RELIABILITY PERFORMANCE OF TE SUBCOM'S GENERATION-3 DPSK HPOE

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Abstract: During the development of Tyco Telecommunications' Generation 3 HPOE, we improved our process for qualification of components used in terminal equipment. Where appropriate, approaches used in the qualification of submerged equipment were applied. The equipment was first shipped in December, 2005; the active Gen3 HPOEs in the field have accumulated 20 million device-hours. The field experience has been much better than original conservative estimate; an average point estimate of less than 5000 FITs has been observed over the past year.

1. INTRODUCTION

The final capacity per Digital Line Segment in undersea communication systems has roughly doubled in the past five years. This increase in capacity was enabled most significantly by the deployment the RZ-DPSK modulation format and the enhanced Forward Error Correction in the Line Terminating Equipment. The transmission baud rate has remained at 10Gb/s over the period.

One consequence of the increased capacity is the possibility of over 100 transmit/receivers (High Performance Optical Equipment or HPOE) per line-pair in a station. Although the HPOE can be protected on both the Client-side and the Line-side, the reliability of the HPOE is critical and there remains the possibility of a '4-sigma' event with multiple cards alarming in a short time period. This situation adds cost, both in terms of outage mitigation, sparing and required staffing in the station.

Addressing this performance challenge was central to the approach taken in assessing the reliability of the components that were selected for the HPOE and all other subsequent products in the Generation 3 suite of LTE.

2. GENERATION-3 HPOE

The Gen-3 HPOE [1] consists of a single circuit pack providing both directions of transmission (transmit and receive). Each HPOE occupies a single slot in the Common Shelf, allowing as many as 32 HPOEs in a fully-equipped bay. This represents an increase in floor space density of a factor of 4 over previous generations.

A functional diagram for the HPOE is shown in Figure 1. As previously noted, the Gen-3 HPOE employs enhanced FEC capabilities compared to the first two generations of equipment. A tunable laser provides wavelength adjustability over the full wavelength range supported by undersea repeaters. Most importantly, the HPOE employs a Differential Phase-Shift Keying (DPSK) modulation format on the Line-side. These features were implemented using new component technologies, new components and some new component suppliers, all of which had potentially significant reliability impact on the final product.

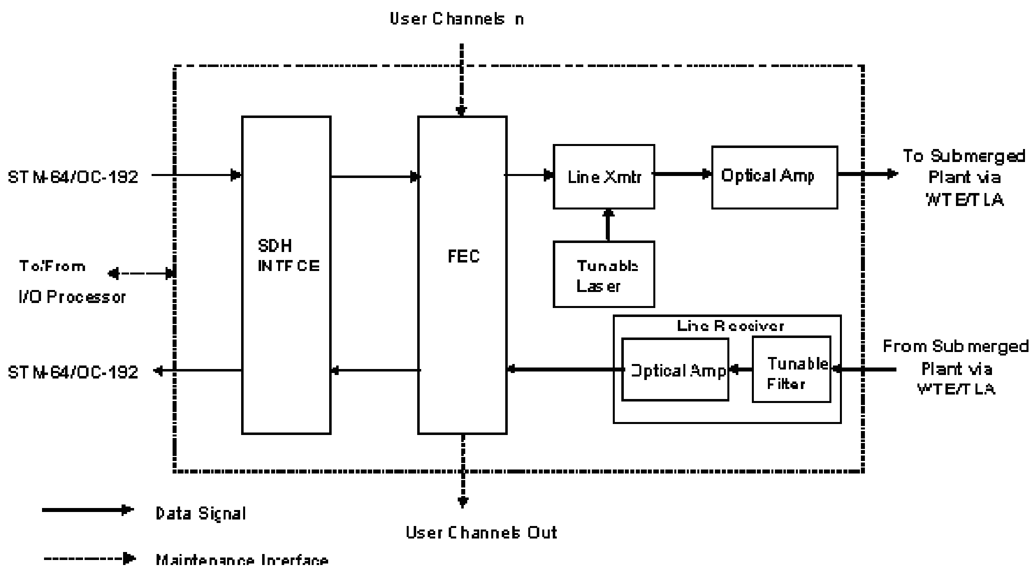

Figure 1 Functional Block Diagram of HPOE

The SDH Interface converts OC-192 / STM-64 signals to and from electrical clock and data format. The optical interface modules are Customer accessible and are available in short- medium- and long-reach.

The FEC encodes the incoming data signal into a higher rate digital signal in the transmit direction, and uses the redundant information added to correct errors in the receive direction. The FEC block is capable of SDH performance monitoring on both the incoming and outgoing OC192/STM64 signals. The FEC also adds User Channels to the transmitted signal and removes them from the received signal.

The Tunable Laser provides an optical carrier at the appropriate wavelength for the channel. The laser is tunable over the full C-band, allowing a single circuit pack code to be used for all channels and spares. The wavelength of the tunable laser is set from information in a non-volatile memory on the Common Shelf.

The Line transmitter takes the electrical output from the FEC Encoder and modulates the light generated by the Tunable Laser.

The Optical Amplifier provides a higher optical power at the HPOE transmit output to facilitate certain system designs. The HPOE transmit output power can be adjusted to perform channel amplitude pre-emphasis in which the transmit signal level of each channel in a WDM system is adjusted relative to the others to obtain similar end-to-end error performance on each channel.

The Line Receiver accepts any of the wavelengths specified for the Line Transmitters. It provides optical pre-amplification, demodulation of the optical signal and conversion to an electrical signal, regeneration, and re-timing.

3. KEY ELEMENTS IN IMPROVING RELIABILITY IN TERMINAL EQUIPMENT

(a) Optical and Electro-Optical Components

The development of the Gen-3 HPOE occurred during the telecommunication downturn of 2001 – 2005. At the time, almost all critical optical and electro-optical component suppliers were experiencing changes in business models, consolidations, or shutdowns. The decision was made that the new terminal equipment would be designed with parts from those optical and electro-optical suppliers that had proven to deliver reliable components in earlier generations or that also supplied components to the submerged equipment product. While the statement is self-evident, execution brought advantages to both sides. Key suppliers had increased business from TE SubCom, while the HPOE design process benefited from the use of suppliers that had incorporated a high-reliability culture into aspects of their business model and were familiar with working very closely with TE SubCom on qualification and reliability.

Another facet in applying the approaches used in the qualification of submerged equipment to the design of the HPOE was to identify a few key improvements to component design with potentially large reliability improvement.

An example of such was the elimination of epoxy in the optical path. While there are some suppliers and components that have successfully used designs with epoxy in the optical path for a decade or more, there are also known problems with the approach. Eliminating epoxy in the optical path generally does not increase complexity of manufacture significantly, and eliminates a critical process-control point in the manufacture of the component. We found that all suppliers that were approached with this request were willing to accommodate it or, in fact, were already designing such a part.

(b) Electronic Components

The electronic design of the Gen 3 HPOE took advantage of improvements in monolithic integration, with more of the required functionality executed in fewer ICs. This approach is inherently more reliable than, for example, a chip-and-wire hybrid solution. Improvements in the bandwidth of RF-ICs also resulted in a more robust design.

While there is much less overlap between terrestrial- and submerged-equipment use of electronic components, some common quality approaches still apply. Strict management of component qualification and monitoring of component manufacture was instituted. Technologies were chosen to achieve excellent reliability. Supplier capability, including manufacturing processes and quality systems, were reviewed as part of qualification approval. In particular, details of the qualification of wafer fabrication suppliers or packaging suppliers were requested.

(c) Failure Mode Analysis

Many more components are ultimately manufactured and deployed than are ever subjected to qualification testing. Consequently, it is possible that failures of an unanticipated nature will occur during the supplier's initial production run. For this reason, it is imperative that component suppliers perform Failure Mode and Root Cause Analysis on failures that occur during production. As part of due diligence with suppliers, failure history of components was requested and arrangements were made for FMA support during the production run of the Gen-3 equipment.

4. BOTTOM-UP ESTIMATE OF HPOE RELIABILITY

Failure rate estimates for critical components were obtained from the selected suppliers. Because the failure rate of optical and electro-optical components and modules are generally estimated by the results of standard qualification testing [2], these estimates tend to be conservative and limited by the sample size. Failure rates for electronic components were estimated from field returns.

In addition, we conservatively allocated 500 FITs for each Printed Circuit Board (PCB) in the circuit pack. This value was based on previous experience and was meant to cover issues with the PCB, soldering, passive electronics and firmware.

From these sources, a bottom-up estimate for the reliability of the HPOE was generated and is presented in Table 1. For planning, this result was rounded up to 20,000 FITs

Table 1 Early Estimate of HPOE Reliability from Component Qualification

Module Functionality	FITs @90% c.l., 65°C
Client Interface	2,100
FEC Processing	690
Line Transmitter	3,080
Line Receiver	5,150
Optical Amplifiers	4,550
Optical Jumpers	450
PCB, passive electrical components, firmware	3,000
Estimated Total FITs	**~19,000**

5. RESULTS – RISKS AND SURPRISES

As is the case for many projects, there were instances of unexpectedly high failure rate during the circuit build. The majority of these occurred during the prototype and models phase of the design process and, because of the relationship built with the supplier, these were dealt with in a way that maintained both schedule and reliability goals.

An example of such an event was the occurrence of unexpected ESD failures in an InP IC. The ceramic package of these devices had been used for early evaluation, but the supplier intended to migrate to a plastic package. When the plastic parts arrived during the models phase, there were unexpected performance shortfalls and ESD failures. The recovery approach with the supplier was two-fold: to understand the root cause and investigate any opportunity for immediate improvement; and to accelerate the supplier's plan to qualify and additional foundry for fabrication of the die. The second approach proved faster and packs went into production deploying the plastic package and the newly-qualified die. To date, there have been no field failures of these devices.

By far, the category of risk found during the development stage that was most troubling was the discovery of counterfeit parts. Counterfeit parts are a recognized problem throughout the electronics industry, affecting applications from consumer products to military and space-qualified systems.

Counterfeit parts fall into the following categories [3]:

- Dummy packages;
- Parts with labeling that misrepresent the part's form, fit or function;
- Parts that are labeled as having undergone additional reliability screening, but have not;
- Parts rejected by the manufacturer's test and inspection process;
- Used parts represented as new.

Note that parts from the last three categories can have legitimate serial or lot numbers and be more difficult to discover.

Our experience with counterfeit parts ranged from chip capacitors to integrated circuits to flash memories. Counterfeit chip capacitors clearly belong to either the 'rejected' or 'used' parts categories. The other few examples of counterfeit parts appeared to be purpose-made, with illegitimate lot numbers and incorrect internal construction.

Many suppliers are willing to work with customers to help them identify the legitimate parts visually and to identify distributors that are certified as sources of legitimate parts. Procuring parts from the certified list of distributors is a key step in protecting the build from counterfeit parts, with visual inspection of samples an important back-up for components from manufacturers that do not have a certified distributor program.

6. RESULTS – FIELD DATA

Gen-3 SLTE was first shipped from the factory in December, 2005, with contractual transfer to customers occurring in the second half of 2006. The equipment has been successfully deployed in situations ranging from upgrades of systems that were originally designed for as few as 8 channels to new long-haul systems with state-of-the-art capacity capability.

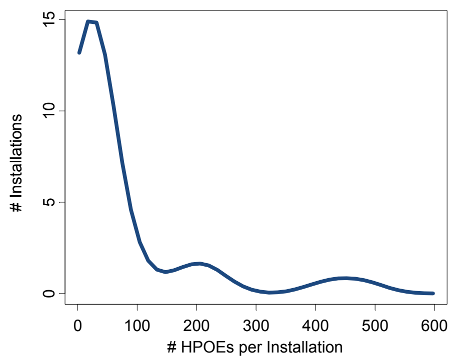

Figure 2 Number of HPOEs per Installation

Figure 2 presents a view of the distribution of the size of installations in terms of active HPOEs. As can be seen, the majority of projects involved fewer than 100 HPOEs installed; the median is 26 HPOEs. This figure is important when statistical tests are performed to determine if the return rate of a particular installation aligns with the expectation given from the bottom-up analysis; that is, to determine if a difference between the failure rate experienced and the predicted failure rate is 'statistically significant'. The allowed difference for a given level of significance will be larger for smaller sample sizes.

One way to analyze field results is to track the evolution of the return rate with time[1]. Figure 3 illustrates this concept. Each point on the plot represents the returns during the half-year period ending at the date indicated (or quarter-year for the 2009 results). The number of returns is normalized by the number of HPOES in service by the end of the time period. This calculation provides a point estimate for the return rate. There is no confidence limit associated with the calculation and thus the values cannot be used for predictive purposes. Rather, the values reported are the actual combined experience of the systems.

The growth of the number of HPOEs that have been contractually handed off to customers is also plotted.

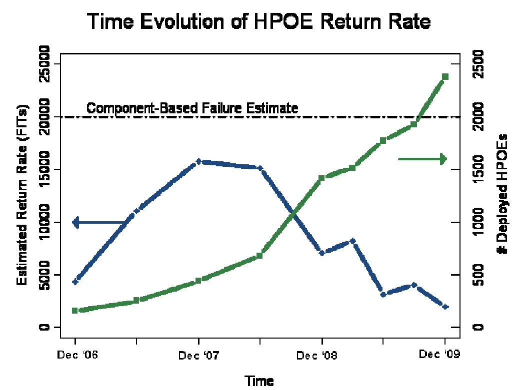

Figure 3 Evolution of HPOE Return Rate

The first observation is that the return rate of the population of all deployed HPOEs was at all times less than originally estimated from component failure rates. However, there was an increasing trend in the first year of deployment. Because of the limited sample sizes associated with evaluation and qualification, unexpected or rare failure modes may be discovered at the beginning of the product life cycle. These unexpected failure modes were addressed quickly as is evident from the subsequent sharp decrease in the return rate.

To further illustrate: the return rate point estimates for 2009 are re-plotted in Figure 4. Along with the data that appear in Figure 3 are the 2009 return rate point

[1] In the following analysis, we report the return rate with no further comment on whether the returned pack had indeed failed functionally, had a non-conformance that did not affect functionality or was classified 'No Trouble Found.

estimates for the first 500 HPOEs deployed and the last 500 HPOES deployed in 2008. Both sub-populations have significantly improved return rates compared with the peak observed in 2007, illustrating that the measures taken upon discovery of unexpected failure modes were effective for all populations of HPOEs.

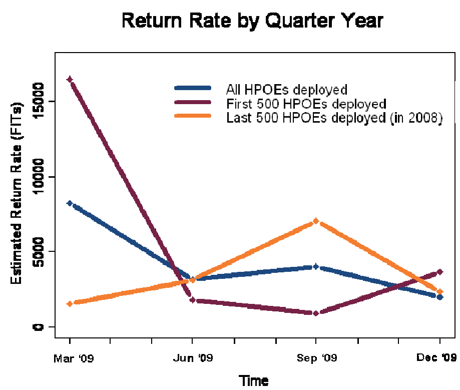

Figure 4 HPOE Return Rates for 2009

Finally, it is clear that the average point estimate of return rate over the past 9 – 12 months is less than 5,000 FITS and that the trend continues downward.

7. CONCLUSIONS AND IMPLICATIONS FOR GENERATION 4

The history of the failure rate of the Gen-3 HPOE showed that the bottom-up estimate appropriately captured the initial risk for a new design. Further, close cooperation with component suppliers and key design or process requests ultimately led to a significant decrease over the original estimate.

For designs going forward [5], the program will be continued and expanded with emphasis on the lessons learned from the successful deployment of Gen-3 equipment.

8. REFERENCES

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