Practical Oscilloscopes at Workaday Prices

15-MHz bandwidth, 2mV sensitivity, 3% accuracy, sweeps usable to 20ns/div and an 8 × 10 cm CRT with internal graticule would normally class these oscilloscopes as laboratory instruments but they will find wide use in the service shop, technical school, and industry.

by Hans-Günter Hohmann

ADVANCES IN INSTRUMENTATION nowadays do not always involve the bettering of previous performance specifications but rather the bettering of performance/price ratios. Several new instruments recently described here—a counter[1], a digital voltmeter[2], and a function generator[3]—are of interest because their design made high-quality performance attainable for the technical school, service shop, and other low-budget operations, as well as for the well-equipped electronics laboratory.

Now joining the family of instruments available for restricted budgets are two new oscilloscopes. With a frequency range of dc to 15 MHz, these belong among the basic tools for everyday work in the lab, service shop and production area. Advances in technology made it possible to design these instruments with a better performance/price ratio than would have been possible 5 or 6 years ago.

One of the new oscilloscopes, Model 1220A (Fig. 1), is a dual-channel instrument and the other, Model 1221A (Fig. 2), is a lower-cost, single channel version. These instruments have the performance needed for meeting a wide variety of applications (15 MHz bandwidth, 2 mV sensitivity, 3% accuracy, and calibrated sweep times from 0.5 s/div to 100 ns/div—even faster with the magnifier) and they have the most useful oscilloscope features (×10 sweep magnifier, beam finder, X-Y display capability, internal CRT graticule, TV sync separator). Above all, they have traditional HP reliability, and they have an affordable price.

Easy Operation

Despite the minimal cost, the new oscilloscopes have a number of operating conveniences that make them easy instruments to use. Considerable thought was devoted to achieving an uncluttered front-panel layout with controls placed so operation is easily understood. Automatic triggering assures that a baseline is present even in the absence of a signal or if the trigger level control is set beyond the range of the signal. Although the dual-channel Model 1220A oscilloscope operates in either a chopped or an alternate sweep mode when displaying two signals, the operator need not concern himself with making the choice. The choice is made by the TIME/DIV switch, which selects the alternate-sweep mode (display channel A on one sweep then channel B on the next) when the sweep rate is fast enough to avoid flicker. On the slower sweeps, 1 ms/cm or longer, the switch selects the chopped mode (the CRT spot switches back and forth from one waveform to the other at a 200-kHz rate to trace both waveforms on the same

Cover: *As new developments bring instrument costs down, TV service shops join the many other budget-restricted establishments that can now avail themselves of quality instruments, like the Model 1220A Oscilloscope described here. Our thanks to Alco Home Electronics Service Center, Santa Clara, California, and to technician Jim Hagan for providing the setting for this photo.*

In this Issue:

Fig. 1. *New Model 1220A dual-channel Oscilloscope has performance and quality usually found only in laboratory instruments, yet it carries a down-to-earth price. Suitable for the general run of audio, video, logic, and control measurements, it can also make low-level measurements.*

sweep). Similarly, when triggering from a TV signal, the sweep triggers on either the horizontal or the vertical sync pulses according to the setting of the TIME/DIV switch.

But even with their operating simplicity, the instruments have the flexibility needed for a wide range of applications. The operator can select the source of sweep triggers (internal, external, ac line, TV) and he can select the point on the waveform where he would want triggering to occur (slope, level). External signals can also be applied to the horizontal deflection amplifiers for making X-Y plots or the Lissajous figures commonly used for phase-shift measurements. There is also a rear-panel Z-axis input for modulating the CRT beam intensity.

These instruments also have reduced bulk and weight, weighing about 16 lbs (8 kg) each.

Fig. 2. *Lower-priced Model 1221A Oscilloscope is identical to Model 1220A except that it has only one vertical channel.*

Reducing Costs

Obtaining reliability and versatility at low cost required some departures from traditional practice. A major expense in producing a complicated instrument like an oscilloscope is in assembly and test. The design of the new oscilloscopes eliminates several production steps both in fabricating parts and testing the circuits. For example, the cabinet is made of a molded, thermosetting resin (Fig. 3) that has a mechanical stability comparable to that of aluminum and that is widely used as a replacement for metal in automobiles and household appliances. It allows these oscilloscopes to be used in production areas, around process control equipment, and in other areas where ruggedness is needed. Because the cabinet can be molded in one operation with all mounting posts, bar stiffeners, access holes and the like in place, several manufacturing steps are eliminated. The cabinet is metallized on the inside surfaces where RF shielding is desired.

The internal chassis parts were designed in modular form for quick assembly by plugging together. This has the further advantage that the modules can

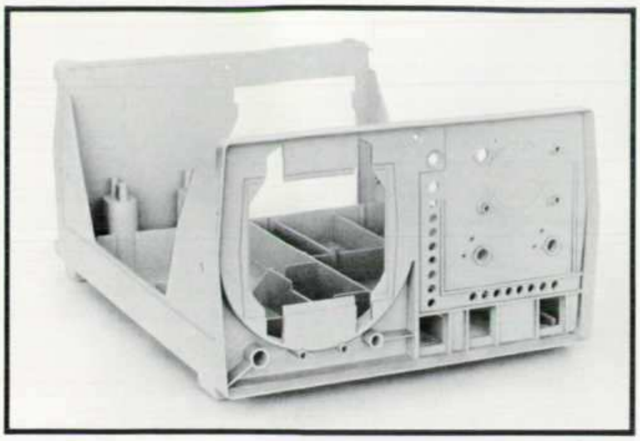

Fig. 3. *The major structural component is molded with a thermosetting resin, greatly reducing the number of operations needed to manufacture the instrument.*

be completely pre-tested by an automatic test system before final assembly. Most interconnections are made on printed-circuit boards with intermodule connections made by plug-in flat cables, significantly reducing wiring and assembly time.

In some cases, costs were reduced by using premium components rather than the least expensive. For example, precision resistors and capacitors are used in the sweep timing circuits. It was therefore not necessary to include the trimmers that otherwise would be needed had lower cost components with looser tolerances been used. Hence, no time is taken at the test station for adjusting those variable components that are no longer included.

Part of the cost reduction is simply a matter of advancing technology. High-performance solid-state components are now obtainable at lower prices and the wide variety of available off-the-shelf integrated circuits make it possible to be almost extravagant in the use of functions. For instance, selection of most input sensitivity ranges is performed by switching the gain of the amplifiers. The input attenuator therefore needs only two positions and a straight-through position, reducing the number of adjustable frequency-compensating capacitors needed.

The Overview

A simplified block diagram of the new Model 1220A dual-channel oscilloscope is shown in Fig. 4. As can be seen, the general scheme of things is not much different from other dual-channel oscilloscopes. The Model 1221A single-channel version is similar except that it omits channel B and the circuits needed to multiplex two input channels into the single vertical CRT drive channel.

Solid-state circuits are used throughout. Power consumption is low, less than 40W, reducing internal heat rise with a consequent enhancement of reliability. No vent holes are needed, lessening the problems associated with operating in adverse environments.

The CRT

Although the design of any oscilloscope begins with the cathode-ray tube, the CRT design has to take into account the circuits that may be used. The Hewlett-Packard Model 1310A large-screen Graphic Display had shown that substantial drive voltages at high frequencies can be obtained at moderate cost from solid-state circuits.[4] This meant that the expansion-mesh electrode—which had originally made high performance economically possible in all solid-state oscilloscope[5]—would not be needed for the new

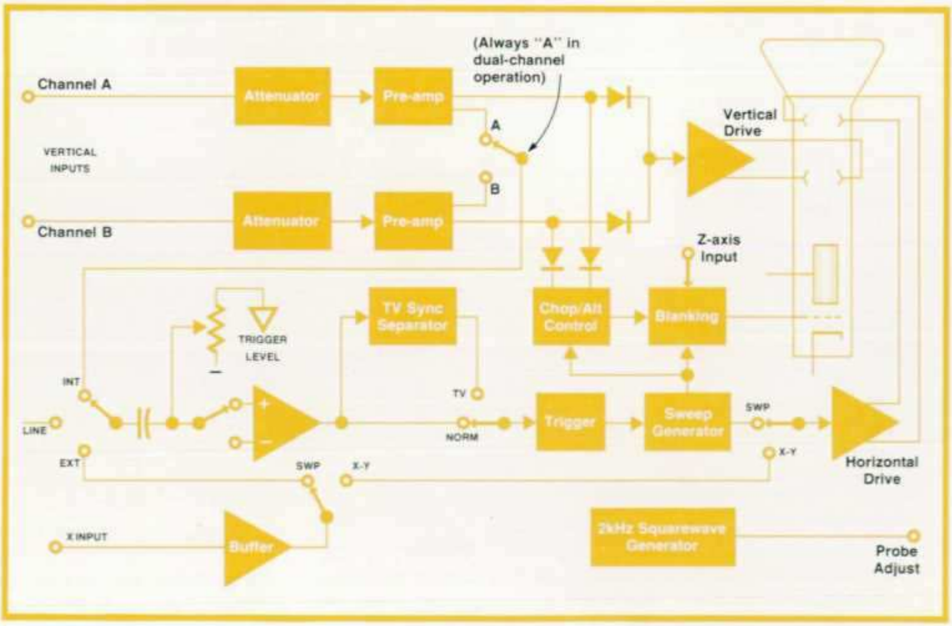

Fig. 4. *Simplified block diagram of the Model 1220A Oscilloscope. The Model 1221A is similar except that it omits channel B and the chop/alt control.*

Fig. 5. *The cathode-ray tube for the new oscilloscopes uses an uncomplicated structure that reduces the number of manufacturing steps.*

scopes. Furthermore, the drive voltage available meant that beam acceleration could be obtained entirely in the electron gun, and a post-accelerating field would not be needed. All this added up to a relatively simple structure that eliminated several processing steps.

One processing step that was not eliminated was insertion of the internal graticule. The black graticule lines are deposited on the inner surface of the faceplate and fused onto the faceplate before the phosphor (P31) is deposited, placing the graticule in the same plane as the phosphor. This eliminates the parallax errors that otherwise occur when the graticule is external to the CRT (Fig. 6). The improvement in reading accuracy is considered to be well worth the extra expense. Vertical deflection accuracy is within 3%, about as close as the eye can discern. This accuracy enables the oscilloscopes to be used as voltmeters as well as waveform tracers.

Gain Switching

A skeleton diagram of the input attenuator and first preamplifier stage is shown in Fig. 7. Input impedance on all ranges is 1 MΩ in parallel with 30 pF. The input signal goes to a high-impedance FET stage that is part of a differential amplifier. The other input to the amplifier is a dc balance voltage. The two input FET's are mounted on the same substrate and thus have good thermal stability so once the balance voltage is set, it seldom needs readjustment. This made practical the instruments' high sensitivity (2mV/cm deflection factor).

The gain of the differential amplifier is changed by switching current sources Q5 and Q6. On the three most sensitive ranges, Q6 is turned on and Q5 off so emitter resistors R1 and R2 in parallel with R3 and R4 determine the gain of the amplifier. On all other ranges, Q5 is on and Q6 off so the smaller resistors are effectively cut out of the circuit by the decoupling diodes, reducing the amplifier gain by a factor of 10. As gain switching is performed by control voltages, the electrical and mechanical design could be simplified.

The output of the first stage passes through a second differential stage (not shown) that has adjustable feedback to calibrate the gain of the vertical amplifier. From there, the signal goes to another stage that uses three sets of switched emitter resistors to give gains proportional to ×1, ×2, and ×5.

The signal then passes through a dc shifter to give vertical positioning control and a diode gate that multiplexes the two channels into a single channel (Fig. 4). The single channel goes to the CRT driver.

Economical Drive

One leg of the CRT driver stage is shown in Fig. 8. By dividing the 95V supply voltage across four transistors, lower-cost, low-voltage, high-frequency transistors may be used to obtain the 60V swing needed for each CRT deflection electrode.

The lower two transistors (Q10, Q11) are connected as a cascode amplifier for better high frequency response. The upper two (Q12, Q13), also in cascode, serve as a constant-current load for Q10 and

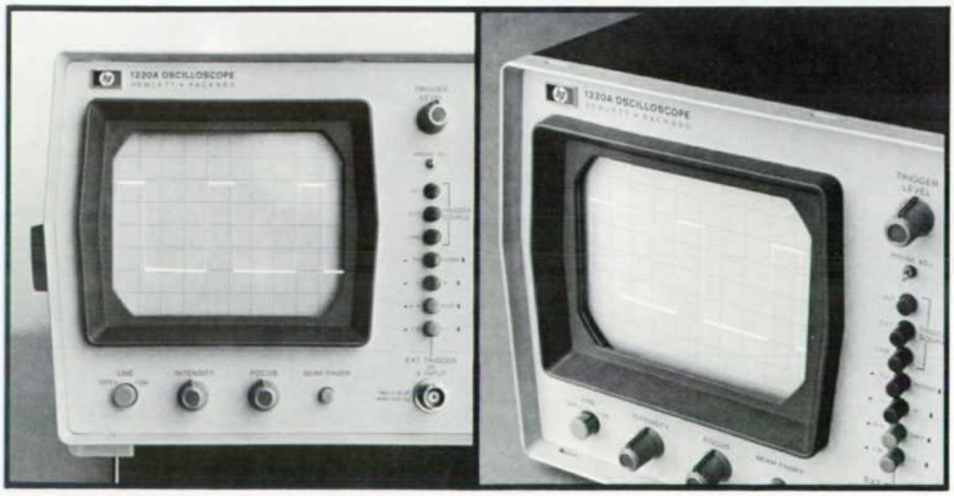

Fig. 6. *Placing the CRT graticule in the same plane as the phosphor assures high measurement accuracy from any viewing angle by eliminating parallax.*

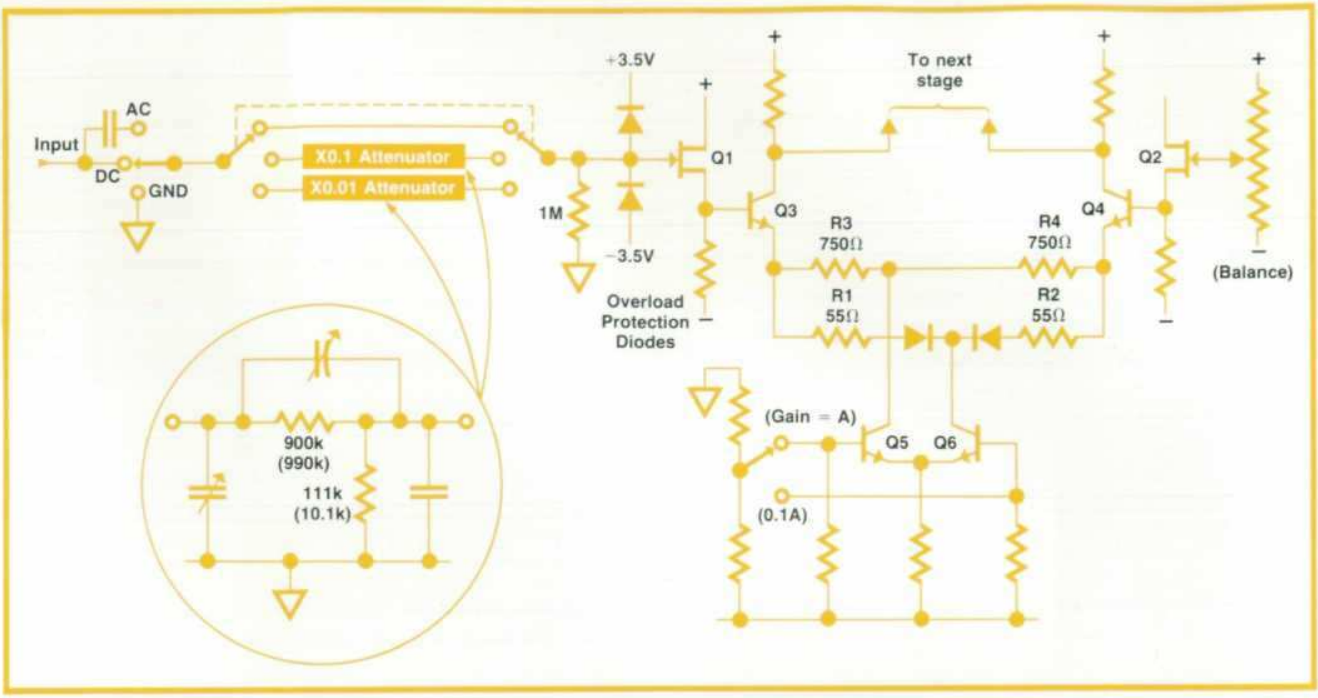

Fig. 7. *Vertical input needs only two frequency-compensated attenuator sections. The other ranges are obtained by using dc voltages to switch the gain of the amplifiers.*

Q11. A constant-current source supplies more current for charging the distributed load capacitance than a passive load would (at the same power dissipation), thus speeding up the transient response.[4] However, the steady-state current flow normally establishes the maximum charge rate. To permit the steady-state current to be small, and hence keep power dissipation low, the current source in this circuit is modulated by the signal through capacitor C11. High-speed transients passing through C11 to Q13 increase available current during fast transients to speed up the response of the amplifier. This configuration thus gives fast transient response with low steady-state current.

The circuit shown in Fig. 8 supplies the drive voltage for one CRT vertical deflection electrode and an identical amplifier drives the other electrode in the opposite phase. The horizontal drive amplifiers use a similar configuration but with higher-voltage transistors operating from a +210V supply. This obtains the higher drive voltage needed for the horizontal deflection plates.

Logical Triggering

Triggering is often a problem with oscilloscopes, most of the problems arising because a new trigger may occur before the sweep circuits have fully recovered from the previous sweep. This results in an erratic display.

Basically, the new oscilloscopes' trigger and

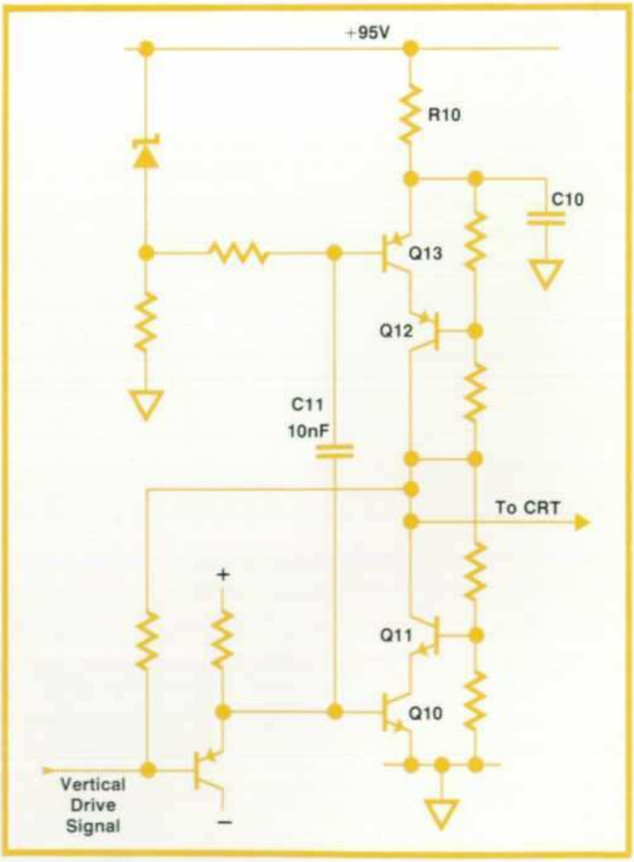

Fig. 8. *Output stage uses a cascode driver (Q10, Q11) with a constant-current load (Q12, Q13). R10 establishes the steady-state current.*

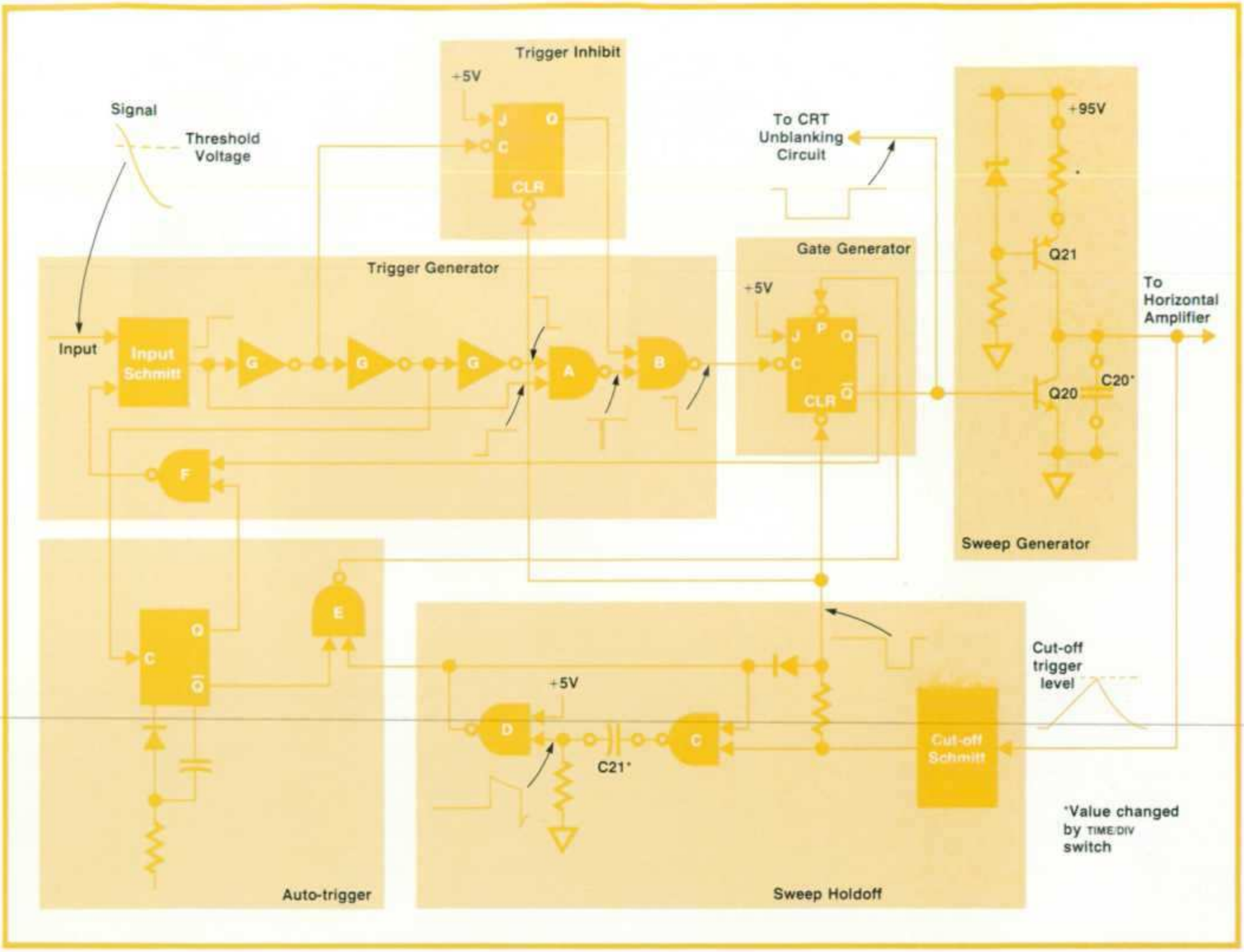

Fig. 9. *Trigger and sweep generating circuit uses two holdoffs to prevent erratic sweeps (see text).*

sweep circuits follow established laboratory oscilloscope practice. The trigger signal is applied to a differential amplifier and the polarity switch selects one of the inputs according to the trigger slope desired (Fig. 4). The negative-going slope of the output switches a Schmitt trigger as it crosses the threshold-voltage level (Fig. 9). The resulting positive-going step at the output of the Schmitt circuit triggers the gate generator, a flip-flop. It in turn switches off the ramp capacitor discharge switch (Q20 in Fig. 9) and unblanks the CRT. Ramp capacitor C20 now charges through constant-current source Q21, generating the sweep voltage. Once triggered, the Q output of the gate generator holds off the Schmitt trigger by way of gate-inverter F.

When the sweep ramp reaches 10V, it triggers the cutoff Schmitt trigger circuit which in turn resets the gate generator flip-flop. To prevent retriggering while the ramp capacitor is discharging, the negative-going reset trigger is processed through NAND gates C and D, which act as a sweep hold-off circuit. The output of gate D, which serves merely as an inverter, is fed back to gate C, clamping the output of gate D low until sweep holdoff capacitor C21 discharges sufficiently to allow the gate D output to rise again. By holding the CLR input to the gate generator low while sweep holdoff capacitor C21 discharges, gate D prevents a new sweep from being initiated during the holdoff period.

This raises a new problem—an erratic sweep could occur if a trigger arrives at the gate generator at the same time that the holdoff circuit is removing the CLR signal. An erratic sweep would result because the switching time of the gate generator would be different in this case. Therefore, a trigger inhibit flip-flop and a signal delay have been added.

Normally, the low-to-high transition at the output of the input Schmitt trigger initially causes a high-to-low transition at the output of gate A, but the Schmitt transition is also delayed and inverted in inverters G so it causes the gate A output to go high again a few nanoseconds later. This delayed transition passes through gate B and triggers the gate generator, starting the sweep. Gate B was enabled by the trigger inhibit circuit which had been clocked by the Schmitt trigger a few nanoseconds earlier.

During the holdoff period, the triggering transition cannot pass gate B so long as the trigger inhibit flip-flop's Q output is held low by the holdoff signal at the CLR input. However, if a trigger arrives at the trigger inhibit flip-flop at the same time that the holdoff signal is being removed, the switching time of the Q output would be affected, but this causes no problem because the transition will be complete by the time the trigger arrives at gate B because of the delays in the inverters G. Thus it is not possible for a trigger to arrive at the gate generator at the same time the holdoff signal is being removed. The result is solidly stable triggering.

The total delay from trigger Schmitt transition to CRT unblanking and sweep start is about $0.1\mu s$.

Always a Baseline

In the absence of triggers, the sweep circuit becomes self-triggering so the CRT trace is never lost—there is always a baseline. The trailing edge of the holdoff pulse starts a new sweep whenever the autotrigger circuit enables gate E.

The autotrigger circuit is a monostable multivibrator. With no input triggers, the Q output of this circuit is high, allowing the output of gate E to go low on occurrence of the trailing edge of the sweep reset pulse. The negative-going step out of gate E is applied to the "preset" input of the gate generator, starting a sweep. As long as gate E is enabled, sweeps will occur automatically.

An input trigger sets the autotrigger monostable multivibrator, blocking gate E. The monostable resets itself 0.5 s after the last input trigger so in the absence of any input triggers, a baseline appears on the CRT. Whenever there are triggers, the monostable remains in the set state and gate E is closed, preventing self-triggering of the sweeps.

Few Parts

The two Schmitt triggers are on one integrated circuit and the two flip-flops on another. Four of the gates are on one IC and two more are on another (two other gates in this IC are used elsewhere in the instrument). All three amplifiers in the delay chain are on one IC (three other amplifiers in the same IC are used elsewhere). In other words, most of the trigger circuitry is implemented with six integrated circuits, and these are low-cost, standard TTL logic circuits, another example of how improved performance can now be obtained at lower cost.

TV Sync

Because it is expected that these oscilloscopes will find wide use in service shops, a TV sync separator is included (Fig. 4). This works along conventional lines in that it clamps to the peak value of a composite TV waveform and clips off 60% of the waveform, leaving the TV sync pulses. These are cleaned up by applying them to a Schmitt trigger before sending them on to the sweep trigger circuit, or they are passed through a low-pass filter to obtain the vertical sync pulse, then shaped by a Schmitt trigger. The vertical pulses are passed to a ÷2 circuit, however, so that the resulting triggers occur on every second field, and hence at the same point in each frame for a clean display.

Economical Regulated High-Voltage

To assure a constant deflection factor and hence deflection accuracy, the new oscilloscopes have a regulator on the high-voltage supply for the accelerating electrodes. Recent practice has been to derive the accelerating voltages by using an ultrasonic oscillator to drive a step-up transformer that supplies the high-voltage rectifier, making it possible to apply level control signals at low voltage levels to the oscillator.

The Models 1220A and 1221A have a high-voltage regulating system that does not require a separate os-

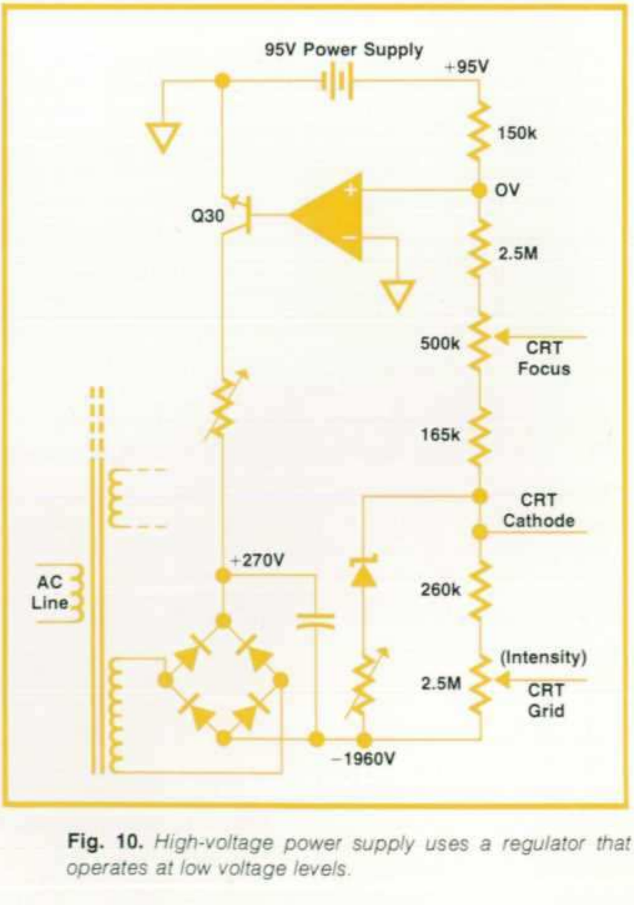

Fig. 10. *High-voltage power supply uses a regulator that operates at low voltage levels.*

cillator to enable control with low voltages. As shown in the diagram of Fig. 10, the high voltage is obtained from a separate winding on the power transformer. The ground return, however, passes through a series-pass transistor Q30. The regulator amplifier causes the voltage drop across Q30 to change in the right amount to compensate for voltage changes in the high-voltage supply, as sensed at a tap on the resistive divider, using the regulated 95V supply as a reference.

All the other voltages in the oscilloscope are regulated too, a feature that costs relatively little to implement nowadays because of the availability of low-cost integrated-circuit regulators.

Acknowledgments

The Models 1220A and 1221A Oscilloscopes resulted from the efforts of many people. Project leader was Ulrich Hubner, who also designed the high-voltage power supply and blanking circuits. Stefan Traub developed the vertical amplifiers while Frank Rochlitzer and Horst Schweikardt designed the sweep and trigger circuits. Mechanical design was by Rudiger Plessner and Bruno Holzer with the assistance of Siegfried Dippon of the process engineering group.

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SPECIFICATIONS
Models 1220A and 1221A Oscilloscopes

Modes of Operation (1220A)

CHANNEL A; CHANNEL B: channels A and B displayed alternately on successive sweeps (Alt), triggering by A channel; channels A and B displayed by switching between channels at approx 200 kHz rate with blanking during switching (Chop); automatic selection of alternate or chop mode. Chop, at sweep speeds from 0.5 s/cm to 1 ms/cm; Alt, 0.5 ms/cm to 0.1 μs/cm.

Vertical Amplifiers

BANDWIDTH: (3 dB down from 50 kHz, 6 div reference signal from a terminated 50-ohm source)
DC-COUPLED: dc to 15 MHz.
AC-COUPLED: lower limit is approx 2 Hz.
RISETIME: approx 23 ns.

DEFLECTION FACTOR
RANGES: from 2 mV/cm to 10 V/cm in 1,2, 5 sequence ±3% accuracy with vernier in calibrated position on 10mV/cm to 10V/cm ranges, ±5% on 2 and 5 mV/cm ranges.
VERNIER: continuously variable between ranges, extends maximum deflection factor to 25 V/cm.

INPUT RC: approx 1 MΩ shunted by approx 30 pF.

INPUT COUPLING: ac, dc, or gnd selectable. Gnd position disconnects signal input and grounds amplifier input.

Time Base

SWEEP
RANGES: from 0.1 μs/cm to 0.5 s/cm in 1, 2, 5 sequence, ±4% accuracy with Expander in calibrated position.
EXPANDER: continuously expands sweep to more than 10 times. Maximum usable sweep speed is approx 20 ns/cm.

SWEEP MODE: sweep is triggered by internal or external signal. Bright baseline displayed in absence of input signal.

TRIGGERING
INTERNAL: approx 2 Hz to 15 MHz on signals causing 1 cm or more vertical deflection.
EXTERNAL: approx 2 Hz to 15 MHz on signals 0.1 V p-p or more.
EXTERNAL INPUT RC: approx 1 megohm shunted by approx 30 pF.
LINE: triggers on line frequency.
TV SYNC: separator for + or − video, requires 1 cm of video signal to trigger, automatic frame (0.5 s/cm to 100 μs/cm) and line select (50 μs/cm to 0.1 μs/cm). Usable also as a low-pass filter.

LEVEL AND SLOPE
INTERNAL: at any point on positive or negative slope of displayed waveform.
EXTERNAL: continuously variable from +0.5V to −0.5V on either slope of trigger waveform. ÷10 extends trigger range to +5V to −5V.

External Horizontal Input

BANDWIDTH: dc to 1 MHz.
COUPLING: dc.

Expander	Input Attenuator	Deflection Factor
Cal	1:1	1V/cm
Cal	1:10	10V/cm
cw	1:1	100mV/cm

Continuous adjustment between ranges by Expander.

INPUT RC: approx 1 megohm shunted by approx 30 pF.
X-Y PHASE SHIFT: <3° at 100 kHz.

Cathode-Ray Tube and Controls

TYPE: mono-accelerator, approx 2 kV accelerating potential, P31 phosphor. Blue light filter furnished. P7 phosphor and amber filter in lieu of P31 available.

GRATICULE: 8 × 10 cm internal graticule; 0.2 cm subdivisions on major horizontal and vertical axes.

BEAM FINDER: returns trace to CRT screen regardless of setting of horizontal and vertical controls.

PROBE ADJUST: approx 3 V peak, 2 kHz square wave for adjusting probe compensation.

INTENSITY MODULATION: +5 V (TTL compatible) dc to 1 MHz blanks trace of any intensity. Input R approx 1 k ohm.

General

POWER: 100, 120, 220 V, +5, −10%, 48 to 66 Hz, approx 35 W.
WEIGHT:
1220A: net, 16¼ lb (7.3 kg).
1221A: net, 15½ lb (7.0 kg).
DIMENSIONS: 12¼ in W × 7⅛ in H × 16¼ in D (31.1 × 18.1 × 41.3 cm).
OPERATING ENVIRONMENT
TEMPERATURE: 0 to +45° C; non-operating to 75° C.
HUMIDITY: to 95% relative humidity to +40° C.
ALTITUDE: to 15,000 ft (4600 m).
VIBRATION: vibrated in three planes for 15 minutes each with 0.010 in (0.25 mm) excursion 10 to 55 Hz.

Accessories

VOLTAGE DIVIDER PROBE: Model 10013A 10-to-1 voltage divider probe provides 10 MΩ input resistance shunted by 10 pF. Maintains full 15 MHz bandwidth.

CAMERA ADAPTER: Model 10373A Camera Adapter allows Model 123A Camera to be used.

FRONT PANEL COVER: Model 10117A Front Panel Cover provides protection and storage space for probes.

RACK MOUNTING KIT: Model 10119A Rack Mounting Kit mounts 1220A or 1221A oscilloscopes in standard 19 in (48.3 cm) rack requiring only 8¾ in (22.2 cm) of vertical space.

PRICES IN U.S.A.
Model 1220A Dual Channel Oscilloscope, $695.
Model 1221A Single Channel Oscilloscope, $575.
P7 phosphor instead of P31, add $20.
Model 10013A Voltage Divider Probe, $30.
Model 10373A Camera Adapter, $45 (tentative).
Model 10117A Front-panel Cover, $20.
Model 10119A Rack Mounting Kit, $65.

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Obtaining a Diplom Ingenieur in electronics from the Technische Hochschule in Aachen, Germany, in 1967, Hans-Günter Hohmann joined Hewlett-Packard GmbH shortly thereafter, starting in research and development on instruments for acoustic measurements. He subsequently became project leader on several products, including the 8064A Real-Time Audio Spectrum Analyzer, and group leader for acoustic products. He then became group leader for low-cost oscilloscopes. Active in seasonal sports and other light athletic events, Hans-Günter also enjoys reading about history, both natural and cultural. Since becoming a father a year ago he does less of the former and more of the latter.