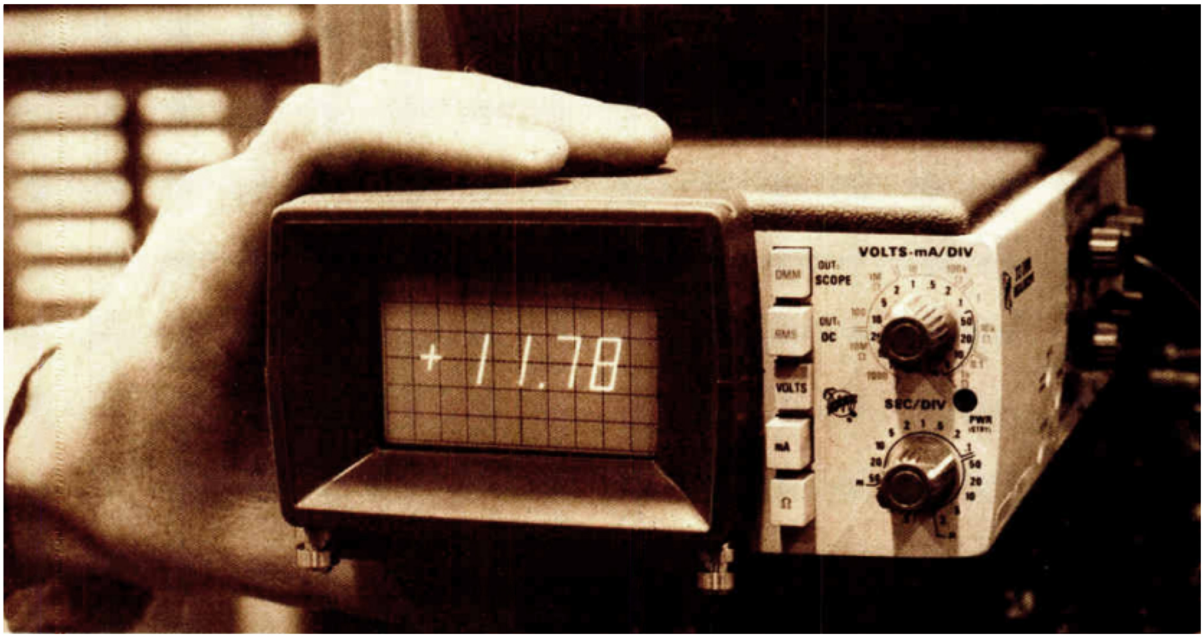
Product development profile

Tektronix' DMM/scope: a new record in portability

Aiming at the industrial and computer markets, designers of the series 200 miniature oscilloscopes packed ever more performance into the same small volume—then squeezed a digital multimeter in

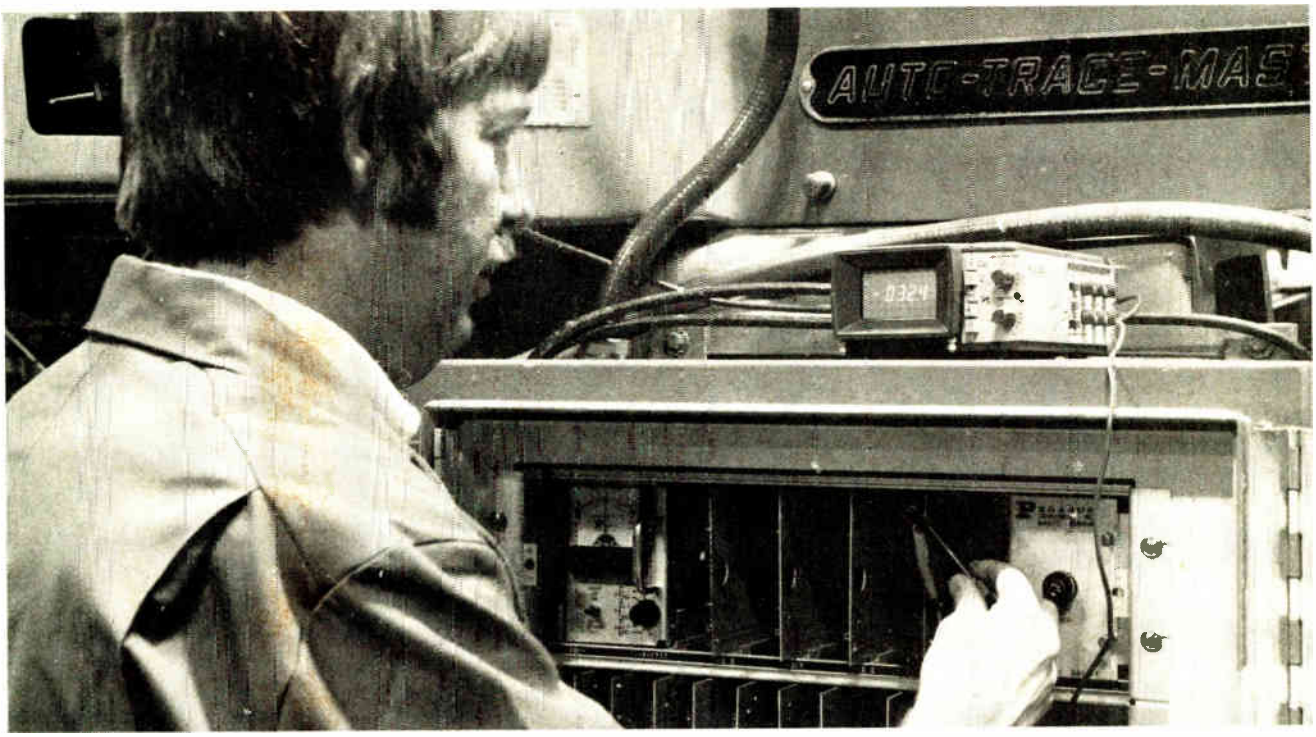
by Andy Santoni, *Instrumentation Editor*



□ A high-quality oscilloscope both portable enough for a field engineer to carry around all day long and small enough to fit in a raincoat pocket: that was Tektronix Inc.'s goal when the company began work on a line of miniature oscilloscopes. The fifth in the series—the model 213 combination digital multimeter and scope—was announced recently [*Electronics*, Feb. 6, p. 123], and, like its predecessors, it meets or betters expectations in both performance and portability.

Weighing less than four pounds, the DMM/scope is housed in a handy package that measures 3 by 5¼ by 9 inches—small enough to hold in one hand, but not quite small enough for the average raincoat pocket (Fig. 1). Still, to fit a 1-megahertz scope, plus a true-rms DMM, plus batteries, into less than 142 cubic inches is an undoubted achievement.

Along the way, Tektronix engineers had to develop small cathode-ray tubes sensitive enough for battery operation, compact multiposition switches, and power supplies flexible enough for battery or line operation. And though linear monolithic ICs today seem a natural choice for high-density circuitry, eight years ago, when



1. **Industrious.** A 3½-digit (2,000-count) multimeter and a 1-MHz-bandwidth oscilloscope are packed into Tektronix' model 213, the fifth 200 series miniscope. Battery operation makes miniscopes ideal for troubleshooting electronic equipment wherever ac-line power or reference to earth ground is unavailable or undesirable

this story begins, they were still a very new technology to apply in oscilloscopes.

It was in 1967 that Howard Vollum, chairman of the Beaverton, Ore., company, first put the idea of a pocket-sized scope to Hiro Moriyasu, then head of Tektronix' advanced circuit and techniques development group and currently manager of calculator engineering, Information Display division. But it was 1971 before the first "miniscope" appeared—the single channel model 211, which has a 500-kilohertz bandwidth. Three miniscopes were added to the line in 1973—the two-channel model 212, the two-channel storage model 214, and the single-channel, 5-MHz model 221—and the single-channel model 213 DMM/scope was added this year (Fig. 2).

The advanced circuit and techniques development group originally began designing a miniscope as a blue-sky effort. Among the engineers involved was David Allen, who was working at Tektronix in the summer of 1967 between semesters at Brigham Young University. When Allen returned to Tektronix after graduation the following year, Moriyasu, eager to get things moving and remembering Allen's experience, assigned him the design project.

Allen finished the last miniscope he'd started the summer before, then settled in to designing a marketable product. At a product planning meeting in June, 1969, a 1971 target introduction date was set, and the miniscope effort changed from a feasibility study to a product development project.

First, design goals were set. Preliminary electrical parameters to be met included a bandwidth of 50-kilohertz and sensitivity of 10 millivolts per division. Input parameter goals were 10-megohm impedance and less than 10-picofarad capacitance. To simplify the layout of the control signal path and the input attenuator switch, circuit design was to include a gain-controlled operational-amplifier input instead of the standard resistive attenuator driving a fixed-gain amplifier.

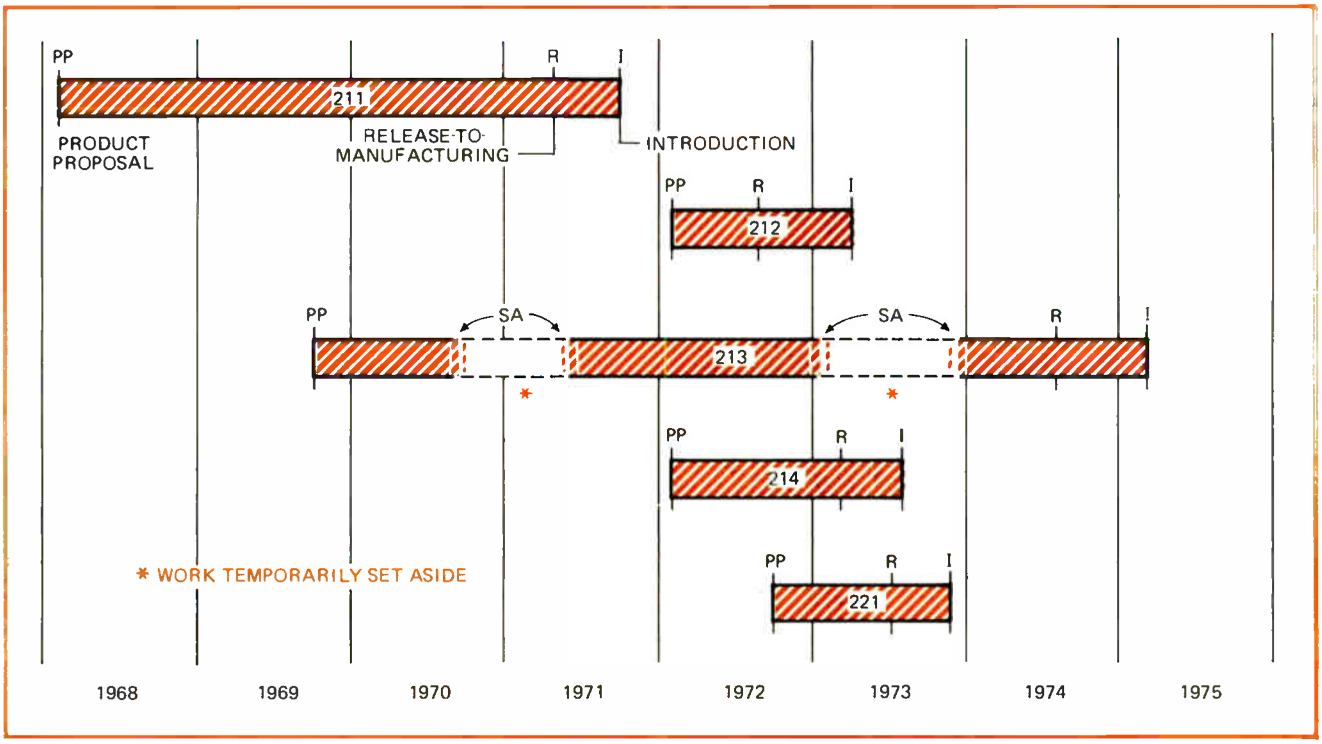
To be useful in the field, the scope had to be lightweight, small enough to be held in one hand, and easy to use and maintain. To withstand the rigors of portability, the case had to be rugged and the controls and cathode-ray tube be protected against moderate jolts and bumps. And to prevent the user from misplacing a line cord or probe at a test site, those parts had to be integrated into the package.

Since the scope was to be portable and battery-operated, it was to be double-insulated to enable it to make measurements independently of earth ground. Also, of course, it had to be priced low enough to be marketable.

CRT development

Packing all the components into a small case created problems, most obviously over the cathode-ray tube. There were no small low-cost CRTs available, says Allen that were sensitive enough and had a flat face and internal graticule at a reasonable price. Tektronix also wanted to make its own miniature CRT in order to control the cost and technology of such an important component.

Development began on a tube with an envelope made entirely of ceramic materials—except for the faceplate. This would have been much sturdier and less expensive than a standard all-glass CRT envelope. But Tektronix engineers became uncertain that a working ceramic-envelope CRT could be made in time and at a low enough cost, and discontinued the effort. "It was



2. Schedule. Although a DMM-scope combination was the second miniscope product to be proposed, it was the fifth to be introduced. Along the way, its development was delayed twice: first to concentrate on completing the model 211 and again when the effort of carrying out four design projects concurrently became too great.

too much of a gamble," says Allen.

Tektronix also tried developing a CRT that used hybrid deflection—magnetic for the horizontal and electrostatic for the vertical. This design would have allowed the two deflection mechanisms to be placed in the same plane, making the CRT an inch shorter, but it proved to be too expensive, consuming too much power and requiring too much circuitry.

The tube finally used, a unit designed by Tektronix staffer Connie Wilson, uses electrostatic deflection for both horizontal and vertical. It achieves a sensitivity of 17 volts per centimeter, compared with sensitivities of about 25 V/cm in CRTs then commercially available.

The line on ICs

Integrated circuits then commercially available didn't meet Tektronix' requirements, either. At the time, notes Allen, "there weren't many linear ICs that fitted well into an oscilloscope."

Tektronix' goal was to integrate the entire vertical amplifier in one IC and the entire sweep circuit in another IC. As part of the 200 series development program, work began on those two parts, along with a third IC for driving the horizontal and vertical deflection plates.

While Allen feared the ICs could not be readied quickly enough to meet the 211 development schedule, the first two parts—the sweep-trigger circuit and the CRT driver—were designed within 10 months. The third, however, took a little longer.

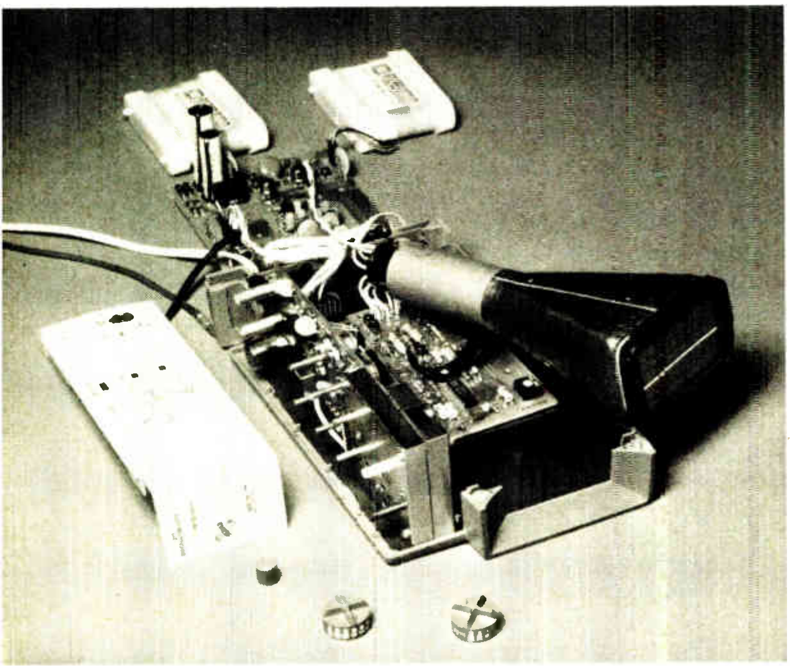
The first vertical amplifier circuit was designed specifically for the model 211. It contained two operational amplifiers that had positive inputs in common and tied to ground, permitting operation only in the inverting mode. Output dynamic range was about 1.5 V around zero, and open-loop gain was about 2,000.

"It was what we needed," says Allen, "but it wasn't universally useful." He therefore decided to switch to developing a more general-purpose design that would be more economical in the long term. This second device contained two isolated, FET-input op amps with open-loop gains of 100,000 and unity-gain bandwidths of 4-MHz—but its delayed start led to fears it would not be ready in time.

Fortunately, a group within Tektronix' Information Displays division was developing a quad op amp for a graphic terminal. This IC more than met the 211's requirements, and since it was close to completion, Allen chose to run with it instead of the other vertical amplifier circuits. To make this circuit operate in the model 211, the metallization pattern on the die had to be altered. Parts of two of the four op amps were used as constant-current sources for the FET inputs on the other two op amps. The rest of the circuitry was not needed. The result was a simple circuit that performed much like the earliest vertical amplifier design but could be used in a wider range of applications.

The sweep and trigger circuit IC was made by a proprietary Tektronix FET and bipolar manufacturing process. It suffered from unwanted interactions between the two sections, which were eliminated by distributing power and ground separately.

As with many linear IC designs, all three of the 211 circuits had oscillation problems. Two were modified internally to eliminate the problem, but the circuitry external to the CRT driver was modified instead. Next time, says Allen, he would prefer to make all ICs stable



3. Flexible. With the bottom cover removed, most components of the model 211 are accessible for testing or repair. The subassemblies of the models 211, 212, and 214 are cabled together so the instruments can operate when in a semi-assembled state. The 221 and 213 plug together without cables; extender boards are available should troubleshooting become necessary at any point.

without external circuitry—a goal much easier to attain nowadays, thanks to the advent of computer-aided design.

As for packaging the ICs, the original goal put small size above every other consideration, but it had to be modified twice to take ease of repair and handling into account also (Fig. 3). The earliest ICs were housed in flat packages that occupied less space than dual in-line plug-in types; but the fact that they had to be soldered to the printed-circuit board would have made IC replacement difficult, so plug-in packages were selected after all. The 16-pin round package that was next designed proved hard to handle because it was so small, and a rather larger 16-pin package was the final choice.

Integrated circuits were an obvious solution to shrink board space requirements. Not so obvious was how to implement sweep speed and attenuation switching when standard selector switches would be too large.

The model 211 would need two multiposition switches that would take as little space as possible and still be low in cost. The solution worked out by Scott Long of Tektronix' switch department was to etch the switch patterns onto the multilayer input circuit board and to clamp the wipers over the board. This simple design uses inexpensive injection-molded plastic housings and requires no discrete wiring to the contacts.

The requirements for small size and battery operation also meant that standard power-supply designs would not be adequate. In the supply designed for the model 211 by Wendell Damm, an electrical designer on the 200 series team, the ac line current was limited by a series capacitor and rectified; then it was used to charge the 10 internal rechargeable AA nickel-cadmium cells, which also acted as large filter capacitors. The dc voltage was fed to a dc-ac converter multivibrator which was connected to a newly developed small, efficient coaxial bobbin power transformer. This transformer, which supplied the necessary operating voltages to the oscilloscope, had an insulation voltage of 4,000 V dc which, along with its efficiency, would make it ideal for double-insulated applications.

The finishing touches

From the user's point of view, perhaps the most intriguing part of the model 211's design is its packaging. The job of putting all of the pieces together in the smallest possible box, while maintaining operational simplicity, went to industrial designer Al Hill.

At first, attempts were made to put the controls on the front of the oscilloscope. But, notes board chairman Vollum, "When you hand-hold it, you can put controls in various places." It was decided, then, that the instrument would be right-handed: held in the left hand and with controls mounted on the right side.

The probe and line cord were spooled around the back of the scope to make them easier to carry along, and while both are permanently attached to prevent misplacing them, the probe plugs in internally so that it doesn't have to be unsoldered should replacement ever be necessary. Unfortunately, the hoped-for automatic cord-reel design did not work out because it would have been too bulky and expensive, says Allen.

The first designs for the miniscope case proposed using Tektronix' standard vinyl-clad aluminum. Hill felt, however, that plastic housing could offer the same strength with less weight and smaller size. After convincing Tektronix management that plastic was a viable case material, Hill designed a three-piece, glass-filled ABS housing that measured 3 inches high, 5 inches wide, and 9 inches deep.

The plastic moldings were fairly large and complex for Tektronix, and the die-maker had to make some slight changes in the design to improve manufacturability. Since production began, only details have been changed, and cases presently being manufactured can be retrofitted onto older instruments.

Since the case was not metallic, electromagnetic interference was a possible problem. To prevent it, aluminum, carbon, and silver paints were applied to the inside of the case. Finally, more economical aluminum tape was chosen.

As the pieces came together, most of the design goals were realized. In fact, both bandwidth and sensitivity were better than expected—500 kHz rather than 50 kHz, and 1 millivolt per division instead of 10 mV/div. Size and cost were within range. About the only real disappointments were in the input circuits: input impedance was only 1 megohm and capacitance was over 100 picofarads, and the gain-controlled op-amp input circuit was abandoned in favor of a standard resistive attenuator.

Standard resistive attenuators use fairly complex switches and variable-capacitor networks, which between them compensate the input circuitry for stray capacitances and inductances and maintain frequency response over the oscilloscope's bandwidth. Trimming a half-dozen compensation capacitors, though, can be a tricky job.

A gain-controlled op-amp circuit could eliminate much of this complicated circuitry by varying the gain of the input amplifier rather than the level of the input signal. Tektronix attempted to design an input circuit that used variable feedback on an op amp to control the circuit's gain. Since the input to a negative-feedback op-amp circuit is a virtual ground, the effects of stray parasitics would be eliminated. But Allen found that at high frequencies, where the op amp's response began to fall off, the circuit did not have enough open-loop gain to require enough feedback to provide this virtual ground, and the circuit became too noisy for use in an oscilloscope.

After the gain-controlled op-amp circuit was discarded, a more standard switched attenuator with an input impedance of 10 megohms was attempted. This circuit could not be relied upon to meet its specifications because the small spacings between circuit-board paths did not have a consistently high enough impedance, especially under humid conditions. Finally, a switched attenuator with an input impedance of 1 megohm, where variations in pc-board impedances would have less effect, was incorporated.

In September, 1969, while development work on the model 211 was just getting up speed, Bill Walker, Tektronix' group vice president in charge of engineering, suggested to Moriyasu that the miniscope should incorporate a digital multimeter, to make it an even more versatile tool (Fig. 4). Work on a DMM/scope began immediately, but was deferred or delayed twice: first it was temporarily set aside to allow completion of the model 211 design, which was released to manufacturing in 1971; then it was continued parallel with the development of models 212 and 214, but had to be halted a second time shortly after the point when model 221 development also began.

The second and third models

Design work on both the 212 and 214 began early in 1972. Model 212, a two-trace version of the model 211, turned out to be a fairly straightforward design. It resembles the 211 except for the input amplifier board, which now had to contain two channels, and the rear-panel probe carrier, which had to have space for two probes.

The only real problem encountered during the model 212 development project was getting all of the necessary input and control circuitry on one printed-circuit board—and doing it in such a way that the two vertical deflection controls and the horizontal deflection control would be visible to the scope's user. In the end, the two vertical deflection controls were mounted in the same locations as the horizontal and vertical controls in the model 211, and the 212's horizontal deflection control was located near the back of the instrument's side panel. This led to crosstalk problems between the vertical and trigger circuits as signal paths ran the length of the board, but these were eliminated by careful shielding and layout—accounting for printed-circuit runs that aren't connected on one end.

The extra circuitry was fit onto the board first by making the board longer. On the 211, there was about an inch of space between the end of the board and the back of the cabinet which meant about two square inches of pc board space could be squeezed into the 212. Components were mounted on the board standing up rather than lying flat, and they were mounted on both sides of the board. In addition, the four op-amps of the vertical amplifier were now all used, two for each channel, and the amplifiers were redesigned to eliminate the need for current sources.

Model 214, the storage scope, took advantage of these changes. Also, a new, low-current storage CRT, capable of operation from a battery, was developed. Careful design of the cathode cut power consumption from the ½ to 2 W of standard storage CRTs to about 250 mW in the 214 storage CRT. Small push buttons, with extenders to reach the front panel, actuate the storage feature. The instrument was introduced in August, 1973.

While the model 211's bandwidth was 500 kHz, 10 times the 50-kHz design goal, some customers needed response to 5 MHz. The model 221, as the 5-MHz scope was named, required a higher-capacity power supply and more sensitive CRT to operate at higher frequencies. The new CRT achieves a sensitivity of 13 volts per centimeter while using many of the same mechanical parts as earlier units. The power supply, though, was a completely new design, in which the power-line voltage is rectified and used as the power source for an isolated power inverter. The output of the power inverter is used to charge the battery and supply the instrument's internal power supply. This contrasts with earlier designs, which had the battery charger and batteries floating on the power line. The design also permits operation from dc power sources.

New input amplifier circuits also had to be designed

4. Prime movers. Tektronix board chairman Howard Vollum (seated left) suggested that the advanced circuit and techniques development group, then headed by Hiro Moriyasu (standing right), work on a small, battery-operated oscilloscope, which led to the 200 series. Bill Walker, (left), group vice president in charge of engineering, first conceived of a DMM/scope combination, and David Allen headed development of the five 200 series instruments.

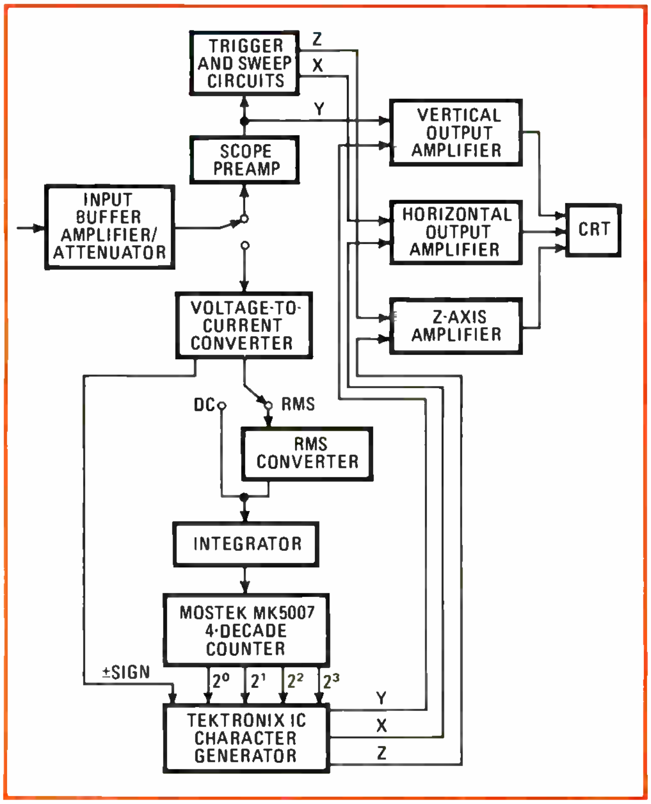
to operate at the higher speed, and Tektronix decided to go with discrete components because new large-scale ICs would not have been developed quickly enough, explains Allen.

The DMM/scope

With the 221's introduction in October, 1973, the 200 series design team could again pick up on the DMM/scope. To the user, model 213 is a DMM added to a 211 with double the bandwidth. Internally, however, the 213 is much different from the 211 (Fig. 5).

Because the instrument has current and resistance measuring capabilities, the input circuitry has to perform conversion functions not necessary in an oscilloscope, which only displays voltage waveforms. To handle the input range switching for all three functions, Tektronix abandoned the wafer-type switch of earlier 200-series instruments in favor of a cam switch controlled by a front-panel knob and actuating contacts on the input board. More switch functions can be performed by this design because an increase in the number of switched circuits increases only the length of the cam and board space required, rather than increasing the radius of the board space taken up by the switch.

This flexibility also permits wider pc-board line spacings, so the resistance between runs does not drop so drastically as humidity increases. This was a major factor in improving the 213's input impedance from 1 megohm to 10 megohms, as previously attempted but abandoned for the 211. In the 213, higher input impedance was a must: customers would expect the 213 to have as high an input impedance as other DMMs.



5. Paths. In the model 213, an input signal is amplified, then switched to either scope or DMM circuitry. Either the voltage or current waveform, or the numerical value of a voltage, current, or resistance input, can be displayed on a six-by-10-division CRT.

Product development profiles

Unusually successful products and product lines do not succeed without the perception of a real need, without a well-thought-out and sustained design effort, and without a record of problems either solved or circumvented. Because that kind of development history has ideas to offer other engineers, *Electronics* here offers the latest in its continuing series of "Product development profiles."

The story of Tektronix' 200 series of miniature oscilloscopes begins with the imaginative conception of a "pocketable" scope and ends with a whole range of precise, portable instrumentation that fits an increasingly electronic society's growing need for on-the-spot troubleshooting.

Other articles in the series have covered the HP-35 scientific calculator [*Electronics*, Feb. 1, 1973, p. 102]; the Intel 1103 MOS random-access memory [April 26, 1973, p. 108]; the HP 5345A counter [Feb. 7, 1974, p. 114]; and the Cambridge Research and Development Group's variable speech control system [Aug. 22, 1974, p. 89].

Following the input attenuator, the signal is amplified by an input buffer amplifier, then switched to either the oscilloscope preamplifier or to the DMM circuitry. In the scope mode, it is fed to the trigger/sweep circuits, which drive the horizontal output amplifier, and to the vertical output amplifier. In the DMM mode, the signal is routed to an integrating converter and a Mostek MK 5007 4-decade counter to determine its value in BCD form. A Tektronix-made BCD-to-seven-segment decoder/character generator, the only new Tektronix IC in the 213, provides X-, Y-, and Z-axis outputs to the horizontal, vertical, and blanking amplifiers. Since both DMM and scope inputs are required in the output amplifiers, and earlier 200-series output amplifiers did not have two inputs, new circuits had to be designed. Because of the simplicity of the circuits, discrete components were used for most of the amplifier functions.

The one IC in the output stages is a differential amplifier with potentiometer-controlled gain. This permits dc control of the variable horizontal magnifier rather than routing the signal itself through a potentiometer.

The 213's voltage-deflection factors range in 14 steps from 200 mV/div to 100 V/div over its full-rated bandwidth, and down to 5 mV/div at a 400-kHz bandwidth. As a spin off from its DMM mode, the instrument can also display current waveforms: the 14 deflection factors here go from 5 microamperes to 100 mA/div on bandwidths of dc to 200 kHz on the 5-μA/div and 10-μA/div scales, dc to 400 kHz for the other scales. Horizontal deflection factors are 2 microseconds to 500 milliseconds per division in 17 steps, and sweep rate can be increased up to five times by a variable sweep magnifier.

As for the 213's DMM mode, the full-scale voltage, current and resistance ranges run from 0.1 to 1,000 V rms or dc, 0.1 mA to 1 A rms or dc, and 1 kilohm to 10 megohms. □