Application Note

De-embedding and Network Extraction

Removing the effects of test fixtures from a VNA measurement

MS4640B Series Vector Network Analyzer,
VectorStar

Overview

Embedding and De-embedding (EDE) is the insertion or removal of networks or circuits around a DUT that may represent fixtures, launching structures, tuning elements, or other items. To perform EDE, the parameters of the network must be known and provided in the form of an sNp file. While there are many methods of deriving these parameters (including simulation), measurement in some way is often preferred. Because of the complex and incompatible media that may be involved, techniques using multiple calibrations (in different connectors or different media) or techniques using a pair of adapters/fixtures back-to-back are sometimes employed. This application note will focus on the process of removing the effects of a 2-port test fixture during the VNA measurement process when a full set of calibration standards are not available. The techniques describe will use the capabilities provided in the VectorStar Universal Fixture Extraction (UFX) Software Option 21.

2-port Extraction

For the two port VectorStar VNA, with Option 21 – Universal Fixture Extraction included, there are six types of extraction techniques available and are shown in the dialog in NETWORK EXTRACTION Dialog Box - 2-Port VNAs (Option 21 Enabled) .

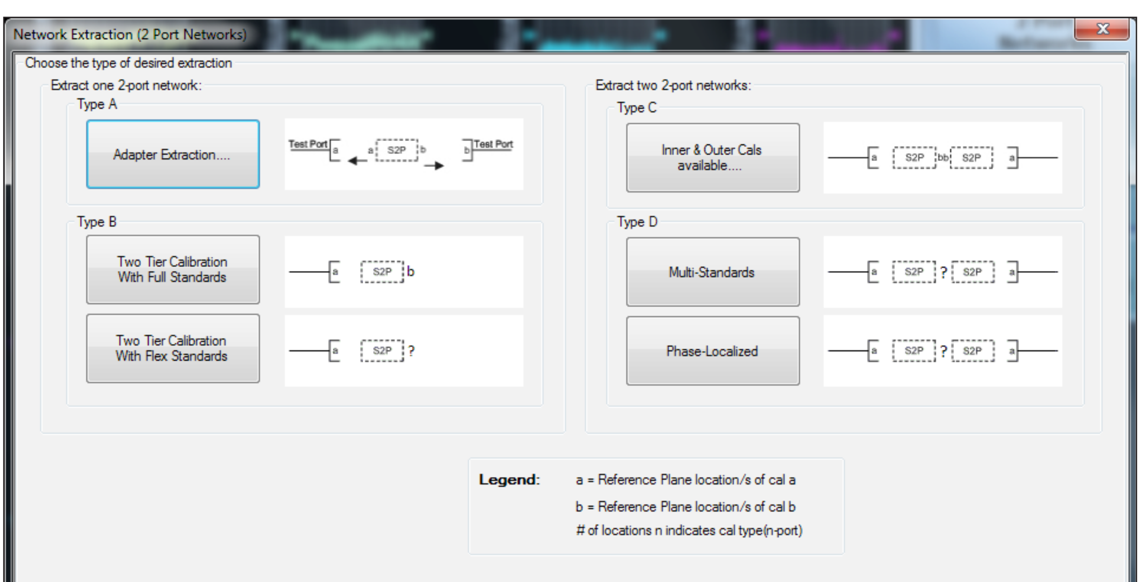


Figure 1. NETWORK EXTRACTION Dialog Box - 2-Port VNAs (Option 21 Enabled)

Type A - Adapter Extraction

Two full 2-Port calibrations are performed; one each with the adapter/fixture attached to one port then the other. A single S2P file describing the adapter/fixture is generated. This is directly the method of standard adapter removal except the parameter file is generated explicitly rather than the calibration being directly modified.

Type B - Two Tier Calibration With Full Standards

A two tier calibration, sometimes called 1-Port de-embedding or the Bauer-Penfield technique. Here a one port cal is performed and then additional standards are measured with the adapter/fixture in place. A thru connection is not required which can be convenient in many cases and a single .s2p file is generated. In the full standards case (an entire second calibration is required at the end of the adapter/fixture), the calculation is similar to Type A except the outer match is handled differently.

Type B - Two Tier Calibration With Flex Standards – Option 21 UFX (Generalized B)

Algorithmically, this is similar to the full standards case but a different, or incomplete, calibration may be performed at the fixture output plane. Additional assumptions are made as the standards count drops (e.g., with one standard, fixture match is neglected).

Type C - Inner and Outer Cals Available

This is the network extraction method available in earlier generations of Anritsu VNAs where full 2 port calibrations are performed at the outer plane (often coaxial or waveguide) and at the inner plane (often a fixtured environment). Two S2P files are generated in this case.

Type D - Outer Cals Using the Divide-By-Two Method (Multi-Standards)

This simplified method is used when standards at the inner plane are difficult to create (as in a complicated fixture structure). Two adapter/fixture “halves” are connected back-to-back and/or with some standards between them and the combination measured using a single outer cal. Assuming the interconnect between the two halves is well-matched and the two halves are identical, S-parameters can be extracted. At least one thru interconnect between halves is needed and an additional (different length) interconnect can be used or high reflection standards can be used at the inner plane. If only one interconnect is used, inner plane match is assumed perfect. Additional information is obtained and accuracy generally improves as more standards are added. Two S2P files are generated.

Type D - Phase Localized – Option 21 UFX

A variation of type D makes use of knowledge of fixture length (through user entry or model fitting) to better localize mismatch and enable a more accurate extraction if the fixture is electrically long enough.

4-port Extraction

The UFX option also supports EDE functionality for differential devices and test fixtures when operating the four port version VectorStar VNA as shown in the dialog in Figure 2.

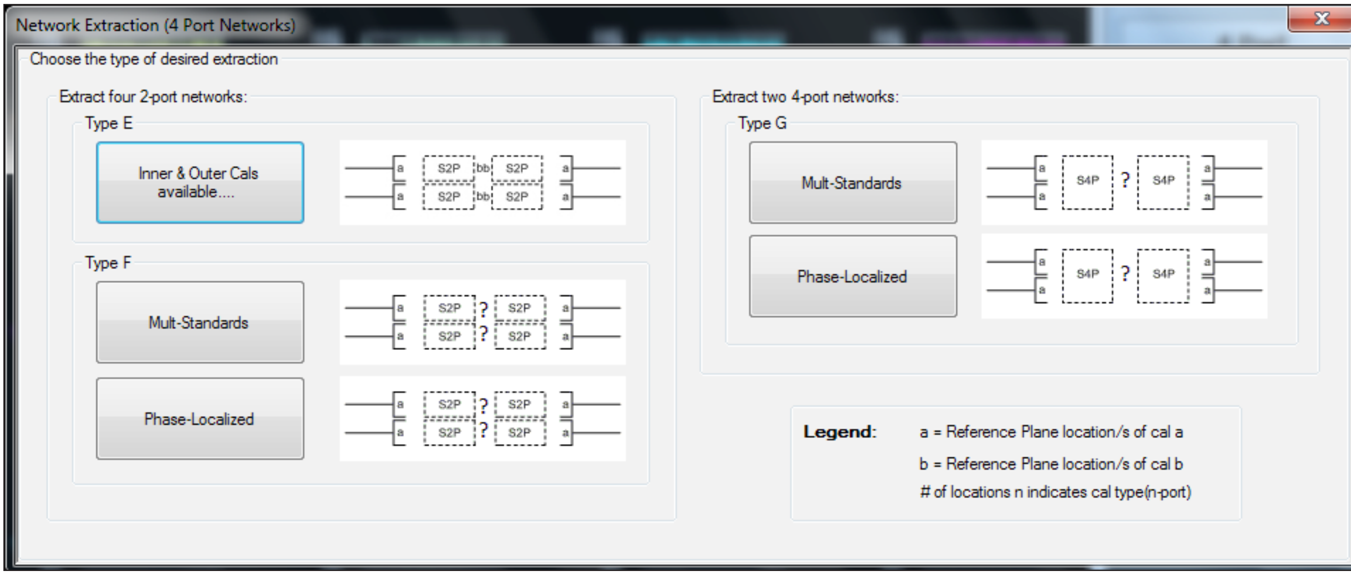


Figure 2. NETWORK EXTRACTION Dialog Box - 4-Port VNAs (Option 21 Enabled)

• Type E Network Extraction

Uses a pair of full 4-port calibrations to fully extract four S2P files describing the arms of the adapter/fixture assembly. This is a complete solution but assumes the arms of the assembly are not coupled together. This is a 4-port extension of Type C.

• Type F Network Extraction

This is a 4-port back-to-back method where four S2P files are extracted and the four arms of the adapter/ fixture assembly are assumed uncoupled. As with Type D (the 2-port equivalent), match is assigned to the outer planes. Port 2 of the .s2p files is assigned to the port nearer the DUT as is consistent with the de-embedding system operation.

• Type G Network Extraction

This is a 4-Port back-to-back method where two S4P files are generated and the sides are assumed coupled (in a half-leaky sense). Measured cross-coupling is assigned to the outer planes. Port assignments on type G can be complex and the examples in the text should be noted.

• Universal Fixture Extraction

With Universal Fixture Extraction additional choices are available for Types F and G:

- Multiple Standards can be used (two lines, one line plus reflect standards, two lines plus reflect standards) instead of using just the single thru line in traditional F and G.
- The use of Phase Localization (with either a line standard or a reflection standard set) to get better estimates of network parameters based on the phase slope of the measured data.

De-embedding a 2-port Test Fixture

The remainder of this application note will describe the process of de-embedding a 2 port test fixture using the two choices available for the Type D de-embedding tool with the UFX option. These techniques support typical situations when a test fixture is used to mount a non-connectorized 2-port device for measurement. The two methods described will use the Type D Multi Standard method and the Type D Phase Localized approach. Compared to the Type D without the UFX option (Figure 3), the two methods offer choices determined by the type and number of calibration standards available as well as the characteristics of the test fixture (Figure 2). Additional description on which of the two techniques should be used and when will be discussed at the end of this note. For guidance in additional EDE techniques, including support for 4-port differential measurements, please refer to the VectorStar Calibration and Measurement Guide (PN 10410-00318) available on the Anritsu website at www.anritsu.com.

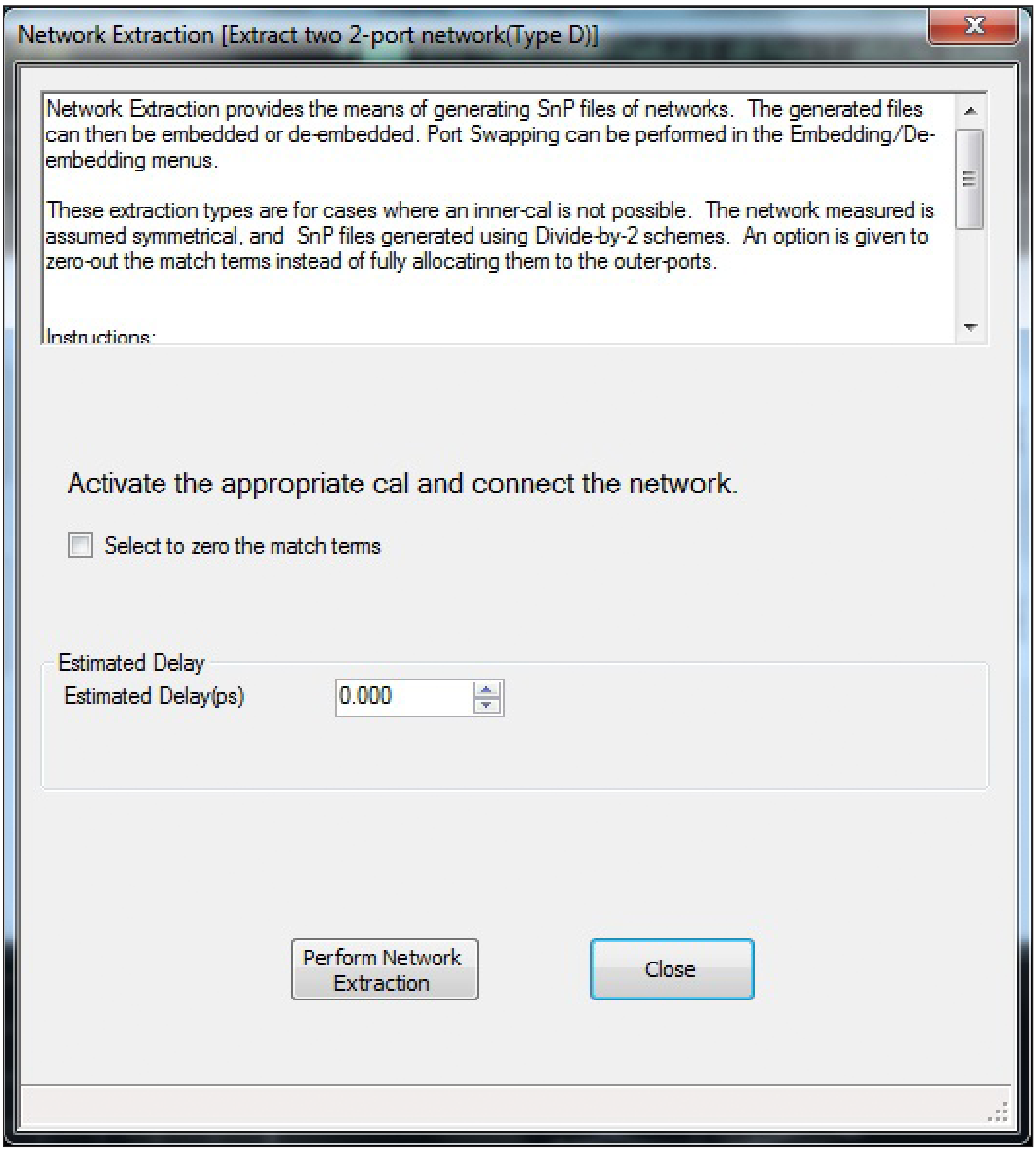


Figure 3. NETWORK EXTRACTION Dialog Box Type D (Without Option 21)

Without the UFX Option 21 characterization of the fixture is limited to assuming fixture is symmetrical and with perfect match at the inner plane.

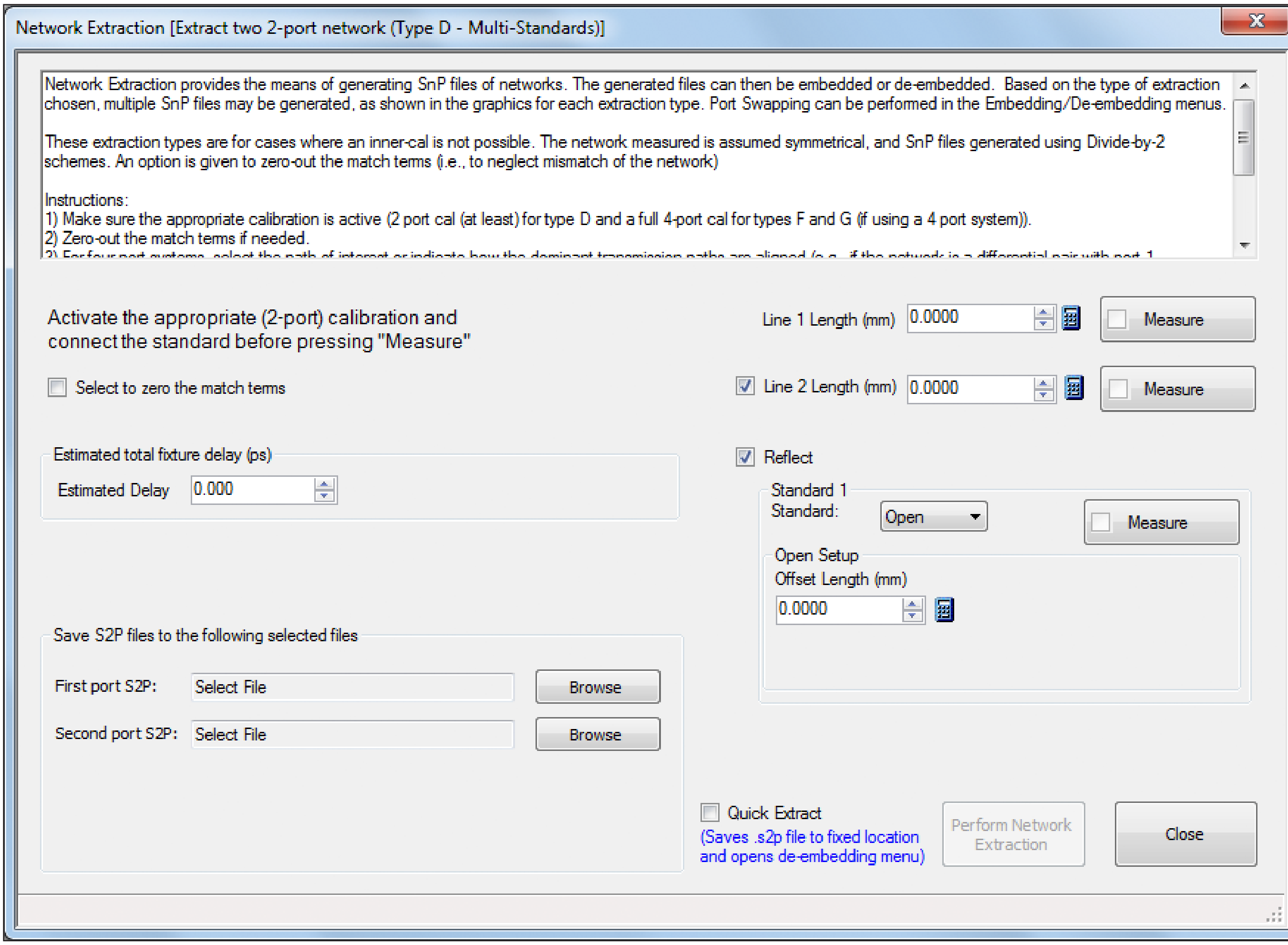


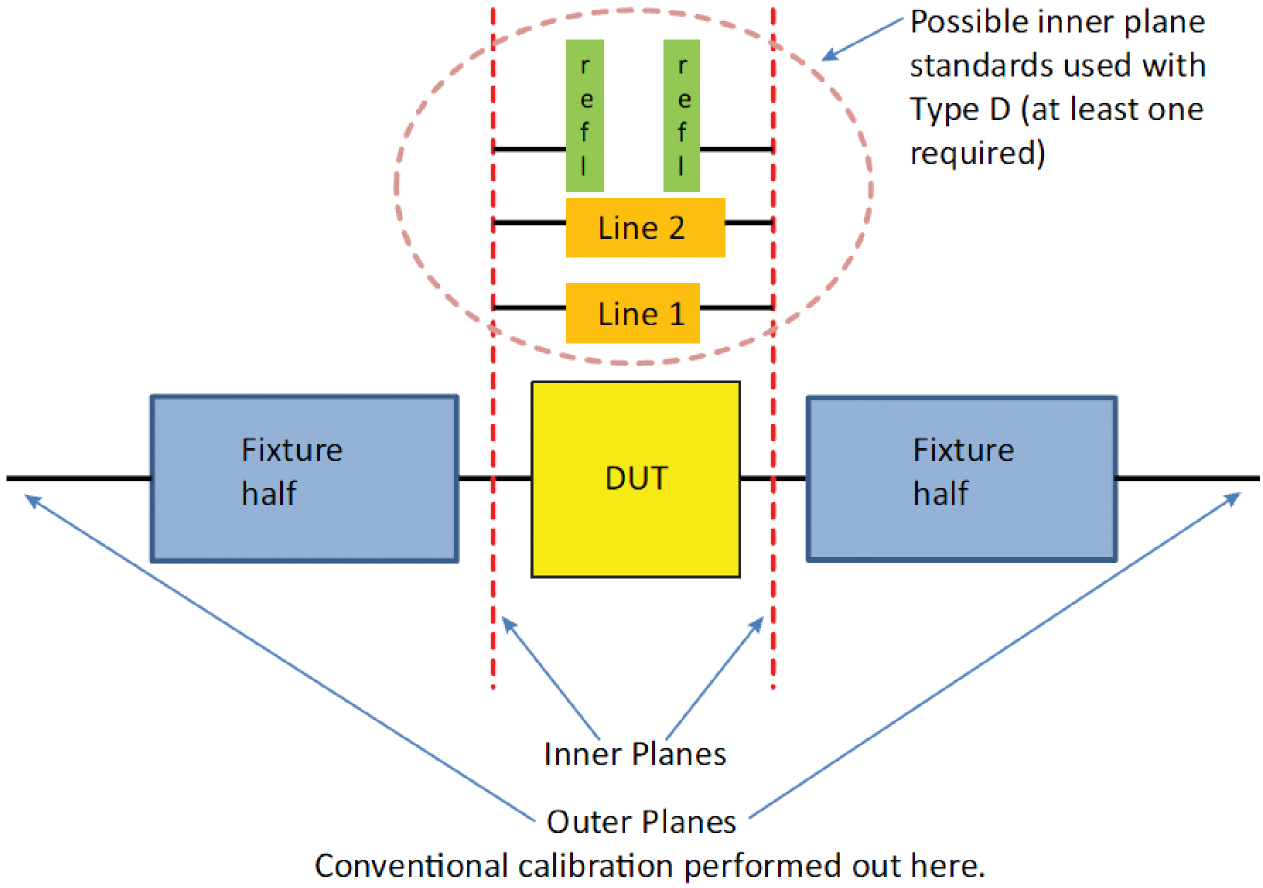
Figure 4. NETWORK EXTRACTION Dialog Box Type D Multi-Standards (With Option 21)

Type D Network Extraction – Multi Standards (with Option 21)

The UFX technique is different from the traditional techniques in that it relies only on a limited number (1-3) of measurements to extract parameters rather than relying on the manipulation of a pair of full 2-port 12-term calibrations. A full 2-port calibration is performed at the outer planes (often in coax or waveguide or with on-wafer probes) and then simple standards (one or more lines and possibly a single high-reflect standard) are connected between the fixture halves as suggested in Network Extraction Type D .

This technique belongs to a class of approaches that have been termed 'partial information techniques' since they make additional assumptions about the fixture to avoid the necessity of a full calibration at the inner plane. As such, these techniques are particularly attractive when the inner plane has a complex structure or geometry that makes it difficult to create many standards for that plane or difficult to accurately model those standards. There are also cases where such methods are useful because the repeatability of connection at the inner plane is degraded. By de-emphasizing inner plane match in those cases, sensitivity to repeatability issues can be reduced.

There are a number of different ways to use Type D and this application note will explore the differences and how one might choose the sub-approach to take.



The basic structure of Type D extraction is shown here. There is considerable choice in the standards used at the inner plane but the combinations all share the fact that the set is not 'complete' in the sense of a full calibration at that plane. Some fixed error is accepted in exchange for simpler standards and more immunity to repeatability issues.

Figure 5. Network Extraction Type D

Quick Extract

The Quick Extract check box disables the file entry fields and instead saves the output file to a pre-determined location and automatically starts the de-embedding engine. The file just saved will automatically be loaded into the de-embedder (where it can be edited). This process can help save time if the desire is to immediately de-embed a fixture that was just extracted. Note that any de-embedding in place prior to the extraction will be cleared (and the system will warn if this is about to happen). If de-embedding was on when extraction was run, those de-embedded values will be used during extraction so some caution is advised as it is possible to partially negate an extraction by using already partially-de-embedded data.

Type D Network Extraction – Multi Standards Procedure

Type D Multi Standards Instructions:

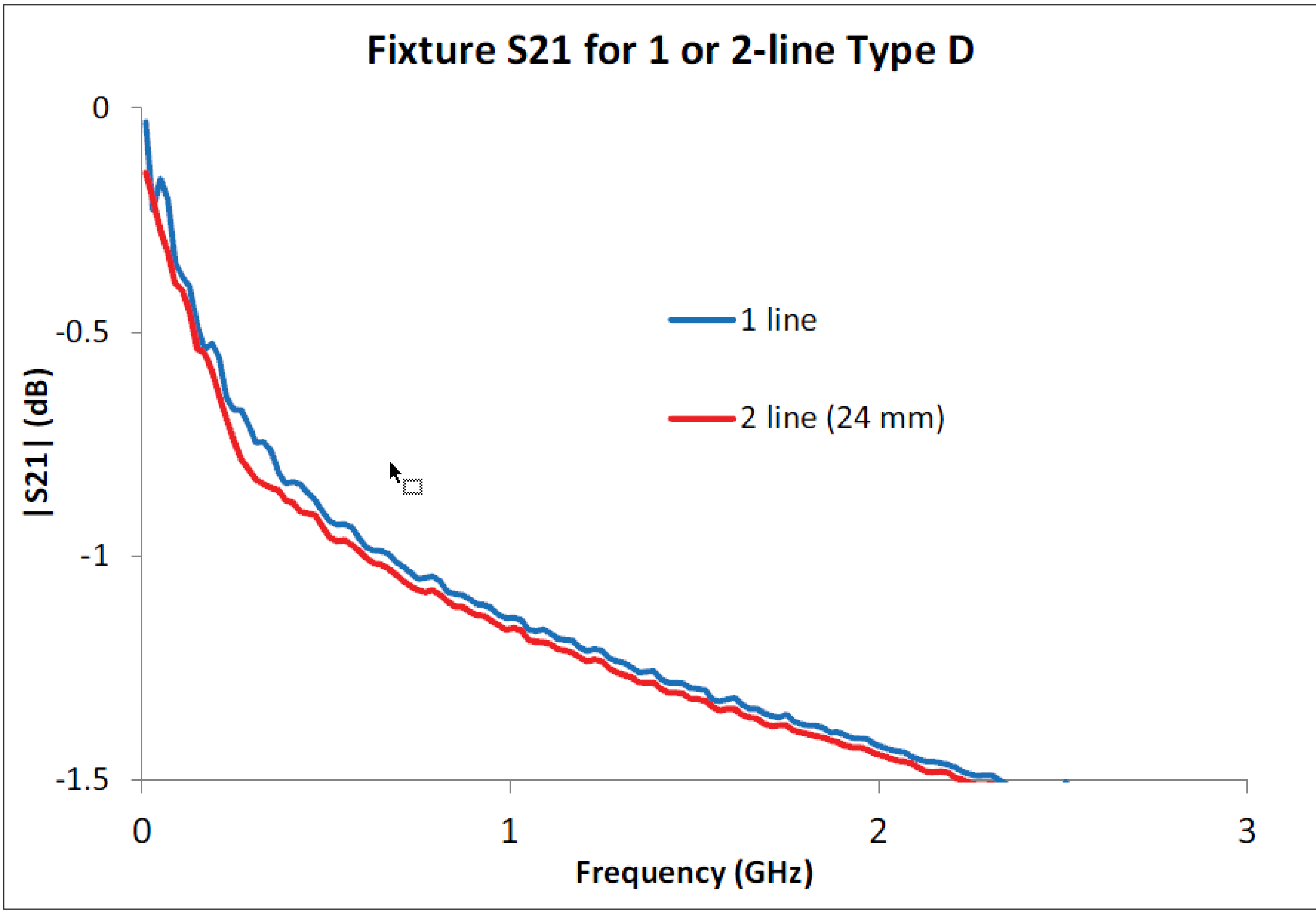
1) Make sure the appropriate 2 port calibration is active for type D.
2) Zero out match terms if desired (this sets all reflection terms to 0 and may be helpful if the fixture is extremely unrepeatable).
3) Select the number of standards to be used and their definitions. Line 1 is always required.
4) Connect each standard (or standards in the case of Reflect; all ports must have the Reflect connected simultaneously) before pressing Measure.
5) Enter the file names and path where the output .s2p files will be stored. The Quick Extract option can be used instead: time stamped files will be saved to a predetermined hard disk location and the de-embedding engine will automatically load those files. Remember to keep track of available disk space.
6) When all fields have been entered and all standards measurements have been completed (all of the check boxes marked), press ‘Perform Network Extraction’. If successful, a confirmation dialog will appear.
7) If Quick Extract was not selected, after the .s2p files have been saved, go to Measurement / Edit Embed/ De-embed / Edit Network configuration panel to recall the .s2p files and configure the network.

The basic Type D extraction starts with a line between fixture halves as mentioned and will assume symmetry of the fixture halves. This line can have any length but that length must be specified and any errors in that specification will map through to the phase lengths of the extracted fixtures. If one stops here, the mismatch at the inner planes of the fixture will be ignored (S22 will be zero in the extracted files). One can also elect to set all match terms to zero and that will force both S11 and S22 to zero no matter how many standards are used. This zero-match choice can be useful if repeatability at the inner plane is particularly poor and insertion loss/phase correction for the fixture is the primary concern (doing a closer-to-full match correction with a very non-repeatable interface can often further reduce the transmission extraction accuracy). A fixture length entry is requested (represents both halves together) and this is used just for root selection so precision is not normally required. If zero is entered for the fixture length, an automatic routine is used to estimate the length.

One can also add a second line of some different length (and its transmission amplitude can be entered independently) and inner plane match will no longer be ignored. Note, however, that the accuracy of the entered line lengths is more important in this case. Also, the line length difference between the first and second lines should not approach 180 degrees within the frequency range of interest (or be too close to 0). Generally, the line length difference should be between ~10 and 160 degrees over the frequency range of concern.

The use of reflection standards (which must be placed on the inner planes of both fixture halves) will also allow for solving for inner plane match. Finally, one can use all three standards which will generally improve accuracy on both insertion loss and inner plane match. The choice on how many of the standards to use should depend on how well those standards can be made (e.g., can a second line length be made that is still relatively well-matched as a transmission line, can reflect standards be made that have relatively uniform reflection magnitude over the frequency range of interest, etc.). Implicit in this is that the measured characteristics going from the first standard to the second standard do not change for other reasons (e.g., if the structures being measured are different implementations of the same fixture, then they must be quite identical). Generally, if additional standards perform well in this sense, using them will improve the overall extraction.

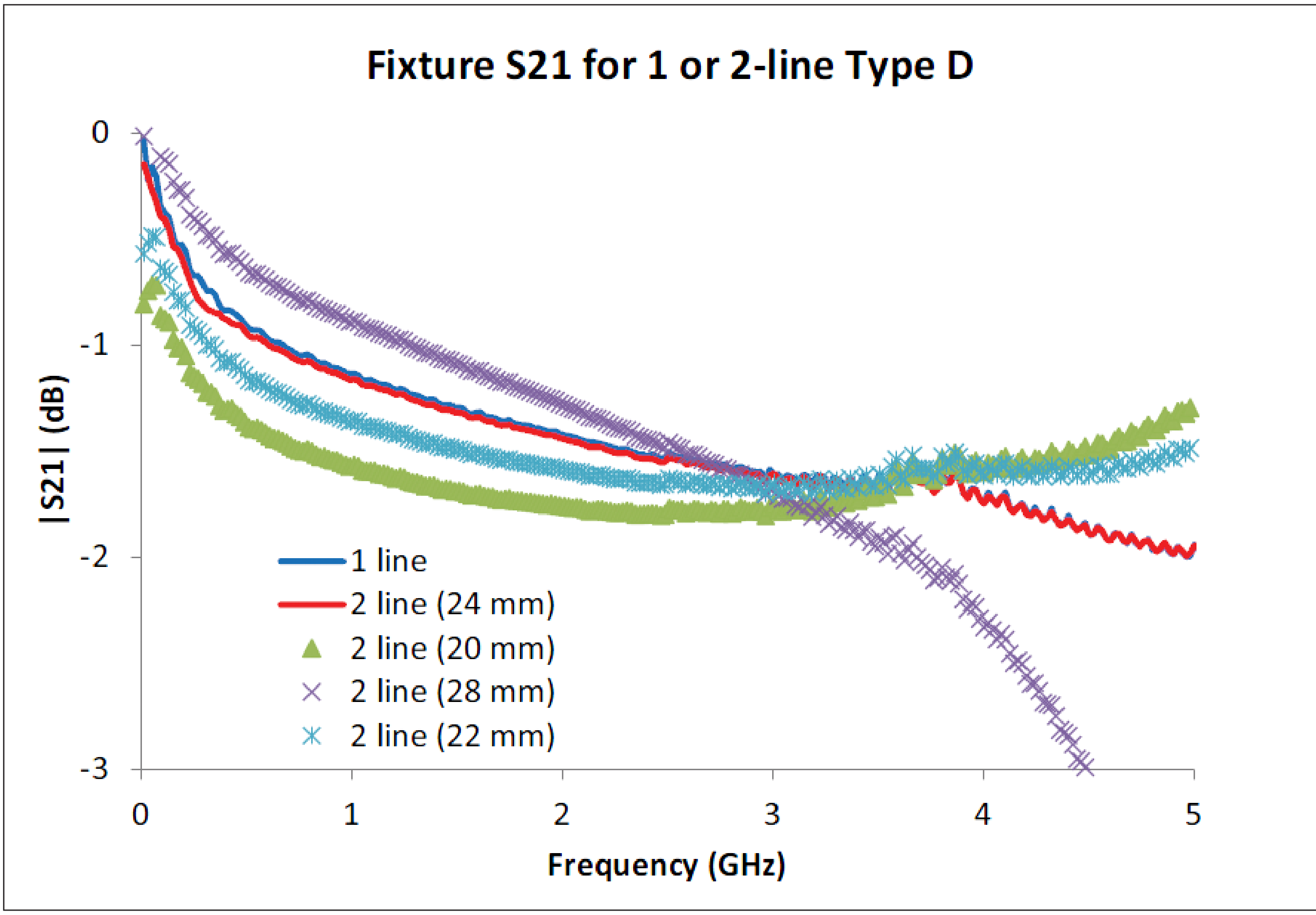
As an example, consider the measurement of a back-to-back cable assembly where two different thru lengths are possible at the inner plane (0 and 24 mm). If one compares the single line approach to the two line approach on extracted insertion loss, one can see some differences (Comparison of Single and Double Line Type D Extractions of Insertion Loss). The single line approach produces an insertion loss with slightly more ripple and a slightly more optimistic overall value (although errors in either direction are possible).



A comparison of single and double line Type D extractions of insertion loss are shown here. With a correct standard length entry and sufficient repeatability, the double-line method can increase accuracy of the extraction.

Figure 6. Comparison of Single and Double Line Type D Extractions of Insertion Loss

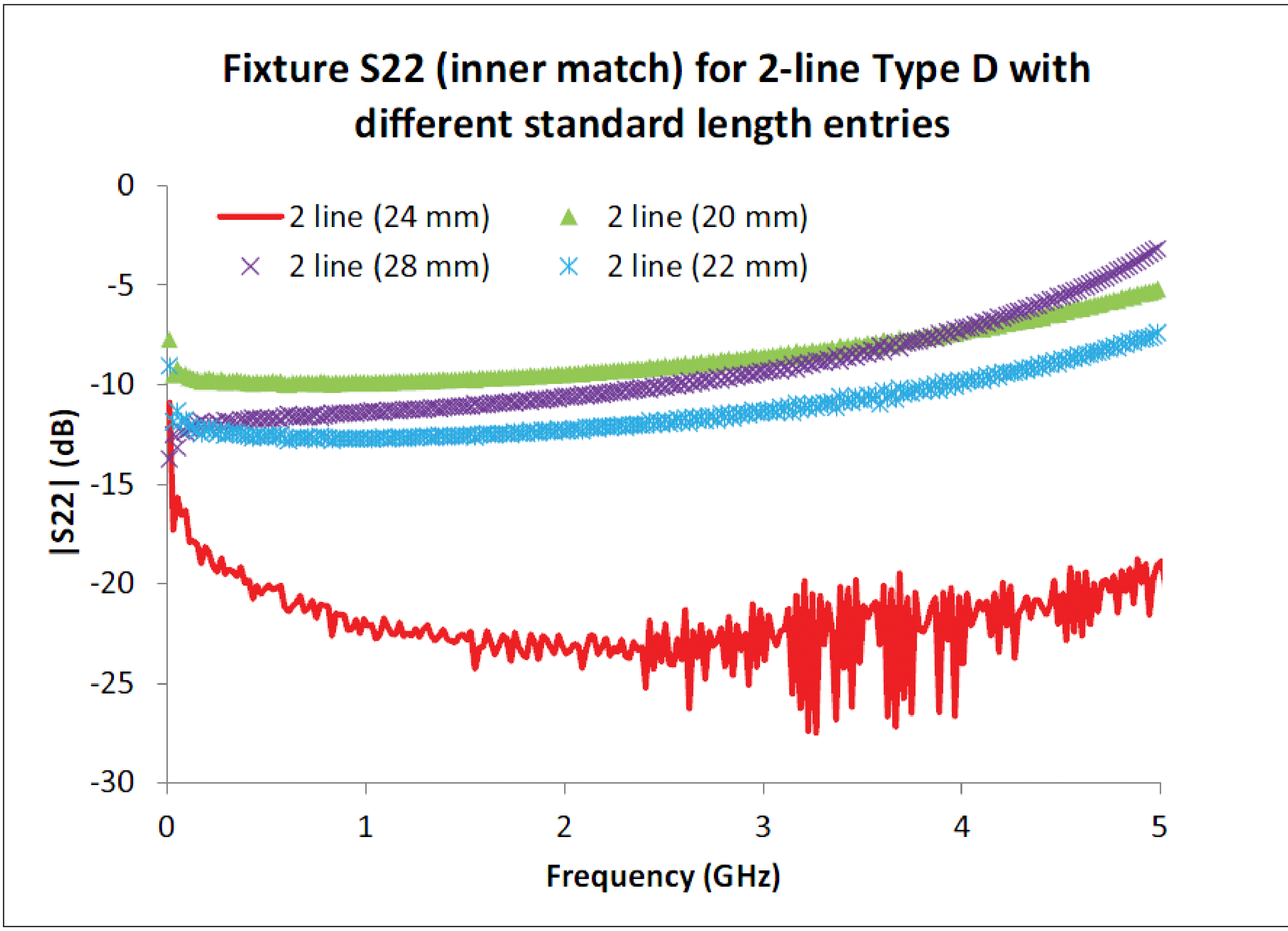
If the entry of the standard line length is not accurate, however, substantial errors can result. The extraction of the previous figure is repeated in Resulting Error with Inaccurate Standard Line Length Entry for the added cases when the 2nd line length is off by ~10 or 20 %. The errors are a few tenths of a dB at low frequency but grow larger at high frequencies as the standing wave that is being corrected grows more dense. Also, in this case, the 28 mm entry brings a singularity to lower frequencies and this has an even more substantial effect on the error.



The results of Comparison of Single and Double Line Type D Extractions of Insertion Loss are augmented here with two line cases when the entered length of the second line is incorrect (correct value is 24 mm).

Figure 7. Resulting Error with Inaccurate Standard Line Length Entry

One reason for using the two line approach (or line+reflect) is to get more reasonable values for inner plane match which can be important for sequential de-embedding and modeling. Again, the parameter entry accuracy is important for the inner plane match as it was for insertion loss extraction. The inner plane match values for the fixture of Resulting Error with Inaccurate Standard Line Length Entry are shown in Inner Plane Match Values for the same length entries.



The inner plane match values for the experiment of Resulting Error with Inaccurate Standard Line Length Entry are shown here. Even a 10 % length entry error causes ~10 dB errors in return loss.

Figure 8. Inner Plane Match Values

The single-line version of Type D is best obviously for well-matched fixtures relative to loss (i.e., very well matched if low loss and moderately well-matched for moderate loss). With a 20 dB return loss, there will be generally 0.3 dB or more of insertion loss uncertainty with this technique (as opposed to ~<0.1 dB with other techniques if good standards are available). With a 10 dB return loss fixture, it will be several dB of uncertainty. With additional standards (assuming accuracy of length entries and sufficient repeatability), the method becomes more mismatch tolerant – often keeping errors under 1 dB for a 10 dB return loss fixture – but the results will still be worse in an absolute sense than with a complete method (assuming the latter was possible).

Additional Notes Regarding Type D – Multi-standards

- A full 2-port calibration must be active and the extraction will be run over that frequency range. For four-port systems, at least a full 2-port calibration must be active.
- The line and reflect offset lengths are entered in millimeters although a calculator is available if values are in picoseconds. If the material type is setup (from the current calibration or manually thereafter), that and any active dispersion relations will be used in the calculations. In two-line cases, the first and second lines must be electrically distinct (i.e., phase length differences not too close to 0 or 180 degrees within the frequency range of interest).

Type D Network Extraction – Phase Localized (with Option 21)

Another variation of Type D is termed ‘Phase Localized’ where a single standard (either a line or a reflect/reflect pair) is used along with the assumption that the fixture is electrically long enough (based on the frequency range being used) and the bulk of the fixture mismatch is not too close to the inner plane. The dialog for setting up phase localized extraction is shown in NETWORK EXTRACTION Dialog – Type D – Phase Localized (With Option 21) .

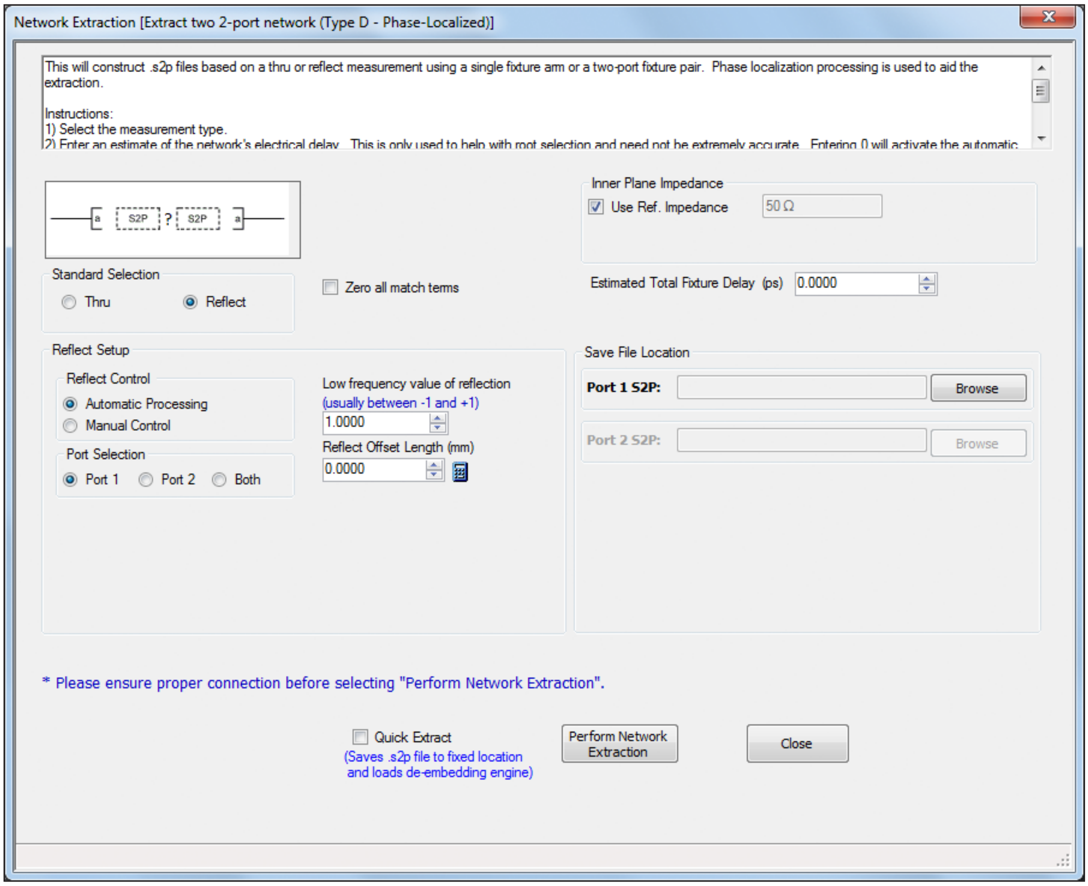


Figure 9. NETWORK EXTRACTION Dialog – Type D – Phase Localized (With Option 21)

Type D Phase Localized Instructions:

1) Make sure the appropriate 2 port calibration is active.
2) Zero out match terms if desired (this sets all reflection terms to 0 and may be helpful if the fixture is extremely unrepeatable).
3) Select the measurement type (using thru or reflect standards). Note that for reflection, the type of reflection must be the same on all ports.
4) Define the standards being used (offset length, transmission or reflection magnitude, include the sign of reflection)
5) Enter an estimate of the network's electrical delay (both sides of the fixture pair). Entering 0 will activate the automatic length estimator. If using a reflect measurement, this can be further refined using ‘Manual Control’ where the fixture halves can be treated as asymmetric and only one side can be done if desired.
6) Enter the file names and path where the output .s2p files will be stored. The Quick Extract option can be used instead: time stamped files will be saved to a predetermined hard disk location and the de-embedding engine will automatically load those files. Remember to keep track of available disk space.
7) When all fields have been entered and proper connection of the standard(s) has(have) been made, click on 'Perform Network Extraction'. If successful, files will automatically be saved and a confirmation dialog will appear.
8) If Quick Extract was not selected, after the .s2p files have been saved, go to Measurement / Edit Embed/De-embed / Edit Network configuration panel to recall the .s2p files and configure the network.

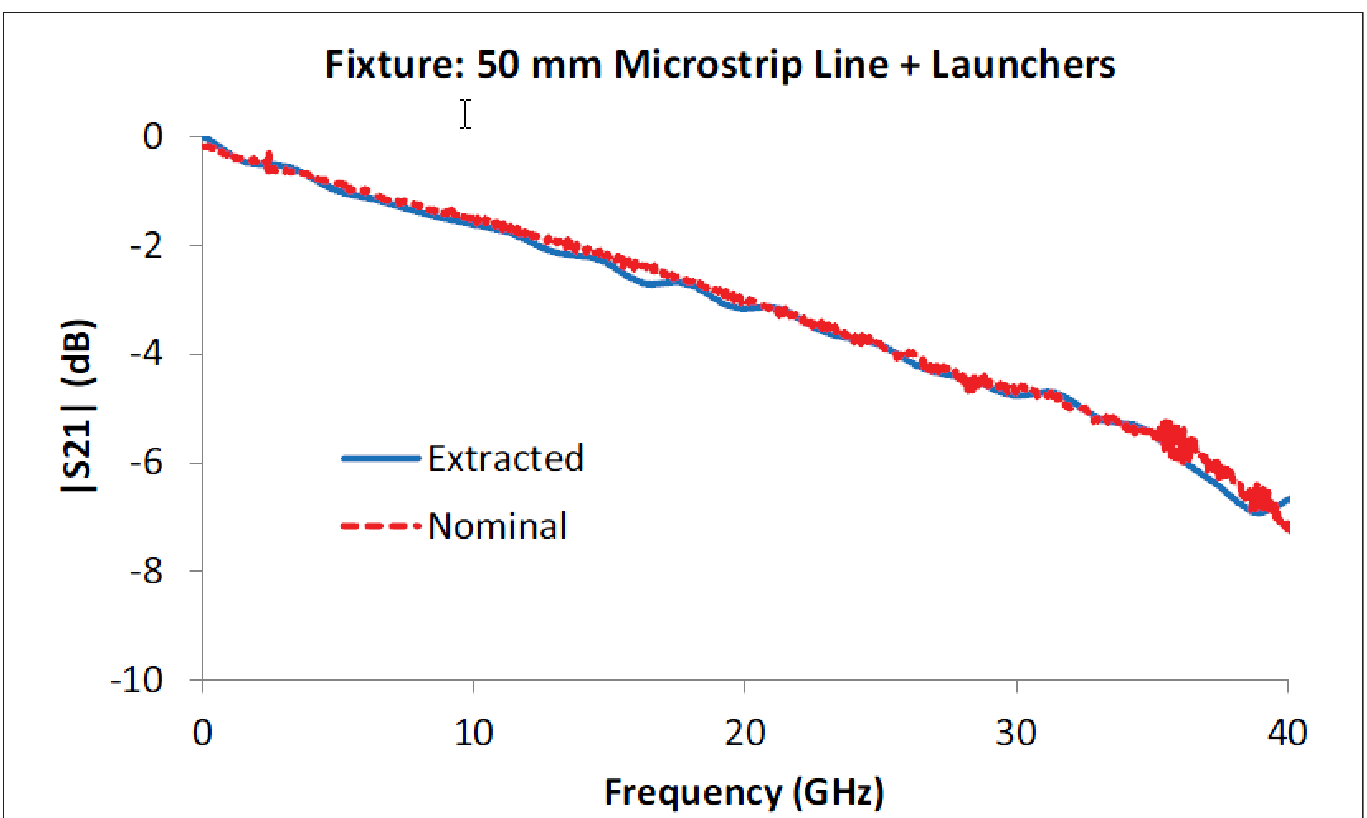
If the assumptions regarding the fixture electrical length and mismatch are met, this method can outperform the previously discussed Type D variations. More central to this method is the fixture length as transmission-line-like: functions are cross-correlated with the measured data to better isolate insertion loss and reflection coefficients of the fixture halves. If the fixture length entry is set to zero, an automatic process will estimate the length. As before, entries for the line length or reflect offset length are required and any errors in those values will translate to extracted parameter phase. If the line is chosen as the standard, symmetry between the fixture halves in terms of insertion loss will be assumed. If the reflect standard is chosen, no symmetry is assumed and only one half of the fixture can be extracted if desired. If both halves are to be extracted, length estimates for the individual arms can be entered. In this variation of Type D, there is no Measure button and the measurement is executed when Perform Network Extraction is selected.

As an example, consider a fixture consisting of a ~50 mm microstrip line, a coaxial launcher on one end and a DUT-local launcher on the other end (for each arm of the composite fixture). Suppose only an open standard is available and one would like to use the phase-localized approach since there was only the one standard and it was believed that most of the mismatch was away from the DUT interface. In this case, it was possible to do a complete calibration at the inner reference plane so a comparison was possible. The extracted vs. nominal insertion loss is shown in Microstrip Line Example . One can see pretty good agreement until about 30 GHz when it did work out that DUT-plane mismatch on the fixture was getting large. Further, the fixture started having significant radiation above about 35 GHz which further complicated the extraction. The return loss (extracted and nominal again) values are also plotted in Microstrip Line Example and again show reasonable agreement until the very high frequencies. Recall that uncertainty in return loss in dB terms gets much larger as the match gets very good just based on a residual directivity argument (a few dB at the –20 dB level for a decent coaxial calibration).

This example does reinforce a couple of points:

- Partial information methods do have some fixed error because of the incomplete 'calibration' at the inner plane
- The further the fixture deviates from the ideal aspects assumed by the method (where mismatch is located in this case), the larger those errors become.

Still, if it was indeed only possible to have an open standard for this fixture, the results shown here are better than one could achieve with a single-standard generalized B method or with a simple normalization.



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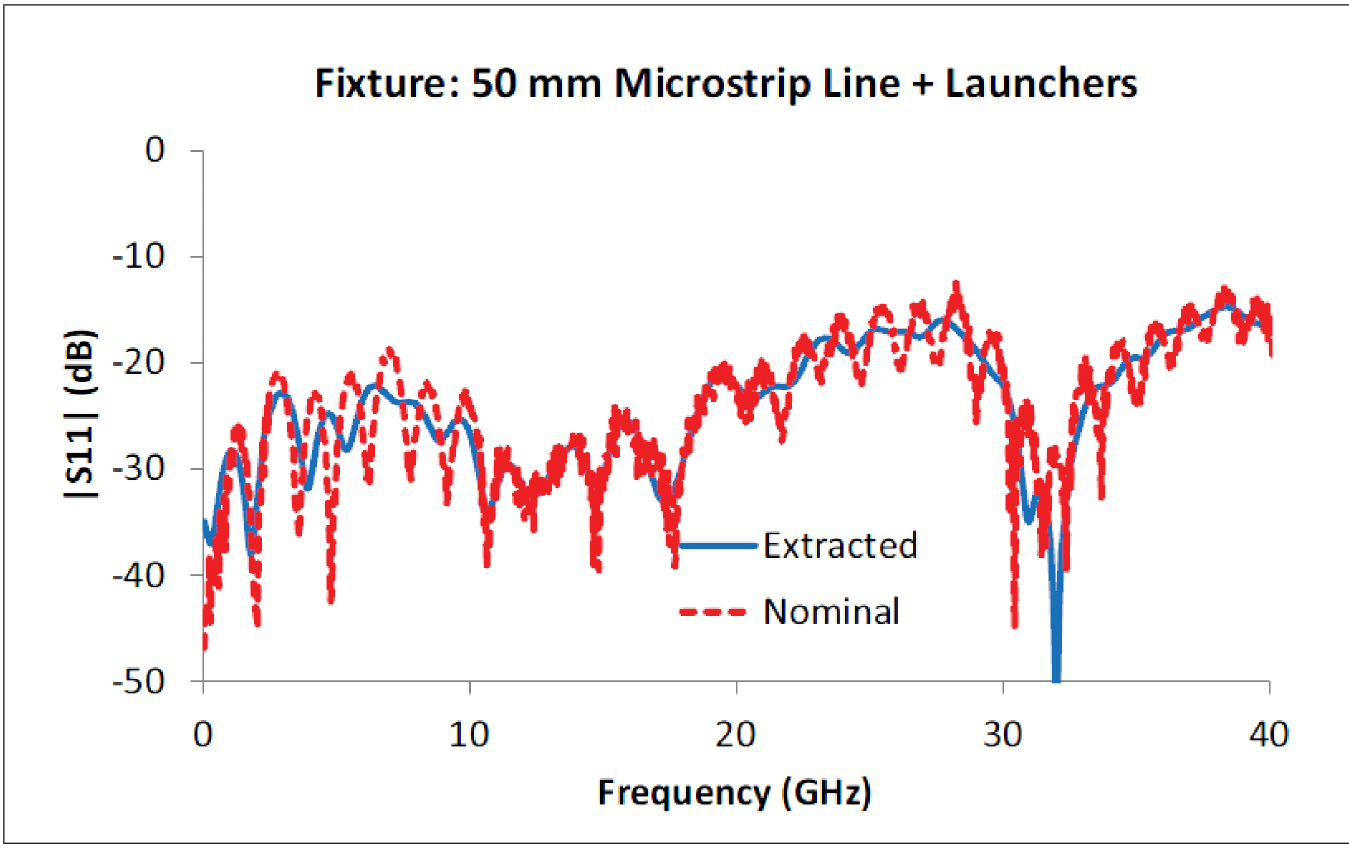
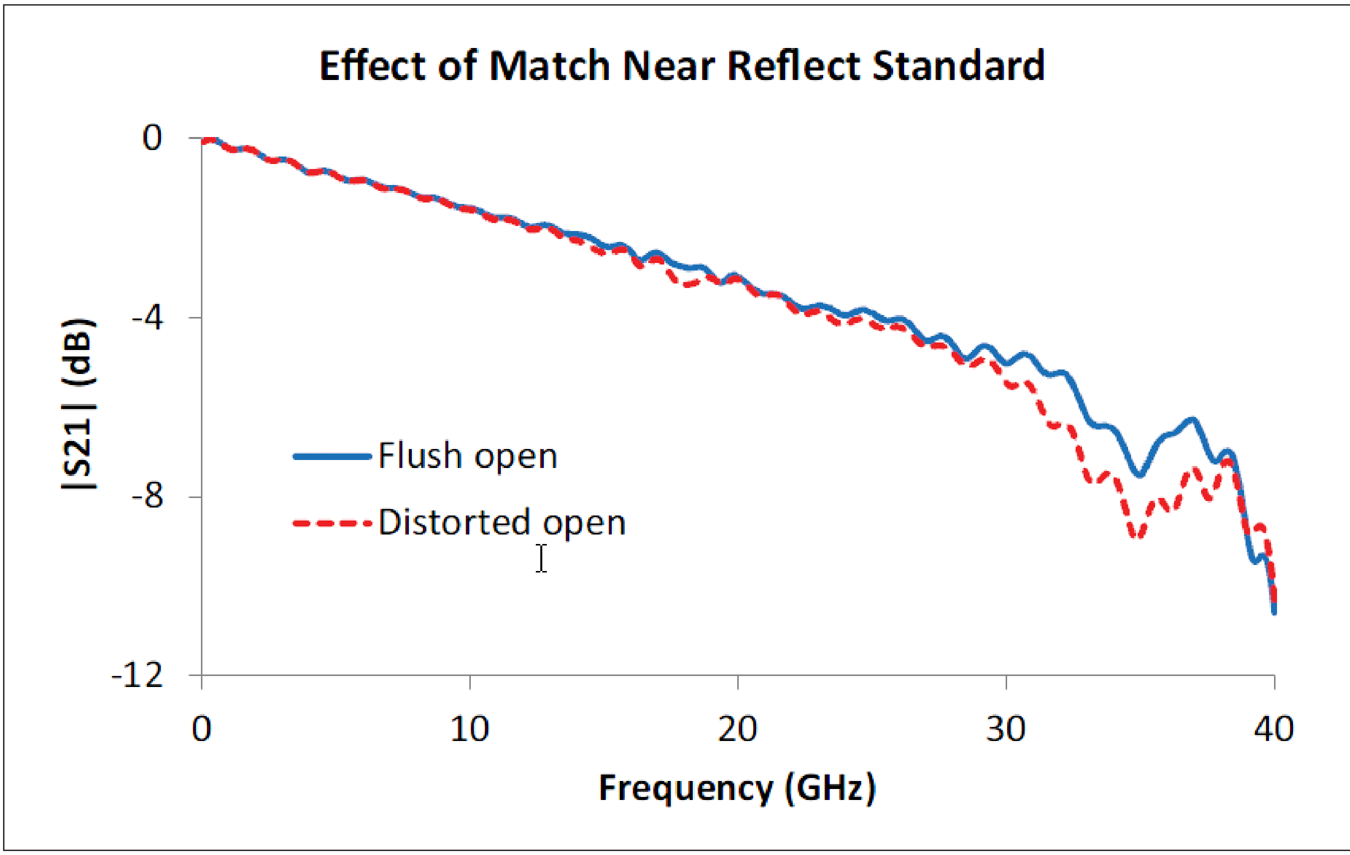


The results for a phase-localized Type D extraction are shown here along with nominal results for a special case when both port of the fixture arm were connectorized (to allow for comparison). The extraction degrades at higher frequency as fixture radiation and inner-plane mismatch hamper the partial information technique. Only an open reflection was used for the extraction process.

Figure 11. Microstrip Line Example

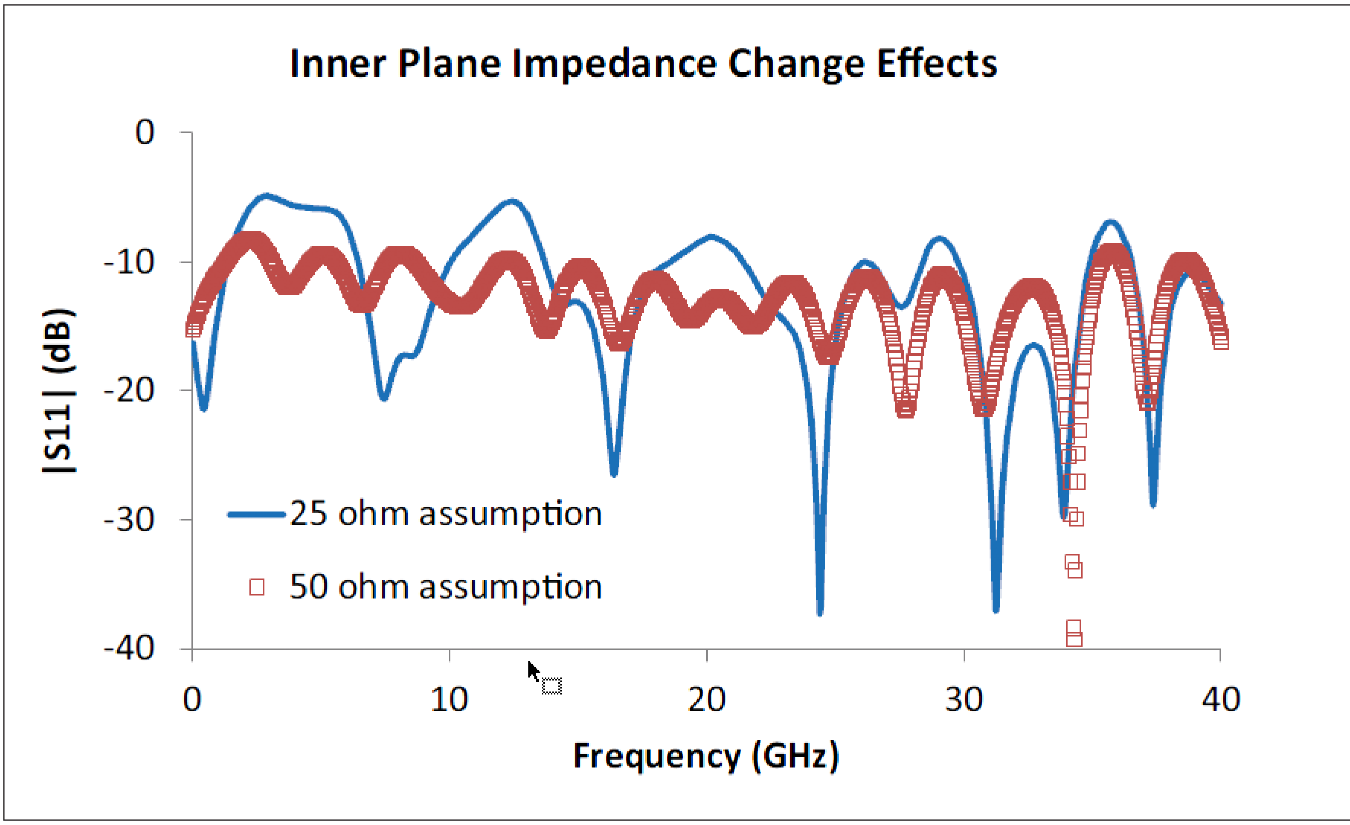
The direct sensitivity to standards definition defects are fairly straightforward since the reflection or transmission coefficient entered is applied multiplicatively to the data prior to a square-root operation. More subtle are non-idealities in the standards (such as mismatch of the line/thru standard). This will have impact through its influence on actual insertion loss during the measurement (in terms of an offset loss and in terms of ripple). Also on the subtle side are the effects of an incorrect fixture length entry. While in normal Type D this is mainly used for root choice, it is used in phase-localized D to determine which phase signatures to correlate against so entering a significantly incorrect value (10s of mm generally) can cause added ripple and, eventually, drop outs in insertion loss extractions as well as incorrect return loss values. The internal length estimate approach (entering 0 in the fixture length estimate field triggers this) can reduce the issues and is recommended unless the fixture phase response is very resonant, in which case a proper manual estimate will yield better results. The issue of where the mismatch is predominantly located has somewhat more of an effect when using the reflect standard (since the fixture mismatch and the reflect standard are almost co-located so phase localization becomes difficult) than using the thru/line standard. As an example, consider the extraction of a microstrip section using a flush open reflect standard native and when the mismatch near that standard has been distorted from the original ~ –15 dB to ~–5 dB at high frequencies. The effects on fixture $|S_{21}|$ are shown in Inner Plane Match Values : added ripple and some substantial differences above 30 GHz (where the mismatch change was the largest).



To further explore the sensitivity to inner-plane mismatch, a (reflect-based) phase-localized D extraction was performed on an original fixture and again after additional mismatch was introduced. In the range of additional mismatch addition, the discrepancies increased as expected.

Figure 12. Inner Plane Match Values

Fixtures with distinct impedance changes, intentionally constructed or otherwise, present an additional challenge. Consider a fixture where the inner plane is at 25 ohms and a thru standard is used for the extraction. If the inner plane impedance is ignored, then one is essentially treating the half fixture as being terminated in a 25 ohm impedance (low reflection for that zone) but that is implicitly changing the reference impedance of the S-parameter matrix. While this may sometimes be desired, it will cause errors if not anticipated when using that file for later de-embedding of modeling. More conventional is to keep the reference impedance (of the matrix) consistent at 50 ohms to facilitate later processing. In this case, the difference in the match parameters is substantial as shown in Phase Localized Type D Extraction – Effects of Inner Plane Impedance Change .



In a (thru-based) phase-localized D extraction, inner plane impedance deviations can create issues if large enough. In this case, the inner plane was at 25 ohms while the launch (and reference impedance for the calibration) was 50 ohms. If the impedance change was ignored (red squares in the plot), the extracted return loss for the fixture half can be significantly in error.

Figure 13. Phase Localized Type D Extraction – Effects of Inner Plane Impedance Change

Additional Notes:

- A full 2-port calibration must be active and the extraction will be run over the current frequency range (which is a subset usually of the calibration frequency range). There is a requirement that the frequency list have nearly uniform frequency steps (an individual step size cannot deviate from the mean by more than 5 %) so some segmented sweep setups (and all log sweep and CW setups) will not be accepted.
- The frequency range of the sweep should be large enough that the total fixture length (ns)>5/(frequency range (GHz)). The frequency step should be small enough that the total fixture length (ns) < 0.3/(Frequency step (GHz)). This helps avoid insufficient phase slope or phase-wrap-aliasing (respectively) that would complicate phase localization.
- The line and reflect offset lengths are entered in millimeters although a calculator is available if values are in picoseconds. If the material type is setup (from the current calibration or manually thereafter), that and any active dispersion relations will be used in the calculations.
- The extracted results are stored as .s2p files with port 1 of each file being the outer plane. Details of the file format options (frequency units, etc.) are set by the entries on the sNp setup menu.
- See Standards Requirements for Generalized B and Type D Extractions for recommendations of extraction types and standards needed for various fixture behaviors.

Table 1. Standards Requirements for Generalized B and Type D Extractions

Method	Standards Needed	Best for Fixtures
Generalized B	Open Open/Short	Well-matched fixtures with very well-matched inner plane. Reflection-only standards possible
Existing D	Thru	Well-matched fixtures with very well-matched inner plane. Thru-line standard possible
Multi-standard D	2 lines Line + (Open OR Short)	Moderately-matched fixtures without structural assumptions other than symmetry. At least one line standard possible.
Phased-localized D	Line Or (Open OR Short)	Moderately mismatched fixture assuming most mismatch not at inner plane. No symmetry necessary. One standard only

Uncertainty and Sensitivity

The selection of a network extraction method is heavily dependent on the standards that are available at the inner plane and the results can vary wildly depending on the quality of and knowledge about those standards. While we cannot be complete in this paper in a discussion on uncertainties and sensitivities, we can give some general thoughts. Many publications exist on the topic that may provide more information, such as J. Martens, “Common adapter/fixture extraction techniques: sensitivities to calibration anomalies, 74th ARFTG Conf. Dig., Dec. 2009, and references therein.

Type D is an alternative approach and is appropriate when it is difficult to create any reasonable standards at the inner interface. Also, when repeatability is problematic (for example, spring contacts, poorly positioned probes, etc.) trying to achieve knowledge of fewer parameters can be useful. The concept is to reduce weight on the inner plane match and/or make additional structural assumptions and focus on improving the accuracy of the insertion loss extraction. The absolute accuracy will be degraded from what one could get from either of the other methods (if good standards were available), but repeatability sensitivity can be greatly improved and the net practical uncertainty can actually be better. This follows from the 1/(1-x) kind of behavior of match terms in the standard methods. If the measurements are not terribly repeatable and the ‘x’ term is moving near unity, the uncertainty on the final parameter in practical terms can balloon. One can see this in a wafer probing example where probe placement was not that accurate. A series of calibrations were done using SOLR and using Type D extraction with a single thru (labeled partial information in A comparison of repeatability effects is shown here for two methods (standard calibration and Ty). The removal of match dependence lowered the scatter in the final insertion loss values. While repeatability sensitivity is better, there is sensitivity to inner plane match and to problems with the underlying calibration at the outer planes (although reduced).

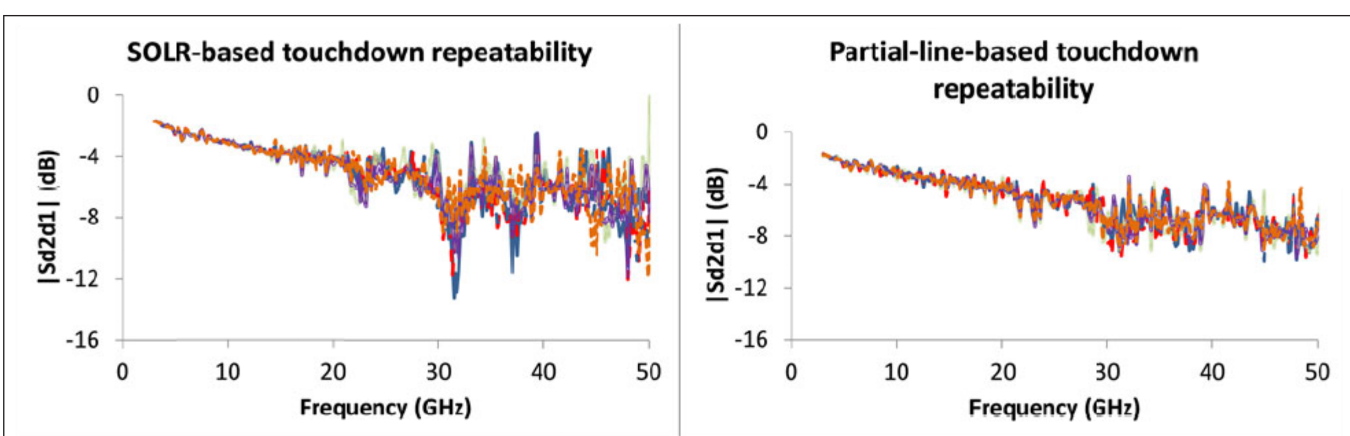


Figure 14. A comparison of repeatability effects is shown here for two methods (standard calibration and Type D) when that repeatability was not good

While repeatability sensitivity is better, there is sensitivity to inner plane match and to problems with the underlying calibration at the outer planes (although reduced).

The effect of an inner plane distortion is shown in The sensitivities of a Ty. The effects can be substantial, but the errors in this particular example would have exceeded 4 dB with a Type C methodology because the media was pin-based and not repeatable.

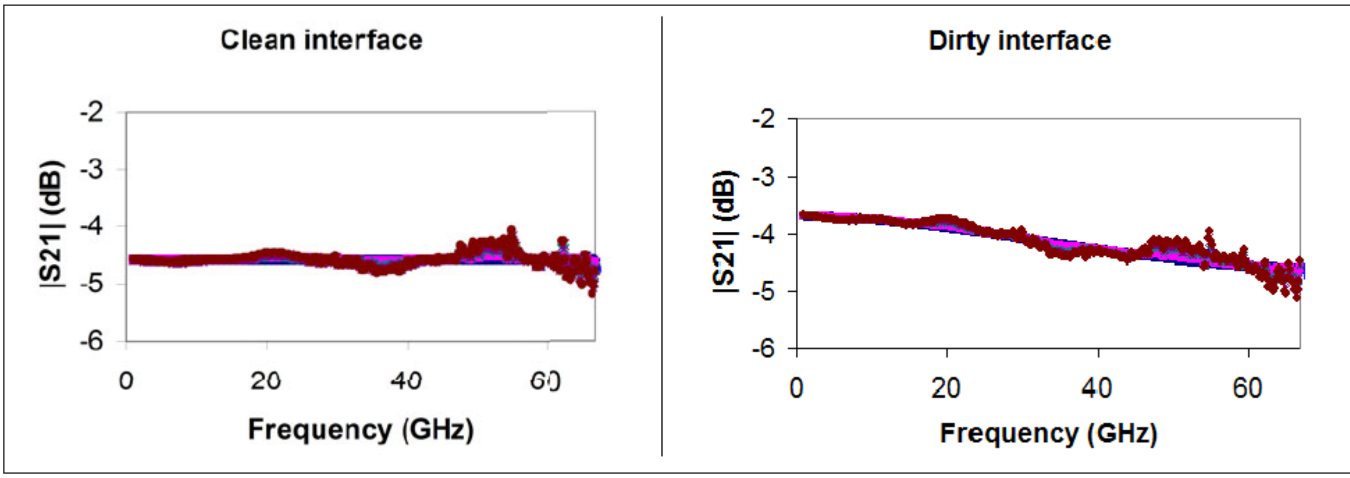


Figure 15. The sensitivities of a Type D extraction to underlying calibration issues (multiple traces per plot, reflect magnitude variations) and introduction of an inner plane match and position problem (the dirty interface plot).

Type D allows one to accept some non-zero absolute error in exchange for reduced sensitivities to standards errors and repeatability. Within Type D, there are a number of choices depending on which standards are available. If a thru is available and the fixture halves are relatively symmetric, phase localized D with a thru standard can do very well unless the fixture is very mismatched at the inner plane. Multi-standard variations of D (using two lines or a line and a reflect) can take over in the latter case. If only a reflect standard is available, reflect-based phase-localized D will usually outperform Type B with one standard.

The various extraction methods discussed here present a variety of choices dependent on standards quality, the media involved, and the possible measurement repeatability. In some sense it is a continuum (C->A->B->D) of choices more appropriate as the environment becomes decreasingly metrology-friendly. This is an oversimplification, but some of the sensitivities presented may help in making a good choice for a given measurement setup.

Summary

Two techniques have been presented for handling and studying the problem of non-insertable DUTs. Adapter removal is a 2-calibration technique for removing the effects of an adapter from a given calibration setup (e.g., when the DUT has one coax port and one waveguide port). Network extraction is somewhat more basic in that it tries to extract the S-parameters of the complicating adapter/fixture so that it can be de-embedded later. The Type D method of extraction was presented with various trade-offs in cal complexity, simplicity, and uncertainty.

For the methods discussed in the section, there is no guarantee that the output .s2p files will be passive (in the sense of the 2-norm of the S-parameter matrix being ≤1) due to underlying issues with the calibration, the assumptions being made, drift, noise or other reasons. As for user-saved .snp files, there is an 'Enforce Passivity' option that is part of .sNp setup and it applies to network-extraction-generated files as well as user saved files if it is enabled.

If enabled, passivity enforcement will force the eigenvalues of the S-matrix to be less than one (by an amount of at least the square root of a user-entered tolerance) in a self-consistent manner. This is equivalent to scaling the 2-norm to be less than unity. Note that since the S-parameters are being modified, errors can be introduced by this process so it is generally advised that it be used only if the passivity deviations are minimal. Further information on how to enable passivity enforcement is located in the VectorStar User Interface Reference Manual (PN 10410-00319).

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