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OPTICAL CONTROL OF RADIATION PATTERN OF ACTIVE PATCH ANTENNAS

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1. Introduction

The beam forming and scanning in linear arrays of antennas have been extensively studied. They are also important in quasi-optical power combining[1]-[3]. Solid-state devices are considered to use less dc power than tube devices, but they need power combining in order to obtain a high power rf source. Spatial power combining in which oscillators are mutually coupled via free-space is an effective method because it has high efficiency and needs no extra combining circuits.

The scanning is accomplished by giving a constant phase progression in the array elements. However it requires as many phase shifters as the elements. Such an array system has rf radiators, rf feeders, circuits for the beam control signal to the phase shifters, and dc biasing network. Therefore their design procedure necessarily becomes troublesome.

Liao and York showed theoretically and experimentally that the radiation beam from an active antenna array could be steered without any phase shifters by changing the intrinsic frequencies of both ends of the weakly coupled oscillators[2]. Based on that results, in this work we tried to apply the optical control of microwave active devices to antenna arrays.

Studies on optically controlled active devices in microwave and millimeter wave range have been done by many researchers[4],[5]. Especially after the concept of optical fibre link systems in which optical signals are carrying microwave or millimeter waves as a subcarrier was proposed, the characteristics of rf active devices as an optical detector have been investigated.

As other examples of the application, Salles[6], Esman et al.[7] reported the control of the oscillation frequency in an oscillator with an illuminated FET. An optically tunable active filter was reported in which a variable reactance is realized by using a FET as a two-port device[8]. There is also a report on arrayed antennas that can switch the power combining modes by illuminating the FET as a reactance component in the oscillator circuits[9].

We have made optically-controlled active patch antennas. Kawasaki and Itoh have reported optical tuning of the oscillation frequency in active integrated slot antennas before[10]. The antennas made by us have features : that they use circular patches which have low cross-polarization level, and that their synthesized pattern can be optically changed.

We have verified experimentally, using two coupled active antennas in X band, that the phase difference in their oscillation is optically deviated and that the deviation causes the change in the radiation pattern. When this result is developed to arrays of many elements, beam scanning can be realized by optical means without separate phase shifters.

2. Principle of beam scanning and its application to optical control

It was introduced in reference 2 that the oscillation phase of every element of a coupled oscillator array can shift by changing the free-running frequencies of only two of the elements without any phase shifters. Assuming that oscillators integrated with radiators are weakly coupled and injection-locked in a linear array, if the free-running (intrinsic) frequencies of both ends of the array elements are de-tuned slightly from the phase-locked frequency within the locking range, then a constant phase progression is established along the array. As a result the beam direction is scanned, which is the same effect as using electronically-controlled phase shifters at each array element.

While the control of the free-running frequency was realized by a change of dc bias to the active devices, the optical control technique is available to change the characteristics of the devices. This work adopted the latter.

Two active microstrip patch antennas using GaAsFETs are synchronized oscillating by a free space coupling. One FET of them is illuminated with a laser light, and its oscillation state is varied. By that the phase difference of their oscillations is deviated, then the radiation pattern is changed.

3. Experimental setup

The fabricated antennas consist of two circular patches and a GaAsFET on PTFE substrates as shown in Fig.1. The patches are connected to the drain and the gate of the FET respectively, and their spacing is about 0.4mm which is insensitive to the circuit performance. The cross polarization characteristics of this shape of patch antennas is considered to be improved comparing to a rectangular patch.

DC biases are fed through inductors of high impedance wires. This antenna has no ground plane on the substrate, and a reflecting mirror is placed behind the patch antenna instead. The spacing is 5mm.

The free-running frequency of two oscillators were inevitably different in practice in spite of using the same type of FETs. We have carried out a cut and try fabrication by resizing the diameters of the patches in order to make their frequencies near within the locking range. The final diameters are 19mm for the optically-controlled active antenna (antenna #1), and 21mm for the other active antenna (antenna #2). The thickness of the substrate is 2mm.

The used FET is an n-channel, low noise, GaAsMESFET : NEC 2SK571, available for up to X band, and the absolute maximum rating for the total power is 300mW.

A semiconductor laser diode is used, whose wavelength is 840nm. The beam up to 19mW illuminated through a small hole on the mirror conductor. The beam was not always focused, and illuminated the whole FET chip with the cover removed.

The radiated rf signal is received by a pyramidal horn antenna 80cm apart from the active antennas, and the oscillation frequency and the power is observed with a spectrum analyzer.

4. Results

First, the characteristics of a single antenna is shown. The drain bias voltage and current are 3.2V and 15mA respectively in the dark state i.e. without illumination, and the gate bias is -1.7V.

Figure 2 shows the variation of the free-running frequency and the received power for a single active antenna. The frequency deviation of more than 70MHz is obtained by the illuminated power up to 0.17mW. We can attribute the deviation to the change of the oscillator circuit parameters due to the photoconductive and photovoltaic effects in the FET. The current of drain-source increased up to 40mA under the illumination.

Figure 3 shows the radiation pattern in H-plane for the single active antenna. The dashed line is the cross-polarization characteristics. The cross-polarization level is more than 10dB smaller than that of the main radiation around the front direction. Outside the range between ±40 degree, their levels are comparable. The pattern was not modified by the illumination to the FET. This fact means an advantage that the design for an array of many antenna elements is not so complicated.

The oscillation spectrum is shown in Fig.4. The band width of -3dB is 0.6MHz, and that of -20dB is 1.2MHz. This spectrum was not modified by the illumination neither.

Next we describes the characteristics of the coupled two antennas. The distance between the centers of the two elements is 37mm, which corresponds to $1.07\lambda_0$ where λ_0 is the free-space wavelength of the synchronized oscillation.

Figure 5 shows the radiation pattern in the dark state. The dashed line represents the cross-polarization. The solid line is the power of the main radiation, which is decreased at the front direction around -10 to 0 degree. This means that the two elements are oscillating in the reverse phase. The reason for the asymmetrical shape with respect to the zero degree direction is attributed to the difference of their oscillating powers.

When the FET of the antenna #1 is illuminated, the pattern alters as shown in Fig.6. The radiated power of the antenna #1 has increased by the illumination, and become comparable to the level of the other antenna #2. Then a clearer null appears than the dark state. The null direction changed from -16 to +6 degree by the optical power from 0.6 to 18.5mW. The direction of the maximum radiation also shifted together with the whole pattern. This means the change in the phase difference of the oscillation. The deviation of the free-running frequency in antenna #1 shown in Fig.2 has an effect like a phase shifter in the synchronized oscillation.

5. Conclusion

We have confirmed experimentally that the radiation pattern from two coupled active antennas can be changed by a laser illumination to the FET. The result can be developed to an antenna array of many elements whose beam is steerable by optical means.

Acknowledgment

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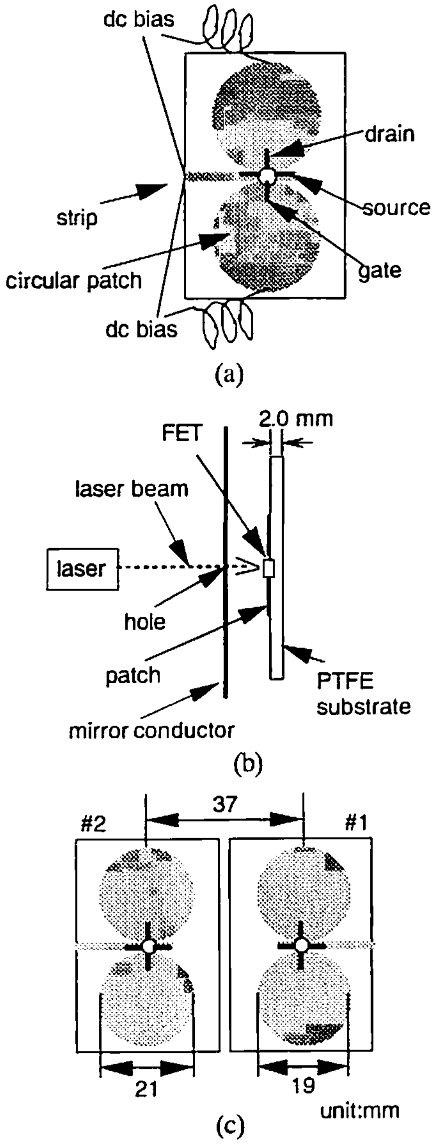

Fig.1 (a) Outline of a FET active antenna with circular patches.
(b) Setup of active antennas with a laser diode and a reflecting mirror.
(c) Arrangement of two active antennas.

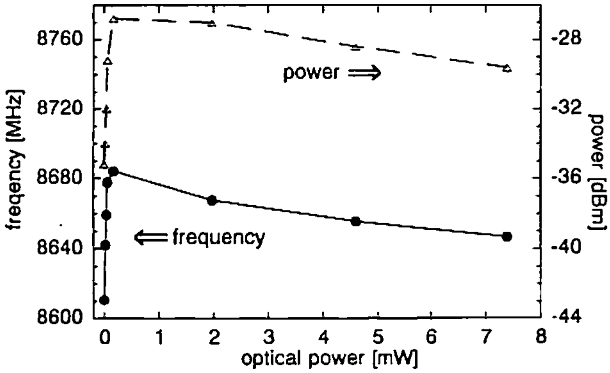

Fig.2 Variation of the oscillation frequency and the received power.

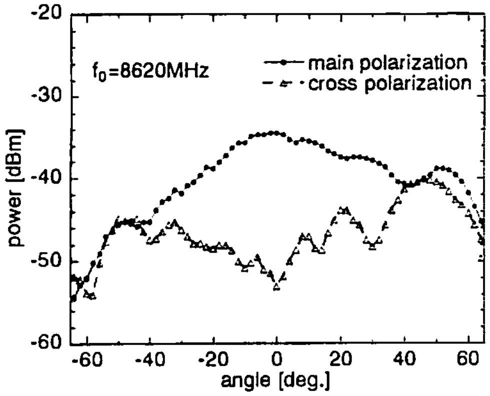

Fig.3 H-plane pattern of a single active antenna without illumination.

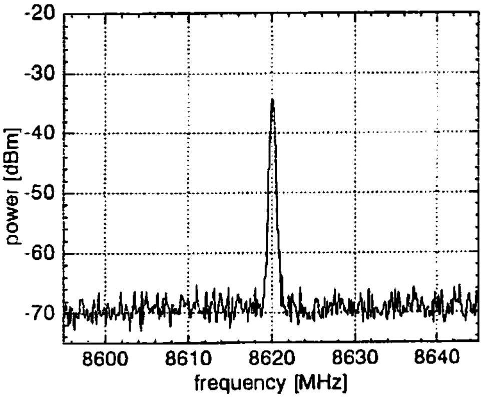

Fig.4 Oscillation spectrum of a single active antenna.

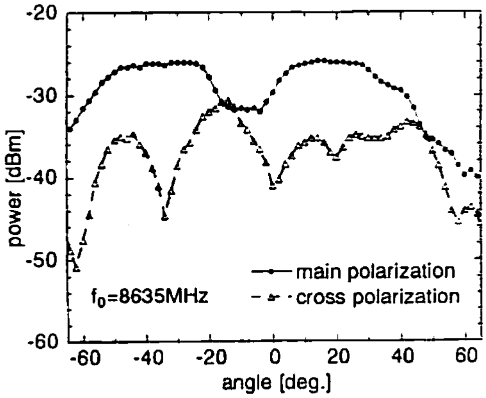

Fig.5 H-plane pattern of two synchronized antenna without illumination.

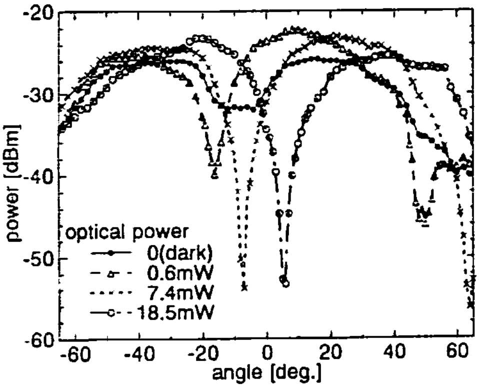

Fig.6 Radiation pattern variation for the illuminating laser power.