Hideo Okawara's
Mixed Signal Lecture Series

DSP-Based Testing – Fundamentals 38
TDR Experiment

Verigy Japan
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Preface to the Series

ADC and DAC are the most typical mixed signal devices. In mixed signal testing, analog stimulus signal is generated by an arbitrary waveform generator (AWG) which employs a D/A converter inside, and analog signal is measured by a digitizer or a sampler which employs an A/D converter inside. The stimulus signal is created with mathematical method, and the measured signal is processed with mathematical method, extracting various parameters. It is based on digital signal processing (DSP) so that our test methodologies are often called DSP-based testing.

Test/application engineers in the mixed signal field should have thorough knowledge about DSP-based testing. FFT (Fast Fourier Transform) is the most powerful tool here. This corner will deliver a series of fundamental knowledge of DSP-based testing, especially FFT and its related topics. It will help test/application engineers comprehend what the DSP-based testing is and assorted techniques.

Editor's Note

For other articles in this series, please visit the Verigy web site at www.verigy.com/go/gosemi.

Preface

The last month's article describes about the TDR simulation performed using the four-terminal matrix method[1]. This month article reports actual measurement results compared to the simulation results.

Test Configuration

Figure 1 illustrates the experimental configuration. The pin driver generates a 50[MHz] clock signal, which is asserted to a 50[Ω] transmission line whose terminal can be terminated with various terminations such as 50[Ω], open, short and LCR impedance. A 1[kΩ] resistor is connected to the point approximately 12[cm] away from the terminal point. The resistor senses the composite signal of the incident and the reflected signals, conveying it to the waveform sampler for waveform analysis.

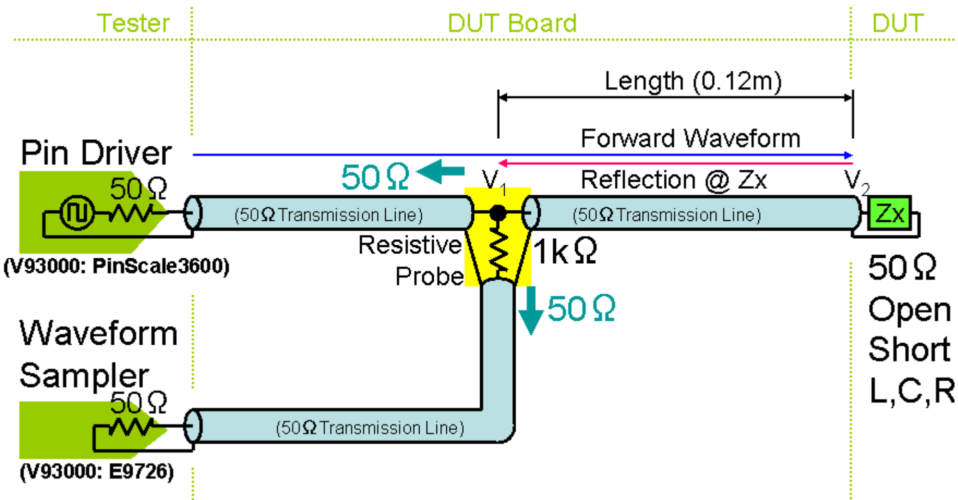


Figure 1: Experimental Configuration

To pick up the signal with minimum interference, the transmission line needs to be sensed with a high impedance condition. One of the most simple and typical techniques for high impedance sensing is a passive resistive probe. As shown in Figure 2, the signal at the probing point is sensed with a 1[kΩ] resistor, and the other end of the resistor is connected to a 50[Ω]-transmission line. The transmission line is terminated with 50[Ω] that is the input impedance of the sampler. So the terminated transmission line can be seen as a 50[Ω]. Consequently the probing point is sensed with 1050[Ω] so that the probe can pick up the signal with little effect. The sensed signal is divided by 50/1050 so that the signal level introduced to the sampler is reduced by approximately 26[dB].

Figure 3 is the photograph of the actual experimental hardware. The transmission lines are semi-rigid coaxial cables. The terminal of the main coaxial cable provides an SMA plug which can be connected to various impedance mounted terminations. The 1[kΩ] chip resistor should be connected to the sensing point as close as possible for avoiding stray components.

[1] Mixed Signal Lecture Series "DSP-Based Testing – Fundamentals 37 F-matrix Simulation TDR"

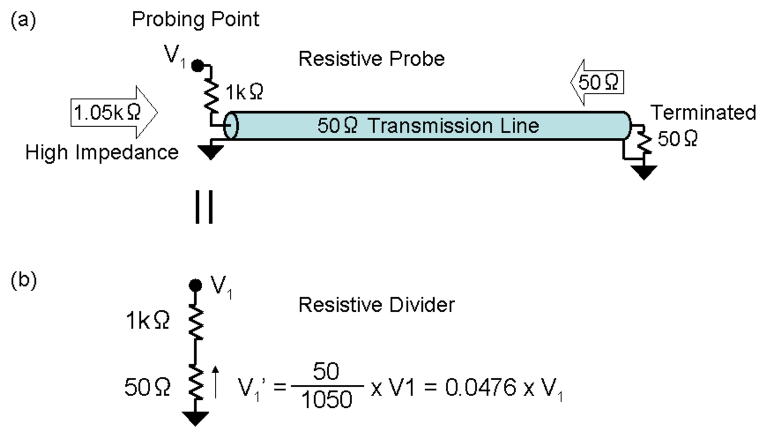


Figure 2 **Resistive Probe**

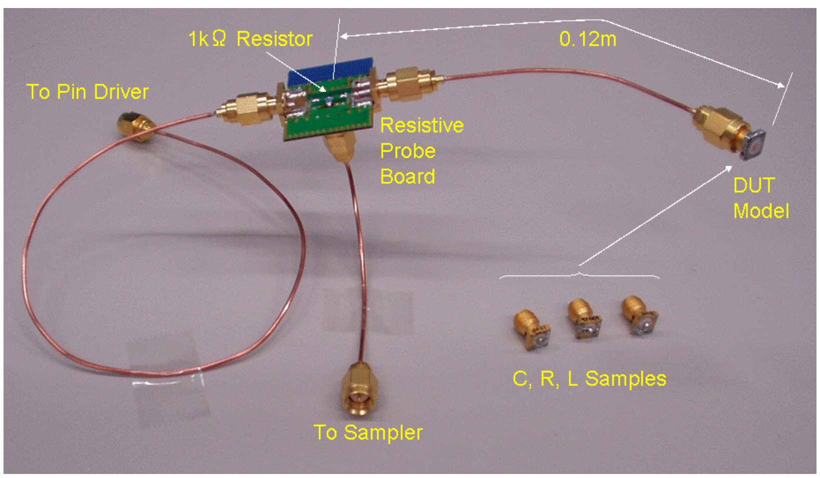


Figure 3: **Photo of Experimental Components**

Measurement Results

When the SMA connector terminal is terminated with the open, 50Ω and short terminations, the simulation results look as Figure 4.

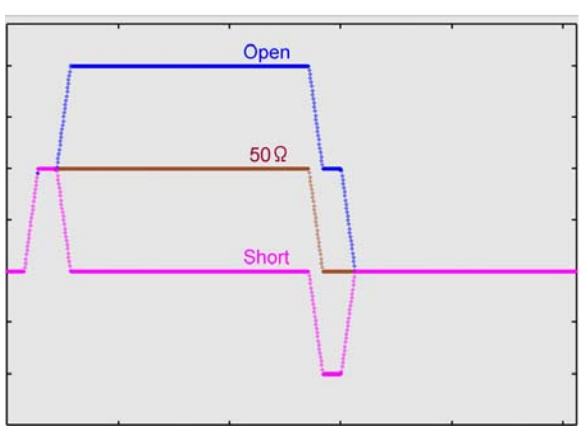


Figure 4: **Simulated Waveforms**

Figure 5 shows the waveforms that the sampler actually captured. Since the resistive probe extremely attenuates the signal by 26dB, the measurement noise looks significant compared to the signal amplitude. TDR needs to analyze the waveform precisely so that these noisy signals are not good for analyses as they are.
Performing the fast Fourier transform (FFT) to each noisy traces in Figure 5, their frequency spectra look as Figure 6, in which the frequency bins are shown from the DC to the 100th spectrum. Looking at the spectrum outlook, you may notice the major part of each spectrum exists from the DC to approximately the 40th spectral bins in this particular example. So let's collect the lowest 40 bins in each spectrum and reconstruct the waveform by performing the inverse FFT (IFFT). Then the noisy traces are refined as the thin, clear traces as Figure 7 shows. This is a low pass filtering performed in the frequency domain. How many lines you should collect depends on the slew rate of the clock waveform. Figure 8 is the simulation result of the clock waveforms vs. their frequency spectra. The yellow waveform has the highest slew rate and the green has the lowest. The noise floor line in Figure 8 is just an example for thinking of how many lines you should collect. The yellow spectrum needs to be collected 50 lines and the red, blue, white and green spectrum would need to be collected 40, 30, 20 and 1 bins respectively.

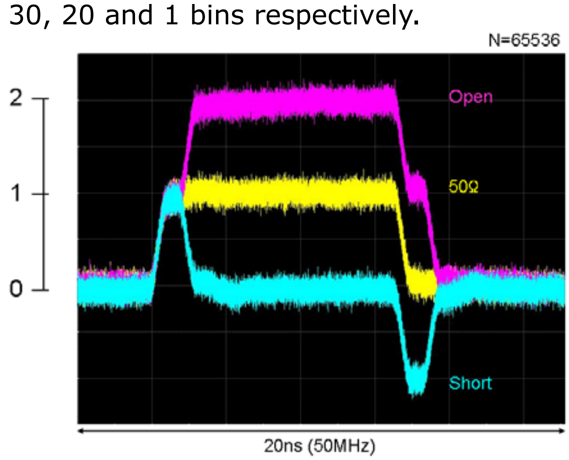


Figure 5: Measured Waveforms

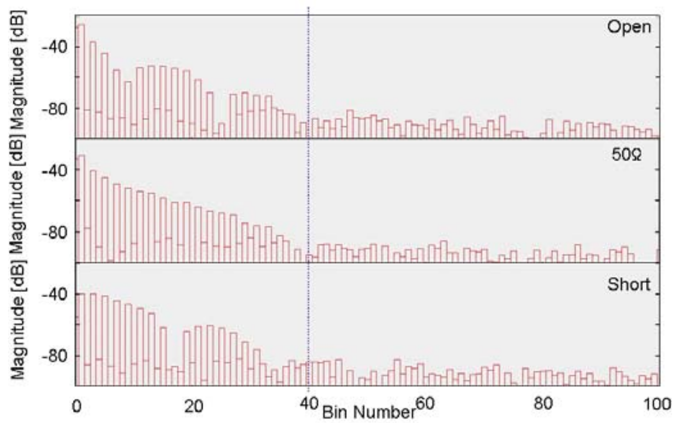


Figure 6: Frequency Spectra

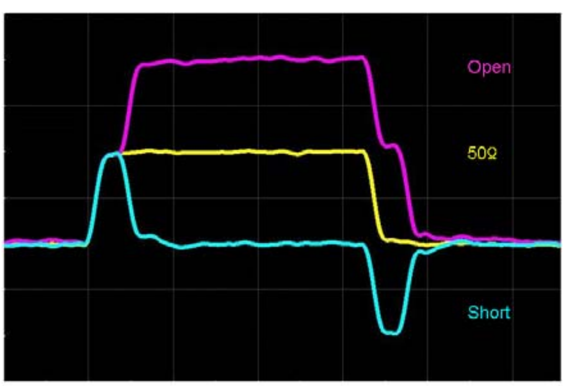


Figure 7: Reconstructed Waveforms

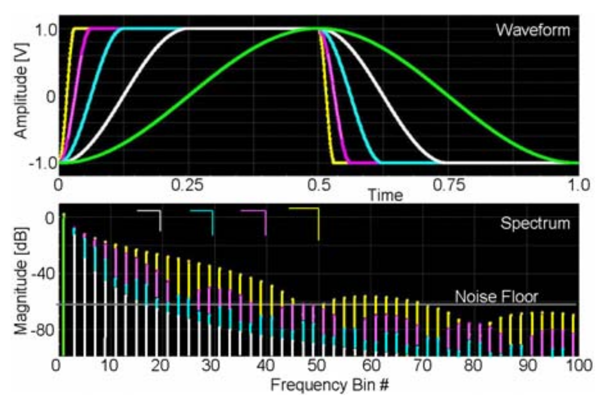
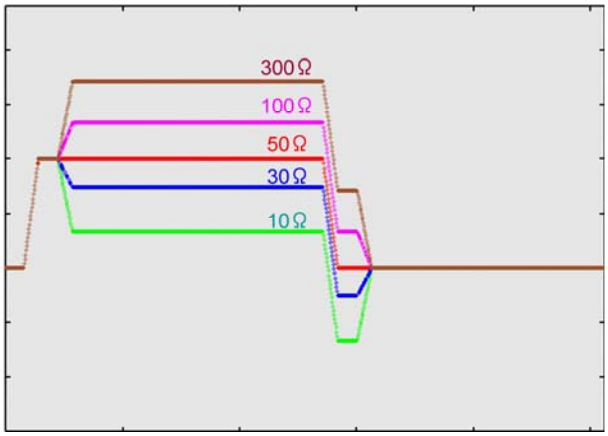


Figure 8: Waveform vs. Spectrum

When the termination is a resistor, the composite signal looks as simulated as Figure 9 shows. The actual measured result is shown in Figure 10 which is already refined by collecting 40 lines of spectra. You can estimate the resistance value by examining the levels of the flat areas. Table 1 summarizes the results estimated from the flat levels in Figure 10.



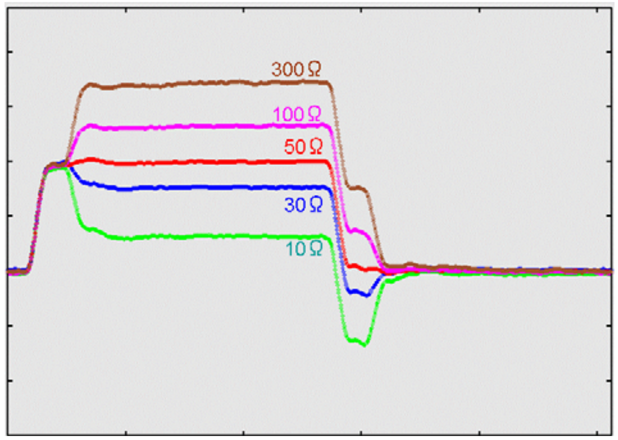


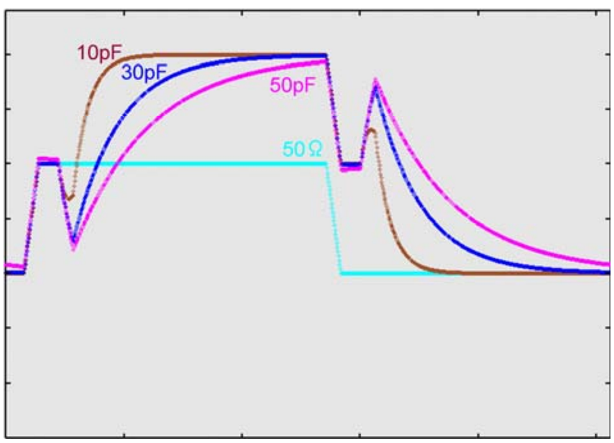
Figure 9: Resistors (Simulation)

Figure 10: Resistors (Measured)

Nominal	LCR Meter	TDR	Error
10Ω	10Ω	9.4Ω	-6%
30Ω	30Ω	31Ω	3%
50Ω	50Ω	50Ω	0%
100Ω	101Ω	98Ω	-3%
300Ω	301Ω	300Ω	-0%

Table 1: Measurement Result

When the terminal is terminated with capacitors, the estimated response looks as Figure 11 shows, and the actual measurement results look as Figure 12.



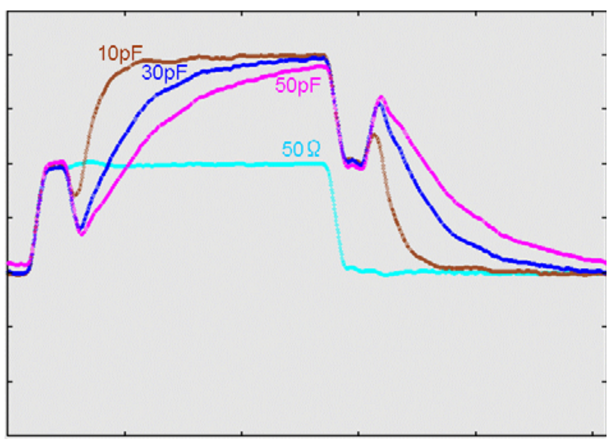


Figure 11: Capacitors (Simulation)

Figure 12: Capacitors (Measured)

Figure 13 shows the case of 30pF. The specific curve in the highlighted area actually shows an exponential curve based on the capacitance connected. By applying a logarithmic conversion to the exponential curve, it looks as the red line in Figure 13. Then applying the linear regression to the red line, the slope of the straight line can derive the capacitance value. Table 2 illustrates the summary of measurement performance.

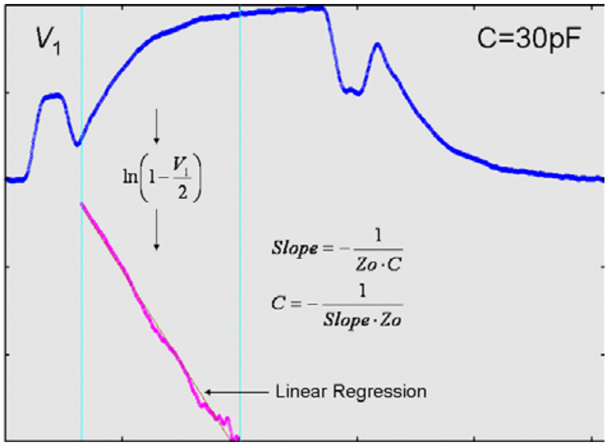


Figure 13: Capacitor 30pF

Nominal	LCR Meter	TDR	Error
10pF	11pF	13pF	18%
30pF	32pF	37pF	16%
50pF	52pF	57pF	10%

Table 2: Measurement Result

When the terminal is terminated with inductors, the simulation result looks as Figure 14 shows and the actual measurement result looks as Figure 15.

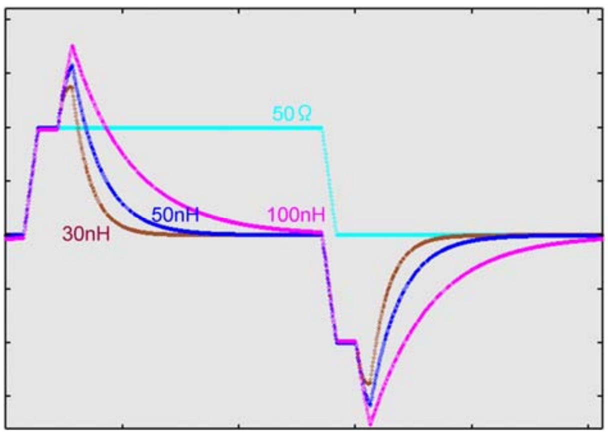


Figure 14: Inductors (Simulation)

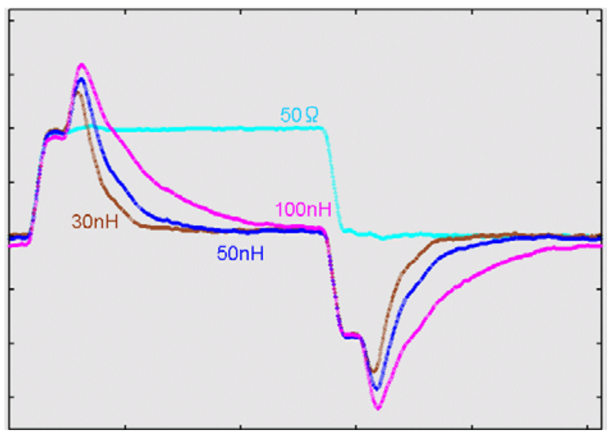


Figure 15: Inductors (Measured)

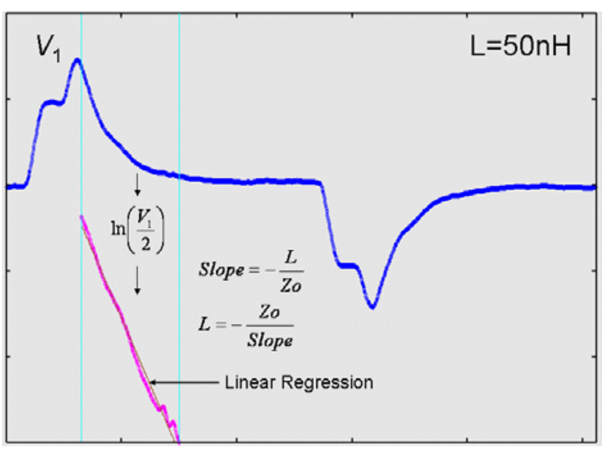


Figure 16: Inductor 50nH

Nominal	LCR Meter	TDR	Error
30nH	35nH	40nH	14%
50nH	58nH	62nH	7%
100nH	118nH	120nH	2%

Table 3: Measurement Result

Figure 16 shows the case of 50nH. The specific curve in the highlighted area actually shows an exponential curve based on the inductance connected. Therefore applying a logarithmic conversion to the curve, it looks as the red line in Figure 16. Then applying the linear regression to the red line, the slope of the straight line can derive the inductance value. Table 3 illustrates the summary of measurement performance.

Component	Range	Error
Resistor	10Ω..300Ω	10%
Capacitor	10pF..50pF	20%
Inductor	30nH..100nH	15%

Table 4: Summary of Performance

As Table 4 summarizes the total LCR measurement performance, it seems available with 10 to 20% accuracy. This TDR method is so simple that it can be deployed on DUT boards. It would be good enough for the input capacitance measurement of device under test.