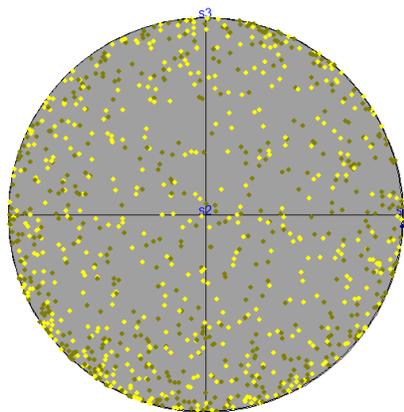


# Keysight Technologies

All-states measurement method for  
PDL and PER with a synchronous  
polarization scrambler



Application Note



## Introduction

There are two general methods for measuring the polarization dependent insertion loss (PDL) of a fiberoptic component, which are standardized in the IEC document 61300-3-2 as the all-states method and the Mueller Matrix method. In the all-states method, the optical test signal to the device under test is varied through a sufficiently large sampling of all possible polarization states such that the relation between the maximum and minimum optical power at the device output represents the PDL with the necessary accuracy. For the Mueller Matrix method, a limited set of known polarization states, typically 4 or 6 states, are applied to the DUT and matrix analysis of the output power levels is used to determine the maximum and minimum power that would be found by scanning all of the possible states. This is generally faster and is well suited for spectral measurements with continuously swept tunable lasers. However this method requires instrumentation that accurately sets specific states of polarization and somewhat more advanced control programs for derivation of the results. For components with high polarization extinction ratio (PER) like polarizers and polarizing beam splitters, the Mueller Matrix method also typically has insufficient accuracy, because the lowest power level is not measured directly and calculating this value is very sensitive to small variations in the measured power levels and their corresponding polarization states.

The all-states method is therefore a good way to measure components with little wavelength dependence, so that only one or a few wavelengths need to be measured. Fiberoptic couplers, splitters and isolators are typical components to test this way. Similarly, tests of polarization beam splitters and other devices designed for high PER benefit from this method.

The implementation of the all-states PDL method described in this note exploits the special characteristics of the Keysight Technologies, Inc. N7785B synchronous scrambler, which can be programmed for repeatable stepping through a sequence of polarization states at high speed while producing synchronization triggers. This can be used to shorten total measurement time, allow optimized detector averaging times, and normalize the results to remove the polarization dependence of the setup from the results, delivering average insertion loss (IL) at the same time.

## Apparatus

The synchronized all-states PDL test setup is shown schematically in Fig. 1. A stable polarized signal, like from a DFB or Fabry-Perot laser, is applied to the synchronous scrambler. The N7785B is the best match for this application, but the N7784B, N7786B and N7788B can also be used in the same way. An optical power meter that logs a series of power measurements, synchronized with triggers from the polarization scrambler, completes the instrumentation.

The power meter can be selected to best match the measurement need. The polarization dependence of the detector and other instrumentation after the DUT, like switches or splitters, can generally not be eliminated with a reference measurement, because the polarization states at the output of the DUT are not the same as during the reference without DUT. Therefore the specified polarization dependence of the power meter should be lower than the desired PDL measurement uncertainty. For the lowest PDL, the 81634B sensor module or the 81624B power head are recommended. Either can log up to 20k samples with an averaging time that can be set down to 100  $\mu$ s. For measuring high PER, where a sequence with many samples is needed to approach the lowest power, the 25  $\mu$ s averaging time of the 81636B sensor module or the N7744A and N7745A multiport power meters reduces the needed measurement time. The higher dynamic range during logging for these instruments also supports the measurement of PER beyond 30 dB.

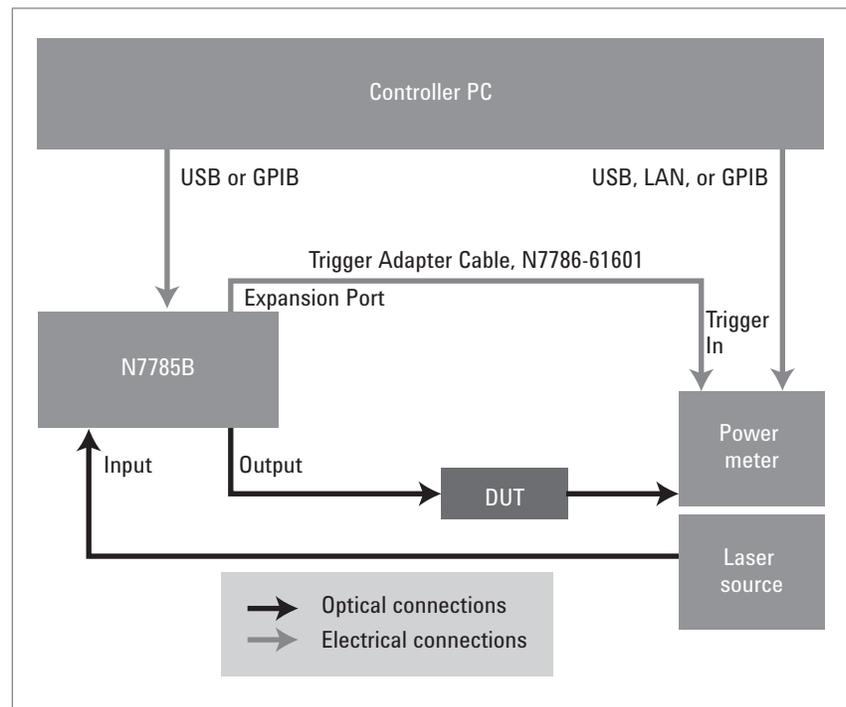


Figure 1. Schematic of the setup for synchronized all-states PDL.

## Apparatus (continued)

The polarization scrambler triggers are output at the first analog pin of the expander port. Part No. N7786-61601 can be used as the trigger cable between the scrambler and the power meter.

The optical fiber connection between the laser source and the scrambler should be stable so that the state of polarization is repeatable. A polarization maintaining fiber can be used to improve this stability if the source has PMF output, as do the 81663A DFB lasers.

A typical minimum setup could include the N7785B together with an 8163B mainframe including a power sensor or module in one slot and a source like the 81657A Fabry-Perot or 81663A laser source in the other slot. Multiport measurements, such as on PON splitter devices, can be made easily using the N7745A multiport power meter. Multiple wavelengths can be tested with the dual-wavelength 81657A or with multiple DFB lasers connected by an N7731A switch or with an N7711A tunable laser source.



## Measurement description and parameter choices

The synchronous scrambler is configured with a sequence of polarization settings that provide sufficient coverage of the Poincaré sphere. These settings can be randomly distributed, since the scrambler switches very rapidly to any other SOP. For measurement of low PDL values, it is usually sufficient to use a hundred settings and 1000 settings can usually be scanned in a sufficiently short time. For measurement of high PER values, like 20 dB or above a sequence of 10k to 20k samples should usually be used.

The power meter is configured to log the power for each of the polarization settings, so the length of this logging sequence is the same as for the polarization sequence. In many applications, a fast averaging time for the power readings can be chosen, like 100  $\mu$ s or even 25  $\mu$ s if supported by the power meter. However to reduce noise for measuring PDL values substantially below 0.1 dB it may be necessary to increase the averaging time and possibly to use the coherence control modulation of the laser source. In the case of coherence control, a long averaging time like 10 ms should be chosen to average out the power variations due to the modulation. The power meter is configured to make a single measurement for each trigger applied to the external input.

The repetition rate of the polarization sequence is then set to give a switching period that accommodates the averaging time of the power meter. A simple and robust synchronization is achieved by triggering the power meter at the mid-point of the switching period, allowing time for the SOP to first settle, and then averaging for one quarter of the period to avoid integrating during the next switching. So the repetition rate is set to give a period 4 times longer than the averaging time. This synchronization is illustrated in Figure 2 and is supported by the SyncOutTrigger of the N7785B. The internal clock of the scrambler is used for running the sequence.

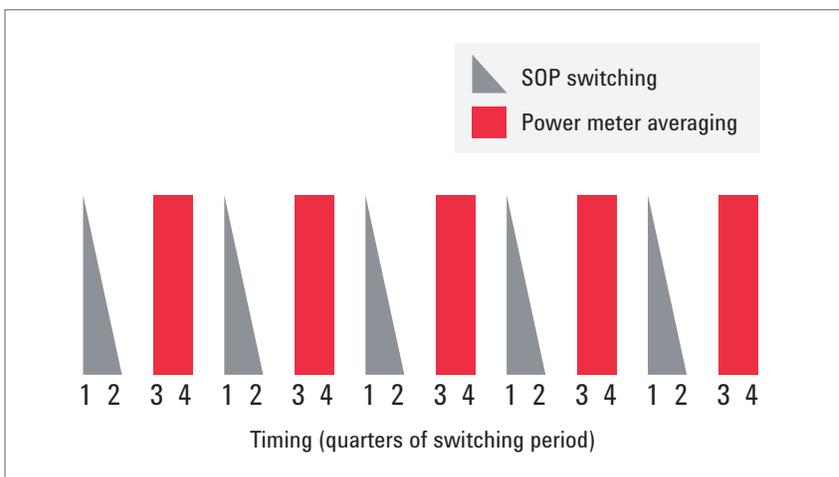


Figure 2. Timing diagram for the SOP switching and power sampling.

## Measurement description and parameter choices (continued)

After thus configuring the sequence operation it is advisable to run the sequence once before measuring, so that each successive sequence after this has the same starting condition. Good synchronization is also supported by adding a short delay, like 0.1 s, after running the sequence before setting the power meter to trigger logging and also a short time like 10 ms after setting the logging for the command to complete before starting the sequence.

Now a reference measurement can be made by connecting the optical signal that will later be applied to the DUT directly to the power meter or otherwise to the path that will be connected to the DUT output. Then run the sequence and save the series of power values. These will usually have a range of 0.1 to 0.2 dB due to the polarization dependence of the scrambler and can be used to remove this influence from the results.

These reference results can be used for normalizing measurements over the next minutes to hours, depending on the PDL accuracy needed and the environmental stability of the setup. For example, the state of polarization input to the controller may change over time, which changes the SOP pattern produced by the sequence. The validity of the reference can be easily checked by making the same connection and repeating the measurement. The difference in the traces can be reviewed, most simply by using the same calculation used to find PDL from the reference and measurement traces, shown below. If the result exceeds the desired uncertainty, then a new reference is needed. This same procedure can be used to check the repeatability and noise level directly after the reference measurement, for example to determine whether the coherence control of the laser source is needed.

Then insert the DUT into the setup and run the sequence again to measure its polarization dependence. These results can be saved as a trace for later evaluation or used immediately to reduce the results to the PDL value, as described below. The sequence can be further repeated on this DUT or successive devices.

## Measurement description and parameter choices (continued)

To obtain the PDL result from the reference trace  $P_i^R$  and the device trace  $P_i^D$ , where the index  $i$  ranges from 1 to  $N$ , the length of the sequence, first calculate the normalized transmittance trace  $T$  as

$$T_i = \frac{P_i^D}{P_i^R} \quad (\text{Equation 1})$$

where all values  $P$  are expressed in linear power units, such as mW.

The PDL (or PER) is then calculated from the minimum and maximum of the  $N$  values in the trace  $T_i$  according to

$$PDL = 10 \log \frac{\max_i T_i}{\min_i T_i} \quad (\text{Equation 2})$$

Making the same evaluation for different lengths or segments of the sequence can be used to investigate the length needed for reliable measurements.

When a reference measurement is made in this way, the polarization averaged insertion loss (IL) can also be calculated, according to

$$IL = 10 \log \left( \frac{1}{N} \sum_i^N T_i \right) \quad (\text{Equation 3})$$

## Programming

The basics for programming this application are given here. Further details to individual commands can be found in the N778xB User's Guide, Fifth Edition or later and a sample VEE program will be installed with the N7700A Polarization Navigator package that is used with these instruments and includes the remote programming interface. This example uses the COM/ActiveX interface and is illustrated in the Appendix. There is also a SCPI form for the commands, as detailed in the User's Guide. The example does not describe control of the light source.

- To begin programming the N778x instruments, select the ActiveX automation library
  - **IVI AgN778x 1.0 Type Library** into your programming environment. This library is installed and registered with the N7700A main package when the Polarization Navigator software is installed. The library is at a location like this.
  - **C:\Program Files (x86)\Keysight\Photonic Application Suite\bin\AgN778xLib.dll**
- Then create an object with this identifier.
  - **AgN778xLib.AgN778x**
- Depending on the form used for the interface paths in the programming environment, the variable
  - **AgN778x** or **IAgN778x** can be set to this COM object for access in the program.
- To find the resource name of the N778xB instrument on the USB, the property `USBInstruments` is used to return an array of text strings, with each string representing one instrument. The desired resource name is selected from this array, which may have only one string. (Note that the N778xB instruments are not listed as VISA resources on the USB by tools like VISA Assistant and Keysight Connection Expert.)
- 
- Programming tip: The `USBInstruments` property is on the **AgN778x.Utility** interface path. For easy access of this and other properties and methods from the object browser, the property for the interface can first be set to the variable used in the browser, **AgN778xUtility** in this case.
- 
- Now the instrument can be initialized by calling the method
  - **AgN778x.Initialize(ResourceName, idQuery, Reset, OptionString)** using the chosen resource name as the first parameter and Boolean values to select whether an `idQuery` and instrument `Reset` are performed. Both can be set to false. The `OptionString` can be blank.

## Programming (continued)

- Two further interface paths,
  - **AgN778x.PolController**
  - **AgN778xPolController.Sequence**  
will be used and should be returned and set as the variables
  - **AgN778xPolController**
  - **AgN778xSequence**  
or corresponding names as used in the programming browser.

Now the sequence operation of the polarization controller can be configured.

- Set this property to false.
  - **AgN778xSequence.AutoOversampling**
- Set the repetition rate in kHz of the sequence.
  - **AgN778xSequence.RepetitionRate**
  - A good value can be based on a period 4 times longer than the chosen power meter averaging time. For the rate  $r$  in kHz and averaging time  $t$  in s, use  $r = 1 / (4000 \times t)$ .
  - Note that for measuring PER at 27 dB or higher using 25  $\mu$ s averaging time with the 81636B, it is better to use a factor of 8, giving a rate of 5 kHz to avoid detector bandwidth limitations.
- Set the property
  - **AgN778xSequence.SyncMode** to the enumeration value 1 (**eN778xPol-ConSyncModeAutoOneshot**) for automatically starting one sequence.
- Set the property
  - **AgN778xSequence.Timebase** to the enumeration value 0 (**eN778xPol-ConTimebaseTimer**) for the internal timer.
  - Load the sequence of SOP with the SeqVoltage method. **AgN778xSequence.SeqVoltage(pVal)**  
With this method, a one-dimensional array of unsigned 16-bit integers defines the sequence. Each SOP is specified with ten voltage setting numbers in the range 0 to 4095. So a sequence of length  $N$  states uses an array with  $10N$  values. For the current application these values can be individually produced by a random number generator. The sequence can be generated new each time or saved on the computer and reloaded as desired.
  - The length property can be returned to obtain the value  $N$  for the power meter logging configuration, especially if it has been set by loading a sequence from a file, so that the instruments use the same length. **AgN778xSequence.Length**

## Programming (continued)

- To use the synchronization output triggers, the Oversampling property must be set to the integer value 4. This also allows the trigger to be positioned at the start of any quarter of the switching period.
  - **AgN778xSequence.Oversampling = 4**
- The SyncOutTrigger property is used to position the trigger in the switching period. Using an integer value of 3 positions the trigger at the start of the 3rd quarter period, so that the power meter averages during this 3rd quarter.
  - **AgN778xSequence.SyncOutTrigger = 3**
- Run the sequence once to reach a repeatable starting condition, by setting the property
  - **AgN778xPolController.Program** to the enumeration value 32 (**eN778x-PolConProgramSequence**) to start.
- Allow a program delay of the sequence duration plus about 100 ms before starting power meter logging to ignore some internal-process triggers from the polarization controller.

The polarization controller is now configured for the measurements.

The power meter must also be configured for the logging. These have a SCPI command set that can be used. It is very convenient instead to use the 816x VXI Plug&Play driver that is also distributed with these instruments. A further alternative for the N7744A or N7745A is the IVI driver. The example here uses the Plug&Play driver. Getting started with this driver is explained in the 816x Programming Guide and a Help file is installed with the driver.

- The triggering of the power meter (or power meters) is configured to make a single measurement for each input trigger. Output triggering is not needed and is disabled.
  - `hp816x_set_PWM_triggerConfiguration(instrHandle, PWMSlot, 1, 0)`
- The power meter is configured to measure in a chosen fixed power range appropriate for the input power level.
  - **hp816x\_set\_PWM\_powerRange(instrHandle, PWMSlot, channelNumber, 0, powerRange)**

After the power meter and polarization controller have been configured as above, the reference and device measurements can be made. In each case, the primary programming steps are these.

- Set up and start the power meter logging function with the parameters for averaging time  $t$  and sequence length  $N$ .
  - `hp816x_set_PWM_logging(instrHandle, PWMSlot, channelNumber, averagingTime, dataPoints, estimatedTimeout)`

## Programming (continued)

- Note that estimated timeout is an output parameter that can be used by the program.
- To assure proper timing, allow a short delay like 10 ms before the starting the polarization sequence.
- Run the sequence, like above, by setting the property
  - **AgN778xPolController.Program** to the enumeration value 32 (**eN778x-PolConProgramSequence**) to start.
- Allow a program delay of the sequence duration plus about 100 ms before again starting power meter logging to ignore some internal-process triggers from the polarization controller.
- Upload the logging results from the power meter to produce the traces  $P^R$  or  $P^M$ .
  - **hp816x\_get\_PWM\_loggingResults\_Q(instrHandle, PWMSlot, channelNumber, true, true, loggingStatus, loggingResult[ ])**
  - The logging result is returned as an array of real64 values. The traces are used to calculate PDL as in Equation 2.

When the program is finished, the connection to the controller should be closed and the logging function should be stopped.

- **AgN778x.Close( )**
- **hp816x\_PWM\_functionStop(instrHandle, PWMSlot, channelNumber)**  
Especially during program development, when the program may terminate inadvertently before this command is reached, it can be useful to start communication with the power meter with this command as well to clear the previous function.

## Characteristics of typical measurement examples

### Quick PDL measurements

The fast SOP switching of the synchronous scrambler allows a fast sampling rate for a short measurement time. The 100  $\mu$ s averaging time, which is the minimum for the 81624B or 81634B power meters with lowest polarization dependence, can be used with a 2.5 kHz repetition rate, so a sequence of 2000 states runs in 0.8 s. A section of such a sequence is shown in Figure 3, to observe the repeatability of the sequence 10 minutes after the reference. The corresponding PDL calculation gives 0.01 dB.

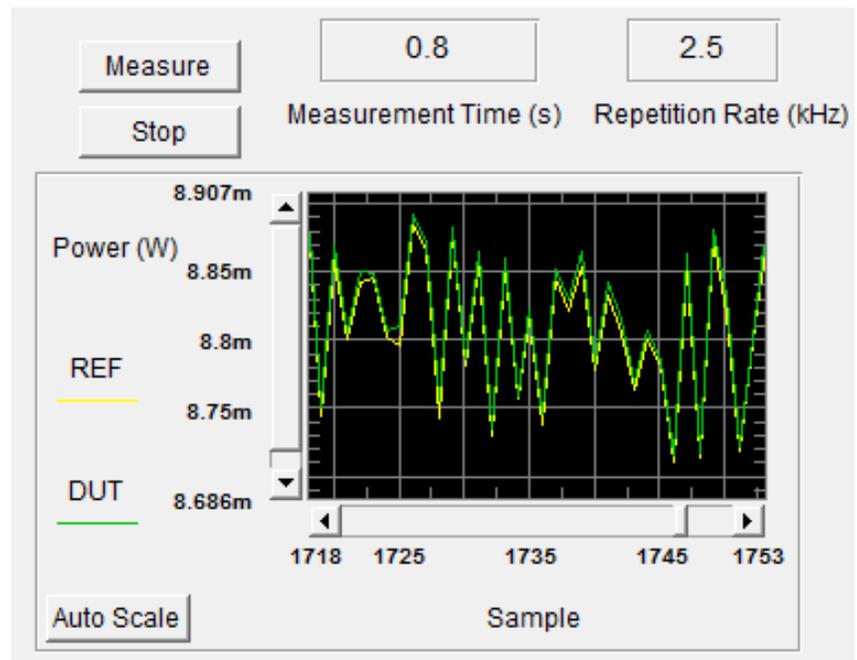


Figure 3. Repeatability of a sequence using 100  $\mu$ s averaging time, after 10 minutes. The yellow trace is the original reference and the green trace is the succeeding measurement.

For measuring PDL values up to 1 dB, about 100 samples are sufficient for the min-max PDL to come within 10% of the full PDL value. So a good measurement is achieved in less than 50 ms.

### Very low PDL

For measuring PDL values significantly below 0.1 dB, the repeatability mentioned above is a limitation. In this case it is useful to increase the power meter averaging time. Using 10 ms averaging time with a stable setup has been seen to give repeatability corresponding to less than 0.005 dB over times of 10 minutes or more. The 10 ms averaging time also supports use of the coherence control function of the laser sources, if needed to avoid interference effects due to reflections in the setup. Again for these values, good measurements are obtained with sequence lengths of about 100.

## Characteristics of typical measurement examples (continued)

### High polarization dependence – PER Test

The range of high extinction ratio measurements is limited by the determination of the lowest transmission value. When using a random pattern of SOP, this is improved by using many samples and having minimum SOP variation during the averaging time of the sample. This latter condition is an advantage of the polarization switching rather than continuous scanning. To assure measurements above 30 dB PER, a minimum of 20k samples is recommended. To minimize the measurement time, short averaging times can be used.

For example using 100  $\mu\text{s}$  averaging time and 2.5 kHz repetition, the 20k sequence requires 8 s.

Reducing the averaging time to 25  $\mu\text{s}$  can be used for faster measurement. But if the rate is increased to 10 kHz, the bandwidth of the 81636B can limit the reliable results to about 27 dB. For higher PER it is better to reduce the repetition rate to 5 kHz for 25  $\mu\text{s}$  averaging time, or the N7744A and N7745A can be used at 10 kHz or even 25 kHz at 10  $\mu\text{s}$  averaging, due to the higher analog bandwidth.

As an example of the dependence on sample length, this figure shows how the minimum value of transmission through a linear polarizer changes during a particular 50k sequence. On this graph, the value 0.001 corresponds to measuring 30 dB PER. The graph shows that this sequence had at least 2 points below this value within 20k samples.

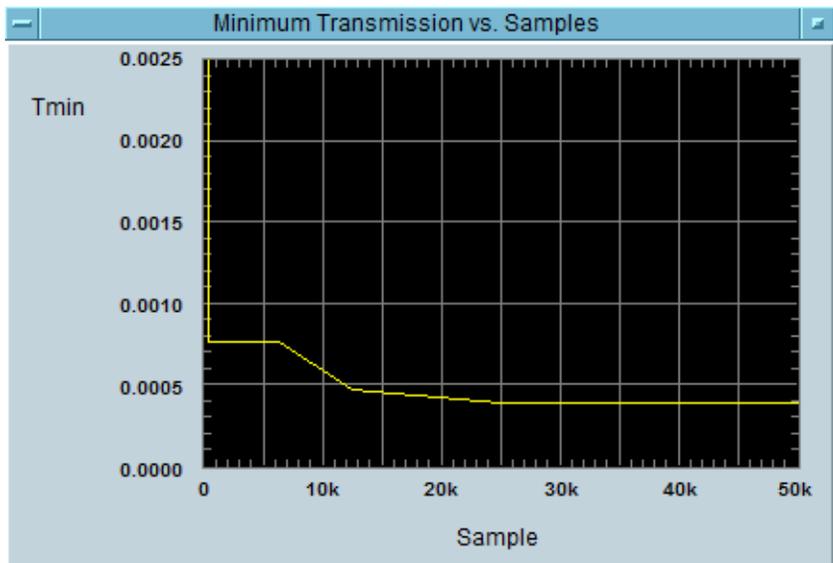


Figure 4. Development of the  $T_{min}$  value over 50k samples.

## Characteristics of typical measurement examples (continued)

### Estimates for required sequence length

Over all possible states of polarization, which can be represented as points on the surface of a Poincaré sphere, the transmittance varies within the full range  $T_{min}$  to  $T_{max}$ . The corresponding states of polarization,  $Z_{min}$  and  $Z_{max}$ , represent two poles of the sphere that can be considered as the end-points of the  $z$  axis, which we scale here from 0 to 1. The transmittance of any SOP is determined by the projection of its position on the sphere onto the  $z$  axis, and the value  $T$  scales linearly with  $z$  between  $T_{min}$  and  $T_{max}$ , that is

$$T(z) = T_{min} + z(T_{max} - T_{min}), \quad 0 \leq z \leq 1 \quad (\text{Equation 4})$$

The density of surface area and thus of polarization states is uniform along  $z$  between  $Z_{min}$  and  $Z_{max}$ .

A finite sequence of states will generally cover a shorter measured range, not reaching the extreme values, and result in a lower measured PDL. Thus the uncertainty of the measured PDL value depends on the length of the sequence. The influence of this underestimation of the range on the calculation is somewhat different for the cases of low PDL or high PER as discussed below.

For measurements of high polarization dependence, like PER above 20 dB, the influence on the result is asymmetric with respect to a gap in sampling close to  $Z_{min}$  or  $Z_{max}$ . For example at 20 dB,  $T_{min} = 0.01T_{max}$ . A 1% sampling gap at the maximum only underestimates the PER by about 0.04 dB, but the same gap at the minimum causes a 3 dB underestimate. Therefore the sufficiency of a sequence length in this asymmetric case is dominated by the probability of sampling within a given distance from  $Z_{min}$ . The probability that at least one of  $N$  samples is with the range  $0 \leq z \leq a$  is also the probability that not all of the samples fall in the range  $a \leq z \leq 1$ . Assuming a random sampling with uniform distribution along  $z$ , this is given by

$$P = 1 - (1 - a)^n \quad (\text{Equation 5})$$

So for the 20 dB PER example, we could choose a value 0.002 for  $a$ . This leaves an underestimate of about 0.8 dB at 20 dB and a 21 dB PER will give at least a 20 dB result. As shown in Figure 5, a sample length of 3000 or more can provide this coverage with very high confidence.

To achieve a similar 1 dB level of uncertainty for a 30 dB measurement, a 10-times smaller value of  $a$  at 0.0002 must be used. As shown in the figure, this would indicate using a sequence of about 30k samples. A compromise could be  $a=0.0005$ , which allows a 3 dB underestimate at 33 dB PER and can be covered by about 12k samples with very high confidence.

## Characteristics of typical measurement examples (continued)

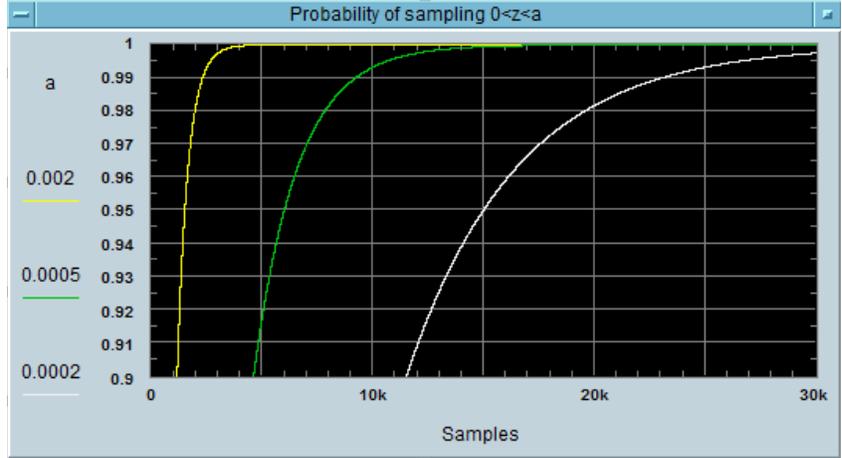


Figure 5. Estimate of the confidence of sampling  $T_{min}$  within a fraction  $a$ .

Please note that the programming procedure described above for randomizing the sequence of polarization states cannot assure a truly uniform distribution. But this is a reasonable approximation for these estimates of sequence length. The validity of the approximation can be checked by measuring a polarizer known to have PER higher than about 35 dB. Increasing the sequence length could be used to compensate for any nonuniformity.

The second case, measuring the polarization dependence of devices with low PDL, has a nearly symmetric dependence on sampling gap at  $Z_{min}$  or  $Z_{max}$ . Based on Eqn. 2, it can be found that if the sampled values cover 90% of the full range, leaving a 10% gap, then for PDL values below about 1 dB, the PDL values in dB will also be underestimated by about 10%. For these PDL values, the position of the measured range between  $T_{min}$  and  $T_{max}$  does not change the calculated result significantly.

In this case, the probability that the samples cover at least the range  $r$  is the probability that the sample with lowest  $z$  is in the range  $0 \leq z_1 \leq 1-r$  and that the sample with highest  $z$  is in the range  $z_1 + r \leq z_N \leq 1$ . This results in the following equation.

$$P = 1 - r^N - n \int_0^{1-r} (1-x)^{N-1} (r+x)^N dx \quad (\text{Equation 6})$$

Note that without the integral term, this equation is identical to Equation 5 when  $r = 1 - a$ . The additional term is added because the target range can be shifted up or down by each sample. The development of this confidence measure with sample length is shown in Figure 6, for several values of  $r$ .

## Characteristics of typical measurement examples (continued)

As shown in the figure, a high confidence for less than 10% PDL ( $r = 0.9$ ) uncertainty can be reached with about 75 samples. An uncertainty due to coverage of 1% could be reached with about 750 samples, but then the noise and repeatability limits of the power measurements will likely dominate the total uncertainty.

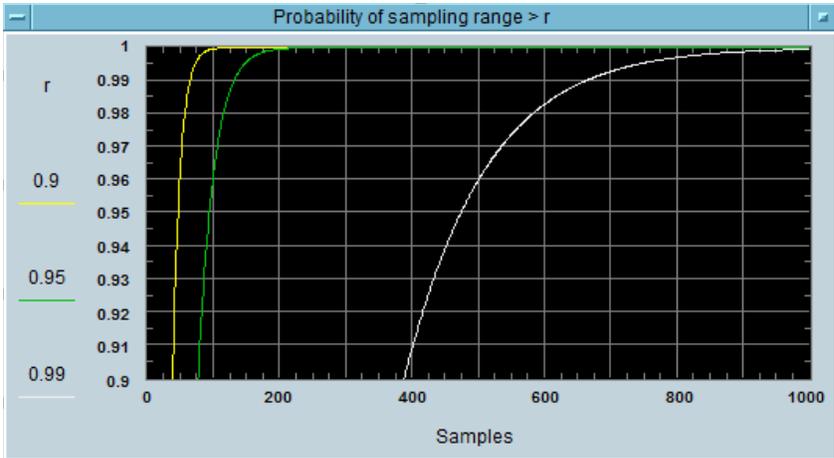


Figure 6. Estimate of the confidence of sampling  $T$  within a fractional range  $r$ .

## Appendix Programming Illustration with Keysight VEE

The following figures are intended to illustrate the programming description, using the Keysight VEE environment.

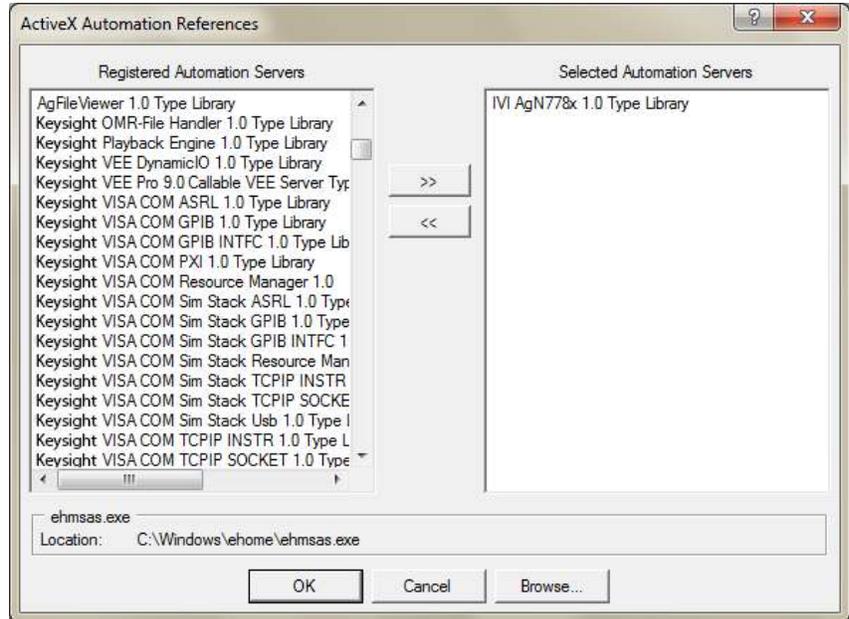


Figure 7. Selection of the library.

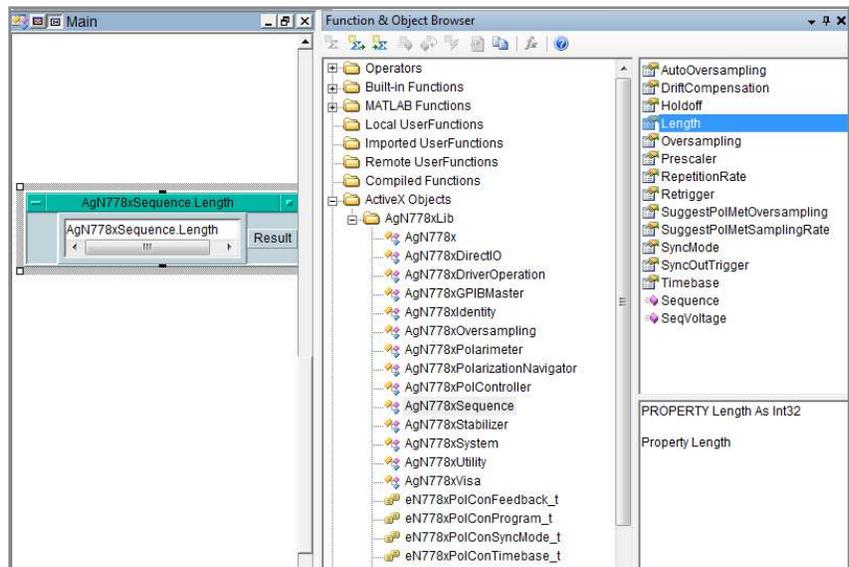


Figure 8. Object Browser.

## Appendix Programming Illustration with Keysight VEE (continued)

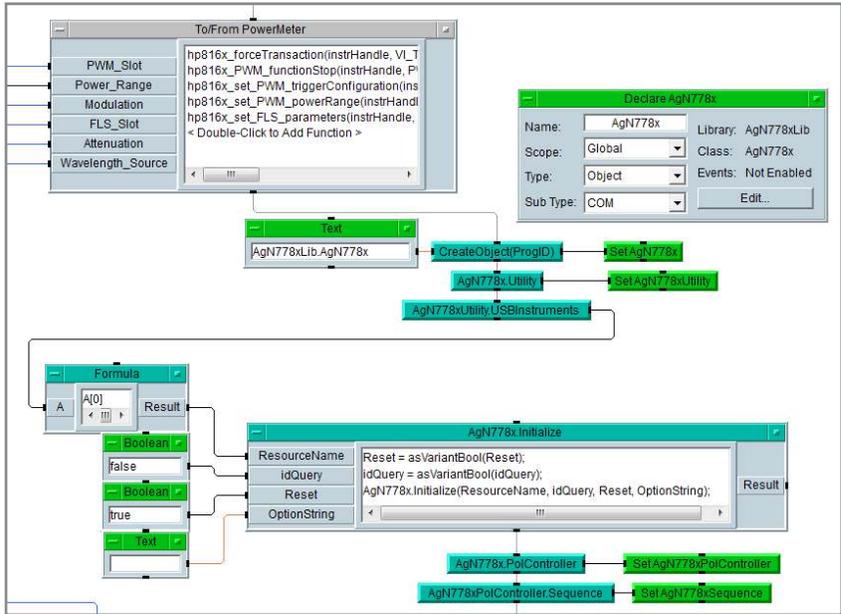


Figure 9. Instrument initialization.

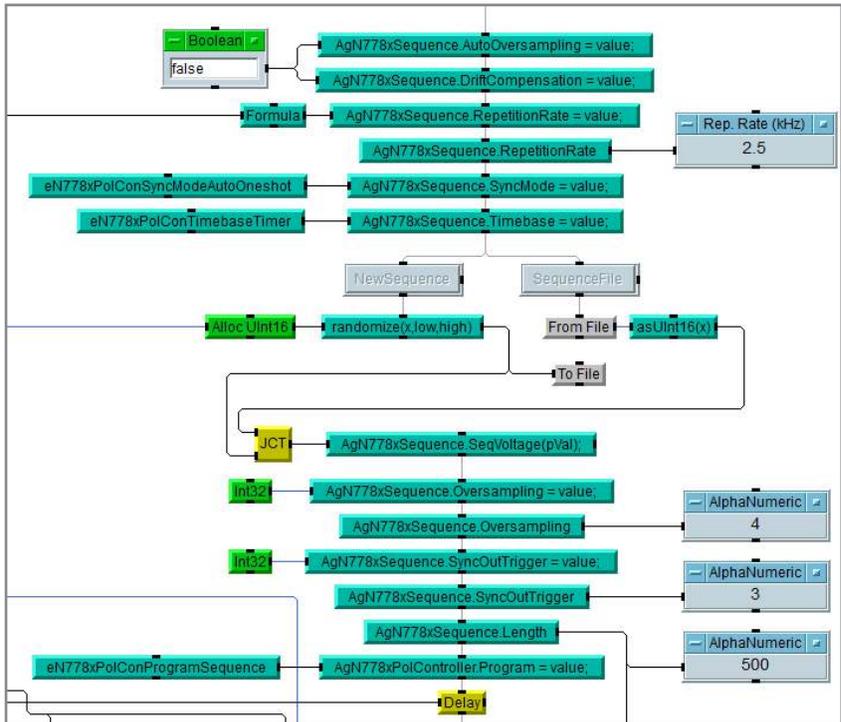


Figure 10. Configuring the Polarization Controller.

## Appendix Programming Illustration with Keysight VEE (continued)

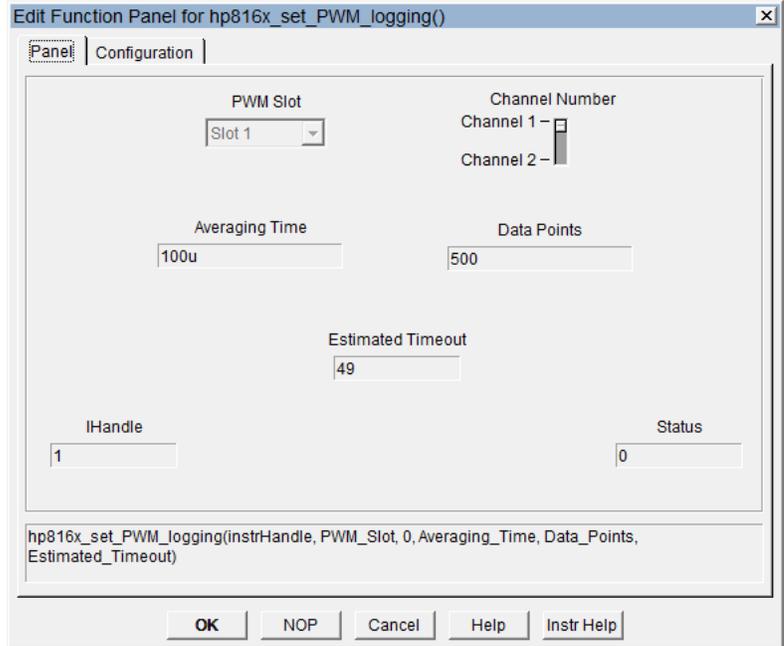


Figure 11. 816x Plug&Play Function Panel for logging function.

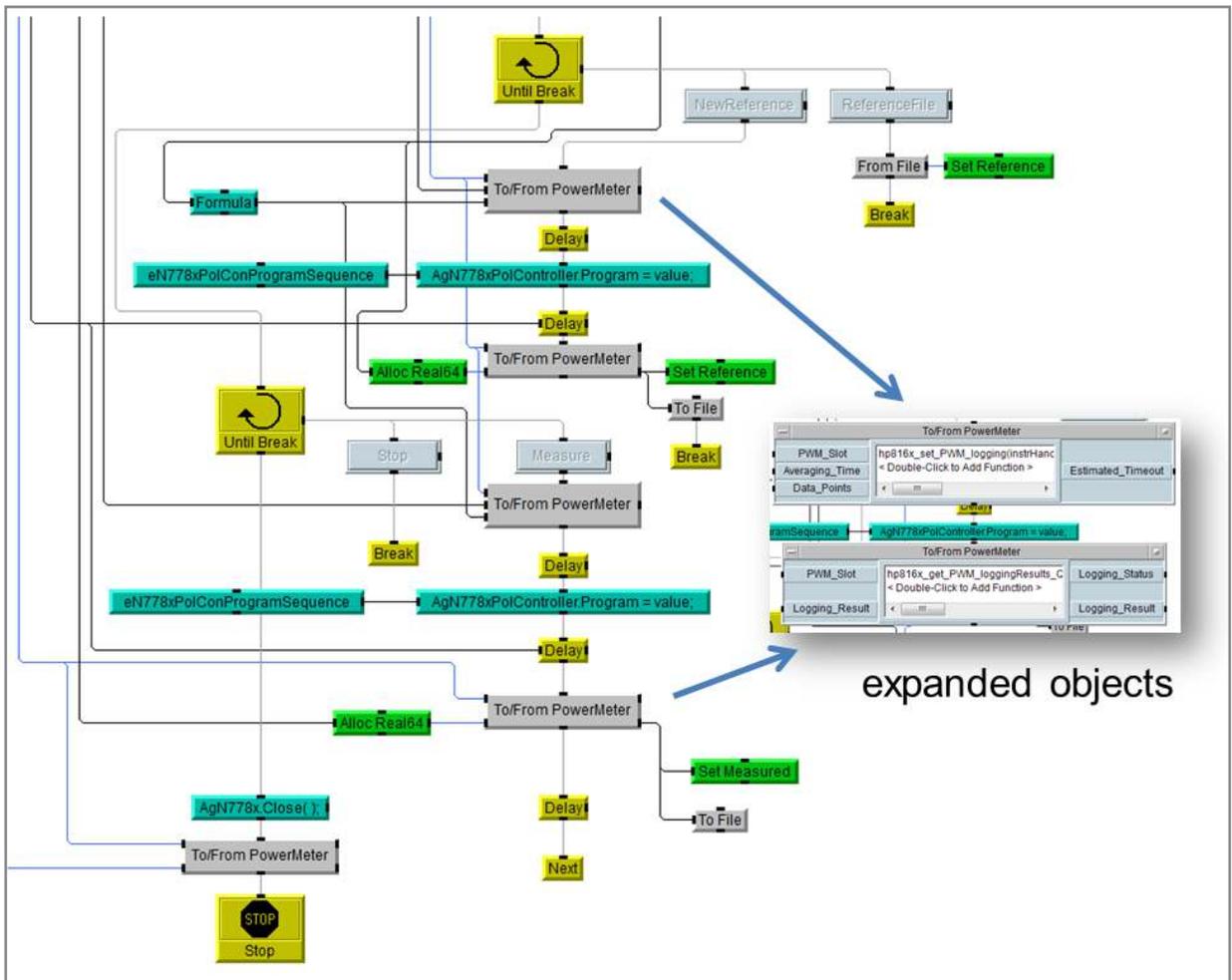


Figure 12. Measurement process.



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