Telcordia Technologies

Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment

A Module of RQGR, FR-796

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GR-468-CORE
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Comments Requested (See Preface)

An SAIC Company

Generic Reliability Assurance Requirements for Optoelectronic Devices Used in Telecommunications Equipment

Prepared by Telcordia Technologies Professional Services

This document replaces GR-468-CORE, Issue 1, December 1998.

This document is a module of *Reliability and Quality Generic Requirements (RQGR)*, FR-796.

Technical contact:

Osman Gebizlioglu
Telcordia
Phone: + 1.732.699.3378
E-mail: ogebizli@telcordia.com

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Telcordia Technologies Customer Service
Piscataway, NJ 08854-4156
1.800.521.2673 (USA and Canada)
+ 1.732.699.5800 (Worldwide)
+ 1.732.336.2559 (FAX)
`http://telecom-info.telcordia.com`

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Preface

The Telcordia Technologies GR Process

Generic Requirements documents (GRs) provide the Telcordia Technologies view of proposed generic criteria for telecommunications equipment, systems, or services, and involve a wide variety of factors, including interoperability, network integrity, the expressed needs of industry members who have paid a fee to participate in the development of specific GRs, and other input.

The Telcordia GR process implements Telecommunications Act of 1996 directives relative to the development of industry-wide generic requirements relating to telecommunications equipment, including integral software and customer premises equipment. Pursuant to that Act, Telcordia invites members of the industry to participate in the development of GRs. Invitations to participate and the participation fees are published monthly in the *Telcordia Digest of Technical Information*, and posted on the Web, at **`http://www.telcordia.com/digest`**.

At the conclusion of the GR development process, Telcordia publishes the GR, which is available for license. The license fee entitles the licensee to receive that issue of the GR (GR-CORE) along with any Issues List Report (GR-ILR) and revisions, if any are released under that GR project. ILRs contain any technical issues that arise during GR development that Telcordia and the other participants would like further industry interaction on. The ILR may present issues for discussion, with or without proposed resolutions, and may describe proposed resolutions that lead to changes to the GR. Significant changes or additional material may be released as a revision to the GR-CORE.

Telcordia may also solicit general industry nonproprietary input regarding such GR material at the time of its publication, or through a special Industry Interaction Notice appearing in the *Telcordia Digest of Technical Information*. While unsolicited comments are welcome, any subsequent work by Telcordia regarding such comments will depend on participation in such GR work. Telcordia will acknowledge receipt of comments and will provide a status to the submitting company.

About GR-468-CORE

Participants in the Development of GR-468-CORE, Issue 2, are:

- Finisar, Furukawa Electric, Intel, iolon, and JDS Uniphase.

Relative Maturity Level

In general, this is a relatively mature technology. However, innovations continue to occur, resulting in improvements such as smaller components, additional functionality, higher system capacities, and lower costs. While these innovations are not expected to necessitate major changes to the criteria, it is likely that at least some of the criteria will need to be adapted to cover the new devices and situations.

In addition, it should be noted that at the time that this document was being generated, it appeared that within the industry much of the “burden of proof” regarding reliability assurance for optoelectronic devices was shifting (or had been shifted) from the equipment manufacturers to the device suppliers. To reflect this trend, many of the criteria that were worded in Issue 1 to be specifically applicable to equipment manufacturers have been revised to apply to the “equipment manufacturer or device supplier” in this issue, and additional revisions to the criteria and/or explanatory text may be made in a future issue. Also, it may be desirable to extend the scope of this GR to replace GR-3013-CORE by specifically covering optoelectronic devices intended for use in “short-life” equipment, and it may be possible to eliminate a number of criteria related to quality control by adding appropriate references to ISO 9000.

GR-468-CORE Plans

As technologies advance and market needs change, this document will be reviewed to determine if a reissue is warranted. If so, the *Telcordia Digest* will announce details concerning the topics that are likely to be addressed and invite the industry to participate in the process.

To Submit Comments

When submitting comments, please include the GR document number, and cite any pertinent section and requirement number. If responding to an ILR, please identify the pertinent Issue ID number. In addition, please provide the name and address of the contact person in your company for further discussion.

Comments are welcome at any time, and should be sent to:

Telcordia — GR-468-CORE
Osman Gebizlioglu
Reliability Assurance for Optoelectronic Devices
One Telcordia Drive, RRC-4D655
Piscataway, NJ 08854-4182

Phone: + 1.732.699.3378
E-Mail: ogebizli@telcordia.com

1 Introduction

1.1 Scope and Purpose

This Generic Requirements document (GR) presents the Telcordia view of proposed generic reliability assurance practices for most optoelectronic devices used in telecommunications equipment such as asynchronous and synchronous fiber optic Terminal and Add-Drop Multiplexers (TMs and ADMS), Digital Cross-connect Systems, optical amplifiers, Universal or Integrated Digital Loop Carrier systems, and Fiber-In-The-Loop (FITL) systems.[1] The devices covered in this document include active devices such as lasers (Laser Diodes and Laser Modules), Light Emitting Diodes (LEDs and LED Modules), photodetectors (Photodiodes and Detector or Receiver Modules), and Electro-Absorption (EA)[2] and External Modulators that have expected operational lives on the order of 20 years, regardless of package style or level of integration.

The document is not specifically intended to cover optoelectronic devices used in short-life equipment, such as the equipment deployed in Local Area Network (LAN) or Metropolitan Area Network (MAN) applications. Instead, GR-3013-CORE, *Generic Reliability Assurance Requirements for Optoelectronic Devices Used In Short-Life*, *Information-Handling Products and Equipment*, is intended to be the applicable document for those devices. On the other hand, it should be noted that GR-3013-CORE, Issue 1, which was available at the time that this document was being prepared, was very similar to GR-468-CORE, Issue 1. In general, it is expected that if GR-3013-CORE is reissued, the changes will be similar to those made in this document. Therefore, parties that are interested in reliability assurance for short-life optoelectronic devices may wish to use this document as a baseline, instead of GR-3013-CORE, with modifications as appropriate based on the shorter product lifetime (e.g., shorter test periods for most of the environmental stress tests) and the lower assumed quality level of the devices (e.g., no requirements to perform periodic requalification or 100% screening of Quality Level II devices).

This GR is directed toward the design, engineering, manufacturing and reliability/quality organizations of both equipment manufacturers and

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[1] One specific exception is the case of a laser with an output optical power level that is high enough to cause significant stress on both the laser package and other components to which it is attached. Such very high power lasers were being considered for use in the network at the time that this document was being prepared, and it is recognized that the criteria contained in this document may not be sufficient (for reliability assurance purposes) for devices that include such lasers.

[2] Note that in previous issues of this document, “EA Modulators” were referred to as “integrated modulators.” The reason for this was that the device in question (the device that modulates the optical signal) is typically fabricated onto the same substrate as the laser diode that generates that signal (i.e., the two diode-level devices can be considered integrated at that level). However, that use of “integrated” was inconsistent with how the word was used in the rest of Issue 1 (and therefore caused significant confusion), and is also inconsistent with how it is used in this document (i.e., to refer to complex assemblies that include one or more optoelectronic modules and additional electronic circuitry, see Section 1.5.1). Therefore, “EA Modulators” is used throughout this issue.

optoelectronic device suppliers. It is intended to help ensure the reliable operation of optoelectronic devices in communications equipment that uses fiber optic technologies and devices, and thus help minimize the life-cycle cost for manufacturers, service providers and end-customers. By identifying a set of minimum reliability assurance practices that balance confidence in component reliability with component cost, the suppliers, manufacturers, services providers, and end-users can all benefit.

The criteria here are not meant to define a specific design or to result in a preferred way of accomplishing the design. By taking into account the need to meet these minimum criteria, the intent is that reliability can be built into the product design rather than pursued through expensive inspection and testing in manufacture.

1.2 Reliability Assurance - Overview and Philosophy

Unlike most functional or performance generic requirements, many reliability assurance criteria do not deal with straight-forward “yes or no” issues. That is, there could be many ways of achieving the same end goal of reliable optoelectronic devices for use in a public telecommunications network. The following sections first describe the tenets of a comprehensive reliability assurance program, and then discuss the philosophy behind the approach taken in this GR.

1.2.1 Overview of Reliability Assurance

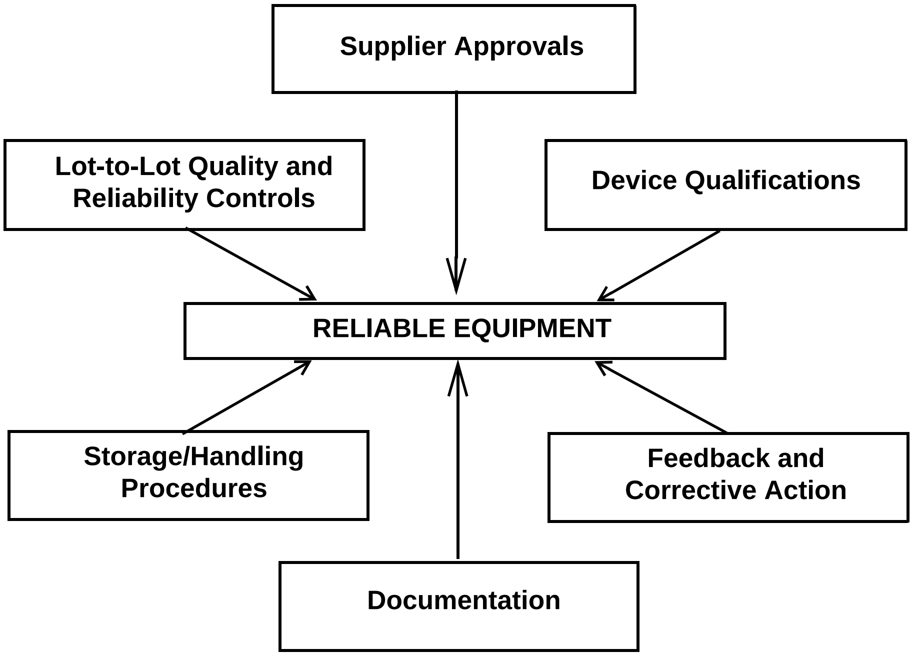
The basic reliability of optoelectronic systems can be no better than the reliability of the components contained in the equipment. Moreover, in many cases it is impossible to thoroughly test the performance and reliability of a component once it is incorporated into a higher level of assembly. It thus becomes necessary for device suppliers and equipment manufacturers to set up programs at the component level to help ensure the necessary level of system reliability.

The major elements of a comprehensive reliability assurance program are:

- Supplier approval
- Device qualification
- Lot-to-lot quality and reliability controls
- Feedback and corrective action
- Storage and handling procedures
- Documentation.

Thus, in a good reliability assurance program the devices are initially qualified, are purchased only from approved suppliers, and are requalified at appropriate intervals. In addition, each lot is tested and analyzed, and any problems detected in the manufacturing processes or reported from field applications are examined and corrected. Relevant information is then fed back to the appropriate supplier, and as input for the supplier approval and device qualification processes. Devices also are stored properly, avoiding excessive heat and humidity, and the suppliers and manufacturer carefully adhere to Electrostatic Discharge (ESD) precautions that they have tailored for their particular situations. Finally, the reliability assurance program is fully documented to ensure consistency and continuity. All of these elements (of a complete reliability assurance program) are depicted in Figure 1-1.

Figure 1-1 Elements of a Comprehensive Reliability Assurance Program



1.2.2 Reliability Assurance Generic Requirements Philosophy

A number of the criteria in this GR deal with necessary elements of a comprehensive reliability assurance program, and thus they can be clearly satisfied (or not) by the device supplier's and/or equipment manufacturer's practices. However, many other criteria deal with the demonstration of device reliability or with levels of confidence. The intent of these latter criteria can sometimes be accomplished in alternative ways. While the qualification tests and lot-to-lot control procedures given in this GR have been developed to establish an appropriate baseline for a comprehensive reliability assurance program, other techniques could prove to be more cost-effective. However, the difficulty of such alternative approaches involves the demonstration of their equivalency or effectiveness by the supplier or manufacturer. Although certain general guidelines can be described, specific steps to demonstrate this cannot be determined in advance for every situation. Nevertheless, suppliers and manufacturers are encouraged to investigate "improved" test methods and practices.

1.3 Document History

This document completely replaces Issue 1 of GR-468-CORE. In turn, that document and Issue 1 of GR-3013-CORE replaced Issue 1 of TR-NWT-000468, *Reliability Assurance Practices for Optoelectronic Devices in Central Office Applications*, and Issue 2 of TA-NWT-000983, *Reliability Assurance Practices for Optoelectronic Devices in Loop Applications*.

Due to the extent of the changes (e.g., rewrites, additions, deletions, reorganization, and consolidation) that were performed on both the text and criteria in this issue of the GR, the locations of the various changes have not been marked with change bars. On the other hand, the most significant changes between Issues 1 and 2 of the document are described below, along with the changes that were made when Issue 1 of this document and Issue 1 of GR-3013-CORE replaced TR-NWT-000468 and TA-NWT-000983.

1.3.1 Changes Between Issues 1 and 2 of GR-468-CORE

Provided below is a list of major changes that were made between Issues 1 and 2 of this document. As indicated above, numerous changes were made throughout the document, and therefore the following list contains only the most significant (in the view of Telcordia) of those changes.

- In order to highlight commonalities (and in cases where they exist, differences) between the tests and procedures that apply to various devices and levels of devices
    - All of the criteria related to qualification testing were consolidated into Section 4
    - All of the criteria related to reliability or accelerated aging testing (i.e., the “for information” tests in Issue 1) were consolidated into Section 5
    - All of the criteria related to lot-to-lot controls were consolidated into Section 6.

  Similarly, all of the information related to test procedures now appears in Section 3, while Section 2 contains general criteria and information related to quality assurance processes, and Section 7 contains information and criteria related to a number of other components with which optoelectronic devices are likely to be packaged.
- The definitions of the various device levels were revised and the scope of the document was expanded such that it now explicitly applies to optoelectronic devices at essentially any level below the circuit pack level.
- A significant amount of information related to tunable lasers and optoelectronic receivers was added to the document.
- In recognition of the fact that technological advancements have rendered inappropriate a number of the specific “normal” or “threshold” values that

appeared for various parameters in Issue 1 (and that future advancements will likely do the same to any new values that could have been included in Issue 2), all such values were removed from the criteria.

- Due to the continuing proliferation of different types of optoelectronic devices and applications for those devices, it was recognized that any list of performance parameters (e.g., to be tested during the characterization portion of the qualification process) that could be provided would include entries that would not be appropriate for some devices and would be missing entries of significant importance for other devices. Therefore, the Issue 1 objectives that indicated specific performance parameters to be included in the testing program were removed, and the various tables that listed those parameters were consolidated into a single table of “Typical Performance Parameters for Optoelectronic Device Characterization.”
- A set of operational shock and vibration conditions, under which some of an integrated module’s performance tests may need to be performed, was defined.
- At the time that this document was being generated, it appeared that within the industry much of the “burden of proof” regarding reliability assurance for optoelectronic devices was shifting (or had been shifted) from the equipment manufacturers to the device suppliers. To reflect this trend, many of the criteria that were worded in Issue 1 to be specifically applicable to equipment manufacturers were revised to apply to the “equipment manufacturer or device supplier” in Issue 2.

1.3.2 Changes Between TR-NWT-000468/TA-NWT-000983 and GR-468-CORE, Issue 1

Listed below are the major changes that were made between TR-NWT-000468/ TA-NWT-000983 and Issue 1 of this document. Note that the section numbers referred to in this list are from Issue 1 of the GR rather than the current issue.

- The scope of the document was broadened to cover all active optoelectronic components.
- The impacts of reliability practices on failure rates were clarified in Section 1.2.
- The use of ISO 9000 certificates was clarified in Section 3.1.2.
- The requirements for provisional use of devices were expanded (Section 3.1.3.5).
- A new section (Section 3.1.4) on “Environment, Health, and Safety” was added, and the flammability test requirement was expanded and moved to this section.
- The requirements of ship-to-stock programs were expanded to allow the approval of a family code as a result of considering the Dense Wavelength Division Multiplexed (DWDM) lasers used for different channels (Section 3.2.1.4).

- Numerical changes were made and details were added to the laser qualification section.
- The measurements for laser diode characterization were changed from Requirements to Objectives (Section 4.1.1).
- The requirements to characterize the optical spectrum quality of multi-longitudinal-mode lasers and thermal impedance of laser diodes were removed (Section 4.1.1).
- Default values of the activation energies used in the Arrhenius relationship were added to Section 4.1.2.
- The parameters measured during the electrical and optical testing portion of the lot-to-lot control process were changed to Objectives (Section 4.2.2).
- Reliability criteria for non-hermetic packages were added in Section 4.3.3 for laser modules, Section 6.3.3 for LED modules, and Section 8.3.3 for detector modules.
- Reliability criteria for pump lasers, at both 980 nm and 1480 nm, were added to Section 4.3.4.
- Criteria based on the considerations of DWDM applications for lasers were added in Section 4.3.5.
- Reliability criteria for modulators were added in Section 10.

1.4 Related Telcordia Documents

This GR complements or supplements the criteria on component and system performance or reliability found in several other GRs. These documents include:

- GR-357-CORE, *Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment* – Component reliability criteria for general types of devices, such as transistors, resistors, diodes, and Integrated Circuits (ICs)
- GR-418-CORE, *Generic Reliability Assurance Requirements for Fiber Optic Transport Systems* – Fiber optic system reliability criteria
- GR-909-CORE, *Generic Criteria for Fiber in the Loop Systems* – FITL system reliability (and functional) requirements
- GR-1221-CORE *Generic Reliability Assurance Requirements for Passive Optical Components* – Passive optical device reliability criteria

- GR-1252-CORE, *Quality System Generic Requirements for Hardware* – Quality and reliability programs for hardware systems
- GR-1312-CORE, *Generic Requirements for Optical Fiber Amplifiers and Proprietary Dense Wavelength-Division Multiplexed Systems* – Generic reliability (and functional) requirements for fiber optical amplifiers (and proprietary DWDM systems).

Other Telcordia TRs and GRs provide additional quality and reliability assurance criteria generally applicable to telecommunications products. GR-874-CORE, *An Introduction to the Reliability and Quality Generic Requirements (RQGR)*, details many of those documents. In addition, various other TRs and GRs, plus national and international standards, are referenced in this GR (see Appendix B, the References section).

1.5 Terminology

To ensure the common application and understanding of terminology, various terms related to criteria, optoelectronic devices, operating environments, and other matters are described in the following sections.

1.5.1 Device Terminology

Five levels of optoelectronic device assembly that are covered in this document are defined below. From the "lowest" level to the "highest," these are the wafer, diode, submodule, module and integrated module levels. Note that these names and definitions are generally consistent with those used in Issue 1 of this GR (although the module level has been expanded to include a number of devices that were previously classified as integrated modules), and that a variety of alternate names are used within the industry. Also note that depending on the design, one or more of these levels may not be applicable as a particular device goes from raw materials to deployment, and that in a number of those cases the inapplicable levels are the submodule and/or integrated module levels.

- Wafer Level - This refers to the stage of fabrication where the individual devices are still bound together on a "slice" of semiconductor material. In general, this document does not contain criteria related to testing of devices at this level. However, in some cases testing or procedures performed at this stage may be found to be a cost-effective alternative to certain tests or procedures specified to be performed at the diode level.
- Diode Level - After a wafer is scribed or otherwise cut apart, each resulting diode or chip is typically mounted on a header, heatsink or other type of carrier that provides mechanical, electrical and thermal contacts. This simplifies manual or automated handling for testing and/or subsequent packaging, but does not add to the functionality of the device. Thus, tests that are performed on this "submount assembly" are effectively being performed on the diode or

chip. Many of the criteria in this GR are concerned with assuring the reliability of devices at the diode level in order to reduce manufacturing and higher level testing costs.

- Submodule Level - In some cases, a submount assembly might be packaged in a Transistor Outline (TO)-style can or similar package, resulting in a submodule. Unlike the module level of assembly (described below), the submodule is usually not in a form that can be directly incorporated into a circuit assembly used in a telecommunications system (e.g., a circuit pack). In particular, most submodule designs do not have the necessary provisions for direct optical interfaces. Therefore, this GR generally does not contain criteria that are specifically applicable to this level. On the other hand, testing at the submodule level may be appropriate for certain devices that are sold/purchased at the submodule level, and some testing results for other types of submodules might be acceptable as a substitute for testing of the corresponding diodes or modules.

- Module Level - A module, as defined here, is a relatively small assembled unit containing one or more laser, LED, photodiode or modulation devices (or one or more smaller modules containing those devices) in a relatively rugged case. In contrast to a submount assembly or submodule, modules usually provide means for easy electrical and optical connections. In addition, a module is generally the highest level of assembly at which the coupling of light can be affected, and is also generally the highest level that can feasibly be hermetically sealed.[3]

  Common module designs can incorporate a variety of components in addition to the primary optoelectronic devices. Some of the possible module components are listed below. In this list, *italics* are used to identify the components that are generally considered necessary for an assembly to be considered an optoelectronic module. Simpler forms that (for example) include an optical window instead of a pigtail, connector, or receptacle would typically fall under the definition of a packaged submount assembly or submodule.

  — *Laser diode, LED, photodiode or modulation device*

  — *Carrier structure*

  — Monitor photodiode (for laser modules)

  — Optical isolator (for laser modules and possibly other modules containing optical sources)

  — Thermoelectric Cooler (TEC)

  — Temperature sensor (e.g., a thermistor)

  — Controller circuitry

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[3] Note that this is not meant to imply that a module has to be hermetically sealed, or that it is impossible to hermetically seal a higher level of assembly.

— Module case with electrical contacts or leads

— *Fiber optic pigtail, optical connector or receptacle.*[4]

Figure 1-2 shows several examples of optoelectronic modules commonly used in telecommunications systems. A generic layout (not to scale) of one type of module is illustrated in Figure 1-3. Note that while these figures illustrate relatively simple modules containing one primary optoelectronic device apiece, a module may contain several independent optoelectronic devices supporting common or separate functions (e.g., a laser and a photodetector in a transceiver or transponder module, or a laser and an external modulator in a high-speed transmitter module). Also note that in some cases test access to the optical and electrical parameters of a module's optoelectronic device(s) may be severely limited. For example, the drive circuitry included in a module may support the transmission of a specific type of signal (e.g., a SONET OC-48 signal), but not the level or type of control necessary to measure the quantum efficiency or threshold current of the laser.

- Integrated Module - In this GR, an integrated module is defined to be a complex assemblage of components that includes at least one optoelectronic device, does not meet the definition of a module given above, and is smaller than a circuit pack. For example, an integrated transceiver module could consist of an optical transmitter module, a receiver module, and number of electronic components mounted on a printed wire circuit board, which in turn is obtained by a Network Element (NE) manufacturer and placed onto a circuit pack that can be inserted and removed from an NE. As is the case for some modules (see above), test access to the optical and electrical parameters of an integrated module's optoelectronic device(s) may be severely limited. In addition, cost considerations may limit the number of integrated module samples that can feasibly be committed for qualification purposes. Therefore, the criteria in this GR indicate that complete testing of a full set of samples needs to be performed at a lower level (i.e., on all of the components to be integrated into the integrated module), and that in some cases it may be acceptable to test a smaller set of samples at the integrated module level. Consistent with the information in Section 2.1.3.3, if particular tests can only be performed at the integrated module level (e.g., for a tunable laser where the circuitry to control the output wavelength is not included in any assemblage below the integrated module level), then those tests may be deferred to this level. Similarly, in some cases an equipment manufacturer or device supplier may find it cost effective to defer certain tests to this level (e.g., so that several components can be stressed simultaneously). However, in any case where tests specified to be performed at

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[4] As used here, a "receptacle" is similar to a fiber-optic connector, but without an outer housing. Thus, it includes a sleeve into which the ferrule on the end of a fiber jumper can be inserted, but does not provide for a mechanical attachment to hold the end of the ferrule a constant distance from the associated optoelectronic device. Receptacles are typically provided on devices such as Transmitter Optical Sub-Assemblies (TOSAs) and Receiver Optical Sub-Assemblies (ROSAs), both of which are typically classified as modules.

a lower level are deferred to the integrated module level, the sample size criteria that apply at the lower level remain in effect.

In general, optoelectronic devices are obtained by NE manufacturers in one or more of the forms defined above, and then are mounted on circuit packs that can be easily inserted into (and removed from) NEs deployed in the network. Thus, documents such as GR-63-CORE, *NEBS™ Requirements: Physical Protection*, provide the reliability assurance criteria that apply to the next level of assembly (e.g., the system level).

Figure 1-2 Examples of Optoelectronic Device Module Designs

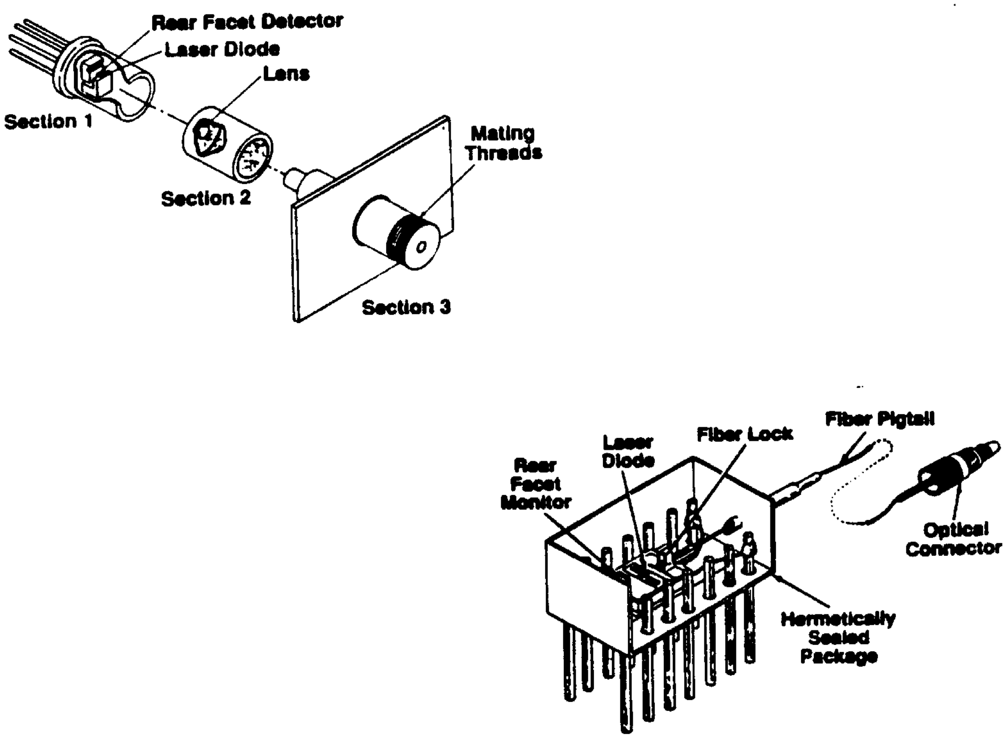
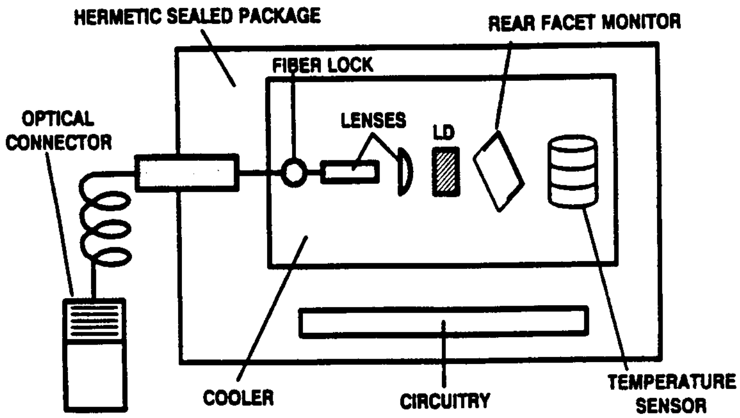


Figure 1-3 Schematic of a Common Laser Module Design



1.5.2 Suppliers, Manufacturers, and Customers

In this GR, the term “device supplier” is used to refer to any entity that supplies a device/component to an “equipment manufacturer” for inclusion in some higher level assembly of devices/components. In addition, “customer” is used to refer to any entity that receives and uses devices/components/equipment (e.g., in the manufacture of a higher level product, or in a network). For example, suppose Company A produces laser diodes and sells them to Company B, which uses those diodes in the production of laser modules that it sells to Company C, which in turn uses the modules in the production of SONET ADMs that it sells to Company D (a service provider). In this example, Company B is an equipment manufacturer and customer in the context of its relationship with Company A (the device supplier in the relationship), and a device supplier in the context of its relationship with Company C. Similarly, Company C is the equipment manufacturer and customer in its relationship with Company B, and has Company D as a customer.

1.5.3 Operating Environments

Optoelectronic devices are generally specified to be able to be used in either of two operating environments. These are typically described as Central Office (CO) and other controlled environments (referred to collectively as CO environments) and Uncontrolled (UNC) environments. These environments have an important impact on the stresses experienced by a device, with resulting consequences on reliability if the device is not sufficiently robust. A number of the reliability assurance criteria are therefore associated with the particular environment in which the device is expected to operate.

Note that depending on the ventilation provided by a system and the locations of the optoelectronic devices in that system, those devices may need to be able to operate at (local ambient) temperatures that are significantly higher than the maximum ambient temperature specified for the system as a whole. In many cases, this is reflected in a supplier's specifications for their devices, which indicate operating temperature ranges that extend 20°C or more beyond the maximum temperatures discussed in the following sections. In addition, it means that most devices can withstand the temperatures specified for use in a number of the environmental stress and reliability tests discussed in this document.[5]

Also note that although this document focuses on (constant, ambient) temperature as the primary operating environment-related variable that needs to be controlled when a device's performance is being characterized, other variables such as temperature changes, humidity, altitude (air density), vibrations and airborne contaminants also need to be considered. If it appears likely that a particular device could be significantly affected by one or more such variables, then that needs to be (and in a few cases, currently is) reflected in the operating conditions specified for use in the appropriate characterization tests.

1.5.3.1 CO Environment

A CO environment, as described in GR-63-CORE, restricts long-term ambient temperatures to a range of +5 to +40°C. In addition, GR-63-CORE indicates that for short periods (i.e., up to 96 consecutive hours, and for a total of no more than 15 days per year), temperatures may go as low as –5°C or as high as +50°C. These same limits can be achieved at remote sites with appropriate environmental controls, as in the case of Controlled Environment Vaults (CEVs). Therefore, "CO" is used throughout this document to refer to both Central Office and other controlled environments.

1.5.3.2 UNC Environment

As used here, UNC environments exhibit conditions that do not meet the criteria for CO environments described in Section 1.5.3.1. The temperature extremes for a UNC environment are based on the criteria in GR-487-CORE, *Generic Requirements for Electronic Equipment Cabinets*. That document defines a temperature range of –40°C to +46°C for the air temperature outside of an

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[5] For most of the devices covered by this document, the minimum temperatures at which high-temperature operations and accelerated aging tests are supposed to be performed are 20°C higher than the temperature limits given in the Sections 1.5.3.1 and 1.5.3.2. This generally will not damage a device (since the test temperature is typically the same as the maximum specified operating temperature), but does accelerate the aging process (since the average temperature at which a deployed device operates is generally significantly lower than the maximum). On the other hand, the temperatures given in this GR for several tests are more than 20°C above the limits given in Sections 1.5.3.1 and 1.5.3.2, and therefore some devices may not be able to tolerate them. In such cases, lower temperatures are allowed to be used.

enclosure. In addition, it is generally assumed that inside the enclosure the air temperature surrounding the equipment can reach +65°C under maximum solar loading and equipment power dissipation.[6] An example of a UNC environment would be a pedestal (such as the optical network unit of an FITL system).

Independent of the temperature issue discussed above, there can be significant variations in a number of other conditions that make up a UNC device's operating environment. Those conditions depend on a number of factors, including the type of system enclosure (e.g., above-ground cabinet, aerial enclosure, pedestal), geographic location, and local effects such as shade from nearby buildings or trees. In this document, the factor that is of primary interest (i.e., that affects the particular conditions under which certain tests are performed, see Section 3.3.3.2) is the anticipated thermal mass of the equipment inside the enclosure in which the optoelectronic device is deployed. For some devices it may be safe to assume that the thermal mass will be large enough to result in temperature change time constants on the order of one or more hours. However, for other devices the time constant could be on the order of minutes due to the small thermal mass of the electronics in the enclosure and the relatively small size of the enclosure itself.

1.5.4 Quality Levels

The term "quality level" as used in this GR and other component reliability documents indicates the scope and depth of a device supplier's and/or equipment manufacturer's component reliability assurance program. It is an indication of the confidence that a device will consistently meet or exceed its specified level of performance through the use of different intensities in the device supplier's and/or equipment manufacturer's qualification and lot-to-lot control practices. Table 1-1, which is based on Table 7-3 in SR-332, *Reliability Prediction Procedure for Electronic Equipment*, defines four levels, with Quality Level 0 being the lowest and Quality Level III the highest.

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[6] For example, see Section 7.1.1 of GR-253-CORE, *Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria.*

Table 1-1 Definition of Quality Levels

Quality Level	Description
0	This level is assigned to commercial-grade, reengineered, remanufactured, reworked, salvaged, or gray-market devices for which steps have been taken to ensure compatibility with the design application, but that are procured and used without device qualification, lot-to-lot controls, or an effective feedback and corrective action program by the primary equipment manufacturer or its outsourced lower-level design or manufacturing subcontractors. In addition, this level is assigned to equipment made using such devices.
I	This level is assigned to commercial-grade devices for which: **(a)** Steps have been taken to ensure that the devices are compatible with the design application (as was the case for Quality Level 0) and also with the manufacturing process **(b)** An effective feedback and corrective action program is in place to quickly identify and resolve problems in manufacture and in the field, but that are procured and used without thorough device qualification or lot-to-lot controls. In addition, this level is assigned to equipment made using such devices.
II	This level is assigned to devices that meet (a) and (b) above, plus the following: **(c)** Purchase specifications explicitly identify important characteristics (optical, electrical, and mechanical) and Acceptable Quality Levels (AQLs) for lot-to-lot controls **(d)** Devices and suppliers are qualified and identified on approved parts/supplier lists (and device qualification includes appropriate characterization and reliability tests) **(e)** Lot-to-lot controls are in place at adequate AQLs to ensure consistent quality. In addition, this level is assigned to equipment made using such devices.
III	This level is assigned to devices that meet (a) through (e) above, plus the following: **(f)** Device families are requalified periodically **(g)** Lot-to-lot controls include early life reliability control of 100% screening (e.g., temperature cycling and burn-in) which, if the results warrant it, may be reduced to a “reliability audit” (e.g., burn-in on a sample basis) or to a “reliability monitor” program that demonstrates acceptable failure values (based on the expected random failure rate) out to 10,000 hours **(h)** Where screening is used, the Percent Defective Allowed (PDA) is agreed upon and specified **(i)** An ongoing, continuous reliability improvement program is implemented by both the device supplier and the equipment manufacturer. In addition, this level is assigned to equipment made using such devices.

Because of the critical impact of optoelectronic devices on the performance of telecommunication systems, the practices described in this GR for those devices are generally consistent with the definition of Quality Level III (unless noted otherwise). The reliability assurance program for these devices, therefore, would include periodic requalification and device screening (neither of which are generally required for Quality Level II devices). However, it is recognized that the PDA, as normally required by Item (h) in Table 1-1, might be difficult or impossible to specify for optoelectronic devices.

1.5.5 Failure Rates

Typically, the rate of failure for a particular type of device is presented in terms of its "FIT rate," where one FIT (Failure In Time) corresponds to one failure per billion device operating hours. Although it is often discussed and presented as if it were a constant, this rate generally varies significantly over time. In addition, different types of failures having different failure-rate characteristics are generally dominant during the various portions of the device's life. In many cases, the dominant types of failures are as follows:

- Infant mortality failures, which occur early in life and at a declining rate, and which can generally be detected during a well-designed screening process (allowing the affected devices to be removed from use before deployment)
- Random failures, which occur at a relatively constant rate that generally cannot be accurately predicted without exhaustive testing efforts
- Wear-out failures, the rate of which generally increases with time and can sometimes be reasonably predicted from the results of accelerated aging tests.

When combined, these three types of failures typically result in an overall failure rate function having a "bathtub shape" with respect to the operating time.

1.5.6 Requirements Terminology

The following requirements terminology is used throughout this document:

- **Requirement** — Feature or function that, in the view of Telcordia, is *necessary* to satisfy the needs of a typical client company. Failure to meet a requirement may cause application restrictions, result in improper functioning of the product, or hinder operations. A Requirement contains the words *shall* or *must* and is flagged by the letter "**R**."
- **Conditional Requirement** — Feature or function that, in the view of Telcordia, is *necessary in specific applications*. If a client company identifies a Conditional Requirement as necessary, it shall be treated as a requirement for the application(s). Conditions that may cause the Conditional Requirement to apply include, but are not limited to, certain client companies' application

environments, elements, or other requirements, etc. A Conditional Requirement is flagged by the letters "**CR**."

- **Objective** — Feature or function that, in the view of Telcordia, is *desirable* and may be required by a client company. An Objective represents a goal to be achieved, and may be reclassified as a Requirement at a specified date. An objective is flagged by the letter "**O**" and includes the words *should*, *it is desirable* or *it is an objective.*

1.6 Requirement Labeling Conventions

As part of the Telcordia GR Process, proposed requirements and objectives are labeled using conventions that are explained in the following sections.

1.6.1 Numbering of Objects

Each Requirement, Objective, Conditional Requirement, Conditional Objective, or Condition (referred to collectively as "objects") is identified by both a local and an absolute number. The local number consists of the object's document section number and its sequence number in the section (e.g., **R3-1** is the first Requirement in Section 3). The local number appears in the margin to the left of the object. An object's local number may change in subsequent issues of a document if other objects are added to the section or deleted.

The absolute number is a permanently assigned number that will remain for the life of the object; it will not change with new issues of the document. The absolute number is presented in brackets (e.g., **[2]**) at the beginning of the object text.

References to an object published in another Generic Requirements document will include both the document number and the object's absolute number. For example, **R2345-[12]** refers to the Requirement with an absolute number of **[12]** in GR–2345-CORE.

1.6.2 Identification of Object Content

An object may have numerous elements (paragraphs, lists, tables, equations, etc.). To aid the reader in identifying each part of the object, rules are used above and below the object content as shown below. In cases where two or more objects appear with no intervening introductory or explanatory information, a single set of rules are inserted before the first object in the group, and after the last object.

Introductory information.

Content of object(s).

Explanatory information.

1.6.3 Requirement Object Absolute Number Assignment

In general, the absolute number assigned to any particular requirement object can be used (along with the following list) to determine the issue of this document in which that object first appeared.

- **[1]** to **[388]** appeared in Issue 1
- **[389]** to **[435]** first appeared in the current issue (Issue 2).

In addition, version numbers (e.g., **[1v2]**) are used to mark criteria that have undergone substantive changes in this issue of the document. Finally, the absolute numbers assigned to criteria that appeared in Issue 1, but that have now been removed, are not reused.

2 Reliability Assurance Processes

This section contains criteria related to various processes that are applicable in assuring the reliability of all types of optoelectronic devices. These processes include supplier approval and device qualification, lot-to-lot controls, feedback and corrective action programs, device storage and handling, and documentation and test data. In addition, several environmental, health, safety, and physical design issues are covered in Section 2.7.

2.1 Supplier Approval and Device Qualification

Supplier approval and device qualification deals with the capability of a prospective supplier and its specific device(s) to meet the needs of the equipment manufacturer. It involves assessment of the supplier's quality and reliability assurance program, measurement of the device's characteristics, and investigation of various aspects of long-term reliability. Since optoelectronic devices are usually critical to the operation of the systems in which they are used, telecommunications equipment manufacturers whose products utilize those devices need to know their optoelectronic device suppliers exceptionally well.

R2-1 **[1v2]** Equipment manufacturers that make telecommunications equipment that utilizes optoelectronic devices shall establish and document formal supplier approval and device qualification programs. These programs shall include procedures for both adding and removing suppliers and devices to/from an Approved Suppliers List (ASL, a.k.a., AVL or AML for Approved Vendor List or Approved Manufacturer List) and an Approved Parts List (APL). (Also see **R2-4 [5v2]**.)

R2-2 **[2v2]** With the possible exceptions discussed in Section 2.1.2, as part of the supplier approval process, equipment manufacturers shall visit the suppliers' manufacturing locations, and shall examine both the facility and implemented test practices. Equipment manufacturers shall pay particular attention to the Quality Assurance/Quality Control (QA/QC) programs that the suppliers have in place, and to the quality and reliability data that the suppliers have accumulated on their products. Only those optoelectronic device suppliers who demonstrate that they are committed to producing reliable devices shall be considered as acceptable sources.

As indicated by device-specific criteria that appear later in this GR, equipment manufacturers generally need to obtain results from a number of qualification and lot-to-lot control tests on the optoelectronic devices they plan to use. In many cases it is expected that the equipment manufacturers will obtain those results by performing the tests themselves. However, in other cases they may choose to have the tests run for them by independent test laboratories, or to use data provided by the supplier (if a formal audit/monitor program of the supplier is run in conjunction).

2.1.1 Specification and Control

The equipment manufacturer is responsible for specifying and controlling the devices that it allows in manufacturing its products. The two primary means of doing this are purchase specifications and ASLs/APLs.

R2-3 **[4v2]** All optoelectronic devices used in system manufacture shall be identified on a purchase specification or some equivalent form of control document. Such documents shall identify all relevant performance, quality and reliability requirements, allowable operating conditions (e.g., minimum- and maximum-rated operating temperatures, supply voltage), and lot-to-lot controls. The functional parameters that are identified shall include most, if not all, of the parameters used to characterize the devices during initial qualification.

R2-4 **[5v2]** ASLs and APLs shall be carefully maintained for routine use by the manufacturing, QA and purchasing organizations, and shall be treated as "controlled" documents (e.g., dated, signed by appropriate management, and removed from use when superseded by newer versions). The ASL and APL shall be provided as inputs to the purchase specification process. Except as discussed in Section 2.1.3.4, only suppliers and part types that have successfully completed approval and qualification shall be referenced on purchase specifications and included in ASLs/APLs.

A computer database with restricted access and change controls can serve as an ASL/APL with quick updating capabilities.

2.1.2 Supplier Approval

Prior to (or concurrent with) device qualification, the device supplier needs to undergo its own approval process. This effort, known as supplier (or vendor) approval, is a formal, documented procedure that typically includes a review or inspection of the supplier's facilities. In addition to the criteria in this section, ISO 9000 standards establish a part of the foundation for building a supplier approval program.

R2-5 **[6v2]** The criteria for determining acceptance of a supplier shall include the supplier's QA/Statistical Quality Control (SQC) data, and the availability of reliability data. Suppliers shall be specifically asked to provide typical quality and reliability test data (e.g., accelerated aging test data and the results of screening). These data shall be examined for evidence that their designs are sound and that their processing has been consistent over time.

R2-6 **[7v2]** The equipment manufacturer shall clearly document the results of supplier acceptance activities (including supplier surveys, if performed) per **R2-1 [1v2]**.

R2-7 **[8v2]** Supplier acceptance reports shall be retained for a minimum of 5 years.

R2-8 **[9v2]** As a minimum, approved suppliers shall be revisited every 2 years.[1]

As indicated by **R2-2 [2v2]**, the equipment manufacturer is normally expected to visit the supplier's facility and complete a survey in person during the supplier approval process. This is intended to apply even if the device processing, assembly, or testing is performed in a different country. However, if the equipment manufacturer deems this impossible, then a thorough review of reliability test data and statistical quality control data may be sufficient to confirm that the supplier's operations are under adequate control. In addition, on-site appraisal of suppliers might not be necessary if they have been formally certified by ISO-accredited inspectors as meeting the relevant standards in ISO 9000. This would be determined by the equipment manufacturer who is considering the particular supplier, based upon other available information. Because ISO 9000 standards are written for any type of product, the reliability needs for telecommunications systems and components lead to certain additional criteria (including those given here, and other considerations that the procuring company might feel necessary).

2.1.3 Common Process-Related Criteria for Device Qualification

Device qualification has two primary purposes. First, the characterization portion of the qualification process is intended to confirm the ability of the device to meet the equipment manufacturer's performance requirements. Equally important, the mechanical integrity and environmental stress testing portions (a.k.a., the stress testing portions) of the process are intended to verify that the basic device design and the fabrication materials and processes are sound, and can be expected to provide adequate long-term reliability.

2.1.3.1 Qualification Test Documentation

Appropriate test programs, sequences, and sample sizes for qualification testing of individual device codes are provided in this document. Other proposed, or currently used, qualification programs may also be acceptable in part or in whole, if they can be shown to be technically comparable. Note that specific procedures for demonstrating this cannot be delineated in advance for all cases. However, some information on alternative approaches for certain situations is provided.

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[1] Note that this is in addition to more frequent, regular communication with the supplier to review any problems (or to confirm the lack of such problems), as described in Section 2.3.

R2-9 **[10v2]** Written notification shall be provided to the customer for any substitution of tests or changes in test limits. In addition, the supporting data shall be provided upon request.

R2-10 **[389]** Documentation of the qualification practices and procedures shall address:

- Scheduling for qualification tests
- Tests and measurements to be performed
- Test and measurement procedures
- Sampling plans and any acceptable deviations of the samples under test (from the device to be qualified)
- Criteria that determine whether a test has been passed or failed
- Specification of the format for the retention of test data
- Distribution of the results and reporting of test failures
- Corrective action to be taken when test failures occur.

R2-11 **[11]** Actual practices and procedures used for device qualification shall be documented.

R2-12 **[12]** Qualification test results shall be clearly recorded and saved for a minimum of 5 years.

R2-13 **[390]** The report that documents the results of a qualification program shall include sufficient information and details such that it is clear what was done. At a minimum, this report shall include the following:

- A statement as to the scope of the qualification program and the operating conditions under which the qualification is valid (e.g., CO, UNC)
- A list of the tests that were performed along with descriptions of (or references to) the test methodologies
- A description of the devices used for each test, along with the starting quantities
- For each stress test, a description of and the justification for each measurement that was performed to determine whether the devices passed or failed the test, along with descriptions or references for each of the measurement methodologies
- The pass/fail criteria for each test or measurement, along with justification for the particular values
- The results of the tests and measurements, including the quantity of devices that passed and the quantity that failed.

O2-14 **[13]** Qualification test results should be saved for a minimum of 10 years.

In addition to the qualification practices, procedures, and results, in some cases it may be useful to retain the actual samples used in the qualification process.

2.1.3.2 Qualification of Devices by Similarity

Because small differences in device fabrication, assembly, or screening can have a significant impact on reliability, optoelectronic devices are not as amenable as general (non-optoelectronic) components to qualification by similarity or "read-across."[2] However, in some cases such qualification may be possible. One possible example would be a "product family" of laser modules with the same laser diode chip in the same module package (made on the same production lines), differing only in the coupled output power. In this case, the product with the most demanding tolerances must be used in the testing for the family. In addition, if a new device is developed based on existing products, it may not be necessary to repeat the entire qualification sequence. Instead, an adequate understanding of failure and degradation mechanisms may be used to identify which qualification tests need to be performed. The qualification data of the existing similar products can be used if they utilize the same technology platform, are made by the same manufacturer, are fabricated using the same process flow and controls at a designated manufacturing location, and are of similar complexity and packaging.

R2-15 **[185v2]** If qualification by similarity is claimed, the basis for that claim shall be documented.

2.1.3.3 Levels of Assembly for Qualification

As discussed in Section 1.5.1, five levels of optoelectronic device assembly are defined and covered in this document (i.e., the wafer, diode, submodule, module and integrated module levels). In addition, many of the criteria in this document are written such that they appear to apply specifically to devices at a particular level. However, as discussed below, in a number of situations it may be acceptable (or necessary) to perform certain tests at different levels than indicated by the criteria.

- In certain cases, it may be acceptable to defer a test that is required at one level (according to this GR) to a higher level at which that test is not normally required, or to combine similar tests required for two or more levels of assembly into a single test performed (typically) at the higher of those levels.[3] In general, when this is done it needs to be justified based on technical evidence. In

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[2] This document also addresses certain special components used in modules. These other components (e.g., thermoelectric coolers) can often be qualified on a family basis. Families need to be defined to restrict members to the same supplier, product line, technology, complexity, overall construction, etc.

addition, if there are differences in the conditions that are specified to be used at the two levels (in cases where similar tests at two levels are being combined and performed at the higher level), then the more stressful of those conditions need to be used.

- In some cases, when a test is deferred to a higher level of assembly, the results of that test can be used in qualifying certain components at the lower level (e.g., certain tests performed on integrated module product “X” can be used in qualifying the component laser module product “x” for possible use in other applications). This is generally referred to as “read-back.”

Regarding the first bullet item above, it should be noted that the long-term performance or reliability of a diode might not be able to be determined in high-temperature operations or accelerated aging tests performed at the module level if the module contains a TEC. The reason for this is that if the test were to be performed without the TEC running (as may be necessary to expose the diode to the temperatures needed to significantly accelerate the aging process), thermal run-away could occur as a result of the poor thermal conductivity of the TEC platform used to mount the diode. In such cases, the operation of the diode at high temperature would need to be assessed at the diode level. On the other hand, if the TEC’s operating temperature can be set to an appropriately high level, then it may be possible to defer the tests to the module level.

R2-16 **[391]** The equipment manufacturer (or device supplier) shall document and provide justification in any cases where tests are performed at a different level than indicated in this GR, or where read-back is used.

2.1.3.4 Provisional Use of Devices

Due to marketing strategies and competitive issues, equipment manufacturers often want to use new products before some of the qualification tests can be completed. This is a sensitive issue with respect to the lengthy tests necessary to demonstrate reliability. Based on experience by many manufacturers, as well as reliability testing performed by Telcordia, it appears that serious reliability problems often become apparent well before the end of the tests. Therefore, “provisional use” (sometimes referred to as “preliminary qualification” or “provisional qualification”) of devices undergoing initial qualification may be considered to temporarily meet the intent of this GR (which is to permit the use of only qualified devices) if the following conditions are satisfied.

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3. As a specific example of this latter case, if the equipment manufacturer is purchasing modules from the supplier that makes the diodes used in those modules, mechanical shock and vibration tests may be deferred to the module level, provided the appropriate electrical and optical measurements can be made at that stage of assembly.

R2-17 **[17v2]** In order to be approved for provisional use, the device code shall have successfully passed the other qualification requirements contained in this GR. In addition, the minimum number of test cycles/hours that have been completed shall be no less than the number given in Table 2-1, which is based on the total duration of the full test (in progress toward timely completion). The duration of the provisional use period of the device shall not exceed the maximum periods shown in Table 2-1.

Table 2-1 Provisional Use of Devices in Qualification

Total Length of Full Test	Provisional Use Allowed After...	Maximum Period for Provisional Use
500 cycles	100 cycles	3 months
1000 hours	500 hours	3 months
2000 hours	1000 hours	3 months
5000 hours	2500 hours	6 months

R2-18 **[18v2]** The equipment manufacturer and (in cases where the device supplier is performing the test) the device supplier shall have procedures in place to notify customers of the device/equipment within an agreed upon number of business days of finding and confirming any reliability problem in the remainder of the test (i.e., during a provisional use period). The equipment manufacturer and device supplier shall also have documented procedures for other appropriate actions (beyond notifying their customers, as applicable) to take in response to the problem.

O2-19 **[392]** The “agreed upon number of business days” referred to in **R2-18 [18v2]** should be less than or equal to five or, if an extension is necessary for the purpose of obtaining preliminary failure analysis results, seven.

Note that an equipment manufacturer may negotiate different notification deadlines with its device supplier and its customers. For example, assume an equipment manufacturer approves a device for provisional use and has agreed to five and two day notification deadlines with its supplier and customers, respectively. If the test in question is being performed by the device supplier, they would notify the equipment manufacturer within five business days of finding and confirming the reliability problem. The equipment manufacturer would then notify its customer of the equipment [e.g., a Local Exchange Carrier (LEC)] within the next two business days. Depending on the nature of the problem, the equipment manufacturer would also take further actions consistent with its documented internal procedures, likely ranging from special testing of the devices or circuit packs to suspension of system assembly pending the results of a detailed failure analysis.

2.1.3.5 Use of Supplier-Provided Data

In many cases, device suppliers themselves will run tests similar to the qualification tests described in this document and normally performed by equipment manufacturers.[4] Where appropriate tests are conducted, it may be possible for an equipment manufacturer to use supplier-provided data to satisfy the requirements of certain portions of their qualification program.

R2-20 **[22v2]** Equipment manufacturers who make significant use of supplier-provided data shall establish a program to verify the accuracy and validity of this information. The audit/monitor program shall be continued as long as supplier-provided qualification data is used.

O2-21 **[23v2]** Such audit/monitor programs should include repeating certain tests (by the equipment manufacturer or an independent test laboratory), and/or reviewing the device supplier's test methods, facilities, and data collection and analysis practices in detail.

R2-22 **[24]** The results of any verification tests shall be documented.

O2-23 **[25]** Verification test reports should be saved for a minimum of 5 years.

2.1.3.6 Treatment of Internally Manufactured Devices

R2-24 **[26v2]** Devices manufactured internally by the equipment manufacturer itself, or by another division of the same parent company, shall meet the same qualification and requalification criteria as specified herein for purchased parts.

R2-25 **[27v2]** The equipment manufacturer's manufacturing location(s) shall have continuous access to the test data for internally manufactured devices, and shall periodically review the information. In addition, the manufacturer shall be capable of readily providing such data if questions arise.

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[4] As discussed in the *Relative Maturity Level* portion of the *Preface* to this GR, much of the "burden of proof" regarding reliability assurance for optoelectronic components has been shifting from the equipment manufacturers to the device suppliers. That shift has not been fully reflected in the form of changes to the criteria and explanatory text throughout this document (e.g., the statement above still indicates that the qualification tests are "normally performed by the equipment manufacturers"). However, that does not mean that an equipment manufacturer that requires its suppliers to perform various tests cannot conform to the applicable criteria without repeating all of those tests. Rather, it means that the criteria in this section are of increased importance to the equipment manufacturer, and a number of other criteria that were originally written to apply to the equipment manufacturer become applicable to the device suppliers.

In general, it is not of critical importance whether the qualification and requalification procedures referred to above are performed at the device production output stage (e.g., by the division that is acting as a device supplier to another division), or at the equipment manufacturing input stage. However, it is always the using organization's responsibility to ensure that the data are representative of the actual devices it will use. The using organization must assess for itself the quality of the devices and their adequacy for the intended application.

2.1.3.7 Sampling for Qualification Tests

2.1.3.7.1 LTPD Sampling Plan

Several sampling-related acronyms and symbols are used in Section 4 of this document (which provides device-specific qualification criteria). Specifically, these are "LTPD," "SS," and "C," each of which is defined below. In general, these correspond to a similar set of terms from Appendix D of MIL-PRF-38535E, *Integrated Circuits (Microcircuits) Manufacturing, General Specification for*, on statistical sampling, test and inspection procedures.

- LTPD refers to Lot Tolerance Percent Defective, which is equivalent to the "Maximum percent defective (sample size series)" in MIL-PRF-38535E and is the maximum percentage of the devices of a particular type that can fail to meet a specification and still have the device be considered appropriate for qualification.
- SS refers to a suggested Sample Size appropriate for the specified LTPD (i.e., the minimum sample size that would need to be tested to ensure, with 90% confidence, that a device type whose percent-defective is equal to the specified LTPD value will not be accepted).
- C is the maximum number of failures allowed for the suggested sample size.

An abbreviated table for LTPD sampling is given in Appendix A.

R2-26 **[105v2]** Device samples used in qualification testing (and/or reliability testing, see Section 5) shall be selected randomly from a minimum of three wafers or lots (if applicable and feasible, and for diodes or modules respectively) and subjected to the normal screening step(s). In cases where it is not applicable or feasible to select the samples from three wafers or lots, the device supplier or equipment manufacturer shall justify and document the approach taken.

Note that particularly in the case of modules, it is recognized that it may not be feasible to select samples from three different lots (e.g., all of the modules available during the qualification period may be from a single lot). Also note that in cases where diode-level tests are deferred to the module level (see Section 2.1.3.3), the diode-level sampling requirement of samples selected from a minimum of three wafers still applies.

R2-27 **[393]** The number of devices to be tested in each qualification or accelerated aging test shall be no fewer than the sample sizes specified in **R4-8 [110v2]** or the "Notes" or "SS" column in the corresponding table (e.g., Table 4-2, Table 4-3). Also, with the possible exceptions discussed below, the number of samples of a device that fail a qualification test shall be no greater than the value of "C" given in the requirement or table.

The exceptions referred to in **R2-27 [393]** are as follows.

- LTPD sampling procedures inherently allow for the use of larger sample sizes, with the number of failures allowed dependent on the actual sample size as shown in Table A-1.
- During preliminary investigations of potential suppliers, accept/reject criteria do not need to be rigid (e.g., there does not need to be a specific value for the number of failures allowed).

In the case of the second exception listed above, the following objective applies.

O2-28 **[111v2]** If failures are found during preliminary investigations of potential suppliers, consideration of the particular supplier or device should be withheld pending failure analysis to determine the cause and extent of the problem.

Note that the LTPD value specified in this GR for any particular qualification test is generally either 10 or 20, and that the minimum sample sizes corresponding to those values are 22 and 11. Based on the information in Table A-1 for an LTPD value of 10, if one defective device is found in the original test of 22 samples, a second set of 16 samples could be drawn from the original population and tested. If there were no defective devices in the second set of samples, the product could be considered to have had 38 samples with one defective, and would pass at the 10% LTPD criteria. Similarly for an LTPD value of 20, if one defective device is found in the original test of 11 samples, a second set of 7 samples could be tested. If no additional defective devices are found, then the 20% LTPD criteria would be met.

2.1.3.7.2 Use of Nonconforming Devices for Qualification

In many cases, devices that do not meet the equipment manufacturer's (or device supplier's) performance specifications for minor reasons may be used for certain qualification tests, thus reducing the cost of qualification efforts. For example, a device that is outside a specification for optical wavelength or spectral width would normally be adequate for various physical characteristics tests (several of which are destructive) or stress tests.

R2-29 **[16v2]** The details on how to use nonconforming devices for qualification testing purposes, as well as information justifying that use, shall be clearly documented by the equipment manufacturer (or device supplier).

2.1.3.7.3 Treatment of Low Volume Parts

Even though they might be used in small quantities, the optoelectronic devices covered by this document are considered critical. As such, they generally do *not* qualify for any exemptions from the full qualification program.

R2-30 **[19v2]** Exceptions to a full qualification program due to usage in small quantities (or for other reasons) shall be justified by technical evidence and that evidence shall be available for review upon request.

2.1.3.7.4 Characterization Test Data for Additional Samples

O2-31 **[394]** In addition to the data obtained for the sample populations referred to in **R4-8 [110v2]** and Table 4-2, where feasible the equipment manufacturer should also obtain data on key parameters from the device supplier on a much larger population (e.g., 50 to 200 devices representing a minimum of three different date codes). Distribution statistics (e.g., minimum, maximum, mean, and 3σ) of the measured parameters should be compared to specification limits and design requirements to assure that adequate margins exist.

Note that the intent of **O2-31 [394]** is not to force a device supplier to perform a full set of characterization tests on a larger number of device samples than indicated by other criteria in this GR. Rather, it is to encourage a more thorough examination of particular parameters that are of critical importance to the performance of the device, can be measured on large numbers of devices at reasonable cost, and/or are likely to show significant variations relative to the allowable ranges of values.

2.1.3.7.5 Additional Considerations for Stress Tests

In general, the same test samples may be (or in one case, are required to be) used for more than one stress test to reduce the total number of samples required for qualification. However, a device failure that occurs in one test cannot be ignored or discounted as being the result of cumulative stress-induced damage, but must instead be counted as a failure in the current test. Thus, care needs to be taken when this approach is used.[5] Also, although stress tests are usually designed to detect one type of failure mechanism, other unexpected failure mechanisms often occur as well, and generally cannot be excluded from the test results. Exceptions are accidental damage or extraordinary circumstances.[6]

R2-32 **[145v2]** If the same sample of devices is subjected to multiple stress tests and the allowable range for a particular parameter that is measured as part of stress test pass/fail determination process is specified in absolute terms (e.g., the optical output power must be between –5.0 and 0.0 dBm), then the cumulative degradation shall be used for comparison with the pass/fail criteria that apply for the current test.

In contrast to the case described in **R2-32 [145v2]**, if the allowable range for a particular parameter is specified in relative terms (e.g., the change in the front-to-rear tracking ration must be less than 5%), then it is acceptable to consider only the changes that occurred as a result of the current test.

R2-33 **[33v2]** Unless otherwise specified (i.e., in the applicable test procedure, or because they were due to accidental damage or extraordinary circumstances), all failures observed in stress tests shall be counted and reported, regardless of the failure mode. Omission of any failures from the test results shall be clearly justified and the information related to those failures shall be available for review upon request.

2.1.3.8 Device Codes that Fail Qualification

Device types that fail any aspect of the qualification sequence are defined as failing the device's qualification evaluation.

O2-34 **[14v2]** Appropriate failure analysis and corrective actions should take place before any retest is attempted for device types that fail any aspect of the qualification sequence.

R2-35 **[15v2]** When the corrective action requires a significant change in the device materials, processing, assembly, or screening, the entire qualification sequence (not just the failed test) shall be repeated.

Conversely, if the corrective action is minor or the failure is determined to be the result of cumulative damage from a series of stress tests (see Section 2.1.3.7.5), then

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5. Except in cases where the same samples are specifically required to be used in certain tests, if cumulative damage is suspected to have caused a failure in the Xth test in a series of Y stress tests, then one approach could be to restart the series at the Xth test using a new set of samples. The results for tests 1 through X–1 would then be those obtained using the first set of samples, while the results from the second set of samples would be used for tests X through Y.

6. An example of accidental damage is a component lead that is broken due to mishandling. Extraordinary events might include electrical overstress due to a proven overvoltage or transient on the bias lines. However, these types of events are expected to be rare since appropriate protective circuitry and handling procedures will typically be in place as a normal precaution.

it may only be necessary to repeat the failed test or restart the series of tests beginning at the test in which the failure occurred.

R2-36 **[395]** The equipment manufacturer (or device supplier) shall provide and document justification in any case where only particular tests in the qualification sequence are repeated following a failure in that sequence.

2.1.4 Requalification

R2-37 **[34v2]** Requalification shall be performed by the equipment manufacturer (or device supplier) if significant changes in product design, materials, processing, assembly (including plant relocation), or screening are made for any reason (e.g., enhanced performance, cost reduction, quality or reliability problems in manufacturing or field use).

The nature of "significant" design or manufacturing changes needs to be clearly defined by the equipment manufacturer. In general, the definition needs to include any changes that could impact the performance, safety, quality or reliability of the product (e.g., a change in the method used to attach the fiber pigtail, a reduction in screening time, production start-up at another facility, new or different suppliers of materials or component parts).

R2-38 **[35v2]** The equipment manufacturer (or device supplier) shall document the conditions for which requalification is to be performed.

R2-39 **[36v2]** The equipment manufacturer's contract or purchase agreement shall require that suppliers notify them in advance of any changes in the design, materials, processing, assembly, or screening of the products.

O2-40 **[37v2]** In the absence of significant changes in the product, each family of devices should be requalified at a minimum frequency of once every 2 years unless an on-going reliability monitoring program that meets **R2-41 [38v2]** is in place.

The periodic requalification referred to in **O2-40 [37v2]**, which is also called "qualification maintenance" (or possibly other names) by some manufacturers, is meant to catch unexpected problems resulting from an accumulation of minor changes that typically occur over time in the product design and manufacturing process. As discussed below, different approaches can be used to avoid problems with staffing levels (for reliability engineers and test equipment operators) and environmental chamber capacity.

- A revolving sequence of tests that cover all of the qualification criteria in this document within a 2-year period (as opposed to performing all of the tests in parallel in a short time interval) is one way to spread out or possibly reduce the cost impact of the periodic requalification objective.

- Another possible way to reduce costs is to use sample sizes that are smaller than the minimum numbers given in the qualification criteria of this document. This would be acceptable for periodic requalification if the tests are repeated for the same product so that the total number of devices tested within the 2-year period satisfies the sample size requirements.
- A third approach uses shorter, but more frequent, performance of the stress tests. In this case the minimum test length would be consistent with the criteria for “provisional use” of these devices (see Table 2-1).

Note that in the second approach discussed above, a single device failure might or might not result in “failure” of the requalification effort, depending upon the total number of devices still to be tested. For example, if a test requiring an LTPD of 20% was split into two sequential groups of nine devices each (with one failure allowed in total), the test is not automatically a “failure” when one device fails in the first group. However, it would be a “failure” if one or more devices failed in each group.

As indicated above, in some cases a device supplier’s “reliability monitor” program can be an effective alternative to repeating some of the tests in requalification performed by the equipment manufacturer.

R2-41 **[38v2]** If results from a device supplier’s on-going reliability monitoring program are to be used as part of the requalification process (see **O2-40 [37v2]**), then:

- The program shall address the failure mechanisms that were addressed during product qualification
- The program shall be tied to failure mode engineering analysis
- The qualification results shall include critical process control information
- Results shall not be reported on a device family basis unless the equipment manufacturer is contacted and agrees on the definition of “family”
- No reliability problems shall have been identified from field returns
- The range of tests and conditions used in the monitor program shall meet or exceed the criteria given for requalification.

R2-42 **[396]** If a device is a member of a family and a reliability monitoring program that reports results on the basis of that family is being utilized, different device codes shall be used on a rotational basis.

2.2 Lot-to-Lot Controls

In addition to the qualification testing that is performed to initially establish the quality and reliability of a device, comprehensive controls are also needed to help ensure the quality and reliability of individual lots. As part of this, important performance requirements need to be clearly detailed in device specifications, and quality and reliability-oriented lot acceptance criteria need to be clearly established for each device or product family. In addition, test results for the products from each supplier need to be summarized periodically, and the quality performance of each supplier analyzed. Documented procedures need to clearly specify actions to be taken to correct problems or to disqualify suppliers that show substandard quality.

For optoelectronic devices, the lot-to-lot controls used to help ensure the quality and reliability of individual lots typically include visual inspections, electrical and optical testing, and screening. In general, it is not possible to adequately perform these tests once the optoelectronic devices are mounted on circuit packs. Therefore, individual device testing can be performed by the equipment manufacturer either at the supplier's location (source inspection) or at the using plant (incoming inspection). Alternatively, the equipment manufacturer and device supplier may agree to a "ship-to-stock" program, in which much of the responsibility for lot-to-lot controls is assumed by the device supplier. In addition, in some cases quality control standards such as ISO 9000 may be a satisfactory replacement for many of the criteria in this section (i.e., a device supplier's conformance to the standards may make conformance to certain criteria unnecessary).

The following subsections address lot-to-lot control issues that are common to all optoelectronic devices, while Sections 6 and 7 contain criteria that apply to specific types of optoelectronic and other devices, respectively.

2.2.1 Definition of a Lot

For the purposes of component lot-to-lot controls, a "lot" has traditionally been defined as a set of devices that meet the following conditions:

- The devices are manufactured by the same supplier and have the same device code and packaging
- The range of package date codes for the devices is less than 6 weeks
- Unless certain sampling and consistency criteria are met (see **R2-45 [39v2]**), the number of devices in the set is less than 5000.

In general, this definition was developed for, and can be directly applied to components made in a series of discrete batches of less than 5000 devices each [e.g., most Integrated Circuits (ICs) and transistors]. However, in many cases optoelectronic devices are not made in that manner. For example, some are made in continuous processes for which individual batches cannot be discerned. Conversely, others (laser diodes in particular) are fabricated in very large numbers from just a few slices of substrate material. In this latter case, a batch of devices (for delivery to the equipment manufacturer and assembly into modules) could last for 6 months or more. Therefore, the definition of a lot to be used for the purpose of meeting the criteria in this document varies as specified in the following criteria.

O2-43 **[40v2]** For optoelectronic devices that are manufactured in discrete batches (e.g., analogous to general components, or in large batches significantly spaced apart in time), the definition of a lot given above should be used.

O2-44 **[397]** For optoelectronic devices that are manufactured in a continuous manner without clearly defined batches, a lot should be defined as a practically sized group (i.e., of less than 5000 unless **R2-45 [39v2]** is met) made sequentially in time.

R2-45 **[39v2]** If the lot size for a device is defined to exceed 5000 parts, then sampling practices that positively ensure the random selection of components for inspection and test shall be implemented. In addition, the device supplier shall demonstrate product consistency within the lot.

R2-46 **[398]** If a different definition of a lot is used (i.e., if neither **O2-43 [40v2]** or **O2-44 [397]** is met), the equipment manufacturer (or device supplier) shall be able to provide technical justification supporting that definition.

R2-47 **[41v2]** The equipment manufacturer's (or device supplier's) definition of a lot shall be clearly documented.

Note that if a batch or shipment of devices is larger than the defined lot size, it can simply be split into smaller groups that meet the definition. Each of these groups is then considered to be a lot and is separately subjected to the full set of lot acceptance tests.

2.2.2 Purchase Specifications

R2-48 **[42v2]** Lot-to-lot controls shall be documented and shall be referenced in purchase specifications.

O2-49 **[43]** If devices are purchased pre-screened (e.g., with burn-in), the PDA should be specified in the purchase specifications.

2.2.3 Sampling for Lot-to-Lot Controls

In many cases, lot-to-lot controls are applied to 100% of the optoelectronic devices in a lot. However, as discussed in other sections of this GR, less than 100% of the devices may need to be subjected to lot-to-lot controls in some situations. In such cases, the use of AQL-based sampling as defined in ANSI/ASQC Z1.4, *Sampling Procedures and Tables for Inspection by Attributes*, is specified.

2.2.3.1 AQL-Based Sampling

In AQL-based sampling, the number of samples from a lot that need to be inspected or tested is determined by the factors listed below.

- Inspection procedure - This parameter is typically “normal,” but may be changed to “tightened” or “reduced” under certain circumstances as described in ANSI/ASQC Z1.4
- Type of sampling plan (i.e., single, double or multiple)
- Lot size (i.e., the number of devices in the lot)
- AQL - This is the designated value of percent defective devices that is considered acceptable (and for which lots will be accepted most of the time). It is analogous to the LTPD value in LTPD-based sampling (see Section 2.1.3.7.1).
- Inspection level - In general, this parameter is the primary factor in determining the probability that a lot will be accepted if the percentage of defective units in a lot is equal to the designated AQL value. It is somewhat analogous to the confidence level mentioned in Section 2.1.3.7.1, except that the user can select the general level of confidence by choosing any of three “General Inspection Levels” or four “Special Inspection Levels,” and that within a particular inspection level the probability varies somewhat with the lot size. Thus, in AQL-based sampling the confidence level is not fixed at 90% as it is in LTPD-based sampling.
- The number of defective samples allowed before the lot is rejected (i.e., a variable that is similar to the “C” value in LTPD-based sampling).

In particular, the lot size and the desired inspection level (typically General Inspection Level II) are used to determine the appropriate “code letter” (see Table A-2 in Appendix A). That code letter, the AQL, and the number of defective samples allowed before the lot is rejected (typically “0”) are then used to determine the sample size from the appropriate table, where the particular table depends on the inspection procedure and type of sampling plan. Two partial tables appear in Appendix A as Tables A-3 (normal/single sampling) and A-4 (normal/double sampling).

2.2.3.2 Treatment of Low Volume Parts

Since the optoelectronic devices covered in this document are considered critical, they are generally not exempted from any of the lot testing criteria.

R2-50 **[62v2]** When lot sizes are small and cannot justify or support the sampling plans for lot acceptance testing, the entire lot shall be subjected to all of the lot-to-lot controls except those that are considered to be destructive (if any).

R2-51 **[63]** The tracking of "low volume" device codes shall be included in the data collection and analysis procedures.

2.2.4 Source Inspection/Incoming Inspection

In general, lot-to-lot controls may be performed by the equipment manufacturer at either the supplier's location (source inspection) or the manufacturer's own location (incoming inspection).

R2-52 **[44v2]** Unless one of the exceptions discussed below applies, conformance to purchase specifications shall be assessed via lot-to-lot control procedures performed on individual devices by the equipment manufacturer at either the device supplier's location (source inspection) or the equipment manufacturer's own location (incoming inspection).

Under certain circumstances, ship-to-stock practices may be substituted for source or incoming inspection (see Section 2.2.10). Any other exceptions to traditional source or incoming inspection will be identified in specific criteria.

2.2.4.1 Use of Supplier-Provided Data

Data provided by the device supplier may also be used by the equipment manufacturer in lieu of self-performed lot-to-lot controls if an agreement is reached between the device supplier and equipment manufacturer, and the following criteria are met.

R2-53 **[66v2]** In cases where supplier-provided data is used for lot-to-lot controls, verifiable test results shall be provided (with the shipment of devices or within a time specified by the equipment manufacturer) for the manufacturer's records on lot quality.

R2-54 **[67v2]** The equipment manufacturer shall periodically audit the results provided by the supplier through a documented verification program.

2.2.4.2 Treatment of Internally Manufactured Devices

R2-55 **[68v2]** Devices manufactured internally by the equipment manufacturer itself, or by another division of the same parent company, shall meet the same lot-to-lot controls as specified herein for purchased devices.

If appropriate lot testing is performed at the equipment manufacturer's device manufacturing locations, this testing does not need to be repeated at other locations.

R2-56 **[69v2]** In cases where equipment assembly locations do not perform incoming inspections of optoelectronic devices made by another division of the company, the assembly locations shall have continuous access to the test results or follow the criteria for ship-to-stock devices. The equipment manufacturer shall also be capable of demonstrating that the correct tests are being run and that lot dispositions are being made properly.

Conformance to **R2-56 [69v2]** normally involves routine review of test results, plus regular technical meetings with the other divisions.

2.2.4.3 Controls for Devices Used in Purchased Modules

R2-57 **[127v2]** If completed modules (or integrated modules) are being purchased, the equipment manufacturer shall confirm that the supplier has appropriate lot-to-lot controls on the optoelectronic diodes or lower-level modules used in the purchased modules. The equipment manufacturer shall also meet periodically with the supplier to review data on the diodes or lower-level modules (in addition to purchased module data).

2.2.5 Lot-to-Lot Control Documentation

R2-58 **[46v2]** Individual device specifications shall either include the actual lot-to-lot control practices or reference the appropriate document(s) in which the practices are described.

R2-59 **[45v2]** When electrical and optical testing is used to confirm conformance to purchase specifications, a comprehensive testing plan shall be established and documented. The program shall cover the tests to be performed, the test methods (or references to those methods), test conditions, sampling levels, pass/fail criteria, data collection, and effective use of the data.

R2-60 **[399]** When screening is included in the lot-to-lot control process, a comprehensive screening plan shall be established and documented. The program shall cover such issues as the screens to be performed (e.g., burn-in, temperature cycling) and their conditions, the tests to be performed to determine if a device has failed during the screening process and the associated test methods and pass/fail criteria, the maximum acceptable infant mortality rate for a lot, and any conditions for discontinuing or reinstituting 100% screening (if applicable, see Section 2.2.6.3).

R2-61 **[48]** Lot-to-lot control procedures shall be subject to a document control program (e.g., dated, signed by appropriate management, and removed from use when superseded by newer versions).

2.2.6 Lot-to-Lot Control Test Areas

As indicated previously, the lot-to-lot controls used for optoelectronic devices typically include visual inspections, electrical and optical testing, and screening.

2.2.6.1 Visual Inspection

One portion of a lot-to-lot control program is a visual inspection of at least a subset of the devices in each lot.

R2-62 **[400]** Lot-to-lot controls for a device shall include visual inspections for outward signs of proper construction. The main inspection items shall be documented, and a minimum AQL of 2.5%, General Inspection Level II, shall be met.

R2-63 **[401]** For visual inspection at the diode level, the inspection items shall include confirmation of the following:

- Good attachment to the header, heatsink or other type of carrier
- Good wire bonding
- No (visible) damage from any rework
- Acceptable shipping or packing materials.

R2-64 **[402]** For visual inspection at the module (or integrated module) level, the inspection items shall include confirmation of the following:

- Proper marking (including marking permanence and legibility)
- Correct physical dimensions
- Good overall module construction, including no evidence of significant rework
- No damage to the fiber optic pigtail, connector or receptacle (if applicable)

- Acceptable shipping or packing materials.

2.2.6.2 Electrical and Optical Testing

In general, 100% of the optoelectronic devices in a lot need to be electrically and optically tested as part of a lot-to-lot control program. However, as indicated below, under certain conditions some or all of this testing may be modified to use a sampling approach, or deferred and performed on a higher level device. Note that these exceptions (which are referred to in **R6-2 [129v2]**) do not apply to parameters that are used as pass/fail criteria in any screening performed on the device.

1. Full (100%) electrical and optical testing by the equipment manufacturer is not required for devices that have been approved for a ship-to-stock program as described in Section 2.2.10.
2. Particular diode-level parametric measurements may be deferred to module-level testing if the module-level failures or “drop-outs” related to those parameters are below 1%, based on results for a total of 100 (or more) devices taken from at least 5 different wafers.
3. For laser diodes, if uniformity across the wafer is demonstrated, the far-field pattern measurement may be done on (as few as) 10 samples from various locations on the wafer.
4. If the equipment manufacturer is able to establish a statistically justified sampling plan for incoming modules (or integrated modules), that plan may be used instead of full (100%) testing.

R2-65 **[403]** In cases where diode-level testing is deferred due to exception 2 above, module-level drop-outs shall be monitored by a statistical process control program to confirm that the maximum allowed rate of 1% is not exceeded. The equipment manufacturer shall have plans for reinstating 100% diode-level testing upon detection of a higher drop-out rate.

2.2.6.3 Screening

In many cases, a lot’s overall reliability can be enhanced by using a screening process that removes “weak” devices. For optoelectronic devices, this process is typically performed at the diode or (in cases where the screening is being performed by the device supplier) wafer level, on other component parts, and at the module (or integrated module) level. In addition, it typically includes a burn-in step at the diode or wafer level, and both temperature cycling and burn-in steps at the module (or integrated module) level. Burn-in provides assurance that the devices will exhibit stable optical performance from the time of their initial use in the telecommunications system, and is also useful in detecting devices with latent ESD damage (which will sometimes result in abnormal changes in threshold current or other characteristics, and might not be observed in other "passive" tests, such as a high-temperature bake). Temperature cycling is useful in eliminating modules that have any instability in the optical alignment of the components (which is a critical aspect for long-term reliability of many modules).

Although screens are usually designed to detect one type of failure mechanism, other unexpected failure mechanisms can occur as well, and generally cannot be excluded from the test results, as they may provide useful information.[7]

R2-66 **[70v2]** Unless otherwise specified, all failures observed in screening shall be counted, regardless of the failure mode.

Normally, screening is performed on 100% of the devices in a lot, and as indicated in Section 6.3.1, it is generally required to be performed as part of the lot-to-lot control process for all optoelectronic devices. However, in some cases it may be possible to modify the process such that only a sample of the devices from each lot are subjected to the screening conditions and associated tests. In particular, this may be done if the results of the screens performed on previous lots indicate that they are unnecessary (i.e., the infant mortality failure rate is negligible). When this is done, the new process is called a "reliability audit." Unlike screening, reliability audits are not intended to remove weak devices, but are instead intended to detect (and trigger the rejection of) "rogue" lots of lower quality or reliability.

R2-67 **[404]** If screening of 100% of the devices in a lot is to be discontinued, the equipment manufacturer (or device supplier) shall provide justification for that decision, and shall institute a reliability audit program that utilizes the screening conditions and tests on a sample of the devices in each lot.

R2-68 **[405]** The equipment manufacturer (or device supplier) shall have documented procedures for dealing with lots that fail a reliability audit (e.g., reject the lot, or perform 100% screening on that lot), and shall also document the conditions under which 100% screening is to be reinstituted (e.g., if two consecutive or X out of Y lots fail the reliability audit).

2.2.7 Data Recording and Retention

R2-69 **[54v2]** All information relevant to lot-to-lot controls shall be recorded and retained for later review and summary. As a minimum, the collected information shall include:

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[7] For example, failures identified as ESD damage could indicate a need to improve device handling precautions.

1. The device code, supplier, lot size, and/or date code and/or serial number
2. The number of devices tested and the number of defectives found for each series of tests performed
3. The disposition of defectives, any follow-up required, and any other special notes (e.g., rejection of entire lot).

2.2.8 Summary of Supplier History Data

R2-70 **[59v2]** The equipment manufacturer shall periodically compile a summary of the results from the lot-to-lot controls performed on the devices from each device supplier. These summaries shall be available upon request.

Note that the summary results referred to above may be compiled as part of a “Supplier Management” program.

O2-71 **[60v2]** Suppliers with poor histories should be required to show corrective action, or else be removed from the ASL, if practical.

O2-72 **[61v2]** Reports detailing these data summaries and correspondence with device suppliers (regarding their corrective action efforts) should be retained for at least 5 years as evidence that an effective feedback program is in place and working.

2.2.9 Treatment of Defective Devices and Lots

R2-73 **[55v2]** Procedures that describe the appropriate practice for handling lots that fail any portion of the lot acceptance testing shall be documented and implemented.

Typical procedures for handling lots that fail lot acceptance testing include testing an additional sample of devices (e.g., if a double-sampling plan such as that shown in Table A-4 is being used) or returning the entire lot to the device supplier with a description of the problem.

R2-74 **[56v2]** The device supplier shall be required to provide timely feedback on the nature of serious or recurring problems and the corrective actions it has taken.

2.2.10 Ship-to-Stock Programs

Ship-to-stock or other alternative inventory programs that bypass “normal” source or incoming inspections are generally not appropriate for Quality Level I and II optoelectronic devices, but may be employed for Level III devices. In general, an equipment manufacturer may propose a ship-to-stock program for an optoelectronic device if it has quality and reliability data demonstrating a long-term history without any evidence of problems (at incoming or source inspection, in equipment manufacture, or from the field). If such a program is to be used, then the following criteria apply.

R2-75 **[51v2]** If a ship-to-stock program is to be used, then the equipment manufacturer shall clearly identify the affected optoelectronic devices, and shall fully document the details of the program.

R2-76 **[52v2]** The equipment manufacturer shall only approve devices for ship-to-stock based on one of the following:

- Individual device codes
- A family code where the device supplier has demonstrated that sufficient technological similarity exists to justify the approval (e.g., this may apply to DWDM lasers with different wavelengths).

R2-77 **[406]** If a ship-to-stock program is to be used for a device, the equipment manufacturer shall be able to demonstrate from incoming or source inspection records and field data (or substantiate via other means) a history of satisfactory quality and reliability performance for that specific device or, in the case of a new device, for the device's product family (see Section 2.1.3.2).

R2-78 **[407]** If a ship-to-stock program is to be used for a device, then either final test measurements on all parameters specified by the equipment manufacturer shall be provided by the supplier for each device and included as routine information with the shipped lot, or the supplier's lot-to-lot controls shall have been previously approved by the customer.

R2-79 **[408]** The equipment manufacturer shall obtain verifiable data for a subset of electrical and optical measurements on a random selection of ship-to-stock lots. At least 10% of ship-to-stock lots (on average) shall be subject to this.

R2-80 **[409]** Periodically, on an interval of 6 months or less, a lot shall be randomly selected by the equipment manufacturer and subjected to the full set of lot acceptance tests (in accordance with the relevant criteria in this document). All devices in the selected lot shall be tested.

R2-81 **[410]** The equipment manufacturer shall document specific criteria for approving and removing device codes from its ship-to-stock list.

R2-82 **[53v2]** A single rejection of a lot based on either:

- Failure to pass a random or periodic audit (**R2-79 [408]** or **R2-80 [409]**)

- Problems found in system manufacturing or from field returns

shall result in the device code being removed from ship-to-stock status.

R2-83 **[411]** When ship-to-stock practices are used, test results shall be made available in a timely manner for review by the organizations receiving and using the components.

It is crucial that the user organizations have quick access to quality and reliability data in order to implement special procedures when unusual results are noted.

2.3 Feedback and Corrective Action

In general, the backbone of an effective feedback and corrective action program is the timely collection and analysis of data. In addition, the information provided by such a program is essential in allowing organizations such as device engineering and QA/QC to have confidence that their in-place programs are proving effective.

Note that although the criteria in this section are worded such that they apply specifically to equipment manufacturers (since the necessary data collection cannot be performed by device suppliers), similar feedback and corrective action programs need to be considered by device suppliers to help control and improve their practices and products. Also note that in order for a device supplier's program to be effective, it is essential that their customers (the equipment manufacturers) provide, in a timely manner, appropriate information regarding the use of the device and any failures that have occurred.

R2-84 **[77v2]** In addition to any supplier-provided data that are received, an equipment manufacturer shall collect device-level failure data from (as a minimum) the following:

1. Incoming or source inspection and screening, or any tests associated with a ship-to-stock program
2. Each stage of equipment manufacture, including
    — Circuit pack test
    — Circuit pack burn-in
    — System-level test
    — System-level burn-in.
3. System installation
4. Repair of field returns.

The collected data shall be analyzed to identify any devices that are failing at higher than expected rates.

Although the analysis of the device drop-out and replacement data helps identify devices that are exhibiting high failure rates, this information will typically have limited utility without additional details on the actual (electrical and physical) causes of the device failures. Detailed findings of device failure analyses can be essential for determining a sensible corrective action plan.

R2-85 **[76v2]** The causes for device failures shall be determined for all common failure modes and summarized in order to help direct the corrective action effort (see Section 2.3.7). Equipment manufacturers shall either have their own internal failure analysis laboratories to perform detailed device failure analysis, or have arrangements with an independent test lab or the device supplier.

O2-86 **[75v2]** Device replacement data associated with the repair of field returns should be made available to the engineering organization responsible for the company's or division's reliability effort.

2.3.1 Lot-to-Lot Control Data

Data collected from the lot-to-lot control program would most directly indicate which device suppliers are consistently in control, and which suppliers need to take corrective action.

R2-87 **[78v2]** When problems are found during the lot-to-lot control program, the device supplier shall be formally notified of the problem. The supplier shall be required to respond with its assessment and any corrective actions that it has implemented.

Problems in correlating results (between testing by the supplier and testing by the equipment manufacturer) may show up at this point, but must be expeditiously resolved.

2.3.2 Circuit Pack Test and Burn-In

Yields at first circuit pack test and burn-in (if applicable) can give some immediate indication of circuit packs that need attention.

R2-88 **[79v2]** Device failure rates (for failures occurring during the circuit pack test and burn-in processes) shall be summarized by the equipment manufacturer for each device type. Such device summaries shall be accumulated for each circuit pack type, as well as across all circuit pack types.

Both types of device summaries are needed because a high device drop-out rate across many circuit pack types could indicate a device or assembly problem, while poor performance on only one or two circuit pack codes could indicate a marginal circuit design or application problem.

2.3.3 System-Level Test and Burn-In

As circuit packs are assembled into a system, devices must work properly with one another at speed and at operating temperatures. In addition, elevated temperatures can exaggerate marginal speed or parametric situations to the point that they cause failures, allowing them to be identified and corrected. Details on device drop-out rates can help point out subtle device problems (including specification inadequacies) or marginal circuit designs. Simple functional failures found at this stage could indicate an inadequacy in the earlier circuit pack test routines.

2.3.4 Repair of Field Returns

Based on the number of units shipped, equipment manufacturers can generally estimate the number of field failures that are expected for each component type. The confidence in this estimate depends on the number of devices in the field and their aggregate service time, with confidence improving as more device-hours are accumulated. Component types failing at higher than expected rates need to receive appropriate attention. However, expected failure rates based on a relatively few samples of a new design might be difficult to predict with the level of confidence desired; therefore, failure analysis may be necessary to resolve any questions.

O2-89 **[80v2]** Using predicted device failure rates for each device code, the equipment manufacturer should estimate the number of failures that would be expected for any given period of field use. Devices that are being removed (during the repair of field returns) at rates higher than expected should be examined to determine why the additional failures are occurring, and to ensure that a major problem is not developing.

2.3.5 Unconfirmed Circuit Pack Failures

A circuit pack (returned from the field) that cannot be confirmed as failed by the equipment manufacturer is known as a No Trouble Found (NTF), No Fault Found (NFF), or similar term. NTFs can indicate inadequate test procedures, marginal designs, unexpected compatibility problems between circuit packs or other reasons for concern.

R2-90 **[412]** NTFs shall be tracked as part of the data collection on field returns.

O2-91 **[84v2]** The equipment manufacturer should set a threshold for the rate of NTFs allowed for each type of circuit pack. When the rate for a type of pack exceeds its threshold, the causes should be investigated and corrected. The equipment manufacturer also should be prepared to explain and justify the NTF thresholds that it has set.

2.3.6 Data Collection and Analysis

R2-92 **[81v2]** The device drop-out/failure data collection system shall be implemented in such a manner that information can be compiled and analyzed for rapid feedback to all responsible groups (e.g., device engineering, QA/QC, manufacturing supervisors).

R2-93 **[82v2]** Reports summarizing device drop-out rates and circuit pack yields at various stages of assembly and test shall be issued on a periodic basis (no less frequently than every three months) for upper level management review. The report shall include the numbers of units received for repair, NTFs, units modified, and units repaired.

O2-94 **[83v2]** The reports required in **R2-93 [82v2]** should track the length of time that identified problems persist and the efforts to resolve them. As a follow-up in later reports, specific actions to confirm that a problem was corrected should be noted.

2.3.7 Device Failure Analysis

R2-95 **[85v2]** Due to their critical nature, all optoelectronic devices that fail in the field after less than one year of operation and are returned to the equipment manufacturer shall be subjected to failure analysis.

R2-96 **[86v2]** The equipment manufacturer shall document the conditions that mandate failure analysis of a representative sample of “bad” devices with similar failure modes.

R2-97 **[87v2]** The equipment manufacturer shall either maintain its own facilities or make arrangements (prior to actual need) with an independent laboratory or the device supplier to perform any necessary failure analysis.[8]

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[8] A complete failure analysis involves identifying the failure mode (e.g., open, short, etc.), the failure mechanism (i.e., the physical, electrical, chemical, thermal, or other process that caused the failure), and the most likely immediate cause of the failure.

2.4 Device Storage and Handling

R2-98 **[88]** The normal flow of optoelectronic devices from when they are received until they have been successfully tested in the circuit pack or system shall be clearly described in flow charts or other documentation.

2.4.1 Nonconforming Material

R2-99 **[89v2]** Devices and lots that do not conform to purchase specifications shall be segregated from good devices and from parts awaiting test.

2.4.2 Material Review System

R2-100 **[90v2]** Equipment manufacturers and device suppliers shall establish and document practices for handling all nonconforming materials.

R2-101 **[91v2]** If nonconforming product is to be used “as is” or after some form of additional testing or screening, appropriate component engineering and quality assurance engineers shall be involved in the decisions (through formal sign-offs on the authorization).

R2-102 **[92]** Detailed records on the disposition of all nonconforming material shall be maintained for at least 1 year. Summary records shall be retained for at least 5 years. Results shall be reviewed periodically to ensure that the same problems are not being encountered repeatedly.

R2-103 **[93]** Problems discovered in the quality system shall be resolved within a specified time limit using the corrective action or quality improvement process. The timeliness and effectiveness of corrective actions shall be monitored and documented.

2.4.3 Stockroom Inventory Practices

2.4.3.1 FIFO Inventory Policy

R2-104 **[94]** Stockroom practices shall be configured to ensure that a First-In/First-Out (FIFO) policy is being followed. Inventory practices and shelf stock shall be audited periodically to check the effectiveness of the current program, and to ensure that no device types are being held for excessive periods in storage.

2.4.3.2 Reworked Parts

R2-105 **[95v2]** All devices that are reworked shall be required to pass incoming inspection before they are returned to the stockroom.

2.4.4 ESD Precautions

ESD is a significant cause of device failures at all stages of production, test, installation and field use, and many optoelectronic devices are especially susceptible to ESD. Damage from ESD (e.g., localized heating or melting, typically affecting oxides or junctions) can cause such problems as complete device failure, parametric shifts, and device weakness. In addition, some devices may have shortened useful lives without obvious initial indications of damage.

Appropriate handling procedures can prevent damaging ESD events during equipment assembly and in the field. Effective ESD-prevention programs are known to be a major factor in the reduction of infant mortality and early life failures for electronic components in general, and the same can be assumed to be true for optoelectronic devices. Therefore, all personnel that handle optoelectronic devices, or boards that contain these devices, need to be aware of the potential damage that can be caused by ESD.

R2-106 **[96v2]** The equipment manufacturer and the device supplier shall define and document an ESD prevention program. This shall be a complete, factory-wide program, and shall clearly identify acceptable and unacceptable handling practices for loose components and assembled circuit boards.

R2-107 **[413]** The equipment manufacturer and the device supplier shall follow ESD precautions in the handling of devices. Where necessary, grounding bracelets and grounded table tops (and/or floors or floor mats) shall be installed. After installation, the integrity of the entire grounding system shall be checked periodically to ensure its continuing effectiveness.

R2-108 **[97]** Appropriate ESD-limiting packaging, handling trays, bins and shipping envelopes shall be selected and used in conjunction with optoelectronic devices. The use of non-treated plastic or styrofoam, in particular, shall be avoided around optoelectronic devices.

Detailed information and criteria on ESD testing and prevention are given in TR-NWT-000870, *Electrostatic Discharge Control in the Manufacture of*

Telecommunications Equipment. Included in that document are definitions of five ESD sensitivity classifications for devices, and criteria related to appropriate ESD preventative measures corresponding to those five classifications.

In addition to the handling considerations discussed above, in some cases it may be useful for equipment manufacturers and device suppliers to explore other methods of preventing ESD damage during the handling of devices prior to assembly onto circuit packs or (for devices that can be swapped out without requiring the replacement of a complete circuit pack) installation in NEs. For example, in some cases it may be possible to use protection circuits built onto the diode chip or included as part of the packaged device, or to use a mechanical part to shunt all of the optoelectronic device's (sensitive) leads together, thus preventing any difference in voltage between those leads.

2.5 Documentation and Test Data

As noted in many places throughout this document, all procedures, practices, and test methods related to reliability assurance need to be properly documented.

R2-109 **[99v2]** All reliability assurance procedures, practices, and test methods shall be documented. Such documents shall be officially recognized and formally controlled.

O2-110 **[100v2]** The equipment manufacturer's quality and reliability manual should identify any special reliability assurance requirements (e.g., testing, screening, handling) that are unique to optoelectronic devices.

Among the documents referred to in **R2-109 [99v2]** (and to which customers must have access, see **R2-113 [102v2]**) are the following:

1. Supplier approval practices
2. Device qualification procedures and requalification practices
3. Individual device specifications
4. Procedures for adding suppliers and devices to the ASL and APL
5. Procedures for removing suppliers and devices from the ASL and APL
6. Incoming or source inspection procedures
7. Screening practices
8. Storage and handling practices
9. ESD control programs
10. Data collection and analysis procedures

11. Procedures describing the handling, repair, failure analysis, and corrective actions associated with field returns
12. Internal auditing procedures to ensure all of the above procedures are being observed.

2.5.1 Availability of Documentation

To understand the reliability program of the equipment manufacturer or device supplier, background information is necessary. Similar information might also be needed in the resolution of field problems or other reliability issues.

O2-111 **[101v2]** Except in cases covered by **R2-112 [414]**, equipment manufacturers and/or device suppliers should provide the following information upon request:

1. Schematics and related information on the temperature control circuit (if used), transmitter circuitry, and receiver circuitry
2. The process flow chart highlighting inspection and testing
3. Device structure
4. Processing techniques
5. Submount carrier and heat sink materials, and adhesion material(s)
6. Assembly procedures (including baking and/or curing steps)
7. Module description
8. Alignment sensitivity
9. Re-work, etc.

R2-112 **[414]** The manufacturer/supplier shall provide a written explanation giving the reasons for any information listed in **O2-111 [101v2]** that it cannot provide (e.g., involving sensitive proprietary information).

R2-113 **[102v2]** The equipment manufacturer and/or device supplier shall make available to customers all documents relevant to its reliability assurance program for optoelectronic devices.

2.5.2 Availability of Other Information

Reviewers of documents related to reliability programs also need access to summary reports and test data to have confidence that the documented practices are actually followed. Where sensitive and/or proprietary information is involved, equipment manufacturers may be allowed to “mask off” sensitive items, or to ask reviewers to sign non-disclosure agreements.

R2-114 **[103v2]** The following information shall be available for review by customers upon request:

1. Long-term environmental stress test results on specific devices
2. Recent incoming or source inspection and screening data on specific devices
3. Drop-out rates or failure levels of specific devices at first circuit pack test, in circuit pack burn-in, at system test, in system burn-in, and from the analysis or repair of field returns
4. Failure analysis results for specific devices
5. Corrective action assignment and follow-up.

2.6 Availability of Devices

In some cases, equipment purchasers (or their representatives) might wish to obtain a small number of optoelectronic devices (typically less than 20) of a particular type for independent reliability tests or other analyses.

R2-115 **[104v2]** Equipment manufacturers shall formally respond to requests for sample devices (plus accompanying functional specifications or performance sheets) in a timely fashion, and shall refuse such requests only if there are extraordinary reasons that would make their fulfillment infeasible.

When such requests are made, the organization making the request would normally be expected to reimburse the equipment manufacturer for the costs of the components.

2.7 Environmental, Health, Safety, and Physical Design Considerations

2.7.1 Environmental Considerations

R2-116 **[28v2]** All optoelectronic products shall meet the applicable environmental regulations based on the authority having jurisdiction (e.g., federal/country, state, city).

2.7.2 Health Considerations

Personnel are strongly cautioned never to look directly into lasers or other light emitting optoelectronic components. Some of the components and materials covered in this document emit non-visible light that may be hazardous. Although most of the optical output power levels are not very high, there are exceptions such as pump lasers. In addition, virtually all of the optical power is concentrated into a narrow frequency band, which implies that the energy can be focused into a very intense spot on the retina by the lens within the viewer's eyes.

R2-117 **[29v2]** Light emitting components and materials shall be labeled according to appropriate standards and regulations.

Some related reference documents are (but are not limited to):

- IEC 60825-1, *Safety of Laser Products - Part 1: Equipment classification, requirements and user's guide*
- FDA CDRH CFR Title 21, Part 1040.10, *Performance Standards for Light Emitting Products*
- OSHA *PUB 8-1.7 – Guidelines for Laser Safety and Hazard Assessment.*

2.7.3 Safety Considerations - Flammability

Although many of today's optoelectronic products are deployed in the form of non-flammable hermetic (i.e., airtight) metal or ceramic packages, a desire for cost reductions is driving the design of non-hermetic packages, which may be flammable. In addition, the fiber pigtails used in many optoelectronic products (both hermetic and non-hermetic) are generally flammable and even allow fire propagation.[9] Thus, many optoelectronic devices need to be tested for flammability (see **R4-2 [106v2]** and Table 4-2), and the results need to be made available to customers.

R2-118 **[30v2]** The results of all flammability tests performed on optoelectronic devices shall be documented and made available to customers.

2.7.4 Physical Design Considerations

2.7.4.1 Hermeticity

Packaging costs, including the costs of the materials, assembly and testing, represent a major contribution to the cost of most modules containing optoelectronic devices, and in general those costs are greater if hermeticity must be provided. On the other hand, serious reliability problems due to moisture have historically been associated with non-hermetic packaging of optoelectronic

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[9] Fortunately, these materials are usually present in limited amounts and used in confined areas inside of the frame.

devices, and therefore many such devices have employed hermetic packaging. To reconcile this conflict (cost versus reliability), in some cases the hermeticity has been pushed from an external package such as a Dual-In Line Package (DIP) that contains most of the parts that make up the module (e.g., for a laser module, the laser diode, rear-facet monitor, TEC, thermistor, isolator, and fiber pigtail coupling mechanism), to individual device packages such as TO cans.[10] In addition, some manufacturers have developed facet coating techniques to move the hermeticity to the diode level, resulting in diodes that can be deployed in non-hermetic packages (e.g., packages of polymeric materials) and still provide reliable operations.

Independent of the level of hermeticity that is provided, technical data is needed to demonstrate that module performance is not affected by exposure to maximum- or minimum-rated environmental conditions or changes in those conditions (e.g., that moisture does not condense inside the module if there is a decrease in ambient temperature). In general, this is accomplished in tests such as the damp heat tests discussed in Section 3.3.2.3. In addition, since the success of a non-hermetic laser or LED module strongly depends on the facet coating provided on the diode, that coating needs to be carefully assessed in the qualification process (e.g., for appropriate thickness and uniformity).

2.7.4.2 Solder Flux

R2-119 **[21]** If soldering is used for any part of the interior assembly of the module (such as component assembly or attachment of the fiber pigtail), the solder flux shall be non-corrosive unless effective cleaning is performed.

The criteria for determining corrosiveness are given in GR-78-CORE, *Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment*, Section 13.1. Cleanliness tests include insulation resistance and solvent extract conductivity, as described in Sections 7.1.3.8 and 7.1.3.9 of GR-78-CORE.

Additional reliability tests might be needed if flux is used in a nonhermetic module.

2.7.4.3 Allowable Terminal and Lead Finishes

R2-120 **[64v2]** Device leads shall be finished in gold plate (for use with gold-contact sockets) or tin plate, or they shall be hot-solder dipped or solder clad. In addition, tin plate that contains less than 2% lead shall only be used if the tin has been subjected to a reflow process, subsequent to plating and lead forming, sufficient to relieve surface stresses and inhibit whisker growth.

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[10] In the latter case, if the full module includes a TEC, then it needs to be carefully designed to avoid any chance of moisture condensation on an optical interface.

O2-121 **[65v2]** The device leads should be checked periodically (with the frequency depending on the past conformance of the particular supplier) for conformance to purchase specifications.

3 Test Procedures

This section deals with test procedures and pass/fail criteria utilized in qualification, lot-to-lot control and accelerated aging tests that are applicable to optoelectronic devices. In addition, the topic of reliability calculations that can be performed using data obtained in certain of these (or similar) tests is discussed.

3.1 General Test Procedure Criteria

3.1.1 Standardized Test Procedures

To help ensure consistent results and allow correlation of data between device suppliers and equipment manufacturers and between equipment manufacturers and their customers, it is important for the same procedures to be used in tests and measurements. This need is a fundamental purpose of national and international standards efforts.

O3-1 **[72]** Procedures used in the performance of tests and the measurement of parameters required by this document should be performed in accordance with available national or international standards, unless otherwise specified in this document.

O3-2 **[73]** If conflicts occur between national and international standards, U.S. national standards should take precedence if the product is manufactured and marketed in the United States.

At the time this GR was issued, the following TIA/EIA Fiber Optic Test Procedures (FOTPs) and Optical Fiber System Test Procedures (OFSTPs) were among the standards that were available and relevant to the reliability assurance of optoelectronic devices:

- TIA/EIA-455-6B, *Cable Retention Test Procedure for Fiber Optic Cable Interconnecting Devices*, (FOTP-6)
- TIA/EIA-455-36A, *Twist Test for Fiber Optic Interconnecting Devices*, (FOTP-36)
- TIA/EIA-455-126, *Spectral Characterizations of LEDs*, (FOTP-126)
- TIA/EIA-455-127, *Spectral Characterization of Multimode Laser Diodes*, (FOTP-127)
- TIA/EIA-455-128, *Procedure for Determining Threshold Current of Semiconductor Lasers*, (FOTP-128)
- TIA/EIA-455-129, *Procedures for Applying Human Body Model Electrostatic Discharge Stress to Package Optoelectronic Components*, (FOTP-129)

- TIA/EIA-526-2, *Effective Transmitter Output Power Coupled Into Single-Mode Fiber Optic Cable*, (OFSTP-2)
- TIA/EIA-526-4A, *Optical Eye Pattern Measurement Procedure*, (OFSTP-4A).

3.1.2 Test Equipment

R3-3 **[49v2]** The equipment manufacturer (or device supplier) shall have access to the test equipment necessary to perform qualification and accelerated aging testing, lot-to-lot electrical and optical testing, and screening. This test equipment shall be maintained and calibrated on a regular basis (at least as often as recommended by the test equipment manufacturer).

O3-4 **[50]** Test equipment should be subject to the maintenance, calibration and other controls that meet the relevant criteria in ISO 9001.

3.1.3 Establishment of Pass/Fail Criteria

R3-5 **[108v2]** The equipment manufacturer (or device supplier) shall establish pass/fail criteria for the parameters measured in all characterization tests (including tests that are performed before and after stress tests, or as part of the lot-to-lot control process), and for all stress tests. In addition, end-of-life thresholds shall be established for each high-temperature accelerated aging test (although see the discussion in Section 5.2 regarding end-of-life thresholds for photodiodes). Where appropriate, the pass/fail criteria for a stress or accelerated aging test shall include visual inspection of the devices for physical damage.

R3-6 **[136v2]** The pass/fail criteria for the characterization tests performed on an optoelectronic device shall be consistent with the required limits and attributes described in the equipment manufacturer's purchase specifications for the device.

R3-7 **[415]** The equipment manufacturer (or device supplier) shall be able to provide technical justification for the particular values/limits used in all of its pass/fail criteria and end-of-life thresholds.

3.1.4 Alternative Test Conditions

In a number of cases, the procedures or conditions provided in this document for a test or operation include specific test times, temperatures and, in some cases, other variables such as optical power levels. In general, different combinations of these variables may be (or may need to be) used for the specified test or procedure.[1] However, in such cases the equipment manufacturer or device supplier needs to demonstrate that its conditions are at least as rigorous or effective as the conditions listed here. In addition, it should be noted that the test conditions identified in later sections correspond to minimum acceptable levels of stress. Equipment manufacturers and device suppliers certainly may, at their discretion, specify greater stresses.

R3-8 **[32v2]** Unless a different relationship has been shown to be applicable for a particular device, equivalent time and temperature conditions for tests focused on temperature-dependent failure mechanisms (e.g., high-temperature operations and accelerated aging tests) shall be calculated using the Arrhenius relationship (see Section 3.1.4.1). Acceleration models for failure mechanisms affected by other stresses [e.g., optical power, current, humidity or Relative Humidity (RH)] shall be demonstrated theoretically (if possible) and empirically. Any associated acceleration/deceleration factors shall be clearly identified.

3.1.4.1 Calculation of Equivalent Test Conditions

For the purpose of deriving equivalent test-time and temperature conditions for tests and procedures that are focussed on temperature-dependent failure mechanisms, it can be useful to express the Arrhenius relationship as shown in Equation 3-1:

$$\frac{D_2}{D_1} = e^{\left[\frac{1}{k}\left(\frac{E_{a2}}{T_2} - \frac{E_{a1}}{T_1}\right)\right]} \qquad \textbf{(3-1)}$$

where

D_1 is the test duration given in this GR

D_2 is the proposed or alternate test duration

k is Boltzmann’s constant (e.g., 8.618×10^{-5} eV/K)

E_{a1} is the assumed activation energy[2] associated with the test conditions listed in this GR (see Table 3-1)

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1. For example, due to differences in designs and assembly practices some devices may have constraints on the temperatures at which they will operate properly, and therefore may need to be tested for longer times at lower temperatures. Alternatively, in some cases it may be possible to significantly reduce the test time by utilizing much more stressful conditions. Such tests are sometimes referred to as Highly Accelerated Stress Tests (HASTs) and Highly Accelerated Life Tests (HALTs).

2. In the context of reliability assurance testing, it can be useful to consider a device’s activation energy as an “acceleration factor.” That is, if the activation energy for a particular aging or failure mechanism is very low, exposure to a temperature that is higher than the normal operating temperature will have a relatively small impact on the rate at which the device ages or fails. Conversely, if the activation energy is high, then high temperatures will significantly accelerate the rate of aging or failures.

E_{a2} is the proposed or alternate activation energy (see **R3-9 [124v2]**)

T_1 is the test temperature given in this GR converted to an absolute temperature scale (e.g., Kelvin)

T_2 is the proposed or alternate test temperature (in the same units as T_1).

Based on this, an equipment manufacturer could [if desired, and within certain limits (e.g., see Section 3.3.3.1)] reduce the time required for a test by demonstrating a higher activation energy and/or conducting the test at a higher temperature. Similarly, if for some reason it is necessary to perform a test at a lower temperature than that listed in this GR, it may be possible to avoid extending the test by demonstrating a higher activation energy.

3.1.4.2 Activation Energies

In general, the equipment manufacturer or device supplier that is performing high-temperature tests on a device is responsible for determining the activation energy (E_a) that is appropriate for that device (although in some cases an equipment supplier may obtain that information from the device supplier). Such information needs to be specific to the particular device since it is expected that different values could be found for different device designs and different manufacturers, and may be different for diodes versus modules. In addition, it is important to note that it is not appropriate to use the activation energy derived for the gradual degradation modes of wear-out failures in random failure rate calculations. It is expected that a majority of random failures will be due to assembly or packaging defects, which generally have lower activation energies (i.e., less temperature dependence) than most wear-out failure mechanisms.

R3-9 **[124v2]** If experimental or other supporting data for a device's activation energies is not available, the assumed activation energies listed in Table 3-1 shall be used in all associated calculations.

Table 3-1 Assumed Activation Energies

Device	E_a for Wear-out Failures	E_a for Random Failures
Laser Diodes	0.4 eV	0.35 eV
Laser Modules	0.4 eV	0.35 eV
LEDs	0.5 eV	0.35 eV
LED Modules	0.5 eV	0.35 eV
Photodiodes	0.7 eV	0.35 eV
Detector Modules	0.7 eV	0.35 eV
Receiver Modules	0.7 eV	0.35 eV
EA Modulators	0.4 eV	0.35 eV
External Modulators	0.7 eV	0.35 eV

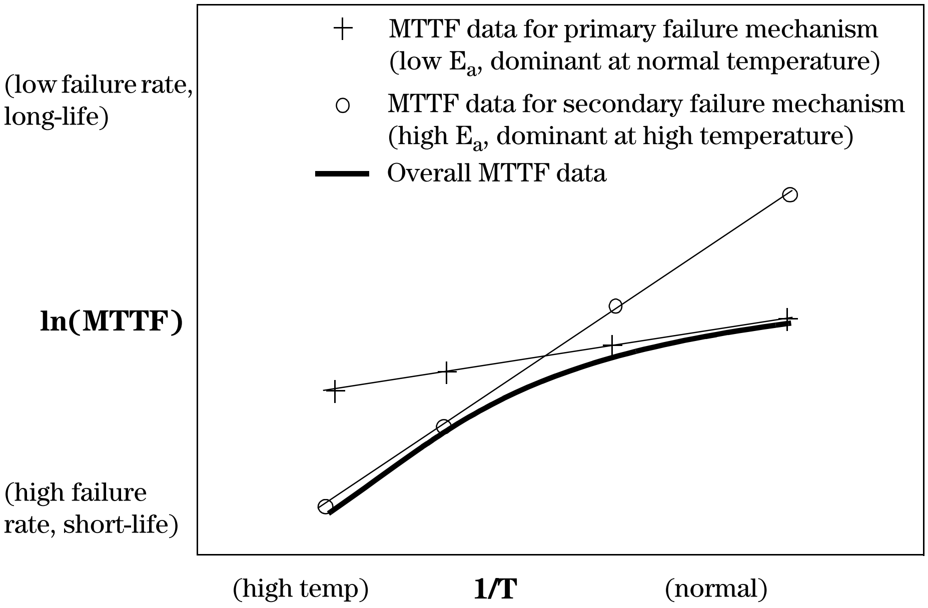
R3-10 **[416]** If activation energies other than those listed in Table 3-1 are to be used, they shall be derived from accelerated aging tests performed to failure (if possible) on a minimum of 25 samples at each of at least three different temperatures.

For example, the activation energy for wear-out failures for a laser diode could be determined by performing aging tests at +65°C, +85°C, and +105°C.

3.1.4.3 Additional Considerations Related to Multiple Failure Mechanisms

In general, high temperatures will accelerate both a device's primary failure mechanism (i.e., the mechanism corresponding to the particular type of failure that will predominate when the device is deployed in the network), and other, secondary failure mechanisms. In addition, in some cases the activation energies associated with the various failure mechanisms may be such that a secondary mechanism that is normally insignificant will become dominant at high temperatures (see Figure 3-1). In a high-temperature operations test, this could result in a device being unnecessarily disqualified (i.e., samples may fail during the test period due to a failure mechanism that will have a negligible impact at normal operating temperatures), while in a high-temperature accelerated aging test the impact will depend on the activation energy used in the various reliability calculations. For example, if the activation energy associated with the primary failure mechanism is used, then the failure rate and Mean Time To Failure (MTTF) calculations will be unnecessarily pessimistic. Conversely, if the (relatively high) activation energy associated with the secondary failure mechanism is used, those calculations will be inappropriately optimistic. In addition, alternate test conditions that are calculated using an activation energy that is “too high” will result in tests of insufficient length or levels of stress. Therefore in tests performed to determine the activation energy to use for a device, it is important to carefully specify the test conditions and examine the results for evidence of multiple failure mechanisms (e.g., a knee in the temperature versus failure rate data, failure analysis results that indicate separate mechanisms).

Figure 3-1 Example for Two Failure Mechanisms with Different Activation Energies



3.2 Characterization Test Procedures

This section contains information regarding a number of parameters and test procedures that are often used to characterize optoelectronic devices for the purpose of device qualification and lot-to-lot controls. In many cases, the parameters and test procedures that are applicable to a device are dependent on the particular type of device (e.g., the parameters and procedures that are used in the characterization of a laser diode are significantly different than those used in the characterization of a photodiode). However, as noted in the following sections and indicated in Tables 4-1 and 4-2, in some cases these parameters and procedures are applicable to several types of devices (e.g., lasers and LEDs).

3.2.1 Spectral Characteristics

In general, the spectral characteristics of a laser or LED at either the diode or module level are measured with the source operating at its nominal and/or maximum-rated optical output power levels, and with the maximum-specified modulation applied, if applicable. [Note that for lasers that are specified to operate in the continuous-wave mode (e.g., pump lasers, and lasers designed to be used in conjunction with external modulators), no modulation need be applied during these tests.] In addition, in many cases these characteristics are specified to be measured in the presence of a worst-case reflection (e.g., –8.2 dB) in the optical path.

For devices containing lasers, the spectral parameters of interest depend on such factors as whether the source is a Multi-Longitudinal Mode (MLM) laser or a Single Longitudinal Mode (SLM) laser (either fixed wavelength or tunable), whether the laser is directly or externally modulated, and the particular bit-rate. As discussed in the following sections, the parameters can include the central or peak wavelength or wavelength range, the spectral width, the Side-Mode Suppression Ratio (SMSR), Source Spontaneous Emissions (SSE), and the source frequency chirp factor (α). Previous issues of this document also included criteria related to the measurement of “secondary peaks/modes” and “spectral shape”; however, those criteria have been removed.[3] A primary reason for this is that the parameters that have been retained are likely to be affected by any problems related to the eliminated parameters, and therefore they should be sufficient in most cases. [For example, if the spectrum of an SLM laser includes two or more significant peaks (e.g., a main peak at the desired wavelength and one or more secondary peaks at other wavelengths), this will be reflected as a “fail” in the SMSR measurement.] In addition, the parameters that are currently listed are generally well defined and specified in a number of standards documents related to optical interface performance issues, while the eliminated parameters were only loosely defined in the earlier issues of this document.

3.2.1.1 Spectral Characteristics for MLM Lasers

In most cases, there are two spectral parameters that are of interest for an MLM laser. These are the central wavelength (λ_c), which is defined as the statistically weighted center of the laser’s optical spectrum, and the root-mean-square spectral width ($\Delta\lambda_{rms}$). These are calculated using the following equations:

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[3] Although the criteria in this document no longer indicate that they need to (or should) be used, an equipment manufacturer or device supplier may still decide to establish characterization criteria and perform measurements related to a laser diode’s secondary peaks/modes or spectral shape. In particular, this would be appropriate in cases where a significant correlation has been established between changes or anomalies in those specific parameters and degradations in system performance parameters such as receiver sensitivity and dispersion tolerance.

$$\lambda_c = \left(\frac{1}{P_o}\right) \sum_{i=-m}^{i=n} p_i \lambda_i \tag{3-2}$$

$$\Delta\lambda_{rms} = \left[\frac{1}{P_o} \sum_{i=-m}^{i=n} p_i (\lambda_i - \lambda_c)^2\right]^{0.5} \tag{3-3}$$

where

λ_i is the wavelength of the i^{th} peak

p_i is the power of the i^{th} peak

P_0 is the total power summed for all peaks from $i = -m$ to $i = n$:

$$P_o = \sum_{i=-m}^{i=n} p_i \tag{3-4}$$

As indicated in the preceding equations, the summations range from $i = -m$ to $i = n$. Unless specified otherwise, the corresponding wavelengths, λ_{-m} and λ_n, are the wavelengths on either side of the maximum peak beyond which all remaining peaks have powers (p_i) more than 20 dB below the maximum peak.[4]

As an example, consider the spectrum shown in Figure 3-2. Calculating the central wavelength and spectral width with Equations 3-2 and 3-3 gives λ_c=1300.2 nm and $\Delta\lambda_{rms}$=1.0 nm.

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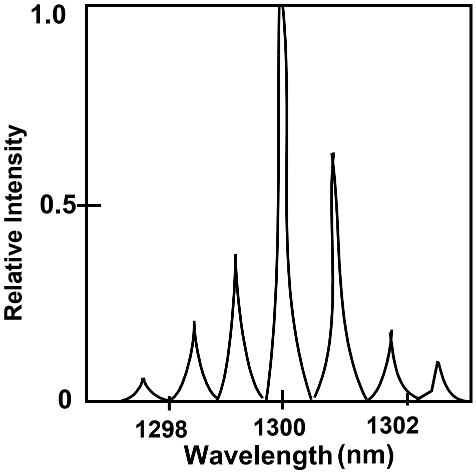
[4] If agreed upon by the equipment manufacturer and laser supplier, the calculations can be based on a narrower range of wavelengths (e.g., peaks out to 13 dB below the maximum).

Figure 3-2 Example of an MLM Laser Optical Spectrum

Relative Power	Wavelength [nm]
0.06	1297.5
0.13	1298.3
0.32	1299.2
1.00	1300.0
0.65	1300.8
0.18	1301.7
0.08	1302.5



Note that in the preceding example, the spectrum consists of a single mode group containing six secondary peaks (i.e., local maxima in the spectrum) grouped around a main peak at 1300 nm. While this type of spectrum is typical, in some cases a laser's spectrum may contain one or more secondary mode groups (i.e., additional sets of spectral peaks) separated from or partially overlapping the main mode group. Depending on the laser's intended application, the presence of secondary mode groups may indicate a problem (e.g., instabilities of the laser or other quality and reliability problems such as lattice defects in the active region), and thus in some cases the equipment manufacturer or device supplier may choose to make the absence of any secondary mode groups an explicit part of their pass/fail criteria. On the other hand, in many cases the impact of any secondary mode groups on the measured/calculated central wavelength and spectral width parameters is likely to be a sufficient indicator of any potential problems.

3.2.1.2 Spectral Characteristics for SLM Lasers

For SLM lasers, the primary spectral parameters of interest are typically the central or peak wavelength (λ_c or λ_p), the spectral width 20 dB down from the peak ($\Delta\lambda_{20}$), the SMSR, and in some cases the SSE. Unlike the MLM case discussed in Section 3.2.1.1, for SLM lasers the primary spectral parameters do not need to be calculated. Instead, they can be determined directly from the spectrum using the following definitions:

λ_c or λ_p – The wavelength at which the output optical power is the greatest

$\Delta\lambda_{20}$ – The full spectral width measured 20 dB down from the maximum of the central wavelength peak[5]

SMSR – The ratio (typically in dB) of the average optical power in the dominant longitudinal mode of an SLM laser to the optical power in the next most significant mode

SSE – The maximum background emission power level with respect to the lasing frequency peak power, typically measured over a 0.1 nm bandwidth and expressed in units of dBc/nm.

In general, the "next most significant mode" referred to in the SMSR definition given above could be a side mode (i.e., an incompletely suppressed mode that is part of the same mode group as the main peak), or a mode in a separate mode group. In either case, the optical power in that mode must be well below the power in the main mode, meaning that the SMSR must be more than some relatively large number such as 30 dB.

3.2.1.2.1 Considerations for Continuous Wave Lasers

In general, the spectral width of an SLM laser that is operating in the continuous wave mode (i.e., that is not directly modulated) will be extremely narrow, and whether or not it is larger than some maximum value may not be relevant in the laser's qualification and lot-to-lot control processes. On the other hand, for some applications it may be necessary to measure the spectral width of such a laser and compare the result to a specified minimum value. The reason for this is that if the spectral width of a high-power laser is too narrow, the Spectral Power Density (SPD)[6] may be large enough to cause Brillouin scattering, resulting in significant performance degradations.

In cases where the spectral width of a laser operating in the continuous wave mode is of importance (and therefore is included as a characterization parameter by the device supplier or equipment manufacturer) it will be necessary to utilize different measurement methods and equipment than are used in measuring the spectral width of directly modulated lasers and the SMSR of both directly modulated and continuous wave lasers. [While the spectral width of an unmodulated SLM laser is likely to be on the order of 10 MHz (corresponding to approximately 8×10^{-5} nm for a signal in the 1550 nm wavelength range), the bandwidth of an optical spectrum analyzer as used in spectral width measurements on directly modulated lasers is generally limited to a minimum of about 0.01 nm (corresponding to 1.25 GHz in the 1550 nm region).] For example, one possible method would be a heterodyne detection technique in which the optical signal of interest is combined with the output of a source with known spectral characteristics and a slightly different wavelength. The beat pattern that results is then measured using an electrical

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5. Note that in some cases a different spectral width may be specified for an SLM laser. For example, in some applications the spectral width of interest may be the Full Width at Half Maximum ($\Delta\lambda_{FWHM}$), which is the full spectral width measured 3 dB down from the maximum of the central wavelength peak. In addition, see Section 3.2.1.2.1 regarding the spectral width of lasers that are specified to be operated in the continuous wave mode.

6. The SPD is defined as the maximum power in any 10-MHz band of a signal's optical spectrum.

spectrum analyzer, providing the information necessary to calculate the spectral width of the original signal.

3.2.1.2.2 Considerations for WDM Lasers

The primary difference between the lasers used in most Wavelength Division Multiplexed (WDM) applications and the lasers used for other fiber optic communications applications is the need, in the WDM case, for a stable and narrow spectrum centered at a specific wavelength (or frequency[7]). This means that even a small shift/offset in the central (or peak) wavelength typically needs to be considered in determining whether a WDM laser passes various qualification and lot-to-lot control tests, and when it is considered to have reached the end of its life in accelerated aging tests.

Although they are almost always much more stringent than for non-WDM lasers, the wavelength accuracy requirements for WDM lasers are still significantly affected by the particular intended applications. For example, based on the criteria in GR-2918-CORE, *DWDM Network Transport Systems with Digital Tributaries for Use in Metropolitan Area Applications: Common Generic Criteria*, a metro DWDM system may use channel spacings ranging from 50 GHz (i.e., about 0.4 nm) to 800 GHz (6.4 nm). The wavelength accuracy requirements for those systems then range from ±3 GHz (±0.024 nm) to ±40 GHz (±0.32 nm). Thus, a laser whose wavelength accuracy is significantly worse than the requirement for one metro DWDM application may be perfectly suitable for use in another such application. In addition, lasers that cannot be used for even the least stringent DWDM application may be suitable for use in more recently defined Coarse WDM (CWDM) applications, which utilize much larger channel spacings and therefore have less stringent wavelength accuracy requirements (possibly allowing the use of uncooled lasers).

In general, the level of wavelength-measurement accuracy that is necessary in the testing of at least some WDM lasers (e.g., DWDM lasers) is beyond the capabilities of optical spectrum analyzers. On the other hand, even the most stringent levels of accuracy can typically be provided by a properly calibrated wavelength meter with correction factors for the temperature, pressure and humidity at which the measurement is performed. (Note that each of these factors has an impact on the index of refraction of the air in which the wavelength measurement is made, and thus affects the conversion of the directly measured wavelength to the vacuum wavelength that is needed for comparison to the applicable specifications.)

One last important point is that many WDM devices are expected to depend on components other than just the laser diode to control the wavelength. Thus, in some cases it may not be possible or meaningful to measure the wavelength and

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[7] Note that in many cases the wavelength-related criteria for WDM lasers are specified in units of frequency (e.g., GHz, THz) rather than units of length (e.g., nm). On the other hand, the particular units used in the criteria should have no impact on the test methods used to measure the various parameters, as the results can be readily converted between the different units.

other spectral characteristics of a WDM laser at the diode (or possibly even module) level, while in other cases the pass/fail criteria for tests performed at the diode level may be significantly less stringent than the corresponding criteria for tests performed at higher levels of assembly.

3.2.1.2.3 Considerations for Tunable Lasers

Similar to the case for fixed wavelength SLM lasers, the spectral parameters of interest for a tunable laser are generally those defined in Section 3.2.1.2 (i.e., the central or peak wavelength, possibly the spectral width, the SMSR, and in some cases the SSE). The difference is that the performance of the device with respect to these parameters needs to be verified at a variety of wavelength settings covering the laser's entire specified wavelength operating range. At a minimum for tunable lasers in general, each of the parameters needs to be measured with the device set to operate at its minimum specified wavelength, a wavelength near the center of the specified range, and the maximum specified wavelength, while for lasers that are designed to be tuned in discrete steps (e.g., tunable in 25 or 50 GHz steps corresponding to the ITU-T frequency grid), the central wavelength measurement needs to be performed at each of the supported wavelength settings. In addition, the ability of the device to meet the applicable wavelength accuracy specifications needs to be verified in both cases where the setting is varied frequently and cases where the same setting is maintained over the long term (also see Section 3.3.3.1.2). Finally, it should be noted that the accuracy of the wavelength measurements for these lasers will generally need to be similar to that for other lasers used in WDM applications (see Section 3.2.1.2.2).

3.2.1.2.4 Considerations for High Bit-Rate Applications

In general, the performance of high bit-rate optical systems can be significantly affected by chirp, which is the change in an optical signal's spectrum that occurs, for example, as the source laser is turned "on" and "off" (i.e., as it is modulated). This effect is sometimes characterized in terms of a parameter called the source frequency chirp factor (α), which is defined as:

$$\alpha = \frac{\frac{d\varphi}{dt}}{\frac{1}{2P}\left(\frac{dP}{dt}\right)} \qquad \textbf{(3-5)}$$

where φ is the optical phase of the signal and P is the signal power. In almost all cases, α is a function of time and is specified in terms of a range of acceptable values when measured at a particular time (e.g., during a particular transition that occurs periodically in a SONET signal). Using this definition, a positive chirp parameter corresponds to a positive frequency shift (blueshift) during the rising edge of a pulse, and to a negative frequency shift (redshift) during the falling edge of the pulse. According to ITU-T Recommendation G.691 *Optical interfaces for single* *channel STM-64 and other SDH systems with optical amplifiers*, a modulator typically has a chirp parameter of –1 to +1 rad, while the turn-on transient of a standard laser may have a chirp factor of 10 to 100 rad.

In some applications the impact of chirp can be beneficial (e.g., the central wavelength may be shifted such that a pulse's initial leading/trailing edges travel through the optical fiber slightly slower/faster than the rest of the pulse, leading to pulse compression over some range of fiber lengths), while in other cases the effect will be strictly adverse. In any case, the impact on system performance needs to be determined. In addition, if that impact is found to be significant, then appropriate limits need to be set and tests performed to verify that a device's chirp characteristics will allow it to perform satisfactorily in its intended applications.

O3-11 **[112v2]** For high bit-rate systems (above ~2.5 Gb/s), laser chirp should be examined by the equipment manufacturer to determine the effect on the system Bit Error Ratio (BER).

O3-12 **[335v2]** EA modulators should be examined by the equipment manufacturer to determine the effect of chirp on the system BER.

3.2.1.3 Spectral Characteristics for LEDs

In general, any of three parameters may be used to specify and report the wavelength of an LED or an LED module. These are defined as follows.

- *Peak Wavelength* (λ_p) – The wavelength exhibiting the highest power in the device's optical spectrum
- *Central Wavelength* (λ_c) – The statistically weighted center of the LED's optical spectrum
- *Average Wavelength* (λ_a) – The average of the two wavelengths at which the optical power has dropped to half of its peak value.

Similarly, either of two spectral width parameters may be used for LEDs. These are defined as follows:

- *Full Width at Half Maximum* ($\Delta\lambda_{FWHM}$ or FWHM) – The width of the optical spectrum between the wavelengths where the power has dropped to half of the peak value
- *Root-Mean-Square Spectral Width* ($\Delta\lambda_{rms}$).

Detailed measurement and calculation procedures for most of these parameters can be found in FOTP-126.

3.2.2 Output Power/Drive Current Characteristics

As discussed in the following sections, a number of important parameters used in the characterization of a laser or LED are related to the optical output power from the device, often as a function of the applied drive current (in which case the output power/drive current data is referred to as the “L-I curve”).

3.2.2.1 General Output Power and L-I Curve Measurement Considerations

Listed below are a number of general issues related to optical output power and L-I curve measurements.

- In some cases, the optical output power from a laser or LED module (or an integrated module containing a laser or LED) may be specified to be within some fixed or user-selectable range, and in such cases it is important to verify that the modules meet those specifications. In many cases this measurement can be performed using a procedure similar to that described in OFSTP-2, *Effective Transmitter Output Power Coupled Into Single-Mode Fiber Optic Cable*. As indicated in that document, it is the optical power that can be coupled into the downstream optical component (e.g., the optical fiber plant or an external modulator) that is of interest, and therefore the test setup used in the procedure includes a 3-inch diameter fiber loop that causes any power that has been launched into higher order transmission modes (a.k.a., cladding modes) to be attenuated.
- Also as indicated in OFSTP-2, if it is necessary to use a test fiber jumper to connect the module to the optical power meter (e.g., if the module includes a connector housing into which a connector on the end of an external fiber is inserted), then the quality of the connection between the jumper and the module can have a significant impact on the optical coupling, and therefore on the measured power. To account for this, the procedure involves disconnecting and reconnecting the jumper a number of times, recording the power after each reconnection step, and calculating the average effective transmitter power. In addition, the following issues (none of which are discussed in OFSTP-2) should be considered.
    - — In cases where a device’s optical output power is specified to be less than some maximum value, any single measurement with a result greater than that value would indicate that the device does not meet the specification (even if the average effective transmitter power is less than the specified maximum).
    - — To avoid degradations that might impact the test results, fiber jumpers that are used for purposes such as qualification testing are typically specified to be able to be connected/disconnected some maximum number of times before they are replaced. Therefore, such jumpers are generally serialized, and the particular jumper used and number of times it is connected and disconnected needs to be recorded.

- — In general, it is expected that the variations in the measured optical power will be smaller from one trial to the next in cases where the same fiber jumper is used in each trial than in cases where different jumpers are used. Therefore, in situations where a device's output power needs to be measured multiple times and the results compared (e.g., during a high-temperature accelerated aging test), it is generally preferable to use the same jumper each time. In addition, in some cases it may be possible (and appropriate) to leave the jumper connected while the stresses are applied, while in other cases that would be inappropriate (e.g., during storage tests, which are intended to simulate stresses that might occur before a product is deployed).

- — In cases where it is necessary to change fiber jumpers during a test in which a device's output power is being measured multiple times and the results compared (e.g., because the fiber has been connected and disconnected the specified maximum number of times, see above), the jumper-to-jumper variations can be determined by making measurements with both the old and new jumpers at the time of the change. The difference between those measurements can then be used to adjust subsequent measurements made with the new jumper.

- Although a number of the parameters related to the L-I curve may be of particular importance for lasers and LEDs that are intended to be directly modulated, the measurement of the L-I curve itself is typically made with the device in the continuous wave (or possibly pulsed, see below) mode of operation.

- Due to the impact of temperature changes on a laser's L-I relationship, the ambient temperature needs to be tightly controlled (e.g., to within ±0.2°C) when these measurements are being made.

- If the laser is contained in a module that includes a TEC, the TEC needs to be set for normal operations. In cases where no TEC is present, the measurements can be made under pulsed (rather than continuous) operation in order to avoid self-heating effects.

- In addition to temperature changes, optical reflections into a laser or LED can also perturb the L-I curve. Therefore, care must be taken to minimize or eliminate reflections in the optical path.

- In performing tests related to the L-I curve, it is important to obtain enough data points to allow the parameters of interest to be calculated. This can be done, for example, by varying the drive current continuously through the range of interest, or by choosing a sufficiently small step size in cases where the measurement is digitized.

3.2.2.2 Laser Threshold Current

A laser's threshold current is the minimum current at which the optical output is dominated by stimulated emissions rather than spontaneous emissions. As discussed below, three methods of analyzing L-I curve data to determine the threshold current are commonly used. In general, each of these methods should give approximately the same result.

- *Method I (Two-Segment Fit):* Fit a straight line to the linear portion of the L-I curve just below the knee and another line above the knee.[8] In general, multiple data points and a linear regression or similar technique needs to be used to fit the lines, although straight lines drawn through two points (each) may be acceptable if adequate linearity of the L-I curve is demonstrated on a periodic basis. The threshold current is defined as the current at the point of intersection of the two lines.
- *Method II (First Derivative):* Take the first derivative of the L-I curve (i.e., dL/dI). The threshold current is then defined as the current at which the derivative reaches one-half of its peak value (along the steep leading edge of the curve).
- *Method III (Second Derivative):* Take the second derivative of the L-I curve (i.e., d^2L/dI^2). The threshold current is then defined as the current corresponding to the peak in the second derivative. This is the preferred method for determining the threshold current.

Note that in both Methods II and III, caution needs to be exercised regarding "kinks" in the L-I curve. In particular, a kink could produce the maximum value of the first or second derivative that is unrelated to the threshold current. On the other hand, the discrepancy should be obvious if the L-I curve is plotted.

3.2.2.3 Laser Threshold Current Temperature Sensitivity

As noted previously, a laser's threshold current can be significantly affected by temperature, and for some applications that effect may be of similar or greater interest (in the characterization of the laser) than the actual threshold current values. In general, the effect can be expressed as shown in Equation 3-6, where T_0 is called the "characteristic temperature" and is a constant for any particular laser diode.[9] For a laser with a large T_0 (high characteristic temperature), the impact of

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[8] The knee is defined as the drive current associated with the maximum value of the second derivative, which as noted in Method III, is also the preferred definition of the threshold current. In most cases, its approximate location can be discerned directly from the L-I curve, making it unnecessary to actually obtain the second derivative when Method I is used.

[9] Note that in order for the exponent in Equation 3-6 to be dimensionless, the units for T_0 must be equivalent to those for T_1 and T_2. By convention, T_0 is generally given in "K" (Kelvin), corresponding to T_1 and T_2 in either C (Celsius) or K.

temperature changes on the threshold current is relatively small, while that impact is relatively large if T_0 is small (low characteristic temperature).

$$I_{TH}(T_1) = I_{TH}(T_2) \times e^{\left[\frac{T_1 - T_2}{T_0}\right]} \tag{3-6}$$

Solving for T_0 results in Equation 3-7.

$$T_0 = \frac{T_1 - T_2}{\ln[I_{TH}(T_1)] - \ln[I_{TH}(T_2)]} \tag{3-7}$$

In cases where the characteristic temperature is used in the characterization of a laser, the recommended temperatures for measuring the threshold current values needed to calculate that parameter are the maximum specified operating temperature (e.g., +70°C or 343 K) and room temperature (e.g., +20°C or 293 K). Typical values of T_0 are in the range from 45 to 90 K.

3.2.2.4 Output Power Levels at Particular Current Levels

3.2.2.4.1 Laser Output Power at the Threshold Current

To avoid adverse effects that can occur (e.g., to the optical spectrum) when a laser begins to lase, a directly modulated laser for digital applications is typically biased slightly above threshold. Thus, the output power at threshold effectively defines the minimum power that can be transmitted when the laser is in the “off” state (e.g., when the transmitted bit is a ‘0’). This in turn limits the possible extinction ratio or modulation depth that can be achieved when the laser is modulated, and eventually the sensitivity of the receiver receiving the transmitted signal.

3.2.2.4.2 LED Output Power

For an LED, the primary optical output power of interest is the output power at the device’s normal operating current (i.e., P_{op}). This can be obtained from the L-I curve if a consistent relationship can be demonstrated between the results for continuous and modulated operation. However, if such a relationship cannot be shown, the optical output power will need to be obtained from a separate test that simulates actual (modulated) operation.

3.2.2.5 Linearity of the Laser L-I Curve

In general, all three of the linearity-related parameters discussed in the following sections are applicable to lasers used in digital applications. On the other hand, for lasers intended for use in analog applications, the overall linearity is the primary parameter of interest.

3.2.2.5.1 Overall Linearity

Three methods for measuring/calculating the overall linearity of a laser's L-I curve are discussed below. In general, the first of these methods is preferred for lasers that are specified for use in digital applications, while Method II is used for analog-application lasers.

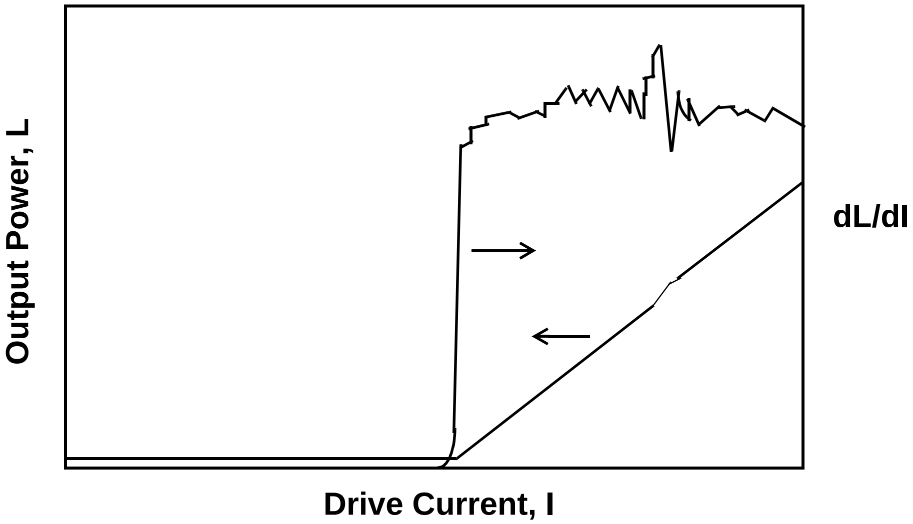
- *Method I (dL/dI):* Take the first derivative of the L-I curve (i.e., dL/dI) and fit a straight line to the (relatively) constant portion of the resulting dL/dI versus I plot between the knee in the L-I curve and saturation (e.g., between the drive currents that resulted in 10% and 90% of the laser's maximum-rated optical output power). The overall linearity is then defined as the maximum difference between the straight line and the dL/dI values. In general, this procedure can be performed in conjunction with the kink test (see Section 3.2.2.5.2).
- *Method II (Harmonics):* Bias the laser at about 50% of its maximum-rated optical power output and then use sinusoidal modulation (e.g., at the maximum-rated frequency) to sweep back and forth over the full operating range. Capture the light output using a linear detector and feed the electrical output from the detector into a spectrum analyzer. Second order (or higher) harmonics in the resulting spectrum are evidence of nonlinearities, and the amplitudes of those harmonics can be compared to appropriate limits.
- *Method III (Graphical Analysis):* Mark the points on the L-I curve that correspond to 10% and 90% of the maximum-rated optical output power and draw a straight line through those points. The linearity is then determined by the largest deviation from the line.

3.2.2.5.2 Kinks

Similar to a number of other parameters related to the drive current/output power relationship, kinks in a laser's L-I curve are generally identified and quantified using a plot of dL/dI versus I. However, unlike those other parameters, the kink criteria and measurements are primarily concerned with the changes in dL/dI in response to very small changes in the drive current (i.e., bumps and abrupt changes in slope in the L-I curve). Therefore, the methods used to measure and process the data may need to provide a finer level of resolution than is necessary for the other parameters. Alternatively, the pass/fail criteria may need to be adjusted to compensate for the lack of resolution or any smoothing techniques inherent in the data measurement and processing system.

Figure 3-3 shows an example of an L-I curve with a possible type of kink, and the resulting plot of dL/dI.

Figure 3-3 Example of L-I and dL/dI Curves With a Kink



3.2.2.5.3 Saturation

Saturation is the drop-off in the slope of the L-I curve from an ideal linear response that occurs in all lasers above some (relatively high) drive current. In general, this effect is quantified in terms of the decrease in the magnitude of dL/dI relative to its maximum value, and a laser is considered unacceptable if it becomes saturated at too low of a drive current/optical output power level.

3.2.2.6 Laser Slope Efficiency

The slope efficiency of a laser is the ratio of the change in optical output power to the change in drive current for some particular range of output powers (i.e., the slope of the L-I curve), and is generally expressed in units of Watts per Amp. For directly modulated lasers intended for use in digital applications, the range of output powers of interest is typically between the output power in the “off” state (e.g., when the bit being transmitted is a ‘0’) and the output power in the “on” state (e.g., when the bit being transmitted is a ‘1’). Those powers are in turn related to more commonly specified parameters such as the minimum and maximum allowable average output power levels and the minimum extinction ratio or modulation depth.

In most cases, a laser’s slope efficiency will decrease (degrade) with increasing temperature. Therefore, in comparing the slope efficiency results obtained from one test with specifications or the results of earlier tests (e.g., the “before” results for a laser undergoing stress tests), the test temperature is an important consideration.

3.2.2.7 Relative Intensity Noise

Relative Intensity Noise (RIN) is a measure of the amplitude fluctuations in the laser's optical output. In particular, it is the ratio of the mean square optical intensity noise to the square of the average optical power:

$$\mathrm{RIN} = \frac{\langle \Delta P^2 \rangle}{P_0^{\,2}} \qquad \textbf{(3-8)}$$

It is usually expressed in units of dB/Hz, and is typically specified to be measured over some particular frequency range (e.g., 10 MHz to 10 GHz for a 10 Gb/s device) and in the presence of a worst-case reflection in the optical path.

3.2.2.8 EELED Superluminescence

Superluminescence is an effect that can occur in an Edge-Emitting LED (EELED) if the drive current is increased past the level at which spontaneous emissions begin to be amplified before exiting the structure. When this occurs, the result is large, nonlinear changes in the device's output power in response to small changes in its drive current. In general, the current and corresponding output power at which superluminescence occurs can be determined from the EELED's L-I curve, and in many applications these values mark the maximum possible limits for proper operation of the device.

3.2.2.9 EELED Lasing Threshold

Another effect that can limit the operational drive current and output power of an EELED is the existence of a lasing threshold. Similar to the case for superluminescence described above, the presence of a lasing threshold (and/or the current level/output power at which it occurs) can be determined from the EELED's L-I curve. In general, this effect is primarily of concern at low temperatures.

3.2.3 Laser Voltage-Current Curve

Along with a laser's threshold current and corresponding optical output power level, the forward voltage at threshold [V_F(TH)] can be an important parameter to be specified and measured in the characterization process. In addition, if the forward voltage is recorded in conjunction with the L-I curve measurements, a voltage-current (V-I) curve can be plotted and examined for any unusual behavior that may be cause for the laser to be rejected or subjected to additional testing. (For example, degradations at reverse biases could indicate leakage problems.)

3.2.4 Modulated Output Characteristics

Unless specified otherwise in the description of a particular parameter, the measurements described in the following sections need to be made at the maximum specified modulation rate of the transmitter in which the laser, LED or modulation device will be used. In addition, the bias and modulation currents generally need to be set at their nominal (system design) values. (Note that in the case of the bias current, this is typically slightly above the threshold current.)

3.2.4.1 Modulated Signal Shape

Depending on the intended application and level of assembly at which a laser, LED or modulation device is being tested, it may be appropriate to characterize the shape of the modulated output signal in terms of either its eye pattern, or its rise and fall times. For example, if a laser diode is specified to be modulated at a relatively low rate and is being tested using external test drive circuitry, then the rise and fall times will generally be the parameters of interest. Conversely, if a laser module designed for use in SONET OC-192 applications is being tested, then the eye pattern is likely to be the specified and tested parameter.

3.2.4.1.1 Eye Pattern

For many fiber optic transmission applications, the shape of the transmitted optical signal is specified in terms of a mask into which the measured eye pattern (or eye diagram) needs to fit. Therefore, it may be convenient and useful to perform eye pattern tests during the characterization of lasers, LEDs or modulation devices used in those applications. In addition, information obtained in an eye pattern test may be needed in the calculation of the values of other parameters such as the extinction ratio or modulation depth (see Section 3.2.4.2).

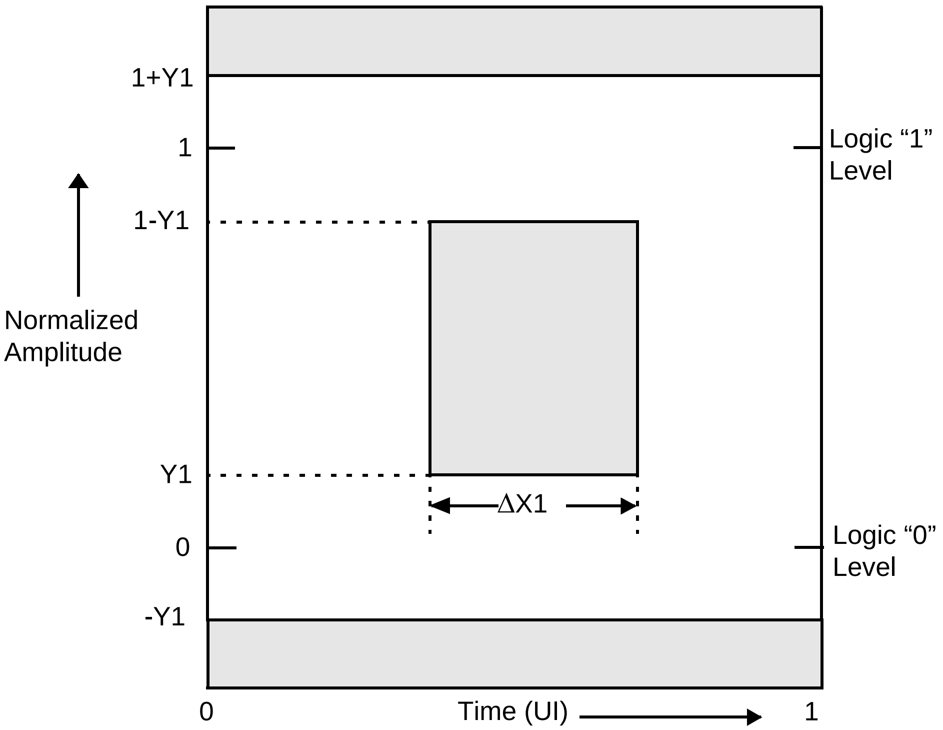
Typically, an eye pattern test is performed using a digital sampling oscilloscope and a procedure such as that given in OFSTP-4A. Key factors in the performance of eye pattern tests include the following.

- Cutoff frequency of the measurement setup - For most applications, the eye pattern is specified to be measured using a particular type of low-pass filter with a certain cutoff frequency (e.g., for SONET applications, a fourth-order Bessel-Thomson filter with a cutoff frequency at three-quarters of the signal bit rate). This can significantly reduce the amplitude of any overshoot or undershoot that may occur when the optical source transitions between the “off” and “on” states, and is similar to the type of filtering that a typical optical receiver would be expected to provide.

- Response of the measurement setup - In general, the response of the measurement system needs to be "flat" from DC to the cutoff frequency of the specified low-pass measurement filter. This is particularly important for the proper determination of the optical power transmitted in the "off" state (e.g., when the bit being transmitted is a '0'), for use in extinction ratio or modulation depth calculations.
- Data accumulation trigger - In a proper eye pattern, the data points stored by the oscilloscope need to be representative of essentially all of the bit patterns that are expected to occur in the signal (with the most important bits in the patterns being those for several bit periods immediately prior to the bit that appears in the eye pattern, the bit that appears in the eye pattern, and the bit immediately after the bit that appears in the eye pattern). Thus, the transmitted signal must not contain a short fixed data pattern, and the signal used to trigger the oscilloscope must not be synchronized to a particular data pattern [e.g., to a particular bit in a Pseudo Random Bit Sequence (PRBS) pattern].

Figure 3-4 shows a typical eye pattern mask. In the figure, a UI is a "Unit Interval" (i.e., one bit period), the shaded areas are the areas in which the signal is not allowed to appear, and the appropriate values of *Y1* and Δ*X1* depend on the particular application.

Figure 3-4 Example Mask for High Bit-Rate Signal Eye Pattern Test



3.2.4.1.2 Rise and Fall Times

As illustrated in Figure 3-5, the rise time (t_r) is the time required for the leading edge of the modulated light pulse to go from 10% to 90% of full amplitude. Similarly, the fall time (t_f) is the time required for the trailing edge of the light pulse to drop from 90% to 10% of full amplitude. For relatively low to moderate modulation rates, these parameters can be obtained using a photodetector, an oscilloscope, and the following equations:

$$t_r = [t_{r_{obs}}^2 - t_{r_{inp}}^2 - t_{det}^2 - t_{scope}^2]^{0.5} \quad \textbf{(3-9)}$$

$$t_f = [t_{f_{obs}}^2 - t_{f_{inp}}^2 - t_{det}^2 - t_{scope}^2]^{0.5} \quad \textbf{(3-10)}$$

where

$t_{r_{obs}}$ and $t_{f_{obs}}$ are the rise and fall times of the optical output observed on the oscilloscope

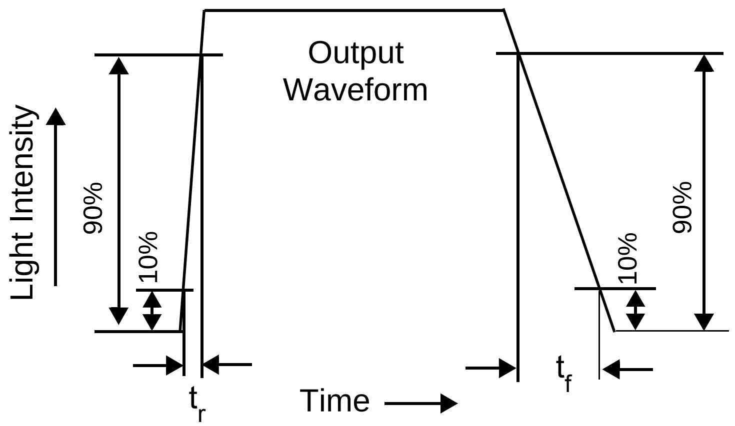
$t_{r_{inp}}$ and $t_{f_{inp}}$ are the rise and fall times of the electrical input pulse

t_{det} is the detector response time

t_{scope} is the oscilloscope response time.

In many cases, the last three terms in these equations can be made negligible (by using a high-speed photodetector, large bandwidth oscilloscope, and drive circuitry that is able to produce an essentially rectangular electrical input pulse), and in those cases the times observed on the oscilloscope can be compared directly to the applicable criteria.

Figure 3-5 Rise and Fall Time Definitions



For higher modulation rates at which it is not possible to record individual waveforms with the necessary resolution, rise and fall times may still be able to be determined using Equations 3-9 and 3-10 and eye patterns recorded on digital sampling oscilloscopes (possibly without the low-pass filter discussed in Section 3.2.4.1.1). In particular:

- If the eye pattern is relatively "clean," then the various times can be determined in essentially the same manner as indicated above for lower modulation rates.
- If there is significant blurring of the rising and falling edges observed in the "normal" eye pattern, it may be due to pattern-dependent behavior such as small variations in the turn-on delay and/or rise time that depend on the number of zeros preceding a pulse. In such cases it may be possible to resolve the blurred edges into a number of relatively clean edges by synchronizing the oscilloscope's sampling function with the occurrence of particular bit patterns (and to specify the rise and fall time criteria as being applicable for a particular pattern).

Finally, in some cases it may not be possible to specify and measure the rise and fall times with sufficient accuracy and resolution to make them useful for qualification or lot-to-lot control testing purposes. In those cases, the eye pattern is the parameter of interest related to the shape of the modulated optical signal.

3.2.4.2 Extinction Ratio and Modulation Depth

Extinction ratio (r_e) and modulation depth (P_{mod}) are very similar parameters related to the different levels of optical power transmitted or passed by a laser, LED or modulation device under fully modulated conditions (and typically in the presence of a worst-case reflection in the optical path). More specifically for digital applications, the extinction ratio is the ratio of the average optical energy in the "on" state (e.g., when the bit being transmitted is a '1') to the average optical energy in the "off" state (e.g., when the bit being transmitted is a '0'), and the modulation depth is the difference between those two levels. In many cases the extinction ratio is specified in dB and the modulation depth is specified as a percentage, and in such cases the following equations apply.

$$r_e = 10 \times \log\frac{E_R(1)}{E_R(0)} \tag{3-11}$$

$$P_{mod} = \frac{E_R(1) - E_R(0)}{E_R(1)} \times 100 \tag{3-12}$$

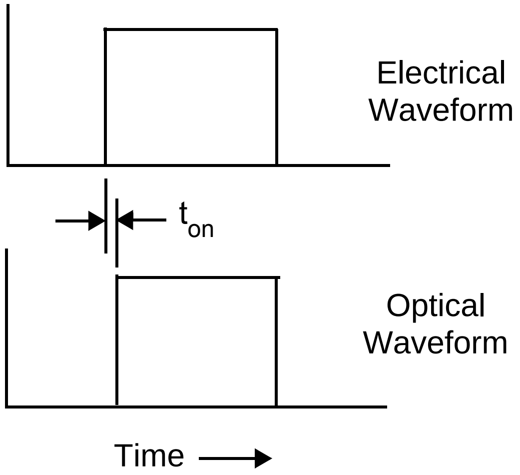
In these equations, $E_R(1)$ and $E_R(0)$ are the two average optical energy levels expressed in linear units. These levels can generally be obtained by calculating the areas under specified portions of an "eye pattern" measured as described in

Section 3.2.4.1.1. Note however, that it is essential for the response of the measurement system (e.g., the O/E convertor, amplifier, oscilloscope) to be linear in order to allow for the accurate measurement of $E_R(0)$. [In the extinction ratio case, since $E_R(0)$ is much smaller than $E_R(1)$, small errors in its value can result in large errors in r_e. In the case of modulation depth, small errors in $E_R(0)$ result in small errors in P_{mod}, but the range of acceptable values of P_{mod} is relatively limited.] Also note that in some cases (particularly for modulators), the parameter of interest in this area is referred to as the on-off contrast ratio.

3.2.4.3 Turn-On Delay

The turn-on delay (t_{on}) is the time required for the leading edge of the modulated light pulse to reach 10% of full amplitude after the electrical “on” signal is applied. This is illustrated in Figure 3-6 for “ideal” waveforms. Note that in order to obtain accurate values of t_{on}, the types and lengths of cables (or other transmission lines) used to interconnect the device and the test equipment must be carefully selected.

Figure 3-6 Measurement of Turn-On Delay



3.2.4.4 Cutoff Frequency

The cutoff frequency (f_c) is the modulation frequency at which the amplitude of the modulation envelope drops 3 dB from its full value, where “full value” is defined as the amplitude measured at a specified modulation frequency that is less than or equal to 0.01 times the expected cutoff frequency.[10] In general, the cutoff frequency

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[10] Note that for a laser the “full value” will not necessarily be the same as the “maximum value,” as effects related to the laser’s relaxation resonance frequency may result in peaking at a frequency less than, but relatively close to, the cutoff frequency.

will be affected by the bias current, and therefore it is important to perform the test using that parameter's normal value. In addition, the measurement is typically performed using a conventional small signal response test setup, and the photodiode and measuring apparatus used to detect and measure the light output must have adequate bandwidth for the expected range of frequencies.

3.2.5 Tunable Laser Characteristics

Listed below are several additional parameters that may need to be included in the characterization of a tunable laser. Additional information about these parameters (e.g., specific test methods) may be provided in a future issue of this document.

- Frequency Tuning Time (t_{tuning}) – The longest time delay between the receipt of a tuning request (from any channel to any channel) and the emission of a light beam with the desired frequency and the specified performance characteristics
- Module Warm-Up Time (t_{warmup}) – The longest time delay between module power-up and the point at which the module is able to successfully execute a tuning command
- Optical Power While Off-Channel or Disabled (P_{tuning}, $P_{disabled}$) – The maximum power emitted by the laser when the lasing frequency is not within the specified frequency limits for the given channel (typically measured while the module is tuning and when the module's optical output is disabled, and expressed in dB).

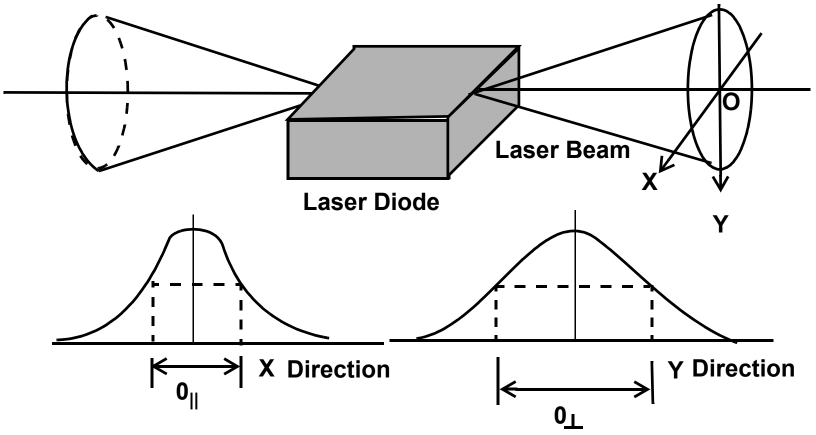
3.2.6 Optical Output Fields and Component Alignment

3.2.6.1 Far-Field Pattern

Although it is not a parameter that is (or even can be) specified for telecommunications end-products, a laser's far-field pattern can have a significant impact on the coupling of the transmitted signal into a fiber, and variations in that pattern (from the expected pattern) can be indicative of quality problems. Therefore, the testing set-up needs to provide adequate resolution and sensitivity to show any anomalies, and the pass/fail criteria need to be selected such that significant anomalies are flagged as failures while normal or expected variations are not.

In general, a laser's far-field pattern is characterized in terms of two "Full Width at Half Maximum" angles. These are the angles at which the power measured in the plane parallel ($\theta_{||}$) or perpendicular ($\theta_{\perp}$) to the laser's active layer corresponds to one-half the peak value (see Figure 3-7).

Figure 3-7 Laser Far Field Pattern Measurement



3.2.6.2 Coupling Efficiency

Coupling Efficiency (CE) is the ratio of the optical power measured at the fiber optic pigtail to the actual output power of the laser diode or LED. Because of (common) correlation problems between different power meters, the concern usually is the variability or trends in the coupling efficiency within or between production lots (rather than the absolute value of CE).

The coupling efficiency of a laser or LED module is typically determined by measuring the optical power of the diode (before assembly into the module) at a specified drive current and repeating the measurement at the same drive current for the module (but now at the output of the fiber pigtail). The recommended current is the value required to reach 50% of the diode's rated optical output power. The ratio must be no less than some minimum specified value.

3.2.6.3 Front-To-Rear Tracking Ratio Deviation

The front-to-rear tracking ratio deviation measurement is concerned with changes in the ratio of the optical output powers at the front and back of a laser (coupled, in the case of a laser module, to the transmission medium and rear-facet monitor, respectively) as a function of the drive current/output optical power. Certain reliability problems such as damaged facets can cause changes or degradations in this ratio. Due to physical constraints, the recommended test method, which is given below, is slightly different for laser diodes and laser modules.

1. For a laser diode, measure the optical output powers at the front and rear facets for a selection of drive currents. Similarly for a laser module, measure the coupled optical output power and the photocurrent at the rear-facet monitor for a selection of drive currents. For both diodes and modules, the selection of

drive currents needs to cover a range that results in front output optical power levels from less than 20% to 120% of the maximum-rated output power.

2. For each drive current, divide the front (facet or coupled) output power by the rear facet power or monitor photocurrent, and plot the result against either the drive current or the front output power.
3. Draw a horizontal line through the data points for use in the following step. In general, this line may be a best-fit straight line with a slope of zero, or it may be a horizontal line drawn through a specific data point such as the point that corresponds to 90% of the maximum-rated optical output power.
4. Measure the largest deviation from the line.

For both laser diodes and laser modules, the deviation must be less than some specified value.

3.2.6.4 Front-To-Rear Tracking Error

The front-to-rear tracking error measurement is concerned with changes in the ratio of the optical output powers at the front and back of a laser resulting from temperature changes. In general, it can be used to detect alignment changes that might occur in a laser module as the temperature varies. Such alignment changes are typically largest when the temperature offset (between the nominal operating temperature and the current operating temperature) is greatest. Therefore, this test involves measurements made at a minimum of three temperatures, with those temperatures being the module's specified minimum, maximum and nominal (or room) operating temperatures.

To perform this test, the laser's drive current is adjusted so that the rear-facet monitor photocurrent is maintained at a constant value corresponding to the rated front optical output power level (at the nominal operating temperature). The front-to-rear tracking error is then calculated using the following equation:

$$\text{F/R Tracking Error (T)} = \frac{[P_f(T) - P_f(T_{nom})]}{P_f(T_{nom})} \tag{3-13}$$

where $P_f(T_{nom})$ is the front power at room temperature, $P_f(T)$ is the front power at the other temperature (i.e., the minimum or maximum operating temperature), and the rear power (P_r) does not appear in the equation because it is a constant that has been cancelled out.

3.2.6.5 Polarization Extinction Ratio

The Polarization Extinction Ratio (PER) is defined as the ratio of maximum and minimum optical powers coupled into an output fiber as measured through a rotating polarizing filter. It is typically specified to be greater than some minimum value, and expressed in dB.

3.2.7 Modulator Optical and Electrical Characteristics

Direct modulation of a laser has historically been the most common method used to superimpose an electrical signal onto an optical carrier. However, that method is limited to (relatively) low data rates and/or short distance applications. As the data rates and distances increase, other techniques need to be used to overcome the modal and spectral dispersion degradations that can occur. These other systems often consist of an SLM laser operating in the CW mode, and a separate modulating component (i.e., a modulator).

Modulators are available in two basic configurations: EA modulators and external modulators. These are discussed in the following sections, along with a number of additional optical and electrical parameters that may need to be included in their characterization processes. Additional information about these parameters (e.g., more specific test methods) may be provided in a future issue of this document.

3.2.7.1 EA Modulator Characterization

EA modulators either pass or absorb light depending on the applied voltage. These are generally manufactured with technology similar to that used to manufacture lasers, and in most cases the modulator is simply a section of a laser chip. Advantages of EA modulators include small size, low driving voltages, high speed, and fairly low chirp.

Many of the characterization parameters for EA modulators (and their associated lasers) are very similar to those for directly modulated lasers (although in some cases their measurement can be more difficult and have higher uncertainty due to the non-linearity of the modulator). These include parameters that are primarily dependent on the laser portion of the device and are performed with the modulator in the full "on" mode (e.g., spectral characteristics, certain parameters related to output power and drive current), alignment/coupling issues, and a number of parameters that are performed with the laser powered and a Radio Frequency (RF) driver connected to the modulator section. In this last case, the device's performance is a function of both the modulator and the driver, and therefore the selection of the driver is a very important consideration.

In addition to the various parameters described in previous sections, several new parameters are likely to be useful in the characterization of an EA modulator. These include the following.

- Electrical Return Loss (S_{11}) – The amount of RF electrical energy reflected back from the modulator when it is being driven by a source with the specified impedance (e.g., 50 ohms). This parameter, which is typically expressed in dB, is a strong function of the RF frequency.

- Bandwidth (S_{21}) – The RF frequency range over which the modulator is designed to perform.
- Modulation Voltage (V_{mod}) – The maximum RF voltage required to drive the modulator to a specified extinction ratio at any frequency within its full bandwidth range.
- Dispersion Penalty (DP) – The reduction in the apparent sensitivity of a reference receiver as a result of the modulator's output signal traversing a length of fiber having specified chromatic dispersion characteristics. This parameter (which is very closely related to the chromatic dispersion tolerance parameter defined for receivers in Section 3.2.9.2) is generally expressed in dB, and calculated with respect to the receiver's sensitivity when the fiber length/dispersion is negligible (although see the discussion below). This is done by measuring BER versus received power data for both the short-fiber and specified-dispersion cases. The resulting data is then plotted and (if necessary) the curves are extrapolated to the BER at which the receiver sensitivity is specified. The difference between the curves at that BER is the dispersion penalty.

Note that for EA modulators intended for use in certain applications,[11] the acceptable chromatic dispersion characteristics of the fiber may be specified in terms of both a maximum value and a minimum value. In such cases, it is expected that the apparent sensitivity of the reference receiver will be worse in the short-fiber case than in the minimum and maximum specified-dispersion cases. Thus, for some modulators it may be necessary to measure dispersion penalties for both the minimum- and maximum-specified dispersion relative to a different baseline (e.g., relative to some "ideal-dispersion" case).

3.2.7.2 External Modulator Characterization

External modulators are typically manufactured by fabricating optical waveguides in the form of Mach-Zehnder interferometers into various substrate materials that have high electro-optic properties (i.e., materials whose indices of refraction change with the application of electric fields). The most common substrate material is lithium niobate, but other material platforms are also available. In any case, both RF and control electrodes are added to apply the electric fields and thus control the optical output of the interferometer. These devices are typically offered as external packages with input and output optical connections in addition to the various RF and control electrical connections.[12] In addition, they generally require special control circuitry, and can be sensitive to the wavelength and state of

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[11] For example, "pre-chirp" applications, in which the reach of the optical system is extended by controlling the chirp characteristics and distorting the shape of the transmitted pulses such that the pulse shape improves as the signal traverses some initial portion of an optical fiber path.

[12] Many of these devices require an external control loop that adds a DC bias voltage, either to a set of control electrodes, or through a bias-T network to the RF electrodes.

polarization of the input optical signal. Relative to EA modulators, they are generally larger and more complex, and can require higher voltage drivers. On the other hand, they generally have excellent chirp characteristics, and therefore have been a primary choice for long-line DWDM systems.

Since an external modulator is generally a stand-alone device with both input and output optical connections (i.e., since it does not include a laser), the various optical parameters discussed in Sections 3.2.1 through 3.2.3 above are generally not applicable (at least until the device is incorporated into a laser module or integrated module). On the other hand, many of the parameters related to the modulated operation of lasers and LEDs (see Section 3.2.4) can also be applied to external modulators. In addition, several parameters (or variations of parameters) discussed in Sections 3.2.6 and 3.2.7.1 also apply to external modulators. These include S_{11} and S_{12} (the electrical return loss and bandwidth, see Section 3.2.7.1), the PER (which for an external modulator is the ratio of the output signal power at the optimal state of launch polarization to the output signal power at the worst state of launch polarization, both with the modulator in the full on position), and the following parameters that are closely related to the modulation voltage parameter discussed in Section 3.2.7.1.

- RF Drive Voltage (RF $V\pi$) – The RF voltage at a particular frequency or bit rate required to take the modulator from the on state to the off state.
- DC Drive Voltage (DC $V\pi$) – The DC (or very low frequency) voltage required to take the modulator from the on state to the off state.

Finally, parameters that are specific to external modulators include the following.

- Operating Wavelength Range (λ_{op}) – The range of wavelengths over which the modulator is designed to perform
- Maximum Optical Input Power (P_{max}) – The maximum optical input power that can be accommodated by the modulator on a continuous basis
- Insertion Loss (IL) – The optical power loss through the modulator when it is in the full on state
- Input Optical Return Loss (ORL) – The ratio of the input optical power to the optical power reflected back into the input fiber. [This parameter (which is typically expressed in dB) is measured with all other fibers connected to low back reflection devices, and is typically measured with the modulator in both the on state and the off state.]

3.2.8 Photodetector Characteristics

3.2.8.1 Efficiency

The efficiency of a photodetector is typically specified in terms of either of two closely related parameters. These are the responsivity (R), which is the ratio of the output photocurrent (I_{ph}) to the incident optical power (P_0), and the quantum efficiency (η_Q), which is defined as the number of electrons produced per input photon. The equations for these parameters are shown below.

$$R = \frac{I_{ph}}{P_0} \qquad \textbf{(3-14)}$$

$$\eta_Q = \frac{I_{ph}}{P_0} \times \frac{1240}{\lambda(\mathrm{nm})} \qquad \textbf{(3-15)}$$

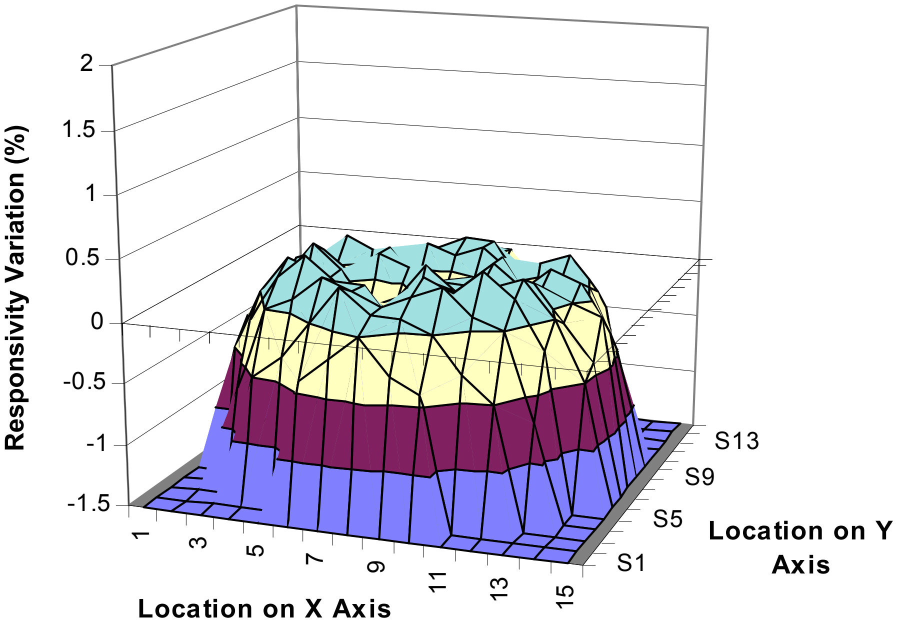
In general, values of these parameters can vary significantly with such factors as the wavelength of the incident signal. Therefore, the measurement needs to be performed under a specified set of test conditions. Commonly used test conditions are:

- Ambient temperatures of 25°C and the device's minimum and maximum specified operating temperatures (i.e., three separate measurements)
- Incident optical power of 100 µW
- Optical wavelength of 1310 nm or 1550 nm
- Reverse bias of 5 V (for *p-i-n* photodiodes) or M=10 [for Avalanche Photodiodes (APDs)].

3.2.8.2 Spatial Homogeneity

Although it is discussed in Section 3.2.8.1 as if (for a given set of test conditions) it is a constant, the responsivity or quantum efficiency of a photodetector will actually vary across the surface of the detector. This variation, or lack of spatial homogeneity, needs to be relatively small for the portion of the detector that will be active when the detector is deployed. For device qualification, the responsivity values measured at various locations across the surface of the device are typically normalized to the responsivity at the center, possibly plotted as shown in Figure 3-8, and checked against specified limits.

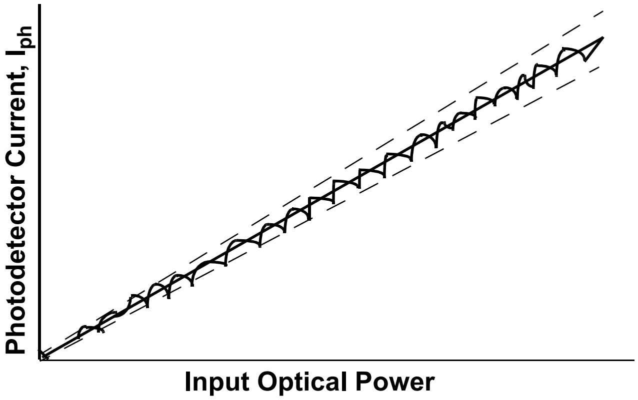
Figure 3-8 Example of Spatial Homogeneity Test Results



3.2.8.3 Linearity

Another important parameter in characterizing the response of a photodetector is its overall linearity (or deviation from linearity). Using a light source of known and variable power as the input, the electrical response of the detector is measured over its entire specified dynamic range and then plotted as shown in Figure 3-9. [Note that in the figure the fluctuations in the photocurrent are exaggerated, and that the figure also includes a solid line corresponding to the straight line described in the following sentence and dashed lines corresponding to possible limits on the (deviations from) linearity.] The linearity is then defined as the maximum deviation of the data from a straight line drawn through the origin and the point corresponding to the photocurrent measured at the highest optical input power.[13]

Figure 3-9 Example of Photodetector Linearity Test Results



3.2.8.4 Monitor Photodetector Photocurrent

For monitor photodetectors such as those used in laser modules, it is generally not necessary to perform as extensive of a set of response measurements as is needed for photodetectors used in optical receivers (i.e., as those described in the Sections 3.2.8.1 through 3.2.8.3). Instead, it may be sufficient to measure the photocurrent (I_{ph}) generated at the laser module's maximum-rated optical output power level [i.e., at P_o(max)]. For laser modules that include a TEC, the TEC is typically set for the normal operating heat sink temperature.

3.2.8.5 Dark Current

A photodetector's dark current is the current that is generated in the absence of any optical input, and typically increases as the reverse bias applied to the detector is increased. In general, this parameter is specified and measured at a reverse bias that is greater than the normal operating reverse bias.

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13. Note that there are a number of other possible methods of plotting the data or quantifying the linearity of a photodetector. For example, instead of a plot as shown in Figure 3-9, it may be useful to represent the data as described in Section 3.2.6.3 for the case of the Front-to-Rear Tracking Ratio Deviation. That is, for each input optical power, divide the photodetector current by the input power and plot the result against either the input power or the photodetector current. The deviation from linearity can then be found by drawing a best-fit straight line with a slope of zero through the data points, and measuring the largest deviation from the line.

Similarly, in some cases it may be more convenient to define a nonlinearity parameter, N, that is a function of the input power, P, as follows:

$$N(P) = [r(P) - r(P_0)] / r(P_0)$$

where $r(P)$ is the responsivity at power level P, and $r(P_0)$ is the responsivity at reference power level P_0.

3.2.8.6 Capacitance

In some cases, the measurement of a photodiode's or detector module's capacitance can be useful for the purpose of detecting certain types of degradations that can occur during various stress tests. It is typically measured with the normal operating reverse bias applied, and at a frequency (or frequencies) that depends on the device's intended applications.

3.2.8.7 Cutoff Frequency

The cutoff frequency of a photodetector is the input-signal modulation frequency at which the peak-to-peak output current decreases by 3 dB from its "full value," where the full value is defined as the value measured at the same input optical power level and modulation depth, and at a specified modulation frequency that is less than or equal to 0.01 times the expected cutoff frequency. In general, this test is performed with the photodetector set up for normal operating conditions (e.g., voltage, load, input optical power). For APDs, the gain is typically set for a multiplication of 10. A sinusoidally modulated light signal from a laser or LED is then used as the input to the device. Note that in order to eliminate the power of the input signal as a variable in interpreting the results of the test, the laser or LED must have a flat response beyond the detector's expected cutoff frequency.

3.2.8.8 Breakdown Voltage

The breakdown voltage of a photodetector is defined as the reverse bias required to cause a specified (unacceptable) dark current level. In general, it is determined by measuring the dark current as the bias voltage is varied over its full range (including into the breakdown region).

In addition to establishing an appropriate voltage level for the pass/fail criteria for this test, it is also important for the device supplier or equipment manufacturer to choose an appropriate dark current level for use in identifying the breakdown voltage. In particular, the value of this current level needs to be chosen such that devices exhibiting "soft" or "secondary" breakdown can be identified and considered failed.

3.2.8.9 Excess Noise Factor

The excess noise factor, *F*, of an APD is calculated from the expression:

$$F = \frac{V_n^2}{2q\,I_{ph}(M = 1)BR_L^2} \qquad \textbf{(3-16)}$$

where

V_n is the root-mean-square output noise voltage of the APD

q is the charge of an electron (1.6022×10^{-19} C)

$I_{ph}(M=1)$ is the photocurrent at unity gain [i.e., at the bias voltage where the ratio of the multiplied photocurrent to the photocurrent without carrier multiplication (the multiplication factor, M) is equal to one]

B is the bandwidth of the filter

R_L is the load resistance.

Note that in determining the value of $I_{ph}(M=1)$:

- The initial voltage needs to be small to restrict the carrier multiplication to a negligible level, and
- The input optical power needs to be adjusted to make the photocurrent without carrier multiplication large in comparison to the dark current.

Also note that in some cases (e.g., for heterostructure diodes) the unity gain point may be inaccessible, and in such cases another reasonable reference gain, such as M = 2, can be chosen and referenced.

3.2.9 Receiver Characteristics

Discussed in the following sections are a number of parameters that can be used in characterizing the performance of optoelectronic receivers during the qualification process.

3.2.9.1 Received Optical Power Levels

The primary parameters related to the power level of a receiver's incoming signal are as follows:

- Receiver Sensitivity (P_{Rmin}) – The minimum value of the average received power to achieve a specified BER (e.g., 1×10^{-10})
- Receiver Overload (P_{Rmax}) – The maximum value of the average received power to achieve the specified BER.

Typically, these parameters are specified and reported in units of dBm. In addition, the applicable specifications are generally supposed to be met when the receiver is connected to a transmitter that has the worst-case central wavelength, spectral width, extinction ratio and pulse shape characteristics allowed by the corresponding transmitter specifications for the particular application.

3.2.9.2 Tolerance to Incoming Signal Degradations

The parameters discussed in this section are related to a receiver's ability to tolerate degradations on its incoming signal. Such degradations can occur at the (far-end) transmitter that generates the optical signal, and as that signal traverses an optical path. In general, the ability of a receiver to tolerate the various types of degradations is highly dependent upon the electronics provided in the device [e.g., the Clock Data Recovery (CDR) circuitry].

- Chromatic Dispersion Tolerance – The maximum amount of chromatic dispersion that can be tolerated by the receiver
- Differential Group Delay Tolerance – The maximum amount of Differential Group Delay [DGD, which is typically caused by Polarization Mode Dispersion (PMD)] that can be tolerated by the receiver
- Jitter Tolerance – The maximum amounts of jitter, as a function of frequency, that can be tolerated by the receiver
- Minimum and Maximum Tolerated Bit Rates – The minimum and maximum incoming signal bit rates that the receiver is able to receive and process.

In the first three cases listed above, the receiver is generally considered to be able to tolerate a particular amount of degradation if the resulting power penalty (i.e., change in the apparent receiver sensitivity) is less than 1 dB. While a similar definition could conceivably be used in determining the minimum and maximum tolerated bit rates, in those cases there are typically bit-rate thresholds beyond which the performance of the receiver degrades significantly (independent of the received optical power level). For a typical application, the minimum bit-rate offset range that needs to be tolerated is dictated by the accuracy specifications that apply to the clock that controls the bit rate of the signal when it is transmitted (e.g., ±20 ppm).

3.2.10 Physical Characteristics of Devices

3.2.10.1 Internal Moisture and Hermeticity

The tests discussed in this section are intended to verify both that the amount of moisture incorporated into a hermetic module during the manufacturing process is limited to an appropriate level, and that the module maintains its hermetic properties (e.g., after exposure to various mechanical and environmental stresses). In most cases, these two goals are expected to be met using separate tests that were developed specifically to measure internal moisture or hermeticity. However, as discussed below, in other cases the internal moisture test may be used for both purposes.

3.2.10.1.1 Internal Moisture

The primary purpose of this test is to measure the water-vapor content of the atmosphere inside a hermetically-sealed device. Three possible procedures are given in MIL-STD-883E, *Test Method Standard, Microcircuits*, Method 1018.3, *Internal Water-Vapor Content*. In each of these procedures, the initial step involves baking the device at approximately 100°C for 16 to 24 hours, after which the water vapor content is measured. In Procedures 1 and 2 the water vapor content is determined by puncturing the device, either in a vacuum chamber connected to a mass spectrometer [in which case the test is sometimes referred to as a Residual Gas Analysis (RGA)] or in an apparatus capable of integrating the moisture picked up by a dry carrier gas. In Procedure 3 (which is generally not expected to be used for the devices covered in this document), the moisture is measured using a calibrated sensor sealed within the device housing.

Note that when a device is punctured in Procedure 1 or 2 above, it is effectively destroyed for further qualification testing purposes. Therefore, in cases where either of those procedures are used in a stress test's (or group of stress tests') pass/fail determination process, the results cannot be compared to the results of similar measurements performed on the same sample of devices before the stresses were applied (as is done with the results of a number of other measurements). Instead, those results will need to be compared to the normal (absolute) limits on internal moisture and/or the results of similar measurements performed on a separate sample of unstressed devices.

3.2.10.1.2 Hermeticity

Traditionally, the hermeticity of ICs has been measured using the tracer gas fine leak test given in MIL-STD-883E, Method 1014.9, *Seal*. In that test, the device is exposed to helium at high pressure for some minimum time that depends on its volume, and then is placed in a chamber that is connected to an evacuation system and mass-spectrometer-type leak detector. When the chamber is subsequently evacuated, any helium that leaked into the device when it was under pressure is drawn out and detected.

In most cases the procedure described above can also be used to test the types of devices covered in this document (in addition to ICs). However, if the device includes a fiber pigtail, then the fiber coating is likely to absorb and release helium, resulting in erroneous leakage indications. Discussed below are two possible methods for avoiding this problem.

- Rather than performing the leak test on fully functional (intact) devices, in most cases it should be possible to cut the fiber pigtails/strain relief boots off of the devices before the test is performed. However, when this is done, it severely limits the other performance parameters that can be measured on those particular samples, and in some cases the additional stress tests that can be performed. In cases where this is an issue, one strategy is to reserve a separate set of samples specifically for this test.[14] In addition, since the leak test is concerned only with the hermetic integrity of the device, the samples that are subjected to this test do not necessarily have to meet the various performance specifications that would otherwise apply. Thus, it may be possible to reduce the cost of the qualification program by using a set of “bad” samples that are mechanically identical to “good” devices but do not meet one or more of the applicable performance specifications (e.g., optical rejects).

- In some cases, Procedure 1 or 2 in MIL-STD-883E, Method 1018.3 may be able to be used to verify the hermeticity of a device in addition to its primary purpose of measuring internal moisture (see Section 3.2.10.1.1). In particular, if the quantity of gases released when the device is punctured in either of those procedures is significantly below the expected amount, then that is an indication that the device was not hermetic and the gases leaked out during the vacuum chamber evacuation step. Note however, that these procedures will generally only be capable of detecting relatively large leak-rate problems. That is, while the level of accuracy that they provide may be sufficient to determine that a device does not meet the leak-rate specification, it will generally not be sufficient to conclude that the device meets that specification.

As indicated in MIL-STD-883E, Method 1014.9, the maximum acceptable leak rate for a device typically depends upon its volume. In addition, the results of a leak rate test and the corresponding pass/fail criteria may be expressed in terms of the “standard leak rate,” the “measured leak rate” and/or the “equivalent standard leak rate,” each of which is defined in Method 1014.9. Thus, care must be taken in interpreting the results of these tests.

3.2.10.2 ESD Tests

In general, ESD tests are performed at room temperature (25°C) on completed devices that have been subjected to the normal incoming or source inspection and screening procedures. To prevent influencing the test results, the following ESD-prevention measures need to be observed:

- Modules for this test are transported only while inserted in conductive foam
- All operators wear grounding straps when handling the devices.

3.2.10.2.1 ESD Threshold Testing of Modules

A detailed test procedure for measuring ESD-damage thresholds of modules is given in FOTP-129, which also provides instructions on verifying the ESD pulse waveform. At the present time, the procedure (and thus the waveform to be used) is based only on the Human Body Model (HBM). As noted in FOTP-129 and

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14. For example, in a series of stress tests, subject two sets of samples to each of the stress conditions, with one set made up of fully functional devices upon which various performance tests are periodically performed, and the other set made up of devices that are tested for hermeticity.

Table 4-2, a minimum of six modules are specified to be tested for ESD. Of these, three are to be subjected to positive pulses, and three to negative pulses.

In determining a device's ESD threshold, a series of pulses of a particular voltage are applied to various pins, and then selected parametric measurements are performed. If the parametric measurements do not indicate that the device has failed, then the voltage is increased and the process is repeated. While significant information could be obtained using only voltages up to (or slightly above) the device's minimum specified threshold (which preferably would be at least 500 V, corresponding to a Class 3 or higher device in the ESD sensitivity classification system defined in TR-NWT-000870), FOTP-129 indicates that the voltage needs to continue to be increased until failure occurs. In addition, FOTP-129 indicates that consideration needs to be given to not only the threshold value for each sample, but also to the consistency of the values obtained for all of the samples.

3.2.10.2.2 ESD Susceptibility Testing of Integrated Modules

For most integrated modules, the required ESD test is that described in Section 9.4 of GR-78-CORE. As in the case of module-level ESD testing, the applicable model is the HBM (which is also referred to in GR-78-CORE as the Body/Finger model). However, unlike the module-level case, the test discharges are not applied to various pins, but are instead applied at up to three points along each edge of the board upon which the various optoelectronic devices and other components are mounted. In addition, discharges of ±8 kV and ±15 kV are used (rather than increasing voltages until failure occurs), and the device is considered to have passed the test if it meets the appropriate performance specifications following those discharges.

For integrated modules that do not include boards to which the test discharges can be applied, alternate ESD tests will need to be performed. In some cases the tests described in Section 3.2.10.2.1 for modules may be appropriate (i.e., if the integrated module includes pins that are accessible for applying the test voltages). Specific procedures for other types of integrated modules may be provided in a future issue of this document.

3.2.10.3 Flammability

In general, optoelectronic modules and integrated modules need to meet the same flammability criteria as other components used in telecommunications equipment. Those criteria appear in Section 4.2 of GR-63-CORE and Section 4.4.2.5 of GR-357-CORE, which indicate that components need to either:

- Pass a needle-flame test, or
- Meet the criteria to be rated UL94 V0, or
- Meet the criteria to be rated Vl and have an Oxygen Index of 28% or greater.

In addition, GR-63-CORE and/or GR-357-CORE indicate that components may need to meet more stringent flammability criteria in some cases (e.g., if required by law for use in a particular locale), provide descriptions of the various test methods, and contain references to several other documents that provide more detailed information. On the other hand, at the time that this document was being prepared, neither the GRs (i.e., GR-63-CORE or GR-357-CORE) nor any of the referenced documents appeared to adequately address flammability tests for most types of fiber pigtails. This is an issue for further study.

To reduce costs, it is not necessary to actually expose non-flammable hermetic metal or ceramic packages to destructive flammability tests (i.e., they can be assumed to meet the criteria). On the other hand, any potentially flammable materials attached to such packages generally need to be tested.

3.2.10.4 Die Shear Strength

The purpose of this test is to determine the integrity of materials and procedures used to attach the various parts of an optoelectronic diode's submount assembly (e.g., the diode's attachment to the heat sink, and the heat sink's attachment to the submount). The procedure for the test appears in MIL-STD-883E, Method 2019.6, *Die Shear Strength*. According to that document, the shear force that a device must be able to withstand (1X) is generally proportional to the area of contact between it and the surface upon which it is mounted (up to a maximum of 2.5 kg), and the force that needs to be applied during the test is the smaller of that which causes separation and twice the minimum value (i.e., 2X). In addition, for cases where separation occurs at a force between 1X and 2X, the pass/fail result depends on the percentage of the die attach medium that adheres as described in the procedure.

3.2.10.5 Solderability

The primary purpose of this test is to evaluate the solderability of the terminations provided by an optoelectronic module that are normally joined by soldering operations. In addition, it is used to help assure that the soldering process will not impact the module's mechanical integrity (e.g., due to thermal shock). The procedure for this test is as described in MIL-STD-883E, Method 2003.7, *Solderability*, except that the steam aging step included in that document (including the associated drying and storage procedures) is not required. In general, the procedure calls for cleaning of the terminations (if desired), a flux-application step, a solder-dip procedure, and an examination of the terminations.

3.2.10.6 Wire Bond Strength

The purpose of this test is to evaluate the bonds holding the wires that are used to provide electrical connections between an optoelectronic diode and the other components to which it is attached. The procedures for this test are given in MIL-STD-883E, Method 2011.7, *Bond Strength (Destructive Bond Pull Test)*, which lists six different test conditions and indicates the particular conditions that are applicable for various types of connections (e.g., internal wire bonds, external wire bonds, flip-chip configurations and beam lead devices).

3.3 Stress Test Procedures

The stress tests that are appropriate in the qualification of the types of optoelectronic devices covered in this document include mechanical integrity tests and environmental stress tests (both powered and non-powered).

3.3.1 Mechanical Integrity Tests

The tests discussed in this section are intended to verify the mechanical integrity of optoelectronic devices and the modules in which they are deployed.

3.3.1.1 Mechanical Shock and Vibration Tests

In general, the purpose of these tests is to verify the ability of the device to withstand mechanical shocks and vibration as might occur due to rough handling, transportation or operation in the field. As indicated below, the same device samples are required to be used in both of these tests.

R3-13 **[417]** In cases where they are both performed, the same sample of devices shall be used for the mechanical shock test and the vibration test.

Note that these shock and vibration *tests* are distinct from the shock and vibration *conditions* under which certain integrated module performance characterization tests may need to be performed (see Section 4.4.2).

3.3.1.1.1 Mechanical Shock

The procedure for the mechanical shock test appears in MIL-STD-883E, Method 2002.4, *Mechanical Shock*, which defines a number of different test conditions (i.e., peak g levels and pulse durations), and indicates that the shocks are normally applied five times in each of six orientations (i.e., X_1, X_2, Y_1, Y_2, Z_1 and Z_2) and the acceleration pulse waveform is half-sine. As listed in Table 4-3, for a diode or module the applicable condition is Condition A (500 g, 1.0 ms), while for an integrated module the applicable condition depends on the mass of the device. In either case, five repetitions need to be performed per direction.

R3-14 **[418]** If the module or integrated module is designed such that it would be damaged by the application of the mechanical shock test conditions listed in Table 4-3 and therefore must be tested using less intense conditions, a “fragile” (or similar) warning shall be applied to it and/or the smallest box used for packaging the unit.

3.3.1.1.2 Vibration

The procedure for the (non-powered) vibration test that applies to all optoelectronic devices appears in MIL-STD-883E, Method 2007.3, *Vibration, Variable Frequency*, which defines three different test conditions (i.e., peak accelerations). In addition, the document indicates that the vibration frequency needs to be varied approximately logarithmically from 20 Hz to 2000 Hz and back over the course of a 4-minute (or longer) cycle, and that four cycles are supposed to be applied to each device along each of three axes. For all of the devices covered in this document, the applicable condition is Condition A (i.e., a peak acceleration of 20 g).

In addition to the test described above, Table 4-3 lists another vibration test that is based on the results of an equipment vibration study presented to the Telcordia Technical Forum during the development of Issue 2 of this document. This additional test is applicable to most integrated modules,[15] and although the device is required to be powered during the test, it is not required to operate within its specifications while the vibrational stress is being applied. Instead, the pass/fail determination is based on physical and/or performance degradations that are observed after the stress has been removed (as is the case for most other mechanical integrity tests). On the other hand, monitoring of selected performance characteristics during this test may prove useful in identifying issues that should be investigated further (e.g., significant degradations at a resonant frequency).

3.3.1.2 Thermal Shock

Thermal shock tests are intended to test the hermetic integrity of a module package. The procedure for this test appears in MIL-STD-883E, Method 1011.9, *Thermal Shock*, which lists three possible sets of test conditions (i.e., hot and cold bath temperatures). For the devices covered in this document, the applicable test conditions are those given in Condition A (0 and 100°C), which allows water to be used in the baths.

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[15] In particular, the test is applicable to all integrated modules except those based on technology that has previously been shown to be insensitive to vibration conditions similar to the conditions specified for use in this test (as justified and documented by the device supplier or equipment manufacturer).

3.3.1.3 Fiber Integrity Tests

In general, fiber integrity tests as discussed in this section need to be performed on all optoelectronic devices that include fiber pigtails. The primary purpose of these tests is to ensure the attachment of the fiber pigtail to the package; however, there may be other factors that will need to be considered (e.g., if the fiber provides a wavelength stabilization function, then the effect of the fiber integrity tests on that function would need to be examined). In addition, the fiber itself and its attachment to any connector need to be tested according to the criteria and procedures in GR-326-CORE, *Generic Requirements for Singlemode Optical Connectors and Jumper Assemblies*.

Note that prior to Issue 2 of this GR, the only fiber integrity test that was listed as being applicable to optoelectronic devices was a fiber-pull test in which the load to be used was dependent on certain transmission characteristics of the fiber [i.e., whether it was “regular” or Polarization Maintaining (PM) fiber] and the likelihood that the fiber would be handled during field installation (e.g., during insertion of the circuit pack containing the device). This was inconsistent with the fiber integrity criteria that were applicable to a number of similar devices (i.e., devices that include fiber pigtails that may or may not be handled during installation in the field), and therefore the criteria in this area were revised as of Issue 2. As discussed in the following sections, three tests related to fiber integrity are now considered applicable,[16] with certain parameters in any particular test dependent on the physical design of the fiber and in some cases its method of attachment. Four types of fiber physical designs are considered here, and are defined as follows:

- Coated (Unbuffered) Fiber – An optical fiber coated with a (colored) protective coating, typically having a nominal outside diameter of 250 µm
- Tight Buffered Fiber – A fiber with a (typically) 250-µm outside diameter coating surrounded by a larger diameter (typically 900 µm) buffer material applied tightly around the coating such that a fiber stripping tool will strip both the buffer and the protective coating in one operation
- Loose Buffered Fiber – A fiber with a (typically) 250-µm outside diameter coating surrounded by a larger diameter (typically 900 µm) buffer material that is in contact with, but applied loosely to the fiber coating such that the buffer material can be removed without damage to the coating
- Reinforced Fiber Cable – A single-fiber or multi-fiber cable with a strength member and/or reinforcing yarn.

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[16] Note that although four fiber integrity tests are described in a number of other documents, only three of those have been included here. Specifically, the fiber flex test was considered unnecessary for the devices covered in this document. On the other hand, it was agreed that each of the three remaining tests need to be performed independent of the particular type of fiber. While this is consistent with some other documents, it is inconsistent with several others that exempt coated and tight-buffered fibers from the twist (and flex) tests.

In the case of loose-buffered fiber, the buffer material may or may not be attached to the device housing and used as a strength member. For devices where the buffer material is not used as a strength member, less stressful conditions than those listed in Table 4-3 apply for the side-pull and cable retention tests. (In particular, the test conditions listed for devices with coated and tight-buffered fiber pigtails apply instead.) In addition, it should be noted that loose-buffered cable generally includes PVC or Hytrel tubing that will stretch and allow the fiber to take up the load. This tubing is typically used to improve the abrasion resistance of the cable, not the tensile strength.

3.3.1.3.1 Twist Test

The test setup and procedure to be used for this test are as given in FOTP-36, with the exception that the load to be used is 0.5 kg or 1.0 kg (for coated, tight-buffered and loose-buffered fibers, or reinforced fibers, respectively) and is located 3 cm from the optoelectronic device housing or the end of the strain relief boot (if present). As indicated in the FOTP, the fiber is twisted through 10 cycles from 0° to 90° to –90° to 0°, and the particular optical power measurements used in determining whether the device passes or fails the test are performed before and after the twisting procedure.

3.3.1.3.2 Side Pull Test

In general, the test setup and procedure for this test are as given in GR-326-CORE (as the 90° portion of the “Transmission With Applied Tensile Load” tests). However, in the cases covered by this document, the load that is applied (at a 90° angle, 22 to 28 cm from the device housing) is either a 0.25 or 0.5 kg tensile side load (for coated and tight-buffered fibers, or loose-buffered and reinforced fibers, respectively), and only “before” and “after” optical power measurements are required for use in determining whether the device passes or fails the test (i.e., the power does not need to be measured while the load is in place).

3.3.1.3.3 Cable Retention Test

The procedure for this test appears in FOTP-6. For the fiber pigtails covered by this document, the load is either 0.5 or 1.0 kg (for coated and tight-buffered fibers, or loose-buffered and reinforced fibers, respectively), is applied to the secured cable at a minimum of 10 cm from the loose end of the fiber, and is maintained for 1 minute. As stated in FOTP-6, the maximum loading rate (i.e., the maximum rate at which the two holding devices are separated) is 400 μm/s and is continued until the maximum load is attained. Finally, any optical power measurements used in determining whether a device passes or fails this test are performed before and after (not during) the time over which the load is present.

3.3.1.4 Connectorized and Receptacle Device Durability Tests

Similar to the fiber integrity tests described in Section 3.3.1.3 for optoelectronic devices that include fiber pigtails, connector or receptacle durability tests are needed for devices that include connectors or receptacles into which external fiber jumpers can be inserted (instead of pigtails). Several possible tests are discussed in the following sections.

3.3.1.4.1 Mating Durability Test

In a mating durability test, an external (test) fiber jumper is repeatedly connected to and disconnected from the device under test, and optical power measurements are periodically performed to verify that the connections meet the appropriate criteria on loss, reflectance and repeatability. A specific test procedure is provided in Section 4.4.3.8 of GR-326-CORE for optical connectors and jumper assemblies in general, and can be adapted for the types of devices covered in this document.[17] That procedure calls for 200 disconnections and reconnections, with cleaning of the fiber ends performed after specific disconnections, and measurements performed after specific reconnections.

In general, this test applies to both connectorized and receptacle devices. However, in the case of a receptacle device it is important to note that the device will need to be equipped with some type of test connector housing with which the connector on the external jumper can be connected. Therefore, the results will depend on the performance of both the receptacle device and the test connector housing.

3.3.1.4.2 Wiggle Test

A “wiggle” test consists of a series of angular pulls applied to the device in different directions. At the time that this document (i.e., GR-468-CORE, Issue 2) was being prepared, several standards bodies were developing (or considering to develop) specific test conditions and procedures. Therefore, a specific procedure is not provided here, but may be included (either explicitly or via a reference to a standard procedure) in a future issue the document. Similar to the mating durability test described in Section 3.3.1.4.1, the wiggle test generally applies to both connectorized and receptacle devices, and in the case of receptacle devices the results will be affected by the performance of both the device under test and the test connector housing with which it is tested.

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[17] For optoelectronic devices, it is not necessary to mount the devices under test at specific heights within the durability test facility as described in GR-326-CORE.

3.3.1.4.3 Pull Test

Unlike the mating durability and wiggle tests described in the preceding sections, the pull test applies only to connectorized devices that include push-pull type connectors. That is, it does not apply to connectorized devices that utilize other types of connectors, or to receptacle devices. For a connectorized device with one or more push-pull type connectors, each sample device is secured as described in FOTP-6 (i.e., the test-procedure reference for the cable retention test described in Section 3.3.1.3.3), and then the steps listed below are performed. (Note that this procedure was derived from FOTP-6 and the procedure given in Section 3.4.1 of GR-326-CORE for testing the latchability of push-pull type connectors provided on fiber jumpers.)

- Insert a connector attached to a test fiber jumper into one of the connectorized device's connector housings using an appropriate insertion force (for the particular type of connector) applied to the boot of the connector plug.
- Test the connection by applying an appropriate load (for the particular type of connector) to the fiber. As in the case of the fiber retention test, the maximum loading rate is 400 μm/s and is continued until the maximum load is attained or the connector pulls out.[18]
- Disconnect the connector (if necessary), and repeat the test procedure until each of the sample's connector housings have been tested at least 10 times.

For SC connectors, the appropriate insertion force and load referred to in the first two bullet items above are those given in Section 3.4.1 of GR-326-CORE, and are between 5 and 6 pounds, and 2.2 kg, respectively. Unless they are overridden by type-specific specifications (presumably developed after Issue 3 of GR-326-CORE was released), these same values also apply for all other types of push-pull connectors. Also, for any particular connector housing, if the connector pulls out in more than 30% of the trials, then the device is considered to have failed the test.

3.3.2 Non-Powered Environmental Stress Tests

3.3.2.1 Storage Tests

One purpose of the tests in this area is to determine whether optoelectronic devices can withstand the high and low temperatures encountered during transportation and storage. Thus, the devices do not operate during these tests, but appropriate functionality measurements need to be made before and after the tests.

In the case of low temperatures, few failure mechanisms related to long-term storage have been observed, and therefore a relatively short-term test that is consistent with the low-temperature storage test described for systems in

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[18] Alternatively, the connection may be tested by pulling on the fiber jumper behind the boot with a force of 5 pounds.

GR-63-CORE (i.e., 72 hours at –40°C or the minimum specified storage temperature, whichever is lower) is considered sufficient. Conversely, a relatively long-term test (i.e., 2000 hours at +85°C or the maximum specified storage temperature, whichever is higher) is specified for high-temperature storage. The reason for this is that in some cases this test has been found to stimulate failure modes in much the same manner as a high-temperature operations test (which is also a relatively long-term test). On the other hand, if the failure mechanisms that are relevant under high-temperature conditions are not significantly affected by whether or not the device is operating, then the high-temperature storage and operations tests may be redundant, and only the more stressful of those two tests may need to be performed (see Section 3.3.3.1.3).

3.3.2.2 Temperature Cycling

In general, the primary purpose of the temperature cycling test depends on the level of the optoelectronic device being tested. More specifically, for a diode the main intent is to ensure that the subassembly is capable of passing the module-level temperature cycling and thermal shock tests to which it will later be subjected, while for a module it is to demonstrate the long-term mechanical stability of the optical alignment within the module package.

The procedure for temperature cycling tests is generally based on MIL-STD-883E, Method 1010.7, *Temperature Cycling*. However, as indicated in Table 4-4, the devices covered in this document are subject to less extreme temperature conditions than any of the conditions defined in the standard (i.e., –40°C and +85°C, versus minimum limits of –55°C and +85°C as listed in the standard), and considerably more cycles than the minimum of 10 cycles listed in standard. In addition, in order to allow the tests to be performed using a single thermal chamber without placing excessive demands on the heating and cooling capacity of that chamber, the maximum “transfer time” between the hot and cold temperatures is relaxed from the standard time of less than one minute to a minimum temperature ramp rate of 10°C/min (resulting in a maximum transfer time of 12.5 minutes). As indicated in the standard, the dwell times at the low and high temperatures must be long enough for the device to reach those temperatures, and also must be at least 10 minutes. (In general, longer dwell times are likely to be more effective in the identification of potential problems due to creep, while shorter times may be effective for identifying thermal coefficient of expansion issues.) Finally, in a powered temperature cycling test of a module that includes a TEC, the TEC needs to be turned on as in normal operation. (Note that although this test is listed as a non-powered environmental stress test, the device being tested may be powered, if desired.)

3.3.2.3 Damp Heat Tests

The simultaneous application of temperature and humidity stresses can be an important test in assessing the reliability of both hermetic modules (e.g., to verify that hermeticity is maintained) and non-hermetic devices (e.g., diodes specified for use in non-hermetic modules, and the non-hermetic modules themselves). For the most part, the test procedure for these tests is that provided in MIL-STD-202G, *Test Method Standard*, *Electronic and Electrical Component Parts*, Method 103B, *Humidity (Steady State)*, and IEC 60068-2-3, *Test Ca: Damp Heat*, *Steady State*. That procedure indicates that the chamber and accessories need to be "constructed and arranged in such a manner as to avoid condensate dripping on the specimens under test, and such that the specimens shall be exposed to circulating air," and includes conditioning, exposure and drying steps along with several measurement steps. One of those measurement steps (i.e., the one in which measurements are made while the samples are still being exposed to the high temperature and humidity conditions) is not considered necessary for the devices covered in this document, and therefore a procedure that includes the following steps is considered sufficient:

- A 24-hour conditioning period at a relatively high temperature (approximately 40°C) and low humidity
- Measurements made at the end of the conditioning period
- A period of exposure to high temperature and humidity
- A 1- to 2-hour drying period at room temperature and humidity
- Measurements made at the end of the drying period.

Other differences between the procedure cited above and the tests required by this document are in the particular temperatures and humidities used during the period of exposure, and the duration of the exposure (e.g., see the conditions listed in Table 4-4). In addition, while the procedure cited above indicates that "a direct-current potential of 100 volts or as specified shall be applied to the specimens during the exposure period," no voltage is required to be applied in the case of the non-powered damp heat tests addressed in this section (which are generally applicable to both hermetic modules and non-hermetic devices[19]).

3.3.3 Powered Environmental Stress Tests

3.3.3.1 High-Temperature Operations

Typically, exposure to high temperatures will accelerate certain of a device's failure mechanisms and reduce its operational life. Thus, the goal of a high-temperature operations test is to verify, in a relatively short time, the long-term performance of the device. Ideally, sufficient time and information about failure mechanisms and

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[19] As noted in Table 4-4, hermetic modules may be biased during this test, if desired. Also, while both non-powered and powered damp heat tests are listed as applicable for non-hermetic devices (in Tables 4-4 and 4-5, respectively), in some situations it may only be necessary to perform one of those two tests. This is discussed further in Section 3.3.3.3.

acceleration factors would be available to allow all devices that are specified to have a certain operational life (e.g., 20 years) to be subjected to equivalent and appropriate tests. In reality, time is limited and much of the desired information is unavailable. Therefore, a number of assumptions and trade-offs are necessary, and were made in determining the test conditions to be included in this GR. These assumptions, as well as several other topics related to high-temperature operations tests, are discussed in the following sections.

In addition, it should be noted that the conditions specified for use in the high-temperature operations tests discussed in this section are generally consistent with those used in the high-temperature accelerated aging tests discussed in Section 3.4.1. In particular, in most cases the only differences are in the number of samples tested and the duration of the tests. In such cases it is generally possible to combine the tests (and reduce the testing costs) by periodically performing the appropriate "end-of-life" measurements during the high-temperature operations tests, and by returning an appropriate number of the samples to the test temperature for additional aging following the completion of the high-temperature operations test.

3.3.3.1.1 Test Time and Temperature Considerations

Listed below are the assumptions and test-design guidelines that were used in determining the high-temperature operations test conditions to be included in this GR.

- The effect of temperature on the device's primary operational failure mechanism will conform to the Arrhenius relationship, and that particular failure mechanism will dominate at both the normal operating and high-temperature test temperatures (see Sections 3.1.4.1 and 3.1.4.3).
- The activation energy to be used in the Arrhenius relationship is dependent on the type of optoelectronic device as listed in Table 3-1.
- With the possible exception of photodiodes (see below), the dominant failure mechanisms that will be observed in these tests are wearout failure mechanisms, and therefore the activation energies of interest are the activation energies for wearout failures.
- For devices with wearout failure activation energies of 0.6 eV or less the initial required test time is 5000 hours, while for devices with wearout failure activation energies greater than 0.6 eV the test time is 2000 hours.
- The normal (average) operational temperature for optoelectronic devices is 40°C.
- With a possible exception for photodiodes, for devices that are specified to be deployed only in CO environments the required test temperature is +70°C or the maximum specified operating temperature, whichever is greater.

- With a possible exception for photodiodes, for devices that are specified to be able to be deployed in UNC environments the required test temperature is +85°C or the maximum specified operating temperature, whichever is greater.
- Even at high temperatures, for the types of photodiodes that were generally available at the time that this document was being prepared, the wearout failure rates (which have relatively high activation energies) are expected to be insignificant compared to the random failure rates (which have very low activation energies). To verify this, and to obtain some initial information related to a product's random failure rate without unnecessarily delaying the qualification process, the time and ambient temperature for high-temperature operations tests on photodiodes are specified as 2000 hours and +175°C.
- If the "insignificant wearout failure rate" assumption in the previous bullet item is not appropriate for a particular type of photodiode (e.g., a type of photodiode that is based on some new technology), then the guidelines listed above for all other types of devices apply.
- The minimum number of diode-level devices to be subjected to these tests is 22, while the minimum number of module-level devices is 11.

If any of the preceding assumptions or guidelines are to be altered such that the test time or temperature can be reduced, the device supplier or equipment manufacturer that is responsible for performing the test is also responsible for demonstrating that the revised assumptions are valid (e.g., if a higher activation energy is claimed, that the proposed value is based on appropriate data as discussed in Section 3.1.4.2). In addition, the following apply regarding any alternate conditions that are proposed.

- For random failure mechanisms, the number of equivalent device hours is the primary time consideration, and therefore the length of the test can be reduced (within limits, see below) by simply increasing the sample size
- For wearout failure mechanisms, the number of equivalent device hours *per device* is the primary time consideration, and therefore it is generally not possible to reduce the length of the test by increasing the sample size
- The minimum test time for any type of device is 2000 hours, independent of the number of equivalent device-hours to which that value corresponds.

3.3.3.1.2 Other Test Condition Considerations

When multiple stresses are applied to a device at one time, the effect can be different than would be predicted based on the expected impact of each stress applied separately. In the case of high-temperature operations and accelerated aging tests, this means that if stresses other than temperature are also applied, the result may be that the number of device-hours simulated by the test will be significantly different than desired or predicted based on the Arrhenius relationship. Therefore, the high-temperature operations and accelerated aging tests in this GR are generally specified to be performed with other variables such as the drive current set to their maximum rated values (i.e., to the maximum values that would be expected to occur in normal operations). Discussed below are several variables for which additional information (beyond a simple "maximum rated value" statement) appears to be needed.

In the case of a tunable laser, both the particular wavelength setting and the frequency at which that setting is changed can have a significant impact on the performance, and possibly the aging, of the device. On the other hand, testing a full set of samples under each possible combination of variables will generally not be feasible. Therefore, it is important to determine the various combinations that are likely to be the most stressful, and to expose subsets of the samples to those conditions [e.g., subject some of the samples to frequent retuning, and set other of the samples to maintain constant wavelengths (covering the full range of possible wavelengths) for the duration of the test].

In the case of external modulators, the primary variable (other than the ambient temperature) that is expected to affect the performance or aging of the device is the modulation rate. Increasing that rate can increase the localized heating that occurs within the device, and therefore Tables 4-5 and 5-1 indicate that the high-temperature operations and accelerated aging tests need to be performed with the device modulated at the "maximum specified modulation rate." For external modulators intended for use in digital applications, this has generally been interpreted to mean the testing is supposed to be performed using a PRBS or similar signal applied at the maximum bit rate supported by the modulator. However, as the bit rates supported by various products have increased (e.g., to 10 or 40 Gb/s), this interpretation has resulted in very high test-equipment costs. Therefore, it is also considered acceptable for the tests to be performed with sinusoidal modulation applied at a frequency that will result in similar internal heating or power dissipation effects. In general, the appropriate modulation frequency needs to be determined and documented by the device supplier or equipment manufacturer, and will be lower than the frequency that would be obtained by simply converting the maximum specified bit rate to frequency units (i.e., in the example above, lower than 10 or 40 GHz).[20]

3.3.3.1.3 Applicability of the High-Temperature Operations Test

For some optoelectronic devices, the device-related failure mechanisms that are relevant in a high-temperature operations test are not significantly affected by whether or not the device is operating. In such cases, this test (i.e., the high-temperature operations test) may be redundant with the high-temperature storage test, and therefore may not need to be performed. This is reflected in the following statement.

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[20] For modulators intended for use in Non-Return to Zero (NRZ) applications, the reason for this is that a PRBS will contain numerous runs of like bits in which no transitions (i.e., from "on" to "off", or from "off" to "on") occur. Similarly for modulators intended for use in Return to Zero (RZ) applications, approximately 50% of the bits in the PRBS will be zeros, for which no pulses are generated.

- If a new optoelectronic module is developed based on an earlier product that has been tested for high-temperature operations and high-temperature storage, and if the failure modes can be demonstrated to be the same for those two tests, there is no need to repeat both tests on the new module. Instead, only the more stressful of the two tests is required to be performed.

Note that in addition to the specified ambient temperatures and test durations for the two tests, any localized heating that may occur in the high-temperature operations test needs to be considered in determining which test is more stressful. Also note that if the result of any localized heating is that different failure mechanisms are relevant in the two tests, then the preceding discussion is not applicable and both tests need to be performed.

One reason that the high-temperature operations test is required for new products is that it can be a more effective test for some failure mechanisms such as those that are sensitive to alignment and temperature gradients (e.g., due to laser heating). Therefore, both high-temperature operations and storage tests are required for new products.

3.3.3.2 Cyclic Moisture Resistance

The intent of the cyclic moisture resistance test is to verify, in a relatively short period, the resistance of a device to the types of degradations that can occur in high-temperature/high-humidity and freezing/thawing conditions such as those that may be present in UNC environments. Some of these degradations are discussed in MIL-STD-883E, Method 1004.7, *Moisture Resistance*, which also describes a procedure to be used for the test. In general, that procedure includes the following:

- Initial conditioning and measurements
- A number of 7-step, 24-hour “cycles,” where each cycle consists of:
    - Two temperature ramps from room temperature to +65°C (at high humidity)
    - Two soaking periods at +65°C and high humidity
    - Two temperature ramps down to room temperature (at high humidity)
    - Either a rest period at room temperature and high humidity, or (in at least half of the cycles) a low-temperature subcycle in which the device is conditioned at –10°C for at least 3 hours.
- Final measurements.

For the purpose of testing the devices covered by this document, no initial conditioning (of the device leads) is necessary. In addition, instead of applying voltages as described in the procedure, during the test the module is set to its normal operating condition. Also, the number of cycles specified in Table 4-5 is “20”; however, this may be reduced to “10” for modules that are specified to be deployed only in applications where the thermal mass of the equipment inside the enclosure will be large enough to result in temperature change time constants on the order of one or more hours (e.g., remote terminals containing shelves of equipment, as opposed to small enclosures such as pedestals). Finally, in either case at least half of the cycles need to include the low-temperature subcycle mentioned above.

3.3.3.3 Damp Heat (Powered Tests for Non-Hermetic Devices)

In addition to the damp heat tests discussed in Section 3.3.2.3 (which are performed on non-powered devices), damp heat tests generally also need to be performed on powered non-hermetic optoelectronic devices. In specifying the test conditions for such tests, consideration must be given not only to the temperature, humidity and duration for the period of exposure, but also to such operational variables as the drive current/optical power level or bias current. For example in the case of a laser module, use of the maximum rated drive current can significantly reduce the local humidity and thus reduce the humidity stress. Therefore, the test conditions for those modules are specified (in Table 4-5) as high temperature, high humidity, and relatively low drive current/output power.

Similar to the situation discussed in Sections 3.3.2.1 and 3.3.3.1.3 for high-temperature storage and operations tests, non-powered and powered damp heat tests may stimulate the same failure modes in some non-hermetic devices while stimulating different failure modes in others. As in the case of the high-temperature tests, if the failure mechanisms that are relevant in a damp heat test are not significantly affected by whether or not the device is powered, then the non-powered and powered tests may be redundant, and only one of them may need to be performed. This is reflected in the following statement.

- If a new optoelectronic device is developed based on an earlier product upon which both non-powered and powered damp heat tests were performed, and if the failure modes can be demonstrated to be the same for those two tests, there is no need to repeat both tests on the new device. Instead, only the more stressful of the two tests is required to be performed.

Note that the durations specified in Table 4-5 for the powered damp heat tests are generally longer than those specified in Table 4-4 for the non-powered tests. If that is the only significant difference in the stresses present in the two tests, then in cases where only one of the tests needs to be performed it would also be considered acceptable to perform the non-powered test for the (longer) duration specified in Table 4-5.

3.4 Accelerated Aging

In general, the tests discussed in Sections 3.2 and 3.3 of this GR are qualitative tests, where the result is that the device either passes or fails the test, and the results of a number of tests are used to qualify/disqualify a device or accept/reject a lot. In contrast the accelerated aging or reliability tests discussed in this section and Section 5 are quantitative tests with numerical results that can be used for purposes such as reliability calculations (see Section 3.4.4) and the adjustment of the conditions (e.g., times, temperatures) used in certain of the qualitative tests.

To accelerate the aging of a device, stresses such as high temperatures, humidities and drive currents are applied to a number of "normal" devices (i.e., samples manufactured and screened using the procedures normally utilized for those devices). As discussed in the following sections, in some cases the applied stresses are intended to accelerate the types of gradual degradations that result in wearout failures, while in other cases they are expected to accelerate the rate at which random failures occur.

3.4.1 High-Temperature Accelerated Aging

In general, the primary environmental stress that is applied during accelerated aging tests is a high temperature, and the effect of that stress on certain performance parameters is assumed to follow the Arrhenius relationship (see Section 3.1.4.1). During these tests, selected parameters are periodically monitored for degradations (preferably in-situ) until either an "end-of-life" threshold is crossed or a specified number of hours has elapsed. For devices that are still active at the end of the test, any degradations that have been observed are extrapolated out to provide estimates of when the end-of-life threshold would have been crossed had the test been continued indefinitely. These estimated times are then used along with the end-of-life threshold crossing times of the other samples in various calculations related to device reliability (see Section 3.4.4).

3.4.1.1 Testing at Constant Temperature

Similar to the case of the high-temperature operations tests discussed in Section 3.3.3.1.1, a number of assumptions and trade-offs were necessary in determining the high-temperature accelerated aging test conditions to be included in this GR. These were the same as those listed in Section 3.3.3.1.1 with the following exceptions:

- The initial required test times are 5000 and 10000 hours, instead of 2000 and 5000 hours
- The minimum number of devices to be subjected to the high-temperature accelerated aging tests is 10 or 5 instead of 22 or 11.

In general, any increase in the high-temperature accelerated aging test device-hours will be reflected in better calculations of the wear-out and random failure rates. This is particularly important for "new" devices (i.e., devices for which field data is not available).

3.4.1.2 Alternative (Variable Temperature) Tests

As an alternative to the constant high-temperature accelerated aging test conditions discussed in Section 3.4.1.1 and listed in Table 5-1, an equipment manufacturer or device supplier may find it useful to perform a variable high-temperature accelerated aging test (e.g., to shorten the time required to complete device qualification). For this, increasingly higher temperatures (e.g., +60°C, +85°C, +100°C) would be used in sequence for specified periods, with the overall result being an actual testing time that is less than or equal to the applicable time listed in Table 5-1 and an effective aging time that is greater than or equal to the aging time implied by the test time and temperature listed in the table.

3.4.1.3 Additional Considerations for Lasers

In addition to time and the operating temperature, some published reports indicate that the degradations in a laser's threshold current (and thus possibly its operational life) also depend on the light output level (i.e., on the optical output power at which the laser is operated). In at least some cases this relationship can be described by Equation 3-17:

$$\frac{\Delta I_{TH}(L_2)}{\Delta I_{TH}(L_1)} \propto \left[\frac{L_2}{L_1}\right]^n \tag{3-17}$$

where n is an empirically derived exponent, and L_1 and L_2 are two different light levels used in different output power-based accelerated aging tests. Based on this relationship it appears that the output power level could be used as a stress in such tests (i.e., a drive current/optical power level that is higher than the maximum-rated current/power level could be used). However, at this time there is not sufficient data available to allow this method to be used except on a case-by-case basis. Therefore, tests that would make use of an acceleration factor based on light output are not specified in this document, but may be appropriate in some cases or as part of a true reliability test program (as opposed to reliability assurance testing, see Section 5).[21]

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[21] Note that although the preceding discussion was written assuming the tests would be performed at constant output power levels [i.e., using Automatic Power Control (APC)], equivalent tests could be performed using constant drive currents [i.e., using Automatic Current Control (ACC)]. In such cases, the tests would be considered "drive current-based" tests, and Equation 3-17 would need to be modified to indicate that the change in threshold current is proportional to the drive currents. In addition, in some cases it may be appropriate to measure the degradations that occur during these tests in terms of (for example) the changes in the output power at a specified drive current instead of the changes in the threshold current.

3.4.1.4 Additional Considerations for Photodiodes

Compared to other types of optoelectronic devices, photodiodes may be more likely to experience sudden (random) failures during aggressive high-temperature accelerated aging tests, and less likely to display gradual degradation of any particular performance parameter. In addition, in some cases photodiodes have appeared to “improve” during such tests (e.g., their dark currents have decreased instead of increasing), and in those cases the times to failure cannot be extrapolated. However, in cases where degradations do occur, it is important to extrapolate those degradations to the specified end-of-life threshold.

3.4.1.5 Additional Considerations for External Modulators

In addition to the temperature, the bias voltage will generally also have a significant impact on the aging of an external modulator, and the modulation rate, modulation voltage and optical power may also have (relatively limited) impacts. However, additional data is needed to verify and characterize those impacts before they can be included in the acceleration factor calculations.

3.4.2 Temperature Cycling

In addition to the temperature cycles to which optoelectronic devices are required to be subjected as part of the environmental stress tests (see Section 3.3.2.2), it can be useful to expose modules to a number of additional temperature cycles for “accelerated aging” purposes. Unlike the high-temperature accelerated aging tests, the primary purpose of the additional temperature cycles is generally not to cause gradual degradation of a particular performance parameter (e.g., a laser’s threshold current). Instead, it is to provide an additional demonstration of the long-term mechanical stability of the optical alignment within the module package.

3.4.3 Damp Heat for Non-Hermetic Modules

Although humidity acceleration factor models have been developed for some types of non-hermetic devices, at this time relatively little data exists on such issues as long-term diode degradation and optical coupling instabilities due to humidity. Therefore, relatively long and severe tests are generally called for in this area, and the results may be primarily of use in the calculation of random failure rates instead of wear-out failure rates.

3.4.4 Failure Rates and Reliability Calculations

3.4.4.1 Failure Rates

The most direct measure of a device's reliability is its failure rate; however, this is an "after-the-fact" indicator. The reliability assurance practices in this GR are meant to provide some level of confidence, and demonstrate to the extent possible, that failure rates will be consistent with the needs of public switched networks. Due to the many possible types of NEs and their various applications, it is not possible to list a definitive set of maximum failure rates that would be appropriate for each situation. In general, there will also be differences due to redundancies in the designs of specific hardware or systems. A further complication is the anticipated change in failure rate for a device over time (see Section 1.5.5).

Since there is only limited field replacement data available for optoelectronic devices, technology-based laboratory testing data is the primary source to estimate the failure rates of these devices. In some cases, wear-out failure rates can be reasonably predicted from the results of accelerated aging tests, and the results of various tests may be useful in identifying devices with unusually high random failure rates. However, in other cases accurate failure rates may not be able to be obtained until the devices have been in operation for millions of device-hours.

At the time when new products are introduced to the market to be installed, there is often less than a million device-hours at the operating conditions, and therefore there are not enough device-hours to prove a failure rate below 1000 FITs. In addition, the conversion of testing device-hours to operating device-hours involves many assumptions, and some data has shown little to no acceleration as a result of exposure to the more extreme conditions typically used in testing (e.g., the applicable failure mechanisms have very low activation energies). As a result, users should be cautious when presented with a low (total) failure rate, and should not necessarily be discouraged by a seemingly high failure rate.

3.4.4.2 Analysis of Gradual Degradations

Typically, few (if any) of the devices in a high-temperature accelerated aging test will actually cross the end-of-life threshold during the test. Therefore, the degradations that do occur (e.g., in the form of an increase in a laser's threshold current) need to be extrapolated to predict failure at some time in the future. Commonly used methods for predicting or extrapolating such degradations include those derived from the model described by Equation 3-18.

$$\Delta X(t) = A \times X(0) \times t^{m} \times e^{\left[\frac{-E_a}{kT}\right]} \qquad \textbf{(3-18)}$$

where

X is the parameter of interest (e.g., I_{TH}, P_{op})

A and m are empirical constants

E_a is the activation energy

k is Boltzmann's constant (e.g., 8.618×10^{-5} eV/K)

T is the absolute temperature (e.g., in Kelvin)

t is time.

For a given temperature, setting m equal to 1 (making Equation 3-18 consistent with the Arrhenius relationship) and adding the initial value of the parameter of interest to both sides of the equation yields a simple linear fit:

$$X(t) = X(0) + A_1 \times t \tag{3-19}$$

where A_1 is another empirical constant.

If m is not equal to 1, a power law model can be derived from Equation 3-18. This can be written as:

$$\Delta X(t) = A_1 \times t^m \tag{3-20}$$

or

$$\log[\Delta X(t)] = \log A_1 + m \times \log t \tag{3-21}$$

Unfortunately, it does not appear that any one model (among those shown here or found elsewhere) or value of "m" will provide the most accurate aging predictions for all types or designs of optoelectronic devices. On the other hand, it appears that a linear fit (m=1) to the aging data can generally be considered a safe "worst-case" model. If results also are obtained for any other model, the equipment manufacturer or device supplier needs to demonstrate that the model it has chosen gives a better fit to the data, particularly for data beyond 1000 hours. Plots of X versus time (based on the data obtained during the accelerated aging test) need to be available for review.

R3-15 **[116v2]** A plot of the distribution of the extrapolated expected lives (or in the case of devices that reach the end-of-life threshold during the test period, the actual lives) for all of the test samples in a high-temperature accelerated aging test shall be available for review.

3.4.4.3 Reliability Calculations

In general, the primary reliability-related parameters that need to be calculated from the results of the accelerated aging tests performed on optoelectronic devices are the wearout failure rate (as a function of time) and the random failure rate [generally calculated for both 60% and 90% one-sided Confidence Limits (CLs) based on an exponential failure distribution model]. These parameters, along with other parameters that may be applicable for a particular wearout failure mechanism/life model,[22] can be calculated by various methods, including the use of any of a number of sophisticated computer programs designed for that purpose.

R3-16 **[165v2]** The random and wear-out failure rates shall be calculated from the accelerated aging test data. These results shall be supplemented with field data as they become available.

In performing reliability-related calculations, it is important to recognize that wear-out and random failure rates are not interchangeable. That is, they result from different failure mechanisms and represent different reliability measures, and a device's total failure rate is the sum of these two contributions (assuming, as a result of successful screening procedures, no infant mortality failures).

3.4.4.4 Reporting of Results

Failure rate information for diodes is generally reported using a format similar to the one shown in Table 3-2. Results for modules, which can be more complex, are documented and reported using the same basic approach, but typically need to provide additional details on the module components.

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[22] For example, in cases where the wearout failure data has a normal distribution (as would be expected based on the Arrhenius relationship), additional parameters that may be of use are the Median Life [ML, which is the time at which 50% of a population of devices has (or is expected to have) failed due to aging], and the corresponding standard deviation (σ).

Table 3-2 Sample Format for Reporting Failure Rate Information

	Wearout Failure Rate @ 40°C (FITs)	**Random Failure Rate @ 40°C (FITs)**	
		@60% CL	**@90% CL**
@ 5 years			
@ 10 years			
@ 15 years			
@ 20 years			
@ 25 years			
Source of failure rates (e.g., accelerated aging tests, field data, SR-332) Wearout failure rates – Random failure rates –			

In addition to this basic information, the equipment manufacturer or device supplier may need to provide (e.g., upon request) other supplemental information. For the typical case where the failure rates were derived from the results of long-term accelerated aging tests, this could include:

1. Sample size
2. Test conditions
3. End-of-life threshold
4. Number of failures allowed and number observed
5. Results of failure analyses
6. Number of failures excluded from the results (and the reasons).

Also, in some cases it may be necessary to report the failure rates at a second operating temperature (e.g., @55°C).

4 Qualification of Optoelectronic Devices

As discussed in Section 1.5.1, in many cases there are either two or three primary levels of assembly that are applicable in the assurance of the reliability of an optoelectronic device. These are the diode level (which is typically tested with the diode packaged in a submount assembly), the module level, and (increasingly) the integrated module level. Also in many cases, diodes cannot be tested for at least some of the necessary parameters after they have been assembled into modules, while other parameters may need to be tested at the module or integrated module level. Therefore, this section (which provides the device-specific qualification testing criteria for various types of optoelectronic devices), Section 5 (which provides criteria related to reliability tests) and Section 6 (which provides criteria related to lot-to-lot controls) generally include entries for diodes, modules and integrated modules. In addition, similar criteria are provided in Section 7 for a number of other components that are often included in optoelectronic modules (either "regular" or integrated).

Note that as technology has improved, devices have gotten smaller and the level of functionality that can be provided in a particular size or type of package has increased substantially. For example, when the criteria in this document were originally written it was generally assumed that the amount of electronic circuitry necessary to perform CDR on an incoming optical signal would be such that a device supporting that function (i.e., a "receiver," as opposed to a "detector") would be classified as an integrated module (or even as a circuit pack). However, in many cases devices that support CDR are now considered to be modules. In addition, in some cases a device that meets the definition of a module may contain one or more smaller devices that also meet that same definition. To reflect this, a number of changes were made in this document as of Issue 2, including the consolidation of similar criteria that were previously applied to specific devices and levels of assembly, the removal of criteria that specified the inclusion of particular performance-related tests, and the addition of the following requirement.

R4-1 **[419]** Qualification of an optoelectronic device shall include the following.

1. *Optoelectronic Component Qualification*: If the optoelectronic device contains one or more lower level or smaller optoelectronic components to which the criteria in Sections 4.1 and 4.2 apply (i.e., optoelectronic diodes or modules), those components shall be qualified according to those criteria.
2. *Other Component Qualification*: If the optoelectronic device contains other optical or electrical components, then those components shall be qualified according to the criteria in Section 7.
3. *Device Qualification:* The fully assembled device shall be qualified according to the criteria in Sections 4.1 and 4.2.

4.1 Characterization

4.1.1 Characterization Tests

R4-2 **[106v2]** Optoelectronic devices shall be tested for performance (e.g., electrical and optical) and physical characteristics, as appropriate.

O4-3 **[107v2]** As a minimum, the characterization tests should include all of the performance parameters that are specified by the device supplier in the advertised literature for the device.

In addition to determining and justifying the particular set of performance parameters to be measured during the characterization process, the equipment manufacturer or device supplier also needs to consider the particular conditions under which those tests are performed. In most cases the primary variable is expected to be the ambient temperature. However, as indicated below, in at least some cases other variables may also need to be controlled.

R4-4 **[420]** For all devices, an appropriate set of parameters shall be measured with the ambient temperature set to the minimum and maximum specified operating temperatures (in addition to room temperature).

R4-5 **[421]** For tunable lasers, an appropriate set of parameters shall be measured with the wavelength set to (as a minimum), the minimum specified operating wavelength, the maximum specified operating wavelength, and a wavelength near the middle of the specified operating wavelength range.

O4-6 **[422]** Unless the condition discussed below has been met, for integrated modules an appropriate set of parameters should be measured while the device is being exposed to each of the three operational (low-level) shock and vibration conditions described in Section 4.4.2 (see Table 4-6).

In general, **O4-6 [422]** applies unless the integrated module is based on technology that has previously been shown to be insensitive to operational shock and vibration conditions similar to those listed in Table 4-6 (as justified and documented by the device supplier or equipment manufacturer).

CR4-7 **[423]** For all devices, a set of parameters may be required to be measured while the ambient temperature is changing at a rate of 1°C/minute.

R4-8 **[110v2]** At least 20 devices shall be subjected to the performance-related characterization tests at the diode and module levels. With the possible exceptions discussed in Section 4.4.1, at least 10 devices shall be subjected to the performance-related characterization tests at the integrated module level. No failures (i.e., results outside the specified limits) shall be allowed.

R4-9 **[424]** The tests/parameters listed as "**R**" in Table 4-2 shall be included in the physical characteristics characterization portion of the qualification process for optoelectronic devices (as noted).

O4-10 **[425]** The tests/parameters listed as "**O**" in Table 4-2 should be included in the physical characteristics characterization portion of the qualification process for optoelectronic devices (as noted).

A list of parameters that are expected to be useful for characterizing the performance of many optoelectronic devices is provided in Table 4-1, along with information about the conditions under which those parameters are typically tested and the types of devices to which they typically apply. In using Table 4-1 it is important to recognize that in some cases some of the parameters that are listed as being applicable to a certain type of device may not be appropriate for a particular device of that type. Similarly, in some cases additional parameters (other than those listed in Table 4-1) may need to be measured in order to adequately characterize a particular device. Reasons for this include such issues as technological advances that make certain parameters irrelevant and increase the importance of other parameters, and new applications that depend on performance characteristics that previously did not need to be considered. In general, this significantly increases the importance of clear and consistent reporting of the characterization test results (see Section 2.1.3.1).

Table 4-1 Typical Performance Parameters for Optoelectronic Device Characterization

Heading	Parameter	Symbol	Ref.	Applicability[1]
Optical Spectrum	Wavelength[2]	λ	3.2.1	Laser Diodes[3] and Modules,[4] LEDs and LED Modules
	Spectral Width[2]	$\Delta\lambda$	3.2.1	Laser Diodes[3] and Modules,[4] LEDs and LED Modules
	Side-mode Suppression Ratio	SMSR	3.2.1.2	SLM Laser Diodes,[3, 4] Laser Modules with SLM lasers
	Spontaneous Source Emission	SSE	3.2.1.2	SLM Laser Diodes,[3] Laser Modules with SLM lasers
	Chirp	α	3.2.1.2.4	Directly modulated Laser Diodes and Modules for >2.5 Gb/s systems, EA Modulators

Table 4-1 Typical Performance Parameters for Optoelectronic Device Characterization (Continued)

Heading	Parameter	Symbol	Ref.	Applicability[1]
Optical Power and the Light-Current Curve	Optical Power	P	3.2.2.1	Laser and LED Modules with specified output power levels
	Threshold Current	I_{TH}	3.2.2.2	Laser Diodes[3] and Modules
	Characteristic Temperature[5]	T_0	3.2.2.3	Laser Diodes[3]
	Optical Power @ I_{TH}	P_{TH}	3.2.2.4.1	Laser Diodes[3] and Modules
	Optical Power @ I_{op}	P_{op}	3.2.2.4.2	LEDs and LED Modules
	Overall L-I Linearity	–	3.2.2.5.1	Laser Diodes[3] and Modules
	Harmonic Distortion	–	3.2.2.5.1	Laser Diodes and Modules for analog applications
	L-I Kinks	–	3.2.2.5.2	Laser Diodes[3] and Modules
	L-I Saturation	–	3.2.2.5.3	Laser Diodes[3] and Modules
	Slope Efficiency	η	3.2.2.6	Laser Diodes[3] and Modules
	Relative Intensity Noise	RIN	3.2.2.7	Laser Diodes[3] and Modules
	Super-luminescence	–	3.2.2.8	EELEDs, LED Modules with EELEDs
	Lasing Threshold	–	3.2.2.9	EELEDs, LED Modules with EELEDs
Voltage-Current Curve	Forward Voltage @ I_{TH}	$V_F(TH)$	3.2.3	Laser Diodes[3] and Modules
Modulated Output[6]	Eye Pattern or Rise & Fall Times	– or t_r & t_f	3.2.4.1	Directly modulated Laser Diodes and Modules, LEDs and LED Modules, EA Modulators, and External Modulators
	Extinction Ratio or Mod. Depth	r_e or P_{mod}	3.2.4.2	Directly modulated Laser Diodes and Modules, LED Modules, EA Modulators, and External Modulators
	Turn-on Delay	t_{on}	3.2.4.3	Directly modulated Laser Diodes and Modules, LEDs and LED Modules, EA Modulators, and External Modulators
	Cutoff Frequency	f_c	3.2.4.4	Directly modulated Laser Diodes and Modules, LEDs and LED Modules, EA Modulators, and External Modulators

Table 4-1 Typical Performance Parameters for Optoelectronic Device Characterization (Continued)

Heading	Parameter	Symbol	Ref.	Applicability[1]
Tunable Laser Char.	Frequency Tuning Time	t_{tuning}	3.2.5	Tunable Laser Modules
	Module Warm-Up Time	t_{warmup}	3.2.5	Tunable Laser Modules
	Optical Power While Disabled or Off-Channel	$P_{disable}$ or P_{tuning}	3.2.5	Tunable Laser Modules
Optical Output Fields and Alignment	Far-Field FWHM Angles	$\theta_{\|\|}, \theta_{\perp}$	3.2.6.1	Laser Diodes, EA Modulators
	Coupling Efficiency	CE	3.2.6.2	Laser Modules
	F/R Tracking Ratio	$r_{f/r}$	3.2.6.3	Laser Diodes[3] and Modules
	F/R Tracking Error	T_e	3.2.6.4	Laser Modules
	Polarization Extinction Ratio	PER	3.2.6.5, 3.2.7.2	Laser Diodes[3] and Modules, and External Modulators[7]
Modulator Electrical Char.	Electrical Return Loss	S_{11}	3.2.7.1	EA Modulators External Modulators
	Bandwidth	S_{21}	3.2.7.2	EA Modulators and External Modulators
	Modulation Voltage	V_{mod}	3.2.7.1	EA Modulators
	DC Drive Voltage	DC $V\pi$	3.2.7.2	External Modulators
	RF Drive Voltage	RF $V\pi$	3.2.7.2	External Modulators
Modulator Optical Char.	Dispersion Penalty	DP	3.2.7.1	EA Modulators
	Operating Wavelength Range	λ_{op}	3.2.7.2	External Modulators
	Max. Optical Input Power	P_{max}	3.2.7.2	External Modulators
	Insertion Loss	IL	3.2.7.2	External Modulators
	Input Return Loss	RL	3.2.7.2	External Modulators

Table 4-1 Typical Performance Parameters for Optoelectronic Device Characterization (Continued)

Heading	Parameter	Symbol	Ref.	Applicability[1]
Detector or Monitor Operation	Responsivity or Quantum Efficiency	R or η_Q	3.2.8.1	Photodiodes and Detector Modules
	Spatial Homogeneity	–	3.2.8.2	Photodiodes and Detector Modules
	Linearity	–	3.2.8.3	Photodiodes and Detector Modules
	Photocurrent @ P_o(max)	I_{ph}	3.2.8.4	Monitor Photodiodes
	Dark Current	I_{dark}	3.2.8.5	Monitor Photodiodes, Photodiodes and Detector Modules
	Capacitance	C	3.2.8.6	Photodiodes and Detector Modules
	Cutoff Frequency	f_c	3.2.8.7	Photodiodes and Detector Modules
	Breakdown Voltage	V_{br}	3.2.8.8	Photodiodes and Detector Modules
	Excess Noise Factor	F	3.2.8.9	Avalanche Photodiodes, APD-based Detector Modules
Receiver Operation	Sensitivity	P_{Rmin}	3.2.9.1	Receiver Modules
	Overload Power	P_{Rmax}	3.2.9.1	Receiver Modules
	Chromatic Dispersion Tolerance	–	3.2.9.2	Receiver Modules
	DGD Tolerance	–	3.2.9.2	Receiver Modules for ≥ 10 Gb/s systems
	Jitter Tolerance	–	3.2.9.2	Receiver Modules
	Bit Rate Offset Tolerance	–	3.2.9.2	Receiver Modules

Notes for Table 4-1:

1 In most cases the optical performance parameters that are important at the integrated module level are the same as (or a subset of) those that are important at the module level. Therefore "module" in this column can generally be interpreted to include both modules and integrated modules.

2 As discussed in Section 3.2.1, the particular wavelength and spectral width parameters and tolerances that are applicable in the characterization of different laser and LED devices may vary, and will depend on issues such as the type of device (e.g., MLM or SLM laser).

3 Including laser diodes associated with EA modulators (see footnote 2 in Section 1).

4 For tunable lasers, the relevant spectral characteristics need to be measured at the minimum specified wavelength, a wavelength near the center of the specified range, and the maximum specified wavelength.

5 Values of T_0 can be calculated using the results of the threshold current test. Whether that parameter is useful in the characterization of a laser diode will depend on that diode's design and specifications.

6 Measured at the maximum modulation rate.

7 Only applies to modulators with PM fiber at both input and output ports.

Table 4-2 Physical Characteristics of Devices

Parameter	Ref.	Additional Information	Sampling			Applicability
			LTPD	SS	C	
Internal Moisture	3.2.10.1.1	–	20	11	0	**R** for all hermetic optoelectronic modules
Hermeticity	3.2.10.1.2	–	20	11	0	**R** for all hermetic optoelectronic devices[1]
ESD	3.2.10.2.1	HBM, with minimum threshold based on device's ESD sensitivity classification, test to failure as per FOTP-129	–	6	0[2]	**R** for all optoelectronic modules except as noted[3]
	3.2.10.2.2	±8 and ±15 kV discharges as per GR-78-CORE	–	2	0	**O** for all optoelectronic integrated modules[4]
Flammability	3.2.10.3	–	–	3 or 5[2]	–	**R** for all optoelectronic modules and integrated modules except as noted[6]
Die Shear Strength	3.2.10.4	Applicable to all relevant connections (e.g., diode/ heat sink and heat sink/ submount)	20	11	0	**R** for all optoelectronic diodes (submount assemblies)
Solderability	3.2.10.5	Steam aging not required	20	11	0	**R** for all optoelectronic modules
Wire Bond Strength	3.2.10.6	Applicable conditions are based on bond type	20	11	0	**R** for all optoelectronic diodes (submount assemblies)

Notes for Table 4-2:

1 May be performed on non-functional devices that are mechanically identical to the functional devices with the exception that any fiber pigtails/boots have been cut off.

2 Note that in ESD threshold testing all of the sample devices are tested until they fail (using increasingly higher stress voltages). The "0" value given here refers to the number of devices whose measured thresholds are less than the minimum acceptable threshold (i.e., less than 500 V or some other specified value based on the ESD sensitivity classification of the device).

3 Applicable unless all components in the module or integrated module were tested and showed ESD thresholds greater than 4000 V, or the device is a Lithium Niobate modulator (which is generally considered to be insensitive to ESD) and this test was previously performed on similar devices.

4 If a particular integrated module does not include a board to which the test discharges can be applied, then an alternate ESD test must be performed (see Section 3.2.10.2.2).

5 Three samples are needed for needle-flame and Oxygen Index tests, while five are needed for UL 94 tests.

6 Non-flammable hermetic metal or ceramic packages are not required to be subjected to a flammability test. However, any potentially flammable materials attached to such packages generally need to be tested.

4.1.2 Characterization Test Pass/Fail Criteria

In addition to the general criteria related to the establishment of pass/fail criteria provided in Section 3.1.3, the following requirement applies in the case of the internal moisture test.

R4-11 **[426]** Unless **R3-7 [415]** is met, the equipment manufacturer or device supplier shall use the pass/fail criterion shown below for the internal moisture test.

- The water vapor content by volume is less than or equal to 5000 ppm.[1]

4.2 Stress Tests

4.2.1 Mechanical Integrity and Environmental Stress Tests

R4-12 **[113v2]** The tests listed as "**R**" in Tables 4-3, 4-4, and 4-5 shall be included in the mechanical integrity and environmental stress testing portion of the qualification process for optoelectronic devices specified for use in CO or UNC environments (as appropriate).

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[1] While it would typically be desirable to establish a lower water vapor content limit (i.e., a limit that is less than 5000 ppm), that is generally not feasible due to measurement technique limitations.

O4-13 **[427]** The tests listed as "**O**" in Tables 4-3, 4-4, and 4-5 should be included in the mechanical integrity and environmental stress testing portion of the qualification process for optoelectronic devices specified for use in CO or UNC environments (as appropriate).

Table 4-3 Mechanical Integrity Tests

Test	Ref.	Additional Information[1]	Applicability[2, 3]
Mechanical Shock[4]	3.3.1.1	Condition A (500 g, 1.0 ms), 5 times/direction[5]	**R** for all optoelectronic diodes and modules
		300 g, 3 ms, 5 times/direction[5]	**R** for all optoelectronic integrated modules ≤ 0.225 kg
		50 g, 11 ms, 5 times/direction[5]	**R** for all optoelectronic integrated modules > 0.225 kg and ≤ 1.0 kg[6]
Vibration[4]	3.3.1.1	Condition A (20 g), 20 to 2000 to 20 Hz, 4 min/cy, 4 cy/axis, non-powered	**R** for all optoelectronic diodes, modules, and integrated modules
		5 g, 10 to 100 to 10 Hz, 1 min/cy, 10 cy/axis, powered	**O** for all optoelectronic integrated modules[7]
Thermal Shock	3.3.1.2	Condition A (0 and 100°C)	**R** for all hermetic optoelectronic modules
Fiber Integrity - Twist Test	3.3.1.3.1	0.5 kg, 10 cycles, 3 cm from device housing or strain relief	**R** for all optoelectronic modules and integrated modules[8] with coated, tight-buffered or loose-buffered fiber pigtails
		1.0 kg, 10 cycles, 3 cm from device housing or strain relief	**R** for all optoelectronic modules and integrated modules[8] with reinforced fiber pigtails
Fiber Integrity - Side Pull Test	3.3.1.3.2	0.25 kg, 90 degrees, 22 to 28 cm from device housing	**R** for all optoelectronic modules and integrated modules[8] with coated or tight-buffered fiber pigtails
		0.5 kg, 90 degrees, 22 to 28 cm from device housing	**R** for all optoelectronic modules and integrated modules[8] with loose-buffered[9] or reinforced fiber pigtails

Table 4-3 Mechanical Integrity Tests (Continued)

Test	Ref.	Additional Information[1]	Applicability[2, 3]
Fiber Integrity - Cable Retention Test	3.3.1.3.3	0.5 kg, 1 minute	**R** for all optoelectronic modules and integrated modules[8] with coated or tight-buffered fiber pigtails
		1.0 kg, 1 minute	**R** for all optoelectronic modules and integrated modules[8] with loose-buffered[9] or reinforced fiber pigtails
Connector/Receptacle Durability - Mating Durability Test	3.3.1.4.1	200 matings	**R** for all connectorized or receptacle optoelectronic modules and integrated modules
Connector/Receptacle Durability - Wiggle Test	3.3.1.4.2	Specific procedure is for further study	**O** for all connectorized or receptacle optoelectronic modules and integrated modules
Connector Durability - Pull Test	3.3.1.4.3	Minimum of 10 connections, no more than 30% pullouts	**R** for all connectorized optoelectronic modules and integrated modules

Notes for Table 4-3:

1 As discussed in Section 3.1.4, the conditions shown correspond to minimum acceptable levels of stress, and alternate conditions may be used (with technical justification) in some situations.

2 In all cases, the applicability of the test is independent of the particular environment in which the device is specified to operate (i.e., CO or UNC).

3 With the possible exceptions discussed in Section 4.4.1 for the case of integrated modules, the applicable LTPD, SS and C values are 20, 11 and 0.

4 In cases where mechanical shock and vibration tests are both performed, **R3-13 [417]** indicates that the same sample of devices must be used for both tests.

5 See **R3-14 [418]** regarding the treatment of devices that are not designed to withstand the mechanical shock test conditions listed here.

6 See Section 4.3.2 of GR-63-CORE for mechanical shock test conditions for integrated modules that are greater than 1 kg.

7 Applies unless the integrated module is based on technology that has previously been shown to be insensitive to vibration conditions similar to those listed here (as justified and documented by the device supplier or equipment manufacturer).

8 If there is no change in the fiber attachment or routing when a module is incorporated into an integrated module, and if fiber integrity tests were performed at the module level, then these tests do not need to be repeated at the integrated module level.

9 This test applies to loose-buffered fiber where the buffer material is attached to the component and is used as a strength member. Where the buffer material is not used as a strength member, the less stressful test for coated and tight-buffered fiber applies instead (see Section 3.3.1.3).

Table 4-4 Non-Powered Environmental Stress Tests

Test	Ref.	Additional Information	Env't		Applicability[2]
			CO	UNC	
High-Temperature Storage	3.3.2.1	85°C, 2000 hours[1]	**R**[3]	**R**[3]	All optoelectronic modules and integrated modules
Low-Temperature Storage	3.3.2.1	–40°C, 72 hours[1]	**O**	**O**	All optoelectronic modules and integrated modules
Temp. Cycling[4, 5]	3.3.2.2	–40°C/+85°C, 50 cycles[1]	**O**	**R**	Laser Diodes, LEDs, Photodiodes, and EA Modulators
		–40°C/+85°C, 100 cycles[1]	**R**	–	All optoelectronic modules and integrated modules for CO applications
		–40°C/+85°C, 500 cycles[1]	–	**R**	All optoelectronic modules and integrated modules for UNC applications
Damp Heat[5]	3.3.2.3	85°C/85%RH, 500 hours[1]	**R**[5]	**R**[5]	All optoelectronic diodes specified for use in non-hermetic modules, and all optoelectronic modules and integrated modules

Notes for Table 4-4:

1 As discussed in Section 3.1.4, the conditions shown correspond to minimum acceptable levels of stress, and alternate conditions may be used (with technical justification) in some situations. In addition, if a device's minimum or maximum specified storage temperature is more extreme than the temperature listed here for the corresponding storage test, then that more extreme value needs to be used in the test.

2 With the possible exceptions discussed in Section 4.4.1 for the case of integrated modules, the applicable LTPD, SS and C values are 20, 11 and 0.

3 See Sections 3.3.2.1 and 3.3.3.1.3 regarding cases where it may not be necessary to perform both the high-temperature storage test and the high-temperature operations test.

4 Following the completion of the nondestructive measurements used in the pass/fail determination for this test, the test conditions may be reapplied to a subset of the devices for additional cycles as specified in Table 5-1 (i.e., for accelerated aging test purposes). If destructive measurements (e.g., an internal moisture test) are used in the pass/fail determination, the results of the measurements performed on the devices that are not used in the accelerated aging test may be considered applicable to the entire set of samples for this test.

5 If desired, hermetic modules may be biased during this test. In addition, see Sections 3.3.2.3 and 3.3.3.3 regarding cases where it may not be necessary to perform both non-powered and powered damp heat tests on non-hermetic devices.

Table 4-5 Powered Environmental Stress Tests

Test	Ref.	General Conditions	Sampling[1]			Env't		Applicability (and Device-Specific Conditions[2])
			LTPD	SS	C	CO	UNC	
High Temp Operations[3]	3.3.3.1	70°C, 5000 hours[2]	10	22	0	**R**	–	Laser Diodes (max. rated power or current[4]), LEDs (max. rated current), and EA Modulators (appropriate conditions[5])
		85°C, 5000 hours[2]	10	22	0	–	**R**	Laser Diodes (max. rated power or current[4]), LEDs (max. rated current), and EA Modulators (appropriate conditions[5])
		175°C, 2000 hours[2]	10	22	0	**R**	**R**	Photodiodes (2×V_{op})
		70°C, 2000 hours[2]	20	11[1]	0	**R**[6]	–	All optoelectronic modules (except External Modulators) and integrated modules for CO applications (max. rated power or current[4] for Laser and LED Modules, normal bias for Detector Modules, normal operating conditions for Receiver Modules)
						O[6]	–	External Modulators for CO applications (appropriate conditions, including the maximum specified modulation rate[5, 7])
		85°C, 2000 hours[2]	20	11[1]	0	–	**R**[6]	All optoelectronic modules (except External Modulators) and integrated modules for UNC applications (max. rated power or current[4] for Laser and LED Modules, normal bias for Detector Modules, normal operating conditions for Receiver Modules)
						–	**O**[6]	External Modulators for UNC applications (appropriate conditions, including the maximum specified modulation rate[5, 7])
Cyclic Moisture Resistance	3.3.3.2	20 cycles[2, 8]	20	11[1]	0	–	**R**	All optoelectronic modules and integrated modules for UNC applications

Table 4-5 Powered Environmental Stress Tests (Continued)

Test	Ref.	General Conditions	Sampling[1]			Env't		Applicability (and Device-Specific Conditions[2])
			LTPD	SS	C	CO	UNC	
Damp Heat for (Powered) Non-Hermetic Devices	3.3.2.3	85°C/85%RH, 2000 hours[2]	20	11	0	**R**[9]	**R**[9]	All optoelectronic diodes specified for use in non-hermetic modules [1.2×I_{TH} for Laser Diodes, 0.1×I_{op}(max) for LEDs, normal bias for Photodiodes, and appropriate conditions[5] for EA Modulators]
		85°C/85%RH, 1000 hours[2]	20	11	0	**R**[9]	**R**[9]	All non-hermetic optoelectronic modules [1.2×I_{TH} for Laser Modules, 0.1×I_{op}(max) for LED Modules, normal bias for Detector Modules, appropriate conditions[5] for External Modulators, and normal operating conditions for Receiver Modules]
		Max. op. temp. (up to 85°C), 85%RH, 1000 hours	20	11[1]	0	**O**[9]	**O**[9]	All optoelectronic integrated modules (normal operating conditions)

Notes for Table 4-5:

1 See Section 4.4.1 regarding possible exceptions to the minimum sample size requirement for the case of testing of integrated modules.

2 As discussed in Section 3.1.4, the conditions shown generally correspond to minimum acceptable levels of stress, and alternate conditions may be used (with technical justification) in some situations. The one exception to this "minimum acceptable levels of stress" statement is the case of a photodiode with a non-negligible wearout failure rate. In that case the alternate conditions will generally be less stressful than those listed above for photodiodes. On the other hand, the alternate conditions need to be consistent with the guidelines provided in Section 3.3.3.1 for other devices, and still must be technically justified. Finally, if a device's maximum specified operating temperature is higher than the temperature listed here for the high-temperature operations test, that higher value needs to be used in the test.

3 Following the completion of the nondestructive measurements used in the pass/fail determination for this test, the test conditions may be reapplied to a subset of the devices for additional hours as specified in Table 5-1 (i.e., for accelerated aging test purposes). If destructive measurements (e.g., an internal moisture test) are used in the pass/fail determination, the results of the measurements performed on the devices that are not used in the accelerated aging test may be considered applicable to the entire set of samples for this test.

4 For lasers, high-temperature operations and accelerated aging tests are often performed under APC, in which a feedback circuit adjusts the drive current for constant optical output (typically the maximum rated power at the test temperature). However, in other cases these tests are done using ACC, in which case the drive current is kept constant (and typically at the maximum rated level) regardless of the optical output power. In addition, see Section 3.3.3.1.2 regarding the wavelength settings for high-temperature operations testing of tunable lasers.

5 For EA and external modulators, the relevant variables may include the modulation rate and voltage, the DC bias voltage, and the optical power level. In general, each of these needs to be addressed, and the selected values justified by the device supplier or equipment manufacturer.

6 See Sections 3.3.2.1 and 3.3.3.1.3 regarding cases where it may not be necessary to perform both the high-temperature storage test and the high-temperature operations test.

7 See Section 3.3.3.1.2 regarding the modulation rate for high-temperature operations testing of external modulators.

8 May be reduced to 10 cycles in some cases (see Section 3.3.3.2).

9 See Sections 3.3.2.3 and 3.3.3.3 regarding cases where it may not be necessary to perform both non-powered and powered damp heat tests.

4.2.2 Stress Test Pass/Fail Determination

In general, a set of the tests/measurements that includes some of those performed during the characterization portion of the qualification process needs to be performed before and after most mechanical integrity and environmental stress tests for use in determining whether each device has passed or failed the latter tests. In addition to the general pass/fail criteria provided in Section 3.1.3, the following specific criteria related to those tests also apply.

R4-14 **[428]** A subset of the electrical and optical measurements defined for use in the characterization of the device (see Table 4-1) and/or other appropriate characterization tests (e.g., hermeticity) shall be performed before and after each stress test or group of stress tests to detect any change in performance or degradation of the device. This set of tests (and the corresponding pass/fail criteria defined by the equipment manufacturer or device supplier, see Section 3.1.3) shall address important optical and electrical performance and physical characteristics (including physical damage) of the optoelectronic device and any other components (e.g., TECs, fiber pigtails[2]) that may be present.

Note that the thermal shock test is specifically intended to test the hermetic integrity of the module package, and therefore electrical and optical measurements are not required after that particular test. Also note that in any case where a test/measurement is destructive (e.g., internal moisture, see Section 3.2.10.1.1), the results cannot be compared to the results of similar measurements performed on the same sample of devices before the stresses were applied (as is done with the results of a number of other measurements). Instead, those results would need to be compared to the normal (absolute) limits on that parameter and/or the results of similar measurements performed on a separate sample of unstressed devices.

R4-15 **[20v2]** For hermetically packaged devices, a hermeticity test (see Section 3.2.10.1.2) shall be included in the set of tests/measurements that are performed to determine if the devices have passed or failed the following stress tests (or series of stress tests that includes any of these tests):

- The mechanical integrity tests in Table 4-3 (individually or in sets of tests)
- High-temperature storage or operations
- Temperature cycling
- Cyclic moisture resistance
- Damp heat.

4.3 Considerations for the Qualification of Pump Laser Modules

Among the major types of pump lasers that are currently available are those operating at 980 nm and 1480 nm. For 1480-nm pump lasers, there are generally no additional qualification-related concerns beyond those that exist for lasers used in fiber optic communications transmitters.[3] On the other hand, GaAs-based lasers such as those used in 980-nm pumps have historically suffered from sudden failures such as Catastrophic Optical Damage (COD), facet damage, and Electrical Over

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[2] Note that for loose buffered fiber, damage resulting from shrinkage of the buffer material can be a significant issue.

[3] As noted in Section 1.1, this document currently does not address issues related to very high output power levels. In general, such power levels are expected to be generated primarily by pump lasers, and in those cases there may be additional concerns.

Stress (EOS) failures. In response to this, significant efforts have been made to develop new techniques, many related to facet coatings, to reduce or eliminate the potential problems. In general, the results of those efforts have been impressive. However, some field return data still show relatively high failure rates that (according to pump manufacturers) can mostly be attributed to EOS. Some of these failures might be of devices that utilized early technologies or have been caused by mis-handling during the equipment manufacturing process. Nevertheless, this represents an area of concern for end-users.

O4-16 **[171v2]** Reliability programs to address sudden failures, such as EOS failures, should be developed by equipment manufacturers or device suppliers for the GaAs pump modules that they utilize or produce.

R4-17 **[172v2]** For GaAs pump lasers, failure mode analysis data on field returns shall address EOS failures.

In addition to the sudden failure issue discussed above, early 980-nm pumps also experienced relatively high levels of defects related to device packaging. These were apparently caused by the presence of trace organic impurities in the package gas, and the problem was solved by the inclusion of oxygen or other gettering materials in the gas. However, this solution has raised concerns related to moisture produced by the oxygen and the organic impurities at high temperatures. Therefore, an internal moisture test is important in determining whether a device has passed the high-temperature operations test.

R4-18 **[173v2]** An internal moisture test (see Section 3.2.10.1.1) shall be performed on GaAs pump module packages at the completion of the high-temperature operations test.

Note that since the internal moisture test is generally a destructive test, it can be performed immediately upon completion of the high-temperature operations test only on those samples that are not going to be returned to the high-temperature condition for accelerated aging test purposes (also see the “Notes” in Table 4-5).

4.4 Considerations for the Qualification of Integrated Modules

4.4.1 Sample Size and Level of Assembly Considerations

As discussed in Section 1.5.1, test access to the optical and electrical parameters of an integrated module’s optoelectronic device(s) may be severely limited. In addition, cost considerations may limit the number of integrated module samples that can feasibly be committed for qualification or accelerated aging purposes. Therefore, complete qualification and accelerated aging testing of a full set of samples typically needs to be performed at a lower level (i.e., on all of the components to be integrated into the integrated module), but in some cases it may be acceptable to test a smaller set of samples at the integrated module level. In particular, a smaller set of samples may be used if it can be justified and if agreements can be reached with the entities that purchase the devices.

R4-19 **[429]** In any case where the sample size used in a qualification or accelerated aging test on an integrated module is less than the size specified in the corresponding criterion or table, the smaller size shall be justified by the equipment manufacturer or device supplier. In addition, in all cases at least three samples shall be tested.

Also as discussed in Section 1.5.1, in some cases the additional electronic circuitry provided in an integrated module may be critical to the proper operation of the lower level device, and therefore some of the tests that are normally specified to be performed at the diode or module level may need to be deferred to the integrated module level. Similarly, in some cases an equipment manufacturer or device supplier may find it cost effective to defer certain tests to the integrated module level (e.g., so that several components can be stressed simultaneously). In all such cases, the sample size criteria that apply at the lower level remain in effect.

4.4.2 Operational Shock and Vibration Tests

As indicated in **O4-6 [422]**, an appropriate set of an integrated module's performance tests should typically be performed while the device is being exposed to operational levels of shock and vibration. Table 4-6 contains a summary of these conditions. In general, these conditions are based on both the test conditions provided in several other documents (e.g., GR-63-CORE, and ETSI EN 300 019-1-3 V.2.1.1 and 019-2-3 V2.1.2), and the results of an equipment shock and vibration study that was presented to the Telcordia Technical Forum during the development of Issue 2 of this document.

Table 4-6 Operational Shock and Vibration Conditions for Integrated Modules

Condition	Ref.	Description
Operational Shock	–	10 g, 0.3 ms half-sine shock pulse, 3 axes
Operational Vibration #1	GR-63-CORE, Section 5.4.2	Swept sine wave at a level of 1.0 g, 3 mm max. displacement, 5 Hz to 100 Hz, 0.1 octaves/minute, 3 axes
Operational Vibration #2	–	Swept sine wave at a level of 2.0 g, 100 Hz to 200 Hz, 8 octaves/minute, 3 axes

Notes for Table 4-6:

1 Since the conditions specified in this table are operational conditions, the device under test is expected to perform within its specifications while the conditions are being applied. In addition, any particular condition (i.e., shock pulse or vibrational sweep) can be repeated as many times as is necessary to allow all of the appropriate performance measurements to be performed. Note however, that in the case of the operational shock condition, sufficient time needs to be provided between shocks such that they can be considered independent events.

5 Optoelectronic Device Reliability Testing

In general, true reliability tests are focused on the physics of failures, are run to failure (not just for a specified length of time) at three or more levels of stress (e.g., three or more temperatures), often use more stressful conditions than those used in qualifying a device, and may use smaller sample sizes. Thus, with the exception of the ESD test (and possibly the die shear and wire bond strength tests) listed in Table 4-2, none of the tests listed in either this or previous issues of this document are true reliability tests.[1] On the other hand, the accelerated aging tests discussed in this section (which are based on the "for information" tests that appeared in GR-468-CORE, Issue 1) can be useful as (for example) a starting point for a true reliability test program on a new device or an on-going part of the reliability assurance process for existing devices. In addition, similar tests have been performed on numerous devices in the past, and comparisons of those results with the results of the tests performed against the criteria in this section may prove useful during the reliability assurance process.

5.1 Accelerated Aging Tests

O5-1 **[430]** The tests listed in Table 5-1 should be included in the accelerated aging testing portion of the reliability assurance process for optoelectronic devices specified for use in CO or UNC environments (as appropriate).

O5-2 **[163v2]** For modules containing "new" optoelectronic devices, it is recommended that either the high-temperature accelerated aging tests be conducted on a larger sample of modules and/or for longer duration (than listed in Table 5-1), or that additional accelerated aging test data be obtained from the diode supplier.

In addition to temperature- and humidity-based accelerated aging tests as listed in Table 5-1, a true reliability program would be expected to include tests intended to investigate other possible acceleration factors. For example, for lasers it may be possible to perform accelerated aging tests (preferably to failure) at the device's normal operating temperature and several different extreme output power/drive current levels (e.g., $1.5 \times I_{max}$, $1.75 \times I_{max}$, $2.0 \times I_{max}$), and to use the results of those tests to perform reliability calculations that will provide information on the wearout failure rate at I_{max}. (Also see Section 3.4.1.3.)

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[1] Note that although the ESD test is a true reliability test (and thus could logically be included in this section), it has traditionally been performed during the optoelectronic device qualification process and is therefore included with those tests in Section 4.1.1 of this document. Also note that unlike the case for most true reliability tests, there are well established classes defined for equipment with different levels of ESD tolerance, which makes the test more useful for device qualification purposes.

Table 5-1 Accelerated Aging Tests

Test	Ref.	General Conditions	Sample Size[1]	Env't		Applicability (and Device-Specific Conditions[2])
				CO	UNC	
High Temp.	3.4.1	70°C, 10,000 hours[2]	10	**O**	–	Laser Diodes (max. rated power or current[3]), LEDs (max. rated current), and EA Modulators (appropriate conditions[4])
		85°C, 10,000 hours[2]	10	–	**O**	Laser Diodes (max. rated power or current[3]), LEDs (max. rated current), and EA Modulators (appropriate conditions[4])
		175°C, 5000 hours[2]	10	**O**	**O**	Photodiodes (2×V_{op})
		70°C, 5000 hours[2]	5[5]	**O**	–	All optoelectronic modules and integrated modules for CO applications (max. rated power or current[3] for Laser and LED Modules, normal bias for Detector Modules, normal operating conditions for Receiver Modules, appropriate conditions, including the maximum specified modulation rate[4, 6] for External Modulators)
		85°C, 5000 hours[2]	5[5]	–	**O**	All optoelectronic modules and integrated modules for UNC applications (max. rated power or current[3] for Laser and LED Modules, normal bias for Detector Modules, normal operating conditions for Receiver Modules, appropriate conditions, including the maximum specified modulation rate[4, 6] for External Modulators)
Temp. Cycling[7]	3.4.2	–40°C/+85°C, 500 cycles[2]	5[5]	**O**	–	All optoelectronic modules and integrated modules for CO applications
		–40°C/+85°C, 1000 cycles[2]	5[5]	–	**O**	All optoelectronic modules and integrated modules for UNC applications

Table 5-1 Accelerated Aging Tests (Continued)

Test	Ref.	General Conditions	Sample Size[1]	Env't		Applicability (and Device-Specific Conditions[2])
				CO	UNC	
Damp Heat	3.4.3	85°C/85%RH, 5000 hours[2]	5	O	O	All optoelectronic diodes specified for use in non-hermetic modules [1.2×I_{TH} for Laser Diodes, 0.1×I_{op}(max) for LEDs, normal bias for Photodiodes, and appropriate conditions[4] for EA Modulators], and all non-hermetic optoelectronic modules [1.2×I_{TH} for Laser Modules, 0.1×I_{op}(max) for LED Modules, normal bias for Detector Modules, appropriate conditions[4] for External Modulators, and normal operating conditions for Receiver Modules]
		Max. op. temp. (up to 85°C)/85%RH, 5000 hours	5[5]	O	O	All optoelectronic integrated modules (normal operating conditions)

Notes for Table 5-1:

1 The devices used in these tests may be subsets of the devices used in the corresponding tests performed for qualification purposes (see Tables 4-4 and 4-5). In such cases, after the nondestructive measurements used in the qualification stress test pass/fail determination process have been completed, the test conditions are reapplied for the remainder of the hours or cycles listed here. If different devices are used in the qualification and accelerated aging tests, then **R2-26 [105v2]** on the selection of sample devices applies for both types of tests.

2 As discussed in Section 3.1.4, the conditions shown generally correspond to minimum acceptable levels of stress, and alternate conditions may be used (with technical justification) in some situations. The one exception to this “minimum acceptable levels of stress” statement is the case of a photodiode with a non-negligible wearout failure rate. In that case the alternate conditions will generally be less stressful than those listed above for photodiodes. On the other hand, the alternate conditions need to be consistent with the guidelines provided in Sections 3.3.3.1 and 3.4.1.1 for other devices, and still must be technically justified. Finally, if a device’s maximum specified operating temperature is higher than the temperature listed here for the high-temperature accelerated aging test, that higher value needs to be used in the test.

3 For lasers, high-temperature accelerated aging tests are often performed under APC; however, in other cases they are done using ACC.

4 For EA and external modulators, the relevant variables may include the modulation rate and voltage, the DC bias voltage, and the optical power level. In general, each of these needs to be addressed, and the selected values justified by the device supplier or equipment manufacturer.

5 See Section 4.4 regarding possible exceptions to the minimum sample size objective for the case of testing of integrated modules.

6 See Section 3.3.3.1.2 regarding the modulation rate for high-temperature accelerated aging testing of external modulators.

7 The device may be either biased or unbiased during this test.

5.2 Accelerated Aging End-of-Life Thresholds and Failures

In general, the parameters that are monitored for the purpose of determining end-of-life for optoelectronic devices need to be determined based on the device design, with a critical consideration being that any degradations in the overall performance of the device need to be reflected in the value of the monitored parameter (and thus be apparent as they occur). Among the parameters that might be monitored are a laser's threshold current, a laser's or LED's drive current at a specific output power level (or output power at a specific drive current), a WDM laser's central wavelength, or a modulator's on/off contrast ratio. In addition, if a device contains a control loop to maintain a particular parameter at a constant value, it may be appropriate (or necessary) to monitor that control loop for changes and use those changes to predict when the controlled parameter will no longer be able to be kept at its setpoint. Finally, as noted in Sections 3.3.3.1.1 and 3.4.1.4 the wear-out failure rate for photodiodes is generally insignificant, even at high temperatures. Therefore the failures that occur during the high-temperature accelerated aging tests on those devices are typically random failures, to which the concept of an end-of-life threshold does not apply. On the other hand, if wear-out failures are a significant issue for a particular type of photodiode, an appropriate end-of-life threshold could be a specified increase in the dark current.

R5-3 **[117v2]** The end-of-life thresholds used in accelerated aging tests shall be specified by the equipment manufacturer or device supplier (with technical justification) and, if applicable, shall be at least as strict as the system alarm condition if that condition is known when the test is performed. If the test is performed by a device supplier without this prior information, the equipment manufacturer shall determine the effect of any difference (positive or negative) between the alarm condition and the test's end-of-life threshold on the predicted life.

R5-4 **[119v2]** Initial, intermediate and final measurements of the parameters used in the end-of-life threshold for a device shall be made at the same temperature (and in situ, if possible).

At the designated end of an accelerated aging test, a subset of characterization tests as described in Section 4.1.1 needs to be performed on all of the "good" devices (e.g., in the case of high-temperature accelerated aging, all devices that have not crossed the end-of-life threshold or otherwise failed during the test).

R5-5 **[125v2]** Devices that do not meet the characterization test specifications in the post-accelerated aging tests shall be counted as random failures in the reliability calculations. In addition, any major parametric shifts shall trigger a plan for further study.

R5-6 **[150v2]** Any failures found during the accelerated aging cycles of a temperature cycling test shall be investigated, and corrective actions shall be implemented.

6 Lot-To-Lot Controls for Optoelectronic Devices

As discussed in Section 2.2, lot-to-lot controls consisting of visual inspections, electrical and optical testing, and screening are needed to help ensure the quality and reliability of individual lots of all types and levels of optoelectronic devices. Also as discussed, unless a ship-to-stock program has been established, the individual device testing is generally performed by the equipment manufacturer at either the supplier's location (source inspection) or the using plant (incoming inspection).

6.1 Visual Inspection

In addition to the requirements in Section 2.2.6.1, the following requirement applies in the case of visual inspection of laser diode and LED lots.

R6-1 **[128v2]** For laser diodes and LEDs, the main inspection items shall include confirmation of a "clean" facet or emitting surface (e.g., no metal overhang, chip-outs, debris nearby, or solder run-up).

6.2 Electrical and Optical Testing

R6-2 **[129v2]** With the exceptions discussed in Section 2.2.6.2, all of the optoelectronic devices in each lot shall be subjected to a documented and justified minimum set of electrical and optical tests.

In general, the set of electrical and optical tests referred to in **R6-2 [129v2]** is expected to be a subset of the optical and electrical tests that are performed on the device during the characterization portion of the qualification process. Similar to those tests, the appropriate optical and electrical tests for lot-to-lot control purposes will vary from one type of device to another, and therefore must be technically justified and well documented. On the other hand, unlike the characterization tests, with some exceptions the lot-to-lot control optical and electrical tests are expected to be performed only at room temperature.

6.3 Screening

6.3.1 Procedures

R6-3 **[131v2]** Unless supporting data is available to justify that it is not needed (see Section 2.2.6.2) or one of the exceptions listed below applies, the screening of optoelectronic devices at the diode (or wafer) level shall include burn-in, and the screening of optoelectronic devices at the module or integrated module level shall include temperature cycling and burn-in.

R6-4 **[431]** The screening conditions and procedures shall be chosen to: {a} stabilize the device with respect to its performance and degradation rate and {b} assure that only "good," stable devices that meet the quality and reliability requirements are accepted.

As noted in **R6-3 [131v2]**, several exceptions to that requirement are applicable. In addition to cases where the equipment manufacturer or device supplier is able to justify an exception, these are as follows:

- Burn-in is not required at the module level if the module consists only of a packaged diode subassembly (subjected to its own burn-in) and a minimum number of passive optical components (e.g., lens, isolator, fiber pigtail, connector)
- Burn-in is not required for monitor photodiodes if the laser module as a whole will be subject to a burn-in
- Burn-in is not required for EA modulators.

Appropriate screening conditions need to be determined based on the results of tests performed on statistically significant populations of devices. Among the variables that need to be considered are the optical power or current levels, bias voltages, modulation rates, temperatures, and exposure times or number of cycles. Ideally, the conditions would be chosen to accelerate the device's early life failure mechanisms (so that those failures occur during the screening procedure) while having minimal impact on the wearout failure rates that will occur for the devices that pass the screening process and are deployed in the network. For temperature cycling, a typical procedure might consist of 20 cycles between –40 and +85°C.

6.3.2 Screening Pass/Fail Criteria

R6-5 **[388v2]** Screening pass/fail criteria shall be developed with technical justifications.

R6-6 **[133v2]** Any "major" changes due to screening (as defined and documented by the equipment manufacturer or device supplier) shall result in rejection of a device.

Among the parameters that might be monitored to determine if a device passes or fails the screening process are the front-to-rear tracking ratio error, coupling efficiency, dark current, breakdown voltage, threshold current, and drive current/optical output power. In addition, in some cases the pass/fail thresholds may be based on the absolute levels of the parameters, while in other cases they may be based on the changes that occur as a result of screening.

7 Qualification and Lot-to-Lot Controls for Other Component Parts

In addition to the optoelectronic device itself, an optoelectronic module or integrated module will generally include a number of other components that can affect its quality and reliability. This section contains qualification and lot-to-lot control criteria applicable to those components. For most components, this primarily consists of references to other applicable documents; however, in the case of TECs this section contains relatively detailed criteria.

R7-1 **[188v2]** All component parts of an optoelectronic module or integrated module shall be subjected to their own qualification tests and lot-to-lot controls.

R7-2 **[189v2]** As a minimum, non-optoelectronic components (e.g., ICs, resistors) shall meet the qualification and lot-to-lot control criteria for Quality Level II in referenced documents such as GR-357-CORE and TR-NWT-000930, *Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment*, and/or the appropriate design and process standards (e.g., IPC-A-610C - *Acceptability of Electronic Assemblies*).

O7-3 **[190v2]** Non-optoelectronic components should meet the qualification and lot-to-lot control criteria for Quality Level III in the referenced documents.

R7-4 **[191v2]** Failure rates shall be calculated or obtained (e.g., from the device suppliers or SR-332) for each component assembled into the module or integrated module.

Note that in some cases, some of the tests (particularly stress tests) that are required to be performed on the various “other” component parts may be very similar to those required for the module or integrated module. In such cases, as long as the applicable criteria related to sample sizes and test conditions are met, those tests can be deferred to the module or integrated module level (i.e., they do not need to be performed on the individual components and then repeated when the components are tested as part of the higher level assembly).

7.1 Thermoelectric Coolers

The TEC is a critical component in many optoelectronic modules because it affects the temperature of other critical components such as laser diodes and the monitor photodiodes, can affect the optical alignment, and impacts heat dissipation.

7.1.1 TEC-Specific Test Information

7.1.1.1 Thermoelectric Cooler and Temperature Sensor Checks

Proper operation of the thermoelectric cooler is typically verified by measuring the TEC current (I_{TEC}) and voltage (V_{TEC}), and comparing them to the specified limits. These tests are generally performed with the ambient temperature set to room temperature and the module's minimum and maximum-rated operating temperatures. In addition, they are usually made with the TEC set for its minimum-specified set temperature.

The characteristics of the temperature sensor also need to be checked. If the sensor is a thermistor, the relevant parameter is generally its resistance (R_{TS}). For diodes, the forward voltage at a reference temperature (V_{TS}) is the usual measurement.

7.1.1.2 Power Cycle Test

For the power cycle test listed in Table 7-1:

- The TEC is typically set to provide its minimum-specified set temperature (or maximum-rated current) when powered
- Assuming the condition in the following bullet item is met, the duty cycle is approximately 1.5 minutes on and 4.5 minutes off
- During the time in which it is on, the TEC's cold-side temperature generally needs to be cooled by at least 90% of the difference between the ambient temperature and T_{min}.

7.1.2 TEC Qualification

R7-5 **[432]** TECs shall be tested against an appropriate set of performance characteristic specifications (e.g., specifications related to the parameters discussed in Section 7.1.1.1).

R7-6 **[433]** At least 20 devices shall be subjected to the performance-related characterization tests. No failures (i.e., results outside the specified limits) shall be allowed.

R7-7 **[434]** The tests listed as "**R**" in Table 7-1 shall be included in the physical characteristics and stress testing portions of the qualification process for TECs.

R7-8 **[435]** The tests listed as "**O**" in Table 7-1 should be included in the stress testing portion of the qualification process for TECs.

Table 7-1 Physical Characteristics and Stress Tests for TECs

Category	Test	Ref.	Level	Sampling			Additional Information[1, 2]
				LTPD	SS	C	
Physical Characteristics	Die Shear Strength	3.2.10.4	**R**	20	11	0	Applicable to all relevant connections (e.g., TEC/heat sink)
Mechanical Integrity[3]	Mechanical Shock	3.3.1.1	**R**	10	22	0	Condition A (500 g, 1.0 ms), 5 times/direction
	Vibration	3.3.1.1	**R**	10	22	0	Condition A (20 g), 20 to 2000 to 20 Hz, 4 min/cy, 4 cy/axis
Non-Powered Environmental Stress	High Temp. Storage	3.3.2.1	**R**	10	22	0	85°C, 2000 hours
	Temp. Cycling[4]	3.3.2.2	**R**	10	22	0	–40°C/+85°C, 100 cycles
			O	10	22	0	–40°C/+85°C, 500 cycles
Powered Environmental Stress	Power Cycling (On/Off)	7.1.1.2	**R**	10	22	0	Hot-side T ≥ max. op. T, 5000 cycles

Notes for Table 7-1:

1 As discussed in Section 3.1.4, the conditions shown correspond to minimum acceptable levels of stress, and alternate conditions may be used (with technical justification) in some situations.

2 In all cases, the applicability of the test is independent of the particular environment in which the device is specified to operate (i.e., CO or UNC).

3 During these tests, a mass is attached to the “cold” side of the TEC to simulate the laser submount.

4 The TEC may be either powered or unpowered during this test.

R7-9 **[192v2]** A set of measurements shall be performed before and after each stress test or group of stress tests to detect any change in performance or degradation of the device. This set of tests (and the corresponding pass/fail criteria defined by the equipment manufacturer or device supplier, see Section 3.1.3) shall address important performance characteristics of the device.

Possible pass/fail criteria could include:

- A drop in the TEC’s maximum cooling capacity below its specified rating at the maximum operating temperature when measured with the maximum load (e.g., with the laser diode operated at the maximum-rated drive current or maximum-rated output power)

- A drop in the TEC's cooling capacity below its specified rating for a given current and temperature (e.g., 65°C) when measured under the maximum load
- An increase in the resistance beyond its specified maximum value.

7.1.3 TEC Lot-to-Lot Controls

R7-10 **[207v2]** Lot-to-lot controls for TECs shall include visual inspection, electrical testing and, unless it is demonstrated to be unnecessary, screening. Electrical testing shall be performed on 100% of the devices as long as screening is required.

If reliability audits are implemented and it is determined that screening is not necessary (and therefore 100% electrical testing is not required for the purpose of identifying devices in which the screening has produced infant mortality failures), then the equipment manufacturer may make an independent assessment of the lot quality to determine if the electrical testing can be reduced from testing of 100% of devices to testing on a sample basis.

7.2 Temperature Sensors

R7-11 **[200v2]** Qualification procedures and lot-to-lot controls for temperature sensors shall be based on relevant criteria in Sections 4.3, 4.4 and 5 of GR-357-CORE or IPC-610, plus additional requirements as necessary to meet the reliability objective of the module.

7.3 Optical Isolators

The detailed qualification and lot-to-lot control criteria applicable to optical isolators are contained in GR-1209-CORE, *Generic Requirements for Passive Optical Components*, and GR-2882-CORE, *Generic Requirements for Optical Isolators and Circulators*.

7.4 Fiber Pigtails and Optical Connectors

As noted in Section 3.3.1.3, GR-326-CORE contains relevant reliability assurance criteria for the fiber pigtails and connectors used in optoelectronic devices. In addition to those criteria, the following also apply.

R7-12 **[201v2]** Fiber pigtails and/or optical connectors shall be qualified by mechanical integrity and endurance tests to demonstrate that they will meet the reliability objective of the module.

R7-13 **[202v2]** Pass/fail criteria shall address the maximum length of the glass fiber allowed to be exposed due to any “pistoning effect.”

R7-14 **[210v2]** Lot-to-lot controls for fiber pigtails and optical connectors shall be established by the supplier and/or the equipment manufacturer.

The “pistoning effect” referred to in **R7-13 [202v2]** is an effect in which the glass fiber is exposed between the back end of the connector ferrule and the cable jacket due to differential expansion or shrinkage of various materials in response to temperature changes. In general, it can result in additional loss in the fiber or breakage.

7.5 General Electrical/Electronic Components

Criteria for the qualification and lot-to-lot control of general electrical and electronic components, including surface mount devices, are given in GR-357-CORE. Alternatively, those components may be qualified based on conformance to the appropriate design and process standards (e.g., IPC-610).

7.6 Hybrids

Criteria for the qualification and lot-to-lot control of hybrids are given in TR-NWT-000930.

Appendix A: Sampling Plan Tables

A.1 Lot Tolerance Percent Defective (LTPD) Sampling

Table A-1 LTPD Sampling Plan[1]

LTPD [%]	50	30	20	15	10	7	5	3	2	1.5
Acceptance Number (C)	**Minimum Sample Sizes (SS)**									
0	5	8	11	15	22	32	45	76	116	153
1	8	13	18	25	38	55	77	129	195	258
2	11	18	25	34	52	75	105	176	266	354
3	13	22	32	43	65	94	132	221	333	444
4	16	27	38	52	78	113	158	265	398	531
5	19	31	45	60	91	131	184	308	462	617
6	21	35	51	68	104	149	209	349	528	700
7	24	39	57	77	116	166	234	390	598	783
8	26	43	63	85	126	184	258	431	648	864
9	28	47	69	93	140	201	282	471	709	945
10	31	51	75	100	152	218	306	511	770	1025

Note:

1 Based on Table D-1, *Sample size series sampling plan*, in MIL-PRF-38535E.

A.2 Acceptable Quality Level (AQL) Sampling

The following tables related to AQL sampling were extracted from ANSI/ASQC Z1.4-1993, *Sampling Procedures and Tables for Inspection by Attributes*.

Table A-2 Sample Size Code Letters 1 (General Inspection Levels)

Lot or Batch Size	**General Inspection Levels**		
	I	**II**	**III**
2 to 8	A	A	B
9 to 15	A	B	C
16 to 25	B	C	D
26 to 50	C	D	E
51 to 90	C	E	F
91 to 150	D	F	G
151 to 280	E	G	H
281 to 500	F	H	J
501 to 1200	G	J	K
1201 to 3200	H	K	L

Table A-3 Single Sampling Plan for Normal Inspection (Master Table)

Sample Size Code Letter	**Sample Size**	**Acceptable Quality Levels (Normal Inspection)**															
		0.10		**0.15**		**0.25**		**0.40**		**0.65**		**1.0**		**1.5**		**2.5**	
		Ac	**Re**	**Ac**	**Re**	**Ac**	**Re**	**Ac**	**Re**	**Ac**	**Re**	**Ac**	**Re**	**Ac**	**Re**	**Ac**	**Re**
A	2	↓		↓		↓		↓		↓		↓		↓		↓	
B	3	↓		↓		↓		↓		↓		↓		↓		↓	
C	5	↓		↓		↓		↓		↓		↓		↓		0	1
D	8	↓		↓		↓		↓		↓		↓		0	1	↑	
E	13	↓		↓		↓		↓		↓		0	1	↑		↓	
F	20	↓		↓		↓		↓		0	1	↑		↓		1	2
G	32	↓		↓		↓		0	1	↑		↓		1	2	2	3
H	50	↓		↓		0	1	↑		↓		1	2	2	3	3	4
J	80	↓		0	1	↑		↓		1	2	2	3	3	4	5	6
K	125	0	1	↑		↓		1	2	2	3	3	4	5	6	7	8
L	200	↑		↓		1	2	2	3	3	4	5	6	7	8	10	11
M	315	↓		1	2	2	3	3	4	5	6	7	8	10	11	14	15
N	500	1	2	2	3	3	4	5	6	7	8	10	11	14	15	21	22
P	800	2	3	3	4	5	6	7	8	10	11	14	15	21	22	↑	

↓ Use first sampling plan below arrow(s). If sample size equals or exceeds lot or batch size, do 100 percent inspection.

↑ Use first sampling plan above arrow(s).

Ac Acceptance number.

Re Rejection number.

Table A-4 Double Sampling Plan for Normal Inspection (Master Table)

Sample Size Code Letter	Sample	Sample Size*	Total Sample Size	Acceptable Quality Levels (Normal Inspection)															
				0.10		0.15		0.25		0.40		0.65		1.0		1.5		2.5	
				Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re	Ac	Re
A	-	-	–	↓		↓		↓		↓		↓		↓		↓		↓	
B	1st	2	2	↓		↓		↓		↓		↓		↓		↓		↓	
	2nd	2	4																
C	1st	3	3	↓		↓		↓		↓		↓		↓		↓		°	
	2nd	3	6																
D	1st	5	5	↓		↓		↓		↓		↓		↓		°		↑	
	2nd	5	10																
E	1st	8	8	↓		↓		↓		↓		↓		°		↑		↓	
	2nd	8	16																
F	1st	13	13	↓		↓		↓		↓		°		↑		↓		0	2
	2nd	13	26															1	2
G	1st	20	20	↓		↓		↓		°		↑		↓		0	2	0	3
	2nd	20	40													1	2	3	4
H	1st	32	32	↓		↓		°		↑		↓		0	2	0	3	1	4
	2nd	32	64											1	2	3	4	4	5
J	1st	50	50	↓		°		↑		↓		0	2	0	3	1	4	2	5
	2nd	50	100									1	2	3	4	4	5	6	7
K	1st	80	80	°		↑		↓		0	2	0	3	1	4	2	5	3	7
	2nd	80	160							1	2	3	4	4	5	6	7	7	9
L	1st	125	125	↑		↓		0	2	0	3	1	4	2	5	3	7	5	9
	2nd	125	250					1	2	3	4	4	5	6	7	7	9	12	13
M	1st	200	200	↓		0	2	0	3	1	4	2	5	3	7	5	9	7	11
	2nd	200	400			1	2	3	4	4	5	6	7	7	9	12	13	18	19
N	1st	315	315	0	2	0	3	1	4	2	5	3	7	5	9	7	11	11	16
	2nd	315	630	1	2	3	4	4	5	6	7	7	9	12	13	18	19	26	27
P	1st	500	500	0	3	1	4	2	5	3	7	5	9	7	11	11	16	↑	
	2nd	500	1000	3	4	4	5	6	7	7	9	12	13	18	19	26	27		

↓ Use first sampling plan below arrow(s). If sample size equals or exceeds lot or batch size, do 100 percent inspection.

↑ Use first sampling plan above arrow(s).

Ac Acceptance number.

Re Rejection number

* If the number of devices from the first sample that fail the test is between the first acceptance and rejection numbers, a second sample is tested and the cumulative number of failures is compared to the second set of numbers.

° Use corresponding single sampling plan (or alternatively, use double sampling plan).

Appendix B: References

Listed below are the documents specifically cited in the text of this GR. These include Telcordia documents, military specifications and standards, International Electrotechnical Commission (IEC) publications, Telecommunications Industry Association (TIA) standards, and other documents.

Telcordia Documents

- GR-63-CORE, *NEBS™ Requirements: Physical Protection (a module of LSSGR, FR-64; TSGR, FR-440; and NEBSFR, FR-2063)*
- GR-78-CORE, *Generic Requirements for the Physical Design and Manufacture of Telecommunications Products and Equipment (a module of RQGR, FR-796, and NEBSFR, FR-2063)*
- GR-253-CORE, *Synchronous Optical Network (SONET) Transport Systems: Common Generic Criteria (a module of TSGR, FR-440)*
- GR-326-CORE, *Generic Requirements for Singlemode Optical Connectors and Jumper Assemblies, (a module of FR-FIBER-1)*
- GR-357-CORE, *Generic Requirements for Assuring the Reliability of Components Used in Telecommunications Equipment (a module of RQGR, FR-796)*
- GR-418-CORE, *Generic Reliability Assurance Requirements for Fiber Optic Transport Systems (a module of RQGR, FR-796)*
- GR-487-CORE, *Generic Requirements for Electronic Equipment Cabinets*
- GR-874-CORE, *An Introduction to the Reliability and Quality Generic Requirements (RQGR) (a module of RQGR, FR-796)*
- GR-909-CORE, *Generic Criteria for Fiber in the Loop Systems (a module of TSGR, FR-440)*
- GR-1209-CORE, *Generic Requirements for Passive Optical Components*
- GR-1221-CORE, *Generic Reliability Assurance Requirements for Passive Optical Components (a module of RQGR, FR-796)*
- GR-1252-CORE, *Quality System Generic Requirements for Hardware (a module of RQGR, FR-796)*
- GR-1312-CORE, *Generic Requirements for Optical Fiber Amplifiers and Proprietary Dense Wavelength-Division Multiplexed Systems*
- GR-2882-CORE *Generic Requirements for Optical Isolators and Circulators*
- GR-2918-CORE, *DWDM Network Transport Systems with Digital Tributaries for Use in Metropolitan Area Applications: Common Generic Criteria (a module of FR-DWDM-1, and FR-SONET-17)*

- GR-3013-CORE, *Generic Reliability Assurance Requirements for Optoelectronic Devices Used In Short-Life, Information-Handling Products and Equipment (a module of RQGR, FR-796)*
- SR-332, *Reliability Prediction Procedure for Electronic Equipment*
- TR-NWT-000870, *Electrostatic Discharge Control in the Manufacture of Telecommunications Equipment (a module of RQGR, FR-796)*
- TR-NWT-000930, *Generic Requirements for Hybrid Microcircuits Used in Telecommunications Equipment (a module of RQGR, FR-796, and NEBSFR, FR-2063)*

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Military Documents

- MIL-STD-202G, *Test Method Standard, Electronic and Electrical Component Parts* (February 2002).
- MIL-STD-883E, *Test Method Standard, Microcircuits* (December 1996)
- MIL-PRF-38535E, *Integrated Circuits (Microcircuits) Manufacturing, General Specification for* (December 1997)

To order military standards or specifications, contact:

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U.S. Government Documents

- FDA CDRH CFR Title 21, Part 1040.10, *Performance Standards for Light Emitting Products*
- OSHA *PUB 8-1.7 – Guidelines for Laser Safety and Hazard Assessment*

TIA/EIA Documents

- TIA/EIA-455-6B, *Cable Retention Test Procedure for Fiber Optic Cable Interconnecting Devices*, (FOTP-6)
- TIA/EIA-455-36A, *Twist Test for Fiber Optic Interconnecting Devices*, (FOTP-36)
- TIA/EIA-455-126, *Spectral Characterizations of LEDs*, (FOTP-126)
- TIA/EIA-455-127, *Spectral Characterization of Multimode Laser Diodes*, (FOTP-127)
- TIA/EIA-455-128, *Procedure for Determining Threshold Current of Semiconductor Lasers*, (FOTP-128)
- TIA/EIA-455-129, *Procedures for Applying Human Body Model Electrostatic Discharge Stress to Package Optoelectronic Components*, (FOTP-129)
- TIA/EIA-526-2, *Effective Transmitter Output Power Coupled Into Single-Mode Fiber Optic Cable*, (OFSTP-2)
- TIA/EIA-526-4A, *Optical Eye Pattern Measurement Procedure*, (OFSTP-4A)

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ISO and IEC Documents

- IEC 60068-2-3, *Test Ca: Damp Heat, Steady State* (1969)
- IEC 60825-1, *Safety of Laser Products - Part 1: Equipment classification, requirements and user's guide*
- ISO 9000: *Quality Management and Quality Assurance Standards - Guidelines for Selection and Use* (1992).

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IPC Documents

- IPC-A-610C - *Acceptability of Electronic Assemblies* (January 2000)

To obtain IPC documents, contact:

IPC
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ITU-T Recommendations

- G.691, *Optical interfaces for single channel STM-64 and other SDH systems with optical amplifiers*

ITU-T Recommendations are available from:

International Telecommunication Union
General Secretariat – Sales Section
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ETSI Documents

- ETSI EN 300 019-1-3 V2.1.1 (2003-03) - *Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 1-3: Classification of environmental conditions; Stationary use at weather protected locations*
- ETSI EN 300 019-2-3 V2.2.2 (2003-04) - *Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-3: Specification of environmental tests; Stationary use at weather protected locations*

Appendix C: Symbols, Units, Abbreviations, and Acronyms

ACC	Automatic Current Control
ADM	Add/Drop Multiplexer
AML	Approved Manufacturer List
ANSI	American National Standards Institute
APC	Automatic Power Control
APD	Avalanche Photodiode
APL	Approved Parts List
AQL	Acceptable Quality Level
ASL	Approved Supplier List
AVL	Approved Vendor List
B	bandwidth
BER	Bit Error Ratio
C	allowed failures (in LTPD sampling)
C	capacitance
C	coulombs
°C	degrees Celsius
CDR	Clock Data Recovery
CE	Coupling Efficiency
CEV	Controlled Environment Vault
CL	Confidence Limit
cm	centimeter
CO	Central Office
COD	Catastrophic Optical Damage
CR	Conditional Requirement
CWDM	Coarse Wavelength Division Multiplexed
D	duration
dB	decibels
dBc	decibels, referenced to the carrier
dBm	decibels, referenced to one milliwatt
DC	Direct Current (0 Hz)
DC Vπ	DC drive voltage

det	detector
DGD	Differential Group Delay
DIP	Dual In-line Package
DP	Dispersion Penalty
DWDM	Dense Wavelength Division Multiplexed
$\mathbf{E_a}$	activation energy
EA	Electro-Absorption
EELED	Edge-Emitting Light Emitting Diode
EIA	Electronics Industry Association
EOS	Electrical Overstress
$\mathbf{E_R}$	average optical energy level
ESD	Electrostatic Discharge
eV	electron-volts
F	excess noise factor
$\mathbf{f_c}$	cutoff frequency
FIFO	First-In/First Out
FIT	Failures In Time
FITL	Fiber-In-The-Loop
FOTP	Fiber Optic Test Procedure
F/R	Front-to-Rear
FR	Family of Requirements
FWHM	Full Width at Half Maximum
g	unit of acceleration, equal to gravity near the earth's surface
Gb/s	10^9 bits per second
GHz	10^9 Hertz
GR	Generic Requirements document
HALT	Highly Accelerated Life Test
HAST	Highly Accelerated Stress Test
HBM	Human Body Model
Hz	Hertz
I	(drive) current
IC	Integrated Circuit

I_{dark}	dark current
IEC	International Electrotechnical Commission
IL	Insertion Loss
ILR	Issues List Report
inp	input
I_{op}	operating current
I_{ph}	photocurrent
I_{TEC}	thermoelectric cooler current
I_{TH}	threshold current
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
K	Kelvin
k	Boltzmann's constant
kg	10^3 grams
kV	10^3 volts
L	light level (optical power)
LAN	Local Area Network
LEC	Local Exchange Carrier
LED	Light Emitting Diode
L-I	light vs. current
LSSGR	LATA Switching System Generic Requirements
LTPD	Lot Tolerance Percent Defective
M	multiplication factor
max	maximum
MAN	Metropolitan Area Network
MHz	10^6 Hertz
min	minimum
ML	Median Life
MLM	Multi-Longitudinal Mode
ms	10^{-3} seconds
MTTF	Mean Time To Failure
NE	Network Element

NEBSFR	NEBS Family of Requirements
NFF	No Fault Found
nm	10^{-9} meters
NRZ	Non-Return to Zero
nom	nominal
NTF	No Trouble Found
O	Objective
obs	observed
OC-N	Optical Carrier - Level N (N = 1, 3, 12, 48, 192)
OFSTP	Optical Fiber System Test Procedure
op	operating
ORL	Optical Return Loss
P	optical power (light level)
PDA	Percent Defective Allowed
PER	Polarization Extinction Ratio
PM	Polarization Maintaining
PMD	Polarization Mode Dispersion
$\mathbf{P_{max}}$	maximum optical input power
$\mathbf{P_{mod}}$	modulation depth
$\mathbf{P_{op}}$	optical power at normal operating current
$\mathbf{P_R}$	optical power received
PRBS	Pseudo Random Bit Sequence
ps	10^{-12} seconds
$\mathbf{P_{TH}}$	optical power at threshold
q	charge of an electron
QA	Quality Assurance
QC	Quality Control
R	Requirement
R	resistance
R	responsivity
$\mathbf{r_e}$	extinction ratio
RF	Radio Frequency

RF Vπ	RF drive voltage
$r_{f/r}$	front-to-rear tracking ratio
RGA	Residual Gas Analysis
RH	Relative Humidity
RIN	Relative Intensity Noise
ROSA	Receiver Optical Sub-Assembly
RQGR	Reliability & Quality Generic Requirements
R_{TS}	temperature sensor resistance
RZ	Return to Zero
S_{11}	electrical return loss
S_{21}	bandwidth
SC	a type of fiber-optic connector
scope	oscilloscope
SLM	Single Longitudinal Mode
SMSR	Side-Mode Suppression Ratio
SONET	Synchronous Optical NETwork
SPD	Spectral Power Density
SQC	Statistical Quality Control
SR	Special Report
SS	Sample Size
SSE	Source Spontaneous Emissions
T	temperature
t	time
T_0	characteristic temperature
TA	Technical Advisory
T_e	tracking error
TEC	Thermoelectric Cooler
t_f	fall time
TH	threshold
THz	10^{12} Hertz
TIA	Telecommunications Industry Association
TM	Terminal Multiplexer

TO	Transistor Outline
$\mathbf{t_{on}}$	turn-on delay
TOSA	Transmitter Optical Sub-Assembly
TR	Technical Reference
$\mathbf{t_r}$	rise time
TSGR	Transport System Generic Requirements
UI	Unit Interval
UNC	Uncontrolled
V	Volts
$\mathbf{V_{br}}$	breakdown voltage
$\mathbf{V_F}$	forward voltage
$\mathbf{V_{mod}}$	modulation voltage
$\mathbf{V_n}$	noise voltage
$\mathbf{V_{op}}$	normal operating voltage
$\mathbf{V_{TEC}}$	thermoelectric cooler voltage
$\mathbf{V_{TS}}$	temperature sensor forward voltage
V-I	voltage vs. current
$\mathbf{V}\pi$	volts to effect a 180 degree phase difference in the arms of a Mach-Zhender interferometer
WDM	Wavelength Division Multiplexed
α	source frequency chirp factor
$\Delta\lambda_{20}$	spectral width 20 dB down from maximum
$\Delta\lambda_{rms}$	root mean square spectral width
λ	wavelength
λ_c	central wavelength
λ_{op}	operating wavelength range
λ_p	peak wavelength
η	efficiency
η_Q	quantum efficiency
σ	standard deviation

$\theta_{\|\|,}$	FWHM angle measured parallel to the laser's active layer
$\theta_{\perp}$	FWHM angle measured perpendicular to the laser's active layer
φ	optical phase of the signal

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