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ESC 320

Full-report

Experiment 2: Baseband Communication System with Deferential Encoding and Nyquist Filter Design

2 October 2015

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Experiment 2

Baseband Communication System with Differential Coding and Nyquist Filter Design

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Abstract—This is preparation to perform a laboratory experiment on baseband communication. In essence building a modem with differential encoding, and a Nyquist filter to prevent inter symbol interference (ISI).

Index Terms—baseband communication, differential encoding, eye diagrams, inter symbol interference (ISI), modem, Nyquist filter, pseudo random binary sequence (PRBS)

I. Introduction

Many examples exist of system that use the baseband for communication, a good example would be the simple fax modem or dial up modem that uses the telephone line normally used for analogue voice communication. Even if a system is to use a modulation scheme to use another band or even be transmitted at radio frequencies these basic techniques used to condition a signal for optimal transmission are still valid as pre and post processing with the modulation scheme considered as part of the channel.

In this experiment a system was designed to condition a non-return to zero (NRI) bipolar signal for optimal transmission at a bit rate of 16 kilobits per second. The signal was prepared for transmission using differential encoding (to reduce long DC sequences) and Nyquist filtering (to reduce inter symbol interference).

Eye diagrams is a simple diagram that can be measured on an oscilloscope from which a qualitative analysis of the communication system can be done, it clearly displays the optimal sampling time, presence of inter symbol interference and timing integrity of the system (not relevant to this experiment but for experiment 3).

II. Theory

A. Pseudo Random Binary Sequence (PRBS)

To test a communication system we need test data, Real world data is inherently random and thus we need some way of emulating this randomness. A PBRS is a binary sequence that at first observation appears random but as it is impossible to generate a truly random signal it ultimately repeats. For this experiment we use the seed 1111 and the function that produces the sequence “111101011001000”.

B.Differential encoding

The encoding function is , and the decoding function . It is clear that this is a reciprocal function. In that sense the decoder is the inverse of the encoder.

C.Inter symbol interference (ISI) and Matched Nyquist Filter

A matched filter is used to shape a pulse shape to obey Nyquist criterion and to prevent ISI.

There is a bandwidth vs. noise trade off between which filter is placed at the receiving end and which is placed ad the transmission end. For optimal bandwidth the filter with the lowest cutoff should be places before the channel. For optimal signal to noise ratio the filter with the lowest cut off should be placed after the channel.

D. Eye Diagrams

An eye diagram is created on an oscilloscope by connecting an external trigger to an oscilloscope from the recovered clock of the data signal, and the output signal. Two things are seen on an eye diagram. The distance between zero crossings shows the efficiency of the clock recovery witch would ultimately determine if the are sampling at the right point where ISI is minimal. The distance between the peeks and lows of the eye shows the noise to signal characteristics of the signal at the sampling interval, the bigger the opening the better the noise immunity of the system.

E. Problems

1) Problem 7.3-4

a)In comparison with Fig 7.12 of the textbook [1] it is clear that the pulse has a roll off factor of 1 and a excess bandwidth of .

b)

c)r =1 and the transmission rate is 10 bits/s

2) Problem 7.3-6

III. Design

A. PRBS Generator

A shift register can be used to achieve a PRBS using a XOR gate to feed back from certain taps, using a 4 bit shift register produces a code of length: . The circuit design is shown below.

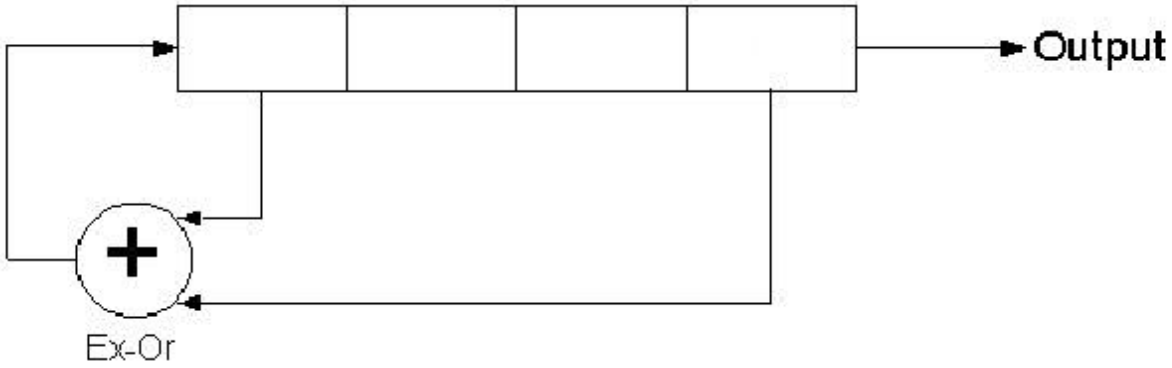


Fig. 1 PRBS Generator

B.Deferential Encoder and Decoder

A differential encoder is achieved using a XOR gate and D-Flip Flop as shown below

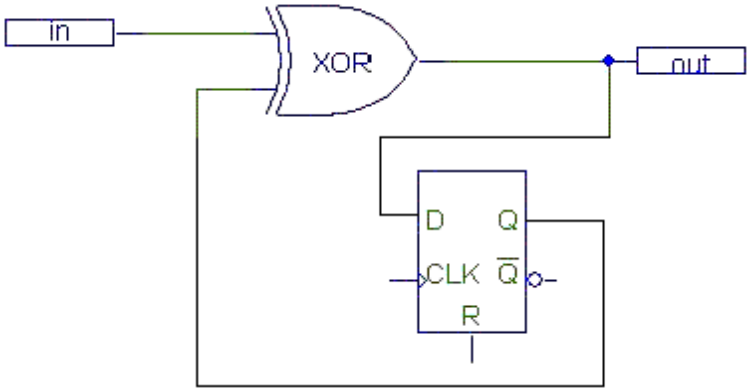


Fig. 2 Deferential Encoder

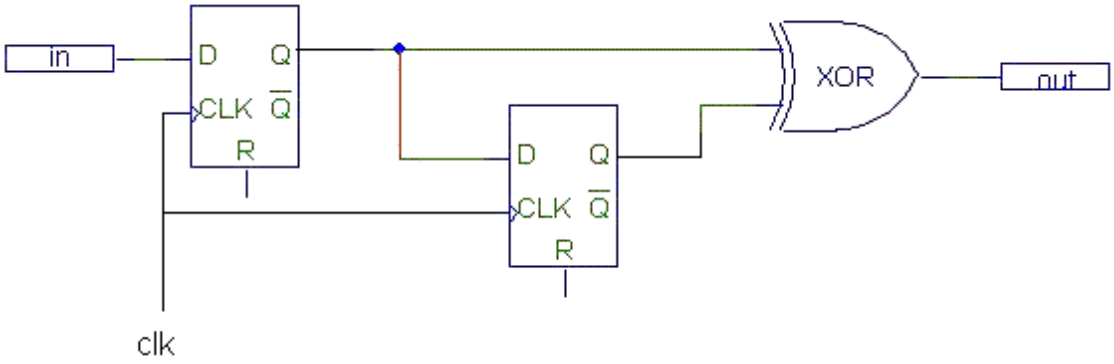


Fig. 3 Differential Decoder

C.Forth Order Nyquist Filter Design

A two part 4th order filter of the cosine squared form is designed to shape the pulses to be transmitted to prevent ISI.

We assume that

(1)

Normalized to

Using method form Study Guide [2]

where and (2)

The poles need to be normalized to 8 kHz so and need to be multiplied to which results in:

(3)

(4)

(6)

Calculating the values for the two filters:

1) Filter 1

(7.1)

(8.1)

(9.1)

(10.1)

(11.1)

(12.1)

(13.1)

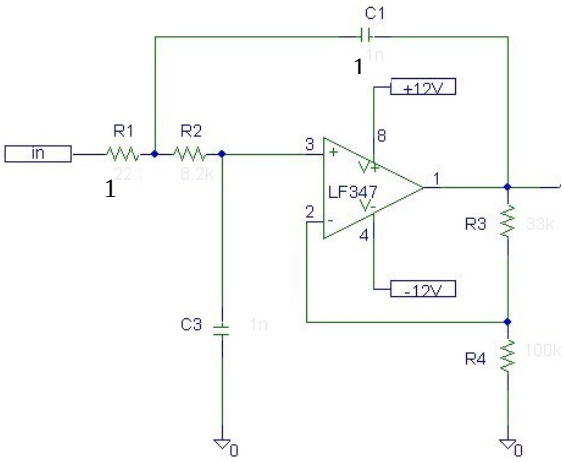


Fig. 4 Filter 1

2) Filter 2

(7.2)

(8.2)

(9.2)

(10.2)

(11.2)

(12.2)

(13.2)

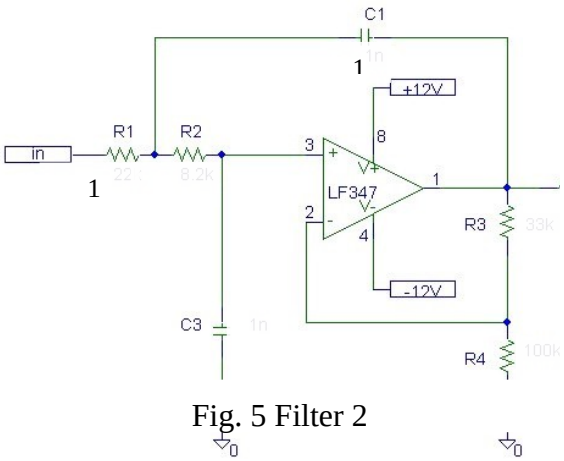


Fig. 5 Filter 2

D. Sample and Hold

A sample and hold circuit is achieved using a controlled switch, a holding capacitor

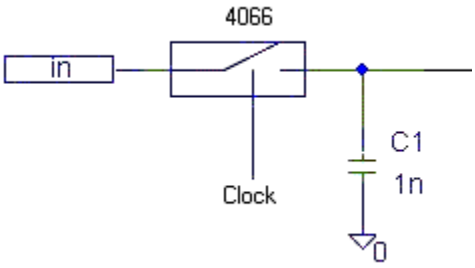


Fig. 6 Sample and Hold

E. Decision Device

A logic signal device and a D flip-flop is used as a Decision device.

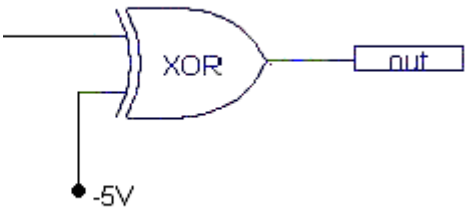


Fig. 7 Decision Device

F. Complete Circuit

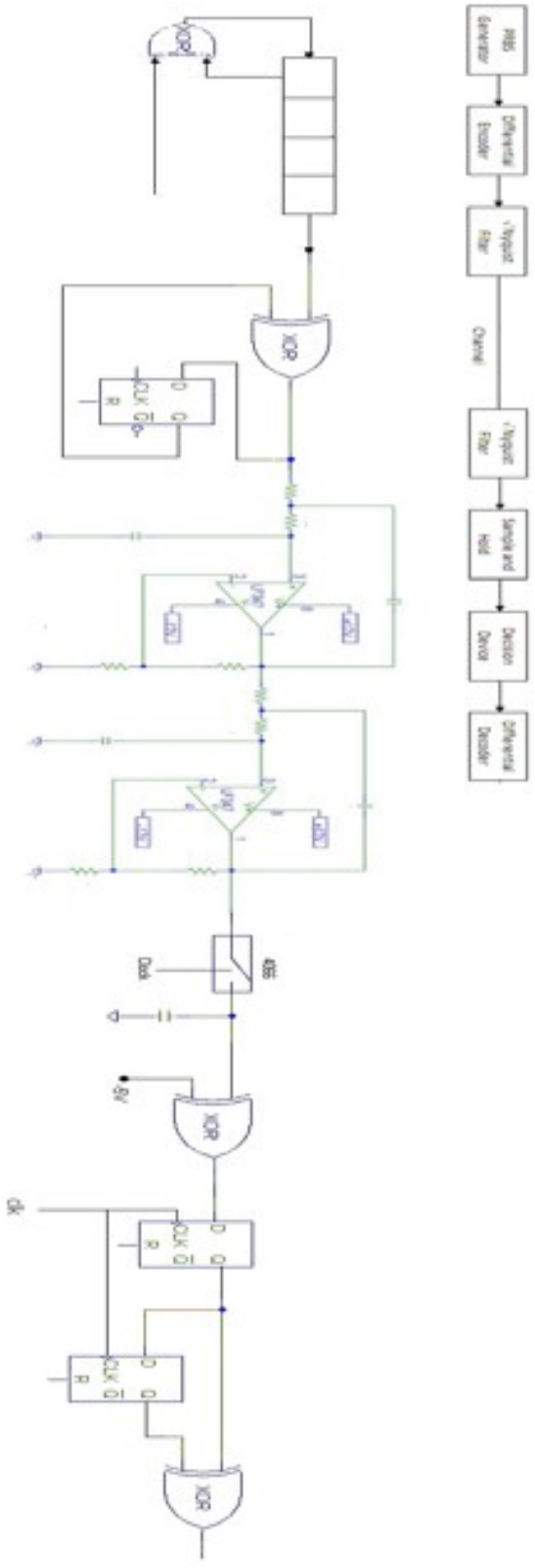


Fig. 8 Circuit

IV. Simulation

A. PBRS Generator

A PRBS can be generated using a simple 4 bit shift register with taps at certain points using a feedback network to feed back these taps to the input. By alternating the tap positions and feedback design a number of combinations could be achieved. For this experiment a tap was taken at the first and and fourth bit, and combined using a XOR function. A seed of "1111" was used. This is represented in the block diagram and a simulated waveform as simulated using MATLAB and SIMULINK is shown. The sequence "111101011001000" resulted.

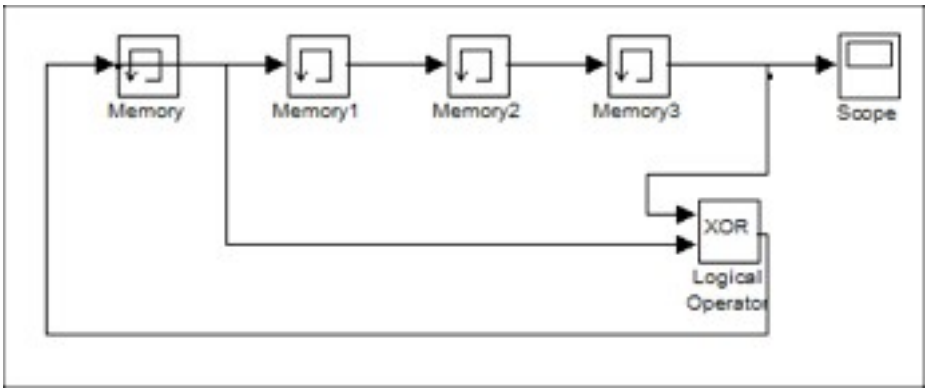


Fig. 9 PRBS generator Simulink model

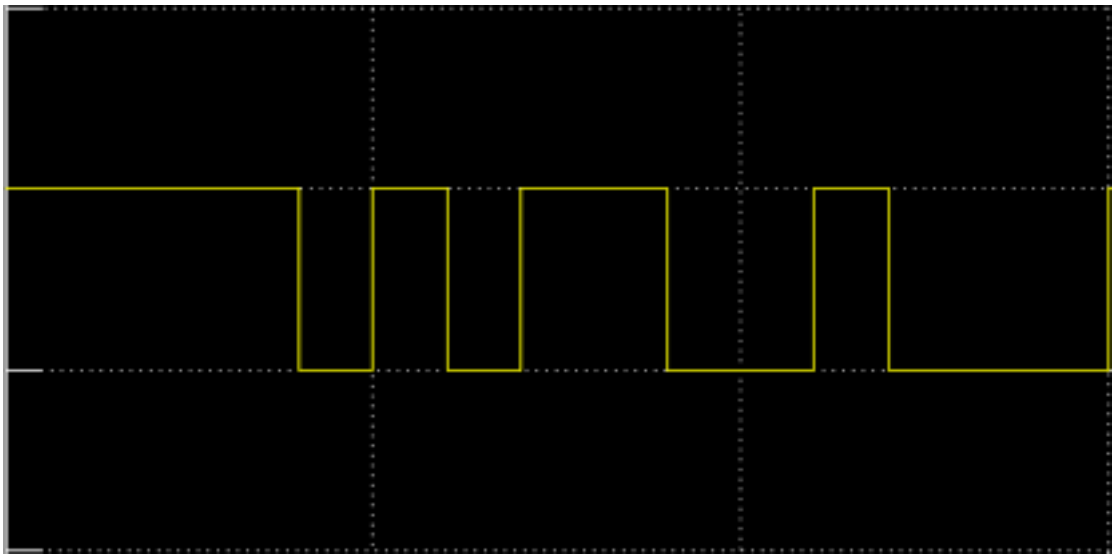


Fig. 10 Simulated output of PRBS generator

Shown below is the PSD of this sequence

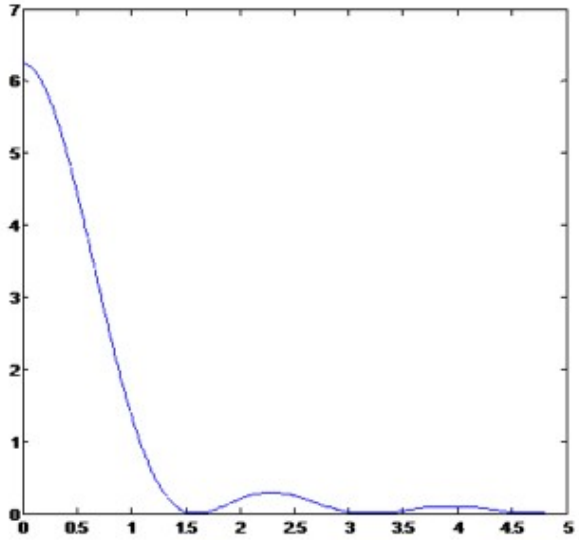


Fig. 11 PSD of PRBS

B.Differential Encoder

The block diagram for a differential encoder is shown below, and the simulated differentially encoded sequence if the PRBS shown above is used as input.

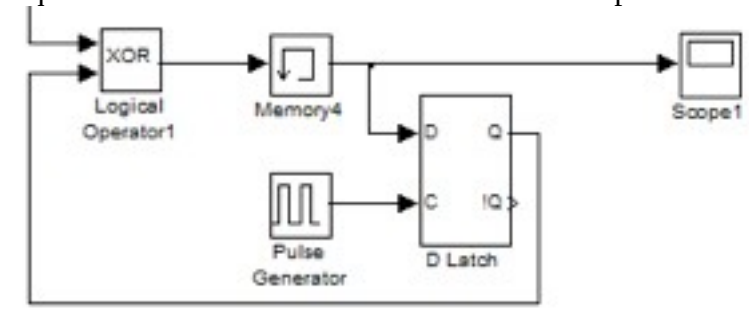


Fig. 12 Simulink model of differential encoder

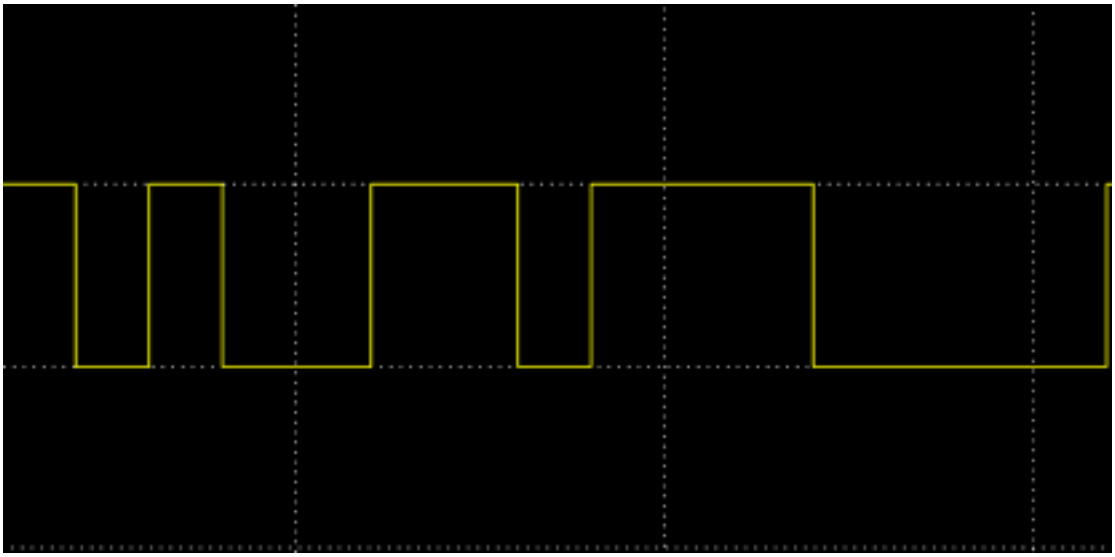


Fig. 13 Simulated output of differential encoder

C.Differential Decoder

The block diagram for a differential decoder is shown below, and the simulated differentially encoded sequence if the PRBS shown above is used as input.

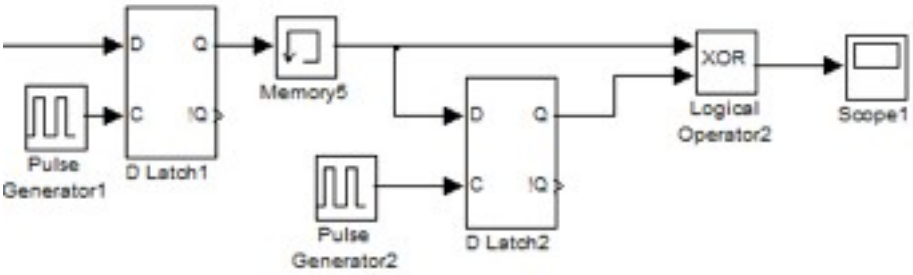


Fig. 14 Simulink model of differential decoder

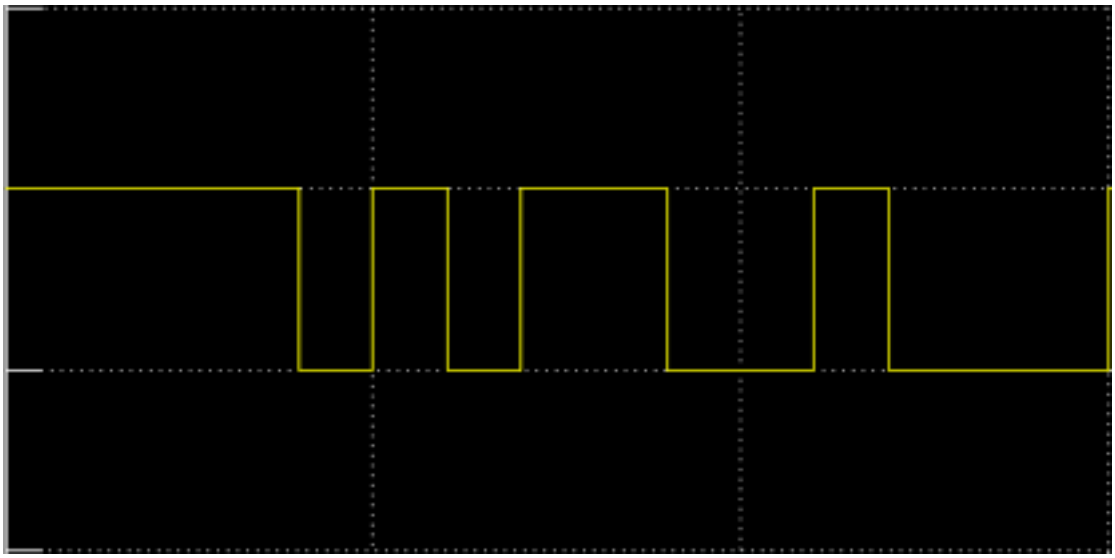


Fig. 15 Simulated output of differential decoder

D. Nyquist Filter

The frequency response for the individual filters as well as the cascaded system are shown below as simulated using Cadence ORCAD PSPICE.

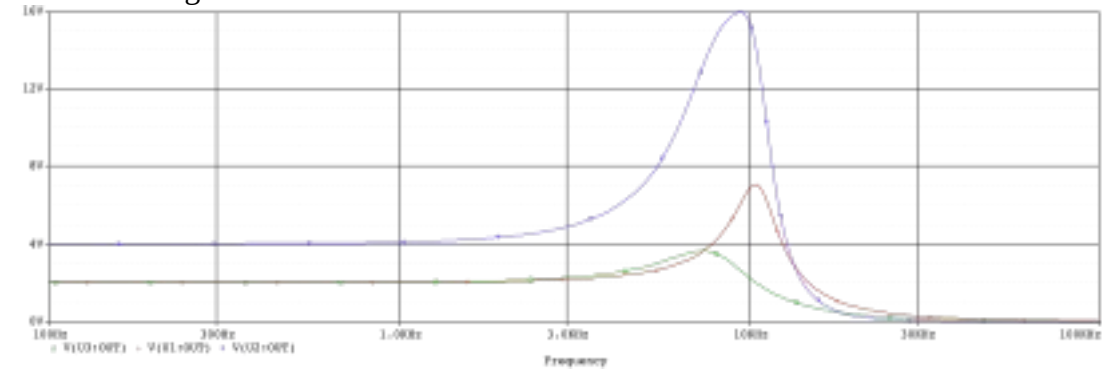


Fig. 16 Bode Plot

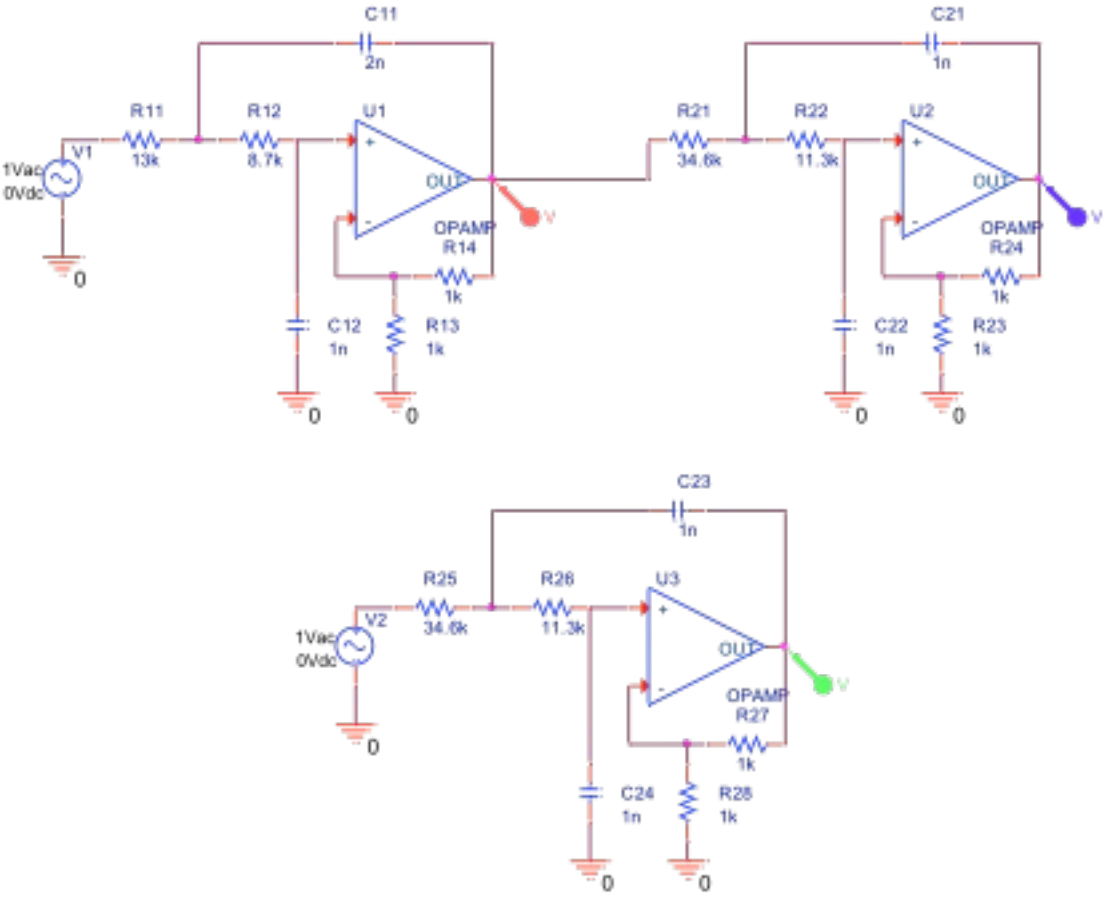


Fig. 17 Filter simulation model

V. Results

The modem was constructed as designed to operate at a frequency of 16kHz .The first measurement shown in figure 18 shows the sequence generated by the PRBS generator.

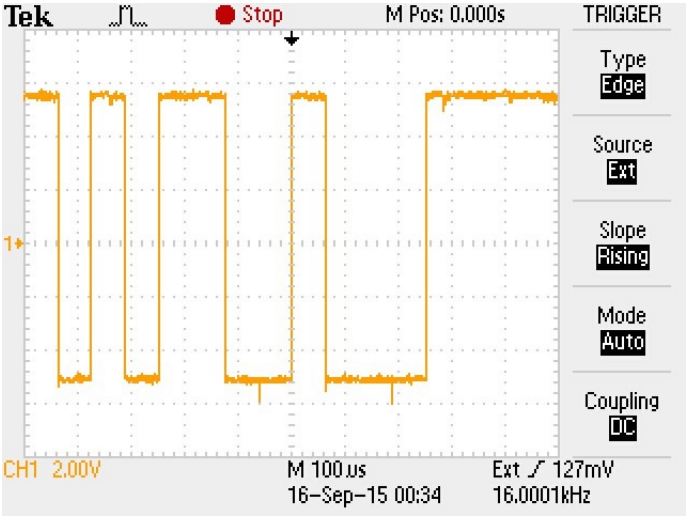


Fig. 18 Signal generated by PRBS generator.

The PRBS is then fed into the differential encoder that produces the signal as shown in figure 19.

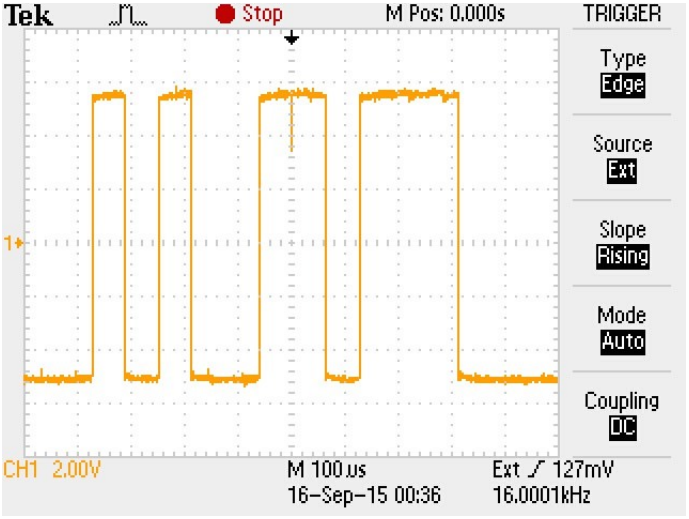


Fig. 19 Signal after differential encoding.

After differential encoding the signal is applied to the pre-channel filter as shown in figure 20 and then into the post channel filter as shown in figure 21.

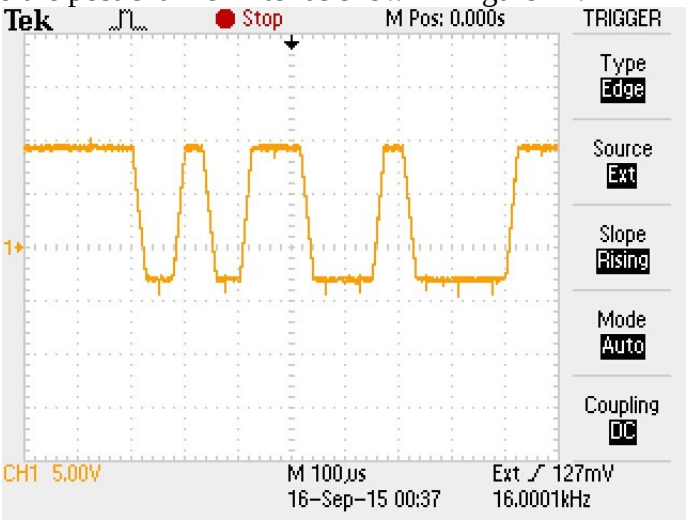


Fig. 20 Signal after pre-channel filter.

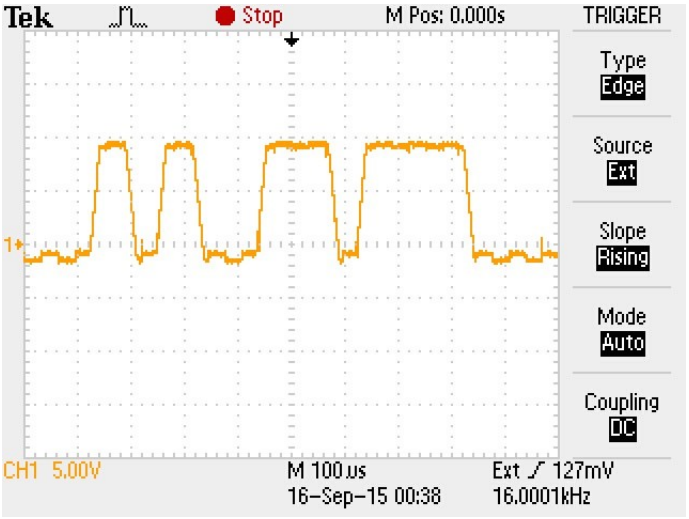


Fig. 21 Signal after post channel filter.

By applying the persist function of the oscilloscope and using an external trigger, triggered by the clock signal, one can attain an eye diagram of the system from the signal measured in figure 21. Such eye diagrams are shown in figure 22 and figure 23. The difference being that figure 22 shows the wide open eye at the design frequency that has built in capacity that would still allow the eye to be open even when timing jitter is introduced in practical 3. Figure 23 show an eye some what past the cut off of the pulse shaping filters that has a very narrow opening and any noise or timing jitter would distort the signal beyond recovery.

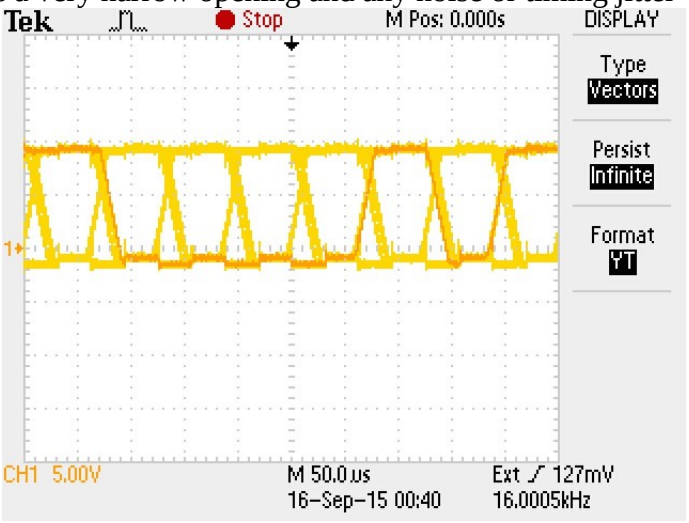


Fig. 22 Eye diagram at design frequency of 16 kHz

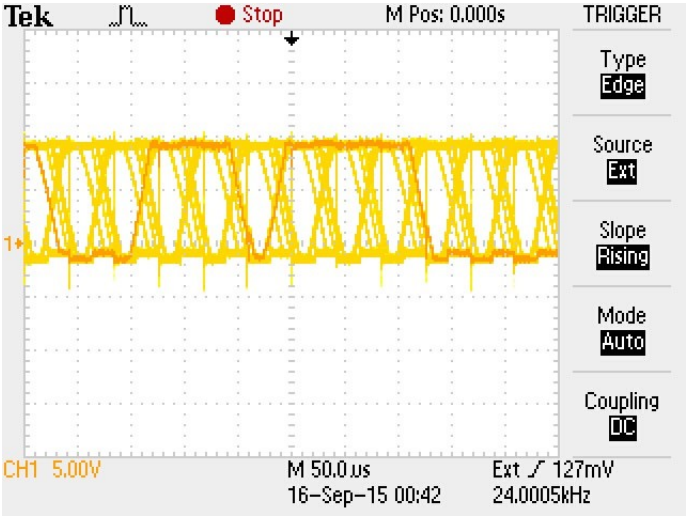


Fig. 23 Eye diagram at 24 kHz

After the post channel filters the signal enters the sample and hold circuit. The capacitor is allowed to charge up for the high half cycle of the clock and at the sampling interval when the clock changes from low to high the switch isolates the signal from the channel entering the hold phase. This signal is shown in figure 24. The signal from the sample and hold circuit enters the decision device and the differentially encoded signal is recovered as shown in figure 25.

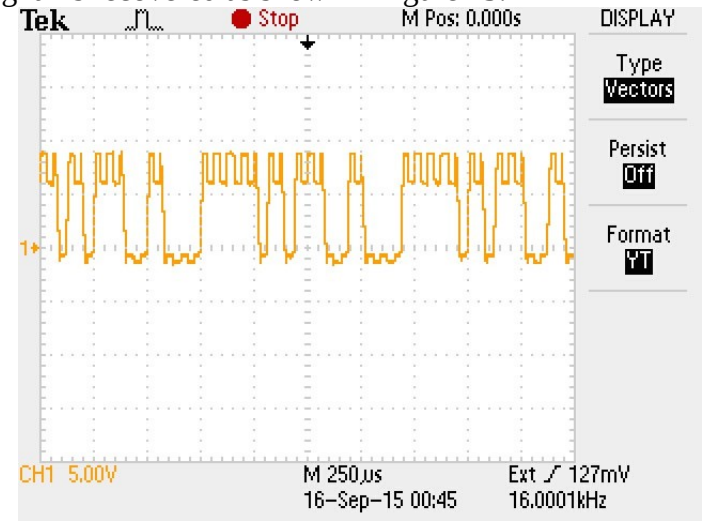


Fig. 24 Signal after sample and hold.

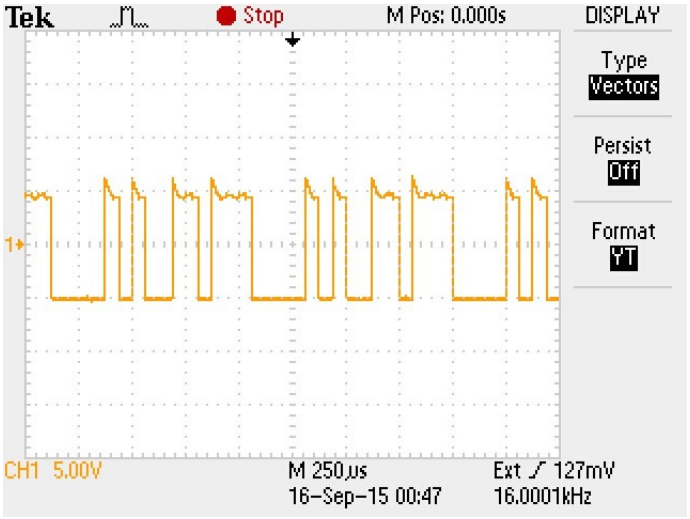


Fig. 25 Recovered differentially encoded signal.

The signal is then differentially decoded and produces the recovered signal as shown in figure 26 and shown in comparison to the input in figure 27. It is clear that the signal recovered suffers from some phase delay introduced by the filters and the digital devices' timing propagation.

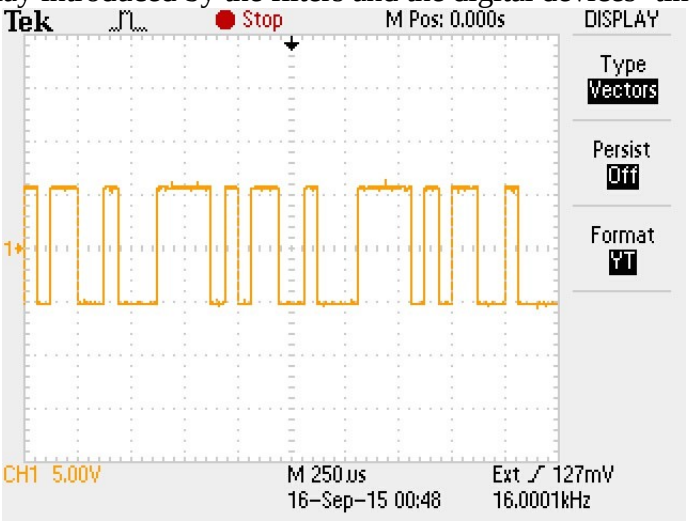


Fig. 26 Decoded recovered signal.

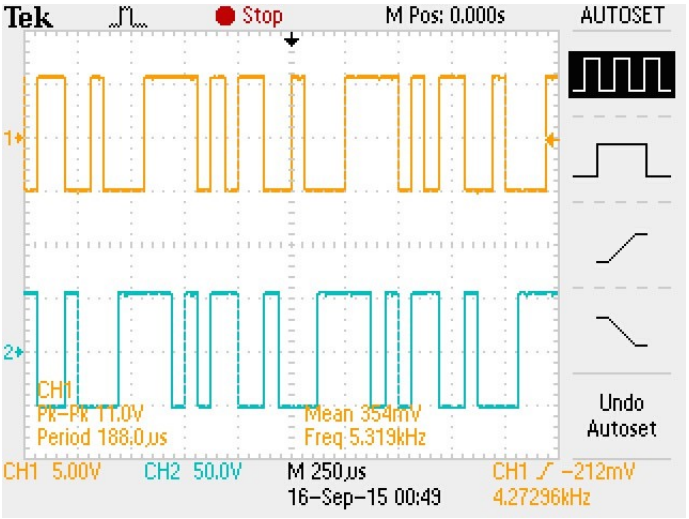


Fig. 27 Input in comparison to recovered signal.

VI. Discussion

In actual practice the signal shown in figure 20 would be amplified and transmitted as a baseband system or a modulation scheme would be applied to modulate this signal onto a high frequency carrier. This would all be considered part of the transmission channel. For this experiment we use the relatively short connection as an ideal transmission line, in other words no noise and the channel introduces distortion. As the system in this practical has no clock recovery implementation a clock signal is transmitted on a separate line. In some rare instances synchronous transmission system to make use of a separately transmitted clock signal as it offers some signal to noise ration improvement buy eliminating errors introduced by timing jitter from the recovery circuit.

The sample and hold circuit ensures that only the signal at the exact sampling interval is considered by the decision device, hence the signal is considered at the point when the eye is completely open an ISI is minimal.

The phase delay shown in figure 27 is one of the main reasons use pulse shaping in the form of Nyquist filters. Such phase delays affect frequencies selectively and this is what causes pulse spreading and the ISI we are trying to minimize. It is true that in this experiment this phase delay is mostly introduced by the filter making one question weather it does not increase ISI, the truth is that the filter limits the frequency ranges the

Actual signal transmits effectively eliminating higher order frequencies that would be spread more. This becomes a problem in real world channels that are not ideal and introduce some phase delay effects of their own.

It is clear from this experiment that the circuit implementation responds as was predicted in the calculations and simulations with the addition of some noise. The biggest source of noise is clock feed through in the non-ideal components. The analog switch used in the sample and hold circuit is particularly prone to clock feed through.

VII. Conclusion

In this experiment the operation of a basic baseband synchronous modem was clearly illustrated and proven to be functional and effective. Synchronous referring to the fact that separates transmission of the clock is necessary. This is not ideal in many environments, as it requires additional channels in a wired system or additional bandwidth. In experiment three we illustrate how to recover the clock from the signal itself.

It was illustrated how Nyquist filters reduce ISI produced by frequency selective channels and channels with phase delay. It is essential that a communication system be able to deal with such phase delays, as it is inherent to most practical channels, filters, and amplifiers.

The use of a PRBS as a test signal for a communication system was clearly illustrated and it is shown to be effective.

Differential encoding breaks up long sequences of 1 and 0 avoiding introducing DC to a signal. It does have the downfall thought that a periodically alternating signal has the opposite effect that it produces DC when differentially encoded. The introduction of a scrambler to randomize the signal would be the solution to this problem. It could be said though that such type of deterministic signal is rather rare in real world data and should not produce problems in most situations.

References

[1] B.P. Lathi and Z. Ding, Modern Digital and Analog Communication Systems, Fourth Edition, OXFORD University Press, 2010, pp492-496. ISBN: 978-0-19-538493-2.

[2] K. Dhuness and L.P. Linde, Stochastic Communication Systems ESC 320, University of Pretoria, 2015, pp.57-66.