Realization of Adaptive NEXT canceller for ADSL on DSP kit

B.V. UMA, K.V. PADMAJA, Dr. S. RAVISHANKAR
ELECTRONICS AND COMMUNICATION DEPARTMENT
VISVESVARAYA TECHNOLOGICAL UNIVERSITY
R.V.COLLEGE OF ENGINEERING, BANGALORE-560059
INDIA

Abstract: - Crosstalk canceller plays a key role in achieving high bit rates in wire line multicarrier Asymmetric Digital Subscriber Line (ADSL) systems. Adjacent systems within a cable binder that transmit or receive data in the same frequency range can create crosstalk interference. In an ongoing effort to study and improve the performance of ADSL Central office and CPE modems, the effect of Near-end crosstalk (NEXT) is examined. In this paper we introduce filter for NEXT mitigation to improve signal to noise ratio(SNR) at the input of the receiver which improves data rate. An Adaptive LMS filter to eliminate the effect of NEXT is designed. Adaptive LMS filter simulation was done in Matlab environment and also implemented on TMS 320C 6713 DSP. An analysis of the Receiver output with and without filter is presented for various lengths. Results presented shows an improvement in SNR with this filter. Efficient bit loading strategies can be adopted to provide a higher user data rate in the presence of NEXT.

Key words - LMS, Crosstalk canceller, ADSL, FEXT, NEXT, Quiet periods.

1. Introduction

In our previous paper titled ‘Simulation and Implementation of a practical ADSL environment on DSP Kit , we had modeled transmitter, receiver, channel and noise and obtained SNR profile. In this paper we introduce adaptive filter for NEXT mitigation to improve signal to noise ratio(SNR) which in turn improves data rate.

Asymmetric Digital Subscriber Line (ADSL), a modern technology, converts existing twisted-pair telephone lines in the plain old telephone service (POTS) into access paths for multimedia and high-speed data communications[6]. Crosstalk is, undesirable signal transmission from one signal pair to another in close proximity. It is a major source of interference in digital service lines as these service lines are tightly bundled into a single cable. Crosstalk is broadly classified into two categories as NEXT and FEXT[2]. Crosstalk NEXT defined as the cross talk between a receiving path and a transmitting path of DSL transreceivers at the same end of two different subscriber loops within the same twisted pair cable as shown in figure 1. FEXT is the noise detected by the receiver located at the far end of the cable from the transmitter that is the noise source. NEXT is a major impairment for systems that share the same frequency band for upstream and downstream transmission[3],[4].

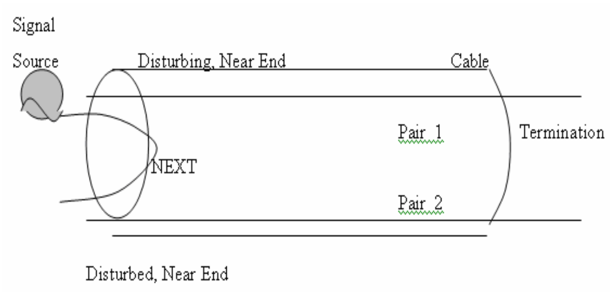

Figure1 NEXT illustration

1.1 Noise model

The PSD of the HDSL disturber is given by equation 1[11]:

$$PSD_{HDSL.\,Disturber} = K_{HDSL} \times \frac{2}{f_o} \times \frac{\left[\sin\left\{\frac{\pi f}{f_o}\right\}\right]^2}{\left\{\frac{\pi f}{f_o}\right\}^2} \times \frac{1}{1+\left\{\frac{f}{f_{3dB}}\right\}^8} -- f_{3dB} = 196KHz, (0 \le f < \infty) \ \ldots(1)$$

Where f_o = 392 KHz, $K_{HDSL} = \frac{5}{9} \times \frac{V^2{}_p}{R}, V_p = 2.70V, R = 135\Omega$

The PSD of the HDSL NEXT is given by equation 2[11]:

$$PSD_{HDSL-NEXT} = PSD_{HDSL.\,Disturber} \times \left(x_n \times f^{3/2} \right) for\ 0 \le f < \infty, n < 50$$
$$Where x_n = 8..818 \times 10^{-14} \times \left(n/49\right)^{0.6} OR x_n = 0.8536 \times 10^{-14} \times n^{0.6} \quad \ldots.(2)$$

The block diagram of Adaptive noise Cancellation as applied to ADSL lines is as shown in figure 2[8]

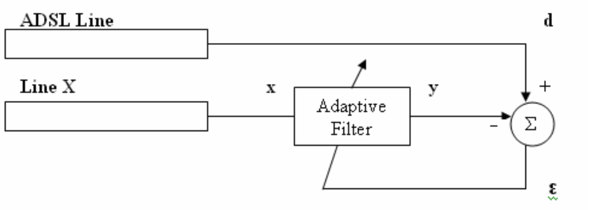

Figure 2 Adaptive noise Canceller

In the diagram above, a service line **X** affects the ADSL line because it is adjacent to the ADSL line in the bundle.

The problem of crosstalk between adjacent lines can be modeled as follows:

- **X** – Service line that interferes with the ADSL line
- **X(f)** – Frequency spectrum of the signal on service line **X**
- **H(f)** – Unknown or variable transfer function that maps **X(f)** to **Y(f)**

Using the above notations we have the following expression for **Y(f)**

Y(f) = H(f) * X(f) ,

The adaptive filter adjusts itself such that it closely approximates the unknown transfer function **H(f)**. Since the input to the adaptive filter is the signal on service line **X** the output of the adaptive filter is a signal that closely resembles the interference due to **X** in the ADSL line, hence after the subtraction operation, the interference on the ADSL line due to the adjacent service line **X** is largely reduced.

The adaptive filter trains or adapts using the Least Mean Squared (LMS) algorithm. Least Mean Squared (LMS) Algorithm is an approximation of the steepest descent algorithm which uses an instantaneous estimate of the gradient vector. The algorithm iterates over each tap weight in the filter, moving it in the direction of the approximated gradient. This algorithm is important because of its simplicity and ease of computation, and because it does not require off-line gradient estimations or repetitions of data.

2 Realization of Adaptive noise cancellation

Practically this process of adaptive noise cancellation is carried out in two distinct phases namely (a) Adaptation or Training Phase and (b) Filtering Phase[9],[10].

2.1 Training Phase

This phase is controlled to occur only during "**quiet periods**" of the ADSL line. During these quiet periods, the signal on the ADSL line is primarily contributed to by interfering signals from adjacent service lines. It is during this phase that the adaptive filter runs its adaptation algorithm to update its weights in such a way that its output resembles the crosstalk signal on the ADSL line. As a result of this training procedure the weights of the adaptive filter are so adjusted that the filter has a transfer function resembling **H(f)**.

2.2 Filtering Phase

Here the adaptive filter that has been trained previously is used to filter the crosstalk signal. The output of the adaptive filter is then used to remove the interference on the ADSL line by subtraction. Hence, at the end of these two phases the crosstalk on the ADSL line is reduced by a large extent. In both these phases, the adaptive filter trains or adapts using the Least Mean Squared (LMS) algorithm.

3. Derivation of the LMS Algorithm

The structure of the adaptive linear combiner is as shown in figure3[5]

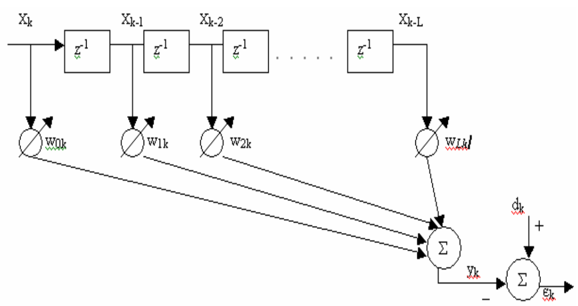

Figure 3 Adaptive linear combiner

The output of the adaptive linear combiner y_k is expressed as a linear combination of the input samples x_k. The error ϵ_k is given by the following equation: $\epsilon_k = d_k - X_k \cdot W_k$, where X_k and W_k are the vectors of the input samples and the weights of the adaptive filter respectively. LMS algorithm uses the squared of the instantaneous value of error ϵ_k as an estimate of the mean squared error $E[\epsilon^2]$. Thus, the gradient which is defined as the derivative of the mean squared error with respect to the weight vectors thus becomes:

$\nabla_k = -2\epsilon_k X_k$

With this simple gradient estimate, we can obtain the equations for updating the weight vectors as follows[5]:

$W_{k+1} = W_k - \mu\nabla_k,$

The above equation yields

$W_{k+1} = W_k + 2\mu\epsilon_k X_k.$

This is the weight vector updating equation for the LMS algorithm. μ is termed as the gain constant. μ regulates the speed and the stability of adaptation.

The following observations regarding μ may be made.

- A small value of μ results in slow convergence of the weight vectors
- A large value of μ results in faster convergence of the weight vectors, at the same time it results in granular noise.

4 Implementation

4.1 Matlab Implementation

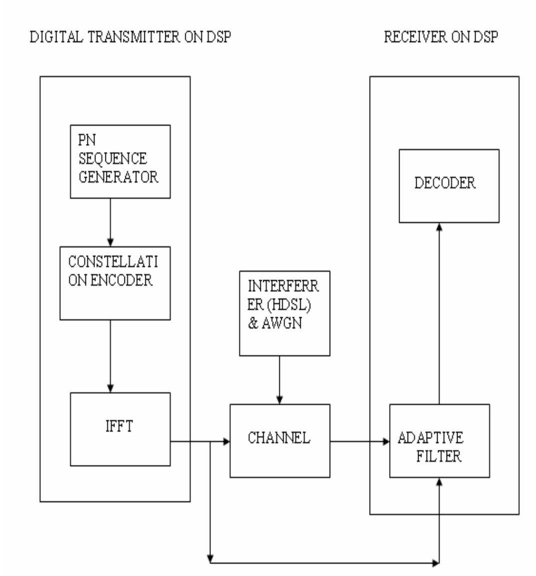

Figure 4 Block diagram of ADSL environment.

Figure 4 shows the block diagram of ADSL environment. Transmitter is realized on DSP chip, channel and noise using Matlab and finally the adaptive filter to cancel interference is realized on DSP chip. First the transmitter output and channel characteristic are known completely, the performance of the adaptive filter is analyzed.

The steps involved are as follows[1],[11][6]:

1. ADSL Transmitter is modeled to obtain ADSL signal. PN sequence generator, constellation encoder and IFFT blocks of Transmitter are simulated using Matlab.
2. Channel is simulated using Matlab .
3. PSD of HDSL (interferer) is modeled using equation 1 and then using equation 2 NEXT is modeled.
4. Practical channel is modeled by adding noise (NEXT) to channel characteristic.
5. Using the structure of linear combiner Adaptive filter is designed
6. The filter is then fed with only NEXT and AWGN to Train filter for interference during quiet period.
7. Removal of NEXT and AWGN is done using trained adaptive filter.
8. SNR values before and after removal of NEXT are tabulated.

4.2 Implementation on TMS 320 C6713 DSP

The high-performance board features the TMS 320C 6713 floating-point DSP. Capable of performing 1350 million floating-point operations per second (MFLOPS), the C6713 DSP makes the C6713 DSK the most powerful DSK development board.

A C Program for the TMS 320C 6713 DSP has been written to implement the Adaptive Noise Canceller applied to removal of NEXT on ADSL lines. The Code implements an LMS filter which trains during the silent periods of the ADSL line. Once the LMS filter is trained it uses the signal on the other lines (DSL, HDSL etc.) as a reference signal and removes the NEXT effect due to these lines on the ADSL line.

5 Simulation Results

The Adaptive Crosstalk canceller simulation was done in Matlab environment[7] . Receiver output with and without filter were plotted and analyzed.
Fig 5.1 Shows channel characteristic. (Ideal case)
Fig 5.2 Shows the PSD of HDSL.
Fig 5.3 Shows the plot of ADSL signal after channel without AWGN and NEXT.
Fig 5.4 Shows the plot of ADSL signal after channel with AWGN and NEXT.
Fig 5.5 Shows the plot of ADSL signal after adaptive filtering.

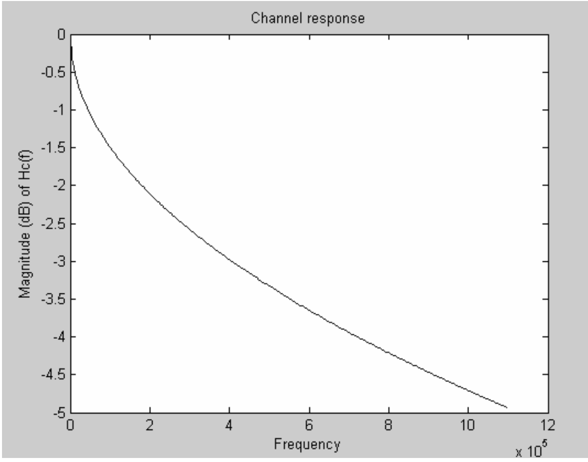

Fig 5.1 channel characteristic.

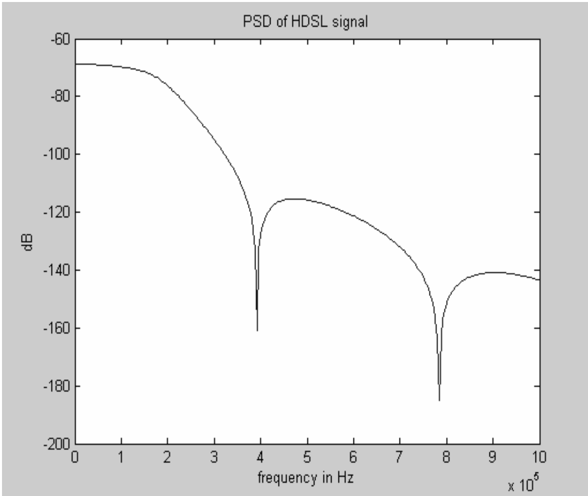

Fig 5.2 PSD of HDSL.

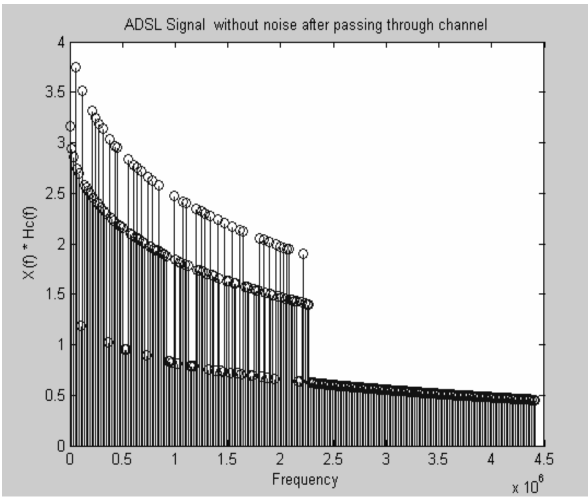

Fig 5.3 ADSL signal after channel without AWGN and NEXT.

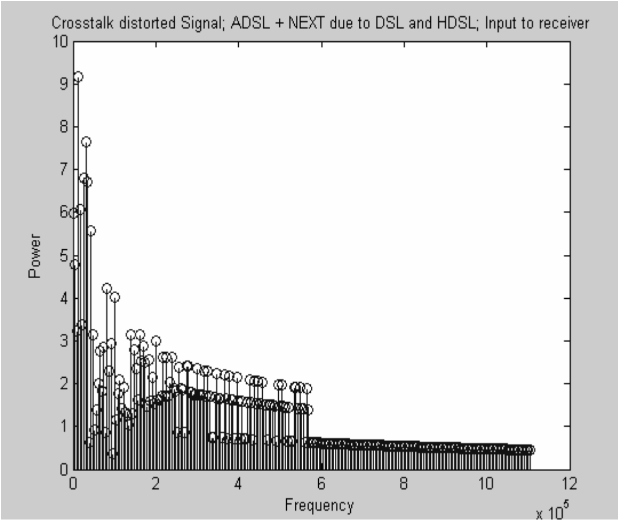

Fig 5.4 ADSL signal after channel with AWGN and NEXT.

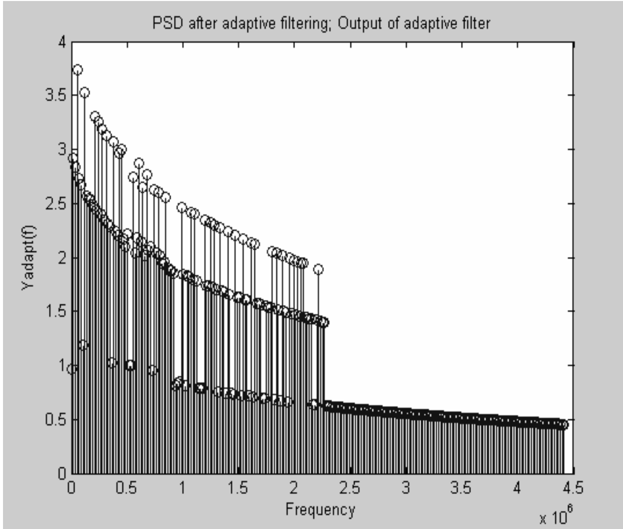

Fig 5.5 ADSL signal after adaptive filtering.

6 Tabulation of results

Tabulations of increase in SNR after adaptive filtering with normalized amplitude of crosstalk signals (HDSL) = 0.2 and Gaussian noise value = 30 dB below signal

	μ = 0.02		μ = 0.03		μ = 0.04	
Length of link (Kft)	**1.50**	**3.00**	**1.50**	**3.00**	**1.50**	**3.00**
Number of iterations	**SNR after filtering - SNR before filtering (dB)**					
1024	0.8982	0.0735	0.7801	2.8351	0.6028	1.3537
2048	4.5201	1.3274	10.7033	5.8241	4.8415	2.977
4096	7.9914	9.9608	15.4876	5.9511	6.6105	11.7034
8192	10.9648	11.8609	13.913	13.0699	15.2127	17.2054
16384	12.0524	10.2818	13.6784	17.085	16.9647	14.5686
65536	18.718	16.0553	24.4454	19.4511	24.7247	19.8399
131072	22.0593	21.8073	32.3108	22.946	24.8745	24.4556
262144	34.6813	22.1754	27.7599	30.1015	27.0235	25.04
524288	28.5015	27.1238	27.7719	25.3677	31.1787	25.742

Table 1 Tabulations of increase in SNR

7 Conclusion:

In this paper, we have designed an adaptive filter for cancellation of NEXT and AWGN effect on ADSL. With adaptive NEXT canceller SNR improvement is achieved as shown in the table1. An LMS filter is designed and simulated. To test the performance of the filter, Transmitter, channel and interference were simulated. Larger the number of training iterations, larger is the improvement in SNR value that is obtained. SNR improvement is better with adaptation constant mu = 0.02. Figure 5.3 and figure 5.5 are similar which implies that filter is efficient in canceling NEXT noise.

Thus a NEXT mitigator running an LMS algorithm with an error for adaptation constitutes whitening LPC filter. This filter of selectable order can be easily trained during the normal modem training time when the TEQ is not operational.

References:

[1] Raju Hormis, Dong Guo and Xiaodong Wang ' Monte carlo Fext canceller for DSL Channels' IEEE Transaction on circuits and systems, vol. 52, No. 9 Sept. 2005

[2]Craig Valenti, 'NEXT and FEXT Models for Twisted Pair North American Loop Plant', IEEE Journal in Selected areas in Communications, Vol 20, No 5, June 2002

[3] Stefano Galli, Kenneth Kerpez, 'Methods of summing Cross Talk from Mixed Sources', Part I: Theoretical Analysis, IEEE Transactions on Communications, Vol 50, No 3, March 2002.

[4] Stefano Galli, Kenneth Kerpez, 'Methods of summing Cross Talk from Mixed Sources', Part II: Performance Results, IEEE Transactions on Communications, Vol 50, No 4, April 2002.

[5] B Farang Boroujeny, Adaptive filters theory and applications , John Wiley& sons ltd, 1998

[6] T.Starr, J.M.Cioffi, and P.J.Silvermann, 'Understanding Digital Subscriber Line Technology', Prentice Hall Publications.

[7] Walter Chen, 'Simulation Techniques and standards for Digital Subscriber line systems, McMillan , Technology Publications.

[8]Simon Haykin, "Adaptive Filter Theory" fourth edition, Printic Hall,1996

[9]John A C Bingham, "ADSL, VDSL and multicarrier modulation" by

[10]Peter M. Clarkson, "Optimal and Adaptive Signal Processing and Techniques"

[11] ITU-G992.1, 'Asymmetrical Digital subscriber line Transreceivers.'
ITU-G992.3, 'Asymmetrical Digital subscriber line Transreceivers-2.'
ITU-G.Test.bis, 'Test Procedure for Asymmetrical Digital subscriber line Transreceivers.'