Transimpedance Amplifiers with 133 GHz bandwidth on 130nm InP DHBT

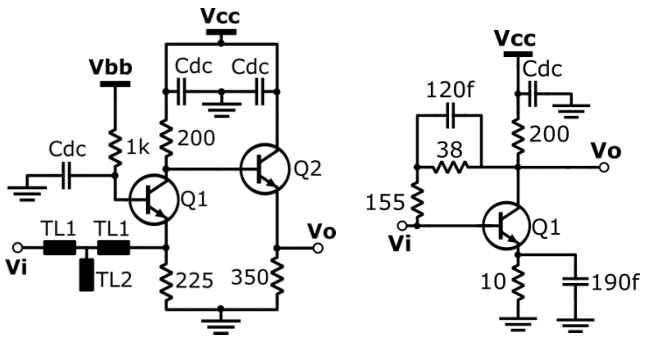
S. Giannakopoulos, Z. He, L. Svensson, I. Darwazeh and H. Zirath

In this work we present two transimpedance amplifier (TIA) circuits designed for fibre optical interconnect systems. We compare a common base (CB) topology with a common emitter (CE) shunt-shunt feedback topology in terms of frequency response, power consumption, noise and input impedance. The two TIAs are designed on a 130nm InP DHBT technology from Teledyne Scientific Company (TSC) and are measured in the frequency and time domains. They exhibit a TI-gain of 42 dBΩ with a 133 GHz bandwidth, the highest bandwidth reported in literature and a power consumption of 32.3 mW for the CB and 25.5 mW for the CE. Time domain NRZ measurements up to 64 Gbps provide energy efficiency metrics of 0.5 mW/Gbps and 0.4 mW/Gbps, respectively.

Introduction: The continual increase of internet traffic and the expansion of the field of high performance computing systems are driving the demands for higher interconnect bandwidth and energy efficiency in datacenters and supercomputing clusters. The high data rate in combination with the requirement to minimise power consumption has allowed the field of short-haul optical interconnects (OI) to develop into one of the fastest growing branches in the OI market. In order to facilitate such electro-optical links, a new generation of integrated transmitter and receiver systems are required.

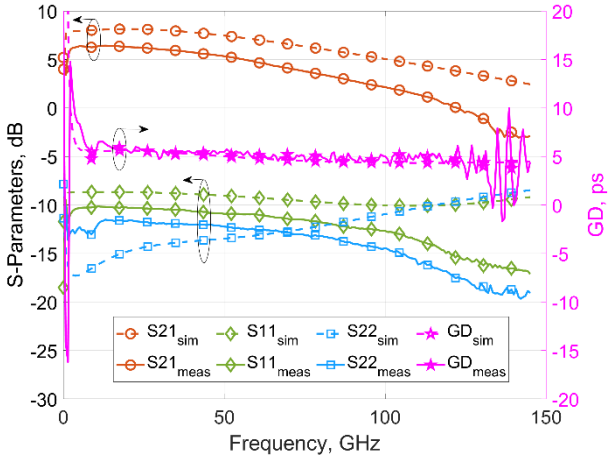
This work presents two transimpedance amplifier circuits , which when integrated with a photodiode, can operate as front-ends of OI receiver systems. In such a systems bandwidth is mainly limited by the optoelectronic transceiver components, namely the transmitter VCSEL diodes [1] and the receiver photodiodes. In order to extend the bandwidth of the receiver, architectures with low input impedance were preferred [2]. The outline of this paper is as follows: we present the design and implementation of the two TIA MMICs, then we discuss the measurements in the frequency and time domains, and we compare obtained results with state of the art literature and we conclude the paper.

Design: The common emitter with shunt feedback topology is the most common feedback TIA and provides adequate gain, relatively low input impedance and good noise performance. The CB topology provides higher voltage gain for the same current and low input impedance, however it suffers from increased noise. Fig. 1a shows the CB topology used in this work, along with an input matching open stub and a common collector (CC) stage used as an output buffer. In Fig. 1b the schematics of the CE design is shown where the feedback resistor is split into two resistors, one of them bypassed by a capacitor to increase feedback at higher frequencies. Additionally, an emitter bypass capacitor is used on the emitter resistor to extend the high frequency performance of the stage. In the case of the CE TIA no CC stage was used as a buffer, rather the output was taken directly from the node *Vo*.



a *b*

Fig. 1 *Schematics of the two TIAs. Resistor values are given in Ohm and capacitor values in Farad. Decoupling capacitor Cdc is equal to 750 fF.*
a Schematic of the Common Base TIA. V_{cc} = 3.6 V, I_{cc} = 8.9 mA, V_{bb} = 1.4 V, I_{bb} = 0.18 mA.
b Schematic of the Common Emitter TIA. V_{cc} = 3 V, I_{cc} = 8.75 mA.



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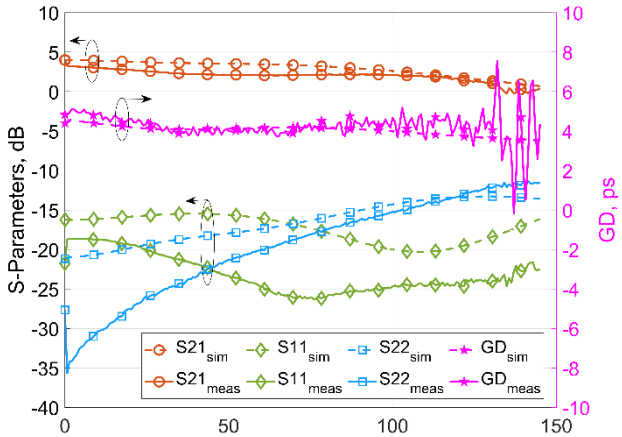

b

Fig. 2 *S-parameter (left axis) and group delay (right axis) results for the two TIAs. The dashed lines indicated simulated response.*
a Common Base circuit and b Common Emitter circuit.

Measurements: The s-parameter on wafer measurements (100MHz – 145 GHz) were done with Anritsu ME7838A vector network analyzer (VNA) with included dc-block capacitors via coaxial Cascade Infinity 67 GHz GSG probes. The input power was set to -30 dBm to avoid saturating the TIAs.

The frequency domain measurements show good agreement with the simulated results. Comparing the s-parameter response of the CB and CE TIAs in Fig. 2 we see that the main difference lies on the voltage gain. The CB has a gain of 6.3 dB with a bandwidth of 80 GHz while the CE has a gain of 3.2 dB up to 130 GHz. The input and output reflection of both designs were well matched, and the group delay was flat on the entirety of the bandwidth with very little variation. The z-parameters of the two designs (seen in Fig. 3) show a transimpedance gain (*Z21*) of 42 dBΩ on both designs with the CB providing 2.5 dB of peaking. The main difference of the two topologies is in their input impedance (*Z11*) with the CB presenting an impedance of less than 50 Ω up to 80 GHz, while the CE only up to 40 GHz and then peaking up to 75 Ω. The input impedance variation is critical as it dictates the bandwidth which is dependent, amongst other factors, on the photodiode capacitance at the input of the TIA.

Time domain measurements were done on wafer using two Cascade infinity 67-GHz GSGSG probes. A 64-Gbaud PRBS-15 datastream generated by the SHF 12103A pattern generator (PPG), was fed to the input of the device under test (DUT). The voltage swing of the data was set to 600 mV to get the best performance out of the PPG and was attenuated down to 30 mV through 26 dB attenuators in order to avoid saturating the input of the TIAs. Additionally, AC coupling capacitors were used at the input and output ports.

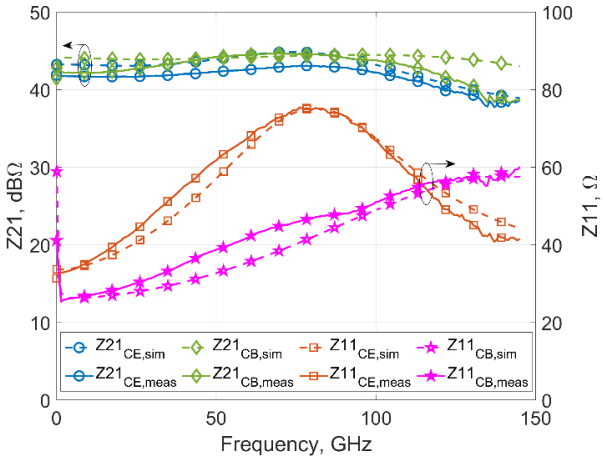

Fig. 3 *Z-parameter results for the two different topologies.*

The output of the DUT was connected to the input of an 86100C Agilent Infinium DCA-J 70 GHz sampling oscilloscope. The noise measurements were carried out with the histogram function of the oscilloscope by leaving the input of the DUT open.

Fig. 4 shows the eye diagrams (left) and noise histograms (right). Fig. 4a-b show the waveform generated by the SHF pattern generator after the attenuator and dc-block coupled in the oscilloscope, essentially the input signal of the DUTs. The signal to noise ratio (SNR) of the input eye is 4 and the noise standard deviation (σ_n) is 1.168 mV. Fig. 4c-d show the response of the CB TIA with an SNR of 3.66 and a σ_n of 1.327 mV. Fig.4e-f show the response of the CE TIA with SNR of 3.1 and a σ_n of 1.211 mV. The CE topology has lower voltage gain (as indicated also from Fig. 2) and lower noise. The CB circuit provides higher gain, at the expense of its increased noise which is characteristic of the common base amplifier topology[2].

*Comparison with state-of-the-art: The c*omparison of the performance of the designed TIAs with the state of the art in reported in open literature is presented in Table 1. Both proposed designs have the highest bandwidth reported. It is worth noting that the TIAs designed of this work would represent only the input stages of a full receiver, therefore the total transimpedance gain is lower than many of those reported with postamplifiers. For the same reason the power consumption is lower relative to the other amplifiers, with the exception of a similar design in [6]. The energy efficiency η_e is the lowest reported, partly due to the power consumption being low, but also due to the high bitrate measured. The noise performance of the CB is worse than amplifiers with higher input impedance, as expected from a common base topology. The CE TIAs noise, however, is significantly lower than most of the state-of-the-art designs, at the expense of the higher input impedance.

Conclusion: We present the design and measurement of two TIAs of different topologies, CB and CE, suitable for next generation optical interconnects. The TIAs, designed on a 130nm InP DHBT process by TSC demonstrate trade-offs between low noise, power consumption and low input impedance. Both designs have a TI-bandwidth higher than 133 GHz, which is the highest reported in literature, to the best of our knowledge.

Table 1: Comparison with state of the art TIAs in literature.

Ref.	BR Gbps	Power mW	TI BW GHz	TI gain dBΩ	IRN $\frac{pA}{\sqrt{Hz}}$	η_e $\frac{mW}{Gbps}$
[3]	43	304	110	50	-	7.07
[4]	40	36.5	108	46	53.9	0.91
[5]	-	48	92	-	17.7	-
[6]	-	27.6	72	38	84.1	-
[7]	100	150	66	65	8	1.50
CB	**64**	**32.3**	**133**	**42**	**30.2**	**0.50**
CE	**64**	**25.5**	**133**	**42**	**13.9**	**0.40**

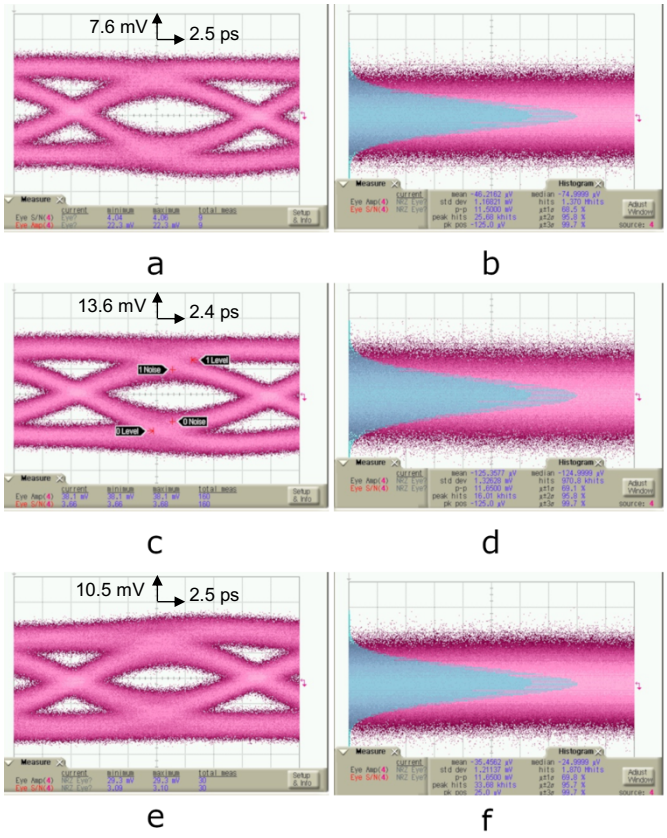

Fig. 4 *Eye diagrams and noise histograms (left) for the oscilloscope output and the output of the two TIAs.*

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