E5533- Running a PRBS 2^31-1 Pattern across Bit Rate

PRBS Pattern primer

A PRBS (PseudoRandom Bit Stream) 2^31-1 pattern consists of each serial bit combination counting from 0 to 2^31). This pattern sequence, for all intents, creates a worst case ISI (InterSymbol Interference) jitter condition in a passive transmission line or channel. The effect of ISI is to distort the rise time and voltage level and time positions of the data transitions from the ideal to a nominal or distorted result in a passive channel. This stems from the physics of the channel charge storage in the capacitive component of the passive network. A PRBS 31 pattern has all long sequential bit levels from 1 to 31 UI (unit Intervals). Depending on the channel bandwidth, which is inversely proportional to the square root of the lumped capacitance of the network, these longer sequences build up more charge than the resulting small UI bit sequences have time to fully discharge. For example, in a PRBS 31 pattern, there is a bit sequence that consists of:

1111111111111111111111111111111011111 1...

the 101 transition in this sequence forms an impulse that is distorted in the voltage dimension and slightly shifted in the time domain, since there is not enough time and or driver current to fully transition the network load from the charged to discharged state. This is what “closes” an eye pattern on an oscilloscope.

Wavelength and Harmonic Content Calculation.

The bit rate UI vs. the spring probe length determines how much of the probe is seen as lumped vs a distributed load. The rule of thumb is a passive structure is consider a lumped element if the delay through the element is <= λ/6 (λ = wavelength). For a bit rate of 2 Gb/s UI = 500ps, frequency = 1GHz, wavelength in stripline pcb conductor is 75mm. A spring probe shorter than 12mm is seen as a lumped element (low pass LC filter). Thus the loss on the first harmonic of a 2 Gb/s bit pattern for an E5533 at 3.02mm operating position is small. We can be estimated as 20 log 3.02/75 or -28dB. This means that 97 % of the 1st harmonic wave form will pass through the probe. We also need to consider the 3rd and fifth harmonic wavelengths since the greater the harmonic content of the signal that passes through the probe, the faster the rise time and the greater the eye opening.

The third harmonic of the 2Gb/s signal is 167ps. This is equivalent to 25.2mm and the wavelength rule of thumb is equal to 4.2mm. The E5533 will pass most of the harmonic content at the third harmonic or to estimate the loss as 20 log 3.02/25.2 or -18.4dB. This means that 88% of the 3rd harmonic of the 2Gb/s signal passes through the spring probe which is still a very high content percentage and the probe is still seen as a lumped element. The fifth harmonics are passed through the spring probe filter with more attenuation so that we start to see the loss increase logarithmically. The fifth harmonic numbers are: the delay is 100ps or 15.2mm wavelength, the wave length estimate is 2.53 mm which is shorted than the spring probe. The probe is acting more like a transmission line but is still dominated by lumped element performance and the loss estimate is 20 log 3.02/15.2 or -14.2dB. This spring probe is passing 81% of the fifth harmonic information at 2Gb/s. A 3mm spring will be completely transparent in a nominal test channel built on a stripline board.

Now when we move to 20 Gb/s everything gets smaller. The probe really starts to take on transmission line characteristics. The UI is 50 ps , so the strip line wavelength is 7.5mm. A 3.0 mm probe does not meet the λ/6 estimate so the probe transmission line characteristics such as impedance and distributed elements dominate. The operation of the probe is now dominated by how well it matches the characteristic impedance of the test channel, how many discontinuities and reflections does it introduce due to mechanical discontinuities, and the resonance quarter wavelength calculations may come into play. The difference in probe performance at these bit rates comes down to minimizing mechanical discontinuities, quality of materials and surface plating, conductor smoothness and finally total operating length or prop delay.

Since the E5533 is a transmission line at this bit rate, the mechanical loss estimates for the first harmonic, estimated as 20 log 3.02/7.5 or -8dB. The -8dB is a figure of merit indicating that the probe is approximately 40/60 lumped vs transmission line and a simple wavelength calculation is no longer valid. This is born out by the VNA measurements seen in figure 1 which would indicate perfomance well beyond 20 GHz with minimal loss.

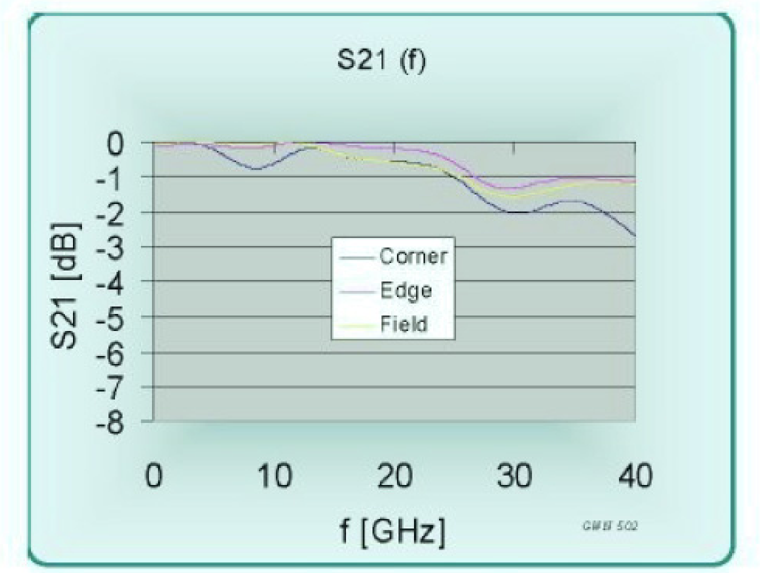


Figure 1: Insertion Loss, S21, E5533-A1

This measurement de-embeds all the measurement channel showing just the effects of the spring probe on a pure swept frequency sine wave(no harmonic content). This measurement indicates that up to a frequency of 23 GHz, the probe acting as a transmission line, stays within a -1dB band for insertion loss . This means that no more than 10% of a monotonic sine wave is lost to dispersive effects at the output of the spring probe.

Operation of the Probe Transmission Line on a PRBS Pattern

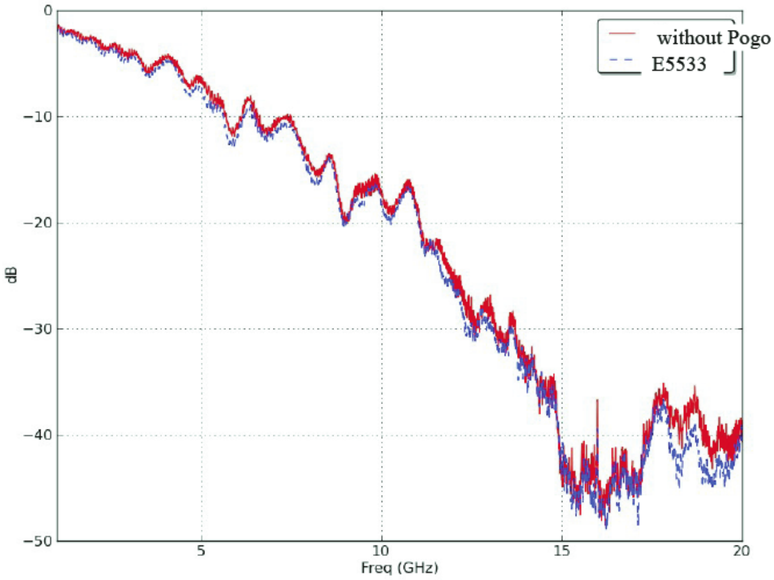
Since a digital bit pattern is made up of multiple harmonics of sine waves that add up to form the square waves in the bit stream we can go back and look at a bit pattern as it operates in the test channel . In order to measure the spring probe performance in a bit stream, we drive a PRBS 2^15-1 pattern into a channel calibrated to have -20 dB loss at 10 GHz. We measure the PRBS bit stream on a 50 GHz oscilloscope, capture the bits and perform an FFT to convert the bit time to frequency. We can now observe the performance of the channel with and without a spring probe. If the spring probe performs within spec, the PRBS 2^15 FFT with and without the spring probe should not vary by more than 1 dB at up to 20 GB/s (Channel calibration to 10 GHz). The difference is the dispersive effects of the probe and the additional ISI introduced by the probe transmission line losses.

In effect, the PRBS pattern creates a multi-frequency spectrum based on the bit density and bit rate and as we sweep the FFT the harmonic performance is also revealed. This frequency spectrum will also contain harmonic content aliased from the base pattern bit rate to a third and fifth harmonic.

Pattern Response – Time to Frequency Conversion

In order to estimae the loss contributed by a pogo pin, a 20 GB/s PRBS^15-1 pattern is input into the channel and measured by a 50 GHz sampling oscilloscope. A FFT is used to convert the time position to a loss calculation in dB. This plot in figure 2 shows frequency as a function of channel loss, much much likeS21 insertion loss. It differs from a pure S21 measurement in that the channel is calibrated to -20dB at 10 GHz. The measurement should show us 1 nominal loss of -20dB at 10 GHz which we can see is the case in figure 2.

Figure 2: PRBS 2^15-1 Pattern FFT



This is a plot of the pattern performance in a channel with and without the pogo pin. This plot indicates we would expect the pattern to show 75% eye closure at 20 GB/s. Also we can see that as we pass the nominal bit rate the channel and driver become bandwidth limited and the roll off becomes more pronounced until the upper harmonic content is lost in the channel noise floor limit above 15 GHz.. We can see the pattern has a smooth loss to 10 GHz. The oscillations are artifacts of the jitter caused by the channel discontinuities (vias, pads, skin effect, surface roughness etc)

The plot in red is without the pogo, the plot in blue is the identical channel with the E553 added . There is very little difference between the two, well within the -1dB band predicted by the VNA measurement. Actual difference is within a -0.4 dB band to 10 GHz Note we used a PRBS^15 pattern in order to process the data and keep the MATLAB sets manageable. This is supported by instrument vendors literature detailing the 99.9% correlation of PRB^15 to PRBS ^32 for ISI analysis. (Original Wavecrest and Agilent jitter measurement papers)

Conclusion:

The E5533 contributes approximately -0.4 dB of eye closure to a PRBS pattern at bit rates up to the 110 % of the channel loss offset calibration. Based on the VNA and scope FFT data the E5533 should be able to hold this performance through 32GB/s on a nominal 20 GB/s channel calibration.