High frequency electric signal sensor using an optical modulator

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Abstract: - This work describes an experimental system for sensing and transmission of electric signals using optical coherence modulation of light. The system consists of a Ti:LiNbO$_3$ *optical coherence modulator acting as electric signal sensor. The main characteristics of coherence-modulated transmissions include the need of using broad-band optical sources and integrated optics lithium niobate electro-optic retarders. Coherence-modulated systems have been studied for the last few years as new potential high-speed optical links useful for local area networks, point-to-point, and bidirectional transmissions, at optical wavelengths around 1300 nm and 1550 nm.*

Key-Words: - Electro-optic, optical modulator, coherence modulation, electric signal sensing, optical delays.

1 Introduction

Coherence modulation of light is actually an interesting alternative among the existing different techniques for optical telecommunications. This technique is based on the modulation of optical delays greater than the coherence length of the optical source. Optical delays can be used as information carriers if a dynamic signal can be imprinted around the static optical delay. This technique has been reported in the area of fiber sensors, and optical telecommunications using series and parallel configurations [1]-[3]. Modulation using optical delays as information carriers is currently known as coherence modulation. Electric field sensors using a Ti:LiNbO$_3$ integrated optics have been studied for more than five years due to a large electrooptic. A typical modulator for sensing applications is Mach-Zehnder interferometric intensity modulator. A mostly configuration based on Mach-Zehnder has been reported [4]-[7]. One-channel coherence-modulated sensor array for sensing of low frequency electric signals was reported at the IMTC´01 [8]. This work describes a novel system for sensing high frequency electric signals using Ti:LiNbO$_3$ coherence modulators as sensor. The system proposed here represents a very interesting alternative measurement technique to the typical intensity Mach-Zehnder sensors. In addition coherence modulation system is attractive for implementing serial coherence multiplexed sensors arrays. We report an experimental setup for sensing electric signals using electrooptic coherence modulator as sensor. The block diagram of a coherence-modulated sensing system is shown in figure 1.

2 Electric signals detecting system

A novel application of optical coherence modulation can be applied to sensing electric signals, using an electro-optical coherence modulator.

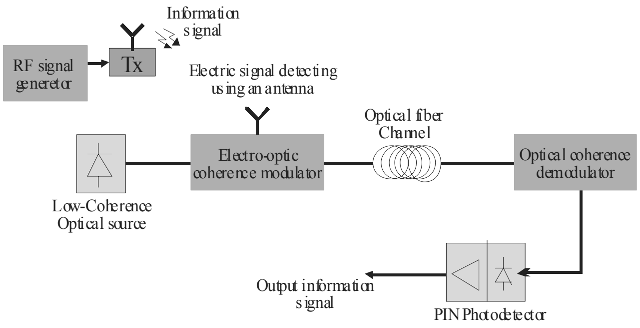

Fig. 1. Coherence-modulated system for detection-transmission electric signals.

From figure 1, the light from the low-coherence optical source is launched into an optical retarder who introduces an optical delay when acting as a two-wave interferometer. At the output of these devices, delayed light wave packets are transmitted through an optical fiber channel. At the receiver end, light is demodulated using a second two-wave interferometer (e.g., Michelson, imbalanced Mach-Zehnder, etc.), which measures the autocorrelation of the received light. At the output of the optical demodulator, a fringe pattern is obtained and detected as light intensity by a standard photodetector. At the transmitter (sensor), electric signals around 915 MHz, can modulate optical delays are transmitted to the receiver through optical fiber channel. For the measurement of high frequency electric signals, an antenna with a broad-band response is used for sensing.

2.1 Principle of operation

The principle of operation of the modulator on a *Z*-cut and *Y*- propagating $LiNbO_3$, used as a coherence modulator of light is based on the introduction of time-varying optical delays between wave groups emitted by a broad-band optical source of low coherence length. Such devices generate a static optical delay, also known as optical-path differences, that can be modulated by detecting electric signal. A coherence modulator is shown in figure 2. The light field is launched in the modulator with a linear polarization oriented at an angle of 45^0 relative to the crystal axes *X* and *Z*, i.e., to the TM and TE propagation modes. Its orthogonal projections generate the TM and TE modes, which travel in the waveguide with different velocities, due to the ordinary index no, and the extraordinary index n_e of $LiNbO_3$. When applying a voltage to electrode, the electric signal modifies the phase of the TM and TE waves via the coefficients r_{33} and r_{13}, respectively of the electro-optic tensor, allowing a dynamic variation $\Delta d(t)$ of the optical delay. After propagation, the two outputs TM and TE modes are projected along the polarization direction of an output polarizer oriented at 45^0 to the TM and TE modes. The value of the crystal length L is chosen so that the resulting static optical delay $d_o = (n_o - n_e)L$ [9] is greater than the coherence length. At the receiver, signal detection is based on the measurement of the auto-correlation of the transmitted optical field. This is accomplished by a scanning Michelson interferometer, which acts as an optical demodulator, on a variable optical-path difference (*d*). The detected intensity is given by,

$$I(d) = \frac{I_O}{4}\left[1 + g(d) + \frac{1}{2}g(d - d_O) + \frac{1}{2}g(d + d_O)\right], \qquad (1)$$

where I_o is the average power of the optical source; $g(\cdot)$ is the normalized autocorrelation of the received optical field; d_o is the static optical delay; $I(d)$ is the received optical power. Equation (1) represents group fringe patterns around $\pm d_o$. As the optical delay is greater than the coherence length of the optical source, no interference occurs at the modulator output and no intensity modulation is produced.

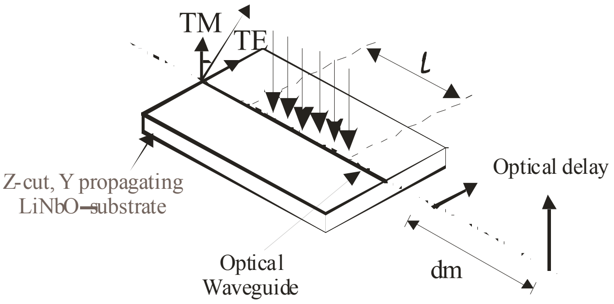

Fig. 2. An electric signal sensor using coherence modulator.

2.1.1 Sensing model

When an electric signal $V_z(t)$ is detected by antenna, it induces a dynamic variation on the optical delay, thus $d_m(t) = d_o + \Delta d(t)$. In this equation the first term is static optical-path difference and the second is time-varying.

$$\text{where } \Delta d(t) = \frac{\lambda_o}{2}\frac{V_z(t)}{V_\pi}. \qquad (2)$$

V_π is the half-wave voltage, $V_\pi = \lambda_o g/(r_{33}n_e^3\Gamma_{TM} - r_{13}n_o^3\Gamma_{TE})l$, where λ_o is the center wavelength of the optical source, g is the electrode gap, r_{33} and r_{13} are the electrooptic coefficients, Γ_{TM} and Γ_{TE} are the electric-optical overlapping coefficients, and l is the interaction length among the electric signal and the optical field.

To detect the electric signal message imprinted on the optical delay, the reception interferometer is adjusted to an optical path-difference of $d_m = d_o - \lambda/4$ to assure a linear detection of $V_z(t)$. The received message is thus given by,

$$I(t) = \frac{I_O}{4}\left(1 + \frac{\pi}{2}\frac{V_Z(t)}{V_\pi}\right) \qquad (3)$$

The transmitted message is then detected as a linear variation of the received optical powerWhen including a sub-subsection you must use, for its heading, small letters, 11pt, left justified, bold, Times New Roman as here.

3 Experimental setup and results

The experimental coherence modulated electric signal detection system is shown in figure 3. This includes a super-luminescent diode (SLD), with emission at $\lambda_o =$

1310 nm and coherence length of about 60 μm. The coherence modulator sensor is placed between two 45^0 polarizers. To detected electric signals a set of two antennas are used with response around 1000 MHz. The optical channel is a 1000 m standard single-mode optical fiber.

In this work, the receiver is composed for an automated scanning Michelson interferometer, which measures the autocorrelation of the modulated light [10], [11]. The light is photodetected, amplified and the output voltage corresponding to the sensed electric signal is digitized and transferred to a PC for signal processing.

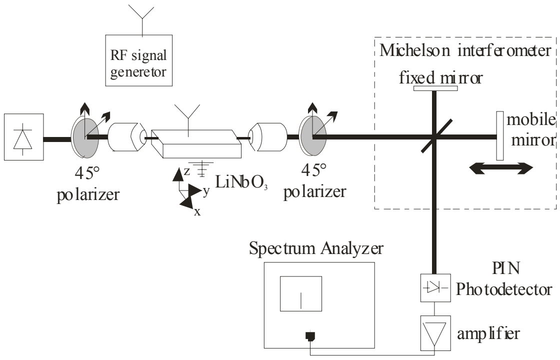

Fig. 3. Experimental setup for electric signal detecting system.

The static optical path-difference was measured by means of a scanning Michelson interferometer working as a coherence demodulator for determining the autocorrelation of the transmitted optical field. Figure 4 shows the autocorrelation fringe pattern of a coherence modulator with crystal length L = 19 mm. The associated static path difference is d_o= 1.53 mm. The position of the 50 % visibility satellite fringe packet indicates the static path difference of the modulator. The sensed electric signal can be detected at the demodulator when is matched to the transmitter, given by $d_m=d_o-\lambda/4$.

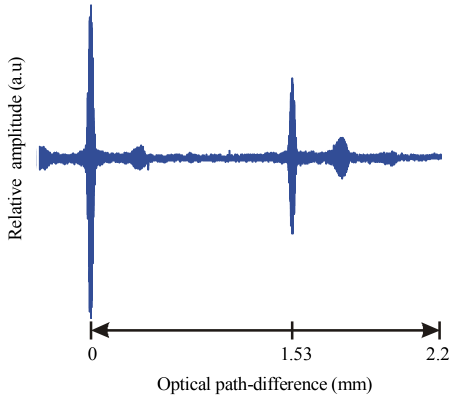

Fig. 4. Measure of optical delay introduced by optical modulator.

The associated coherence length was of about 60 μm, which is much lower than the static optical path difference of the tested modulators. The transfer function of the coherence modulated sensor was obtained by applying saw-tooth voltage. The figure 5 shows the half-wave voltage of coherence modulator. In this case the half-wave voltage (V_π) is measured to be 6 V.

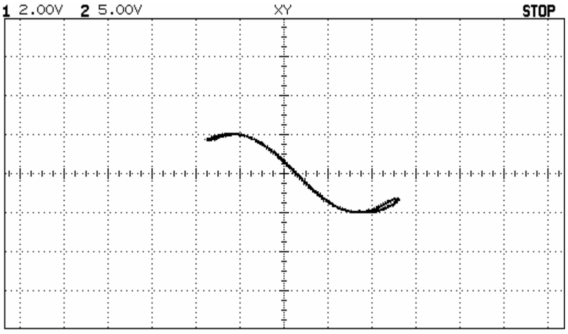

Figure. 5. Shows of transfer function of optical coherence modulator.

From this transfer function, we can determine the linear region of measurement that can be achieved with the coherence modulated sensor system. To test the detecting scheme, a 915 MHz electric signal from a signal generator is used. This electric signal is transmitted by an antenna and sensed by other antenna, it is attached to the coherence modulator sensor which modulated the optical delay. The optical field is transmitted through 1 Km optical fiber channel. The received optical field was applied to Michelson interferometer to measure the autocorrelation function. When it is matched around of the optical path-difference, linear detection of the electric signal was achieved. The voltage ranges applied to the sensor were varied from 0 dBm to 10 dBm, and for all cases linear detection was obtained.

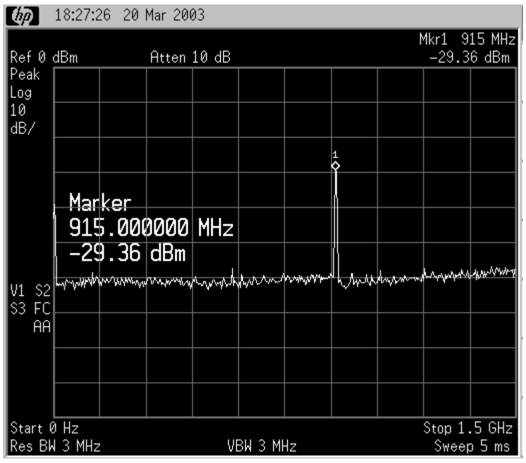

Figure. 6. Sensed electric signal.

Figure 6, illustrates 915 MHz electric signal at the output of the detection system, and registered on a Spectrum Analyzer.

4 Conclusion

In conclusion, detection-transmission electric signals using an electro-optic coherence modulator is proposed here. Detection of high frequency electric signals and low voltages levels is possible with this system. The use of integrated optics devices as sensors allows detection in high frequency ranges. This technique is very attractive for simultaneously multi-point detection of electric signals using coherence multiplexed architectures. Current experimental work consists in series schemes for optical coherence multiplexed electric signals detecting arrays.

ACKNOWLEDGMENT

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