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100 GHz Band Photonic Wireless System employing Passive RoF Transmitters

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Summary

In this paper, we present a compact architecture for a high data rate photonic wireless system operating in the W-band (75-110 GHz). By using a cascaded optical RF and data modulation approach with advanced photonic components as well as radio-over-fiber (RoF) transmission and simple NRZ-OOK modulation format, the system allows flexible adjustment of the wireless RF carrier frequency within the 75-110 GHz (W-band). In first experiments, error-free wireless transmission of 1 Gb/s and 1.25 Gb/s for a wireless span of 2 m has been achieved. The maximum system's data rate of 2.5 Gb/s is limited by the wireless receiver bandwidth. Wireless experiments were carried out in a lab environment up to 2.5 m span using a passive, i.e. amplifier-less W-band RoF wireless transmitter with an EIRP of 21 dBm. The passive RoF transmitter is composed of a high-power broadband InGaAs photodiode and a 21 dBi gain horn antenna.

1. Introduction

The recent and ongoing growth of mobile and wireless communications and the introduction of video-based telephony and multimedia services into mobile communication have led to much higher data rate requirements for high speed point-to-point radio links. The simplest solution to fulfil these requirements is to provide sufficient bandwidth. The classical frequency bands for mobile and wireless communications (0.5 – 10 GHz) do not offer such wide bandwidth due to international frequency regulations. Because of this, strong efforts were put in extending the carrier frequency to the millimetre-wave bands, mainly for developing systems in the 60 GHz band [1-3] where international regulations have opened up a total bandwidth of 7 GHz for license-free wireless usage. Moreover, methods to increase the spectral efficiency e.g. by using higher level modulation formats such as QAM were successfully applied to millimetre-wave wireless systems, increasing data rates up to 27 Gb/s [4].

A disadvantage of the 60 GHz band is that due to the oxygen absorption peak at 60 GHz, the spectral variation of the signal-to-noise (SNR) ratio will vary strongly over the channel bandwidth of 7 GHz for wireless spans in excess of a few hundred meters. Thus, for outdoor wireless point-to-point links with typical wireless spans in excess of 1 km, it would be beneficial to operate at higher millimetre-wave frequencies e.g. in the E-band (71-76 GHz, 81-86 GHz), the W-band (75-110 GHz) or even higher frequency bands [5]. At those frequencies, even larger bandwidth is available and there is no drawback of a spectrally varying SNR.

In this paper, we present a compact photonic wireless system operating in the W-band. The system set-up allows flexible adjustment of the wireless carrier frequency within the W-band. Furthermore, amplifier-less RoF wireless transmitters can be used for short range communications.

2. Photonic Wireless System

Figure 1 shows a block diagram of the system setup. It basically consists of a photonic carrier generator, an optical data modulator, as well as a passive wireless transmitter and a wireless receiver. The photonic carrier generator is composed of a 1550 nm laser diode (LD) followed by a booster semiconductor optical amplifier (BOA), a single-drive Mach-Zehnder modulator (MZM) and an Erbium-doped fiber amplifier (EDFA). The MZM in the photonic carrier generator is biased at minimum transmission point for generating double-sideband signals with a suppressed carrier (DSB-SC). The frequency of the local oscillator (LO) driving the MZM can be tuned between 35-60 GHz. Thus, the generated wireless carrier can be tuned over the entire W-band (75-110 GHz).

The data modulator consists of a second single-drive Mach-Zehnder modulator (MZM2) followed by another EDFA and an optical band pass filter (OBPF). Polarization controllers (PC) were used in front of each MZM and in front of the BOA. Also, optical isolators were used in front and behind the BOA to prevent the BOA from

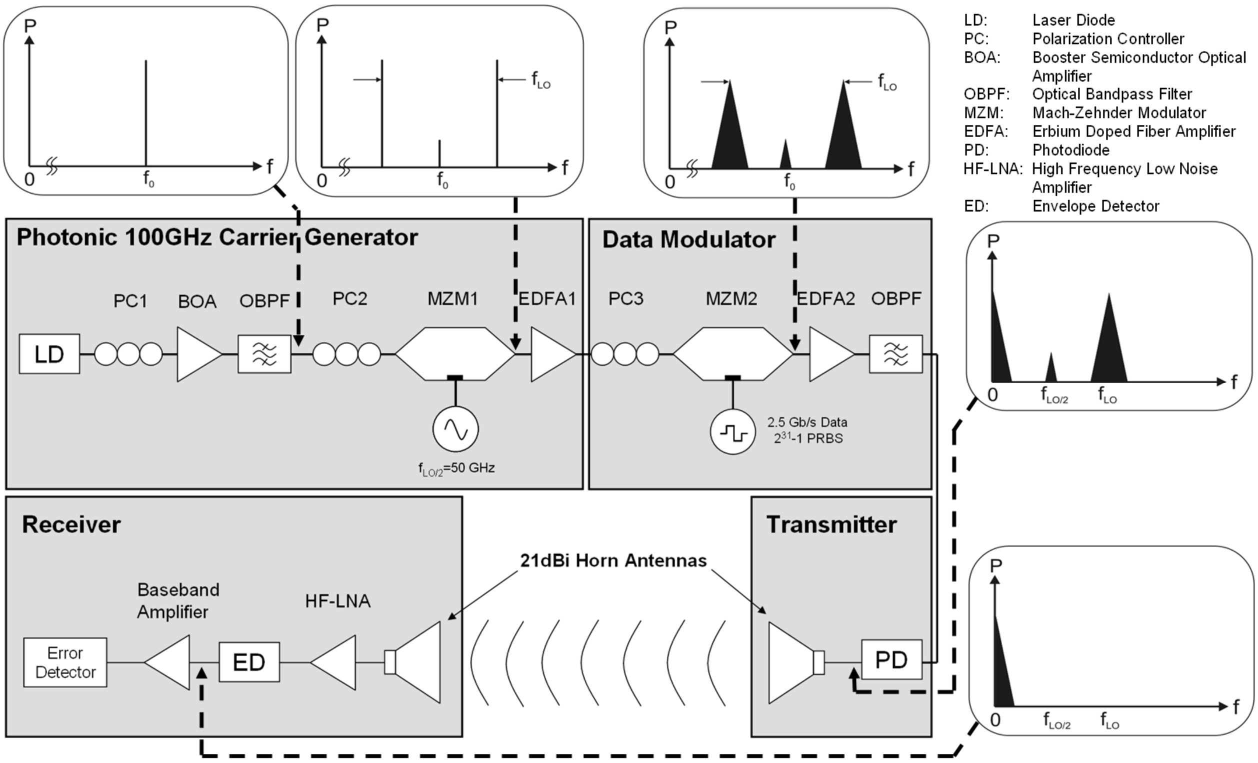

Figure 1. **Block diagram of the 100 GHz photonic wireless system**

starting to lase because of reflections. The MZM2 in the data modulator unit is biased to the quadrature point and it is driven by the non-return-to zero on-off keyed (NRZ-OOK) data signal. The data signal is generated using a pseudo random bit sequence (PRBS) generator with a word length of 2^{31}-1 Bits.

The passive wireless transmitter consists of a photodiode (PD) and a 21 dBi horn antenna. In this work, only short-range wireless communications was experimentally studied, i.e. no amplifier was used in the transmitter to keep it as simple as possible. The PD used in the RoF transmitter is a high-power waveguide PD with a cut-off frequency of 97 GHz.

The wireless receiver consists of a 21 dBi horn antenna, a W-band low nose amplifier (LNA), a zero-biased envelope detector (ED), and a baseband amplifier. An error detector is used to acquire the bit error ratios (BER) of the received signals.

All RF-components, like the horn antennas, the LNA, the envelope detector as well as the waveguides used for connecting these RF components are of course specified for W-Band operation.

3. Experimental Results

Experiments were carried out in a lab environment with a maximum wireless span of 2 m. In our experiments we achieved a carrier suppression of approximately 26 dB in the photonic carrier generator. The transmitted power level was further varied using a variable optical attenuator directly in front of the PD.

In Figure 2, the measured and simulated BERs are shown as a function of the transmitted power level measured at the output of the PD. Measurements were carried out for 1.25 Gb/s and 1.0 Gb/s, representing net data rates for 1 Gigabit Ethernet with and without forward error correction (FEC), respectively. Note that FEC needs a maximum of 25% higher data rate

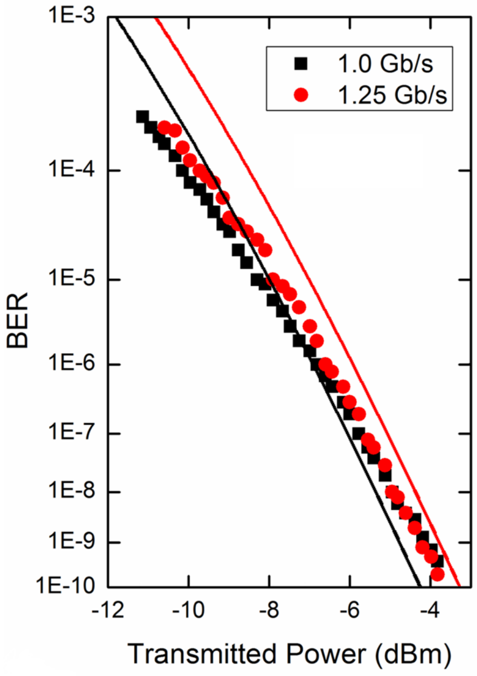

Figure 2. **BER over transmitted power for a distance of 2 m and a carrier frequency of 100 GHz (Dots and squares represent measured values, lines are simulated values).**

depending on the modulation format used. The simulations were performed using a signal-to-noise system analysis in Mathworks MATLAB®.

As can be seen from Figure 2, the measured and simulated values agree very well. The slight difference in the BER at lower transmit power levels are considered to be due to environmental influences that have not been taken into account in the simulation, for example multipath propagation due to walls and laboratory equipment. According to the simulations, a power penalty of approximately 1 dB is expected when increasing the data rate from 1 Gb/s to 1.25 Gb/s. This however implies that the signal bandwidth in the bit error rate test equipment is constant. In case the detected bandwidth is adapted by an electronic filter to the data rate, the power penalty would be much smaller. When applying FEC, the required BER must be better than $2\cdot10^{-3}$. As can be seen from Figure 2, this is already achieved for a transmit power level of -11 dBm. Error-free operation, which we define at $BER<10^{-9}$ without FEC, is achieved at -4 dBm transmit power. Considering the maximum output power of the passive RoF transmitter of 21 dBm EIRP, we expect the maximum wireless span for this system using passive RoF transmitter will be about 7 m.

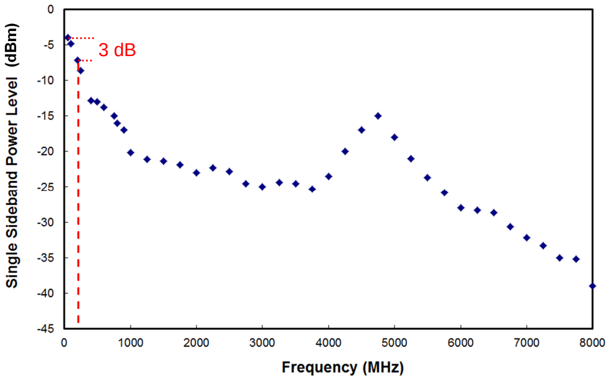

Figure 3. **IF-response of the zero-biased envelope detector**

The highest system's data rate for error-free transmission we achieved was 2.5 Gb/s for wireless spans below 1 m. We expected the data rate to be mainly limited by the IF bandwidth of the envelope detector. To verify this, we measured the IF-response of the ED by applying no data but instead a sinusoidal waveform to the second MZM and measuring the corresponding output power of the envelope detector.

Figure 3 shows the measured IF-response of the envelope detector for a carrier frequency of 100 GHz. The 3 dB cut-off frequency of 250 MHz is extremely low. Since OOK modulation approximately requires a bandwidth of 0.7 times the data rate, it is clear that the low IF bandwidth of the envelope detector is the key limitation in the current set-up. The low IF cut-off not only limits the maximum data rate, but also requires a much higher SNR and thus also limits the maximum wireless span.

4. Conclusion

In this paper, we have presented a compact photonic wireless RoF point-to-point link with passive, i.e. amplifier-less RoF transmitter. Due to a cascaded RF and data modulation approach, the system allows for tuning the wireless carrier over the complete W-band (75-110 GHz). Short-range wireless transmission at 100 GHz of up to 2.5 Gb/s is demonstrated experimentally. At a transmit power level of -11 dBm, a BER below the FEC level is achieved for 1 Gb/s. The maximum achievable wireless span when using amplifier-less RoF transmitter is expected to be 7 m.

5. Bibliography

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