# High Performance Analog Interface Products
## High Speed Interface - HSI

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# Optical Receivers

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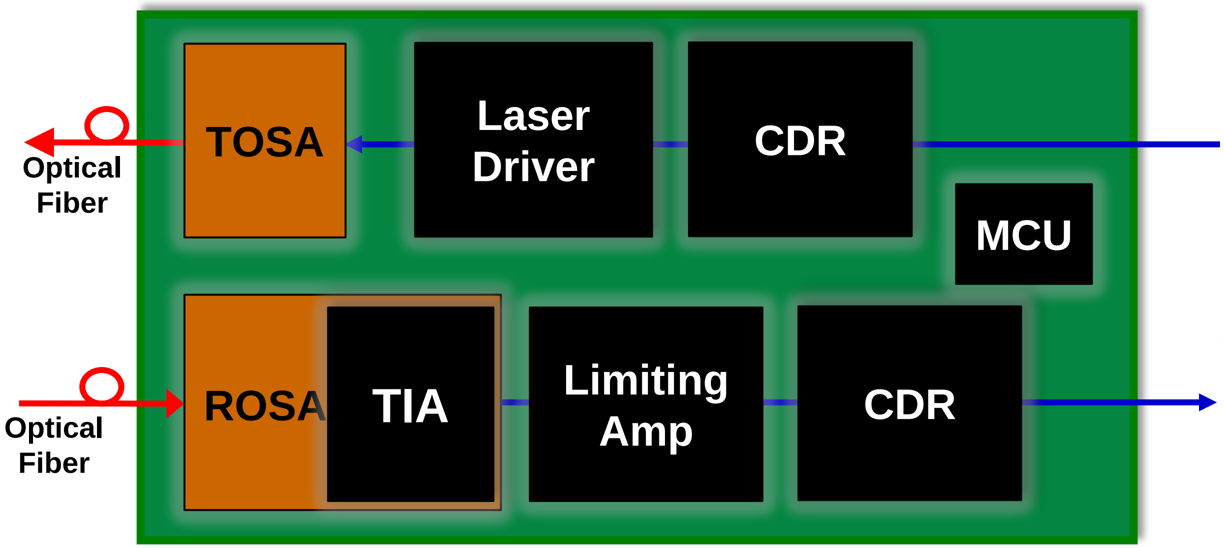
# Basic 10G Module Block Diagrams

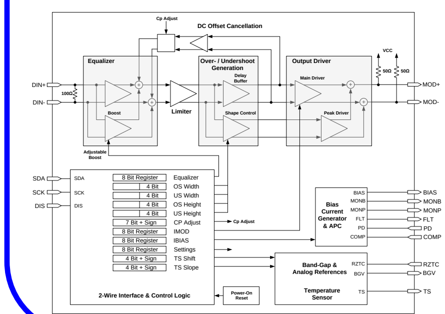



**10Gbps**
CDRs are required for XFP
CDRs are optional for SFP+

# PMD ICs for an SFP+ Transceiver

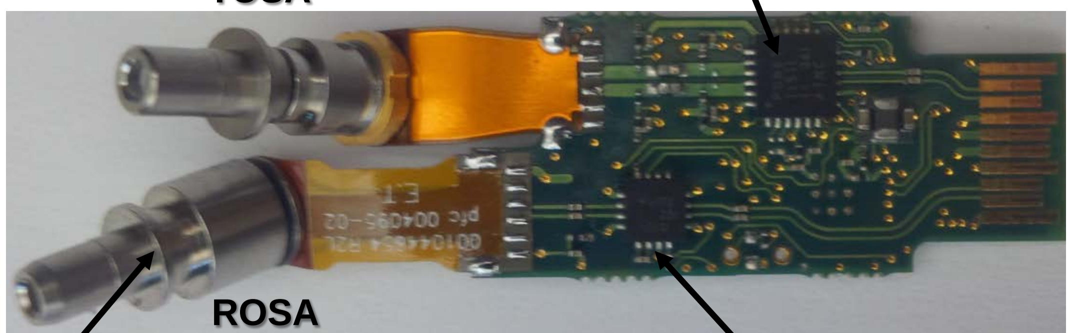
**Typical SFP or SFP+ Transceiver**

## *Laser Driver*



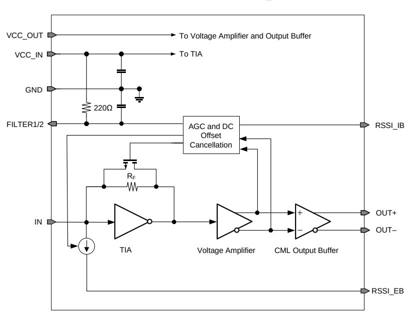
**Function**: Provide bias and modulation currents for VCSEL, FP or DFB lasers

**TOSA**



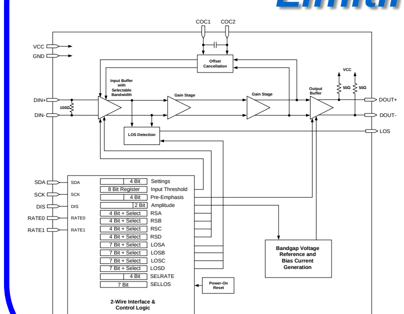
**ROSA**

## *Transimpedance Amplifier (TIA)*




**Function**: Convert current from photodiode into a differential voltage

## *Limiting Amplifier*

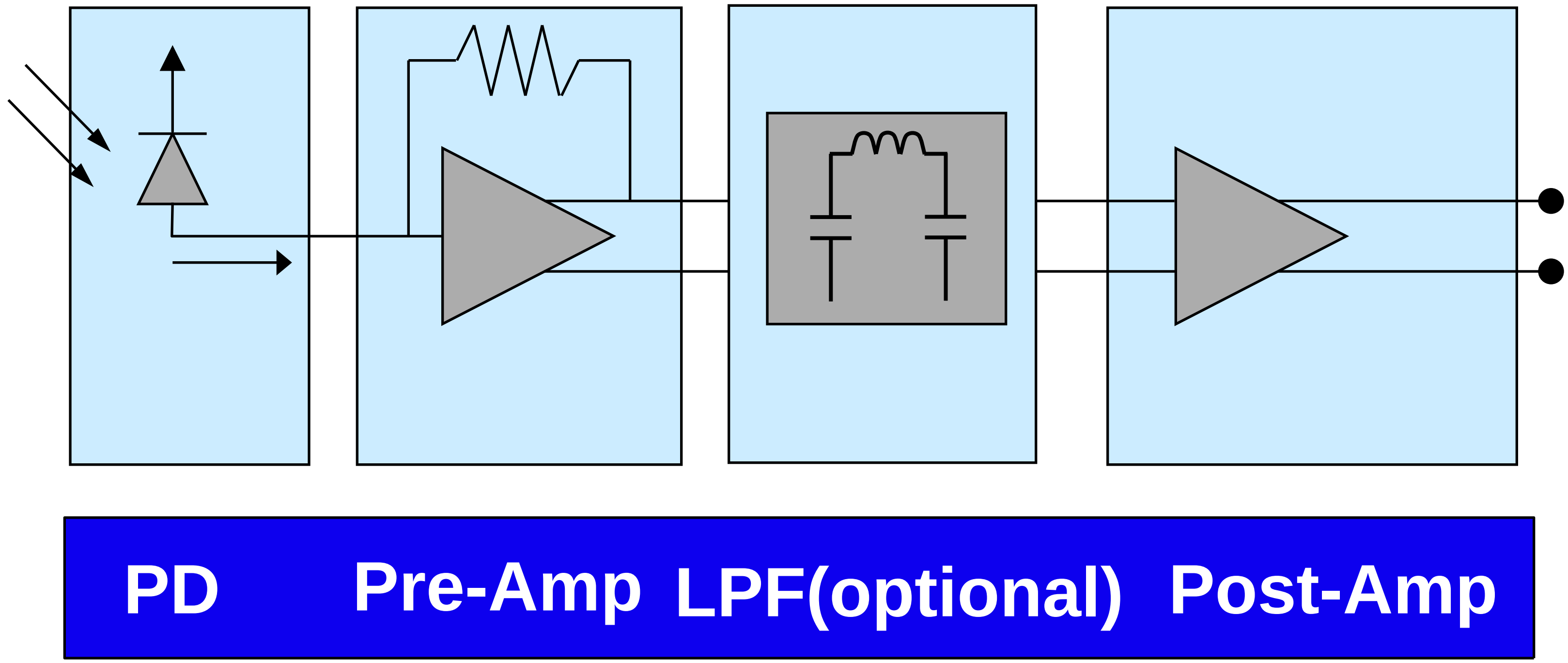


**Function**: Amplify voltage from TIA and maintain constant output level

**High Speed Interface**

Texas Instruments

# Typical Optical Receiver





The basic optical receiver consists of a photodetector to convert the optical signal into a current, a low-noise preamplifier to convert and amplify the current into a voltage, an optional low pass filter to shape the received pulse or limit the bandwidth and a high-gain postamplifier (limiting amp or AGC amp) to produce a constant output voltage for a given input signal.

# Photodiodes

- Photodiodes used for telecommunications are semiconductor devices that convert the optical signal into an electrical signal (current) through the photoelectric effect.
- 2 types: positive-intrinsic-negative (PIN) and avalanche photodiodes (APD).
- Basic operation is that if the energy of the incident photon exceeds the bandgap energy, an electron-hole pair is generated each time a photon is absorbed by the semiconductor.

# Photodiode Output Current

- Important photodiode parameters for receiver design are diode responsivity, **R**, junction capacitance, $C_d$, and dark current, $i_d$.
- $C_d$ affects the receiver bandwidth.
- $i_d$ affects the receiver sensitivity.

- PIN Output Current

$i_o$ = **R**P

**R** = responsivity

P = incident optical power

- APD Output Current

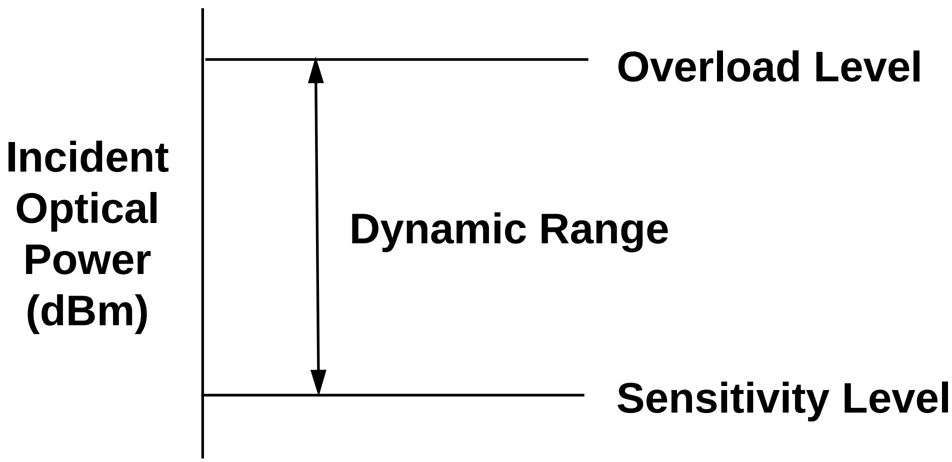
$i_o$ = M**R**P

**R** = responsivity with M=1

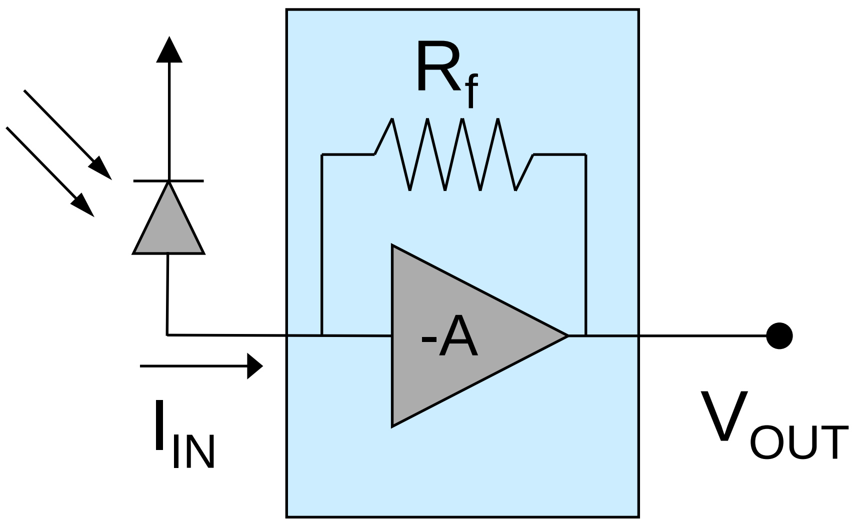
M = average gain

# Receiver Sensitivity & Overload

- **Sensitivity**: the minimum optical input power to the receiver for which it will deliver an acceptable Bit Error Rate (BER).
- **Overload:** the maximum optical input power to the receiver for which it will deliver an acceptable BER. Overload can also be defined by an acceptable limit on jitter.
- **Dynamic Range**: the range of optical input powers for which the receiver will deliver acceptable performance.



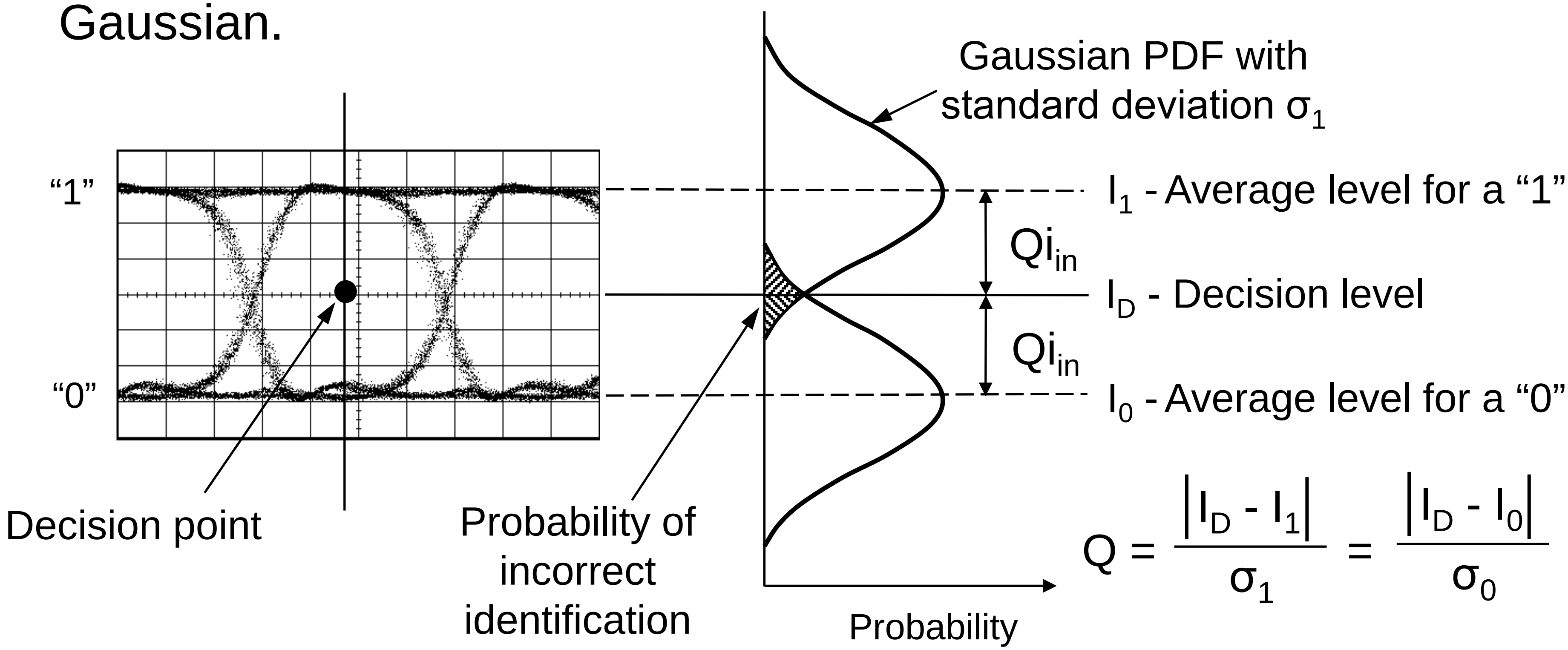
The TIA is the most widely used optical receiver preamplifier because of its wide dynamic range. The value of the feedback resistor influences the the bandwidth, sensitivity and overload.




**Trade-Offs in TIA Design**

- Bandwidth $\alpha$ $1 / R_f$
- Sensitivity $\alpha$ $R_f$
- Overload $\alpha$ $1 / R_f$

- The sensitivity performance criterion for digital receivers is the error probability. The error probability is measured as the Bit Error Rate (BER), defined as the ratio of bits incorrectly identified to the total number of bits transmitted.
- The error probability is statistical in nature and characterized by a probability density function (PDF) most often assumed to be Gaussian.




$$Q = \frac{|I_D - I_1|}{\sigma_1} = \frac{|I_D - I_0|}{\sigma_0}$$

# Receiver Sensitivity with a PIN Photodiode

- The average optical power ($P_{ave}$) required to achieve an error rate defined by the parameter Q is given by

$$P_{ave} = \frac{Q * i_{in}}{\mathbf{R}}$$

| BER | Q |
|---|---|
| 10-9 | 6.0 |
| 10-10 | 6.4 |
| 10-11 | 6.7 |
| 10-12 | 7.0 |

**Where**

Q = Required SNR for a desired BER

$i_{in}$ = Input referred rms noise

**R** = Photodiode responsivity (A/W)

- Taking the transmitter extinction ratio into account, the sensitivity (η) of a PIN-TIA receiver is

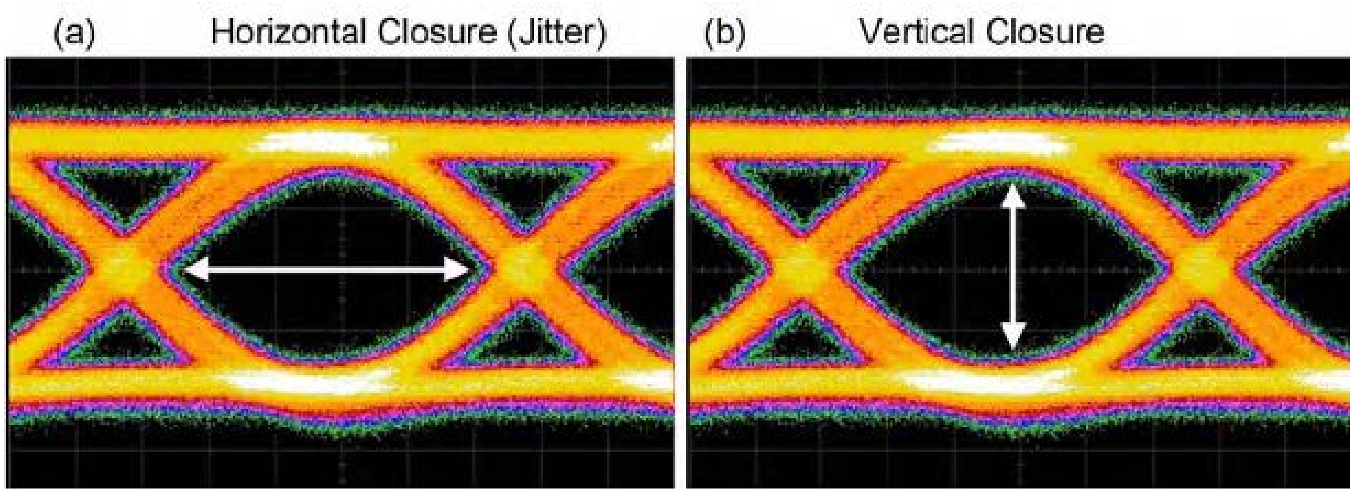
$$\eta\ (\text{dBm}) = 10\log_{10}[1000 * P_{ave} * (ER+1)/(ER-1)]$$

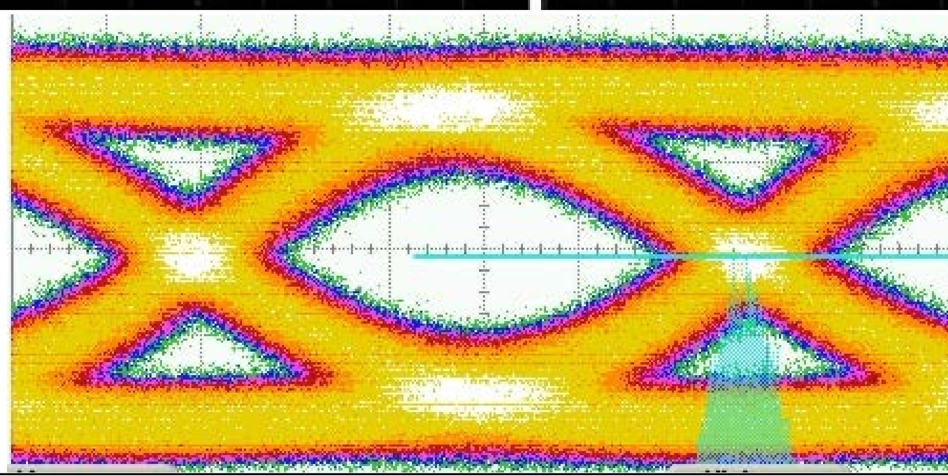
**Where**

ER = transmitter extinction ratio = ratio of the power transmitted during a “1” to the power transmitted during a “0”

# Stressed Receiver Sensitivity (SRS)

- A stressed transmitter test signal is created that includes vertical and horizontal eye closure.
- The particular optical standard (Fibre Channel or Ethernet) typically describes how the stress is created and how much vertical and horizontal eye closure is required.
- The receiver is then tested with this signal to ensure that it meets the specified BER.

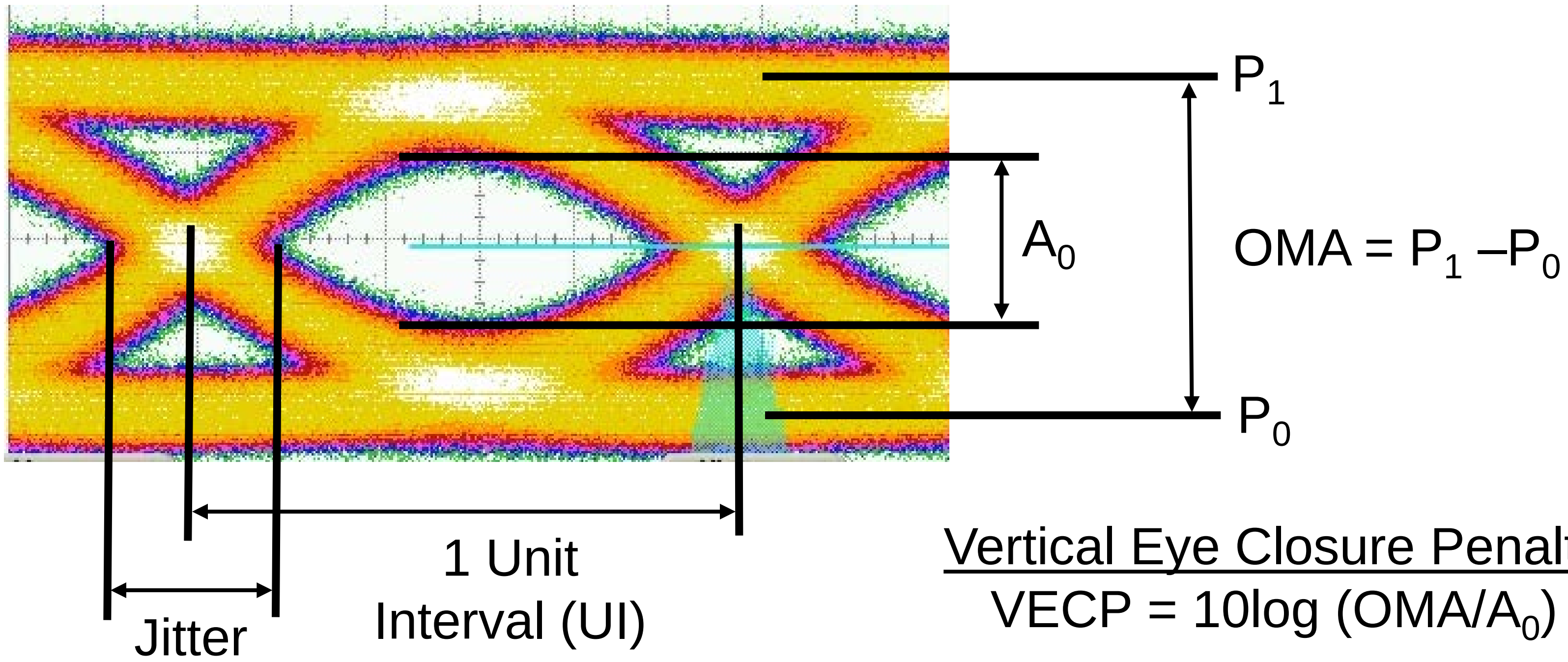


**Example of a stressed transmitter eye for 10GbE with vertical and horizontal closure**

# Stressed Receiver Sensitivity (SRS)

The requirements for the 10GbE stressed transmitter signal are shown below.



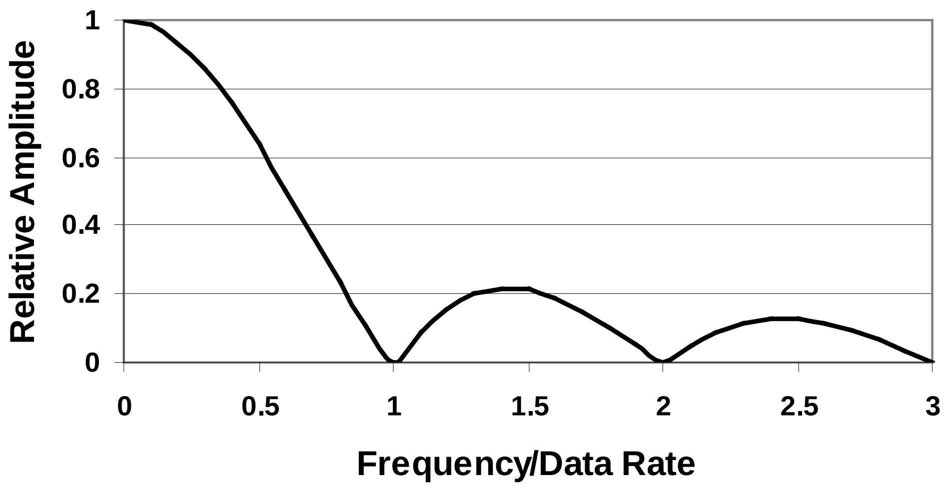

Vertical Eye Closure Penalty

VECP = 10log (OMA/$A_0$)

| 10GbE Requirements | Wavelength | | |
|---|---|---|---|
| | 850nm | 1310nm | 1550nm |
| VECP (dB) | 3.5 | 2.2 | 2.7 |
| Jitter (UI pk-pk) | 0.3 | 0.3 | 0.3 |
| SRS (dBm) | -7.5 | -10.3 | -11.3 |

# Receiver Bandwidth

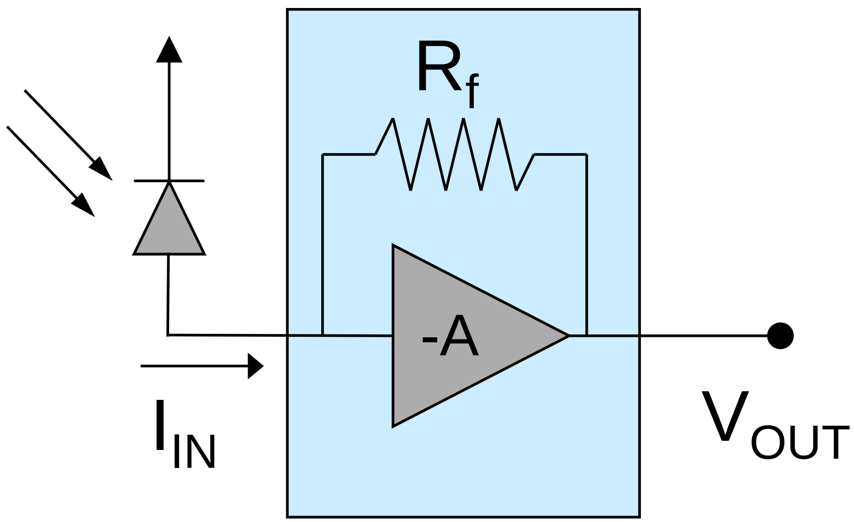
- A pseudorandom NRZ data stream has a frequency spectrum that is a sin(x)/x function.
- For the data to be faithfully transmitted, the data link needs to transmit the portion of the spectrum that contains most of the energy with minimal distortion. If the data link has non-flat frequency response in this critical region, then ISI will result.




**Frequency Spectrum of a Pseudorandom NRZ Data stream**

- 93.6% of the power is accumulated at 75% of the data rate.
- The receiver should cause minimal distortion and, as a rule of thumb, the BW should be 75% of the data rate.
- Increasing the bandwidth too much will result in lower SNR because the noise power increases linearly with the BW but the signal power does not.

# Bandwidth of a TIA




$$B = \frac{A+1}{2\pi R_f C_T}$$

**Where**

A = Open Loop Gain

$R_f$ = Feedback Resistor

$C_T = C_d + C_{in}$

$C_d$ = photodiode capacitance

$C_{in}$ = amplifier input capacitance

- Larger area photodetectors have more capacitance and will decrease the bandwidth of the TIA.

# Receiver Packaging

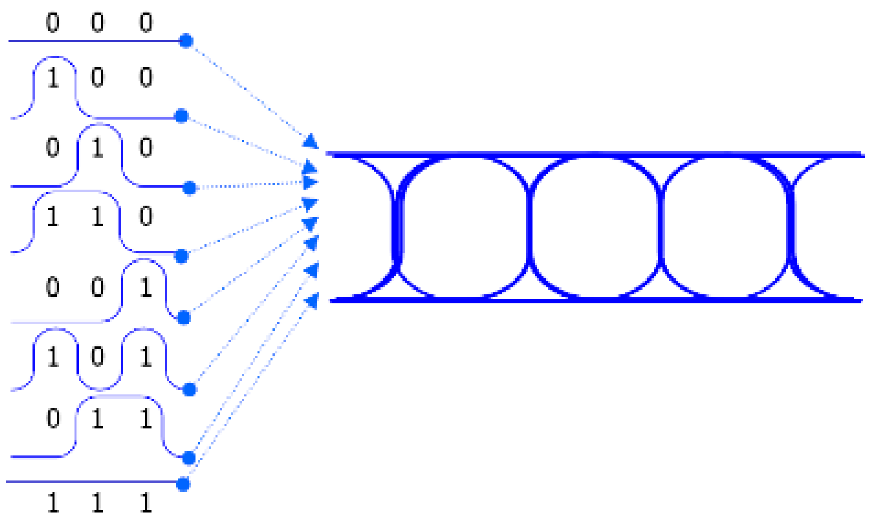
The TO can is the most commonly used package for PIN-TIA photo-receivers up to data rates of 10Gbps.

Benefits of the TO can include:

- Low cost
- Easy to align into a connector (ROSA).
- Hermetic
- Available with flat window or ball lens.

# The Eye Diagram: What is it?

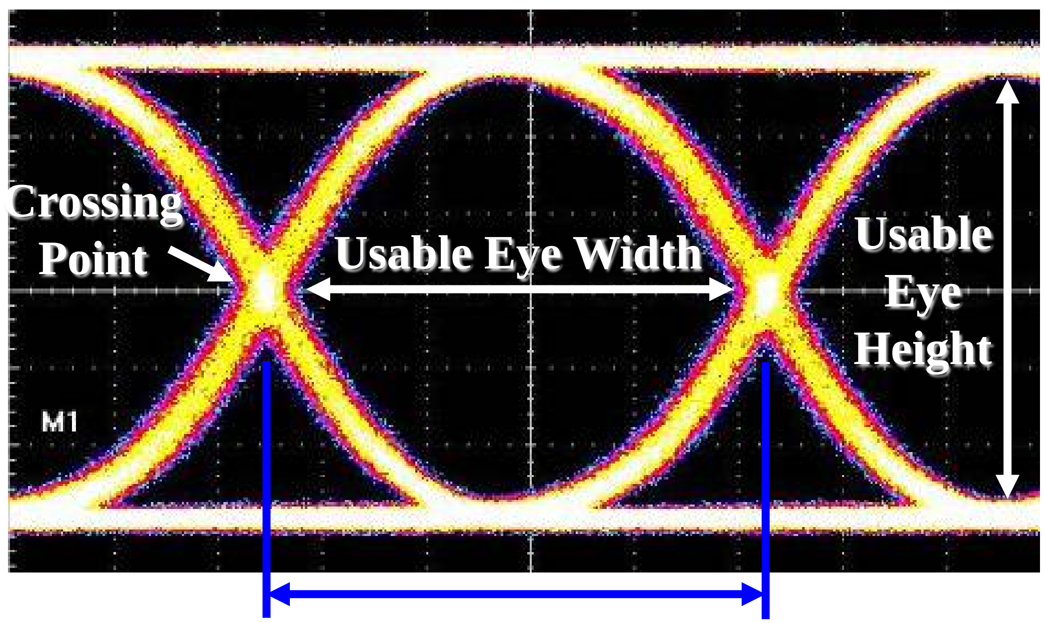
- The eye diagram is a powerful tool for analyzing digital communications links. It provides a quick and intuitive method to asses the quality of a digital signal and offers insight into the nature of possible imperfections.
- The eye diagram is an oscilloscope display of a digital signal that is triggered at the clock rate or a divided clock rate. It contains every possible bit sequence from simple 101's and 010's to isolated ones (or zeros) after long runs of consecutive zeros (or ones).




**Overlaying of Bit Sequences to Form the Eye Diagram**

# The Eye Diagram: What is it?

- Most fiber communications systems at data rates of 10Gbps and below use non-return to zero (NRZ) encoding where the bit period and maximum pulse width are the same. A logical “1” corresponds to the transmission of an optical pulse and a logical “0” corresponds to the omission of an optical pulse.
- High speed communication systems are always bandwidth limited which reduces the harmonic energy relative to the fundamental frequency and slows down the rise and fall times. This is why there is not a sharp transition between a 0 and 1.




**Eye Diagram of a Bandwidth Limited NRZ Signal**

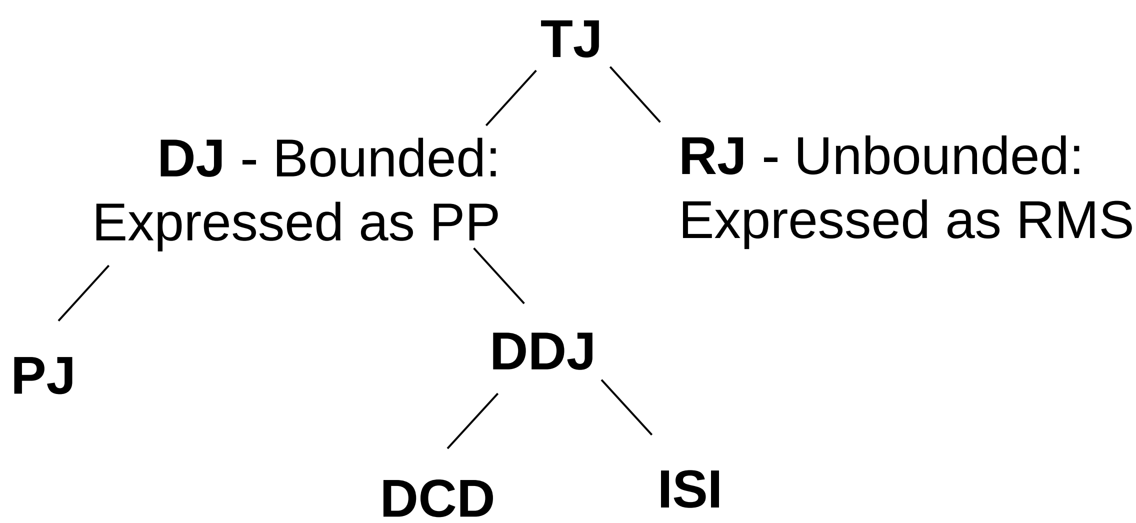
# The Eye Diagram: Jitter

- Jitter is a very important parameter because along with signal-to noise ratio (SNR), it will limit the distance a signal can travel. The study and sources of jitter can be a very complex.
- Simply**, Jitter** is the mis-positioning of the significant edges in a sequence of data bits from their ideal positions. **Total jitter** (TJ) is the sum of all random (RJ) and deterministic (DJ) components and is a peak-to-peak value.
- **RJ** is unpredictable and has a Gaussian probability density function so by definition it is unbounded. It is typically measured as an rms value and caused by electronic (thermal) or optical noise in the system. Random jitter will increase with increasing system bandwidth and decreasing received optical signal.
- **DJ** is predictable and it has defined limits (it is bounded). It is typically measured as a peak- to-peak value. DJ is made up of periodic jitter (PJ) and data dependent jitter (DDJ). DDJ can be subdivided into duty cycle distortion (DCD) and intersymbol interference (ISI).
- **Periodic jitter**, also called sinusoidal jitter, has a signature that repeats at a fixed frequency. For example, it could be the result of unwanted modulation from power supplies or electromagnetic interference (EMI). PJ is typically not a dominant source of jitter in optical transceivers but it is widely used in testing.

# The Eye Diagram: Jitter

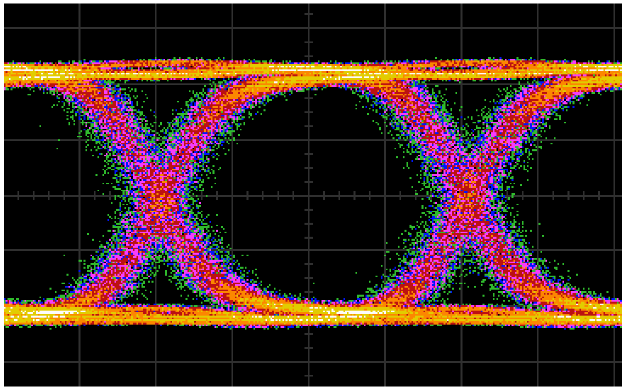
- **DCD**, also called pulse width distortion (PWD), is the difference in pulse width of a one compared to the pulse width of a zero. This causes an eye diagram with the crossings offset up or down from the midpoint. The most common cause of DCD is voltage offsets in differential amplifiers and asymmetrical rise and fall times.
- **ISI** is the pulse spreading that occurs when the transmission channel propagates the frequency components of data at different rates. When the system bandwidth is greater than that required by the pulse, the pulse spreading is small. When the system bandwidth is too small, then pulses are spread into adjacent bit times. Quickly changing bit patterns (1010…) require more power at high frequencies compared to slowly changing patterns (e.g.. 1111100000) which require more power at lower frequencies. Therefore, insufficient bandwidth or low frequency cutoff will cause ISI.

**Components of Jitter**

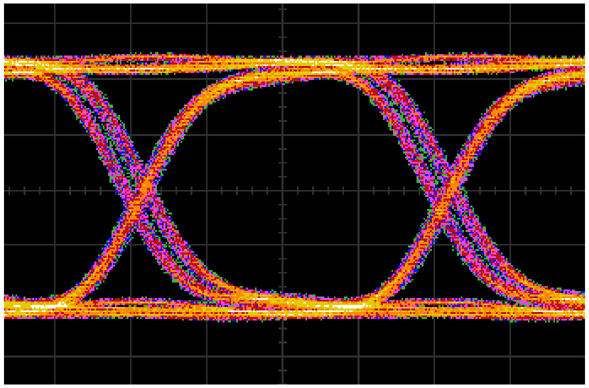


# The Eye Diagram: Identifying Jitter

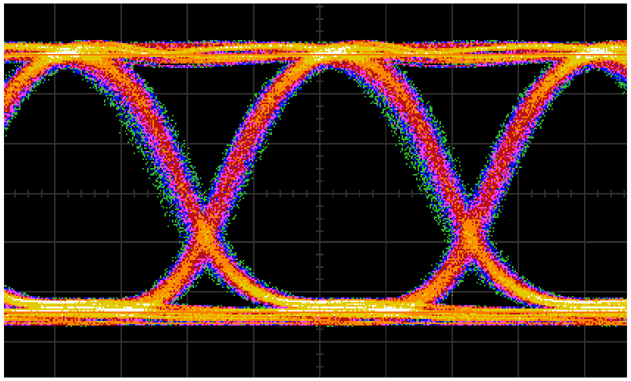
- Some key features of the eye diagram are rise and fall times, jitter at the crossing points, overshoot and the open area in the eye. Ideally, the crossing points should be symmetrical and centered and the open area should be as large as possible.
- The eye diagram can show many impairments such as random jitter, deterministic jitter, bandwidth limitation or reflections.



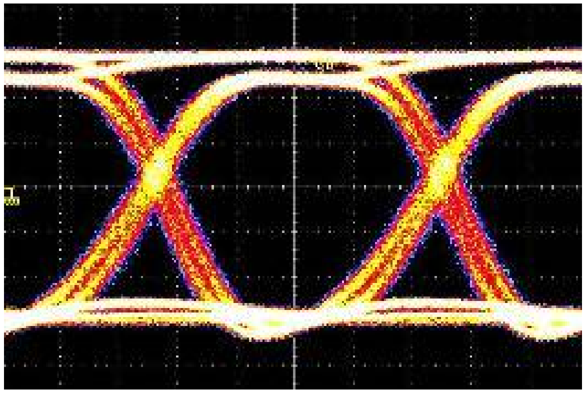
**Random Jitter**



**Deterministic Jitter**



**Duty Cycle Distortion**



**DJ & DCD**