An 80 Gbps QAM-16 PMF Link Using a 130 nm SiGe BiCMOS Process

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***Abstract*— In this work a D-band (110 GHz - 170 GHz) polymer microwave fiber (PMF) link for high data rate communication is presented. The transmitter (Tx) and receiver (Rx) circuits are designed and fabricated in a commercial 130 nm silicon germanium (SiGe) BiCMOS process. The Tx has a peak output power of 5 dBm. The link has been tested over a 2 meter long PMF, demonstrating 80 Gbps using QAM-16 modulation, with a bit error rate (BER) of $8*10^{-4}$, and 48 Gbps using QPSK with a BER $< 10^{-12}$. For a 4 meter long PMF, 24 Gbps using QPSK was demonstrated with a BER $= 7.7*10^{-6}$.**

***Keywords*— D-band, High Datarate, PMF, SiGe**

I. INTRODUCTION

Awareness of the increased need of high data rates is fortunately getting better. More information needs to be sent to fulfill the needs of today's society. Cost efficient solutions, that have a high energy efficiency and are reliable in varying conditions is a win-win for both customer and company, as well as our environment. For high data rate communication at long range, optic fibers are superior, but looking at shorter ranges, and applications that may have temperature fluctuations, polymer microwave fibers (PMFs) are a promising solution. It is potentially cheap and much easier to align (due to the larger size of the fiber) compared to optical fibers [1].

Successful high data rate PMF links has been demonstrated in [2] [3] [4] [5] [6] [7], reaching 30 Gbps, with a bit error rate (BER) less than 10^{-12}, over one meter PMF. Over a shorter distance, at H-band (220 - 325 GHz) 35 Gbps was demonstrated over a 30 cm dielectric waveguide [8].

In this work, a commercial 130 nm silicon germanium (SiGe) BiCMOS process is used to create an ultra high data rate link, which has demonstrated 48 Gbps transmissions over a two meter foam-cladded PMF, with a BER$< 10^{-12}$. Using QAM-16 modulation, 80 Gbps was reached (2 m PMF) with a BER of $8*10^{-4}$.

II. CIRCUIT DESIGN

The transmitter and receiver circuit was implemented in a commercial 130 nm SiGe BiCMOS process developed by Infineon technologies. The process features high speed npn HBTs with maximum f_t/f_{max} of 250 GHz/370 GHz [9]. The Transmitter (Tx) and receiver (Rx) are based on double balanced Gilbert cells mixers. An off-chip local oscillator (LO) is used that is fed to a frequency multiplier (by 4) to reach the desired carrier frequency. The frequency quadrupler consists of two cascaded frequency doublers. Each doubler has an emitter coupled pair which is differentially fed by a folded Marchand balun. The transmitter is using six stage common emitter amplifiers, with high pass interstage matching to achieve a flat gain over the entire frequency band. The receiver uses balanced two stage cascoded amplifiers to increase the bandwidth. Both input and output of the amplifiers use Marchand baluns to go to/from differential signal from/to single ended signal. A block diagram of the link can be seen in Fig. 1.

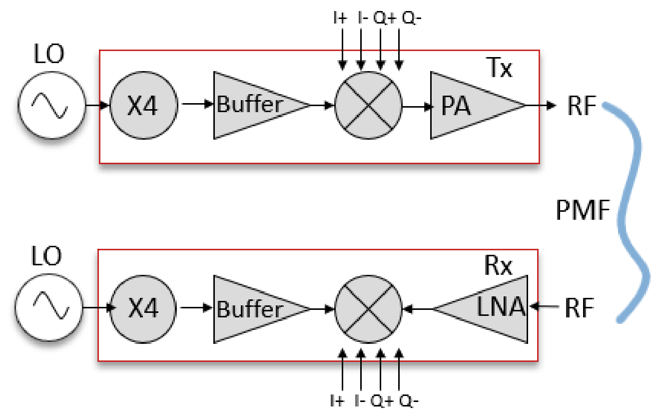

Fig. 1. Overview of the transmitter and receiver link.

A photo of the Tx is displayed in Fig. 2, and Rx is displayed in Fig. 3. Both Tx and Rx has an area of 2.1 mm^2 including pads, bringing the total to 4.2 mm^2.

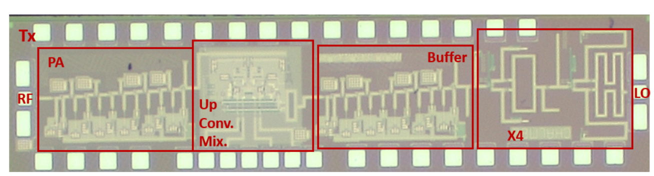

Fig. 2. A photo of the transmitter. The size of the Tx is 3 mm x 0.7 mm.

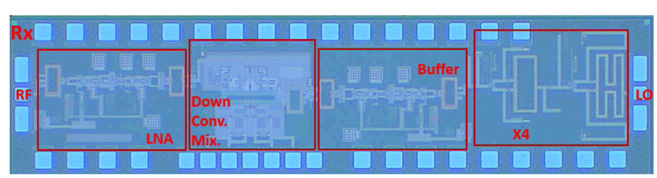

Fig. 3. A photo of the receiver. The size of the Tx is 3 mm x 0.7 mm.

III. Measurement Results

The transmitter and receiver was characterized on wafer using probe stations. Measurements in both frequency and time domain was done.

A. *Frequency domain measurements*

To evaluate the circuits in frequency domain a Keysight PNA-X (67 GHz N5247A) were used together with a VDI D-band extender WR 6.5 at the output of the Tx and as the input for the Rx. The single ended IF-signal was split into/combined from the I/Q+ and I/Q- using an external hybrid (Marki QH-0440)and two baluns (Marki BAL-0050). Measured conversion gain can be seen in Fig. 4 for Tx, and Fig. 5 for RX.

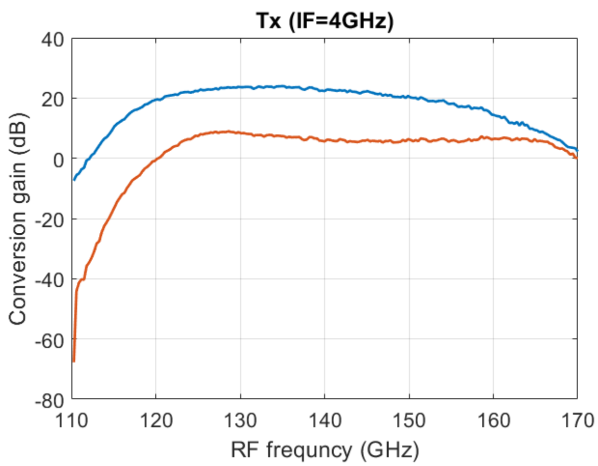

Fig. 4. Measured conversion gain for the Tx using a 4 GHz IF signal.

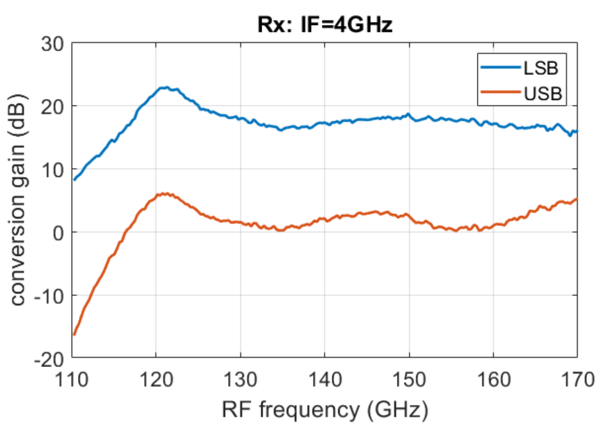

Fig. 5. Measured conversion gain for the Rx using a 4 GHz IF signal.

B. *Link measurements*

The link was tested using I/Q data input that was provided by a Keysight M8195A arbitrary waveform generator (AWG), where a pseudorandom binary sequence (PRBS-10) was generated using root raised cosine pulse shaping with a roll off of 0.7. Direct modulation was used during the link measurements. Measurements were made over a two meter and a four meter PMF provided by Huber+Suhner (H+S). The PMF has a polytetrafluoroethylene (PTFE) core that is 2.1 mm by 1.2 mm, and is covered by a circular polyethylene (PE) foam cladding. The fiber was coupled to a rectangular waveguide (WR.6.5) using an adaptor (H+S) and connected to the probes.

The data output (I+/- and Q+/-) from the Rx was captured by a Teledyne LeCroy LabMaster 10-100Zi oscilloscope. The bandwidth limit (due to the setup) for the baseband signal was 18 GHz. The setup can be seen in Fig. 6. The LO was provided by a Keysight signal generator (Agilent 67 GHz PSG E8257D).

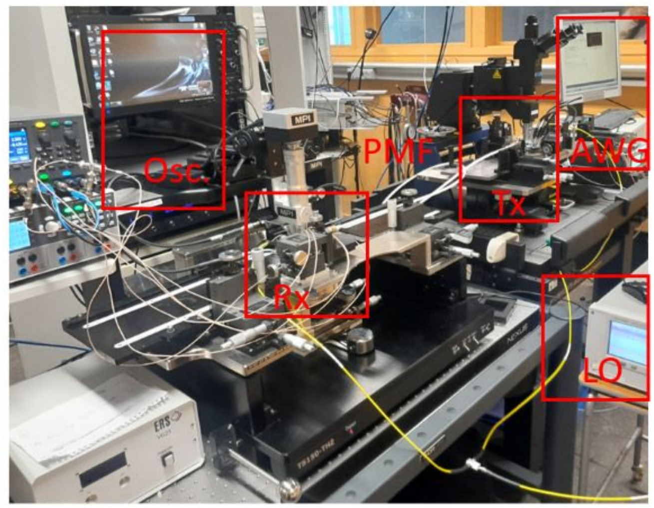

Fig. 6. The setup that was used during the link measurements, here with a 2 meter PMF.

In the link test a carrier frequency of 148 GHz was used. QPSK modulation was tested with a baud rate of 24 GBd corresponding to 48 Gbps. Captured eye diagram and I/Q constellation can be seen in Fig. 7.

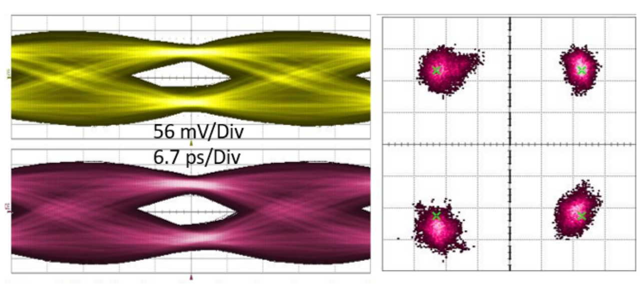

Fig. 7. Received eye diagram and I/Q constellation of a 24 GBd QPSK transmission over a 2 m PMF. LO at 148 GHz and BER $< 10^{-12}$.

Higher modulation order was tested in Fig. 8, where QAM-16 modulation was used with a baud rate of 20 Gbd (80 Gbps).

QPSK modulation was evaluated also over a 4 meter long PMF. At 5 Gbd (10 Gbps) the transmission is error free (BER $< 10^{-12}$), Fig 9.

In Fig. 10, a captured 24 Gbps QPSK signal can be seen, where the BER $= 7.7 * 10^{-6}$.

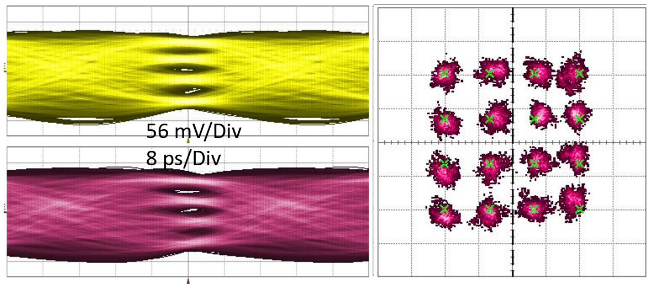

Fig. 8. Received eye diagram and I/Q constellation of a 20 GBd QAM-16 transmission over a 2 m PMF. LO at 148 GHz and BER $= 8 * 10^{-4}$.

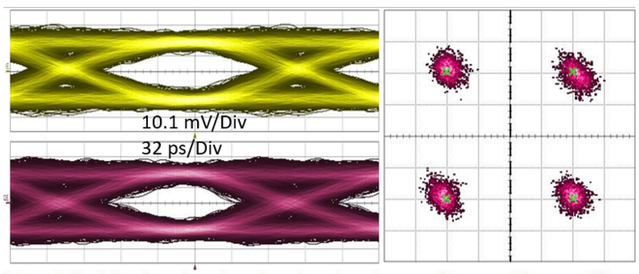

Fig. 9. Received eye diagram and I/Q constellation of a 5 GBd QPSK transmission over a 4 m PMF. LO at 148 GHz and BER $< 10^{-12}$.

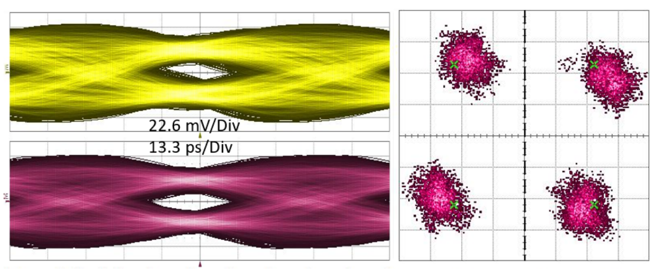

Fig. 10. Received eye diagram and I/Q constellation of a 12 GBd QPSK transmission over a 4 m PMF. LO at 148 GHz and BER $= 7.7 * 10^{-6}$

IV. Conclusion

Table 1. Comparison with other D-band PMF links, with BER $< 10^{-12}$.

Reference	[4]	[5]	[7]	**[this work]**
Technology	28 nm CMOS	28 nm CMOS	250 nm InP DHBT	**130 nm BiCMOS**
Modulation	CP-FSK	ASK	PAM-2	**QPSK**
Frequency (GHz)	140	135	131	**148**
Data Rate (Gbps)	12	27	30	**48**
Fiber Length (m)	1.0	1.0	1.0	**2.0**
Total chip area (mm^2)	2.31	1.94	0.83	**4.2**
Peak output power (dBm)	6	-3	3	**5**

A high data rate PMF communication link at D-band is presented in this work. The circuits are designed and fabricated in a commercial 130 nm SiGe BiCMOS process. In Table. 1 the link performance is compared to similar work. It achieves by far the highest data rate, 48 Gbps, of error free communication (BER $< 10^{-12}$), using a fiber that is twice the length compared to the other links. 80 Gbps was demonstrated over 2 meter PMF using QAM-16 with a BER $= 8 * 10^{-4}$.

This type of short range, high data rate link is suitable for module-to-module or chip-to-chip communication, like in-cabin vehicle communication.

Acknowledgment

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References

[1] P. Reynaert, M. Tytgat, W. Volkaerts, A. Standaert, Y. Zhang, M. De Wit and N. Van Thienen,“Polymer Microwave Fibers: a blend of RF, copper and optical communication ", *2016 European Solid-State Circuits Conference*, pp. 15-20, September 2016.

[2] Y. Zhang, M. De Wit and P. Reynaert,“A D-band Foam-Cladded Dielectric Waveguide Communication Link with Automatic Tuning", *ESSCIRC 2018 - IEEE 44th European Solid State Circuits Conference (ESSCIRC)*, pp. 234-237, September 2018.

[3] N. Van Thienen, Y Zhang. M. De Wit, and P. Reynaert, “An 18 Gbps Polymer Microwave Fiber (PMF) Communication Link in 40nm CMOS", *2016 European Solid-State Circuits Conference*, pp. 483-486, September 2016.

[4] M. De Wit, Y. Zhang, P. Reynaert, “Analysis and Design of a Foam-Cladded PMF Link With Phase Tuning in 28-nm CMOS", *IEEE Journal of solid-state circuits*, vol. 54, no. 7, pp. 1960-1969, July 2019.

[5] K. Dens, J. Vaes, S. Ooms, M. Wagner and P. Reynaert, “A PAM4 Dielectric Waveguide Link in 28 nm CMOS", *ESSCIRC 2021 - IEEE 47th European Solid State Circuits Conference (ESSCIRC)*, pp. 479-482, 2021.

[6] F. Strömbeck, Y. Yan, Z. S. He, and H . Zirath, “A 40 Gbps QAM-16 communication link using a 130 nm SiGe BiCMOS process", *2022 IEEE/MTT-S International Microwave Symposium - IMS*, pp. 1013-1016, June 2022.

[7] F. Strömbeck, M. Bao, Z. S. He, and H . Zirath,“Transmitter and Receiver Circuits for a High-Speed Polymer Fiber-Based PAM-4 Communication Link", *Sensors*, vol. 22, no. 17.

[8] J. W. Holloway, G. C. Dogiamis and R. Han, “A 105Gb/s Dielectric-Waveguide Link in 130nm BiCMOS Using Channelized 220-to-335GHz Signal and Integrated Waveguide Coupler", *2012 IEEE International Solid-State Circuits Conference*, pp. 196-198, February 2021.

[9] J. Böck et al., “SiGe HBT and BiCMOS process integration optimization within the DOTSEVEN project", *IEEE Bipolar/BiCMOS Circuits and Technology Meeting*, pp. 121-124, 2015.