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Kerr Medium for Change of Light Frequency With Saw-Tooth Intensity Pattern Accommodating Multi-Passing Technique

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Abstract— Optical Kerr materials are strongly recommended for optical self-focusing and defocusing, optical switching activities and optical signal processing. The refractive index of Kerr medium depends on the intensity of applied light pulse passing through it. Kerr medium can be used in frequency conversion if signal having time dependent intensity pattern is passed through such a medium. Earlier this Kerr material was successfully used to convert the frequency of the applied light using a saw-tooth type of intensity varying signal. The shift of frequency can be enhanced by sending the output modulated wave from Kerr medium again to the input of the same medium. Greater amount of frequency shift can be achieved by increasing the number of passing of the light wave through the Kerr medium. Here in this paper the authors propose a method of using Kerr medium for change of light frequency with saw-tooth intensity pattern accommodating the multi-passing technique.

Keywords—Optical Kerr materials, Optical switching, Frequency conversion, Multi-passing technique

I. Introduction

Kerr types of nonlinear materials can play significant role in all-optical switching and computing. Many all-optical/photonic switches are already developed using this Kerr material [1-7]. This said application is mainly seen when a Kerr medium with very high nonlinear coefficient is triggered by intense laser beam. The refractive index of Kerr medium is dependent on the intensity of light passing through it [8-12].This property of Kerr medium can be applied to convert the frequency of the light signal passing through the medium. Earlier this property of Kerr material was successfully used to convert the frequency of the applied light by using a saw-tooth type of intensity varying signal [1]. In this paper the authors propose a method of using Kerr type of nonlinear medium for change of light frequency with a saw-tooth intensity pattern accommodating multi-passing technique.

Section I contains the introduction of the proposed scheme, Section II explains the switching character of Kerr medium, Section III and Section IV describe the analytical treatment, and Section V concludes the research work.

II. Switching character of Kerr medium

Kerr type of isotropic nonlinear medium shows the refractive index (n) variation of the medium with the intensity (I) of the light passing through it as [13-16]

$$n = n_0 + n_2 I$$

Where, n_0 is a constant refractive index term and n_2 is a nonlinear correction term. Due to this intensity dependent refractive index the propagation constant of a beam in this medium becomes –

$$\beta = \beta_0 + K_0 n_2 I$$

Where, β_0 is the constant propagation factor in the nonlinear medium and K_0 is the respective free space propagation constant of the light [12-16].

An incident electromagnetic wave having electric field $E = A\exp(i\omega_0 t)$ after passing through a Kerr type of nonlinear medium of length 'l' would emerge as

$$E' = A' \exp[i(\omega_0 t - \beta l)]$$

Hence $$E' = A' \exp[i(\omega_0 t - \beta_0 l - K_0 n_2 l I)]$$

If this output is fed back to the input of the nonlinear medium for another trip through the medium, then electric field of final output wave becomes –

$$E_1 = A'' \exp[i(\omega_0 t - 2\beta l)]$$

Hence $E_1 = A'' \exp[i(\omega_0 t - 2\beta_0 l - 2K_0 n_2 lI)]$

The instantaneous phase of the light can be expressed as –

$$\varphi_1 = \omega_0 t - 2\beta_0 l - 2K_0 n_2 lI$$

So, the instantaneous frequency of the light is expressed as –

$$\omega_1(t) = \omega_0 - 2K_0 n_2 l\ dI/dt$$

Here, intensity 'I' is a function of time't'.

III. FREQUENCY RESPONSE OF KERR MEDIUM WITH A SAW-TOOTH TYPE OF INTENSITY VARYING SIGNAL AFTER FIRST PASSING THROUGH THE MEDIUM

The intensity pattern of a saw-tooth type of signal is represented as –

$$I(t) = K_1 t \ ;\ 0 < t < T_0$$

Where, $K_1 =$ Constant. At, $t = T_0$, $I = I_0$

So, $K_1 = I_0/T_0$

Thus $I(t) = (I_0/T_0)\ t \ ; 0 < t < T_0$

Now, for a saw-tooth type of intensity varying signal the instantaneous frequency of the light signal becomes [1]

$$\omega_1(t)\Big|_{t=T0} = \omega_0 - 2K_0 n_2 l\ I_0/T_0$$

Thus, the frequency shift becomes [1]

$$\Delta\omega = \omega_1(t)\Big|_{t=T0} \sim \omega_0$$

Thus $\Delta\omega_1 = 2K_0 n_2 l\ I_0/T_0$

So, frequency shift is constant, which depends on I_0 and T_0 ratio.

IV. USE OF MULTI-ROTATION PHENOMENA IN KERR MEDIUM FOR CHANGING THE LIGHT FREQUENCY

In feedback technique, if the output modulated wave from the Kerr medium is fed back to the input of the same medium again, then a re-modulated second output wave is derived. If the single time rotated modulated output wave is again made a feedback to the input of the medium, then doubly modulated output wave is obtained. In such a way if the output modulated wave is made feedback for multiple times to the input of the medium, then multiple times modulated output wave can be received.

If the feedback is done 'n' times to Kerr medium, then electric field of final modulated output wave becomes –

$$E_n = A_n \exp[i(\omega_0 t - \beta l - n\beta l)]$$

So $E_n = A_n \exp[i\{\omega_0 t - (1+n)\beta l\}]$

By putting the expression of 'β' one can get –

$$E_n = A_n \exp[i\{\omega_0 t - (1+n)(\beta_0 l + K_0 n_2 lI)\}]$$

Thus $E_n = A_n \exp[i\{\omega_0 t - (1+n)\beta_0 l - (1+n) K_0 n_2 lI\}]$

Therefore, phase of the final modulated wave is

$$\Phi_n = \omega_0 t - (1+n)\beta_0 l - (1+n) K_0 n_2 lI$$

The instantaneous frequency of the modulated wave can be obtained after differentiation of Φ_n with respect to time and it is expressed as

$$\omega_n(t) = \omega_0 - (1+n) K_0 n_2 l\ dI/dt$$

Now, for a saw-tooth type of intensity varying signal the instantaneous frequency becomes –

$$\omega_n(t) = \omega_0 - (1+n) K_0 n_2 l I_0/T_0$$

So $\omega_n(t)\Big|_{t=T0} = \omega_0 - (1+n) K_0 n_2 l I_0/T_0$

Thus, the shift of frequency from the original wave is

$$\Delta\omega_n = \omega_n(t)\Big|_{t=T0} \sim \omega_0$$

Thus $\Delta\omega_n = (1+n)K_0 n_2 l\ I_0/T_0$

In 'Fig.1' the schematic diagram of the frequency shifting scheme for the saw-tooth type signal by using a single passing technique is shown. At first, an electronic saw-tooth shaped current pulse is generated by an electronic circuit. This electronic current pulse is applied to a 'Light Emitting Diode (LED)' or an 'Injection Laser Diode (ILD)' directly. It is well known that 'LED' or 'ILD' produces light signal having the intensity directly proportional to the applied current in it coming from the electronic circuit. That is why intensity of light obtained from the 'LED'/'ILD' follows the same saw-tooth shape. This light signal having saw-tooth intensity pattern with frequency ω_0 is applied to a Kerr medium of length l. Due to frequency conversion property of Kerr medium the frequency of output light signal from Kerr medium will be changed. With the help of four mirrors this output light signal with converted frequency is again made feedback to the input of the same Kerr medium through a different channel. So, amount of frequency shift will become more than the previous one. The final output light signal from Kerr medium after getting first feedback with frequency ($\omega_0 \pm \Delta\omega$) is applied to the input of the frequency detector and at the output of the frequency detector one can get a signal with desired change of frequency. Similarly with a number of feedback with number of passing (multi-passing) the output frequency of the light can be changed more and more.

The shift of frequency can be calculated considering –

$l = 10^{-2}$m, $I_0 = 10^{10}$w/m^2, $n_2 = 10^{-10}$m^2/w (MO/Polyimide), λ = 7000Å, T_0 = 10s.

The shift of frequency for different times of passing of the light wave through Kerr medium is given in 'Table-1'.

Table-1: Frequency shift vs. different times of passing of light wave through Kerr medium

Order of rotation technique	The shift of frequency $\Delta\omega$ (Hz)
n = 1	1.79×10^4
n = 2	2.69×10^4
n = 3	3.58×10^4
n = a	$(1+a)\ 0.89\times10^4$

The graphical variation of intensity with time for a saw-tooth type of intensity varying signal is shown in 'Fig. 2'. The frequency variation with time for a saw-tooth type of intensity varying signal by using different times of passing of light wave through Kerr medium is shown in'Fig.3'.

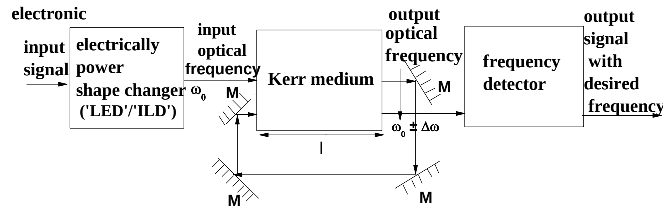

Figure 1: Schematic diagram of optical frequency conversion by Kerr medium using feedback. Here 'M' represents the mirror.

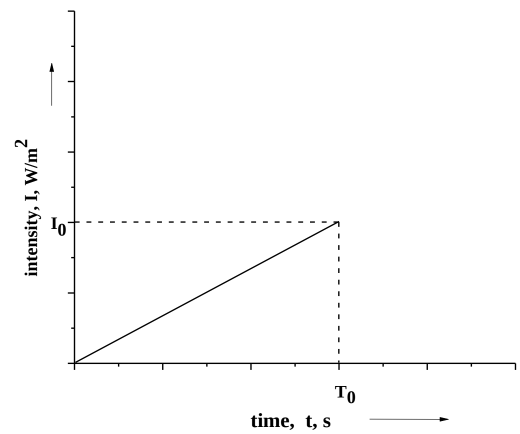

Figure 2: Intensity variation with time for a Saw-tooth type of intensity varying signal

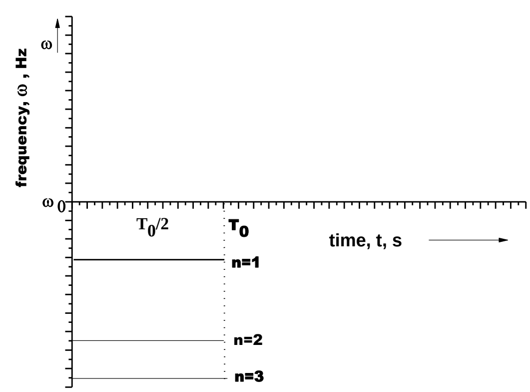

Figure 3: Frequency variation with time of a Saw-tooth signal for different number of passing of light wave through Kerr medium

V. CONCLUSION

The nonlinearity of Kerr medium is applied to convert the frequency of an applied light pulse leaving the pulse envelope unchanged. The shift of frequency can be enhanced by increasing the number of passing of the light wave through the Kerr medium. Therefore it can be concluded that the frequency of the applied light wave can be changed significantly due to the application of the nonlinearity of Kerr medium and multi-passing technique. The proposed scheme is highly advantageous in optical communication, especially in frequency division multiplexing, frequency encoded optical signal processing etc. The whole scheme of frequency conversion is all-optical. Hence it ensures a high speed conversion. The proposed system has a tremendous advantage in real life application, as one can produce a desired frequency of light from a single frequency of light by changing the number of feedbacks and the slope of the saw-tooth curve. Mainly in fiber-optic communication the proposed method can do a lot in wavelength division multiplexing, as well as in data encoding.

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