FIBERS

Simple testing methods give users a feel for cable parameters

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Mechanical as well as optical charcteristics play an important part in the design of optical-fiber systems. In particular, it's necessary for the designer to understand how to prevent mechanical stresses from breaking fibers or causing too much attenuation and how to check cable parameters like tensile strength, attenuation, and numerical aperture.

The risk of breakage is perhaps the major concern of the optical-fiber user, though the availability of cabled fibers has certainly made it less of a worry. Basically, fibers break under too heavy an axial load or when bent in too small a radius. The two breakage modes are related, and determining one breakage point sets the level for the other.

Stress levels

From the cross-sectional area of the fiber and the minimum safe bending radius, the maximum load bearing capability of an unjacketed, uncabled fiber can be calculated. Increasing a fiber's cross-sectional area makes it stronger but also, by increasing its radius, r, limits its minimum bending radius, R_{min}, before breakage. The relationship describing this tradeoff is:

$$S_T = E(r/R_{min})$$

where E is Young's modulus, typically 10^7 psi.

For an uncabled low-loss fiber, which consists of a core and cladding to protect the core material, a reasonable maximum tensile load-bearing level, S_T, is 50,000 pounds per square inch for about a 1-km length. The tradeoff of tensile strength with minimum safe bending radius usually limits the diameter of commercially available fiber to between 2 and 8 mils. A 3.5-mil uncabled fiber, for example, can be tied into a circle less than 3⁄16 inch in radius.

One common method of measuring the tensile strength of uncabled fiber is to clamp a length of fiber at both ends and measure the load needed to break the fiber. This method has the advantage of stressing the entire length of fiber between the clamps. Considerable care, however, is required to assure that clamping or misalignment of the clamps does not cause premature failure of the fibers under loading.

If the necessary stress-measuring equipment isn't available, an alternate approach yields usable data. In this method the fiber is tied into a simple overhand knot. Then, as the knot is tightened, the resulting circle is monitored. The minimum safe radius occurs just before the fiber breaks. From this value and the fiber radius the maximum tensile load-breaking ability of a fiber can be easily calculated from the above equation.

Cabling each fiber individually increases its load-bearing capability. At present, several materials are commercially available for cabling low-loss optical fibers in fiber-bundle, multi-fiber and single-fiber cables. Currently, single-fiber cables with diameters as small as 1/20 in. can withstand tensile load-bearing levels of 475 pounds—better than some multiple-fiber and fiber-bundle cables.

Besides fiber breakage, bends cause losses. They increase the attenuation by reflecting out of the fiber core some of the many light modes that should propagate within it. As these modes encounter a region of bends in a fiber, they enter the core-cladding interface at a larger angle than the one critical for total internal reflection.

The leakage becomes more pronounced as a fiber-core diameter increases or as numerical aperature decreases. But reducing the core diameter to minimize bending loss results in less light being coupled to the fiber—coupling efficiency being proportional to the square of the core diameter. Increasing the numerical aperture also decreases bending loss, but reduces the information-carrying capacity of an optical-fiber waveguide.

In general, commercially available, low-loss optical fibers with glass core and cladding have numerical apertures of between 0.1 and 0.3. Commercial fibers with higher values of numerical aperture have higher attenuation, which in the case of glass-core, plastic-clad fibers, increases drastically in humid or watery environments.

Flat finish

Optical polishing of fiber ends is used only for terminating fiber bundles (see p. 99 and p. 101). With single-fiber cable, cleaving the ends is fast and easy and all that's necessary. Properly cleaved surfaces are flat and perpendicular to the fiber axis and are well suited for coupling to sources and detectors or to other lengths of fiber.

The first step in cleaving a fiber end is to remove any cabling or jacketing material from 3 or 4 inches of fiber. Next the bare fiber is grasped at two points, about half an inch apart, between the thumb and forefinger of each hand. This half-inch section is held taut and gently drawn across the hard edge of a suitable scribing surface, such as a sapphire crystal, so as to scratch the glass fiber but not break it. Then a gentle tug will snap the fiber at the scratch. The fiber must be pulled straight without any bending.

The quality of the cleaved surfaces is then checked under a microscope. A good cleave also produces a circularly symmetric output light pattern when light from the fiber viewed on a screen about a foot away.

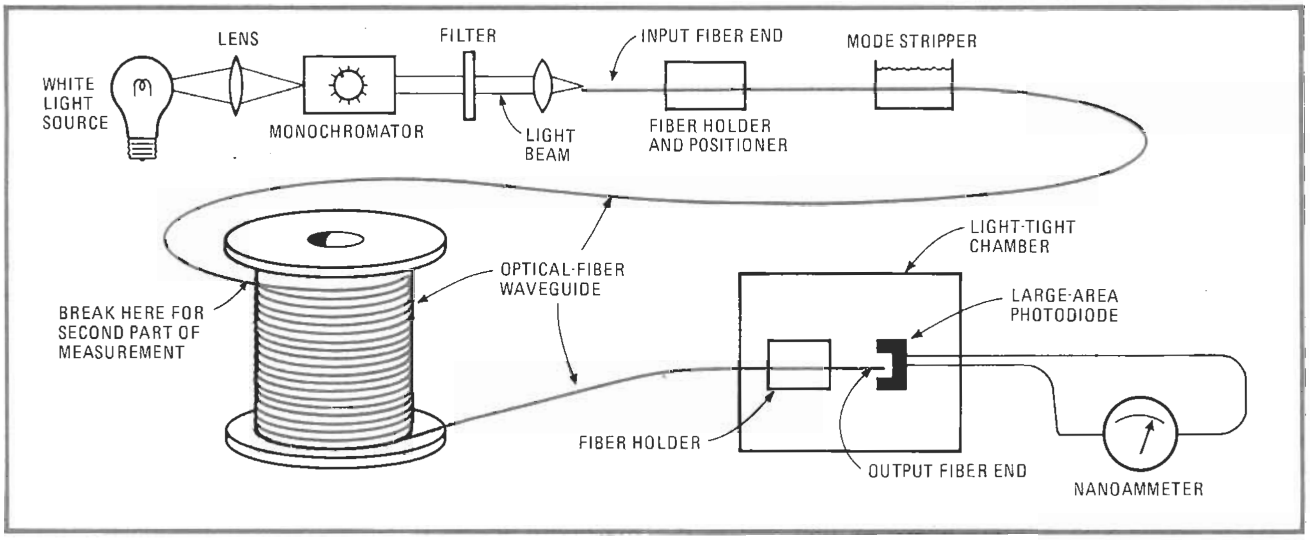
The cleaving technique works well for fiber diameters up to approximately 5 mils. Fibers with larger diameters must be bent around a mandrel and cleaved under tension. Simple instruments and tools for fiber cleaving are available commercially.

Looking for loss

Comparing the magnitude of transmitted light power at two points along a fiber waveguide eliminates the need for measurements of absolute optical power and light coupling efficiency. The typical setup shown in Fig. 1 makes it possible to determine the attentuation spectrum over an entire length of fiber.

Both ends of the entire length of optical fiber, L, to be evaluated are cleaved. One end is mounted in a movable holder, which is later adjusted to maximize the light input to it, and passed through a mode-stripping liquid placed near the input measuring point. Mineral oil or any other liquid with a refractive index close to that of the cladding (between 1.42 and 1.47) may be used. Doing this eliminates the unwanted "cladding" modes—those launched into the fiber because the numerical aperture of the input light beam is greater than the fiber's numerical aperture. This arrangment gives a fairly uniform illumination of all the desired fiber waveguide modes.

The other end of the fiber is placed into an output holder near a detector located in a light-tight chamber. The fiber holder at the input end of the length of cable is then adjusted to maximize detector current as read on the nono-ammeter, and the maximum amount of photodetector current for each wavelength of interest selected



1. Finding fiber loss. This test setup makes it possible to find the attenuation of a long length of fiber directly, without having to worry about measuring either the absolute optical power of the source or the efficiency of the light-coupling arrangement.

by the input monochromator is recorded.

To obtain a consistent set of maximum readings at the desired wavelengths, several readings must be taken, with the fiber being recleaved at the detector end after each reading to eliminate inaccuracies caused by bad cleaves, dust particles on he fiber end, etc. Isolated low readings will occur because of imperfectly cleaved fiber ends, and these should be discarded.

The fiber is then cut about 3 meters from the input end of the fiber without disturbing the positioning of the input end so that the same coupling is maintained. The cut end of the 3-meter-long section is then cleaved and placed into the output fiber holder. Again, measurements at other wavelengths of interest are repeated to obtain another set of consistent data. From these two sets of data, the attenuation, A, expressed in dB/km, of the entire fiber length less 3 meters is calculated for each wavelength:

$$A = (10 \log_{10} f)/L$$

where L is the final length of fiber in kilometers less the 3-meter section that was cut from the initial length of cable, and f is the ratio of the measured input optical power to the measured output optical power of any particular wavelength of light. For cables longer than several hundred meters, L can be assumed to be the initial cable length.

The numerical aperture of an optical fiber waveguide describes the maximum angle about the fiber axis through which light can propagate in the fiber. It is defined as the sine of the half-cone angle of the rays measured in air, and it generally varies with fiber length, because of fiber attenuation characteristics that modify the initial distribution pattern of the light.

Numerical-aperture measurement

Most manufacturers specify the numerical aperture of low-loss fibers by measuring the radiation pattern of a 3-meter-long fiber with all modes excited. This can be done simply and without elaborate equipment. The fiber is excited in the visible region, and the light emerging from the end is displayed on a screen placed several inches to a foot away. A solid circle of light is seen if all fiber modes have been excited; if not, a ring of light results.

Since the boundary of the circle of light is not perfectly sharp, some convention for determining the edge must be adopted. A common choice is the point where the light intensity is 10% of the maximum value. Actually the eye makes a good discriminator, and all that need be done is to measure the diameter or the circle of light with a ruler. Dividing that number by twice the distance from fiber end to the screen gives the value of numerical aperture.