Polarization Crosstalk in PM Fiber

Classification of polarization crosstalk by cause

Polarization crosstalk in a PM fiber arises from three principal causes. 1) Fiber axis misalignment at fiber connection interfaces, such as connectors or fusion splices, typically causes extremely localized, large-amplitude crosstalk. The amplitude depends on the misalignment angle. Examples are shown on the left side of Fig. 1. Fig. 1a shows crosstalk sources along a fiber, and Fig. 1b shows the resulting crosstalk measurement plot. 2) PM fiber imperfections, such as local birefringence variations, internal shape variations, or internal stress, cause polarization coupling that is generally small in amplitude and occurs gradually over a certain length of the PM fiber (see center section of Fig. 1). 3) External mechanical stresses on sections of the fiber, such as fiber bending, fiber crossing, fiber squeezing, or pressure on the fiber, can cause complicated composite crosstalk effects that can include polarization couplings that occur at sharp points in space, as well as some that occur gradually along a length of fiber, with varied amplitudes that depend on the stress orientations with respect to the slow axis and on the stress intensities, as shown in the right section of Fig. 1.

Classification of polarization crosstalk by measurement results

In general, the PXA-1000 distributed polarization crosstalk analyzer can accurately measure the strength of polarization crosstalk occurring at different locations along a fiber with a spatial resolution of a few centimeters. Although the causes of the crosstalk cannot always be identified from measurement results, educated guesses can be made based on the shape and strength of the measured crosstalk at each location. It is also feasible to classify the crosstalk based on the shapes of the measured curves, as discussed below.

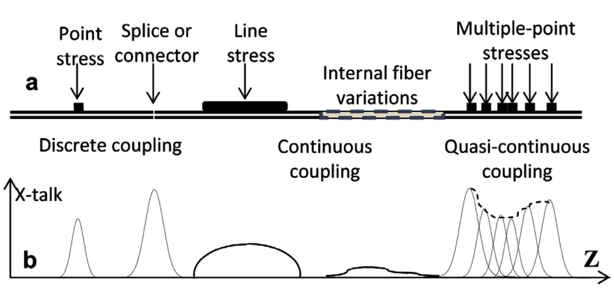
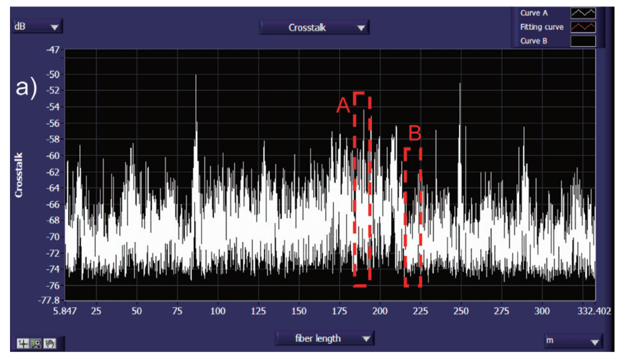


Fig. 1 Illustration of different types of polarization crosstalk. a) Different sources of polarization crosstalk. b) The resulting crosstalk peak profiles. Left: discrete polarization x-talk peaks induced by a point stress or a splice. Each such peak is a Gaussian curve with a shape determined by the coherence function of the light source. The spatial resolution is also determined by the width of the coherence function. Center: continuous polarization x-talk induced by a line stress and by internal fiber imperfections, respectively. Right: quasi-continuous x-talk induced by multiple densely packed stress points spaced on the order of or less than the resolution of the instrument.

1. X-talk caused by discrete polarization coupling points:

This category includes polarization coupling induced by a sharp stress, a splice point or multiple stress/splice points separated by distances much larger than the resolution of the measurement instrument, as shown on the left side of Fig. 1a. These types of discrete coupling result in sharp, distinct peaks in the x-talk measurement trace, with the width of the peak determined by the spatial resolution of the instrument, as shown in Fig. 1b. For this type of coupling, the peak x-talk value for each coupling point conveys useful information. The x-talk values listed in the table at the right of Fig. 2b result from such discrete coupling points.



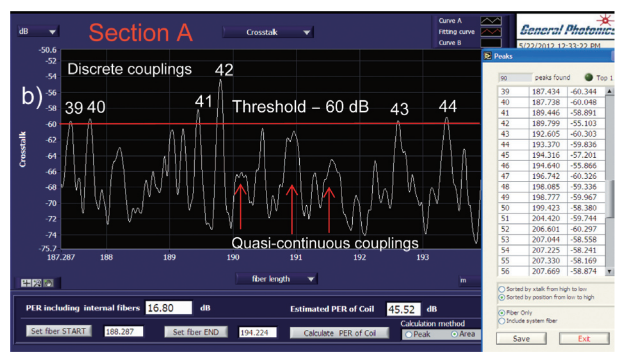
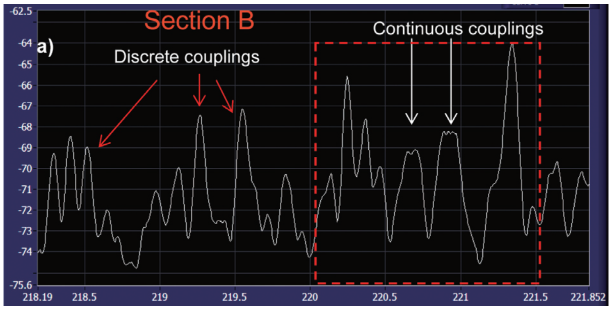


Fig. 2 a) X-talk measurement of a 340 meter long fiber coil. Two significant sections (labeled A and B) are marked. b) Closeup view of section A, showing both discrete and quasi-continuous coupling peaks. The table on the right of the screen lists the magnitudes of discrete x-talk peaks larger than -60 dB. Note that the shape and width of discrete x-talk peaks are determined by the coherence function of the light source.

2. X-talk caused by continuous polarization coupling:

This category includes polarization coupling that accumulates gradually over a section of fiber, induced by a line stress or by fiber internal imperfections, where the length of the affected section of fiber is comparable to or larger than the resolution of the measurement instrument, as shown in the center section of Fig. 1a. The crosstalk measurement result of such continuous coupling is a broad dome with a width and shape determined mainly by the length of the section of fiber under stress, as shown in Fig. 1b. In general, crosstalk caused by a section of imperfect fiber is very small in amplitude - on the order of -60 dB or lower. Because of this curve structure (low amplitude, wide peak), the peak x-talk value for crosstalk resulting from continuous polarization coupling is not meaningful. However, the cumulative coupling occurring in a section of fiber can be obtained by defining the starting and ending positions of the continuous-coupling section of fiber using the PXA-1000 software's cursors, as shown in Fig. 3. In this example, the cumulative value is -61.32 dB.



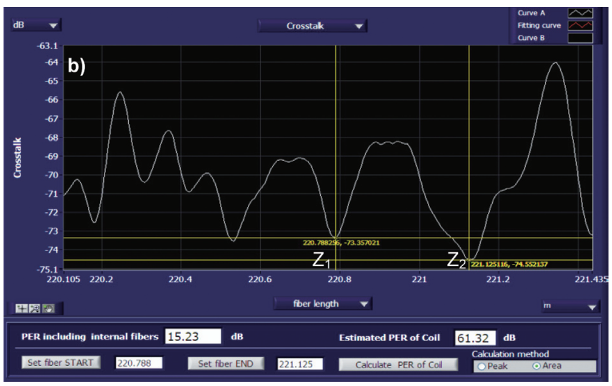
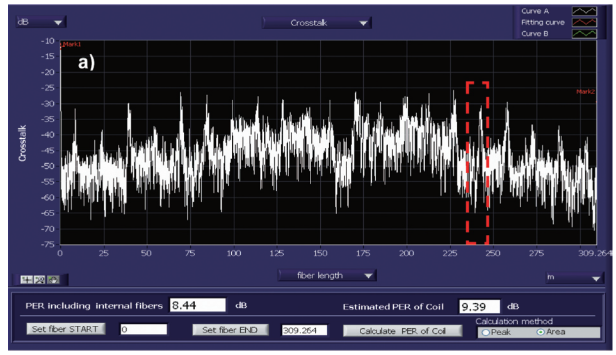


Fig. 3 a) Closeup view of section B of the x-talk measurement plot shown in Fig. 2a, in which two continuous or quasi-continuous x-talk peaks are identified. b) Cumulative x-talk value of a continuous/quasi-continuous coupling is obtained by setting the locations of cursors Z1 and Z2 and calculating the integrated PER of the corresponding fiber section. The resulting value, -61.32 dB, is shown at the bottom right of the screen.

3. X-talk caused by quasi-continuous coupling:

This category includes polarization coupling induced by multiple stress points spaced on the order of or less than the resolution of the measurement instrument, as shown in Fig. 1a. This type of polarization coupling appears in polarization crosstalk measurements as a broad composite peak with height variations, with a width and shape determined by the number of stress points, their relative positions, and their relative strengths, as shown in Fig. 1b. Quasi-continuous coupling cannot reliably be distinguished from continuous coupling. As in the case of continuous coupling, it is not meaningful to give a peak x-talk value for quasi-continuous coupling. However, the cumulative coupling occurring in a section of fiber can be obtained by defining the starting and ending positions of the continuous-coupling section of fiber using the PXA-1000 software's cursors, as shown in Fig. 4b.



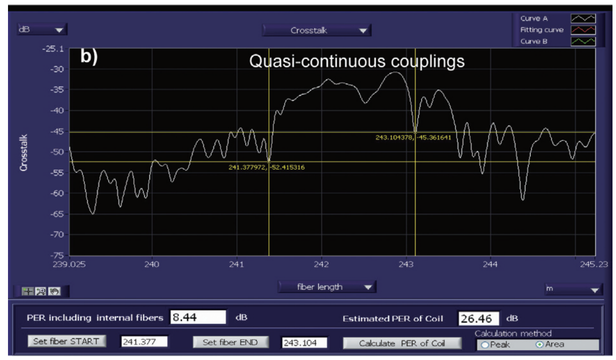


Fig. 4 a) X-talk measurement of a low quality PM fiber coil of length 309 meters. b) Closeup view of the boxed section in a), showing more detailed structure of quasi-continuous couplings. The cumulative x-talk of the region between the two cursors is -26.46 dB.

Capabilities and limitations of the PXA-1000

The PXA-1000 can take crosstalk measurements at spatial intervals of about 4-6 mm, much finer than the specified x-talk resolution of the instrument (on the order of 5 cm). The exact spacing between two adjacent data points is dependent on the birefringence of the fiber; it is defined as the ratio of the delay resolution of the variable delay line used in the PXA-1000 to the fiber birefringence. However, depending on the type of the polarization coupling, a given x-talk reading may not represent the true x-talk value at that point in space, as will be discussed below.

For X-talk induced by discrete polarization coupling points, the PXA-1000 is able to display the corresponding discrete x-talk peaks, to provide an accurate x-talk value for each x-talk peak, and to list in a table all peak values above a defined threshold, as shown in Fig. 2b. Note that each peak has a Gaussian shape corresponding to the coherence function of the light source used; however, only the peak value is meaningful and represents the x-talk value at the point in space at which the x-talk occurs. The other points on the Gaussian curve are due to the light source's coherence function and do not represent meaningful x-talk values for the corresponding points, as shown in Fig. 5. Note that the instrument's x-talk accuracy specification is based on measurement of the peak values of such discrete x-talk points.

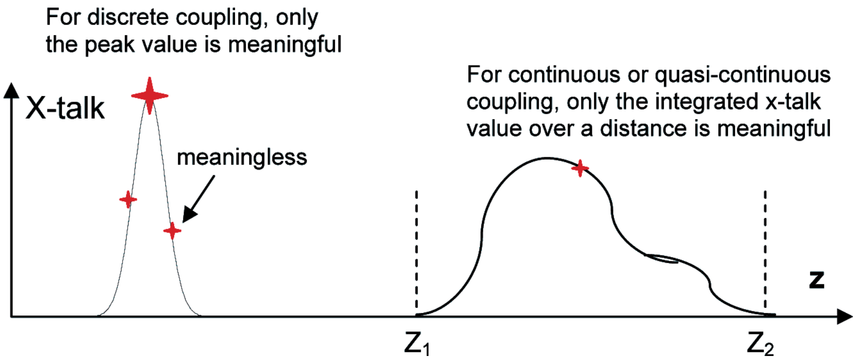


Fig. 5 Left: Illustration of a crosstalk peak caused by discrete coupling, with peak and off-peak values marked. The off-peak values are artifacts caused by the coherence function of the light source; they have no relation to real x-talk points on the fiber. Right: Illustration of a composite x-talk peak induced by continuous or quasi-continuous polarization coupling. A point on this curve does not correspond to a x-talk point on the fiber. In this case, only the integrated cross coupling between the points Z1 and Z2 is meaningful. Points Z1 and Z2 can be defined in the software interface.

For X-talk induced by the continuous or quasi-continuous coupling shown in Fig. 1, the x-talk value of any single point on the broad x-talk composite peak is not meaningful. The PXA-1000 is unable to give an accurate x-talk value for such a point, although the x-talk data file includes data points every 4-6 mm. For a x-talk composite peak caused by continuous or closely packed quasi-continuous coupling points, only the cumulative cross-talk value is meaningful, as shown in Fig. 3b and Fig. 4b. The PXA-1000's data display and analysis software, PolaXView, has a function that calculates the cumulative x-talk from point Z1 to point Z2, where Z1 and Z2 are defined by the locations of the cursors, as shown in Figs. 3b and 4b. In general, the distance between Z1 and Z2 should be much larger than the spatial resolution of the instrument in order to obtain an accurate result. In addition, the two points should also be chosen at valleys on the x-talk curve and the "Area" calculation method should be selected, as shown at the bottom right of Figs. 3b and 4b.

Note that the primary purpose of the PXA-1000 is to obtain accurate x-talk measurements of discrete x-talk peaks; the accuracy of a cumulative x-talk calculation is not guaranteed. However, the instrument records measurement data every 4-6 mm, and this data is available to users to optimize the calculation for specific cases where higher accuracy is required. Data is available to the user in two forms: the raw interferometer signal data as a function of the relative delay between the two arms of the interferometer ("Interferometer Only" data) and the x-talk data as displayed on the screen. The x-talk data is the raw interferometer data with the horizontal and vertical axes shifted according to internal position and x-talk references.