Polarization-Induced Fading in Fiber-Optic Sensor Arrays

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Abstract— The statistics of polarization-induced visibility fading is studied for fiber-optic interferometric (Michelson or Mach-Zehnder) sensor arrays made of either regular single-mode fibers or polarization-maintaining fibers. Performance is measured in terms of the probability to observe visibilities, all of which exceed a given value, for all members of the array. Very poor performance is obtained for arrays made of nonpolarization maintaining fibers, unless the input state of polarization is dynamically controlled to optimize the visibility of the worst sensor of the array. While the use of the more costly polarization-maintaining fibers could, in principle, solve this polarization-related fading problem, finite extinction ratios of couplers and splices make the performance of such arrays comparable to that of nonpolarization maintaining arrays with optimally controlled input polarization.

I. INTRODUCTION

MICHelson or Mach-Zehnder type interferometric fiber-optic sensors and sensor arrays are being tested and used in an increasing number of applications, e.g., hydrophones, magnetometers etc. [1], [2]. Out of the many issues to be addressed in order to ensure proper optimal operation, this paper deals with the statistical characterization of polarization-induced fading in such arrays [3].

In a two-beam fiber-optic interferometric sensor, Fig. 1(a), the physical measurand affects the output intensity according to [1]

\[ I_{\text{out}} \propto 1 + V \cos(\Phi) + \text{Additive Noise} \]  \hspace{1cm} (1)

\( \Phi \) is the phase difference between the two arms and \( V \) is the visibility or the contrast of the interference fringes. Clearly, \( V \) should be maximized to increase sensitivity and s/n. But even after the coupling ratios of the splitting and combining couplers are appropriately optimized, \( V \) is still bounded by the relative parallelism of the states of polarization of the interfering waves, as expressed by the scalar product

\[ V \propto |P_{\text{Sig}}(t) \cdot P_{\text{Ref}}(t)|, \]  \hspace{1cm} (2)

where \( P_{\text{Sig}}(t) \) and \( P_{\text{Ref}}(t) \) are the time-dependent unit-intensity polarization Jones vectors [1a], [4] of the output SOP's of the sensor signal and reference arms, respectively. Thus, no fringes can be observed when the SOP's emerging from the two sensor arms are orthogonal. In sensors, which use conventional low birefringence fibers and fiber components, environmental effects on the down-lead fiber, as well as on the arms fibers, will continuously change the polarization transformation properties of the various fiber segments. Thus, \( P_{\text{Sig}}(t) \) and \( P_{\text{Ref}}(t) \) will vary with time, resulting in time-dependent polarization-induced fading (PIF) of the visibility \( V \) [5]. This environmentally-induced PIF is a major operational problem to be addressed as remote multielement sensor arrays advance into practical applications. Indeed, quite a few schemes have been proposed to completely alleviate or at least reduce the fading. These include: 1) adjustment of the sensor arms to produce parallel output SOP's (a solution which obviously requires access to the sensor itself); 2) polarization scrambling at the input, which solves the stability issue at the expense of less than optimal visibility [6]; 3) the simultaneous use of three polarizers [7], angularly spaced by 120° at the sensor output. Here, the channel with the highest \( V \) is selected, complete fading is always avoided but the detection system is more complicated; 4) the inclusion of a single output polarizer with active birefringence manipulation in the output fiber lead [8] (the last two methods may introduce bias phase noise [6], [9]; 5) the use of orthoconjugate (Faraday) mirrors to compensate for any polarization variations slower that...
the time of travel of light in the interferometer arms [10].
This approach, which uses relatively expensive non all-fiber
components, is very effective but its validity is limited to
Michelson type sensors, where the light retraces its journey to
and back from the mirrors; 6) polarization switching [11]; and,
finally, 7) proper choice of the SOP of the input light which
can completely overcome the PIF penalties in a single sensor
[12], although careful monitoring of the drifting polarization
state of the sensor itself is an obvious prerequisite [12]. Being
very suitable to all-fiber remotely-interrogated interferometric
sensors, where sensors cannot be accessed once the system
is installed, this last method of using an optimal SOP was
recently applied to sensor arrays and it has been shown that
for both serial and parallel arrays with N sensor elements,
the worst sensor will
always perform.

Theoretically, polarization-induced fading could be com-
pletely eliminated, if polarization-maintaining (PM) fibers
and components [1a] could be used along with perfectly
aligned polarized sources. In practice, though, polarization
maintenance is never perfect, especially in splices and
directional couplers. Section III analyzes the PIF phenomena
in interferometric sensors and sensor arrays built from
polarization-maintaining fibers and compares their perform-
ance with the visibility values expected from ordinary
nonpolarization-maintaining single mode sensors.

II. PERFORMANCE OF SENSOR ARRAYS
WITH AN OPTIMIZED INPUT SOP (REGULAR FIBERS)

In this section we study the performance of sensor arrays,
comprising N individual sensors, with observed visibilities
\(V_j, j = 1 \cdots N\) for a given input SOP. Through a proper
choice of the input SOP, the aim is to maximize the probability
that the lowest observed visibility exceeds a given value \(V_o\),
i.e., to maximize
\[
P(V_{min} \geq V_o) = \text{Probability that } V_{min}
\]
\[
(= \min_j V_j, j = 1 \cdots N) \text{ exceeds } V_o.\]

The corresponding ensemble space contains all possible re-
alizations of the polarization transformation properties of the
various fiber segments.

A. A Single Sensor with or without Control Over Its Input SOP

In the sensor of Fig. 1, the original input SOP, \(P_{in}\), is
modified by the down-lead fiber to become \(R_{i} \cdot P_{in}\). (In
Jones calculus, \(R_{i}\) and \(P_{in}\) are represented by a 2 \(\times\) 2
matrix and 2 \(\times\) 1 vector, respectively and \(R_{i} \cdot P_{in}\) stands
for a matrix vector product.) Polarization-wise, Fig. 1(b) is
equivalent to its simpler representation of Fig. 1(c) [12],
so that the signal arm passes the modified SOP, \(R_{i} \cdot P_{in}\),
without change but the reference arm transforms it to become
\((R_{i}^{-1}R_{f}) \cdot (R_{i} \cdot P_{in})\). On the Poincare sphere [1a], [16],
Fig. 3(a), the modified SOP, \(R_{i} \cdot P_{in}\), is denoted by \(C_{inp}\),
and the transformation \(R_{i}^{-1}R_{f}\) is represented by a rotation
(of size \(\Omega\)) around the drawn diameter, the two tips of which
are the eigen-polarizations of the transformation \(R_{i}^{-1}R_{f}\). (In
Jones calculus representation, the angle of rotation, \(\Omega\), is
the difference between the phases of the two complex numbers
representing the eigen-polarizations of \(R_{i}^{-1}R_{f}\).) Thus, \(C_{inp}\)
is transformed to \(C_{out}\) and the visibility is given by \(V = \cos \eta\),
where \(2\eta\) is the angle subtended between the radius
vectors \(OC_{inp}\) and \(OC_{out}\), see Fig. 3(a). Over time (or
over the ensemble of possible realizations), and even for
a given \(P_{in}\) both \(C_{inp}\) (i.e., \(R_{i} \cdot P_{in}\)) and the diameter
(and \(\Omega\)) corresponding to \(R_{i}^{-1}R_{f}\), drift independently over
the Poincare sphere, resulting in a drifting \(\eta\) and a drifting
visibility. Using geometrical considerations on the Poincare
sphere, and assuming uniform distributions of the relevant
parameters, Stowe et al. [3] derived a simple expression for
\(P(V \geq V_0)\) for the case of a given input SOP and a randomly
drifting (in the polarization sense) interferometer
\[
P(V \geq V_0) = 1 - V_o^2.\]

Thus, the probability that \(V \geq 0.5\) is only 0.75. However,
for any possible realization of the polarization transformation
properties of the sensor, one can always choose the input
SOP as one of the two eigen-polarizations of \(R_{i}^{-1}R_{f}\). Since
\(R_{i}^{-1}R_{f}\) does not modify such an SOP, the signal and reference
SOP's emerge parallel and \(V \equiv 1\). Some means must be
provided for the continuous tracing of the temporal changes
of \(R_{i}^{-1}R_{f}\) and a technique for the remote determination of
\(R_{i}^{-1}R_{f}\) was described in [17].

B. Sensor Arrays with and without Control Over the Input SOP

Two typical array configurations are shown in Fig. 2. Since
it has been shown [13] that polarization-wise these two con-
figurations are equivalent, we deal here only with the parallel
case, where the input SOP to any of the sensors does not

\[
\begin{align*}
R_1 & \quad \ldots \quad R_N \\
S_1 & \quad \ldots \quad S_N
\end{align*}
\]
The lowest observed visibility, $V_{\text{min}}$, will exceed $V_0$, only when each of the individual visibilities exceeds $V_0$, i.e., $V_j \geq V_0, j = 1 \cdots N$. Since the sensors are independent and share the same statistical properties, see (5) at the bottom of this page.

This probability, $P_{\text{array}}(V_{\text{min}} \geq V_0)$ for a fixed (though arbitrary) SOP and for several values of $N$ is shown in Fig. 4. For a given $V_0$, the probability $P_{\text{array}}(V_{\text{min}} \geq V_0)$ drastically decreases with increasing $N$ to practically intolerable values.

On the Poincare sphere, each realization of the random polarization properties of the parallel array of Fig. 3(b) can be represented as a set of $N$ diameters and angles of rotation, $\{D_j, \Omega_j, = 1 \cdots N\}$, where the two tips of $D_j$ correspond to the two eigen-polarizations of the $j$th element. The individually observed visibilities, $\{V_j, j = 1 \cdots N\}$, as well as their minimum, depend on the choice of the input SOP, $C_{\text{inp}}$. By scanning the surface of the Poincare sphere (through calculations), one can easily locate that optimal SOP which maximizes $V_{\text{min}} = \min_j(V_j, j = 1 \cdots N)$. To calculate the visibility statistics when the input SOP can be controlled, a simulation was used. For each array size, $N$, the diameter directions and values for the various $\Omega$'s were randomly drawn to form a large (1000) ensemble of uniformly distributed array realizations. For each array, the optimal input polarization was located together with the corresponding minimum visibility. Fig. 4 shows the simulation-based results for $P_{\text{array}}(V_{\text{min}} \geq V_0)$. For the same number of sensor elements $N$ the performance of the array with the optimal input SOP is much better. Moreover, unlike the monotonic decrease of $P_{\text{array}}(V_{\text{min}} \geq V_0)$ with $V_0$ for the case of a fixed SOP, an optimal choice of the input SOP results in $P_{\text{array}}(V_{\text{min}} \geq V_0) = 1$ for all

\[
P_{\text{array}}(V_{\text{min}} \geq V_0) = P_1(V_1 \geq V_0) \cdot P_2(V_2 \geq V_0) \cdots P_N(V_N \geq V_0)
\]

\[
= \prod_{j=1}^{N} P(V_j \geq V_0) = \left( 1 - V_0^2 \right)^N.
\]
values of $V_0$ below an $N$-dependent threshold $V_N$. In other words, if $V_0 \leq V_N$, then visibility values exceeding $V_0$, can be guaranteed with probability one. Following the results of [13], [14], $V_N = \sin(\pi/2N)$, which obviously decreases with $N$. Indeed the optimal SOP curves of Fig. 4 support these claims: when $N = 1$, $P(V_{\min} > V_0) = 1$ for all values of $V_0$, or $V_{N=1} = 1 = \sin(\pi/(2 \cdot 1))$. When $N = 2, V_{N=2} \approx 0.707 = \sin(\pi/(2 \cdot 2))$. However, as $N$ increases, the departure of $P_{array} (V_{\min} \geq V_0)$ from its unity value becomes slower and slower. Thus, in spite of the fast decrease of $V_N = \sin(\pi/2N)$ with $N$ ($V_{N=10} \approx 0.16$), the probability of exceeding a visibility of 0.6 for a 10-element sensor array is higher than 80%. It appears, therefore, that in system designs based on statistical criteria (rather than on an absolute lower bound of the observed visibility), dynamically optimal control of the input SOP may be an attractive approach for moderately long arrays.

III. SENSOR ARRAYS WITH POLARIZATION-MAINTAINING (PM) FIBERS

Here [18] we analyze the performance of interferometric sensors and sensor arrays built from polarization-maintaining fibers, having nonideal polarization maintenance properties. Again, performance will be studied in terms of the probability that the observed visibility exceeds a given value. Comparison will then be made with the performance expected from ordinary nonpolarization-maintaining single-mode sensors.

A. An Ideal Polarization Maintaining Interferometer with Nonideal Inputs

Referring back to Fig. 2, we now assume that each sensor is made of ideal polarization maintaining fibers and couplers with perfect relative alignment. Here, the sensor comprises the input and output couplers, as well as the signal and reference arms. The launched SOP into the sensor is obviously $R_i \cdot P_{in}$, which includes the polarization transforming effects of the down-lead fiber. Such a polarization maintaining interferometer is in fact equivalent to two independent, though slightly different, fast and slow single-polarization interferometers. Linearly polarized light parallel to the fast (or slow) axis of the PM fiber will maintain its SOP through the splitting and combining couplers, and the reference and signal waves will emerge with a relative phase of $\Delta \Phi_{fast} + \Delta \Phi_{signal}$ (or $\Delta \Phi_{slow} + \Delta \Phi_{signal}$), where $\Delta \Phi_{fast}$ (or $\Delta \Phi_{slow}$) is related to the optical path-length difference, $\Delta L_{fast}$ (or $\Delta L_{slow}$) between the reference and signal arms as experienced by light polarized parallel to the fast (or slow) axis and $\Delta \Phi_{signal}$ is the signal-induced phase difference. The difference $\Delta \Phi_{fast} - \Delta \Phi_{slow}$ depends on the birefringence of the fiber, as well as on the environment, and its variations can easily exceed $\pi$ for modern PM fibers with a beat length of only few millimeters [1a].

Clearly, when any such sensor is fed with linearly polarized light parallel to either axis of the fiber, the outputs from the two sensor arms will emerge from the combining coupler with parallel polarizations, resulting in maximum visibility. But these ideal launch conditions cannot be guaranteed. The downlead fiber is long and even a polarization maintaining fiber has only a finite extinction ratio [1], e.g., 15–20 dB · km, so that linearly polarized light launched parallel to either the fast or slow axis of the down-lead fiber will reach the more remote sensors of the array with an elliptical SOP. The situation is only aggravated when the down-lead fiber comprises a few PM sections spliced together with nonideal splices. Now, both single-polarization interferometers will be excited and the total output intensity is given by

$$I = I_{fast}(1 + \cos(\Delta \Phi_{fast} + \Delta \Phi_{signal})) + I_{slow}(1 + \cos(\Delta \Phi_{slow} + \Delta \Phi_{signal}))$$

where $I_{fast}$ and $I_{slow}$ are the launched intensities into the fast and slow axes of the sensor, respectively. When $\Delta \Phi_{fast} - \Delta \Phi_{slow} = 0$, the visibility is unity. Otherwise, lower visibilities are obtained, e.g., if $\Delta \Phi_{fast} - \Delta \Phi_{slow} = \pi$, the visibility drops to $I_{fast} - I_{slow} |I_{fast} + I_{slow}| < 1$. We, therefore, conclude, that nonideal launch conditions affect the visibility, and in view of the statistical variations of $\Delta \Phi_{fast} - \Delta \Phi_{slow}$, it is useful to determine the probability distribution function of the observed visibility and compare it to previously obtained results.

Referring to the Poincare sphere of Fig. 5, we assume the principal axes (the fast and slow ones) of the PM fibers of our ideal sensor to correspond to the $S_1$ diameter of the sphere. Again, $C_{inp}$ denotes the input SOP. Since the eigen-polarizations of the PM fiber lie at the two tips of the Fast-Slow diameter, the polarization transformations imposed by the reference and signal arms are equivalent to rotations, $\Omega_{ref}$ and $\Omega_{sig}$, around this diameter, and both output SOP's, $C_{ref}$ and $C_{sig}$ are to be found on the same circle together with $C_{inp}$. This conclusion is consistent with the fact that the ratio $I_{slow}/I_{fast}$ is preserved for light propagation through PM fibers. In fact, the angle, $\theta$, subtended by the common circle, is related to $I_{slow}/I_{fast}$ by $\theta = \pi \arctan(I_{slow}/I_{fast})$. We further assume that the angular difference between the two output SOP's, $\Omega(= \Omega_{sig} - \Omega_{ref})$, is uniformly distributed in the range $[-\pi, \pi]$, so that the probability density function for $\theta$ is

![Fig. 5. A Poincare representation of an ideal polarization-maintaining Mach-Zehnder type sensor. However, the input SOP, $C_{inp}$, does not necessarily coincide with either the fast or slow axes.](image-url)
Fig. 6. A polarization maintaining single sensor: $P(V \geq V_0)$ for various values of the extinction ratio $-10 \log (I_{slow}/I_{fast})$. The numbers in parentheses denote the angle between a launched linearly polarized light and the fast axis, such that the extinction ratio has the corresponding value in dB. More generally, the results apply to any input SOP with the given extinction ratio. Also shown is $P(V \geq V_0)$ for the nonpolarization maintaining fiber, (4).

$$\Omega$$

$$f_\Omega(\Omega) = 1/2\pi \quad \Omega \in [-\pi, \pi].$$

(7)

The visibility $V$ is given by [5], [16]

$$V = \cos(\frac{1}{2} \text{Angle}[C_{\text{ReI}} CO_{\text{Sig}}]) = [1 - \sin^2 \theta \sin^2(\Omega/2)]^{1/2}.$$  

(8)

Following standard procedures [19], the probability density function of $V$, $f_V(V)$, can be derived from (7) and (8) to give

$$f_V(V) = \begin{cases} 
\frac{2V}{\sqrt{(1-V^2)(V^2-\cos^2\theta)}} & V \in [\cos \theta, 1], \\
0 & \text{otherwise}
\end{cases}$$

(9)

Finally, the probability that $V$ exceeds $V_0$ can be analytically derived as

$$P(V \geq V_0) = 1 - \int_0^{V_0} f_V(V) dV = \frac{2}{\pi} \arcsin \frac{\sqrt{1-V^2_0}}{\sqrt{1-\cos^2 \theta}}.$$  

(10)

Fig. 6 shows $P(V \geq V_0)$ for various values of the extinction ratio $-10 \log (I_{slow}/I_{fast})$. Also shown is $P(V \geq V_0)$ for a regular non-PM sensor. Clearly, even when fed with an elliptical SOP, a sensor made of perfect PM fibers and components is statistically superior (visibility-wise) to a non-PM one, as long as $I_{slow}/I_{fast}$ of the input SOP is not too close to unity.

Thus, even for an ideal polarization-maintaining sensor, nonideal launch conditions at the sensor input coupler may result in a degraded $P(V \geq V_0)$, which was shown to depend on the input SOP through the ratio of its intensities parallel to the two principal axes of the sensor ($I_{slow}/I_{fast}$).

**B. Numerical Investigations of Sensor Arrays with Imperfect Couplers and Splices**

Fig. 7 shows a blowup of one PM sensor from the parallel array of Fig. 2(b), detailing the relevant couplers and all fiber splices (marked by $\times$) involved in the assembly of the array. All in all, each sensor involves 4 couplers and 10 splices. The SOP of the light launched into the down-lead fiber is aligned to excite just one of the two polarization modes of the PM fiber. While propagating through the system, the initially perfectly-polarized light will experience cross-polarization coupling as a result of the finite extinction ratios of the fiber and directional couplers and the slight misalignments of the principal axes at the splices. However, the exact state of polarization at a given point along the system cannot be predicted without full knowledge of the relative phase delays of the two polarization modes as they propagate through the various sections of the array. Since these phase delays are seriously affected by the environment we again find it more convenient and meaningful to use statistical methods. Thus, instead of calculating the visibility as a function of the many uncontrollable system delays, we focus on the complementary cumulative probability $P(V \geq V_0)$. Here the statistical ensemble extends over all possible realizations of the unknown parameters, mainly the relative propagation delays in the fiber sections of the array. Results were obtained through numerical simulations.

The array of Fig. 2(b) can be easily simulated on a computer once the following parameters are specified: a) The SOP of the incident wave and its orientation with respect to the principal axes of the down-lead fiber; b) the degree of polarization maintenance in the fiber; c) the coupling and extinction ratios of all couplers; d) the extinction ratios of the fiber splices; and e) the differential phase delay between the two polarization modes propagating through each of the fiber sections.

The simulation modeled the evolution of a Jones polarization vector through a series of transformations corresponding
to the various parts of the system. In its own principal axes coordinate system, every fiber segment was modeled by a diagonal Jones matrix (i.e., cross coupling in the characteristically relatively short fiber sections was ignored), having two different randomly drawn phase delays:

\[
J_{\text{delay}} = \begin{bmatrix}
\exp(i\Phi_{\text{fast}}) & 0 \\
0 & \exp(i\Phi_{\text{slow}})
\end{bmatrix} \quad (i = \sqrt{-1}).
\]

At fiber splices we expect a small angular relative rotation, \(\delta_{\text{splice}}\), between the two relevant sets of principal axes, resulting in a transformation matrix (between the two sides of the splice) of the form

\[
J_{\text{splice}} = \begin{bmatrix}
\cos(\delta_{\text{splice}}) & \sin(\delta_{\text{splice}}) \\
-\sin(\delta_{\text{splice}}) & \cos(\delta_{\text{splice}})
\end{bmatrix}.
\]

Each coupler has four input fields, namely, the fast and slow inputs to the reference and signal arms, and four corresponding outputs. Due to the finite polarization-maintenance of available PM couplers, each coupler was modeled by a product of two 4 \(\times\) 4 matrices, that of an ideal polarization maintaining coupler (having the same coupling ratio, \(K\), for both polarizations) followed by a scattering matrix (\(\delta = 0\) results in perfect polarization maintenance), see (13) at the bottom of the page.

While fixed values have been assigned to all other parameters, the phase delays were randomly drawn from an ensemble having a uniform distribution over \([-\pi, \pi]\). Using the Jones calculus, fringe visibility can be easily calculated at the output of each of the sensors for any particular choice of the random delays. To construct an estimate for \(P(V \geq V_0)\), the calculation procedure was repeated for a large number (500) of random drawings to ensure proper convergence.

**Single Sensor Results:** To check the accuracy of the simulations, Fig. 8 depicts \(P(V \geq V_0)\) for a perfectly polarization-maintaining sensor (i.e., \(\delta_{\text{splice}} = \delta = 0\), but with \(I_{\text{slow}} = I_{\text{fast}}\) and random phase delays in the various PM segments. Good agreement is observed with the theoretical predictions of (10). Then, Fig. 9 shows \(P(V \geq V_0)\) at the output of a real PM single sensor with finite extinction ratios for splices and couplers and assuming a linearly polarized input aligned with one of the birefringent axes of the input fiber. For high extinction ratios (solid curve), visibilities as high as 0.8 can be expected with a probability which exceeds 98%. \(P(V \geq V_0)\) decreases as the extinction ratios assume lower and lower values. The cross-polarization coupling processes transfer power from the polarization mode of launch into the other mode, again establishing two interferometers, one for each of the polarization modes of the fiber. But due to the different phase velocities of the modes, the differential phase delays between the signal and reference arms in the two interferometers are also different, resulting in outputs which are not in phase with a decreased overall visibility, cf. (6). In case of severe cross-polarization coupling, where both interferometers are equally excited, complete fading may take place (when the two outputs are exactly out of phase), in spite of the use of polarization-maintaining fibers and components, as indicated by the nonzero slope of \(P(V \geq V_0)\) in Fig. 9. Anyway, for the chosen practically attainable extinction ratios of the fiber, all curves show better performance than that obtained for a nonpolarization-maintaining sensor. Still, if the input SOP could be dynamically adjusted to optimize the output visibility for every realization of the polarization state of the sensor, \(P(V \geq V_0)\) is always unity for both types of the single sensor.

**Sensor Array:** While the first sensor in the array of Fig. 2(b) sees the same input SOP as in the case of a single
sensor discussed above, the input light to the deeper sensors in the array has to pass through an increasing number of splices and couplers (even more splices and couplers are to be traversed in the serial case of Fig. 1(a)). Naturally, more power will be now coupled from the principal mode of launch to the other mode. Fig. 10 shows the average fraction of launched power which retains its original SOP after passing through the splices and feed couplers of N sensors in the architecture of Fig. 2(b). Indeed, for a large enough N (decreasing with increasing extinction ratios of the splices and couplers), equal powers propagate in the two polarization modes. Since a sensor which is equally excited by its both polarization modes will exhibit higher probability of complete fading, this depolarization of the input SOP tends to establish a practical upper limit on the number of sensors in the array.

Fig. 11 shows $P(V \geq V_0)$ for the individual sensors of the array, calculated over an ensemble of simulated 10 sensor parallel arrays (Fig. 2(b)) with 20 dB couplers and 15 dB splice extinction ratios. One can observe the performance decrease for sensors further away on the down-lead fiber (requiring passage through more and more imperfect couplers and splices). This performance decrease can be attributed to the gradual transfer of energy from the initial polarization mode to the other mode. For each (statistical) realization of the array, the performance of the array as a whole, is governed by the worst performing sensor $V_{array} = \min_j V_j$, j = 1…N, where $V_j$ is the visibility of the jth sensor. The probability $P(V_{array} \geq V_0)$ for this sensor array is also depicted in Fig. 11. The array performance is substantially lower than that of its individual sensors. Fig. 12 compares the performance of the polarization maintaining array of Fig. 11 with that of the same array when constructed from nonpolarization maintaining fibers, Fig. 4 ($N = 10$). When both arrays are fed with a fixed input SOP (arbitrary SOP in the case of a non-PM array and linearly polarized parallel to one of the principal axes of the PM array), the advantages of the polarization-maintaining array are quite evident. But, when an optimal input SOP is used for the nonpolarization maintaining array, performance is comparable with that of the polarization-maintaining one.

In summary, finite extinction ratios of couplers and splices degrade the performance of polarization-maintaining fiber-optic sensor arrays. Nevertheless, for practically available extinction ratios, the polarization-maintaining array has a much better performance when compared with a similar array made of regular single mode fibers. However, when dynamic control over the input SOP is possible, an array made of nonpolarization-maintaining fibers offers comparable visibility performance.

IV. SUMMARY

In this paper we presented a statistical study of polarization induced fading in interferometric sensor arrays made of either regular or polarization-maintaining optical fibers. The impact of the dynamic optimal choice of the input state of polarization on array performance was studied in terms of the probability of exceeding a given visibility. Indeed, with such dynamic control, a nonpolarization maintaining array is quite comparable in performance to a polarization maintaining system comprising finite extinction couplers and splices. Both approaches are
expensive but for moderate size arrays (N ≤ 10) efficient control techniques may prove attractive. Such a closed-loop system will quite often produce higher visibilities when compared with other anti-PIF techniques such as input polarization scrambling [6] or polarization diversity receivers [7].

ACKNOWLEDGMENT
The authors thank H. Regev for helpful comments.

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