How important is it to keep fiberoptic connections clean?

The results of a recent NEMI study range from predictable to surprising.

Anomalies that commonly occur in manufacturing processes can affect signal performance in an optical connector. Scratches and/or contamination in the form of particles and even oil from fingerprints often negatively impact insertion loss (IL), return loss (RL), and bit-error rate (BER).

The National Electronics Manufacturing Initiative (NEMI) Fiber Optic Signal Performance project is working to quantify the severity of optical-signal loss due to common hazards in manufacturing. The goal of the project is to develop industry-standard criteria and specifications for fiber-connector end-face inspection. The project also plans to develop guidelines for cleaning procedures and contamination prevention.

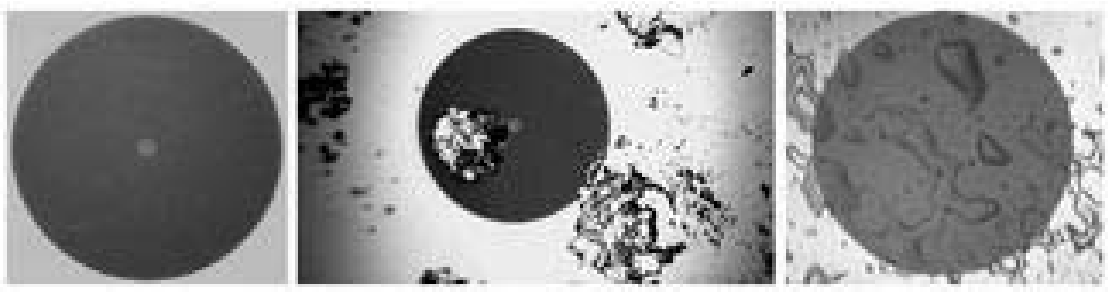

FIGURE 1. Common defects seen at the optical connector end face include scratches (left), particles (center), and oil (right).

The NEMI team tested three groups of cables with SC singlemode simplex connectors featuring 2.5-mm ceramic ferrules. Scratches were introduced to the first group of cables, the second group was contaminated with carbon particles, and the third group was contaminated with oil. Each device under test consisted of 20 to 24 cables and launch cables, polished to UPC performance. Each cable connector was visually inspected before and after defects were introduced to its end face, using a 200× or 400× fiberscope. Measurements of IL, RL, and BER were taken for the clean (defect-free) and defected connectors.

Scratches

The scratch experiment involved two sample groups. In one group, scratches were induced within the cladding region—outside the fiber mode field diameter (MFD)—while, in the second group, scratches were applied to the fiber MFD. The results indicate that scratches made during connector cleaning or polishing outside the fiber MFD have no impact on IL and RL of the mated optical connectors (see Fig. 2).

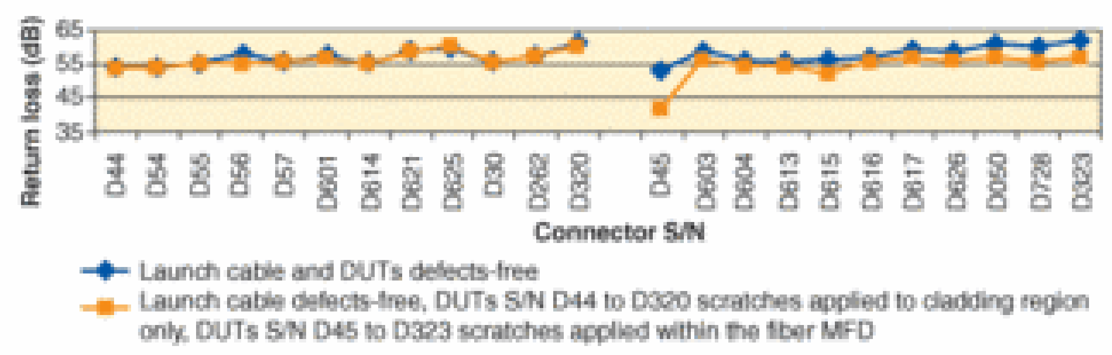

FIGURE 2. The two scratch groups in the experiment revealed that scratches within the fiber MFD degrade the return loss of mated connectors (wavelength is 1550 nm).

Similarly, scratches 2 µm wide or less within the MFD have no impact on IL; the change observed is within the measurement uncertainty of the test equipment. However, scratches within the fiber MFD can degrade the RL of the mated connectors, with the level of degradation depending on the width, depth, and number of scratches crossing the fiber MFD. In the NEMI investigation, the average difference in RL due to scratches within the fiber MFD was 4 dB.

Particle contamination

In the particle contamination analysis, carbon particles were used to contaminate connector end faces. Particles can be trapped on any of three basic areas of the connector end face: the core, cladding, and ferrule. Seven possible anomaly conditions may exist, with contaminants found on the core only, cladding only, ferrule only, core/cladding, cladding/ferrule, core/ferrule, or core/cladding/ferrule.

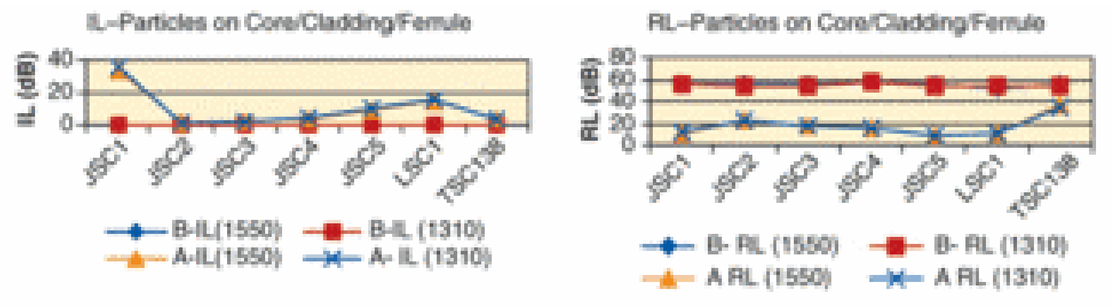

FIGURE 3. Insertion loss measurements (left) and return loss measurements (right) varied depending on the percentage of the fiber core and connector end faces blocked by particles. In the JSC1 case, more than 90% of the core region was blocked. In JSC2, approximately 5% to 10% of the core was blocked. In JSC4, 60% to 70% of the core was blocked, and in TSC138, 20% to 40% of the core was blocked.

The study showed that mating caused loose contaminants to spread. Through connection, a significant amount of the particles were transferred from the contaminated connector to the clean reference connector in a pattern similar to that seen on the contaminated connector.

The study also showed that particles on the core of the fiber resulted in catastrophic failures (tremendous increase in IL and decrease in RL), while the presence of particles on the ferrule did not degrade performance (see Fig. 3). The team is planning further study of the proportion of increase in IL and decrease in RL and the percentage of blocked core area.

Particles on both the ferrule and the cladding area created mixed results. In many cases, measurements of IL and RL showed no significant difference between the clean and contaminated connectors. However, a few exceptions showed that the presence of particles on the cladding very near the core can increase the IL and/or RL. In one case, the particles spread out during mating and blocked a small portion of the core and, as a result, both the IL and RL of this connector increased significantly. In another connector, there was no evidence of particles blocking the core, but the IL increased from 0.25 to 1.07 dB, while its RL didn't change significantly. More research is needed in this area.

Oil contamination

To test the effects of oil contamination, the team introduced finger oil to the connector end face before mating with the reference connector. The location of the oil contamination has a two-dimensional random distribution. Small oil drops of 2 to 60 μm provided coverage of the core, cladding layer, and ferrule. The oil distribution changed during mating with a clean test connector, transferring partially from the test connector to the reference connector (see Fig. 4).

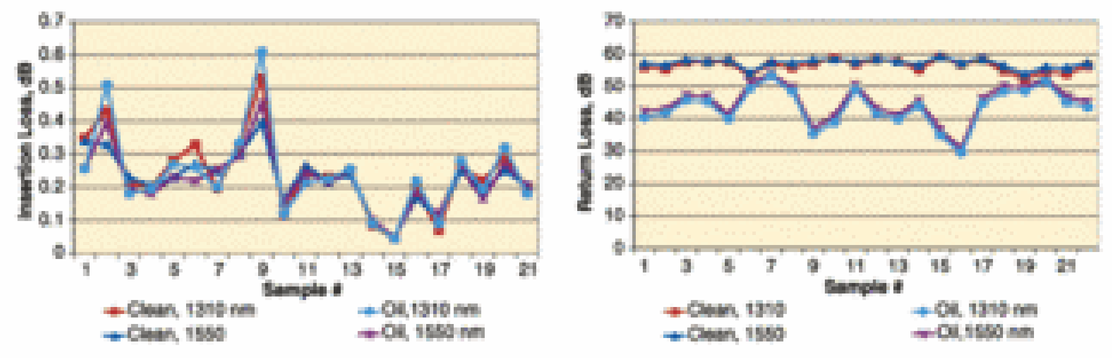

FIGURE 4. Measurements of clean and oil-contaminated samples at λ = 1550 nm and 1310 nm show that insertion loss is not greatly affected by oil contamination (left). Return loss, however, is significantly reduced by the contamination at both wavelengths (right).

Test results indicate that oil contamination does not affect the IL of the connector; however, it causes significant decrease in RL. The average RL decreased from 56.37 to 43.64 dB at λ = 1310 nm and from 57.18 to 45.15 dB at λ = 1550 nm.

The small difference between the refractive indices of fingerprints (1.4602) and fiber (1.467) indicates that the behavior of oil contamination is similar to the behavior of refractive-index matching material.* (Index matching material is applied to fill the gap between the two fiber end faces to reduce the Fresnel reflection resulting from the discontinuity in propagation medium.) This similarity can explain why IL did not change after oil contamination.

Conclusion

Testing done to date by the NEMI project shows that the effect of contamination/scratches on connector optical performance is dependent on the type of contamination (fingerprints, carbon, metallic particles, and so on), size of the contaminated area, and location on the connector end face. The influence of the contamination/scratches becomes more evident if they are located in the core/cladding areas. Particle contamination may cause a significant increase in IL (up to ten times), decrease in RL (up to three times) and increase in BER test results (two to ten times) if they are located near the core. Scratches applied to the fiber MFD decreased RL by up to 25%, while scratches located in the cladding layer showed little effect on IL, RL, or BER test results. Multiple heavy scratches passing through the core caused severe performance degradation in IL and RL and catastrophic BER test failures.

The project team is planning further research to develop mathematical modeling for scratches, particles, and oil contamination. Future studies will also investigate the effects of particles located at the cladding (and close to the core) area and focus on particle size, quantity, and different particle types.

Typically, OEMs and electronics manufacturing services (EMS) providers have their own inspection criteria. However, these specifications differ from company to company, and the differences can cause materials to be "nonconforming" at user/customer sites. If a supplier has ten customers and must meet ten different sets of specifications, product costs will increase. Defining industry-wide standards for inspection criteria will help ensure quality while keeping costs under control.

Data from the NEMI investigations will be used to help define industry-standard specifications for cleanliness of fiberoptic connectors. NEMI is already collaborating with the International Electrotechnical Committee (IEC), Telecommunications Industry Association, and IPC-Association Connecting Electronics Industries. The standard being developed will be jointly submitted to IEC Working Group 6 (interconnecting devices) and to IPC for incorporation into the existing IPC-0040 standard (Optoelectronic Assembly and Packaging Technology). Initial results were presented to the IEC WG6 last October.

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REFERENCE

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Who is NEMI?

The National Electronics Manufacturing Initiative is an industry-led consortium of approximately 70 electronics manufacturers, suppliers, and related organizations whose mission is to assure leadership of the global electronics manufacturing supply chain. For additional information, visit www.nemi.org.