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INTERNATIONAL STANDARD

Fibre optic interconnecting devices and passive components – Basic test and measurement procedures –
Part 3-2: Examination and measurements – Polarization dependent loss in a single-mode fibre optic device

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FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES –

Part 3-2: Examination and measurements – Polarization dependent loss in a single-mode fibre optic device

FOREWORD

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International Standard IEC 61300-3-2 has been prepared by subcommittee 86B: Fibre optic interconnecting devices and passive components, of IEC technical committee 86: Fibre optics.

This third edition cancels and replaces the second edition published in 1999. It constitutes a technical revision.

The main changes with respect to the previous edition are listed below:

- This edition includes both the all-states method of the previous edition as well as the Mueller matrix method from IEC 61300-3-12.

The text of this standard is based on the following documents:

FDIS	Report on voting
86B/2783/FDIS	86B/2811/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

A list of all parts of IEC 61300 series, published under the general title *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures,* can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this standard may be issued at a later date.

FIBRE OPTIC INTERCONNECTING DEVICES AND PASSIVE COMPONENTS – BASIC TEST AND MEASUREMENT PROCEDURES –

Part 3-2: Examination and measurements – Polarization dependent loss in a single-mode fibre optic device

1 Scope

This part of IEC 61300 specifies measurement methods to determine the dependence of loss in a single-mode fibre optic device to changes in polarization. This procedure focuses on measurements with a fixed wavelength source; therefore, this procedure is applicable to devices whose properties at a single wavelength can represent those over the broader wavelength band. Typical examples of such devices are single-mode interconnecting devices and passive components, including connectors, splices, branching devices, attenuators, isolators, and switches. The maximum observed variation in transmission loss is referred to as polarization-dependent-loss (PDL).

This standard applies to broadband devices and not to narrow-band devices like filters and multiplexers. The reader is referred to IEC 61300-3-29 for such measurements.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61300-3-29, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-29: Examinations and measurements – Measurement techniques for characterising the amplitude of the spectral transfer function of DWDM components*

3 Measurement methods

Two methods for measuring polarization-dependent-loss are described. The all states method determines the maximum variation in transmission loss by stimulating with a representative set of all possible polarization states including linear, circular, and elliptical. The Mueller matrix method determines the sensitivity using a set of fixed states and applying the Mueller matrix mathematical analysis.

This procedure originally consisted of only one method, but has been updated to incorporate the technique previously described by IEC 61300-3-12[1]. That standard will be discontinued.

3.1 All states method

In this method, the PDL is determined by rotating the source polarization over a representative set of all possible polarization states while monitoring the transmission

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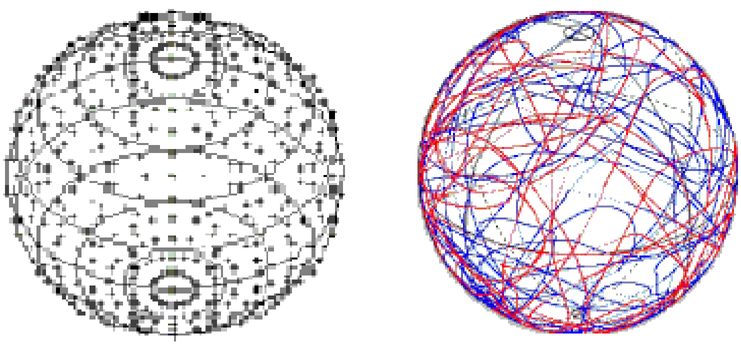
1 IEC 61300-3-12, *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Part 3-12:Examinations and measurements – Polarization dependence of attenuation of a single-mode fibre optic component: Matrix calculation method*

response of the device using a power meter. The rotation can be accomplished in either a deterministic or a pseudo-random fashion.

The term “deterministic” refers to techniques that scan a large subset of the entire polarization state space in a repeatable way. This method scans the Poincaré sphere along predetermined trajectories to produce a good approximation of full sphere coverage.

The term “pseudo-random” refers to techniques that scan the polarization through a pseudo-random variation of retardance in the optical path, usually using the distributed retardance of optical fibre loops in motion.

Figure 1 shows the difference in coverage between the two techniques. In either case, the accuracy of the method is dependent on the degree of coverage over the Poincaré sphere due to the combination of the states generated by the polarization controller and the response time of the power detector with respect to the polarization scan rate.



IEC 2363/08

Figure 1 – Polarization mapping of deterministic and pseudo-random techniques

3.2 Mueller matrix method

The Mueller matrix method involves the measurement of the behaviour of a device under test, DUT, when illuminated by a small set of well-defined states of polarization of input light. These measurements are followed by a matrix calculation to determine the PDL of the DUT. Generally, there are two matrix formalisms that can describe and quantify the polarization behaviour of light based on Mueller and Jones calculus respectively. For fully polarized light, as required for the PDL measurements, the Mueller and Jones formalisms are equivalent. Since measurements with polarization instrumentation on only one side of the DUT directly obtain the necessary elements of the Mueller matrix, that is elements corresponding to power ratios rather than field amplitude and phase, the test procedure described here uses Mueller mathematics to determine PDL.

The Mueller matrix formalism entails an optical power representation of the performance of components. This matrix is a square 16-element matrix. Here, the state of polarization (SOP) of light is described as a 4-element Stokes vector. The Stokes vector of the incident light multiplied by the Mueller matrix of the DUT gives the Stokes vector of the output light, and this output light may be from transmission, reflection or scattering. In the determination of PDL of a component using Mueller matrices, it is normally not necessary to determine the full Mueller matrix but rather only the first row of the matrix, which provides complete information on light intensity but not on the resultant state of polarization.

The accuracy of the method is dependent on the source wavelength stability, the system signal to noise ratio, and the drift in system birefringence.

4 Apparatus

The basic apparatus for making PDL measurements is shown in Figure 2.

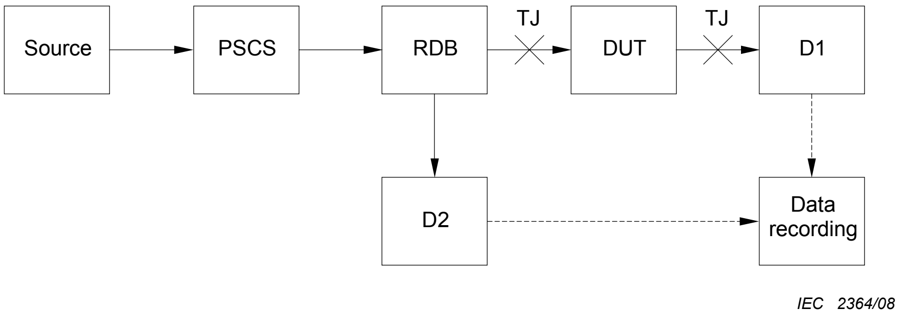


Figure 2 – Measurement apparatus

The apparatus consists of the following devices.

4.1 Optical source (S)

An optical source capable of producing the spectral characteristics defined in the relevant specification (both wavelength and spectral width) shall be used. Unless otherwise specified in the relevant specification, the spectral width shall be appropriate for the degree of wavelength resolution required.

The source power must be capable of meeting the dynamic range requirements of the measurement when combined with the detector sensitivity.

The source must be polarized to at least 13 dB extinction ratio, unless otherwise specified in the relevant specification. An extinction ratio of 20 dB may be used to assure that this parameter makes no significant contribution to the measurement uncertainty. If the source is not already polarized to this level, a polarizer should be used to maintain this extinction ratio over the range of wavelengths of the measurement.

The optical power stability, degree of polarization (DOP), state of polarization (SOP) stability, and wavelength stability of the source shall be sufficient to achieve the desired measurement accuracy over the duration of the measurement. For some applications, a narrow linewidth source such as a single longitudinal mode laser may be used though care shall be exercised to prevent back-reflections that could lead to multi-path interference and resulting spurious PDL.

The output from this source is either via a single-mode fibre or a coupling system capable of launching into a single-mode fibre. Care shall be taken that only the fundamental transverse mode of the fibre is propagating as outlined in Clause 5**.**

NOTE Multimode lasers may not provide sufficient polarization stability for this measurement.

4.2 Temporary joint (TJ)

This is a method, device, or mechanical fixture for temporarily aligning two fibre ends into a reproducible, low-loss, low-PDL joint. This may be mechanical connectors, mechanical splices, a direct optical launch into the pigtail, or a splice onto the source's pigtail. Typically, a fusion splice is used after the polarization controller since mechanical connections may exhibit some polarization sensitivity if the end-faces are not perpendicular to the fibre axis. The stability and insertion loss of the temporary joint shall be compatible with the required measurement precision and dynamic range, respectively.

4.3 Polarization state change system (PSCS)

The selection of the PSCS will be dependent upon the test method selected.

4.3.1 All states method

For the all states method, the polarization state adjuster is used to vary the polarization of the input signal over the entire Poincaré sphere. This may be done by continually adjusting a quarter-wave/half-wave retarder pair placed in the optical path in a well-defined phase relationship (deterministic) or by using a polarization scrambler (pseudo-random, e.g. consisting of three or more movable fibre loops). Some examples are provided as follows:

– bulk optics elements

  This may be formed by a cascade of three polarization selective optical elements (only two optical elements may be sufficient if the state of polarization before the polarization adjuster is already established by the source). The alignment of the system shall be adequate to ensure the reproducibility of launched power for the same orientation of the optical elements. The example in Figure 3a shows a linear polarizer P, half-wave retardation plate H, and a quarter-wave retardation plate Q mounted on rotation stages and inserted into a collimated optical path.

– in-line all-fibre polarization adjusters

  This may be formed by a cascade of three rotatable mandrels around which single-mode optical fibre is wound. This solution is shown in Figure 3b.

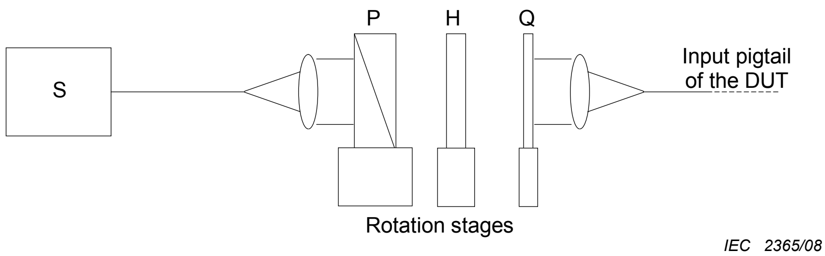


Figure 3a – Bulk optic PSCS

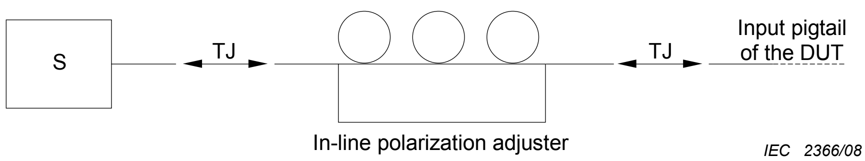


Figure 3b – In-line fibre PSCS

Figure 3 – Examples of PSCS for the all states method (deterministic and random)

The accuracy of the all states method is highly dependent upon the ability of the PSCS and detector combination to sufficiently sample the polarization space and the stability of the PSCS insertion loss as the polarization is varied. Annex A discusses the uncertainty associated with the all states method.

4.3.2 Mueller matrix method

For the Mueller matrix method, the PSCS is the means by which the launch light can be conditioned into several well-defined states of polarization representing linearly independent Stokes vectors. Although any such states can be used, a typical choice is the set of linear horizontal, linear vertical, linear diagonal, and right hand circular. The equations of 6.2 are based on this choice. The required accuracy of determining the four states depends on the required PDL accuracy; as a guideline an accuracy of <+/– 0,5° is proposed. An example of this system is shown in Figure 4.

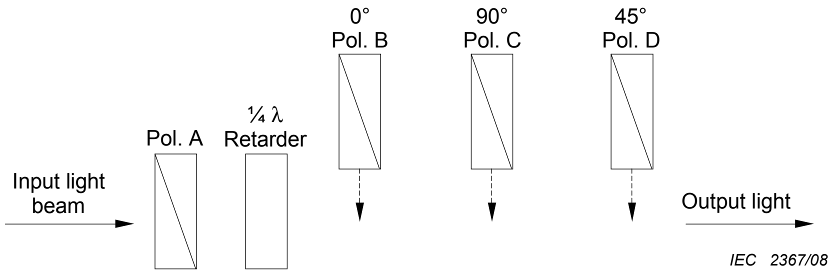


Figure 4 – Polarization state change system (example)

This arrangement can launch four states of polarization consisting of circularly polarized light plus three linearly polarized states oriented at 45° with respect to each other. The input light is first conditioned to a highly linearly polarized state by a polarizer (A). It is then converted to circular polarization by a quarter-wave retarder oriented at 45° to the polarizer. The three linear states of polarization can be created sequentially by sequentially inserting the three polarizers labelled B, C, and D into the beam. Polarizers B, C, and D are oriented at 45° with respect to each other when they are in the beam. The alignment of the system shall be adequate to ensure the reproducibility of launched power for the same orientation of the polarizers.

Other means to reproducibly adjust the state of polarization are permitted, for example using bulk optical elements like in Figure 3a, or using liquid crystal variable retarders or pre-programmed fibre polarization controllers.

4.4 Reference branching device (RBD) (optional)

This is a device that transfers power from the input port to two output ports with approximately a 50:50 or other suitable coupling ratio. The optimum ratio will depend on the signal level available and the power sensitivity of the reference detector. Unless otherwise specified, it shall exhibit less than 10 % of the minimum polarization dependence specified as acceptable. Note that the dynamic range of the measurement will be dependent on the coupling ratio.

The use of the RBD is optional as it is only suggested to use a source power monitor. If the source power is stable to an order of magnitude better than the DUT PDL to be measured, it can be omitted.

4.5 Detectors (D)

All detectors used shall have sufficient dynamic range to make the measurement in conjunction with the rest of the measurement apparatus. The detectors shall have a polarization sensitivity that is an order of magnitude better than the measurement to minimize the error. If required, a depolarizer may be used after the DUT and before the detector to achieve the required accuracy.

The detectors shall be linear over the optical power levels expected to be encountered. Any detector nonlinearity and polarization dependence contributes directly to measurement error. Therefore, it is important that the detector and associated amplification circuits exhibit good linearity over all measurement ranges. Measures shall be taken to ensure that the power density at the detector is always sufficiently below the saturation level of the detector. It is recommended to operate at least 3 dB below the saturation level, defined as the power level at which the relative accuracy specification of the measurement equipment is exceeded. In this case, the amplifier usually contributes the most to nonlinearity, particularly when the transimpedance is changed as the ranges are switched. Measurement of low PDL values can usually be achieved without changing ranges.

The detector(s) shall have sufficient active area and be placed sufficiently close to the output to capture all of the light exiting the output fibre of the DUT.

For the all states method if the polarization is scanned continuously, the detectors shall be able to measure power quickly enough, in relation to the polarization scanning rate, such that the measured values correspond to well resolved states of polarization. This is usually determined by the bandwidth and the averaging time of the detectors.

4.6 Data read-out / recording / processing devices

These provide a means to collect the transmitted power as the state of polarization is scanned, to perform the calculations, and to report the results at the end of the test. A computer-based system may be used to fulfil this data acquisition and analysis function.

5 Procedure

5.1 Preparation of specimens

Prepare and clean the specimen in accordance with the manufacturer's instructions.

5.2 Pre-conditioning

No pre-conditioning is required for this measurement unless otherwise specified in the relevant specification.

5.3 Initial measurements

Complete initial examinations and measurements on the specimen as required by the relevant specification.

5.4 Test precautions

Movement of any of the fibres during the measurement may affect the SOP and lead to measurement error. Therefore, care shall be taken to ensure that no movement of the fibres or apparatus is allowed. This is particularly true for the Mueller matrix method and is generally less of an issue for the all states method.

Cladding modes shall be stripped at the entry and exit ports of each element of the apparatus. If this is not accomplished by the fibre coating, cladding mode strippers are required.

5.5 Reference measurement

Starting with the apparatus as shown in Figure 2, remove the DUT from the set-up as shown in Figure 5. The DUT may be completely removed as shown in the upper setup of Figure 5 or a fibre loop of length equivalent to the length of the pigtails on the device may be substituted as shown in the lower setup of Figure 5. In either case, none of the apparatus test cables should be removed during this step.

Begin with the PSCS set to the first polarization state, and collect the power in watts from D1 and (if used) D2.

Rotate the PSCS through all SOP to be used in the measurement method and collect the power from D1 and D2 for each point.

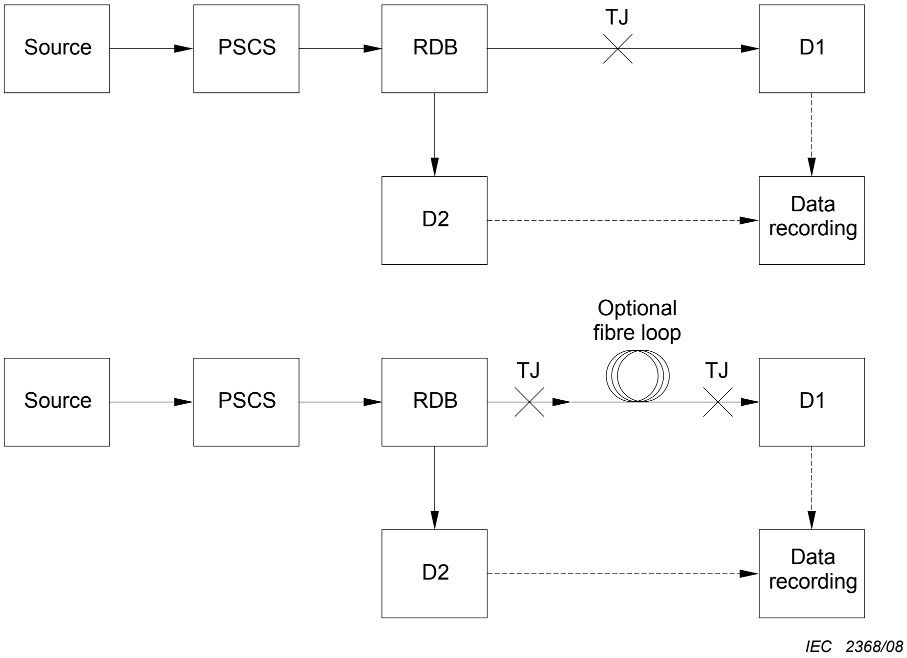


Figure 5 – Reference measurement apparatus

The reference shall be recorded for each measurement point i as

$$P_{ref}(i) = \frac{P_1(i)}{P_2(i)} \tag{1}$$

where

P_1 is the power reading at D1; and

P_2 is the power reading at D2

or if D2 is not used, then

$$P_{ref}(i) = P_1(i) \tag{2}$$

5.6 Device measurement

Reconfigure the apparatus as shown in Figure 2.

Begin with the PSCS set to the first polarization state, and collect the power in watts from D1 and (if used) D2.

Rotate the PSCS through all SOP to be used in the measurement method and collect the power from D1 and D2 for each point.

The DUT measurement shall be recorded for each measurement point as

$$P_{msd}(i) = \frac{P_1(i)}{P_2(i)} \quad (3)$$

where

P_1 is the power reading at D1; and

P_2 is the power reading at D2

or if D2 is not used, then

$$P_{msd}(i) = P_1(i) \quad (4)$$

6 Data analysis

6.1 All states method

For the all states method, if the sampled polarization states of the measurement can be assigned to those of the reference, then calculate the transmission for each data point as:

$$T(i) = \frac{P_{msd}(i)}{P_{ref}(i)} \quad (5)$$

Calculate the PDL (maximum delta) and average insertion loss, IL, expressed in dB, as:

$$\text{PDL} = 10 \text{x} \log_{10}(T_{max} / T_{min}) \quad (6)$$

$$\text{IL} = -10 \text{x} \log_{10}((T_{\max} + T_{\min)}) / 2) \quad (7)$$

where

T_{max} is the maximum value for all $T(i)$ and

T_{min} is the minimum value for all $T(i)$.

If the reference and measurement samples are not made at the same polarization states, as with pseudo-random scanning, then the transmission cannot be separately calculated for each sample. In this case calculate PDL as

$$\text{PDL} = 10 \text{x} \log_{10}(P_{msd,max} / P_{msd,min}) \quad (8)$$

and calculate the PDL of the setup as

$$\text{PDL}_{setup} = 10 \text{x} \log_{10}(P_{ref,max} / P_{ref,min}) \quad (9)$$

where

$P_{msd,\max}$ is the maximum value for all $P_{msd}(i)$;

$P_{msd,min}$ is the minimum value for all $P_{msd}(i)$;

$P_{ref,max}$ is the maximum value for all $P_{ref}(i)$;

$P_{ref,min}$ is the minimum value for all $P_{ref}(i)$.

The PDL_{setup} is then a contribution to the measurement uncertainty and the setup should be designed to minimize this.

6.2 Mueller matrix method

For the Mueller matrix method, the set of states of polarization described in 3.2 shall be generated during the reference and measurement processes.

From these states, it is required to generate the first row of the Mueller matrix using the Stokes parameters.

For the case where the four states used are: linear horizontal (i = 1), linear vertical (i = 2), linear diagonal (i = 3), and right hand circular (i = 4); the calculation proceeds as follows.

Calculate the DUT transmission factors as:

$$T(1) = \frac{P_{msd}(1)}{P_{ref}(1)} \tag{10}$$

$$T(2) = \frac{P_{msd}(2)}{P_{ref}(2)} \tag{11}$$

$$T(3) = \frac{P_{msd}(3)}{P_{ref}(3)} \tag{12}$$

$$T(4) = \frac{P_{msd}(4)}{P_{ref}(4)} \tag{13}$$

Next calculate the first row of the Mueller matrix as:

$$m_{11} = (T(1) + T(2))/2 \tag{14}$$

$$m_{12} = (T(1) - T(2))/2 \tag{15}$$

$$m_{13} = T(3) - m_{11} \tag{16}$$

$$m_{14} = T(4) - m_{11} \tag{17}$$

Calculate the maximum and minimum transmission factors as:

$$T_{max} = m_{11} + \sqrt{m_{12}^2 + m_{13}^2 + m_{14}^2} \tag{18}$$

$$T_{min} = m_{11} - \sqrt{m_{12}^2 + m_{13}^2 + m_{14}^2} \tag{19}$$

Calculate the PDL and average insertion loss, IL, of the DUT, expressed in dB, as:

$$\text{PDL} = 10\text{x}\log_{10}\left(T_{max} / T_{min}\right) \tag{20}$$

$$\text{IL} = -10\text{x}\log_{10}\left(m_{11}\right) \tag{21}$$

7 Details to be specified

The following details, as applicable, shall be specified in the relevant specification:

- source peak wavelength and spectral width;
- degree of polarization of the source;
- description of polarization state change system;
- effective sphere coverage of apparatus if all states method is used;
- description of the reference branching device;
- pigtail lengths;
- measurement accuracy requirements;
- measurement method selected;
- reference method selected;
- any deviations from this test method.

Annex A
(informative)

Measurement uncertainties

A.1 All states method

For the all states method, the polarization scrambler used must be able to convert a fixed input polarization state from a stable optical source into all possible output polarization states. The PSCS may operate in either a step mode or a continuous scanning mode. In either case the accuracy is a function of the degree of sphere coverage and the ability of the apparatus to resolve unique states of polarization for measurement. As this is the case, the PSCS scan time and the response time of the detector weigh heavily upon the system accuracy.

In general, there are two scanning rate parameters of the polarization scrambler that influence accuracy. First, the amount of change in SOP over the averaging time of the detector determines the polarization resolution of the setup. If this change is too large, the samples will not determine the maximum and minimum values to sufficient accuracy. This can be improved by either changing the scan rate or the detector averaging time. Second is the amount of time to sufficiently cover all states of polarization. The relationship between total measuring time and SOP coverage depends on the method of polarization scanning. If the PSCS changes the SOP in a random way, then the coverage is determined statistically and generally continues to increase with longer measuring time. If the PSCS changes in a deterministic way, it may be repetitive and the coverage does not increase after the full scanning cycle has been completed.

To establish system accuracy, a polarization analyser can be used to monitor the SOPs generated for either the deterministic or pseudo-random techniques. As an example, the error dependence on run time was calculated (Figure A.1) for the case of a commercial fibre loop scrambler running at a rate that covers the sphere to 95 % accuracy in 10 s using a detector with a 20 ms averaging time. It is important to realise that because of internal system drift, extremely long scans may be counterproductive and the measurement error may begin to increase.

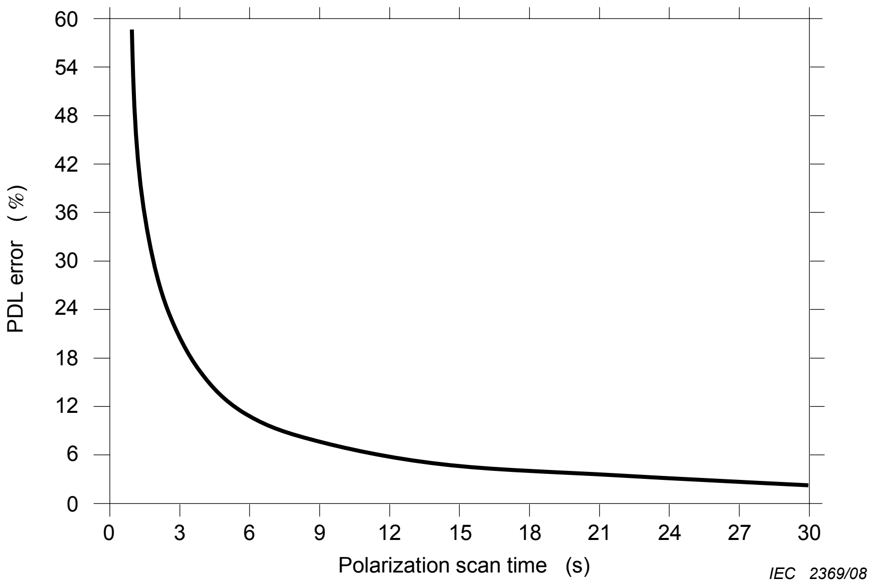


Figure A.1 – All states apparatus uncertainty (example: see text for details)

The influence of source stability and detector polarization dependence can usually be determined easily be evaluating the variation in power values from the reference measurement of 5.5.

A.2 Mueller matrix method

This method is also subject to certain restrictions in order to produce consistently meaningful results. Significant uncertainty and inaccuracy may be observed when measurement system components such as the PSCS and the detectors (D1 and D2) exhibit PDL of the same magnitude as the test DUT and when the DUT is terminated with long pigtails possessing non-negligible birefringence. In addition to internal stress, external coiling in the pigtails produces stress birefringence in an amount proportional to the coil radius. Stress birefringence generates optical path retardance that alters the relative orientations of the PDL axes of the PSCS, the DUT and the detector D1. This additional retardance is sometimes irrelevant in the all-states approach but leads to a non-removable calibration uncertainty in a four-state measurement. Large static lead birefringence removes required polarization symmetry between initial baseline measurements without the DUT in place and the final measurement with the DUT in place. The net effect of large static birefringence is to scale the PDL by different factors in the baseline and final measurements. In addition, the dynamic lead birefringence of long interconnecting fibres alters the baseline PDL level during the course of extended measurements.

To minimize these problems, the following recommendations are made. Use short, straight leads anchored to a surface for interconnections where possible along with detectors of low intrinsic PDL (<10 % expected specimen value) and limit measurement time between baseline measurements. When these conditions are not possible, the orientation of the fibre leads should be randomised between complete measurements and the measurements averaged in order to minimize the lead birefringence effects. Note that the most complete randomisation of the leads must include orientations where the fibre coils do not lie in a single plane. Alternatively, a second adjuster, PSCS2 with low PDL such as a fibre-loop adjuster, may be necessary and inserted between the first PSCS and test DUT as in Figure A.2.

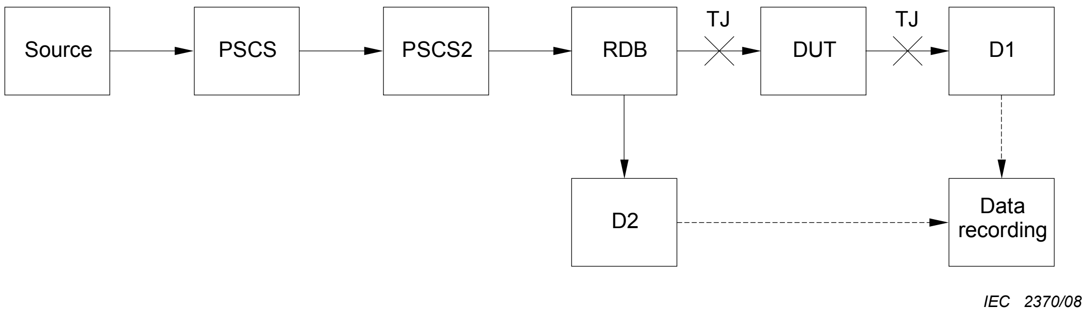


Figure A.2 – Alternate apparatus for Mueller Matrix

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