

Design Note:

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# **Accurate Loss-of-Signal Detection in 10Gbps Optical Receivers using the MAX3991**

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MAXIM High-Frequency/Fiber Communications Group



*Maxim Integrated Products*



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## 1 Introduction

A loss-of-signal (LOS) monitor is required for system digital diagnostics in 10Gbps XFP optical modules. Monitoring for insufficient optical power detects system faults that will result in excessive bit errors. The MAX3991 clock and data recovery with limiting amplifier IC is optimized for the 10Gbps receiver in XFP modules. The device features an accurate LOS detector that monitors the output signal amplitude from the trans-impedance amplifier (TIA). This output signal amplitude is proportional to the receiver peak-to-peak optical power (known as optical modulation amplitude, or OMA), within the TIA linear range. The module designer can program the LOS assert threshold for a given bit-error-rate (BER).

This application note outlines the characteristics of the MAX3991 LOS detector, and describes how to set the optical assert power in a 10Gbps receiver for a specified BER. A method for increasing LOS hysteresis for operation at low power levels is also described.

## 2 10Gbps Receiver

Figure 1 shows a typical 10Gbps optical receiver in an XFP module. The 10Gbps transimpedance amplifier converts the photo current into a voltage. The MAX3991 restores the signal amplitude and timing.

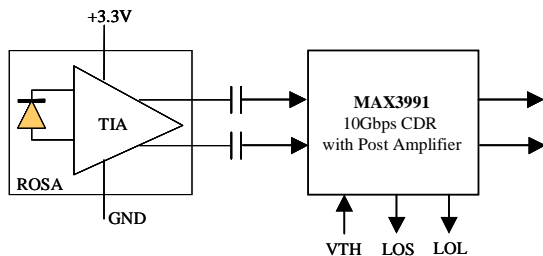


Figure 1. 10Gbps XFP Optical Receiver

Signal-to-noise ratio and BER are directly related to each other in noise-limited optical receivers. For an input noise limited receiver, the BER is a function of the received signal power. Therefore, an accurate solution for monitoring BER degradation is to detect the signal amplitude at the input of the limiting amplifier, which is proportional to the OMA for small optical power levels. This kind of OMA detection is critical when the optical transmitter has no modulation control and therefore can not maintain high extinction ratio over temperature and aging.

## 3 LOS Detector Characteristics

The MAX3991 LOS detector is implemented as a root-mean-square power detector. The simplified LOS detection scheme is shown in Figure 2.

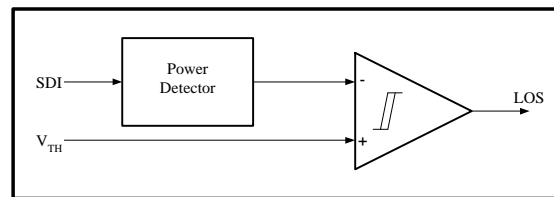


Figure 2. MAX3991 LOS Detection Scheme

With Maxim proprietary design, the MAX3991 LOS detector achieves high accuracy and high stability with minimum power consumption. For a fixed control voltage  $V_{TH}$ , the assert accuracy is better than  $\pm 1.5\text{dB}$  over process, temperature and supply, and the assert stability over temperature and supply is better than  $\pm 10\%$ . High accuracy and stability allow the module designer to set the optical assert threshold without recalibration for environmental variations.

The MAX3991 assert voltage range is from 15mVp-p to 50mVp-p. A control voltage that is 10 times the desired assert level is applied to the

V<sub>TH</sub> pin to set the assert level. Figure 3 shows the characteristics of the LOS assert (V<sub>assert</sub>) and de-assert (V<sub>de-assert</sub>) voltage versus control voltage V<sub>TH</sub>.

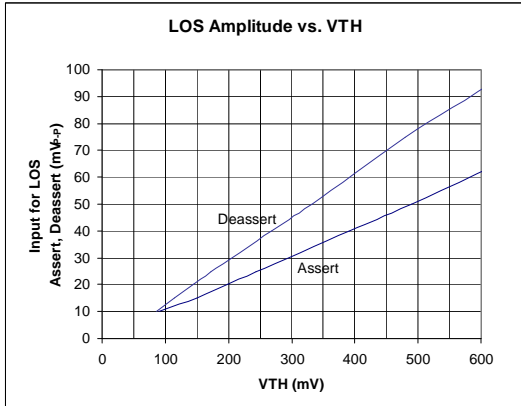


Figure 3. LOS Assert versus Control Voltage

The threshold V<sub>TH</sub> determines the expected value of the detected power for LOS to assert. Due to intrinsic noise of the power detector, the output of the power detector may vary from its mean value. This variation has a Gaussian distribution and may affect the repeatability of the LOS assert level. For the MAX3991, the measured standard deviation,  $\sigma$ , of the Gaussian distributed power detector output is approximately 0.4mVrms. For example, if the expected mean assert voltage is 20mVp-p, then the device will assert between 18.8mVp-p and 21.2mVp-p ( $\pm 3\sigma$ ) 99.8% of the time.

If not used, the LOS power detector can be disabled by connecting the V<sub>TH</sub> pin to VCC, which forces the LOS output low. This will reduce the power consumption by about 15mW.

#### 4 Increasing LOS Hysteresis with External Resistors

Because of its digital implementation, the MAX3991 has a tightly controlled built-in hysteresis, from 3.5dB minimum to 3.9dB maximum. This translates to an optical hysteresis of 1.75dB to 1.95dB. The hysteresis is defined as:

$$Hysteresis = 20 \times \log\left(\frac{V_{de-assert}}{V_{assert}}\right) \text{ (dB)} \quad (1)$$

Figure 3 shows the nominal hysteresis for assert and de-assert. Considering the noise in the power detector, if the desired input assert voltage is close to or below 15mVp-p, occasional chatter may occur. To avoid LOS chattering at small input, the hysteresis can be increased using external resistors as shown in Figure 4.

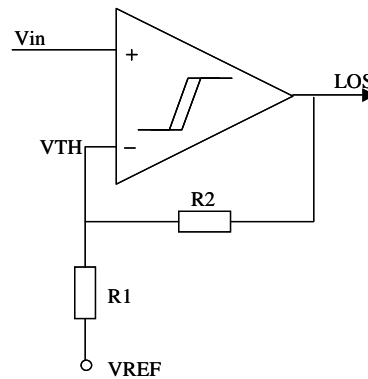


Figure 4: Increasing LOS Hysteresis with External Resistors

Assuming V<sub>REF</sub> (V) is the external voltage applied, the threshold control voltage V<sub>TH</sub> is given by:

$$V_{TH(Assert)} = V_{REF} \cdot \frac{R2}{R1 + R2} + 0.2 \cdot \frac{R1}{R1 + R2} \quad (2)$$

$$V_{TH(de-assert)} = V_{REF} \cdot \frac{R2}{R1 + R2} + 3.0 \cdot \frac{R1}{R1 + R2} \quad (3)$$

The added hysteresis will be:

$$Hysteresis_{Added} = 20 \log\left(\frac{R2 \times V_{REF} + 3.0 \times R1}{R2 \times V_{REF} + 0.2 \times R1}\right) \text{ (dB)} \quad (4)$$

The total hysteresis is the sum (in dB) of the internal hysteresis and the added hysteresis given by equation (4).

The resistor R2 is selected to prevent loading of the LOS pin. A value of greater than 40k $\Omega$  is suggested. The resistor R1 is selected to increase the hysteresis to the desired level. For example, if R2=44k $\Omega$ , R1=1.5k $\Omega$ , V<sub>REF</sub>=0.3V, the

additional hysteresis will be 2.4dB, and the total hysteresis is about 6dB.

## 5 Combining LOS and LOL Outputs

The received optical signal must have sufficient power and the correct data rate for error free reception. The LOS detector monitors the signal power only. For a better qualification of the received signal, it is also necessary to monitor the PLL loss-of-lock (LOL) status. The LOL detector compares the frequency difference

between the recovered clock and the reference clock. In the absence of the input signal, the time it takes to indicate a PLL lock failure will be dependent on the internal VCO drift rate, and is difficult to predict. To prevent the uncertainty on LOL assert time when the input signal has no transitions, the user can combine the LOS and LOL outputs externally, as indicated in table I.

Table I. Combined LOL and LOS Functionality

Status	LOL	LOS	LOL+LOS
Input signal power above threshold, and PLL in lock	0	0	0
Input signal power above threshold, and PLL out of lock	1	0	1
Input signal power below threshold, PLL in lock	0	1	1
Input signal has no transition, PLL will be eventually out of lock.	0→1	1	1

## 6 Setting the MAX3991 LOS to a given BER

The following example shows how to set the optical assert power of the MAX3991 LOS indicator, assuming the following receiver parameters:

1. Optical Sensitivity:  $P_{ave} = -18\text{dBm}$  at  $BER \leq 10^{-12}$
2. Extinction Ratio:  $r_e = 6.6$
3. PIN diode responsivity:  $0.85\text{A/W}$
4. TIA trans-impedance gain:  $3.0\text{k}\Omega$

The relationship between the average optical power and OMA is given in equation (5) below.

$$P_{ave} \text{ (dBm)} = 10 \log \left( \frac{\text{OMA}}{2} \times \frac{r_e + 1}{r_e - 1} \times 1000 \right) \quad (5)$$

Table II shows the relationship between BER and signal levels at various points in the receiver, based on the assumption that the receiver sensitivity is determined by the receiver input referred noise.

For example, if we want the LOS to assert at  $BER = 10^{-3}$ , the MAX3991 assert threshold should be set to  $26\text{mVp-p}$ . This corresponds to an optical average assert power of  $-21.6\text{dBm}$  and de-assert power of  $-19.85\text{dBm}$ , with an optical hysteresis of  $1.75\text{dB}$ , as indicated in Figure 5.

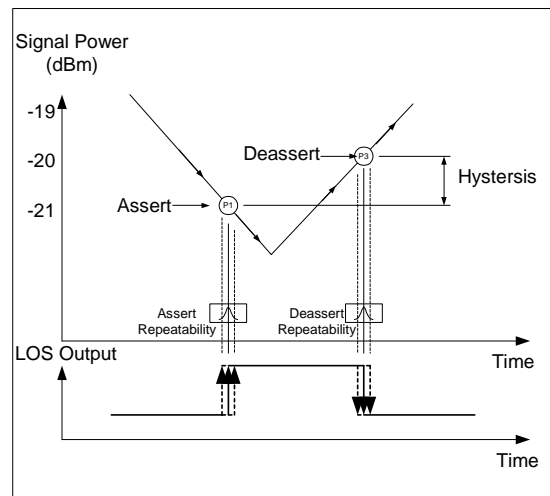


Figure 5. Loss of Signal Function

Table II. Typical Receiver Bit Error Rate and Signal Levels

BER	$S_{p-p}/N_{rms}$	Pave (dBm)	OMA ( $\mu W_{p-p}$ )	TIA input ( $\mu A_{p-p}$ )	MAX3991 input (mVpp)
$10^{-3}$	6.18	-21.6	10.3	8.7	26
$10^{-4}$	7.438	-20.8	12.4	10.5	31
$10^{-6}$	9.507	-19.7	15.8	13.4	40
$10^{-8}$	11.224	-19.0	18.6	15.8	48
$10^{-9}$	11.996	-18.7	19.9	16.9	51
$10^{-10}$	12.7	-18.4	21.1	17.9	54
$10^{-12}$	14.069	-18	23.3	19.9	59

## 7. Conclusion

The MAX3991 provides a solution that accurately detects low OMA in 10Gbps receivers. The user can set the LOS assert indicator that corresponds to a certain BER. Additional hysteresis can be added for reliable LOS detection for small input signals.