Bidirectional Multi-Standard RoMMF Transmission Using a Reflective Electro-Optic Transceiver

I. Möllers, D. Jäger
Universität Duisburg-Essen, Zentrum für Halbleiter- und Optoelektronik, Lotharstr. 55, Duisburg, Germany
* Phone: +49 203 379 4635, Fax: +49 203 379 2409, E-Mail: ingo.moellers@uni-due.de

Abstract – A characterization of a Radio-over-Multimode fiber link for picocellular architectures using a novel reflective electro-optic transceiver (REOT) for bidirectional transmission over a single fiber is presented. Spurious-free-dynamic-range (SFDR) analysis and error-vector-magnitude (EVM) measurements for multi-standard and subcarrier-multiplexed (SCM) wireless signals are carried out.

Introduction – The ever increasing demand on high data rates in conjunction with mobility for different services leads to a convergence of fixed and wireless access systems supporting picocellular networks [1,2]. Especially for short-range and in-building systems highly integrated but low-cost solutions are required. Radio-over-Multimode Fiber (RoMMF) or Radio-over-Polymer Optical Fiber (RoPOF) systems can address exactly this scenario by providing high bandwidth and reliability coexisting with relatively low installation costs. Distributed Antenna Systems (DAS) based on RoMMF techniques together with one or more central units and several fiber linked distributed base stations, both containing active devices, have been reported [2-4]. We propose a DAS by coeally reusing frequency channels in separate picocells. This enables using separate frequency channels for full-duplex transmission for up- and downlink in one picocell. New developments show that self-sustaining or even passive base stations, e.g. by power over fiber techniques [5] or using fully passive eo/oe-components, could be a solution for DAS in the future. Addressing these systems we present the characterization of intensity modulation-direct detection (IM-DD) RoMMF WDM link using a passive full-duplex vertically integrated reflective electro-optic transceiver as key element for DAS base stations for the first time. No bias voltage or current is needed for the system due to a 0 V biased modulator and photodiode operation. Multi-standard signal transmissions like WLAN, GSM, UMTS and DPRS are demonstrated.

Transceiver Design – The transceiver is a monolithically integrated epitaxially grown GaAs/AlAs/AlGaAs heterostructure with pinip-configuration resulting in two pin-diodes. A bragg with an intrinsic resonator layer composes a vertical modulator changing the reflected intensity of a continuous incident beam at 790 nm wavelength utilizing the well known Franz-Keldysh-Effect. The modulator is quasi transparent for a modulated incident beam at a wavelength of 850 nm. This signal is detected by the subjacent nip-photodiode structure for the downlink [6]. Fig. 1 shows a block diagram of the RoMMF link containing the passive bidirectional full-duplex REOT as key oe/oe-element for low-power consuming base stations in DAS systems.

![Fig. 1: Block diagram of bidirectional RoMMF system using separate channels (f₁, f₂) for up- and downlink](image)

![Fig. 2: System block diagram for RoMMF uplink measurements using the modulator function of the REOT](image)
considering a measured noise level of -122 dBm

power of fundamental and third order intermodulation signal

edge emitting LD (fig. 1) the uplink turns out to be the more critical transmission; hence we focus on the uplink experiment in this paper. A RoMMF link with the REOT device was set up for SFDR and EVM uplink measurements of multi-standard wireless access signals, shown in fig. 2. All fibers used were 62.5µm core diameter with graded-index (GI) profile. A continuous wave signal, provided by a fiber pigtailed edge emitting LD (λ = 790 nm, \( P_{opt} = 5.8 \text{ dBm} @ 110 \text{ mA} \)), is guided through an optical isolator and y-coupler, multimode glass optical fiber (MM-GOF), over different lengths and types of MMF/POF fibers. A MM-GOF pigtail bare end is free-space coupled to the REOT device. An Agilent vector signal generator (VSG) E4438C is directly connected to the REOT modulator with 0 V bias using microprobe contact equipment. The modulated signal is received by the same fiber and guided through the y-coupler to a ROSA package (\( f_{\text{Mx},\text{ROSA}} = 9 \text{ GHz} \)). The demodulation was provided by an Agilent MXA N9002A vector signal analyzer (VSA).

Experimental Setup – In the proposed system (fig. 1) the uplink turns out to be the more critical transmission; hence we focus on the uplink experiment in this paper. A RoMMF link with the REOT device was set up for SFDR and EVM uplink measurements of multi-standard wireless access signals, shown in fig. 2. All fibers used were 62.5µm core diameter with graded-index (GI) profile. A continuous wave signal, provided by a fiber pigtailed edge emitting LD (λ = 790 nm, \( P_{opt} = 5.8 \text{ dBm} @ 110 \text{ mA} \)), is guided through an optical isolator and y-coupler, multimode glass optical fiber (MM-GOF), over different lengths and types of MMF/POF fibers. A MM-GOF pigtail bare end is free-space coupled to the REOT device. An Agilent vector signal generator (VSG) E4438C is directly connected to the REOT modulator with 0 V bias using microprobe contact equipment. The modulated signal is received by the same fiber and guided through the y-coupler to a ROSA package (\( f_{\text{Mx},\text{ROSA}} = 9 \text{ GHz} \)). The demodulation was provided by an Agilent MXA N9002A vector signal analyzer (VSA).

**Link Analysis** – The SFDR of a transmission system is used to analyze the uplink performance with respect to intermodulation distortion (IMD) of the link. A dynamic range measurement according to [7] has been done with the proposed optical link for input powers ranging from -4 dBm to +12 dBm at a frequency of 2.45 GHz. Fig. 3 displays the SFDR analysis of the system. A SFDR value of 77.1 dB/Hz\(^{2/3}\) and a link gain of -38 dB was observed considering a measured noise level of -122 dBm (1 Hz). The IP3 value was found to be -17 dBm. An uplink with this value achieves the requirements of WLAN 802.11b/g transmission systems of 75 dB/Hz\(^{2/3}\)[8].

![Fig. 3: SFDR analysis (RBW = 1 Hz) with input vs. output power of fundamental and third order intermodulation signal (IMD3)](image)

**Table 1:** EVM requirements [4] and measured results of IEEE and ETSI standard signal transmission using the proposed uplink with a GOF length of 25 m (fig.2)

<table>
<thead>
<tr>
<th>Standard/Technique</th>
<th>Modulation</th>
<th>Carrier Frequency</th>
<th>Chip Data Rate</th>
<th>Fiber</th>
<th>Required EVM (%rms)</th>
<th>Measured EVM (%rms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSM 900 (TDMA)</td>
<td>GMSK</td>
<td>900 MHz</td>
<td></td>
<td></td>
<td>≥ 7.0</td>
<td>1.19</td>
</tr>
<tr>
<td>DCS1800 (TDMA)</td>
<td>GMSK</td>
<td>1800 MHz</td>
<td></td>
<td></td>
<td>≥ 7.0</td>
<td>1.74</td>
</tr>
<tr>
<td>DPRS (TDMA)</td>
<td>64QAM</td>
<td>1.88 GHz</td>
<td>1.152 Mbps</td>
<td></td>
<td>≥ 2.6</td>
<td>2.51</td>
</tr>
<tr>
<td>UMTS (WCDMA)</td>
<td>GMSK</td>
<td>990 MHz</td>
<td></td>
<td></td>
<td>≥ 2.6</td>
<td>2.61</td>
</tr>
<tr>
<td>WLAN 802.11b (GSM)</td>
<td>QPSK</td>
<td>2.45 GHz</td>
<td>11 Mbps</td>
<td></td>
<td>≥ 35</td>
<td>6.82</td>
</tr>
<tr>
<td>WLAN 802.11g (OFDM)</td>
<td>64QAM</td>
<td>2.45 GHz</td>
<td>54 Mbps</td>
<td></td>
<td>≥ 5.6</td>
<td>9.79</td>
</tr>
</tbody>
</table>

In addition to the analog analysis RoMMF data transmission measurements were carried out for different wireless standards, lengths and types of fibers. Table 1 summarizes the EVM measurement results for different wireless standards such as GSM (GSM900 and DCS1800), DPRS (DECT), UMTS, and WLAN 802.11 b/g. It can be seen that the EVM requirements for all GSM, UMTS, DPRS and WLAN 802.11b transmissions can, to some extend, be highly exceeded with the proposed system. Selected constellation and eye diagrams are displayed in fig. 4. Clearly open eye diagrams were observed for GSM (DCS1800) and UMTS transmission experiments.

![Fig. 4: Selected constellation (1) and eye diagrams (2) for transmission experiments listed in table 1:](image)

(a) DCS 1800 EVM: 1.74 %\(_{\text{rms}}\), (b) UMTS QPSK 2 GHz EVM: 2.61%\(_{\text{rms}}\), (c) WLAN 802.11b DSSS EVM: 6.82 %\(_{\text{rms}}\), (d) WLAN 802.11g OFDM EVM: 9.79 %\(_{\text{rms}}\)

In order to relate the link performance to carrier frequency up to 5 GHz EVM/SNR vs. frequency measurements were carried out applying a 16QAM 24 Mbps (6 MHz modulation bandwidth) signal (fig. 5). By adjusting the applied modulator input power for each measurement point separately EVM values
below 5% rms were recorded up to carrier frequencies of 3.5 GHz. This allows IEEE 802.16e WiMAX WCDMA transmission (Germany: 3.4 GHz - 3.6 GHz) with medium data rate performance. For in-building scenarios different types of fibers and lengths will be of interest for such RoMMF systems. Therefore we investigated the influence of fiber types of 62.5µm GI-GOF and 62.5µm perfluorinated (PF)-GI-POF and lengths for the system, respectively. A QPSK signal at a carrier frequency of 2.44 GHz with a data rate of 2 Mbps was used for EVM analysis. The results of the measurement are summarized in fig. 6. For both fibers we obtain a somehow linear correlation of fiber length and EVM value for this uplink system. The comparison of both slope values for the different fibers shows ten times higher slope in PF-GI-POF compared to GI-GOF. The difference of NA between both fibers (PF-GI-POF and pigtail GI-GOF) results in coupling losses at both, the y-coupler and to the pigtail fiber of the REOT causing signal loss and EVM rising. For all measurements a broadband circulator for a wavelength range from 790 nm to 850 nm could increase link performance significantly due to optical loss reduction by y-coupler and isolator. Coupling efficiency of the REOT to the fiber and modulator matching or matched driving circuitry could further improve measurement results.

Conclusion – In this paper we have proposed a RoMMF transmission system using a passive bidirectional full-duplex transceiver for eo-conversion at the base station for the first time. A SFDR value of 77.1 dB/Hz(2/3) was found for 2.45 GHz by achieving a uplink gain of -38 dB. EVM analysis show that multiple standard wireless access signals such as GSM, UMTS, WLAN 802.11b and WiMAX can be transmitted with values partially far below the required ones according to the standards. Different scenarios on fiber type and length were tested in order to demonstrate their dependence for in-building installations.

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References