Improved Microwave-Optical Reception Applying Double Amplification in Photo Transistors

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Abstract – **The detection efficiency of photo transistors is improved by a new approach. Its basic principle is the double utilization of the transistor gain mechanism. As a result a significant increase in the responsivity (e.g. 25 dB) is obtained in a narrow band. The new approach is advantageously applicable for the reception of subcarrier multiplexed signals.**

I. INTRODUCTION

The efficient detection is a crucial problem for the reception of optically transmitted microwave signals. In the most commonly used receivers PIN photo detector diodes are applied to convert the optical signal into the microwave domain. The PIN diode has many advantages: it exhibits a very high cut-off frequency, a good quantum efficiency and low noise. However, it has some drawbacks as well: its output resistance is high making wideband matching troublesome, it cannot be easily developed for a monolithic circuit because it requires a different technology than the transistors. Nevertheless, the PIN photo detector diode is well applicable for wideband optical receivers.

Recently a new transistor type called photo transistor has been developed [1,2] which has a high photo sensitivity and simultaneously significant inherent gain for the detected signal [3]. This way the photo detection, impedance matching and microwave amplification are accomplished in a single device. The photo transistor seems to be a good candidate for advanced optical receivers [4.5] although the optical coupling efficiency is poorer than that of the PIN diode.

II. NEW APPROACH

The detection efficiency of photo transistors is improved by a new approach presented in this paper. The basic principle of the new approach is the double utilization of the transistor gain mechanism. Fig. 1 shows the details of the new approach. The intensity modulated laser beam is coupled into a fiber which is used to illuminate the photo transistor. The laser is modulated by the signal of a sweeper. The photo transistor serves for optical detection. A part of the detected signal appearing at the transistor output is coupled back to the transistor input via a feedback loop. The feedback loop consists of a phase shifter and attenuator to control the amplitude and phase of the feedback signal. This way a part of the detected signal is amplified again and in case of phase coherence it is added to the original detected signal. That double utilization of the transistor gain results in a significant increase of the detected signal or by other words of the detection sensitivity. As the feedback loop is frequency dependent the response also exhibits frequency dependence. That means a relatively narrow band operation.

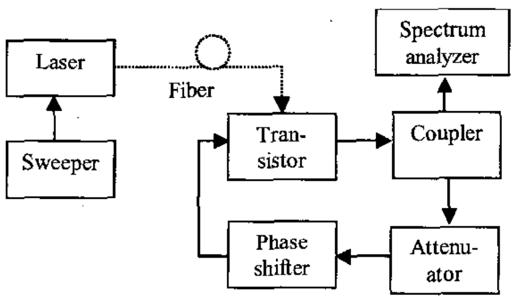

Fig.1. Block diagram of the new method

III. EXPERIMENTAL SET-UP

In the experiments a GaAs MESFET device with enhanced photo sensitivity is used as the photo detector. A Fabry-Perot type laser diode serves for illuminating the transistor device. The wavelength of the laser beam is 795 nm, its optical power is 590 μW. The laser bias current is directly modulated using a microwave sweep oscillator. The output signal of the transistor is tested by a spectrum analyzer. The curves of the spectrum analyzer are plotted and presented here.

First the detection process is investigated without feedback. The dependence of the detected signal on the bias voltage is shown in Fig. 2. The detected signal is remarkably reduced when the bias voltage approaches the pinch-off voltage. At small negative bias voltage the detection is only slightly dependent on the bias voltage. As seen the detected signal is high at small negative gate-source voltages where the amplification is also high. That is an advantageous behavior in the new approach.

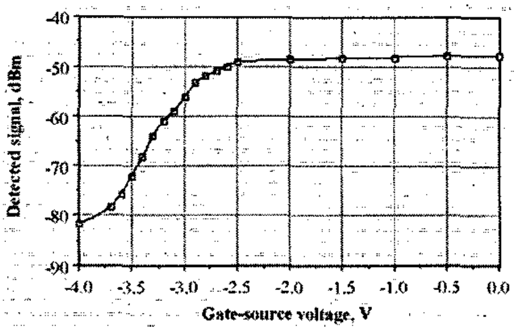

Fig. 2. The detected signal without feedback versus the gate-source voltage

IV. Experimental Results

Now the effect of the feedback is studied. In this experiment a coaxial cable is used as a phase shifter in the feedback loop. Therefore the phase shift exhibits a periodic function. The amplitude of the feedback signal is adjusted by varying the coupling at the output of the transistor. The results are presented in Figs. 3, 4, and 5 showing the output plot of the spectrum analyzer.

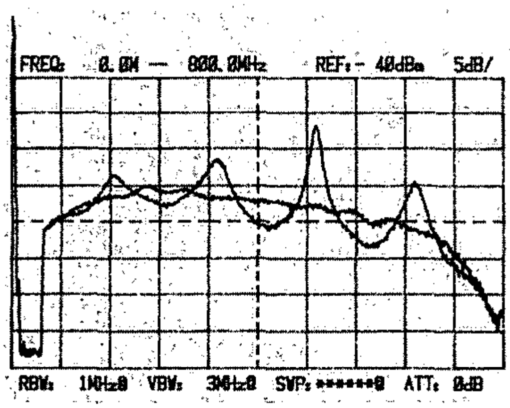

Fig. 3 Detected signal versus frequency in the band from 40 MHz to 800 MHz; smooth curve: detection without feedback and periodic curve: detection with feedback

In case of Fig. 3 the modulation of the laser is varied between 40 MHz and 800 MHz. Two curves are presented. The smooth curve shows the detected signal without feedback and the periodic curve depicts the detected signal with feedback. Depending on the phase shift of the feedback loop the original detected signal and its feedback part can be added or subtracted. Using a proper feedback significant increase is obtained at a specific frequency. The bandwidth of the enhanced detected signal is significantly narrower than that of the original detected signal. The higher the increase in the detected signal the narrower the bandwidth. In spite of this behavior the enhancement of the detected signal is advantageous in many cases, e.g. in the case of subcarrier multiplexed signal transmission when the modulation bandwidth of a subcarrier is usually narrow.

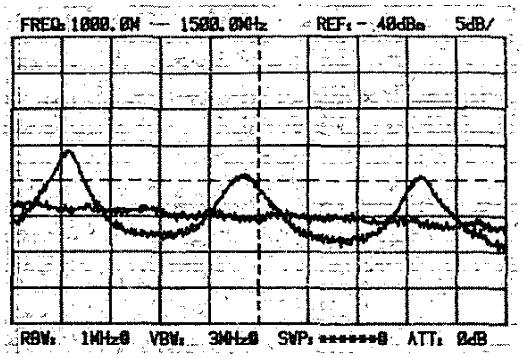

Fig. 4 Detected signal with feedback versus frequency in the band from 1000 MHz to 1500 MHz

Fig. 4. shows the detected signal with feedback when the modulation frequency is varied between 1000 MHz and 1500 MHz. That frequency band is above the cut-off frequency of the detection process without feedback. Due to the significant increase in the detected signal with the feedback we get detection peaks above the cut-off frequency even as high as the detected signal below the cut-off frequency without feedback.

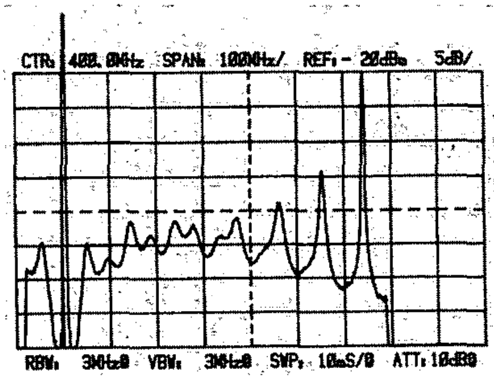

Fig. 5 Detected signal with tighter feedback versus frequency in the band from 40 MHz to 800 MHz

Fig. 5 shows the result of another arrangement with tighter feedback. In that case a very pronounced peak is seen at 740 MHz. At that peak the increase in the output power is 25 dB compared to the no feedback case. However, the bandwidth is much smaller. Actually, the gain-bandwidth product remains constant when the feedback coupling factor is varied.

The location of the local maxima is shifted with changing the length of the feedback coaxial line. The amplitude of the output signal is adjusted by varying the coupling at the output. However, utilizing an electronic phase shifter inserted into the feedback loop the local maxima can be swept over a very wide band. The application of a bandpass filter in the feedback loop makes possible selective photo reception. That is very useful when several subcarriers are transmitted over the fiber and only one of them is to be received.

V. THEORETICAL INVESTIGATION

For the theoretical investigation the simplified model presented in Fig. 5 is used. Here the current source i_d represents the gain mechanism and the current source i_{ph} stands for the photo detection process. The current source i_d is controlled by the gate-source voltage v_g via the transconductance g_m:

$$i_d = g_m v_g \tag{1}$$

The current source i_{ph} is controlled by the incident optical power:

$$i_{ph} = S_{ph} p_{opt} \tag{2}$$

where S_{ph} is the photo sensitivity of the transistor and p_{opt} is the modulation intensity of the incident optical beam.

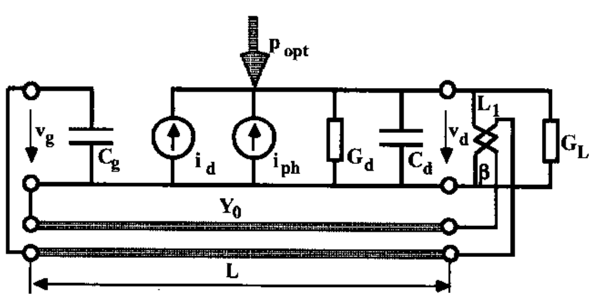

Fig. 6 Simplified model

The lower case letters designate the a.c. components. The d.c. components are not considered now. Both the transconductance and the photo sensitivity are dependent on the bias voltages of the transistor. Beside this the photo-sensitivity is also significantly dependent on the modulation frequency.

For simplicity a single resonant circuit is applied at the transistor output consisting of the drain-source capacitance C_d and the inductance L_1.

A part of the output voltage is fed back to the input of the transistor via a transmission line. The investigation is performed for the vicinity of the enhanced output signal where resonance is encountered.

The maximum output power is obtained at the resonance as follows:

$$p_{L\max} = S_{ph}^2 p_{opt}^2 \frac{G_L}{(G_d + G_L - \beta g_m)^2} \tag{3}$$

where G_d is drain-source conductance, G_L is the load conductance and β is the voltage feedback coupling factor from the output to the input of the transistor.

When βg_m is approaching $(G_d + G_L)$ the output power is increasing rapidly. However, a strong feedback can cause instability what has to be avoided. Therefore the enhancement of the detected power is limited.

The 3 dB bandwidth is given as:

$$B = \frac{\omega_0}{Q_L} \frac{(G_d + G_L - \beta g_m)}{G_d + G_L} \tag{4}$$

Here ω_0 is the resonant frequency, and the loaded Q factor is:

$$Q_L = \frac{\omega_0 L_1}{G_d + G_L} \tag{5}$$

If the increase of the output power is higher the bandwidth is smaller assuming an unchanged Q_L factor.

The enhancement or gain G_p - achieved by the double utilization of the transistor gain - is obtained when the maximum output power with feedback is related to the detected power without feedback.

$$G_p = \frac{(G_d + G_L)^2}{(G_d + G_L - \beta g_m)^2} \tag{6}$$

Therefore the product of the bandwidth and the square root of the power gain is:

$$B\sqrt{G_p} = \frac{\omega_0}{Q_L} \tag{7}$$

Consequently the gain - bandwidth product is not dependent on the feedback coupling factor.

When a high output power is to be achieved the stability condition has to be considered as well. The amplifier should be stable even without illumination. The condition for stability is:

$$\beta g_m < (G_d + G_L) \tag{8}$$

The same result is obtained for the case when the transistor is illuminated.

VI. Selective reception of a subcarrier signal

In the presently used optical systems the reception of modulated subcarrier signals is performed - after optical detection - in two different ways:

- the subcarriers are separated by a series of fixed frequency filters and the wanted subcarrier is selected by a switch; that is a very complicated and expensive method,
- a specific subcarrier is selected by a tuned filter. In this case keeping the performance of the filter unchanged when it is tuned is very difficult because several resonators and their couplings are to be simultaneously controlled.

The selective reception method of the present paper offers new perspectives. In the subcarrier type optical communications each transmitter has its own subcarrier frequency. The transmission capacity of the network can be increased by applying new subcarriers and thus the digital processing rate per subcarrier remains fixed.

Utilizing the new method for the reception of the subcarrier multiplexed optical signal transmission a much simpler receiver structure and channel selection can be achieved. By tuning the feedback circuit a specific subcarrier signal is separately received. That is a big advantage because beside the significant increase in the detected signal the filtering effect is also utilized. As the bandwidth of the subcarrier channels is usually relatively small the narrow bandwidth of the present approach does not cause any problem in the reception.

VII. Conclusions

The detection efficiency of photo transistors is improved by a new approach presented in this paper. As the result of the new approach a significant increase in the responsivity (e.g. 25 dB) is obtained in a narrow frequency band. The new approach is advantageously applicable for the reception of subcarrier multiplexed optical signals.

VIII. Acknowledgements

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