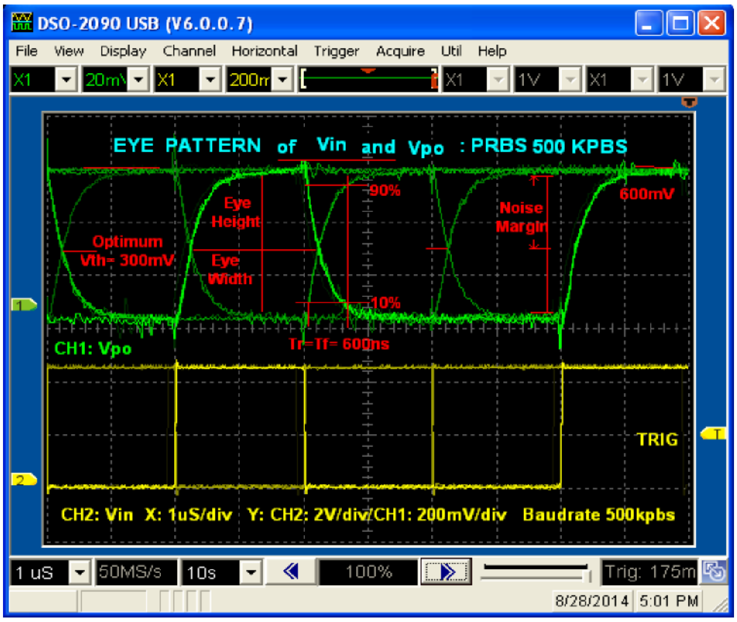
Study of Eye Patterns in Fiber Optic Digital Links

LABORATORY MANUAL: TESTER EPS04



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1. Eye Pattern Tester EPS04

1.1 Introduction to Tester EPS04

Tester EPS04 described here is an optimized set-up to conduct a comprehensive study of eye patterns or eye diagrams of a fiber optic digital transmission system. References are made to Fig1, Fig2 and Fig3 while describing Tester EPS04.

The Tester EPS04 is centered around two popular and proven optical fiber digital transmission micro-modules that have been in use for 20 years. These modules designated DHM-T/660 (digital transmitter) and DHM-R/HS (digital receiver), are described at length in **Annexure I.** The modules are terminated with industry standard SMA receptacles that facilitate coupling with SMA-SMA connectorised PMMA (plastic) optical fiber (POF) cables. Industrial grade teflon insulated electrical wires are employed in the modules for reliability and durability. The wavelength of operation is 660nm.

The other key feature of Tester EPS04 is the built-in pseudo random bit sequence generator that can be set for operation at baud rates of 2.5Mbps, 1 Mbps and 500 Kbps. The microcontroller based PRBS generator, is described further in **Section 1.2.** The microcontroller uses a 20MHz crystal for high timing stability. Output waveform is settable through a single push button switch.

Tester EPS04 includes a 1-metre SMA-SMA connectorised PMMA cable. The only other T&M equipment required is a dual channel 20-Mhz oscilloscope (analog or digital) with matching probes. An oscilloscope that has settable persistence will be an added advantage.

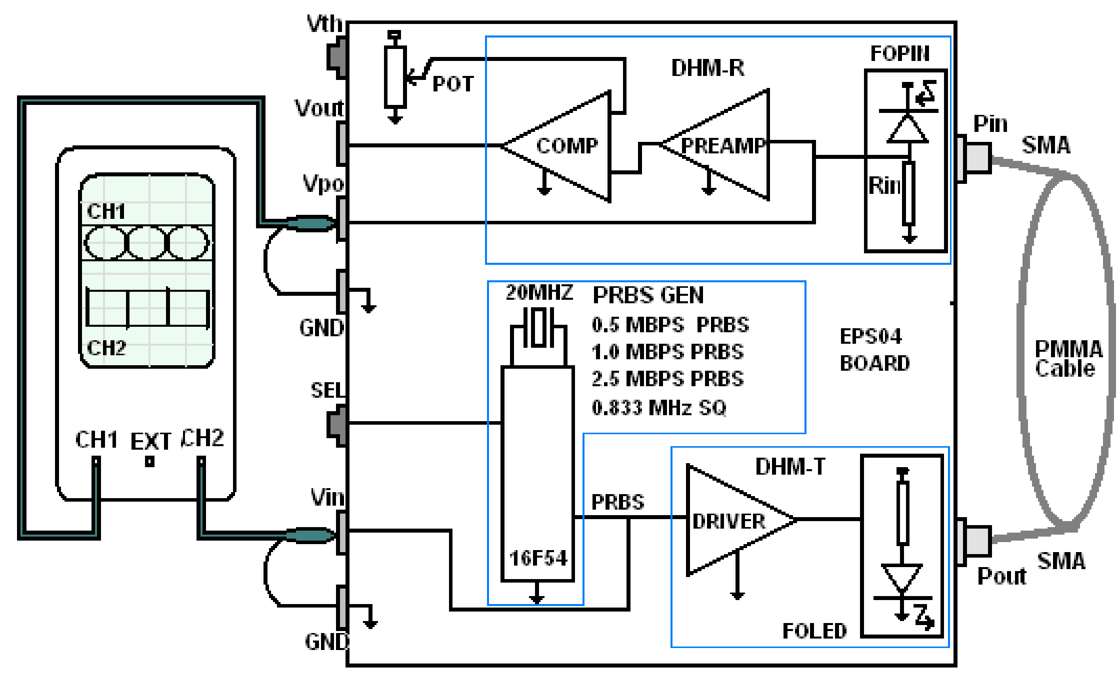


Fig1 Block Schematic of Eye Pattern Test Set-up

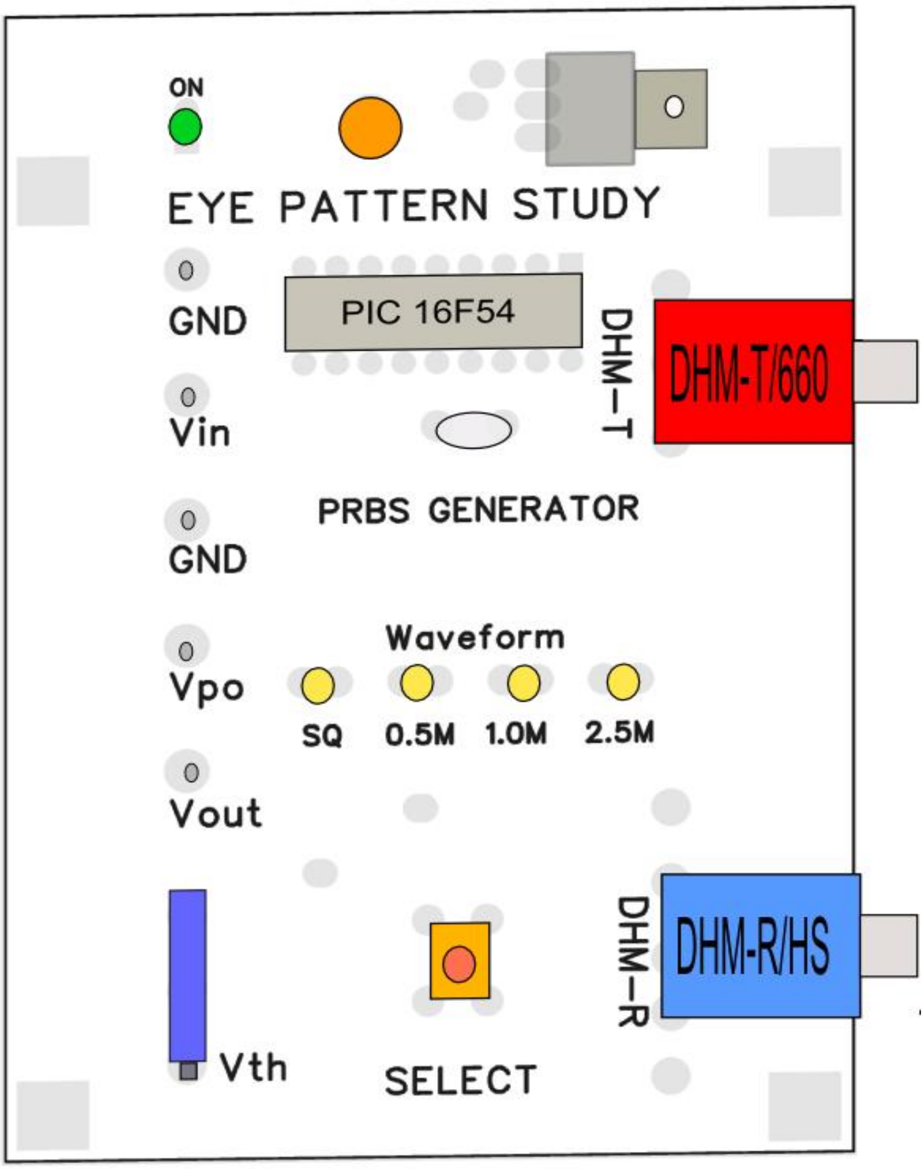


Fig 2 Schematic of EPS04 PCB

1.2 Detailed Description of Tester EPS04

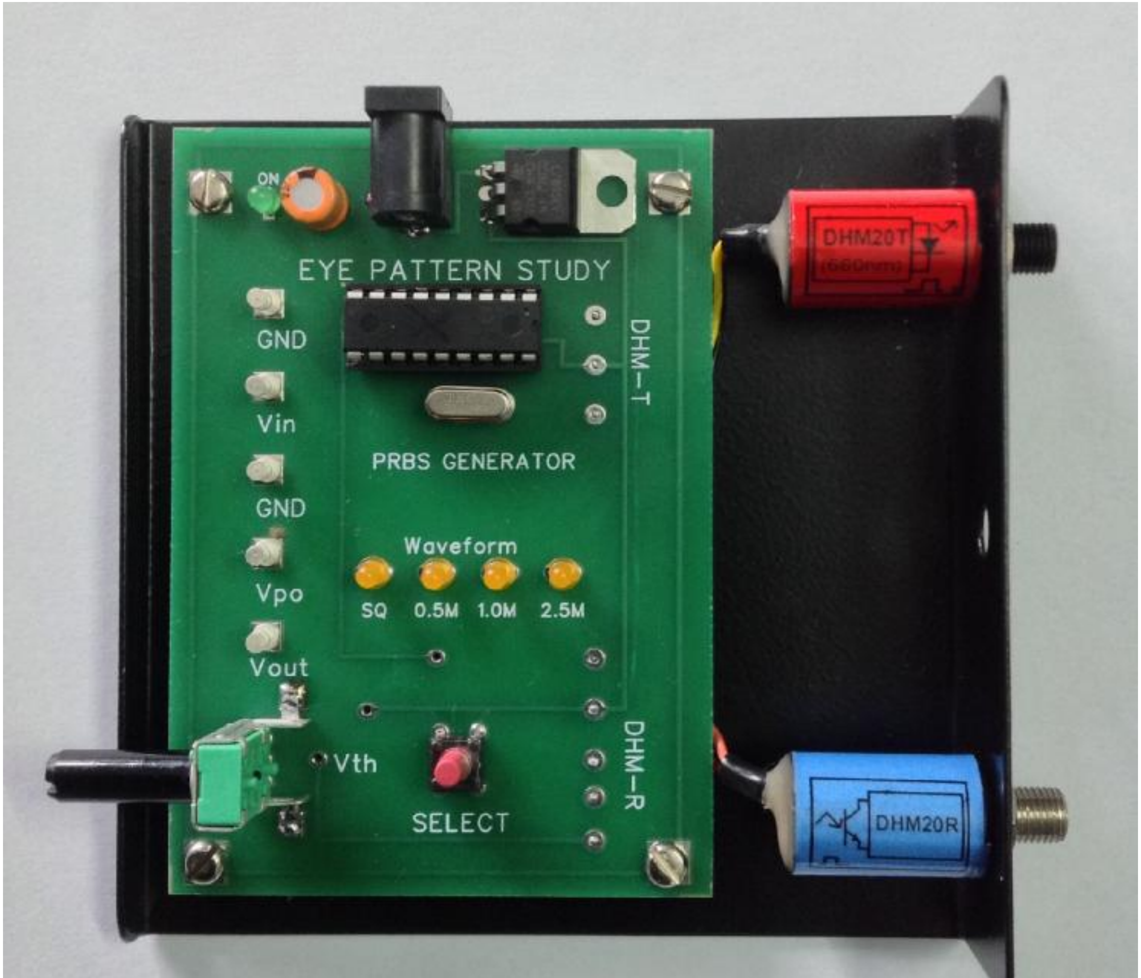
Please refer to Fig1, Fig2 and Fig 3 that display the various schematic diagrams of the test set-up. Salient features are described in the following sub-sections.

1.2.1 FO Digital Transmitter

The transmitter unit converts input digital electrical signals (TTL/CMOS) to optical signals for transmission through an optical fiber. The DHM-T/660 micro-module converts electrical signal to an optical output, by driving the FO LED to cut-off condition for state '0' and to full on condition for state'1'. The circuit is designed to provide fast turn on and turn off of the FO LED. Optical power is coupled to the optical fiber through an SMA connector.

P_o This is an SMA connectorised optical output port. The SMA connectorised PMMA cable connects the transmitter to the receiver.

V_{in} This is a TTL compatible input. Speeds range is from 0 to 5 Mpbs. The input may be a simple square wave or a complex pseudo random bit sequence from a function generator. In this trainer the output of the microcontroller (PBRS-OUT –Pin No.17) is internally connected to V_{in} and hence *no external V_{in}* should be applied to it. V_{in}, connected to CH2 will be used as the reference waveform for (a) an ideal eye pattern as well as (b) the trigger source in the course of this study. **One may choose to use CH1 for this purpose, instead.**



Tester EPS04

SELECT This push button switch facilitates selection of 4 types of wave patterns in the sequence shown below. At the end of the 4th selection the cycle repeats.

Operation	Waveform	Baud Rate/Speed	Pulse Width
Power-Up	Square wave	0.833Mbps	600 ns
First Press	PRBS	0.5 Mbps	2.00 us
Second Press	PRBS	1.0 Mbps	1.00 us
Third Press	PRBS	2.5 Mbps	400 ns
Fourth Press	SQ	0.833Mbps	600 ns

GND The two terminals marked GND are the common system ground.

1.2.2 FO Digital Receiver

The signal at the far end of the optical fiber cable is coupled to the optical port P_{in} through an SMA connector. The micro-module DHM-R/HS converts the input optical signal into a TTL compatible electrical signal employing a preamplifier followed by a high speed comparator. The bandwidth of the received signal is determined by the input resistance $R_{in.}$ In our study, the internal R_{in} of 5.1K will remain unchanged.

P_{in} This is the optical input port, terminated with an SMA receptacle that mates with the SMA connectorised PMMA cable.

V_{out} This is the TTL compatible output from the built-in high speed comparator

V_{po} This is the analog inter-stage output that precedes the preamp and the high speed comparator stages. It provides for setting receiver gain and bandwidth. The built-in R_{in} is **5100 ohms.** The system gain is directly proportional to the value of R_{in} and is given by **$G_{Rin} = k.V_{o(DIG)} / R_{in}$.** R_{in} may be set in the range 1000 to 5000 ohms through external fixed metal film resistors. The system bandwidth and rise time are related and are inversely proportional to R_{in}. Proper selection of R_{in} determines optimum bandwidth (or rise time) and gain. For the eye pattern studies in this manual, **R_{in} will not be changed**.

V_{th} This potentiometer sets the threshold for the comparator. This voltage is settable in the range 0 to 600 mV. The shaping of the TTL output waveform is done with this. The best performance is achieved for V_{th}= 0.5 $V_{po.}$

1.2.3 PRBS Generator

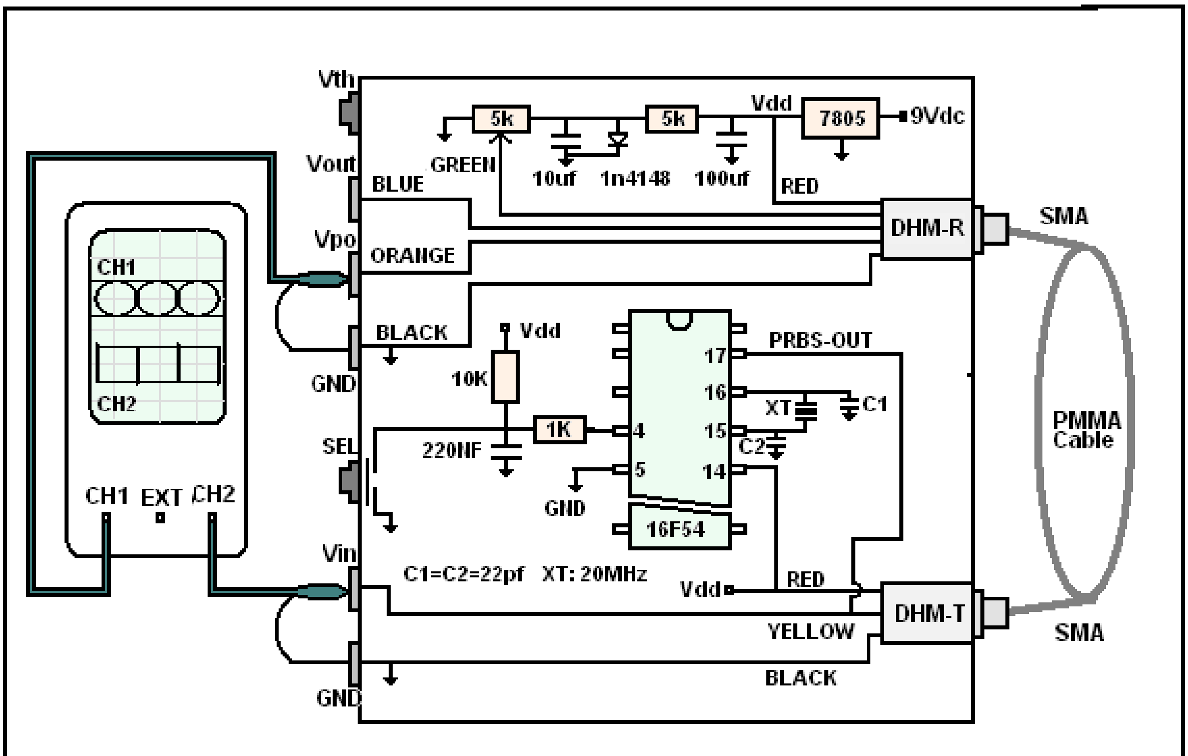
Brief description of PRBS Generator is given below:

Microcontroller: 16F54
Output: On A0 (Pin17)
Rise & Fall Time 20 ns
Supply 5 Vdc
Pseudorandom Number: 32 bit long
Square Wave: 833Khz 50% duty cycle
Output Modes: 4 Mode (described below)

Frequency of Operation: 20 MHz
Frequency Stability: 30 ppm
Pin Count 18 Pins
Reset: Used for Mode Selection
LED Indication of Waveform Mode

Operation	Waveform (A0)	Baud Rate	Pulse Width
Power-Up	Square wave	0.833 Mbps	600 ns
First Press	PRBS	0.5 Mbps	2.00 us
Second Press	PRBS	1.0 Mbps	1.00 us
Third Press	PRBS	2.5 Mbps	400 ns
Fourth Press	PRBS	0.5 Mbps	2.00 us

2. Basic Fiber Optic Digital Link Set-Up



Schematic of Set-Up for Study of Eye Pattern

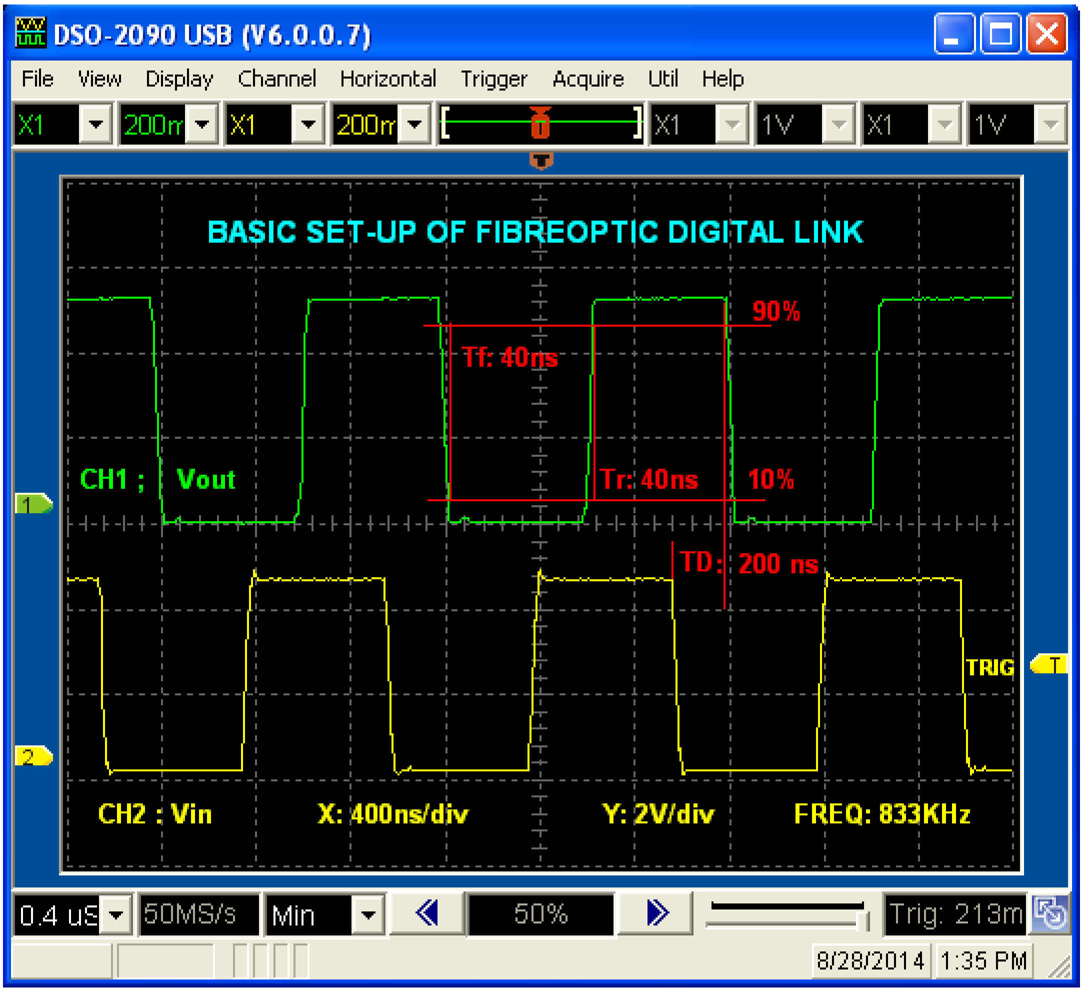
The procedure to set up a basic digital transmission system with the Tester EPS04 and evaluation of the same is discussed here. The basic set-up will be used for all other studies in this Manual

Step1: Turn the Tester on. Connect the OF cable as shown. Connect oscilloscope **CH2** to **V_{in}** and **CH1 to V_{out}**. Use **CH2 as the trigger source** for the oscilloscope.
Step2: Set SELECT to the SQ_WAVE mode. Set Oscilloscope **time base to 400 ns/ div.** Set Y- amplifiers of both channels to **2 Volts/div**. Observe the square wave on CH2.

Step3 Gradually increase V_{th} from the minimum position (extreme counterclockwise position, observing waveform on CH1 Initially no signal will appear on Ch1. As V_{th} increases, waveform on V_{out} will appear. Set V_{th} **to match pulse widths of the transmitted and the received waveforms**. To do this, closely observe the two waveforms and fine tune V_{th}. When this is done, the digital link has been set up for optimum transmission. V_{th} may be left undisturbed unless otherwise specified.. Please note that there will be a delay between the transmitter train (ie V_{in}) and the received train (ie V_{out}).

Step 4: Measure the rise time, T_r, of the transmitted and received pulses. T_r is the time taken for a pulse to rise from 10% to 90% of its amplitude. Next measure T_f of the transmitted and received pulse. T_f is the time taken for the pulse to fall from 90% to 10% of its amplitude. Next measure PD, the propagation delay, which is the time delay between the rising edges of the transmitted and the received pulses assuming equal pulse widths. While the PD will be around 200 ns, Tr and Tf will be in the region of 20 to 40 ns in both cases.

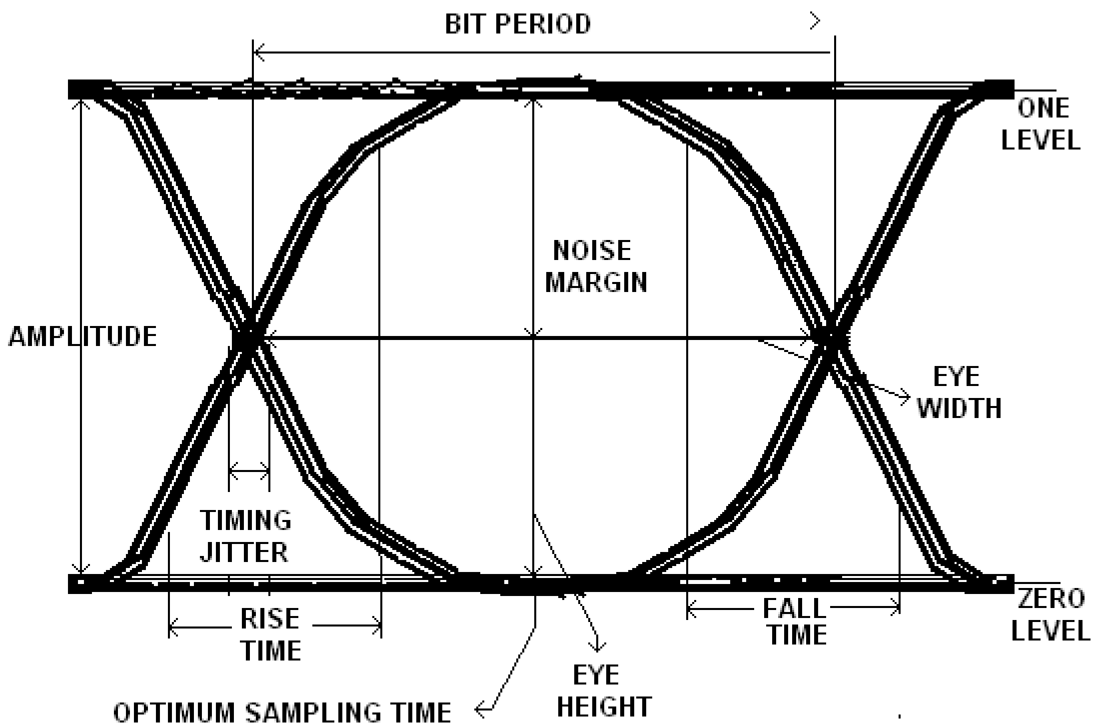
The screenshot from a DSO depicts the waveforms captured. Tr=Tf= 40ns; PD=200ns..



3 Eye Pattern Studies in a Fiber Optic Digital Link

3.1 Introduction to Eye Pattern

Serial data transmitted through an optical fiber digital transmission system suffers distortion and impairment, travelling from the transmitter to the receiver. Distortions caused to the signal amplitude and time related parameters severely affect and limit the performance of the system in terms of transmission bandwidth and distance. A rapid and effective method of assessing the performance and quality of the transmission systems is to employ the eye pattern technique.



2.2 3 TYPICAL EYE DIAGRAM MEASUREMENTS

An oscilloscope is employed to generate an eye pattern by overlaying sweeps of different segments of a long data stream controlled by a master clock, which may be used as the oscilloscope trigger source. The stream of output pulses from the transmission system, resulting from a pseudo random bit sequence generator at the input, creates an eye pattern when the ‘0’s and ‘1’s are superimposed. By adjusting the persistence of the oscilloscope suitably, an eye pattern as shown above is displayed on the scope. Differences in timings and amplitude from bit to bit result in spread of these parameters. Various transmission parameters may be assessed visually from the eye diagram. An ideal digital transmission system will have a rectangular eye pattern fully open. With increase in timing jitter and amplitude variations, the eye opening begins to shrink. The transmission parameters that can be assessed employing an eye diagram are shown above.

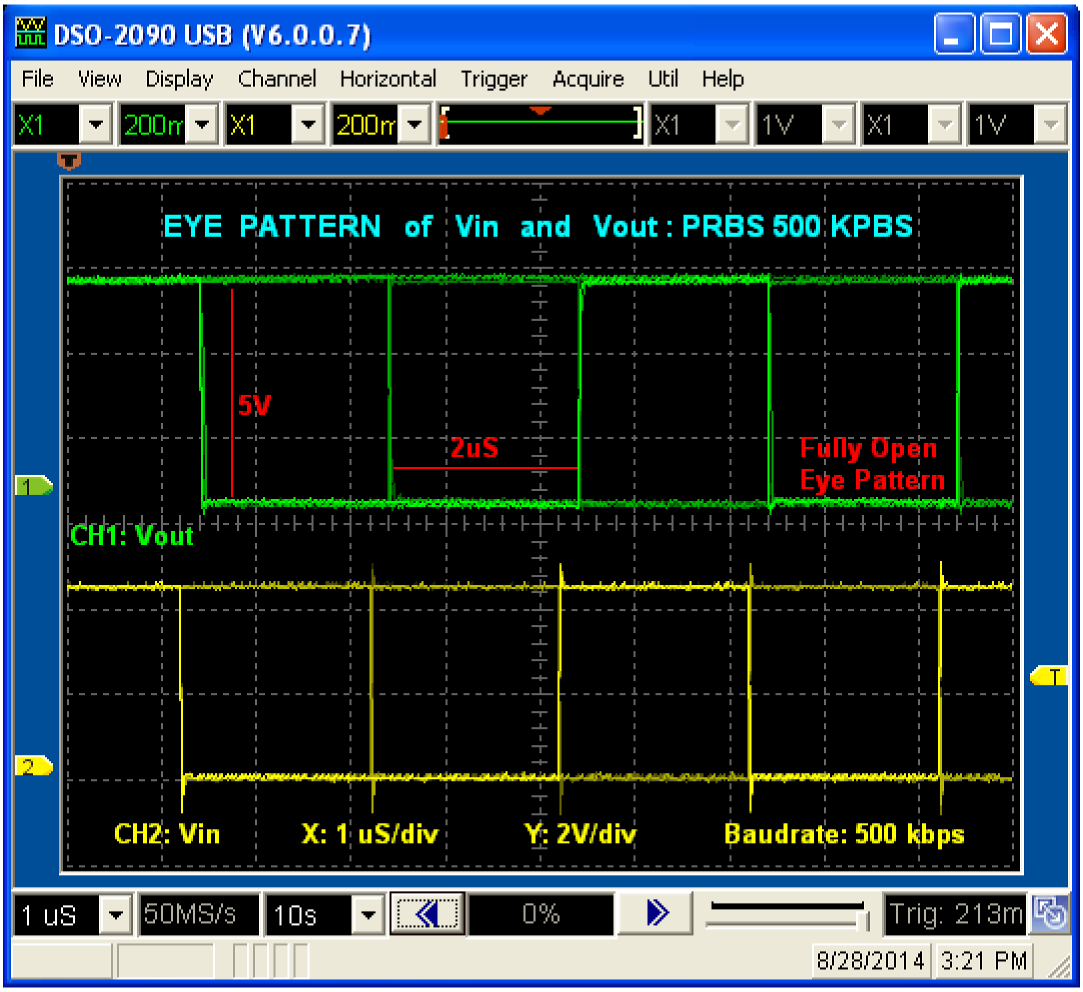
3.2 Procedure to Generate Eye Pattern on Vout and V_{in}

The first experiment will be to set up the eye patterns for the input (V_{in}) and the output (V_{out}) of the fiber optic digital link after initially setting up the basic digital link for optimum performance, as described in Chapter2. The experiment will be conducted with PRBS speeds of 500 Kbps, 1000 Mbps and 2.5 Mbps. Measurements may be recorded as shown below:

Step1 Set up the optimum digital link as described in detail in Chapter 2.

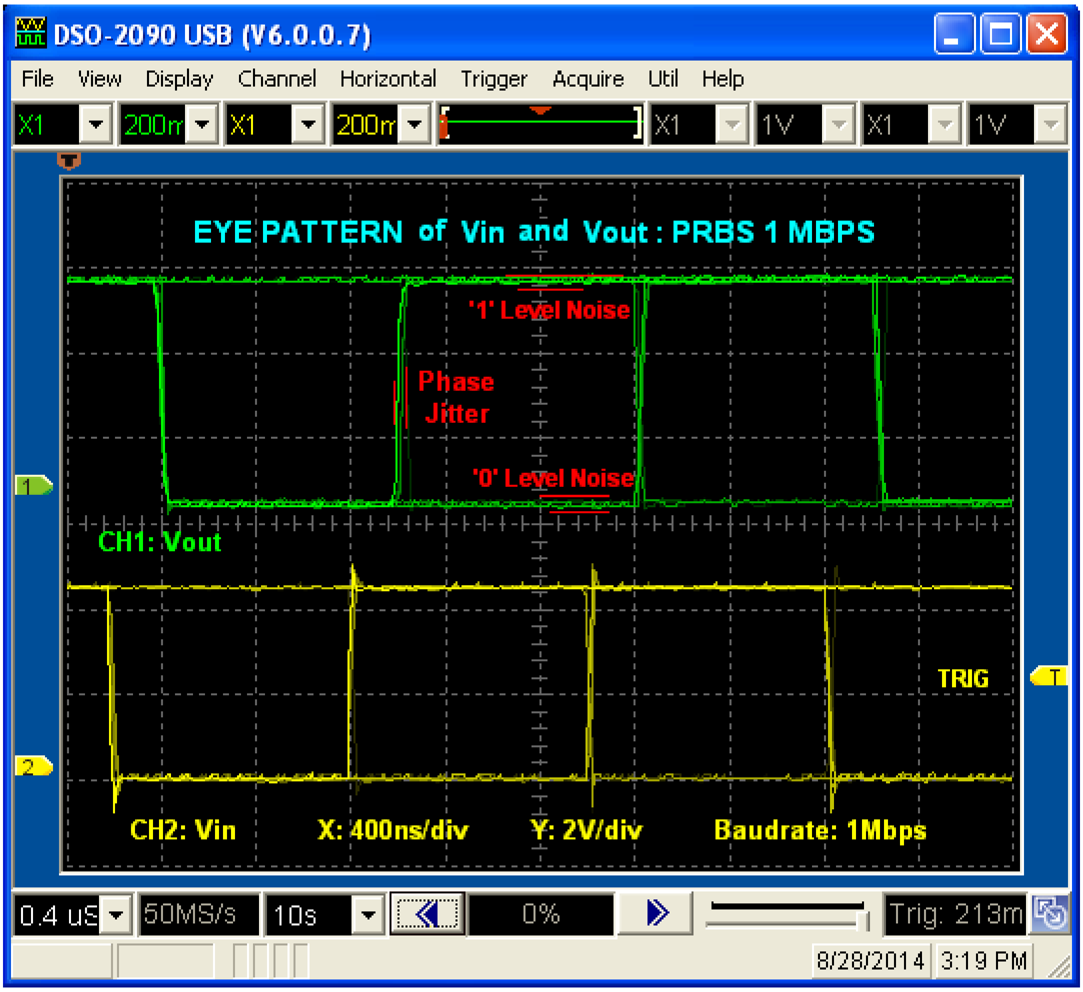
Step2 Next set SELECT to the **500 KBPS** mode. Set oscilloscope sweep rate to **1 us/div.** The Y settings of the scope may remain unchanged at 2V/div. The trigger source too may remain on CH2.

Step3 Now, increase the **persistence setting** of the oscilloscope to as high a value as possible. In a DSO, 10 seconds will be reasonable. In analog oscilloscopes, with no persistence control, one may increase the intensity until a pattern shown below appears. The eye patterns for the transmitted train (V_{in} on CH2) and the received train (V_{out} on CH1) will have close resemblance.



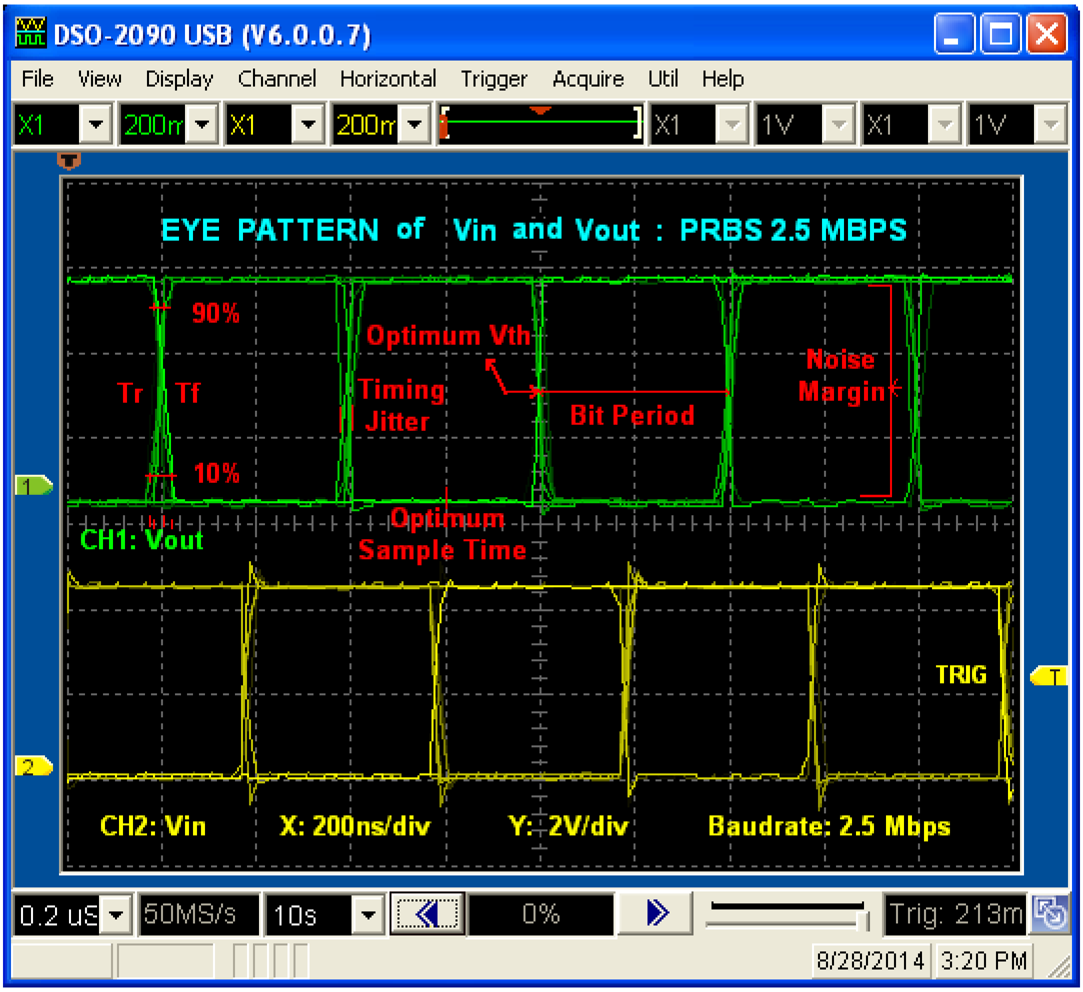
In this experiment we have familiarized ourselves with the oscilloscope settings required to generate an eye pattern. The eye patterns generated for V_{in} and V_{out} are almost ideal, in that the rectangular eyes are fully open. Other than the eye width and the eye height, other measurements may not be too meaningful.

Step4: Now set **SELECT to 1MBPS** mode. Next, set the X sweep rate of the oscilloscope to **400 nanosecond /div**. Keep all other settings unchanged. Note that the oscilloscope pattern should be close to what is shown below.



In this experiment change in the eye patterns of V_{in} and V_{out} is a bit more noticeable. The rise and fall times are more significant, still not measurable. The phase or the timing jitter on V_{out} is a little greater than that on V_{in}. At a baud rate of 1 Mbps, the performance of the digital link is close to being ideal, in that the received train (V_{out}) is almost identical to the transmitted train (V_{in}) except for the propagation delay, PD (equal to 200ns) .

Step 5 Next, set **SELECT to 2.5 MBPS** mode. Next, set the X sweep rate of the oscilloscope to 2**00 nanosecond /div**. Keep all other settings unchanged. Note that the oscilloscope pattern should be close to what is shown below.



Notice the change in the eye patterns of V_{in} and V_{out} which from being rectangular at lower baud rates, has now closed.

The rise time Tr and the fall time Tr are now measurable from the V_{in} eye diagram. They can be estimated at 30 to 40ns.

Timing jitter is in the magnitude of on V_{out} is in the region of 40 ns. Please notice that V_{in} also has a timing jitter. This is due to the limitations of (a) the PBRS generator output and (b) the oscilloscope as well.

There is no change in the noise margin, which is equal to half the eye height.

Optimum sampling time is the midpoint of the data bit. In this case it is 200 ns from the rising or falling edge of the bit.

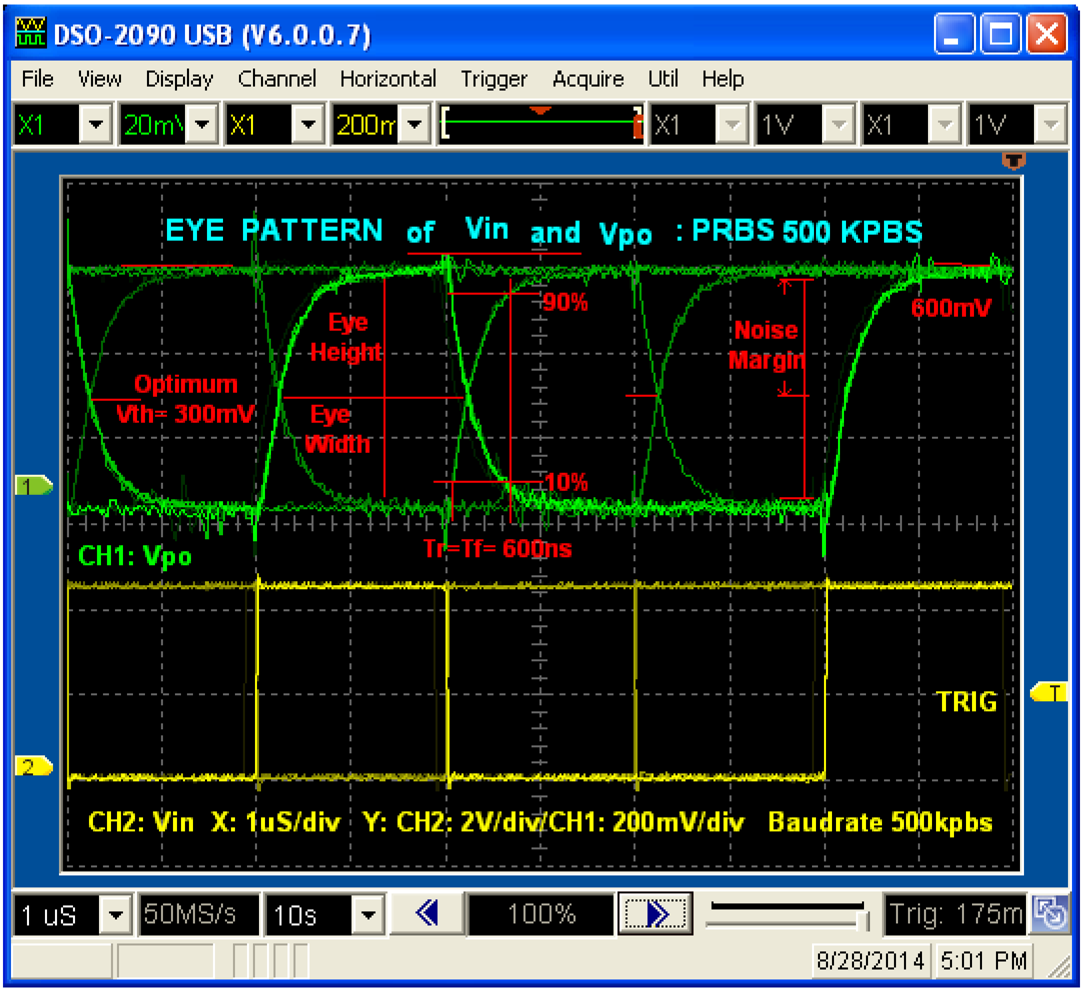
The crossover of the rising and falling edges of V_{out} occur at the midpoint of the eye height when V_{th} is set at the optimum level. This will be explained in the next experiment.

3.3 Procedure to Generate Eye Pattern on Vop and V_{in}

In this experiment eye patterns for the input (V_{in}) and the PIN diode output (V_{po}) of the fiber optic digital link will be studied. **V_{po} is an analog voltage**. As shown in the block schematic in **Section 1.2** V_{po} results from the photocurrent through the PIN diode and it appears across the built-in R_{in} of 5.1k. This experiment may be repeated for other settings of R_{in} down to 1K. For the built-in R_{in}, the experiment will be restricted to PRBS speeds of 500 Kbps and 1000 Mbps. Since the preamplifier and comparator do not have a role in this study, to isolate these components V_{th} will be set to one of the extreme settings (0 V or 0.6 V). This will ensure that no transitions occur on the comparator.

Step1: Turn the Trainer on. Connect the OF cable as shown. Connect oscilloscope **CH2** to **V_{in}** and **CH1 to V_{po}**. Use **CH2 as the trigger source** for the oscilloscope. Set **Vth to 0Vdc** by turning to the fully counterclockwise position.

Step2: Set SELECT to the **PRBS 500KBPS** mode Set oscilloscope **time base to 1uS/ div.** Set Y- amplifiers of **CH2** to **2Volts/div and CH1** to **200mV/div**.



Step3 Now, increase the **persistence setting** of the oscilloscope to as high a value as possible. In a DSO, 10 seconds will be reasonable. In analog oscilloscopes, with no persistence control, one may increase the intensity until a pattern shown above appears.

The eye patterns for the transmitted train (V_{in} on CH2) and the received train (V_{po} on CH1) will be different from the ones studied so far. While the eye pattern for the transmitted train (V_{in}) remains an ideal one, the eye pattern on V_{po} will be a partially closed one due to timing and amplitude distortions through the medium of transmission. This waveform is a typical representation of a high speed long haul fiber optic digital transmission system where both timing and amplitude distortions occur.

A number of measurements may be made on the eye pattern shown above:

The optimum level of the comparator reference voltage (V_{th}) will be around the midpoint of the eye height. In this case it is 300 mV. At this setting, the cross-over points for 1 to 0 and 0 to 1 transitions even for V_{out}, will occur at the middle voltage thereby reducing the timing jitter.

The timing jitter is not measurable here because the X sweep rate is very high at 1 uS/div.

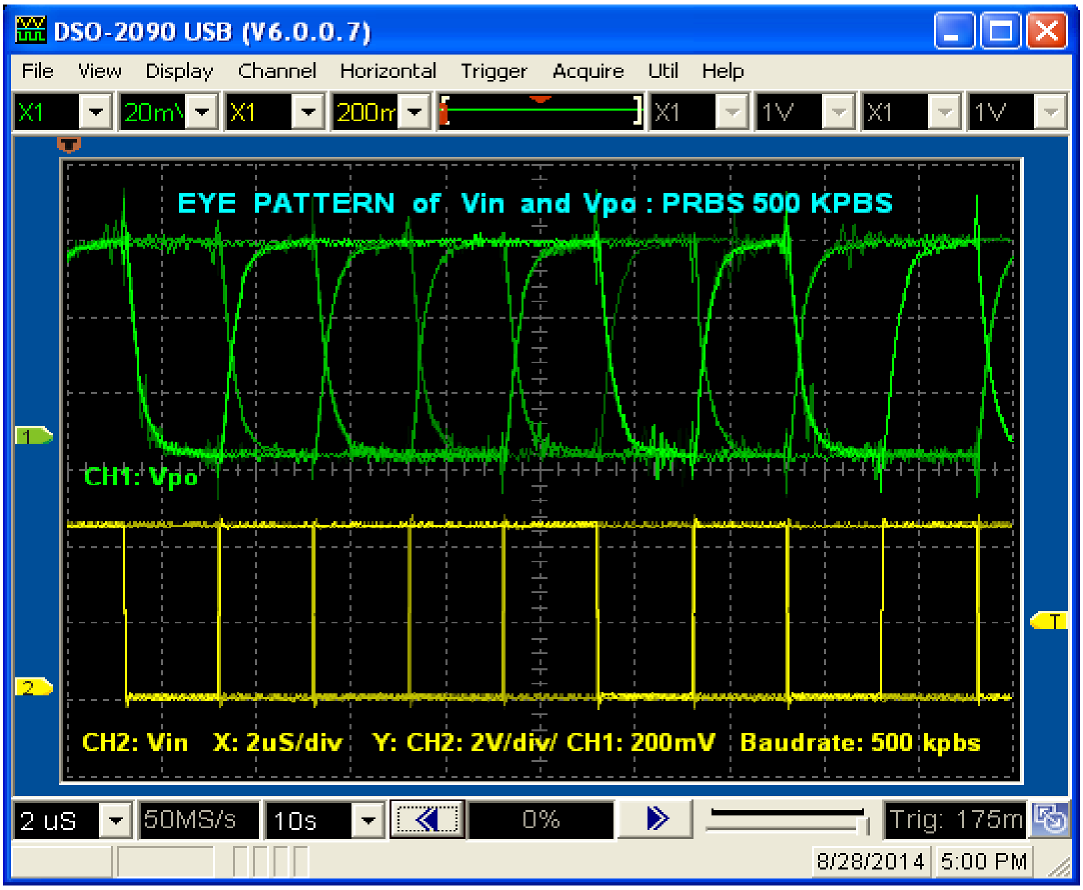
Rise time, T_r and fall time T_f are measured as 600ns for this analog section. The speedup at the digital output is achieved, employing a high speed comparator with digital cross-over taking place at the middle of the eye height.

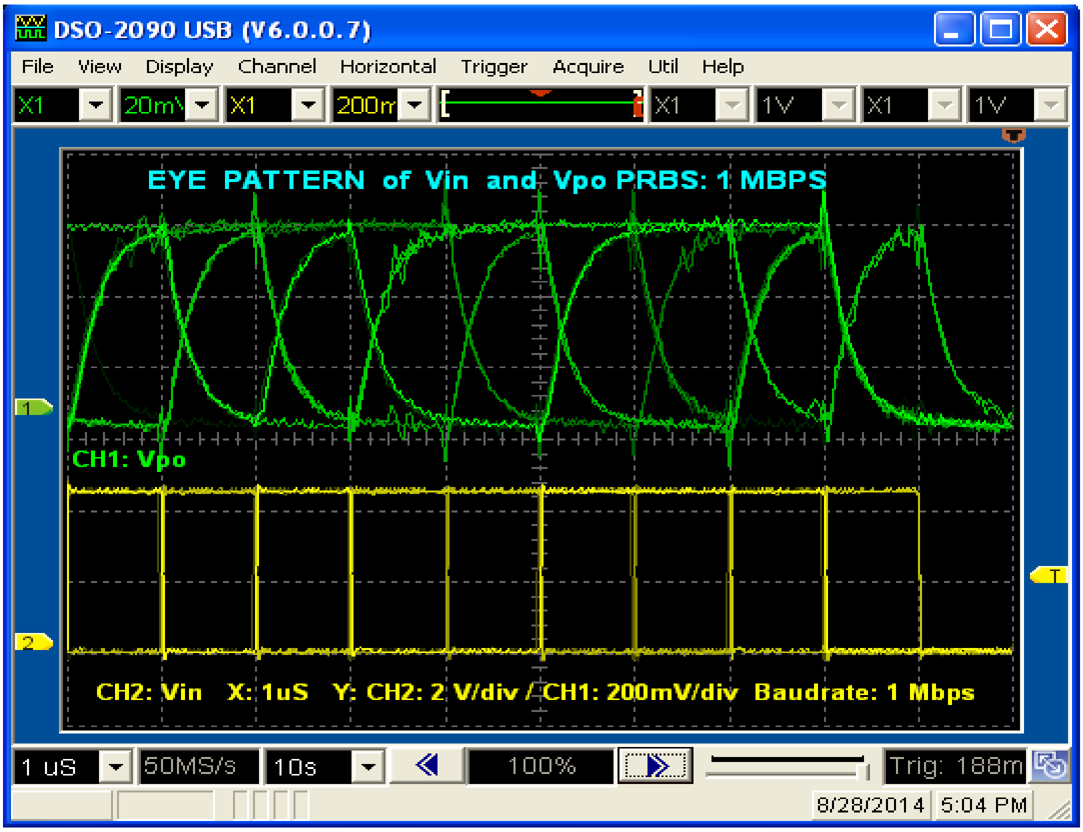
Other Eye Pattern Studies

Eye patterns on V_{in} and V_{po} may be studied at other baud rates and other settings of the oscilloscope X sweep rate as shown in the two DSO screenshots below.

Eye patterns with lower values of R_{in}, employing MFR fixed resistors across V_{po} and GND may also be studied. One may use resistors in the range 1.2k to 5.1k for this purpose. It must be noted that while the bandwidth will increase in direct proportion, the amplitude of V_{po} will reduce inversely.

Eye patterns on V_{in} and V_{po} may be studied after V_{th} is set for optimum performance as described in **Section 3.1,** followed by the procedure for setting up the eye pattern as shown in this section**,** but **without** disturbing the V_{th}. The eye pattern on V_{po} will be squarer but a little distorted when the high speed comparator switches levels. This is due to loading of the comparator inputs. This eye pattern will have an improved T_r and T_f, though.


DSO-2090 USB (V6.0.0.7)
File View Display Channel Horizontal Trigger Acquire Util Help
EYE PATTERN of Vin and Vpo : PRBS 500 KPBS
CH1: Vpo
CH2: Vin X: 2uS/div Y: CH2: 2V/div/ CH1: 200mV Baudrate: 500 kpbs
2 uS
50MS/s
10s
0%
Trig: 175m
8/28/2014
5:00 PM


DSO-2090 USB (V6.0.0.7)
File View Display Channel Horizontal Trigger Acquire Util Help
EYE PATTERN of Vin and Vpo PRBS: 1 MBPS
CH1: Vpo
CH2: Vin X: 1uS Y: CH2: 2 V/div / CH1: 200mV/div Baudrate: 1 Mbps
1 uS
50MS/s
10s
100%
Trig: 188m
8/28/2014
5:04 PM

ANNEXURE I

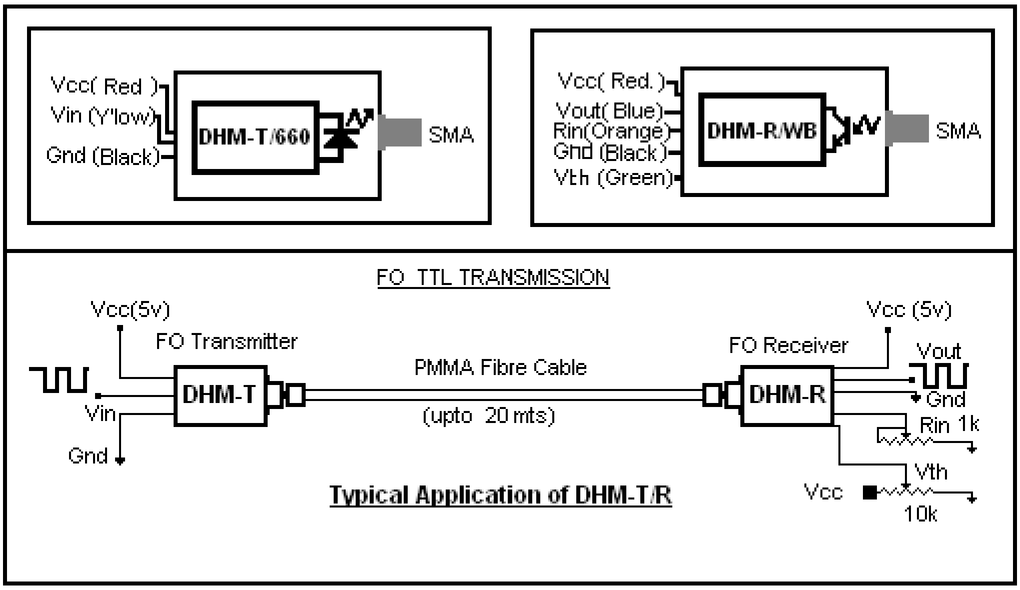
FIBER OPTIC MICROMODULES FOR DIGITAL TRANSMISSION, MODELS DHM-T and DHM-R

General Information:

The fiber optic micromodules, DHM-T/660 & DHM-R/HS comprise two encapsulated (with teflon insulated leads) devices that transmit TTL signals through a multimode step index plastic Fiber at 660nm. The fiber optic modules employ SMD technology to achieve a high degree of reliability and compactness. Industry standard fiber optic SMA connectors provide for rugged and consistently repeatable operations.

Specifications of DHM-T/R

Wavelength:	660 nm
Fiber:	PMMA/ Step Index/Multimode
Connector:	SMA
Cable Length:	1 to 10 metres
Optical Power:	80 uw (Peak)
Power Supply	5Vdc
Vin/Vout:	TTL Compatible (0-5V)
Speed:	dc to 5 Mbps (min)



Applications:

The DHM modules require external 5Vdc power supply, digital signal generator and a PMMA patch-cord terminated with SMA connectors. On the transmitter side, there are no external settings. The LED current when on is approximately 50 ma. When off, it is 0ma. On the receiver side, V_{th} (diagram) sets the threshold detection level for the internal comparator. Using this the rise time & fall time distortions may be suitably set. R_{in} sets receiver gain and bandwidth. By adjusting R_{in} to around 2500 ohms and also suitably trimming the V_{th}, one can achieve good rise and fall times. Please note that the V_{in} is TTL signal and V_{out} is TTL compatible.

Telenet Systems employ these devices in TNS20ED, to (1) design and evaluate digital optical links and (2) optical communication encoding techniques.

Ordering Code

Micromodule DHM-R/HS Micromodule DHM-T/660