Multilevel Coding for Partial Response Channels

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Overview

- Partial Response Channels
- Maximum Likelihood Sequence Detection(MLSD) Decoder
- Multilevel PRML Channel
- Simulations and Results
- Future Work

Partial Response Channels

- At high recording densities, there is a shift in the peaks of readback signals due to superposition of pulses, i.e. a phenomena known as InterSymbol Interference occurs(ISI). As a result, peak detection systems cannot detect correctly.
- A magnetic recording channel can be regarded as a "Partial-Response" (PR) channel because of its inherent differentiation in the readback process[1].
- In magnetic recording, bandwidth is very limited. The basic idea of using PR signalling is to maximise the spectral/bandwidth efficiency by introducing a controlled amount of ISI into the data pattern.

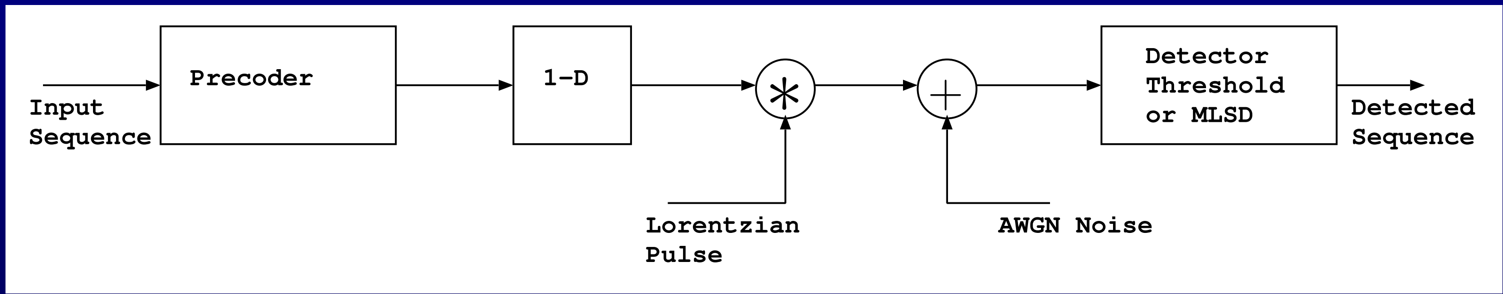

Figure 1: Simulated Dicode Magnetic Recording Channel

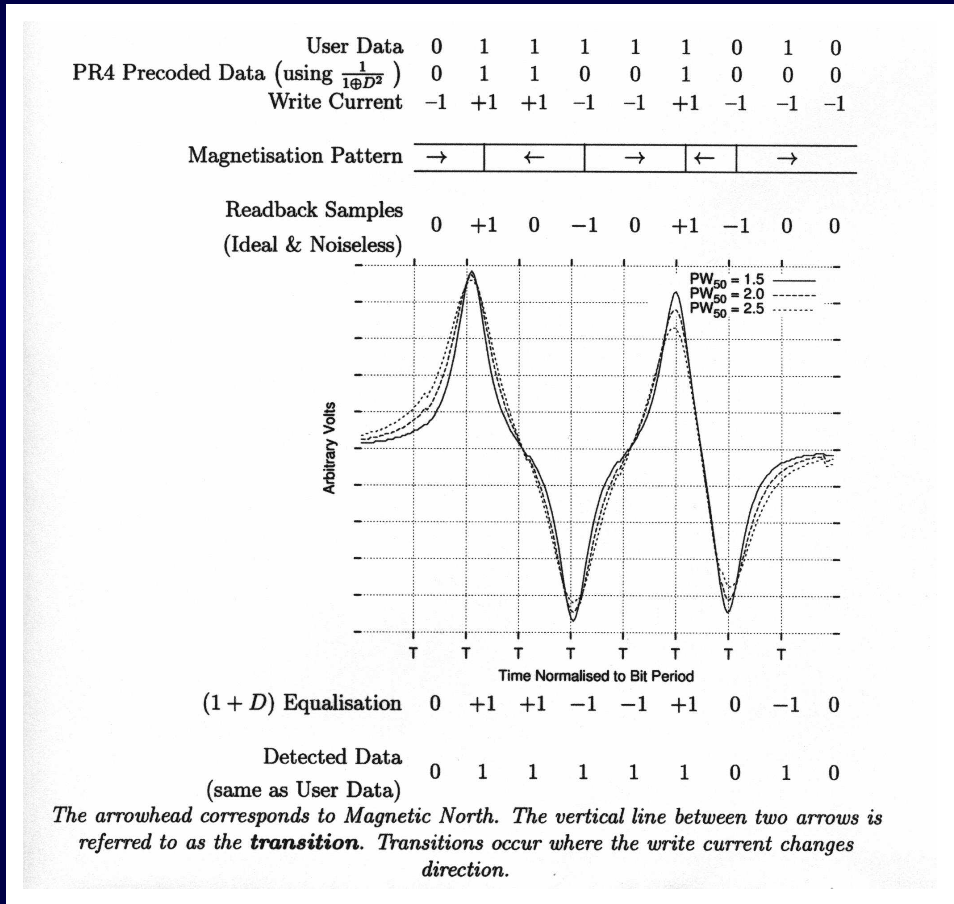

Figure 2: Various Stages of PR4 Longitudinal Recording [2]

- Kretzmer[3] defined the classes of PR signalling and PR4(Class 4) is a particular case of a more general family of PR polynomials given by the equation:

$$P_n(D) \quad = \quad (1 - D)(1 + D)^n, \qquad where \quad n = 1, 2, 3......$$

- n is chosen depedent upon the desired channel response, data rate(density) and desired noise characteristics. As n increases, more controlled ISI is introduced resulting in a large number of output levels at the sampling instants.
- Applying PR polynomial to a binary data system, the output would no longer be binary, but would have more number of levels depending upon the PR polynomial[4].

- Readback voltage from an isolated transition can be approximated by a Lorentzian function:

$$v(t) = \frac{1}{1 + (\frac{2t}{PW_{50}})^2}$$

where PW_{50} is a measure of bit recording density, representing the pulse width at 50% of the maximum amplitde and normalised to bit period T [5].

- As PW_{50} increases, more equalisation is required to force the read-back waveform to a PR target.

- A filtering technique, called PR Equalisation is used to remove the ISI introduced by the Lorentzian pulse into the data pattern . This leads to zero-voltage at all sampling levels except at the location of transition and the next sample instance from the transition.

Maximum Likelihood Sequence Detection (MLSD)

- The design of a partial response filter/equaliser is a sub-optimal scheme normally used as the structure of the Maximum Likelihood Sequential Detection (MLSD) detector for a PR system.
- Since the PR channel generates more than two-levels of output, the threshold detector would not perform better because it leaves the extra levels. While, the ML decoder, takes this redundant information into account resulting in an improvement of error performance.
- In case of an Additive White Gaussian Noise (AWGN), the probability of error is minimised by MLSD. MLSD detector detects the sequence with minimum euclidean distance metric.

- MLSD detection is “hard” decision detection scheme. It outputs $1's$ and $0's$ and conveys no information on the reliability of each decision. It is a Soft Input and Hard Output Detector [2].
- Bit-by-bit detection is not considered in ML detector.
- ML decoder considers the entire sequence and finds a sequence among all possible sequences that has the highest probability of being correct.
- ML algorithm, widely known as Viterbi algorithm by A.J.Viterbi(1967) used in the system design was first implemented by Kobayashi in 1971 and by Forney, Jr. in 1973.

- A block diagram of the simulated Multilevel PRML Channel is as shown.
- Usually the levels used are -1,$-1/3$,$1/3$ and 1. But for convenience 0,$1/3$,$2/3$ and 1 are used.
- Only AWGN noise is considered for now.
- Only four levels are considered for now.
- Symbol Error Rate Versus SNR plots are presented later in results section with specific PR targets.

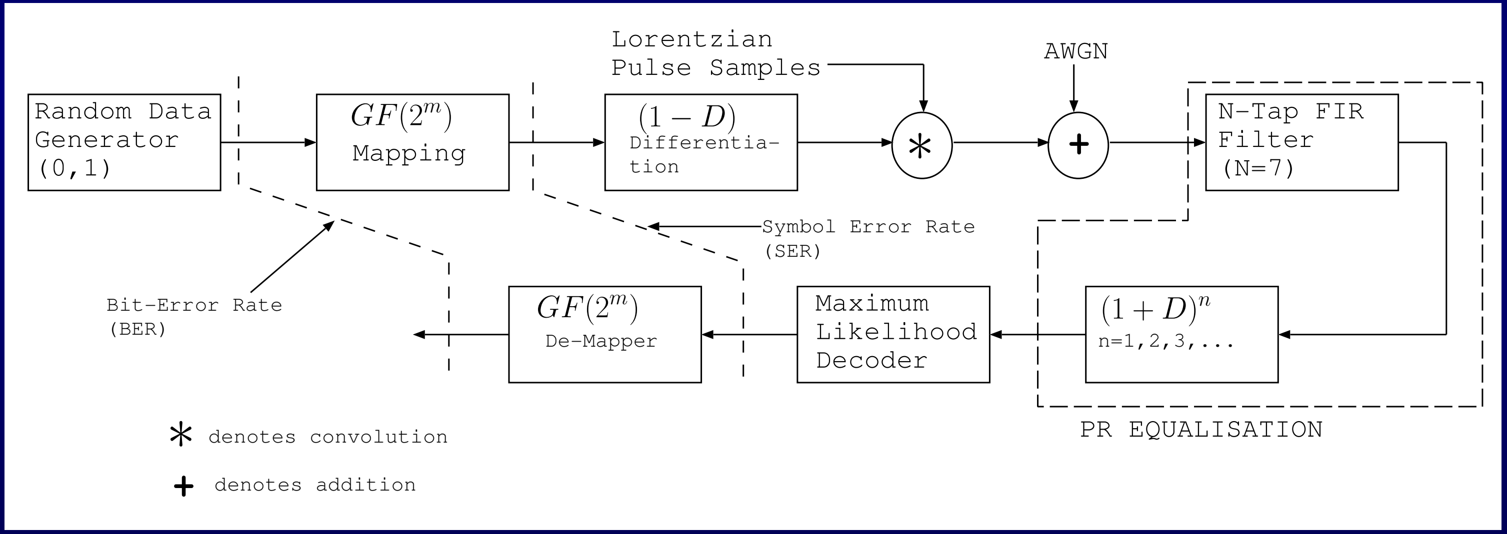

Figure 3: Multilevel PRML Channel Implementation

Multilevel PRML Channel

- Multilevel Technique offers little, if any improvement of the channel capacity in currently used systems and is eventually limited by amplitude irregularities[6].
- Multilevel Recording shows that the required Signal to Noise Ratio (SNR) for low error rate is relatively higher for multilevel magnetic recording[7].
- The whole idea behind multilevel encoding for magnetic recording is to enable storing of more information bits per transition on the magnetic medium.

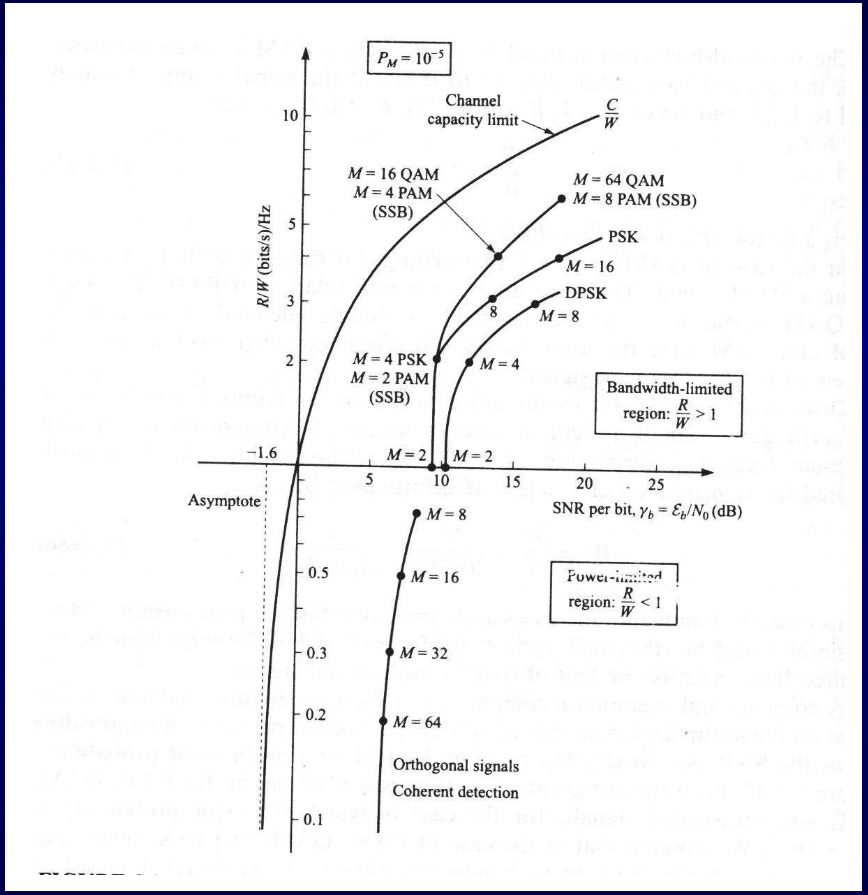

Figure 4: Performance Comparison of Various Level Schemes [7]

- From the previous figure, we noticed that levels higher than binary have a better performance in terms of matching the channel capacity.
- At high recording densities, high rate error correction codes are employed. At high code rates for all channels, we know that binary codes deviate very quickly from their theoretical performance.
- Thus, the only option to achieve the best capacity of the channel is to increase the amount of information stored in each magnetic transition, i.e. multilevel encoding of data.
- Increase in the number of output levels in contrast to binary inherent in higher order systems could provide added flexibility in designing better codes for magnetic recording channels[8].

- Several magnetisation levels could be used with multilevel channel. Instead of two levels $+1$ and -1, four levels $0 \rightarrow 00$, $1/3 \rightarrow 01$, $2/3 \rightarrow 10$, $1 \rightarrow 11$ could be utilised with each level representing two information bits.

- If the transition rate could be kept the same as binary using signal processing schemes, we could achieve an improvement in packing density with a factor of 2 for four levels and a factor of 3 for eight levels and so on[6].

- Complexity of the ML decoder grows exponentially with the degree of PR polynomial, since each PR polynomial defines a linear finite state machine with 2^{n+1} states for binary inputs, where n is the degree of PR polynomials. Hence the complexity of the ML decoder for multilevel inputs is even more, depending upon the number of levels utilised.

Simulation and Results

Simulation Parameters:

- SNR=18 to 24.5 dB
- PW_{50}=0.75
- Maximum Frames in Error=100
- Data Length/ Sector Length=4096
- Mapping=[0,1/3,2/3,1] (equally spaced)
- Exhaustive Search for Best PR targets.

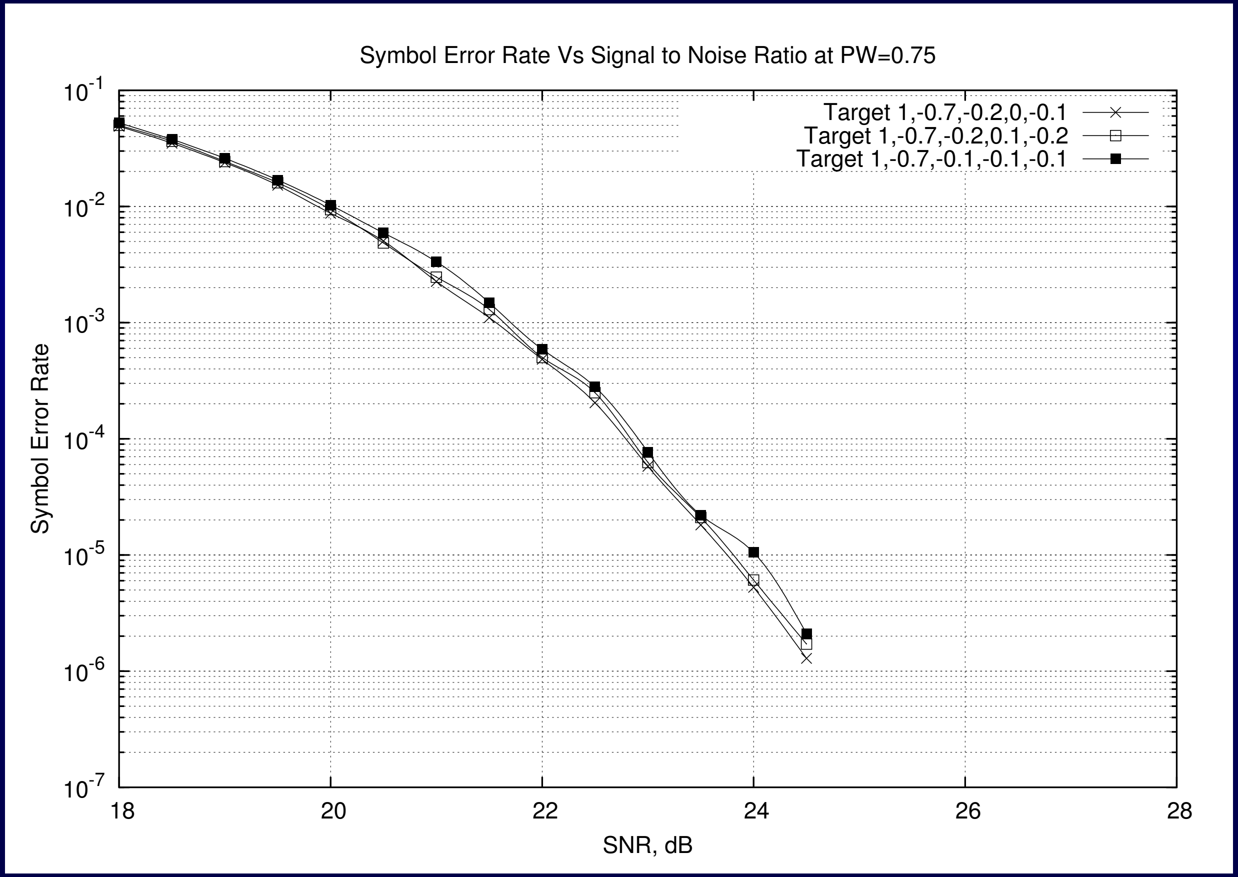

Figure 5: Symbol Error Rate Performance for Various SNR for PR Length=5

Presentation : 14-07-05

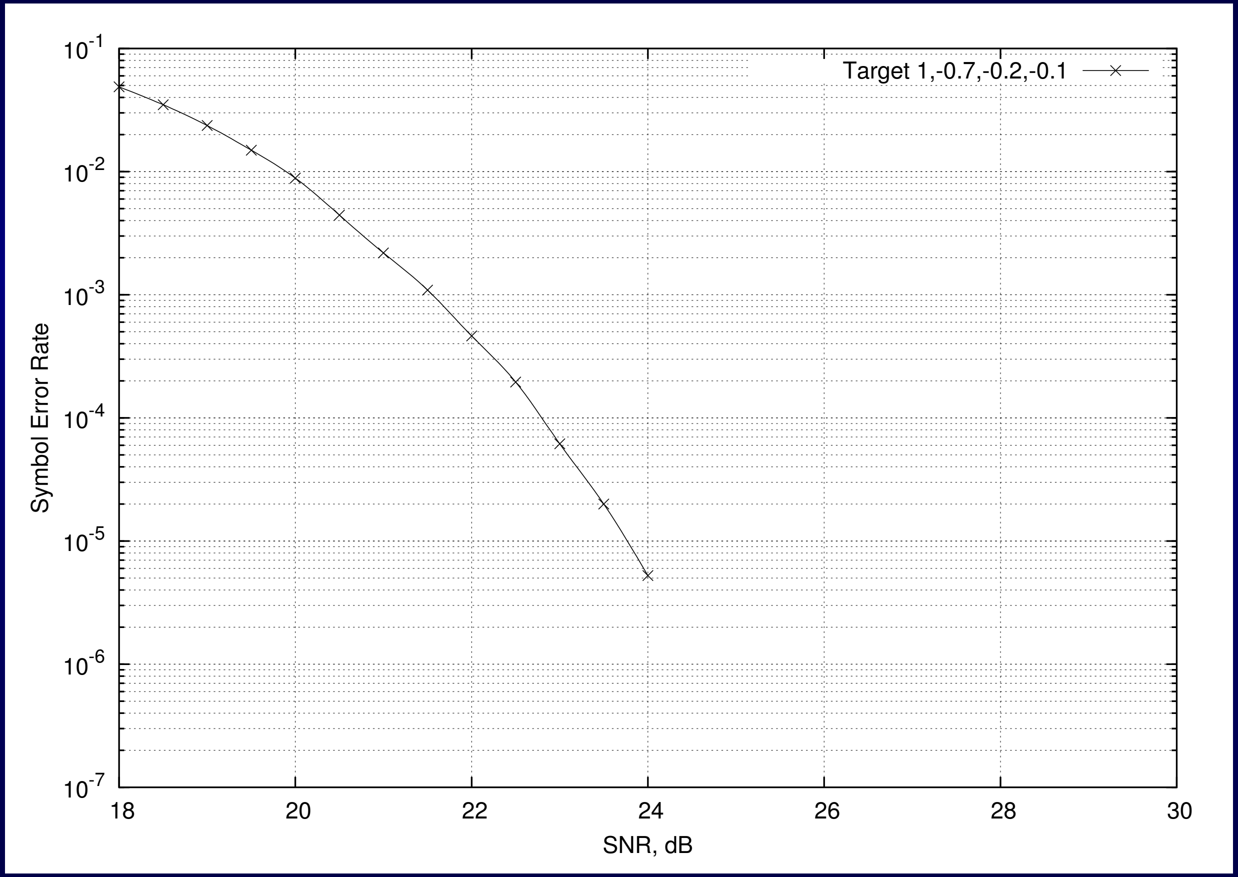

Figure 6: Symbol Error Rate Performance for Various SNR for PR Length=4

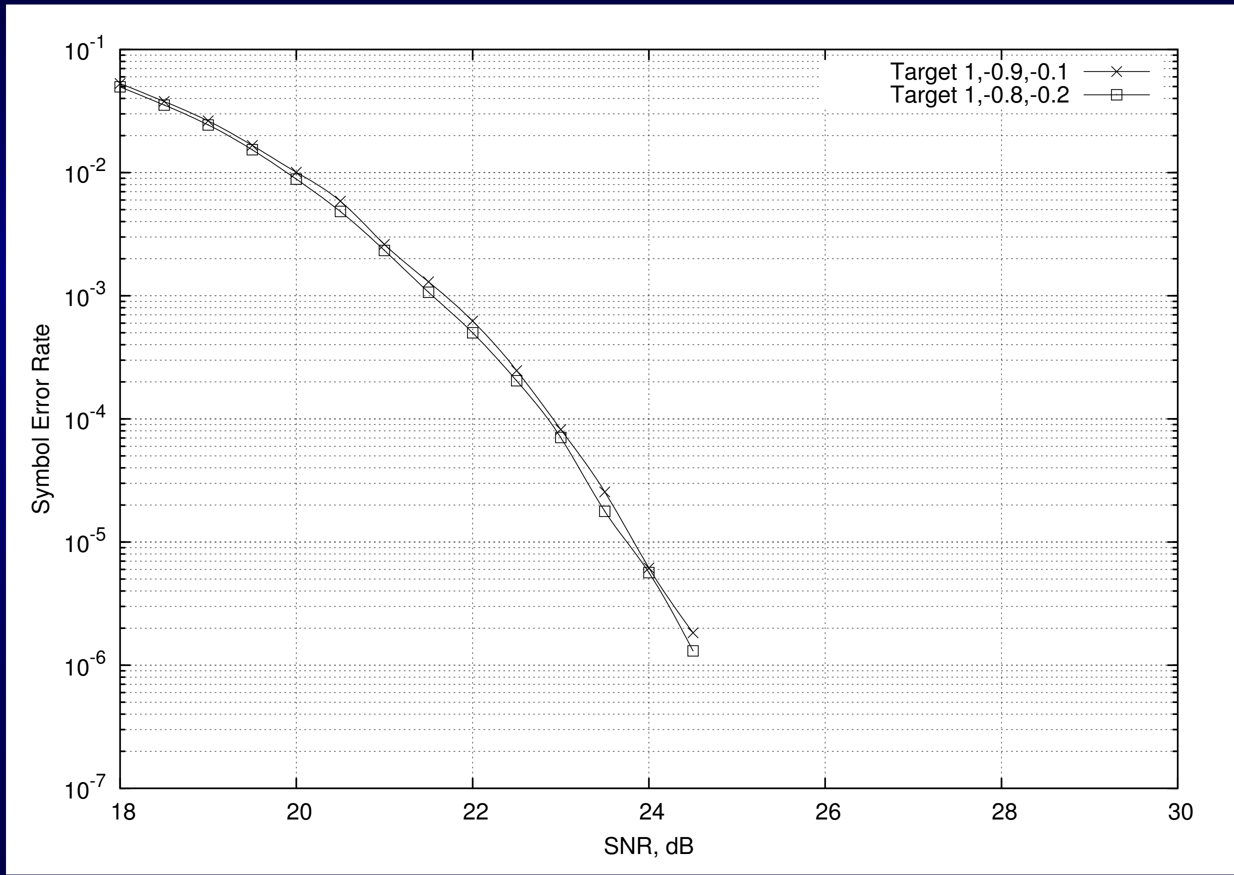

Figure 7: Symbol Error Rate Performance for Various SNR for PR Length=3

Future Work

- Implementation of Turbo Equalisation using soft-feedback equaliser is one of the possible solutions to achieve channel capacity [9].
- Turbo codes, which work at a relatively lower SNR than the magnetic channel, used in conjuction with multilevel encoding, would help to reduce the overall SNR of a multilevel magnetic channel.
- There is a potential that recording densities could be improved greatly as a result of this work[7].
- Problems like clock recovery, sampling jitter and iterative synchronisation will be dealt with reference to multi-level magnetic storage.

References

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