RELIABILITY CONSIDERATIONS FOR TERMINAL AMPLIFIERS

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Abstract: Terminal Line Amplifiers (TLAs) are a critical sub-system from a reliability perspective in an undersea communications network. The reliability of the TLA must be commensurate with the reliability of the undersea plant since a TLA failure affects service. Pump lasers have historically been weak links in the TLA reliability chain. Field experience shows the next most prevalent failure mode is pump connector failure. Analysis of the optical and mechanical physics at the connector interface, together with amplifier field experience, allows us to determine the conditions under which the connector itself becomes a greater risk factor than the pump laser.

1 BACKGROUND

Terminal Line Amplifiers (TLAs) are a critical sub-system from a reliability perspective in an undersea communications network. In Wavelength Division Multiplexed (WDM) systems, the most common transmission architecture has all transmission wavelengths passing through a single TLA immediately before launch into the undersea segment. This proximity to the undersea plant, as well as the broadband nature of the TLA is similar to the characteristics of the repeaters employed in the undersea portion of the network. Just as in the case of a repeater, a failure in the TLA in this configuration can result in the complete loss of all traffic on a segment until the TLA fault can be restored. For this reason, the reliability of the TLA must be commensurate with the reliability of the undersea plant. Moreover, in order to meet contractual availability requirements, the TLA must also be serviceable in the 2 to 4 hour Mean Time to Repair window typically required by customers.

To meet these requirements, the internal architecture of the TLA has usually been divided into modules, with the components most likely in need of field service or replacement grouped together. A natural division in the TLA lies between the amplifier module, composed primarily of fiber and other passive optical components and the pump module, which contains the pump lasers. Historically, it is the pump lasers that have been considered to be the weak link in the reliability chain. Figure 1 below illustrates such a design, where the pump modules are coupled to the amplifier module through optical connectors.

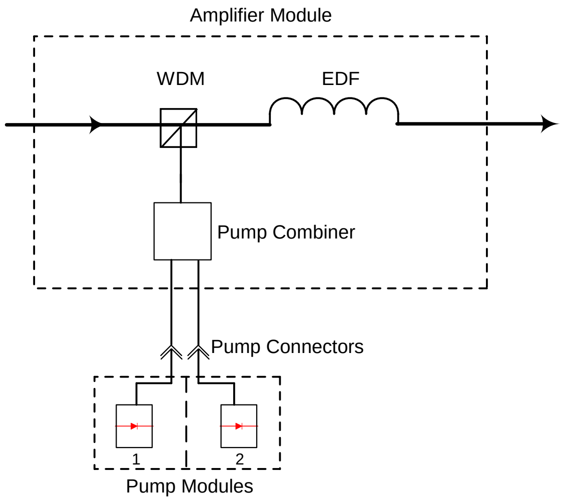

Figure 1: Simplified TLA architecture

The configuration shown in Figure 1 contains two pump modules. In a typical TLA architecture, each pump module contains one 980 nm pump laser and one 1480 nm pump laser. The light from each pump laser is connected independently to the amplifier module through appropriate optical connectors. Within the amplifier module, light from the two 980 nm pump lasers is combined to form a single 980 nm optical source. The 1480 nm lasers are similarly combined into a single pump source. These two optical sources are then used to power both Er-fiber spools of a dual-stage amplifier. A single pump failure then requires the replacement of a single pump module. The independence of pump modules built into the architecture thus allows a single pump module to be replaced in the field without loss of traffic on the link, since the other pump module can independently power the amplifiers.

A general observation is that pump lasers have historically been weak links in the reliability chain for TLAs. Analysis of returns data has shown that a pump laser failure was indeed the most prevalent failure mode. The data yield a more interesting observation. If a pump laser fails and the pump module is replaced in the field, catastrophic failure of the connector between the pump and amplifier modules may follow. This failure mode generally affects both connectors of an inter-mated pair, so that the amplifier module itself must be replaced. The replacement of the amplifier module will interrupt traffic.

1.1 Strategies for Improvement

Keeping these relationships in mind, several strategies can be investigated to improve on the field data discussed above, beginning with improvement in the pump lasers. Pump laser reliability has steadily improved, even as pump powers have more than quadrupled over the past few years. High-power terrestrial pumps with failure rates lower than 500 FITs have been advertised. It should be noted that even these FIT rates may be very conservative, since many of these terrestrial lasers share both technology and manufacturing facilities with their undersea-qualified counterparts. Since demonstration of lower FIT rates requires more extensive and time consuming (and thus more costly) testing than for more modest levels, it is thus quite possible that the stated reliability of some terrestrial pump lasers is limited more by statistical confidence than by any intrinsic factors. Assuming overall FIT rates in the range of 100—500 FITs, the probability of a pump laser failure over a typical 25 year system life is approximately 2—10%. If these results can be shown to be applicable to the environment of the TLA, the reduction in the number of pump lasers in the TLA can be considered. It is still advisable to keep the active sparing, redundant architecture, since this architecture provides the simplicity of replacing failed lasers in the field.

As previously discussed, the replacement of a pump module can lead to a subsequent failure involving both sides of the inter-mated pair of the connector from the pump module to the amplifier module. Connectors often fail when contamination on the connecter face absorbs the photon energy and pyrolizes. The resultant material can often be seen as a burn spot on the face. The failure symptom is excess loss at the connector.

Contaminants can be introduced during the unmating/mating of the connector or inadequate cleaning prior to mating. More subtly, if the connector pairs are not intimately mated, the interaction between the intensity gradient of the laser beam and the induced dipole moment of microscopic contaminants can further attract contaminants in the near environment directly into the center of the beam, to be burned into the connector faces.

Assuming a well-designed connector and diligent cleaning that minimize these effects, the last defense against connector failure is to reduce the power density of the light beam at the connector face. One possibility here is to use expanded-beam connectors that enlarge the optical mode near the connector interface so that the effective optical intensity is decreased. This decrease in intensity, typically about an order of magnitude, results in less dissipated power on any imperfections at the facet and thus a lower probability of connector damage. One tradeoff is that these types of connectors typically have somewhat increased insertion loss over more traditional connector types, necessitating a slight increase in pump power to compensate. Nevertheless, the overall effect is to decrease the incidence of connector damage due to high-power operation. It should be noted that these types of connectors do not obviate the need to thoroughly clean the connector interface before mating. While the decreased intensity does slow the rate of connector damage caused by absorption on dust and other imperfections, damage can still occur and may proceed to catastrophic levels unless proper connector cleaning methods are practiced.

Finally, the use of optical connectors rather than a splice to couple the pump modules to the amplifier also facilitates field service, although there is no reason a priori that a splice could not be used in this place. Given the current trend of higher reliability 980 nm pump lasers at ever increasing powers and in light of the increasing importance of optical connector failures, it is reasonable to consider elimination of the optical connector in favor of a splice. Given the difficulties of splicing in the field, this solution implies the loss of the ability to replace the pump laser without disturbing traffic. Nonetheless, with further improvements in pump laser reliability, it may be possible to show that the use of splices in place of connectors actually decreases the expected number of traffic-interrupting events.

2 CONCLUSION

In summary, the reliability requirements for Terminal Line Amplifiers have traditionally been very high given the critical role they play in system transmission. In the past, this requirement has been satisfied by making use of independently replaceable, redundant pump lasers. Because pump lasers have become much more reliable over the past few years even as their output power has increased, they may no longer dominate the overall reliability of the TLA. Other components, such as the optical connectors in the pump path, are now recognized as a potential source of failure, particularly in light of the high pump powers currently available. To minimize the effects of this failure mechanism, Tyco Telecommunications has deployed several of the improvements discussed herein in its next generation Terminal Equipment and will continue to explore methods of increasing the overall reliability of its terminal equipment.