A Comparison of Analog and Digital Oscilloscopes

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Introduction

Modern oscilloscopes, usually referred to by engineers as simply scopes for short, have come a long way since the vacuum tube era when just seeing what a waveform looked like on a display was an exciting event. For modern day TEMPEST applications, the underlying need is to see not only the easily detected fundamental waveform, but also the small telltale signals immersed in background noise or appearing as oscillations riding modulated on the primary signal. In this regard, a host of options including a wide bandwidth (400 MHz), Dual Bea~ capabilities, and Storage capabilities are normally required. This paper looks at the advantages of newer digital scopes as compared to their older analog counterparts, and discusses the proper uses for each type.

Sampling and Equivalent Time

Sampling scopes were first introduced in the early 1960's. Early scopes have low sampling rates, dynamic range, and sampling efficiency. However, even the early versions could achieve bandwidths to 14 GHz, especially after digitizers for waveform storage were added, which provided a significant increase over previous analog capabilities.

Present day scopes have greatly extended their bandwidth capacity again with the addition of equivalent time digitizing techniques. These methods provide the engineer with the capability to reproduce waveforms using sampling rates much lower than the signal being evaluated. For example, a 20 Meg sample/second rate can digitize a signal at 1 GHz. Using real time digitizing, the sampling rate would need to be at least 2 GHz.

The equivalent time method collects samples from each signal repetition, and then using the signal trigger point as a reference, reconstructs the samples into a picture of the signal. Basically, one sample is taken r6r each triggered sweep, with a time offset for each successive sample. What appears on the display is the entire waveform reconstructed from the successive samples. Digitizers with bandwidths greater then 2 GHz use this method, but have the limitation of long waveform acquisition time for low repetition rate signals.

Multiple Sampling

Acquisition time can be reduced by taking multiple sample points per sweep, using the trigger to begin the clocked sample rate. Since the sample cannot capture information until the trigger occurs, and since the signals are very fast, the potential exists for signal distortion due to waveform delays. Analog delay line equalizers are used on long transmission lines to correct lower frequency problems as shown in Figure 1. However, delaying the signal with a delay line circuit reduces the effective bandwidth of the circuit, thus it is impractical for oscilloscope applications.

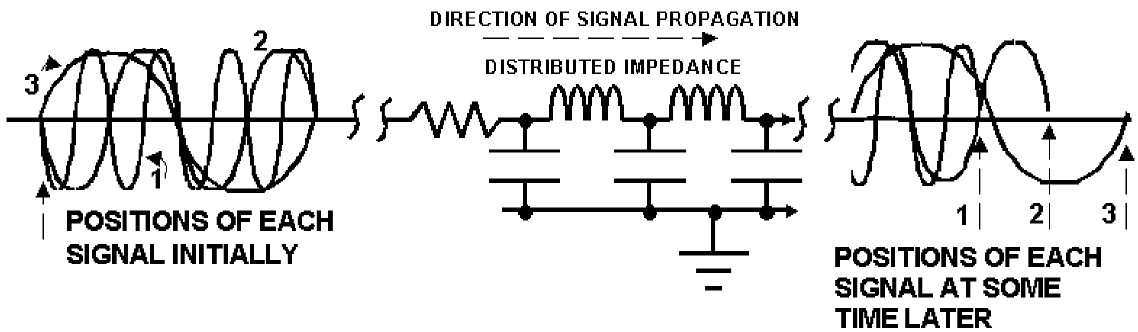

Figure 1 - Effects of Propagation Delays

To correct for signal delays, random digitizing is used. This technique collects samples before as well as after the scope trigger is activated. The ability to view events before the trigger is one of the primary benefits digitizing scopes have over analog scopes.

The normal technique used to achieve random sampling is to use a free-running clock to activate one or more samples for collection into a circular type acquisition memory. Data collection is begin before the trigger, and ends a specified number of samples after.

By adding equivalent time techniques to the random digitizing, the effective bandwidth and timing resolution of the scope can be greatly enhanced. In the random equivalent time technique, collected data in initially stored in acquisition memory. Next, the data is sorted by trigger-to-strob time, and then transferred to the final waveform storage and/or display. This technique can enhance the scope's effective sample interval to about 10 psec. with a real time digitizer, this level of resolution would require a rate of 100 G samples/second. Equivalent time sampling is shown in Figure 2.

One of the problems with random equivalent time digitizing is that it acquires some points many times, while needing multiple passes to acquire other points. This often requires three to five times as many acquisition cycles to complete a waveform. This extended digitizing time, combined with the data processing time, can result in long waveform acquisition cycles, low display update rates, and of most concern to TEMPEST engineers, the possibility of missing data.

While sampling rate is a major factor in waveform acquisition time, the dominant factor in performance is usually the processing time for data to move through the system. Most digitizing scopes use general purpose microprocessors that handle multiple tasks, and take from 5 to 10 usec for each instruction executed. Using a dedicated- processor to perform the necessary data related calculations accelerates the waveform transfer time (processing time per acquisition cycle) to as short as 10 usec. with dedicated processors, digitizing techniques, and special displays, storage scopes can acquire and display waveforms with the update rates of analog scopes.

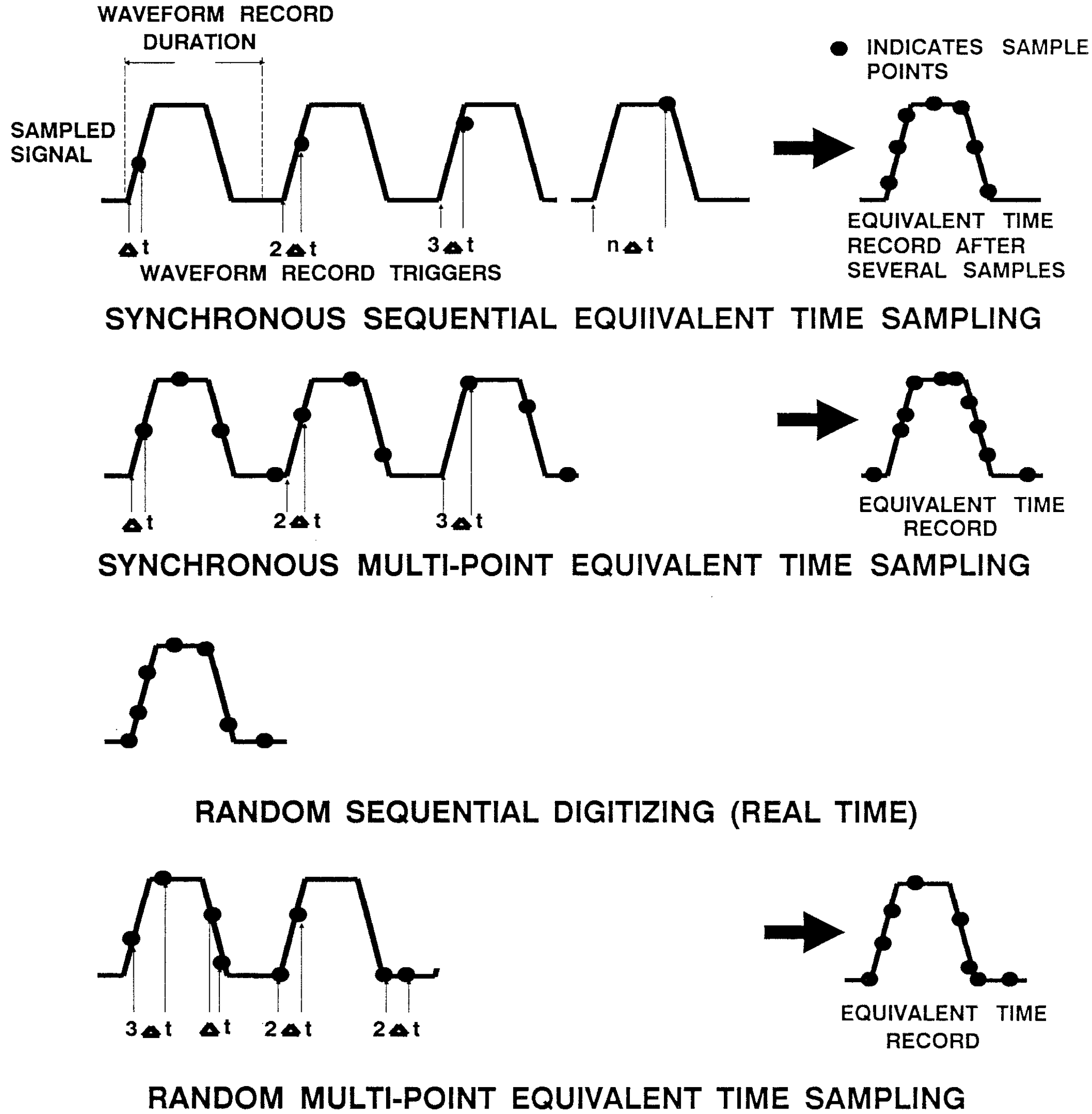

Figure 2 - Methods of Equivalent Time Sampling

Equivalent time digitizing methods help the random sampling process by making better use of the scopes high-speed acquisition memory. The pre-trigger time available with a real time digitizer is limited to the acquisition memory length times the sampling rate. For example, a real time digitizer with a 1 G sample/second sampling rate and a 1000 point acquisition memory is limited to only 1 usec of pre-trigger capture. By contrast, an equivalent time sampling rate of 100 M samples/second increases the pre- trigger time available to 10 usec, and the lower sampling rate maintains the 1 nsec timing resolution.

The scopes vertical linearity can be easily improved with equivalent time methods since the amplifiers used to drive the analog CRT's are eliminated. The linearity of the front-end amplifiers, the sampling gate, and the A/D converter are the only limits to overall linearity. When earlier scopes without equivalent time methods were used for real time digitizing up to 1 G sample/second, they required the use of multiple high-speed (lower resolution) flash A/D converters. Both linearity and cost suffered from the additional components involved.

Functional Usage

Having described the capabilities of digital (and analog) scopes, their function in the test environment should also be addressed. Specifically, an oscilloscope ;is used primarily to display signals in the time domain. What is unique about a scope is its ability in the presence of low level signals to use the trigger in a way that allows viewing of a specific signal while disregarding other signals with different phase characteristics.

As shown in Figure 3, triggering the scope at a specific time, or on a particular repetitive pulse, will enhance visibility of the intended repetitive signal while reducing the visibility of other similar signals. Basically, the scope samples a nearly identical waveform at the same voltage position more often then it samples other similar, but of slightly different phase and frequency waveforms with changing voltages. The effect is to make the repetitively sampled signal appear darker then other similar signals existing in the same channel. This is more noticeable when the scope is used in conjunction with front end bandwidth selection and pre-amplification such as available with a tunable receiver.

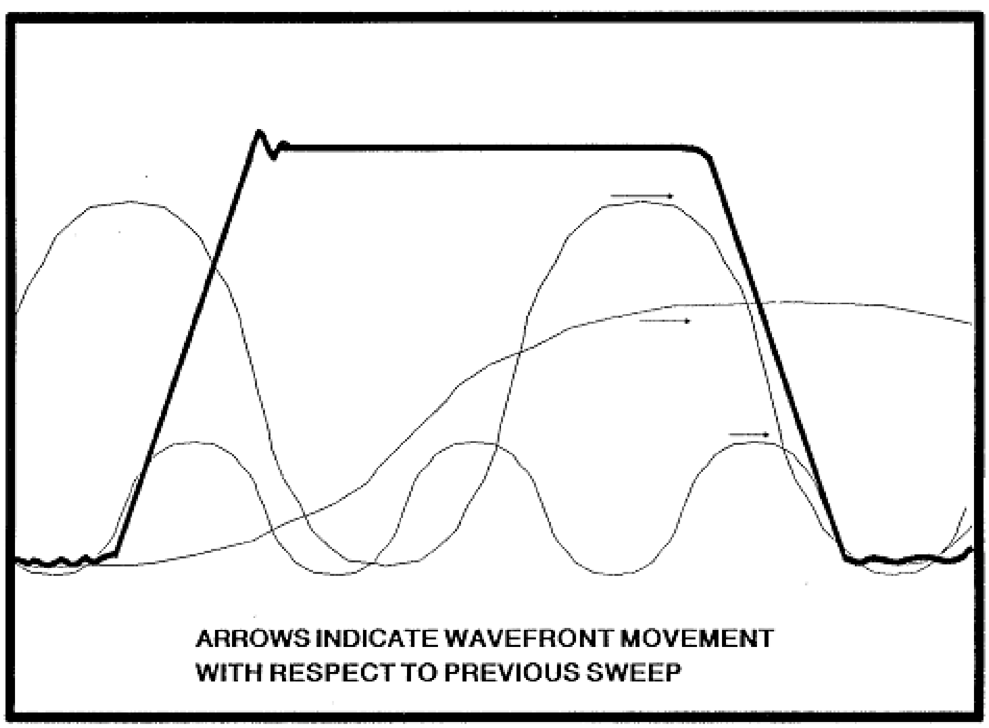

Figure 3 - Scope Display Showing Primary Triggering Signal

In order to see very fast (sub-nanosecond rise time) signals in real time, dual beam scopes are recommended. Single beam scopes use a chopped sweep to alternately display the signals appearing on the two input ports. As the time sweep is decreased for very fast signals, holes appear in the display for one channel during the period when the beam is displaying the opposite channel. To overcome this limitation, a dual beam device is used whereby considerably faster signals can be viewed.

For EMI diagnostic work, using a wideband scope is extremely effective when evaluating signal lines for potentially noisy ringing conditions. Figure 4A shows a typical digital waveform for a F series IC a clock line operating in the 10 MHz region. Using a scope with at least 100 MHz bandwidth, the overshoot and undershoot of the waveform will be clearly visible. This waveform distortion usually indicates ringing on the circuit trace, and results in clock radiated emissions from the circuit trace. By adding wave shaping components to the circuit driver until the waveform appears smooth (Figure 4B), the designer can be reasonably certain that the fix also reduced the radiated emission problem. Again, the limitation on visually seeing the potential problem is directly dependent on oscilloscope bandwidth. For higher frequency work, a bandwidth of 300 to 400 MHz is recommended.

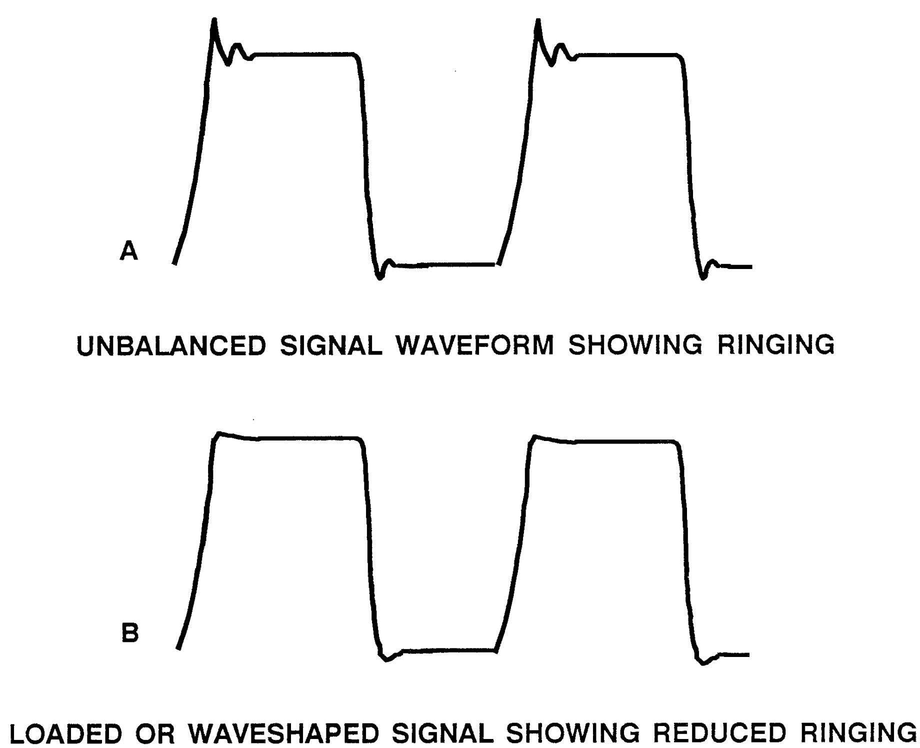

Figure 4 - Oscilloscope Display Showing Ringing

Conclusions

Digital oscilloscopes with fast microprocessors and enhanced sampling techniques are beginning to provide high timing resolution and screen update rates that produce a "live" look on continuously digitized waveforms. For emission diagnostic work, especially when high frequency problems exist, wide bandwidths are a must if effective identification and suppression techniques are employed. The combination of a scope with pre-tuning and amplification results in an extremely useful test tool for radiated or conducted emission evaluation work.

References

Jack Collins and David White, Oscilloscopes: Analog vs. Digital, Tektronix, Inc, Beaverton, Ore, 1988.