Keysight Technologies
Practical Application of the
InfiniiSim Waveform Transformation Toolset

Application Note

S-Parameter Series

KEYSIGHT
TECHNOLOGIES

Introduction

In between the comprehension of the theory and the real world's trials there is a chance to put into practice what has been learned. Simulating, anticipating and solving real world problems saves time, money and offers confidence.

The previous five papers in this series have systematically treated the engineer's overall task when considering applying transfer functions to realtime oscilloscope acquired waveforms for the purpose of rendering waveforms that are 'hard' to physically access—either because the measurement location is unprobable or the circuit analysis is simulating circuit elements that are not physically present. In so doing we have discussed the utility of s–parameter files in deriving these transfer functions, requirements of these s-parameter files and in measuring them, measuring s-parameters on vector network analyzers and time domain reflectometers, and finally applying simulation tools to the effort of describing channel models with s-parameters. All of these processes are dedicated to derive accurate representations of circuit elements for the purpose of trans-forming waveforms to simulated waveforms that provide the insight engineers need to validate their designs. This final paper will put together the concepts and theory already presented in the preceding papers. The approach will be to present and address five common problems that confront engineers when trying to measure performance on high speed links using an oscilloscope.

For each of these problems, the key issue is to transform, or filter, the real time oscilloscope waveform measurement to render a view of what the waveform would look like at some other location; for example, if the probed (measurement) point was in a different location than actually needed of if the measurement circuit was modified in some way. The term used for this, is co-simulation: the merging of measurement with simulation. The tool used to create the transforms or, transfer functions, will be Keysight Technologies, Inc. InfiniiSim Waveform Transformation Toolset.

InfiniiSim Waveform Transformation Toolset

InfiniiSim is an integrated software toolset that provides for both the generation and the analysis of transfer functions. In transfer function generation, InfiniiSim presents various circuit topologies in a graphical user interface for the sole purpose of creating transfer functions which convert from the circuit used in measurement to the simulated circuit desired. [An earlier paper has addressed this two circuit approach.] For analysis of transfer functions, InfiniiSim provides a frequency domain view to illustrate gain charac-teristic versus frequency, and two time domain views (impulse and step response) of the resulting time domain filter. Effective use of infiniisim demands that the engineer critically assess these portrayals for 'reasonableness', and be ready to enter into the 'design it, analyze it' loop several times. The principles addressed in the first two papers should be fully understood to ensure the transfer function filter is properly rendered.

InfiniiSim is elegant in its simplicity but can handle a wide variety of tasks and circuit models. In any circuit topology chosen, two intermediate transfer functions are derived conceptually. One is from the measurement circuit where the user has modeled all circuit elements that are truly in place at the time of measurement. Included in this is the probed, or observed measurement point. A similar circuit model is created with another circuit, called the simulation circuit, which manifests the desired circuit for simulation. Assuming linearity and time invariance, the transfer functions of both relating the observed node to the source node are related to yield an overall transfer function. When the time domain version of the overall transfer function is convolved with the oscilloscope wave-form, a filtered waveform results that reflects the simulation desired.

To create the transfer function, InfiniiSim requires the circuit topology, the observation nodes and definitions of the circuit elements. There are 12 standard circuit topologies as presets for the user: varying from the simplest one block model to the most complex 9 block model. To enable even more sophisticated circuit modeling each block can be described by three sub-blocks so, in fact, Infiniisim can actually handle 27 total blocks. By examining all the presets, one can notice they are special cases of the generalized 9 block model: some have more unused blocks than the others.

Each block may be defined several ways and they may independently defined in any circuit topology. Circuit elements may be defined with RLC models (resistor, inductor capacitor), transmission line models, shorts or opens, or with s-parameters. All of these are demonstrated in this paper.

To aid in the analysis as we drive to deriving a transfer function, each circuit element is internally converted to a set of y-parameters using a common frequency set to be used in the overall analysis. The frequency set is usually driven by the s parameter frequencies used in the files used to define the circuits. Using y-parameters enables the simplicity of nodal analysis of each circuit (measurement and simulation) at each frequency. When so performed and related to one another, the result is the frequency domain transfer function previously alluded to. On this transfer function, an inverse fourier transform is performed to yield an impulse response of the transfer function. The impulse response is sampled at the sampling rate of the oscilloscope to yield an FIR filter that is convolved with acquired waveforms to render the simulated waveforms desired.

Knowledge Base – In applying the transfer functions, FIR filters coefficients are generated and downloaded to an FPGA in the front end of the Infiniium oscilloscope to enable real time generation (through convolution) of the simulated waveforms. This direct connection to hardware control is the reason that the InfiniiSim graphical user interface (GUI) is under the channel resource tab and not an independent application

InfiniiSim Waveform Transformation Toolset

Setting up InfiniiSim

In analyzing a circuit for de-embedding or embedding purposes, the user will have to know the attributes of, and have models (either files or idealized components) for the circuits to be analyzed. Fundamental to this is whether the co-simulations are to be of 2-port or 4-port networks, and whether the signals evaluated for waveform measurements, (i.e. acquisitions) will be applied directly to the scope channels, or will be probed. If 2-port measurements then only one channel of the scope is used and it can receive the signal directly (front panel input), or from a single-ended (SE) probe. If 4-port is selected, the user will either have two single ended outputs to be analyzed by direct connection to the scope (say, channels 1 and 3), or they may be applied to a differential probe (for instance, a differential sma probe head). In the single ended case, the engineer has the option of observing the transformed single ended channels, or transformed differential and common mode versions of these. The input can be either channels 1 & 3, OR one differential probe to channel one may be selected. The user must understand that choices in input selection (2-port vs. 4-port, SE vs. differential, and probed vs. direct) greatly affect the modeling and the InfiniiSim attributes chosen.

Finally, if there is S-parameter data that will be used, it should be evaluated for attributes that will invalidate the results. A brief reiteration of these is listed below, for review.

Absolute minimum attributes

- The S-parameter sets have a maximum frequency higher than the maximum bandwidth of interest.
- The S-parameter resolution (step size) is linear and small enough to capture the longer time constants present in the circuit impulse response.
- Frequency responses that do not exhibit quickly moving magnitude and/or phase responses. Responses that are not sampled well enough are nearly impossible to discern after the measurement and will give rise to time domain aliasing.
- Responses that do not have a wide range of magnitude over bandwidth of interest for example, > 20 dB.

Activating InfiniiSim

For this discussion, the complete series of steps in using InfiniiSim will be presented for the first problem only. Subsequent problems will present the only procedures and steps that relate to the differing problem aspects.
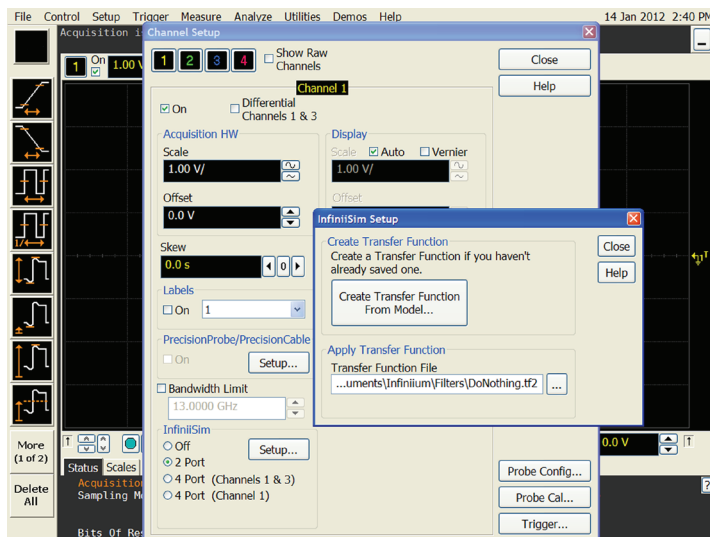

Figure 1. Activating InfiniiSim: select channel dialog (Ch1), select port model (2-port selected), then click on the Setup tab.

InfiniiSim Waveform Transformation Toolset

Activating InfiniiSim

It should be noted that the InfiniiSim software is intimately connected to the channel found in the channel tab - it is not stand alone software. It is activated by selecting the channel menu and turned on by selecting the n-port model to use (two or four). If the selection is 4-port, it presents the option of identifying whether a differential probe is used. If so, select 4-port 1-channel as the differential probe and the amplifier will be connected to one channel (see Figure 1 for menu of selection).

After activation, the first step is to create the transfer function. Selecting "Create Transfer Function" brings up an "Application Preset" dialog box, which offers common use models. Figure 2 shows this by highlighting the "add insertion loss of a fixture or cable" as a preset (the presets are simply to give a head start on our first problem by simplifying the under-standing of the use of InfiniiSim). At this time the software is ready to address the first exercise, which is embedding a cable.
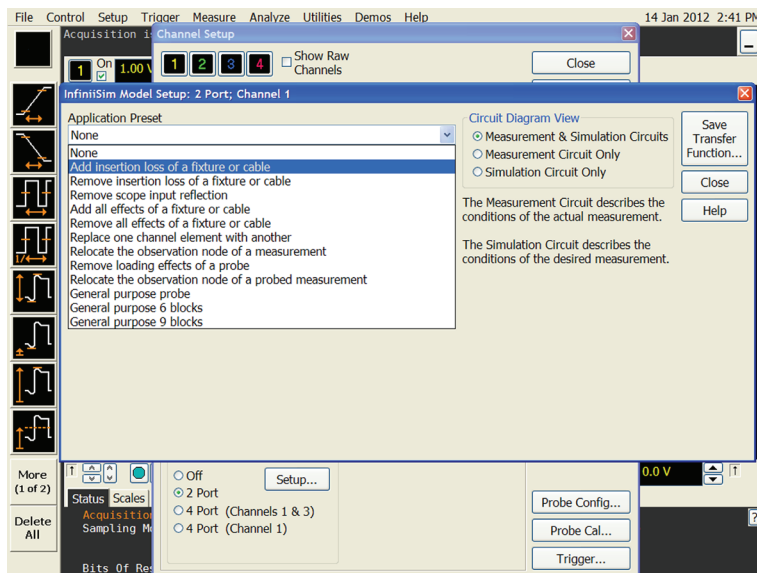

Figure 2. Application Preset menu.

Problem 1: Embedding a cable

Objective: To quantify how a cable affects the eye of a transmitter signal. In order to this, we must impress the effects of a cable (s-parameter file) on a direct measurement of a transmitter, and perform before and after comparisons of the eye.

Comments

1. If the actual cable is available, it should be evaluated on a time domain reflectometer (or other time domain device) to measure its real time delay, t_{DELAY}. If the frequency spacing of the S-parameters is $> 1/(2* t_{DELAY})$ it will exhibit frequency domain to time domain aliasing problems. InfiniiSim will warn you if the spacings exceed $1/(4* t_{DELAY})$.
2. It needs to be determined if the analysis will be performed using nominal impedance for the transmitter and the receiver (i.e. 50Ω) or if actual impedances will be used. If the latter, then the impedance change between measurement and simulation circuits (i.e. the difference between the oscilloscope impedance and the actual impedance of the circuit) needs to be considered.

Details

The procedure will be to perform a 2-port analysis (the S-parameter file will have an .s2p extension). In this case, the nominal 50Ω impedances for the transmitter/receiver is the choice. Note: in this case, the S_{11} and S_{22} columns of s-parameter data are unnecessary as there are 'perfect terminations' on either side of the cable (it is a simplifying assumption in this preset). This is why Keysight refers to this case as the "Add Insertion Loss of a cable or fixture" case as ONLY the insertion loss is being considered (see comment 2 above).

Process

Select the application preset called "Add Insertion Loss of a Cable or Fixture." This action brings up the circuits to calculate the transfer function (see Figure 3).
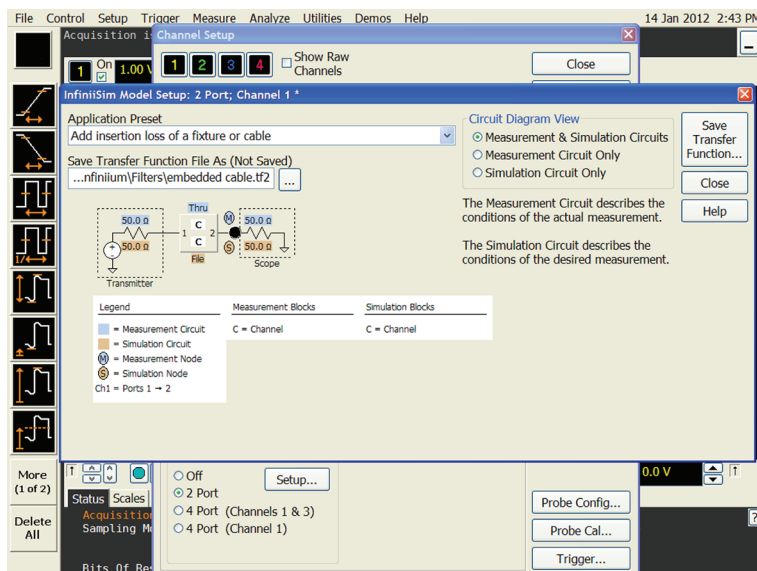

Figure 3. The InfiniiSim measurement and simulation circuit diagram for "Adding Insertion Loss of Cable or Fixture".

Problem 1: Embedding a cable

Process

Refer to circuit portrayal in Figure 3. The measurement circuit, which is comprehended by the blue notated portions (on top of the circuit elements), models a direct connection from the transmitter to the oscilloscope where the measurement point, or node is depicted by the blue "M". Observe that block "C" is set to a 'Thru' which is a zero loss, zero length element- this circuit, therefore, models direct connection of the scope to the transmitted device. The simulation circuit, highlighted in brown, depicts the simulation of an element between the transmitter and the oscilloscope. In this case the element is only labeled as "file" which means that an s parameter file is to be used to describe the simulation behavior of block "C". The simulation point is depicted by a brown "S" after block "C". The simulation will have the oscilloscope render what the waveform would look like had the cable actually been in the circuit.

The next step is to define block C. In the circuit model, select it and note that a new dialog box appears. In this case, the application preset block setup dialog defaults to the simulation circuit view. (Recall the measurement circuit behavior of block "C"). Once this dialog box appears, enter the file for the cable's S-parameters; cable 1.s2p. The file will now load into InfiniiSim. Once loaded, click on "Close" to return to the circuit model shown in Figure 3 to continue the process. At this time, the circuit has been totally described (according to the assumptions). The next step is to name the transfer function (embedded cable.tf2) and apply the calculation by selecting the "save transfer function" in the upper right hand corner (see Figure 4). When the infiniiSim is done calculating the transfer function, the user is alerted that transformation is now active on the designated channel by virtue of the tab labeled 'InfiniiSim' on the oscilloscope screen. All subsequent acquisitions on this channel will now be transformed using the transfer function just created.

Observing the transfer function

Once the transfer function has been generated, it is strongly recommended that three graphs of the transfer function provided by InfiniiSim be closely examined for their characteristics. The three graphs represent the frequency domain view, step response and impulse response. For this case (and only this case), the transfer function frequency information is the S21 S-parameter set. For a cable, these should all be below zero-dB and be sloping downward vs. frequency, ideally in linear monotonic manner.
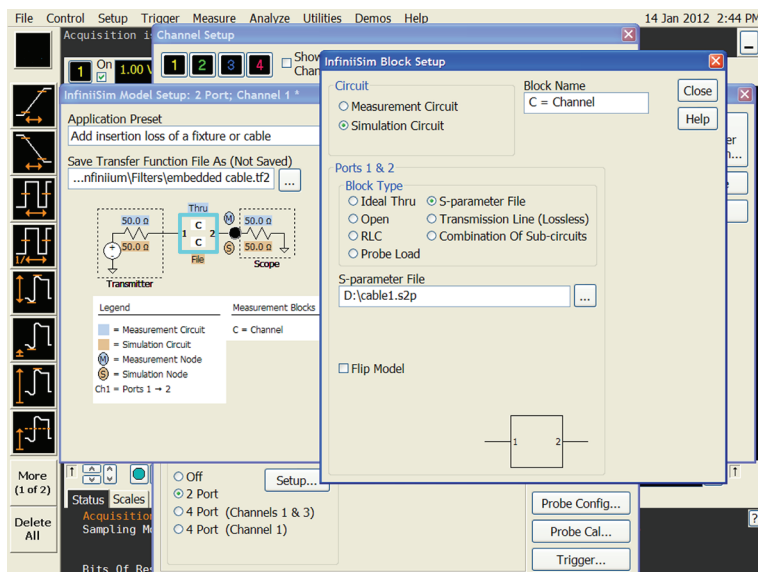

Figure 4. InfiniiSim Block Setup: entering the given S-parameter description for the cable.

Problem 1: Embedding a cable

Observing the transfer function

In Figure 5a our previous statement regarding the cable characteristics is confirmed: it starts at ~ 0 dB and slopes gently downward and it exhibits no irregularities. In the graph with the step response the function should come to a stable final value and more or less look like a low-pass filter response. The last graph to analyze, the impulse response (not shown), is less intuitive, however, but it should also go to a final value of zero. In some cases (with long time constants) it may be necessary to lengthen the filter response to capture the entire response. The filter length setting is also available in the InfiniiSim Setup dialog after a valid transfer function is active (see Figure 1 for the dialog before a transfer function is active, and Figure 21 after it is active).
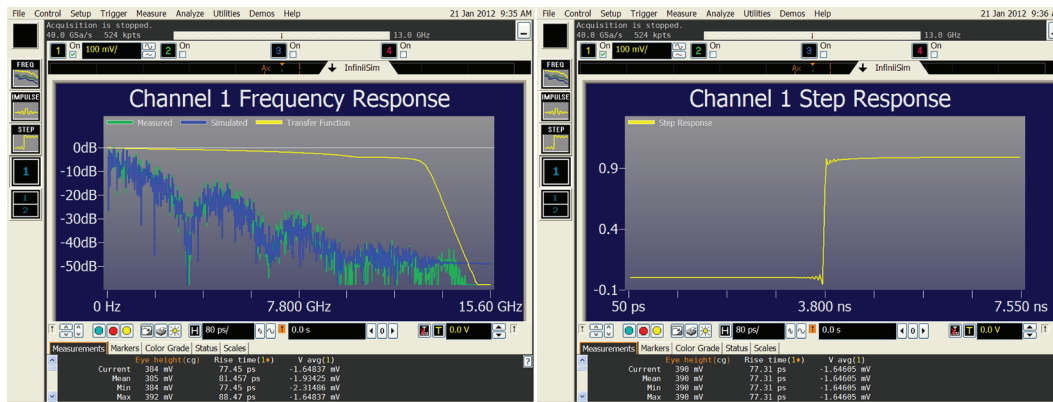
Figure 5a–b. Graphs of the transfer function.
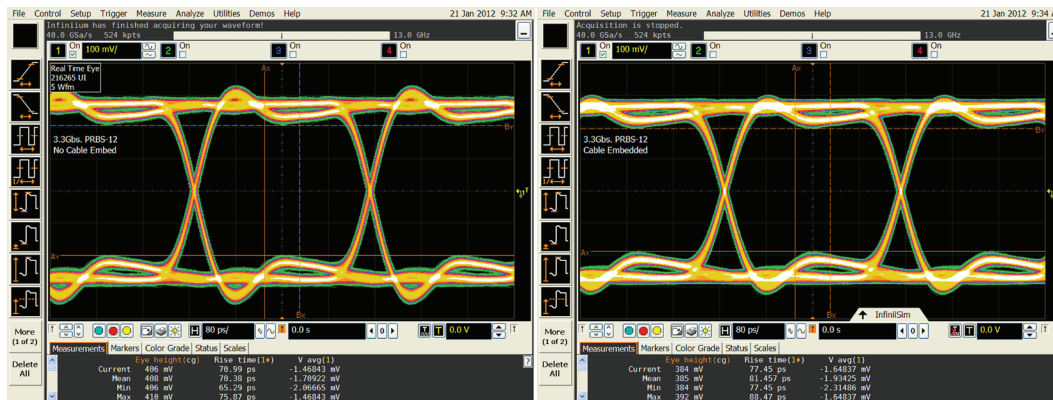
Figure 6a–b. Eye diagram function: a–no cable embedded; b–cable embedded.

Problem 1: Embedding a cable

A twist...

If in the definition of the problem there is interest in modeling the receiver block impedance to capture the difference between measurement with an oscilloscope (input channel) and an actual circuit whose impedance is defined by an S-parameter file set, file.s1p. An option is to select the "remove scope input reflection" application preset (refer back to Figure 2) and define the input reflection files for the measurement circuit (oscilloscope input impedance) and the simulation circuit (file2.s1p – see Figure 7). The oscilloscope file is a function of scale and can be found under c:/document and settings/InfiniiSim/filters/90000A/inputs. The capability to change the transmitter and receiver characteristics can also be used in 'what if' scenarios to determine worst case performance.
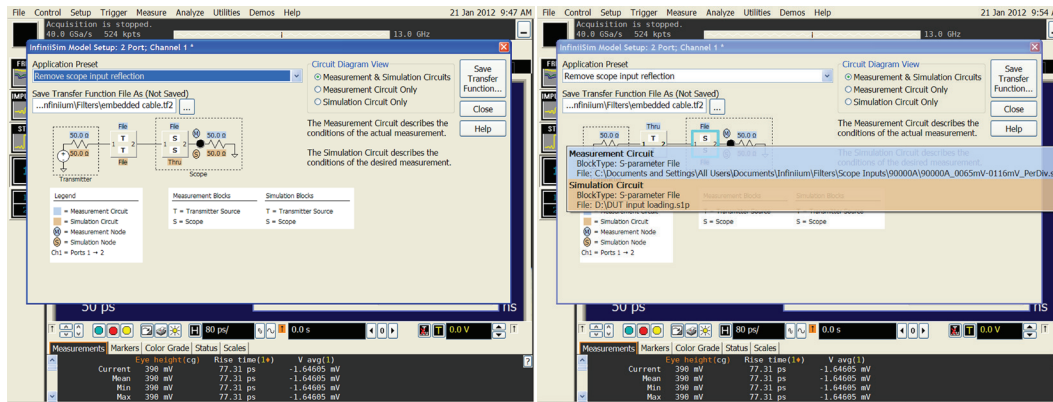
Figure 7a-b. GUI for the "remove scope input reflection" option of the measurement circuit (oscilloscope input impedance) and the simulation circuit.

Problem 2: De-embedding a fixture

Objective: The goal is to remove the effects of a test fixture and associated cabling used in connecting to the device under test. Fixtures, termed Test Point Adapters (or TPAs), are frequently required to access signals on the high speed digital interface by breaking those signals out to standardized RF connectors such as the SubMiniature version A (SMA) connectors.

Comments

1. The same general process as in the cable embed case (problem one) applies.

2. The first step is to determine the measurement bandwidth. The maximum frequency for the oscilloscope bandwidth should be set no greater than the point at which this the fixture's loss drops below -20 dB. The bandwidth is settable in the InfiniiSim "Setup" dialog after the transfer function has been loaded or created. In the event that the input signal frequency content drops precipitously before the selected frequency, the bandwidth should be set at approximately where the composite signal (green trace on the frequency domain plot, as shown in figure 5) drops below -30 dB.

3. Determine how the 4-port S-parameter set was ported. Determine if it is a 1->2, 3->4 or a 1->3, 2->4. A simple method to discern this is to look at the S-parameter file itself. The process is detailed as follows. Locate the S-parameter header string that identifies whether Magnitude (linear or dB) or real and imaginary representations are used. Both are acceptable but magnitude/phase is easier to understand. The assumption we make is that there is slight loss between the input and output and low frequencies. For a test fixture, examine the S-parameter values for the first frequency point (16 pairs) and look for this data. If the file is ported as 1->2, 3->4 then in the second column of magnitude/pair values observe that the magnitude is either close to unity (if linear), or zero (if dB). If it is ported as 1->3, 2->4 then the third column will exhibit these values. Also in the case of passive networks the S_{21} value is similar to S_{12} and S_{31} is similar to S_{13}. It is prudent to confirm this, as well. In this case, the file to be used is ported as a 1->2,3->4.

Problem 2: De-embedding a fixture

Details

This exercise will perform a 4-port analysis (the S-parameter file of fixture will have a .s4p extension). Confirm that the nominal impedances of 50Ω for the transmitter and receiver are acceptable for the desired objective.

Confirm by examining the fixture, that there are two cables per lane, from the fixture to the oscilloscope. The information for this setup is given in an S-parameter file that represents one of these cables and it is assumed that the cables are matched to within 5-ps. Finally, decide whether to go directly into the oscilloscope channels (single ended connection) or to apply these to a differential SMA probe head.

A natural question that arises is if there is a difference in measurement accuracy due to the different connection models. The answer is that there can be. Single ended connections can take the common mode element into account while the differential probe will remove it. The other consideration that is generally minor is the termination impedance of the single ended input versus that of the differential probe. They are both good, but the scope input is usually better. Regardless, matching differences can be accounted for by proper modeling in InfiniiSim.

Regarding cable skew (i.e. 5 ps phase matching of cables), there is no magnitude issue because the loss for five picoseconds of cable is insignificant. The phase, on the other hand, is significant. The phase for 5 picoseconds of skew at 5.4GHz is about 9 degrees, which will affect vector summation. To account for skew in this problem we have chosen to insert 5 picoseconds of 50 Ω line in one side of the 4-port cable model. Incidentally, this same approach can be used to comprehend scope channel skew as well. For this analysis a single ended connection model to the scope will be used (selecting scope channels 1 and 3).

Problem 2: De-embedding a fixture

Process

To begin, select "4 port (1&3)" in the InfiniiSim portion of the channel setup dialog (refer back to Figure1). Proceed to the InfiniiSim Model setup screen and select "General Purpose 6 Block" (see Figure 8). This selection will give us more blocks than necessary: we need three: one block for the fixture, one for the cable network, and a block to model skew of one of the cables. Three blocks remain for further circuit inquiry- for instance, the "S" block could be used to model the real loading of the scope in the measurement circuit, and, anticipated loading of the receiver device in the simulation circuit. The extra two blocks do not affect the outcome (configured as thru's) and they are available if any other conditions need to be considered. Note that the termination impedance for the circuits is 50 Ω as described in Detail section.
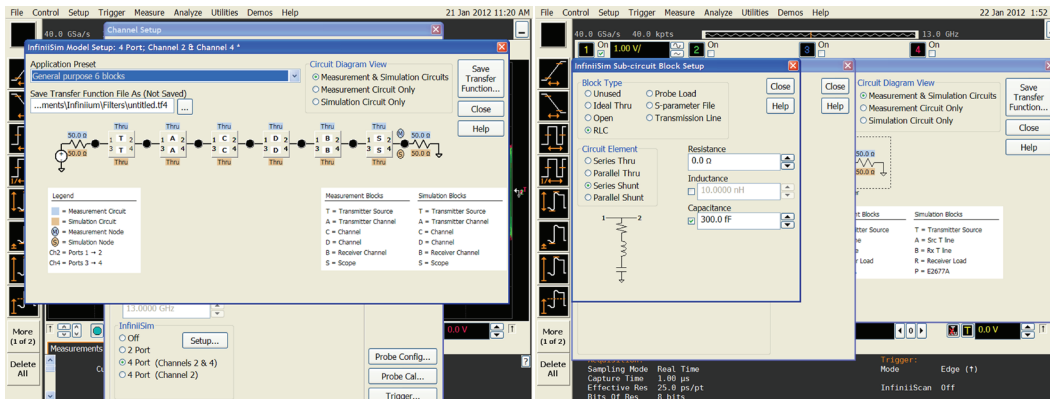
Figure 8a. General Purpose 6 Block Model   Figure 8b. 4 Port S Parameter Definition for Block "C"
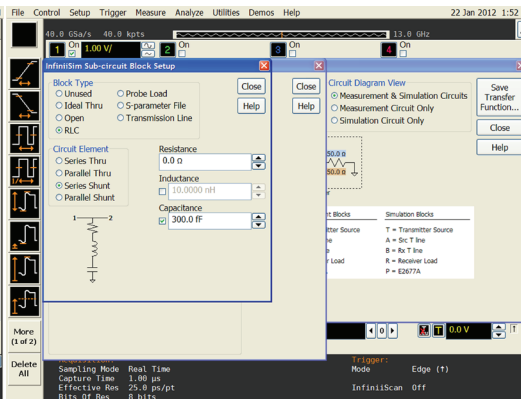
As in the previous example, the circuit elements for both the measurement and simulation must be described. In this example, all simulation circuit elements are modeled with "thru" because the objective is to undo the effects of fixture and cable. The user needs to understand the usage of a 'thru' element to remove a block's effects as well as to realize that blocks are used to implement circuits and are NOT restricted to specific physical elements.

For block "C" (see figure 8b), a 4 port s parameter file given for the fixture is loaded. For documentation purposes, the block can be labeled (upper right). Note that the labeling is different between the measurement and simulation circuits. When entering the file name, the user needs to describe the porting as well (lower left in figure 8b). To describe the cable network, block "B", we are committed to describing a 4 port structure though all we have is an .s2p file (two port) for one of the cables being used. This is accomplished by defining the block as a "two 2 port" which allows separate definitions of each port connection, using the existing 2 port model (Figure 9a).
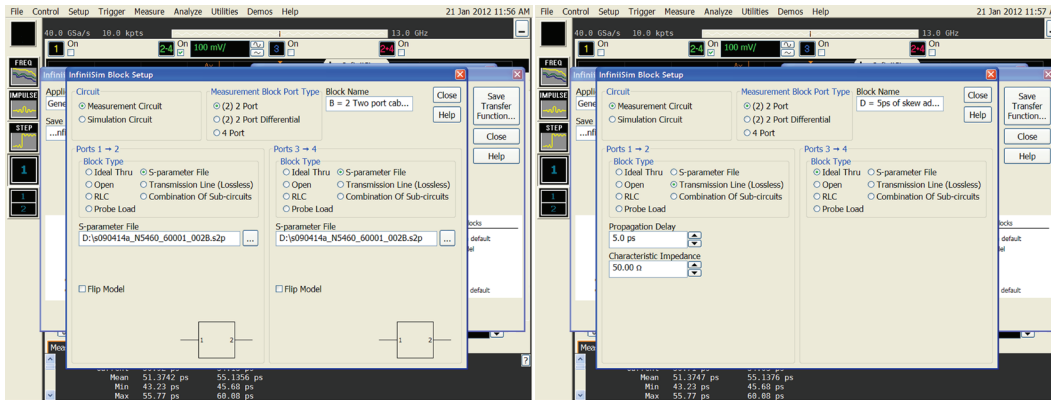
Problem 2: De-embedding a fixture

Figure 9a. InfiniiSim block"B"setup for cable network: two 2 port definition.

Figure 9b. InfiniiSim block "D" description to add 5 ps of skew using two 2 port model.

Process

Next, the skew implications (which is the 5-ps cable variance, or the modeling of the channel skew of the oscilloscope), need to be addressed. This is accomplished by defining block "D" as a "two, 2-Port." The 5-ps will be added via the "transmission line" description. The second 2-port will be defined as a ''thru". At this point a natural concern is whether it matters on what side of the cable the additional skew is added. Firstly, let's first point out that the best solution is always to have the measured files for the cables being used. In the absence of having both files and using one as we are here with a skew element, we understand that the skew will affect the uncertainty in the interaction be-tween blocks. If placed adjacent to an ideal termination there will be no interaction and therefore, no added uncertainty. Otherwise, the uncertainty of interaction of the reflec-tive elements that the skew element is between will be altered—the problem is you don't know how and results will vary based on skew amount and bit rate. Once all of the values for the circuit blocks have been entered and the calculation run, the circuit (generalized 6-Port) is generated (see Figure 10).
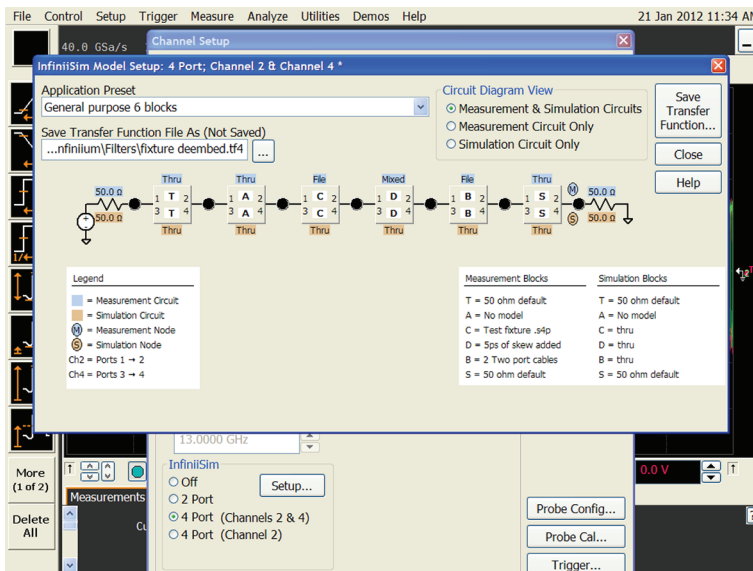

Figure 10. The generalized 6 block circuit, filled out.

Problem 2: De-embedding a fixture

Process

As before, the transfer function is calculated and its spectrum presented (see Figure 11). In this case, a clock signal is applied, which allows observation of harmonics out to the fifth harmonic (~13 GHz). The spectrum of the clock is shown in green and the augmented spectrum (applied signal plus transfer function) is shown in blue.
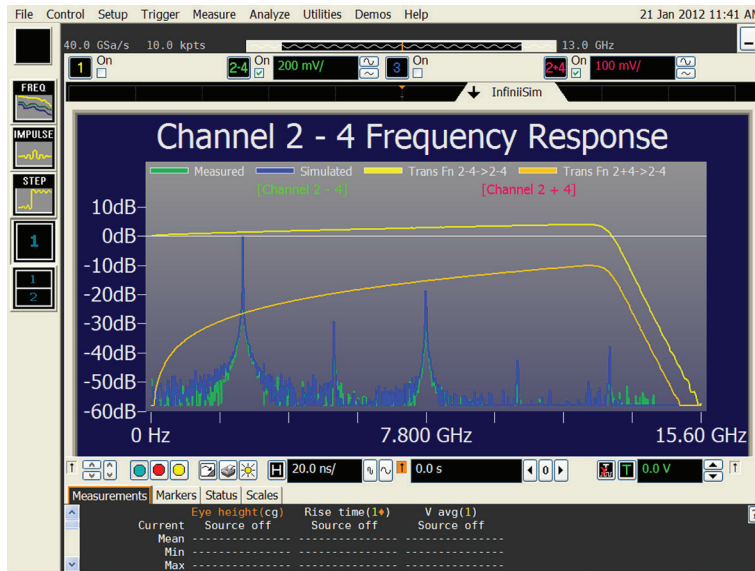

Figure 11. Spectrum of the de-embedded fixture and cable transfer function, with the input a clock signal.

It is worthwhile to note that that the 5th harmonic is about 40 dB down from the main lobe (first harmonic). It is approximately 1/100 of the level and will provide somewhat more accuracy for rise time measurements. However, that benefit must be weighed against the degradation in jitter, by virtue of noise in the 8 to 13 GHz frequency band.

This completes the analysis of problem two. Problem three follows.

Problem 3: Remove the effects of probe loading

Objective: Remove the effects of the probe from a probed measurement. Probes, though designed with low loading objective, do present some loading on the circuit probed and will affect the rise and fall time measured.

Comments

1. The S-parameter model of the particular probe that Keysight has provided will be required. This can be found under c:/document and settings/InfiniiSim/filters/ 90000A/ probes. There are differential loading files (with .s2p extensions) and there are single ended loading files (.s1p extensions). Select the particular file that best suits the application.
2. Accurate element removal (removing the effect of a probe) ideally requires that all circuit elements be known. The reason for this is that the effective network impedance for the measurement circuit transfer function is different between the measurement and simulation circuits. However, a qualitative analysis can still be achieved without knowing the precise impedance of transmitter and receiver.

Details

This is a probed measurement configuration that will demonstrate what it would look like if the probe was perfect (i.e. very high impedance). This can be easily conducted with the accessories commonly available with oscilloscopes. In this example we will do a single ended analysis so the 2-port selection in infiniiSim will be selected. The measurement and simulation circuits will be identical except the measurement circuit will comprehend the probe loading while the simulation circuit will not. It is important to understand that the circuit model identifies the real elements up to the point where the probe is physically located. If, for instance, a printed circuit trace is being probed, it should be modeled as a transmission lines to and from the probe point. Not modeling the pc traces as transmission lines will cause phase error in the simulation and will greatly affect the waveforms. In this example, the transmission lines will be considered 50 Ω.

Process

To begin, in the InfiniiSim model setup screen where the application presets are shown, select the "Remove Loading effects of a Probe" model (observe resulting circuit from this selection in Figure 12).
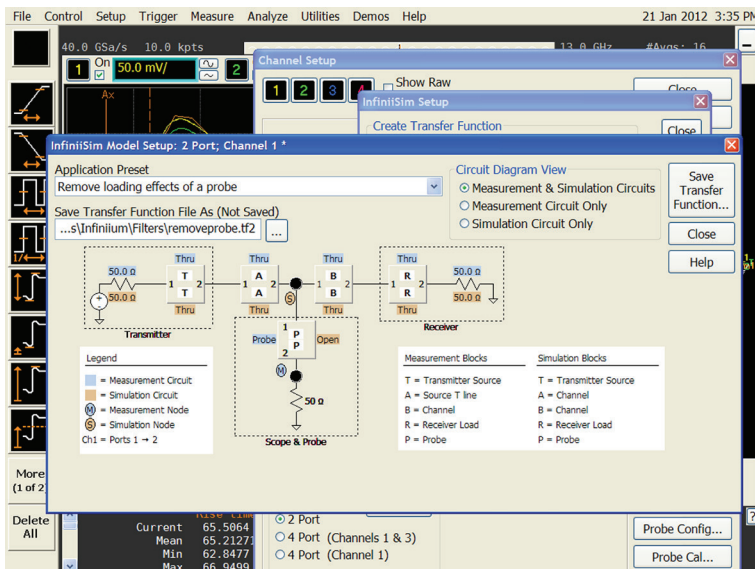

Figure 12 Image of the "Remove effects of a probe Preset" screen.

Problem 3: Remove the effects of probe loading

Process

Blocks "A" and "B" will be defined as models of transmission lines that are located on either side of the probe. We will set the propagation delay values to 100 ps because the transmission line lengths are about an inch. Since an idealized source and receiver is assumed, the transmission lines will not play a role in the simulation. However, in general, these models must be captured in real-world applications (see Figure 13).

Figure 13. "A" and "B" block definitions.

The next step is to define the "P" block, which is the loading model of the probe. In this example an E2677a is used. Import this .s1p model from C:\...90000a/probes/. It is possible to define the "R" block (the scope input) by similar importing of .s1p files at C:\...90000a/inputs/. The full model of the circuit is shown in Figure 14.
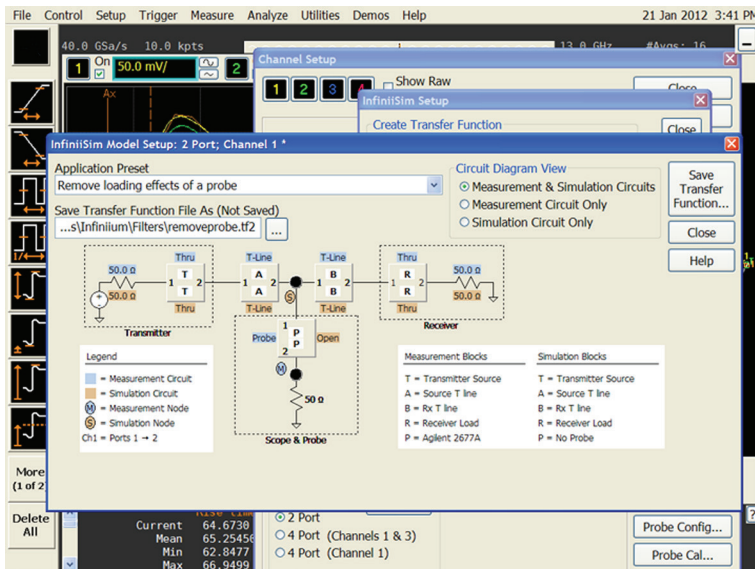

Figure 14. Full model of the circuit

Keysight probes always show the voltage seen at the probe tip regardless of transmitter and receiver impedance. Other companies will only be accurate if their 50 Ω assumptions are satisfied.

Problem 3: Remove the effects of probe loading

Process

The transfer function is shown in figure 15 and the difference in time domain waveforms is shown in Figure 16. The transfer function is not dramatic in this instance, about 2 dB from minimum and maximum regions in the spectrum. This is about 25% difference for an individual frequency component in these bands.
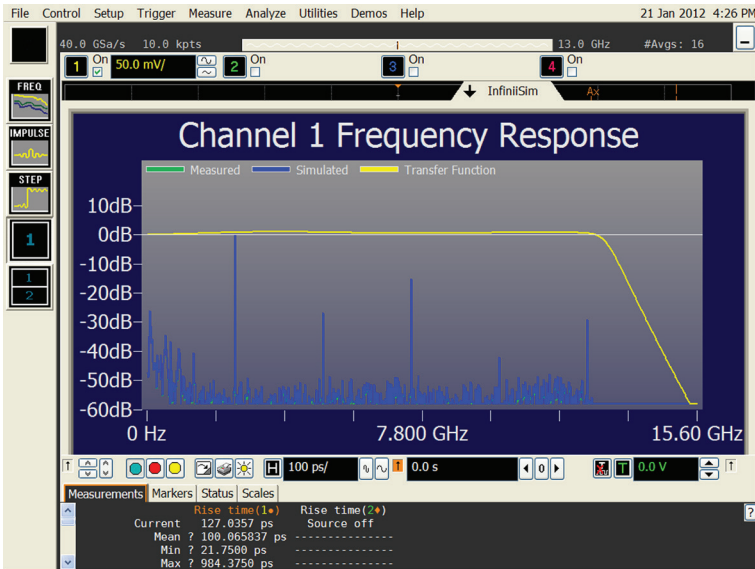

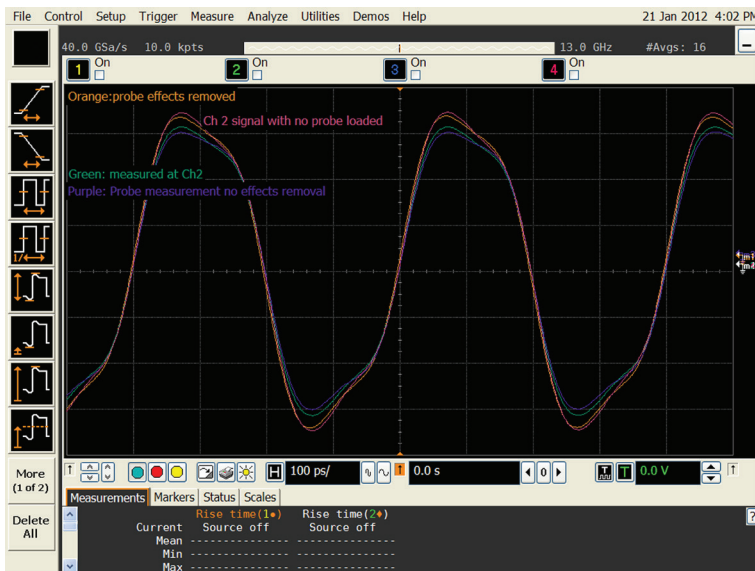Figure 15. Transfer function to remove the effects of the probe.

Figure 16. Waveform comparison: Before probe loading, after probe loading and after probe loading but effects removed.

This completes the analysis of problem three. Problem four follows.

Problem 4: Measuring the eye of signal at the cable end or at the input to the receiver

Objective: To observe the waveform or the eye at some remote, inaccessible point inside a receiver chip package.

Comments

1. This problem is similar, in nature, to problem three. The difference is that the simulated voltage waveform desired is not at the probe point, but a physically inaccessible point within the receiver chip.
2. A model of the chip package and the termination impedance of the receiver chip will be required.
3. Model the circuit carefully. There will be potential for interaction between all the circuit elements so models must be close and distances known.
4. We have the option to remove the probe effects as in problem three, or just leave in the probe loading, for both measurement and simulation circuits.

Details

The same circuit elements are used as in problem three. However a package model will be added to model the receive chip. It will be defined to include a via, a pad capacitance of 0.3 pF, a lead inductance of 1.0 nH, and an on chip capacitance of 0.2 pF, which shunts the receiver impedance of 60Ω. Since the objective is to view the waveform at some point within the receiver chip, a preset application is needed that will allow relocation of the simulation point to the receive chip. This is accomplished using the "Relocate the Observation node of a probed measurement" selection offered in the InfiniiSim model setup dialog (see Figure 17).
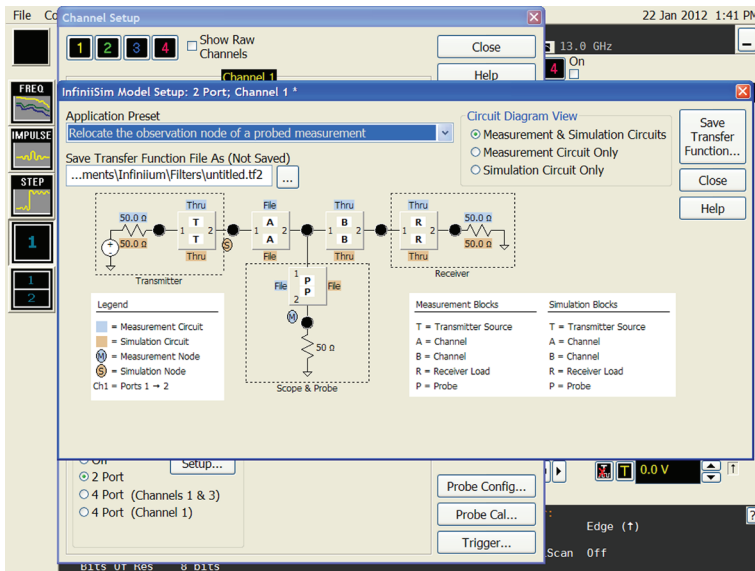

Figure 17. View of the "Relocate the observation node of a probed measurement" interface.

Problem 4: Measuring the eye of signal at the cable end or at the input to the receiver

Process

First, enter the transmission line models in blocks "A" and "B" as done in example 3. The package model will be manifested in the "R" block (see Figure 17). The assignment of block "R" will be defined as a sub-circuit and is depicted in detail in figure 18a. In the subcircuit description there are 3 sub blocks we may define. The first one we will assign to the pad capacitance, the second to the lead inductance and the third will be on chip capacitance. Note: any block in InfiniiSim can be defined as a subcircuit, which permits a great deal of flexibility in device and circuit modeling.

> Knowledge Base – This exercise requires defining a new construct called the sub-circuit (shown in Figure 13). In the sub-circuit definition, InfiniiSim will allow up to 3 different blocks to be defined. This extension capability greatly increases the kind of complexity InfiniiSim can handle; the only caveat is that InfiniiSim will not let you probe between the elements in a sub-circuit so some care is required in the circuit element definitions.
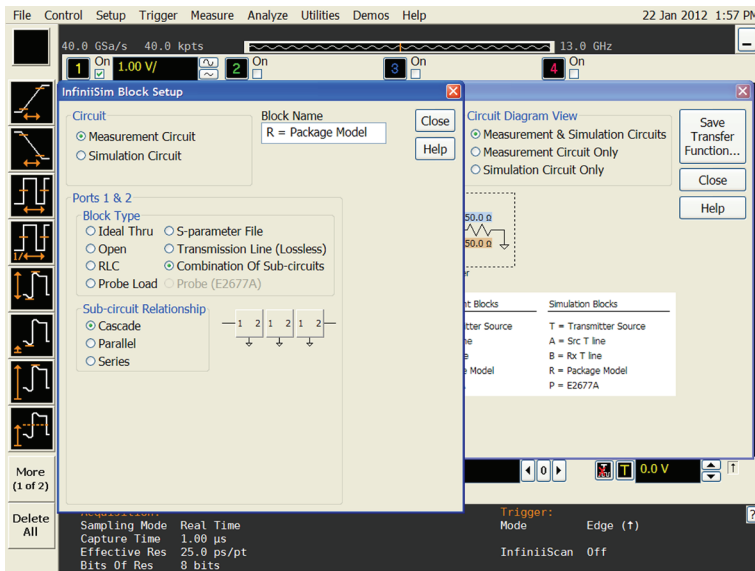

Figure 18-a. View of the "R" block and the entry selections.

Referring now to Figures 18b, 18c, and 18–d, these views guide the user through the entry of the package model details, which are required for both measurement and simulation circuits. For the receiver termination, set it to 60 Ω from the default setting of 50 Ω (see Figure 18e). The final change to the application preset is to change the node for simulation. By clicking on the black dots in the circuit, the location of the simulation or the measurement observation nodes can be defined. In this case, select the node between block "R" and the receiver input (60 Ω) and move selection to simulation. The completed circuit is now presented in Figure 19. Note: In this model there is no choice as to where the measurement node goes.
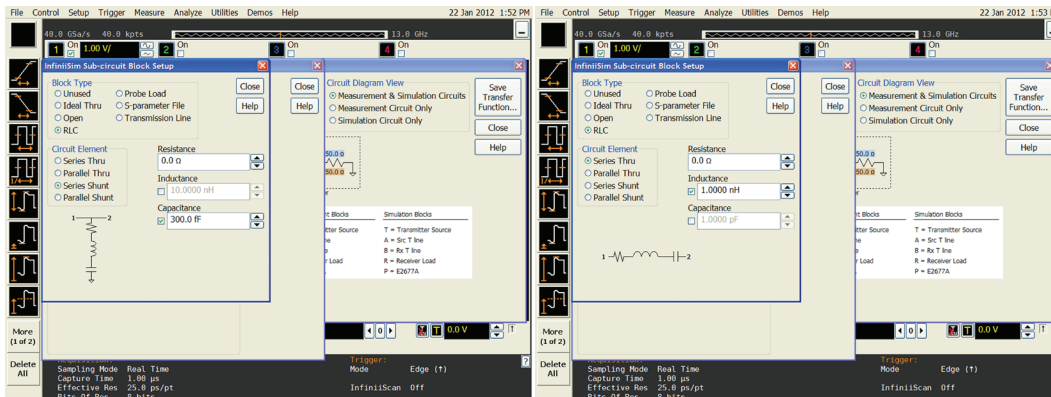

Figure 18-c. Series Thru selection and entry data.

Figure 18-b. Series shunt selection and entry data.

Problem 4: Measuring the eye of signal at the cable end or at the input to the receiver
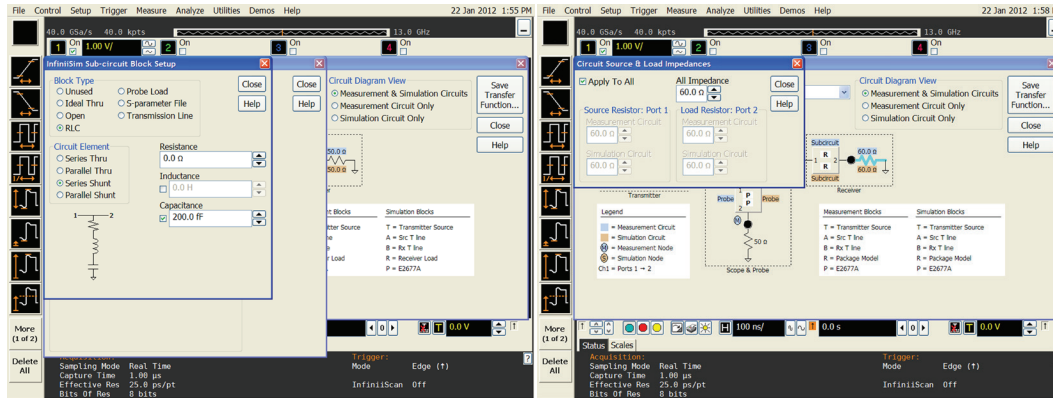

Figure 18-d. Second Series Shunt selection and entry data.

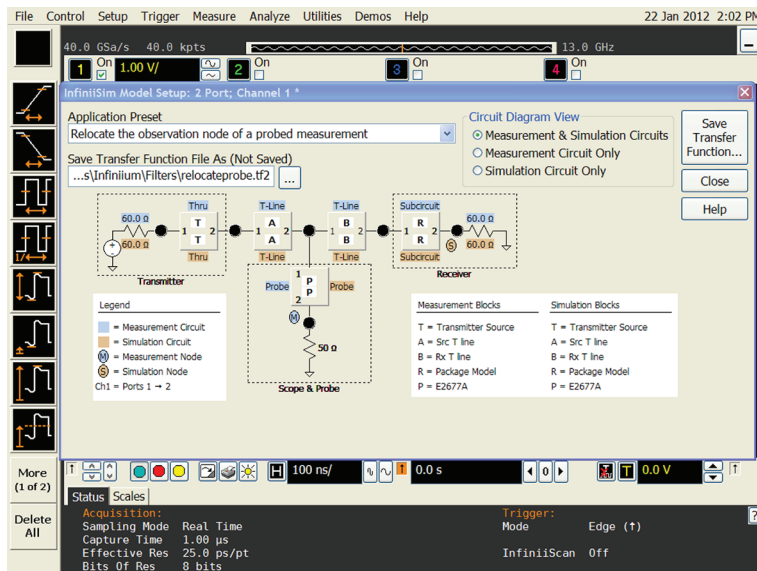Figure 18-e. The receiver model impedance selection screen.

Figure 19. The completed circuit model with values

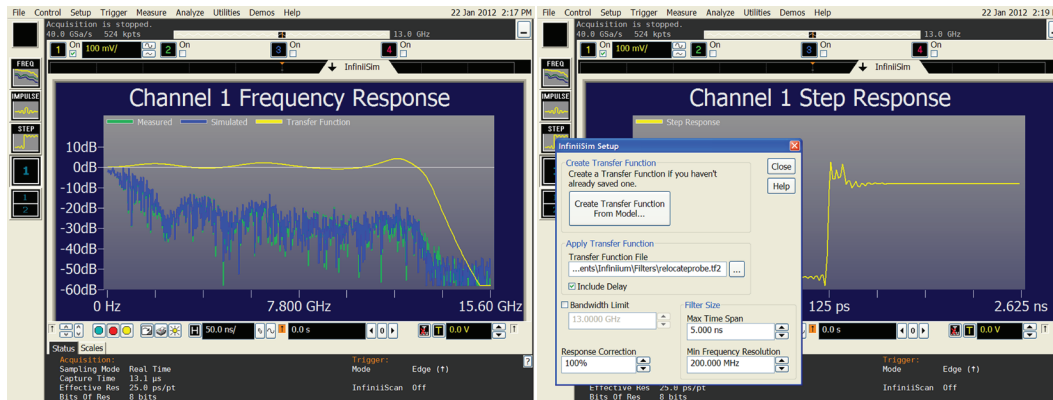# Problem 4: Measuring the eye of signal at the cable end or at the input to the receiver

Figure 20. The transfer function.

Figure 21. The step response for example 4. The default filter length is 10 ns but is adequately covered with 5ns of length. The InfiniiSim Setup dialog box is also shown to illustrate filter length control capability.

Process

Once all the data has been entered and saved, the transfer function (see Figure 20) and its corresponding step response (see figure 21) can be viewed. A final note – this setup could be used to observe the eye diagram at this point in the receiver and we could also apply an equalizer function (CTLE) to open the eye. This option could be useful to predict what the eye looks like in the receiver after a frequency compensation stage. If used for this purpose, there will generally be a channel compliance model that must be impressed on the acquired waveform to close the eye. The use of the equalization software, jitter or any software in Infiniium oscilloscopes is the same, whether or not InfiniiSim is being used; and therefore, not shown here.

This completes the analysis of problem four. Problem five follows

Problem 5: De-embedding a DDR interposer

Objective: To remove the effects of an interposer board in validating a dual data (DDR) memory system where the signals of the ball grid array (BGA) are not exposed and are unavailable for direct probing.

Comments

1. The use of a Keysight interposer, mounted between the BGA and the printed circuit (PC) board is necessary. The interposer routes the particular signals required to its edge for probing (see Figure 22).
2. Optimal results will require models of the memory device and memory controller, which are generally unavailable. Further complicating this measurement is the fact that often the signals are routed to several chips which creates impedance discontinuities.
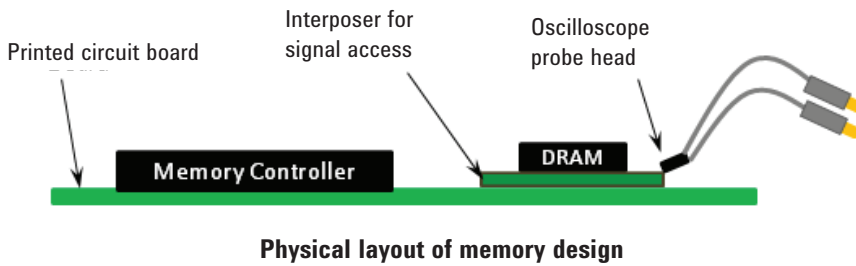

Physical layout of memory design

Figure 22. DDR physical layout using the interposer.

Details

This problem brings together the challenge of modeling all the devices of the circuit. Of particular focus in this exercise will be the interposer, which is shown block diagramatically with the DDR device in Figure 23. There is a direct connection between the dynamic random-access memory (DRAM) device and the PCB through a via. In this case, the via is such a small transmission line that it's effect can be considered insignificant (this will not be true as edge rates decrease), however, the via does present a capacitance that must be modeled. The Keysight interposer has a resistor embedded in it that has a nominal value of approximately 75Ω, but may vary considerably from device to device and even within the device. After this resistor, a printed circuit trace is routed to the edges of the PCB where it is probed by a differential probe.
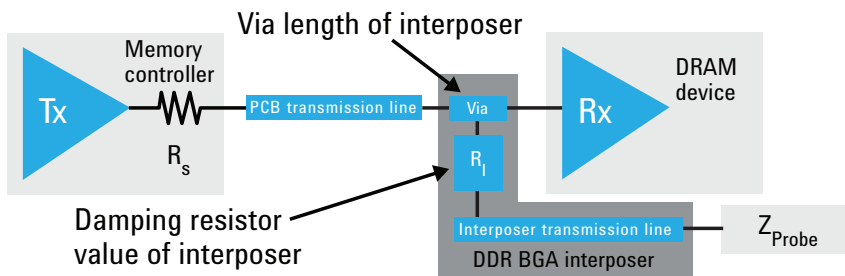

Figure 23. The block diagram of physical devices in the DDR circuit memory measurement.

Problem 5: De-embedding a DDR interposer

Details

The interposer can be measured directly by a vector network analyzer (VNA) probing system or it can be modeled. Keysight has done both to create a model to handle the variation of the interposer resistor (see Figure 24). This model allows a user to measure the resistor in his own interposer and use it in the model. Figure 25 presents the actual vs. measured traces of the DDR signal up to 5-GHz with reasonable agreement.
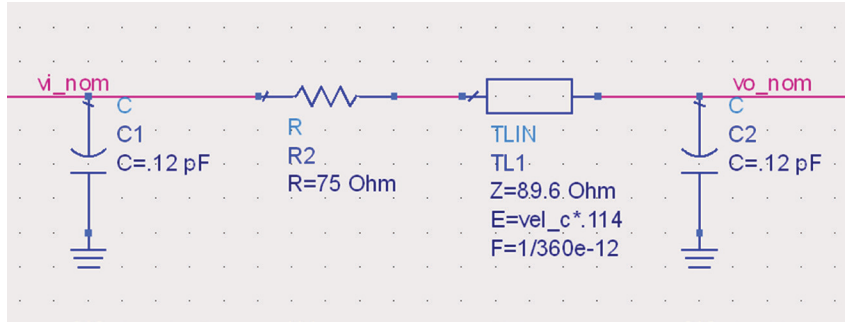

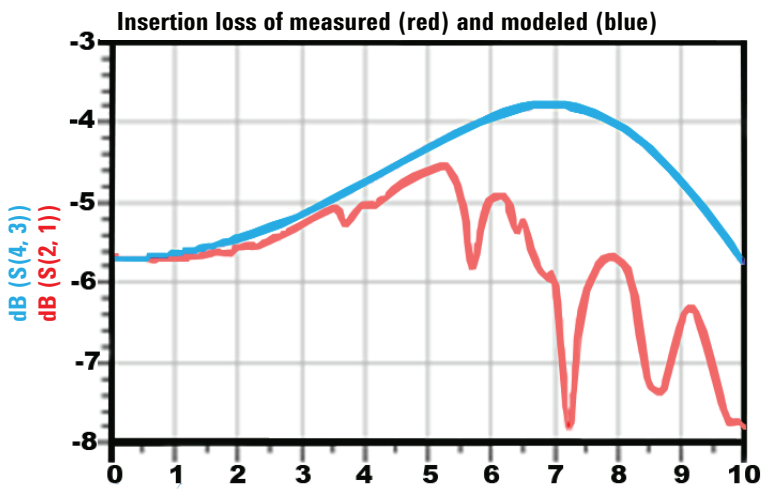Figure 24. Schematic of the Keysight W2635A DDR interposer.

Figure 25. DDR model versus actual measurement indicating good correlation to 5GHz.

Problem 5: De-embedding a DDR interposer

Process

To begin, determine whether the measurement is a 4-port or 2-port. In the InfiniiSim model setup select the "General Purpose 9 blocks" model (see Figure 26). In this case, the 2-port will be chosen for simplicity.
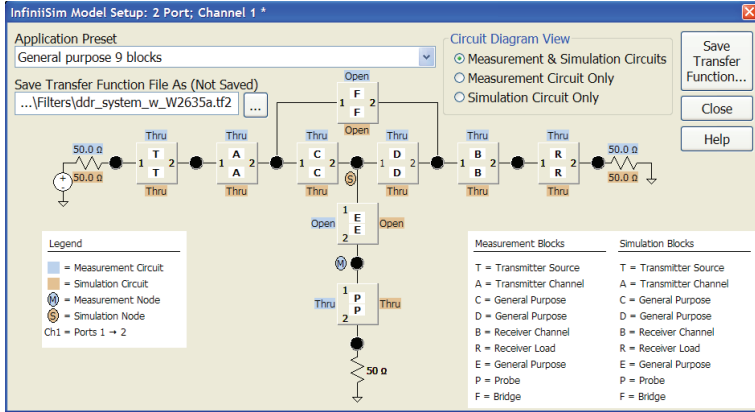

Figure 26. InfiniiSim General Purpose 9 block model.

Again, this will provide more blocks than necessary as was true in the other problems. In this scenario three blocks, "E", "P", and "D" will be defined. Blocks "B" and "R" are available for modeling of the DDR device, and blocks "T" and "A" can be used to model the memory controller. Block "C" is available to model the transmission line from the memory controller to the DDR device.

Block "E" will capture the model for the DDR interposer and block "R" will be the model of the device. Block "D" will be defined as the capacitance of the interposer (C1 in figure 24) because it is tapping off the connection between the transmission line from the memory controller and the DRAM memory device. Finally, we will need to use the s parameter model for the loading of the probe (block "P") similar to the process in problems three and four.

In order to capture the interposer model in block "E," note there are four discrete elements to comprehend; shunt capacitance, series resistance, transmission line and another shunt capacitance. These cannot all be modeled in one sub-circuit. The sub-circuit can only handle three of the four elements. Therefore, block "F" will be used to capture the first shunt capacitance and the sub-circuit will capture the remaining components (see Figure 27). The overall model is shown in Figure 28.
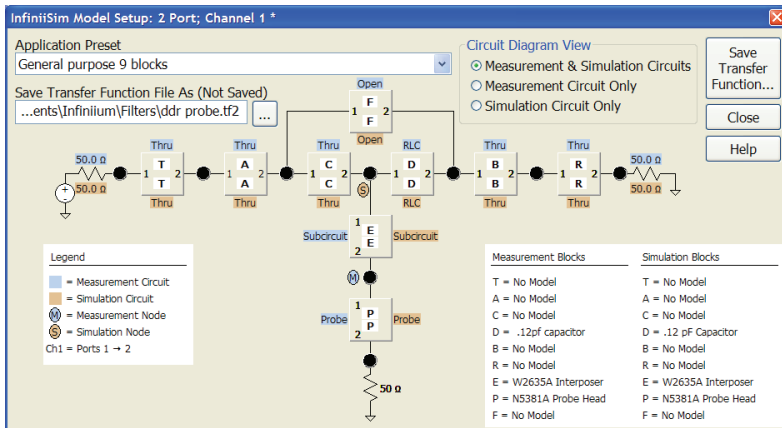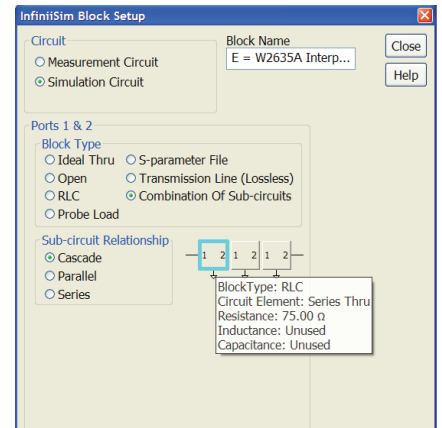

Figure 28 Overall circuit model.

Figure 27. Sub-circuit rendering of the interpose

Problem 5: De-embedding a DDR interposer

Process

One the convolution has been processed, the transfer function is shown in Figure 29 and the results of this correction in waveforms are shown in Figure 30
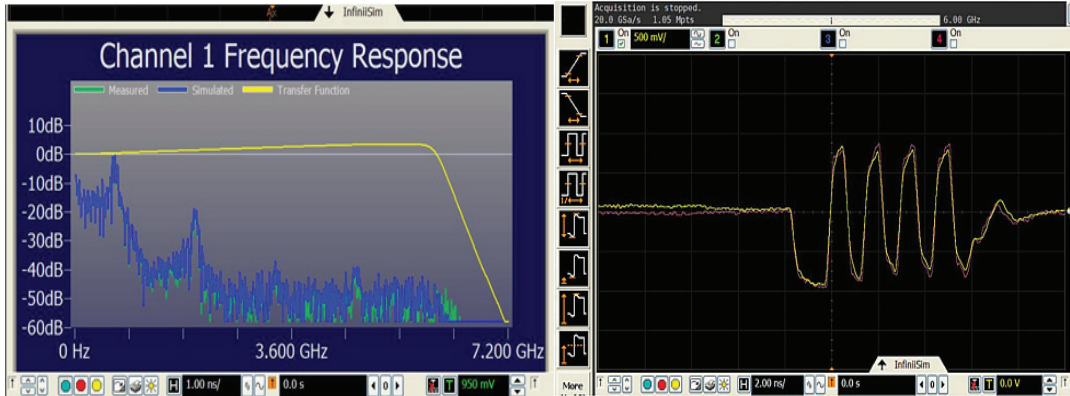

Figure 29. Transfer function for DDR interposer.

Figure 30. Waveforms showing the improvements made by application of the transfer function

This completes the analysis of problem five and concludes this paper.

Conclusion

This paper's objective was to illustrate the process of transforming waveforms on a real time oscilloscope using models of circuits and circuit elements. These models may come from simulations from software designed for that purpose, or can be measured as in the case of S-parameters to model channels. It presented five real-world scenarios, and illustrated the use of the InfiniiSim tool set software to address them. Each problem was presented, the issues identified and the results achieved. Through this series of exercise, the reader was tasked to apply the knowledge gained in capturing the signal with various types of hardware. Once captured, the signal was analyzed in various signal domains for insight on the reasonableness of the simulation. Information was also presented to allow the reader to extend the application for what-if scenarios and how the InfiniiSim Waveform transformation tool set can such analysis.

It is hoped that though this series of papers, the reader now has a good working knowledge of the issues surrounding de-embedding, embedding, waveform transformation in general, issues associated with the measurement, simulation and use of s parameters in the endeavor of characterizing devices and systems which are getting harder to analyze as data rates increase.

Appendix A:
Admittance/S-parameter review

For a generic multi-port network definition, it is assumed that each of the ports is allocated an integer n. For port n, the associated Y-parameter definition is defined by its related input voltages and output currents, V_n and I_n.

In many cases it is easier to analyze n-port networks in the admittance (Y) domain where zero is a valid number. For all ports the output currents may be defined in terms of the Y-parameter matrix and the input voltages by the following matrix equation: I=YV, where Y is an n × n matrix, of which the elements are indexed using conventional matrix notation. In general, it is assumed that the elements of the Y-parameter matrix are complex numbers and functions of frequency. For a single-port network, the Y-matrix reduces to a single element, the admittance measured between the two terminals.

Since 2-port networks are the most common, they have been chosen for this discussion, and will be defined by the standard relationship between input voltages and output currents. The general Y-parameter matrix is given by:

$$\begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{21} \\ Y_{21} & Y_{22} \end{pmatrix} \begin{pmatrix} V_1 \\ V_2 \end{pmatrix}$$

Where

$$Y_{11} = \left.\frac{I_1}{V_1}\right|_{V_2=0} \qquad Y_{12} = \left.\frac{I_1}{V_2}\right|_{V_1=0}$$

$$Y_{21} = \left.\frac{I_2}{V_1}\right|_{V_2=0} \qquad Y_{22} = \left.\frac{I_2}{V_2}\right|_{V_1=0}$$

The input admittance of a two-port network is given by:

$$Y_{in} = y_{11} - \frac{y_{12}y_{21}}{y_{22}+Y_L}$$

where Y_L is the admittance of the load connected to port two. Similarly, the output admittance is given by:

$$Y_{out} = y_{22} - \frac{y_{12}y_{21}}{y_{11}+Y_S}$$

Appendix A:
Admittance/S-parameter review

where Y_S is the admittance of the source connected to port one. Y-parameters are directly related to S-parameters by the following convolution:

$$Y = \sqrt{y}\,(1_N - S)(1_N + S)^{-1}\sqrt{y}$$
$$= \sqrt{y}\,(1_N + S)^{-1}(1_N - S)\sqrt{y}$$

and:

$$S = (1_N - \sqrt{z}Y\sqrt{z}\,)(1_N + \sqrt{z}Y\sqrt{z}\,)^{-1}$$
$$= (1_N + \sqrt{z}Y\sqrt{z}\,)^{-1}(1_N - \sqrt{z}Y\sqrt{z}\,)$$

where 1_N is the identity matrix, $\sqrt{y}$ is a diagonal matrix having the square root of the characteristic admittance (the reciprocal of the characteristic impedance) at each port as its non-zero elements,

$$\sqrt{z} = \begin{pmatrix} \sqrt{y_{01}} & & & \\ & \sqrt{y_{02}} & & \\ & & \ddots & \\ & & & \sqrt{y_{0N}} \end{pmatrix}$$

And $\sqrt{z} = \sqrt{y}^{-1}$ is the corresponding diagonal matrix of square roots of characteristic impedances. In these expressions the matrices represented by the bracketed factors can be commuted and may be written in either order.

Two-port
In the special case of a two-port network, with the same characteristic admittance $Y_{01} = Y_{02} = Y_0$ at each port, the above expressions reduce to:

$$Y_{11} = \frac{((1 - S_{11})(1 + S_{22}) + S_{12}S_{21}}{\Delta_S} Y_0$$

$$Y_{12} = \frac{-2S_{12}}{\Delta_S} Y_0$$

$$Y_{21} = \frac{-2S_{21}}{\Delta_S} Y_0$$

$$Y_{22} = \frac{((1 + S_{11})(1 - S_{22}) + S_{12}S_{21}}{\Delta_S} Y_0$$

Where:

$$\Delta_S = (1 + S_{11})(1 + S_{22}) - S_{12}S_{21}$$

The above expressions will generally use complex numbers for S_{ij} and Y_{ij}. Note that the value of Δ can become zero for specific values of S_{ij} so the division by Δ in the calculations of Y_{ij} may lead to a division by zero.

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