Calibrate scope jitter using a transmission-line loop

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Digital-clock-period jitter is the variation in the period of a clock cycle compared with a nominal (average of many cycles) clock period. To accurately measure period jitter using an oscilloscope, you must subtract the oscilloscope jitter from the measured jitter. However, oscilloscopes rarely have a jitter specification, so you must determine the oscilloscope jitter. One method of measuring oscilloscope jitter is to use the oscilloscope to measure the jitter of a pulse generator with known jitter. The measured jitter, assuming the jitter has a Gaussian distribution, is

\[ \sqrt{\text{scope jitter}^2 + \text{generator jitter}^2} \]. Rearranging the formula to solve for oscilloscope jitter, the scope jitter is \( \sqrt{\text{measured jitter}^2 - \text{generator jitter}^2} \). The ideal generator for measuring oscilloscope jitter would have zero jitter. **Figure 1** is a circuit for generating a calibration signal with near-zero timing jitter.

![Figure 1](image.png)

**Figure 1** You can use a transmission-line delay loop to accurately measure an oscilloscope's jitter.

A transmission-line delay loop creates a delayed pulse at the oscilloscope. **Figure 2** shows the circuit in operation. You set the oscilloscope for internal triggering on the first pulse and then configure the scope to measure the time between the first pulse and the delayed pulse. You set the trigger hold-off such that the oscilloscope always triggers on the first pulse. The second pulse in each set of pulses is the first pulse delayed through the transmission-line delay loop. Two 50Ω coaxial transmission lines implement the circuit and connect to the oscilloscope using two BNC T adapters. The line from the 50Ω generator to the 50Ω oscilloscope can be of any length. The length of the delay-loop line determines the delay between the first pulse and the delayed pulse. You set the
The transmission-line delay loop creates a delayed signal with near-zero jitter for calibrating the oscilloscope.

The waveforms in Figure 2 represent a pulse period of 62 nsec and a pulse duration of 6 nsec. The delay loop consists of 2.4m of RG-58 coax and creates a delayed pulse 13 nsec after the first pulse. The 13-nsec delay is equivalent to calibrating the oscilloscope with a zero-jitter, 77-MHz signal. The impedance relationships are such that the delayed pulse has the same amplitude as the first pulse. With the 50Ω pulse generator set for 1V into 50Ω, the generator sends a 1V incident pulse toward the oscilloscope. As the incident pulse "sees," the node at the oscilloscope consists of the 50Ω scope in parallel with the two 50Ω ends of the delay loop. Therefore, the impedance at this node is 16.7Ω, and the reflection coefficient is -0.5. The impedance mismatch causes a pulse amplitude of 0.5V to appear at the oscilloscope and a reflected pulse of -0.5V to travel to the generator, where it dissipates. Two 0.5V pulses travel in opposite directions through the delay loop and meet 13 nsec later at the oscilloscope, forming a 0.5V pulse with a source impedance of 25Ω.

The 50Ω oscilloscope, in parallel with the 50Ω line to the generator, forms a 25Ω load that matches the 25Ω pulse source impedance. The delayed-pulse amplitude at the oscilloscope is 0.5V, and a 0.5V pulse travels to the pulse generator, where it dissipates. You can analyze the circuit's action by keeping track of where the energy goes. The 1V generator sends a 20-mW pulse down the 50Ω line. When this pulse encounters the oscilloscope and delay loop, the energy splits four ways. In this split, 5 mW reflects back to the generator where it dissipates, 5 mW dissipates in the oscilloscope, and 5 mW enters each end of the delay loop. When the two 5-mW pulses exit the delay loop, 5 mW dissipates in the oscilloscope and 5 mW travels to the generator, where it dissipates. You can calibrate several oscilloscopes and one pulse generator with the delay loop. Because the loop has near-zero jitter, the jitter that an oscilloscope measures is virtually all oscilloscope jitter. The loop allowed a generator with 19-psec rms jitter to calibrate an oscilloscope having 3.8-psec jitter.

The delay loop has some jitter, created by the conversion of amplitude noise to jitter. Without the loop, generator-amplitude noise causes the leading edge of each pulse to cross the oscilloscope's trip point either early or late. In this way, amplitude noise translates to jitter. The following formula gives jitter versus amplitude noise:
An ideal loop would produce a delayed pulse that is identical to the first pulse. Amplitude noise on the delayed pulse would be identical to that on the first pulse; thus, jitter attributable to the noise would cancel out. Because of signal loss in a real loop, the delayed pulse is not identical to the first pulse. Therefore, the amplitude noise of the delayed pulse will be less that that on the first pulse, and a conversion of amplitude noise to jitter will occur. The following formula gives amplitude noise versus jitter in the loop:

$$ \text{JITTER} = \frac{\text{AMPLITUDE NOISE}}{dV/dt}. $$

The pulse generator used to calibrate the oscilloscopes exhibits 250 µV of rms noise and a dV/dt of 0.35V/nsec. The signal loss on the leading edge of the delayed pulse is 0.2V. The amplitude-noise-to-jitter conversion is thus:

$$ \text{LOOP JITTER} = \frac{250 \mu V}{0.35 V/nSEC} \times (0.20) = 143 \text{fSEC}. $$

The loop jitter of 145 fsec is so far below the jitter noise floor of the oscilloscopes under calibration that you can consider the delay loop as a zero-jitter source. Because digital-oscilloscope jitter is a function of the timebase setting and the amount of ADC dynamic range you use, you should calibrate the scope with a loop delay and amplitude that match the signal to the actual system or device under test.

Reference

Related articles:
- A method of demonstrating transmission-line behavior on a dual-channel oscilloscope
- Why a scope cannot do it all
- Design Ideas Submission Guide