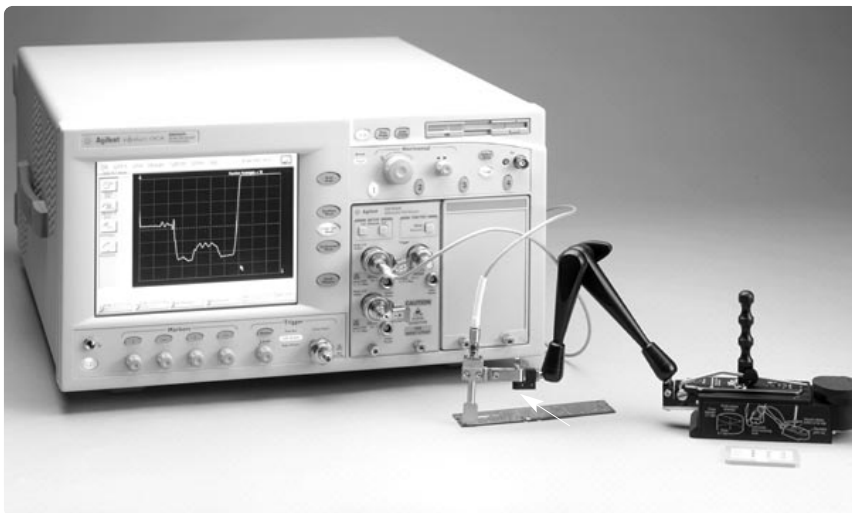


# Measuring Characteristic Impedance of Short Rambus® Motherboard Traces and Small-Outline RIMM™'s

Application Note 1304-4



**Agilent 86100A  
Infiniium DCA with  
N1020A TDR Probe**



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## Overview

When making highly sensitive measurements on high-speed digital boards, there is little room for error. Rambus® memory architecture produces extremely fast signals (250-picosecond risetime) on computer motherboards and memory boards and thus requires special measurement tools. The challenge is even greater for the digital design engineer when faced with Rambus traces that are only 1-2" in physical length. Smaller form factor printed circuit boards for new laptop applications and motherboards are creating a need for more precise measurement techniques. By using a test procedure called Time Domain Reflectometry (TDR) normalization, high-speed oscilloscopes can accurately measure the characteristic impedance of these short traces by removing sources of error. This application note will describe the test equipment and general methodology that is recommended to make these signal integrity measurements.

## Test Equipment

The basic measurement tools required to measure characteristic impedance of short Rambus traces are a high-speed digitizing oscilloscope which has a modular TDR plug-in, a 10-GHz TDR probe and a TDR calibration substrate (see equipment list in Appendix A). Please note that the TDR oscilloscope must have the capability of normalization\*. This equipment is ideally suited for an R&D environment and is very versatile. If a high-volume manufacturing capability is required, additional test equipment is recommended (see equipment list in Appendix B).

## TDR Calibration Substrate

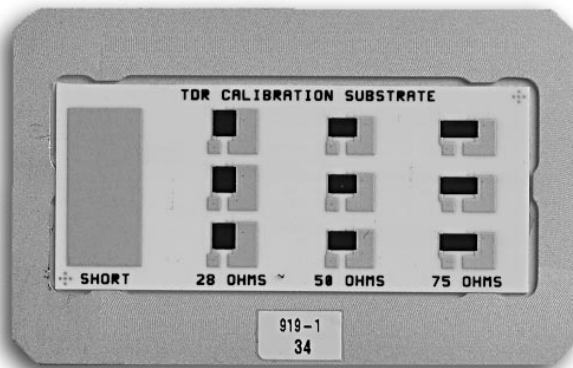


Figure 2. TDR Calibration Substrate  
(included within Agilent N1020A probe kit)

The TDR calibration substrate is used to remove the errors introduced by the test. Probe tip ground lead inductance reflections from connectors and cable loss are typical examples of test fixture error. With the normalization process, the user performs a two-point calibration at the probe tip so that an appropriate digital filter can be automatically configured in the oscilloscope firmware. It is recommended to perform this calibration process when probing Rambus In-line Memory Modules (RIMM's) and Continuity RIMM's (CRIMM™'s), but it is mandatory when probing short traces on motherboards and Small Outline RIMM's (SO-RIMM™'s).

The substrate shown in Figure 2 has precision, thick film resistors that are laser trimmed to yield the utmost in accuracy. Durable gold electrodes are fired onto the alumina substrate to insure a long life with various probe tip configurations. The calibration substrate is a non-reactive standard that is recommended for TDR measurements due to the lower frequency content of time domain reflectometers. A 28-ohm airline is not recommended for TDR calibration, but it can be used effectively with a vector network analyzer.

## Calibration and Verification

Using the process of calibration and verification together will enhance the confidence of Rambus board designs. To minimize measurement error, it is best to calibrate a 50-ohm output impedance instrument in a 50-ohm environment. After this calibration is accomplished, the next step is to verify the calibration by measuring a well-known impedance value that is close to the characteristic impedance of the device under

\* Normalization is firmware built into the Agilent 54750A that is based on the Bracewell transform which was originally licensed from Stanford University. Detailed normalization measurement technique is described on the Intel website Appendix C: (<http://developer.intel.com/design/chipsets/applnots/298179.htm>)

test (DUT). This two-step process assures that the measurement equipment is highly accurate in the region of interest.

The two step process is done as follows: using a TDR probe with suitable bandwidth, and a TDR oscilloscope with normalization capability, first probe the short standard on the calibration substrate. This is the electrode area indicated on the left side (see Figure 2). Next, probe the 50-ohm precision resistor, making sure to place the ground pin of the TDR probe on the larger electrode pad. This is done because the excess capacitance of the larger electrode effectively compensates for the excess inductance associated with most probe ground tips. After confirmation from the TDR scope, the calibration is complete. Next, a verification must be done.

Probing one of the 28-ohm  $\pm 0.25\%$  thick film resistors located on the calibration substrate does the verification. The  $\pm 0.25\%$  resistor tolerance translates into  $\pm 70$  milliohms for the 28-ohm standard. This resolution is important for Rambus applications where the  $\pm 2.8$ -ohm tolerance is essential for proper operation of the signal channel. To change the response rise time, click on the "Response" icon in the left tool bar. Choose the response waveform associated with the activated channel, then change the rise time 250 ps for Rambus applications. When performing verification, it is important to use the Normalized TDR waveform. The standard TDR waveform will include secondary reflections that will introduce significant inaccuracies at the front end of the DUT (up to 3 ohms of error for Rambus SO-RIMM's).

## Motherboard Measurements

Using TDR on printed circuit boards provides useful insights for the digital design engineer trying to understand signal integrity issues. Launching the TDR step into the circuit trace with a high-bandwidth TDR probe is a common procedure when there are no connectors conveniently located nearby. Finding the optimal location on the board to probe is not always a simple task and the results obtained will vary depending on the launch point chosen. The figures below show various results based on the launch point on the Rambus motherboard.



Figure 3. Probing a Rambus motherboard from the RIMM connector side

A recommendation will be given with the hope of standardizing Rambus motherboard TDR measurements.

Observing the memory architecture of Rambus circuit topology shown in Figure 4, the first microstrip segment under test measured is located between the Rambus Memory Controller chip (RMC) and the first RIMM connector. Figure 3 shows the impedance profile of this motherboard microstrip trace when probing from the RIMM #1 connector side of the trace. This particular motherboard has already been populated with the various components associated with the Rambus physical layer. Most TDR measurements are performed on bare PC boards, but it is sometimes useful to the designer to troubleshoot the whole Rambus channel with all its components. A notable component in this TDR waveform is the higher impedance of the Ball Grid Array (BGA) structure of the RMC package. This particular BGA adds excess inductance to the 28-ohm characteristic impedance of the motherboard microstrip and therefore pulls the impedance higher.

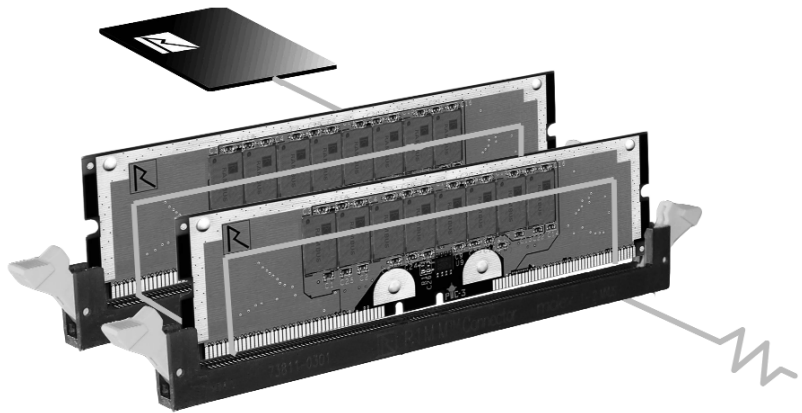


Figure 4. Rambus motherboard architecture

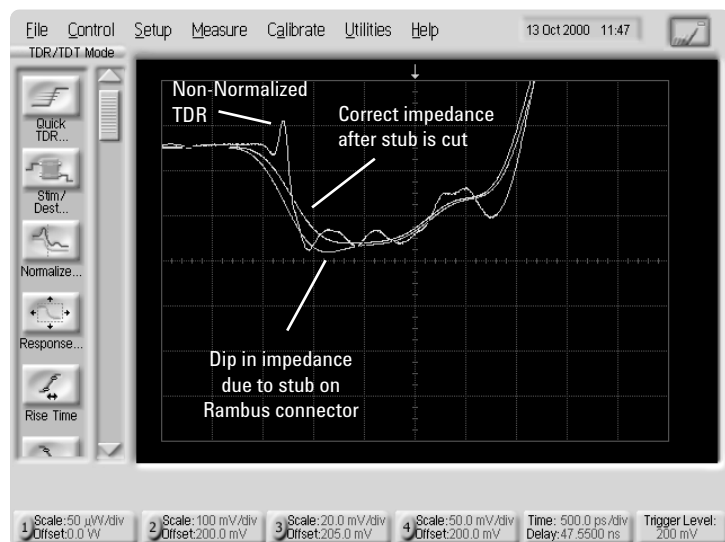


Figure 5. Probing from RIMM connector after cutting connector stub

## Capacitance Pad Compensation

Various high-speed digital design techniques are employed during layout to enhance signal integrity. One such technique being used on Rambus motherboards is the capacitance pad or “C-Pad”. This trace structure is around 0.075” long and can be visibly seen on the underside of the motherboard as a short stub. The purpose of the C-Pad is to compensate for the excess inductance of the RIMM connector lead which penetrates the via after board population. This is a well-known design technique that enhances signal integrity at high speeds by closely controlling the impedance environment. When a fast risetime edge from a Rambus signal encounters this structure, it will travel both directions and essentially see two 28-ohm transmission lines in parallel for a very short distance. This creates an area of effective low impedance and compensates for the higher impedance of the excessively inductive connector wire.

An interesting design flaw of a motherboard C-Pad has been discovered in Figure 5. The impedance profile shows a low dip in the front side of the waveform. This indicates that the designed geometry of the C-Pad has overcompensated for the inductive connector lead by pulling the impedance too far down. In this case, the correct geometry for proper impedance compensation would be a reduction in trace width or to remove the C-Pad completely. The normalized TDR waveform shows the impedance profile after the stub has been removed with an X-Acto knife.

Choosing the proper point to launch the TDR step can make the measurement easier. Figure 6 below shows the results when using the recommended procedure for measuring Rambus motherboard traces, that is, probing a trace from the memory controller side of the microstrip segment. This means the motherboard must be unpopulated, but this allows the easiest access to most of the Rambus traces under interest. The benefits of this probing location can be seen by the flat and uncluttered impedance profile of the trace. Additional advantages of this method are that many ground vias are available in this area of the motherboard and the smaller via size doesn't require a stub for compensation.

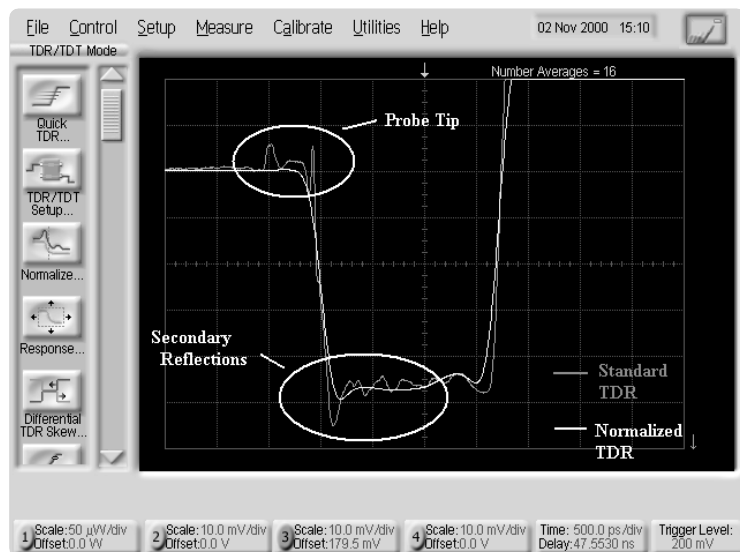


Figure 6. Probing bare motherboard from Rambus Memory Controller side

## Rambus SO-RIMM Measurements

The Small Outline RIMM is a new form factor memory module that will be used for laptop computer memory and is therefore much smaller in size than a typical desktop RIMM. The challenging part of measuring the characteristic impedance of a SO-RIMM module is the very short 28-ohm microstrip segment, typically only 1" to 1.5" long.

Figure 6 shows the characteristic impedance profile of a SO-RIMM. The SO-RIMM has three distinct segments: the first 28-ohm segment, a higher impedance (typically 56-ohm) segment in the middle, and the back end 28-ohm segment. The high impedance segment in the middle is where the silicon memory devices are loaded onto the board. At Rambus signal speeds, the silicon is modeled as a RLC equivalent circuit with an effective 56-ohm impedance shunted to ground. After the silicon is loaded onto the board, the high-speed data indicates two 56-ohm microstrips in parallel (28-ohm). The post-silicon controlled impedance environment produces minimal reflections and is the basis for choosing the 28-ohm characteristic impedance value for Rambus memory architecture. This principle of bare board impedance modulation is also used in standard RIMM's, not just SO-RIMM's.

The enhanced accuracy of TDR normalization is easily seen in the SO-RIMM measurement. The secondary reflections that would ordinarily obscure the correct impedance reading in this short trace are nonexistent on the normalized TDR waveform. This is because the calibration substrate was used with a high frequency TDR probe to set the reference plane at the probe tip. The standard TDR waveform shows how secondary reflections produce measurement error.

A notable phenomenon visible in this TDR measurement is the lossy nature of the particular SO-RIMM used in this experiment. The upward slant of the middle 56-ohm segment would normally indicate a microstrip with increasing impedance. However, since the geometry of the known test device was well controlled, this cannot be the case. This upward slope indicates either dielectric loss or skin effect loss of the microstrip. The second 28-ohm segment near the end of the SO-RIMM seems to be higher impedance, but it is not. In a similar fashion to the upward slope aforementioned, the losses encountered in the printed circuit board construction create a distributed impedance effect that makes it seem higher impedance. The point to remember is that the characteristic impedance of the trace has not changed. This fact can be proven by reversing the device under test and launching the TDR step from the opposite end. A similar upward slope will be observed and will confirm this effect.

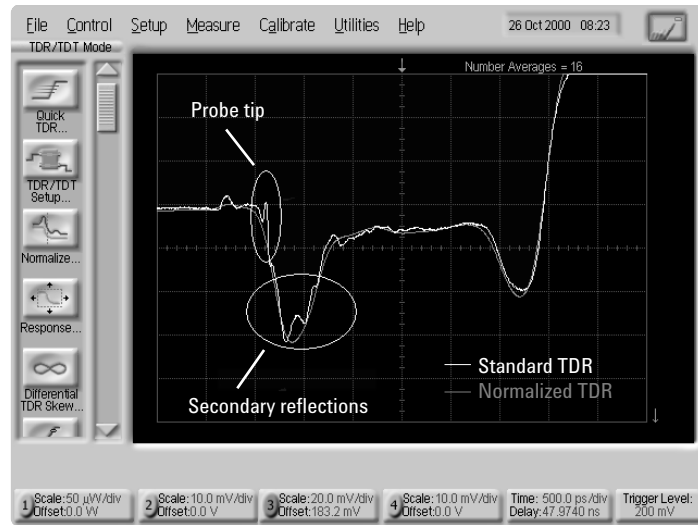


Figure 7. Small Outline RIMM before silicon is attached shows three distinct impedance levels.

## Short Rambus Coupon Measurement

An experiment was performed to validate the accuracy of the TDR measurement on progressively shorter Rambus traces. A six-inch long 28-ohm microstrip test coupon fabricated from F4 material was used and then the characteristic impedance was measured with the 10 GHz TDR probe. The resultant TDR measurement is the longest trace waveform in figure 8. The board was then cut in half to measure the remaining 3-inch section (middle waveform) and then cut one more time to yield a 1.5-inch section. A measurement marker was placed 26.4 millimeters from the probe tip reference plane, thus marking the physical location within the micro-strip structure where the measurements were taken. At the 26.4 mm marker location, the three measurements were within 300 milliohms of each other.

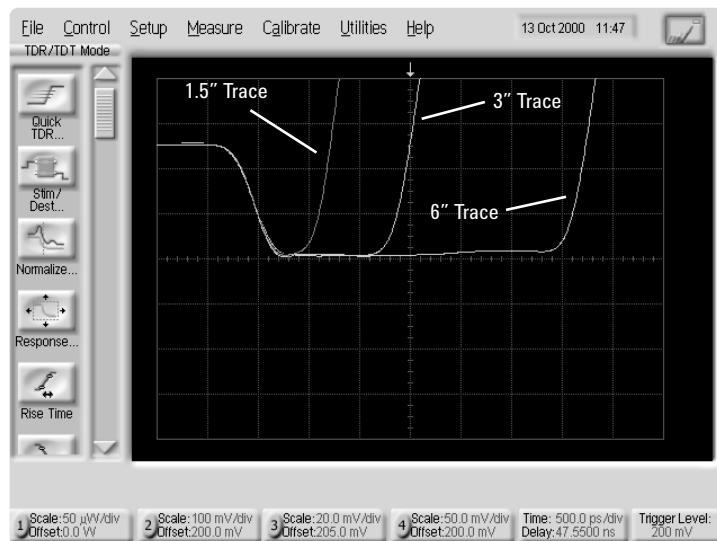


Figure 8. Progressively shorter Rambus coupon measurements

## Conclusion

When performing characteristic impedance measurements of Rambus mother-boards and SO-RIMM's, it is important to remove errors that are introduced by the test fixturing and probes. The critical nature of Rambus signal integrity measurements call for calibration procedures beyond the standard TDR test methodologies. Effects of ground lead inductance, cable attenuation and connector reflection increase measurement error outside acceptable limits for short Rambus traces. Time Domain Reflectometry normalization and verification with a precision calibration substrate gives the confidence needed with Rambus motherboard and SO-RIMM signal integrity applications.

### Appendix A - List of Equipment (R&D Test)

Agilent 86100A Infiniium DCA  
Agilent 54754A Differential TDR Plug-in Module  
Agilent N1020A TDR Probe Kit  
Agilent 54006A 6 GHz Resistive Divider Probe  
Agilent 54701A 2.5 GHz Active Probe  
Agilent 54121-68701 RF Accessory Kit

### Appendix B - List of Equipment (Manufacturing Test)

Agilent 83480A-K16 Rambus RF Switch Matrix  
Agilent 83480A-K17 Rambus RIMM Test Fixture

## References

1. Resso, M., "The Right Technique Yields Critical Direct Rambus Signal-Integrity Measurements", Engineering Design News, August 5, 1999
2. "Evaluating Microstrip with Time Domain Reflectometry", Agilent Application Note 1304-1, Agilent Publication 5968-0007E, 1998
3. Dascher, D., "Measuring Parasitic Capacitance and Inductance Using TDR", HP Journal, April, 1996  
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