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dWhite Paper

Clarifying Optical Parameters, Power Budgets, and Fiber Plant Requirements for 10GBASE-E and 10GBASE-L

GLOSSARY

APC	Angled Polished Connectors
Er	Extinction Ratio
OMA	Optical Modulation Amplitude
ORL	Optical Return Loss
OTDR	Optical Time Domain Reflectometer
CD	Chromatic Dispersion
PC	Polished Connectors
UPC	Ultra Polished Connectors

ABSTRACT

The 10 Gigabit Ethernet optical interfaces defined by IEEE 802.3 have a relatively complex set of requirements and parameters that ensure interoperability and allow for cost-effective implementations. Some of the optical parameters and procedures defined by the IEEE 802.3ae-2002 document depart from the traditional Gigabit Ethernet and SONET/SDH. Implementers need to understand which are the necessary criteria for compliance to correctly use legacy handheld equipment to qualify and configure a 10 Gigabit Ethernet optical link.

This paper clarifies the IEEE 802.3ae-2002 optical requirements and presents engineering rules to guide the successful deployment of IEEE 802.3ae-2002 compatible 10GBASE-L and 10GBASE-E optical interfaces across Cisco® switches and routers.

There are two aspects to deploying these links: the fiber plant and the optical transceivers. Accordingly, the first section of this paper deals with the underlying fiber plant. It presents the set of criteria for qualifying the fiber infrastructure. When satisfied, these criteria allow for plug-and-play of the 10 Gigabit Ethernet interfaces.

The second section looks at the optical transceivers, starting with the theoretical background for the 10 Gigabit Ethernet optical parameters defined in IEEE 802.3ae-2002. We then look at the two interfaces of concern, namely 10GBASE-E and 10GBASE-L, and present their specific optical parameters highlighting the mandatory and informative requirements. This section also presents and explains pass/fail criteria to accept and troubleshoot 10 Gigabit Ethernet optical transceivers.

The Appendix presents the theory in more detail by showing some numerical examples and figures.

GUIDELINES TO VALIDATING A 10 GIGABIT ETHERNET FIBER PLANT

The intent of this section is to minimize the amount of optical design required to set up an IEEE 802.3ae-2002 10 Gigabit Ethernet link. In general, as long as the fiber plant has certain well-known characteristics, from an operational perspective we can treat 10GBASE-E and 10GBASE-L as "plug and play" devices with minimal link engineering design required.

The following table reports all you need to know to successfully install and maintain a 10 Gigabit Ethernet single-mode fiber plant.

Table 1. Fiber Plant Testing Criteria for 10GBASE-E and 10GBASE-L

Criterion	10GBASE-E	10GBASE-L	Validation Method
Fiber	ITU-T G.652	ITU-T G.652	Check with fiber vendor
Patch Cords and Fiber Cable Connectors Connecting to the Transceiver	PC/UPC	PC/UPC	Visual inspection: • **Green:** APC—NOT OK* • **Blue:** UPC—OK • **Black:** PC—OK
Channel Insertion Loss (min—max)**	5–11 dB	0–6 dB	Modern optical time domain reflectometers (OTDRs) are capable of performing all these measurements in an automated fashion.
Distance	40 km	10 km	
Total Optical Return Loss* (ORL max)**	• 21 dB	• 21 dB	
Maximum Reflectance (for each connector/splice)	• –26 dB	• –26 dB	

* Using APC connectors can severely degrade the performance.

** Channel insertion loss computed as total sum of connectors + fiber + splice(s) attenuation.

*** ORL includes both connectors and fiber.

In most cases, the above information should be sufficient to qualify your fiber plant to run a 10GBASE-E or 10GBASE-L link. A modern OTDR can be used to validate the fiber plant parameters.

The chromatic dispersion requirements of 10GBASE-ER allow for up to 40 km of any G.652 compliant fiber.

IEEE 10 GIGABIT ETHERNET OPTICAL PARAMETERS: CRITERIA FOR ACCEPTANCE TESTING

For a basic pass/fail testing of optical transceivers, end users have traditionally validated the transmit power and receiver sensitivity against the minimum transmit power and maximum receiver sensitivity reported in the data sheet. For example, an end user of a XENPAK-10GB-ER would look up a minimum transmit power of –4.7 dBm and receiver sensitivity of –15.8 dBm. Moreover, it is common practice to take the difference of these two numbers to compute the power budget available and compare it against either the budget reported by the standard or the budget available to a particular fiber plant.

This rule-of-thumb methodology has worked well for Ethernet interfaces that operate at lower signaling speed. For 10 Gigabit Ethernet interfaces, such an approach will not work. The underlying reason, to be detailed in this section, is that the IEEE 802.3ae-2002 standard affords implementers an extra degree of flexibility in building the optical transmitters. This allows optical manufacturers to build more cost-effective implementations that are capable of robust 10 Gigabit data communications. Nevertheless, this violates some of the underlying basic assumptions that have allowed us to simply just look at the transmit power and receiver sensitivity.

This section first reviews the underlying theory at play and compares what the legacy and new parameters are measuring. Then it covers the specific numerical values that 10GBASE-E or 10GBASE-L take on. The Appendix presents more numerical examples and details.

OMA, TRANSMIT POWER, AND EXTINCTION RATIO

The transmitter side of the optical specification for Gigabit Ethernet, typically found under the transmit table of the PMD to MDI specification in 802.3 documents, reports two mandatory parameters in the 1000BASE-LX transmit table:

- Average launch power (min)
- Extinction ratio (min)

The extinction ratio (Er) is defined as the ratio of the power to transmit a “1” symbol to the power to transmit a “0” signal. Together, these values are used to describe the *content strength* of the signal that the transmitter puts on the wire. It is necessary but not sufficient to look at the average launch power—how strong the light is. We need to also consider the difference between the two digital levels (zero and one) that the transmitter puts out to properly assess the signal-to-noise ratio at the other end of the link.

The argument above presents an interesting question. Can we trade off launch power for extinction ratio, and vice versa, while maintaining the quality of the link? The answer is yes.

This answer makes intuitive sense as one can see how at higher extinction ratios less power would be needed to overcome the impediments in the channel while maintaining the same quality of the link. To that effect IEEE 802.3ae-2002 introduces a new mandatory measurement called OMA (optical modulation amplitude), which is the difference between the optical power in the ones and the optical power in the zeros. It is related to the average power Pout and the extinction ratio Er and summarizes them into one measurement:

$$OMA = 2P_{out}(Er – 1)/(Er + 1)$$

where P_{out} is the optical power in milliwatts and Er is the extinction ratio reported as a pure ratio.

Note the following two points about the three quantities:

- By definition, fixing two of the quantities automatically generates the third quantity as they are related through a linear mathematical equation, thus one only needs to measure two quantities at any one point.
- To satisfy a *minimum* OMA, a range of power and extinction ratio numbers can be found.

The IEEE 802.3ae-2002 standard requires a minimum OMA and minimum Er but does not mandate a minimum average transmit power, because that number depends on the actual value of the Er that the manufacturer produces. Put differently, the standard clearly states that the average transmit power value is an *informative* quantity, and a value within spec does not necessarily guarantee that the optic is standard-compliant. Instead, the standard defines the lower possible bound of the range that *could* satisfy the OMA, given the proper Er. For example, in the case of 10GBASE-E a value of transmit power below –4.7 dBm (min Tx power) cannot be compliant; however, a value above –4.7 dBm does not ensure compliance either.

So why do this? Again, the answer is to give flexibility to the designers of the modules. So why even mention minimum power in the data sheet? It happens that this is the only characteristic of the optical signals that is measurable with standard legacy field equipment. End users should not rely solely on the power number as a pass/fail acceptance criteria. For that a digital oscilloscope to measure Er and calculate OMA is mandatory.

Similarly, the average received power is considered an informative quantity, and receiver sensitivity is specified as an OMA number in the Standard.

So what actually guarantees compliance with the standard? It is time to take a deeper look at the IEEE strategy to define optical parameters.

10GBASE-L AND 10GBASE-E PARAMETERS

Table 2 summarizes the requirements for 10GBASE-L and 10GBASE-E. In the language of the standard, “normative” is equivalent to mandatory and “informative” is for informational consumption only.

Table 2. IEEE OMA and Er Specifications for 10GBASE-L and 10GBASE-E

Parameter	10GBASE-L	10GBASE-E	Parameter Class
Tx OMA Min	–5.2 dBm	–1.7 dBm	Mandatory IEEE requirements
Rx Sensitivity in OMA	–12.6 dBm	–14.1 dBm	
Er	• 3.5 dB	• 3 dB	

Parameter	10GBASE-L	10GBASE-E	Parameter Class
Min Launch Power	–8.2 dBm	–4.7 dBm	Informative IEEE limits
Min Rx Power	–14.4 dBm	–15.7 dBm	

The available power budget in a link can be allocated to channel insertion loss, which in single mode point-to-point links such as these, is determined by the fiber attenuation, and penalties. Note that unlike SONET, penalties of the transmitter are accounted for as well as power penalty. The allocation for penalties is typically calculated by subtracting the channel insertion loss from the available budget. Keep in mind that the link power budget tables presented in the Standard (Table 3) are *informative* and serve only as a guideline to what should be expected. Moreover, keep in mind that these quantities are recorded for a specific example of a link. In practice, the actual attenuation of the fiber plant and the penalties vary, so these numbers should not be taken as a hard and fast rule.

Table 3. IEEE Power Budgets for 10GBASE-L and 10-GBASE-E

Budget Breakdown	10GBASE-L	10GBASE-E
Power Budget	9.2 dB	15 dB
Channel Loss at the Maximum Distance (fiber, connectors, splices)	6 dB	11 dB
Allocation for Penalties	3.2 dB	4 dB

The way that these power budgets and penalties are calculated is outside the scope of this paper; however, the official 10 Gigabit Ethernet link model calculator can be accessed at http://www.ieee802.org/3/ae/public/adhoc/serial_pmd/documents/10GEPBud3_1_16a.xls.

For further information on the link model refer also to: "Review of the 10Gigabit Ethernet Link Model" by David Cunningham & Piers Dawe, http://literature.agilent.com/litweb/pdf/5988-5908EN.pdf

Note that the channel insertion loss numbers match what we presented in the first section on the fiber plant. Also, the power budget numbers are computed at the minimum transmitted OMA.

To summarize, the power budget numbers presented in the IEEE document are informative and only reflect a particular scenario. The IEEE specifies a minimum ER and minimum OMA but does not mandate the power requirement. The actual power budget for a particular link will depend on the actual performance of the transceiver and the losses and dispersion of the fiber plant.

APPENDIX

An Introduction to Extinction Ratio (Er)

Er is defined as the ratio of the power to transmit a "1" symbol to the power to transmit a "0" symbol:

$Er = P_1/P_0$

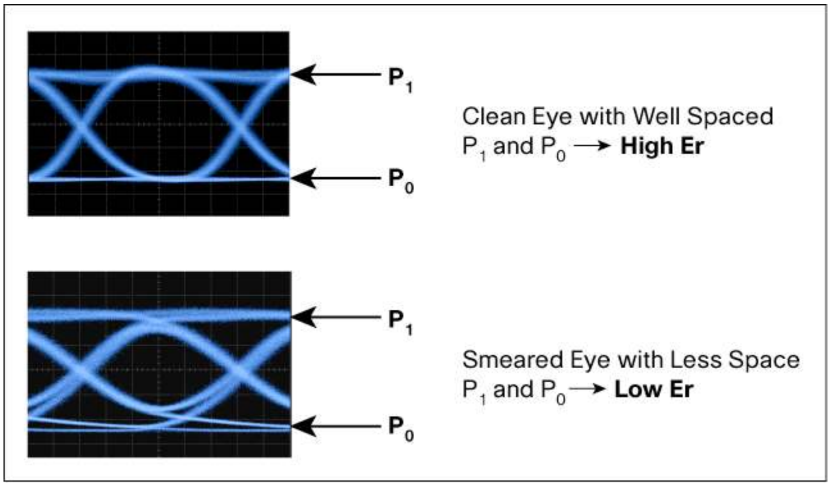
The greater the distance is between P_1 and P_0 the easier it is for the receiver to distinguish a one from a zero. Unfortunately, building transmitters with a high Er is more challenging and costly. In practice, transmitters are always on, even when transmitting zeros, and the higher is P_0 (and the lower is P_1) the easier and less expensive is the design of the transmitter.

By specifying the OMA, IEEE gives manufacturers of modules two degrees of freedom: optical power and extinction ratio. One can satisfy the OMA by trading off P_{out} against Er.

Although OMA may not be a convenient parameter to measure in the field, it is a more accurate representation of the quality of the signal than the P_{out} alone. The whole idea boils down to: "You need to scream louder (higher P_{out}) if you have noise in the room (Er smaller)."

To measure Er a digital oscilloscope is required. Er is part of a variety of eye diagram measurements performed by the oscilloscope (Figure 1).

Figure 1. Typical Oscilloscope Eye Diagram Measurement and P1, P0



For a more detailed treatment of Er and OMA, see: http://pdfserv.maxim-ic.com/en/an/3hfan222.pdf

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