ELECTRONICS NOTEBOOK

Chart Recorders & Storage Oscilloscopes

By Forrest M. Mims III

Most of us who experiment or work with electronics spend a good deal of time making measurements with instruments like multimeters and oscilloscopes. Usually, I measure things like ohms, volts, frequency and the shapes of pulses, but I've lately spent a good deal of time measuring various kinds of natural phenomena.

For example, every day that the sun shines, I measure its peak ultraviolet (UV) radiation at a wavelength of 300 nanometers. This wavelength is near the peak susceptibility of human skin to sunburn. I've been making these measurements almost every day since July 1988 and have learned a good deal about daily and seasonal variations of the ultraviolet.

In addition to my UV project, I've been preparing for the arrival of Africanized bees, the so-called "killer bees," by measuring the wing beat frequency of European honey bees. I've been studying the various electrical and acoustical signals produced by lightning and thunder, and I've been experimenting with several different kinds of do-it-yourself seismometers and humidity sensors. For these measurements, the Cole-Parmer Instrument Co. (7425 N. Oak Park Ave., Chicago, IL 60648) Catalog No. 8376-60 two-channel chart analog recorder shown in Fig. 1 has proved invaluable.

In view of the availability of digital oscilloscopes and sophisticated data-logging software for personal computers, you might be wondering why I spent some $1,400 for an "old-fashioned" chart recorder. Even though I've had experience with all these recording methods, this isn't an easy question to answer. Perhaps the best way to answer it is to make some side-by-side comparisons of a chart recorder with a digital storage oscilloscope (DSO).

Now where do *you* come in? If you aren't yet using any of these recording instruments, chances are you soon will. Many new kinds of recording instruments are being manufactured, and their prices have fallen considerably. Hopefully, some of my experiences with these instruments will help you make batter decisions about which to use for a particular measuring situation.

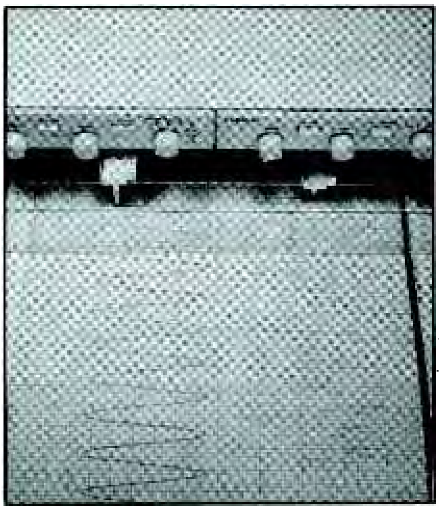

Fig. 1. Author's two-channel analog chart recorder in operation.

Analog Versus Digital

Let's begins this discussion with a brief review of analog and digital displays. For many years, I've taught Sunday School classes. While it's not all that important that the class begins at the set time, it is important that it ends on time. Therefore, as the class winds down, I look at my watch more and more often.

I've worn both digital and analog watches while teaching, and I could never pinpoint which style of display seems easier to read with a quick glance. Then I started wearing a watch with both an analog *and* a digital display. During most of the class, a quick glance at the minute hand on the analog display provided a good time check. Then, during the last few minutes of the class, I began looking at the digital display.

In other words, the analog display provided a fast, general idea of the remaining time, while the digital display provided an exact time reading. The drawback of the digital display is that it requires more brain processing time to understand what is being displayed. The analog display is a picture of the time, the digital display a set of symbols.

Now, let's compare a conventional multimeter equipped with an analog meter movement and a digital multimeter. The latter is perfect for precise measurements of fixed voltages, currents and resistances. However, an "old-fashioned" analog meter is often a better choice in measuring applications in which the signal level fluctuates. For example, a DMM can function as a digital display device for my homemade UV radiometer. It provides precise measurements that can be logged into my notebook. But the DMM is of no use in understanding the wave-like variations in the ultraviolet radiation from the sun. The slowly oscillating pointer of an analog meter movement clearly shows these fluctuations.

Analog meters are also ideal for observing the increase and decrease of the charge on a capacitor. And such meters are well suited for monitoring slowly changing signal levels from various kinds of sensors and transducers.

What all this means is that there is an important place for both analog and digital displays schemes. This explains the existence of wristwatches that have dual displays. It also explains why a radio or tuner with a digital frequency display has an analog level indicator.

The moving-coil level meter is being rapidly replaced by various kinds of digitally controlled analog bargraph displays. Many tuners and equalizers feature one or more rows of bargraphs, each representing a particular audio frequency band. The result, in the case of the equalizer, is an audio spectrum analyzer. The picture provided by such a display is easily grasped. Replacing each analog bargraph with a digital display would provide a confusing and meaningless array of fluctuating numbers.

The Chart Recorder

The chart recorder or oscillograph can be considered a low-frequency oscilloscope with hard-copy output. In most chart recorders, variations in an input signal

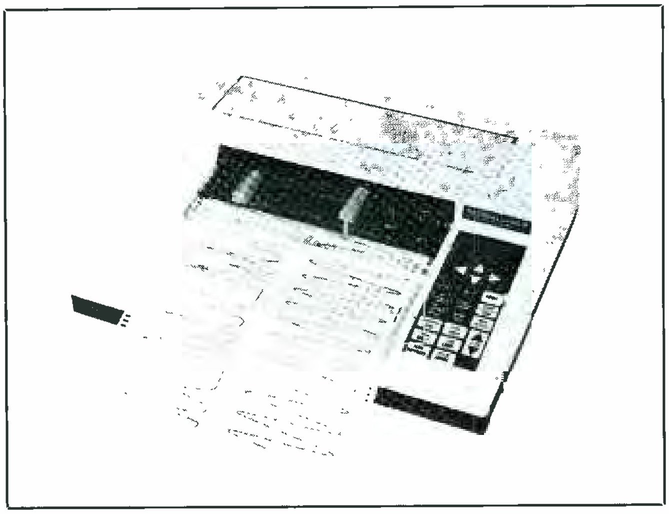

Fig. 2. Series 4500 Microscribe™ microprocessor-controlled chart recorder. (Photo courtesy of The Recorder Co.)

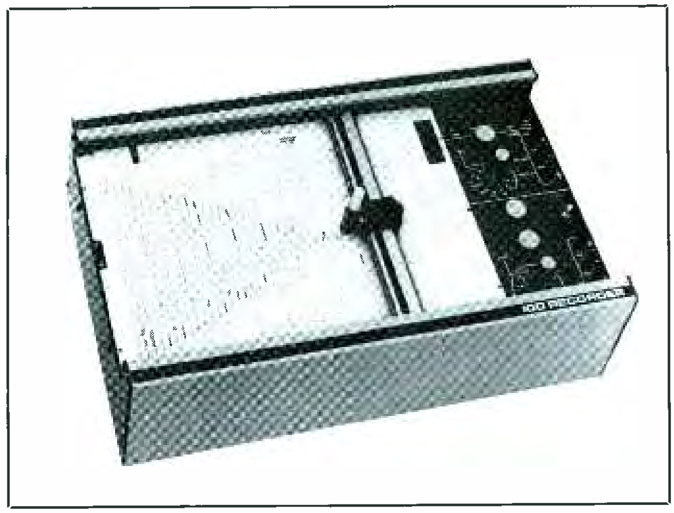

Fig. 3. Series 100 X-Y recorder incorporates capacitance position transducer. (Photo courtesy of The Recorder Co.))

cause proportional changes in the position of a moving pen or stylus. The pen is moved by either a galvanometer mechanism or a servo system. The paper is moved by a regulated motor-driven mechanism.

Many different methods are used to write the signal received by the recorder onto a moving strip of paper. If a pen is used, a line of ink records variations in the signal on the moving paper. Some recorders achieve the same result with a heated stylus and thermal paper, while others use a pointed stylus and pressure-sensitive paper.

The frequency response of all such recorders is limited by the mechanics involved. One way to obtain a faster response is to replace the moving pen with a tiny mirror mounted on the moving axis of a galvanometer. The mirror reflects a narrow beam of light toward a moving sheet of photographic film. Since a galvanometer/mirror assembly has very little mass, it achieves much faster response times than simple galvanometer-driven pens and servos.

The frequency response of a chart recorder can be greatly increased by replacing the moving stylus or pen with a thermal printhead. This printhead consists of a row of closely spaced elements that print small dots on thermal paper. The printhead of some thermal recorders will annotate the paper with such information as the date and time of a measurement and the sensitivity of the recorder and timebase settings.

Figure 2 shows the Series 4500 Microscribe™, one of a line of chart recorders manufactured by The Recorder Co. (P.O. Box 8, San Marcos, TX 78667). This recorder, which was originally developed by Houston Instruments, has 34 chart speeds and 18 sensitivity ranges. A dedicated microprocessor controls the recorder and drives its LCD status display. A single-pen 4500 costs approximately $1,090, while a dual-pen version costs about $1,650.

Chart recorders record information on long rolls of paper. The X-Y recorder is variation of the chart recorder in which the pen is mounted on a slider that can move up and down along a bar that can be swept back and forth across a single sheet of paper.

While the chart recorder can record information over a long period of time, the X-Y recorder is usually—but not always—used to record information relatively quickly. For example, X-Y recorders are used by optical filter makers to record the transmission of their filters as a function of wavelength.

Figure 3 shows a Series 100 X-Y recorder manufactured by The Recorder Co., the same company that makes the recorder shown in Fig. 2. The movable sliders of the Series 100 family use no sliding contacts. Instead, a capacitance position transducer provides nearly frictionless operation with no electrical noise. The Series 100 X-Y recorder sells for approximately $2,600.

The recorders shown in Fig. 2 and Fig. 3 are merely representative of what's available. On my desk as this is being typed is a file I've labeled "Chart Recorders" that's slightly more than 2 inches thick! Therefore, if you're in the market for a chart recorder, be sure to check one of the electronics trade directories under this heading.

Another good source for information on chart recorders is the catalogs put out by companies that sell various recorders. Among the best of these are those from Omega Engineering (Box 4047, Stamford, CT 06907), Transcat (Box D-1, Rochester, NY 14606) and Cole-Parmer Instrument Co.

Digital Storage Oscilloscopes

When I was assigned to a military laser laboratory many years ago, I used dozens

Fig. 4. Model 100 battery-powered, dual-trace portable digital storage oscilloscope. *(Photo courtesy of Leader Instruments, Inc.)*

of packages of Polaroid film to record oscilloscope traces that displayed the power produced by various kinds of lasers. Scope cameras are still an important laboratory tool, but a new kind of oscilloscope can transfer the image on its screen directly to a computer for printout by a printer. No camera is needed to accomplish this feat. This new kind of scope is known as the "digital storage oscilloscope," or DSO for short.

DSOs incorporate a fast analog-to-digital (A/D) converter that digitizes the incoming signal. The most important advantage of the digitized signal is that it can be temporarily stored in a memory in the DSO that saves one or more screens. Alternatively, it can be transferred to a desktop computer and saved on the computer's disk drive. Some DSOs include

Fig. 5. HP 54501A digitizing oscilloscope has four input channels and 100-MHz bandwidth. *(Photo courtesy of Hewlett-Packard Co.)*

built-in floppy-disk drives for saving screen displays.

Another important advantage of the digitized signal has already been mentioned. Since the signal is in digital form, everything displayed on the screen of the DSO can be printed on paper. Yet another advantage is that some DSOs can be used in a roll mode that simulates a chart recorder. A single screen can represent minutes or even hours of data.

Though DSOs are still more expensive than analog scopes, their prices have fallen considerably in recent years. On the low end, Hameg, Inc. (8890 Harbor Rd., Port Washington, NY 11050; Tel. 800-247-1241) sells its Model HM 205-2 for less than $1,000. Optional accessories available for this 20-MHz scope include an IEEE-488 bus, X-Y plotter output, and a graphics printer. Also available is a software package that permits the scope to be used with an IBM PC-AT or compatible computer. This combination provides such capabilities as data logging, wave analysis, automatic measurements, calibration and various kinds of mathematical processing. Waves displayed on the CRT screen of the scope can be saved in disk files and printed.

If you need a portable DSO, Leader Instruments Corp. (380 Oser Ave., Hauppauge, NY 11788; Tel. 800-645-5104) manufactures the single-trace Model 100P and dual-trace Model 200 battery-powered DSOs. Both miniature scopes double as digital multimeters, and both can be used with a miniature thermal printer that provides a printout of everything displayed on the screen.

Both Leader scopes store up to three screens in an internal nonvolatile memory for later review and, if desired, printout. The Model LCD-100 sells for $895; the Model 100P and a companion thermal printer together sell for $1,612; and the Model 200, shown in Fig. 4, sells for $1,645. The Model 710 printer costs an additional $480.

If your budget permits, you can consider an advanced DSO like Hewlett-Packard's Model HP 54501A. This 100-MHz, four-channel DSO sells for around $3,500, which includes a built-in

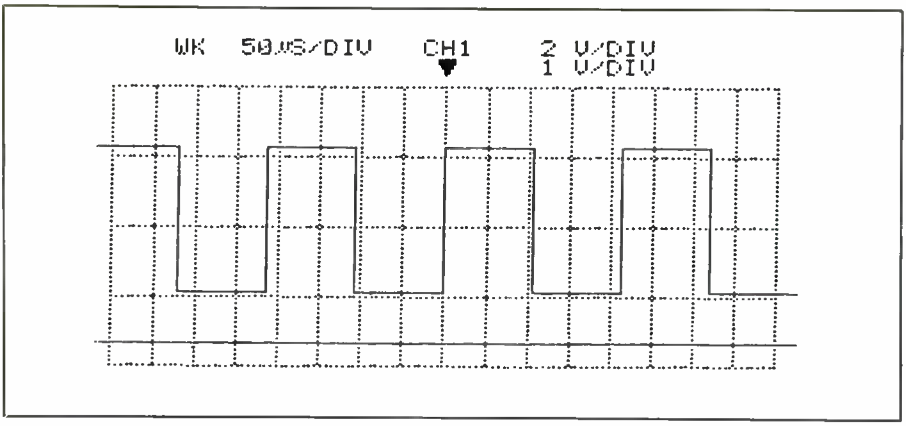

Fig. 6. Square wave displayed and printed out by Leader Instruments Model 200 digital storage oscilloscope.

IEEE-488 interface and hardcopy output to a graphics printer. As Fig. 5 reveals, the front panel of the HP 54501A has only one analog control. Otherwise, all control over this instrument is by means of pushbuttons.

Besides Hameg (West Germany) and Leader Instruments (Japan), major domestic manufacturers of DSOs include Tektronix, Inc. (P.O. Box 500, Beaverton, OR 97077; Tel.800-426-2200) and Hewlett-Packard Co. (19310 Pruneridge Ave., Cupertino, CA 95014; Tel. 800-752-0900).

Bill Siuru, jr., reviewed DSO basics in the March 1989 issue of *Modern Electronics*. That same issue included a DSO Buyer's Guide. If you're in the market for a DSO, be sure to see this article.

Data-Acquisition Computer Software

The same computer into which these words are being typed can perform many of the functions of both chart recorders and digital storage oscilloscopes. The October 1988 installment of this column described how my son transformed a Tandy 1000 personal computer into a chart recorder. The April 1989 column described how I transformed a PC into a slow-scan storage oscilloscope with the help of reasonably priced 8-bit A/D conversion board made by Alpha Products (242-M West Ave., Darien, CT 06820).

If you don't need a full eight bits of resolution, you can use the analog game ports of some computers as built-in A/D converters. This means these computers can be used as DSOs with only the addition of software and without the need for any external hardware. It's especially easy to transform Radio Shack's Color Computer and IBM's PC*jr* and similar machines into basic DSOs. For full details on how to accomplish this, including program listings and sample screens, see *Forrest Mims's Computer Projects* (Osborne McGraw-Hill, 1985).

Comparing Chart Recorders & Digital Storage Scopes

As I mentioned early on, I recently purchased a two-channel chart recorder. About the same time, Leader Instruments Corp. lent me a Model 200 portable digital storage oscilloscope and printer to evaluate for *Modern Electronics*. I've also had the opportunity to work with various data-acquisition systems, including do-it-yourself versions and an IBM AT-compatible computer connected to a 110-MHz Tektronix Model 2230 DSO and various kinds of data-acquisition and interface hardware. What follows is based upon my experience with these and similar instruments.

Shown in Fig. 6 is a printout of a square wave provided by the Leader Model 200 DSO and its companion thermal printer.

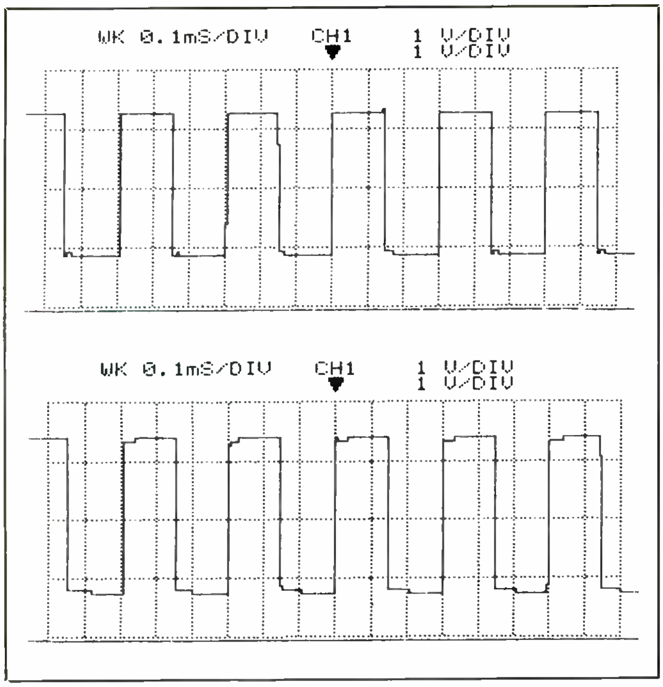

Fig. 7. Resolution-limited square wave displayed and printed out by Leader Instruments Model 200 DSO.

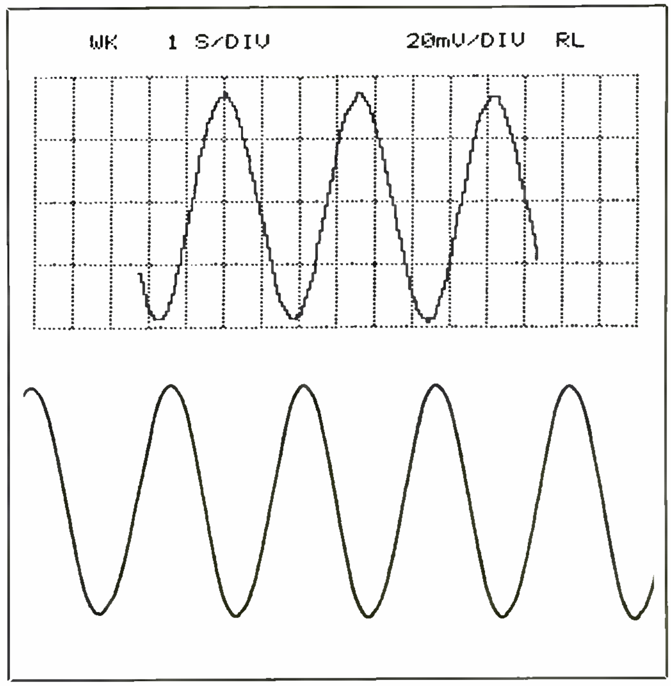

Fig. 8. Identical sine waves printed out by Model 200 DSO (upper) and drawn by analog chart recorder (lower).

The trace is displayed on channel 1 and no signal is applied to channel 2. Note that the printout is annotated with the settings for each channel.

The resolution of the most expensive DSO is less than that of the least expensive analog scope or chart recorder. This resolution limit is clearly revealed in Fig. 7, a pair of printouts of a square wave displayed on a Model 200 DSO. The actual square wave has no overshoot and almost perfectly flat tops and bottoms. However, the amplitude of the wave falls between two of the DSO's resolution points; hence the choppy tops and bottoms shown in Fig. 7.

The two sine waves shown in Fig. 8 illustrate another aspect of the resolution limit of DSOs. Here, the same sine wave has been applied to the Model 200 DSO (upper) and my Cole-Parmer chart recorder (lower). The limited resolution of the DSO transforms the smooth sine wave into a stepped function.

The waveform shown in Fig. 8 is clearly recognizable as a sinusoid. At slow sweep speeds, however, the display of a DSO can become very confusing because of a phenomenon known as "aliasing." For example, Fig. 9 shows a collection of printouts of the sine wave shown in Fig. 8 displayed at a range of sweep speeds by the Model 200. Fortunately, storage scopes like the Model 200 have an auto-ranging feature that automatically seeks out a sweep speed that presents a clear, easy-to-read display.

Incidentally, the lower two printouts in Fig. 9 were made by placing the Model 200 DSO in its roll mode. This causes the display to resemble a chart recorder. When the Model 200 is in its roll mode, the printer prints only the on-screen portion of the display. All other Model 200 screen printouts in Fig. 9 show the scope's entire memory contents.

While old-fashioned chart recorders have superb resolution, their response time is slower by far than the slowest DSO. This can easily lead to missed events. In Fig. 10, for example, is shown a particularly interesting comparison of the printout from the Leader Model 200 and the chart from the Linear Instruments recorder. The two images are simultaneous recordings of the 300-nm ultraviolet radiation from the sun at my office in south-central Texas at 1120 hours CST on March 29, 1989. The DSO sweep speed was 5 seconds per division, and the chart speed was 5 centimeters per minute. The UV flux was 0.016 watt per square meter. According to Sunsor, Inc. (and both my exposed ears), that level will cause mild burning of unprotected Caucasian skin in about an hour.

Notice in Fig. 10 the two square-shaped negative pulses. These were recorded when I placed a UV blocking filter in front of the ultraviolet detector for approximately 5 seconds. The reason for this was to keep tabs on the small amount of sensitivity of the UV detector to red light. The trace on either side of and between the two negative pulses is the total signal from the UV detector.

Also note that the DSO trace is perfectly flat, while the chart-recorder trace is an endless sequence of tiny squiggles. At first glance, these squiggles might appear to be electrical noise. Actually, though, they indicate the constantly changing nature of the atmosphere's transmission of UV energy. Ozone, water vapor, sulfur-dioxide and dust are some of the most important absorbers of UV energy in the air. In other words, the squiggles on the chart represent the noise level of the atmosphere's optical transmission at a wavelength of 300 nm.

The most interesting aspect of these two traces is the narrow negative spike inside the two circles. This occurred when a small branch about 25 feet above the detector was momentarily blown into the field of view of the detector. This spike is much more pronounced on the DSO trace because the scope had a much faster response time than the chart recorder. Indeed, had I not been monitoring the sun with with DSO at the same time, I would probably have not noticed the tiny negative spike n the chart recorder's trace.

During the measurement session, I adjusted the Model 200 DSO to show the subtle variations so easily indicated by the chart recorder. As Fig. 11 reveals, the DSO display is not nearly as interesting as that of the chart recorder. (The negative square wave in Fig. 11 was produced when I placed a UV blocking filter over the ultraviolet detector.)

Summing up, the DSO recording does not provide the fine detail of the chart recorder's squiggly trace. On the other hand, the DSO clearly displays fast, transient events that might be missed by the much slower chart recorder. Of course, even the DSO will miss spikes that occur *between* the scope's A/D time samples.

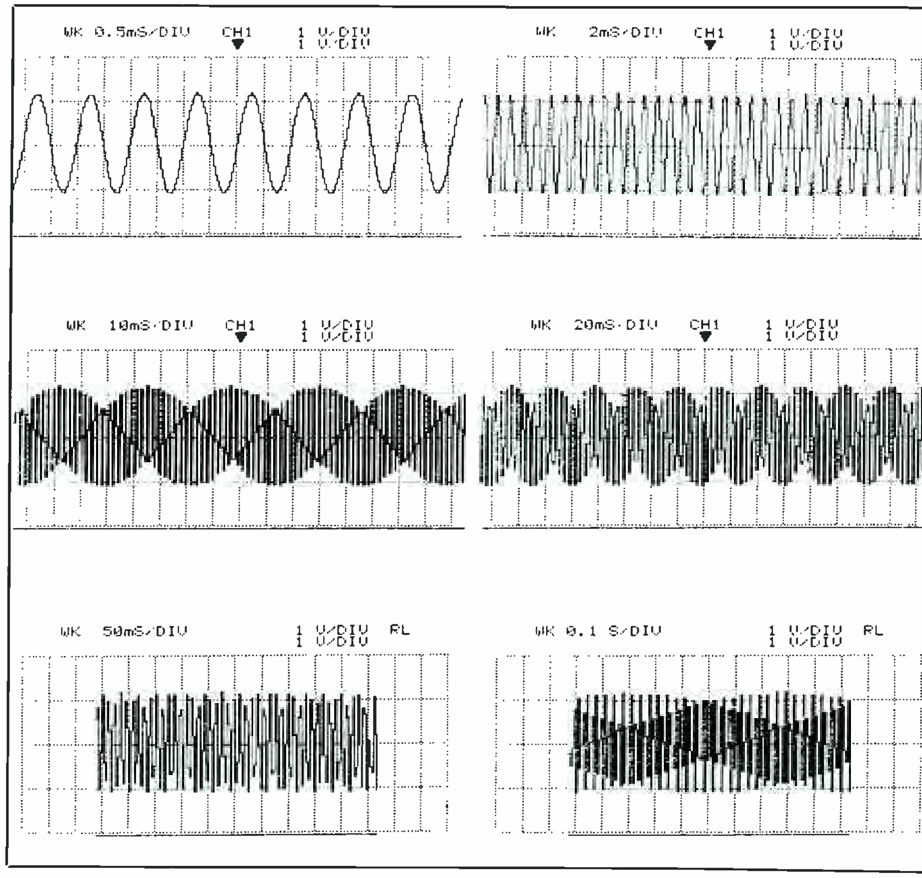

Fig. 9. Identical sine waves displayed at different sweep speeds on Model 200 DSO.

Why Use a Chart Recorder?

Readers of *Modern Electronics* have such diversified backgrounds in electronics that I'm sure many of you must have strong ideas about the relative merits of the various recording instruments discussed in this column. Leader Instruments' Model 200 DSO has a limited capability, but it is portable and battery powered. Full-featured digital storage oscilloscopes have much faster sampling rates than the Model 200, and their CRT displays provide significantly better resolution than the liquid-crystal display (LCD) of the Model 200.

Chart recorders are inherently slow and tend to swamp their users, especially this one, with endless rolls of charts. Since only the most expensive chart recorders have an automatic annotation feature, you have to remember to write down the recorder's settings.

One thing we can probably all agree upon is that each instrument has its role to play. That's why I bought a chart recorder to supplement my do-it-yourself computerized data logger. The various computer data loggers I've designed require several minutes or more to set up from scratch. I can begin recording data with my new chart recorder in less than a minute, and the recorder shows very subtle trends that are sometimes lost when data is digitized.

I've already made many lightning and thunder measurements with my chart recorder. Soon, I plan to build an automated tracking system to monitor the radiation from the sun at several wavelengths. My present plan is to feed the signals from the detectors into a multi-channel A/D converter. The digitized signals will be stored in a computer for later presentation and analysis.

The computer can easily be programmed to sound an alarm when something unusual occurs. For example, I'll probably program a set point that will sound an alarm when the UV energy exceeds a certain level. If the alarm sounds, I can then decide if what is happening is interesting enough to supplement the relatively low-resolution digitized data with a high-resolution chart recording. The chart recorder will show subtle signal variations and trends that the digital approach will miss entirely.

In a few years, we'll be able to store vast quantities of data on CD ROMs. Consider that a single compact disk can store up to 600 megabytes, or approximately 300,000 pages of data! Even then, I suspect, there will still be a role for analog chart recorders.

Going Further

Please keep in mind that this discussion touches on only some of the high points of the ins and outs of storing data with DSOs and chart recorders. For more information, be sure to contact some of the manufacturers whose names and addresses are given above. Various electronics trade directories will point you to additional makers of DSOs and chart recorders. ME

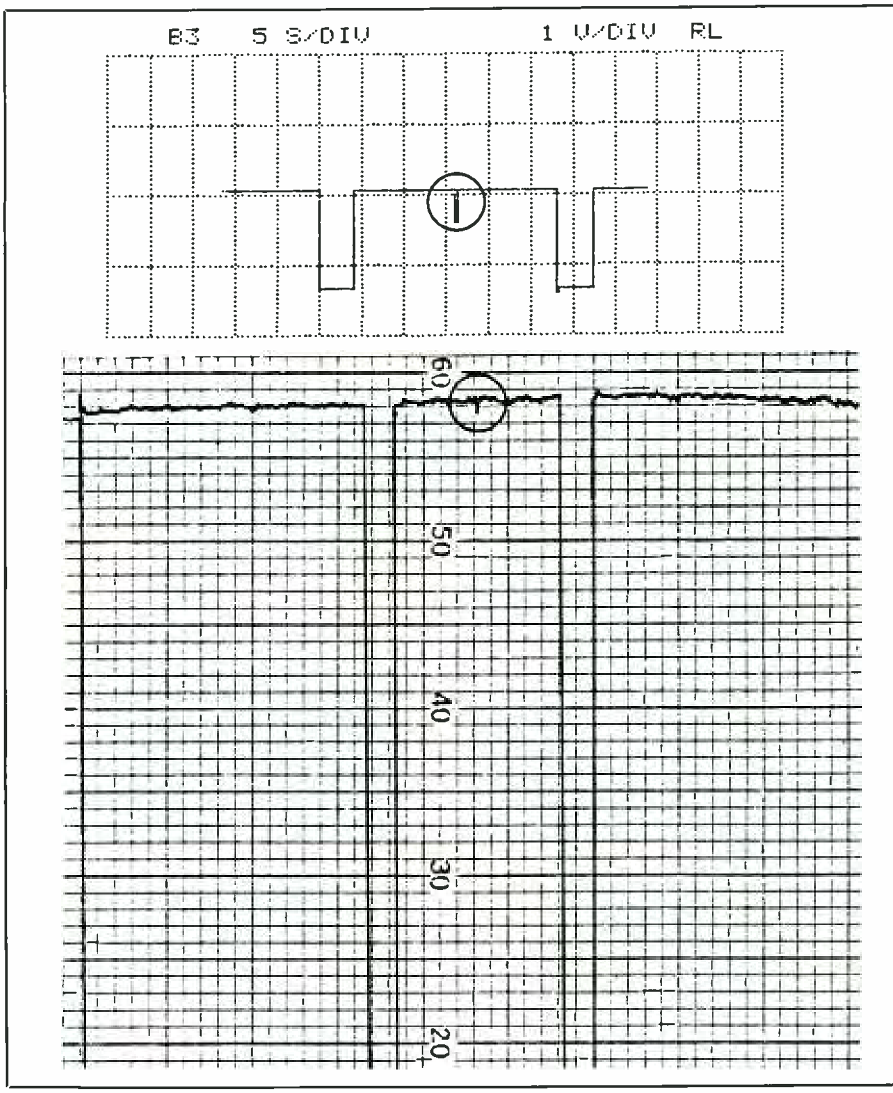

Fig. 10. How Model 200 DSO captured a glitch and displayed it better than it was drawn by chart recorder at same time.

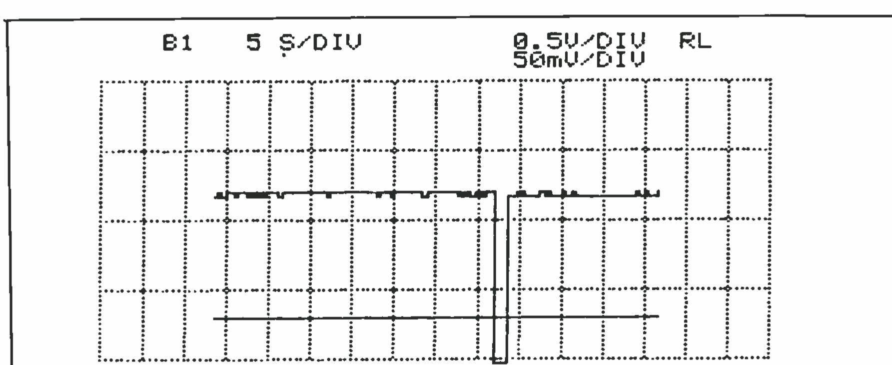

Fig. 11. How Model 200 DSO displays minor fluctuations in ultraviolet flux from the Sun.