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60 GHz Analog Radio-over-Fiber Single Sideband Transmitter Chipset with 55nm SiGe BiCMOS Driver RFIC and Silicon Photonics Modulator PIC

Nishant Singh[(1)], Joris Van Kerrebrouck[(1)], Piet Demeester[(1)], Xin Yin[(1)], Guy Torfs[(1)]

[(1)] IDLab, INTEC, Ghent University – imec, B-9052 Ghent, Belgium, nishant.singh@ugent.be

Abstract *An all-silicon transmitter chipset is presented for narrowband operation in the unlicensed 60 GHz band. The PIC consists of parallel electro-absorption modulators and thermo-optic phase shifters which are driven with both in-phase and quadrature components by the RFIC. A sideband suppression ratio of 25 dB is demonstrated with a full chipset size of 1.1 mm² and a power consumption of 45 mW. Link experiments are conducted with QAM signals. ©2022 The Authors*

Introduction

The RF V-band around 60 GHz is an industrially important piece of spectrum as it is the only unlicensed mmWave band below 100 GHz with large bandwidths for communications and sensing applications [1]. Standardization is well underway with both the WiFi alliance and the 3GPP paving the way for high capacity unlicensed standalone networks [2]. Effective use of mmWave frequencies requires the use of small cells as path loss is high, while centralized processing allows for capacity sharing and performance improvement through the use of distributed beamforming.

A significant challenge in distributed antenna topologies is the fronthaul links that carry signals to the remote radio heads (RRHs). Fiber-to-the-antenna (FTTA) provides a low-loss fronthaul solution but mmWave RRHs can get quite complex and costly with digital fronthauling standards such as the Common Public Radio Interface (CPRI) [3]. Simpler solutions are needed for low-cost systems that have the potential to be widely deployed. Analog radio-over-fiber (aRoF) with optical single sideband modulation (OSSB) has been shown to be a low-cost fronthaul solution for mmWave frequencies while overcoming dispersion based power penalties [4].

Silicon based solutions benefit from growth in mass production and offer low cost with steady performance improvements. Leading edge CMOS development has brought significant advances to speciality technologies like SiGe BiCMOS [5] and silicon photonics [6] as a majority of CMOS users move to leading edge nodes and free up tooling capacity for development of speciality nodes. Furthermore, III-V on silicon technologies are expected to improve modulator performance [7] and integrate lasers [8].

Previously published integrated mmWave RoF chips have been demonstrated up to 30 GHz [9][10][11]. The 30 GHz OSSB modulator in [9] integrated a quadrature hybrid on the PIC, which required a driver with a higher single channel output linearity while the hybrid is made with lumped inductors. The lumped inductors scale poorly to higher frequencies due to limited self-resonance. [10] demonstrated a 28 GHz GaAs driver while the PIC did not support OSSB. The PIC in [11] supports OSSB but the driver requires external in-phase and quadrature generation off the chipset.

This paper furthers the state-of-the-art by demonstrating an all-silicon 60 GHz OSSB narrowband photonic transmitter (NBPhoTx) consisting of a SiGe BiCMOS RFIC and a silicon photonics PIC. The PIC consists of parallel electro-absorption modulators (EAMs) and thermo-optic phase shifters which are driven with both in-phase and quadrature components by the RFIC. Sideband suppression of 25 dB is achieved with a full chipset size of 1.1 mm² consuming 45 mW. Link experiments are demonstrated with QAM signals. Such small and low-power aRoF chipsets can enable mass-produced solutions for remote antennas.

Narrowband transmitter

An overview of the proposed OSSB NBPhoTx chipset is shown in Fig. 1 with a macrograph of the assembly under test in Fig. 2. It consists of a

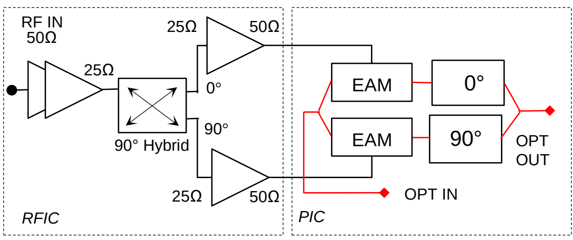

Fig. 1: OSSB NBPhoTx chipset.

low noise quadrature driver (LNQD) RFIC with a single sideband electro-absorption modulator (1BEAM) PIC. The LNQD RFIC consists of a low noise input stage, followed by gain stages, a quadrature hybrid and output stages while the 1BEAM PIC consists of parallel EAMs followed by thermo-optic phase shifters. The RFIC is manufactured using a 55nm SiGe BiCMOS process while the PIC is manufactured using the iSiPP50G process.

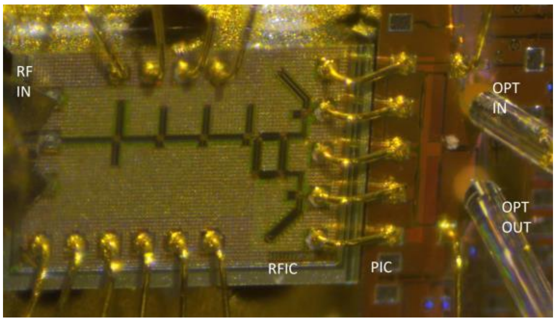

Fig. 2: NBPhoTx chipset under test.

The LNQD RFIC has been built around the integrated quadrature hybrid where our implementation sought to improve copper losses by using a reduced size hybrid with inductive lines loaded with MIM capacitors [12]. The size was further reduced by designing it for a characteristic impedance of 25 Ω. The input impedance of the input stage was 50 Ω and so was the output impedance of the output stage, other than that all the interstage impedances were designed for 25 Ω. The output network was designed to match to the capacitive EAMs while accommodating inductive wirebonds and a built in-bias tee for the EAMs.

The 1BEAM PIC consists of grating couplers for input and output as well as 1x2 multi-mode interferometers (MMIs) to split and combine light from two identical arms. Each arm contains an EAM [13] and a doped-silicon thermo-optic phase shifter [14].

The chips were diced close to the RF pads, thinned to 250 µm and assembled on a PCB with wirebonds. Very short ball-stitch-on-ball (BSOB) shapes were used for the 60 GHz connections while long ball-stitch shapes were used for DC connections. The EAMs were biased through the RFIC while the heaters were biased through the PCB.

Single-tone modulation characterization

The single-tone response of the chipset was characterized using a measurement setup as shown in Fig. 3. The 60 GHz input signal was generated using an oscillator (Anritsu MG3696B) and interfaced to the DUT using a GSG probe

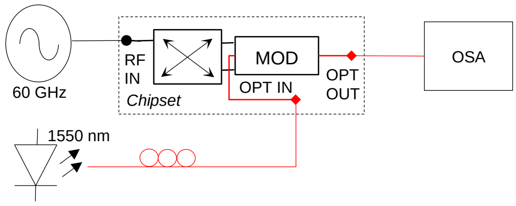

Fig. 3: Experimental setup for single-tone modulation characterization.

(Picoprobe 67A). A 1550 nm continuous wave laser source (Tunics T100S-HP) was coupled in and out of the chipset using optical probes positioned over grating couplers. A polarization controller was used to optimise the input optical power as the grating couplers are polarization sensitive. The EAMs were biased with -1 V while one of the thermo-optic phase shifters was biased for π/2 phase shift with 6.9 V which resulted in 10 mW of power through the 4.7 KΩ device. The output was observed using an optical spectrum analyser (OSA, Anritsu MS9740A) and the obtained spectrum is shown in Fig. 4. It can be seen that this implementation has a sideband suppression ratio of 25 dB. This result was compared to VPIphotonics transmission maker model of the PIC and the response was fitted to extract the dynamic extinction ratio of each EAM at 60 GHz while driven with 2 Vpp and was found to be 2.8 dB.

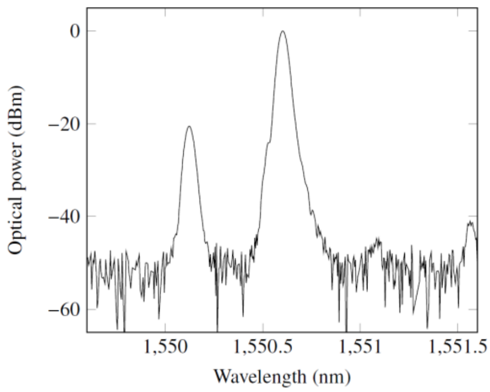

Fig. 4: Optical spectrum of single-tone modulation.

Link Experiments

In order to demonstrate the NBPhoTx with complex modulated aRoF signals, a back-to-back link experiment was set up as shown in Fig. 5. The RF signals were generated using an arbitrary waveform generator (AWG, Keysight M8195A) and upmixed to 60 GHz using a mixer (VDI WR12eCCU) and an oscillator. The output of the mixer was coupled to the chip using GSG probes. The modulated optical signal from the chip was amplified using and erbium doped fiber amplifier (EDFA, Keopsys CEFA-C-HG) and

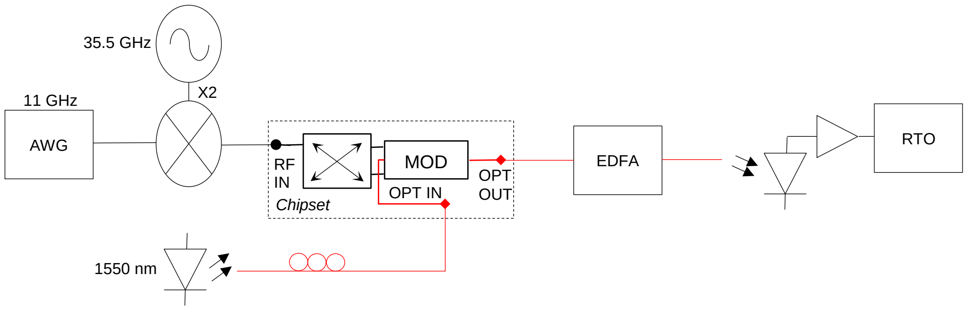

Fig. 5: Experimental setup for link experiments.

received with a commercial packaged high-speed photodiode (Finisar XPDV2120RA), an amplifier with 10 dB gain (SHF M827A) and a real time oscilloscope (RTO, Lecroy LabMaster 10-65ZiA) where the signal was demodulated in real time. The DSP receive chain on the RTO was made with four blocks, a downmixer, IF filter, equalizer and phase estimator.

The obtained constellations are shown in Fig. 6. The link was tested at 100 MBaud and 200 MBaud with QAM16 while QPSK was used at 500 MBaud and 1 GBaud. A comparison with other published chipsets is shown in Tab. 1. It can be seen that this chipset has the smallest size as

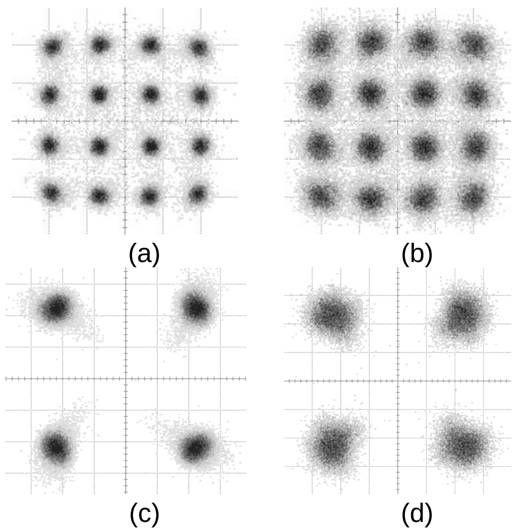

Fig. 6: Obtained constellations from link experiments (a) 100MBd QAM16 with 8% EVM (b) 200MBd QAM16 with 10% EVM (c) 500MBd QPSK with 14% EVM (d) 1GBd QPSK with 16% EVM.

well as the lowest power consumption while offering good performance. The current limitations are mainly the high loss of grating couplers and the low dynamic extinction ratio of the EAMs. Performance improvements can be obtained by using lower-loss optical coupling and modulators with higher extinction ratio.

Conclusions

In this paper we propose and experimentally demonstrate an all-silicon 60 GHz mmWave analog radio-over-fiber transmitter chipset with optical single sideband modulation. The transmitter chipset consists of a driver RFIC and a modulator PIC. The driver has 25 dB gain and two 2 Vpp outputs for both in-phase and quadrature signals. The modulator PIC has two parallel EAMs with thermo-optic phase shifters. They are assembled on a PCB with very short wirebonds for the 60 GHz connections. The transmitter chipset has a sideband suppression of 25 dB and was demonstrated with complex modulated RF signals.

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Tab. 1: Comparison with RoF transmitter chipsets.

		Chipset			**Driver**			
	Freq	**Technology**	**Size**	**Features**	**Power**	**OP1dB**	**OVpp**	**Gain**
This	60 GHz	All silicon	1.1 mm^2	OSSB	35 mW	10 dBm	2 V	25 dB
[10]	28 GHz	GaAs + silicon	5.5 mm^2	REAM	124 mW	5.2 dBm		25 dB
[11]	28 GHz	All silicon	2.1 mm^2	OSSB SDM	140 mW		2 V	20 dB

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