Modeling of Mach-Zehnder and Electroabsorption Modulator Pulse Generators and Extraction of the Chirp Factor

Michael J. Connelly. Javier Romero-Vivas, Aidan Meehan and Lukasz Krzczanowicz

Optical Communications Research Group, Dept. Electronic and Computer Engineering, University of Limerick, Limerick, Ireland. E-mail: michael.connelly@ul.ie.

Abstract- The chirp factor of optical modulators is an important parameter that relates how the induced phase varies with the instantaneous power of a generated optical pulse, from which the dynamic chirp can be obtained. The two most common modulators are Lithium Niobate Mach-Zehnder and electroabsorption modulators. This paper describes simple models of the modulator response and uses a linear pulse characterization method to measure pulse intensity and phase. The experimental chirp measurements are used in conjunction with the models to determine modulator chirp factor.

I. INTRODUCTION

[*] Lithium Niobate Mach-Zehnder Modulators (MZMs) and Electroabsorption optical modulators (EAMs) are routinely used to generate optical pulses for use in optical transmission systems. Both modulators impose chirp on the generated pulses [1]. This chirp broadens the pulse spectrum and when the pulse train is uses to transmit data through optical fiber, it will consequently experience more dispersion than would be the case if there were no chirp. It is therefore important to model modulator power and phase response.

The normalized output optical power dependency on drive voltage V of an MZM is given by

$$P(V) = \cos^2\left(\frac{\pi V}{2V_\pi}\right) \tag{1}$$

, where V_π is the drive voltage required to induce a π phase shift in the drive arm of the MZM interferometer. The MZM (OptiLab IM-1550-20) is a low-chirp device with $V_\pi = 5V$. For an EAM, the output optical power depends on the drive voltage dependent insertion loss and input light polarization. The insertion loss characteristics of the EAM (CIP Photonics 10G-PS-EAM-1550 - optical sampling window generator) are shown in Fig. 1. (1) and Fig. 1 can be used to determine the instantaneous output power of the modulator for a given applied time-varying voltage.

[*] This research was supported by Science Foundation Ireland Investigator Grant 09/IN.1/I2641.

The frequency chirp $\Delta\nu(t)$ of both types of modulator can be described by

$$\Delta\nu(t) = \frac{\alpha}{4\pi\, p}\frac{dp}{dt} \tag{2}$$

, where α and p are the modulator chirp factor and instantaneous output optical power [1]. α is the derivative of the n' versus n'' curve, where n' and n'' are, respectively, the real and imaginary parts of the modal index of the modulator waveguide,

$$\alpha = \frac{dn'}{dn''} \tag{3}$$

If the generated pulse instantaneous power and chirp is measured, then it is possible to determine α using (2).

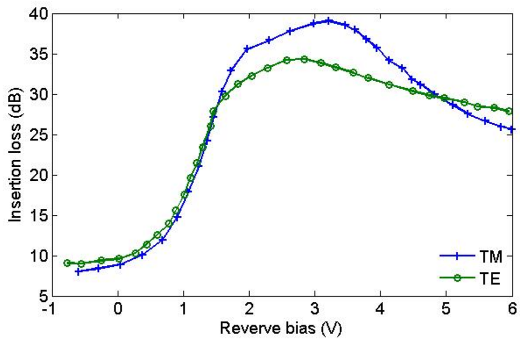

Fig. 1. Measured EAM insertion loss versus drive voltage.

II. EXPERIMENT AND SIMULATIONS

The MZM and EAM were driven by sinusoidal drive voltages of the form $V(t) = V_{bias} + V_m \cos(2\pi f_m t)$, with a DC bias, to generate optical pulses streams at repetition rates f_m of 20 and 10 GHz respectively. In order to determine the chirp factor, it is necessary to measure the instantaneous pulse phase $\phi(t)$. This was achieved by using a pulse characterization system in which the pulse temporal power and phase profile

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can be calculated by carrying out signal processing of a series of acquired pulse stream optical spectra, obtained by modulating the pulse stream with a second modulator driven by a time delayed sinusoid at half the clock frequency used to drive the modulator under test [2]. The chirp is then obtained as the time derivative of the phase divided by 2π. The chirp factor determined is by carrying out a fit between the measured and simulated chirp in the region where the normalized pulse power is greater 0.5.

Fig. 2 shows the MZM experimental and modeled pulse power and chirp for a 2.4 V amplitude sinusoidal drive voltage with a bias of 6.6 V. the amplitude and bias parameters were obtained by fitting (1) with the measured normalized power. These values were close to the measured values of 2.5 V and 7.2 V obtained at the modulator input. The experimental and theoretical pulsewidths are 17.7 and 20.0 ps respectively. The peaks in the chirp plot are caused by a phase reversal effect that occurs when the modulation voltage approaches and then departs from the transmission response minima. The extracted chirp factor is 0.065. The modulator chirp factor is specified to be less than 0.1, which is confirmed by our experimental and simulation results. The pulse power spectrum as shown in Fig. 3(a) can be determined by applying a fast Fourier transform to the complex time domain pulse signal $p(t)\exp[j\phi(t)]$, from which the Time-Bandwidth Product (TBP) can be determined. For the MZM, the measured and simulated TBPs are 0.56 and 0.53 respectively.

Fig. 4 shows the EAM experimental and modeled pulse power and chirp for a 0.6 V amplitude sinusoidal drive voltage with a bias of 1.0 V. The input signal is TE polarized. These voltage values were obtained by fitting the EAM sinusoidal normalized response to the measured normalized power. The experimental and simulated pulsewidths are 40.0 and 39.4 ps respectively. As is the case for the MZM, the peaks in the chirp plot are caused by a similar phase reversal. The extracted chirp factor is 2.2. The pulse power spectrum is shown in Fig. 3(b) and the measured and simulated TBPs are 0.63 and 0.68 respectively.

III. CONCLUSION

Simple models of the chirp of two types of optical modulator have been described, which show good agreement between simulation and experiment. Suitable fitting of the model to experiment allow determination of the modulator chirp factor. Future work will investigate the dependency of the chirp factor on modulator operating conditions such as bias and input signal polarization.

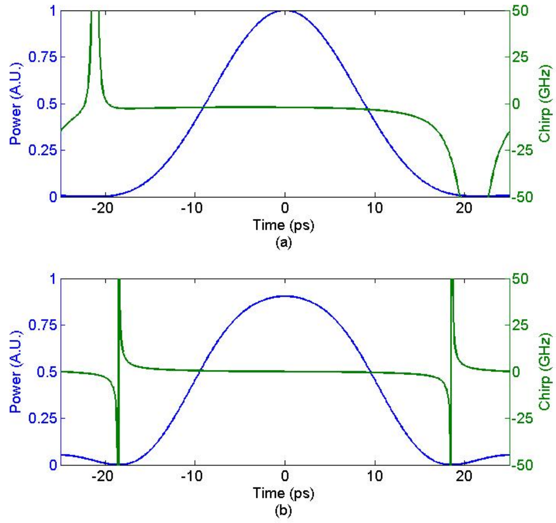

Fig. 2. MZM (a) experimental and (b) simulated pulse power and chirp.

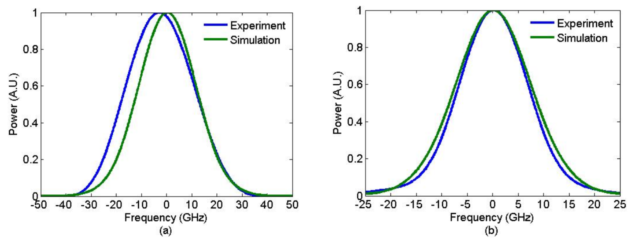

Fig. 3. (a) MZM and (b) EAM experimental and simulated pulse power spectrum.

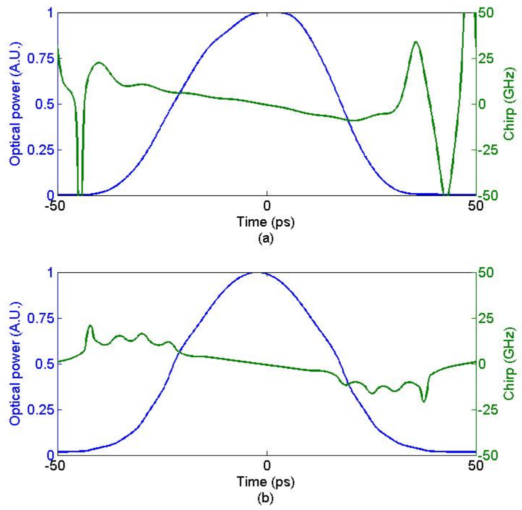

Fig. 4. EAM (a) experimental and (b) simulated pulse power and chirp

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