Dynamic Properties of Optically Controlled FET Amplifiers

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Abstract

The transmission of FET amplifiers can be controlled by a laser light illuminating the device. Due to the illumination the gain of the amplifier is increased significantly. In this paper the dynamic properties of the gain mechanism under illumination is investigated experimentally. The laser light is modulated and the effect of modulation is studied. As it is observed the influence of the optical modulation is strongly dependent on the gate-source voltage, and a significant decay is obtained when the modulation frequency is increased.

Introduction

The transmission of FET amplifiers can be controlled by a laser light illuminating the device. Due to the illumination the gain of the amplifier is significantly increased. In this paper the dynamic properties of the gain mechanism under illumination is investigated experimentally. The laser light is modulated and the effect of modulation is studied. The dynamic behavior is very relevant when combined optical-microwave functions are performed. The effect of light modulation has already been observed in this application [1,2], however, it has not been investigated in detail yet.

The FET amplifier under illumination has two inputs: a microwave and an optical input [3,4]. The dynamic property means the effect on the transmission characteristics caused by the variation of the input signals. The speed of that variation is modified by varying the frequency of the signals. Thus the dynamic transmission properties were tested varying the input microwave frequency and the modulation frequency of the laser light.

Scattering parameter measurements

The scattering parameters were measured in the dark case and under optical illumination. First we were interested in the dynamic behavior of these characteristics representing the dependence of the device parameters on the light intensity. The device was illuminated by a laser beam carrying intensity modulation. The incident optical power was 1 mW and the optical modulation depth was 2 %. For illumination a GaAs/GaAlAs laser diode was used at a wavelength of 780 nm. The laser beam was focussed by two lenses to produce a light spot with a diameter of 10 μm. The reflectance of the device surface was checked by tilted beam. The result was quite good: the reflected beam intensity was only 45 % of the incident beam. That figure includes the reflection from the metal surfaces of the electrodes as well.

The scattering parameters are shown in Figs. 1, 2, 3, and 4. The microwave frequency was varied from 1 to 12 GHz in 1 GHz steps. The incident light intensity was 0; 0.4; 0.8; and 1.2 mW. The smooth line represents the dark case, for the curve denoted by a square the incident light intensity is 0.4 mW, the curve denoted by ◇ refers to 0.8 mW and for the curve denoted by × the light intensity is 1.2 mW. In Fig. 1 the S_{11}, in Fig. 2 the S_{21}, in Fig. 3 the S_{12}, and in Fig. 4 the S_{22} scattering parameters are depicted in a Smith chart form.

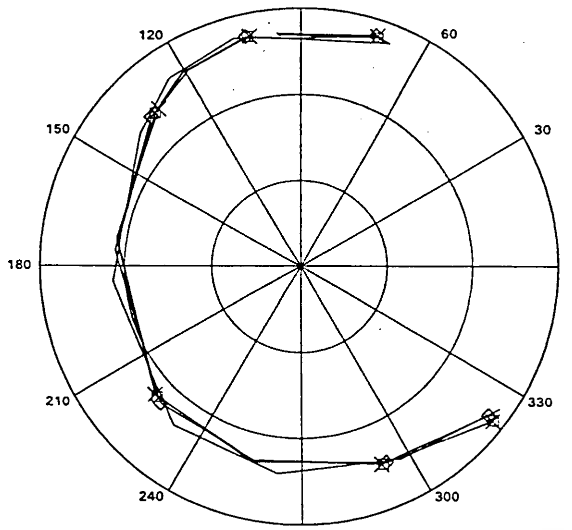


Fig.1 The S_{11} scattering parameter of the FET device under illumination

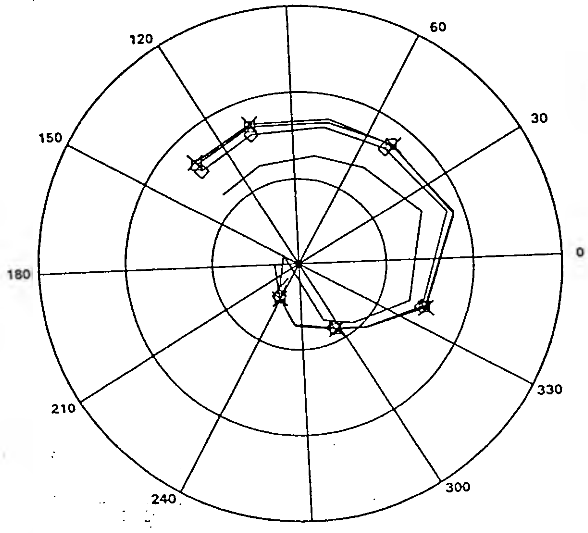


Fig.2 The S_{21} scattering parameter of the FET device under illumination

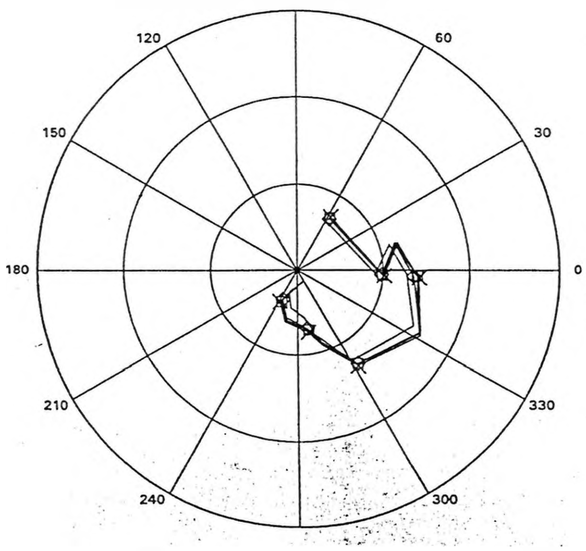


Fig.3 The S_{12} scattering parameter of the FET device under illumination

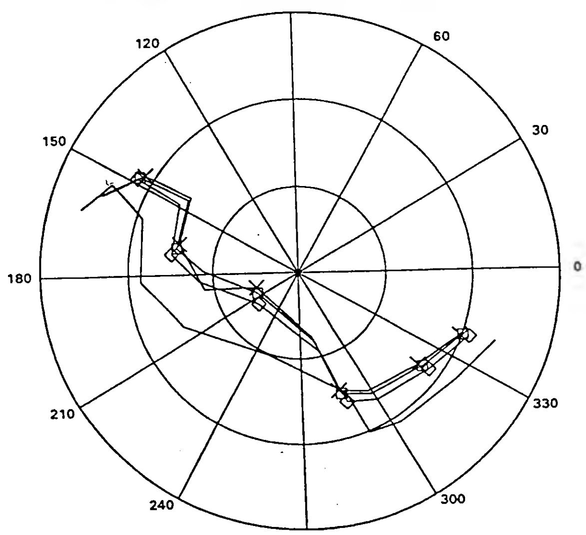


Fig.4 The S_{22} scattering parameter of the FET device under illumination

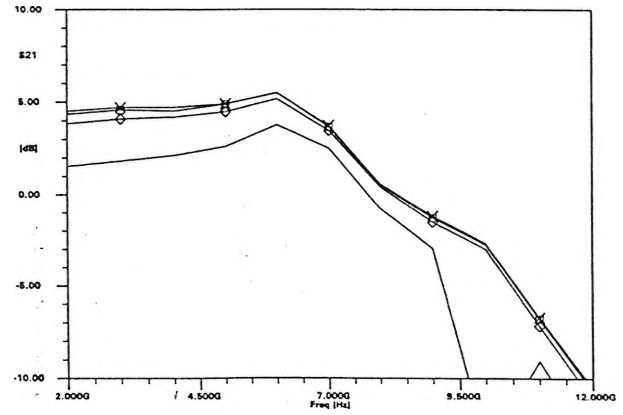


Fig.5 The magnitude of the S_{21} scattering parameter of the FET device under illumination as a function of the frequency

As seen in Figs. 1, 2, 3, and 4 the illumination has a significant effect on the S_{21} and S_{22} scattering parameters while the S_{11} and S_{12} parameters are unchanged. The magnitude of S_{21} is increased and the magnitude of S_{22} is decreased with increasing light intensity. However, their phases are not affected by illumination.

The effect of illumination can be better seen in Fig. 5 presenting the magnitude of the S_{21} parameter versus the frequency of the input microwave signal. The parameter of the curves is the light intensity as earlier. The illumination not only increases the magnitude of the S_{21} parameter but also shifts the cut-off frequency toward higher values. That is achieved in spite of the increase in the capacitances caused by the illumination.

Circuit model

The scattering parameters were used to develop a circuit model for the device. The elements of the model were extracted for each light intensity. Based on that procedure the dependence of the model elements on the light intensity was obtained.

The most important element, the transconductance is presented in Fig. 6 as a function of the light intensity. The drain-source voltage is 4 V, the gate-source voltage is -1 V. The relationship is logarithmic as seen in the Figure providing the equation of the approximation as well.

The dynamic behavior is dependent on several other parameters as well because the reactive elements of the model are dependent on the bias voltages and light intensity as well. The effect of bias voltages is well known.

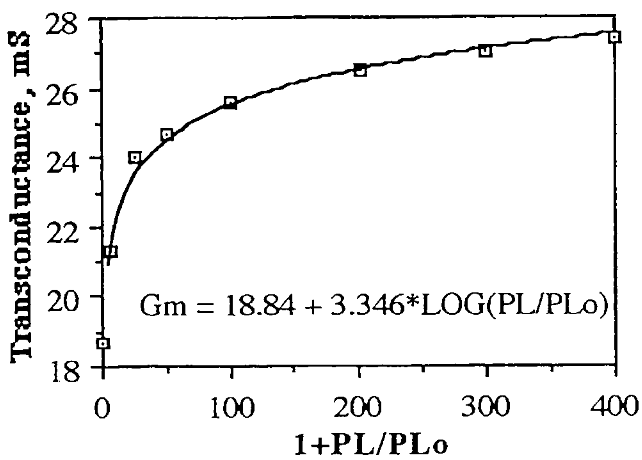


Fig. 6 Transconductance as a function of the relative optical power

However, the influence of illumination is interesting and thus it was also investigated. As an example Fig. 7 shows the gate-source capacitance as a function of the gate-source voltage with and without light. As seen the shape of the curves is very similar. That means the illumination does not influence the input capacitance - gate-source voltage relationship. Otherwise the device input capacitance on the light intensity follows a logarithmic function.

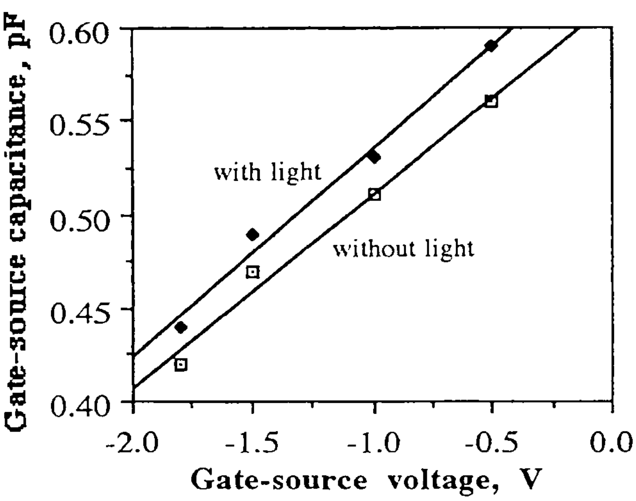
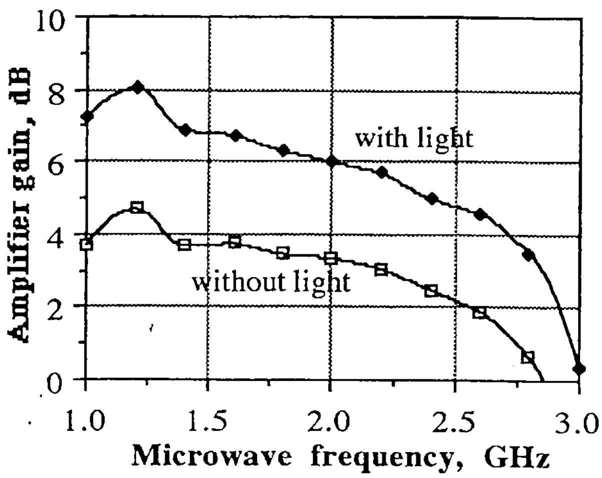


Fig. 7 Gate-source capacitance versus gate-source voltage

The effect of the illumination on the gain of a FET amplifier is shown in Fig. 8. The gain is plotted as a function of the microwave frequency with and without illumination. At this measurement the light intensity was 1.5 mW. The gate-source voltage was -1 V. The drain-source voltage was 4 V.



Fig, 8 Gain response of the amplifier with and without light

As seen in the Fig. 8 a significant increase (3-4 dB) is observed in the gain due to illumination. The shape of the gain response is not changed by the illumination. However, the decay in the gain is shifted to higher frequencies.

Influence of the modulation frequency

The influence of the modulation frequency of the light was then investigated. The modulation characteristic of the laser is almost linear thus its influence on the transmission property is negligible. However, the demodulation characteristic of the FET device is never linear enough what results in sideband signals at the output of the device. The frequency difference between the first sideband signals and the microwave signal is equal to the modulation signal frequency.

To test the dynamic behavior of the FET device under optical illumination the sideband signal level was measured. Thus the light illuminating the device is modulated to check the dynamic behavior. The level of the generated sideband signal is measured at the output with different gate-source voltages and modulation frequencies.

First the gate-source voltage is varied to observe its effect on the sideband level. Fig. 9 shows the relative level of the first sideband as a function of the gate-source voltage. The modulation frequency is 30 MHz. The drain-source voltage is 4V. The frequency of the microwave input signal is 2 GHz and its power is 0 dBm. The optical modulation depth is approximately 2%. As seen the influence is strongly dependent on the gate-source voltage.

At low gate-source voltages that effect is minimum, however, close to the pinch-off voltage it exhibits a maximum.

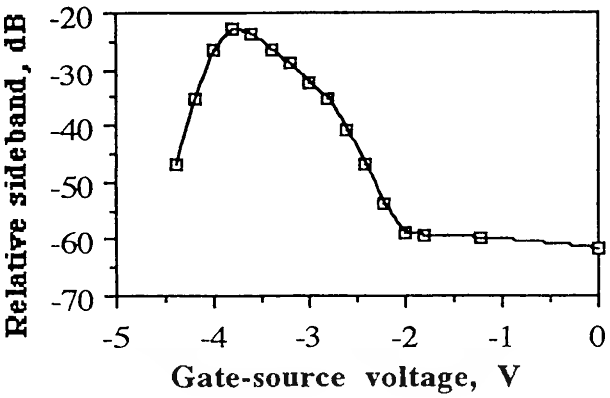


Fig. 9 Relative sideband versus gate-source voltage

Then the effect of the modulation frequency is tested. The result is shown in Fig. 10 where the relative sideband level is plotted as a function of the modulation frequency. The gate-source voltage is -2.6 V, the drain-source voltage is 4 V. The frequency of the microwave input signal is 2 GHz and its power is 0 dBm. The optical modulation depth is again approximately 2%. As seen in Fig. 10 a significant decay in the sideband level is observed when the modulation frequency is increased.

Conclusion

It can be concluded that the influence of the optical modulation is strongly dependent on the gate-source voltage, and a significant decay is obtained when the modulation frequency is increased. That means the dynamic behavior of the optically controlled FET amplifier is differing from the static one, and it exhibits a high frequency dependence.

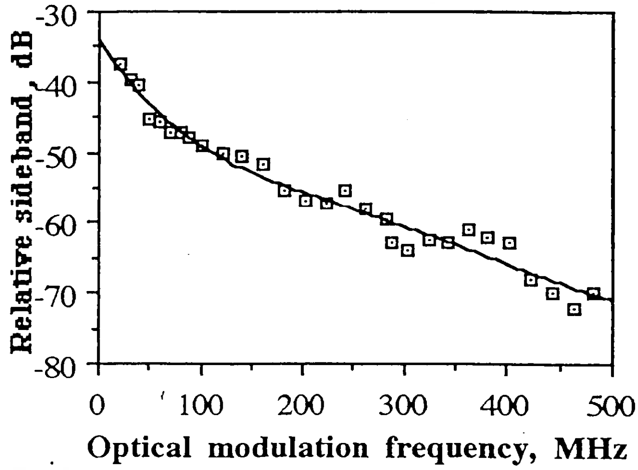


Fig. 10 Relative sideband versus optical modulation frequency

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