A 0.15-μm GaAs MHEMT Transimpedance Amplifier IC for 40-Gb/s Applications

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Abstract — **The design and performance of a 0.15-μm MHEMT transimpedance amplifier IC suitable for 40-Gb/s receiver applications is presented. Experimental results for the circuit demonstrate 263 Ω of transimpedance and 42.6 GHz 3dB-bandwidth with 0.075 pF of photodiode capacitance connected at the input. The IC dissipates 180 mW of power from a single +6 V supply and has a die area of 0.72 mm^2.**

I. Introduction

Wideband, low cost optical receiver components will be crucial to the development of 40Gb/s fiber optic communication systems. One such component is a transimpedance amplifier (TIA) which converts photodiode current to an amplified output voltage and isolates the remaining receiver components from the impedance of the photodiode. Significant effort has been spent to develop 40-Gb/s transimpedance amplifier ICs utilizing InP based HEMT and HBT as well as SiGe process technologies [1]-[5]. Various transimpedance amplifier design methodologies have been investigated. One approach is to simply use a distributed amplifier as a TIA [4]-[5]. The transimpedance gains of the ICs were reported to be 180 Ω to 220 Ω consuming approximately 500 mW of DC power. Another method is to direct couple an actively matched transimpedance circuit with a distributed amplifier [2]. The transimpedance of this circuit was reported to be 400 Ω with die area and power consumption of 5.4 mm^2 and 520 mW respectively. A third approach is to design the entire IC as an actively matched transimpedance circuit [1],[3]. These circuits typically realize somewhat less transimpedance gain, 125 Ω to 165 Ω, however exhibit small die size, typically < 2 mm^2.

GaAs based MHEMT transistors have demonstrated a level of performance similar to that of InP HEMTs with significant manufacturing and cost advantages [6]-[7]. To investigate the feasibility of 0.15-μm GaAs MHEMT process technology for 40-Gb/s receiver components, an actively matched transimpedance amplifier IC was designed and fabricated. Details regarding the design and experimental results for this circuit are presented in the remainder of this paper.

II. Technology

The requirement of high transimpedance gain and greater than 40-GHz bandwidth motivated the utilization of a 0.15-μm T-gate MHEMT process technology [7]. A composite InGaAs channel with an Indium mole fraction of 53% to 63% was grown with molecular beam epitaxy on 100-mm GaAs wafers. The MHEMT process is characterized by f_T>150GHz and a typical maximum transconductance of 800 mS/mm at a drain voltage of 1.5 V. Average pinch-off voltage of processed devices is –0.1 V with good uniformity. Gate to drain breakdown voltage and maximum drain current density are 5 V and greater than 500 mA/mm, respectively.

III. Circuit Design

The first electronic component in most optical receiver systems is a transimpedance amplifier [8]. The input of the TIA is connected to a photodetector, typically a reversed biased PIN diode which presents a reactive impedance that must be compensated for in the design of the circuit. For this work the photodiode is modeled as a shunt junction capacitance (C_{PD}) in series with a 10 Ω contact resistance, trace inductance (L_{PD}) and bond wire inductance (L_{BW}). A simplified schematic diagram for the transimpedance amplifier IC and photodiode model is shown in Fig. 1. The input stage of the amplifier utilizes a common gate topology to buffer the remainder of the circuit from the photodiode impedance. A resistively loaded common gate amplifier has an input impedance approximately equal to,

$$Z_{in} \approx C_{gs} \parallel \left(\frac{1}{g_m} + j\omega C_{ds} \left(\frac{g_m R_L - 1}{g_m^2} \right) \right) \quad (1)$$

where g_m, C_{gs} and C_{ds} are the transconductance, gate-source capacitance and drain-source capacitance of the first stage transistor respectively. When operated as an amplifier the input impedance of the common gate configuration has an inductive component (L_{CG}). By properly sizing the input

0-7803-7239-5/02/$10.00 © 2002 IEEE

device, a four pole low pass filter (neglecting the contact resistance) may be formed with the photodiode as shown in Fig. 2. The second stage is in a common source configuration designed for high input and output impedance. The final two stages are source followers that transform the impedance level to 50 Ω at the output of the TIA. Resistive shunt feedback is applied between the TIA output and the input of the second stage to stabilize the low frequency transimpedance. A photograph of the fabricated transimpedance amplifier IC is shown in Fig. 3. The die dimensions are 0.85x0.85 mm^2.

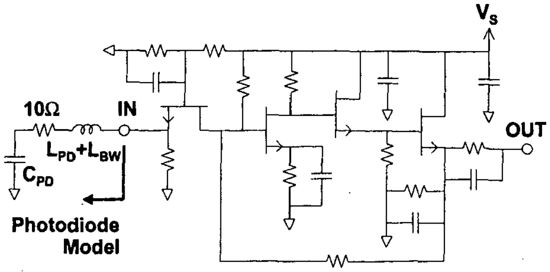

Fig. 1. Transimpedance amplifier schematic.

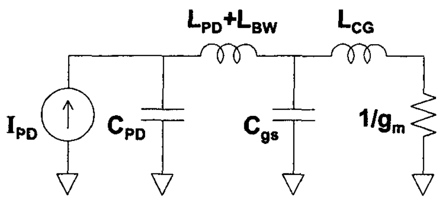

Fig. 2. Filter model for TIA/photodiode input impedance.

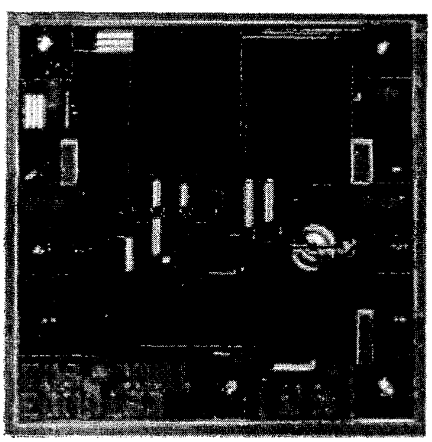

Fig. 3. Photograph of transimpedance amplifier IC.

IV. RESULTS

Fabricated devices were 100% tested on-wafer at the TriQuint production test facility. The photodiode model as shown in Fig. 1. (C_{PD}= 0.075 pF, L_{PD}+L_{BW}= 0.25 nH) was cascaded with the measured S-parameters. The transimpedance of the cascade at 35 GHz is plotted in Fig. 4 for 1409 devices from one wafer. The mean transimpedance at 35 GHz was observed to be 278 Ω with a 17.9 Ω standard deviation.

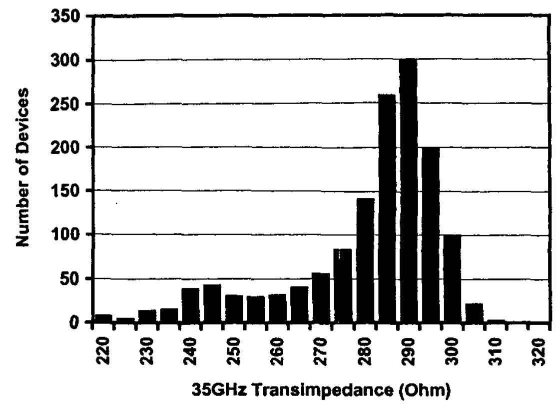

Fig. 4. Transimpedance at 35 GHz measured on-wafer for a 1409 device sample from one wafer.

Separated devices were then mounted to carrier assemblies for in-fixture testing. The TIA input and output pads were attached with three wedge bonds to 10 mil thick, GSG probable alumina tranmission lines. The on-chip bypass capacitors were supplemented with off-chip end-metalized 0.1-μF capacitors. S-parameters were measured from 1 GHz to 50 GHz with 2.4-mm GSG RF-probes. The photodiode model was cascaded with the measured S-parameters as previously discussed except that the series inductance was reduced to 0.1 nH since the bond wire inductance is included in the data.

Plotted in Figs. 5-7 are the transimpedance, output return loss and group delay for three different values of photodiode capacitance. The transimpedance at 1GHz was observed to be 263 Ω, and the bandwidth was found to increase as the photodiode capacitance was reduced. There was however a corresponding increase in group delay and transimpedance ripple. The observed 3-dB transimpedance bandwidths for photodiode capacitances of 0.05 pF, 0.065 pF and 0.075 pF were 42.6 GHz, 44.6 GHz and 47.3 GHz respectively. The group delay variation from 1-40 GHz was ±8 ps to ±10 ps depending on photodiode capacitance. The output return loss degraded slightly with increasing photodiode capacitance, however is less than −13.5 dB up to 42 GHz. Test results with a 12.5-Gb/s 2^{31}-1 PRBS signal indicate a saturated output voltage of about 700 mVpp.

To characterize noise performance, an open stub of alumina trimmed to approximate a given value of shunt capacitance was bonded to the input of the TIA to emulate the photodiode impedance. Test results for equivalent input noise current are shown in Fig. 8 for approximate input capacitance values of 0.05 pF and 0.075 pF. The measured equivalent input noise current is typically less than 14 pA/√Hz and 20 pA/√Hz for capacitance values of 0.05 pF and 0.075 pF respectively.

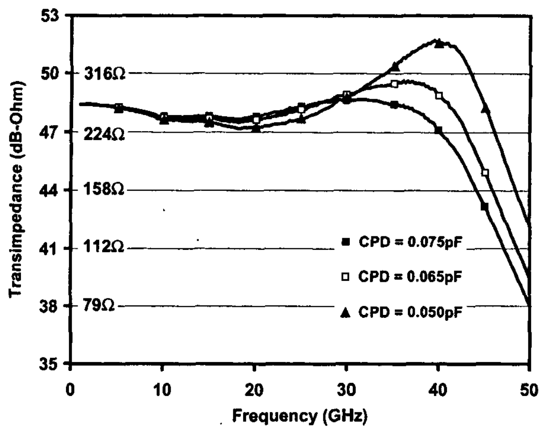

Fig. 5. Transimpedance calculated from the measured in-fixture S-parameter data.

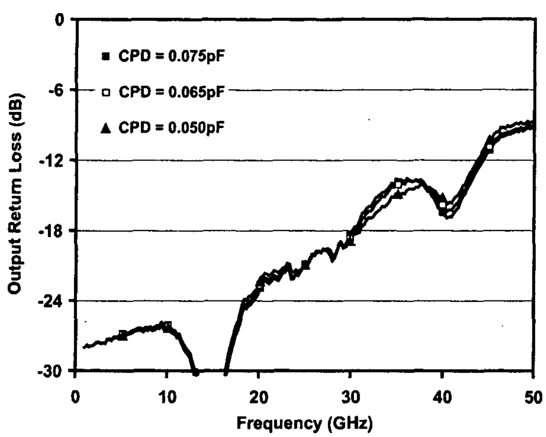

Fig. 6. Output return loss measured in-fixture.

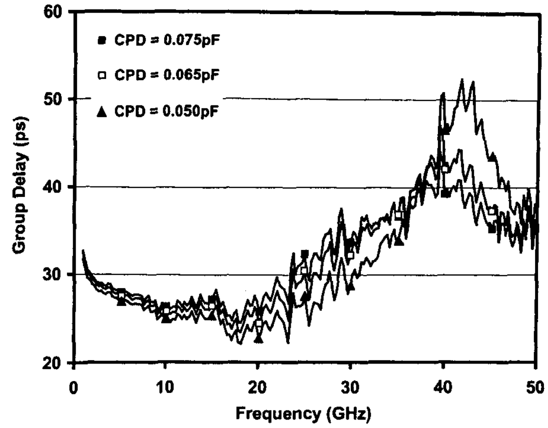

Fig. 7. Transimpedance group delay measured in-fixture.

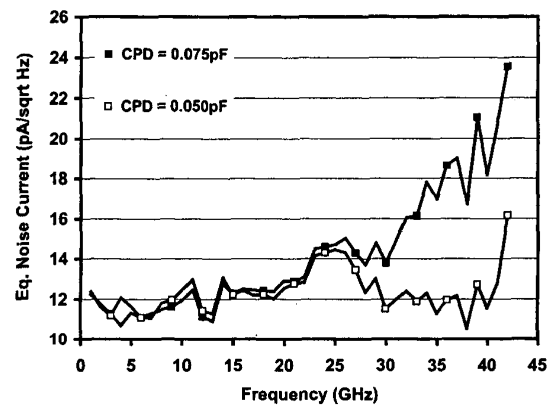

Fig. 8. Equivalent input noise current measured in-fixture.

V. Conclusion

In conclusion, the design and performance of a 0.15-μm GaAs MHEMT transimpedance amplifier IC suitable for 40-Gb/s applications has been presented. Experimental results demonstrate a transimpedance of 263 Ω and 42.6 GHz 3dB-bandwidth for the cascade of a 0.075 pF photodiode model with TIA S-parameters measured in-fixture. With approximately 0.075 pF of capacitance connected at the input of the TIA, measured equivalent input noise current is typically less than 20 pA/√Hz. Power consumption for the IC is 180 mW and the die area is 0.72 mm^2. With respect to the parameters listed above, the authors believe these results to be among the best published for MHEMT transimpedance amplifier ICs.

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