OPTICAL TUNING RANGE COMPARISON OF UNIPLANAR ACTIVE INTEGRATED ANTENNA USING MESFET, GAAS HEMT AND PSEUDOMORPHIC HEMT

Shigeo Kawasaki and Tatsuo Itoh

UCLA
Electrical Engineering Department
Los Angeles, CA 90024-1594

ABSTRACT

This paper describes experimental data from uniplanar active integrated antennas with three types of FET's; a MESFET, an AlGaAs/GaAs HEMT and AlGaAs/InGaAs pseudoumorphic HEMT. These are designed at 10 GHz and operated at 8.8 GHz, 10.4 GHz and 10.5 GHz, respectively. A maximum optical tuning range of 70 MHz was obtained from the MESFET circuit, while 7 MHz and 10 MHz were obtained from both HEMT circuits. In each case, only one DC bias was applied to the drain and the gate is floating. The optical tuning ranges of both HEMT circuits had a similar drain-voltage dependence, while the MESFET circuit had the minimum value for the optical tuning range when the drain voltage was tuned.

1. INTRODUCTION

An active integrated antenna using FET's has been of growing interest for integrated circuits operating at higher frequencies[1]. Although in the microwave region there are many FET's suitable for the active integrated antenna, it is hard to obtain an FET at submillimeter-wave frequencies. However, it is important to investigate the optical tuning range to investigate the possibility of a submillimeter-wave uniplanar optical-controlled active integrated antenna.

There are two important phenomena for optical illumination of a microwave device; a photovoltaic effect and a photoconductive effect. In the case of the photovoltaic effect, the presence of a change of the carrier distribution due to illumination results in lowering the Schottky-barrier potential. This mechanism is equivalent to the forward bias between the Schottky-barrier contact and the ground plane. Meanwhile, the photoconductive effect is a bulk type effect. The photogenerated carriers can contribute to a current flow, therefore, the conductivity of a semiconductor increases by illumination.

A MESFET and a HEMT have a Schottky-barrier contact at the gate. Therefore, the photovoltaic effect is expected for both FET's[2],[3]. However, an optically controlled quasi-optical power combining array using a HEMT can be expected to be realized at high frequencies, since a typical cut-off frequency of a MESFET is lower than that of the HEMT. Meanwhile, a wider optical absorption area of the MESFET creates a large change in the circuit parameters such as the gate-source capacitance and drain-source resistance[4]. As a result, a wide tuning range can be expected[5]. If only the photoconductive effect is desired, the photon energy of the optical source should be selected so as to be greater than the bandgap energy of the active layer but to be smaller than that of the depletion layer. This operation method is important for applications[6].

This paper reports the optical tuning ranges of active integrated antennas made of a MESFET, a GaAs HEMT or a pseudomorphic HEMT incorporated with coplanar waveguides (CPW's). Comparison of the tuning ranges of the active integrated antennas with different type of FET's is discussed.

2. DESIGN

Three types of 2-element uniplanar active integrated antennas were designed in a hybrid MIC technique. The first is the 2-element array using a GaAs MESFET, while the second is the array using an AlGaAs/GaAs HEMT. The third array uses AlGaAs/InGaAs pseudomorphic HEMT. These three FET's were used to make the difference of illumination effect clear. In order to demonstrate a topology for a uniplanar monolithic integrated circuit, a high dielectric constant substrate (ε_r=10.5 : Duroid 6010) was selected. In the case of the MESFET, the slot radiator coupled with the CPW is $0.80\lambda_s$ long and $0.062\lambda_s$ wide at 10 GHz (λ_s is a slot guided wavelength). Meanwhile, in the cases of the GaAs HEMT and the pseudomorphic HEMT, the slot is $0.51\lambda_s$ long and $0.031\lambda_s$ wide at 10 GHz. These dimensions were determined by preliminary experience.

The configuration of a 2-element active integrated antenna is shown in Fig. 1. Each oscillator was designed at 10 GHz by using small signal S-parameters. A unit active antenna has a double matching stub configuration. One matching stub consists of a CPW double stub and another constitutes a CPW-slot cross junction at the top of each unit active antenna as shown in Fig. 1. A single CPW with the length of $1\lambda_c$ and the characteristic impedance of 50 Ω was used to accomplish strong coupling between the oscillators (λ_c is a CPW guided wavelength). The moding resulting from the signal phase from each oscillator was taken into account in the design. To invoke the desired in-phase mode, the unit active antenna with a coupling line was designed by replacing one half of the coupling line with an open stub[7]. This results from the fact that a field maximum point corresponding to an open status is located at a middle point of each oscillator. Due to use of the high dielectric constant substrate, physical separation between two slots can be reduced, keeping the length of the coupling CPW at $1\lambda_c$. In these cases, the length of $1\lambda_c$ corresponds to $0.55\lambda_o$ at 10 GHz (λ_o is a wavelength in a free space). Since the separation became less than $1\lambda_o$, problems of grating lobes are eliminated.

3. EXPERIMENTAL RESULTS

The 2-element MESFET active integrated antenna array operated at 8.8 GHz with Vds=3.58 V and Vgs=floating gate. Therefore, only one DC power supply for Vds was required to obtain the operating frequencies. The package-type FET used was NE72084. The optical control was carried out by illuminating the cap-removed package-type FET with an optical source in these three cases. As the optical source, a fiber illuminator with a halogen lamp was used. Air bridges are provided to suppress unwanted modes in the CPW circuit. The cause of the lower operating frequency may be due to parasitic unknown reactances from the CPW-slot cross and the CPW double stub. Using this circuit, an optical tuning range was measured and the maximum tuning range of 70 MHz near 8.8 GHz was obtained as shown in Fig. 2. Note that only one FET was illuminated. In addition, antenna patterns were observed. Fig. 3 shows the typical antenna patterns. No significant change occurs in the antenna pattern due to illumination. Under the active integrated antenna with strong coupling, illumination of the oscillator only creates a change of the resonant frequency.

The 2-element GaAs HEMT active integrated antenna array operated at 10.4 GHz under Vds=3.5 V and the floating gate condition. The GaAs HEMT used was NE 32184A. A relatively large receiving power results from good matching at the CPW-slot cross junction as well as the CPW cross junction. The maximum optical tuning range with single-oscillator illumination was 7 MHz at 10.4 GHz with Vds=1.5 V as shown in

Fig. 4, while a very small tuning range was measured with Vds=4.4 V at 10.4 GHz. Compared with the case of the MESFETs, the tuning range was one-tenth.

The third result is for the AlGaAs/InGaAs pseudomorphic HEMT (NE 32484) circuit operating at 10.5 GHz with Vds=2.0 V. By tuning Vds, the maximum tuning range of this circuit was 10 MHz as shown in Fig. 5. When Vds increases, the characteristic of the tuning range of the MESFET is different from that of the GaAs HEMT and the pseudomorphic HEMT as shown in Fig. 6. This may result from the difference of photo detection mechanisms. More details should be investigated by a large signal analysis with equivalent circuit parameters dependent on photon energy.

4. CONCLUSIONS

Optical illumination of FET's in the active integrated antenna circuit was demonstrated. By optically tuning the impedance of the MESFET, the circuit operating frequency was tuned near 8.8 GHz without changing the radiation pattern significantly. In addition, to investigate the illumination effect on the FET's, the GaAs HEMT operating at 10.4 GHz and pseudomorphic HEMT operating at 10.5 GHz were illuminated by the optical source. Their tuning ranges became one tenth of that of the MESFET circuit. In each case, the gate voltage was unnecessary to obtain not only the operating frequency of an active integrated antenna but the optical tuning range.

The techniques described in this paper are for a planar configuration and are suitable for a fabrication in a monolithic wafer-scale integrated circuit. Although techniques for a uniplanar active integrated antenna are still in its infancy, realization of simple, multi-functional and compact transceivers can be facilitated with potentially low cost by combining the quasi-optical technology with the optical control method. Further, this technology is very promising for application at very high frequencies where a reasonable power output is needed.

ACKNOWLEDGMENT

This work was supported by US Army Research Office under contract DAAH 04-93-G-0068.

REFERENCES

[1] T. Itoh, "Active Antennas", Journees In't De Nice Sur Les Antennes, France, Nov.1990, pp 435-438

[2] A.A.A. de Salles, "Optical Control of GaAs MESFET's", IEEE Trans. Microwave Theory Tech., vol. 31, pp 812-820, Oct. 1983.

[3] M.A. Romero, A.L.A. Cunha and A.A.A. de Salles, "Theory and experiment for the HEMTs under optical illumination", 1991 IEEE MTT-S Int'l Microwave Symposium Dig. vol. 2, Boston, MA, June 1991, pp 495-498

[4] A. Madgar, P.R. Herczfeld and A. Paolella, "Analytical Model for Optically Generated Currents in GaAs MESFET's", IEEE Trans. Microwave Theory Tech., vol. 40, pp 1681-1691, Aug. 1992

[5] S. Kawasaki and T. Itoh, "Optical Control of 2-elelment CPW Active Integrated Antenna with Strong Coupling", to be appeared in 1993 IEEE AP-S Int'l Symposium Dig., Ann Arbor MI, June 1993.

[6] R. Simons, *Optical Control of Microwave Devices*, Artech House,1990

[7] S. Kawasaki and T. Itoh, "Quasi-Optical Planar Arrays with FET's and Slots", to be appeared in IEEE Trans. Microwave Theory Tech., Oct. 1992.

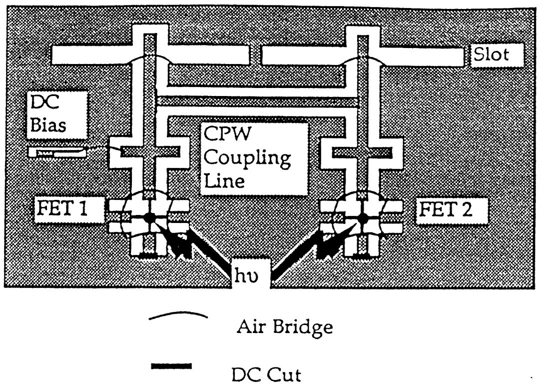

Fig.1 2-element Uniplanar Linear Array

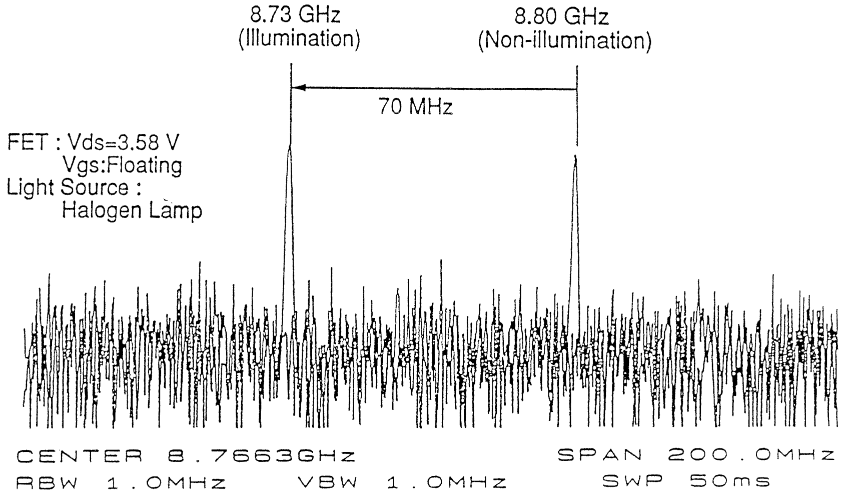

Fig.2 Operation Spectrum Shift
of Optically Controlled Active Integrated Antenna

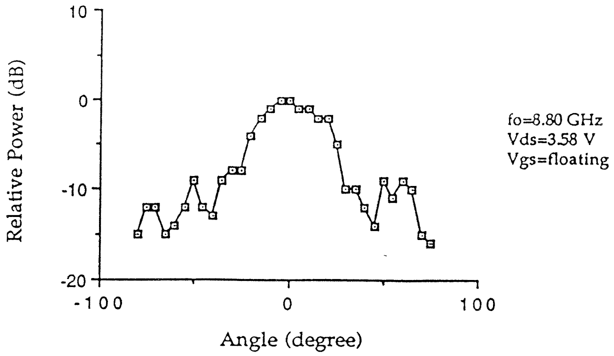

Fig.3 Antenna Pattern of 2-element
Optically Controlled Uniplanar Linear Array

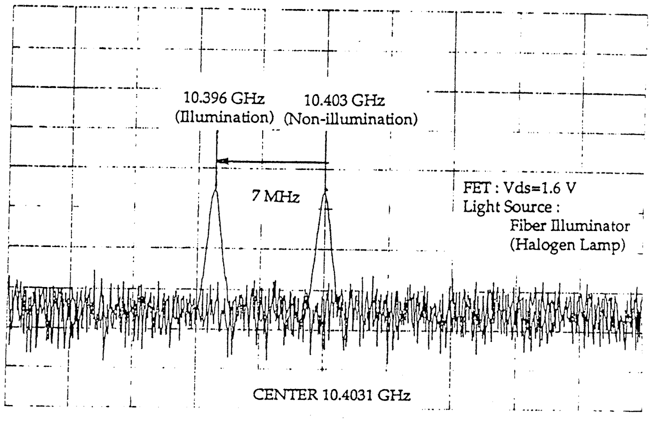

Fig.4 Operation Spectrum Shift of 2-element Optically Controlled Uniplanar Linear Array Using GaAs HEMT

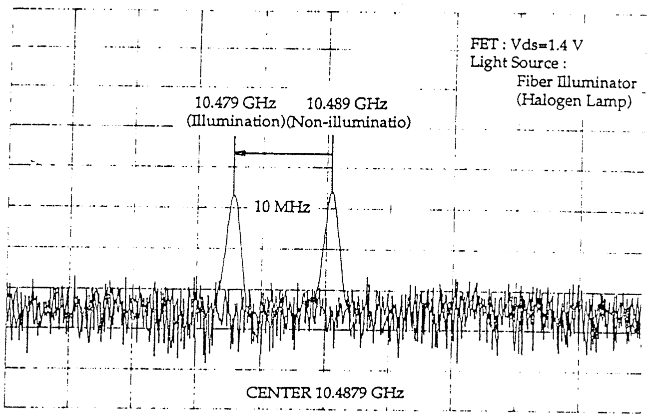

Fig.5 Operation Spectrum Shift of 2-element Optically Controlled Uniplanar Linear Array Using Pseudomorphic HEMT

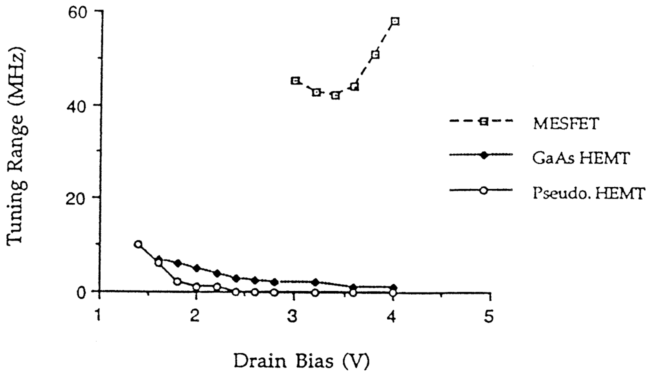

Fig.6 Comparison of Voltage Dependent Tuning Range