ANALYSIS OF FIBRE-OPTIC RING RESONATOR AND SENSING SYSTEMS

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Dedicated to

my wife, *Minoo*
and
little daughter, *Melika*

CERTIFICATE

This is to certify that the thesis entitled "*ANALYSIS OF FIBRE-OPTIC RING RESONATOR AND SENSING SYSTEMS*", which is being submitted by *FARAMARZ ESMAILI SERAJI* to the Department of Electrical Engineering, Indian Institute of Technology, Delhi, in fulfillment for the award of the Degree of Doctor of Philosophy, is a bonafide record of the research work carried out by him under my supervision and guidance. He has fulfilled all the requirements for the submission of the thesis, which has reached the requisite standard.

The results contained in the thesis have not been submitted in any form to any other University or Institute for award of any Degree or Diploma.

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ABSTRACT

This thesis presents an analysis of fibre-optic ring resonators (FORR). Applications of the FORR for optical fibre sensing and optical signal processing are also analyzed and studied.

First, the steady state response of the FORR is described in detail under various operating conditions. In practice, the loop phase of the FORR will be modulated or scanned to force the FORR to go through the resonance condition. The modulation will affect the steady state behaviour of the FORR leading to an oscillatory transient response, if the frequency of modulation is high. Such a dynamic behaviour of the FORR is analyzed when the loop phase of the FORR is modulated sinusoidally by a PZT. It is shown that when the period $(1/f_m)$ of the modulating voltage waveform, applied to the PZT, becomes comparable to the loop delay time the FORR response deviates from the steady state response. The upper limit on value of $f_m\tau$ required for the steady state response of the FORR is tabulated for different parameters of the FORR. Experimental results on the FORR are given by using a He-Ne laser source and a loop length of 225 m for modulation frequencies up to 340 kHz. The experimental results agree well with the developed theory.

A theoretical dynamic analysis of the FORR is given when the excitation is provided by a laser diode with its injection current modulated sinusoidally, thereby producing an optical frequency modulation along with an amplitude modulation. Simulation results are given for different conditions of the FORR, namely, modulating frequency f_m, amplitude modulation index, power coupling coefficient of the coupler, loop delay time, and the phase angle between the FM and AM response of the laser diode.

When the product $f_m\tau$ exceeds a factor of about 0.0002, the output response of the FORR deviates from the steady state and exhibits an oscillatory behaviour with overshoots. Interestingly, when the value of $f_m\tau$ becomes greater than unity, the response does not show any resonance in the ring and the output in this case approximates to intensity modulation of the laser diode source. A method of measuring the FM characteristics of a given laser diode is proposed by using the FORR. It is shown that both the magnitude and phase responses of the FM can be estimated.

An optical fibre electric current sensor based on Faraday effect is experimentally built by winding 980 turns of a single mode fibre of length about 200 m around a bus bar. To tackle the polarization problems that arise due to linear birefringence effect in long fibre of 200 m, an effective method is proposed to control the polarization state of the output light to remain always linearly polarized. A noise analysis for the sensor system is given. For an optical output of 17 μW the system could sense a 50 Hz electric current in the bus bar from 200 mA to 60 A rms.

A theoretical analysis for the FORR (in steady state) is given by assuming a polarization modulation in the loop fibre. If the change in polarization angle θ is large the output intensity will have two resonance dips separated by an angle equal to 2θ when the loop phase of the FORR is scanned from 0 to 2π. When θ is small, the FORR output produces only one resonance dip and the amplitude of this resonance dip is a measure of θ. By placing a polarizer sheet at the FORR output a resonance peak in the intensity is produced with an amplitude that increases with θ. Such a proposed system has potential applications, for example, in Faraday current sensing with an increased sensitivity. The effects of birefringence in the loop and the angle of polarization of the input light are also analyzed and it is shown that the sensitivity of the system would decrease if a significant amount of birefringence is present in the loop fibre.

The applications of the FORR for rotation sensing are reviewed. A novel method for rotation sensing is proposed and analyzed theoretically, where a resonance spike of variable amplitude in the system output gives a measure of rotation rate. The advantage of the proposed method is that no stabilization circuit to fix the operating point of the FORR is required and the output is obtained by simply scanning the loop phase and detecting the peak value of the resonance spike in a peak-detector circuit.

Also, in this thesis, a theory on optical pulse response of the FORR is developed for the first time. The theory predicts that the FORR can have several potential applications in optical signal processing. For instance, it is shown that under steady-state operation with different conditions, the FORR with an optical input pulse can be employed to perform various tasks such as differentiation (like an RC circuit in electronics), integration of an optical pulse, and generation of a sharp optical trigger pulse of strength up to 4 times the input pulse power. The theoretical analysis shows that the FORR can be used as an optical fibre equalizer.

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