Electronic processing for generation and detection of multi Gbit/s CDMA over fibre

Invited Paper

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Abstract
The use of distributed electronic transversal filter circuit techniques for the generation and detection of OCDMA signals is investigated. New circuit designs are proposed with simulation results indicating suitability for 40 GChip/s OCDMA systems.

Introduction
Optical Code Division Multiple Access (OCDMA) network proposals are becoming increasingly popular for local area and access network applications. OCDMA offers secure communication and simple architectures as it allows asynchronous operation and can be operated with passive star topologies. One of the key limitations of OCDMA networks is associated with complex terminal equipment and the need to employ user specific optical encoders and decoders. Over the past few years we have been developing OCDMA electronic circuits that can overcome the requirements for terminal specific optical components for signal generation and decoding and more recently for dispersion compensation in multi wavelength OCDMA links. This paper presents concepts of electronic CDMA encoding and decoding.

Time-Domain OCDMA Encoding/Decoding
For an OCDMA network (Fig. 1), the transmitter encoder and the receiver decoder may be implemented using the distributed structure of Fig. 2. The Distributed transversal filter (DTF) [1,2] may be implemented to effect high rate encoding and decoding. Such structures found several applications in high speed optical communications, ranging from filtering and equalisation to pulse shaping [3] and more recently high chip rate CDMA applications [4,5]. In [4], a DTF is proposed to encode and decode bipolar CDMA signals at chip rates up to 40 GChip/s. Such design required the number of active devices (stages) to be equal to the spreading gain. The design was modified in [5] to allow a reduction of the number of the active devices.

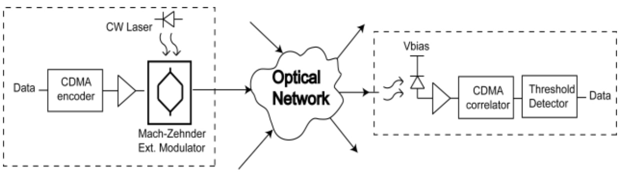

Fig. 1. Simplified block diagram of the proposed Optical CDMA network

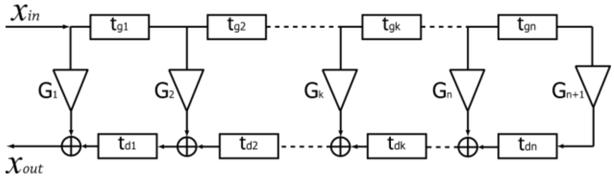

Fig. 2. Distributed Transversal Filter in reverse-mode operation

In a time-domain Optical CDMA network, each user is assigned a unique binary unipolar sequence characterized by its length **n** and the weight **w**; each element of this sequence is called a chip. This (0,1) sequence can be described by the vector:

$c = (c_1, c_2, \ldots, c_k, \ldots, c_w)$ with $c_{k+1} > c_k$ and $c_k \leq n$,

where each element represents the position of a "positive" chip relative to the beginning of the sequence. For example, if the user sequence is 10010100, the vector c is (0,3,5), n = 8 and w = 3. The user transmits data bit "one" by sending the sequence of the intended user in the time T_{bit} and transmits nothing for bit zero [6]. The chip period T_{chip} is equal to T_{bit}/n.
The encoder of the Optical CDMA system generates a unipolar sequence when a pulse $x_{in}(t)$ with width T_{chip} is applied. Therefore, the time-domain response of the encoder may be represented as:

$$x_{outENC}(t) = \sum_{k=1}^{w} x_{in}(t - c_k T_{chip})$$

Conversely, the OCDMA decoder should be able to generate a correlation peak whose amplitude is proportional to the number of "positive" chips, when the correct sequence is applied. To achieve this, the time-domain output response of the decoder is given by:

$$x_{outDEC}(t) = \sum_{k=1}^{w} x_{in}(t - (c_w - c_{w-k+1})T_{chip})$$

The Distributed Transversal Filter (DTF) structure shown in Fig. 3 is an attractive component to encode and decode unipolar sequences. For such purpose, the number of transversal filter stages is equal to the sequence weight **w** and the delay between stages is a multiple of the time T_{chip}, depending on the distance between positive chips in the codeword. The gain blocks are implemented with two transistors in cascode configuration. Additional delay is achieved using LC-elements which comprise MIM capacitors and thin microstrip lines.

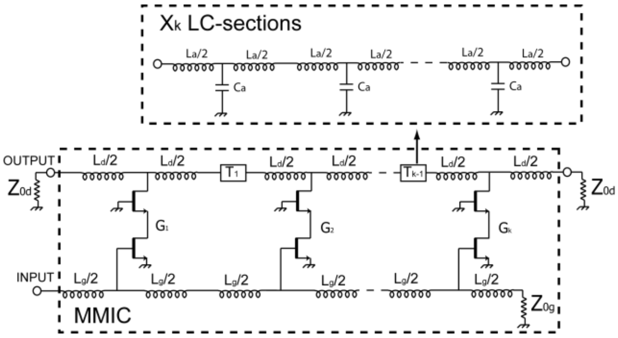

Fig. 3. Schematic of the circuit implementation (bias not shown)

For concept verification and study of the practical feasibility of the design ideas above, a three-stage distributed transversal filter was designed using a commercially available pHEMT 0.2 µm process with f_t = 60 GHz. The circuit is designed to encode the codeword "10010100" at 40 GChips/s. It can also function as a decoder for the reciprocal sequence "101001000".

Fig. 4 shows the transient response of the encoder for the sequence "100101000" with an input of a single Gaussian impulse having "1/e" width of 25 ps and peak amplitude of 10 mV. Line and device attenuations were compensated by individually adjusting the HEMT device gains. The resulting signal of Fig. 4 shows small (but acceptable) variations in pulse widths and amplitudes as a result of imperfect compensation and line dispersion.

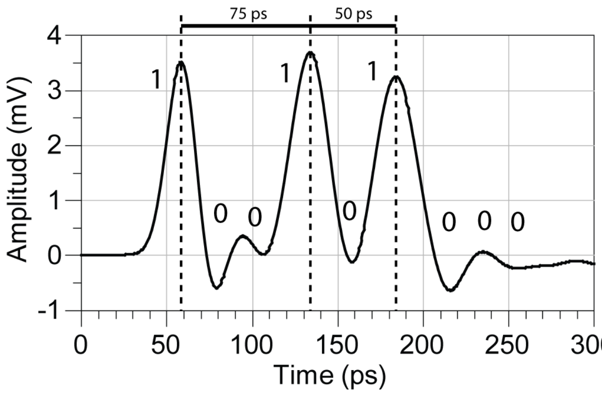

Fig. 4. Transient response of the encoder for the codeword "100101000"

Fig. 5 shows the DTF time-domain response for the matching input sequence "101001000" and for an unmatched input sequence "110000010". For the matched sequence, a clear correlation peak is generated which could be detected with a threshold device. The unmatched input sequence generates output levels below that of the matched sequence, indicating appropriate operation of the designed circuit as a correlator allowing information recovery.

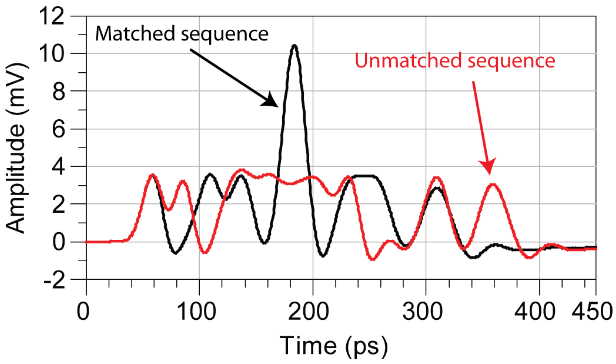

Fig. 5. Transient response of the correlator with the matched input sequence "101001000" and unmatched input sequence "110000010"

Conclusions

A new concept of electronic encoders and correlators for ultra high speed sequences is introduced in this work. The intrinsic broad-bandwidth characteristics of the LC ladder and the distributed nature of the circuit allow the design of transversal filters for very-high bit rate applications. These structures are promising for Optical CDMA systems and other applications where encoding and decoding of fast signals (few 10s of ps) are needed. The DTF is simulated on a standard pHEMT GaAs 0.2 µm process. Full device, circuit level and 3-D electromagnetic simulations demonstrated the feasibility of the proposed circuits for encoding and decoding at 40 GChip/s. The work reported here shows good time and frequency behaviour of the newly designed structures.

References

[1] A. Borjak, P. Monteiro, J. O'Reilly, and I. Darwazeh, "High-Speed Generalized Distributed-Amplifier Baser Transversal-Filter Topology for Optical Communication Systems," *IEEE Transactions on Microwave Theory and Techniques*, vol. 45, pp. 1453 – 1457, 1997.

[2] A. Hajimiri, "Distributed integrated circuits: an alternative approach to high-frequency design", *IEEE Commun. Mag. 40 (2002) (2)*, pp. 168–173.

[3] P. Monteiro, A. Borjak, F. Rocha, J. O'Reilly, and I. Darwazeh, "10-Gb/s Pulse-Shaping Distributed-Based Transversal Filter for Optical Soliton Receivers," *IEEE Microwave and Guided Wave Letters*, vol. 8, pp. 4 – 6, 1998.

[4] J. Aguilar-Torrentera and I. Darwazeh, "Dual drain-line distributed cell design for multi-Gbit/s transversal filter implementations," in *Circuits and Systems, 2005. ISCAS 2005. IEEE International Symposium on*, 23-26 May 2005, pp. 3958–3961.

[5] M. Pimenta and I. Darwazeh, "Novel encoder and correlator for optical code division multiple access networks", *IEEE Lasers & Electro-Optics Society, Oct. 2006*, pp. 422–423.

[6] P. Prucnal, "Optical Code Division Multiple Access: Fundamentals and Applications", P. Prucnal, Ed. Taylor and Francis, 2005.