Today we stand at a crossroads in waveform measurement. Behind us lies a long and difficult path dotted with items such as traveling-wave cathode ray tubes, oscillographs, rooms darkened for personal viewing of the trace, photographic development equipment, strip-chart recorders, etc. Ahead lies the world of automated oscilloscopes or waveform recorders which promises to eliminate much of the tedium that has kept time-domain measurements from being as widely applied as frequency-domain measurements. In spite of the fact that the time domain represents the real world, or events as they happen, adequate attention has not been paid to the development of time domain instrumentation.

A prime mover in the present proliferation of waveform recorders has been the development of inexpensive digital recording equipment using microprocessors. One can even buy an adapter for an Apple computer which the company claims will turn it into an oscilloscope with memory. This ready availability of waveform recording equipment, and the resulting increase in popularity of time domain measurements, has led to increased interest in the correlation of time domain measurement data among laboratories. This in turn requires the development of performance standards for waveform recorders.

To satisfy the need for measurement correlation, a new technical committee of the IEEE Instrumentation and Measurement Society (IMS) has been formed and has been assigned the task of developing generic performance standards for waveform recorders. The formation of this committee was first discussed at the Waveform Recorder Seminar held at the Boulder Laboratories of the National Bureau of Standards (NBS) in October 1981. An organizational meeting was held in conjunction with the Solid State Circuits Conference in San Francisco in February 1982. Less than one month later at the NBS ADCOM meeting in Boulder, the committee was officially adopted as a technical committee of IMS.

The committee organization is as follows:

Chairman:  Robert Lawton, NBS
Vice Chairman:  Paul Stuckert, IBM
Secretary:  Michael Souders, NBS
Subcommittee Chairman for Time:  Bruce Peetz, Hewlett-Packard
Subcommittee Chairman for Amplitude:  Fernando Herrera, USAF
Michael Souders, NBS
Subcommittee Chairman for Frequency/Impulse Response:  David Hutton, EG&G

The second committee meeting was held in June of 1982 in Boulder, in conjunction with the Conference on Precision Electromagnetic Measurements. The three subcommittees submitted their reports stating the measurement needs in their respective areas. The next meeting is planned in conjunction with the International Solid State Circuits Conference in New York in February 1983.

The committee also has representation from Tektronix, Los Alamos National Lab, Gould Biotron, Sandia, NRL, and the National Research Council of Canada. We have requests for at least two other companies to be added to the committee. The Power Engineering Society of the IEEE has also asked that it be kept closely informed of all committee activities through the chairman of its Digital Techniques in Electrical Measurements Subcommittee, Richard Malewski of Hydro Quebec Institute of Research.

Contact has also been made with the International Electrotechnical Commission (IEC) through Bill Walker of Tektronix, Chairman of IEC Subcommittee 66B on Oscilloscopes. This contact appears to be the means through which some preliminary IEC efforts will be made viable and will be on the agenda at the October 1982 meeting of IEC in Budapest, Hungary. With all this interest the committee keenly feels the need of a reliable waveform standard. The standard most widely used at present for evaluating waveform recorders is a fitted sinewave or, more appropriate to transient measurements, a gated sinewave. The use of both techniques is fully described in the Proceedings of the Waveform Recorder Seminar mentioned earlier.

The National Bureau of Standards is progressing on the development of waveform standards which more nearly fit the shape of signals most commonly encountered in waveform recording. These are steps and impulses, with the goal of the work being done on step waveforms since a step can more completely characterize a system performance than an impulse can.

What are the desired characteristics of a reference waveform standard? The most commonly used parameter in characterizing a pulse generator is the first transition duration (risetime). This is the time it takes for the signal to go from one reference (voltage, power, etc.) level to another, commonly the 10 percent to 90 percent points. To accurately determine the 10 percent and 90 percent points one must first accurately determine the 0 percent and 100 percent points. This means that the baseline and topline must be flat and have no slope or wiggles. In addition, the transition from the 0 percent level to the 100 percent level must be smooth, without any steps, so that the conversion of level to time will be unambiguous. Finally, the waveform of the standard should be derivable by modeling the parameters in the waveform generation process using means that are independent of the waveform measurement itself.

Our approach at NBS has been to use a low-pass filter excited by a tunnel diode whose transition duration is significantly faster than the filter step response. Thus, the transition duration of the waveform is essentially determined by the filter. A filter which fits the above criteria of a flat baseline and topline with a smooth transition in between is one with dielectric loss predominate. It consists of a coaxial line filled with a liquid dielectric which is a dilute solution of 2-heptanone in heptane. This dilute solution satisfies the Debye dielectric equations which are used as part of the modeling of the device. The realization of this waveform standard is more fully described elsewhere. Suffice it to say that three versions of the filter have been fabricated having 50,
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100, and 200 picosecond transition durations, respectively. Besides our own set, we have also provided sets of standards for four other laboratories. The complete documentation on these standards is a monograph now in draft form and should be available soon. Earlier preliminary reports are available now. The 100 picosecond model is shown in figure 1 and a typical output as measured by the NBS Automatic Pulse Measurement System (APMS) is shown in figure 2. The APMS is a 20 picosecond sampling oscilloscope interfaced with a minicomputer for automatic waveform acquisition and data processing. These standards have been very carefully made. For example, very precise machine work was required to make the connectors leak-tight. As an indicator of the liquid-holding capability of these lines, we have monitored the low-frequency capacitance over a period of several months and have found the fractional fluctuation of capacitance, ΔC/C, to be less than 2.6 x 10⁻⁴.

This machine work is expensive which makes the cost of these standards out of reach for many industrial laboratories. These standards have an additional disadvantage of a temperature coefficient of about 1 picosecond per degree centigrade.

Research is continually under way at NBS to make better standards. One of our present efforts is to investigate the feasibility of making transition duration standards out of solid-state materials such as silicon. A two-layer dielectric in the form of a Maxwell-Wagner capacitor has been analyzed as a transmission line by Hasegawa. Nahman has applied Hasegawa's results to the filter problem in question. The dielectric consists of a lossless layer (SiO₂) on top of a lossy layer (doped silicon). The equivalent circuit equations that result for this transmission line are identical to those for the lossy liquid Debye dielectric line. This stripline realization is illustrated in figure 3.

One can easily select the proper length for a desired transition duration because the characteristic impedance of a transmission line filter does not vary with length although its transmission bandwidth decreases with length.

This length/bandwidth tradeoff was available to the NBS designers of the present liquid filters. However, the present length of about 24 centimeters is nearly the maximum length that can be used for convenient portability. For simplicity in production, the length was held constant and the dielectric solution was adjusted for the proper transition duration. Care was necessary to not exceed concentration limits which would violate the dilute solution condition required to achieve the Debye relaxation response. Consequently, because the solid-state transmission line filters could be made so small, a design for a response in the nanosecond range could easily be made, e.g., 50 ohm filter of length, width, and height of 24, 0.4, and 0.3 millimeters, respectively, would provide a 1 nanosecond transition duration.

In addition to the compactness of the solid-state filter, there are other advantages:
1. Mechanically rugged.
2. Improved temperature stability.
3. Hybrid integrated circuitry could be used to integrate the tunnel-diode transition generator onto the filter substrate.
4. Amenable to the integration of an optical pulse generator to produce the electrical transition step.

Summary

Waveform measurements have matured to the point where a proliferation of digital waveform recording equipment has led to the organization of a Waveform Measurement and Analysis Committee. The first task is the development of a standard for waveform recorder evaluation and measurement. The Committee has representatives from industry, user laboratories, and NBS. To support this effort, waveform standards are being developed to meet the requirements of waveform recorder evaluation. These include sinewave testing and standard step waveform testing which show promise of providing compact, economical, and rugged standards which should further accelerate the development and use of the time domain in system evaluation.

References

Figure 1. Debye dielectric reference waveform generator.

Figure 2. Debye dielectric reference waveform generator typical output.
Using a strip line geometry very compact, stable, and low cost waveshaping filters can be made.

0.02 mm

0.126 mm

\( \varepsilon_{r1} = 4 \)
\( \varepsilon_{r2} = 12 \)
\( \sigma_2 = 18.9 \text{ mhos/m} \)

n-Si: \( 8 \times 10^{14} \text{ atoms/cm}^3 \)
p-Si: \( 2.5 \times 10^{15} \)

Figure 3. Proposed solid-state waveform filter realization.