Considerations in the Design of Electro-Optic Modulators and Drivers for 40 Gb/s and Beyond

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Abstract – **This paper describes the physical and electrical models which were developed for a driver amplifier realised on gallium arsenide and an electro-optic modulator on lithium niobate. The performance of a combined 40 Gb/s driver modulator design was investigated bearing in mind the additional degrees of freedom allowed in the design of integrated components.**

I. Introduction

Indirect optical modulators are used in long haul communication networks where the requirement for zero or controlled chirp (change in optical wavelength within a symbol period) generally precludes direct modulation of the laser. The optical modulator investigated in this study was the Mach-Zehnder interferometer using the electro-optic or Pockels effect in lithium niobate. Lithium niobate is a well proven material for modulator construction, although other materials, such as gallium arsenide, indium phosphide and specialised polymers, can also be used. A simplified system schematic of a long haul network is given in Figure 1. The multiplexer uses time division multiplexing to switch between a number of different channels at lower data rates. The output signal from the multiplexer is typically 0.4 V – 0.8 V at 10 Gb/s depending on the logic family used. Voltage levels down to 0.25V are being considered for 40 Gb/s operation. This signal needs to be amplified to a sufficient level to drive the optical modulator. The most commonly used methods of coding the data stream at 10 Gb/s are NRZ (non return to zero), RZ (return to zero) and 'chirped' RZ. Examination of the spectral content of these data streams shows that the driver must have a very flat gain and group delay characteristic from a few 10's of kHz to at least the Gb/s bit rate in GHz to represent the data stream sufficiently accurately with an acceptable bit rate error, eg 30 kHz – 12GHz for a 10 Gb/s driver.

The model developed for the driver in this study was based on the use of a cascade of travelling wave amplifier circuits realised on gallium arsenide. A comprehensive model was developed for a well proven design used for operation at 10/12.5 Gb/s and 20 Gb/s, which has been available commercially for several years. The generic models developed incorporated over 750 individual circuit elements in order to represent accurately all the key aspects of the physical elements used in the driver circuit. The circuit representation was modelled using the AWR software Microwave Office 2000™ together with extensive use of three dimensional modelling tools to model the transition between individual stages and the connectors used on the input and output.

The model developed for the modulator was based on modelling the properties of the microwave guide, representing the characteristics of the electrodes carrying the digital data signal, and the optical guide, propagating the optical signal, separately. The microwave propagation was modelled using the Ansoft software Maxwell Spicelink and the High Frequency Structure Simulator, HFSS, while the optical guide was modelled using CTS Microwave Studio. The definition of the diffusion profile for the optical guide and the calculation of the overlap integral and V_{pi} from the above simulations were determined using in-house software specially developed for this purpose. The results for the line and guide parameters together with the value for V_{pi} were used to determine the overall modulator performance using the models developed by Zandano[1], which have been implemented as user defined components within the framework of the Microwave Office 2000™ design suite[2].

II. The Driver

The driver model comprised a cascade of three, seven stage, MMIC (Monolithic Microwave Integrated Circuit) travelling wave amplifiers. Each stage used a cascode pair of FETs and had the facility for electronic gain control via the second gate of the cascode pair. The travelling wave amplifier concept is well known and essentially absorbs the parasitic capacitances of the input and output of the active devices into artificial transmission lines. Since the driver had to operate over a very wide bandwidth, typically 30 kHz – 15 GHz for 10/12.5 Gb/s applications, it was necessary to use decoupling and bias components with a similar bandwidth. This was a major challenge as any 'real world' capacitor or inductor suitable to achieve the necessary reactance values at 10's of kHz exhibits resonances at several 100's of MHz due to the parasitic elements within them. This meant that the function of these devices had to be realised in practice with a combination of components to achieve the ultra broadband performance required.

A model was developed for the driver which represented all the main characteristics of an existing 10/12.5 Gb/s driver and this was used to predict the eye diagram when driven with a 10 Gb/s PRBS (Pseudo Random Bit Sequence). Very good agreement was obtained between simulated and measured results enabling the generic model to be used to investigate the performance at other higher data rates, eg 40 Gb/s.

III. The Modulator

A model was developed for a commercially available Mach Zehnder optical modulator on lithium niobate operating at 40 Gb/s based only on a knowledge of the physical dimensions of the structure and the diffusion profile of the optical guides in the lithium niobate. Very good agreement was obtained between the simulated and measured results at 40 Gb/s. During the course of the device modelling, it became clear that there were a number of limitations in existing modulator designs which meant that it was difficult to achieve a sensitivity of better that about 5.5 V at 40 Gb/s with a volume manufacturing process. Investigation of these restrictions led to a more sensitive design using an improved electrode structure and cross sectional geometry which had about twice the sensitivity of current designs on lithium niobate. Simulated results were verified against designs available commercially together with measurements made on individual structures. These provided confidence in the modelling technique and led to a patent for an improved modulator structure. Figure 2 shows a plot of drive level required for a 40 Gb/s modulator against length of the electrode for the following cases: 1) the results for a typical device available commercially, 2) the ideal lossless case with perfect velocity matching between the microwave and optical signal and 3) the results for the improved design developed on this programme. The points indicated by the arrows are: a) the representative drive level for a device available commercially, b) the improvement which could be obtained by using the new electrode structure and c) the further improvement by increasing the electrode length. Further investigation showed that the extra degrees of freedom provided by integrating both the driver and the modulator in a single package enabled additional improvements in performance to be obtained.

The benefits of the new integrated driver modulator design are:

- smaller overall size than individual components
- improved voltage sensitivity of the modulator
- decreased DC power requirements for the driver
- an improved eye diagram
- use of lower cost semiconductor technologies to realise the driver circuit
- decreased risk to the system integrator due to only having to specify one component

Figure 3 shows the DC power consumption of the driver as a function of voltage drive level for the modulator. This Figure shows very clearly how the sensitivity improvement of the new design translates to a significant reduction in DC power consumption, which considerably reduces the heat sinking and thermal conditioning requirements. The points a), b) and c) represent the same points described for Figure 2 previously.

IV. Potential for Exploitation of the Technology

The original motivation for this work was the development of detailed models for the driver and modulator with applications to the next generation 40 Gb/s long haul communication systems. However, it is expected that the improvements in sensitivity and electrical performance will also be exploited for the next generation 10/12.5 Gb/s systems.

V. Conclusions

This report has described the modelling of an ultra wideband driver based on the principles of the travelling wave amplifier and an optical modulator on lithium niobate using the principle of the Mach Zehnder interferometer. Theoretical results for both components were confirmed with measurements on devices available commercially. Further study identified a new electrode design and cross sectional geometry, which significantly increased the sensitivity compared with current designs available commercially. The integration of the driver and the modulator was shown to give further improvements in electrical and optical performance compared with separate components. Although the work was originally motivated by the requirement for 40 Gb/s components for future high capacity long haul communication links, it is expected that the integrated driver modulator concept will be applied first at 10/12.5 Gb/s.

VI. Acknowledgements

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VII. References

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2. Applied Wave Research, Inc., El Segundo, California, USA.

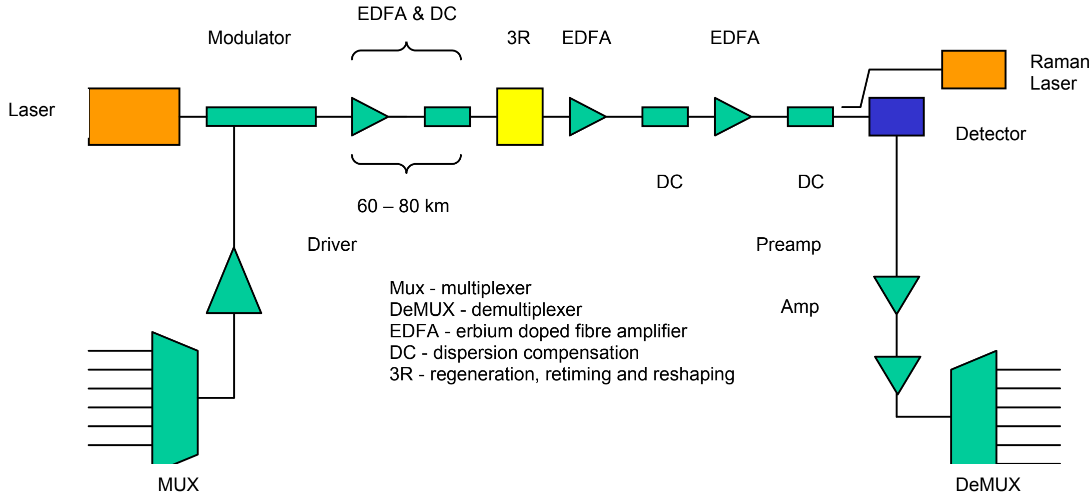

Figure 1. Simplified Schematic of a Long Haul Communications Network

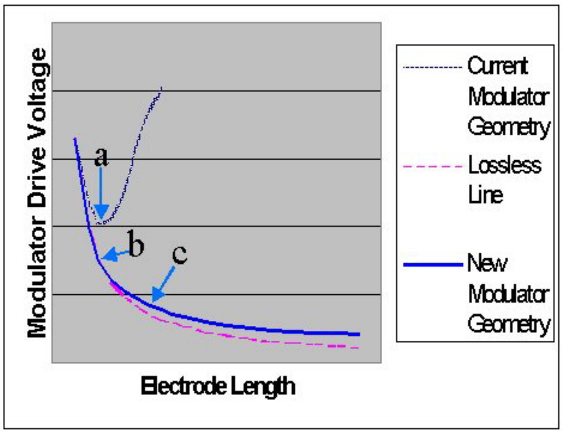

Figure 2. Modulator Driver Voltage versus Electrode Length

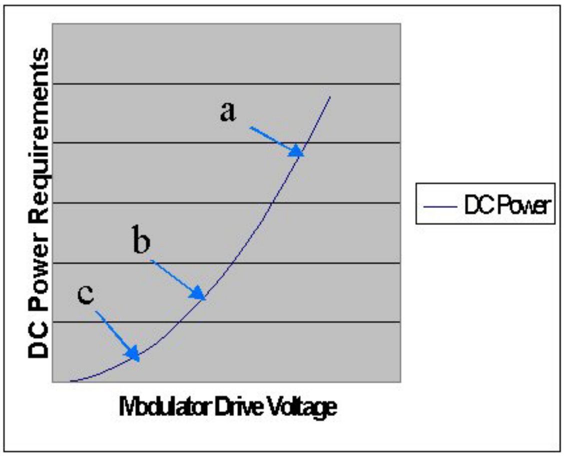

Figure 3. Driver DC Power Requirements versus Modulator Drive Voltage