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Measurement of Chirp Parameters and Halfwave Voltages of Mach Zehnder-Type Optical Modulators by Using a Small Signal Operation

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***Abstract* — A method is described for measuring the chirp parameters and the halfwave voltages of Mach-Zehnder-type optical modulators. These parameters can be obtained from the optical spectrum components by using a small signal operation, while the conventional method needs large voltages. We demonstrated the measurement of the frequency responses up to 40 GHz.**

***Index Terms*—Chirp parameter, halfwave voltage, Mach-Zehnder (MZ) structure, optical harmonics, optical modulator.**

I. INTRODUCTION

$LiNbO_3$ (LN) OPTICAL modulators, using Mach−Zehnder (MZ) waveguide structures, are essential for optical and wireless telecommunication networks, such as broad-band optical networks up to 40 Gb/s for trunk lines [1], and narrow-band optical networks for fiber-radio systems [2]. For such optical modulators, the estimation of the halfwave voltage and the chirping at high frequency is required. The halfwave voltage, which is the voltage to switch an optical output power from the maximum to the minimum, is required to drive an optical modulator. In addition, *Z*-cut LN optical modulators have small chirping because the radio frequency (RF) electric fields applied to the optical paths of the MZ structures are asymmetric. The chirp parameter of an optical modulator can be easily measured by using dispersive media such as optical fibers [3]. However, by the conventional method, we can not measure a chirp parameter at a specific frequency. We reported a method to measure simultaneously chirp parameters and halfwave voltages of LN optical modulators by using a large signal operation [4]. We calculated these parameters from the high-order optical harmonics. Chirp parameters, halfwave voltages, and even bias points were accurately measured at specific frequencies by this method. But it was difficult to measure these parameters over a wide frequency range because of a narrow-band operation of a high power amplifier. In this letter, we propose a method to measure chirp parameters and halfwave voltages of an MZ-type optical modulator by using a small signal operation. These parameters are calculated from two optical spectrum components, the carrier and the first harmonic. Thus, the frequency response of these parameters over a wide frequency range can be evaluated without using higher order optical components.

II. PRINCIPLE

Consider an output lightwave from an MZ-type optical modulator whose electric field $E(t)$ is described by

$$
\begin{aligned}
E(t) &= \frac{E_i e^{j\omega_0 t}}{2}\{\exp[jA_1 \sin\omega_m t + j\phi_{B1}] \\
&\qquad + \exp[jA_2 \sin\omega_m t + j\phi_{B2}]\} \qquad (1)\\
&= \frac{E_i e^{j\omega_0 t}}{2}\left\{\sum_{n=-\infty}^{\infty} J_n(A_1)\exp[jn\omega_m t + j\phi_{B1}]\right. \\
&\qquad \left. + \sum_{n=-\infty}^{\infty} J_n(A_2)\exp[jn\omega_m t + j\phi_{B2}]\right\} \qquad (2)
\end{aligned}
$$

where $E_i e^{j\omega_0 t}$ is the electric field of the incident light. ϕ_{B1} and ϕ_{B2} are the phase delays due to the difference in optical length between paths. ω_m $(=2\pi f_m)$ is the angular frequency of the electric signal fed to the optical modulator. J_n is the first kind Bessel function of the order n. A_1 and A_2 are the magnitude of the optical phases induced by the RF electric field applied to each optical path of the MZ waveguides.

As shown in (2), the modulated output lightwave from an optical modulator has many frequency components. Now we attend to two frequency components. One is the frequency component of the carrier (carrier component, henceforth) and the other is that of the first-order harmonic (first component). The optical power of the carrier component, $n = 0$ in (2), is expressed by

$$
\begin{aligned}
P_0 = E_i^2\,[&\{J_0(A_1)\}^2 + \{J_0(A_2)\}^2 \\
&+ 2J_0(A_1)J_0(A_2)\cos(\phi_{B2} - \phi_{B1})]/4. \qquad (3)
\end{aligned}
$$

The optical power of the first component, $n = 1$ in (2), is expressed by

$$
\begin{aligned}
P_1 = E_i^2\,[&\{J_1(A_1)\}^2 + \{J_1(A_2)\}^2 \\
&+ 2J_1(A_1)J_1(A_2)\cos(\phi_{B2} - \phi_{B1})]/4. \qquad (4)
\end{aligned}
$$

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When no electric signal is applied to the optical modulator, A_1 and A_2 are equal to zero. From (3), the optical power P'_0 is expressed by

$$P'_0 = E_i^2\left[1+\cos(\phi_{B2}-\phi_{B1})\right]/2 \tag{5}$$

$$\equiv P_{0N}\left[1+\cos(\phi_{B2}-\phi_{B1})\right]/2. \tag{6}$$

P_{0N} shows the peak power of the carrier from an optical modulator. P'_0 depends on the phase delay ϕ_B ($=\phi_{B2}$ - ϕ_{B1}) which is proportional to the dc-bias voltage applied to an optical modulator. We used two dc-bias points, the Bias I ($P'_0 = P_{0N}$) and the Bias II ($P'_0 = 0$), because these dc-bias points were at $dP'_0/d\phi_B = 0$. At the Bias I, P_0 has the maximum (P_{0a}) while P_1 has the minimum. At the Bias II, P_1 has the maximum (P_{1b}) while P_0 has the minimum. Thus, we can accurately measure P_0 at the Bias I and P_1 at the Bias II because the other frequency components are much smaller than the desired component. P_{0a} and P_{1b} are normalized by P_{0N} , and are expressed by

$$P_{0a}/P_{0N} = \left[\{J_0(A_1)\}^2+\{J_0(A_2)\}^2+2J_0(A_1)J_0(A_2)\right]/4 \tag{7}$$

$$P_{1b}/P_{0N} = \left[\{J_1(A_1)\}^2+\{J_1(A_2)\}^2-2J_1(A_1)J_1(A_2)\right]/4. \tag{8}$$

The number of these equations is equal to that of unknown variables, A_1 and A_2, but these equations are transcendental. We solve these equations for A_1 and A_2 where we select the smallest answers, because the voltage applied to the optical modulator is small. By using A_1 and A_2, we calculate the halfwave voltages and the chirp parameters of an optical modulator. The halfwave voltage V_π is expressed by

$$V_\pi = \pi V_m/(A_1-A_2) \tag{9}$$

where V_m is the amplitude of applied voltage to the optical modulator.

On the other hand, chirp parameters are dependent on the dc-bias points ϕ_B and the induced optical phases A_1 , A_2 . When we assume that $\phi_B = -\pi/2$ and a small amplitude modulation (A_1 , $A_2 \ll 1$), the chirp parameter α_0 can be expressed by [4]

$$\alpha_0 = (A_1+A_2)/(A_1-A_2). \tag{10}$$

Thus, V_πs and α_0s are the intrinsic parameters to an optical modulator and depend on the device structures of optical modulators, such as the relation between the optical waveguides and the electrodes.

We note that these parameters for a dual-drive modulator can be obtained by a couple of successive measurement where one of the electrodes is short-circuited and the RF signal is fed to the other.

III. EXPERIMENTAL RESULTS

Fig. 1 shows the experimental setup. We tested a *Z*-cut MZ-type $LiNbO_3$ optical-intensity modulator. A polarization of an incident light was adjusted to the maximum electrooptical efficiency of the tested modulator by a polarization controller.

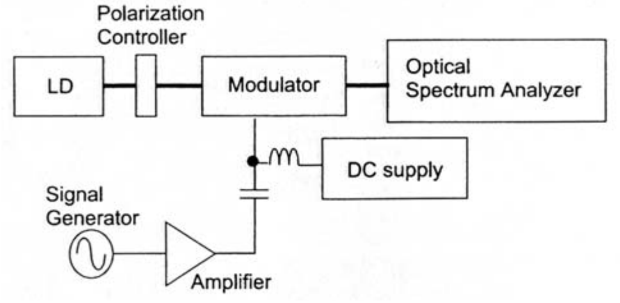

Fig. 1. Setup of measurement.

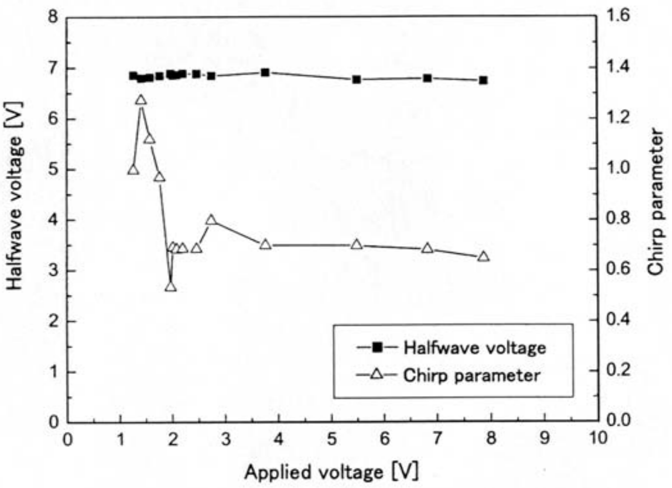

Fig. 2. Halfwave voltage and chirp parameter as a function of applied voltage. The frequency of the electric signal fed to the tested modulator was 10 GHz.

We measured P_{0N}, P_{0a}, and P_{1b} by using an optical spectrum analyzer (OSA). Fig. 2 shows a result which is measured by various amplitude of the applied voltage at 10 GHz. As a result, the V_π of the tested modulator is 6.9 V in a 1.55-μm region. The V_πs were constant when the amplitude of applied voltages was changed from 1.3 to 8 V, where the amplitude corresponded from about 0.2 to 1.2 V_π. This result shows the method to be effective, because the measured values were independent of the applied voltages. And α_0 was 0.76 by the proposed method while α_0 was 0.79 by the conventional method [3]. But, in the proposed method, when the applied voltage was smaller than 2 V (0.3 V_π), the measured values changed widely, while α_0 is theoretically independent of the voltage. When the applied voltage is small, the signal-to-noise ratio (SNR) in the measurement of A_2 is much smaller than that of A_1, where $|A_1|$ is assumed to be larger than $|A_2|$. As shown in (9) and (10), α_0 depends on the ratio between A_1 and A_2 , while A_1 is dominant in the denominator of V_π , so that the SNR of α_0 was much smaller than that of V_π.

Fig. 3 shows frequency response from 10 to 40 GHZ When the amplitude of the applied voltages is about 3 V. The lower frequency limit was dominated by the resolution of the OSA (6 GHz). We compared the result between the proposed method and the previous method [4]. α_0 and V_π at 32 GHz Were 0.77 and 9.7 V by this proposed method while these parameters were 0.77 and 10 V by the previous method , respectively. These results are in agreement with the conventional methods [3], [4].

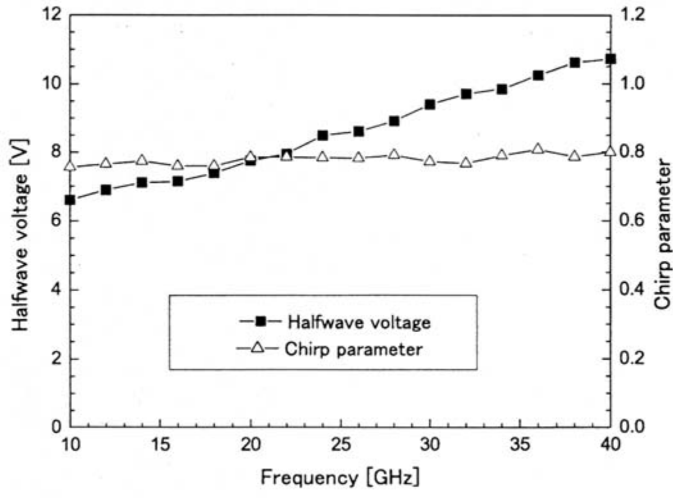

Fig. 3. Halfwave voltage and chirp parameter as a function of applied frequency. The amplitude of applied voltages was about 3 V when we measured these parameters.

IV. CONCLUSION

We proposed a method to measure the halfwave voltages ($V\pi$s) and the chirp parameters of MZ-type optical modulators. In this method, we obtained these parameters by using a small signal operation. We demonstrated that it was possible to measure these parameters by using 0.3 V_π and to evaluate the frequency response of these parameters from 10 to 40 GHz.

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