

# Index Matching Gel and Mechanical Fiber Splice Technology for Last Mile FTTH

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## **Abstract:**

This paper examines Index Matching Gel (IMG) for mechanical splices and mechanical splice connectors in Fiber Networks (FTTH). Concerns voiced by telecommunications providers are addressed using analytical test data and service provider feedback to demonstrate IMG's "permanent" nature for FTTH applications.

## **1. Introduction**

Index matching gel (IMG) is a fundamental fiber to the home (FTTH) component for meeting the immediate needs of both last mile build out and long-term network operations. IMG is a “light bridge” in mechanical splice mechanisms, allowing efficient fiber connections. This technology is already widely adopted in the telecommunications industry and has a proven track record of economical and flexible installation combined with permanent stability.

FTTH networks have been rapidly deployed in Asia and now reach over 18 million households [1]. Millions of those broadband connections rely on existing IMG mechanical splice technology. Reports from the field conclude that the drop technique meets performance standards, is less complex and faster than fusion splicing, and requires substantially lower capital investment [2].

Even with the combined track record of mechanical splice techniques in telecommunications and overseas FTTH networks, some out-dated concerns about IMG reliability persist in the North American telecommunication industry. Some network engineers have expressed apprehension that the IMG may change with time, affecting optical properties by yellowing, leaking or hardening, ultimately causing transmission losses. Concerns about water intrusion have also been voiced. Extensive testing by IMG, splice and optical fiber manufacturers provides definitive data to the contrary. This paper directly addresses IMG performance concerns and offers a historical profile from both a manufacturing standpoint and an examination of industry applications.

## **2. Index Matching Gel**

Index matching gel (IMG) is a silicone based synthetic fluid that is combined with insoluble microscopic powders to produce a thixotropic gel. IMG is a ready-to-use, single component material requiring no curing. It is highly inert and chemically stable within a temperature range of -59°C to in excess of 270°C [3]. The most important characteristics of an IMG are optical clarity and refractive index (RI).

IMGs can be produced with different specific RIs. In the case of FTTH mechanical splice technology, the IMG is synthesized to have a RI that matches the fiber core. The IMG optically couples fibers within the splice mechanism and eliminates signal losses caused by reflection or refraction of light due to an air gap between the fibers. By matching the fibers' index of refraction, the gel creates a light bridge, effectively transferring light from one fiber to another without significant insertion loss.

Mechanical splices represent a comparatively simple drop technique that requires little training and can be implemented with low-cost tools and in difficult to reach or otherwise restricted areas. The thixotropic nature of the IMG, coupled with the high precision of the splice and installation equipment allows for technicians already trained in coaxial or copper wire installations to adapt to optical fiber with relative ease. A 2006 study by Tyco Electronics Corporation demonstrates only moderate differences in success rates between highly trained technicians and those who were provided with nothing more than a service manual [4].

There are several mechanical splice products available on the market today. The exact specifications for each vary in terms of hardware, tools and technique but all utilize IMG as the core light bridge. Each manufacturer has independently verified IMG's viability and considers it a proven and reliable technology.

### 3. Sources of concern about IMG performance

In the late 1970s telecommunication companies began building new infrastructure with fiber optics. In 1988 the first transatlantic fiber cable was activated. During that infancy period first generation IMGs were implemented in some mechanical splice techniques. Real world experiences with those first generation IMGs revealed problems with the original chemical composition. Changes in optical and rheological properties including yellowing, oil separation and gel hardening or crystallization were rumored to be observed. Early gel formulations were also alleged to show some susceptibility to water, permitting moisture intrusion and therefore signal attenuation.

Current IMGs are specifically synthesized under precise laboratory conditions. Even slight variations in the IMG formulation or processing can contribute to variations in performance. In short, first generation IMGs were not processed with the same strict manufacturing controls, including class 10,000 clean room packaging, that today's IMGs routinely undergo. By the 1990s, when large-scale projects such as Fiber Optic Link Around the Globe (FLAG) were undertaken, IMG performance was markedly improved. Table 1 [5] shows the changes in IMG performance between first generation and current formulations.

**Table 1:** Comparison of first generation and current IMGs

	<b>Previous Index Matching Gel Formulations</b>	<b>Index Matching Gel of Today</b>
<b>Oil Separation</b>	1.0 %	0.2% max, 0.075% average
<b>Evaporation</b>	2.1%	0.2 % max
<b>% Transmittance *</b>	79%	97% after 80°C heat aging

\*1 cm optical path

Oil separation, a measure of a material's tendency to leak fluid, shows current IMGs have an average of 13 times better performance over past formulations. Oil evaporation, which could cause an IMG to shrink or harden, shows at least a tenfold improvement. Overall light transmittance has increased to >97%, even after samples have been heat aged. Note that the percent transmittance is measured through a 1 cm thick sample of IMG. The actual path length through the IMG in a mechanical splice is approximately 1,000 times shorter.

Current IMGs are specifically designed to overcome the evaporation and oil separation issues that led to yellowing and gel hardening in older generation gels. Nye Lubricants and leading splice manufacturers jointly developed new base formulas and manufacturing processes to bring IMG performance up to industry required standards. The body of this paper discusses many of the tests used to guide that development. The data reflects the overall improvement in IMG performance and is intended to dispel persistent misconceptions about IMG and mechanical splice reliability and longevity.

### 4. History and Evolution of IMG at Nye Lubricants Inc.

The history of IMG at Nye Lubricants dates back to 1985. Nye was involved in the supply of optical materials for telecommunications nearly from the inception of optical fiber in the industry. Nye was brought into the supply chain early to supplement material preparation. Since that time Nye has become the leading IMG supplier for mechanical splice and mechanical splice connector manufacturers.

The first generation of IMG was marketed as a "grease like" optical coupling compound under the brand name General Electric Silicone Compound 688 or G688 [6]. Before the advent of fiber optic mechanical splice technology, this material was used as an optical couplant in cameras and scintillators.

Those early generation gels were not designed as index matching materials for fiber optic systems. Working with mechanical splice manufacturers, Nye made fundamental improvements starting with the raw materials. The synthesis processes of the raw materials were improved to enhance the silicone base oil properties such as evaporation and optical

clarity. Modern IMGs now exhibit an order of magnitude improvement with regard to evaporation as compared to G688 as shown in Table 1. Nye also developed proprietary production methods that resulted in much improved oil separation levels, and applied their expertise in the formulation of synthetic lubricants to establishing greater control over IMG consistency. Reducing particulate matter is also crucial to modern IMG production. Nye's processes eliminate impurities and hard particles that could absorb or deflect light by packaging the gel in a class 10,000 clean room environment.

## 5. Testing

### 5.1 IMG Thermogravimetric Stability

Thermogravimetric analysis (TGA) provides an indicator of the long-term stability of a gel. In this experiment, a small amount of gel is placed in a high precision balance pan and the temperature is ramped at a consistent rate of 5°C per minute [3]. The percent weight loss is plotted vs. temperature as shown in Figure 1. Data was collected for several index-matching materials including IMGs, optical epoxy, conventional silicone sealants and two-part curing gels. The IMGs exhibit superior thermal stability as evidenced by the relative temperatures at which a 1% weight loss is attained. For Nye's IMG, 1% weight loss is not realized until the temperature is >300°C while for an optical epoxy, for example, it is approximately 100°C.

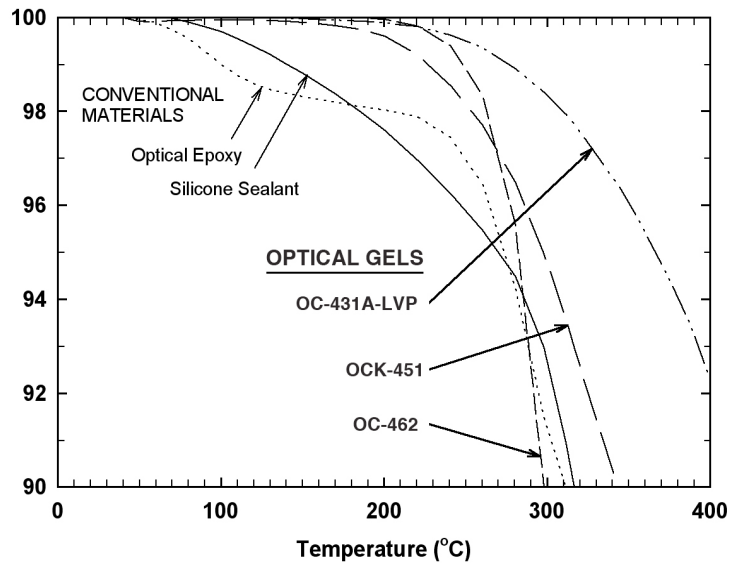


Figure 1: Thermogravimetric data for IMG vs. a conventional silicon sealant and epoxy

### 5.2 IMG Heat Age Testing

Extensive heat-age testing was conducted on IMGs by all the major mechanical splice manufacturers. Overwhelmingly, the test results demonstrate the gel to be resilient, exhibiting no significant levels of insertion loss or rheological degradation. Various test methods are compiled in this section to demonstrate the long service life of the gel material.

One manufacturer [2] subjected their splices to 60°C for 15 days continuously after which 30 splices were installed into a fiber test environment. Mean insertion loss for the group was 0.05 dB at 1300 nm and 0.04 dB at 1550 nm. This is within accepted standard tolerances and is comparable to non-heat aged samples. Further testing by the same company [7] exposed splice samples to 85°C with 85% relative humidity for 8,812 hours. Subsequent measurements showed insertion losses were comparable to attenuation in unspliced single mode optical fiber at 1310 nm and 1550 nm. Of the sixteen splices tested, most exhibited <0.15 dB insertion losses with only one splice exceeding a 0.2 dB loss at both 1310 nm and 1550 nm.

Similar tests have been conducted directly on the IMG itself [5]. The percentage of light transmitted through a 1 cm gel path was measured at 850, 1300, 1310, 1490, and 1550 nanometers. Transmittance was measured before and after heat aging at 80°C for 136 days under ambient humidity. The test results show exceptionally low levels of change and suggest actual transmission losses in a mechanical splice due to the IMG would be in the ten thousandths of a dB. Again, the 1cm test length is 1,000 times longer than the gel path in a mechanical splice, which is approximately 10 nm. Table 2 below shows the percent change in light transmitted (%T) at each wavelength after aging.

**Table 2:** Change in %T after 136 days of heat aging at 80°C [5].

Wavelength (nm)	Change in %T After Heat Aging (1 cm path)
850	-2.7%
1300	0.9%
1310	0.8%
1490	1.2%
1550	-3.0%

The effect of heat aging on the RI of IMGs has also been examined. One manufacturer [8] subjected 1ml gel samples to 21 days of 80°C oven controlled heat. The samples were sequentially removed from the oven after 4, 8, 11, 16 and 21 days and tested for changes in RI at 589 nm. Before heating, the RI was measured as 1.4623. After heating the index deviation was measured at a maximum of  $\pm 0.0002$ , well within specified industry tolerances of  $\pm 0.01$  (Table 3). The same samples were tested further for evaporation loss and rheological behavior. Neither test showed any significant deviation from reference measurements.

**Table 3:** RI measurements at 589 nm after thermal aging [8].

Sample	Refractive Index
Reference	1.4623
After 4 days	1.4625
After 8 days	1.4622
After 11 days	1.4621
After 16 days	1.4622
After 21 days	1.4622

These results were confirmed through additional testing. While evaluating gels for their mechanical splice product, high humidity tests were conducted, exposing 1 ml samples of Nye’s IMG to 80°C and 93% humidity for 3 days. The exposed samples were returned to room temperature for 12 hours after which the RI was measured and evaporation levels were determined. No evaporation loss was observed and the refractive index before and after the oven controlled tests remained the same at 1.4623.

Further aggressive testing was conducted. Samples were placed in an environmental chamber at 85°C with 85% humidity and removed after 41 days and 75 days. The RI was then measured at room temperature and testing showed that even after such extreme conditioning the only deviation was well within the specified tolerance of  $\pm 0.01$ . The manufacturer concluded that long term high temperature and high humidity will not affect an IMG’s optical properties. On the whole, through variations of heat age testing, both incorporated in a splice mechanism and as an isolated sample, the IMG demonstrates resiliency and reliability for permanent service life in fiber optic applications.

### 5.3 Water / Humidity Absorption Testing

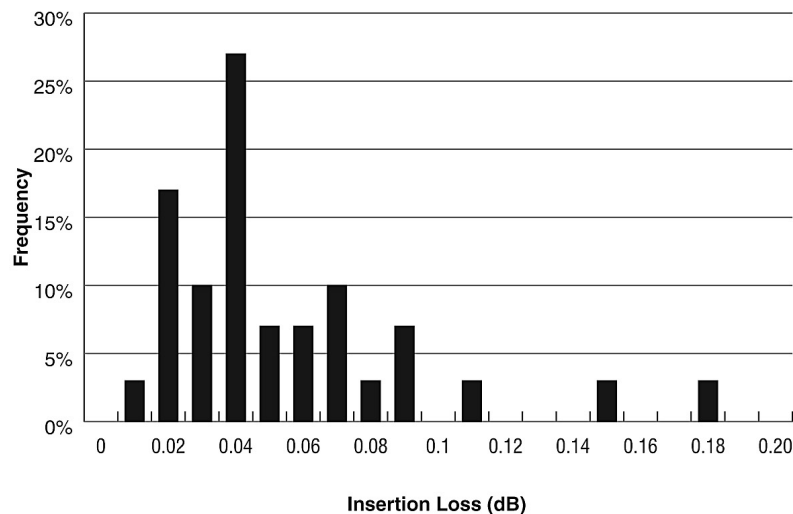
Network operators are understandably concerned about splice performance in harsh outdoor conditions and stability at temperature and humidity extremes. With millions of last mile connections at stake, this concern has been addressed directly by both mechanical splice and mechanical splice connector manufacturers and by Nye as the primary IMG supplier. Gels have been tested for moisture absorption under both high humidity and water immersion conditions. The previous section outlines tests that were completed under high heat and humidity conditions. In this section, we consider a worst-case scenario in which the gel is completely immersed in water.

This test measured the percent of light transmission (%T) through a 1cm path of IMG before and after seven days of immersion in de-ionized water at ambient temperatures. Table 4 [5], summarizes the results of this test at several wavelengths. Results show no significant change in %T.

**Table 4: IMG Water Immersion Test [5].**

<b>Wavelength (nm)</b>	<b>Change in %T after Immersion</b>
<b>850</b>	-0.27%
<b>1300</b>	0.03%
<b>1310</b>	-0.01%
<b>1490</b>	-0.13%
<b>1550</b>	-0.08%

One splice manufacturer [7] subjected fully assembled splice mechanisms to prolonged water immersion for thirty months (over 21,000 hours). The test utilized distilled water at room temperature. Insertion loss for each splice was measured with results indicating a maximum loss of less than 0.20 dB. Even after this prolonged immersion the splice exhibits essentially no change in performance. Measurements taken prior to the water immersion show the same maximum splice loss of less than 0.20 dB see (Figure 2).



**Figure 2:** Insertion loss distribution of water immersed splices (30 months)

These water immersion test results indicate that the IMG and the mechanical splice, even under extreme conditions, demonstrate performance that should be considered permanent in nature. From 1988 to 2003 this particular type of optical fiber splice accounts for over 8,000,000 installed units in the field.

## 6. FTTH Market

### 6.1 Industry Concerns About Mechanical Splice Technology

Doubts about mechanical splice limitations as a permanent last mile FTTH solution are often traced back to a 1994 BellCore paper [9] where experiments simulated splice techniques to track water intrusion. The paper hypothesized that splices may fail as a result of fluid migration specifically along the fiber/gel interface, or fluid diffusion through the gel. It is important to note that all of the experiments cited in the paper used simulated splices and not commercially available mechanical splice mechanisms. It is difficult to assess the true value of an analysis that does not include the actual technology in question.

BellCore technicians hypothesized that instances of submerged splice failures were due specifically to the progression of water into the fiber/gel interface. Their experiments were designed to allow observation of such migration. However, a closer examination of the data suggests that the procedures used actually allowed said migration. Though often cited in mechanical splice reliability objections, the BellCore testing does not directly address whether such migrations are in fact common. Nor does it address the actual nature of mechanical splices, which are designed specifically to prevent water intrusion.

BellCore's simulated splices were merely cleaved fibers inserted into glass capillaries with 5ml of IMG. This does not mimic the actual design of mechanical splice mechanisms, which use several patented strategies to isolate and protect splices.

Also it is important to note the amount of IMG used in the BellCore testing represents quantity of gel on the order of 5,000 times that which is used in a mechanical splice. This introduces the possibility that procedures used in the BellCore experiments may have been designed for the purpose of utilizing the proposed photographic analysis, rather than for reaching conclusions about splice failure.

Other problems with the test methodology include the use of a silicone sealant in conjunction with non-reactive silicone IMG. Silicone IMGs are highly inert. However combining an IMG with a chemically reactive silicone sealant compound could introduce unintended reactions such as crosslinking which would alter the consistency of both materials. This alone could potentially skew test results.

The BellCore study also suggests that the IMGs absorb water, causing insertion loss concerns. To determine how water ingress might affect the light transmittance of an IMG, Nye conducted an extremely aggressive test regimen [10]. Water was mixed directly into the gel at 10 parts per million, 100ppm and 1000ppm. The RI was measured before and after mixing. Results show a maximum variance of .0003, well within the specifications of all optical fiber and mechanical splice manufacturers, as shown in Table 5.

**Table 5:** IMG RI exhibits minimal change from the addition of water [10].

	<b>Refractive Index @ 25°C</b>
OC431A	1.4642
+ 10ppm water	1.4644
+ 100ppm water	1.4645
+ 1000ppm water	1.4645

## 6.2 Misinformation in Marketing

Recent marketing by a large Japanese conglomerate has suggested that mechanical splice techniques utilizing IMG have a limited life span and present exposure to a potential toxin. It is important to note that the distributed information is part of a marketing campaign for a more costly fusion splice solution. There are no documented or laboratory verified health hazards associated with silicone IMGs. This is a level of concern that is on par or below that of many commercially available household items such as detergents, plastics and even skin care products. Silicone is a highly inert material that does not readily combine with organic compounds.

The recent marketing also implies that mechanical splice technology cannot be used as a permanent solution due to the IMG component. However, independent testing by Swisscom, the company responsible for the entire national and international fixed network infrastructure of Switzerland, puts IMG service life on a much longer time scale. In their gravimetric analysis, using constant temperatures similar to real world conditions of 40°C, the IMG service life was calculated to be 203 years [11].

## 6.3 Why Fusion Splicing is a Concern in Last Mile Deployment

As the name suggests, fusion splicing superheats cleaved fibers, momentarily raising the temperature to molten levels causing the glass ends to fuse into a single span of optical cable. The splice is then heat-sealed with replacement cladding. The implied advantage to network designers is a “fix-it-and-forget-it” solution. However, in particular in last mile FTTH, fusion splicing does carry disadvantages. Economic and logistical concerns make fusion splicing as much an obstacle as a solution for network deployment.

First and foremost are the upfront costs. There is little debate in the industry that fusion splice technology carries a higher price tag than other FTTH drop options. High levels of training also compound the basic equipment costs. A power source is necessary, which may incur further expenses in terms of adequate current for the electric arc. By contrast mechanical splice techniques have similar tooling to traditional copper and coaxial lines. Existing labor pools can be tapped with limited transitional training and multiple crews can be equipped at with a cost comparable that of a single fusion splice system.

Purely from an economic interpretation, fusion splicing represents a return on investment (ROI) disadvantage. The higher initial cost does not translate into greater revenue. Nor, as this paper demonstrates, does it offer a level of reliability that differs significantly from mechanical splices and mechanical splice connectors. In the end customers do not pay monthly fees based on installation methods; drop costs therefore should be kept as low as possible to maximize network revenue. Furthermore the speed at which mechanical splices/mechanical splice connectors can be deployed vs. fusion splices means more subscribers are connected in a shorter time span translating into more revenue at a faster rate. As detailed in the May/June 2006 issue [12], of the online publication *lastMILE*, a major service provider reports a cable splice performance

success rate of almost 99.99% using mechanical splices. At the same time the company claims mechanical splices have reduced drop costs by approximately 20%.

Fusion splicing was designed for long-haul fiber infrastructure with deployment under relatively controlled and prepared conditions. Historically fusion splicing was not intended as a practical option for making a great number of connections over a wide area, which is the essential landscape of FTTH in North America. In addition wind, rain, humidity, high altitudes and some underground environments can introduce delays or entirely preclude fusion splicing. In contrast, mechanical splices/mechanical splice connectors are not hampered by these same limitations.

By its very nature FTTH installation demands a high degree of flexibility. Work conditions vary significantly from location to location and the rate of household conversion will be seemingly random from an installation perspective. Crews need ease of movement as much as a simplified drop technique. Mechanical splices or mechanical splice connectors reduce complexity on both counts.

Environmental conditions are another area where mechanical splicing techniques introduce simplicity. High humidity is suspected to be a cause of faults in failed fusion splices while potentially explosive vapors in underground areas pose a hazard to using any equipment that requires a superheated spark.

In general, technicians can install new drops or repair damaged lines in less time and in more varied environments with mechanical splicing than with fusion systems. FTTH customers typically depend on providers for all their voice, video and data transmissions and will be less tolerant of down time or delays, tilting the advantage again towards a faster, less complex splicing solution. Fusion splicing perhaps represents an ideal solution for long underground or undersea fiber cables, but it does not address the more nimble requirements for last mile FTTH network deployment.

#### **6.4 Mechanical Splice Acceptance and Success in Asia**

2007 estimates for FTTH subscribers in Japan is between 9 and 12 million, making Japan the current world leader in FTTH installation [1]. Japan has been experimenting with FTTH since 1978 [13], and the publicly reported target for FTTH installations in Japan is 30 million homes by 2010.

FTTH deployment in Japan, Korea and China utilizes a heavier reliance on mechanical splice technology for last mile build out than similar operations in the US. "Users in Asia report the technology meets performance standards, is less complex and faster than fusion splicing, and requires substantially lower capital investment." [2].

Mechanical splice technology has gained wide acceptance in this mature market. Japanese FTTH service providers have almost entirely eliminated fusion splicing, reporting that mechanical splice technologies have reduced capital investment by 90% and decreased installed costs by 50% while doubling the speed of making splices at drop sites. Perhaps most significant, installers report the only challenges to optimal mechanical splice performance are in fact the same challenges which confront fusion splice performance, namely a clean fiber cleave and the need for attention to cleanliness at the splice point [2].

Expansion of FTTH networks in Asia continues unabated. While numbers for the region as a whole are difficult to compile, new connections in Japan alone are estimated at more than 200,000 per month. The speed at which these networks are deployed owes largely to the reliance on affordable and relatively simple installation equipment, namely mechanical splice rather than fusion splice technology.

#### **7. Conclusions**

Rigorous tests on IMG performance demonstrate a stable and predictable material that should be considered as a permanent solution when incorporated in mechanical splice technologies. Fiber deployment is in a period of accelerated demand across North America, Asia and Europe. Keeping pace requires low cost, easily deployed, and highly reliable drop solutions. Mechanical splices deliver reliability, cost advantages, and adaptability to existing environments and labor skill sets. Repeated studies on mechanical splice mechanisms demonstrate the technology is resilient in outside plant conditions and offers long-term "permanent" performance. As a case study example the Japanese FTTH market shows mechanical splicing technologies can reduce tool costs by up to 90%, improve productivity by 50% and deliver a 50% reduction in the general cost of each FTTH cable drop. Concerns about mechanical splice mechanisms and IMG technology are based on outdated information. Mechanical splices and mechanical splice connectors have a successful decades-long track record in the telecommunications industry and represent a best-fit option for network designers and last-mile infrastructure contractors. Testing performed by Corning, Inc., 3M and Tyco Electronics support the conclusions presented in this paper.

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