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# Intensity to Frequency Conversion Technique in Intensity Modulated Fiber Optic Sensing Systems

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# INTENSITY TO FREQUENCY CONVERSION TECHNIQUE IN INTENSITY MODULATED FIBER OPTIC SENSING SYSTEMS

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ABSTRACT

A novel sensing technique based on intensity-to-frequency conversion is explained and demonstrated. Experimental data are presented and a comparison with a theoretical model is made.

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Among different configurations of intensity modulated fiber optic sensing systems, those with the signal and reference channels separated in the time domain are the most commonly used. Such a configuration has been already discussed.[1] The configuration involves a short duration pulse sent towards a sensing element through a delay line. The resultant signal consists of two pulses, signal and reference. The measurand affects the amplitude of the signal pulse. The amplitude of the reference pulse remains unchanged. The information about the measurand is then retrieved from the relative amplitudes of the pulses in the signal and reference channels. Several techniques have been proposed to do this.[2,3] These techniques are based on measuring either the relative amplitude of the pulses in the time domain directly or the strength of the resultant signal at particular frequencies in the frequency domain.

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The technique described in this paper employs a conversion from the relative intensity to a frequency value. To achieve the conversion, a signal in the reference channel consists of two pulses of the same amplitude $V$ and duration $t$. The time delay between the first and second pulse in the reference double pulse is $2\Delta$. The signal channel consists of a single pulse of the same duration as the pulses in the reference channel. The signal pulse is delayed from the first reference pulse by $\Delta$. Thus the signal pulse occurs in the middle of two reference pulses and forms a triple pulse. Assume that the pulses in this triple pulse have a rectangular shape and the triple pulse itself is periodic with a period $T$. Then, using Fourier analysis[4] the amplitude spectrum of such a triple pulse can be written as:

$$|F(w_m)| = \frac{Vt}{T} \left|\frac{\sin(w_m t/2)}{w_m t/2}\right| \left[2 + a^2 + 4a \cos(w_m \Delta) + 2 \cos(2w_m \Delta)\right]^{0.5} \qquad (1)$$

where $w_m$ is the angular frequency, $w_m = 2\pi m/T$, $m$ is an integer, and $a$ is a ratio of the amplitude of the second (signal) pulse to the amplitude of any other (reference) pulse in the triple pulse. Analyzing the last term in Eq. (1), the modulating factor $S$,

$$S = \left[2 + a^2 + 4a \cos(w_m \Delta) + 2 \cos(2w_m \Delta)\right]^{0.5} \qquad (2)$$

it is easy to show that the function $|F(w_m)|$ equals zero if the following relationship between frequency $f_m = w_m/2\pi$ and the coefficient $a$ is satisfied:

$$a = -2 \cos(2\pi \Delta f_m) \qquad (3)$$

Thus for any value of $a$ from $0 \leq a \leq 2$ there is a frequency at which the function $|F(w_m)|$ goes to zero. A change in the value of $a$ is reflected as a change in the value of the frequency at which the amplitude vanishes. This frequency will be referred to as the "zero" frequency $f_0$. Figure 1 shows calculated plots of the modulating factor $S$ described by Eq. (2) as a function of the frequency $f_m = w_m/2\pi$ for three different values of $a$, $a = 1$, 1/2, and 0.

The experimental setup is shown in Fig. 2. An 18 ns duration repetitive light pulse from a light emitting diode (LED) enters a 1 by 3 optical coupler and is sent into three fiber ports. The repetition rate of the initial light pulse is 10 μs. The ports are connected to fibers of different lengths to generate delays of approximately 36 and 72 ns for the second and the third pulses with respect to the first one. Another 3 by 1 optical coupler combines the three pulses into one triple pulse. To imitate a change in the amplitude of the second pulse, a variable attenuator (VA) with a readout (RO) is placed in the port used to generate this pulse. The triple pulse is then received by the photodetector (PD) and sent to the signal analyzer (SA). The position of the "zero" frequency on the displayed spectrum is observed and detected as a function of the ratio $a$, the relative intensity of the light pulse in the signal channel.

To obtain the experimental data, readings from the attenuator were used to calibrate the position of the "zero" frequency $f_o$ against the ratio $a$. This was done in three steps. In the first step, measurements were made to determine the relationship between $a$ and the attenuator readings. The second set of data taken was to determine the relationship between the attenuator readings and the "zero" frequency. Finally, the relationship between $a$ and $f_o$ was established. Data was taken 10 times at each datapoint and their average values were used later. During collection of the first set of measurements the standard deviation from the average of $a$ at each datapoint did not exceed 0.015. At the second stage the maximum deviation of the average value of the "zero" frequency from the predicted one at each datapoint did not exceed 1 percent of the average value at that datapoint. The theoretical and experimental data for the "zero" frequency tracking is presented in Fig. 3.

The technique described is inherently independent of the reference pulse amplitude. A system based on this technique performs the intensity to frequency conversion and determines the relative intensity of the light pulse in the signal channel without actually measuring the intensity. Thus, a novel sensing technique has been demonstrated. The experimental results match closely with that predicted. The accuracy and repeatability of the measurements could be improved by choosing an appropriate repetition rate and by improving the "zero" frequency detection technique.

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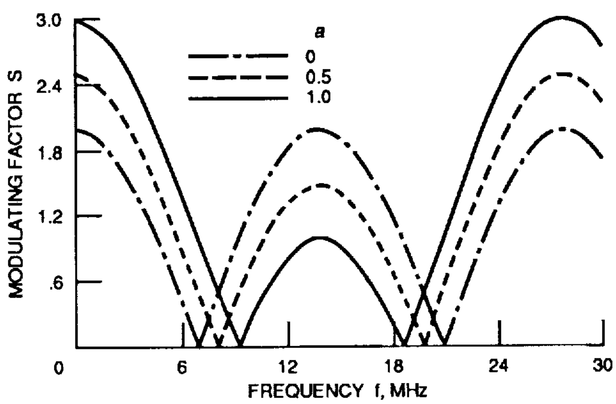


Figure 1. - Calculated plots of the modulating factor S described by Eq. (2) for three values of $a$, $a = 1$, 1/2, and 0 .

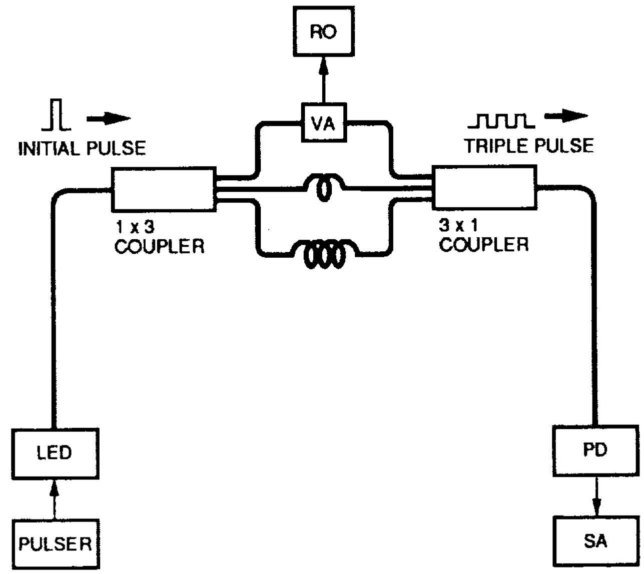


Figure 2. - Schematic of experimental setup LED = light emitting diode, VA = variable attenuator, RO = readout, PD = photodetector, SA = signal analyzer.

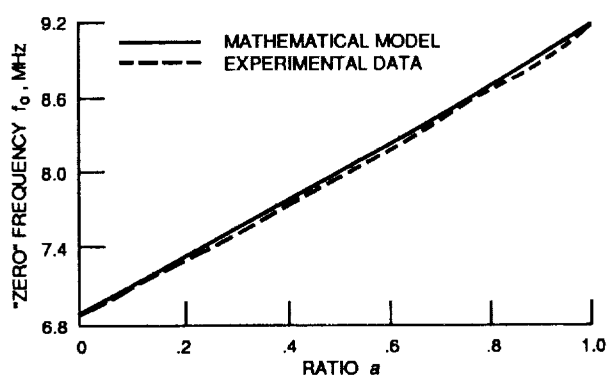


Figure 3. - Theoretical and experimental plots of the "zero" frequency $f_0$ as function of the ratio $a$.

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15. Supplementary Notes

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16. Abstract

A novel sensing technique based on intensity-to-frequency conversion is explained and demonstrated. Experimental data are presented and a comparison with a theoretical model is made.

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