Analog-to-digital conversion experiments using a $LiNbO_3$ balanced bridge modulator

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One-bit electro-optical analog-to-digital conversions of up to 100-MHz signals were carried out in a system using a Ti-diffused $LiNbO_3$ balanced bridge modulator and a 1.15-μm cw He-Ne laser. The modulators have a new configuration with a phase shifter formed by Ti double diffusants and revealed relatively low half-wave voltages and high extinction ratios.

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A new analog-to-digital conversion (ADC) method, utilizing optical waveguide modulators, has been proposed by Taylor.[1] It is expected that, using the proposed method with gigahertz optical modulators, such high-bit rate conversion as 10^8–10^9 samples/sec can be realized in a simple system. Taylor also reported[2] the fundamental ADC operation performance of a $LiNbO_3$ *Y*-branched interferometric modulator. The derive has low half-wave voltages V_π, such as 1.2 V for TE polarization and 3.1 V for TM at $\lambda = 0.63\ \mu$m with a 17-mm phase shifter electrode. However, these modulators are comprised of *Y*-branched and curved waveguides, which lead to the deleterious effects of large insertion loss and low extinction ratio.

From this point of view, the balanced bridge-type Ti-diffused $LiNbO_3$ modulators were designed for ADC applications. This letter presents the characteristics of the modulators and the results of a 100-MHz, one-bit electro-optic ADC operation first using these kinds of devices.

The configuration of the $LiNbO_3$ balanced bridge modulators[3] fabricated for ADC application is shown in Fig. 1. The device is composed of two 3-dB couplers and a phase shifter built in a pair of straight waveguides. The phase shifter is formed by a Ti double diffusion in the cross-hatched regions in Fig. 1, instead of by the ion etching method.[4] The couplers[5] have a pair of electrodes for adjustment. The dimensions of each part of the fabricated devices are summarized in Table I. An Al_2O_3 1100-Å-thick buffer layer is used.[6] It was separated with a 4-μm gap between the waveguides for suppressing[7] dc drift. Three pairs of Al lumped electrodes are formed on top of the buffer layer.

Table II shows the low-frequency modulation characteristics for two fabricated devices. The guided modes are

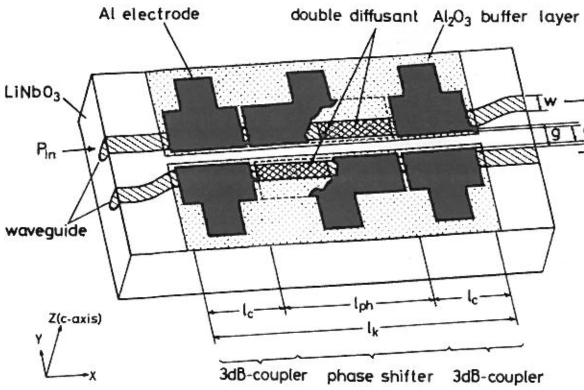

FIG. 1. Configuration of an $LiNbO_3$ balanced bridge modulator fabricated for ADC operation.

TM-like fundamental modes in both cases. Although the values of V_π are relatively low, they are 40–60% larger than the calculated values (3.3 V for No. 1 and 2.4 V for No. 2) for reasons not yet clear. A phase shifter length l_{ph} (8 mm), which is about half that of Taylor's device, was selected for a smaller optical transition time in high-speed operations in future. The values of the extinction ratios (ER) were obtained with no dc biases applied to 3-dB couplers, and were not as high. In order to improve the ER, 10–20-V dc voltages were applied to the couplers. The resultant ER values are 16.8 dB for No. 1 and 11.4 dB for No. 2.

High-speed ADC operation is carried out in the experimental arrangement as shown in Fig. 1 of Ref. 1. The modulator No. 1 is used and the bandwidth to the 3-dB power point was estimated at about 1 GHz. The comparator has ECL outputs and typically 1–2-ns rise and fall times. As pointed out by Taylor,[1] a functional merit of the balanced bridge-type modulator is its two complementary outputs, which are equally affected by light-source fluctuation. By using devices of this structure in ADC systems, the effects of fluctuations, which are an important source of conversion error, can be eliminated.

Figure 2 shows the conversion results. Two kinds of conversion operations were carried out. One is a one-bit conversion applying $V = V_\pi$ peak microwave voltage plus $V_{dc} = V_\pi/2$ dc bias to the phase shifter electrode. The other is a quasi-two-bit conversion obtained when $V = 2V_\pi$ peak microwave voltage. The results of the former operation are indicated in Figs. 2(a) and 2(b) for $f = 10$ MHz and $f = 100$ MHz, respectively. In these figures, analog sine waves are correctly converted to the rectangular waves with the same period. However, the comparator output at 100 MHz begins to show distortion, mainly due to its bandwidth limitation. The latter conversion is shown in Fig. 2(c). In this case, a 10-

TABLE I. Dimensions of fabricated modulators. L is the overall length of the sample. Others indicate dimensions shown in Fig. 1.

Sample No.	L	l_k (mm)	l_c	l_{ph}	w	g (μm)	g_c
1	25	15	4	8	8.0	5.4	5.4
2	27	20	6	8	5.5	5.6	5.4

TABLE II. Low-frequency characteristics of the modulators. ER is the extinction ratio, IL the insertion loss, and V_{dc} the dc biases applied to the 3-dB couplers.

Sample No.	λ (μm)	mode	V_π (V)	ER (dB)	IL (dB)	V_{dc} in (V)/ out (V)
1	1.15	TM_0	5.31	15.3	10.5	0/0
2	0.85	TM_0	3.44	8.9	...	0/0

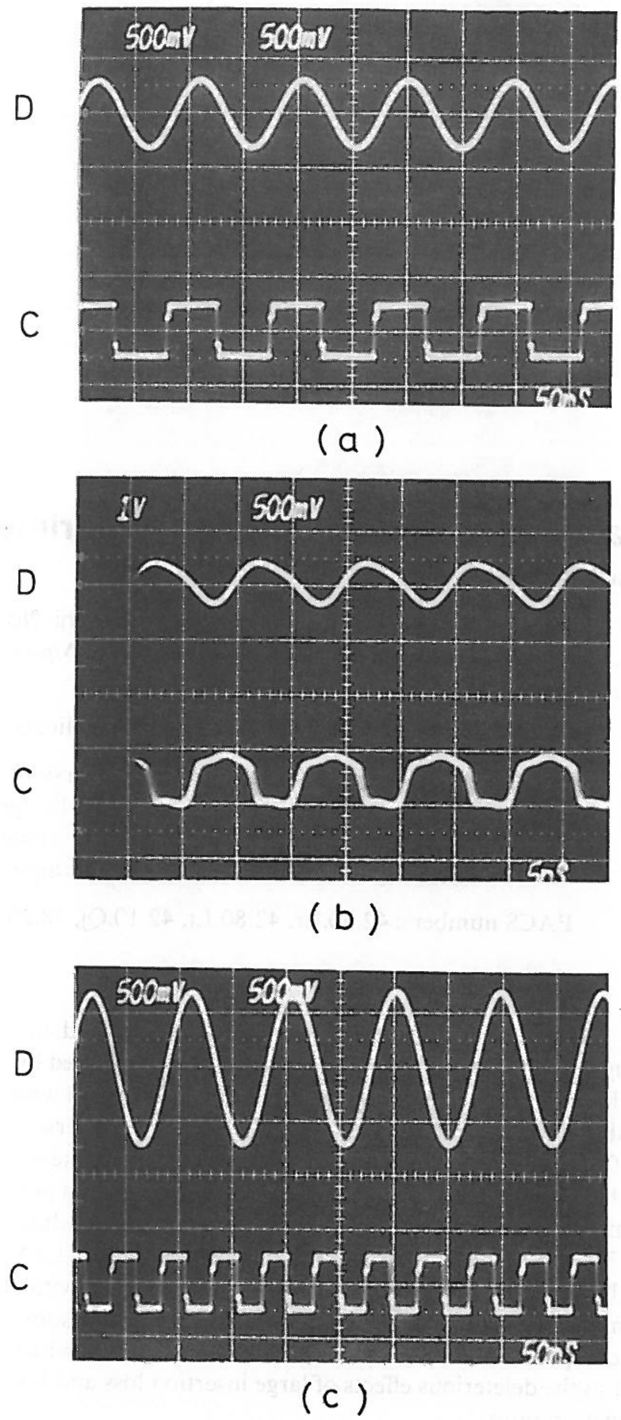

FIG. 2. One bit cell ADC experimental results using modulator No. 1: D = driving voltage, C = comparator output. (a) $f = 10$ MHz, (b) $f = 100$ MHz, (c) $f = 10$ MHz quasi-two-bit conversion.

MHz sine wave is converted to a rectangular wave of twice the period (20 MHz). The results obtained here confirm the possibility of a high bit rate and a multibit converter using this kind of device.

Ti-diffused $LiNbO_3$ balanced bridge modulators, which have a phase shifter formed using a double diffusant method, were fabricated for use in a high-speed optical ADC system. Fundamental performances of the device were $V_\pi = 5.3$ V and ER = 15.3 dB for $\lambda = 1.15\ \mu$m, and $V_\pi = 3.4$ V and ER = 8.9 dB for $\lambda = 0.85\ \mu$m. The phase shifter length was 8 mm. Well-regulated sinusoidal output characteristics were observed in both cases.

Using this device, one-bit cell ADC operation was carried out with a $\lambda = 1.15$-μm cw light source. Successful conversions were confirmed up to the comparator bandwidth limit of about 100 MHz.

The results reported here prove that the devices perform sufficiently well to be applied in an optical ADC system. However, they are still only the first step in realizing an ADC system utilizing optical waveguide modulators. Several problems such as multibit and monolithic device fabrication and faster electronic or optic comparators development remain to be solved.

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