A HIGH SPEED GaAs MONOLITHIC TRANSIMPEDANCE AMPLIFIER

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ABSTRACT

This paper describes the design method and test results for a novel transimpedance amplifier suitable for very high speed optical communications systems. The amplifier chip is developed for four different bit rates: 188, 565, 1130, and 1500 Mb/s with optical sensitivities -38.5, -33, -30, and -28 dBm, respectively. The amplifier provides 2 V peak to peak output voltage and 30 dB dynamic range.

INTRODUCTION

This paper discusses a novel circuit configuration, for current to voltage amplification, to be used at very high bit rates in optical communication receivers. The circuit is optimized for maximum gain and sensitivity, and lowest power consumption in the monolithic form on GaAs substrate using half micron gate length processing. The theoretical performance presents state-of-the-art results.

In the design of an optical communication receiver, the basic goal is to minimize the received optical power required to achieve a given S/N ratio for analog systems or the bit error rate (BER) for digital systems. The noise performance of an optical receiver depends on both the photo detector and the preamplifier. The preamplifier is designed to provide current to voltage amplification with minimum possible noise contribution.

CIRCUIT DESIGN

The transimpedance amplifier is the most suitable preamplifier configuration for optical communication receivers. This topology offers: (i) high current to voltage conversion, (ii) good noise performance, (iii) wide bandwidth, and (iv) large dynamic signal range. In the transimpedance amplifier design to be presented here, the cascode configuration is used at the input side to reduce Miller capacitance (for higher bandwidth) and a common drain (source follower) configuration is used at the output to provide low output impedance. The amplifier has been designed using an in-house computer aided design program (TRANS). The SPICE program has also been used to adjust bias voltages. The TRANS program uses a nodal analysis technique and includes an accurate noise characterization of passive and active circuits. This program accepts input noise and signal currents, diode and MESFET characteristics to calculate current-voltage gain, and optical sensitivity at a given BER.

Both dc coupled and ac coupled amplifiers have been studied using .5 x 300 μm MESFETs. The schematic of an optimum transimpedance amplifier is shown in Figure 1. Four different

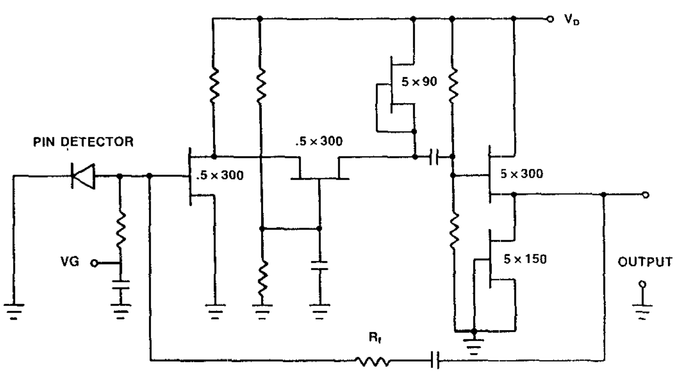


Figure 1 Schematic of a transimpedance amplifier circuit. Dimensions are in microns.

bandwidths can be obtained by adjusting the feedback resistance. The highest value feedback resistor (which gives 200 MHz bandwidth) is permanently connected. The other three bandwidths are obtained by connecting (using a single wire bond) two other resistors on the chip. Design goals for these four different amplifiers built in a single chip are summarized in Table 1.

The optical sensitivity calculations are based on operating optical wavelength $\lambda = 1.3$ µm, BER $= 10^{-9}$, and a Lasertron PIN diode having quantum efficiency $\eta = 70\%$, capacitance $C_d = .5$ pF and dark current $I_d = 20$ nA. A possible improvement in optical sensitivity might be obtained using a FET with higher g_m and a better PIN diode as follows:

g_m from 25 mS to 40 mS	≃ 1 dB
C_d from .5 pF to .3 pF	≃ .8 dB
I_d from 20 nA to 10 nA	≃ .2 dB
η from 70% to 90%	≃ 1.1 dB
Total improvement in optical sensitivity	≃ 3.1 dB

FABRICATION

The circuits were fabricated using the standard ITT Gallium Arsenide Technology Center (ITT/GTC) microwave process for ion implanted GaAs. The active layer has doping $n = 2 \times 10^{17}$ cm^{-3} and thickness $t \simeq .15$ µm. The process includes AuGe/Ni metallization for ohmic contacts, .5-µm-long Ti/Pd/Au Schottky gates, Si_3N_4 overlay capacitors and mesa resistors. The resistors were tuned using an additional resistor tuning mask layer. The air bridges, microstrip lines, and bonding pads are 3-µm plated gold. The wafer is lapped to its final thickness of 200 µm and diced. A photograph of the ac coupled transimpedance amplifier is shown in Fig. 2.

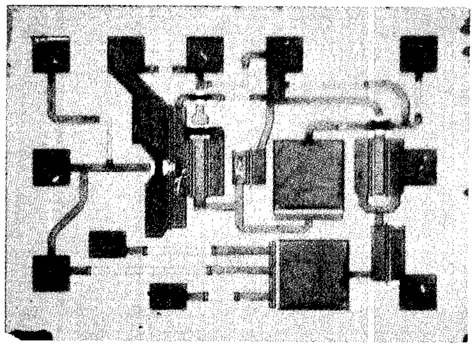


Figure 2 Photograph of an AC coupled transimpedance amplifier

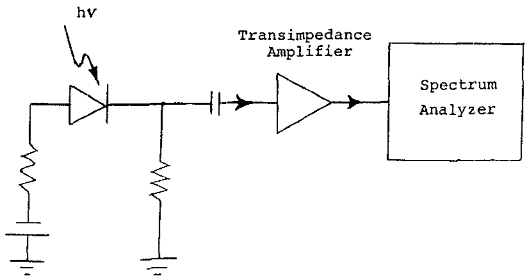
TEST RESULTS

Several transimpedance amplifiers have been mounted and tested using .828 micrometer lasers. The maximum modulating frquency of this laser is 1 GHz. The sensitivity of an optical receiver is determined by measuring equivalent input noise current spectral density as shown in Fig. 3. At each frequency of interest, the signal-to-noise ratio out of the receiver is measured using a spectrum analyzer. Then the input equivalent noise current spectral density $i_n/\sqrt{Hz}$ (in units of Amp. per square root Hertz) is calculated using the following equation:

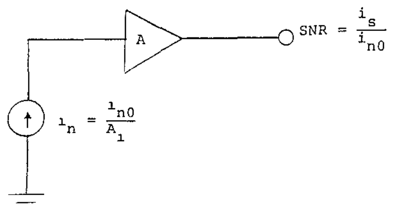
$$i_n/\sqrt{Hz} = \frac{m\ I_{dc}}{\sqrt{2}\sqrt{BW_n}\ 10^{SNR/20}}$$

Table 1 CALCULATED PERFORMANCE OF THE TRANSIMPEDANCE AMPLIFIER

Bit Rate (Mb/s)	R_f (kΩ)	Gain (dB)	3 dB Bandwidth (MHz)	Output Voltage (V_{pp})	Dynamic Range (dB)	Optical Sensitivity (dBm)
188	14	81	200	2	34	-38.5
565	5	72	600	2	33	-33
1130	2.6	67	1200	2	31	-30
1500	1.95	64	1600	2	30	-28



(a)



(b)

Figure 3 (a) Equivalent noise current measurement setup
(b) Equivalent noise current representation

where I_{dc} is the average photocurrent flowing through the bias resistor, m is the modulation index of laser, BW_n is the noise bandwidth of the spectrum analyzer, and SNR is the true signal-to-noise ratio. Finally, the sensitivity is calculated as follows:

$$\text{Sensitivity} = Sn = \sqrt{K}\,\frac{hv}{\eta e}\,\langle i_n \rangle$$

where $h = 6.6 \times 10^{-34}$ Joule -sec
$e = 1.6 \times 10^{-19}$ Coul
$v = c/\lambda$
$= 3.62 \times 10^{14}$ Hz at $\lambda = .828$ µm
$K = 36$ for BER $= 10^{-9}$
η = quantum efficiency = .7 (same as used in all calculations)

Therefore,

$$Sn = 12.7 \langle i_n \rangle \quad \text{(Watts)}$$

where $\langle i_n \rangle = i_n/\sqrt{Hz} \cdot \sqrt{NBW}$,
NBW: Noise Bandwidth

Packaged pigtail PIN diodes were used as detectors. These diodes operate at $\lambda = .828$ µm. Measured and calculated results for gain, bandwidth and sensitivity are summarized in Table 2.

TABLE 2 SUMMARY OF TEST RESULTS OF TRANSIMPEDANCE AMPLIFIERS

CIRCUIT	PERFORMANCE PARAMETER	MEASURED	CALCULATED*
R_f = 14 kΩ	Gain (dB)	77	78
	3 dB BW (MHz)	110	100
	Sensitivity (dBm)	-36.8	-38
R_f = 5 kΩ	Gain (dB)	74	73
	3 dB BW (MHz)	260	250
	Sensitivity (dBm)	-34	-34.8
R_f = 2 kΩ	Gain (dB)	65	64.8
	3 dB BW (MHz)	510	520
	Sensitivity (dBm)	-29.5	-30

*C_d = 2.0 pF

As these diodes have much higher capacitance than the design values, the design bandwidths for these circuits could not be obtained. However, the designed bandwidths were obtained when the same amplifiers were tested with built-in photo conducting diodes as a current source. The photo conducting diode is an interdigital structure which changes resistance with optical signal. Measured output power versus frequency for three different transimpedance amplifiers is shown in Fig. 4. As these diodes have parasitic capacitance very close to the design value, the measured results agree very well with the theoretical calculations.

The testing of these amplifiers with chip PIN diodes working at 1.3 µm wavelength and having low capacitance is in progress.

ACKNOWLEDGEMENTS

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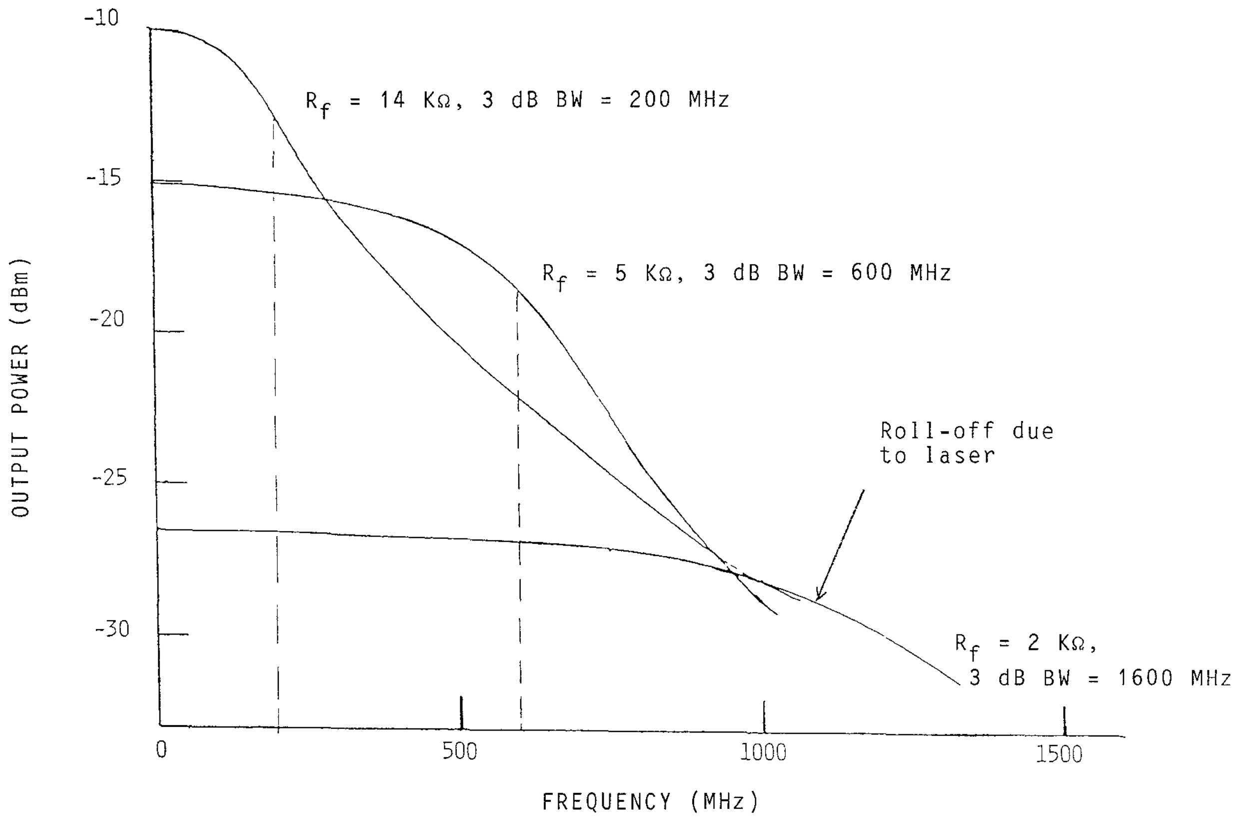

Figure 4 Measured performance of a transimpedance amp with built-in diode