A NEW LIGHTWAVE-MICROWAVE SIGNAL CONVERSION METHOD

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ABSTRACT

A new method of lightwave-microwave signal conversion has been developed and studied in detail. In many applications there is a need for mixing modulated lightwaves and microwaves. The new method offers many advantages providing a high mixing product in a wide frequency range. An optimum adjustment has also been found. The comparison of results achieved by utilizing HEMT and FET devices will be presented as well.

INTRODUCTION

The combined lightwave-microwave processes are very important for efficient interfaces between optical and microwave systems. In many applications there is a need for mixing modulated lightwaves and microwaves. A method of that type of mixing has already been investigated [1]. In this paper, a new approach is presented for the lightwave-microwave signal conversion which offers many advantages. The optimum adjustment and comparison of results achieved by utilizing HEMT and FET devices will be presented.

PRINCIPLE OF THE NEW LIGHTWAVE-MICROWAVE CONVERSION METHOD

In the method presently applied for lightwave-microwave conversion, the microwave signal is fed to the gate and source of an FET along with a simultaneous illumination by a modulated lightwave. This technique is well applicable for many practical purposes, however, usually the converted signal is not high enough, and the bandwidth and driving range are also limited.

The new lightwave-microwave conversion method utilizes the higher nonlinearity offered by a FET or a HEMT device if they are driven simultaneously both at the gate-source and drain-source ports. The light illumination generates a light induced voltage across the gate and source [2]. The microwave signal is then led to the drain and source of the device. The converted signal is obtained at the drain and source, and is separated by a ferrite circulator or appropriate filtering.

To determine the nonlinearity of the device in that new operation mode, several investigations were carried out under optical illumination. The drain-source current was measured as functions of the gate-source and drain-source voltages under illumination. Thus a two dimensional map of the drain-source current was generated.

Based on the measured results, a relationship was established describing the drain-source current by a two-dimensional function. However, in a specific validity region, this function can be generated as the multiplication of two one-dimensional functions as follows:

$$I_d = (a_0 + a_1 V_g + a_2 V_g^2 + a_3 V_g^3 + a_4 V_g^4 + a_5 V_g^5) \cdot (b_1 V_d + b_2 V_d^2 + b_3 V_d^3 + b_4 V_d^4 + b_5 V_d^5) \qquad (1)$$

Here I_d is the drain-source current, V_g is the gate-source voltage, V_d is the drain-source voltage, a_0, a_1, a_2, a_3, a_4, a_5, and b_1, b_2, b_3, b_4, b_5 are coefficients dependant on the specific device.

In the expression (1) describing the drain-source current, terms up to the fifth power have to be included if the conversion is to be investigated as a function of the biasing voltages. In Eq. (1) the first one-dimensional function is a power series of the gate-source voltage, the other one-dimensional function is a power series of the drain-source voltage.

The lightwave illuminating the FET and HEMT devices is modulated in intensity by a sinusoidal time function:

$$L = L_0 (1 + m_1 \cos \omega_1 t) \qquad (2)$$

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L_0 is the average light intensity without modulation, m_l is the modulation index or depth, ω_l is the radian frequency of the modulating signal, and t is the time.

Based on previous investigations [3] the effect of illumination is given by the light induced voltage V_{li} appearing across the gate and source. That voltage is expressed by the light intensity:

$$V_{li} = c_l L^p \qquad (3)$$

L is the intensity of the lightwave, c_l and p are the experimentally determined coefficient and power, respectively. In our case $c_l = 0.29$ and $p = 0.14$.

Eq. (3) is expanded into a power series around L_0 and Eq. (2) is substituted into it. Keeping only the first power or linear term, the a.c. component of the light induced voltage V_{li1} is obtained as a function of the light intensity variations:

$$V_{li1} = c_l \, p \, L_0^{p-1} \, m_l \, L_0 \cos \omega_l t \qquad (4)$$

The microwave signal applied at the drain and source is given as:

$$V_d = V_{d0} (1 + m_2 \cos \omega_2 t) \qquad (5)$$

V_{d0} is the biasing drain-source voltage, m_2 is the modulation index or depth, and ω_2 is the radian frequency of the modulating signal.

The mixing effect is characterized by the conversion ratio C_r, i.e. the ratio of the mixing product in the drain-source current to the a.c. components of the two driving voltages what is obtained as follows:

$$C_r = \frac{1}{2} (a_1+2a_2V_{g0}+3a_3V_{g0}^2+4a_4V_{g0}^3+5a_5V_{g0}^4) \cdot (b_1+2b_2V_{d0}+3b_3V_{d0}^2+4b_4V_{d0}^3+5b_5V_{d0}^4) \qquad (6)$$

V_{g0} is the biasing gate-source voltage. In Eq. (6) the first term is the partial derivative of the drain-source current with respect to the gate-source voltage, and the second term is the partial derivative of the drain-source current with respect to the drain-source voltage. The conversion ratio is high when both derivatives are simultaneously high enough.

The validity range of Eq. (6) has been checked using measured data. The validity range is larger with enhanced drain-source voltage. In the low drain-source voltage region the validity range is reduced. The measurement points were chosen in accordance to the beforegoing.

MEASUREMENTS ON FET AND HEMT DEVICES

Some cross-sections of the drain-source current two dimensional map are plotted in Figs. 1 and 2 for FET and HEMT devices. Fig. 1 shows the drain-source current as a function of the gate-source voltage for several drain-source voltages. As it is noticed the shape of the curves is remarkably changed when the drain-source voltage is varied. On the contrary, the shape of the HEMT curve is not dependent on the drain-source voltage as seen in Fig. 2 presenting the drain-source current as a function of the gate-source voltage for low values of the drain-source voltage.

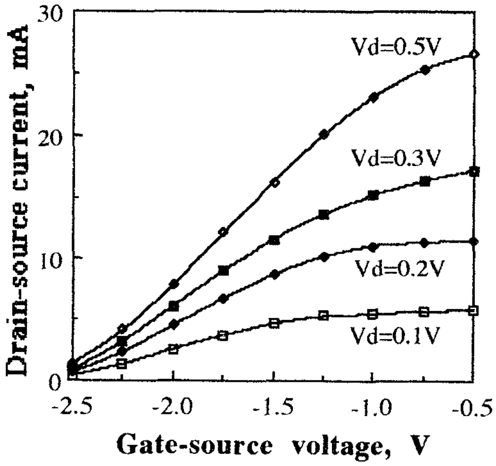

Fig. 1 Drain-source current versus gate-source voltage for a FET device

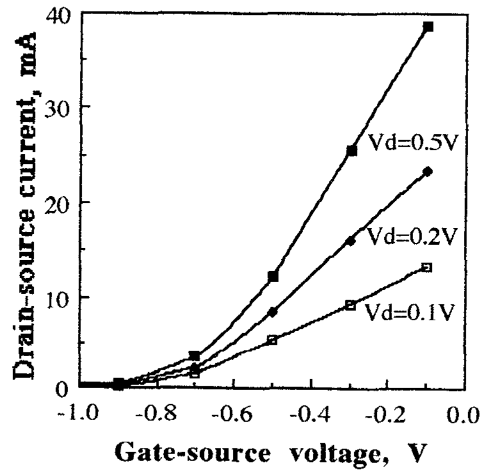

Fig. 2 Drain-source current versus gate-source voltage for a HEMT device

A comparison has been made between the FET and HEMT characteristics. A significant difference has been observed which is seen in Figs. 1 and 2 presenting the drain-source current versus gate-source voltage curves for the low drain-source voltage region. The shapes of the curves in the two Figures are completely different which is reflected in the mixing effect as well.

For the new operation mode the low drain-source voltage region is interesting where the slopes of the drain-source current curves are high. Therefore the drain-source current is depicted for the low drain-source voltage region in Fig. 3 as a function of the drain-source voltage in the case of the FET device. The parameter of the curves is the gate-source voltage.

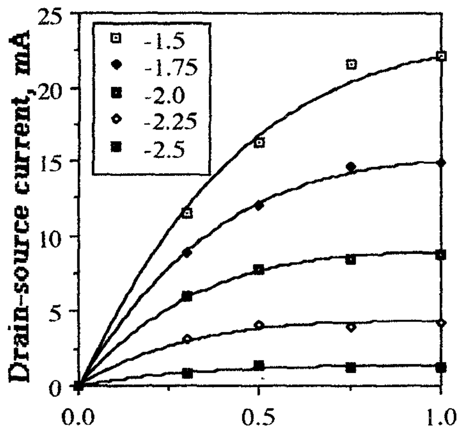

Fig. 3 Drain-source current versus drain-source voltage for a FET device, the parameter is the gate-source voltage.

As Eq. (6) shows the conversion ratio is dependent on the slope of the drain-source current versus gate-source voltage curve and on the slope of the the drain-source current versus drain-source voltage curve. These two slopes are multiplied. To obtain a high conversion ratio both slopes should be simultaneously high. As seen in Fig. 1 at low drain-source voltages the slope of the drain-source current versus gate-source voltage curve is higher if the magnitude of the gate-source voltage is higher. However, at the same time the slope of the drain-source current versus gate-source voltage curve is reduced as seen in Fig. 3. Therefore an optimum adjustment is expected for the mixing effect.

INVESTIGATIONS ON THE MIXING EFFECT

First the mixing product is investigated as a function of the gate-source biasing voltage. The result is shown in Fig. 4 in case of FET device presenting the conversion ratio as a function of the gate-source voltage. The parameter of the curves is the drain-source voltage. As seen there is a maximum conversion ratio at an optimum gate-source voltage. The maximum is higher if the drain-source voltage is smaller. The location of the maximum is shifted toward lower magnitudes of the gate-source voltage when the drain-source voltage is increased.

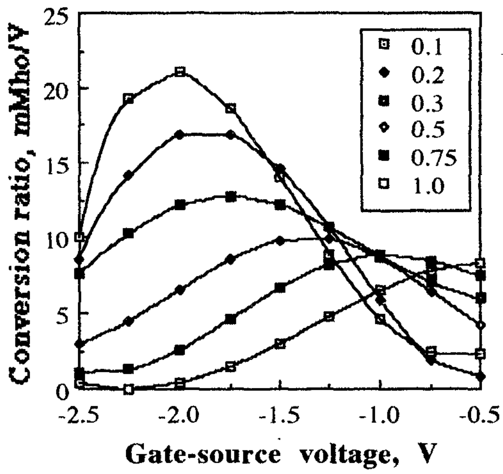

Fig. 4 Conversion ratio of the FET versus gate-source voltage, the parameter is the drain-source voltage

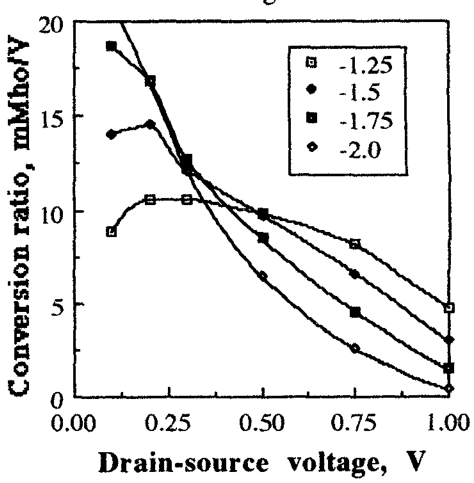

Fig. 5 Conversion ratio of the FET versus drain-source voltage, the parameter is the gate-source voltage

The effect of the drain-source biasing voltage is seen in Fig. 5 in the case of the FET device. In this Figure the conversion ratio is plotted as a function of the drain-source voltage. The parameter of the curves is the gate-source voltage. At small negative gate-source voltage an optimum drain-source voltage is obtained. However, at high negative gate-source voltage there is no optimum. Then the mixing product is increased with reduced drain-source voltage.

The conversion ratio of the HEMT device is shown in Fig. 6 as a function of the gate-source voltage. The parameter of the curves is the drain-source voltage. Comparing Figs. 4 and 6 it is seen that the maximum conversion ratio of the HEMT is significantly higher than that of the FET.

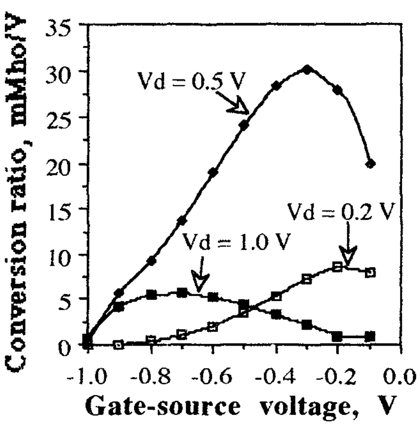

Fig. 6 Conversion ratio of the HEMT device as a function of the gate-source voltage

EXPERIMENTS

Lightwave-microwave mixing experiments were performed applying the new conversion method. The microwave signal was led to the drain-source port, and the modulated laser light illuminated a FET device. The frequency of the microwave signal was around 6 GHz. The laser diode was modulated with a modulation depth of 1 percent. At the drain-source port a circulator served to separate the driving microwave signal from the mixing product which was observed by a spectrum analyzer.

The measured converted signal is plotted versus the gate-source voltage in Fig. 7. A definite maximum is obtained close to the predicted optimum gate-source voltage which is in a good agreement with the previous investigations.

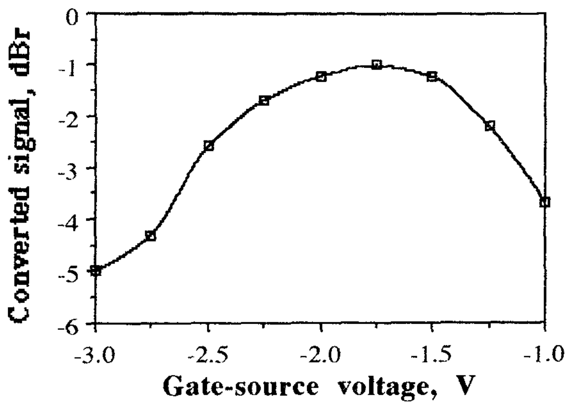

Fig. 7 The measured converted signal versus the gate-source voltage

CONCLUSIONS

A new method of lightwave-microwave signal conversion has been developed and studied. The new method provided a high mixing product. An optimum adjustment has also been found. The HEMT lightwave-microwave mixing results in a higher converted signal compared to the FET mixing. The performed experiments are in a good agreement with the derived results.

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