10 Gbit/s Lithium Niobate Modulator Driver

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As 10 Gbit/s long-distance optical communication systems become more and more pervasive, requirements rise relating to increased levels of performance, as well as the miniaturization of key devices that configure such systems. Lithium niobate (LN) modulators are used primarily as optical modulators that change high-speed electrical signals at 10 Gbit/s to optical signals for long-distance communication systems. Driver ICs intended for driving such LN modulators are becoming key devices that impact the performance of a system as much as LN modulators. High quality output waveforms with little noise are required of LN modulator drivers, since signal waveforms output by LN modulator drivers extensively impact optical waveforms output by LN modulators, as well as their optical transmission characteristics. Furthermore, not only are waveform characteristics vital but miniaturization is also essential for long-distance transmission systems, since wavelength division multiplexing is often incorporated in long-distance transmission systems.

At OKI we have thus far developed electro-absorption (EA) modulator drivers and commercialized them using a Gallium Arsenide (GaAs) Pseudomorphic High Electron Mobility Transistor (PHEMT) structure, which offer superior high speed and waveform characteristics[1]. Using the PHEMT structure, we have also been developing a driver amplifier that operates at 40 Gbit/s[2]. LN modulator drivers, however, are required to have not only such high speed characteristics but also a high output amplitude of 6Vpp, more than double of EA drivers, making it difficult to satisfy both operationg speed and output amplitude, because they are in a trade-off relasionship.

Our report on the configuration, circuit and device design is provided, as well as operating characteristics of the LN modulator driver, as we were able to realize high-speed operations at 11.3 Gbit/s and high output amplitude characteristics with the 6 Vpp output amplitude through our development of LN modulator driver by applying our device structure and circuit design technologies that have been nurtured over the years during our development efforts.

Configuration of LN modulator driver

For LN modulator driver to realize both high speed operation and high output votalge of 6 Vpp, transistors used in the drivers are required to have both high speed and a high breakdown voltage characteristics. Since the PHEMT used in our EA modulator drivers do have an excellent performance as for high speed characteristics but not enough for breakdown volatage, we adopted two chip configuration by segregating final stage of amplification and applied the newly developed PHEMT with high breakdown voltage to the final stage. The configuration of LN modulator driver is shown in **Fig. 1**. This driver is configured by two chips, a preamplifier and booster amplifier, which are mounted on a single package. Furthermore, we decided to build a bias inductor for the booster amplifier in the package in order to ensure that users will be able to obtain the waveform characteristics of the LN modulator driver in a stable manner. A sophisticated and complex high frequency design was required for bias inductors and since their performance impacts the waveform characteristics of drivers the building of it in the package produced a major valuable addition for the LN modulator driver. Miniaturization using the built-in bias inductor was achieved by optimizing the circuit configuration and component parts.

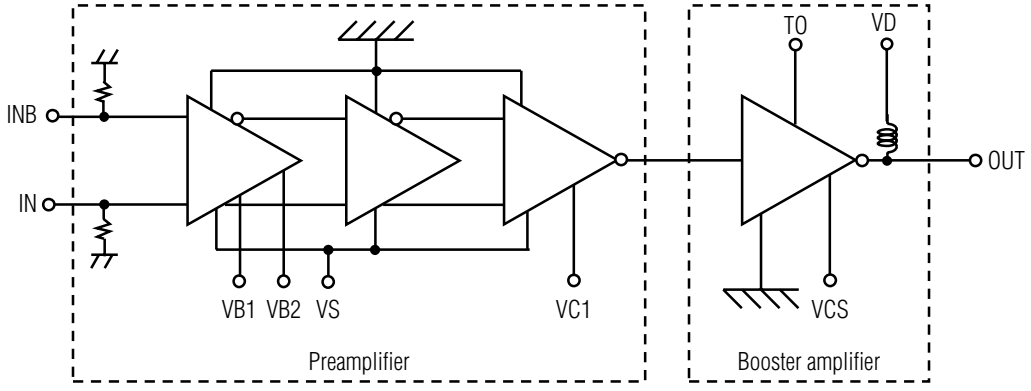


Fig. 1 Configuration of LN modulator driver

Design of preamplifier

A differential amplifier circuitry was adopted as our preamplifier, as it can easily realize limiting operations, cross-point adjustments and output amplitude varying functions. We optimized the design for amplifier gain to ensure that the output amplitude of the preamplifier is performed with limiting operations constantly at all times for a large dynamic range of input amplitude that spans from 0.4 to 1.0 Vpp. Furthermore, we incorporated a cross-point adjustment function for output signals from VB1/VB2 terminals, as well as an output amplitude varying function using a VC1 terminal. We adopted the GaAs PHEMT structure with a gate length of 0.15 µm in order to miniaturize the size of the chip, which was achieved by reducing the number of steps of the amplifier. This cutoff frequency (fT) of the PHEMT has a superior high frequency characteristic of 103 GHz, which made it possible to reduce the number of stages of the amplifier, allowing us to miniaturize the chip to a size of 1.2 mm by 1.2 mm.

Design of booster amplifier

For a high-speed and high output amplitude characteristic of the LN modulator driver, the transistor used in the booster amplifier must have a deeper threshold voltage and lower off-state leakage current, while maintaining the high frequency performances. In order to realize such transistor characteristics, the PHEMT with a double recess structure was applied for the booster amplifier. Furthermore, the booster amplifier was designed by using the distributed amplifier configuration, which realize the wider bandwidth, to obtain both a high-speed operation at 10Gbit/s and a high output amplitude of 6Vpp.[2)]

First of all, the PHEMT with a double recess structure applied for the booster amplifier is explained. As shown in the cross-sectional view of **Fig.2**, the device structure consists of the source/drain electrodes and a T-shaped gate electrode with the gate length of 0.15µm. The double recess structure was formed by selective etching technique using the double stopper layers, which enables the precise control of the etching depths for both the upper and the lower recessed regions. By applying this double recess technology, it became possible to arbitrarily design a carrier concentration under the gate and also beside the gate regions, and then the accurate control of both the threshold voltage and the breakdown voltage of device has been realized.

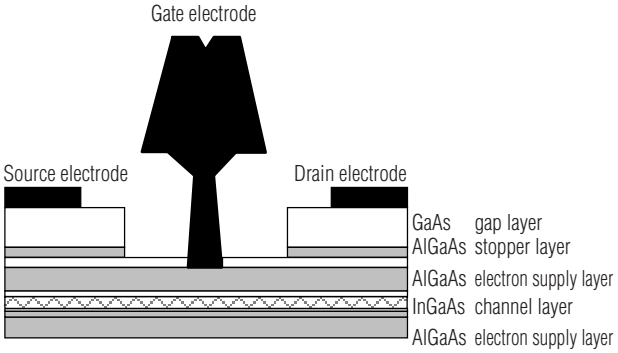


Fig. 2 Structure of double recessed PHEMT

Fig.3 shows a comparison of I-V characteristics for a conventional single recessed PHEMT and a double recessed PHEMT. As compared the double recessed PHEMT with the single recessed PHEMT, the double recessed PHEMT has achieved the very good pinch-off characteristic, that is a lower drain conductance of 10 mS/mm and a smaller off-state leakage current. The breakdown voltage of the double recessed PHEMT is about 15V, which is sufficiently high for the operation of the booster amplifier. The current gain (h21) versus frequency for the double recessed PHEMT is shown in **Fig.4**. The cut-off frequency (fT) extrapolated from this result was 72GHz.

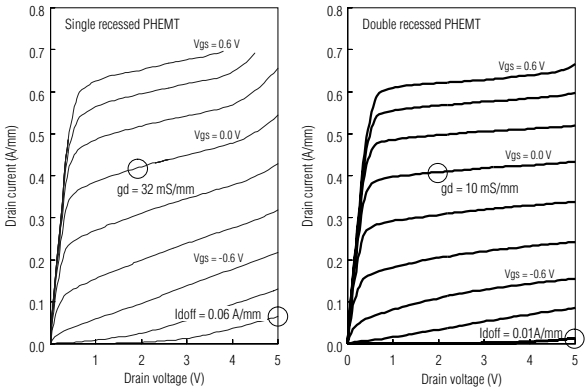


Fig. 3 I-V characteristics of PHEMT

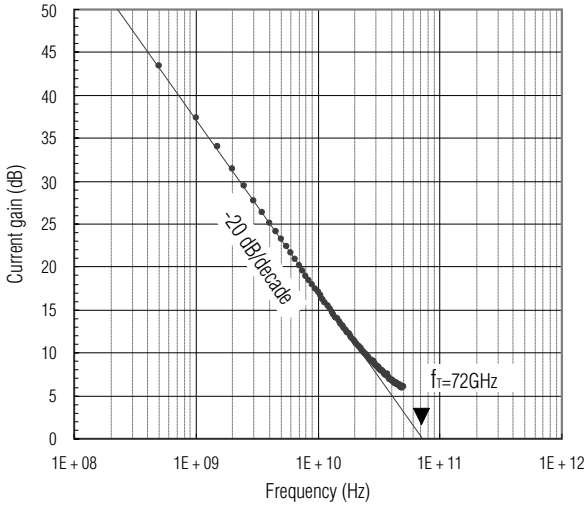


Fig. 4 High frequency characteristics of double recessed PHEMT

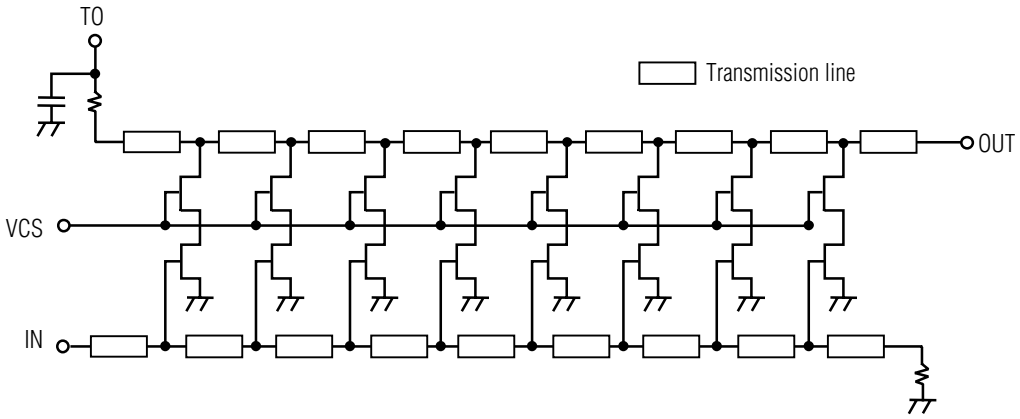


Fig. 5 Circuit configuration of booster amplifier

Descriptions of the circuit method are provided next. The circuit configuration of a booster amplifier comprised of distributed amplifier circuitry is shown in **Fig. 5**. A cascode amplifier with two FETs vertically stacked was considered to comprise a single section, with eight of these arranged parallel to comprise an eight-section configuration. We carefully optimized the number of sections and the size of FETs in each section since they are important parameters to determine the frequency bandwidth of distributed amplifier. A simulation model for the FETs aligned with precision to the wide band of DC-40 GHz was prepared, since harmonic response must be considered in order to figure out a 10 Gbit/s waveform with a high degree of precision in simulation. The EEHEMT1 model from Agilent Technologies Inc. was adopted as our FET simulation model.

The characteristic impedance and line lengths were determined for the transmission lines that connect the respective sections in order to ensure that the input and output impedance of the booster amplifier is 50 Ω. With an ideal transmission line it is possible to keep track of the characteristics using a logical equivalent circuit model. In order to attempt miniaturization of the chip, however, it was necessary to deal with complex and intricate shapes of the transmission lines inside the IC. The characteristics of such transmission lines tend to deviate further from logical values as the frequency is raised, which means that there is a limit to the extent of accuracy that can be expected from a design made by using an equivalent circuit model. Therefore, we sought to increase the accuracy of the circuit design by analyzing the characteristics using electromagnetic field analysis, particularly with regards to the transmission line patterns of complex shapes.

The S-parameter characteristics for the booster amplifier we developed, using a distributed amplifier, are shown in **Fig. 6**. We have obtained excellent performances with small signal gain of 18dB and 3dB bandwidth of 11GHz. S11 and S22 were better than -12dB at up to 20GHz. These results were successfully agreed with simulation, confirming the targeted characteristics of the booster amplifier.

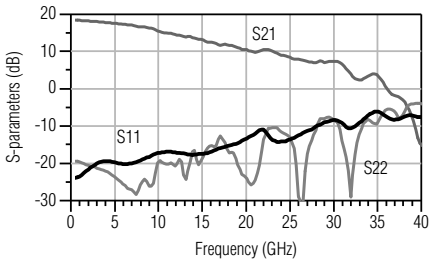


Fig. 6 S-parameter characteristics of booster amplifier

Evaluation of characteristics of LN modulator driver

The preamplifier and the booster amplifier were mounted in a 38-pin ceramic package. A bias inductor circuit for supplying power to the booster amplifier was also implemented in the package. We were able to achieve a package size with dimensions of 10.9 mm × 8.0 mm × 2.5 mm, which places it into the smallest category for LN modulator drivers with a built-in bias inductor. An external view of the package is shown in **Photo 1**.

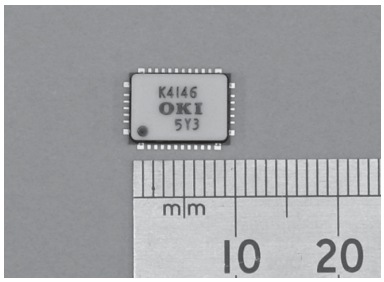


Photo 1 External view of IC

The characteristics for the packaged driver were evaluated with the package mounted on the evaluation board, as shown in **Photo 2**. The output waveform for operations at 11.3 Gbit/s is shown in **Fig. 7**. An extremely favorable waveform for 6 Vpp output amplitude is depicted in this figure. The rising time (Tr) and falling time (Tf) of the waveform are 22.7 ps and 23.6 ps respectively (20 to 80%). The operating conditions for the aforementioned figures include differential 0.4 Vpp for input amplitude of the LN modulator driver (0.2 Vpp each for IN and INB, respectively), -5.2 V for the power supply voltage Vs of the preamplifier and 5 V for the power supply voltage VD of the booster amplifier. Power consumption was 1.4 W.

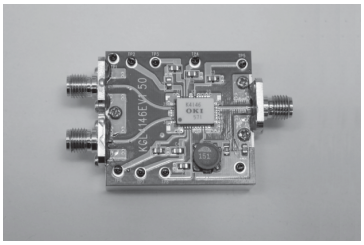
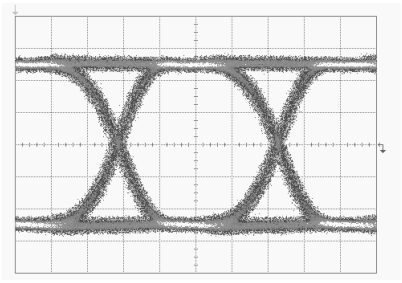


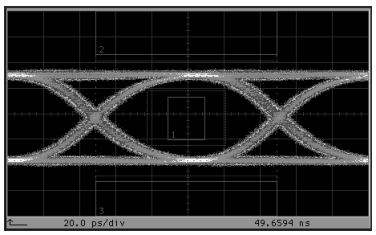
Photo 2 Evaluation board of LN modulator driver



V: 1.2 V/div.; H: 20 ps/div.

Fig. 7 Output waveform of LN modulator driver

The optical output waveform obtained during evaluation of the LN modulator driver, in combination with the LN modulator, is shown in **Fig. 8**. Favorable characteristics with an extinction ratio of 13.0 dB and mask margin of 29% were obtained, indicating that the characteristics of the LN modulator driver are sufficient for practical implementation.



H: 20 ps/div.

Fig. 8 Optical output waveform for evaluation of LN modulator driver in combination with LN modulator

Conclusion

We developed the LN modulator driver with a built-in bias inductor for the purpose of implementing 10 Gbit/s long-distance optical communication systems. The driver is comprised of two chips, a preamplifier and a booster amplifier. Double recessed PHEMT with a high breakdown voltage and distributed amplifier circuitry were adopted for the booster amplifier in order to realize high-speed operations at 11.3 Gbit/s and high output amplitude characteristics of 6 Vpp. A GaAs PHEMT structure with a gate length of 0.15 μm, as well as increased precision for distributed circuit design, were accomplished in order to miniaturize the chip, resulting in the successful miniaturization of the package size to 10.9 mm × 8.0 mm × 2.5 mm, which places it in the smallest package category.

Optical communication systems are expected to evolve to cater for longer distances and provide higher speeds. We intend to aggressively undertake activities for the development of drivers to increase speeds and raise output amplitudes that can accommodate new optical communication systems by applying a technology for higher speeds and higher output amplitudes, obtained through the development of the LN modulator driver.

References

1) Tamotsu Kimura: GaAs IC Set for Optical Transmission Module (from 10 Gb/s to 40 Gb/s), Oki Technical Review, Issue 190, Vol. 69, No. 2, pp. 68-71, April 2002.
2) Makoto Kosugi: Amplifier IC for 40 Gbit/s Optical Communications, Oki Technical Review, Issue 196, Vol. 70, No. 4, pp. 84-87, October 2003.

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