Manual for Communication Systems Laboratory (EEE/ECE F311)

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8. Line Coding & Pulse Shaping

Aim: This experiment is intended to make the student to perform experiments on generating line codes, corresponding to random bit sequences and examine their time and frequency domain properties, using Emona Telecoms-Trainer 101 kit. The experiment includes passing the line coded digital data through a band-limited channel and observe the effect of ISI using Eye Pattern.

Basic Theory

As you know, logic-0 and logic-1 in digital systems are represented by assigned voltages. For example, the TTL logic-0 is represented by 0V and the TTL logic-1 is represented by 5V (or by acceptable voltages relatively close to 0V and 5V). As you also know, the logic levels for other logic families like CMOS, ECL, etc are not necessarily 0V and 5V. This tells us that logic levels can be represented by any pair of voltages we like. That said, the choice of which voltages to use is not as arbitrary as that may seem. It's usually an engineering decision made to confer an advantage.

Importantly, this is also true for the choice of voltages used when sending digital signals over transmission lines like telephone lines. Standard TTL and CMOS voltages are less than ideal for this purpose. Moreover, even the basic premise of holding the voltage at a particular value for the entire duration of the logic state's value can be disadvantageous. For these reasons, digital signals within systems are often conditioned for transmission line communications and this is called *line coding*.

There are quite a few line codes. Four of them are:

- **Non-return to zero – level (bipolar) (NRZ-L):** As you can see from Figure 1 on the next page, this code is a simple scale and level shift of the original digital signal.

- **Bi-phase – level (BiΦ-L also known as Manchester code):** Figure 1 shows that this code changes state from +V to –V in the middle of the bit period for all logic-1s and changes from –V to +V in the middle of the bit period for all logic-0s. For consecutive bits with the same logic level, the voltage must invert after half a bit length in order to satisfy this rule for the next bit.
- **Return to zero – alternate mark inversion (RZ-AMI):** Figure 1 shows that this code uses 0V to represent logic-0 and a half-bit pulse to represent logic-1. Importantly, the polarity of the pulses alternates for every successive logic-1 (even if they're not consecutive bits).

- **Non-return to zero – mark (bipolar) (NRZ-M):** Figure 1 shows that this code changes state for each new logic-1 and doesn't change state for any logic-0s.

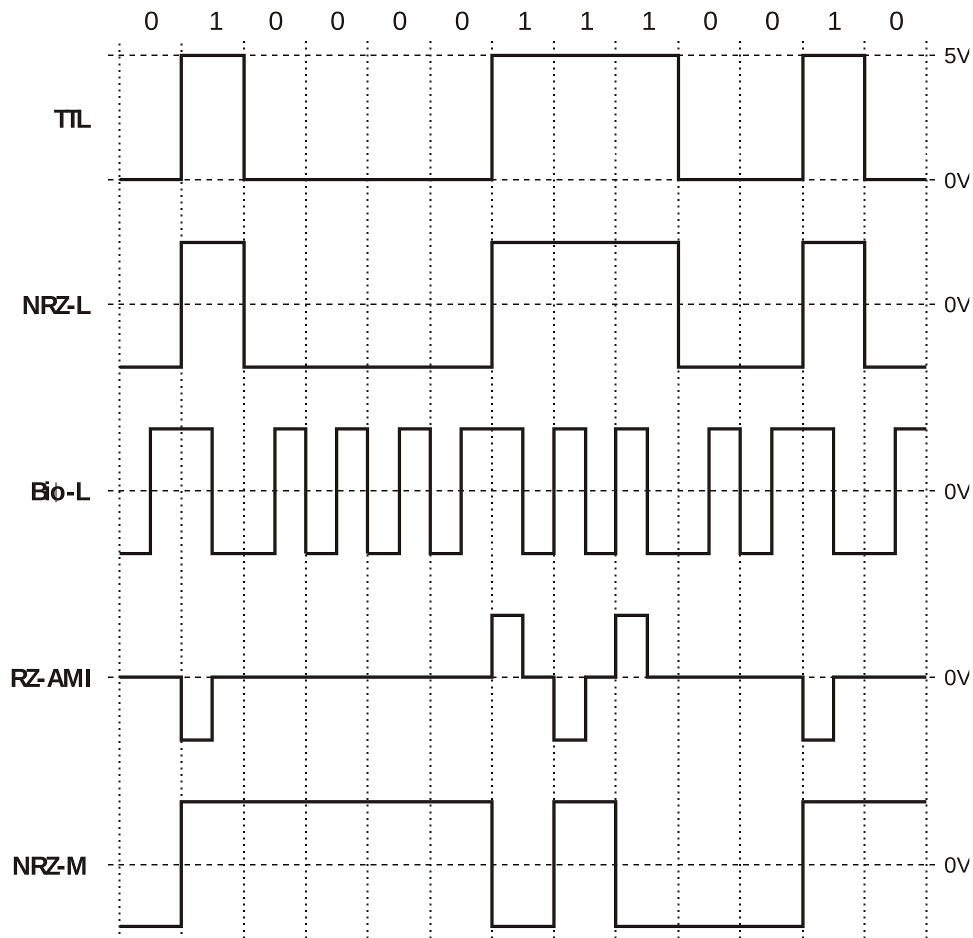

Figure 1

Table 1 in the next page compares the minimum bandwidth requirements for propagating these signals along transmission lines. It also shows the line code's usefulness for bit-clock regeneration. As you can see from the table, RZ-AMI offers the best compromise of the four between bandwidth and bit-clock regeneration (as well as other line code characteristics not mentioned here) and so it is widely used.

Table 1

Line code	Minimum Bandwidth	Bit-clock regeneration
NRZ-L	R_b	Poor
BiΦ-L	$2R_b$	Very good
RZ-AMI	R_b	Good
NRZ-M	R_b	Poor

An Important Note

Digital signals that are generated by a message such as a sine wave, speech or music cannot be used directly in this experiment. This is because the data stream is too irregular for the scope to be able to lock onto the signal and show a stable sequence of 1s and 0s. *To get around this problem the Sequence Generator module's 32-bit random sequence with equiprobable "1"s and "0"s is used to model a digital data signal.*

A – Observations on the random bit pattern in both Time and Frequency domains

1. On the Emona kit, locate the Sequence Generator module. It has 2 DIP switches, CLK input port, X output port, Y output port, SYNC output port and LINE CODE output port.

    a. The rate at which the random digital sequence is generated is decided by the frequency of the clock, connected to CLK input.

    b. A 31 bit random sequence, at a rate decided by the CLK input, is outputted at X output. At Y output port we get a 255 bit random sequence, at a rate decided by the CLK input

    c. The SYNC output provides a synchronization signal that can be used to trigger the DSO, in case the X or Y outputs are not stable on the screen.

    d. DP switch positions will decide the type of line coded waveform, at the LINE CODE output, corresponding to the random bit sequence at X.

2. First, let us observe the SYNC sequence, generated from the sequence generator module. Connect the circuit as in Figure 1.

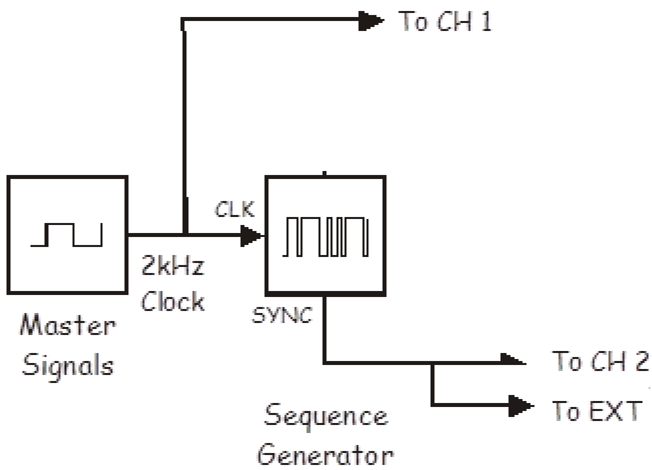

Figure 1: Generation of Random Bit Sequence

3. In this experiment the DSO channels are all to be kept in DC coupling mode. (Why?). Observe the clock and the sync signals on the screen. Trigger the waveforms using External Trigger.

4. Measure the clock period, sync pulse width and the sync pulse period. How many clock cycles exist within one period of the sync pulse sequence?

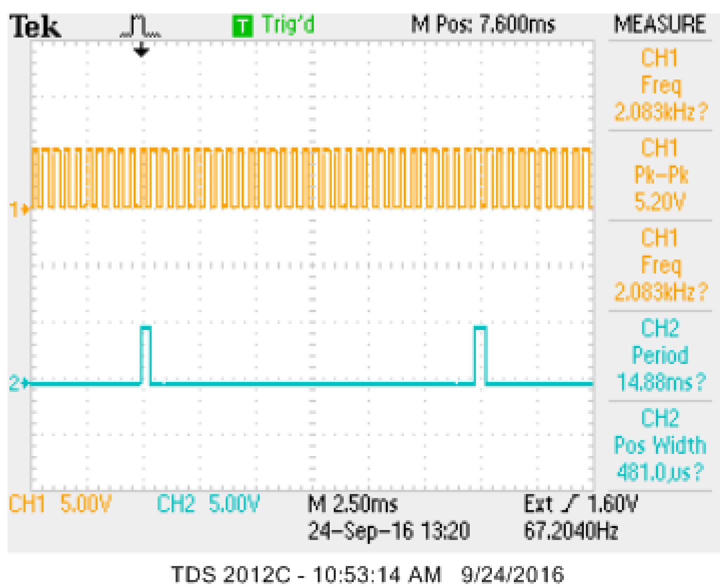

Figure 2: Clock and SYNC pulse train sequence

5. Next let us observe the random bit sequence generated at the X port. You may use the connections as in Figure 3.

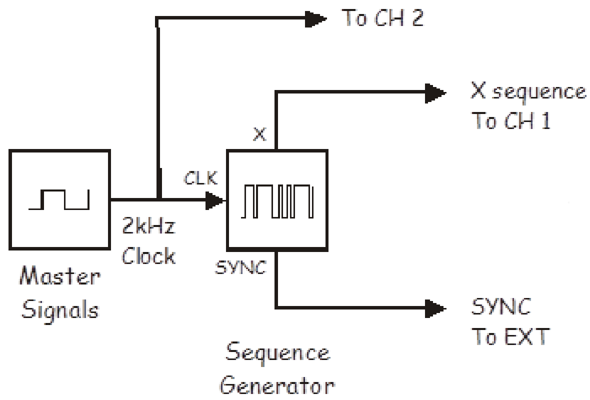

Figure 3: Generation of Random Bit Sequence

6. Trigger the waveforms using External Trigger. Do you see the X sequence waveform, as a combination of digital “HIGH” and digital “LOW” corresponding to a random sequence of “1”s and “0”s, respectively?

7. Measure the voltage value corresponding to digital “HIGH” and digital “LOW”. Are the number of “1”s (HIGHs) and “0”s(LOWs), as seen within the DSO screen window, approximately equal?

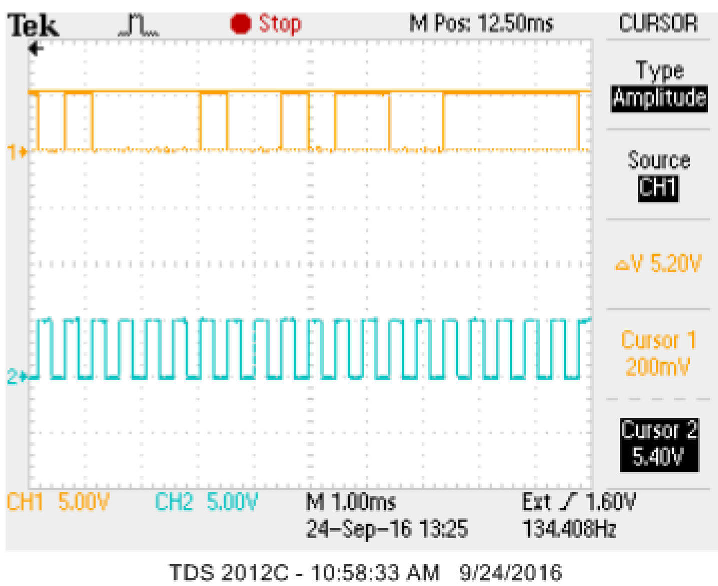

Figure 4: Clock with X sequence

8. Do you see any repetitive pattern in the sequence? Count the number of clock cycles within one repetition duration of the random sequence. Are there 31 clock cycles within one repetition period?

9. What is the bit rate ***(R_b)*** for this X sequence?

10. Next we obtain the spectrum of the X sequence. First, by adjusting the time scale of the DSO, *make sure that, in time domain, at least 2 full repetitive X sequences are displayed on the screen.* Using FFT mode obtain the spectrum of X sequence. Use FFT zoom (X 5 or X 10) to display the spectrum clearly. ***Do not change the time scale for zooming.*** Measure the parameters as required in Table 2 and fill the contents. If the first deep null amplitude is fluctuating, we can use the "Acquire" feature of the DSO, as in following steps:

    a. Select the acquire feature by pressing the "Acquire" knob.

    b. Select the "averages" from soft screen. Set the number of averages to 128.

    c. You will have a smoothened out spectra and you should be able to identify the frequency of the first deepest null easily.

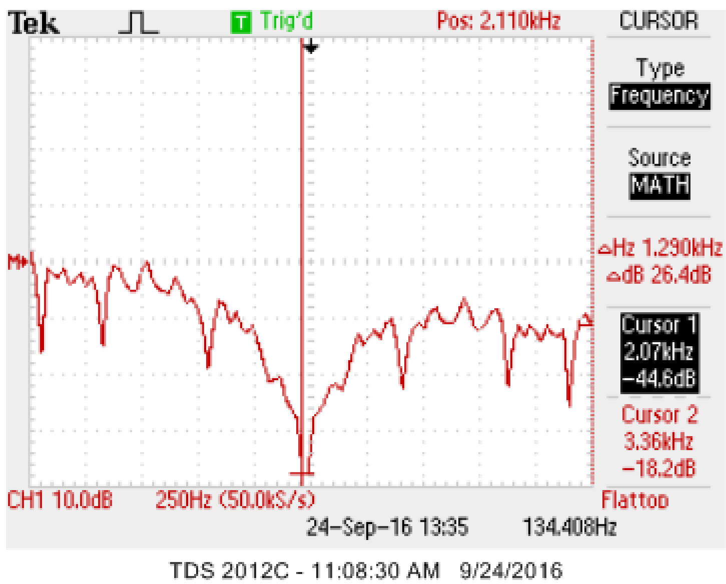

Figure 5: Spectrum of X sequence

Table 2. Time & Spectral Domain Properties of X-Sequance

Digital Bit	X Sequence Voltage	Bit Rate	Power at 0 Hz	First Deep Null Frequency	Power at First deep null
1					
0					

B – Observations of NRZ-L Line code in both Time and Frequency domains

Next we generate line codes corresponding to the X sequence. As said before, there are 4 different line codes that can be generated on the Emona kit. Let us first look at NRZ-L code. Use the connection diagram as in Figure 6.

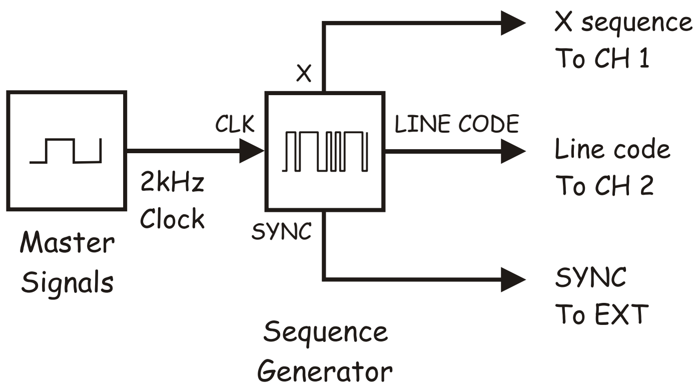

Figure 6: Block diagram for generating Line Codes

1. Set the DIP switches on the sequence generator to "00" position as this corresponds to NRZ-L code. Display the X sequence and the LINE CODE output on the DSO and use the SYNC output to trigger the DSO externally.

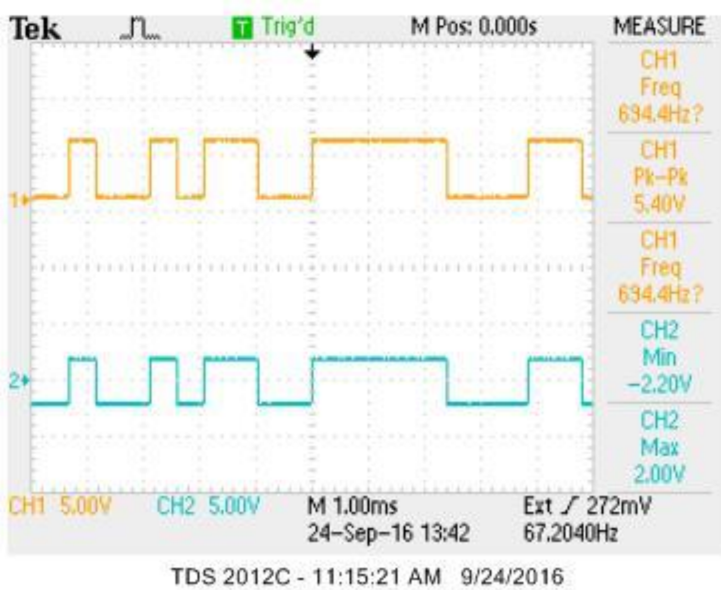

Figure 7: ***X sequence and the*** **NRZ-L Line code**

2. Measure the voltage values of the NRZ-L waveform, corresponding to digital "HIGH" and digital "LOW" of the X sequence and tabulate in Table 3.

Table 3. Time & Spectral Domain Properties of NRZ-L Code

DIP position	**Digital Bit**	**X Sequence Voltage**	**Line code Voltage**	**Bit Rate R_b**	**Power at 0 Hz**	**First Deep Null Frequency**	**Power at First deep null**	**Essential BW / R_b**
00	1							
	0							

3. Obtain the spectrum of the NRZ-L sequence. First, by adjusting the time scale of the DSO, make sure that, in time domain, at least two full repetitive NRZ-L sequence is displayed on the screen. Using FFT mode obtain the spectrum of X sequence. Use FFT zoom (X5 or X 10) to display the spectrum clearly. ***Do not change the time scale for zooming.*** Measure the parameters as required in Table 3 and fill the contents. If the first deep null amplitude is fluctuating, we can use the "Acquire" feature of the DSO, as done before.

4. If we consider the frequency corresponding to the first deep null as essential bandwidth required for transmitting the NRZ-L line coded waveform, what is the BW required for transmission? What is its relation to the bit rate ***(R_b)?***

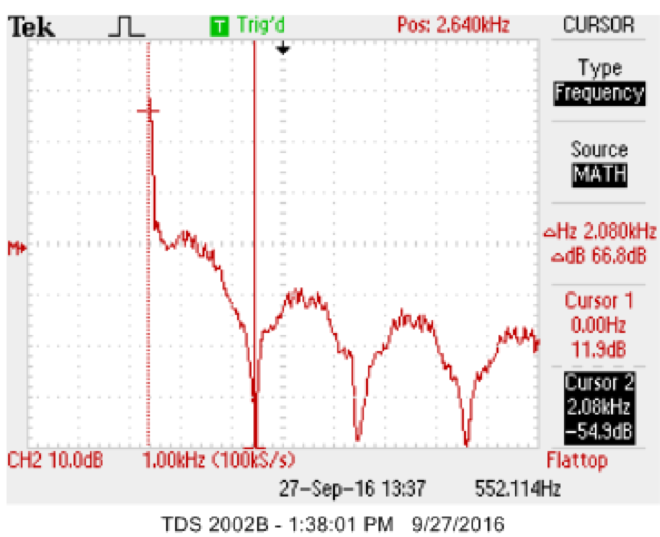

Figure 8: Spectrum of NRZ-L Line code

C – Observations of other Line codes in both Time and Frequency domains

In this part of the experiment, we observe the properties of different line codes. The selection of a given line code is done by the position of DIP switches. The procedure and the measurements to be performed is same those done in Section B above. First perform the experiment with BiΦ-L code and fill in the Table 4. Repeat the experiment with RZ-AMI and NRZ-M and tabulate the data in Table 5 and Table 6.

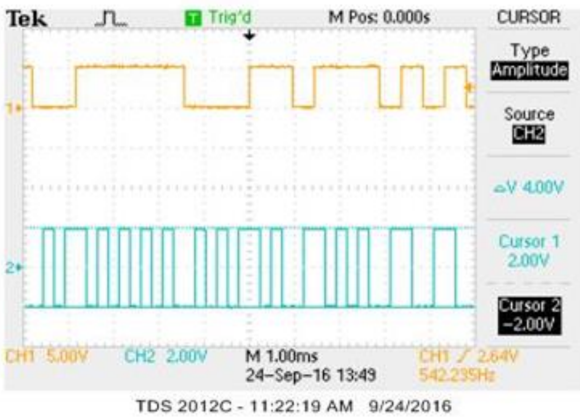

Figure 9: ***X sequence and the*** **BiΦ-L code**

Figure 10: Spectrum for the BiΦ-L code

Table 4. Time & Spectral Domain Properties of BiΦ-Line code: *R_b= 2Kbps*

Line Code	DIP position	Bit	X Sequence Voltage	Line code Description	Frequency and Power of null close to 0 Hz	Frequency and Power at First deep null	Essential BW / R_b
BiΦ-L	01	1					
		0					

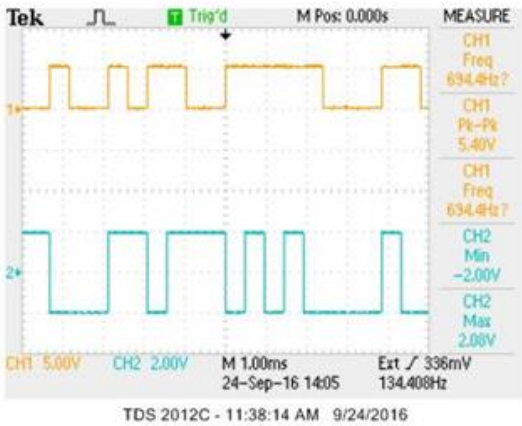

Figure 11: *X Sequence and the RZ-AMI code*

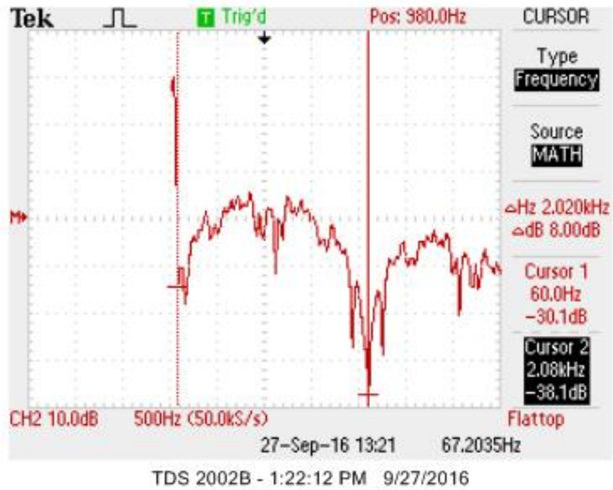

Figure 12: **Spectrum for the RZ-AMI code sequence**

Table 5. Waveforms & Spectral properties for RZ-AMI line code: *R_b= 2Kbps*

Line Code	DIP position	Bit	X Sequence Voltage	Line code Description	Frequency and Power of null close to 0 Hz	Frequency and Power at First deep null	Essential BW / R_b
RZ-AMI	10	1					
		0					

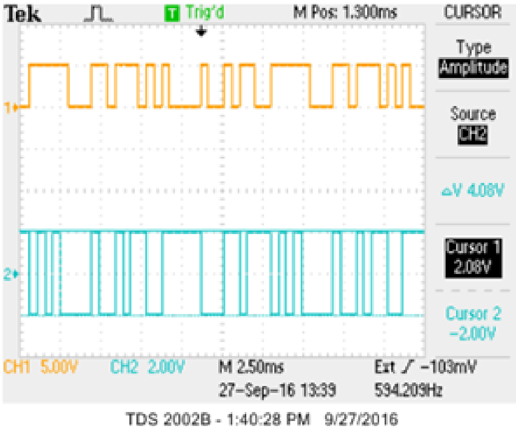

Figure 13: *X Sequence and the NRZ-M code*

Figure 14: Spectrum for the NRZ-M code sequence

Table 6. Waveforms & Spectral properties for NRZ-M **line code: *R_b= 2Kbps***

Line Code	**DIP position**	**Bit**	**X Sequence Voltage**	**Line code Description**	**Frequency and Power of 0 Hz**	**Frequency and Power at First deep null**	**Essential BW / *R_b***
NRZ-M	11	1					
		0					

D – Effect of Bandwidth Limiting of channels

As we discussed in the class, bandwidth limiting in a channel can distort digital signals and upset the operation of the receiver. This part of the experiment demonstrates this using line coded digital data passing through a channel, represented by a tunable low pass filter. Since we are using a tunable low pass filter as a channel, we need to know its operation and characterization clearly. For this:

1. Locate the Tunable Low-pass Filter module and set its *Gain* control to about the middle of its travel.
2. Identify the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control. To know to what cut off frequency the filter has been tuned to, Emona gives an output port as fc X 100. This gives out a square wave whose frequency is 100 times the cut off frequency, tuned by the *Cut-off Frequency Adjust* control.
3. To understand the effect of various cut off frequencies on signals, the student is advised to connect the following circuit and observe the output of the filter for various cutoff frequencies.

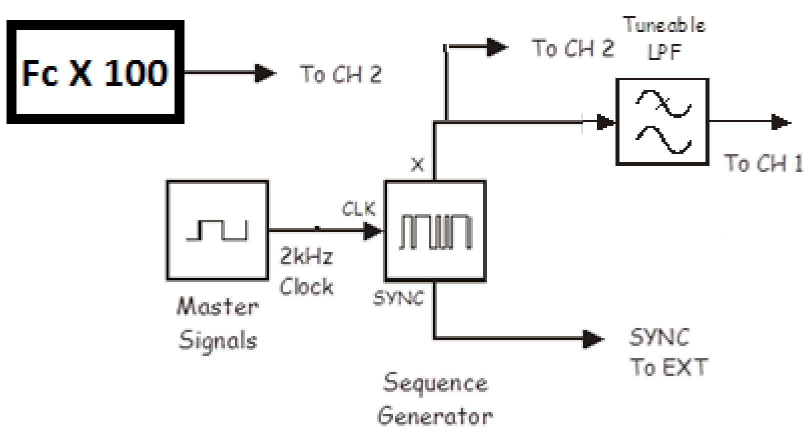

Figure 12: Block diagram for to study the Tunable Low pass filter

4. Turn the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control to extreme right position.
5. Obtain the X sequence on the screen and trigger the DSO using external trigger. Observe the waveforms at filter input and output. You will notice that both waveforms are almost identical.

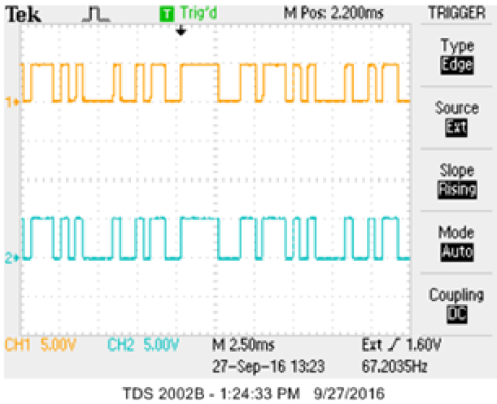

Figure 13: Waveforms at the input and output of LPF with fc is in the Extreme right most position

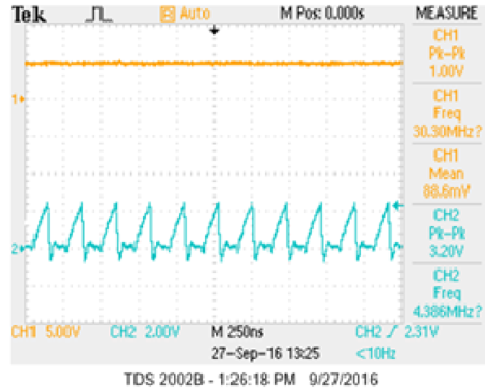

Figure 14: Waveform of fc*100 when fc is in the Extreme right most position

6. Deduce the filter's Cutoff frequency value, by connecting the Fc X 100 port to Ch2. *In this measurement, you may have to trigger the DSO using Ch2 input for getting accurate measurement.* What is the measured frequency at *Fc X 100 port*? What is the Cutoff frequency **Fc** of the filter for this tuning? What is the ratio of this cut off frequency **Fc** to the First Deep Null Frequency (Bandwidth of the signal) from Table 2? Is it less than or greater than 1?

7. Turn the *Cut-off Frequency Adjust* control *anti clock wise to about 3/4th way through its travel*. Measure the cut off frequency again. How much is the ratio now? What is its effect on the signal at the filter output? Does filter maintain the waveform as is, compared to input? Comment on your observation.

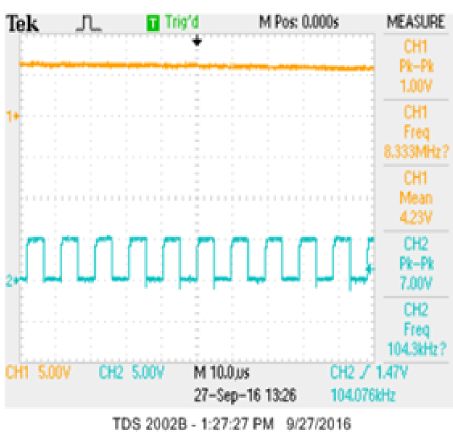

Figure 15: Waveform of fc*100 when fc is around 1 KHz

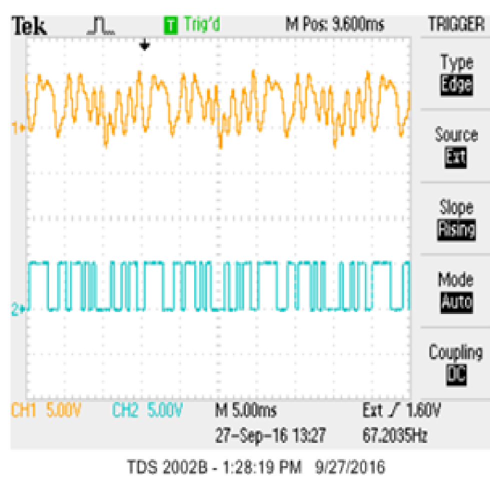

Figure 16: Waveforms at the input and output of LPF when fc is around 1 KHz

8. Turn the *Cut-off Frequency Adjust* control anti clock wise to obtain the cut off frequency to be around 2 KHz and observe its effect on the signal at the filter output? Does filter maintain the waveform as is, compared to input?

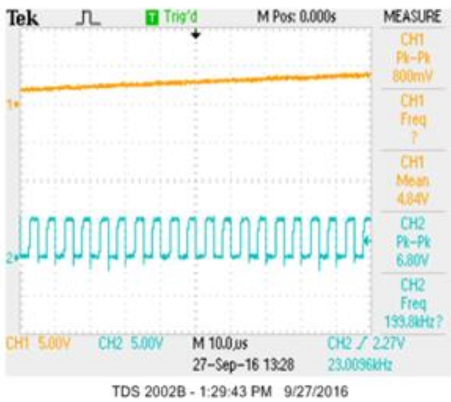

Figure 17: Waveform of fc*100 when fc is at around 2 kHz

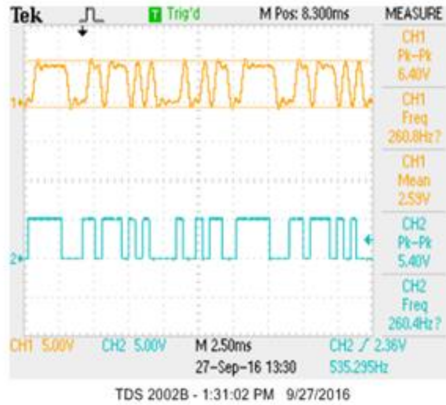

Figure 18: Waveforms at the input and output of LPF when fc is 2 kHz.

E – Effect of Bandwidth limited channels on Line Coded Signals & Eye Patterns

As we discussed in the class, bandwidth limiting in a channel causes Inter Symbol Interference (ISI). The effect of ISI is to stretch the digital signal into neighboring bit durations and hence upset the operation of the receiver.

In practical scenarios, to know the status of the channel, with respect to ISI and sampling point, a random binary pulse sequence is sent over a channel and Channel output is applied to the vertical plates of the oscilloscope. Time base of the scope is triggered at the same rate as that of the pulse sequence. This will result into what is called EYE PATTERNS, as shown in Figure 19.

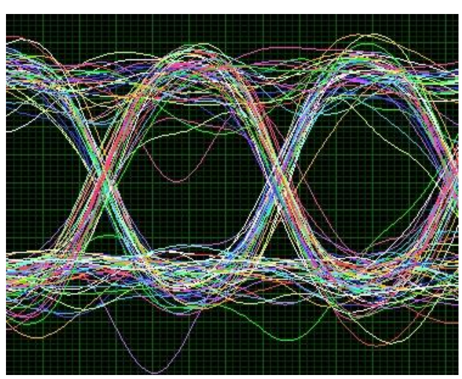

Figure 19: Eye Patterns

This part of the experiment demonstrates eye patterns, using line coded digital data passing through a channel, represented by a tunable low pass filter. For this we use NRZ-L line coded digital data. Follow the steps given below:

1. Make the connections as in Figure 20.

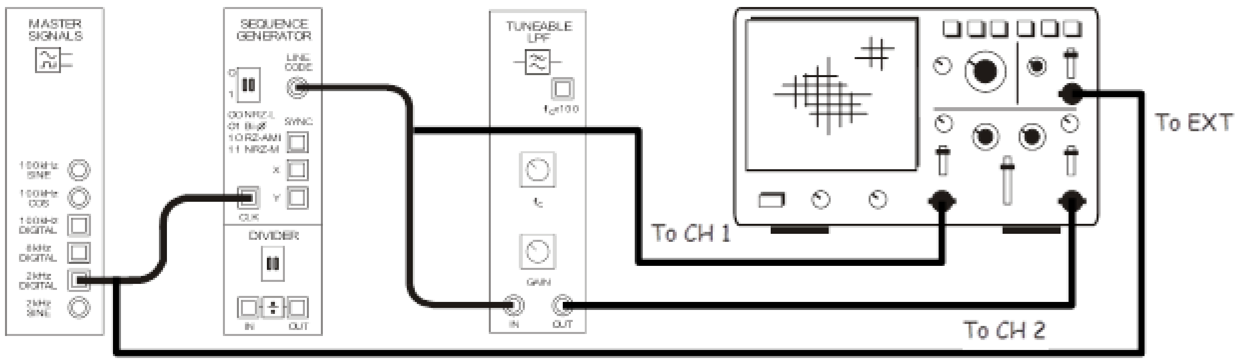

Figure 20: Setup for generating eye-patterns

1. Note that we are using NRZ-L line code settings. Use the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control to set the cut-off frequency to its highest value. Stop turning the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control once f_c is set.
2. Note that DSO is now being triggered by the system clock instead of the Sequence Generator module's *SYNC* signal. This forces the scope to draw the Sequence Generator module's data bits over each other and should look something similar to the figure shown below.
3. In Channel 1, you will see eye-pattern corresponding to a non-distorted digital data. To see the underlying Line Code, you may have to use the RUN/STOP feature of the DSO (See Figure 22). You may note that the least duration a square box (Figure 21) corresponds to 1 bit duration. The line code output is a sequence of random levels of +2.0 V or -2.0V, corresponding to random bits sequence of "1"s and "0"s. *It is easy to understand that one can sample the waveform at any instant during the bit period and declare the presence of bit 1or 0. This state is called as eye being completely open.*

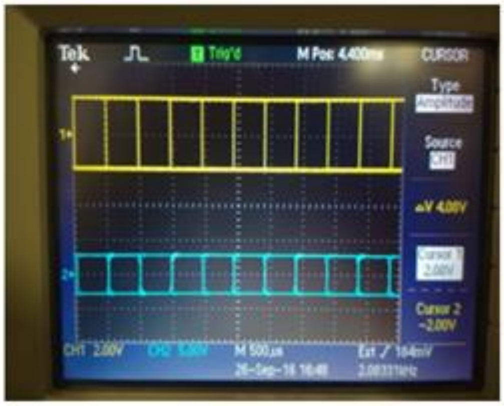

Figure21: : Eye patterns when fc is high

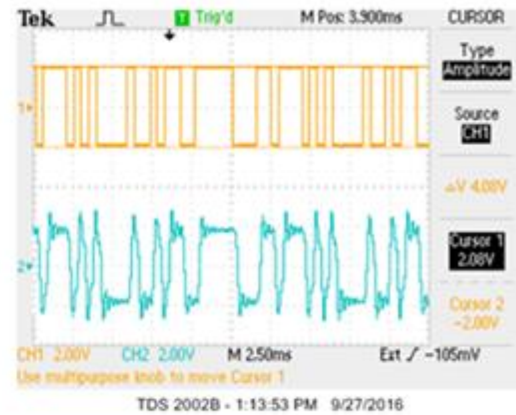

Figure 22 : Eye patterns when fc is high with STOP feature

4. Now, tune the Low-pass Filter module's *Cut-off Frequency Adjust* control to set the cut-off frequency as R_b. Stop turning the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control once f_c is set.
5. In Channel 1, you will see eye-pattern corresponding to a non-distorted digital data. In Channel 2, (Figure 23) you will see eye-pattern corresponding to the line coded waveform, after passing through the channel, represented by a low pass filter with cut off frequency as Rb KHz. This is a distorted line code. *It is easy to understand that one cannot simply sample the waveform at any instant during the bit period and declare the presence of bit 1or 0. In this case, the eye is not completely open.*

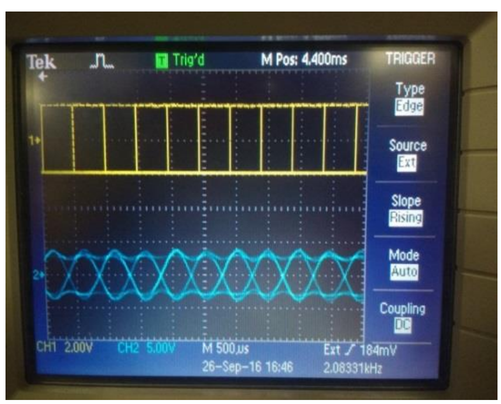

Figure 23: Distorted and Non distorted eye patterns when fc is at 2 kHz with RUN feature

6. Now turn the Tunable Low-pass Filter module's *Cut-off Frequency Adjust* control anti clock wise and see its effect on closing of the eye. This makes the location of the sampling instant to be critical. If time permits, you may try to get the eye patterns for other 3 line codes also.

F – Line Decoding and Effect of Bandwidth limited channels on Line decoded Coded bits

This part of the experiment is to observe the line decoding operation and the effect of channel bandwidth on the decoder performance. For line decoding, Emona kit has an add-on module. Locate the same. Connect the blocks as in Figure 24 and follow the steps given below:

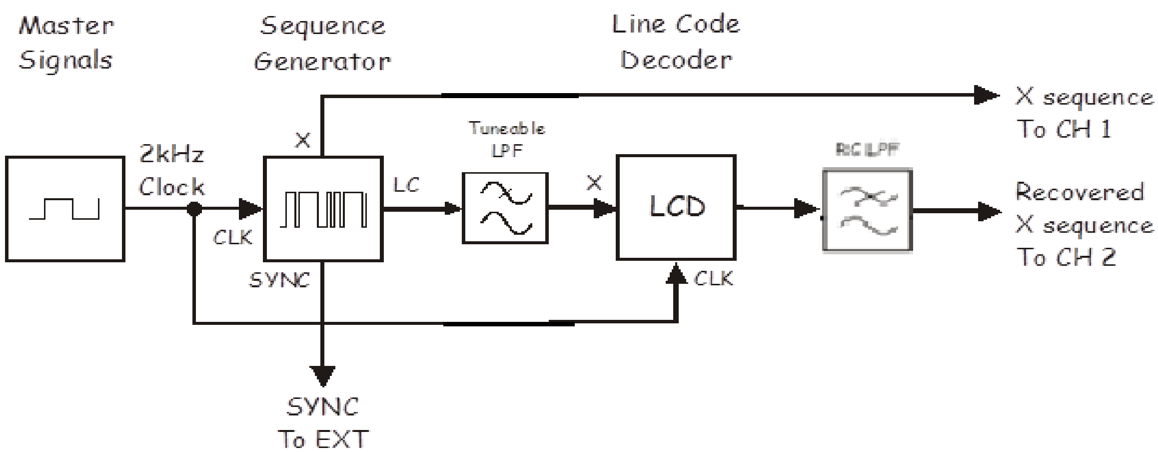

Figure 24: Block Diagram for Connecting Line Decoder.

1. Set the line coder to NRZ-L mode. Set the same on the line decoder module also. Set the frequency adjust control of the tunable low pass filter to extreme position, so as to have a large bandwidth channel. Adjust the DSO trigger if required. You may use the ALIGN control on the add-on module if the CH1 and CH2 do not display the same sequence.
2. Are the Ch1 and CH2 sequences aligned? If not what is the reason?

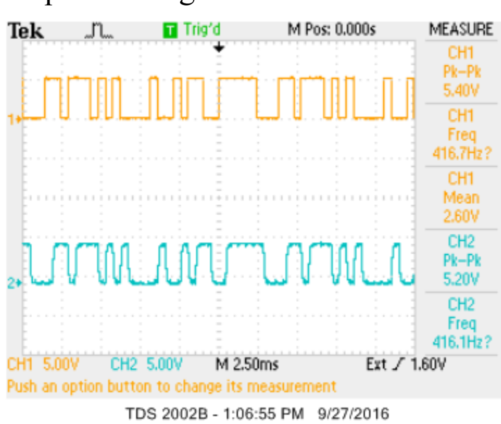

Figure 25: Waveform of the X sequence and the Recovered Sequence when fc knob is at the extreme position.

3. Try other Line Codes also. Make sure that both line coder and decoder are set to same line code option.
4. Now reduce the Band width of the channel to just ***Rb or 2 Rb***, depending on the line code you have chosen, by adjusting the LPF frequency control. What is the effect on the line decoder performance? Is the decoded sequence same as that of the X sequence?

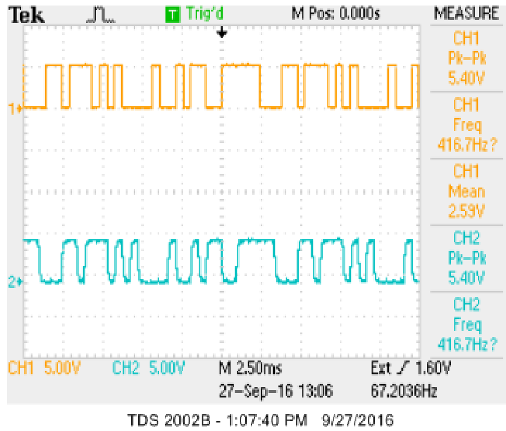

Figure 26: Waveform of the X sequence and the Recovered Sequence when fc knob is at the halfway point.

5. Reduce the channel bandwidth and see the effect on the decoder performance? By observing the CH1 and CH2 sequences, do you see any bits being detected wrongly?
6. If time permits, observe the effect of adding noise to the channel by connecting the output of Tunable LPF to Signal Input in the Adder Module. Add a noise of -20dB and connect the Channel Out to the input of Line Decoder. Observe the output waveform.
7. Change the noise to 0dB and observe the waveforms again. What differences do you see?

G –Conclusions:

1. List out your learnings from the experiments.