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NEW MMIC COMPATIBLE OPTICAL SIGNAL DISTRIBUTION METHODS FOR PHASED ARRAY ANTENNAS

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Introduction

The optical beam forming of phased array antennas is a very promising technique because of the advantages of the fibre optic signal transmission and the optical control of MMICs [1]. In phased array antennas one of the most important tasks is the carrier distribution for the T/R modules. Performing this task the main requirements are: a high frequency-stability, low amplitude and phase noise, agile frequency switching, fast amplitude and phase control, and MMIC compatibility. The strict specifications can be met by the new optical distribution method which can be used in the millimeter wave band as well.

New optical carrier distribution method

The base of the new method is a combined optical-microwave phase detector what is used in the phase locked loop (PLL) of the microwave oscillator generating the carrier frequency [2]. The frequency is stabilized by a reference signal which is transmitted to the phase detector via an optical fiber. The phase detector is composed of FETs as shown in Fig. 1. The FETs are illuminated by an intensity modulated light, and simultaneously they are fed by a signal coupled out of the oscillator. The error signal is generated in a comparator and is used to control the frequency of the oscillator.

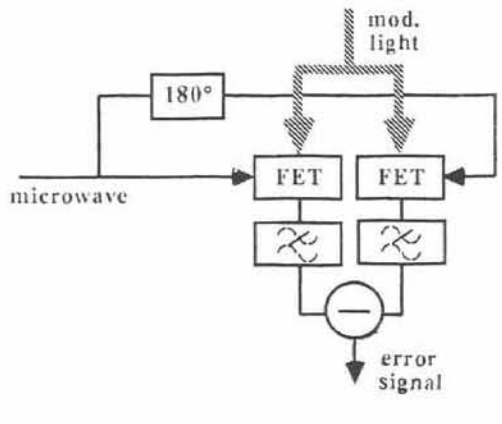

Fig. 1 Combined optical-microwave phase detector

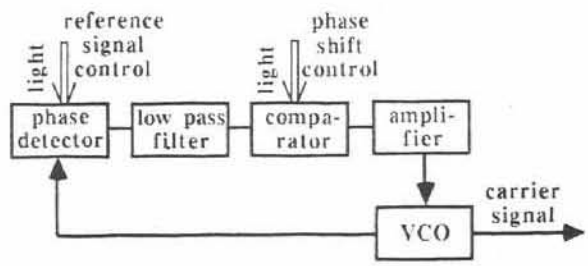

Fig. 2 Optical stabilization circuit for an MMIC oscillator

The reason why FETs are used in the optical-microwave phase detector is that they detect the intensity modulated light very effectively and can also be used in a MMIC construction. A FET is also applied for the 180° phase shifter. The operation of the optical-microwave phase detector is based on two effects:

1) The photon-electron interaction makes possible the optical detection, the result of that is the regained reference signal,

2) The nonlinearity of the FET drain-source current versus gate-source voltage relationship produces the dc component depending on the phase difference between the reference signal and the signal of the oscillator.

Under illumination the drain-source current (I_{dl}) as a function of the gate-source voltage (V_{gl}) can be expressed by a power series:

$$I_{dl} = I_{d0} + a_1 V_{gl} + a_2 V_{gl}^2 + a_3 V_{gl}^3 + \dots$$

I_{d0} is the drain-source current at the bias, a_1, a_2, and a_3 are coefficients.

Further V_{gl} is given as:

$$V_{gl} = V_{li} + V_s$$

where V_{li} is the light induced voltage, and V_s is the signal coupled out of the oscillator and fed to the gate-source input of the FET in the phase detector:

$$V_s(t) = V_{s0} \cos(\omega t + \varphi)$$

V_{s0} is the amplitude, ω the Radian frequency, φ the phase of the FET input signal, and t is the time.

V_{li} is also expressed by a power series:

$$V_{li} = c_{li} L_0^p + c_{li}\, p\, L_0^{p-1} (L - L_0) + \dots$$

where L is the intensity of the lightwave, L_0 is the average light intensity, c_{li} is a coefficient and p an exponent determined experimentally.

The light is intensity modulated by the sinusoidal reference signal:

$$L(t) = L_0 + m\, L_0 \sin \omega_r t$$

here m is the optical modulation depth (OMD), and ω_r is the Radian frequency of the reference signal.

Thus the error signal is obtained as follows:

$$I_{error} = 2\, a_2\, m\, p\, c_{li}\, L_0^p\, V_{s0}$$

Optical stabilization of the carrier frequency

The optical-microwave phase detector is applied to stabilize the frequency of the MMIC oscillator in the T/R (transmit/receive) module. The block diagram of the stabilization circuit is shown in Fig. 2. In this arrangement the phase of the carrier can also be optically controlled by illuminating the comparator circuit. That is a big advantage because the fast reaction time of the optical phase control makes possible a very agile beam switching or sweeping. However, for a fast action of the phase locked loop its bandwidth should be wide enough. The wider band results in a higher noise, therefore a trade-off is to be obtained between the control speed and oscillator noise.

There is an increasing need for higher frequencies and thus carrier frequencies in the millimeter wave band are to be used in phased array antennas as well. The optical transmission of millimeter waves faces many obstacles. First of all, the modulation frequency of the semiconductor lasers is limited by the relaxation resonance in the laser. The frequency of relaxation resonance is around 10 GHz. It is dependent on the bias current and thus it can be increased up to 20 GHz. Effective modulation of the laser is only possible below the relaxation resonance frequency.

The frequency of optically transmitted signals is limited at the reception side as well. Namely the sensitivity of the photo detectors is significantly reduced above 20 GHz. Thus the optical transmission of signals is more and more lossy when the frequency is increased into the millimeter wave band.

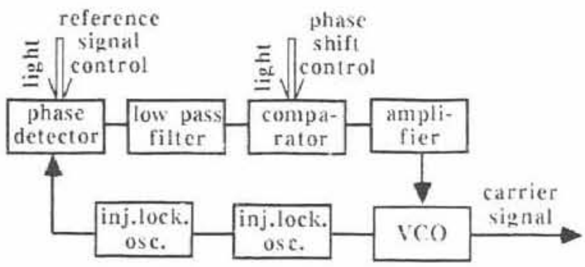

Fig.3 Optical stabilization of a millimeter wave MMIC oscillator

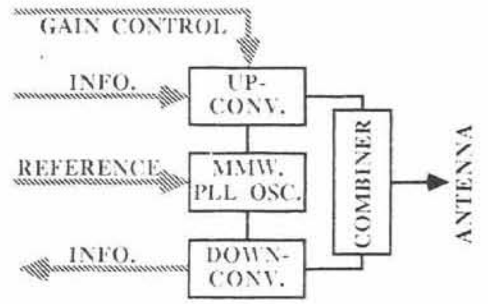

Fig. 4 Block diagram of an optically controlled MMIC T/R module

Fig. 3 presents a block diagram for the optical stabilization of a millimeter wave MMIC oscillator which is used in a T/R module. The signal coupled out of the oscillator is led to one (or more) frequency divider(s). This way the frequency of the millimeter wave signal is divided down into the microwave region and this signal can be compared with a reference signal in the optical-microwave phase detector. The advantage of the new arrangement is: a microwave signal is used as a reference for the millimeter wave oscillator.

The frequency division can be performed by the so called superharmonic injection locking technique. In this case the oscillator is operating at its fundamental frequency and is injection locked at one of its superharmonic frequencies. This technique can easily be used in MMICs as well.

Optically controlled T/R module

The complete block diagram of an optically controlled MMIC T/R module is shown in Fig. 4. The carrier signal is generated by a MMIC oscillator which is optically stabilized. The phase of the carrier is also controlled by a lightwave. The carrier signal is used as local oscillator (LO) signal for both the up-converter and down-converter. In the transmitter there is power amplifier, and in the receiver a low noise preamplifier as well.

For gain control the optical illumination of the converters can be used. The conversion loss of the up-, and down-converter is influenced by illumination. Therefore, this effect is used for the optical gain control of the T/R module. That is also shown in the block diagram of Fig. 4.

The effect of illumination is dependent on the bias voltages as well. In Fig. 5 the mixing product of a microwave mixer is plotted as a function of the gate-source voltage with and without light. With light the level of the mixing product is decreased because the linearity of the $I_{dl}(V_{gl})$ relationship is improved by illumination. This effect can be used for the gain control.

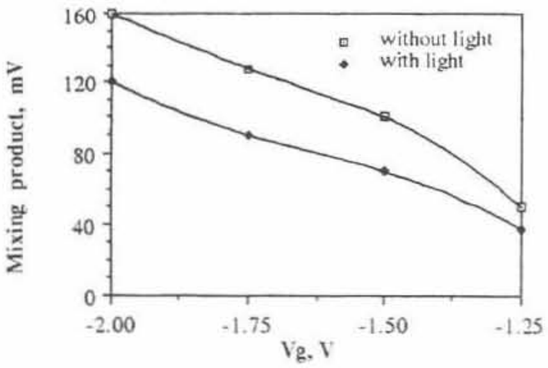

Fig. 5 The mixing product of an illuminated microwave mixer

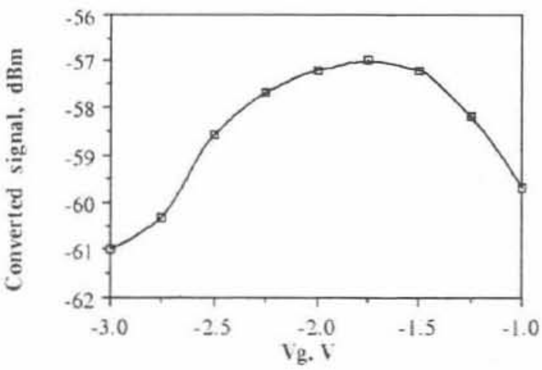

Fig. 6 The converted signal of the optical-microwave mixer

The information signals for the transmitter and receiver can be transmitted via optical fibers as well. That is also shown in Fig. 4. In this case special combined optical-microwave mixers are needed because a modulated lightwave is mixed with the microwave LO signal. The converted signal of the combined optical-microwave mixer is depicted in Fig. 6 as a function of the gate-source voltage. As seen an optimum performance is obtained between -1.5 and -2.0 V gate-source voltage.

Conclusion

A new optical carrier distribution method has been presented for phased array antennas. The method is well applicable to MMIC T/R modules and can be used in the millimeter wave band as well.

References

1. Herczfeld, P. R., Daryoush, A. S., Rosen, A., Berceli, T., Paolella, A.: "Optically Controlled Beamforming of Phased Array Antennas--New Results", Symposium Proc. of SBMO International Microwave Symposium / Brazil, Sao Paulo, pp 39-46, July 1989.
2. Berceli, T.: "A MMIC based new lightwave-microwave phase detector", Proc. of the 21st European Microwave Conference, Stuttgart, Germany, pp. 1311-1316, September 1991.