Higher Data Rates Require New De-embedding Techniques

By Jon Martens and Bob Buxton

Higher data rates can create challenges for traditional de-embedding techniques. As frequencies approach 70 GHz or even 110 GHz, errors related to fixturing can be greater than those of the “device under test” or DUT. Fixtures and connectors to DUTs come in many forms. Poor de-embedding can lead to both passivity and causality errors. In addition, high fixture loss may affect the accuracy and repeatability of de-embedding. Achieving accurate measurements at these higher frequencies offers the advantage of improved ability to locate discontinuities, impedance changes, and crosstalk issues.

Newer more flexible and repeatability-tolerant methods of calibration and de-embedding techniques help resolve complex 28 Gbit/s problems. This white paper discusses the available de-embedding techniques and the tradeoffs between them.

Fixture De-Embedding

There are many situations where it may not be possible to connect directly to the DUT. In this case it is necessary to de-embed the DUT from the surrounding test fixtures. The opposite is sometimes required: it may be useful to take a device and assess its performance when it is surrounded by other networks. Figure 1 illustrates this.

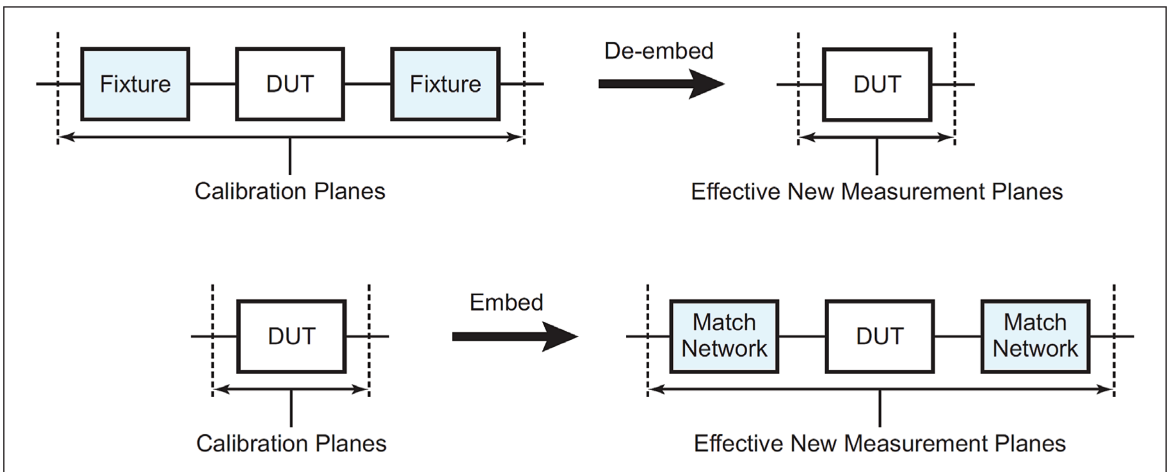


Figure 1. *De-embedding can be used to remove test fixture contributions, modeled networks and other networks described by S-parameters (S2P files) from the measurements. Embedding is the reverse process.*

Poor de-embedding can lead to both passivity and causality errors. Poor causality, where outputs can appear to happen in negative time, can be caused when there is insufficiently high frequency content. Passivity errors occur when it appears that a passive device has gain or is otherwise converting energy. The passivity effect can be subtle and due to small de-embedding problems, but it can have large effects on follow-on modeling or simulation. For example a minor calibrations standards problem can lead to small changes in the measured fixture match with apparent gain.

Using Flexible De-Embedding Techniques

The solution is to have a wide range of techniques available that can handle different situations. By matching the calibration and de-embedding method to your specific DUT and fixture structures, you will improve the accuracy and repeatability of your measurements. Table 1 lists several of the possible extraction methods for de-embedding.

Method	Standards complexity	Fundamental accuracy	Sensitivity to standards	Media preferences
Type A (adapter removal)	High	High	High (refl.)	Need good reflect and thru stds
Type B (Bauer-Penfield)	Medium	High	High (refl.)	Only need reflect standards, not great for coupled lines
Type C (inner-outer)	High	High	Medium (refl.)	More redundant than A so less sensitive but need good stds still
Type D (2-port lines)	Med	Low for low-loss or mismatched fixtures	Medium (line def'n.)	Only need decent lines; match relegated to lower dependence; can handle coupled lines
Type E (4 port inner-outer)	High	High	Medium (refl.)	Somewhat redundant (like C) but need decent standards. Best for uncoupled multiport fixtures
Type F (4-port uncoupled)	Med	Low for low-loss or mismatched fixtures	Medium (line def'n.)	Only need decent lines; match relegated to lower dependence; can handle coupled lines
Type G (4-port coupled)	Med	Low for low-loss or mismatched fixtures	Medium (line def'n.)	Only need decent lines; match relegated to lower dependence; can handle coupled lines well

Table 1. *De-embedding Methods*

As can be seen there are many extraction methods available, and the choice is somewhat context dependent. For signal integrity applications, the most common methods are B/D/F/G. Types A/C/E are more commonly used for active device testing such as transistors or power amplifiers.

The Bauer-Penfield method, or Type B, offers the best accuracy and is the most commonly used method when the fixture can be treated as uncoupled. It requires that you have a good set of standards – the equivalent of open/short/load or offset shorts. Figure 2 highlights the sensitivity of this method to the quality of the standards being used. This method also requires good repeatability.

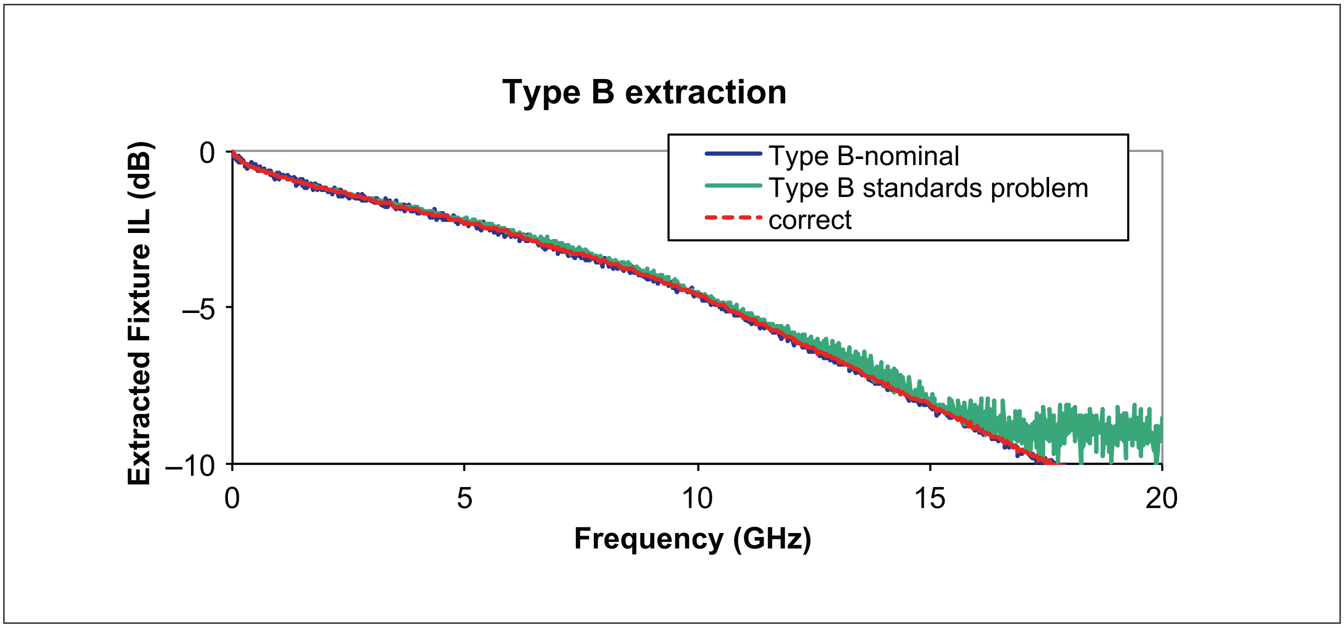


Figure 2. *Type B is the most accurate method, but requires quality standards. This example shows the impact of a load standard return loss of 10 dB instead of the intended 30 dB.*

When one has an interface with poor repeatability in terms of placement accuracy sensitivity, then types B and E may respond badly, whereas types D, F and G are more tolerant (Figure 3).

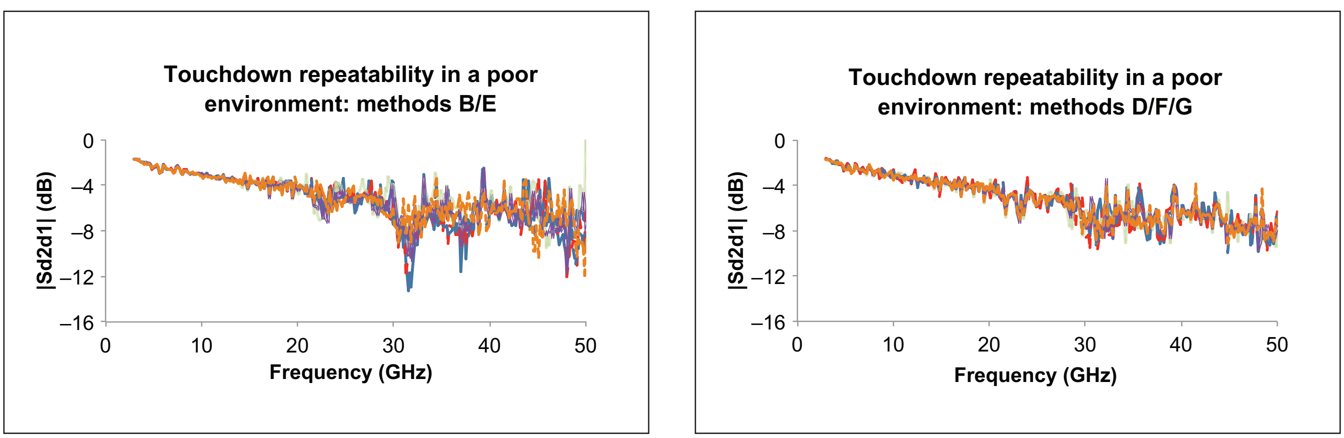
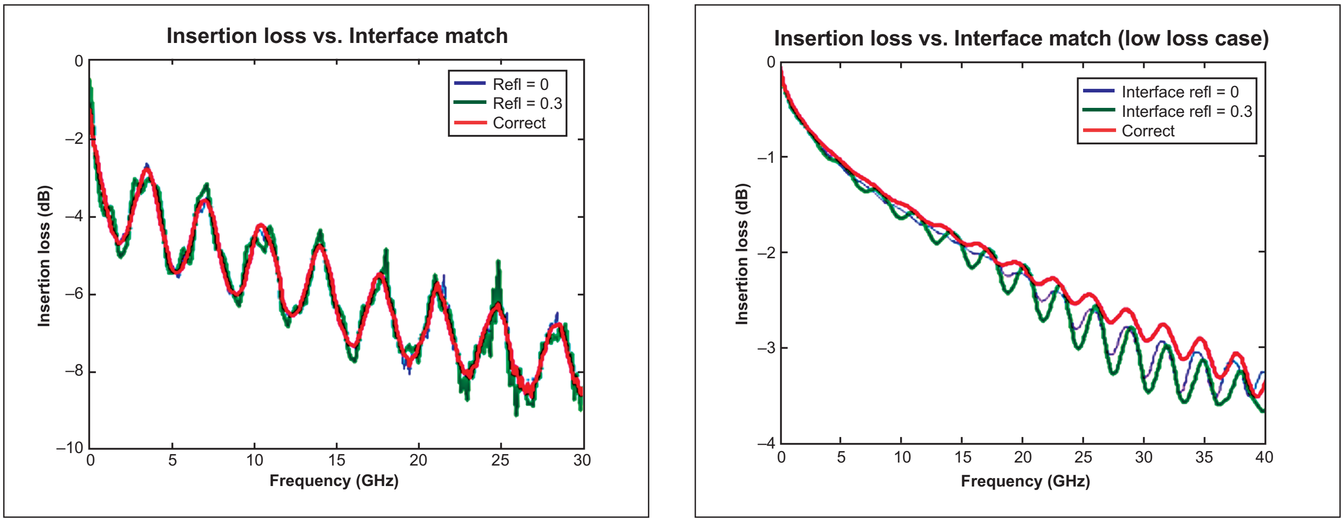


Figure 3. *Contact repeatability is a determining factor in selecting your de-embedding method. This example shows the result of the different techniques on a fixture with large pads and not very accurate positioners.*

The methods of type D/F/G only require transmission line interconnects and while they offer a reduced accuracy from type B, they perform well in situations where a complete set of standards is not possible. These methods are designed to de-emphasize inner plane match (on the fixture side) and mainly go after insertion loss. As such, if the loss is high and/or the inner plane match is good, they do well. If the fixture is low loss and poorly matched, they will not do well. An example is shown in Figure 4.



(A) High loss fixture example *(B) Low loss fixture example*

Figure 4. *Types D/F/G are designed to de-emphasize inner plane match and work well with high insertion loss and are less sensitive to matching (figures show results for type F).*

The main differences between the D/F/G methods relate to the number of ports needed and whether the transmission line coupling is an issue or not. For some low-end products, the insertion loss is the critical specification, and coupling issues such as cross talk are not required, and so type D or F may be used depending on whether the application is 2 or 4 port. For products where energy transfer between lines is a concern, such as backplanes, the type G method is required. Figure 5 highlights the difference between the coupled and uncoupled methods.

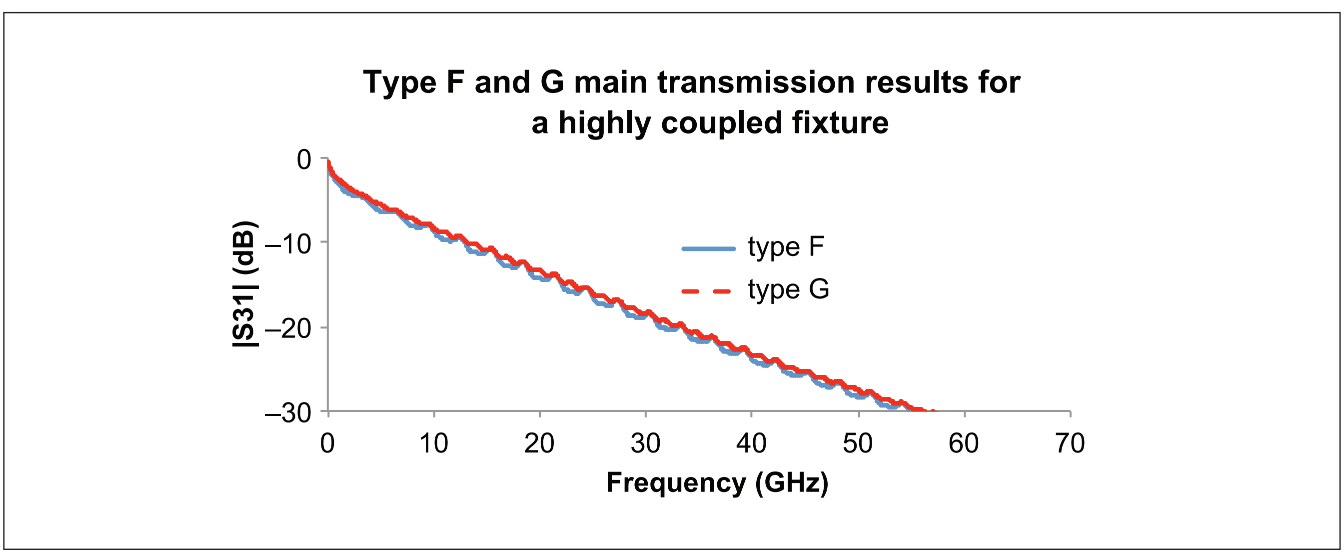


Figure 5. *Type F is a slightly simpler method, but will have issues if the fixture arms are tightly coupled. This example shows a highly coupled fixture with approximately 20 dB fixture loss.*

Conclusion

The de-embedding challenges created by higher data rates are met with the wider variety of methods now available. Higher frequencies require that signal integrity designers use careful consideration as to which method best meets their fixture needs. Considerations such as fixture loss and probe/contact repeatability must be considered at these higher frequencies. Achieving accurate measurements is even more critical in reducing passivity and causality errors so that there is an improved ability to locate discontinuities, impedance changes, and crosstalk issues. Table 2 shows a summary of recommended methodologies for de-embedding in signal integrity applications.

Method	**Practical Use**
Type A (adapter removal)	Well-defined planes on a mixed-port DUT. Decent reflection and transmission standards
Type B (Bauer-Penfield)	Well-defined and repeatable DUT plane. Decent reflection standards at that plane. Multiport
Type C (inner-outer)	Well-defined and repeatable DUT plane. Decent reflection and transmission standards at that plane. 2 port
Type D (2-port lines)	Less repeatable DUT plane but reasonably matched. Decent transmission standard. 2 port
Type E (4 port inner-outer)	Well-defined and repeatable DUT plane. Decent reflection and transmission standards at that plane. 4 port
Type F (4-port uncoupled)	Less repeatable DUT plane but reasonably matched. Decent transmission standard. 4 port but relatively uncoupled fixture arms
Type G (4-port coupled)	Less repeatable DUT plane but reasonably matched. Decent transmission standard. 4 port and highly coupled fixture arms

Table 2. *De-embedding Method Recommendations for Signal Integrity*

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