A PAM-4 Link for High Data Rate PMF Communication

Frida Strömbeck*, Herbert Zirath
Chalmers University of Technology
Gothenburg, Sweden
*stfrida@chalmers.se

***Abstract*—In this work a high speed PAM-4 link for polymer microwave fiber (PMF) communication at D-band (110-170GHz) is presented using a commercial 130 nm SiGe BiCMOS process. Link measurements are performed over a one meter long foam-cladded PMF which verifies that the link can support data rates up to 30 Gbps with a bit error rate (BER) of $3 * 10^{-8}$. The transmitter is RF-DAC based including and LO multiplier and a six stage amplifier. The receiver consist of an LNA and a power detector (PD). The DC power consumption is 143 mW for the transmitter and 126 mW for the receiver.**

***Index Terms*—High data rate, PAM-4, PD, PMF, RF-DAC**

I. Introduction

The development of functionality of connected devices is moving forward at a fast pace. More information needs to be shared in less amount of time. To be able to meet the demands by all the new future applications, a higher data rate is expected from these communication links. For many autonomous devices ultra high data rate communication is needed within the device, at a short distance up to a few meters, for example within a car [1]. Millimeterwave bands can offer wide available bandwidth for such high data rate transmissions.

The way to transfer these high data rate signals is not straight forward. Polymer microwave fibers (PMF) offer lots of benefits for short range communication systems. The PMFs are flexible and made of low cost plastics. Compared to optical fibers the alignment to the PMF is much simpler, because of the larger size of the PMF, which is why the PMF is a more robust solution. For these reasons, PMFs have recently become an interesting alternative for short range (1-10 meters) links [2] [3] [4] [5] [6].

In this work, we demonstrate a PMF link based on a commercial automotive-certified 130 nm BiCMOS process. A parallel stacked RF-DAC, with integrated local oscillator (LO) multiplier and power amplifier (PA) is proposed as transmitter and a passive balun integrated power detector (PD) is used as receiver. The benefits of using an RF-DAC based PAM-4 modulator/PD for PMF communication is the high speed, no need for carrier recovery, low complexity and small circuits. Real time transmissions of a PAM-4 signal are demonstrated which supports 30 Gbps with a bit error rate (BER) of $3{*}10^{-8}$ at 152 GHz over a one meter foam cladded PMF.

II. Circuit Design

Both circuits, transmitter (Tx) and Receiver (Rx), are designed and fabricated using a 130 nm SiGe BiCMOS process (B11HFC) that is offered by Infineon Technologies [7]. The transmitter include a local oscillator (LO) frequency doubler, followed by the RF-DAC core and a six stage common emitter power amplifier (PA) at the output. The RF-DAC core consists of a parallel stacked transistor pair. A simplified schematic of the RF-DAC core can be seen in Fig. 1.

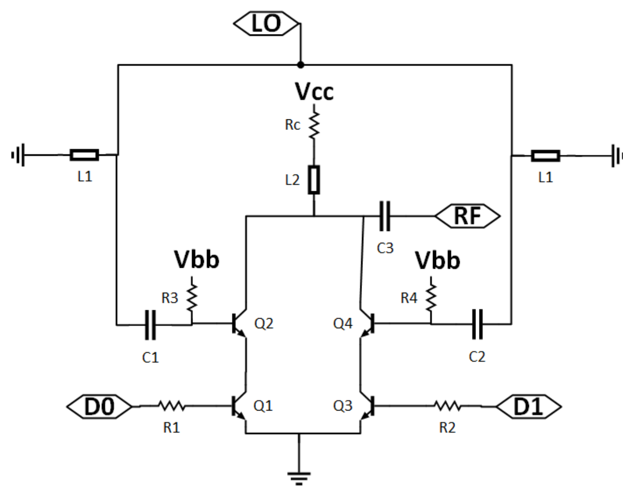

Fig. 1. Simplified schematic of the stacked RF-DAC core.

When a voltage (1 V) is applied at the data input port, corresponding to logic value ‘1’, it will turn on transistor Q1 for port D0 and Q3 for port D1. The current will flow through Q2 and Q4 which are connected to the LO input at the base, and the LO-signal is modulating the collector current. The output RF-signal is taken at the combined collector of Q2 and Q4. For logic value ‘0’, which in this case is 0 V applied at the data ports, Q1 and/or Q3 are turned off correspondingly, which in turn, turns off transistor Q2 and/or Q4, thus giving less power at the output. To create a most significant bit (MSB) and a least significant bit (LSB), transistor scaling is used. Q1 and Q2 have an emitter width of 6 μm while Q3 and Q4 have an emitter width of 3 μm. The resistor Rc is 200 Ω.

A photo of the fabricated transmitter can be seen in Fig. 2. The total area including pads is 0.67 mm^2.

The receiver consists of a six stage low noise amplifier (LNA) and a PD that uses a passive Marchand balun at the input. The balun is there to cancel out the carrier signal and all other odd harmonics of the carrier. A simplified schematic of the PD core can be seen in Fig. 3, and a photo of the entire receiver can be seen in Fig. 4.

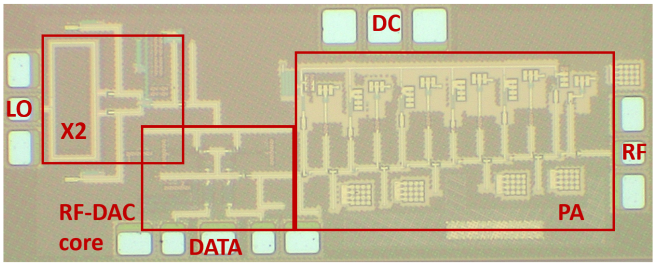

Fig. 2. Photo of the manufactured transmitter. The size is 1.41 mm by 0.55 mm including the pads.

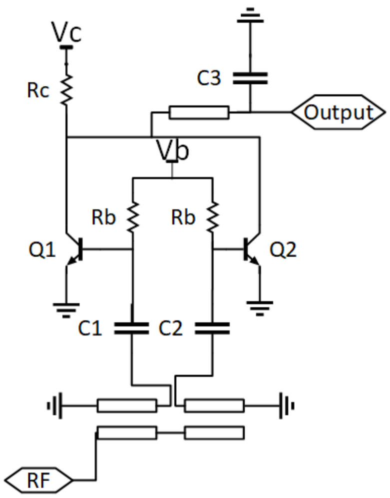

Fig. 3. Simplified schematic of the PD core.

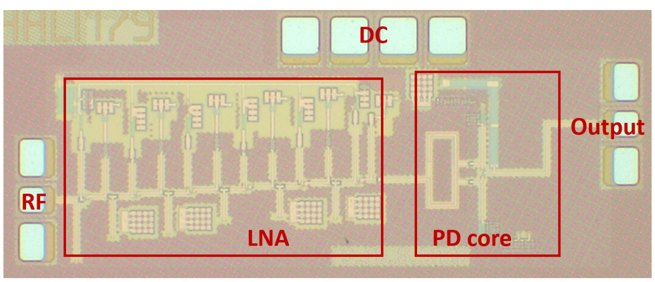

Fig. 4. Photo of the manufactured receiver. The size is 1.27 mm by 0.5 mm including the pads.

III. Measurement Results

The transmitter was measured in frequency domain using a Keysight PNA-X (67 GHz N5247A) together with a VDI extender WR-6.5 at the output, and WR-12 at the LO input. The LO input power was set to 0 dBm. Measurement results can be seen in Fig. 5, where the four different traces represent different data input. The saturated output power was measured to >6 dBm between 135-165 GHz with peak output power of 7 dBm.

The PD was characterized using different input power (Keysight PNA-X (67 GHz N5247A) + WR 6.5 extender) and measuring corresponding output voltage using a voltage meter.

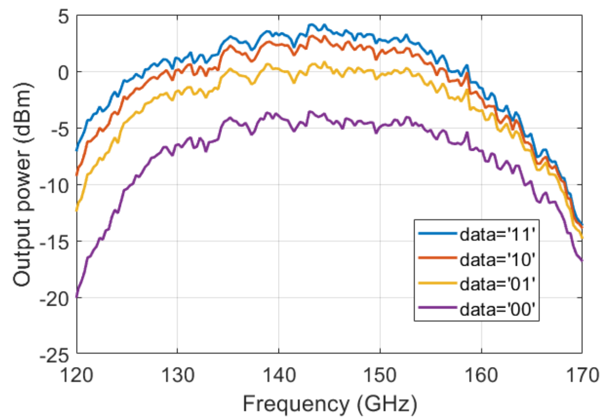

Fig. 5. Measured output power for different output frequencies at 0 dBm LO input.

It was measured both at 140 GHz and 160 GHz. Results can be seen in Fig. 6.

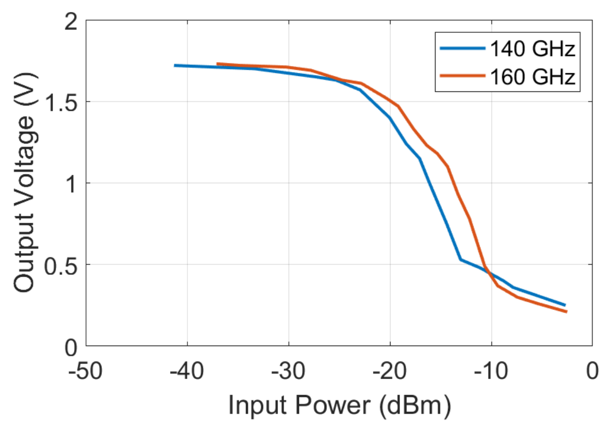

Fig. 6. Output voltage for different input powers (dBm) at 140 GHz and 160 GHz.

The setup that was used during the link measurements can be seen in Fig. 7. The transmitter was probed on the right probe station and the receiver on the left probe station. The one meter long PMF provided by Huber+Suhner can be seen in the middle connecting Tx and Rx.

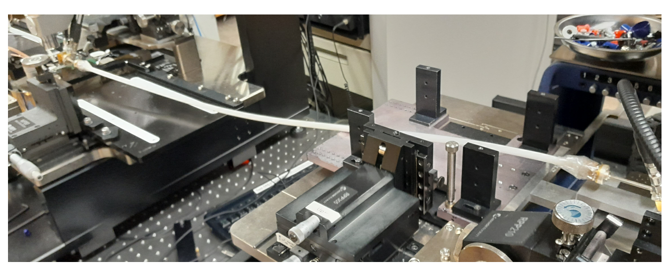

Fig. 7. Setup that was used during the link measurements.

In the link measurements the LO input frequency was set to 76 GHz, resulting in a center RF-frequency of 152 GHz. Two pseudorandom binary sequences (PRBS-9 and PRBS-10) was provided by a Keysight M8195A arbitrary waveform generator (AWG) to generate the data stream. Different combinations of pulse shaping of the input stream, by the AWG, and equalization of the output stream, by the oscilloscope (Lecroy LabMaster 10-100Zi), were used. De-emphasis (DE) of the input data stream was used to attenuate the lower frequency components of the signal to counter the dispersive effects of the PMF. Eye diagrams of the measured output captured by the oscilloscope for different data rates (12-30 Gbps) using different setting can be seen in Fig. 8, 9, 10 and 11.

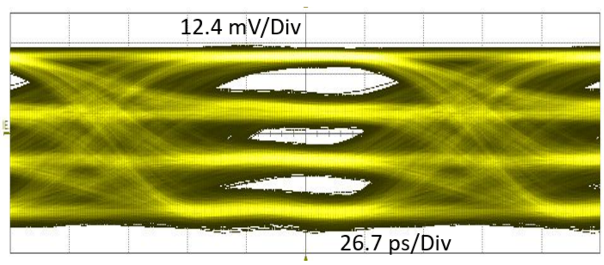

Fig. 8. Eye diagram of the output from the PD captured by the oscilloscope. 12 Gbps using a carrier at 152 GHz. Rectangular pulse shaping. BER $< 10^{-12}$

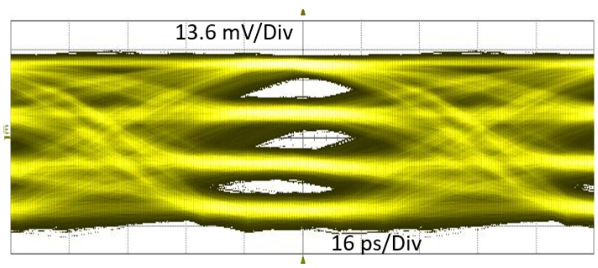

Fig. 9. Eye diagram of the output from the PD captured by the oscilloscope. 20 Gbps using a carrier at 152 GHz. Rectangular pulse shaping and DE (one post cursor tap -4 dB). BER $< 10^{-12}$

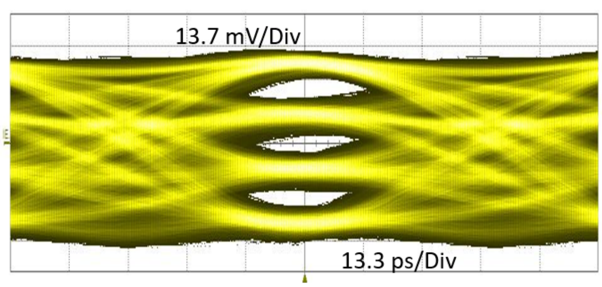

Fig. 10. Eye diagram of the output from the PD captured by the oscilloscope. 24 Gbps using a carrier at 152 GHz. RRC pulse shaping and DE (one post cursor tap -4 dB). BER = $4 * 10^{-12}$

The DC power consumption is 143 mW for the Tx, and 126 mW for the Rx.

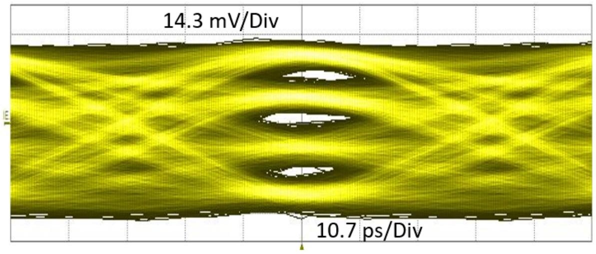

Fig. 11. Eye diagram of the output from the PD captured by the oscilloscope. 30 Gbps using a carrier at 152 GHz. RRC pulse shaping and DE (one post cursor tap -4 dB), equalization is used at the output. BER = $3 * 10^{-8}$

IV. Discussion and Conclusion

A high speed PAM-4 link is designed and measured in this work, using a commercial 130 nm SiGe BiCMOS process. Link measurements are performed over a one meter long foam-cladded PMF which verifies that the link can support data rates up to 30 Gbps with a bit error rate (BER) of $3*10^{-8}$. This type of communication link is suitable for short distance, high data rate communication, for example in-cabin vehicle communication for autonomous vehicles. It is shown that pulse shaping and/or equalization can be used with benefit to counteract the dispersive effects of the PMF.

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