

Method for measuring frequency chirping in external Mach-Zehnder modulators

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We propose a new simple and direct method for measuring the frequency chirping of Mach-Zehnder modulators. The interest of the method lies in the low optical and microwave powers that are required for the experiments.

Keywords: chirp measurement, Mach-Zehnder, modulation, spectral density

Introduction

Knowledge of the chirp parameter α of Mach-Zehnder modulators is essential to account for the propagation of short pulses in fibres. Several indirect [1,2,3] techniques have been suggested to determine the chirp. More direct evaluations [4] have also been proposed to extract the chirp parameter from the output density spectrum. All these experiments require several manipulations, or high optical power and driving voltage. We propose a new method to allow for the measurement of the chirp parameter at very low optical and microwave powers. This method consists in directly evaluating the sidebands amplitude in the output spectrum for two cases of bias. Part I describes the relationships that yield the determination of the chirp parameter α , and part II illustrates the method with experimental results.

Experimental setup and theory

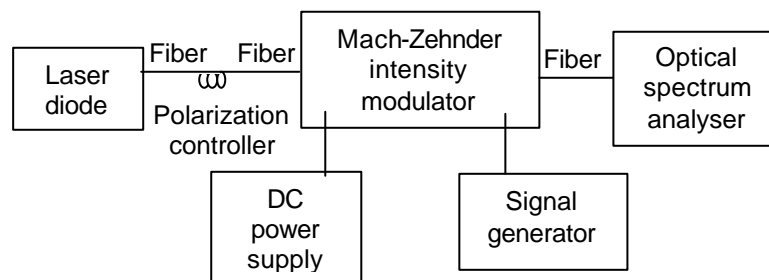


Figure 1 : Setup used to measure the chirp parameter of a Mach-Zehnder external modulator

The experimental setup for measuring α is shown in figure 1. A polarized $1.55\mu\text{m}$ light is launched at the input of a Mach Zehnder modulator. An adjustable continuous bias : $\Delta\phi_{\text{DC}}$ is imposed between the two optical channels of the Mach-Zehnder modulator by means of a DC power supply. A high frequency sinusoidal voltage : $V(t)=V_0\cdot\cos(2\pi ft)$ is applied to the transmission lines of the modulator, in order to generate a sinusoidal difference of phase $\Delta\phi(t)$

between the two arms of the modulator. V_0 is the amplitude of the applied voltage, and f is the modulation frequency. The spectral density of the output optical field is measured by the help of a scanning Fabry Perot used as an optical spectrum analyser. This output optical field can be described as :

$$\underline{E}(t) = E_0 \cdot e^{j\omega_0 t} \cdot e^{j\varphi(t)} \cos\left(\frac{\Delta\varphi(t)}{2} + \frac{\Delta\varphi_{DC}}{2}\right) \quad (2)$$

where ω_0 is the pulsation of the optical wave, and E_0 is the amplitude of the optical field.

The chirp parameter of Mach-Zehnder modulators is strongly dependant on $\varphi(t)$ and $\Delta\varphi(t)$. In fact, at small signal regime and quadrature bias, the output intensity is linear with $\Delta\varphi(t)$. So the general expression of the chirp parameter [5] can be simplified to :

$$\alpha = \mp \frac{\varphi(t)}{\Delta\varphi(t)/2} \quad (3)$$

This expression leads to $\alpha = \Phi/(\Delta\Phi/2)$ in case of a sinusoidal modulation, where Φ and $\Delta\Phi$ are the magnitude of $\varphi(t)$ and $\Delta\varphi(t)$ respectively.

The presented method aims at determining the above parameter (3), by evaluating the output spectrum for two different bias. In case where $\Delta\varphi_{DC}=0$, the output density evaluated from (2) is :

$$I_0(f) = E_0^2 \cdot \delta(\omega_0) + \frac{E_0^2}{2} \cdot \Phi^2 \cdot \delta(\omega_0 - f) + \frac{E_0^2}{2} \cdot \Phi^2 \cdot \delta(\omega_0 + f) \quad (4)$$

Let us now consider the case where $\Delta\varphi_{DC}=\pi$. The output density spectrum becomes :

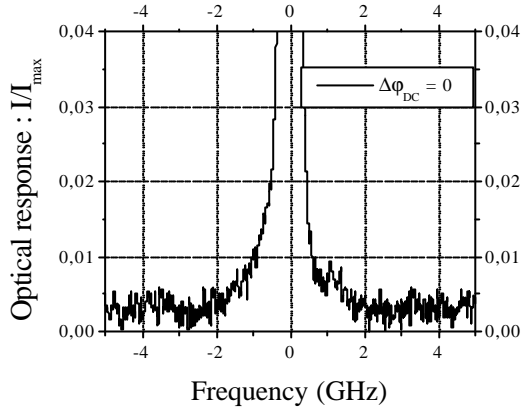
$$I_0(f) = \frac{E_0^2}{2} \cdot \left(\frac{\Delta\Phi}{2}\right)^2 \cdot \delta(\omega_0 - f) + \frac{E_0^2}{2} \cdot \left(\frac{\Delta\Phi}{2}\right)^2 \cdot \delta(\omega_0 + f) \quad (5)$$

The method for evaluating the chirp parameter $|\alpha|$ can be summed up by two steps : at first, the 0-bias is set by monitoring the power supply so that the central intensity is maximal, which corresponds also to the minimum of the first harmonic peak. The measurement of the first sideband magnitude is then followed with the same measurement at π -bias, which is characterised by the maximum of the first order peak. The ratio of these two evaluations is the square of α .

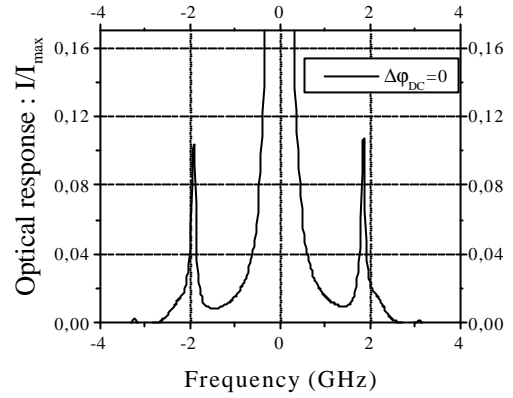
Examples of application

We performed the measurements as specified above with two kinds of LiNbO₃ Mach-Zehnder modulators. The microwave power was set to 15dBm, so that the magnitude of second side band was negligible. The free spectral range of the scanning Fabry Perot was 10GHz, which allowed measurements from 500MHz to 4GHz.

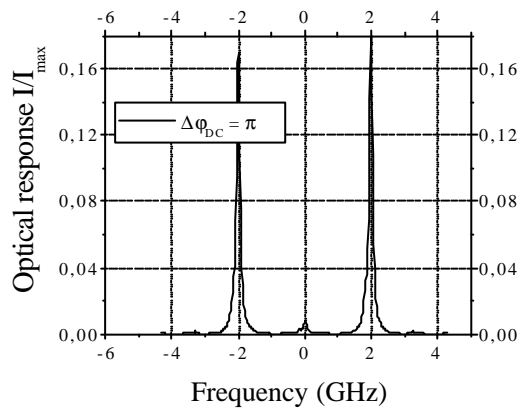
The line spectrum of the modulators are shown in fig.2, for a 2GHz modulation frequency : figure 2 a) and b) represent the normalized optical response for a 0 bias, while figure 2 b) and 2c) are relative to the optical response for a π bias. The optical power was kept the same for both spectra ($P=0.2mW$), so that the magnitudes inherent to each case of bias could be compared. Two kinds of modulators were successively tested. Figures 2b) and 2d) show the experimental result corresponding to a Z-cut modulator, which chirp parameter was known to be 0.80. The line spectrum associated to a X-cut LiNbO₃ modulator are depicted in figures 2a) and 2c).



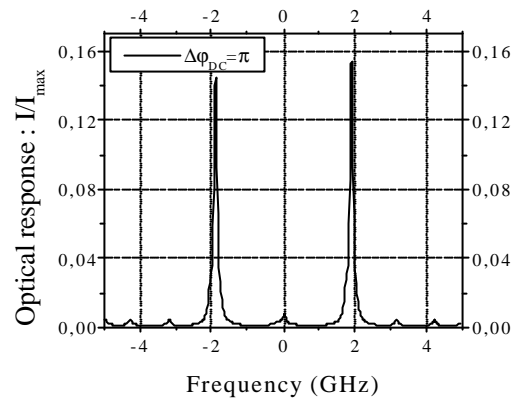
a) X-cut, $\Delta\phi_{DC}=0$



b) Z-cut, $\Delta\phi_{DC}=0$



c) X-cut, $\Delta\phi_{DC}=\pi$



d) Z-cut, $\Delta\phi_{DC}=\pi$

Figure 2 : Optical spectrum lightwave from modulator;
Amplitude of applied RF electric signal = 2 V, Frequency of applied rf electric signal = 2GHz

The α parameter of the Z-cut modulator is evaluated from the magnitude of first sideband, as previously described, and shows out to be 0.83, which is in good agreement with the 0.80 predictions. The same method was applied for a symmetric X-cut modulator, which has theoretically a zero-chirp parameter due to its symmetric structure. The very low amplitude of first sideband at 0-bias confirmed this theoretical prediction. Figure 3 shows the evolution of α with frequency for the two modulators tested. The dashed line stands for the α parameter of the Z-cut LiNbO₃ standard modulator, while solid line stand for the α parameter of a X-cut LiNbO₃ modulator. It can be seen from the figure that α is poorly dependant on f.

It should be emphasized that the above manipulation can also yield the evaluation of other main characteristics of modulation. In fact, the ratio between the central intensity at 0-bias and the central intensity at π -bias corresponds to the extinction ratio R: (R=20,6dB in case of the Z-cut modulator); Φ and $\Delta\Phi$ can be easily extracted from the relative strength of first sideband; and the knowledge of Φ , $\Delta\Phi$ and V_0 enables the determination of variation of phase per volt (η_1 , η_2) for

each arm of the Mach-Zehnder modulator : $\eta_1 = \frac{\Delta\Phi + \Phi}{2V_0}$ for one of the optical channel, and $\eta_2 = \frac{-\Delta\Phi + \Phi}{2V_0}$ for the other optical channel.

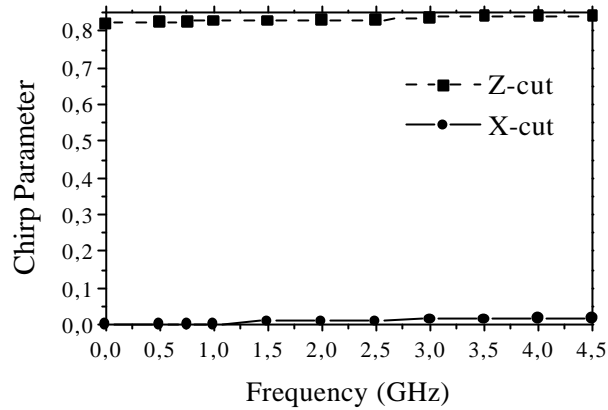


Figure 3 : Experimental evolution of α with frequency.

Conclusion

Two simple measurements with an optical spectrum analyser can yield the determination of the α parameter of Mach Zehnder modulators, with drive voltage lower than 5V, and very low optical power. In addition to the simplicity of equations and manipulation, another advantage of the experimental setup is its ability to account for the dependance of α on frequency. Finally, the proposed technique enables the evaluation of other main characteristics of the modulator, such as extinction ration, modulation depth and overlap electric/optical field coefficients.

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