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FM-1 Mode Scrambler



INSTRUCTION MANUAL

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Operation of FM-1 Mode Scrambler

1.1 Mode Scrambling

Light in an optical fiber communications system may have traveled several kilometers when it passes through a connector or splice or is measured by a detector. As the light travels this distance, the different fiber modes are attenuated at different rates, with the optical power in the higher-order modes decaying at a greater rate than the power in low-order modes. In addition, perturbations of the fiber waveguide, whether “intrinsic” (e.g. perturbations of the refractive index or core diameter) or “extrinsic” (e.g. deviations of the fiber from straightness), will cause light scattering and redistribution of the power among the guided modes of the fiber. This phenomenon is called mode coupling. Mode coupling also causes power transfer from higher-order guided modes to radiation modes, and is the reason that high-order modes experience greater losses than lower-order modes.

After a considerable distance, which can be kilometers in length, a power distribution develops in the fiber which is independent of the initial modal distribution caused by the light-launch conditions. The power in each mode remains constant with respect to the power in the other guided modes as the light continues to propagate down the fiber. This is the so called “stable distribution”.

The measured value of most fiber properties depends on the light distribution among the modes which is present in the fiber. This is important to remember when making measurements of fiber properties and of losses due to components, such as connectors and splices. For example, when measuring connector losses, high-order modes contribute more to the losses than low-order modes do. Therefore, if in the laboratory test set-up low-order modes are launched preferentially, lower losses will be measured than will actually occur when a connector is installed in the field. On the other hand, if high-order modes are preferentially launched, the measured losses will be higher than will occur in the field. Mode coupling to generate an approximation of the stable distribution from a low-order launch by coupling light among the guided modes is known as mode scrambling. The use of mode coupling to generate a stable distribution from a high-order launch by coupling light from high-order guided modes to radiation modes is known as mode filtering.

An optical power distribution which is independent of the launch conditions of the light can be achieved by propagating light through long lengths of fibers to ensure that a stable and repeatable mode distribution has evolved. The measurements will then reflect the properties of the fiber rather than the circumstances of the light’s launch. Since the length of fiber required depends on the degree of mode coupling within the fiber and may exceed several kilometers, increasing the mode coupling via external means can make fiber experiments easier and more practical.

Newport’s FM-1 Mode Scrambler uses a precision translation stage to press a short length of multi-mode fiber between specially designed surfaces that introduce microbending in the fiber. This dramatically increases coupling among the guided and radiation modes of the fiber. (The FM-1 is being used as a mode scrambler when low-order modes have been preferentially excited. It is being used as a mode filter when mostly high-order modes have been launched). The FM-1 repeatably achieves a stable modal distribution in the fiber without requiring kilometers of intervening fiber.

1.2 Using the FM-1

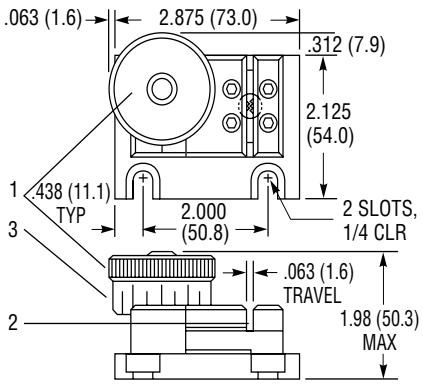


Figure 1
FM-1 Mode Scrambler

1. Place the FM-1 near the input end of the fiber. See Fig. 1.
2. Rotate the knob (1), counter-clockwise to fully separate the two corrugated surfaces.
3. Place the fiber between the corrugated surfaces and into the slot (2). No special preparation of the fiber is required; it is suggested that the fiber jacket be left on to protect the fragile glass fiber.
4. Rotate the knob clockwise until the corrugated surfaces just contact the fiber. Note the position of the knob on its graduated scale (3). Each major graduation represents a 25 µm change in the separation of the corrugated surfaces; the smaller graduations represent 12.5 µm displacements.
5. Most laboratory applications require 75 to 175 µm of displacement (three to seven major graduations) for adequate microbending and mode filtering (Some soft fiber jackets will require a brief stabilization period after the microbending displacement is set).

1.3 Mode Scrambler Theory and Design

The initial modal distribution in a fiber is determined by the characteristics of the launch conditions of the light into the fiber and can depart significantly from the stable distribution. For example, if the fiber is overfilled (launch beam NA > fiber NA and launch beam radius > fiber core radius), many high-order and leaky modes will be excited. On the other hand, only lower-order modes will initially be excited in an underfilled fiber (launch beam NA < fiber NA and small spot focused at center of core).

In most laboratory applications, it is much more practical to generate an approximation of the stable mode distribution by perturbing the fiber than to develop one in a long length of fiber. Microbending induces mode coupling by introducing a longitudinal perturbation of the fiber waveguide, quickly establishing a mode distribution mimicking the stable mode distribution.

In graded-index fibers, modes exist in groups with approximately the same propagation constant. The difference in propagation constant between nearest-neighbor mode groups is independent of the order of the group and is equal to

$$\Lambda\beta = \frac{2\sqrt{2\Delta}}{\mathrm{d}} \qquad (1)$$

where d is the fiber core diameter and is the fractional index difference between core and cladding. Mode coupling will be maximized when a longitudinal perturbation has a spatial period such that the principal Fourier component of its power spectrum equals $\Delta\beta$. This implies a spatial period

$$\Lambda = \frac{2\pi}{\Delta\beta} = \frac{\pi d}{\sqrt{2\Delta}} \qquad (2)$$

For typical graded-index communications fibers, d = 50 µm, and = 0.01. This yields $\Lambda = 1.1mm$.

The FM-1 has two microbend periods of 1.1 mm. This optimizes mode coupling in the most common multimode communications fibers (with core diameters of 50 and 100 µm).

1.4 Test Results

We tested the FM-1 under two different launch conditions. The modal distributions were obtained by scanning a detector across the near field images of the fiber ends.

First, a 100 µm-core graded-index fiber (Newport Model F-MLD) was underfilled (its low-order modes were excited) by using a microscope objective lens to focus the beam from a TEM_{00} HeNe laser on the center of the fiber core. Three modal distributions are given in Figure 2. The first curve (a) is the distribution caused by the launch condition with no externally induced mode coupling, the second curve (b) shows the result of a 100 µm microbend displacement by the FM-1, and curve (c) gives the theoretical distribution for a fully-filled launch (The curves are normalized to unity at their maxima). The scrambled mode distribution is seen to lie close to the theoretical fully-filled distribution, but fall away as we go to higher-order modes. This is a good approximation of the stable distribution.

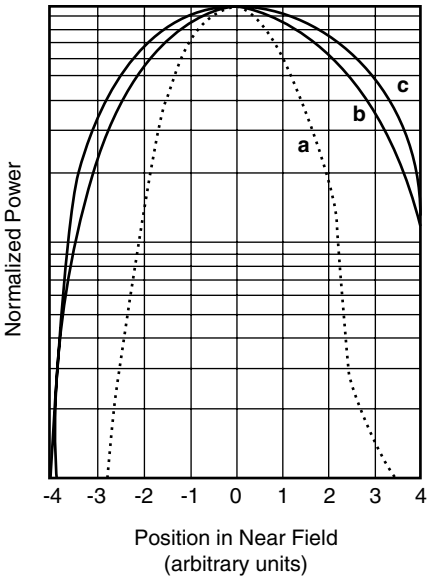


Figure 2

The second, overfilled, launch condition was achieved by first coupling power from a HeNe laser into a step-index plastic clad silica fiber with a NA of 0.4 and a core diameter of 200 µm. (A stable mode distribution is established in this fiber after only a few meters). The fiber was butt-coupled to a 50 µm-core graded-index fiber (F-MSD). Figure 3 shows the results of this experiment. The first curve (curve a) shows the input mode distribution, obtained without mode coupling, which is rich in high-order modes from the step-index fibers. A 175 µm microbending displacement by the FM-1 results in a mode distribution closely resembling the stable distribution (curve b).

Figure 4 illustrates that the microbending loss caused by the FM-1 is negligible for most applications. The curves show low losses for both 50 µm- (F-MSD) and 100 µm-core (F-MLD) fibers in both underfilled and overfilled launch conditions: the underfilled F-MLD fiber experienced less than 0.1 dB loss, while the overfilled F-MSD fiber had about a 2.3 dB loss. As expected, the overfilled fibers had higher losses than the underfilled fibers, since mode filtering removes light from high-order modes, while mode scrambling couples light from low-order modes to higher-order modes.

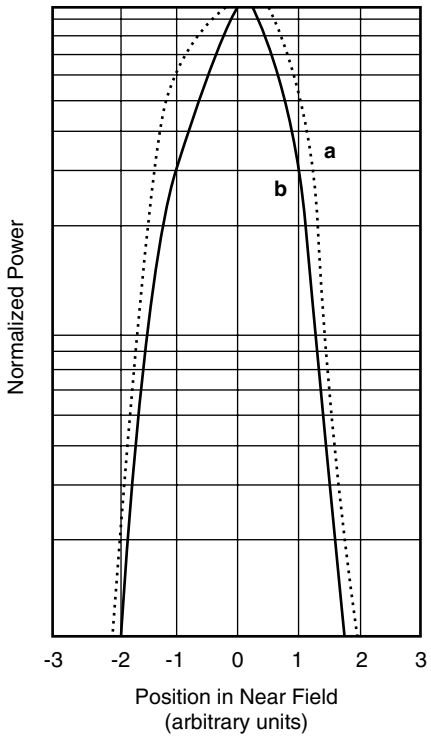


Figure 3

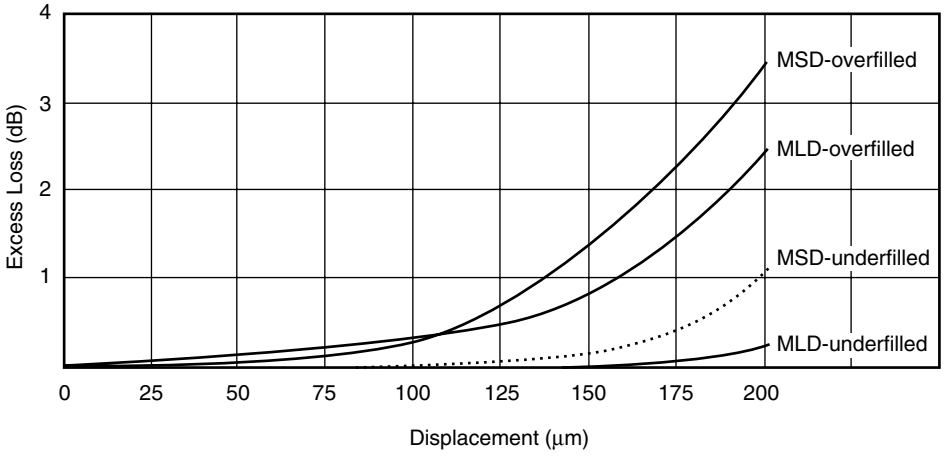


Figure 4

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