Amplitude and Phase Measurements of Optical Signals using a Coherent Technique

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Abstract- **A measurement method to extract amplitude and phase information of an optical signal using an optical 90° hybrid and a real-time oscilloscope is presented. A local oscillator is mixed with the signal as a reference to extract the phase information. The measurement technique is suitable for characterising optical components and the extraction of the chirp parameter for a Mach-Zehnder Modulator (MZM) using the coherent detection is presented.**

I. Introduction

Coherent techniques can be used to extract amplitude and phase information of optical signals [1]. A local oscillator is mixed with a signal as a reference in an optical 90 ° hybrid to provide the in-phase (*I*) and quadrature (*Q*) components of the signal. The coherent measurement technique and the characterisation of the 90 ° hybrid are presented below.

As an application of the investigated measurement technique we characterised the alpha parameter, α_c, of a Mach-Zehnder Modulator (MZM). Frequency chirping originates in MZMs that produce a phase shift as the intensity is varied. Controlled frequency chirping of $LiNbO_3$ MZMs can mitigate transmission pulse broadening and minimise the dispersion penalty. The transmission distance can therefore be extended without dispersion compensation. The chirp parameter is therefore a key element to be characterised for MZMs as it directly influences the performance of transmission systems.

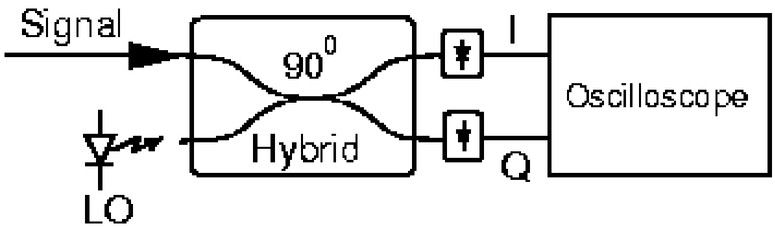

Figure 1. Measurement system layout to measure amplitude and phase of the optical signal

II. The Measurement System

The experimental setup to measure the amplitude and phase of an optical signal is shown in Fig. 1. A local oscillator is mixed with the signal to be measured in an optical 90° hybrid to give the in-phase (*I*) and quadrature (*Q*) components of the optical signal. The detected signals are then sampled by a real-time oscilloscope and are given as

$$I \propto \mathrm{Re}\{E_s \cdot E_{LO}^*\} \quad (1)$$

$$Q \propto \mathrm{Im}\{E_s \cdot E_{LO}^*\} \quad (2)$$

The two components in (1) and (2) can then be used to reconstruct the complex electric field E as follows:

$$E \propto I + jQ = \sqrt{I^2 + Q^2}\, e^{j \arctan(\frac{Q}{I})} \qquad (3)$$

III. Characterisation of the 90^o hybrid

The hybrid shown in Fig. 1 is a key component in the receiver and its characterisation is of essential importance to ensure optimum performance in the measurement setup. Also of importance in the coherent receiver is the propagation delay between the *I*- and the *Q*-channels which includes, for instance, the contribution of different electrical path lengths of the sampled data. Once characterised, the propagation delay and the nonorthogonality can be digitally compensated from the sampled data. Two external cavity lasers (ECLs) with linewidths less than 100 kHz were used and the optical signals were launched into the signal and the LO input ports of the hybrid shown in Fig. 1. The optical frequency of the LO was then tuned to vary the intermediate frequency (IF) between the two lasers. Using FFT, we then extracted the phase of the IF signals at the different frequencies. The propagation delay and the orthogonality of the hybrid were then extracted from a least-squares fit to the measured data and were found to be 58 ps and 91^o, respectively, in our measurement setup. The characterisation technique described above provides the propagation delay in addition to the orthogonality between the *I*- and the *Q*-channels in one measurement setup.

IV. Measurement of chirp parameter

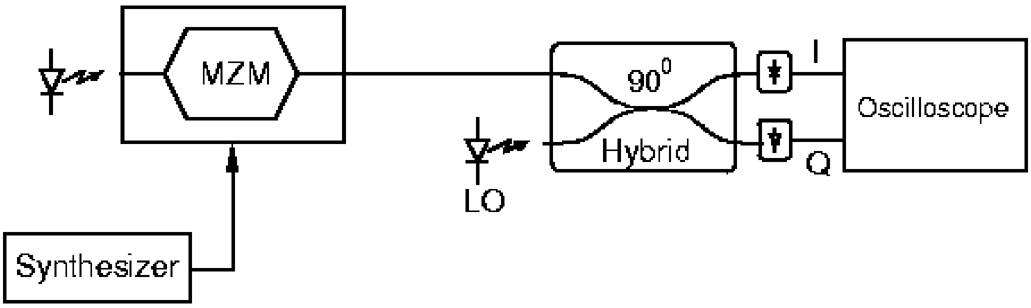

Figure 2. Measurement system layout for measuring the chirp parameter

The experimental setup to measure the amplitude and phase information of the optical signal at the output of the MZM is shown in Fig. 2. A synthesizer was used to drive the MZM biased at the quadrature point with the sinusoidal signal

$$V(t) = V_m \sin(2\pi f t) \qquad (4)$$

where V_m is the driving amplitude and f is the modulation frequency set to 1 GHz. The 90^o hybrid at the receiver side mixed the optical signal with a LO as a reference before the in-phase (I) and quadrature (Q) components were detected and sampled at 20 GSamples/s with a real-time oscilloscope. External cavity lasers were used as the transmit laser and the LO in the experimental setup shown in Fig. 2 for measuring the chirp parameter. At the output of the 90° hybrid, the interference of the two optical fields produces beatings in the optical power and, hence, shifts the spectrum into the low frequency domain in a heterodyne detection scheme [2].

The chirp parameter, the ratio of phase modulation to amplitude modulation, is expressed as

$$\alpha_c = 2P \frac{\frac{d\phi}{dt}}{\frac{dP}{dt}} \qquad (5)$$

where ϕ and P ($\propto |E|^2$) are, respectively, the instantaneous phase and power of the modulated signal. Measurements were performed on a tunable chirp MZM. The modulator had 3 different electrodes for the chirp control, bias setting and the RF input. The chirp of the device under test can be tuned by controlling a DC voltage. The chirp voltage was varied from -8 V to 8 V and the biased point was adjusted at quadrature for each chirp measurement. A synthesizer was used to drive the modulator with a 1 GHz sinusoidal signal. Imperfection in the hybrid was corrected as described in Section III.

The measured optical power and phase of the modulated signal are shown in Fig. 3 for a chirp voltage set to 4 V. The chirp parameter can then be calculated using (5). The variation of the chirp parameter at different voltage settings was investigated for the tunable MZM. As shown in Fig. 4, the extraction technique also gave the sign of the chirp parameter which is of importance to counteract chromatic dispersion in a transmission system. Also shown in Fig. 4 is the extinction ratio of the MZM measured for the different chirp settings.

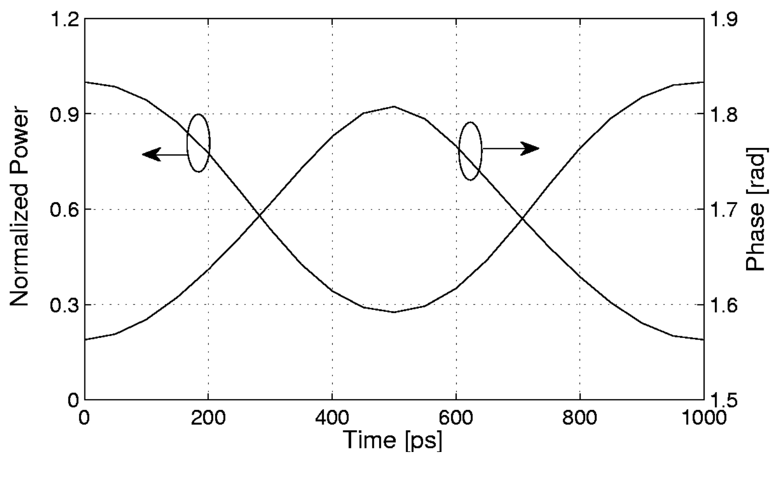

Figure 3. Measured optical power and phase for a MZM.

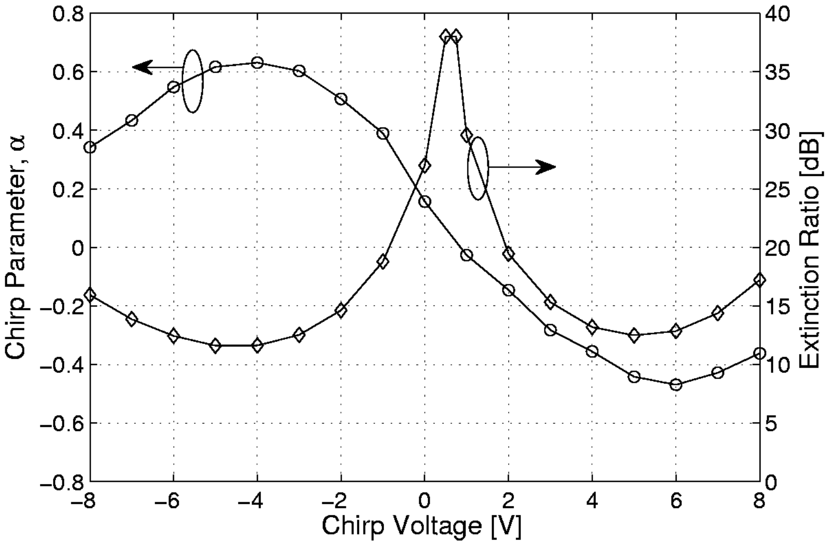

Figure 4. Variation of the chirp parameter, α_c, for different voltage settings.

V. Conclusion

A measurement method to extract amplitude and phase information of an optical signal using an optical 90° hybrid and a real-time oscilloscope has been presented. As an application of the measurement method, the chirp parameter of a tunable MZM has been extracted for different voltage settings.

Acknowledgement

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References

[1] S. Betti, G. D. Marchis, and E. Iannone, *Coherent Optical Communications Systems*, Wiley Blackwell, 1995.

[2] D. Derickson, *Fiber Optic Test and Measurement*. Englewood Cliffs, NJ: Prentice-Hall, 1998.