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Polarization Modulation for Communication

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Abstract- *Polarization is one of the most fundamental property of Electromagnetic (EM) wave, which describes it completely. The study of polarization of light through Faraday Rotation Effect, rotation of plane of polarized wave when traveling through Terbium Gallium Garnet (TGG) crystals placed inside solenoid, subjected to a strong axial magnetic field can be a novel approach in communication. Experiment shows conversion of polarization modulated light into intensity modulated light, and phase shifted demodulated waveform w. r. t. input modulating signal. Insertion of properly matched and tuned circuit before coil and amplifier after demodulation leads to better reception of signal.*

Keywords- Faraday rotation, Polarization Modulation, Analog communication.

I. INTRODUCTION

In radio communication, modulating signal can be modified based on the properties of wave, such as, amplitude (AM), frequency (FM) and phase (PM). Similarly, modulation of light can be done by varying its properties; like intensity (ASK), frequency (FSK), phase (PSK), wavelength or polarization. All these techniques use State of Polarization (SOP) of fully polarized light-wave as an information carrying parameter. The greatest difference between radio-wave AM techniques and optical modulation techniques is that the output of radio receiver is usually proportional to amplitude of incoming signal, while output of optical receiver is proportional to intensity of incoming signal, because of the use of square-law photo detectors. Amplitude of a signal contains both magnitude and phase information, while intensity of a signal is the square of its magnitude. Amplitude modulation of light can be done by internal or external way. Internal modulation can be achieved by varying supply source (voltage or current) of artificial source of radiation, for eg., laser, while external modulation can be through controlling the light absorption in semiconductors by varying voltage or current [13]. The different effects used to modulate the light are: Kerr and Pockels Effect (Electro-optic), Faraday Effect (Magneto-optic) and Acousto-optic Effect [1] [13].

In Faraday Effect, the phase modulation of two mutually perpendicular components of linearly polarized light results into polarization modulation, which is then transformed into Amplitude Modulation by analyzer. The Faraday Effect originates from the effect of static magnetic field on the motion of electrons in the presence of light and Lorentz force [1]. The magneto-optic modulators are based on the rotation of optical polarization as light propagates along the magnetic field in a material, by the Faraday

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Effect. These modulators can be made of Faraday material (for eg., Terbium Gallium Garnet-TGG crystals)placed inside an electric coil (solenoid) with modulating electric current. Electro-optic modulators can be of transverse and longitudinal type, which require several thousands of drive voltage to achieve a desired phase shift. In Acousto-optic modulator, the frequency response is limited by the acoustic transit time across the finite width of light beam, acoustic propagation loss in that medium and frequency response of acoustic transducer. There is a need of sharply focused laser beam to reduce the acoustic transit time. Also, Acousto-optic effect has limitation of width of frequency band $< (1-2)*10^6$ [13]. To overcome these limitations we tried to modulate the light beam by varying its SOP using Faraday Effect and hence using Magneto-optic modulators. Polarization of a laser beam is modulated or switched between two orthogonal states. Like intensity modulation, polarization modulation does not require sophisticated stabilized laser. Since, the optical sensitivity of a polarization modulated light is about twice as high as intensity modulated signal, it provides better receiver Signal to noise ratio (SNR) [1]. Polarization Shift-keying (POLSK) modulation is an abstract scheme of modulation, due its applicability to fiber communication; microwave communication and light wave inter satellite communication. POLSK modulation needs 3dB less power than ASK and FSK in absence of laser phase noise [2].

II. THEORY

Christian Huygens was the first to suggest that light was not a scalar quantity, based on his work on the propagation of light through crystals. (This vectorial nature of light is called as Polarization.) If we follow mechanics and equate an optical medium to an isotropic elastic medium, it should be capable of supporting three independent oscillations (optical disturbances): $u_x(r, t)$, $u_y(r, t)$ and $u_z(r, t)$.

In a Cartesian system $u_x(r, t)$ and $u_y(r, t)$ are the transverse components, while $u_z(r, t)$ is longitudinal component of light wave.

$$u_x(r, t) = u_{0x} \cos(\omega t - kr + \delta_x) \quad (1a)$$

$$u_y(r, t) = u_{0y} \cos(\omega t - kr + \delta_y) \quad (1b)$$

$$u_z(r, t) = u_{0z} \cos(\omega t - kr + \delta_z) \quad (1c)$$

From Fresnel and Argo's investigation (1818) on Young's interference experiment using polarized light, it is concluded that Eq.(1c),does not exist, i.e., light consists of transverse components only [4] [15]. Plane wave propagation in the z-direction, the components of optical field in x-y plane are represented as:

$$E_x(z, t) = E_{0x} \cos(\omega t - kz + \delta_x) \quad (2a)$$

$$E_y(z, t) = E_{0y} \cos(\omega t - kz + \delta_y) \quad (2b)$$

Where, $\tau = \omega t - kz$ is a propagator, E_{0x} and E_{0y} are maximum amplitudes of x and y components. δ_x and δ_y are phases of x and y components. In the x y-plane, we can construct a vector as:

$$E(z, t) = E_x(z, t)\cdot i + E_y(z, t) \cdot j \quad (3)$$

Where, i and j are unit vectors in x and y directions respectively.

III. EXPERIMENTAL SETUP

The system shown in Fig.1 includes the Laser (Red, 632.8nm), as a light source. The light is then passed through a Polarizer, which then is rotated due to magnetic field induced in the magnetic coil or Solenoid (1200 turns) with the Faraday material TGG crystals are placed inside. The rotated light is then analyzed through another polarizer, called as 'Analyzer'. The exact detection had been done at Detector. In the whole system, the laser light acts as a carrier, whereas the input signal, applied to solenoid acts as the modulating signal. The modulating signal produces the magnetic field in the solenoid in the direction of propagation of light beam. This magnetic field rotates the plane of polarization of the incoming light, due to Faraday Effect, i.e. the original state of polarization (SOP) of light have been changed, which ultimately results into the polarization modulation. The rotation of the plane of polarization through an angle θ can be calculated by:

$$\theta = V \cdot B \cdot L$$

where, 'V' is the property of material known as Verdet constant, 'B' is the induced magnetic field in the solenoid (in gauss) and 'L' is the length of the optical beam through a material, placed inside the solenoid.

Helmholtz coil is special coil to generate a uniform magnetic field at the center of the coil. It consist of pairs of circular coil, when charges are in motion the magnetic field is generated around it. Both circular coils spaced on radius apart and wound so that the current flows through both coils in the same direction. The Helmholtz coil is designed in the lab as shown. Each coil has 500 turns witch generate around 120 Gauss of magnetic field at 1A of current. The crystal is placed at the center of the coil with help of spider arrangement, the laser is pass through the crystal and signal get modulate in the presence of magnetic field. Helmholtz coil used in many applications from canceling the Earth's magnetic fields to generate uniform magnetic field for many experiments, it can generates static, time varying DC or AC. It also used for measurement of a permanent magnetic moment, removing or ruling background magnetic field, it also used in TV production for picture alignment procedures.

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Figure 1. Block diagram of a system

IV. OBSERVATIONS

The sinusoidal signal of 1 kHz, 25Vp−p was applied as an input to the solenoid; the output is sinusoidal signal of 1 kHz, 100mVp−p, which is then amplified. Fig. 2 shows the phase difference between input and output signal. Here, the polarized laser light (Red) carries sinusoidal signal combines with sinusoidal (modulating) signal at solenoid al, which then gets rotated due to presence of TGG crystals, i.e. SOP of original light has got changed, i.e. 'Polarization Modulation'. This modulated light when passes through analyzer, the polarization modulated light gets converted into intensity modulated light. This light is then demodulated using the photo-detector. The demodulated signal shows the phase difference w. r. t. the input signal. Except the loss in energy of signal, the nature of the original signal has been successfully retrieved at the detector side. The solenoid gives a stable response for the frequency range 10Hz-100 kHz. Insertion of impedance matching and tuning circuit before solenoid leads to a better reception of signal. To test it further, we used audio signal as a modulating wave. An audio signal in form of '.wav' file format was sent through a solenoid for around 30sec. The modulated audio is received at photo detector. Demodulated signal is amplified through an audio amplifier. The Fig.3 shows an audio input applied, with its time sequence (above) and spectrogram (below), while Fig.4 is the detected output.

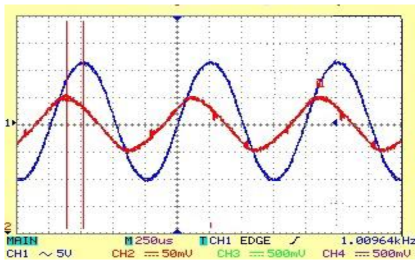

Figure 2. Graph showing input signal (blue) and phase shifted output signal (red), $\Delta t = 125\mu sec$

From the time sequence plots, the variation of magnitude at a particular time instant is nearly same for both the plots. From spectrogram of input audio, the highest frequency components is ~3kHz, and lowest of ~1kHz. The same levels have been observed at output too. Along with this, sudden drop in input (at t ~20sec) has been perfectly reflected in the demodulated signal. The level of magnitude in spectrogram, for input is 72.78 dB and for output it is 70.76 dB. The grayish part at the background of spectrogram shows the energy at particular time instant, darker the region, more is the energy. The output spectrogram shows small amount of loss in energy.

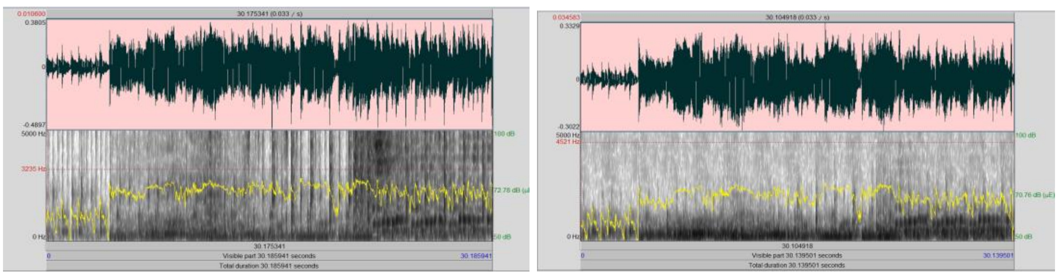

Figure 3. The time sequence (above) and spectrogram (below) of the transmitted (Left) and received (right) audio signal

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