A Transversal-Filter for High-Speed Fibre-Optic CDMA Receivers

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Abstract: A novel microwave transversal-filter for Fibre-Optic CDMA (FO-CDMA) is described. The proposed distributed transversal-filter permits the development of receivers for high-speed networks. The transversal filter is aimed to receive efficiently spread signals at speeds of tens of Gchip/s. In order to demonstrate the concept a transversal filter was designed to operate at 10 Gchip/s and programmed with a bipolar maximal length sequence. Simulation results show that the transversal filter is a viable alternative for FO-CDMA receiving systems.

1 Introduction

Due to its great advantages, Fibre-Optic Code Division Multiple Access (FO-CDMA) has become an attractive technique for high-speed optical communication networks. The improvement on the network throughput with no synchronisation or receiver frequency stabilisation makes FO-CDMA an interesting access technique to the optical channel. Generally, an optical matched filter is used at the receiver with the aim of detecting user data at multi-Gbit/s speeds. High-speed FO-CDMA receivers have been implemented with optical delay lines and diffraction gratings. Although optic al delay lines enable efficient orthogonal optical codes (OOC´s) to be employed [1], such systems require ultra short pulses rendering the system expensive and difficult to implement for systems with a large pool of users. Incoherent processing of optical pulses using optical delay lines was proposed for first high-speed receiver implementations [1].

Current research on FO-CDMA systems is devoted to Spectral Coding of incoherent optical sources using fibre Brag gratings. This method of coding is favoured since it allows multiuser interference to be completely eliminated. The spectral frequency pattern centred in the grating frequencies utilises the huge bandwidth of the optical fibre [2]. Nonetheless, in order to support more users in the system without spoiling the orthogonality among coded signals, higher spectral resolutions and steady broadband optical sources are needed. However, such conditions cannot be met in practical systems. Broadband sources like luminescence diodes (LED's) have variations across the power spectrum and the optical resolution cannot be increased beyond the limit of the fibre gratings. Despite these physical constraints, to date fibre Brag gratings have been recognised as the most convenient component to generate and demultiplex optical codes [3], [4].

In this paper we propose a novel electrical transversal-filter for OF-CDMA receiver implementations. The transversal filter could be implemented as a monolithic microwave integrated circuit (MMIC) avoiding the optical losses usually featured in optical matched filters. Simulation results show that the transversal filter is a viable alternative for high-speed OF-CDMA receiver implementations.

2 Theoretical background

The proposed transversal filter for OF-CDMA receivers is based on the analogy between transversal filter and distributed amplifier topologies [5]. Due to their broadband and linear phase characteristics, transversal filters have been designed for high-speeds lightwave systems. Recent developments using the transversal filter analogy are the construction of tunable post-detection filters [6]; shaping filters for high-speed optical soliton receivers [7] and transversal adaptive equaliser for lightwave doubinary systems [8].

The use of the transversal filter for spread-spectrum receivers has not been proposed before. In this approach, narrow pulses with widths in the region of picoseconds are delayed and multiplied by an appropriate selected gain coefficient (or tap gain). The frequency response of an N-tap transversal filter is given by:

$$H_F(jw) = \sum_{k=1}^{N} G_K \exp\left(-jw\sum_{i=0}^{k-1} t_i\right) \qquad [1]$$

where G_K corresponds to tap gains and t_k corresponds to interstage delay, which is set to be equally to the bit period. Coefficients in equation 1 correspond to the signature sequence for the receiver matching filter. The number of devices in the filter depends on device and line losses which ultimately limit the performance. Nonetheless, there are techniques for reducing losses and pulse dispersion along artificial transmission lines. Pulses at the output are limited in such a way that their maximum frequency is equal to (or less than) the cut-off frequency of the artificial transmission line. Hence, the cut-off frequency sets a limit on the speed of the chip reception, which may be higher than the current cut-off frequency of active devices [9].

3 The transversal filter concept

The transversal filter is considered as a postdetection circuit with bandwidth of the order of the chip rate. The transversal filter could be sited in a postdetection stage as depicted in the scheme depicted in fig 1.

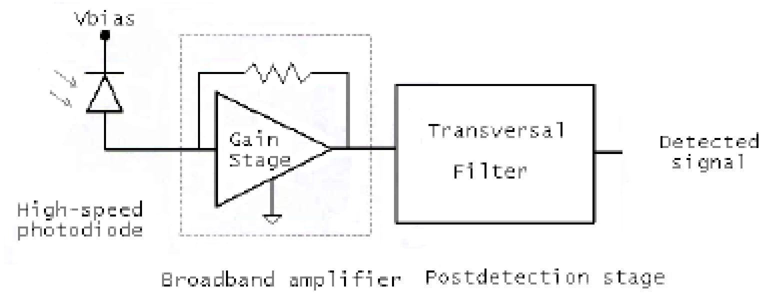

Fig 1 Scheme of a high-speed direct-detection receiver based on a transversal filter

In this scheme, a high-speed photodiode detects bandwidth-limited signals from multiple users sharing the common channel. High-speed photodiodes detect signals up to frequencies of several tens of GHz enabling spread signals to be detected in the electrical domain. The broadband amplifier couples baseband signals to the transversal filter. Multiple user interference is eliminated by the transversal filter programmed with the proper signature sequence.

The proposed transversal-filter for spread-spectrum signals is depicted in fig 2. It consists of two rows of active devices, sharing a common ATL at the gate inputs and each with separate drain artificial transmission lines. The broadband inverter allows signals from both external rows to be summed in anti-phase at the output port, thereby positive and negative pulses are obtained at the output. To the best of the authors' knowledge, this distributed filter structure has not been reported before.

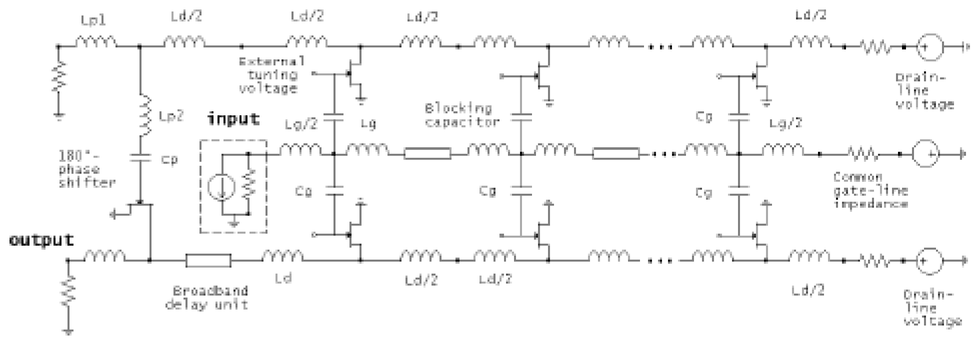

Fig 2 Transversal-filter proposal for FO-CDMA receivers

The proposed transversal-filter structure provides the basic functions to achieve broadband filtering: signal delay and gain multiplication. Signal delay is obtained by introducing delay units along the common gate-line. Delay lines can be synthesised using microstrip transmission lines to provide accurate delays at microwave frequencies. On the other hand, external biases at the gate permits adjusting the device transconductance so as to multiply input parallel signals with the proper tap gain.

When a transversal filter is tuned by changing external biases, the input capacitance of the active device varies. This outcome spoils the uniformity of the artificial transmission line and reduces the effective bandwidth. The poor performance of the filter stems from mismatching among sections when the range of external voltages is wide so as to realise a specific function. In such conditions, equation 1 cannot describe the filter response [6]. The mismatching among sections can be avoided using the filter topology depicted in fig 2. Using this structure, it has been demonstrated in [9] that applying appropriate external bias voltages results in a constant capacitance per section in the gate artificial transmission line. Accordingly, the gain of the taps can be set from a maximum to a minimum value while maintaining the electrical characteristics of the transmission line without change. This active matching characteristic is described in [9] and its application to the structure depicted in fig 2 makes available the development of high-performance transversal-filters. This concept is employed in the design and analyses of the filter.

4 Filter response analyses

In order to evaluate the proposed structure, a 7-tap, 10 Gchip/s transversal filter was designed following the proposed approach and having a structure similar to that of fig 2. Additionally, the filter was programmed with the bipolar m-sequence (+1, +1, +1,-1, +1,-1,-1).

When a 0.1 nsec pulse is provided at the input, the pulse is delayed and multiplied by an appropriate transconductance gain. The response of the filter to a squared pulse is depicted in fig 3(a). The smoothness of the waveform is a result of input pulses with very little energy beyond the cut-off frequency of the artificial transmission line. It is important to mention here that the filter response can be optimised since the active matching technique enable the active device gain to be adjusted without reducing the speed. Additionally, the oscillatory component of the filter is reduced because the filter was designed for an almost linear phase response.

Periodic reciprocal sequences are used to test the impulse response of the matched filter. The convolution property of the structure is analysed by providing at the input pulses which periodic pattern is based on the reciprocal sequence of the bipolar m-sequence. According with the theory given in [10], the reciprocal sequence of a bipolar m-sequence is a unipolar one and their periodic convolution is a perfect impulse. Taking into account this property, the unipolar periodic sequence was provided at the input so as to analyse the response. Simulation results are depicted on fig 3(b).

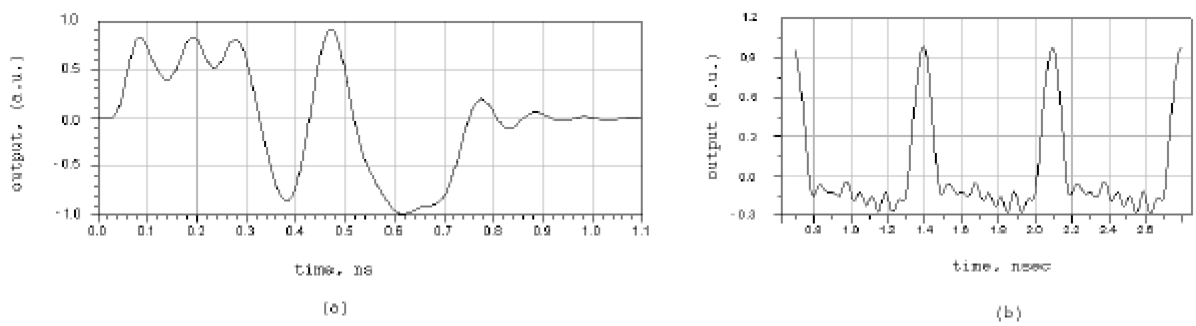

Fig 3 **(a)** Filter response for a single pulse at the input; **(b)** Filter response for a reciprocal-sequence-based periodic signal

The transversal filter presents an impulsive response with low side lobe responses. Despite the oscillatory component in the single pulse response, the symbols can be detected with low intersymbol interference as showed in fig 3(b). The bipolar capacity of the filter permits the correct reception of CDMA signals.

5 Conclusions

It is shown that the transversal filter proposal is a viable alternative for CDMA receiver implementations. The transversal filter was designed based on MESFET's with cut-off frequency of 15 GHz. Higher speeds could be attained by using commercially available HEMT processes. The transversal filter is to be developed as a MMIC after its optimisation. The proposed filter is aimed to receive spread signals with very little energy beyond the chip rate. The development of such receiver could point towards bandwidth efficient FO-CDMA systems.

Acknowledgments

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