Ultra short Optical Pulse Generation using electro-optic Mach-Zehnder light intensity modulator placed in an optical feedback loop

Madhumita Bhattacharya

Abstract— **In this paper, a method for the generation of ultra short optical pulse is proposed by using an electro-optic Mach-Zehnder light intensity modulator placed in an optical feedback loop. The Mach-Zehnder modulator is driven by a microwave signal. The CW lightwave from a laser diode undergoes multiple modulation in traversing the optical feedback loop. The repetition frequency of the generated optical pulse is equal to the microwave drive frequency applied to the modulator. By tuning the microwave drive frequency, the repetition frequency of the generated optical pulse can be varied. The normalized optical pulse intensity and width of the generated pulse has been calculated. The variation of optical pulse width with applied microwave modulation signal power and signal frequency is also studied. Typical value of calculated optical pulse width is 1 picosecond for modulation frequency of 50 GHz and modulator drive parameter equal to 1.5.**

Index Terms— **Optical pulse generation, repetition frequency, pulse width, Mach-Zehnder modulator, optical feedback loop**

I. INTRODUCTION

To exploit the ultra wide bandwidth of optical fiber which is nearly 50 THz, optical time division multiplexing technique is very attractive. In optical time division multiplexed (OTDM) communication system, ultra short optical pulses propagate down the optical fiber. As a result, ultra short optical pulse generation technique is an important topic of research in the present time. The optical pulses required in an OTDM system should have a narrow pulsewidth, high repetition frequency and low phase noise. The required extinction ratio should also be high. Mode locking of lasers, gain switching and Q switching of lasers are the commonly used methods for the generation of optical pulses. Electro-optic phase modulation and intensity modulation techniques are also used to generate optical pulses [1-10].

In this paper, we propose a simple method of generating optical pulse using an electro-optic Mach-Zehnder light intensity modulator placed in an optical feedback loop. The CW lightwave from a tunable laser diode is intensity modulated by a Mach-Zehnder(M-Z) modulator. A microwave signal drives the M-Z modulator. Since the intensity modulator is placed in an optical feedback loop, multiple intensity modulation of the lightwave can be achieved. The effective intensity modulation index of the light wave increases. In each round trip passage, a part of the lightwave appears at the output. In effect, a large number of intensity modulated (IM) lightwaves superpose at the output yielding an optical pulse train at the output. An optical erbium doped fiber amplifier (EDFA) is placed in the feedback loop, which compensates for optical losses encountered by the lightwave in the circuit.

II. SYSTEM DESCRIPTION AND PRINCIPLE OF OPERATION

The schematic circuit diagram of the proposed optical pulse generator is shown in Fig.1. The CW (continuous wave) optical signal from the tunable laser diode (LD) is modulated using an electro-optic Mach-Zehnder light intensity modulator, MZM. A microwave signal drives MZM. HM1 and HM2 are half-mirrors acting as beam splitters. A part of the intensity modulated lightwave enters the optical feedback loop through HM1. An optical amplifier, which can be an EDFA is placed in the feedback loop. The intensity modulated lightwave is amplified each time and appears at the input of the Mach-Zehnder modulator. Each time the IM lightwave makes a passage through the loop, a portion of the wave is transmitted through half mirror HM2 to the output. The process is cumulative and the initial CW lightwave gets intensity modulated infinite number of times. At the output, an ultrashort optical pulse is generated.

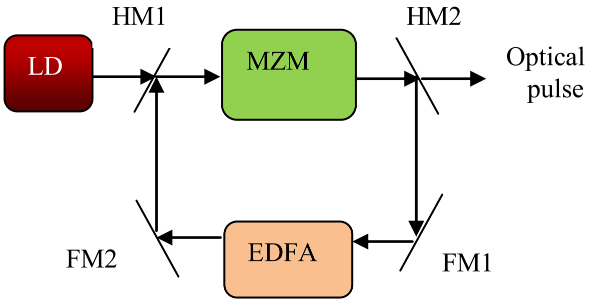

Figure 1. A schematic diagram of the proposed optical pulse generator. LD: tunable laser diode; MZM: Mach-Zehnder modulator; HM: half-mirror; FM: Full mirror; EDFA: Erbium doped fiber amplifier

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III. ANALYSIS

Let the CW lightwave from the laser diode (LD) be expressed as

$$a = |a| \exp j(\omega_c t + \theta) \qquad \text{.............(1)}$$

where $|a|$ is the peak amplitude of the optical electric field, ω_c is the angular frequency of the lightwave and θ is the phase angle.

Let the microwave signal applied to the MZM be given by

$$v_m(t) = V_m \cos(\omega_m t) \qquad \text{...........(2)}$$

where V_m is the voltage amplitude of the microwave signal and ω_m is the angular frequency of the modulating signal. The dc bias applied to the modulator (MZM) is chosen to be $V_{dc} = V_\pi / 2$, where V_π is the half-wave voltage of the modulator.

The intensity modulated lightwave at the output of the Mach-Zehder modulator (MZM1) can be expressed as

$$E_1(t) = (|a|/2)(\cos(\phi_{dc} + \phi_m(t)))\exp j(\omega_c t)$$

...........(3)

where $\phi_{dc} = \pi \dfrac{V_{dc}}{V_\pi}$ and $\phi_m = (\pi \dfrac{V_m}{V_\pi}) \cos \omega_m t$.

If $V_{dc} = V_\pi / 2$, eqn.(3) can be recast as

$$E_1(t) = (|a|/2) \sin(m \cos(\omega_m t)) \exp j\omega_c t$$

.................(4)

where $m = (\pi \dfrac{V_m}{V_\pi})$ is the modulator drive parameter.

Now, eqn (4) can be expanded as

$$E_1(t) = \frac{|a|}{2}[2 \textstyle\sum_{n=1}^{\infty} J_{2n-1}(m) \cos(\overline{2n-1}\omega_m t)] \exp j\omega_c t$$

................(5)

where $J_k(x)$ is Bessel function of first kind of order k with argument x.

A part of the intensity modulated lightwave travels through the optical feedback loop and is again modulated by the MZM. The process goes on for an infinite number of times theoretically. The optical EDFA is assumed to compensate the optical loss suffered by the lightwave at the half mirrors HM1 and HM2. The resultant electric field at the output of the proposed optical pulse generator can be expressed as

$$E_r(t) = \frac{|a|}{2} \sin(m \cos(\omega_m t))[1 + \sin(m \cos(\omega_m t) +$$
$$(\sin(m \cos(\omega_m t))^2 + (\sin(m \cos(\omega_m t))^3 + ...] \exp j\omega_c t$$

$$\cong \frac{|a|}{2}\{ \frac{\sin(m \cos(\omega_m t))}{1 - \sin(m \cos(\omega_m t))} \} \exp j\omega_c t$$

..........(6)

The normalized optical intensity of the pulse can be expressed as

$$\frac{I_r(t)}{I_r(t=0)} = \left\{ \frac{\sin^2(m \cos(\omega_m t)}{(1 - \sin(m \cos(\omega_m t))^2} \right\} / \left\{ \frac{\sin^2(m)}{(1 - \sin(m))^2} \right\}$$

..........(7)

The variation of the normalized optical pulse intensity with time is shown in Fig.2(a), 2(b) and 2(c). In numerical calculations, the frequency of the microwave drive signal is taken to be 50 GHz and the drive parameter m = 0.5 , 0.75 and 1 respectively.

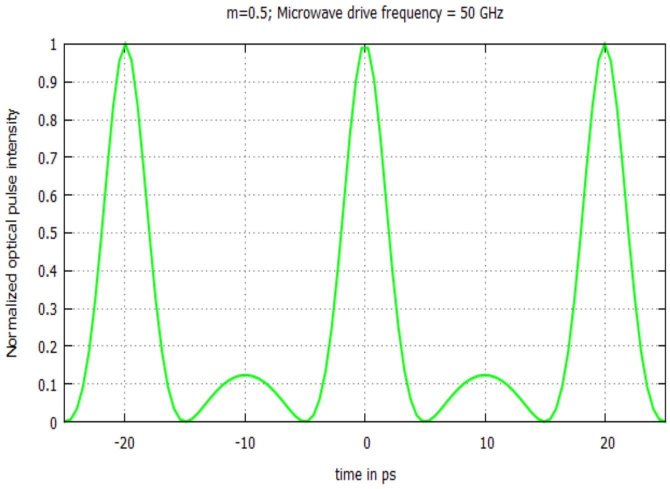

Figure 2 (a)

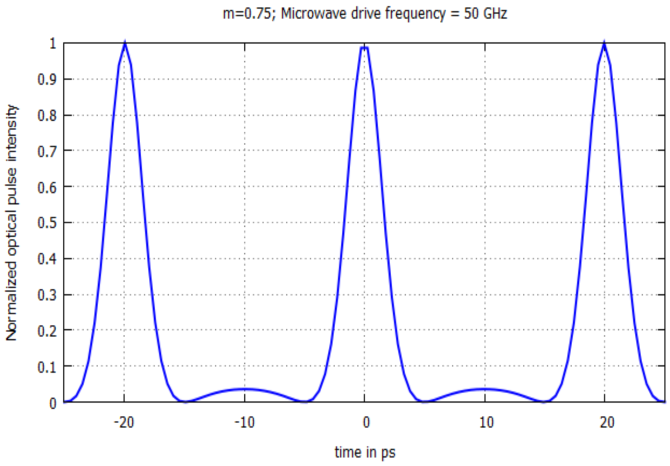

Figure 2(b)

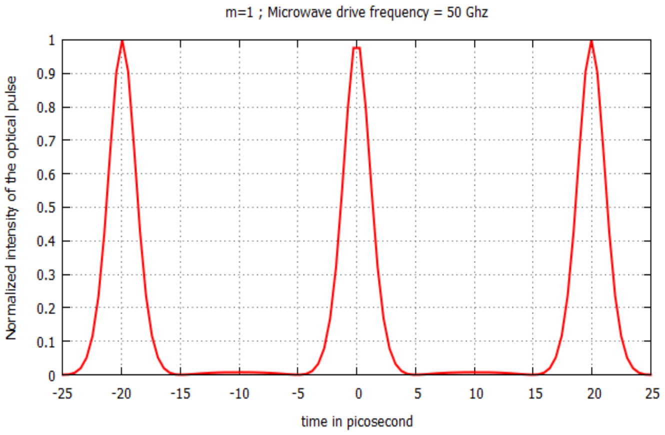

Figure2(c)

Fig.2. The variation of the normalized optical pulse intensity with time.

From Fig.2., it can be observed that keeping the applied microwave drive frequency at 50 GHz, an increase in the value of the drive parameter produces a change in the shape of the generated optical pulse and a decrease in the optical pulse width. In Fig.3, the variation of the normalized intensity profile of a single optical pulse with time is shown taking the modulator drive parameter m as a parameter. The full width of the optical pulse at half intensity maximum (FWHM) has been calculated from this figure. The optical pulse width of the generated pulse can be made as small as 1 picosecond (ps) when m is chosen to be 1.5.

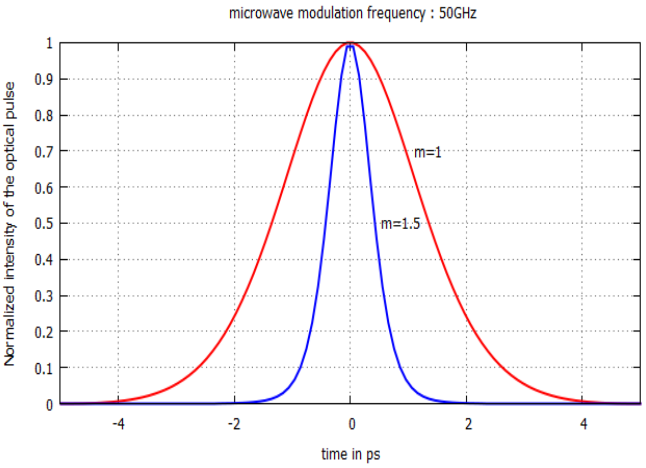

Fig.3. The variation of normalized pulse intensity with time for a single pulse taking the modulator drive factor "m" as a parameter.

The variation of the optical pulse width with modulation drive frequency is shown in Fig.4. It can be observed that the optical pulse width decreases with the increase in modulation frequency.

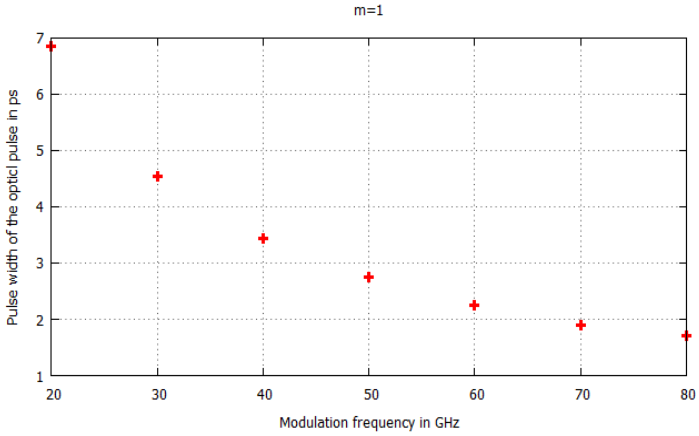

Fig.4. The variation of the optical pulse width with modulation drive frequency.

IV. CONCLUSION

A technique for the generation of ultrashort optical pulse using Mach-Zehnder light intensity modulator placed in an optical feedback loop is proposed. The optical feedback loop is constructed using a pair of half mirrors and full mirrors.

An erbium doped fiber amplifier is included in the feedback loop. Since the M-Z modulator is placed in an optical feedback loop, the CW lightwave from a laser diode is intensity modulated multiple times. The intensity modulated lightwaves are superposed to produce the optical pulse. The variation of the normalized intensity of the pulse with time is plotted. The generated pulse shape and pulse width depend on the applied microwave drive voltage and drive frequency. The pulse width decreases with the increase in modulator drive voltage and frequency.

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