cross-point of the driver output waveform was adjusted. Fig. 3 shows the measured 40Gbit/s bit error rate (BER) versus the received optical power with optical output waveforms. We measured the BERs of all 10Gbit/s 4 channels, and plotted the average of the BERs. The minimum receiving sensitivity was less than -7.0dBm, and the degradation in sensitivity after SMF 2km transmission was 0.5dB at BER of 10^{-12}. Since electrical multiple reflection was suppressed by the shorten length between EA modulator chip and driver IC, optical output waveform with good S/N was obtained, which contribute the good minimum receiver sensitivity. The small-chirp EA modulator chip with novel tensile strained asymmetric quantum well absorption layer suppressed the power penalty caused by chromatic dispersion after 2km single mode fiber transmission to be less than 0.5dB with clearly opened eye.[7] Extinction ratio of 9.0dB was obtained with 0.5Vpp driving. Table 1 shows a summary of module properties. The power consumption of the module was 2.1W, the wavelength of CW LD was 1565nm, and insertion loss was 8.2dB at 0V-bias.

4. Conclusion

We have fabricated 0.5Vpp-drive small-chirp 40Gbit/s EA modulator module with hybrid-integrated driver IC for 40Gbit/s transmission systems. Since the optical output vs. EA bias voltage has non-linear curve, the driver IC's electrical output waveform is adjusted to have inversely non-linear, which result the compensation. 40Gbit/s NRZ operation with extinction ratio of 9.0dB, minimum receiver sensitivity of -7.0dBm, and power penalty after SMF 2km transmission of 0.5dB were demonstrated with differential input of 0.5Vpp supposing MUX output. Since the small chirp modulator suppressed the power penalty caused by chromatic dispersion, clearly opened eye was obtained even after SMF 2km transmission. This module is very promising compact solution for the 40Gbit/s transmission systems.

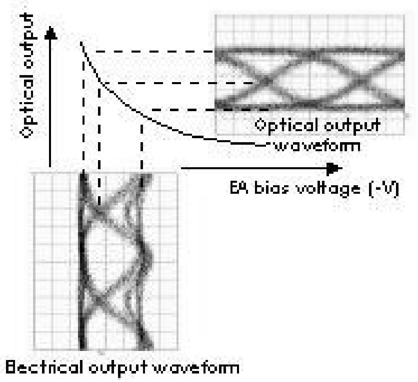

Fig. 2. Schematic of extinction characteristics.

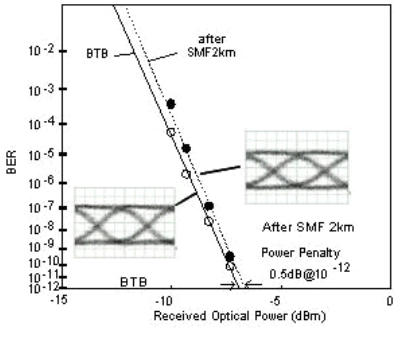

Fig. 3. Measured 40Gbit/s BER vs. received optical power.

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FO7 12:00 PM

High Gain 40 Gb/s InP HBT Drivers for EO/ EA Modulators

K. Krishnamurthy, R. Pullela, J. Chow, J. Xu, S. Jaganathan, D. Mensa, Gtran Inc, Newbury Park, CA; M. Rodwell, *Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA, Email: karthik_krishna@yahoo.com*.

Single chip high gain InP HBT modulator drivers for 40GB/s systems are presented. With 30dB gain, 41GHz bandwidth and 6Vp-p differential output, the need for external pre-amplifiers and bias networks are eliminated. Transmitter performance with EO/EA modulators are evaluated.

1. Introduction

As OC-768 (40 Gb/s) systems reach commercial deployment, there is a need for low cost integrated IC solutions that enable transponder manufacturers to meet performance, power and size constraints. The typical transmit section in a 40 Gb/s transceiver consists of a modulator driver, an optical modulator and an externally modulated CW laser. Such transmitters require modulator drivers (MD) with high bandwidth and large modulation swing. Lithium Niobate electro-optic (EO) modulators require up to 6 Vp-p drive and electro-absorption (EA) modulators could require up to 3 Vp-p swing to obtain good extinction ratio. Distributed amplifier (DA) based drivers have been reported [1,2], but with voltage gains typically less than 10 dB under large signal limiting conditions. In such cases pre-amplification IC's are required between the 40 Gb/s multiplexer providing CML level swings and the driver. Off-chip broad-band biasing networks are often required to interface these different IC's with the penalty of increased size, complexity and packaging cost. Alternatively, high gain single chip lumped 40 Gb/s drivers employing cascaded differential amplifiers offer higher gain and differential output [3,4,5]. Capacitances associated with the large transistor sizing at the output, limit the designs to lesser swings or reduced bandwidth. A combination of lumped pre-driver and distributed driver using differential amplifier cells has been realized at 10 Gb/s with high gain and fast edge speeds, and was intended for differential drive EO modulators [6]. Realization of DAs with differential cells at 40 Gb/s is complicated because of layout issues. Mismatch of differential transmission lines, coupled with the reduced line lengths at higher frequencies, makes the layout impractical at times.

We report InP DHBT based 40 Gb/s differential modulator drivers (GT40-1010MD-2) using broadband lumped preamplifier stages and a differential DA stage. With 30 dB small signal gain and 41 GHz bandwidth, a 250 mVp-p single-ended input drive is sufficient to provide 6Vp-p differential output from a single chip and without external biasing networks. Additional features include modulation current control to adjust the output swing, cross-point control to change the zero crossing from 40% to 75% and output power down option. Monitor pin for modulation current is available for external closed-loop automatic power control. Transmitter performance when driving a differential EO modulator is evaluated. A second IC (GT40-1010MD-1) with similar performance, but with a single-ended output was also designed to drive electro-absorption (EA) modulators requiring less than 3 Vp-p drive. Test results when driving a EA modulator is provided. Typical power dissipation of the differential and single-ended drivers are 2.8W and 1.8W respectively.

2. Circuit Design

Fig. 1 shows the schematic block diagram of the differential MD. To obtain 30 dB linear gain, a broadband preamplifier stage consisting of alternating trans-admittance (TAS) and trans-impedance (TIS) stages was used. Low inter-stage impedance provided by this architecture [7] greatly extends the bandwidth. Under large-signal operation the pre-driver provides a limiting output of 1.8 Vp-p differential with as little as 250 mVp-p single-ended input. The differential output drives two individual 10 cell DA designed for 3 Vp-p swing. Each cell of the DA consists of an emitter follower stage driving a differential pair with emitter degeneration. The unused input of the differential pair is connected to a DC reference (Vxpp, Vxpn in Fig. 1) that sets the cross-point of the output.

The DA was optimized for best large signal performance. As a starting point, frequency domain simulations using linear models were used to design the transmission line sections for maximum overall bandwidth and minimum return losses. In large signal operation variation of the junction capacitances have to be accounted. Time-domain simulation using a step input was used to further optimize the transmission line lengths to minimize reflections. Also the loaded transmission line propagation delays were matched for the input and output lines. This approach optimizes the design for reduced jitter, faster transition times and minimum overshoots. Simulations showed that a positive small-signal gain slope with frequency was required for faster transition times. The DA was designed for 3 dB small signal gain peaking about 40 GHz. A second design with single-ended output, intended for EA modulators, was implemented by using a single DA output stage and terminating the complementary output of the preamplifier.

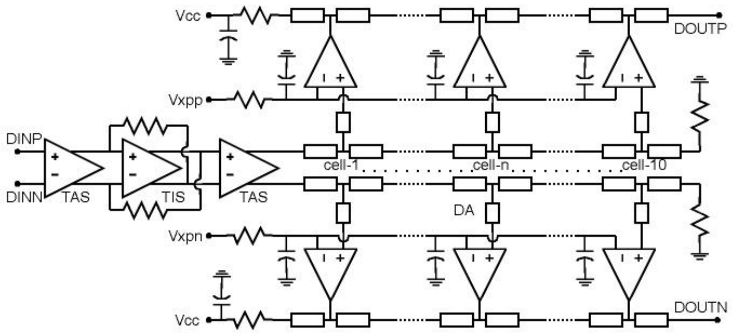

Fig. 1. Schematic block diagram of the differential modulator driver.

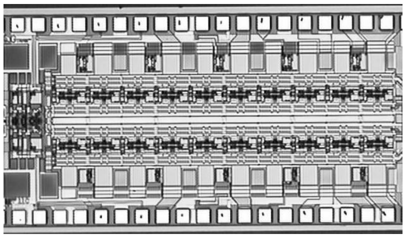

Fig. 2. Photograph of the differential modulator driver IC (GT40-1010MD-2X).

IC's were fabricated (Fig. 2) in a InP/InGaAs DHBT technology with 140 GHz ft and 160 GHz fmax. The drivers were packaged in a high frequency ceramic package with 2.4 mm connectors, and operate from +3.3 V / -4.2 V supplies, dissipating 2.8 W for the differential version and 1.8W for the single-ended version. The die sizes are 3.3 mm x 1.5 mm and 3.3 mm x 1 mm respectively.

3. Measurement Results

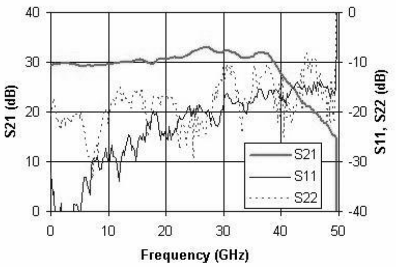

Fig. 3. On-wafer S-parameters of the differential modulator driver.

Measured on-wafer single-ended S-parameters of the differential MD (Fig. 3) shows a midband gain of 30 dB, 41 GHz bandwidth, and lower than 10 dB return losses up to 43 GHz. The driver was packaged and tested at 40 Gb/s using a 2^{31}-1 pseudo-random bit sequence (PRBS) generated by a 4:1 MUX, from 4 channels of uncorrelated 10 Gb/s PRBS data. The MUX outputs 490 mVp-p differential signal with 1.19 ps rms jitter. All measurements were done using a Tektronix oscilloscope with a 40 GHz sampling module (80E01).

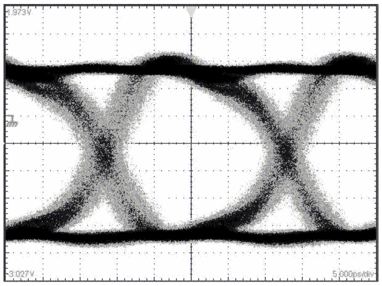

Fig. 4. 40 Gb/s single-ended output eye pattern from the differential modulator driver.

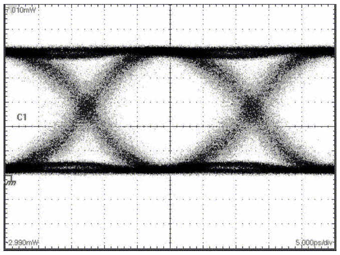

Fig. 5. 40 Gb/s optical eye pattern from the differential EO modulator.

The measured single-ended output from the differential MD (Fig. 4) shows 2.93 Vp-p swing with 20-80% rise and fall times of 6.4 ps and 7.1 ps respectively. Measured rms jitter of 1.29 ps corresponds to an added jitter of 0.5 ps. The amplitude can be further increased to 3.2 Vp-p. The differential output from the MD was used to drive a differential EO modulator (Agere - 2625C) using a matched pair of cables. A 13 dBm, 1550 nm CW laser source (Agere -2547P) was modulated. 4.25 dBm of optical power with 12.85 dB extinction ratio and 1.6 ps rms jitter was observed (Fig. 5). After 2.2 km of SMF fiber the extinction ratio dropped to 9.97 dB, with 1.79 ps rms jitter and 40% crossing.

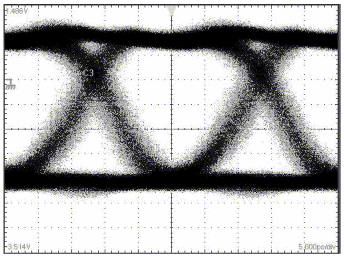

Fig. 6. 40 Gb/s eye-pattern from the single-ended modulator driver at 75% crossing.

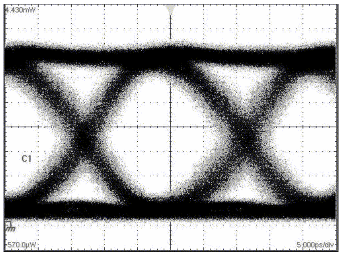

Fig. 7. 40 Gb/s optical eye pattern from the EA modulator.

Transmitter measurements of the single-ended MD were done with a EA modulator (Oki - OM5753C-30B). Strong non-linearity in the optical insertion loss vs. applied voltage for EAMs call for driving voltages with high duty-cycle ratio to obtain maximum opening in the optical eye. With the MD crossing point set at 75% (Fig. 6), a 2.77 Vp-p signal with 9.1 ps transition times and 1.45 ps rms jitter was used to drive the EAM. About 2.37 dBm of optical power with 10.87 dB extinction ratio and 1.46 ps rms jitter was observed (Fig. 7).

4. Conclusions

We have developed modulator drivers in InP HBT technology for differential EO modulators requiring 6 Vp-p swing and EA modulators requiring 3 Vp-p single-ended swing. With 20-80% transition times of 8ps and 0.5ps additive jitter these drivers are suited for 40 Gb/s systems. 30 dB small-signal gain provides a single chip interface between MUX and modulator in transceivers. Added features like crossing point control and modulation swing control allow further optimization of the drive for modulators.

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Athermal Birefringent Solid Etalon for 25GHz-Spacing Built-in Wavelength Monitor

M. Imaki, Y. Mikami, M. Sato, Y. Nishimura,
A. Adachi, Y. Hirano, *Mitsubishi Electric Corporation, Kamakura, Japan, Email: imaki@isl.melco.co.jp*.

We have newly devised an athermal birefringent solid etalon for a built-in 25GHz spacing DWDM wavelength monitor, which has a thermal property as low as 0pm/°C. This monitor integrated DFB-LD module is confirmed to have a high stability.

1. Introduction

Since ITU-T grid spacing becomes narrower in the DWDM systems, the wavelength stabilization of LD module with wavelength monitoring function is required more strictly to avoid cross-talk between channels. The requirement of wavelength stabilization for 25GHz-spacing DWDM system is less than +/-8pm (EOL). However, a suitable built-in type wavelength monitor, which has a small size, a simple configuration, and sufficient stability to maintain high wavelength stabilization for a long time over a wide-temperature range, has not been developed despite a number of reports of wavelength monitoring methods[1],[2],[3] . The most popular and simplest wavelength discriminating filter is an etalon. In addition, an etalon has very high discriminating slope and is suitable for accurate wavelength locking with high discriminating sensitivity. Unfortunately, a discriminating wavelength of a conventional glass etalon is sensitive to temperature such as more than 5pm/ºC, since temperature change is uniquely determined by isotropic material parameters. Although an air-gap etalon, which realizes a low temperature dependence of refractive index and a low expansion with air-gap cavity and supported low expansion glass, provides a temperature change of less than 1pm/ºC, a size of air-gap etalon is bigger than solid etalon because of low reflective index of air and a complex support mechanism. For example, the size of air-gap etalon is more than 10mm for 25GHz-spacing and it is very difficult to install it in conventional 14-pin butterfly package. Independent temperature stabilization of built-in solid etalon has been the only way to realize 25GHz system [3] . However, the two temperature stabilization for LD and etalon seems to be too pompous and, consequently, costly way for both LD module and operating circuit.

To solve the problem, we have newly devised an athermal solid etalon using a birefringent crystal, and also developed a 25GHz-spacing wavelength monitor integrated DFB-LD module with this new athermal solid etalon.

2. Athermal solid etalon filter

Temperature change of discriminating wavelength of solid etalon is given by

$$\frac{d\lambda}{dT} = \frac{dn/dT + \alpha \cdot n}{n} \cdot \lambda , \qquad (1)$$

where n is isotoropic refractive index, dn/dT is temperature dependence of the refractive index, and a is thermal expansion coefficient. In general, these parameters are fixed and no material, which has athermal condition (dn/dT+α×n=0), has been found.