Calibrating Optical Paths in Spectral Test Stations Using the N7700A IL/PDL Software Engine

IL De-embedding

The Keysight N7700A IL/PDL software engine, widely used for parametric measurements of optical-to-optical and optical-to-electrical devices, now has functionality to simplify system calibration in test solutions with multiple optical paths, to support use of optical switches, splitters and especially optical probes for measuring wafers and chips.

This functionality, labeled "IL De-embedding", provides for measuring the wavelength-dependent insertion loss (IL) for the various path segments relative to a common reference, usually during the initial installation or later modification of the test station. The resulting data, or equivalent calibration data obtained in another way, are then saved and can be applied to the corresponding device port measurements. These test station calibration data can retain validity over long duration when the corresponding paths are stable, as when using switches with high repeatability and when avoiding changes of fiber connections.

This note gives an example to illustrate how IL de-embedding can be used.

Optical switching example for an MxN device

Optical switch instruments can provide extremely repeatable selection among multiple optical paths. In an automated test station, this provides rapid path configuration and avoids the delay and insertion loss uncertainty associated with changing physical-contact fiber connections. However, there is usually some difference in IL among the switched paths, both due to possible internal details of the switch and to nearly unavoidable variations in the optical connections between patchcords and the instrument. For best measurement accuracy, instead of frequently repeated reference measurements at each port, it is valuable to calibrate the stable port-to-port differences when the switch is installed, so that later reference measurements made with one path can be correctly applied to the other paths as well. The same approach can also be used when a fiber splitter is used to provide multiple paths.

Optical IL and PDL of a device relate the signal output from the device with the input signal, previously recorded or calibrated as reference measurement. For best results, the reference is repeated periodically and made with the same settings to be used on the device. By using IL de-embedding, the reference data can be applied to multiple optical paths without repeating at each port.

In this example, we consider the use of a switch to extend the basic N7700A IL/PDL setup for measurement of a device with multiple inputs. The basic setup uses a tunable laser and polarization synthesizer to apply an optical signal with variable wavelength and polarization to the device input and uses synchronized optical power meters to measure the signal of each device output port. The additional switch permits selectively addressing any of the device input ports. As a concrete example, we assume an 8x8 device under test (DUT), with the 8 outputs connected to the 8 ports of the N7745A power meter and with an N7734A 1x13 switch connecting to the 8 input ports, as shown in Fig. 1. Other configurations can be handled in a similar way.
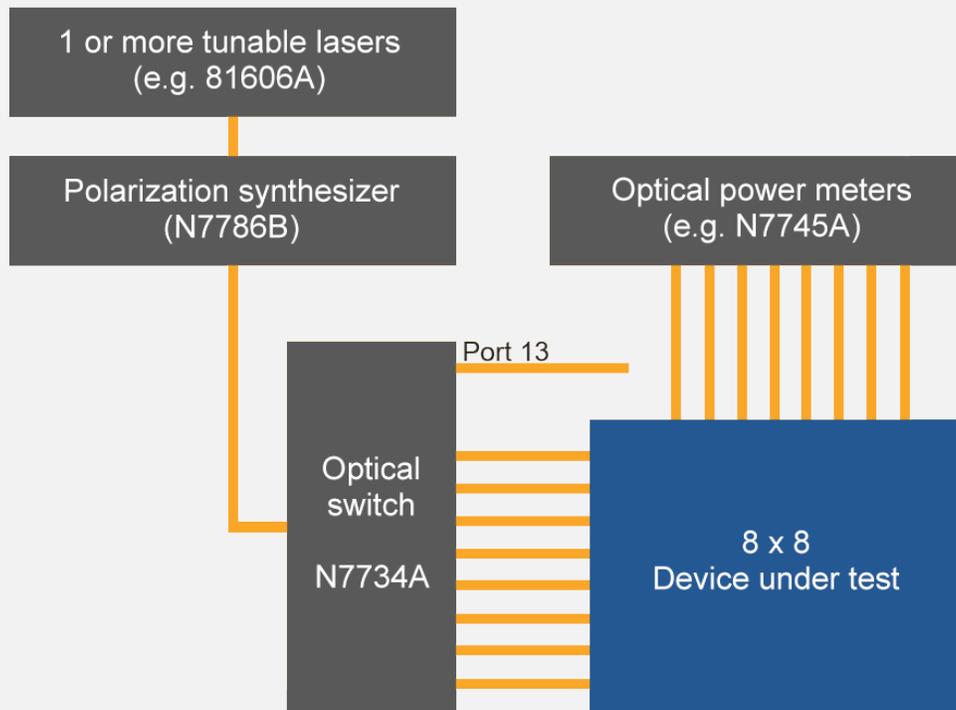

Figure 1: Example setup for measuring an 8x8 optical device

When the test station is installed, the synchronization trigger cabling and optical fiber cords between instruments are connected as described in the documentation for the N7700A IL/PDL software. The fiber connections from the laser, through the polarization synthesizer to the switch should be stable before making the de-embedding calibration measurements on the switch. The stability of the connection from the laser to the N7786B is particularly important as a change in the polarization input to the N7786B between calibration steps can influence the results.

Note: although not required, use of polarization maintaining fiber (PMF) for this connection can be helpful, and is possible since the laser has a PMF output connector.

Next, the hardware should be configured in the N7700A software, which can be installed with the Keysight Photonic Applications Package Manager. Running the Configuration Wizard from the IL/PDL Client, the software will recognize and allow configuring of all appropriate instruments that are connected to the PC and registered with VISA. The IL/PDL configuration must include at least one tunable laser (additional lasers can be included for more wavelength range together with an 81595B switch module for changing the laser signal), one N7786B and one or more detection instruments, like the N7745A multiport power meter or the B2900A-series source/measure unit for photocurrent measurement. The N7734A switch here will not be configured in the N7700A measurement software but should instead be controlled directly from the automation software used to control the workflow, which can also control the N7700A IL/PDL server.

Switch calibration

In our example, the de-embedding calibration measurements should include the IL of the fiber connections to the switch output, so fiber cords that will remain on the switch should be connected for the calibration and these cords will then be used for connecting to the device. The IL of the connections to the device remains as a source of uncertainty in the final measurement result, as usual for measuring IL. One way to minimize this uncertainty is by making a fiber splice connection to the device if it has permanent input fibers without connectors.

The path-specific de-embedding data are determined relative to a chosen "Master Port" measurement. The path for this measurement should ideally be easy to use for future reference measurements. In our example, the 1x13 switch has several output ports free, so we could choose to use Port 13, and connect a fiber cord for these measurements that is then temporarily connected to one of the power meters, e.g. Port 1 of the N7745A as the Master Port. The switch itself should be switched to Port 13.
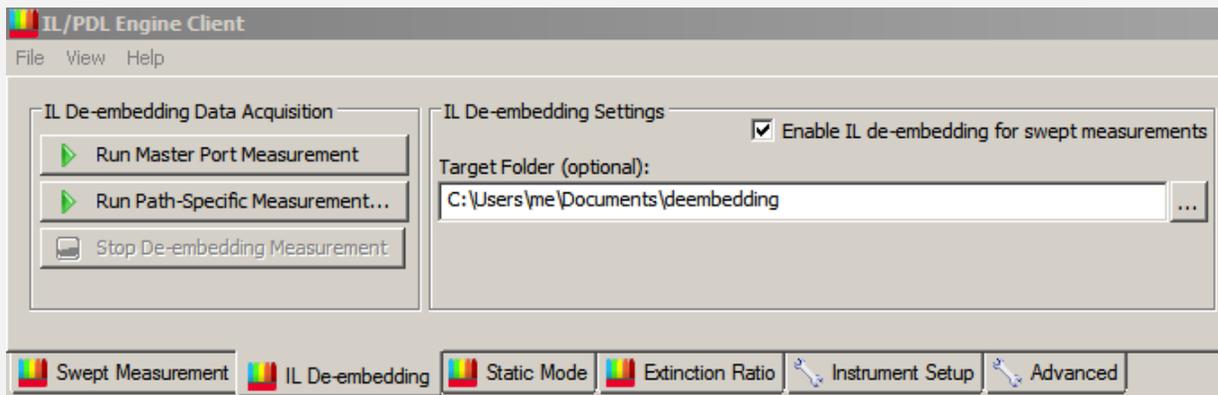

Figure 2: IL De-embedding tab of IL/PDL Engine Client

From the IL De-embedding tab in the IL/PDL software client, the button for "Master Port Measurement" can now be pressed. This will start a measurement sweep over the full range of the tunable laser or lasers and the data will be taken from the power meter port that gets the signal. Like with the polarization dependent loss (PDL) measurements themselves, this sweep is run while the polarization synthesizer repeatedly switches through a set of polarization states, optimized before the sweep starts. This will allow the polarization dependence of the setup to be removed from the IL de-embedding data.

Once the measurement is finished, the software is ready to proceed with a series of measurements for specific paths.

For the first specific port measurement, disconnect the reference cord from Port 1 of the power meter (but leave it connected to Port 13 of the switch for future reference measurements) and connect the cord on Port 1 of the switch to Port 1 of the power meter. The switch should be set to Port 1. In the IL De-embedding tab, a folder can be selected for saving the results. Press the button for "Path-Specific Measurement" and choose a convenient name for the file, like e.g. "Sw1". The measurement sweep will be run in the same way as for the Master Port. The result in the file Sw1.omr will represent the polarization-averaged attenuation difference in dB, relative to the Master Port path. The process should then be repeated for each of the switch output ports, each time connecting the cord on that port to the power meter at Port 1 and switching to that port. The resulting data should have long-term validity for the station under stable conditions, when the connectors are not changed.

Using the IL de-embedding data

The N7700A software measures the wavelength dependent IL and PDL by comparing the signal output from the device with the previously measured signal to be input to the device. This previous step is referred to as the reference measurement. For best accuracy, the device measurement is made with the same sweep settings (wavelength range, sample spacing, polarization states) as the reference. Therefore, the reference measurement is usually replaced periodically to reestablish optimized polarization state settings that can evolve with system and environment temperature, fiber movement, etc., as well as for selection of other sweep parameters. When the path for reference measurement is established, a set of references for different parameter settings, especially wavelength range, can be taken and saved. By using the IL de-embedding data, the reference data can be normalized for application to other optical paths, without needing to make the reference measurement at those ports each time. The software also applies appropriate interpolation, so that the same de-embedding data can be used for measurements with different wavelength ranges and sample spacing (step).

In our case, the reference measurements should be made with the reference cord from Port 13 connected to Port 1 of the power meter, as with the Master Port measurement, of course setting the switch to Port 13 as well. (In some setups, it may be convenient to use a separate quad-adapter on the reference cord for attachment to the N7745A or even a permanent connection to another power meter, instead of disconnecting one of the fibers from the DUT.) The desired settings for the measurement should be chosen on the "Swept Measurement" tab. Then press the button for "Port/Ref. Config". If a previous reference exists, this can be removed with the "Clear Ref." button at the bottom of the Channel Browser, so that a newly optimized set of polarization states can be used. Pressing "New Ref." at Port 1 will then result in making a new reference measurement. When finished, the average power of the measurement is shown, to permit quickly checking whether the connection was correct. Another good confirmation check can be made now by pressing "OK" to close the Browser and then pressing "Run Single" to make a regular measurement on this port. The result should show IL and PDL traces close to 0 dB (assuming no de-embedding data is applied!), confirming repeatability between the reference and measurement sweeps. Otherwise there may be a reason that the reference needs to be repeated.
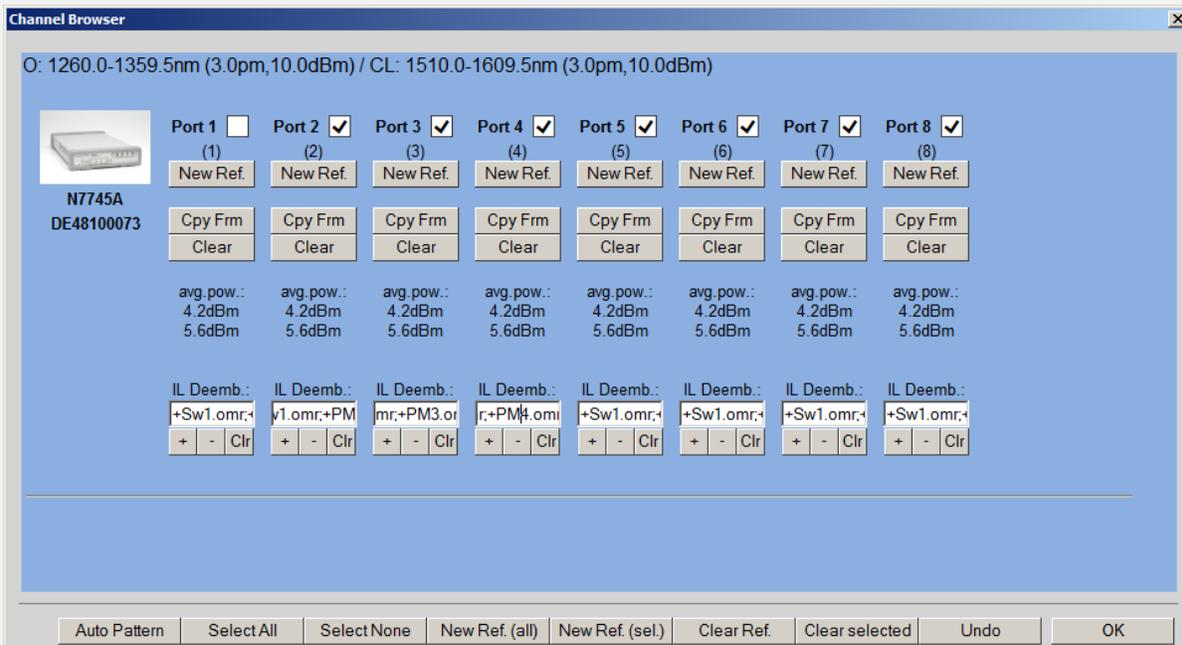
Figure 3: Channel Browser used for configuring the reference measurement and the IL de-embedding

Then, returning to the Channel Browser, the reference measurement can be applied to all desired ports. In our case, we can press "Select All" at the bottom to mark the check boxes of all 8 ports of the N7745A. Then press "Cpy Frm" at Port 1 to "copy from" this port to all selected ports. Now we are ready to apply the de-embedding data files.

The switch de-embedding is used to calibrate the path to the input of the DUT, so all output ports need to use the same switch data. For measurements to the first input port of the DUT, the file Sw1.omr should be used. So in the Channel Browser, under the "IL Deemb.:" field of Port 1, press "+" and find and select this file. The same should be repeated for all 8 ports and can also be done with cut and paste from the first field. Now when the switch is set to Port 1, the station is properly calibrated for this setting. If the 8 output cords from the switch are connected to the power meter, they should give IL close to 0 dB, especially from Port 1 of the power meter. When the measurement signal should be switched to the second input port, the de-embedding settings should be changed to use the file Sw2.omr. This will usually be done with automation commands together with the command to set the switch.

Detector path calibration

The same procedure as used above for calibrating the switch paths into the DUT can be used to calibrate the paths from the DUT to the individual power meters. This is particularly useful if the path includes additional components like switches, couplers, or intermediate connectors. But this can also be used to correct for the usually small differences in power readings among the power meters, which can be estimated from the specifications for absolute power uncertainty and in the case of the N7744A and N7745A from the narrower relative port-to-port uncertainty. Calibrating these differences improves the accuracy of measurements on one power meter based against the reference measurement on another power meter, as was described above.

In our example, the measurements for the detector path calibration files can be made as part of the same procedure used to calibrate the switch. After making the Master Port measurement on Port 1 of the power meter, the same fiber cord on Port 13 should be moved to Port 2 of the power meter for a Port-Specific measurement, written to a file, possibly named PM2.omr. This should be repeated for all power meter ports.

These files can then be added to the corresponding ports in the Channel Browser. So at Port 1 the IL Deemb field could use "+Sw1", at Port 2 "+Sw1;+PM2", at Port 3 "+Sw1;+PM3" and so forth on the remaining ports.

Note that this concatenation of files for de-embedding can also be used with the '-' polarity, in which case the IL data in dB is applied with reversed sign. This is appropriate for example when the file characterizes a component that is present in the reference path, but not in the DUT measurement path.

Example summary

Following the procedure outlined above, measurements properly calibrated for the various paths of the test station can be made, based on a single reference measurement performed with a path that can be conveniently configured when required.

It will usually be most practical to make the measurements for the de-embedding data manually using the IL/PDL GUI client, but to use the automation interface when repeatedly changing the settings and de-embedding configuration for measurements. The software also supports making the measurements with or without de-embedding configured and then later applying the correct de-embedding configuration as post-processing of the saved .omr measurement file. Refer to the N7700A IL/PDL Measurement Engine User's Guide for automation information and further detail.

Application to wafer probing

The IL de-embedding functionality is likely to be helpful for parametric testing with automated wafer probing, where manual steps for referencing and reconfiguration need to be avoided when possible. Some additional flexibility is helpful for this case.

It is not necessary to generate the de-embedding calibration data using the function in the IL/PDL software. If the signal attenuation or insertion loss of a component is known or can be otherwise measured, then that data can also be loaded from a csv text file or an otherwise generated .omr file, as described in the User's Guide.

The csv file can actually be very simple, since the wavelength points will be interpolated as needed. For example, a file to make a wavelength-independent 3-dB offset could look like this, with just 2 pairs of wavelength and loss values.

> 0, 3.0
> 2e-6, 3.0

Providing the IL de-embedding data for a pair of optical probes from a measurement is a good example for using the csv file format as well.

The attenuation of a fiber probe will normally be dominated by the coupling efficiency at the wafer. Assuming this is reproducible for the coupling pads over some area of the wafer, a calibration artefact consisting of two pads connected with a short low-loss waveguide can be measured to obtain the expected loss of coupling to this structure.

A complication is that such coupling pads typically have strong polarization dependence and the relevant measurement data from the DUT is not the polarization averaged IL, but the IL for the preferred state of polarization, such as the transverse-electric (TE) polarization. The IL/PDL software provides analysis to determine the IL spectrum for the polarization axes of the DUT, labeled TE and TM. Often only one of these spectra is of interest and the other may correspond to very weak signal transmission. In this case, the IL de-embedding data should also correspond to that state of polarization. This can be obtained by measuring the artefact structure with the IL/PDL engine (including de-embedding of other elements in the test station if appropriate), then exporting that data to an Excel or csv file (supported by the GUI client) and copying the appropriate data from the TE/TM analysis to a csv file that can then be used for the probe de-embedding.

The same procedures can also be used for test stations that determine responsivity of optical-to-electrical devices with integrated photodiodes by measuring the photocurrent rather than optical power from the device.

For further information, please refer to the documents at http://www.keysight.com/find/n7700.

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