ALTERNATIVE APPROACHES TO THE SUPPLY OF HIGH-RELIABILITY COMPONENTS

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Abstract: Reliability management of undersea systems has traditionally involved qualification of components with custom designs, specifications, and manufacturing processes. This approach yields high quality components with low failure rates and high cost. Recent downward price pressure on the industry has created a conflict between the continued need for high reliability and the costs associated with managing reliability according to the historical paradigm. Given the fiscal constraints, coupled with reliability requirements, innovative approaches have been developed to make use of redundant architectures, in concert with commercially available high reliability components, to provide the required reliability with lower-priced components.

1. BACKGROUND

The financial implications of traffic loss and repairs in a submarine telecommunications network have mandated tight reliability requirements for the submerged equipment. These requirements flow down from the system level to the subsystem level and, finally, the component level. For years, undersea systems have incorporated expensive and specialized components as the backbone of a reliable design.

Undersea repeaters, for example, have traditionally used customized components, manufactured specifically for the undersea applications. Examples of customer components include special undersea-qualified pump lasers, customized ASIC's, and specially packaged electronic and optical components. In addition, most components were subjected to stringent acceptance testing, in excess of the high reliability standards used in other industries [i]. Components ranging from optics, to IC's, to discrete electronics such as resistors and capacitors, were subjected to lengthy screens, burn-ins, and very rigorous qualification programs.

In response to the reliability requirements, system suppliers might, for example, require that component suppliers segregate high-reliability manufacturing lines from their normal production lines. Such lines would have separate and more diligent quality systems, as well as specially qualified personnel and facilities, and specialized process technologies. In some cases, the need for high reliability led to the use of technologies that were very conservative, and not in-line with the larger component market. Examples of such conservative designs are leaded resistors and capacitors (as opposed to surface-mount), hermetic IC's and solid state electronics, and specially designed optical components with additional jacketing for protection of optical fiber.

1.1. Alternative Approach for Achieving High Reliability

The paradigm described above has worked well over the years, as submarine systems have proven themselves to be very reliable. Tyco Telecom's undersea Amplifier-Pairs, for example, have demonstrated a failure level of less than 8 FITs with 95% confidence. In order to achieve such a low failure rate, the individual components of the amplifier, many of which represent single points of failure, must have exceedingly low failure rates. The standard failure requirements for repeater components is on the order of tenths of a FIT over the 25-year system life, with some variation allowed depending on the particular component technology used.

Assuring high reliability at the component level has resulted in very expensive component, qualification and materials costs for undersea repeaters. To provide <<1 FIT, even discrete components, depending on their function, have been historically priced at tens or hundreds of dollars. When these prices are compared to prices of commercially available parts, for example , to a few dollars for military-qualified parts, or to a few cents for commercial-grade parts, it becomes clear that there are opportunities for cost savings *if the reliability can be maintained*.

Since the end of the "Telecom Bubble," potential system owners have provided tremendous downward pressure on undersea systems pricing. Since system costs are strongly driven by materials costs, the current market environment no longer supports the old paradigm.

The need to change comes not only from the customer base, but also from the supply chain. The overall volume of components needed by the undersea industry is far less than it was before. It is much more difficult, then, for component manufacturers to justify maintaining separate product offerings and separate manufacturing lines that have very low overall throughput compared to their other product lines. Additionally, a number of key suppliers who previously provided undersea-qualified parts no longer do so. These facts drive the industry to turn to the “broader” and more mainstream component supply chain where it makes sense.

The problem faced by undersea telecommunications system suppliers is that, although cost must be reduced, there has been no accompanying reduction in reliability requirements. For submerged equipment, the reliability metric of interest is the number of ship repairs expected over system lifetime due to equipment failure. Ship repair requirements have essentially remain unchanged over the years. The customer’s expectation for ship repairs in a trans-Atlantic span is 2 repairs over system life for a 4 fiber pair system. This expectation can be scaled to system length and fiber pair count to represent the system of interest.

The number of expected ship repairs is directly related to the repeater and component FIT rates as well as cable and joint FIT rates. In order to calculate the ship repair expectation for a given undersea span, the failure probability of each element of the system is summed, over all cable, joints, and repeaters in the undersea plant.[ii] Repeaters can consume on order of half of the ship repair budget for a span. The expected number of ship repairs in a segment attributed to repeaters is given by:

$$SR_r = N_{r*}(1\text{-}\exp(-FIT_r{*}t_{sys/}10^9))$$

where FIT_r is the repeater FIT rate, N_r is the number of repeaters and t_{sys} is the system lifetime, typically about 219,000 hours (25 years). From this relation, we can see that, in a digital line segment containing a large number of repeaters, the FIT rate must remain small.

The challenge we face is then how to keep the expected repeater failure rate low, targeting 20 FITs or less, while using more common, less costly components. In order to maintain reliability with the reduced cost model, there are 2 strategies that can be used together:

Use redundant design, trading off complexity for reduced materials cost.

Use commercially available high reliability parts designed for other applications

Redundancy has often been used in repeaters to actively spare pump lasers. Depending on the reliability of the pump lasers, either 4 or 2 lasers are used. To date, pump lasers have not achieved sufficient reliability to function unprotected. The same philosophy used with lasers can be extended to repeater electronics very effectively.

Since a repeater or branch unit may contain multiple amplifiers or modules, a single circuit with complex functionality and hundreds of components is required to have a failure rate of no more than 1 or 2 FITs. One method to achieve this high reliability is through the prudent use of redundancy. In addition to protecting against component failures, redundant circuits can also reduce the risks associated with the use of certain manufacturing techniques. Surface mount component packages, for example, have become the standard in the commercial electronics industry. Surface Mount Technology (SMT) provides the advantages of dense packaging, automated assembly, and low cost. We have historically avoided the use of SMT in undersea systems, however, because SMT design are introduced in low volumes we introduces some small additional reliability risk. SMT boards are more difficult to inspect thoroughly, and are slightly more susceptible to hidden processing mistakes, faulty solder joints and stress damage components. Redundant circuit architectures can be invaluable in protecting the repeater’s reliability against low-occurrence board-level manufacturing defects.

Use of redundancy permits the use of components with higher FIT specifications but also permits some relaxation on the testing and data requirements for electronic components. Over recent years, the state of quality control in manufacturing has greatly improved. Many component manufacturers now adhere to strict quality controls which include SPC, defect reduction programs, and preventative action philosophies which make the product more inherently reliable. Even low-end commercial grade parts are significantly better quality than they were in the past. These basic processes obviate the need for additional, specialized certification programs, when the undersea system use of the part is in a redundant circuit.

Several electronic component manufacturers have been qualified to the (US) military QML (Qualified Manufacturers List). These manufacturers have demonstrated a quality system and process control sufficient to allow them to manufacture parts for the defense industry without providing individualized certification or qualification data for all parts shipped. Such suppliers practice regular internal screening, surveillance testing and re-qualification on the product, as prescribed for the component type. These routines are standard production processes, and no longer considered to be a “special” requirement. The requirements, standards and reliability methodologies for the components supplied by QML manufacturers are well documented and provide detail on a par with the traditional qualification and certification programs used for undersea parts. We believe that QML manufacturers are a usable source of high-reliability components for submerged equipment, especially when used in redundant circuit configurations.

2. CAUTIONS

There are a few cautionary statements to consider when implementing the strategy described above. First, redundancy can add to complexity in assembly. Parts count is increased, and there are more opportunities for manufacturing defects such as faulty solder joints. These risks ensure that we continue to use manufacturing processes which exceed normal commercial processes in quality, and also use high reliability components which are defect-free and have traceability back to the manufacturer. For this reason, we believe that commercial and industrial grade electronic components are not suitable for undersea use, even in redundant or protected architectures. There are too many opportunities for manufacturing defects and uncertainty in quality due to lack of pedigree data or traceability.

Although standard commercial and industrial grade parts are not usable in undersea systems, components qualified under the US Department of Defense programs can be adequate for use in undersea systems when used correctly. These components are manufactured under tightly controlled processes and are intended for high reliability applications. They are also fully traceable, and data packages can be assembled which support repeater pedigree and customer acceptance.

Although the reliability requirements and methodologies for these parts are well documented, each manufacturer has the freedom to determine the exact level of reliability their components will attain and the confidence level that their qualification and surveillance programs will achieve. Prospective users of these parts must determine if these levels are adequate for their application. In addition, surveillance programs might be structured to encompass all components made with the same technology. In this case, surveillance data for the particular component purchased might not be available.

One final complication is that components from QML manufacturers are available through a broad supply chain of distributors. It is then incumbent on the system supplier to ensure the traceability of the component through the supply chain, including proper storage, handling etc. This can usually be accomplished by using only "franchise" distributors, and understanding the requirements component makers place on their distributors in order to give them the franchise status.

3. CONCLUSION

In summary, we find that there are now cases where commercially available components can be used in undersea systems. Significant diligence is still required by the component engineer and the reliability engineer of the system supplier to ensure all parts have been manufactured and tested with the appropriate levels of qualification and process control. In many cases, the designer can reduce reliability concerns by using redundant circuit architectures coupled with high reliability, but commercially available parts. The net result of these techniques is a reduction in repeater materials cost, without compromising the stringent reliability requirements of our customers.

4. REFERENCES

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[i] Y. Matsushima, "High Reliability Technologies for Optical Submarine Cable Systems", in SubOptic 2004 Proceedings.

[ii] Summing the FIT rates does not introduce significant error because the FIT values are sufficiently small. This would not be the case for terminal equipment, where the FIT rate for a dense card can be as high as 10,000 – 20,000.