New Techniques in Automated, High Performance, Oscilloscope Calibration

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The adoption of quality standards, such as ISO 9000, coupled with the growth in computerized, digital-storage-oscilloscope-based measuring systems has led to a demand for cost-effective, automated, oscilloscope calibration. Historically, the calibration of 100 ps pulse response in oscilloscopes has proven to be the most troublesome area for both the calibrator manufacturer and the end user, primarily due to the technical difficulties in generating and delivering a traceable, low-distortion pulse. Wavetek Corporation has introduced an oscilloscope calibrator that delivers 100 ps pulse response in an automated system.

Historically, the calibration of 100 ps pulse response in oscilloscopes has proven to be the most troublesome area for both the calibrator manufacturer and the end user. This is primarily due to the technical difficulties in generating and delivering a traceable, low-distortion pulse. Although the IEEE standards on pulse measurement have been available since 1977 (IEEE-194-1977 and IEEE-181-1977), they have not been widely adopted. This has lead to inconsistencies in terminology and in the definition of distortion.

To overcome these problems, a dedicated pulse head has usually been the favored solution, eliminating cabling and switches from the delivery system by injecting the signal straight into the oscilloscope input. If automation was required, however, either manual intervention or the reintroduction of multiplexers and cabling was needed. The reintroduction of routing multiplexers and cabling increases the errors and uncertainties of the system. Also, these wideband routers proved to be cumbersome and expensive, resulting in very few calibration laboratories using them.

Demand for automated, cost-effective oscilloscope calibration has led to the design and introduction of a new generation of calibrators that addresses these issues.

Pulse Generator Topologies

To meet the calibration system requirements, a design target of low distortion, good matching, variable output (±1 V to ± 3 V) and compactness was set.

Several technologies were considered to achieve these design goals with the following conclusions:

Mercury-Wetted Relay (Fig. 1)

This is one of the earliest fast pulse generation techniques. The relay is switched at approximately 100 Hz and uses a delay line to form the desired flat top pulse. This technique is

Wavetek Model 9500 Oscilloscope Calibrator with 100 ps pulse response.

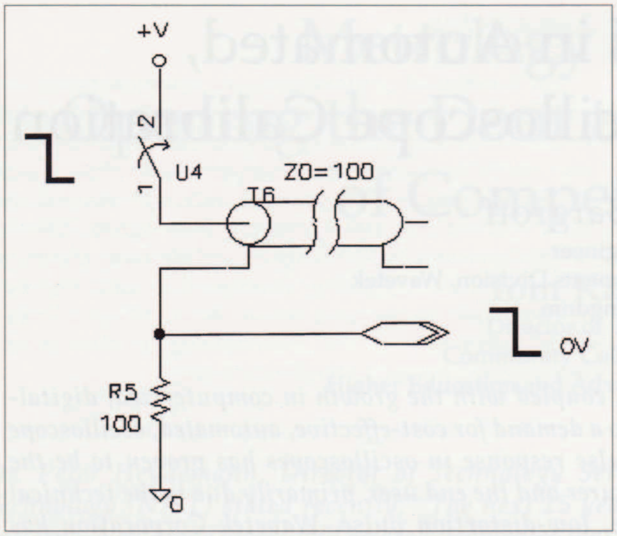

Figure 1. Mercury wetted relay and delay line.

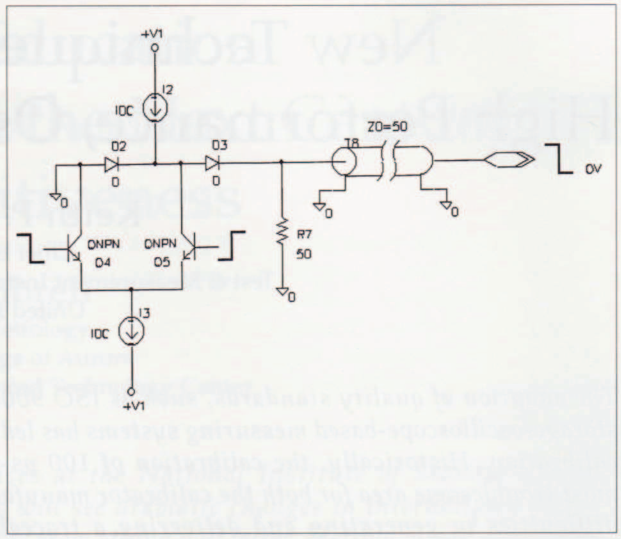

Figure 3. Schottky diode turn-off.

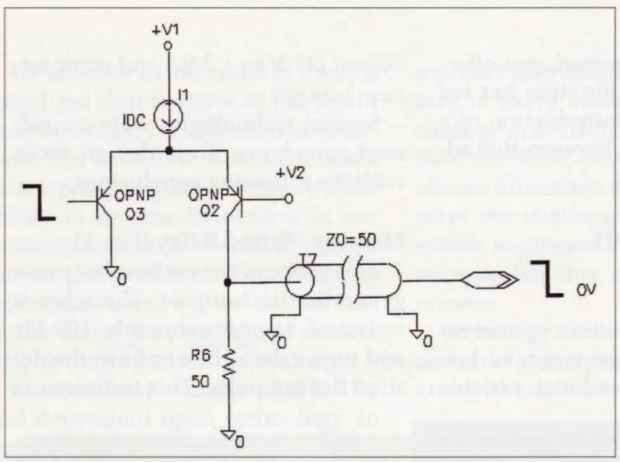

Figure 2. Bipolar junction transistor turn-off.

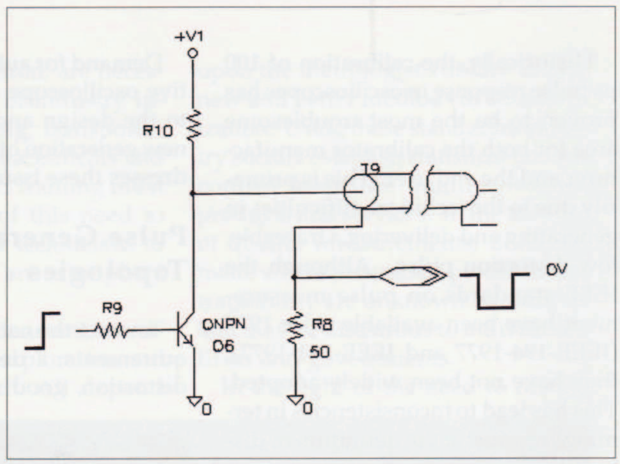

Figure 4. Bipolar junction transfer avalanche breakdown.

capable of producing a pulse with a 250 ps risetime at 50 V. Its main disadvantages are distortion, poor reliability (<100 hrs mtbf) and physical size.

Bipolar Transistor Turn-off (Fig. 2)

This is a very effective method of generating 0.5 ns to 1 ns risetime pulses (at < 3 V), but is too slow to generate 100 ps risetime pulses. The output stage is a differential pair driven hard enough for the output transistor to turn fully off. Once the transistor is off, its collector becomes reasonably well isolated from the emitter; overshoot is kept small. This generator can be switched at 100 MHz plus and produces pulses with low distortion (except when edge speeds are pushed to the limit). It offers medium-level matching, good reliability and compactness.

Schottky Diode Turn-off (Fig. 3)

In this technique, the high speed edge is generated by a BJT turn-on followed by reverse biasing of the output diode. As Schottky diodes do not store charge and are available with low depletion capacitance (GaAs devices have depletion capacitances as low as 0.05 pF), low distortion pulses are produced with a good output match. Edge speeds of 150 ps at 2 V are possible.

Bipolar Junction Avalanche Breakdown (Fig. 4)

The transistor is driven into secondary breakdown by the simultaneous application of a high voltage and a high collector current. Once broken down, the transistor shorts the precharged delay line to ground, producing a flat-topped pulse on the coax outer. This method can produce

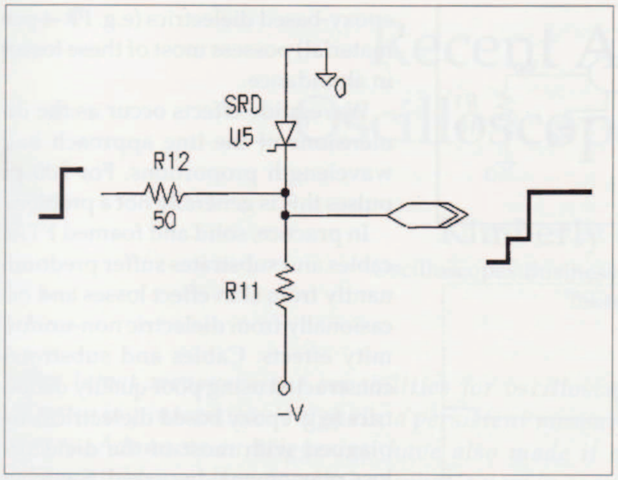

Figure 5. SRD Simple shunt mode.

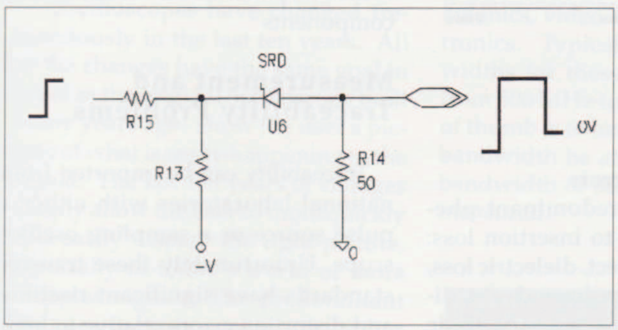

Figure 6. SRD Simple series mode.

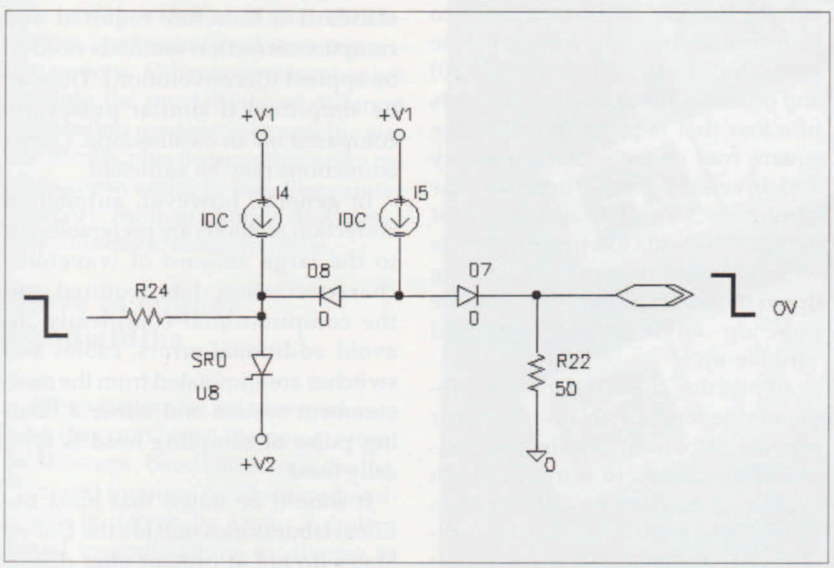

Figure 7. SRD modified shunt mode.

a 250 ps pulse at 100 V. Unfortunately, both pulse distortion and reliability are usually poor.

Step Recovery Diode Shunt and Series Mode (Fig. 5, 6)

This technique makes use of the step recover diode shunt's (SRD) turn-off characteristics. When the SRD is forward biased, it stores charge. When a reverse bias current is applied, the SRD remains in a low impedance state until all the charge has been removed, then switches rapidly (< 50 ps) into a high impedance state. A large amplitude pulse (<50 V) can be produced with medium levels of distortion and matching.

Step Recovery Diode Modified Shunt Mode (Fig.7)

This approach combines the best features of SRD and Schottky diode turn-off techniques. Pulses with edge speeds as fast as 40 ps at 4 V are possible with low distortion and good matching.

Pulse Forming Filters

By producing a generator with edge speeds in the 40 ps region it is possible to filter the output with a quasi-Gaussian low-pass filter to achieve 100 ps edge speeds. The filter reduces the sensitivity of the output pulse to generator variations. It also improves the match at high frequency (6 to 15 GHz).

For 100 ps edge speeds, the modified SRD generator with an output filter provides the best combination of low distortion, good output matching, generator desensitization and a ground-return edge. This was, therefore, selected for Wavetek's new Model 9500 oscilloscope calibrator.

Delivery and Measurement Problems

Matching Errors

In a transmission line system the relationship between the source, line and load impedances determines the system response. Ideally the source and load impedances will be identical to the line impedance (for oscilloscopes, typically, Z_0 = 50 ohms). If they are not, then the system is said to be "mismatched," in which case signals travelling down the transmission line will be partly reflected at the points of mismatch.

Mismatching anywhere in the pulse delivery system can lead to distortion. If resistive, the waveform

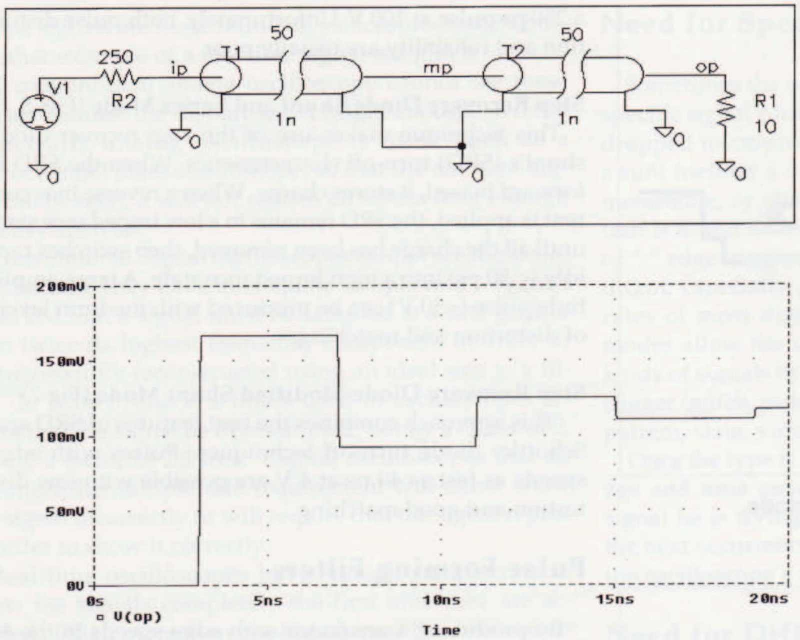

Figure 8. Source and load mismatch.

will develop steps (Fig 8), if reactive it will develop spikes, and rounding and ringing will also be seen (Fig 9).

Taking the mode of the transmission line system impedance as the reference, step and spike distortion will occur only if there are two or more mismatches (Fig 8 - source and load. Fig 9 - source and midpoint cap load.)

Rounding will occur with a single mismatch. The time between aberrations on the waveform is dependent on line length, propagation velocity and the positions of the mismatches. It is important to note that all elements of the transmission system can introduce significant mismatches including connectors, cables, switches, substrate transmission lines, source impedance and load impedance.

To provide switchable input impedance (50 Ω and 1 MΩ) oscilloscope designers are usually forced to compromise the front-end matching characteristics, especially at frequencies above the oscilloscope's 3 dB point. It is therefore desirable to provide a good source match and to eliminate unnecessary interconnections.

Insertion loss Errors

There are six predominant phenomena that lead to insertion loss: ohmic loss, skin effect, dielectric loss, dielectric frequency dependency, dielectric non-uniformity and waveguide effects.

Skin effect is the tendency for the current flowing in the conductor to be forced to the outer surface by the self-induced magnetic field (Fig 10) and occurs in all conductors. It results in a loss that is proportional to the square root of the signal frequency and inversely proportional to the conductor's surface area per unit length. This leads to a pulse response with increased risetime and a tilting down of the first 1 ns to 50 ns of the pulse top – an effect sometimes called "dribble-up."

In practice, dielectric loss and frequency dependency leads to another type of dribble-up. Dielectric non-uniformity tends to introduce both dribble-up and ringing. Solid or foam PTFE (Polytetrafluroethylene) dielectrics have relatively insignificant insertion loss contributions whereas epoxy-based dielectrics (e.g. FR-4 pcb material) possess most of these losses in abundance.

Waveguide effects occur as the dimensions of the line approach half wavelength proportions. For 100 ps pulses this is generally not a problem.

In practice, solid and foamed PTFE cables and substrates suffer predominantly from skin effect losses and occasionally from dielectric non-uniformity effects. Cables and substrates constructed using poor quality dielectrics (e.g. epoxy based dielectrics) are plagued with most of the dielectric loss phenomena discussed. Switches also suffer from most of these phenomena, and in many systems they are the dominant distortion inducing components

Measurement and Traceability Problems

Traceability can be imported from national laboratories with either a pulse source or a sampling oscilloscope. Unfortunately these transfer standards have significant risetime and distortion errors relative to high performance oscilloscope calibrators. Full characterization of the transfer standard is therefore required and complex correction methods need to be applied (deconvolution). This can be simplified if similar pulses are compared on an oscilloscope. Linear corrections may be sufficient.

In general, however, automated correction methods are preferable due to the large amount of waveform characterization data required and the computational complexity. To avoid additional errors, cables and switches are eliminated from the measurement system and either a floating pulse or sampling head is typically used.

It should be noted that most national laboratories outside the United States do not at present offer distortion traceability.

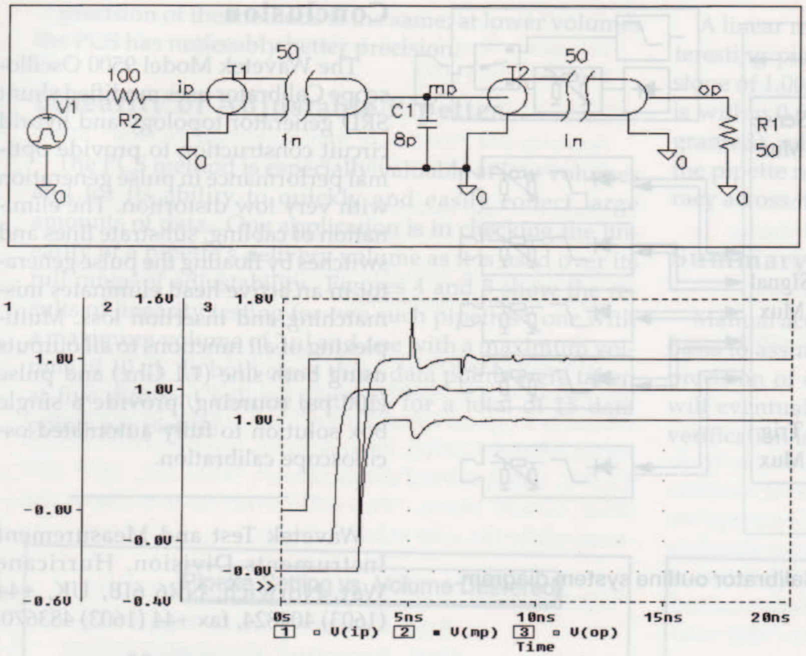

Figure 9. Source and midpoint mismatch.

Oscilloscope Calibrator 100 ps Pulse System Integration

To meet the conflicting requirements of good performance and full automation, the optimal solution is to mount the generator in the head, routed to the output connector via short microstrip lines and a high quality wideband switch (Fig 12). To achieve these goals it was necessary for the circuitry to be implemented using proprietary composite hybrid-circuit technology and to house it in a lightweight diecast aluminum box.

Also integrated into this active head are a sine level detector, 0.5 ns pulse generator, wideband attenuator bank and additional routing mechanisms. This allows all output signals to be routed through the same output connector. The calibrator chassis provides multiplexing so that the calibration signal can be output from any one of five heads attached to the calibrator. The trigger signal can be routed via any one of the unused heads or via a simple interconnect cable.

The Model 9500 has two types of active heads. Both of these are capable of delivering 3 V, 500 ps rise/fall time pulses, and one of them also delivers 100 ps rise/fall time pulses as described. A switchable 50 Ω termination in the head provides matching when the head is driving high-impedance oscilloscope inputs.

The same active heads that deliver these fast edges also deliver precision DC levels up to ±200 V, precision amplitude squarewaves up to 200 Vpk-pk from 10 Hz to 100 kHz, leveled sinewaves from 0.1 Hz to 1.1 GHz and three different styles of timing marker from 0.5 ns to 50 s. A single active head plugged directly into one of the oscilloscope's input connectors therefore delivers all the calibration waveforms required to calibrate an oscilloscope's input amplifier gain, offset, pulse response, bandwidth and flatness, LF and HF triggering and timebase accuracy.

The Model 9500 has a basic amplitude accuracy of ±0.025% and a basic timing accuracy of $\pm 10 \times 10^{-6}$ (10 ppm). An optional high-stability internal crystal allows timing accuracy to be improved to $\pm 0.25 \times 10^{-6}$ (.25 ppm) in order to calibrate the latest generation of high-accuracy digital-storage oscilloscopes.

In addition to comprehensively calibrating an oscilloscope's deflection amplifiers and timebases, the Model 9500 can measure the input resistance and capacitance of oscilloscope inputs. It also outputs DC and squarewave currents up to 100 mA to calibrate current probes.

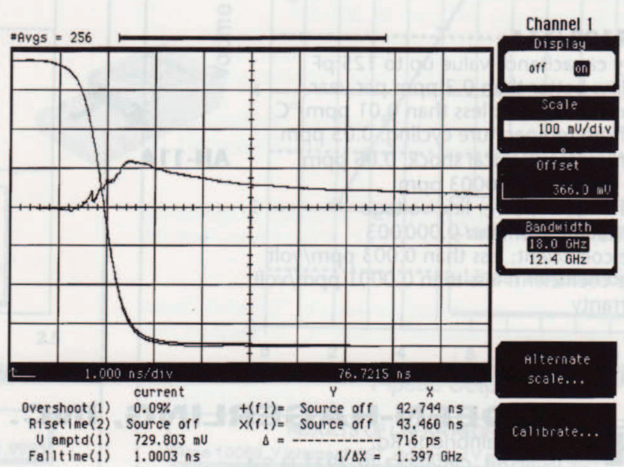

Figure 10. Skin effect - LF switch.

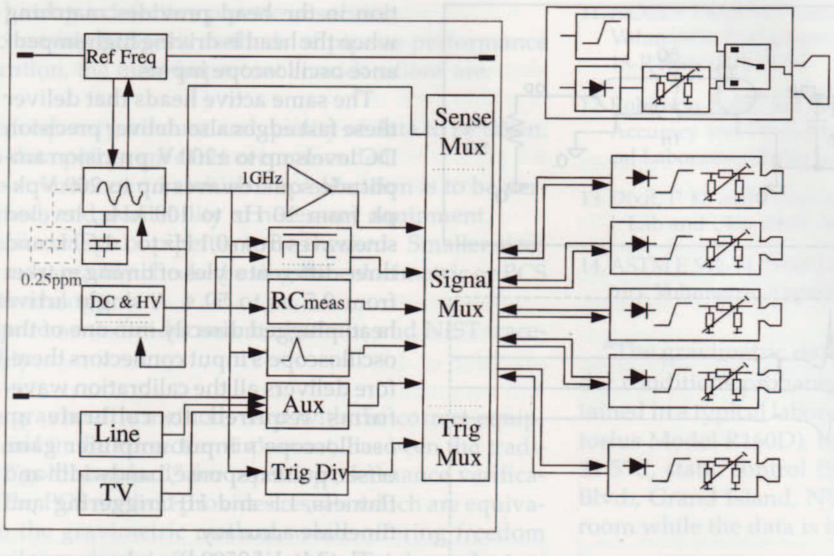

Figure 11. Model 9500 Oscilloscope Calibrator outline system diagram.

Conclusion

The Wavetek Model 9500 Oscilloscope Calibrator uses modified shunt SRD generator topology and hybrid circuit construction to provide optimal performance in pulse generation with very low distortion. The elimination of cabling, substrate lines and switches by floating the pulse generator in an active head eliminates mismatching and insertion loss. Multiplexing of all functions to all outputs using both sine (1.1 Ghz) and pulse (100 ps) sourcing, provide a single box solution to fully automated oscilloscope calibration.

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