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Experimental Evaluation of R-EAM Performance in RoF Networks

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Summary

The performance of a reflective electro-absorption modulator (R-EAM) transceiver is assessed in terms of both slope efficiency (SE) and responsivity in a Radio-over-Fiber (RoF) network. Different biasing schemes are analyzed, specifically, zero bias (passive solution), bias for maximum SE and bias for maximum responsivity. Finally, a case study on Ultra-Wide-Band (UWB) is presented, for which the optimum setup parameters are determined.

1. Introduction

The radio-over-fiber (RoF) concept involves the transmission of RF signals by an optical fiber between a control station (CS) and a number of base stations (BSs). In the base stations, the RF signal is transmitted to end users by a wireless link. Integration of both optical and wireless broadband infrastructures into the same backhaul network leads to a significant simplification and cost reduction of BSs since all routing, switching and processing are shifted to the CS. This centralization of signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance. The concept of RoF is shown in Figure 1.

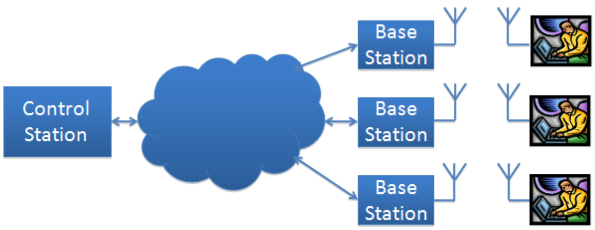

Figure 1 - RoF Concept

RoF systems can be completely transparent to all signals transmitted in the optical channel. It has been experimentally shown that RoF networks are well suited to simultaneously transport several wireless standards like wideband code division multiple access (WCDMA), IEEE 802.11 wireless local area network (WLAN) [1], global system for mobile communications (GSM) [2], WiMAX [3] and ultra-wide band (UWB) [4, 5]. Moreover, the RoF systems are attractive for future avionics communication networks since they are lightweight and immune to electromagnetic interference. Furthermore they facilitate the provision of wireless services to passengers and satisfy the requirements for future RF communications between the aircraft and earth stations.

In a RoF system, an optically modulated mm-wave signal can suffer several impairments namely nonlinear distortion and power penalty from the E/O/E conversion process, chromatic dispersion and attenuation from the optical fiber. Moreover, optical sources with narrow line-widths are required to minimize degradation due to phase noise and, hence, very stable and expensive lasers are mandatory [6]. For the downlink signal transmission an ultra-stable and common optical source can be used. Yet, in the uplink, it is not attractive in terms of complexity, size, power consumption and cost to have an optical source for each BSs. Furthermore, by eliminating the need of an optical source at each BS, the wavelength assignment is also performed at the CO, turning all BSs to be colorless.

In this paper we study the performance of a reflective electro-absorption modulator (R-EAM) transceiver in a RoF network. In section 2, a description of the EAM is performed and its role as a transceiver in RoF systems is discussed. In section 3 we analyze the R-EAM slope efficiency (SE) and responsivity ($\mathcal{R}_e$) for different wavelengths, optical powers and bias points. In section 4, a case study of UWB signal transmission is addressed, where the optimum operation points are discussed for different scenarios: bias for maximum SE, bias for maximum RE and zero bias. Finally, conclusions are given in section 5.

2. Electro-Absorption Transceivers in RoF Systems

There are two main BS schemes that are usually used in source free RoF systems. The first scheme is based on an external modulator, photoreceiver and optical filtering techniques that use wavelength reuse or a more convenient method in which the optical carrier is provided remotely from the CO [7, 8, 9]. Another scheme of source free BSs is based on a single electro-absorption waveguide device in which a single

component acts as a modulator for the uplink and as photoreceiver for the downlink [10,11]. Therefore, this transceiver device is a very attractive solution for a full-duplex RoF transmission.

Although a RoF system based on electro-absorption transceiver (EAT) leads to low power consumption as well as low component count, a more desirable solution based on powerless passive EATs have also been already reported [12]. Moreover, a dual lightwave approach can also be performed. By using two different wavelengths it is possible to optimize the insertion loss of the transceiver for both uplink and downlink signal transmission, i.e., segregation of uplink and downlink signals is performed using different wavelengths. Some authors have been appointing optical transceivers as a key component to realize low-cost BS in the long run [12].

The reflective EAM is an interesting device for operation simultaneously as a modulator and photoreceiver where the rear facet is coated with high reflection layer. The performance of the R-EAM will be discussed in the next section.

3. R-EAM performance analysis

The experimental setup for the characterization of the R-EAM transceiver is shown in Figure 2.

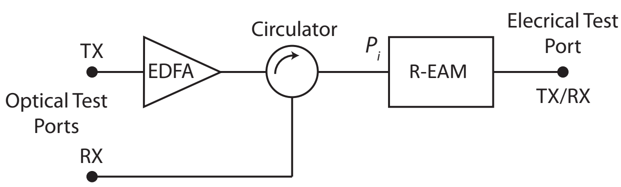

Figure 2 - R-EAM characterization setup

Both electrical and optical test signals are used in order to obtain the electro-optical (EO) and optical to electrical (OE) response, which correspond to the slope efficiency and responsivity, respectively. We assume the decibel units for these variables to be obtained by $20log_{10}(.)$, as defined in the measurements of the laboratory equipment. shows the EO response as a function of reverse bias voltage, for different frequencies and wavelengths. The R-EAM average optical input power, P_i, is varied using an optical Erbium Doped Fiber Amplifier (EDFA). It is apparent that the optimum bias voltage increases with both wavelength and the optical input power. It is also apparent that SE degrades slightly with frequency especially for high P_i, and lower wavelengths. Furthermore, it is easily seen that SE at the optimum bias voltage increases with P_i.

Figure 4 shows the OE response as a function of reverse bias voltage, for different frequencies and wavelengths, excluding the EDFA gain. Due to the similarity of results, only two wavelengths are plotted, in order to allow a clear visualization. Similarly to what was observed for the EO case, the responsivity degrades with frequency, particularly for high values of P_i, shorter wavelengths and decreasing reverse bias. Nevertheless, responsivity is shown to be more affected than SE. Furthermore, results also show that responsivity increases monotonically with reverse bias voltage.

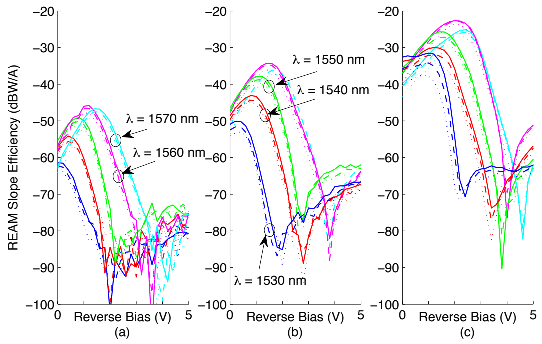

Figure 3 - EO response versus reverse bias voltage, for different wavelengths and frequencies, at P_i = {-6 (a), 0 (b), +7 (c)} dBm. Solid, dashed and dotted lines correspond to frequencies of {2.4, 5, 15} GHz, respectively

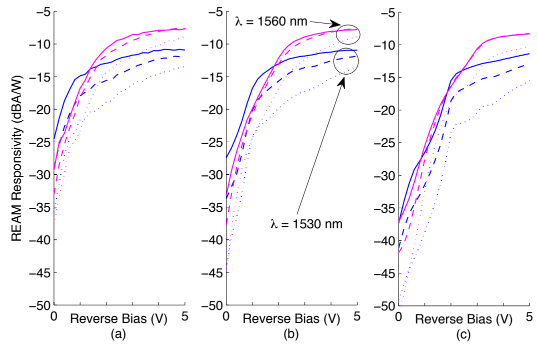

Figure 4 - OE response versus reverse bias voltage, for different wavelengths and frequencies, at P_i = {-6 (a), 0 (b), +7 (c)} dBm. Solid, dashed and dotted lines correspond to frequencies of {2.4, 5, 15} GHz, respectively

The optimum bias points for maximum slope efficiency and responsivity have been extracted from the results of Figures 3 and 4. Considering these values the R-EAM performance is assessed in terms of slope efficiency and responsivity for the following cases: bias for maximum SE, bias for maximum RE and zero bias. The results of this analysis are plotted in Figures 5 and 6.

The results in Figure 5 show that the best performance is obtained for a wavelength of 1560 nm, when the EAM is biased for maximum SE. However, when zero biased, the optimum wavelength is reduced to 1530 nm, where a penalty of 13 dB is incurred, compared to the case of maximum SE. Finally, when the EAM is biased for maximum responsivity, the optimum wavelength is 1560 nm and the SE decreases by 15 dB,

compared to the zero bias case. It has also been verified experimentally that, as expected [9], the slope efficiency is proportional to the input optical power, as seen in Figure 5 (a) and (b), until it saturates at high optical powers, as shown by Figure 5 (c). Nevertheless, high optical input powers should be used in order to maximize the SE.

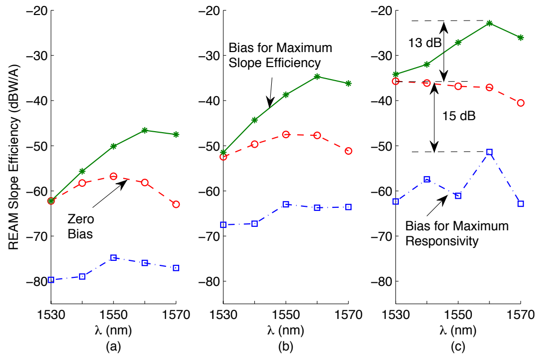

Figure 5 - EO response versus wavelength, for different bias configurations, at P_i = {-6 (a), 0 (b), +7 (c)} dBm.

In Figure 6 the REAM responsivity is analyzed also considering the same 3 scenarios.

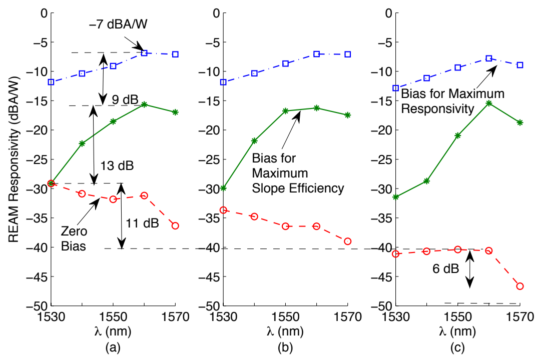

Figure 6 - OE response versus wavelength, for different bias configurations, at P_i = {-6 (a), 0 (b), +7 (c)} dBm.

At P_i = -6 dBm $\mathcal{R}_e$ is optimum, while a noticeable reduction is observed with increasing P_i, especially for zero bias. The optimum wavelength for both cases of maximum $\mathcal{R}_e$ and SE is 1560 nm, regardless of the P_i value, where $\mathcal{R}_e$ = {-7, -16} dBA/W are obtained, respectively. For the zero bias case, the maximum $\mathcal{R}_e$ equals -29 dBA/W, its value decreasing with wavelength, being optimum at 1530 nm for both P_i = {-6, 0} dBm, while being relatively constant with the wavelength at P_i = +7 dBm, except for 1570 nm where it degrades by 6 dB. The responsivity degradation with increasing P_i, translates into a penalty of 11 dB when P_i is increased from -6 to +7 dBm.

4. Case study: UWB MB-OFDM [ECMA-368]

Ultra Wide Band (UWB) signals [13] are characterized by their huge bandwidth capacity, data rates up to 480 Mbit/s, and very low power density (-41.3 dBm/MHz), which gives them a noise-like signal characteristic and provides both interference mitigation and very low device power consumption. Additionally, its coverage is limited to a few meters, due to the low signal intensity, making it a good candidate for deployment in future aircraft in-flight entertainment networks, where the high user density benefits from a reduction of the sharing factor between wireless cells.

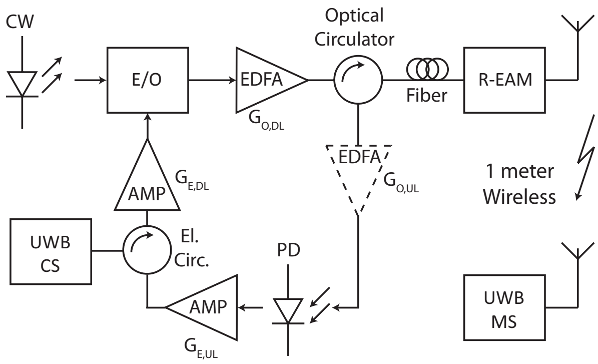

Figure 7 - Considered setup for UWB case study. CW represents a continuous wave light source. CS and MS, represent the UWB transceivers at the Control Station and Mobile Station, respectively. PD represents the CS photodiode.

The schematic of the UWB RoF link in study is shown in Figure 7. The present analysis considers the usage of typical UWB transceivers, which operate in band group 1 (from 3.168 GHz to 4.752 GHz) and have a maximum transmission power of approximately -19 dBm [14].

The downlink (DL) signal is generated by the UWB CS, passes though an electrical circulator and amplifier ($G_{E,DL}$), and drives an ideal E/O modulator. The optical downlink signal is then amplified by an EDFA ($G_{O,DL}$), then passes through an optical circulator, and reaches the R-EAM though an optical fiber. The RF modulated optical signal is converted to the electrical domain through the R-EAM responsivity, and then reaches the mobile station through the wireless channel. A wireless link distance of one meter is considered, which gives a 34 dB attenuation, when using 5 dBi gain antennas. The uplink (UL) signal is converted from the electrical to the optical domain with a conversion efficiency given by the SE. The uplink signal might be further optically ($G_{O,UL}$) and/or electrically ($G_{E,UL}$) amplified before reaching the UWB CS.

In order to analyze the link margin of both DL and UL paths, the required electrical gains of the downlink ($G_{E,DL}$) and uplink ($G_{E,UL}$) amplifiers have been found, considering the target signal level of -70 dBm which allows for the UWB receiver to maintain a reliable 480 Mbit/s transmission [13]. The preferable case would be to avoid the usage of any amplification in the UL path, since the wireless channel has affected the Signal to Noise Ratio (SNR), and the amplification operation further degrades the SNR due to the amplifier noise.

However, in the DL path, the implementation of signal amplification is not critical due to the high SNR of the signal before reaching the wireless channel.

Figure 8 (a) shows the results of this analysis for the zero bias case. Since the modulator SE improves with increasing P_i, the necessary $G_{E,UL}$ is reduced. In addition, given that the modulator responsivity degrades with increasing P_i, the required $G_{E,DL}$ increases adequately to compensate the reduction in responsivity. The optimum scenario consists in using the maximum P_i value, in this case, +7 dBm, which allows for the minimum required $G_{E,UL}$ = 19 dB, at the wavelength of 1530 nm, as expected from Figure 5. Furthermore, the DL path does not require any electrical amplification, since the inline EDFA already provides sufficient amplification. Concerning the bias for maximum SE in Figure 8 (b), there is a minimum required $G_{E,UL}$ = 6 dB, at the wavelength of 1560 nm, as expected from Figure 5 and the DL path also obviates any electrical amplification. Considering the bias for optimum SE, there is still a 6 dB gain requirement for $G_{E,UL}$, hence there is no advantage in analyzing the scenario of bias for maximum responsivity.

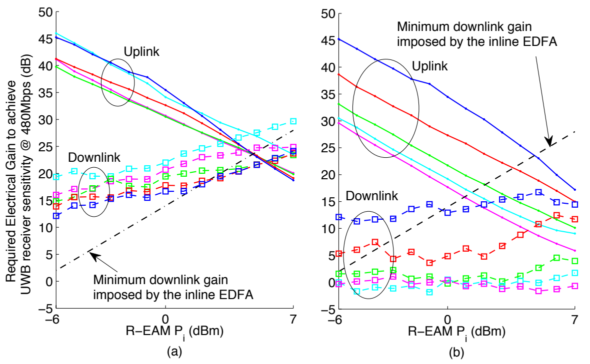

Figure 8 – Analysis of minimum downlink ($G_{E,DL}$) and uplink ($G_{E,UL}$) electrical amplifier gain necessary to meet the UWB receiver sensitivity @ 480Mbit/s, for zero bias (a) and bias for optimum SE (b). The wavelengths of {1530, 1540, 1550, 1560, 1570} nm are represented by {blue, red, green, magenta, cyan} colors, respectively.

5. Conclusion

This paper presented an analysis on the performance of the slope efficiency and responsivity of a R-EAM transceiver for different wavelengths, optical powers and bias points. The optimum operation point for UWB transmission was found to be the biasing for maximum slope efficiency, using an high optical input power, and a wavelength of 1560 nm. In this case, the minimum required electrical uplink gain $G_{E,UL}$ equals 6 dB. Furthermore, in the case of passive transceiver (zero bias), the optimum wavelength was found to be 1530 nm, the minimum required uplink gain being equal to 19 dB. It can be concluded that the analyzed R-EAM transceiver is an interesting device for UWB RoF networks, offering the possibility to operate passively.

6. Acknowledgment

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