Modelling Laser-Diode Non-linearity in a Radio-over-Fibre Link

G. Baghersalimi, V. Postoyalko, T.O'Farrell

School of Electronic and Electrical Engineering
University of Leeds
Leeds
LS2 9JT
eengba@leeds.ac.uk

Abstract**:** *In this paper, we investigate the AM/AM characteristics of a RoF link in the presence of laser-diode non-linearity. Based on theory, an analytical model of the laser-diode input/output function is developed. The parameters of the function are fitted by translating the parameters of a polynomial fitted to measured results. The analytical and measured results are compared and found to give very close agreement.*

1. Introduction

The continuing increase in customer demand for broadband applications coupled with mobile cellular and personal communications has become a global phenomenon. A key enabling technology supporting the provision of cellular communications is Radio-over-Fibre (RoF), alternatively known as Hybrid Fibre Radio (HFR). This technology combines two media: radio and optical. Typically, the optical part is used to interconnect a central radio processing facility with a remote radio antenna, the latter providing coverage to wireless broadband users. Some of the advantages offered by a RoF system include low signal attenuation (in the fibre), improved coverage and system performance, enhanced capacity, low RF power dissipation, reduced complexity due to the centralised processing of RF signals and ultimately low system costs [1,2].

However, the performance of RoF systems can be severely affected by non-linear effects in the transmission channel. In the RF part of a RoF system the main source of non-linearity is the power amplifier. There are two basic types of power amplifier, the travelling wave tube amplifier (TWTA) and the solid state power amplifier (SSPA). RoF and SSPAs tend to be used in mobile cellular communications infrastructure. While TWTAs tend to be used in high power applications such as satellite communications [3, 4]. In the optical part of a RoF system the main sources of non-linearity include the laser-diode light source, the optical fibre and the PIN photodetector. For short haul optical links the fibre non-linearity is usually small and can be neglected from system considerations.

In this paper, we investigate the AM/AM characteristics of a RoF link in the presence of laser-diode non-linearity. Based on theory, an analytical model of the laser-diode input/output function is developed. The parameters of the function are fitted by translating the parameters of a polynomial fitted to measured results. The analytical and measured results are compared and found to give very close agreement

2. Analysis

In [5] the authors experimentally measured the AM/AM and AM/PM characteristics of a RoF subsystem under microwave intensity modulation. The RoF subsystem consisted of a laser diode (LD), a one metre length of multimode fibre, and a PIN diode for the photodetector. A schematic of the experimental system used in [5] is reproduced in Figure 1.

The AM/AM curve which shown in Figure 2, illustrates that by increasing the input power from -20 to 0 dBm, the output power changes from -20 to approximately -2.8 dBm, corresponding to a maximum power attenuation of 2.8dB.

The overall signal attenuation is attributable to non-linear effects in all three optical components, i.e. the laser-diode, fibre cable and PIN diode. However, for laser transmission powers below 5mW, the non-linear effects of the PIN diode can be neglected. Furthermore, for short span RoF systems, as is the case considered in this paper, the non-linear effects of the fibre can be neglected too. Therefore, the main component contributing to the system non-linearity is the laser-diode

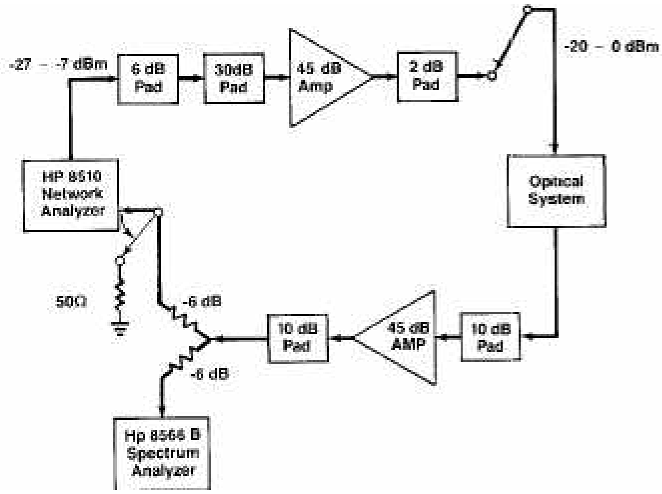

Figure1: RoF Experimental Set-Up

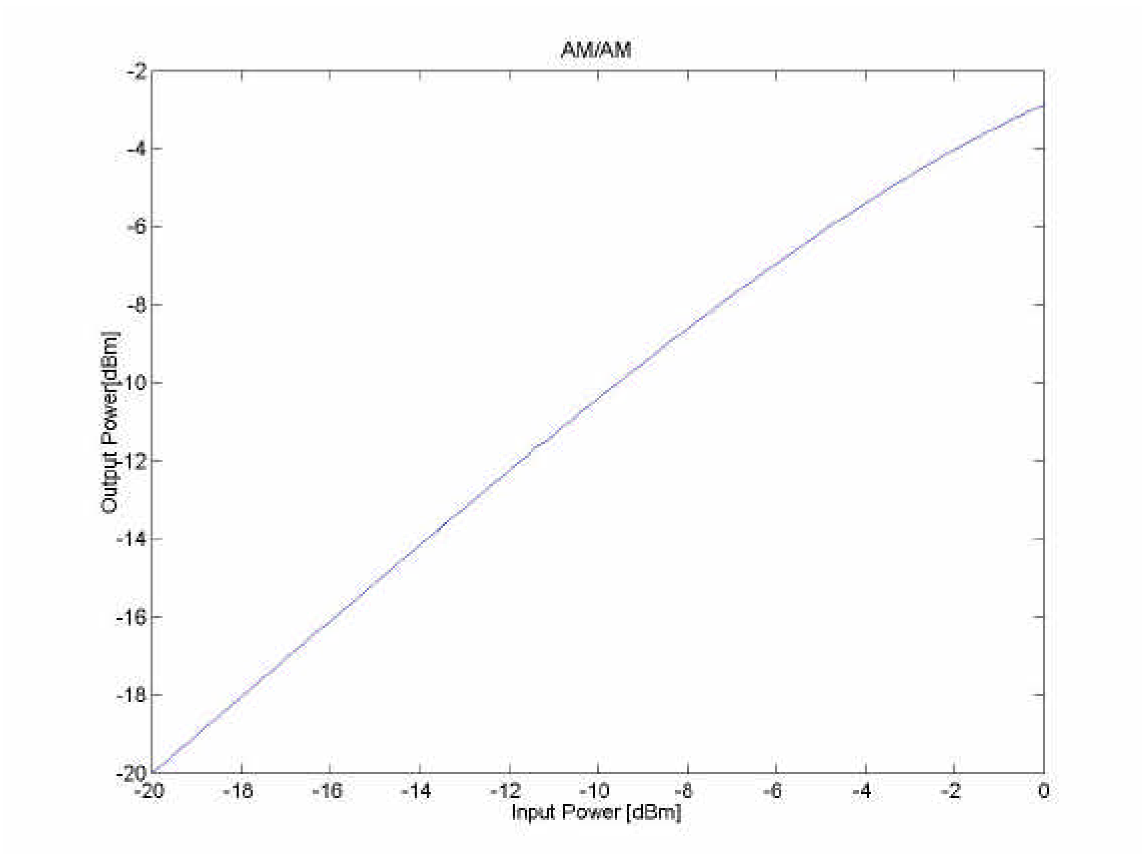

Figure 2: Measured AM/AM Characteristic of the RoF System Under Test

In general, a laser-diode exhibits a non-linear behaviour with memory which is called weak non-linearity. The Volterra series may be used to model the diode input/output characteristic. When the laser-diode is driven well above its threshold current, its input/output relationship can be modelled by a Volterra series of order 3 [2] . When the kernels of the Volterra series are taken as Dirac delta functions, then the system is modelled without memory. To simplify the analysis, a power series of order 3 can be used to adequately model the non-linear behaviour, because simple models can be used more readily for the analysis of wide-band systems such as OFDM as well as narrow-band systems [2, 4]. For an ideal linear characteristic, the laser-diode input/output relationship is given by (1) [2].

$$P_{opt}(t) = r(I(t) - I_{th}) \quad (1)$$

Where $I(t)$ is the input current of the microwave signal including the DC bias, I_{th} is the diode threshold current, r is the "P-I" slope (i.e. the gradient of the output optical power vs. input electrical current curve) and P_{opt} is the output optical power of the laser-diode.

For the non-linear case the input/output relationship is assumed to be given by (2), where the terms *a*, *b*, *c* and *d* are constants

$$P_{opt}(t) = a + b(I(t) - I_{th}) + c(I(t) - I_{th})^2 + d(I(t) - I_{th})^3 \quad (2)$$

For a bias current of 25.5 mA and a threshold current I_{th} of 19.5 mA [5], we can express the microwave input current as $I(t) - I_{th} = B\cos(4p\,10^9 t) + 0.006$ Amps., where *B* is the amplitude and the carrier frequency is 2 GHz. Then an expression for the instantaneous output electrical power is given by (3) assuming all other components have linear characteristics [2], where constant k_0 takes into account the cascaded gains and losses within the system.

$$P_{e,out}(t) = k_0 P_{opt}^2(t) \quad (3)$$

Now we consider the AM/AM characteristic of Figure 2. Using curve fitting techniques we can fit a polynomial of degree 3 as shown in (4)

$$p_y = 2.3\times10^5 p_x^3 - 670 p_x^2 + 0.95 p_x + 1.4\times10^{-6} \quad (4)$$

where p_x and p_y are the *average* input and output powers, respectively. In order to justify the existence of equation (2), the time average of equation (3) is determined over the photodiode response time $T = 0.5ns$, i.e. $\frac{1}{T}\int_T P_{e,out}(t)dt$. Then, equating coefficients of the resulting equation with those of equation (4) for corresponding powers of p_x gives the coefficient values shown in (5). In determining (5), an overall amplification in the electrical front-end of 19 dB (i.e. k_o) is assumed and $p_x = 25B^2$ (for a 50 Ohm termination) is used as in [5]. The coefficients in (5) are not unique.

[a b c d] = [-0.0045 0.32 147.05 -12033] (5)

Therefore, an expression for the final relationship between input current and output optical power of the laser-diode is shown in (6). Equation 6 is only valid for the power range over which measurements were taken i.e. -20 to 0 dBm.

$$P_{opt} = -0.0045 + 0.32(I(t) - I_{th}) + 147.05(I(t) - I_{th})^2 - 12033(I(t) - I_{th})^3 \quad (6)$$

3. Numerical results and Conclusions

Figure 2 shows a plot of input power versus output power comparing the measured and theoretical AM/AM characteristics where input power $p_x = 25B^2$ for $0.63\langle B\langle 6.3$ mA. The results show that the theoretical approach offers a very close match to the measured results demonstrating the validity of using a third order power series to model non-linearity in a laser diode.

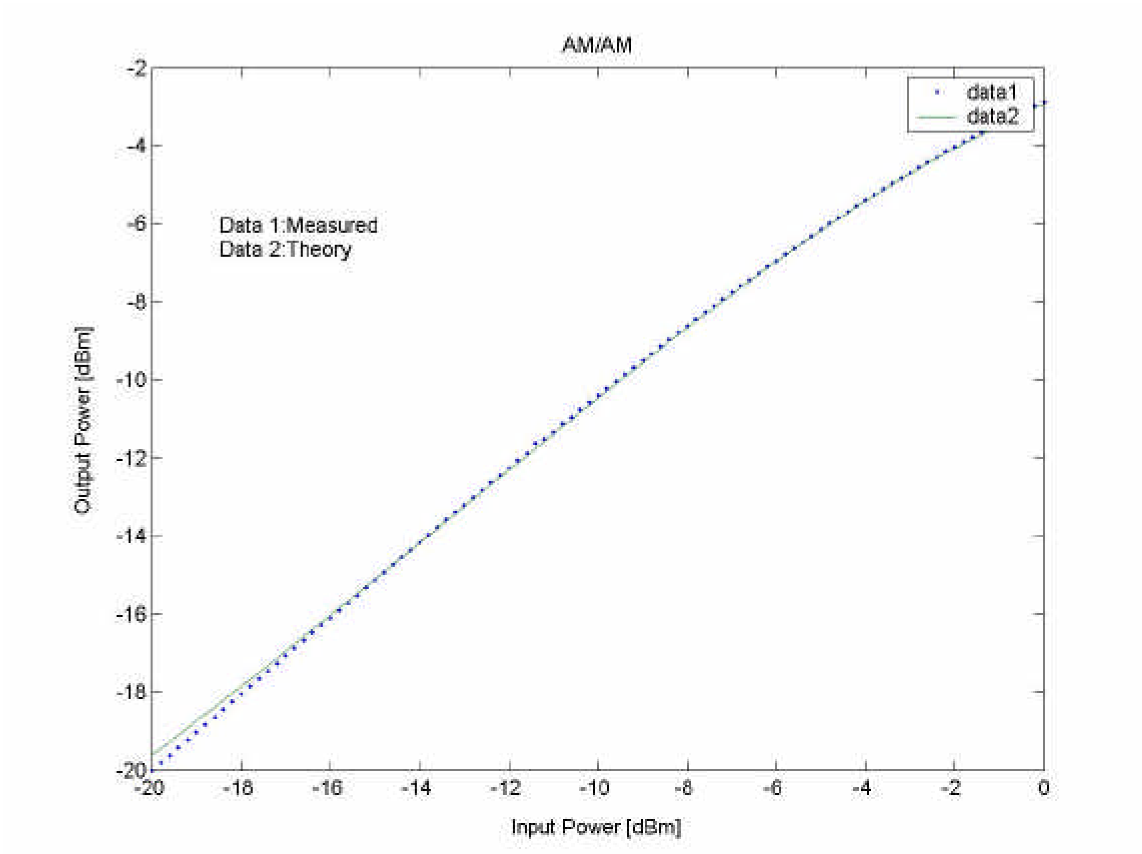

Figure 2: Measured and Theoretical AM/AM Characteristic of RoF System Under Test.

In this paper a mathematical model of a laser-diode's non-linear input/output relationship has been developed. The results show that a 3rd order power series adequately models the observed non-linear behaviour. This result may be used to investigate the impact of RoF non-linearity on the performance of wideband modulation schemes such as OFDM which is the topic of further investigation by the authors.

References

1. "Implementation Frameworks for Integrated Wireless-Optical Access Networks: Deliverable 4", EURESCOM Project P816-PF ,February 2000.
2. H. Al-Raweshidy and S. Komaki," Radio over Fiber Technologies for Mobile Communications Networks" Artech House,2002.
3. N. Hathi, M. Rodrigues, I. Darwazeh and J. O'Reilly," Performance Assessment of MC-CDMA and MC-DS-CDMA in the Presence of High Power Amplifier Non-linearities" IEEE Vehicular Technology Conference,vol.3 ,pp.1467-1471, Spring 2002.
4. Y. Guo and J.R. Cavallaro, "A Novel Adaptive Pre-Distortion Using LS Estimation of SSPA Non-linearity in the Mobile OFDM Systems " IEEE International Symposium on Circuits and Systems, Vol.3, pp.453-456, May 2002.
5. W. I. Way ,and A. Afrashteh, "Linearity Characterization of Connectorized Laser Diode Under Microwave Intensity Modulation by AM/AM and AM/PM Measurements", IEEE Microwave Symposium Digest(MTT-S '86).pp.659-662,1986.