Pre-qualifying optical components for space applications

Yuanjian Xu, Bradley Scott, and Yongqiang Shi

A new method has been developed for selecting and qualifying commercially available optical communications components for use on spacecraft.

The possibility of using lasers for space communications, whether ground to spacecraft or spacecraft to spacecraft, has been attractive since the 1960s. Lasers offer the potential for higher data rates over long distances and for secure communications links, as compared to radio or microwaves. Implementation has been elusive for several reasons. Space applications require high reliability because of the lack of serviceability after launch. Also, hardware must survive radiation, vibration, shock, vacuum, and temperature extremes, and the stresses of launch loads followed by zero-gravity effects. Designing optical systems to meet such a rigorous environment has not always been successful.

In recent years, optical component technologies have evolved to where they are mature enough to deliver systems for space applications with high data rate, high security, and lower cost per data bit. This is not to say there is no risk. Many optical components have no space-flight heritage and must still 'prove themselves'. On the other hand, as long as risk is properly managed, we can control the cost and effort required to qualify optical components for space.

At the Boeing Satellite Development Center (BSDC), we have developed systematic methodologies to qualify optical components for space environments by choosing reliable technologies and suppliers based on a good understanding of component design, failure modes, and reliability modeling.

By maximizing the technology overlap between space needs and commercial-off-the-shelf (COTS) components, the scope of optical component prequalification can also be effectively managed. We have developed rigorous and carefully chosen tests and analyses of small quantities of parts to identify the best technologies, components, and suppliers to drive the prequalification process.

Figure 1. Space components require additional qualifications in addition to the conventional Telcordia requirements on commercial-off-the-shelf (COTS) components.

In the terrestrial market, the telecoms industry has the widely accepted Telcordia standard for optical components to be deployed in the field. Many high-quality components are qualified with robust design, and meet or even exceed equivalent space requirements. However, this can only be a good starting point for components to be used in space because Telcordia qualification does not ensure reliability. Though it requires COTS components to pass vibration, shock, high/low temperature storage, humidity, and other tests—as shown in Figure 1—the space environment has additional requirements. These include radiation, vacuum, zero-gravity, outgassing, lifetime thermal cycle, high reliability, etc. Custom component design is sometimes necessary to meet these additional requirements.

BSDC pre-qualification activities focus on these space requirements.

We tested components in a wide range of environments to ensure that we captured design and fabrication issues that are not so obvious when considering space applications. Most of the tests are complete. We also conducted component constructional

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analyses to better understand component construction, materials, design, packaging methods, and potential failure modes. We offer optical isolators as an example.

Optical isolators are widely available with free-space component design from numerous commercial suppliers. Figure 2 shows the optical isolator operating principle. The isolator input is collimated and then split into two orthogonally polarized components by a spatial walk-off prism (SWP). These components are then sent through a Faraday rotator, which rotates the beam polarizations by 45°. A half-wave plate then rotates the beam polarizations another 45° and a second SWP recombines the beams at the output: see Figure 2(a). The Faraday rotator makes the reverse-propagating beams orthogonally polarized to those incoming, so the reverse propagating beams are directed away from the input fiber by the first SWP: see Figure 2(b). A dual stage isolator performs this operation twice to improve isolation. Constructional analysis is also very useful in analyzing why some components perform better than others. Using isolators as examples again, we have seen some suppliers’ outperform others in power handling, total dose, shock, and other tests.

We have identified qualifiable technologies for all optical components, identified path-to-flight improvements, and mitigated key-component risks for flight. With these space qualifiable optical components and BSDE’s long history of electronics flight hardware, we have built many close-to-flight engineering models. These include: high-power optical amplifiers with the power capacity for low, medium, and geostationary-Earth-orbit systems; brass-board test models of low-noise optical amplifiers; high performance demodulators; and ultra-widebandwidth photodetectors.

Challenges remain. These optical components have minimal flight history, and failure-in-time (FIT) values are not well established for many of them. Some COTS components are not designed for space requirements. Size, weight, and power (SWAP) form yet another design issue. Better component reliability estimates can certainly help to reduce it. Mechanical structures and electronics necessary for meeting operational and environmental requirements all increase system SWAP. We will continue leveraging new cutting-edge component technologies—such as micro-electromechanical systems, photonic crystals, and integrated planar light circuits—when they are qualifiable.

In conclusion, BSDE has implemented pre-qualification risk management, which is effective in reducing space-based optical component risks and for advancing path-to-flight component development. We continue to apply these processes in our development of space-qualifiable subsystems.

Author Information

Yuanjian Xu, Yongqiang Shi, and Yongqiang Shi
The Boeing Company
El Segundo, CA

References

1. Telcordia 468, pp. 1209–1221.