OPTICAL SAMPLING WITH FAST ELECTRO-OPTIC MODULATORS

Jean-Pierre von der Weid*, Marc Niklès, Luc Thévenaz and Phillipe Robert
EPFL, Swiss Federal Institute of Technology, Metrology Lab
1015 Lausanne, Switzerland
Jean-Paul Pellaux
Group of Applied Physics, University of Geneva
1211 Geneva 4, Switzerland

Abstract

A simple system for optical and microwave signal analysis developed based on the optical sampling technique. The system was a commercial Lithium Niobate travelling wave Electro-optical modulator as an optical gate. The ultimate performance of the system was analysed and a comparison with a conventional detection system was also made.

1. Introduction

High speed optical waveguide switches and modulators are important components for present and future applications in coherent lightwave communication systems(1)and instrumentation(2)(3) . Several configurations and materials have been employed seeking for larger bandwidths, the Gallium Arsenide and Lithium Niobate being the most employed electro-optic materials(4)(5) . Presently, Lithium Niobate Travelling wave modulators have been reported with modulation bandwidths in excess of 40 GHz.(6)(7) At these frequencies, bandwidth measurements are frequently limited by the finite speed of the photodetector and amplifier. Results are usually obtained by a deconvolution calculus involving the detector and amplifier response curves.

A number of different techniques have been proposed to overcome the problem of finite detector risetime in fast optical waveform analysis. These techniques are usually referred to as optical sampling as they make use of a short optical pulse as a probe sampler. The first reported optical sampling technique employed a sinchronously pumped dye laser producing 5 ps pulses at $\lambda = 600$ nm to analyse a Ti-diffused Lithium Niobate waveguide modulator(8). Other optical sampling techniques include the use of nonlinear optical mixing by up-conversion of the optical waveform with short optical pulses from mode-locked or gain switched laser diodes(9)(10) , or the use of the Kerr effect induced by short high power pulses from Nd:YaG Lasers(11). All these techniques involve either the use of high power lasers or non-linear optical components and discrete optics, restricting its applications to research laboratories.

In the last few years, the fabrication tecnology of Lithium Niobate Electro-Optic modulators and switches has been considerably improved. Devices with modulation bandwidths in the Gigahertz range are now commercially available in pigtailed presentation. Characterization techniques and applications are now being developed and the forecast of future applications seem to indicate that the cost of such devices may soon be dramatically reduced by large scale fabrication factors.

In this paper we report applications of high speed electro-optic modulators/switches to either optical or microwave signal analysis using the optical sampling technique. As it will be shown; no discrete optical components or high power lasers are needed. The technique makes use of comercially available devices, is easy to handle and the requirements for eletronic signal analysis involve low frequency detectors and amplifiers.

Optical sampling

Consider an optical system consisting of an optical source, connected to a photodiode detector via an electro-optic intensity modulator. If the optical source emits an arbitrary, but periodic, waveform with a repetition rate f_0, the time dependent optical signal launched into the electro-optic modulator can be described by its Fourier series:

$$P_{\mathrm{in}}(t) = \sum_j P_j \cos 2\pi j f_0 t \tag{1}$$

when P_j is the optical power in the j'$^{\mathrm{th}}$ harmonic of the fundamental frequency f_0.

Consider now that the electro-optic modulator is also driven by a periodic electric signal, whose repetition rate is f_m. Whichever the DC bias voltage is, the time dependent power transfer function of the modulator can also be described by its Fourier series.

$$H(t) = \sum_\ell h_\ell \cos 2\pi \ell f_m t \tag{2}$$

therefore, the optical signal output from the electro optic modulator, which is the product of the input power by the transfer function, will be given by.

$$P_{\mathrm{out}}(t) = \sum_{j,\ell} P_j h_\ell \cos 2\pi j f_0 t \cos 2\pi \ell f_m t \tag{3}$$

By using the trigonometric relations, we can write (3) as

$$P_{\mathrm{out}}(t) = \frac{1}{2} \sum_{j,\ell} P_j h_\ell [\cos 2\pi (j f_0 + \ell f_m)\, t + \cos 2\pi (j f_0 - \ell f_m) t] \tag{4}$$

If the bandwidth of the detector is much smaller than the frequencies f_0 or f_m, the high frequency components of eq.(4) will be completely averaged out, and only low frequency components will dominate the time dependent detected signal output:

$$S = S_0 + \frac{1}{2} \sum_{j,\ell} P_j H_\ell \cos 2\pi (j f_0 - \ell f_m)\, t \tag{5}$$

In the optical sampling technique, we are interested in the time dependent part of eq.5, when either the optical light signal or the modulation function can be approximated by an impulse function. For instance, when the light source emitted signal is an optical pulse whose duration is much smaller than its repetion time f_0^{-1}, all coefficients P_j in eq.(5) are close to unity. Conversely, if the modulation function $H(t)$ is a very short impulse compared to its repetition time, the coefficients h_ℓ are all close to unity. In the simplest case, consider a periodic optical signal being analysed by a short electro-optic gate. By using a driving frequency f_m close to the optical signal repetition rate f_0, only the terms for $j = \ell$ will fall within the detector bandwidth, and the AC part of the detected signal will be given by

$$S(t) = h \sum P_j \cos 2\pi j (f_0 - f_m)\, t \tag{6}$$

where h is arbitrary constant which includes the detector sensitivity, the electro-optic attenuation, etc. Equation (6) means that the detected signal will reproduce the optical signal with its frequency scale down-shifted from its initial value f_0 to the beat frequency $(f_0 - f_m)$ of the optical and modulator signals.

With this principle, the analysis of a periodic optical signal can be easily done by driving an electro-optic modulator with an impulse train whose repetition rate is close enough to the optical signal repetition rate so that all the relevant harmonics of the fundamental beat frequency are smaller than the detector bandwidth, in order to avoid distortion of the down-shifted signal.

Optical gate characterization

The electro-optic modulator used in our experiment was a commercial $LiNbO_3$ travelling wave modulator pigtailed with polarization maintaining single mode fibres. When biased in a linear region, the device acts as a light modulator with a linear response, provided that the amplitude of the driving modulation signal is small enough. If the device is to be used as an optical gate at this bias voltage, it must be driven by fast electric pulses of amplitude not greater than ~1 V. In this case the bandwidth of the optical gate will be limited by the time response of the electrodes. In our experiment, this time response was measured by comparison of the input/output electric pulses, both measured with a sampling oscilloscope with a 25 ps risetime sampling head. This limitation may be overcome by using a bias voltage which places the device in a minimum (or maximum) of its transfer function. In this case the non-linear response will shorten the optical gate with respect to the electrical pulse, giving a superior performance. Furthermore the modulation depth will be much larger than the one allowed in the linear bias, the only restriction being the saturation behaviour which arises when the driving electric pulse beings the device beyond the linear region

The experimental set-up used to measure the characteristic response of the electro-optic gate is shown in figure 1. A 10 MHz master clock was used to drive two RF generators at frequencies f and $f + f\Delta$. The frequency f was chosen to be either 100 MHz, 250 MHz or 500 MHz, depending on the comb generators used. The beat frequency Δf was correspondingly chosen to be 100 Hz or 500 Hz. Therefore, the beat frequency was always 10^6 times smaller than the original RF frequency. One of the generators was used to drive $\sim$ 8 V, 200 ps risetime electric pulses on a $1.3\mu m$ semiconductor laser, which operated in gain switched condition. The 50 ps laser pulses were launched on the electro-optic device pigtail after passing through a set of polarization control fibre loops in order to match the input polarization with the optimum conditions of the device.

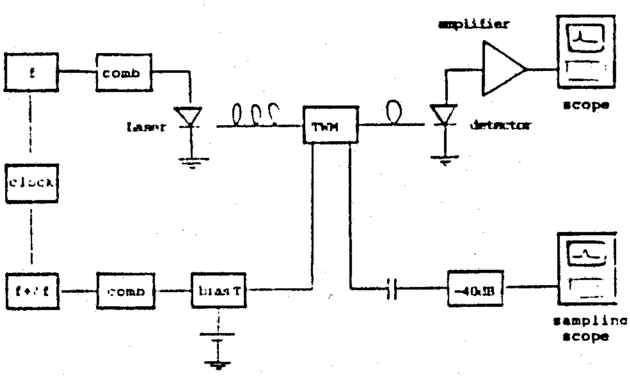

Figure 1 – Experimental set-up

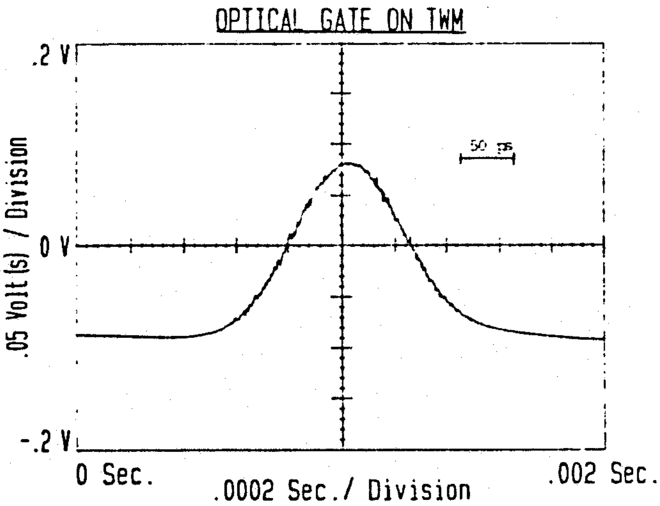

Figure 2 – Optical gate measured at the down-shifted frequency

The second RF generator was used to drive 6 V, 75 ps electric pulses on the electro-optic modulator electrodes. The pulses were then attenuated and measured with the sampling scope. The bias tee was used to adjust the operating conditions of the E/O device. The output signal was connected to an InGaAs pin photodiode followed by a high gain operational amplifier. By changing the feedback resistance, the gain and bandwidth of the detecting system was controled so that the low frequency electronics never introduced signal distortion.

In this configuration, the short optical pulses were used to probe the transfer function of the electro optic modulator, so that it could be completely characterized in time domain. Figure 2 shows the impulse response of the electro-optic modulator as measured with the set-up described above. The expected gatewidth calculated from the electrical pulse shape and the dc transfer function should be 100 ps, while the measured width is 112 ps. This difference arises from the finite width of the optical pulse used to probe the E/O device. Comparison of the measured and calculated gatewidth allows an estimation of the optical pulse width to be close to 50 ps, as previously mentioned.

Optical and microwave signal analysis

An arbitrary optical signal waveform can be analysed by the electro-optic sample by adjusting the sampling frequency close to the unknown frequency, looking the detected signal at the low frequency oscilloscope. Knowledge of the beat frequency as well as the optical gate repetition rate allows the calibration of the unknown signal frequency and also the frequency shift factor.

Figure 3 shows the application of the optical sampling technique to the waveform analysis of an optical signal from a $1.55\mu m$ semiconductor laser compared to the same waveform directly detectly detected by a fast photodiode and amplifeir (300 MHz bandwidth), showing a better signal to noise ratio as well as a much larger bandwidth capability.

The optical sampling technique can also be used to analyse fast electric signals provided they have their peak-to-peak value samll enough to operate the electro-optic modulator in the linear regime. Figure 4 shows the comparison of the optically sampled signal as compared to the electrically sampled detection. The electric detection used a sampling oscilloscope with a 25 ps risetime sampling head, whereas the optical pulse used as gate sample had $\sim$ 50 ps risetime. The agreement between the two signals is remarkable, but in this case the system is limited by the 200 ps risetime of the electro-optic device electrodes.

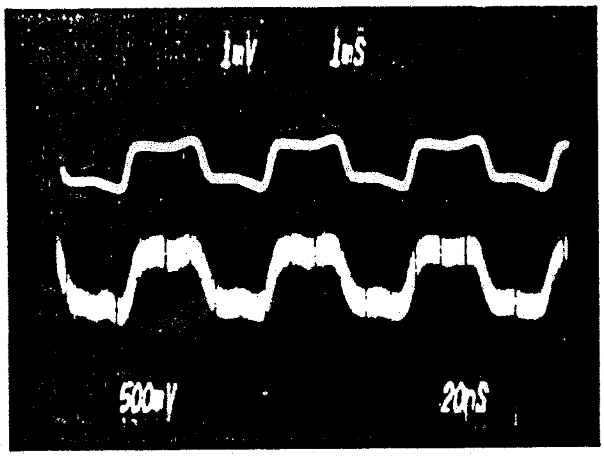

Figure 3 – Comparison between optical sampling and conventional detection

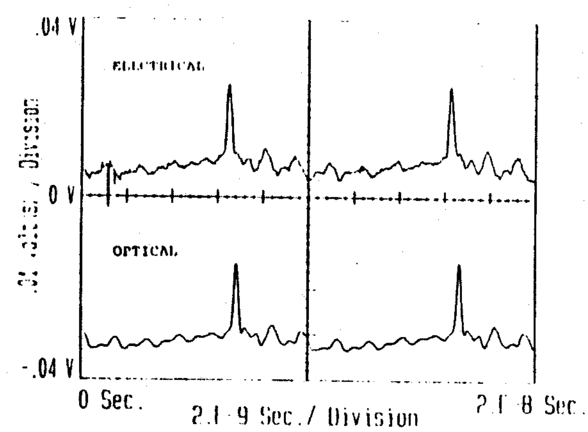

Figure 4 – Comparison between optical and electrical sampling

Conclusions

Optical sampling with electro optic modulators appears to be very promising technique not only for optical signal analysis but also for microwave analysis. One of the most critical problems which must still be controled is the need of polarization control of the optical input signal. However new electro-optic components are now coming up into the market, which can easily do this job. On the other hand, faster E/O devices are being developed, so that limiting bandwidths as high as 40 GHz can be foreseen in a near future. In this care the limiting feature may be the generation of the short electric pulses.

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* - Present address: CETUC, Pontifícia Universidade Católica do Rio de Janeiro, C.P. 38071, 22452 Rio de Janeiro RJ, Brasil