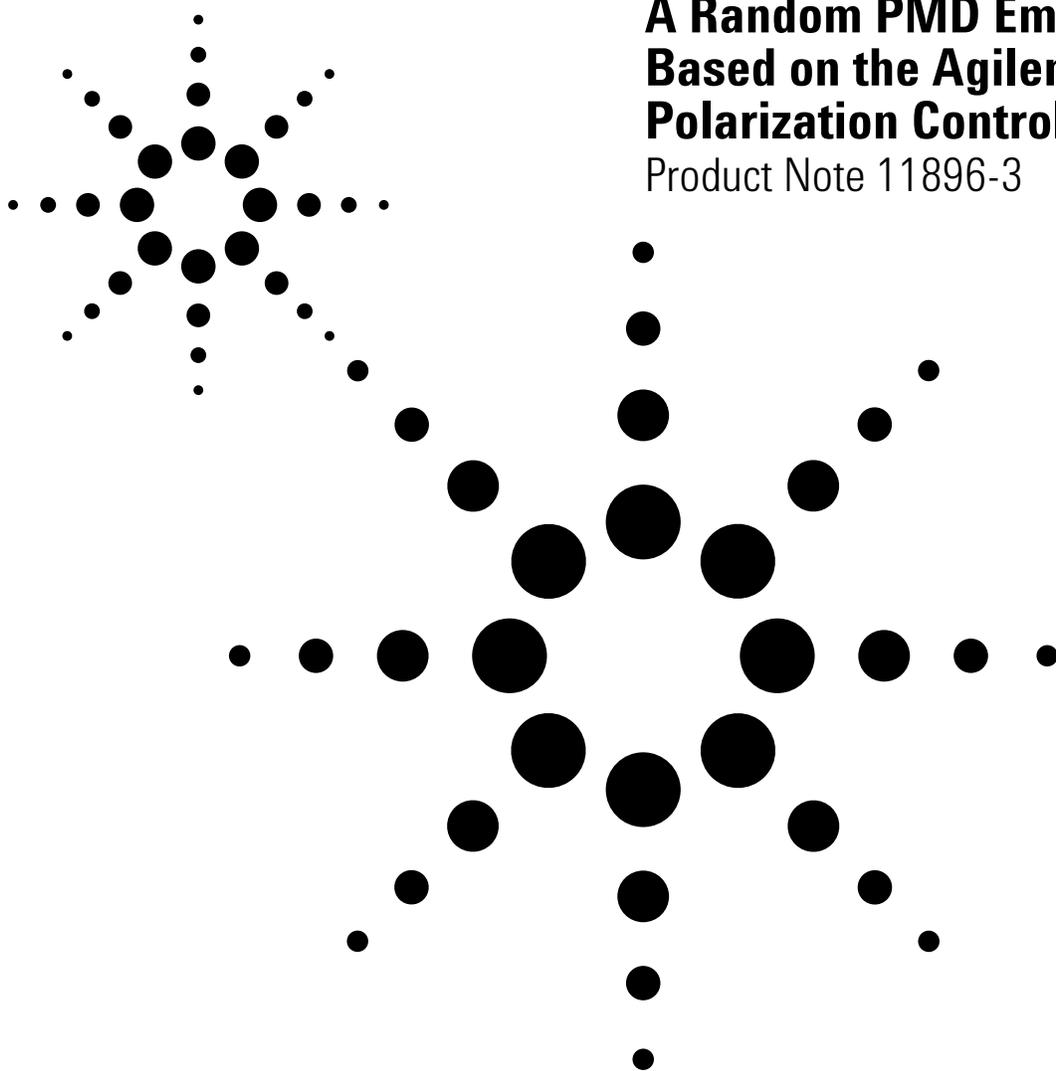


A Random PMD Emulator Based on the Agilent 11896A Polarization Controller

Product Note 11896-3



Introduction

This product note describes the random emulation of first- and second-order polarization-mode dispersion (PMD) using a setup consisting of multiple polarization maintaining (PM) fibers and Agilent 11896A polarization controllers. The use of PM fibers as the differential group delay (DGD) element has the advantages of economy and polarization stability. The polarization controllers allow step-wise or continuous random control of the PMD configuration to simulate, in accelerated fashion, the statistical behavior of PMD in a real communication link.

The need for realistic PMD emulation

Meaningful testing of PMD mitigation hardware requires a way of emulating the PMD of installed fiber links. The task would be easy if a long optical fiber could be modeled as a simple birefringence, but in reality a long optical fiber is best modeled as a concatenation of simple birefringent elements. The waves propagating in the fast and slow polarization modes of a given birefringent element decompose into the fast and slow modes of the following segment, as shown in Figure 1. This is called polarization-mode coupling, and it is a central aspect of fiber PMD. Occurring at hundreds or thousands of sites along the fiber, mode coupling makes PMD sensitive to environmental conditions, makes the differential group delay and principal states frequency dependent, and gives PMD its overall statistical character.

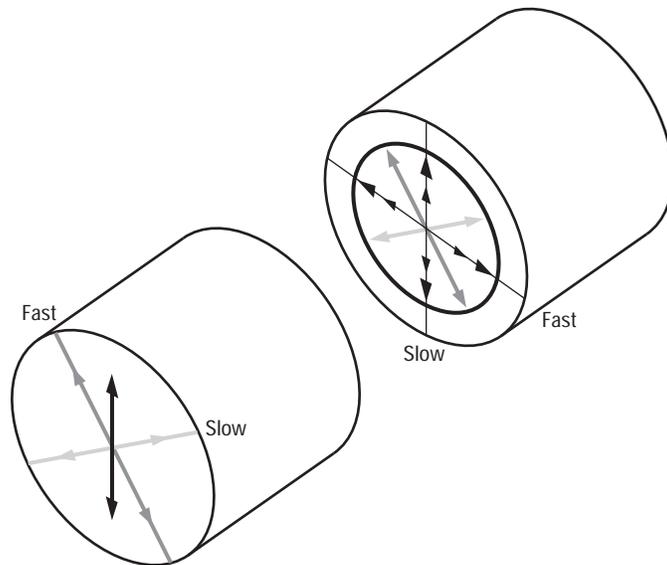


Figure 1. Model of polarization-mode coupling between birefringent fiber segments. At each equivalent fiber interface, the input wave decomposes into the polarization modes of the following segment.

This model suggests that long-fiber PMD can be convincingly emulated by concatenating multiple differential group delay elements and placing random polarization transformers at the interfaces between them.

A typical link contains many elements - fibers and components - that exhibit PMD. The total PMD is usually expressed as the average differential group delay (DGD) where the average is taken over a wide measurement wavelength range. The overall PMD can be estimated from knowledge of the mean DGD values of the constituent pieces by the RSS rule:

$$\text{Mean DGD} = \sqrt{\text{DGD}_1^2 + \text{DGD}_2^2 + \dots + \text{DGD}_N^2}$$

In the emulator application described here, multiple DGD elements are concatenated. Assuming that the DGD values of an N-element concatenation are nearly identical, the mean DGD expression simplifies to:

$$\text{Mean DGD} = \sqrt{N} \cdot \text{DGD}_{\text{element}}$$

Early PMD emulators

The simplest first-order PMD emulator is a length of polarization maintaining (PM) fiber, exhibiting a differential group delay in the range of 1-2ps/m. In recent years, adjustable first-order PMD emulators have become commercially available. One example of such an emulator is the polarizing delay line, involving a pair of polarizing beamsplitters in a split-and-recombine configuration. One of the parallel optical paths contains an optical line stretcher for adjusting the differential group delay. In some emulator applications, a pair of polarization scanners such as the Agilent 11896A is used before and after the first-order PMD emulator to simulate the random change of a link's polarization characteristics over time.

One drawback of motor-controlled, polarizing delay line PMD emulators is that the output polarization state of the emulator may be quite unstable due to mechanical vibration and temperature. This can be seen on the Poincare sphere display of the Agilent 8509C polarization analyzer as a noisy arc that evolves around the sphere in an erratic way as the temperature changes. The vibration-related instability may not be characteristic of an actual link. A second drawback is that using concatenated first-order emulators to emulate second-order PMD is very expensive. The PMD emulator described in this note avoids the vibration sensitivity problem.

Theory of operation of fiber coil polarization controllers

The 11896A polarization controller contains four quarter-wave fiber coils, each rotated by an individual stepper motor that in turn can be rotated manually (via the front panel knobs) or scanned automatically at various rates. In the random PMD emulator application, one 11896A is used before each PM fiber (DGD) segment.

The use of fiber coils to transform polarization is based on the fact that when single-mode fiber is bent into a loop, the resulting asymmetrical mechanical stress field sets up a linear birefringence through the stress optic effect. The input light decomposes into the fast and slow waves of a coil as shown in Figure 2.

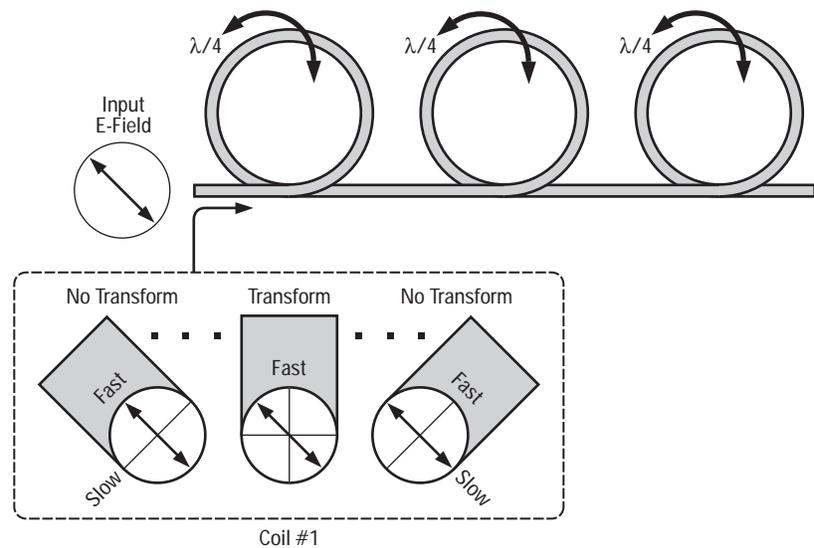


Figure 2. Fiber coil type of polarization controller. Coiling the fiber induces fast and slow linear polarization modes. The input wave decomposes into these modes. Tilting a coil changes the decomposition, and thus the polarization transformation. The process repeats at each coil.

In the configuration shown, each coil creates a phase shift of approximately a quarter wave. Rotating a given coil about its tangential pivot point changes the decomposition of the input wave into the fast and slow modes, thereby changing the polarization transformation produced by the coil. The process repeats for each coil.

The 11896A can be adjusted manually or automatically. In the automatic mode, the individual fiber coils are rotated back and forth at non-harmonically related speeds to randomly change the polarization transformation. The overall speed of this process is adjustable over a wide range (scan rate settings are 1-8 in arbitrary units).

The Agilent 11896A is especially well suited to the emulator application because its fiber coil-type design exhibits less than ± 0.002 dB of insertion loss variation over all polarization transformations. Thus, the optical signal level remains nearly constant, allowing the user to better isolate link PMD effects. In addition, the path is entirely fiber, so this technique does not suffer the short-term polarization jitter found in polarizing delay line emulators.

Emulator setup and operation

The randomizing PMD emulator setup is shown in Figure 3. The DGD elements may be PM fiber patch cords or lengths of PM fiber spliced into single-mode fiber jumpers.

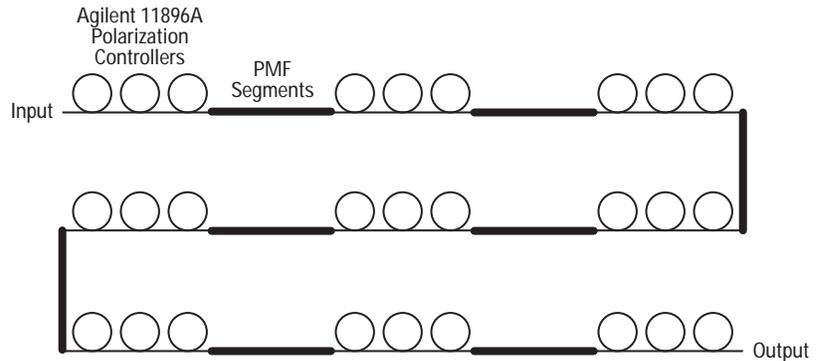


Figure 3. Schematic of randomizing PMD emulator

Assuming N DGD elements having nearly identical DGD values, the expression for the mean DGD simplifies to:

$$\text{Mean DGD} = \sqrt{N} \cdot \text{DGD}_{\text{PMF segment}}$$

A journal article by R. Khosravani et al., referenced at the end of this application note, provides a discussion of the performance of emulators with different numbers of segments. The authors conclude that 15 PM fibers would yield the Maxwellian DGD distribution expected from highly mode coupled fiber. However, if a Maxwellian distribution of DGD values is not required, the number of pairs can be greatly reduced.

The emulator described in this product note can be operated in stepped or swept modes. The step mode involves randomizing all of the polarization controllers for 2 seconds at a scan rate of 8, then stopping the scan. This results in a new, randomly selected PMD emulation (a new fiber PMD representation).

The swept mode involves setting the polarization controllers in the automatic scan mode at a desired scan rate.

Further reading

R. Khosravani et al., Time and frequency domain characteristics of PMD emulators, *IEEE Photonics Technology Letters*, vol.13, no.2, p.127, February 2001.

D. Derickson, *Fiber Optic Test and Measurement*, Prentice Hall, New Jersey, 1998, Chapters 6, 12.

Agilent Product Note 11896-2 (go to <http://www.agilent.com/comms/lightwave>, enter 11896A in the Quick Search box, and go to Library link).

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