Introduction

Modern day high-bandwidth conventional oscilloscopes are typically supplied with a maximum of four input channels, and with as few as one or two channels at a higher bandwidth rating, owing to practical design tradeoffs between bandwidth and channels. Recently, several oscilloscope applications have required more channels at high bandwidth than are available in a conventional oscilloscope. These applications include:

- “Parallel” serial data transmissions at very high bit rates, such as PCI Express and 40/100 GbE. These schemes utilize 4 to 16 lanes of serial data to increase effective data rates, and where it is desired to understand the crosstalk or skew behaviors of multiple lanes in the system, up to 20 input channels of up to 20 GHz each is required.
- DP-QPSK or 16-QAM coherent optical modulation analysis at very high baud rates. This requires real-time analog-to-digital conversion of four electrical tributaries using very high bandwidths at 30 GHz to 45 GHz (or more).
- High speed 25+ Gb/s Serializer/Deserializer (SerDes) analysis. This requires a two channel differential cabled input at very high bandwidths, such as 45 GHz.

To meet the above needs, oscilloscope manufacturers have developed methods to connect multiple conventional oscilloscopes, each with their own acquisition timebase, using 10 MHz external clocking with one conventional oscilloscope as the timebase clock reference for the others. However, this method leads to an increase in the overall time interval error (TIE) and trigger jitter of the combined oscilloscope channels. Moreover, the steps required to connect multiple conventional oscilloscopes together are both difficult and time consuming. A modular oscilloscope system with a single distributed timebase and a single trigger circuit provides better measurement results with accurate time synchronization for up to 20 channels and simple setup and operation.
**Conventional Oscilloscope Architecture**

The basic internal structure for a single channel in a digital storage oscilloscope is shown in Fig. 1. Here, a 10 GHz clocked timebase drives a sampler and analog-to-digital converter (ADC), as well as an integrated trigger circuit. Input signals arriving at the sampler are digitized and stored into memory. When a valid trigger condition is found, the trigger circuit instructs the memory chip to cease updating and to transfer stored data for processing so that it can be displayed onscreen. Once the data transfer is complete, the trigger circuit directs the memory to resume updating, and prepares for the next valid trigger condition by arming itself.

![Oscilloscope Architecture Diagram](image)

The internal architecture of the timebase, as shown in Fig. 2, consists of a clock module comprised of an oscillator operating at 10 MHz. The output of this oscillator passes through a PLL frequency multiplier to achieve the required 10 GHz to drive the sampler and trigger circuit. The clock module also accepts an external 10 MHz clock as a reference, or it can output its own 10 MHz clock for referencing with an external device, which could be another oscilloscope. Additional components in the timebase (not shown) exist to keep the clock signal as stable as possible.
The sole purpose of the timebase in any oscilloscope is to clock components at uniform time intervals. The sampler and ADC, for example, sample and digitize the input signal based on the 50% rising edge level of the timebase. At this instant, the sampler acquires a data point and the ADC digitizes it, repeating the process with each cycle of the timebase clock. Ideally, the time interval between each sample point is the same; however, in practice, errors affecting the timebase accuracy cause the time interval between samples to vary slightly. This variation is defined as the Time Interval Error (TIE), or Phase Jitter, and a non-zero value represents the short-term timebase instability with respect to a perfect timebase.

**Connecting Two (or More) Conventional Oscilloscopes – Timebase Phase Errors**

Each conventional oscilloscope contains its own independent timebase. Therefore, connecting multiple conventional oscilloscopes together requires that the phase of each timebase be synchronized. This is accomplished by using the 10 MHz timebase output of one conventional oscilloscope to reference the timebase of other oscilloscopes. Fig. 3 shows this procedure for two conventional oscilloscopes. However, this method is not perfect, as in doing so may lead to increase in the TIE of the timebase.
The primary issue is that the 10 MHz external reference used here to synchronize the timebase of multiple oscilloscopes is characterized by a low slew rate, and may therefore be susceptible to high time uncertainty. From Fig. 4, it can be seen that amplitude noise creates vertical uncertainty and manifests as time uncertainty in
the sampling process. Moreover, time uncertainty worsens with decreasing slew rate. In general, time uncertainty can be expressed as a function of vertical uncertainty by $\Delta t = \Delta v \cdot \text{SR}$, where \text{SR} is the sampling rate.

Secondly, the 10 MHz clock signal must pass through a considerably longer and inferior path to reach other oscilloscopes; therefore, there is the potential for noise to cause the TIE to increase. This negatively affects oscilloscope operation as the sampler, in turn, samples the input signal at non-uniform time intervals, causing the phase of the input signal to vary over long record lengths.

Finally, the use of a PLL to multiply the frequency of the 10 MHz clock by 1000 times to 10 GHz may add to the TIE. While this can be minimized by using a high quality PLL, it cannot be eliminated. Moreover, this becomes worse when multiple oscilloscopes are connected together, as the total TIE between oscilloscopes due to the PLL adds in quadrature. For some applications, this increased TIE due to the PLL clock multiplier may be acceptable, but not in a precision measurement system if it can be avoided.

For example, coaxial RG-58C cables that differ in length by 0.1 inches (2.5 mm) will have an 8 ps difference in their respective propagation delays.

Another issue is that the bandwidth rating of the auxiliary inputs is typically much lower than that of the input channels. Since this is akin to passing the trigger signal through a low-pass filter, its slew rate is reduced. As previously discussed, this causes an increase in the amount of noise, and thus leads to an increase in the amount of time uncertainty in triggering.

Finally, integrating the trigger of two conventional oscilloscopes poses an additional problem: the trigger jitter, or the time variation around the trigger point of the input signals, between channels of each oscilloscope increases as the quadrature sum of each individual oscilloscope’s trigger jitter. Because noise in the signal input and oscilloscope enter the integrated trigger circuit, there exists some time uncertainty as to the exact trigger instance. Since each connected oscilloscope in the system has its own independent trigger circuit, the total trigger jitter between them is the trigger jitter of each oscilloscope added in quadrature.

**Connecting Two (or More) Conventional Oscilloscopes – Trigger Jitter Errors**

The trigger systems in each conventional oscilloscope must also be connected so that when a valid trigger condition is found, both oscilloscopes are able to trigger simultaneously. Using the auxiliary input/output of each oscilloscope, a common trigger source can be connected in such a way that allows one oscilloscope to cross-trigger the other. Additional software or hardware is generally required to ensure that the oscilloscopes do this at the exact same time. This is important, as the cables used are often unmatched in length, and even small differences in length can have a significant impact in trigger signal propagation delay.

**Connecting Two Conventional Oscilloscopes – Static Skew Between Oscilloscope Channels**

In a conventional oscilloscope, each channel will generally have some non-zero static skew between other oscilloscope channels. This can be easily corrected using the deskew adjustment (typically located in the channel menu). However, when two conventional oscilloscopes are connected together, the static skew between each separate oscilloscope acquisition system can be quite large, making it difficult to determine the amount of deskew to apply in order to correctly align all acquisition channels.
Connecting Two Conventional Oscilloscopes – Total Error Conclusion

Consider the impact of all of the combined TIE (phase) and trigger jitter errors with 28 Gb/s signals on two conventional oscilloscopes connected using a 10 MHz reference clock. These TIE and trigger jitter errors cause dynamic skew between the signals, or skew that cannot be eliminated with calibration processes. At 28 Gb/s, the unit interval is approximately 36 ps. If the conventional oscilloscopes are connected together to yield 1 ps rms of time jitter (or 6 ps pk-pk for three standard deviations) between acquisition systems, as is typically specified, the result becomes an added phase uncertainty of nearly 20% of the unit interval due solely to the oscilloscope acquisition system. This is more than enough to wreak havoc on the phase relationship of the captured signal, and is especially noteworthy when working with phase and frequency modulated signals, such as dual-polarization quadrature phase shift keyed (DP-QPSK), quadrature amplitude modulated (16-QAM), and orthogonal frequency domain multiplexed (OFDM).

Clearly, with all the introduced errors due to connecting multiple conventional oscilloscopes, it is difficult to have as much confidence in the measurements as one would have when using a single conventional oscilloscope. With very careful and repetitive calibration, these errors can be minimized but not eliminated. However, this requires experience and a significant investment of time.

Modular Oscilloscope Synchronization Advantages

All of the dynamic skew issues discussed with connecting multiple conventional oscilloscopes issues can be resolved by designing the acquisition system of the oscilloscope to be modular. In the LeCroy LabMaster 9 Zi-A modular oscilloscope design, ChannelSync™ architecture completely synchronizes acquisition and triggering, and displays all oscilloscope channel captures on a single display.

The modular oscilloscope uses a distributed 10 GHz timebase (1000 times faster than a 10 MHz reference clock) for precise synchronization. Recall that in a conventional oscilloscope connection, one oscilloscope provides the other oscilloscope a 10 MHz reference, which can introduce a significant amount of acquisition system inaccuracy. In contrast, the modular oscilloscope generates a single 10 GHz timebase clock in the Master and distributes it directly to the samplers and ADCs of each Slave. Furthermore, with a 10 GHz clock rate, the slew rate of this clock is comparably high and results in no measurable increase in the TIE as a result of amplitude noise. Finally, since the Slaves do not generate their own timebases, there are no additional PLLs in-circuit that would add to the acquisition system TIE.

The modular oscilloscope also uses a single, full bandwidth trigger circuit in the Master that directly controls the sampler, ADCs, and memory of each channel in the Slaves via PCI Express x4 synchronizing cables. This completely synchronizes the trigger between all acquisition modules and, since only a single trigger circuit exists, the trigger jitter of the system is only that arising from the single trigger circuit. Moreover, if the acquisition is a single-shot, then the trigger jitter is zero — a significant improvement over the integration of two separate conventional oscilloscopes.
Finally, all oscilloscopes will have some amount of static skew between channels – this is true of both conventional and modular oscilloscopes. However, the modular oscilloscope system uses a semi-automatic routine to correct for the static skew caused by slightly differing synchronizing cable lengths connecting the Master to the Slaves. A simple, one-time ChannelSync calibration is performed to correct for the very small static skew between acquisition modules caused by minor differences in length of the PCI Express x4 synchronizing cables. To perform a complete deskew to the reference plane of the oscilloscope inputs, the oscilloscope operator simply connects a cable from the fast edge output of the Master acquisition module to each channel, and runs through the ChannelSync calibration utility. This is a one-time process that would typically take less than one minute to complete and involves no work on the operator’s part aside from disconnecting and reconnecting a single cable to multiple input channels on the Master and the Slaves.

LeCroy's ChannelSync architecture in LabMaster Modular Oscilloscope Systems provides a more accurate and simple method to achieve many channels at very high bandwidths, and eliminates the multiple sources of errors and connection difficulties present when connecting multiple conventional oscilloscopes together.

More information on LeCroy’s LabMaster Modular Oscilloscope Systems can be found at www.lecroy.com.