Chapter 4

Simulation Platform and Simulations

This chapter presents the results of the simulations that were performed to test the proposed time domain equalizer algorithm. The performance of the proposed methods is put into context by comparison with representative previously published time domain equalizer design methods. The transmission channels included standard carrier service area (CSA) loops [12] as shown in Fig.4.1, transmitter and receiver and various noise sources included in the subchannel signal-to-noise ratio model of Chapter 2. The simulation results compare the performance of the proposed time domain equalizer design with minimum mean squared error [13][14], maximum shorting SNR [15], maximum geometric SNR, minimum inter-symbol interference, and maximum bit rate time domain equalizer design. The results of the simulations show that the two proposed time domain equalizer method achieves on average more than 97% of time domain equalizer performance with significantly simpler architecture.

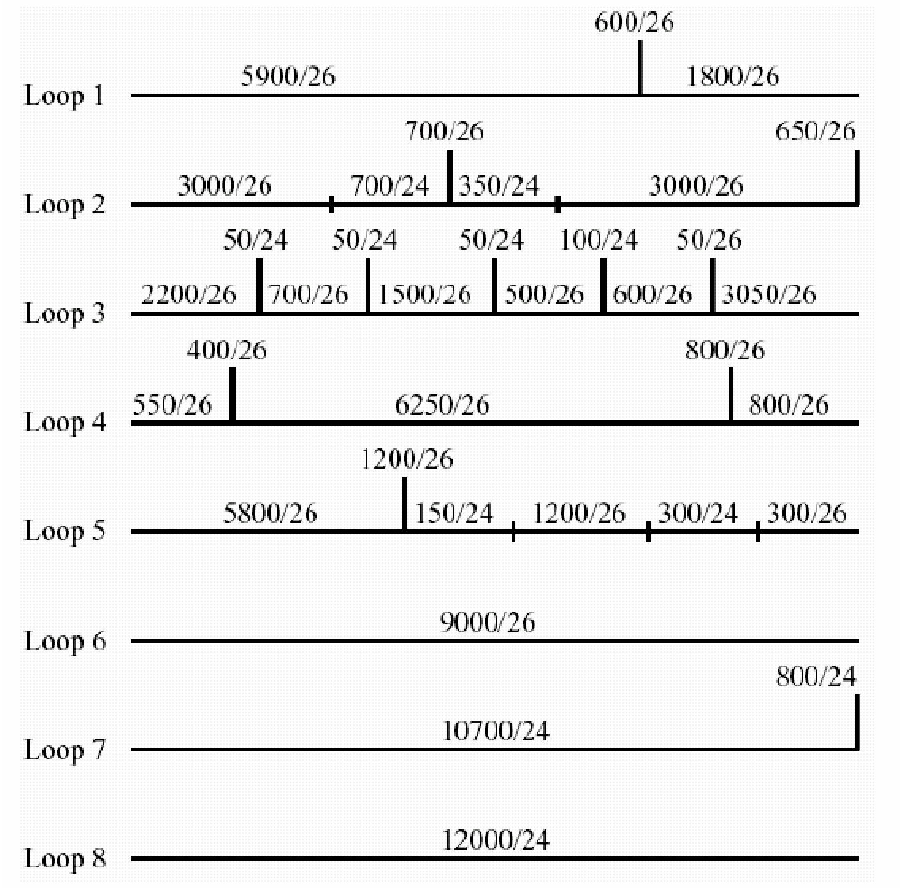

Fig.4.1 CSA Test Loops

4.1 Simulation Platform

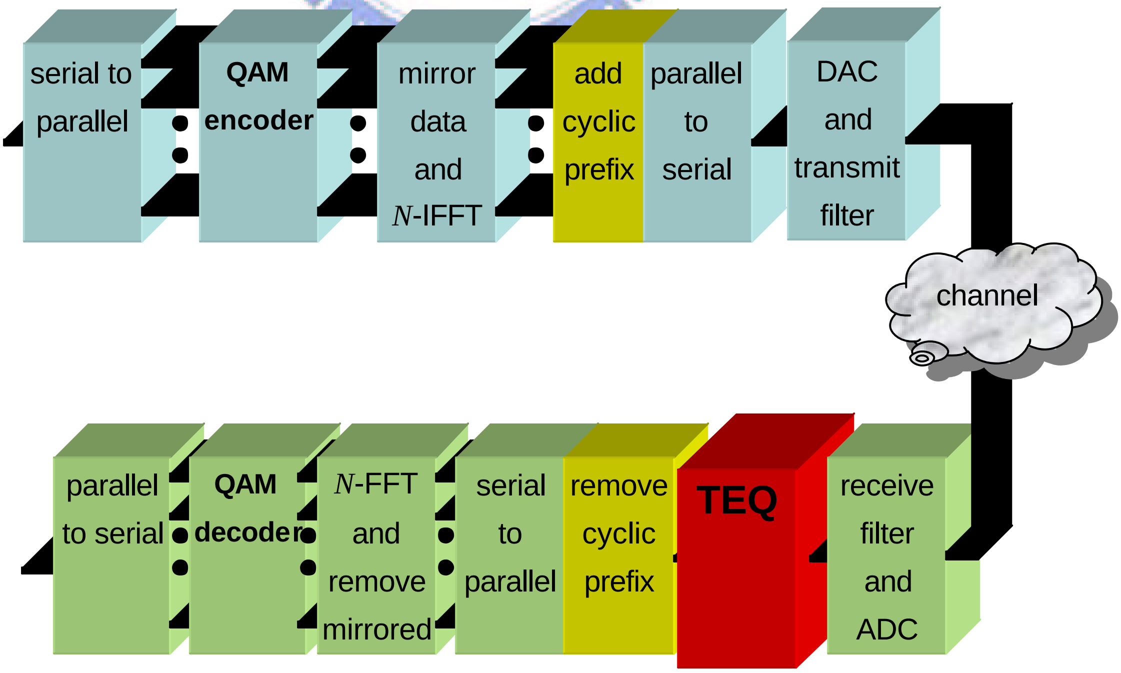

Fig.4.2 Simulation Platform

4.2 Simulation Results

In the simulations, all loop channel impulse responses consist of 512 samples sampled at 2.208 MHz. The input signal power is 23 dBm and the power of AWGN is -140dBm. The FFT size is set to N = 512. We model the NEXT noise as the transfer function $|H_{NEXT}|^2 = k_{NEXT} f^{1.5}$ where $k_{NEXT} = \frac{1}{1.134\times10^{13}} \times (\frac{10}{49})^{0.6}$.

Sources of digital subscriber loop noise can be classified into two parts: crosstalk noise, and AWGN. Crosstalk noise is caused by adjacent subscriber loops transmitting data. Since the power level of the signal attenuates due to the channel, FEXT noise is generally less powerful than NEXT noise. Therefore, we may pay more attention to NEXT. Crosstalk noise is generally modeled as a coupling filter fed by a random signal. The random signal has the same bandwidth and statistical properties of a signal modulated with the modulation method being used by the adjacent loops. For example, if the adjacent loops are using ADSL, then the random signal should be a multicarrier modulated random signal. In modeling the electromagnetic coupling between two copper wires, the coupling filter is generally a highpass filter with increasing gain as frequency increases.

Part A: Performance Versus Number of Equalizer Taps N_w

When we analyze the performance, we want to observe the effect of different number of equalizer taps. From the observation, we may get a suitable number of taps to implement the design method without a waste of hardware. In this simulation, we set the cyclic prefix n to 32. The results are shown in Fig 4.3, Fig 4.4, and Fig 4.5.

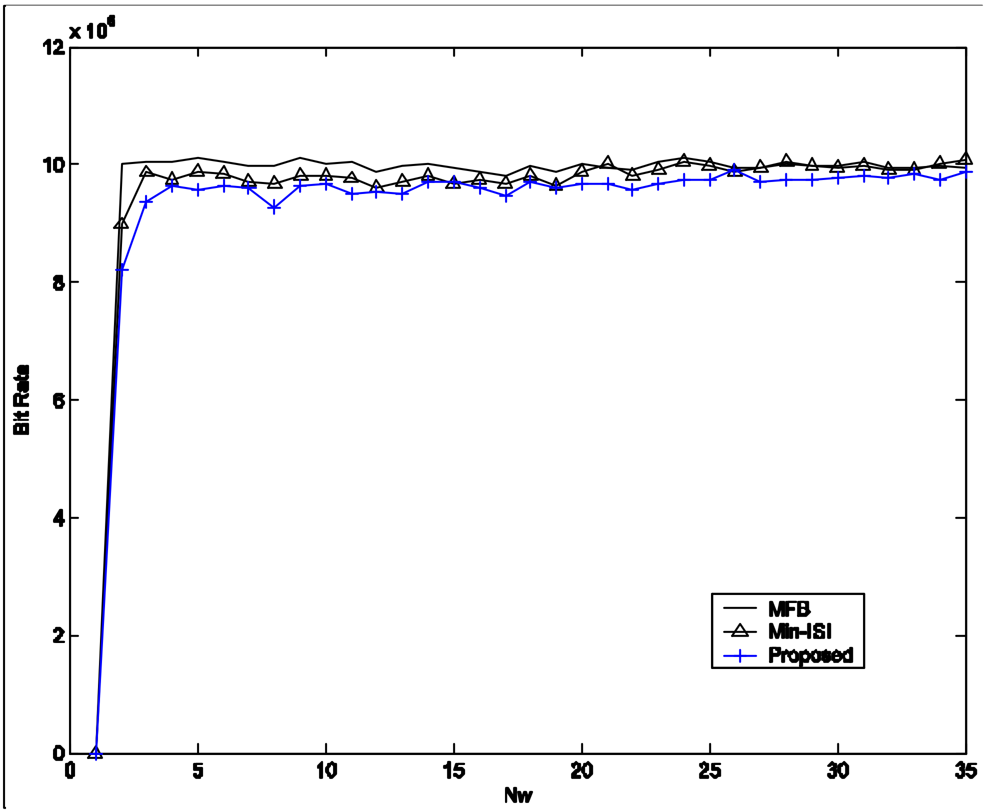

Fig 4.3 Achievable bit rate versus the number of equalizer taps for CSA loop 2, ?=32, The proposed method is “Off & On” method.

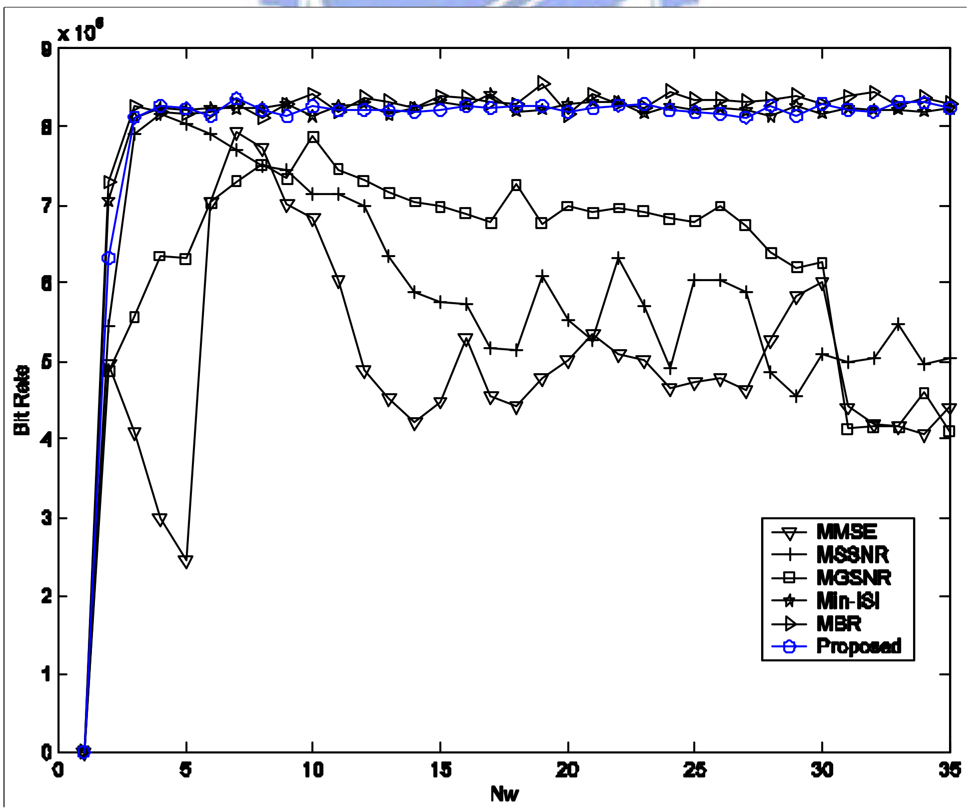

Fig 4.4 Achievable bit rate versus the number of equalizer taps for CSA loop 4, ?=32, The proposed method is “Four level” method.

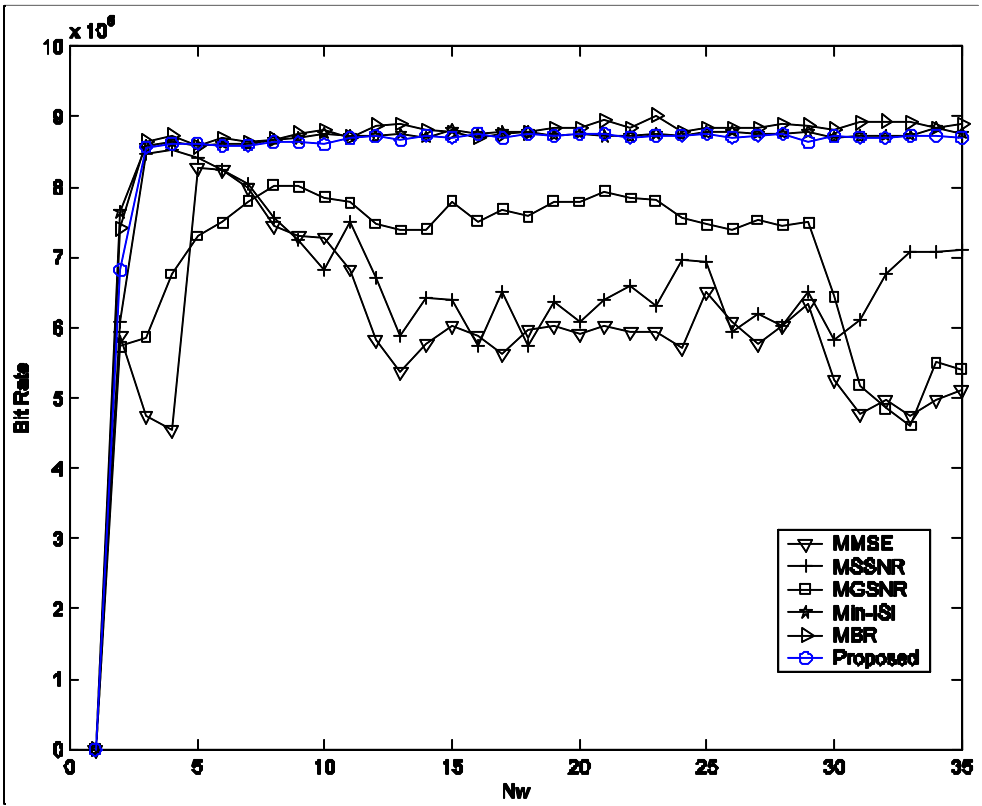

Fig 4.5 Achievable bit rate versus the number of equalizer taps for CSA loop 5, ?=32, The proposed method is "Four level" method.

By surveying the Fig 4.3, we can see that the proposed "Off & On" design method almost achieves as high bit rates as the MBR and Min-ISI method. It is about 97% of the matched filter bound. The aim of Fig. 4.4 and Fig. 4.5 is to show the other proposed algorithm, "four level" method. Its performance is also close to the MBR and the Min-ISI method. The other feature that we would like to mention is that for more than three or four equalizer taps, the "four level" method will reach a stably good performance. It suggests that a three-tap equalizer can effectively shorten a channel.

Part B: Performance Versus Cyclic Prefix Length *n*

Because large cyclic prefix reduces the throughput of the channel, we would like to find the smallest length under which the upper bound on bit rate can achieved. The

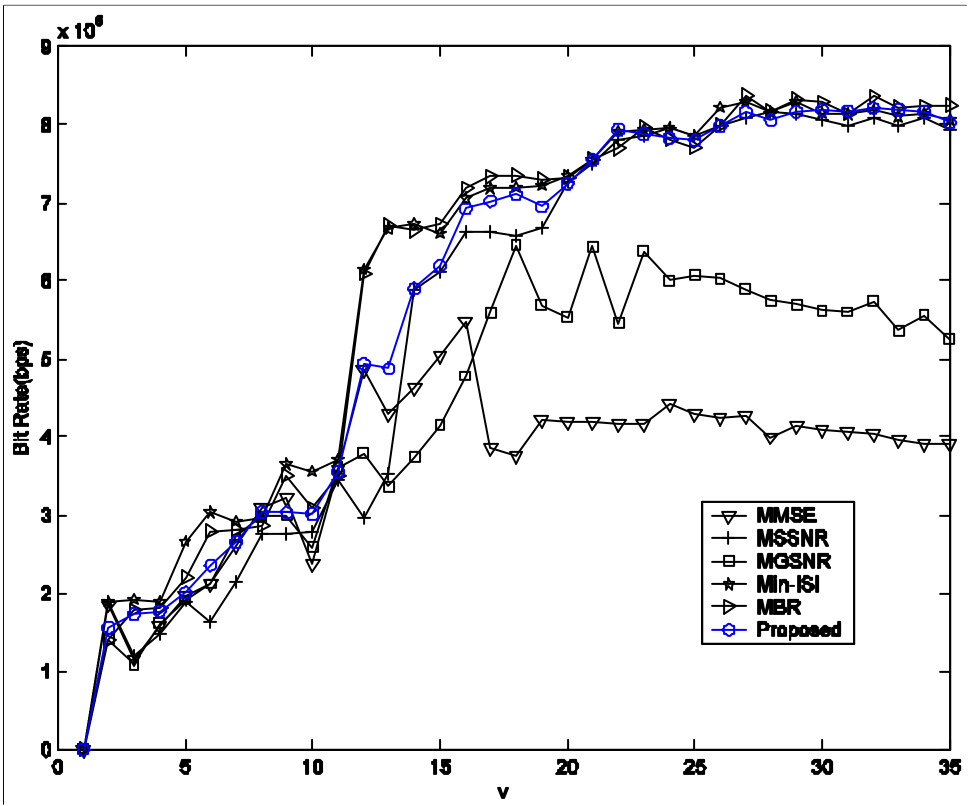

Fig 4.6 Achievable bit rate versus the number of equalizer taps for CSA loop 4, Nw=3, The proposed method is "Four level" method.

objective of Fig. 4.6 is to find the smallest possible cyclic prefix length given a suggested three-tap equalizer. We can see that a three-tap equalizer using our proposed method with a cyclic prefix of 24 or 25 can outperform the MMSE and the MGSNR TEQ methods. That is, the MBR, Min-ISI, MSSNR, and proposed method can achieve the upper bound on bit rate for $n = 24$. In Fig. 4.7, the MBR and min-ISI methods achieve the maximum bit rate for a cyclic prefix of 11 samples when a 17-tap TEQ is used. The MGSNR method outperforms the MSSNR method (except for cyclic prefix lengths of 3, 13, and 14) and the MMSE method. The MGSNR method is only competitive with the MBR and min-ISI methods for short cyclic prefix lengths $(n \leq 8)$. As increases, the bit rates achieved by the MSSNR, MGSNR, and MMSE methods essentially decrease, then increase, and finally decrease.

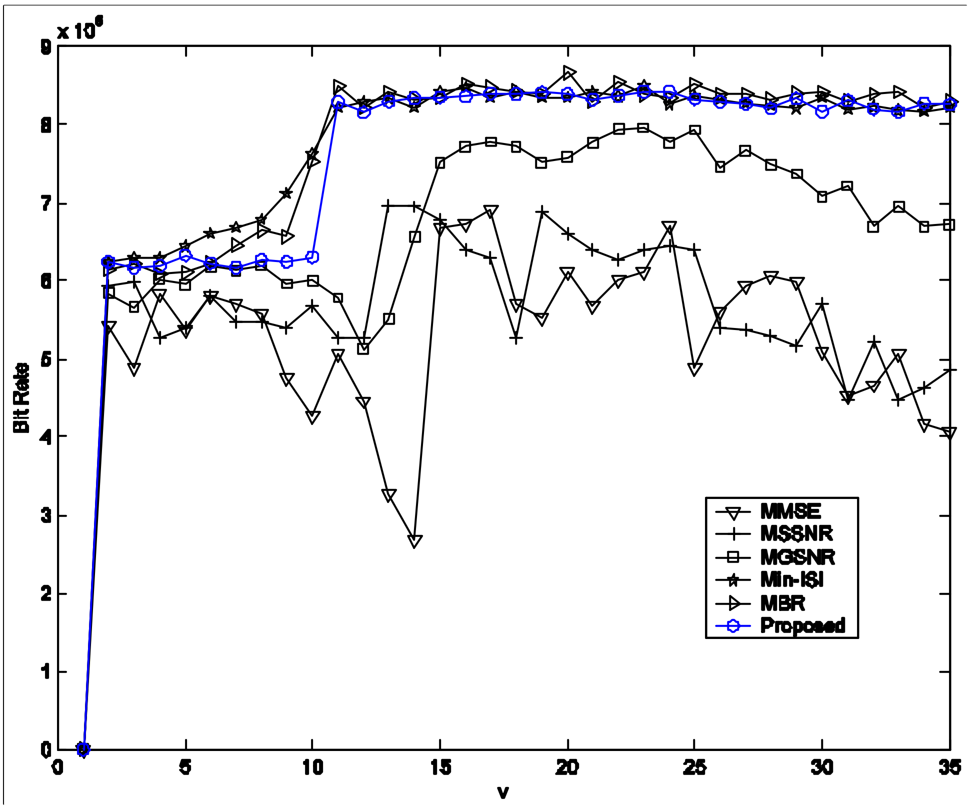

Fig 4.7 Achievable bit rate versus the number of equalizer taps for CSA loop 4, Nw=17, The proposed method is "Four level" method.

Part C: Achievable Bit Rate for the DSL Loops

We choose five CSA test channels are listed in Table 6.1 to test the bit rate results for all six TEQ design methods including our modified method. The setting coefficient are $N_w = 3$ and ? = 32 in the Table 4.1 and $N_w = 15$ and ? = 32 in the Table 4.2. All results are obtained by averaging 20 simulationruns for each case.

Table 4.1 shows that for a three-taps equalizer, MMSE only achieves about half of the upper bound on bit rate. The bit rate loss is up to 10% for the geometric TEQ methods, 4% for the MSSNR method, and less than 1-2% for the MBR, Min-ISI and our proposed methods. The results given in Table 4.2 show that a 15-tap equalizer can perform within 2% capacity loss provided that either the Min-ISI, MBR or our proposed method is used to design it. We can observe that the bit rate is not very high by using the MMSE design. The poor performance of the MMSE method can be

	Achievable bit rate (Mbps)						
Loop	MFB	MMSE	MSSNR	MGSNR	MBR	Min-ISI	Proposed
1	8.7108	4.5826	8.3735	6.0878	8.5569	8.5419	8.5437
3	8.3862	5.0680	7.7689	5.9740	8.3008	8.3009	8.2637
4	8.3223	4.0804	8.0213	5.6881	8.2149	8.0417	8.0767
5	8.8048	4.7291	8.5077	5.8793	8.6227	8.4355	8.5631
7	8.0211	3.7412	7.5386	5.0509	7.7780	7.7180	7.7590

Table 4.1: Achievable bit rates for the five CSA loops equalized with the MMSE, geometric TEQ, MSSNR, the Min-ISI, the MBR, and the proposed methods, as a percentage of the maximum achievable bit rate in the case of no ISI or equivalently with an SNR equal to the matched filter bound (MFB). Nw = 3, ? = 32, N = 512, coding gain = 4.2 dB, margin = 6 dB, input power = 23 dBm, AWGN power =-140 dBm/Hz.

	Achievable bit rate (Mbps)						
Loop	MFB	MMSE	MSSNR	MGSNR	MBR	Min-ISI	Proposed
1	8.6715	6.6003	5.5083	7.9793	8.6416	8.5929	8.6372
3	8.3470	6.7094	6.9413	7.4476	8.3130	8.1847	8.2976
4	8.3746	4.4926	5.2261	6.9636	8.2481	8.1922	8.2122
5	8.7869	5.9340	6.4811	7.8785	8.7483	8.5884	8.7066
7	8.0683	5.8749	5.7288	6.7959	7.9659	7.9819	7.9756

Table 4.2: Achievable bit rates for the five CSA loops equalized with the MMSE, geometric TEQ, MSSNR, the Min-ISI, the MBR, and the proposed methods, as a percentage of the maximum achievable bit rate in the case of no ISI or equivalently with an SNR equal to the matched filter bound (MFB). Nw = 15, ? = 32, N = 512, coding gain = 4.2 dB, margin = 6 dB, input power = 23 dBm, AWGN power =-140 dBm/Hz.

explained as follows: We use the MMSE method to minimize the difference between the TIR and SIR. It minimizes both the difference inside and outside the target window. Since the TIR is zero outside the window, minimizing the difference outside means forcing the SIR to lie inside the target window. However, the difference between the TIR and SIR inside the target window does not cause any ISI. Moreover, the TIR and SIR have larger magnitude inside the target window than outside the target window, which means that the difference between them inside the window causes the major part of the error. This means that the MMSE method tries to minimize the difference inside the window, which does not cause ISI, than outside the window, which causes ISI. A TEQ that has larger MSE caused by the difference inside the target window could give better performance than one that gives smaller MSE that is only caused by difference outside the target window. Therefore, to minimize the MSE may be not a good choice to design a TEQ for DMT modulation.

Chapter 5

Conclusions

Based on the new subchannel SNR definition, there are some algorithms to aim at maximizing the bit rate. That is the MBR and Min-ISI TEQ design method. The Min-ISI design method does not require nonlinear optimization, but it is still computationally complex. Calculating the cost matrices in the objective function is the most computationally intensive part of the design method. To reduce complexity, we adopt the idea of quantization. We quantized ISI frequency weightings to reduce the complexity. That is the "Off & On" method. However, it may be not exactly accurate. Therefore, we introduce the four thresholds and assign four special weighting values and the weighting can be implemented by using shifting. In this way, it will not increase the computation of multiplications, so that it is suitable to implement in real-time digital signal processors. Furthermore, we also introduce the generalized eigenvalue problem for Min-ISI method.

In simulations, we know that our two methods still outperform than MMSE, SSNR, and MGSNR in bit rate. Besides, the performance is very close to the MBR and Min-ISI TEQ design method.