

Keysight Technologies

High Frequency Probing Solutions for Time and Frequency Domain Applications

Application Note



Introduction

Increasing consumer and business demand for cellular, wireless connectivity, digital entertainment, and information transmission is driving the need for high speed systems such as routers, servers, mobile phones and PCs. Technologies are evolving from first generation cellular to multimedia services and the current 4G telecommunication. In high-speed digital technologies, a similar trend is to push the data rates beyond Gbps. For example, SATA II 3 Gbps and USB 3.0 (4.8 Gbps) data rates are well beyond 1 Gbps.

As we push the data rates beyond gigabits per second, signal integrity is a major issue. Signal integrity raises two concerns in electrical design aspects:

- Timing - does the signal reach its destination when it supposed to?
- Signal quality - is the signal in good condition when it reaches its destination?

Under these conditions, high-speed analog effects, previously only seen in high frequency RF and microwave engineering, can impair the signal quality and degrade the bit error rate of the link. Testing the physical layer ensures that the devices, boards, and interconnects, have electrical characteristics that can support the high data rates without any significant signal degradation.

High-speed digital designers need to design their boards with signal integrity in mind to minimize signal degradation issues. If you suspect signal integrity related problems, the first instrument you turn to is an oscilloscope and a probe. The scope is the best instrument for finding out what a signal looks like in the time domain. It will continue to be an important tool for understanding signal integrity problems, but it is only one of many tools that are now required. Other instruments such as signal/spectrum analyzers, signal source analyzers, and network analyzers are important tools used to analyze the signal integrity; these instruments fundamentally operate in the frequency domain. It is often the case that the path or the points you want to look at do not have a connector for instrument connection. A high frequency probe is required to pick up samples of the original signal for signal analysis without adversely affecting the original signal characteristic. It is common to use a probe with an oscilloscope to see what the actual signal looks like. However, it is less common to use a probe with a signal/spectrum analyzer for in-circuit troubleshooting of a high-speed digital sub-assembly or a RF/microwave circuit design.

In this application note, a high frequency probe with a frequency domain instrument application will be discussed.

Probing Application

Probing is a significantly complex area when designing and testing high-speed digital communication systems. In the event that an individual component within a module is to be separately tested or monitored, it is necessary to probe on the components pins or traces. Probing can be a solution, but it is time consuming due to two reasons,

1. Probes require high impedance and low capacitance to avoid loading the circuit and introducing errors.
2. The modules and interconnects themselves are quite small and difficult to probe, it is recommended to probe under a microscope.

For high frequency probing there are passive and active probes. As the names imply, the active probe has an amplifier to amplify the probe signal and passive probe is without active components, it can be a thru-line interface or a passive attenuator.

A general probe solution with a time domain instrument such as an oscilloscope or logic analyzer will not be discussed here, details can be found in *"Infiniium Series Oscilloscope Probes, Accessories, and Options Selection Guide Data Sheet"* literature number 5968-7141EN.

Passive probes are generally used to probe interconnects electrical characteristics such as the S-parameters, time domain reflections/transmissions, or the transmission line impedance. Probing points, starting point and end point of the interconnects are critical to note otherwise the measurement will not be accurate. Figures 1A, B, and C are examples using two passive probes. Figure 1A shows interconnects between two ICs. Figure 1B shows incorrect probing methodology using a passive probe for TDR or S-parameters. Since we are using a passive probe, the input impedance of the probe is 50 ohm, when NOT probing the end point of the transmission line, the passive probe will effectively see an open stub or the parallel of two transmission lines. The correct way to probe is to remove both ICs and probe as seen in Figure 1C. Figure 1C is a thru probe, the probe effectively measures the signal from IC1 to IC2 correctly.

When using active high-impedance probes you can probe at any location. In this case, samples of signals are picked up by the active probe which does not adversely affect the signal characteristic. The only drawback of using an active probe is that you can only measure the received signal and cannot source the signal back to the transmission line. We can use active probe to probe at IC1 then IC2 to compare their signal amplitude to see whether interconnects degraded the signal or not.

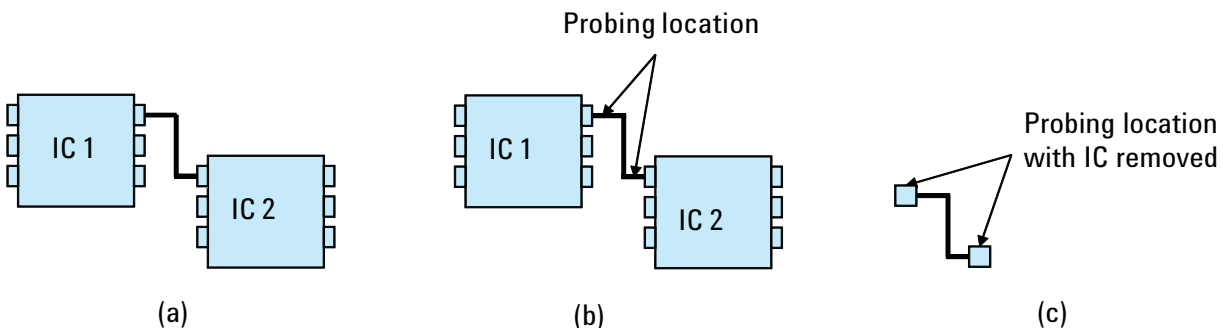


Figure 1. Typical IC to IC interconnect

Probing Application *(continued)*

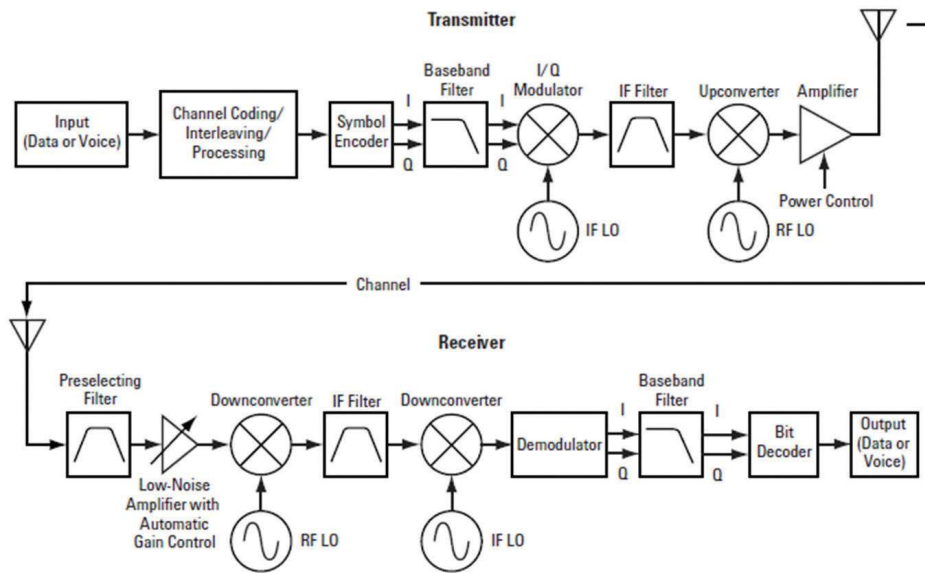


Figure 2. Block diagram of a digital radio system

Figure 2 is a typical communication system block diagram. Using an active probe with a network (NA), spectrum (SA), or signal source analyzer (SSA) you can measure at any RF, baseband, LO path, and DC path to check the signal condition (i.e. spurious signals, harmonics, phase noise, signal level, etc.). Without the probe, you either need to determine the possible root cause based on a functional test measurement or isolate specific components for verification. “*Wireless Test Solutions Application Note 1313*” literature number 5989-3578E and “*Testing and Troubleshooting Digital RF Communications Receiver Designs Applications Note 1314*” literature number 5968-3579E, discuss digital testing and troubleshooting in more detail.

A probe with a signal source analyzer can be used to probe at the carrier frequency or LO frequency to look at the phase noise performance which might be the root cause to the error vector magnitude (EVM). The SSA can separate the carrier to phase noise and AM noise to diagnose the root cause. A spectrum analyzer with probe can be used to measure the spurious signal or out-of-band signal level. A network analyzer with probe can be used to measure the frequency response step-by-step provided the input can be connected to the network analyzer.

High Frequency Probing

Frequency Domain Solution versus Time Domain Solution

The frequency domain solution refers to a probe using a spectrum analyzer, signal source analyzer, and/or a network analyzer. These instruments have excellent dynamic range and can accurately measure very low signal amplitude. The noise floor of high bandwidth oscilloscopes is around -40 dBm, whereas in an economy-class signal/spectrum analyzer (such as Keysight EXA) the noise floor can reach 120 dBm at 1 kHz resolution bandwidth. Hence, using a frequency domain instrument that has better dynamic range over the time domain instrument when you need to measure small signal amplitude is preferred. In wireless communication systems, the measured signal or noise level can be very low. For example, the receiver sensitivity can be as low as -90 dBm. In high-speed digital low voltage differential signaling (LVDS) running at 350mVpp compare to TTL of 5V for high-speed digital signaling.

The time domain solution refers to the probe used with a real time oscilloscope and sampling oscilloscope. An oscilloscope is needed to find out what the actual signal looks like. Below is a summary table of frequency domain versus time domain solution measurement parameters and selection:

Table 1. Summary of frequency domain versus time domain measurement parameters and selection

Applications	Measurements and troubleshooting Capabilities	Time Domain Solution		Frequency Domain Solution			Comments
		Real Time Oscilloscope	Sampling Oscilloscope	Network Analyzer	Signal/Spectrum Analyzer	Signal Source Analyzer	
Wireline Communication	Rise/Fall Time	x	x	o			Rise time can be approximate by 0.35/BW
	Overshoot	x	x	o			Return loss can cause overshoot
	Inter-symbol Interference	x	x	o			Maybe due to limited bandwidth
	System Noise	x	x		x	x	Frequency Domain Solution has better dynamic range
	Crosstalk	x	x	x	x		
Wireless Communication	Sensitivity			x	x		
	Selectivity			x	x		
	Spurious response rejection				x		
	P1dB			x	x		
	AM to PM			x			
	Phase Noise					x	
	Harmonics			x	x		

* Note: x = direct measurement and o = calculated measurement

High Frequency Probing *(continued)*

Network analyzer with probe application

Below are examples of a prescaler board that accepts frequencies from 200 MHz to 12.4 GHz and divides by 4096, 0.39 MHz to 24.2 MHz with some signal conditioning such as, limiter for over power protection and amplifier for sensitivity improvement. The low frequency signal will then be fed to the next stage thru a ribbon cable for further signal processing.

During production test, a synthesizer connected to the input of the DUT with frequency and power sweep, the output is connector to parent instrument for functional verification to check the minimum and maximum sensitivity. When the DUT fails, you can only check on the biasing current, DC voltage probing for components biasing. There is no accurate way to check on the RF path. There is a common way to pick up the RF path power by using a DC block with a passive thru-line probe and connect to a spectrum analyzer, but there is significant loading since the RF signal sees a RF split path to the spectrum analyzer. If you don't add a DC block, it could potentially damage the spectrum analyzer because DC is already present on the spectrum analyzer.

In order to measure the frequency response of components individually, a test board can be created although very time consuming, or you can use high-frequency active probes to access the required components frequency response.

In Figure 3, you can use a network analyzer with an active differential probe, see setup below. The probe tip has two pins, one pin can be connected to the signal trace and the other pin can be connected to the ground for single ended probing. The procedure below describes how to measure the frequency response of the path from A to B.

1. Set the NA frequency range from 200 MHz to 12 GHz and connect port 1 to prescaler input connector.
2. Connect the probe from port 2 of NA to point A of the DUT.
3. Perform the thru calibration. This will calibrate out all the losses moving the measurement plane to probe tip and point A. The response calibration yields 0 dB S21 as shown in Figure 5.
4. Probe at point B to get the frequency response from A to B. You can probe to any RF path location to see the frequency response up to the input of the 1/8 divider.

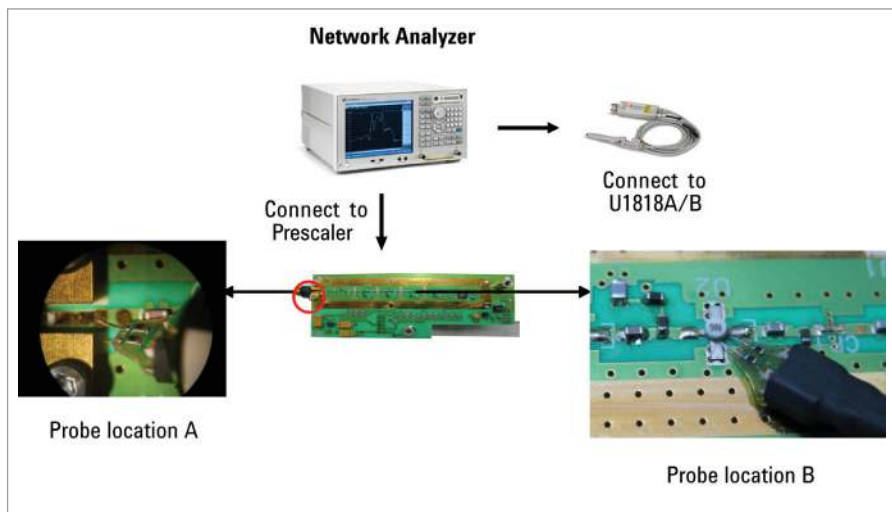


Figure 3. Test setup for frequency response measurement with network analyzer

High Frequency Probing *(continued)*

Clearly, this is a very good tool for troubleshooting where users can access any point on the RF path. As for the receiver selectivity testing, you can perform the same test to see the frequency response. By using the same setup, you can also test the P1 dB, AM to PM, and sensitivity test at each stage using the NA.

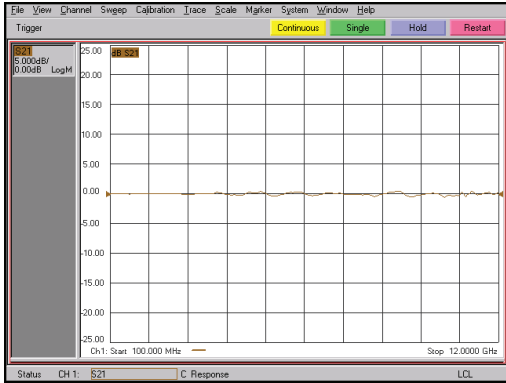


Figure 4. Response calibration results probing at location A

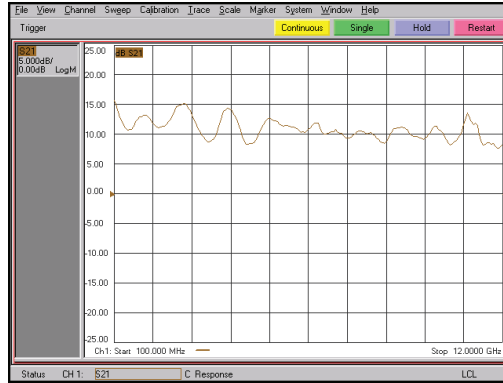


Figure 5. Probing results at location B

Signal/Spectrum Analyzer with probe application

Using an active differential probe with a signal/spectrum analyzer you can measure the signal power level, spurious signal, and harmonics on the same DUT. To compensate for insertion loss of the probe, load the 10 dB nominal insertion loss of the probe to the amplitude correction provided by the signal/spectrum analyzer and turn correction on.

As you probe on the RF path, you can see spurious signals and harmonics at each probing point using the signal/spectrum analyzer. Sometimes it's necessary to add an inline attenuator to reduce the input power to the probe to avoid compression or apply a preamplifier to measure low level harmonics. In these cases, you will need to apply the inline attenuator or preamplifier correction in the signal/spectrum analyzer.

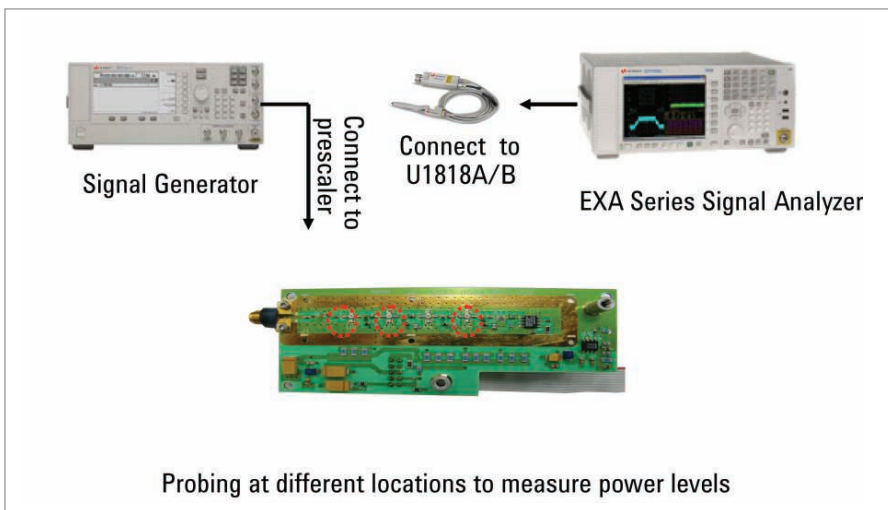


Figure 6. Test setup for power level measurement with signal analyzer

High Frequency Probing *(continued)*

Source Analyzer with probe application

The topic of jitter is becoming increasingly critical to the proper design of digital sub-systems. At data rates exceeding a gigabit per second, 500 fs jitter may not be significant for a clock running at 100 MHz but significant if the clock frequency is 1 GHz. As jitter is an integral part of the phase noise over a bandwidth, SSA is an essential instrument with jitter conversion features for phase noise measurements. Below is an application example of a phase noise and jitter measurement using an SSA as a prescaler and also demonstrates the how to diagnose the source of the jitter.

Notes: prescaler output may need to terminate to 50 ohm and the probe at the differential output when using the U1818A or U1818B.

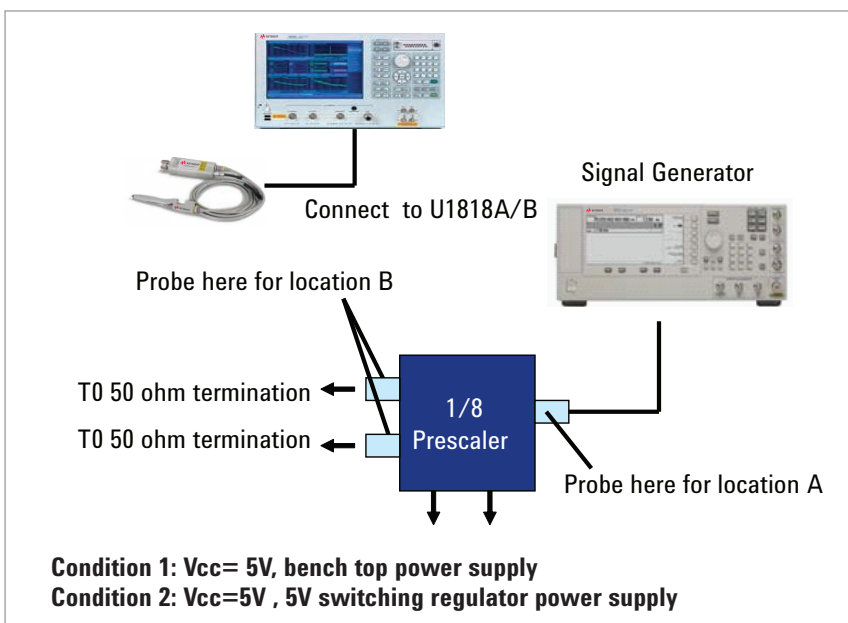


Figure 7. Test setup for prescaler measurement with signal source analyzer

Figure 7 shows a block diagram for the measurement setup. Several input carrier frequencies have been measured with specific integration frequency range of jitter. The measurements are summarized in Table 2 for jitter performance comparison between bench top power supply (clean power supply) and switching regulator power supply from PCA (noisy with spur). As you can see, with output carrier frequency of 1.25 GHz, the integral jitter from 10 kHz to 80 MHz increases from 119 fs to 158 fs when using a bench top power supply and switching regulator power supply. In terms of UI, it increased from 0.15 mUI to 0.2 mUI. Hence, it is very convenient to use active differential probes with an SSA for jitter measurements and module troubleshooting where there are a few stages in the module.

Prescaler Test Board Jitter Performance

Probe Amp: U1818A/B

Probe Tip Use: N5381A

Table 2. Jitter measurement comparison using bench top power supply and switching regulator

Prescaler Input Frequency: 2.5 GHz at 0 dBm

Prescaler Output Frequency: 312.5 MHz at -6.9 dBm

Integration Range	Bench Top Power Supply		+5V Swithing Regulator	
	RMS jitter (fs)	mUI	RMS jitter (fs)	mUI
100 Hz - 40 MHz	944	0.295	958	0.299
10 kHz - 20 MHz	663	0.207	672	0.210

Prescaler Input Frequency: 4 GHz at 0 dBm

Prescaler Output Frequency: 500 MHz at -6.9 dBm

Integration Range	Bench Top Power Supply		+5V Swithing Regulator	
	RMS jitter (fs)	mUI	RMS jitter (fs)	mUI
100 Hz - 40 MHz	426	0.213	434	0.217
10 kHz - 20 MHz	298	0.149	306	0.153

Prescaler Input Frequency: 6 GHz at 0 dBm

Prescaler Output Frequency: 750 MHz at -7.3 dBm

Integration Range	Bench Top Power Supply		+5V Swithing Regulator	
	RMS jitter (fs)	mUI	RMS jitter (fs)	mUI
100 Hz - 40 MHz	117	0.059	131	0.066
10 kHz - 20 MHz	81	0.041	96	0.048

Prescaler Input Frequency: 10 GHz at 0 dBm

Prescaler Output Frequency: 1.25 GHz at -7 dBm

Integration Range	Bench Top Power Supply		+5V Swithing Regulator	
	RMS jitter (fs)	mUI	RMS jitter (fs)	mUI
100 Hz - 100 MHz	133	0.166	177	0.221
10 kHz - 80 MHz	119	0.149	158	0.198

Prescaler Test Board Jitter Performance *(continued)*

Figure 8 is a snap shot of the output carrier frequency of prescaler at 1.25 GHz. The light yellow trace is the measurement from switching regulator power supply and the yellow trace is the measurement from bench top power supply. It's clearly shows that with a clean power supply to the prescaler, the phase noise or jitter performance is significantly improved.

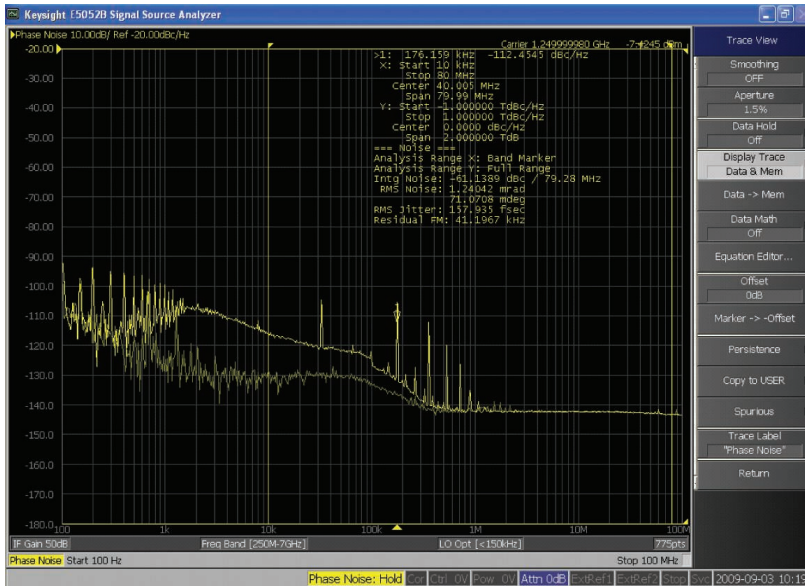


Figure 8. Measurement results at prescaler output frequency of 1.25 GHz

Conclusion

The combination of high frequency active differential probes and RF/microwave instruments with excellent dynamic range provide insight into in-circuit performance for both time and frequency domain. This solution is particularly beneficial when performing design validation and troubleshooting up to 12 GHz.

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