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A radio-over-fiber link for OFDM transmission without RF amplification

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Abstract: **We study the feasibility of a radio-over-fiber (ROF) link with external modulation and an unamplified photodetector; we show high-quality (EVM -38dB, RF power -1dBm) 64-QAM-OFDM transmission when optimizing the photodiode impedance matching and the modulator bias point.**

I. INTRODUCTION

Optical-to-wireless transceivers for base stations in radio-over-fiber (ROF) links have major challenges in improving signal-to-noise ratio and increasing transmitted radio-frequency (RF) power. It has been shown recently that the ROF link can produce high RF gain and high carrier-to-noise ratio as a result of optimization of the bias of an external Mach-Zehnder modulator (MZM) in the central office [1]. However, in [1] the power had to be attenuated optically at the last stage of the link in order to respect the maximum input power of the photodiode (PD). To achieve the RF power suitable for the wireless transmission, a power amplifier (PA) is usually used in the base station inline with the PD, which results in additional cost, noise, and distortion.

Distortion is of particular concern in IEEE 802.11a/n based on orthogonal frequency division multiplexing (OFDM). OFDM is sensitive to clipping from the nonlinear response of the PA and any other nonlinear effects. To avoid clipping, the PA is dimensioned to have 1 dB compression power several times higher than the mean power of the transmitted OFDM signal, which is very inefficient. Without a PA in the receiver, the amplification could be done optically using an erbium-doped-fiber amplifier (EDFA), leading to higher linearity of the link. A high power link with good linearity and low intermodulation distortion by means of optical amplification, bias optimization, and high-power PD has been shown recently [2]. RF power may, on the other hand, be increased by up to 12 dB (at 6 GHz) by impedance matching of the PD [3-6]. We consider combining these two approaches and increasing OFDM signal transmission quality over the optically-amplified link, by joint optimization of the PD impedance matching and MZM bias. In this paper we study and demonstrate this approach without RF power amplification for an OFDM ROF link at 5 GHz.

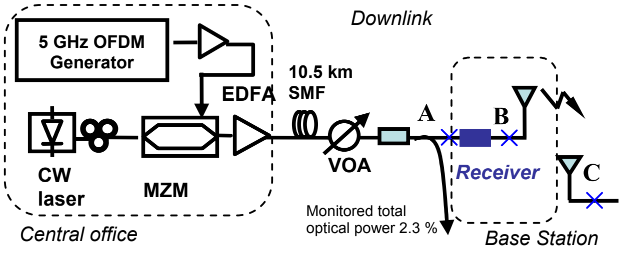

Fig. 1. Schematics of the ROF set-up.

II. EXPERIMENTAL RESULTS AND DISCUSSION

The schematic of the ROF link set-up is shown in Fig. 1. The signal is generated by external modulation of a tunable laser (7 dBm, lasing at 1550 nm with extinction ratio of 60 dB) using a MZM. An OFDM signal of 5 dBm is generated by a pattern generator at 5 GHz with 20 MHz bandwidth. After amplification by an erbium doped fiber amplifier (EDFA) with 37 dB gain, the signal travels 10.56 km of single-mode fiber (loss 0.191dB/km, dispersion 17.1 dB/km/meter). At the base station, a variable optical attenuator (VOA) is used and power is monitored with a 2.3% tap. The base station received optical power was ≤ 5 mW.

We studied two types of receivers: an HP lightwave converter (LC), with a photodiode (PD1) and a built-in PA with 15 dB gain, and an unmatched, 50 GHz photodiode (PD2) connected to an external impedance matching tunable stub (TS).

Fig. 2 compares the RF power for these two types of receivers measured at point B (Fig. 1) in the link with unmodulated 5GHz carrier. The optical link was optimized to achieve the highest RF power before the antennas using the bias voltage of the MZM. Due to the internal PA, the output power of the LC can be as high as 10 dBm. Two configurations of the link with PD2 were measured: PD2 unmatched to the 50Ω antenna, i.e. without TS, and PD2 with a TS to impedance match to 50Ω. Fig. 2 shows that when PD2 impedance matching is optimized by means of TS (line (c) in Fig.2), the RF power can increased by at least 13.5 dB, and can reach -0.95 dBm.

OFDM modulation performance is evaluated via the error vector magnitude (EVM). Fig. 3 shows EVM vs. RF power after LC and PD2 (with and without TS) at point B (Fig. 1) of the link. Although RF power of LC can be high, the RF amplifier causes a drastic increase in the EVM (line (a)). The PD2 link without TS (curve (b) in Fig. 3) gives EVM of less than -30 dB, far from the performance with a TS. With a TS, EVM between -45 dB and -42 dB can be achieved with the optimal impedance of the TS (curve (c) in Fig. 3).

Above 3 mW optical power, the impedance matching for the PD2 should be re-adjusted to optimize the EVM. This is due to the changing output impedance of PD2 at high power.

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This effect is seen in the different performance of curves (d) and (e) in Fig. 3. In curve (d) the TS setting is maintained at that of curve (c), and only the MZM bias is optimized to reduce EVM. Curve (e) was obtained after additional optimization of the TS for maximum power transfer and subsequent MZM bias optimization to minimize EVM. As shown theoretically in [7], the optimization of the bias point can give maximum RF gain and minimum EVM. Thus, EVM can be improved by ~15 dB when the link is optimized for EVM in the OFDM regime using both: TS optimization for maximum power transfer and MZM bias optimization for minimum EVM (curve (e) in Fig. 3).

EVM with dual optimization varies only by 1-2 dB from the very best LC results; this variation is within the EVM measurement uncertainty when dealing with distortion. Clearly for the same optical power in the ROF link, the link with the PD2 and optimal impedance matching has EVM < -37 dBm, suitable for OFDM transmission.

Measurements at point C of Fig. 1 are reported, that is, after wireless transmission of the OFDM signal, for the LC receiver only. Two dual-bandwidth PCB antennas, kindly provided by Antenova Ltd., were tested. Curve (*i*) in Fig. 4 shows measured EVM. For comparison, RF power (curves (a)-(b)) and EVM of the OFDM signal, (c)-(d), at point B before the transmission antenna are also shown.

Maximum RF power available in the experiment from PD2 with optimal impedance matching is -0.95 dBm when the optical power in the link is 4.5 mW. EVM measured before the antennas (point B in Fig. 1) in this case is -38 dBm. The same RF power (-0.95dBm) can be brought to the antennas using LC. Optical power in the link is then ~0.6 mW and EVM is ~-38 dBm at point B of the link. When this signal is transmitted with LC via two antennas in similar conditions (RF power=-0.95dBm, Opt. power=0.6 mW), EVM measured at point C is -34.7 dBm, which is only by 3 dB higher than EVM measured after the receiver. For a link with PD2 and optimal matching, EVM after wireless transmission may be estimated as a sum of EVM at the highest RF power, available from the PD2+TS, and the 'EVM loss' due to the antennas, measured for PD1+PA, for comparable power levels on the transmitting antenna for the two cases. Therefore, EVM may be as low as -35 dBm in the case of wireless transmission over the link with PD2+TS. Moreover, the output power of the PD2 may be increased further and, as shown in our measurements, EVM can be kept low when PD2 is used without a PA.

III. CONCLUSION

We have demonstrated the impact of the optimal photodiode impedance matching on the EVM of the 64-QAM OFDM signal transmission over the ROF link. The transmission over the wireless channel has been measured. We have shown that RF output power and EVM of the link with PD and impedance matching can be comparable with RF power and EVM of the link with a PD and PA due to optimization of MZM bias and PD impedance matching. Therefore, the amplification can be moved from electrical to optical, which allows, for example, having an optical amplifier at the central office and simplifying the base station. Work is ongoing to demonstrate a fully-characterized OFDM transmission using the PD2 without a PA in the base station.

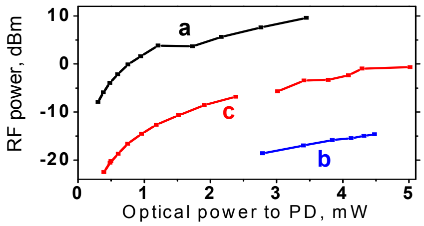

Fig. 2. RF power measured at point B in Fig. 1 vs. the optical power in the link (without OFDM modulation), measured at point A in Fig. 1, for a link with: (a) LC, (b) PD2 without TS, and (c) PD2 with TS.

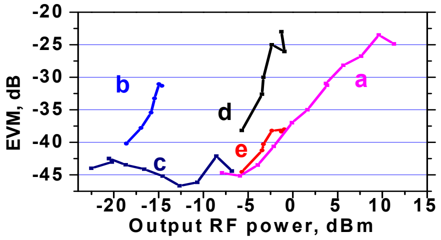

Fig. 3. EVM of the link measured at point B in Fig. 1 for a link with (a) LC, (b) PD2 without TS, and PD2 with TS at (c) low optical power in the link and high optical power (d) without dual link optimization and (e) with dual link optimization.

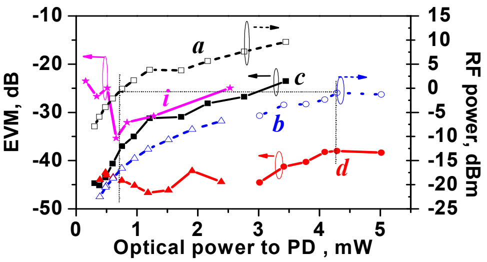

Fig. 4. RF power: (a) after LC receiver and (b) after PD2 with optimal impedance matching. EVM: (c) before and (*i*) after wireless transmission with LC. (d) EVM after PD2 with dual link optimization.

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