PICOSECOND OPTICAL PULSE GENERATION USING CASCADED MACH-ZEHNDER ELECTRO-OPTIC LIGHT INTENSITY MODULATORS

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Abstract

In this paper, the author proposes a technique for the generation of picosecond optical pulses using cascaded Mach-Zehnder electro-optic light intensity modulators. Each individual Mach-Zehnder modulator is driven by the same microwave signal. By providing proper dc bias to the modulators, the repetition frequency of the generated optical pulse can be made equal to twice the frequency of the applied microwave drive signal. By tuning the microwave drive frequency, the repetition frequency of the generated optical pulse can be varied. The normalized optical pulse intensity and pulse width of the generated pulse have been calculated. The variation of the pulse width with different system parameters is also presented. Typical pulse width of 2.52 picosecond can be achieved using a cascade of four modulators driven by 60 GHz mm-wave signal.

Keywords: *Optical pulse generation, pulse repetition frequency, pulse width, Mach-Zehnder modulator, cascade modulation.*

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1. INTRODUCTION

Optical time division multiplexing is an attractive multiplexing technique for carrying high bit rate data over optical fiber. One of the main components in an OTDM communication system is a short optical pulse generator with high repetition rate. The shorter the optical pulse width, the more is the number of optical channels multiplexed in time domain. Different pulse generation techniques are found in literature [1-14]. Mode-locked lasers act as the optical pulse source in OTDM communication system. CW lasers externally modulated by electro optic modulator or electro absorption modulators are also used as short pulse generators.

In this paper, we propose a method of generating short optical pulse with high repetition frequency using LiNbO3 Mach-Zehnder (M-Z) electro-optic light intensity modulators connected at tandem. The CW light from a laser diode (LD) is intensity modulated by the M-Z modulators. Each M-Z modulator is driven by the same microwave signal. The components required for the implementation of the proposed pulse generator are commercially available. The intensity profile of the generated pulse is calculated and the pulse width is evaluated.

2. SYSTEM DESCRIPTION

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 a cascade of four Mach-Zehnder light intensity modulators (MZM1, MZM2, MZM3 & MZM4). The light wave from the LD is fed to MZM1. The optical intensity modulated light at the output of MZM1 is fed to MZM2 and so on. The modulators are assumed to be identical. Each modulator is driven by the same microwave signal. The dc biases applied to the modulators are chosen to be equal to V_π, where V_π is the half-wave voltage of the modulator. The half-wave voltage of the modulator is defined to be the voltage which when applied to the electrodes of the modulator produces a phase shift of π radian of the propagating light wave. By choosing the dc bias $V_{dc} = V_\pi$, the output light intensity is modulated by second and higher order even harmonics of the modulation frequency. At the output of the fourth modulator (MZM4), the optical pulse is generated.

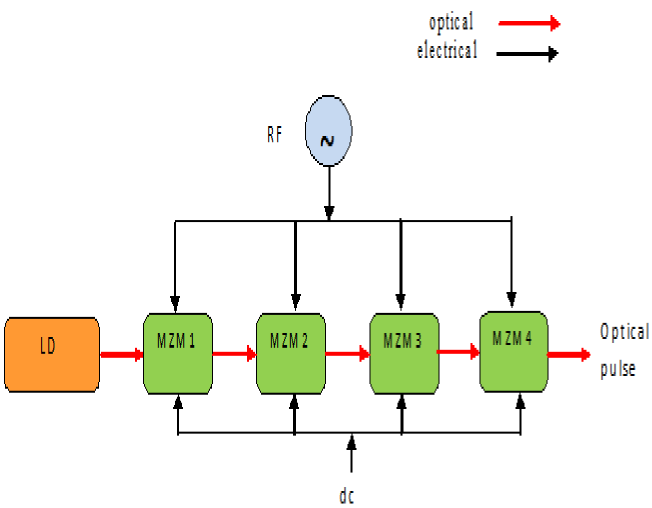

Fig 1 A schematic circuit diagram of the proposed optical pulse generator. LD: laser diode; MZM: Mach Zehnder modulator ; RF: microwave modulating source ; dc: dc bias

3. ANALYSIS

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

$$a=|a|\exp j(\omega_c t+\theta) \qquad (1)$$

Where $|a|$ is the peak amplitude of the electric field is, ω_c is the angular frequency of the lightwave and θ is the phase angle. The CW frequency of the lightwave corresponds to the operating wavelength of 1.55 µm. The optical fiber loss at this wavelength is minimum and is equal to 0.2 dB/km.

Let us assume that same microwave signal is applied to the four identical Mach-Zehnder modulators (MZM1, MZM2, MZM3 and MZM4).

The microwave signal voltage applied to each modulator is given by

$$v_m(t) = V_m \cos(\omega_m t) \qquad \ldots\ldots\ldots\ldots(2)$$

Where V_m is the voltage amplitude of the microwave signal and ω_m is the angular frequency in radian.

The dc bias applied to the modulators, $V_{dc}=V_\pi$ where V_π is the half-wave voltage of the modulator.

The optical intensity at the output of the Mach-Zehnder modulator (MZM1) can be expressed as

$$I_1(t) = (I_{in}/2)[1+\cos(\phi_{dc}+\phi_{m)}(t)] \qquad (3)$$

Where I_{in} is the input optical intensity, $\phi_{dc}=\pi\frac{V_{dc}}{V_\pi}$ and $\phi_m(t)=(\pi\frac{V_m}{V_\pi})\cos\omega_m t$.

The dc bias is chosen so that $V_{dc}=V_\pi$ and hence $\phi_{dc}=\pi$. Under this condition eqn.(3) is given by

$$I_1(t)=(I_{in}/2)[1-\cos(m\cos(\omega_m t)] \qquad (4)$$

Where $m=(\pi\frac{V_m}{V_\pi})$ is a measure of the intensity modulation index.

Eqn (4) can be expanded as

$$I_1(t)=\frac{I_{in}}{2}[1-\{J_0(m)+2\sum_{n=1}^{\infty} J_{2n}(m)\cos(2n\omega_m t)\}] \qquad (5)$$

Where $J_k(x)$ is Bessel function of first kind of order k and argument x.

It can be seen that the output intensity is modulated by second and higher order even harmonics of the modulation frequency. This intensity modulated lightwave is again modulated by the second modulator.

The optical intensity at the output of the second modulator (MZM2) is

$$I_2(t)=(I_1/2)[1-\cos(m\cos(\omega_m t)] = (I_{in}/2^2)[1-\cos(m\cos(\omega_m t))]^2 \qquad (6)$$

Similarly, the optical intensity of the generated optical pulse at the output of the 4th modulator (MZM4) is calculated to be

$$I_4(t)=\prod_{n=1}^{4}\frac{I_{in}}{2^n}[1-\cos(m\cos(\omega_m t))]^n = \frac{I_{in}}{2^4}[1-\cos(m\cos(\omega_m t)]^4 \qquad (7)$$

The normalized optical intensity of the pulse can be expressed as

$$\frac{I_4(t)}{I_4(t=0)} = [1-\cos(m\cos(\omega_m t))]^4/(1-\cos(m))^4 \quad (8)$$

In Fig.2, the variation of the normalized optical pulse intensity with time is shown. In numerical calculations, we took microwave modulation frequency $f_m = 40\,GHz$ and intensity modulation index, $m = 2$. The full width of the generated pulse at half the maximum intensity is found to be 3.92 ps. The repetition frequency of the generated optical pulse is 80 GHz. By changing the microwave drive frequency, the repetition frequency of the pulse can be tuned.

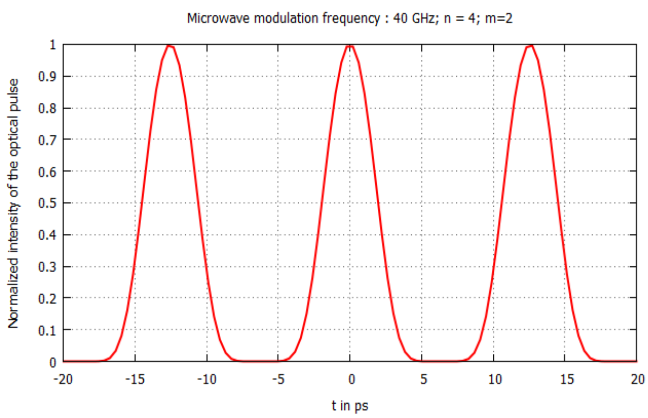

Fig 2 Variation of the normalized intensity of the generated optical pulse with time

If two Mach-Zender modulators are taken, the calculated intensity profile of the generated pulse is shown in Fig.3. From the fig., we can see the pulse width decreases with the increase in the number of modulators.

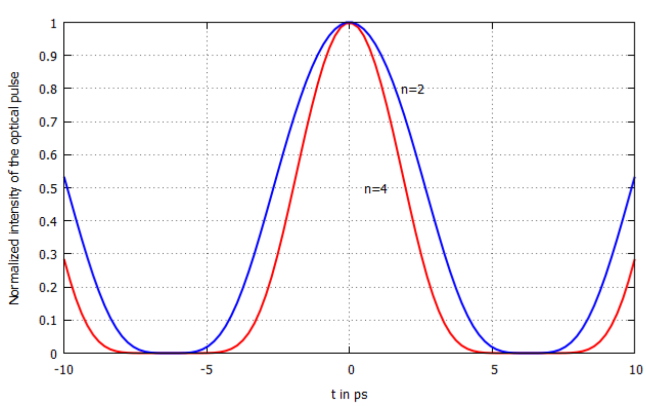

Fig 3 Same as in Fig.1 showing a single pulse. "n" corresponds to the number of M-Z modulators.

The effect of the microwave modulation drive frequency f_m on the characteristics of the pulse can be observed from Fig.4. All the other parameters remaining the same, if f_m is increased, optical pulse width decreases. If f_m = 60 GHz, the pulse width is 2.52 ps.

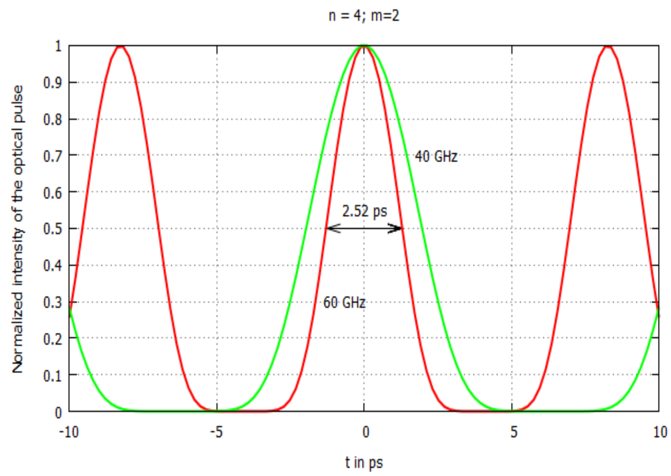

Fig 4 Normalized intensity profile of the pulse using microwave modulation frequency as parameter

Typical optical pulse widths for different cases are summarized in Table –1.

Table-1

Number of M-Z modulators connected in tandem (n)	Microwave modulation frequency (GHz)	Repetition Frequency of the generated optical pulse (GHz)	Generated Optical pulse width (ps)
2	40	80	5.4
2	60	120	3.5
4	40	80	3.92
4	60	120	2.52

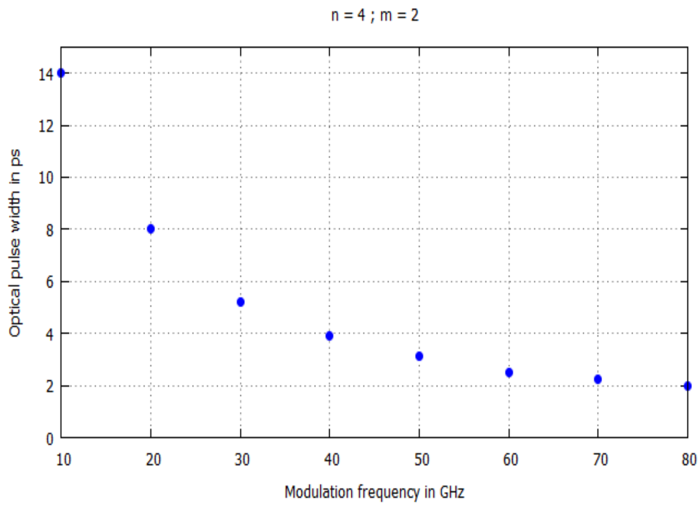

Fig 5 Variation of generated optical pulse width with applied modulation frequency.

Fig.5 shows that the pulse width decreases with increasing modulation frequency.

4. CONCLUSIONS

A method for the generation of picosecond optical pulse using Mach-Zehnder light intensity modulators is proposed. The same microwave signal source drives the multiple Mach-Zehnder modulators connected at tandem. The CW lightwave from a tunable laser diode is repeatedly modulated by the multiple M-Z modulators. By applying proper dc bias to the modulators, the repetition frequency of the generated optical pulse can be made twice the value of the applied microwave frequency. So, by changing the microwave drive frequency, the repetition rate can be tuned. The normalized intensity profile of the generated pulse is numerically calculated and its variation with time is shown. The pulse width of the generated optical pulse at half intensity maximum can be evaluated from the intensity profile curve. Using four Mach-Zehnder modulators, and choosing microwave modulation frequency f_m to be 60 GHz, the pulse width is found to be 2.52 ps. If f_m is further increased, the pulse width can be made smaller. The center frequency of the pulse can be varied by tuning the laser diode. The novelty of the proposed design is the high repetition rate of the pulse and its tunability.

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