50G Burst-Mode Receiver Using Monolithic SOA-UTC and Burst-Mode TIA

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Abstract: We demonstrate a 50G-PON upstream SOA-UTC based receiver integrated with a BM-TIA, without optical filtering. The OMA sensitivity is -24.3 dBm, the dynamic range exceeds 20 dB and the loud-soft penalty is 1 dB.

1. Introduction

To answer to the ever-increasing bandwidth demand in access networks, thanks to new use cases such as industry 4.0 and next generation mobile X-haul, passive optical networks (PONs) are more and more used to deliver high-speed fiber-to-the-X services in a cost-effective way. Recently, the ITU-T published the 50G-PON standard (G.9804) with up to 50 Gbps symmetric rates [1]. The point-to-multipoint architecture uses time-division multiple access (TDMA) for upstream traffic, so the OLT receives consecutive bursts from the various ONUs. Given the high budget classes, e.g. the N1 budget is 29 dB, and large dynamic range requirements, e.g. >20 dB, the OLT receiver needs high sensitivity while handling consecutive soft and loud bursts with minimal overhead in settling time. In [2], we presented record 50 Gbps performance, an optical modulation amplitude (OMA) sensitivity of -23.7 dBm and a dynamic range exceeding 21.7 dB using a burst-mode transimpedance amplifier (BM-TIA) and a commercial high-speed avalanche photodiode (APD). More recently, the slowing evolution of the gain-bandwidth product of APDs needs to be alleviated with more advanced equalization or other modulations formats like PAM4 [3]. Pre-amplified receivers using semiconductor optical amplifiers (SOA) and high-speed photodiodes (PD) are a strong candidate for current and next-generation IM/DD based PON technologies. In [4], 50 Gbps NRZ burst-mode operation with 33 dB loss budget is shown using a discrete SOA, an optical filter to suppress the amplified spontaneous emission (ASE) noise, and a PIN-PD with continuous-mode TIA. A monolithic SOA-UTC-PD with up to 90 A/W responsivity and more than 33 GHz bandwidth is shown in [5]. This device integrated in a butterfly module achieves an average power sensitivity of -26.3 dBm for 50 Gbps NRZ in burst-mode [6]. However, the photodiode was directly coupled to an oscilloscope, while system integration requires a burst-mode TIA to correct the offset induced by the average photocurrent and to reduce amplitude variations. In this work, we demonstrate, the first integration of an SOA-UTC [5] with a BM-TIA [2] realizing an OMA sensitivity of -24.3 dBm without optical filtering. The SOA bias current was only 50 mA, resulting in a low power consumption. The dynamic range exceeds 20 dB, limited by the measurement setup.

2. Device design

The realized prototype integrates a monolithic SOA-UTC receiver and a BM-TIA together on a high-speed PCB. The SOA-UTC uses a 700 µm long SOA in buried ridge stripe (BRS) technology with input and output active spot size converter (SSC) and the UTC photodiode uses deep ridge technology to reduce the parasitic capacitance [5]. The UTC-PD is 5×25 µm² and has a bandwidth of around 35 GHz. The SOA-UTC chip was measured before packaging, without any submount so with low thermal dissipations, and demonstrated a responsivity of 60 A/W at 1280 nm and 80 mA SOA drive current. Direct access to the noise figure was not available for this specific device, but it is estimated to be 7 dB from similar devices [5]. The 3-dB input saturation power is -5 dBm and the TE/TM polarization dependent loss (PDL) is around 5 dB, both measured at an SOA drive current of 140 mA [5]. The device measures 1.2×0.5 mm^2. The 50G, linear BM-TIA is made in a 130 nm SiGe BiCMOS technology [2]. The TIA consists of a transimpedance stage with an automatic high or low gain mode, selected depending whether a soft or loud burst is received and an automatic offset correction to remove the offset induced by the average photocurrent. Next, a cascade of three variable gain amplifiers performs fine gain control such that the output signal amplitude equals the desired set level. A fine balancing loop encompassing the three VGAs removes any residual offset on the signal. An output driver is used to differentially drive a 100 Ohm load. When a burst arrives, indicated by an external start-of-burst (SoB) signal, the coarse gain control determines whether the front-end should operate in high gain (soft burst) or low gain (loud burst). The gain is coarsely set to avoid overloading the TIA and the average photocurrent is subtracted at the input of the TIA. Next, the fine gain and offset correction balancing loops reduce output swing variations and remove any residual offset. The initial gain-bandwidth product of both loops is high to achieve fast settling, and then gradually decreased to avoid data-dependent effects. The total settling time is around 150 ns. Due to the digital interface, various BM-TIA settings can be optimized depending on the input device (APDs or SOA-UTC). The BM-TIA consumes between 260 and 310 mW depending on the received optical power. The chip measures 1.2×1.7 mm^2 [2].

The SOA-UTC and the BM-TIA are assembled together on a high-speed PCB (see Figure 1). The BM-TIA features on-chip biasing such that both the cathode and anode can be directly wirebonded to the TIA, minimizing wirebond parasitic inductance and maximizing bandwidth [2]. A thermistor is placed next to the SOA-UTC for the TEC-control loop. The three devices are placed in a cavity in the PCB. The TIA output is wirebonded to high-speed differential traces. The differential transmission line on the PCB bridges 12 mm to a TR70 connector with 150 mm long cables.

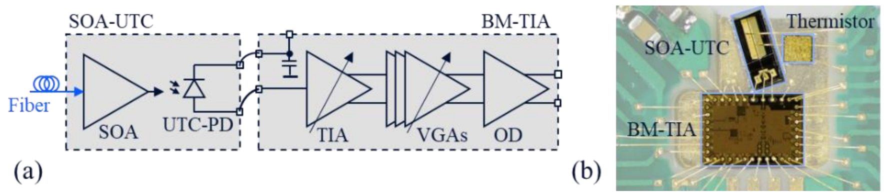

Figure 1: (a) schematic overview of the assembly, (b) micrograph of the SOA-UTC, BM-TIA and thermistor on the PCB.

3. Experimental setup

The block diagram of the measurement setup is shown in Figure 2 (a). An electrical 50 Gbps NRZ signal (PRBS15) is applied to an MZM through a pre-emphasised DAC and amplifier. The transmit eye closure evaluated according to ITU-T G.9804.3 [1] was 2.4 dB. The extinction ratio (ER), measured on a long run of consecutive identical bits, was 10.6 dB. The DFB laser wavelength is 1308.7 nm. An SOA is used as burst-carver, the ASE noise of this TX-SOA is suppressed with a 2 nm optical filter. After this filter, the OSNR for all bursts exceeds 40 dB. Bursts of 10 µs are generated with guard times of 100 ns. The power of each burst follows a staircase pattern (optical power of each burst increases with approx. 1 dB) or a loud-soft pattern (maximum power burst followed by a burst with varying power). In the latter case, the BER is evaluated on the burst with varying power to evaluate the loud-soft penalty. A variable optical attenuator is used to adjust the power of the carved burst in the target range, for this experiment the VOA was set to minimal attenuation. The burst-envelope generator driving the SOA also provides the start-of-burst signal for the BM-TIA. The receiver assembly is mounted on a heat spreader and a TEC. The SOA-UTC is regulated at 23°C. The optical alignment is done using a lensed fiber (modal field diameter 6 µm). The SOA input facet is placed over the PCB edge to allow fiber alignment. Fig. 2 (b) shows the mounted assembly. The differential output of the BM-TIA was AC-coupled to an RTO, where the samples are acquired for offline processing. This processing consists of zero-crossing clock recovery and digital equalization. The equalizer taps were trained on a preamble of 500 bits (10ns), while BER was calculated over the whole equalized payload data. The frequency response of the receiver including the PCB traces and the TR70 cable is shown in figure 2 (c), with the BM-TIA in high-gain mode. The frequency response was derived from the received time domain waveform, with the TX frequency response de-embedded. The 3dB-bandwidth is around 23 GHz, while the 3dB-bandwidth with a 25G and 50G APD is 7 and 17 GHz respectively [2]. Furthermore, the 6dB-bandwidth is around 30 GHz for the SOA-UTC and around 17 and 25 GHz for the 25G and 50G APD. This shows the potential of SOA-UTC based receivers for high-speed optical access.

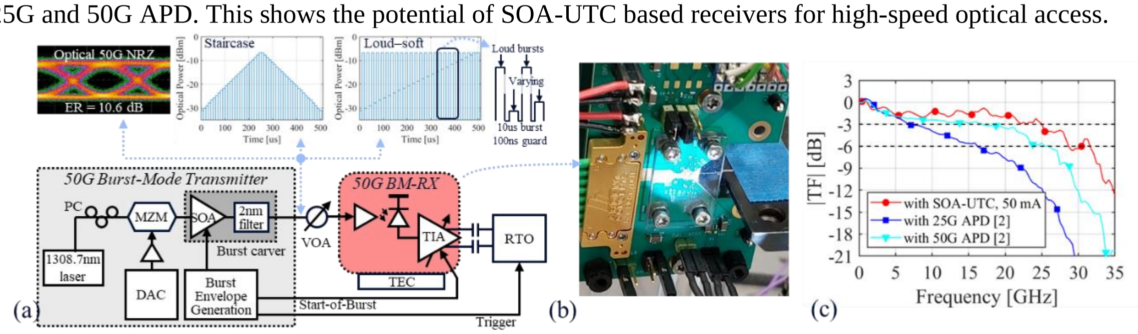

Figure 2: (a) block diagram of the setup: polarization controller (PC), digital to analog converter (DAC), Mach-Zehnder modulator (MZM), variable optical attenuator (VOA), real-time oscilloscope (RTO), (b) picture of the PCB, (c) receiver transfer function, incl. PCB traces and cables, with the TIA in high-gain mode.

4. Receiver prototype measurement

The BER curves (optical back-to-back (B2B)) in Figure 3 (a) are measured with the staircase burst pattern, the TIA settings and SOA current were optimized for best performance. It is worth noting that this preliminary trial shows no influence of the polarization state on the BER which confirms calculations showing that we are signal-ASE noise beat limited. Therefore slow variations of the received polarization can be compensated by the automatic gain control in the BM-TIA without SNR impact. The OMA sensitivity is measured at a BER of 1e-2, corresponding to the G.9804 pre-FEC BER limit [1]. Without any equalization, the OMA sensitivity is -23.4 dBm. With a 13-taps feedforward equalizer (FFE) and a 1-tap decision feedback equalizer (DFE), the sensitivity improves to -24.3 dBm (-26.6 dBm average power). The SOA bias current is 50 mA, resulting in a low SOA power consumption of only 65 mW which will also help reducing the TEC power consumption in future integrated systems. The SOA-UTC outperforms the 25G APD-based receiver [2], which has an unequalized OMA sensitivity of -18.2 dBm and an equalized sensitivity of -23.7 dBm (for the same equalizer). The high bandwidth of the SOA-UTC provides excellent sensitivity without equalization, causing limited equalization gain (only 0.9 dB w.r.t. 5.5 dB for the 25G APD-based RX). Note that depending on the employed wavelength and fiber reach, some equalization may be required to compensate for the accumulated chromatic dispersion. Compared to [6], the SOA is used far from peak gain (1308 nm vs 1260-1280 nm), at a lower bias current (50 mA vs 180 mA), and at a slightly higher temperature (23°C vs 20°C), indicating lower power consumption and a large extension of the SOA-UTC operating window thanks to the BM-TIA.

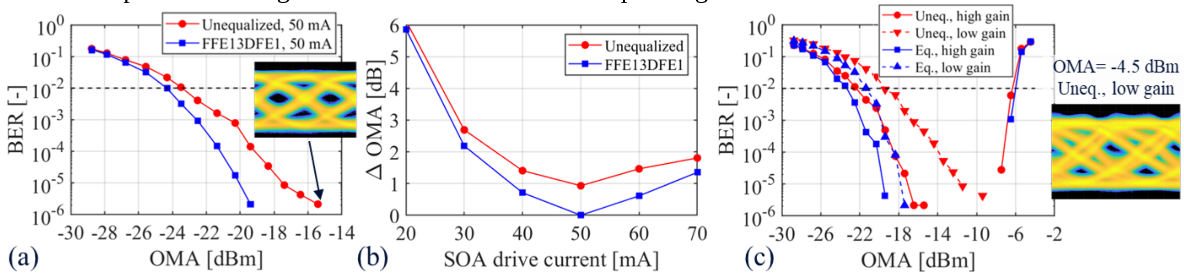

Figure 3: (a) BER curve at 50 mA SOA bias, (b) OMA sensitivity penalty for various SOA bias currents, normalized to the OMA sensitivity at 50 mA with equalization (c) dynamic range without and with equalization (FFE13DFE1) at 50 mA for fixed low and high gain mode of the TIA.

The relative penalty on sensitivity, depending on the SOA bias current, is shown in Figure 3 (b). As can be observed, at low drive current (<50 mA), the sensitivity worsens due to the lower SOA gain and higher noise figure. For higher bias currents, the high ASE noise combined with the small input signals at sensitivity causes difficulties in the front-end offset correction. The residual offset worsens the sensitivity for signals at sensitivity. The BER curves in high and low gain mode for 50 mA SOA bias are shown in Figure 3 (c). The TIA automatically switches between gain modes [2], however for this measurement, the gain was temporarily fixed to better visualize the tradeoffs. The high gain mode causes signal distortions at loud bursts while the low gain mode has a worse sensitivity and no bit errors at loud burst up to -4.5 dBm (maximum of the setup). The dynamic range of the SOA-UTC receiver is at least 20 dB without signs of errors at overload, hence it can be concluded that the dynamic range is compliant with the 50G-PON N1 optical budget class. This shows that the non-linearity of the SOA doesn't disturb the receiver performance for the loud bursts in an optical back-to-back configuration. The loud-soft penalty was measured using the loud-soft pattern, see Fig. 2 (a). The loud-soft penalty was found to be 1 dB at sensitivity, indicating that the SOA has no significant impact on the loud-soft behavior of the receiver.

5. Conclusion

We demonstrated a 50G receiver based on an SOA-UTC device closely integrated together with a 50G burst-mode TIA without optical filter. In an optical back-to-back configuration, the resulting OMA sensitivity at a BER of 1e-2 is -23.4 dBm without equalization and -24.3 dBm with 13-taps FFE and 1-tap DFE. Longer fiber reaches can be covered with no or limited equalization depending on the employed wavelength thanks to the limited chromatic dispersion in the O-band. The SOA bias current is only 50 mA, resulting in a low SOA and TEC power consumption. The dynamic range is at least 20 dB, indicating that the SOA non-linearity does not disturb the receiver performance in optical B2B. The loud-soft penalty is found to be 1 dB. We show that an SOA-UTC integrated with an BM-TIA and without optical filter, achieves 50G-PON N1 budget class sensitivity with and without equalization in an optical B2B configuration.

6. References

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