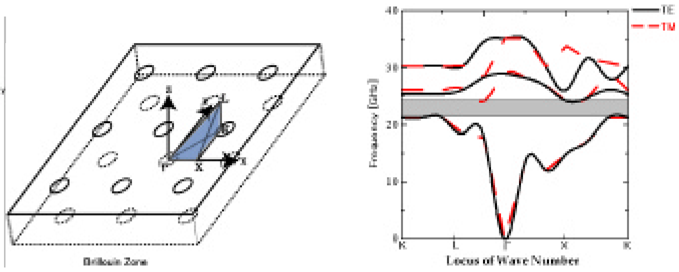
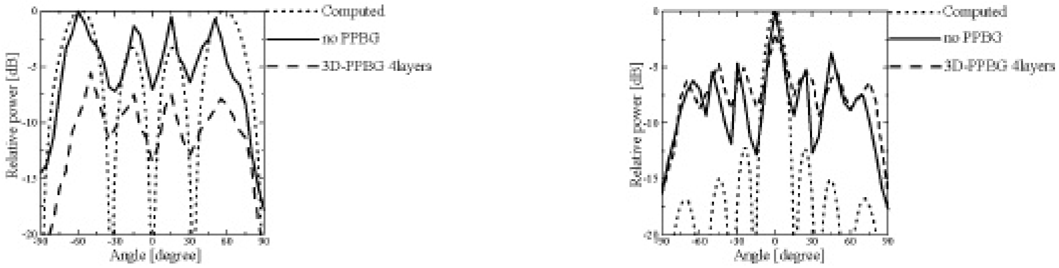


Fig.4 Band diagram of 3D-PPBG



(a)Fundamental

(b)Second Harmonic

Fig.5 Antenna patterns