Simplifying crt character generation

Scheme uses multilevel analog code and LSI bipolar character generator to minimize data transfer lines; symbols are unlimited and easy to program

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Behind any alphanumeric characters displayed on a cathode-ray tube screen stands a lot of circuitry and a great deal of transferred information. The sheer bulk of these requirements has prohibited using conventional crt alphanumeric display technology in oscilloscope instruments, desirable as it would be. The quantity of integrated circuitry would make the instrument too expensive, and the connections would be excessive.

However, an approach to the problem using a combination of analog information coding and bipolar read-only memory IC's seems to have removed these objections. With the display technique developed by Tektronix for its new 7000 series oscilloscopes, the dial settings are written by the electron beam directly on the screen of the crt. As a result, the scale factor—50 millivolts, 10 nanoseconds, or whatever—is always directly in front of the operator where it can be easily read. The scale factors are automatically included in a photographic record, and since detailed markings are no longer needed on the dials, there is more panel space for additional dials and controls.

The present character generator for the oscilloscope contains 50 symbols. But this is really only scratching the surface; the technique is so flexible and it's so easy to provide new symbols that much more extensive use in describing and analyzing waveforms is practical.

Briefly, the crt uses time-sharing. The electron beam takes time out from tracing the waveforms, its primary job, to trace the symbols representing the scale factors of the input channels and time bases. The scope's persistence masks the gaps in the waveform traces. Bipolar large-scale-integration circuits generate the symbol-control signals when they receive instructions via an analog multilevel code from the switch positions and probes.

A basic consideration in designing the display system was to keep the circuitry for encoding the switch positions to an absolute minimum, since it must be repeated in every plug-in. And the display method had to be flexible, since future plug-ins might use unusual symbols or require unusual readout features. Finally, the leads needed to connect the display data to the mainframe had to be kept to a minimum.

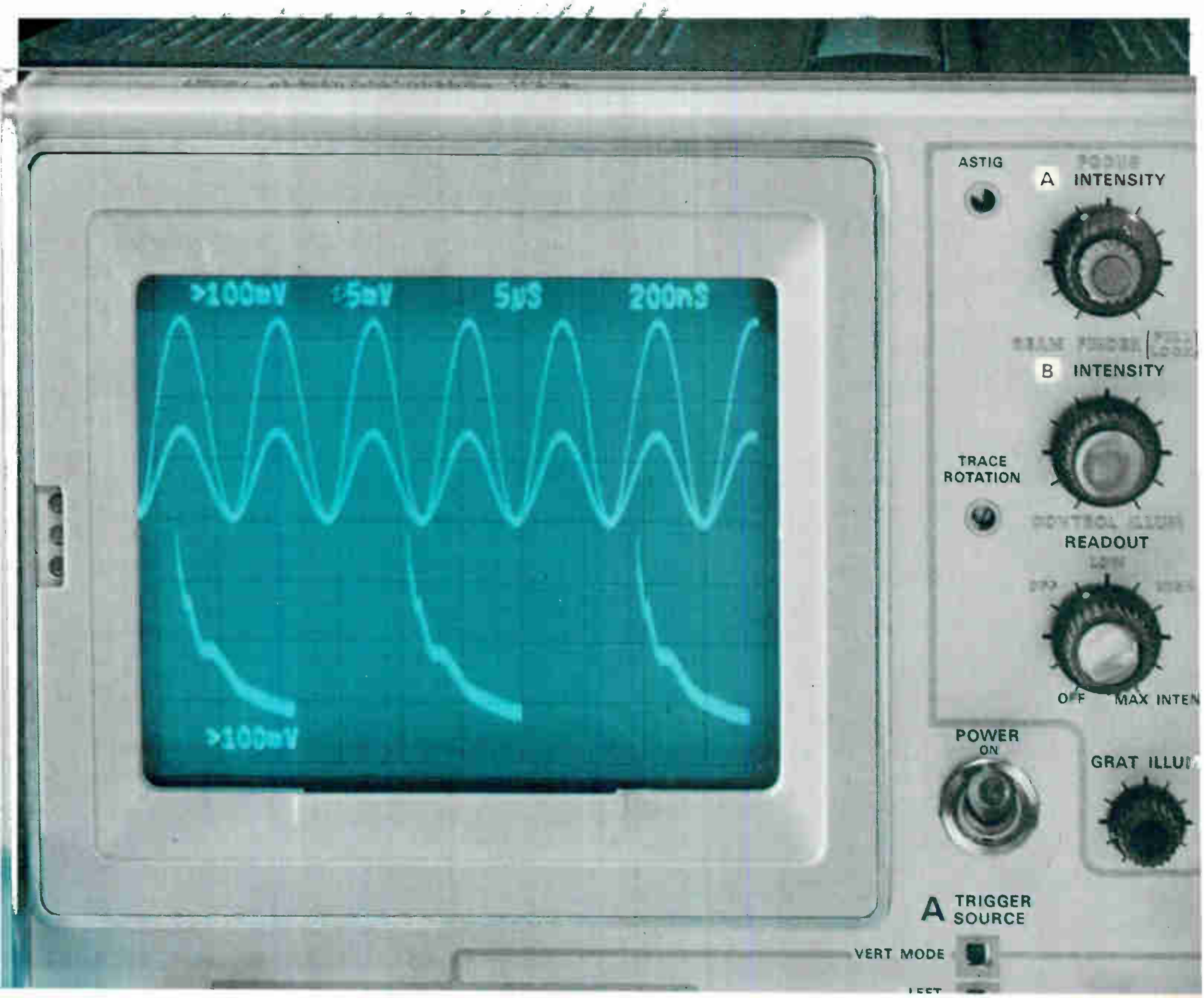
Tektronix considered several other routes for data display before deciding on the IC character-generator approach. In the Tektronix 576 semiconductor curve tracer, ground closures activate tungsten-lamp readout units [*Electronics*, Oct. 28, 1968, page 149]. But the 576 isn't a plug-in unit, and therefore doesn't have the interface density problem. In a plug-in scope, the ground-closure method would require too many connections.

A second possibility incorporated a fiberoptic bundle for each plug-in. Each bundle would connect with the main frame via an optical interface and terminate on the panel, just below the crt. The readout characters could be varied at will by inserting a new transparent film or disk in the plug-in. The benefit was unlimited flexibility; anything—symbols, colors, even pictures—could be piped over the optical interface.

But closer examination revealed snags. In the first place, an optical interface of adequate resolution is not impossible to design but it is extremely difficult. Secondly, the sheer bulk of the data encoder—light source, collimator, film or disk, and drive mechanism—was too great. Moreover, it made the plug-in too expensive and used up valuable plug-in space. Finally, no simple way could be found to change the scale factor when a probe or dial setting was changed.

The time-shared crt display, on the other hand, offered all these advantages:

▪ Flexibility. A given set of symbols can be displayed anywhere on the crt, in any order, any number of times, with size and style changeable electronically. Readout words can be long or short, compressed to have no redundant spaces (particu-



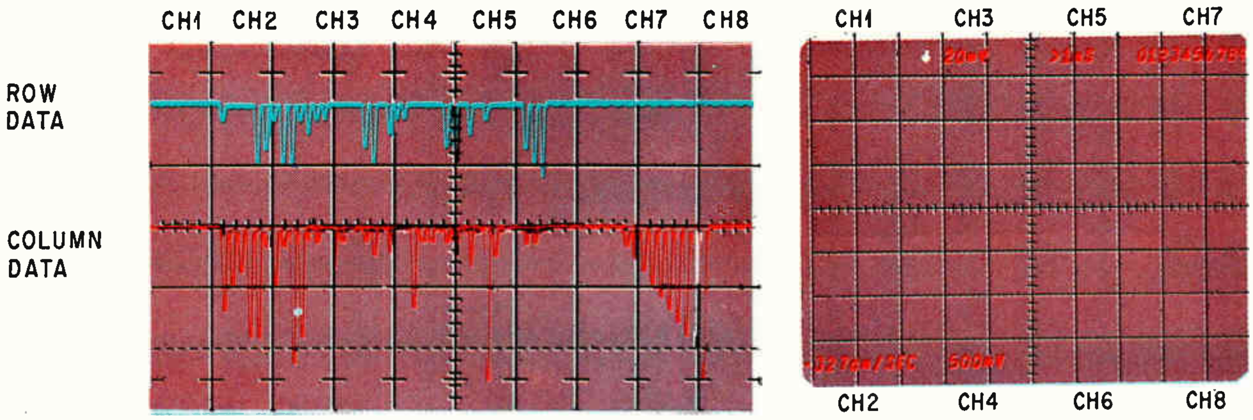
It is written. Scale of waveforms, in units per graticule division, is traced out on cathode-ray tube of Tektronix 7704 oscilloscope. Characters are generated by complex integrated circuits, instructed by multilevel analog pulse code that represents dial settings and probe attenuations.

larly difficult with "fixed" readout devices). The display isn't limited to alphanumerics; such things as arrows, limit markers, and pictorial symbols can be included. And external information, not from the plug-in, can be mixed into the display.

- Selectivity. Only pertinent data need be displayed; there's no need to clutter up the display area with nonsignificant data—an unselected channel, for example. This is in sharp contrast to fixed-format readouts surrounding the crt, which must be bulky to allow space for future multiword displays, even though a typical display might only be two short words.
- Appearance. Symbols are not constrained by a predetermined matrix, as for example, are seven-bar character displays and five-by-seven electroluminescent diode displays. Nor is there any need to compromise readability by making one character fit "inside" another.
- Easy photography. The characters are in the

Typical instructions for changing scale factor

Instruction (row-column)	Column-data amplitude, microamperes	Interpretation
30	0	Go to next step
31	—100	Add one zero after first digit
32	—200	Add two zeroes after first digit
33	—300	Delete zeroes, shift prefix down one unit
34	—400	Add one zero and shift prefix



Analogs and digits. Multilevel analog pulses, top, built up in increments of −100 microamperes, represent dial or probe setting for each channel displayed on scope screen (right). With analog code, fewer connections are needed between plug-in and main frame than if binary digital code code were used.

same plane, have the same color, and can have the same intensity as the waveforms on the crt. Even high-speed motion-photography, with readout data constantly updated, is possible.

- Small size. The circuitry fits on one small board that can be located at any convenient spot in the instrument—it doesn't have to be positioned near the crt or on the front panel.
- Low cost. Since the display circuitry is entirely integrated, production costs will tend to drop. Systems with many mechanical or optical parts, on the other hand, tend to become more expensive.

The complete electronic character-generating system for a time-shared crt display fits on a 5-by-4½ inch board and uses 14 Tektronix-made bipolar IC's, into which are packed the equivalent of nearly 8,000 active devices. It can generate a display of eight words with up to ten symbols per word, from a font of 50 characters, and it can execute a variety of instructions.

The character generator proper incorporates two novel circuit techniques—these techniques, in fact, make the whole calibrated display scheme possible. First, multiple emitters—7,200 in all—are used as precise current-splitting elements. The resulting packing density of components is vastly greater than that of resistive current-splitting.

The method of scanning the symbol on the crt is the second innovation. The character generator puts out a total of eight coordinate points to define a symbol. But a simple sequential pulsing of the coordinates would produce only an eight-dot display. To trace out the full symbol requires smooth scanning from one point to the next. This is achieved by using a resistive ladder network connected to the bases of the coordinate-generating transistors. Continuously varying the bias on the ladder provides a smooth transition from one coordinate point to the next.

A triangular waveform smoothly sequences through the coordinate pairs to produce x- and y-current waveforms corresponding to the symbol. Scanning rates can be from d-c to 1 megahertz.

Each symbol is thus composed of seven strokes. However, unlike commonly used seven-stroke generators, the break-points of the strokes can be placed at any one of several hundred locations, as determined by the coordinate points. The strokes can have virtually any length and angle. The upshot is that only a small number of coordinate pairs are needed to generate symbols of highly legible quality and in almost infinite variety.

The coordinates of the points are determined by the emitters connected through oxide holes to the metalization layer on the IC chip.

One way of looking at the character generator is as an analog read-only memory; its outputs are x- and y-waveforms that trace out the symbol on the crt. (Each symbol is traced twice at each display time, for a total display time of 10 microseconds.) Just as a binary read-only memory can be "programed" by making a special pre-ohmic mask (the mask for making holes in the oxide under the metalization layer), so can the analog read-only memory. To make an IC for generating new symbols, it's only necessary to make a new pre-ohmic mask; no changes in the chip are necessary.

The display system actually turned out to be slightly simpler than Tektronix anticipated. Originally, it was planned to put a separate gun in the crt for the symbols; however, a method was developed for interrupting the analog display—the waveforms—that avoided interference patterns.

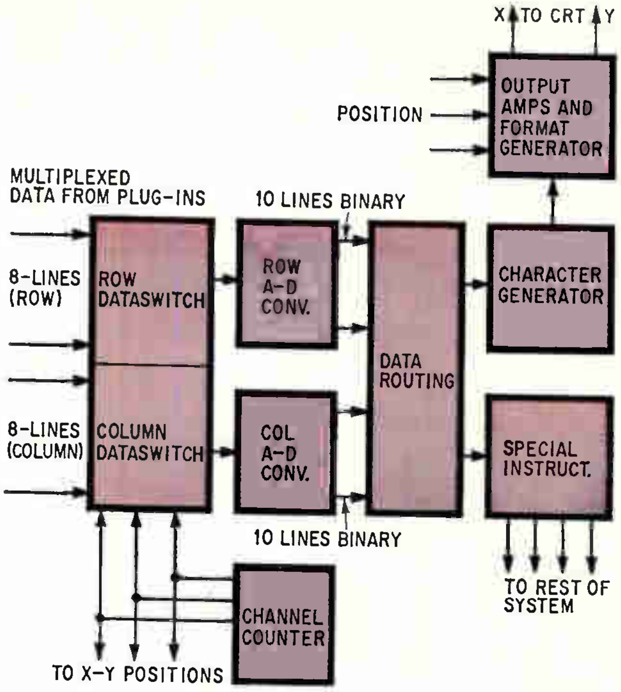
Interrupted pseudorandomly

This interruption method operates in pseudorandom fashion. It permits the electron beam to write, in 15 μsec, one character at the appropriate location on the crt and then to return to the waveform display for an average interval of 250 μsec before it's again interrupted to write the next character. In typical operation, only 1% or 2% of the total available display time is spent in writing characters, and the viewer is unaware of gaps in the waveform display.

The display data originates in the plug-in and is based on the positions of the switches. These positions are encoded into electrical form within the plug-in (by means of resistors connected between the data output lines and pulsed sequencing lines fed to the plug-in).

With this encoding technique, only two data output lines are needed per channel; one selects a row and the other a column from a matrix containing symbols and instructions. Analog-to-decimal converters—one monolithic IC for each channel—decode the analog signal from the plug-ins so that the selection can be made. The outputs of the converters address the character generator, a matrix of ten rows and ten columns containing instructions for the crt to write specific characters or special instructions for adjusting the scale factor (for example, adding or deleting zeroes or changing the prefix m to μ).

To understand how the multilevel analog code works, consider a hypothetical case: channel 2 of the scope is set at 500 millivolts, and it is therefore desired to display "500 mv" on the crt screen at the channel 2 position. The plug-in containing channel 2 sends a series of pulses to the character generator along two lines (row and column). Each pulse can assume one of ten levels in increments of 100 microamperes.



Conversion. Multilevel analog code from plug-ins is changed to binary for use by character generator.

Efficient modification

A special feature of the coding scheme is the scale factor instructions. These provide an efficient way—in terms of the quantity of data—of modifying the basic data pattern to display the correct scale factor. For example, the zeroes that follow the initial numbers in a scale (such as 50 mv, 200 μsec) are added by an instruction that causes both the number of zeroes and the prefix to be changed when the X10 or X100 probes are added, or when the sweep magnifier is turned on.

A typical set of scale-factor instructions, shown in the table on page 73, indicates that a display of, say, 5 μv becomes 50 μv when the attachment of a X10 probe causes one extra increment of coding current to be added to the column data line. This increment causes a "31" instruction (row 3, column 1 in the matrix) to be put into a small semiconductor memory until it can be used, after the first digit has been written. If the readout is 500 μv, the extra increment of current produced when the probe is attached would change a 32 instruction to a 33. Thus 500 μv (and the instruction ADD TWO ZEROES AFTER THE 5) becomes 5 mv (DROP THE ZEROES, CHANGE THE μ TO m). The multilevel pulses for a complete display are shown opposite.

These metamorphoses are much simpler to accomplish with the analog code than with a binary code. And an even more significant advantage of the analog code is the data-handling capacity it affords: given two data lines and a particular clock rate, more data can be transmitted in ten-level analog code than in two-level binary code. At any instant, there are a total of four possible states with the two-line binary code, but 100 possible states with the analog code—a 25-times improvement. And since there are eight such two-wire channels in the scope, a 200-to-1 improvement in data transfer is achieved without an increase in clock rate.

Avoids crosstalk

This is a significant advantage, because a relatively slow clock of about 4 kilohertz is necessary to avoid cross-talk in the plug-ins, many of which are simultaneously wideband and sensitive. For the same reason, the analog pulses have a trapezoidal form. Sharp pulses would cause unwanted spikes to creep into the waveform display on the oscilloscope.

The character-generator circuitry interrogates the plug-in in the following sequence:

- Number of zeroes to follow the first digit?
- Normal or inverted waveform display?
- Status of variable controls?
- First digit?
- Prefix (nano, micro, milli, etc.)?
- Units (volts, amperes, seconds, etc.)?

After the interrogation for each word is complete, the logic switches to the next channel. If a plug-in is missing or not used, the logic skips until the next data source is encountered; the waveform display isn't interrupted.

There is a special instruction for determining which scale display applies to which waveform on the crt. To actuate it, the operator depresses the "Identify" button on the plug-in or the probe. This changes the scale display to IDENTIFY and deflects the corresponding waveform upward a few millimeters. ■