A Comparison of Pre-polished Connectors vs. Fusion-Spliced Pigtails as Field Terminable Solutions

Will McAvoy

Panduit Corp., Fiber Research, Orland Park, IL

ABSTRACT

This paper compares two different methods of field termination for multimode fiber: fusion spliced pigtails and pre-polished connectors. Each method has its inherent advantages and disadvantages. This paper will study the performance, material cost, tooling cost and installed cost of each method. The research and data in this paper reflects the use of multimode terminations for both pre-polished connectors and pigtails.

1. INTRODUCTION

Terminating fibers in the field is a necessity when installing a network. Higher port density means higher volumes of cables must be run through ducts, conduits, ceilings, etc. In order to enable pulling these cables safely and easily, they need to be un-terminated. Installers are then left to terminate these fibers using the method that gives not only the highest quality termination, but also has the lowest installed cost.

2. PERFORMANCE

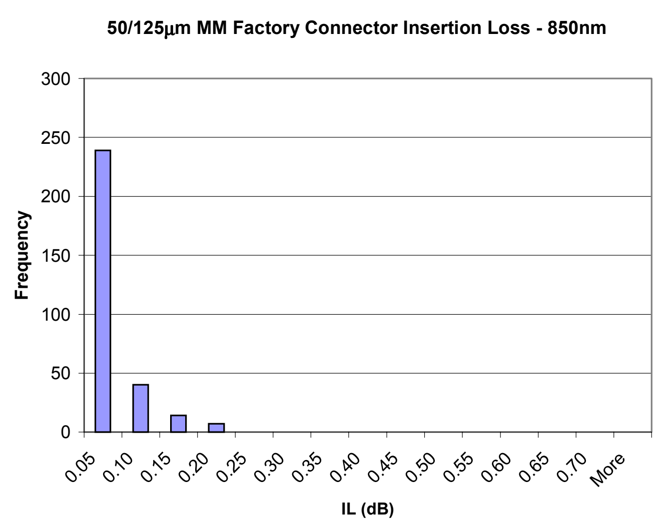
2.1 Pigtails:

The measure of the effectiveness of any termination is the optical performance. With multimode fiber optic connectors, this is evaluated by the insertion loss, or the total optical power loss caused by insertion of an optical component such as a connector, splice or coupler. The insertion loss is measured in decibels, or dB. A decibel is not a measure of the absolute power loss, but rather a measure of the ratio of power loss.

A factory-terminated pigtail should have very low loss. The connector has been terminated in a clean environment using well-maintained equipment and strictly controlled termination procedures. Most importantly, the product is tested per TIA-455-171 (FOTP-171), likely using reference quality launch cables. Many pigtails can be purchased with the insertion loss (IL) numbers included. However, these numbers are not necessarily an accurate measure of the performance of the pigtail; insertion loss cannot be measured across a single connector. Insertion loss measurements can only be taken across a mated pair, and if one of the connectors is a properly maintained reference-quality launch cable, the numbers can be skewed to indicate superior performance. While the included IL reading will probably not reflect the installed measurement, it should at least be an indication that a quality pigtail has been purchased.

The following table shows the distribution of a typical sample of factory-terminated *PANDUIT*® multimode connectors.

Table 1



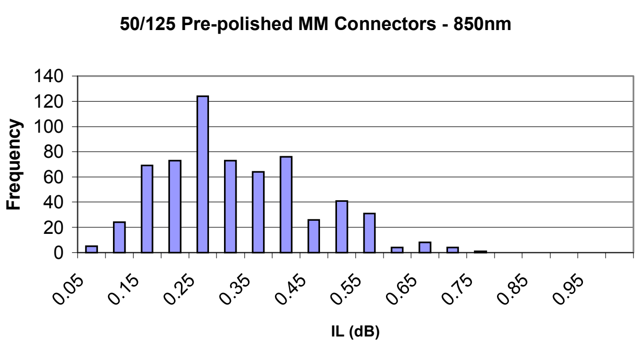
As shown in Table 1, the insertion loss is very good. The majority of the connectors are approximately .05dB. The average IL for this sample of connectors is actually 0.04 dB using the procedures and equipment in manufacturing.

2.2 Pre-polished connectors:

Manufactured pigtails can be tested for insertion loss prior to shipping. This is not necessarily true for pre-polished connectors. While the quality of the connector can be verified, it is not always possible to fully terminate the connector onto a cable. This is because, in many pre-polished connectors, there are irreversible steps such as crimping. Therefore, the data used for pre-polished connectors is from actual terminations in the field and not terminations tested against reference quality cords.

Table 2 shows a sample of *OPTI-CRIMP*® Connectors (50/125µm) terminated and tested for insertion loss at 850nm.

Table 2



The data alone shows that the *OPTI-CRIMP* Connectors did not perform as well as the pigtails. The average insertion loss is closer to 0.30 dB, or about 0.26 dB higher on these connectors. The distribution is also much more spread out in the case of these connectors. These insertion losses range from 0.04 dB to 0.75 dB, while the losses of the factory-terminated connectors range from 0.01 dB to 0.20 dB.

The difference in these methods is indeed significant, but not necessarily comparable. The difference in the testing methodology has been discussed already, but that still does not take into account the inherent differences in the products.

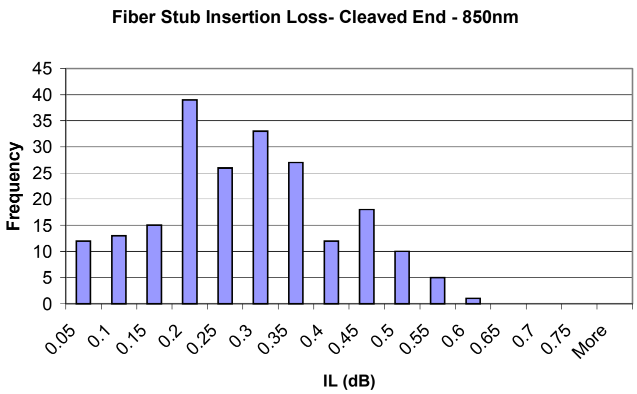
3. COMPARISON

Pigtails are usually built as patch cords and then cut in two. When they are tested, they are tested as patch cords and mated to a reference cable. Only one glass-to-glass interface is tested at a time while using FOTP-171. The pre-polished connector contains a small piece of glass inside the ferrule. One end is polished to a smooth surface equal to the endface of the fiber on the pigtail; the other end is cleaved to a smooth surface perpendicular to the fiber. Therefore, the insertion loss from testing a pre-polished connector reflects the power loss across two glass-to-glass interfaces: one between mated polished ends and one between mated cleaved ends.

The pigtail does not have the advantage of having fewer glass interfaces; it *has* the advantage of having fewer glass interfaces *during factory testing*. In order to install a pigtail, the unterminated end will need to be stripped, cleaved and spliced, supplying the missing interface. Typical fusion splice loss is less than 0.05 dB. It is very common for fusion splicers to give insertion loss readings after a splice. These are not true readings of power loss; these are estimates based on cladding alignment and splice integrity. They do not account for physical differences between the fibers being spliced, such as the shapes of the core or the index of refraction of the glass. Losses from fusion splices typically run less than 0.05 dB, but in most cases are 0.01 dB or less. Splice loss can be considered negligible. We can assume the polished end of the pre-polished connector is the same as the polished end of the connectorized pigtail, since they are likely to be done using the same procedures and equipment. Therefore the difference in performance between a fusion-spliced pigtail and a pre-polished crimp connector is still on the average 0.26 dB, which should be solely attributed to the cleaved interface at the back of the pre-polished fiber stub.

Table 3 is the difference of randomly selected pre-polished connector terminations minus a selection of random pigtails. The average insertion loss is approximately 0.26 dB, which is consistent with the previous averages. This value is equal to the difference in the average of the pre-polished terminations (0.30 dB) minus the average insertion losses of the pigtails (0.04 dB). The interface in the pre-polished connector is essentially identical to a mechanical splice and the losses reflect this.

Table 3



The values in Table 3 are also very spread out. This distribution is not a normal one, so a true standard deviation does not apply, but one can be calculated from the data set to measure the variability. The resulting number would not be applicable for calculating the upper and lower limits of the data set, but would still give an indication about the variation of the data points from the modal value. Using the standard deviation calculations, the data in Table 3 has a measurement of variability of 0.13. The data in Table 1 (Factory-Terminated Pigtails) has a measure of variability equal to 0.03. This suggests it is very difficult for an operator to control the amount of loss at the cleaved end of the fiber stub. As it is much easier to have a smaller range of losses from a terminated pigtail, it becomes necessary to control the losses at the cleaved endface of the fiber stub. This can only be done through the termination procedure.

Multiple samples of pre-polished connectors using multiple operators were used to acquire the data presented. Each of these operators did use an identical method of terminating, which involved blind insertion of the fiber into the mechanical splice apparatus of the connector. There is an inherent difficulty in knowing exactly when optimum surface contact has been achieved, since the operator cannot verify the quality of the connection at the spliced end. Since most of the loss does occur at the interface, the overall quality of the termination is heavily dependent on the ability of the operator to position and secure the field fiber. Therefore the quality of the termination becomes a product of the operator experience and skill.

In order to remove some of the questions involved in terminating fibers blindly, many trainers recommend the use of a Visual Fault Locator (VFL), to see exactly when the fibers achieve full contact. The use of a VFL for terminating pre-polished connectors can be used to improve the quality of terminations. A VFL is a visible laser source with an output wavelength between 600 and 665nm, emitting a bright red light. This light can easily be seen if it is not guided or contained within the confines of the fiber core. Hence, a bright red light can be seen when the fiber has a break or when the fiber simply ends.

The procedure is to connect the pre-polished connector to the VFL. In the absence of a mated field fiber, the light emanates from the connectors cleaved fiber end resulting in a bright red glow. As the field fiber is inserted into the pre-polished connector assembly, the light begins to couple into the core of the field fiber. Once the fibers are fully mated, the light is guided from core-to-core significantly reducing the bright red glow. The glow can continually be observed as the fiber is inserted into the pre-polished connector and a judgment of when the fibers are fully mated is usually obvious.

A second study was performed on the pre-polished connector using terminations with and without a VFL. One operator terminated 100 connectors, using the VFL on random terminations. The VFL enabled the operator to see when the field fiber was optimally positioned (fully mated) for one half of the samples.

The data in Table 4 on Page 4 shows a noticeable improvement in the quality of the termination when a VFL is used to position the fibers. The average of the terminations in Table 4 is 0.13 dB, and the average of the terminations in Table 5 is 0.19 dB. Further examination shows that the data with the VFL is also much more concentrated. The measurement of variability using the VFL was approximately 0.07 dB, while the measurement of variability without using the VFL was 0.11 dB. The VFL not only improved the average loss of the terminations by 0.06 dB, but also gave more consistent terminations.

Table 4

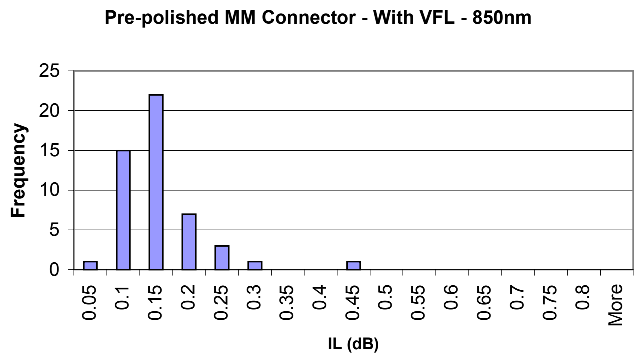
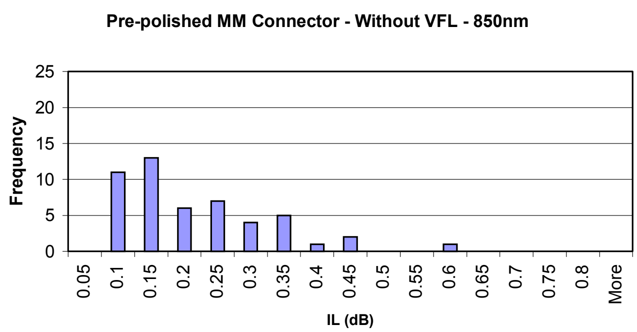


Table 5



The measurement of variability of 0.07 is interesting. This number can be compared to measures of variability from previous data sets. For instance, the measure of variability of the factory-terminated connectors (Table 1) was 0.03 and the measure of variability for the pre-polished connector in Table 5 was 0.11 dB. Therefore, using the VFL reduces the variability in the termination process by 50%. This is a significant reduction, and leads to the conclusion that half of the variability comes from the operator inserting the fiber blindly. One would never expect the variability from each sample set to equal each other, because the pre-polished connector still will have some variability from the quality of the interface between the cleaved end of the fiber stub and the cleaved field fiber.

The average of the non-VFL terminations in Table 5 compares favorably to those in the previous studies. The previous data in Table 2, as mentioned earlier, was a compilation of multiple operators. The dramatic reduction in the average IL of the terminations shows that the operator can have a significant impact in the quality of the termination. Therefore, it is important to be trained properly in the termination of a pre-polished connector. So if we assume a splice loss is negligible, the average loss of a spliced pigtail is still 0.04 dB. If a VFL is used, the average loss of a pre-polished connector is 0.24 dB. This creates a difference in performance of 0.20 dB in favor of fusion-spliced pigtails.

4. PROCEDURE

The procedure for terminating a pre-polished connector is precise, but it is not difficult. All pre-polished connectors are packaged with detailed instructions that should prove effective. The procedure for fusion splicing is very simple, as well.

When there is a large quantity of fibers to be terminated, the time involved in preparing each cable can lead to a considerable cost difference. The steps to prepare each fiber for termination will no doubt be similar. The basic procedure to terminate either product is the same, strip the fiber(s), clean the fiber(s), cleave the fiber(s), and then terminate the fiber(s).

Terminating a fiber with a pre-polished connector begins with inserting the fiber into the connector. If a VFL is being used, the operator will watch for the red glow to diminish. Then the operator secures the connector to the cable. In the case of the SC *OPTI-CRIMP*® Connector line, this consists of cycling the crimp tool to fasten the connector in place. Depending on the cable type, buffer crimping and jacket crimping may also be required.

In the case of the fusion splicer, the stripping preparatory work must be done twice; the pigtail and the field fiber must both be stripped and cleaved. A single fiber splicer also requires other additional steps that can slow the termination process.

In order to fusion splice, the first step is to install a splice protector. Then, after the fibers are stripped and cleaved, they are positioned in the fusion splicer. While no splicers demand the fibers be positioned precisely, the splicer will still require that the fiber ends be in a general area relative to the electrodes and each other. The fibers are then secured, and the

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door can be closed. The splicer will then shift the fibers into the proper position for splicing and fire the arc. After the splice, some fusion splicers will perform a brief tension test on the splice. Then the fiber can be removed and the protective sleeve slid into place over the splice. The splice is then placed onto the heater to allow the protective sleeve to shrink in place, securing it to the cable.

The splicer will take considerable time to position the fibers and to cure the protective tubing. While this idle time will allow for the operator to perform other tasks, these steps will still have to take place on every single splice. The fusion splicer itself can align and splice two fibers while another sample is being cured, but the curing process is typically longer. The practice of fusion splicing therefore has a “bottleneck” in the operation at the point where the splice protector is cured and shrunk. This means fusion splicing can take as much as 40 seconds longer per connection than terminating pre-polished connectors. Assuming a typical loaded labor rate of $45.00 per hour for a cable assembler, this can add up to a greater cost on a large install.

5. MATERIAL COST

The price of factory-terminated pigtails can vary depending on the supplier. Many companies use lower cost labor and are able to produce multimode pigtails that cost the customer about twice the price of a standard “pot and polish” version of the equivalent connector. Pre-polished connectors are usually priced competitively, but typically cost more than pigtails. One reason for this extra cost is the specialized automated equipment used in the assembly process. Typically, the price of the pre-polished connector is about two to three times the price of the standard “pot and polish” version of the same connector. This means a pigtail can cost 33% less than the equivalent pre-polished connector per unit.

6. TOOLING COST

The most obvious of all the expenses is the tooling cost. The main requirement for a pre-polished connector is a tool kit from the supplier. These tool kits can cost around $800-1000, not counting the additional expense of a VFL kit. In order to fusion splice pigtails, the largest expense is a fusion splicer. New fusion splicers cost anywhere from $20,000 to $55,000, depending on the manufacturer and the model. The cost of maintaining, repairing, and replacing worn parts on a fusion splicer is greater than the corresponding costs on a crimp tool.

The cleavers used by fusion splicers are more expensive than those included in field termination kits as well. Tabletop cleavers can cost over $1,000.

Also, pre-polished connectors have virtually no consumables cost other than cleaning materials, and these will be required on fusion spliced pigtails as well. Since the manufacturer already polishes the connector, neither method requires any expensive polishing films to be purchased. In addition to cleaning supplies, fusion splicing also requires splice protectors, which cost about $0.40 per splice. Splice protectors come in two standard sizes, but the cost is typically the same.

7. VERSATILITY

Most fusion splicers are just under a cubic foot in volume and not equipped to be readily portable. They are designed to be used on tabletops and work benches. Not all terminations take place in these environments. Sometimes it is necessary to access the ceiling tiles or sit on the ladder top in a closet or crawl down into the sewers or climb the utility pole to access the connectors being terminated. A large fusion splicer is not ideal to carry into these environments. In many of these cases, a pre-polished crimp connector is easier to accommodate than most fusion splicers. Some companies have developed hand held fusion splicers that are not limited in these applications. These splicers do not come with a curing oven for the splice protector. A curing oven would need to be purchased separately or an alternate method of shrinking the splice must be utilized.

Splicers also require a power source. Even in areas where an AC power source is not accessible, many fusion splicers can still be used since they are equipped with battery packs. These battery packs typically have a life of 2-3 hours, depending on manufacturer, and will require recharging.

Fusion splicers do allow for variability when terminating different fibers in the form of having multiple programs. The programs vary several parameters, including arc length, time, curing temperature and curing time (for the protector). These programs can be easily saved, eliminating the need for the operator to memorize the required settings.

The operation of a fusion splicer is not complex, but not nearly as simple as the operation to crimp a pre-polished connector. Operators have successfully terminated pre-polished connectors overhead in suspended ceilings with poor lighting while standing on top of a ladder. While terminations such as these are extreme and rare, pre-polished connectors still allow for this versatility. It is important to remember that not all terminations will take place on a nice clean bench top or in an air-conditioned central office.

8. MANAGEMENT COSTS

The cost of managing splices is greater than the cost of managing terminated pre-polished connectors. A pre-polished connector is managed identically as a factory-installed or field-terminated connector. The interfaces between the glass surfaces are all contained within the singular unit. A spliced pigtail requires that the splice protector be managed separately and in a much more costly fashion.

Splices and splice protectors need to be maintained within a splice tray. Splice trays not only provide the stability to protect the splice, but also enable easy removal for future access. Each splice tray usually holds up to 12 splices and a sufficient amount of buffered cable for future servicing. Splice trays typically cost about $30. For a tray containing 12 splices, this adds an additional cost of $2.50 per spliced pigtail. Splice tray holders to maintain not only the trays, but in some cases, the bend radius of the fiber, also add cost. A $9.90 splice tray holder, which holds up to three splice trays, adds additional cost of $0.41 per spliced pigtail.

Splice trays are necessary not only for maintenance and protection, but also for performance. Proper installation in a splice tray guarantees the fiber will not have the tight radii that can increase the insertion loss. The size of a splice tray enables easier and smoother transition bends throughout the fiber. But in order to achieve these bends, splice trays must have considerable size and take up a fair amount of enclosure space.

Additional enclosure space is required to hold splice trays. Most enclosures for terminated fibers do not have sufficient space to accommodate splice trays. If a 72-port rack-mount enclosure is in place, there will not be space inside the enclosure to accommodate six splice trays. Some units do have "patch and splice" enclosures capable of holding both terminations and splice trays, but these enclosures can either become very large, have limited capacity or have restricted access to the connection points. For instance, some designs of "patch and splice" enclosures have the connectors and adapters within specially designed splice trays that hold both the fusion splice and the connection point. Six trays are then stacked, to allow for all 72 ports to be held within one enclosure with the splices. This can make it difficult to access a particular connector. Ports that are exposed enable the operator or maintenance technician to service the connectors more easily and rapidly, as opposed to ports that are buried amongst all the slack cabling.

If an additional enclosure is required to hold the splice trays, the cost differential becomes substantial. This type of enclosure can cost anywhere from $180 to $600. Assuming the minimum cost enclosure for 72 splices, the additional cost comes to approximately $2.10 per port.

The use of a separate enclosure to manage the splice trays can mean that the rack itself will hold fewer terminations. Space in the telecommunication room itself becomes a factor in the cost difference. Each cubic foot dedicated to managing splices becomes one less cubic foot dedicated to managing connection points. A rack-mount splice enclosure capable of holding six splice trays can occupy approximately about 0.75 cubic feet of volume in the rack. Rack space has a loaded cost of $100-200/cubic foot. Therefore the space required will cost an additional $1.05-2.10 per connector.

The use of spliced pigtails can add between $6.05 and $7.10 per port just in cable management costs. This addition is almost equal to the cost of the pigtail itself.

Not all terminations take place at the rack. There are other termination points, including at the wall, the desk and the outlet. But in each of these cases, if a spliced pigtail is used, it will be necessary to manage this pigtail using a splice tray or equivalent. Many outlets or junction boxes themselves are too small not only for the splice tray, but in some cases the splice protector itself. Forcing a 40-60mm splice protector into a 4" outlet enclosure will cause bending in the fiber that will induce excess insertion losses.

Wall mount cabinets need to be capable of "patch and splice" and will use the same splice trays. But these trays require more complex splice tray holders because the function of the wall mount is different. Wall mount enclosures also serve as a demarcation point for the responsibility of the fiber. This limits the interior space owned by the end-user, and also creates the necessity for more internal slack if there is maintenance or repair work to be done. A splice tray holder for a wall mount enclosure might cost an additional $30, but would be capable of holding up to 48 splices. Still, there is the additional hardware cost of $0.63 per splice.

9. CONCLUSION

In comparing two methods of fast termination, fusion-spliced pigtails and pre-polished connectors, two obvious advantages are for the pigtail. One of these advantages is lower insertion loss. A spliced pigtail should be about 0.20 dB better than a pre-polished connector, and even lower quality splices will still be 0.15 dB better on average than a termination using a pre-polished connector. The other advantage of the pigtail is a lower unit cost. A factory-terminated pigtail can cost 33% less than the equivalent pre-polished connector.

While the pre-polished connector does not have these advantages, there are still many other benefits.

Cost Advantages:

- The start-up costs for the spliced pigtail are significantly higher, as fusion splicers can be very expensive. Even the cheapest fusion splicer will cost nearly $19,000 more than the most expensive crimp kit.
- It is faster to terminate a crimp connector, saving labor time ($0.75 per splice), and splicing also requires additional material costs in the form of splice protectors ($0.40 per splice).
- The most significant advantage of the pre-polished connector is the management hardware involved. A pre-polished connector requires no additional hardware over a standard connector. The additional material and closet space for managing splices can cost an additional $6.05-7.10 per connector. Not counting the initial start-up costs, splices will run anywhere from $7.20 to $8.25 more per splice.

Other Advantages:

- Pre-polished connectors also have the advantage of being more versatile. A pre-polished connector can be terminated anywhere a pre-terminated pigtail can be installed with little difficulty.
- There is no need to worry about power supplies or sufficient table space for a fusion splicer.

The bottom line will come down to the customer requirements. If cost is not an issue and the 0.20 dB insertion loss is important, then fusion splicing is the proper method. However, cost is often a driving force, if not the most important one. For these customers, if there is sufficient room in the loss budget for the additional 0.20 dB, then the proper method to achieve the optimal "low cost, high quality" solution will be to use a pre-polished connector such as *PANDUIT*® *OPTI-CRIMP*® Connectors (SC, ST and FJ®).