# A DIRECT EQUALIZATION METHOD

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**ABSTRACT**

The unshielded twisted pair can be used as a transmission media for local distribution networks. To maintain a high transmission throughput, an analog or a digital adaptive channel equalizer is usually required in the receiver to minimize the effect of inter-symbol interference. Under the observation that the high sampling rate high precision A/D and subsequent digital adaptive signal processing is an expensive approach, a direct equalization method, where the equalizer is implemented in the transmitter, is proposed for symmetrical twisted pair transmission channels. This direct equalization method can also be applied to the analog equalization approach for reduced system complexity.

## 1. Introduction

The unshielded twisted pair (UTP), can be used as a transmission media for high throughput local distribution networks. To increase the baud rate, an analog or a digital adaptive channel equalizer is usually required in the receiver to minimize the effect of inter-symbol interference. The analog adaptive equalization approach can be implemented with a combination of active filters, comparators, and variable gain amplifiers. The more accurate digital adaptive equalization approach requires high sampling rate D/A and A/D converters, high rate digital filters, and timing recovery circuits.

In this paper, the local transmission environment of the CAT 5 UTP is first examined in Section 2. The conventional analog and digital adaptive equalization approaches are discussed in Sections 3 and 4. The idea of the direct equalization method[1], where the equalizer is implemented in the transmitter, is proposed in Section 5. For digital implementation, the direct equalization approach can simplify the timing recovery task, relax the A/D precision requirement as well as reducing the digital filter complexity.

## 2. Twisted Pair Local Symmetrical Transmission

Many twisted pair based local transmission systems, such as 10BaseT Ethernet, 100BaseTX Ethernet, 55 Mbps Home ATM Network, and the developing 1394 Home Network have a symmetrical channel response. A pair of transceivers, one located at the hub and the other located at a terminal, are connected with a straight unshielded twisted pair. Because there are no bridged taps, channel transfer functions in opposite directions are identical.

In these cases, the channel response can be identified by examining received signal. Specifically, the required channel equalization can be identified by using training sequences during the initialization period and updated through periodic transmission of the training sequence or by comparing the received signal strength at a particular frequency, where the equalization gain is unit, against a calibrated reference, particularly, for analog implementation.

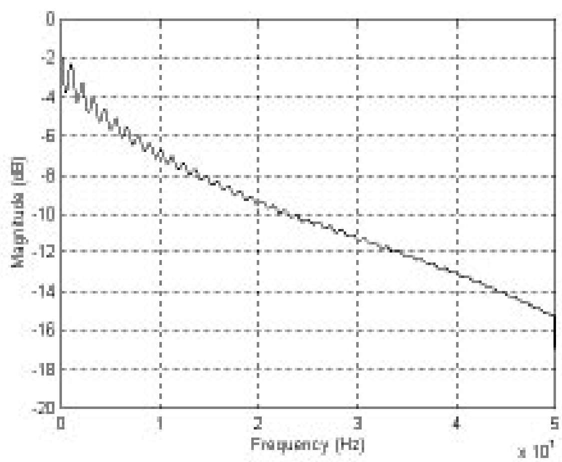


**Figure 1. Transfer Function of a Twisted Pair**

The transfer function of a CAT 5 UTP cable can be expressed as[2,3]

$$H(l,f) = e^{-l(a\sqrt{f}+bf)}e^{-jl2\pi f\beta}$$

where $a = 0.00267$, $b = 0.000274$, and $\beta$ is related to the propagation delay. *l* is in unit of meter, and *f* is in unit of Hz.

Figure 1 shows the channel transfer function of a 100 meters CAT 5 UTP cable. Figure 2 shows the impulse response. According to the channel impulse response, the transmission delay of an 100 meter CAT 5 UTP is about 0.44 µs and the delay spread is about 0.1 µs. In comparison, the baud intervals are 0.01 µs, 0.02 µs, and 0.04 µs for baud rates of 100 MHz, 50 MHz, and 25 MHz respectively. Since the delay spread is well beyond a baud interval, channel equalization, in analog or digital format, is necessary to minimize the effect of inter-symbol interference.

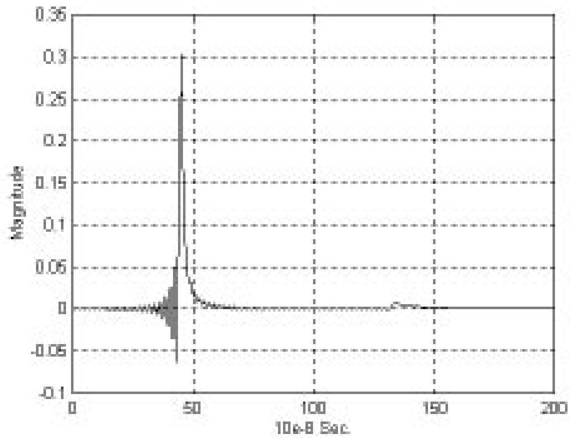


**Figure 2. Impulse Response of a Twisted Pair**

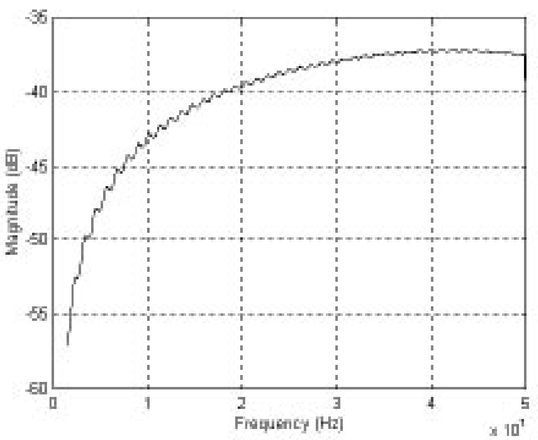


**Figure 3. FEXT Loss of A Twisted Pair**

Besides background noise, the crosstalk noise is a major transmission impairment for UTP. For a single access/bus based transmission system only the effect of Far End Crosstalk (FEXT) noise needs to be examined if the use of multiple pairs is necessary. The FEXT loss can be expressed as

$$FEXT = klf^2 |H(f)|^2$$

where $H(f)$ is the channel transfer function, $k = 3.2 \times 10^{-20}$, $l$ is in the unit of meter, and $f$ is in unit of Hz. The FEXT loss of a CAT 5 UTP is about -38 dB at 30 MHz.

The other potential limitation of CAT 5 UTP is its possible emission to affect the performances of other transmission systems. At a distance of 10 meters, a CAT 5 UTP can cause a field strength of 0 dB μV/m with a common model current of 1 μA at frequencies below 40 MHz.[4] Above 40 MHz, the field strength can be 14 dB stronger. There is usually a 30 - 40 dB of current strength reduction when a common mode current is caused by a differential model current. The FCC class B requires a filed strength of less than 30 dB μV/m also at a distance of 10 meters.

Figure 5 shows the channel capacity of an 100 meter CAT 5 UTP cable. This background and FEXT noise limited channel capacity is calculated according to:

$$C_u = \int_0^{F_1} \log_2 \left[ 1 + \frac{1}{3.2 \times 10^{-20} l f^2 + \frac{N}{S^2 |H(f)|^2}} \right] df$$

A transmission throughput which is about a half of the channel capacity can usually be achieved with a good channel equalizer.[5]

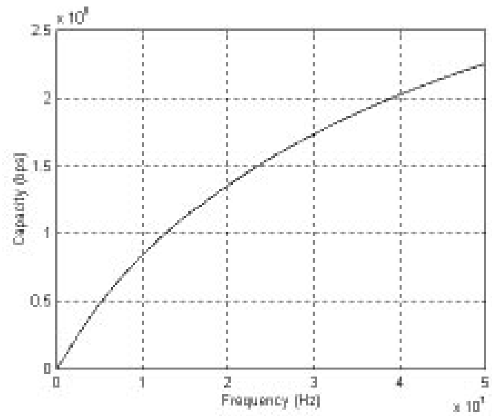


**Figure 4. Channel Capacity of A Twisted Pair (FEXT)**

## 3. Analog Adaptive Equalization

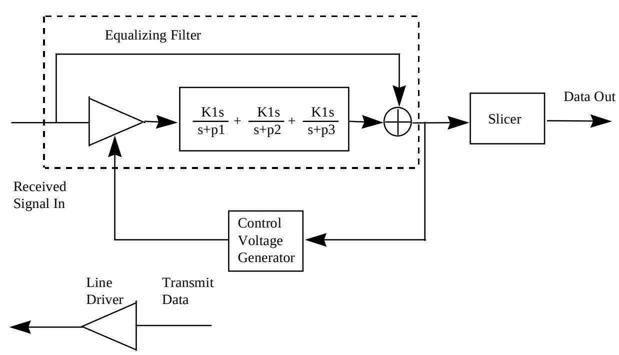


**Figure 5. An Analog Adaptive Channel Equalizer**

Analog adaptive channel equalizers have been successfully implemented in transceiver chip sets compatible with FDDI, 100BaseTX, and STS-3C ATM standards.[6] An analog adaptive channel equalizer could consists of an equalizing filter whose frequency response can be adjusted by a control voltage and a control voltage generator.

The equalizing filter should consists of a unit gain and an active filter with a number of poles simulating the worst case channel response. When the gain of the active filter is adjusted to a specific value, the frequency response of the equalizing filter will resemble the inverse of the cable transfer function at a particular cable length. The control signal can be generated according to the received signal strength or the shape of the equalized signal. There could be a variety of different analog adaptive equalizer implementations.[7,3]

## 4. Digital Adaptive Equalization

Digital adaptive channel equalizers have been used for voice band modems and Digital Subscriber Lines (DSL). Recently, the use of digital adaptive channel equalizer has also been proposed for local transmission systems.[2,8] The digital adaptive channel equalizer is usually implemented in the receiving path of a transceiver. The received signal is amplified and converted into digital format. A programmable filter with adjustable coefficients is used to compensate the channel distortion. These filter coefficients are calculated to minimize the mean squared error between the filter output signal level and the desired signal level. The calculation can be carried out based on the Least Mean Square (LMS) algorithm.[9]

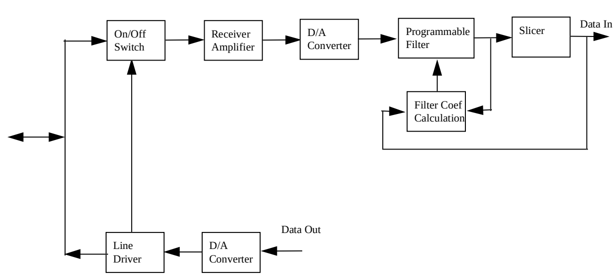


**Figure 6. A Digital Adaptive Channel Equalizer**

The realization of the conventional equalizer usually requires a full-precision programmable filter. Depending on the channel distortion and the number of signal levels, an A/D converter with 6 to 10 bits of resolution is necessary. This A/D converter must operate at or above the symbol rate. A baud rate based channel equalizer ranging from 10 MHz to 30 MHz also needs a highly accurate timing recovery circuit. The programmable filter after the A/D converter should have the same or higher bit resolution in the data path to make the equalization process effective. The high resolution and high sampling rate A/D converter and the following programmable filter of the same resolution and the same operating rate translate to a high transceiver cost.

## 5. The Direct Equalization System

The proposed direct equalization system uses the programmable digital filter in the transmission path for the purpose of pre-channel equalization. The high precision high sampling rate A/D convertor can be replaced with a lower resolution slicer. Similarly, the data path resolution of the digital filter is also reduced. It only requires a precision corresponding to the number of signal levels. Filter coefficients are identified during the initialization period using a training sequence and is updated periodically using the same training sequence without going through the programmable filter.

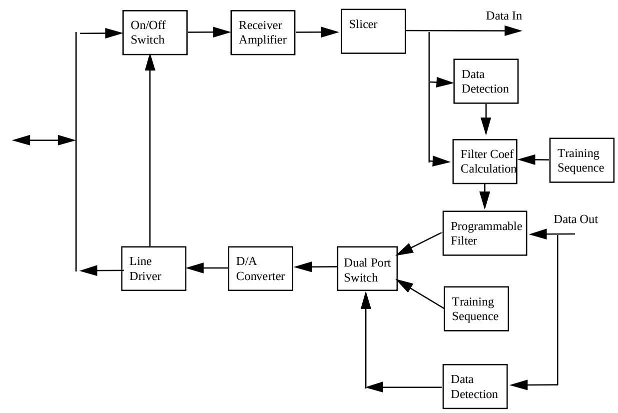


**Figure 7. The Direct Equalizer System**

A baud rate adaptive channel can only compensate for channel distortion at its precise sampling points. Hence, a receiver needs an accurate timing recovery circuit to keep track of these optimal sampling points (Figure 9).

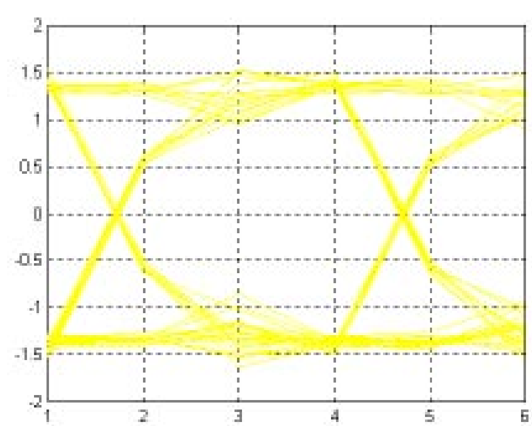


**Figure 8 The Effect of Baud Rate Equalization**

The sampling window size can be expanded using a fractionally spaced direct channel equalizer. Figures 10 shows the effects of a fractionally spaced direct equalizer for equalizer operating rates of 2 times of the baud rate.

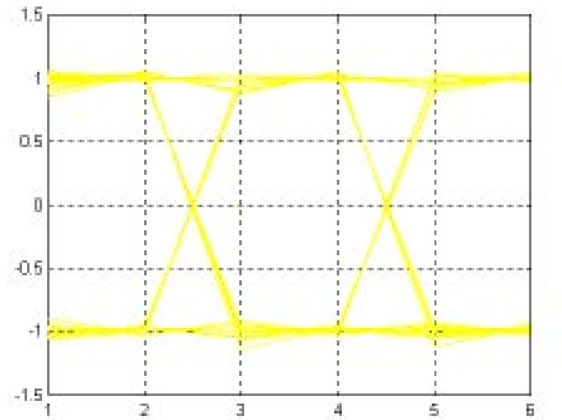


**Figure 9 Double Baud Rate Equalization**

An analog version of the direct equalization system is shown by Figure 10. With received signal pre-equalized, the receiver circuit complexity might be reduced.

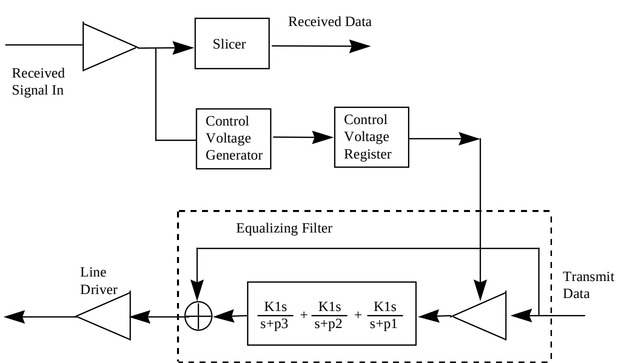


**Figure 10. An Analog Direct Equalization System**

## 6. Summary

A direct equalizer system with an adaptive filter in the transmitter has been proposed for symmetrical dispersive transmission channels. The direct equalization approach avoids the use of an expensive high precision high sampling rate A/D converter and a high precision adaptive filter in the receiver. In the transmitting data path the adaptive filter only needs a precision equal to the symbol bit resolution. The adaptive filter coefficients can be identified by using training sequences during the initialization period and updated through periodic transmission of the training sequence. This direct equalization approach can also be applied to analog implementation. The required analog channel equalization can be identified by comparing the received signal strength at a particular frequency, where the equalization gain is unit, against a calibrated reference. This direct equalization method could be an inexpensive approach for the realization of high data rate transmission systems over symmetrical dispersive channels.

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