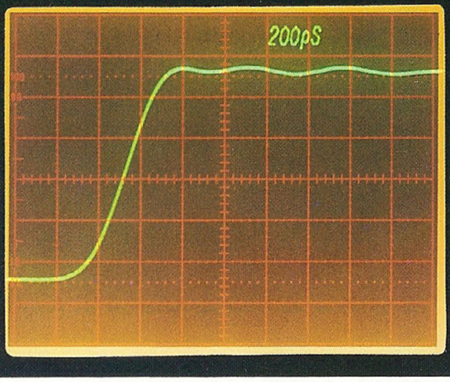
VOL. 27 NO. 2

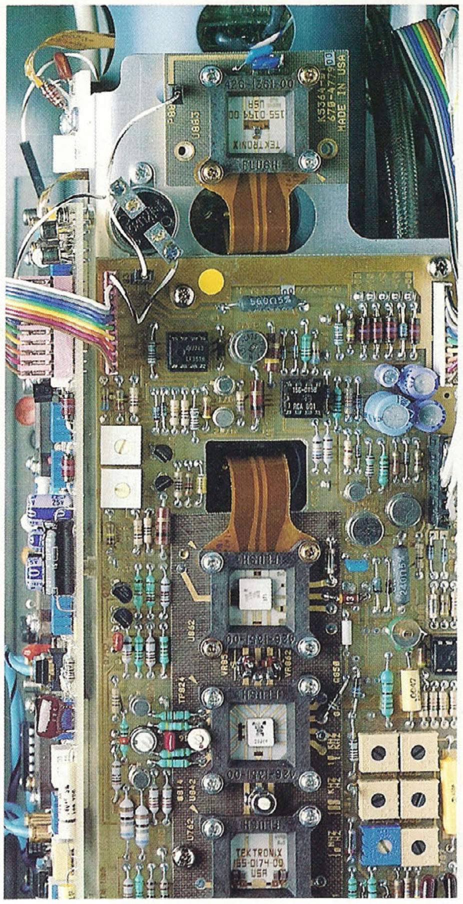
Electronic Design®

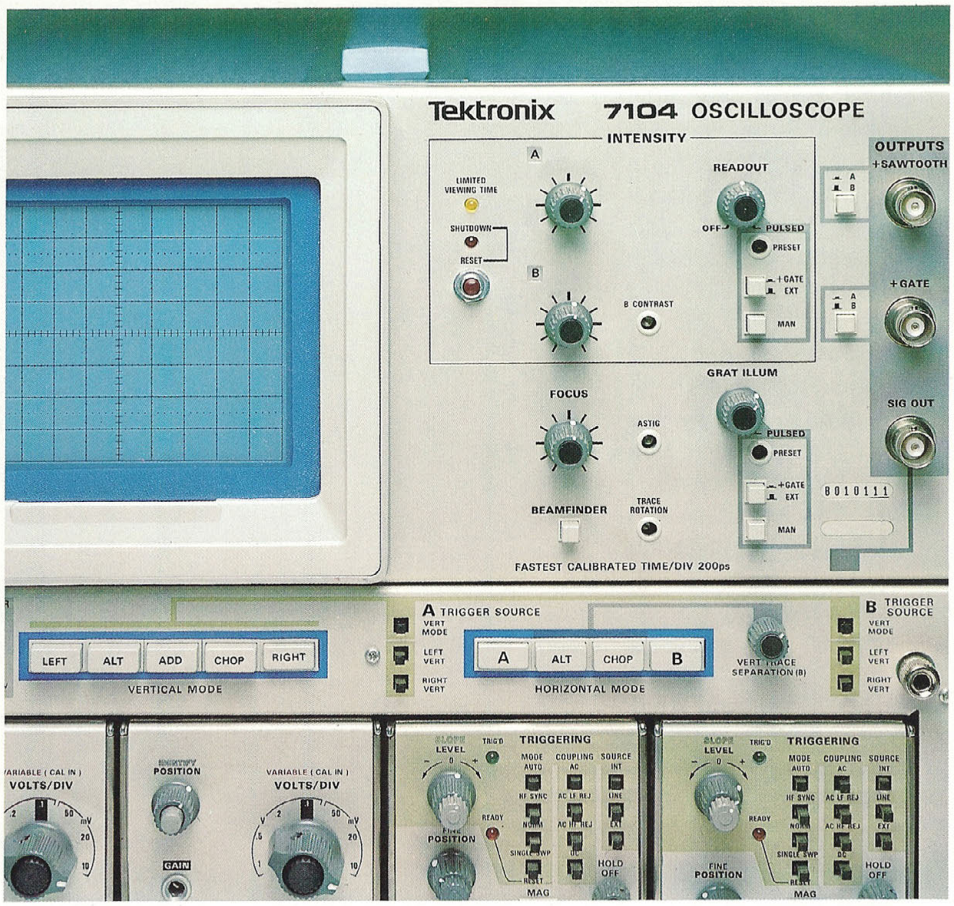
FOR ENGINEERS AND ENGINEERING MANAGERS — WORLDWIDE

JAN. 18, 1979



World's fastest oscilloscope breaks the 1-GHz barrier





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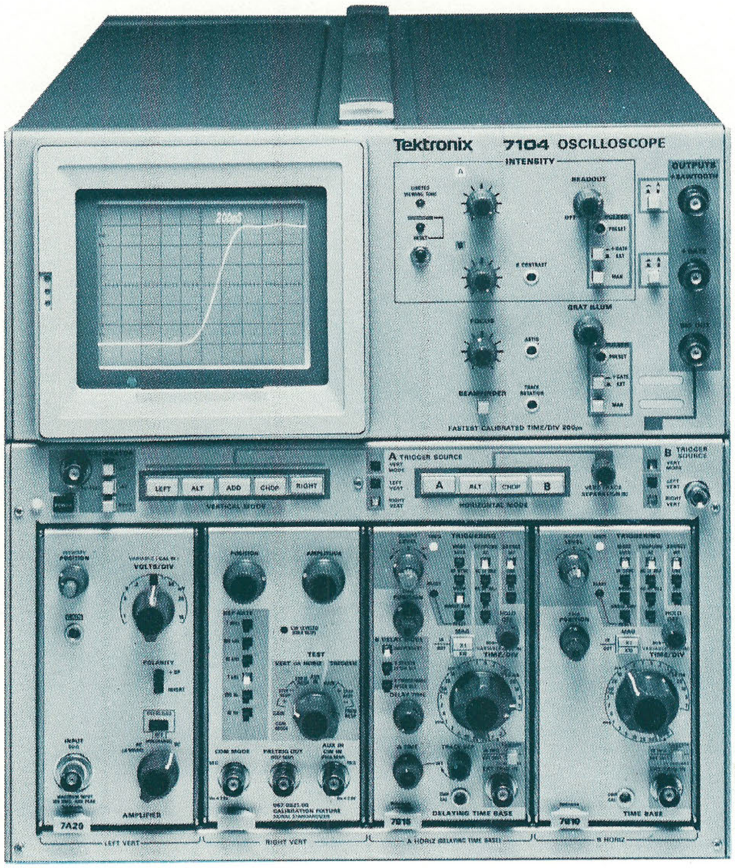
"Viewing the unviewable: A 1-GHz scope unveils fleeting events"

"Breakthroughs throughout push scope to 1 GHz"

Breakthroughs throughout push scope to 1 GHz

To break through an oscilloscope bandwidth barrier wide enough to stand for seven years, and to bring 1-GHz performance to a general-purpose, plug-in oscilloscope requires design breakthroughs throughout the scope—from the vertical and horizontal amplifiers and delay lines, to transmission lines and even interconnections (Fig. 1). However, some key advances stand out: the microchannel-plate CRT and scan-expansion lens, and the special high-frequency packaging (instead of standard PCBs).



Severe requirements were placed upon the new CRT. Relative to existing CRTs, vertical-deflection sensitivity had to be improved by a factor of three to ease demands on the vertical amplifiers. This required distributed deflectors on both axes. Bandwidth had to more than double, while maintaining good spot size and trace resolution. The most important requirement was, of course, the most difficult to satisfy—the ability to view and photograph high-speed, single-shot events without special phosphors, film fogging, high-ASA film ratings or reduced-scan techniques. And the fastest single shots had to be viewable without a camera.

How to do it?

Investigations into which CRTs could handle all this seemed to point to the microchannel plate concept—an electron-beam multiplier, or beam amplifier inside the CRT, just ahead of the phosphor, which can tremendously increase writing rate.

A new CRT

Important goals governing the development of this microchannel-plate CRT included long lifetime and the ability to manufacture it on a large scale at moderate cost. In addition, the tube has to possess greater than 2-GHz vertical bandpass at 1-V/cm deflection, with similar horizontal characteristics.

In construction, both the vertical and horizontal deflectors consist of differential helical transmission lines (Fig. 2). The velocity of signals propagating along the deflectors matches the speed of the electrons in the beam passing between the deflectors.

The investigation into what would be required for increased deflection sensitivity and wide bandpass led to a rather startling conclusion: A conventional CRT would have to be over seven feet long to meet specs. The solution: A scan-expansion lens and a spot demagnification lens.

Consisting of seven lens-shaped plate elements, each connected to a different voltage, the lens expands a passing electron beam 4½ times vertically and four times horizontally. Since the lens elements are capacitive and draw no current, simple resistive dividers across the cathode supply provide the operating potentials. Variable resistors in the divider control trace deflection, geometry and linearity parameters to very close tolerances.

Once out of the scan-expansion lens, the electron beam encounters the microchannel plate electron

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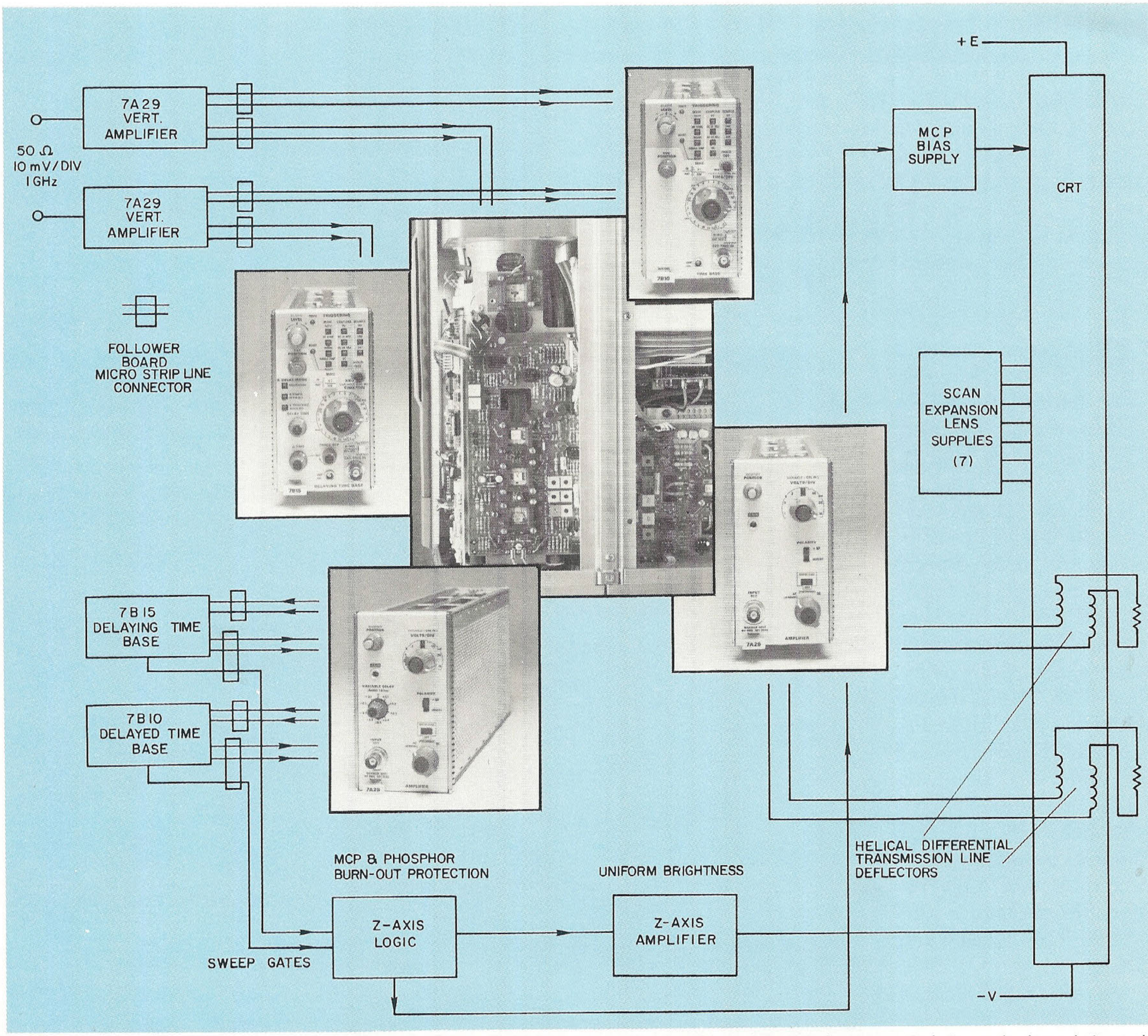


1. **To push an oscilloscope through existing bandwidth** barriers, design breakthroughs must run throughout the scope. Not only are both the vertical and horizontal systems "caught up" in a complete redesign, internal frequencies up to 3.5 GHz require stringent rethinking of all transmission paths—particularly all interconnections.

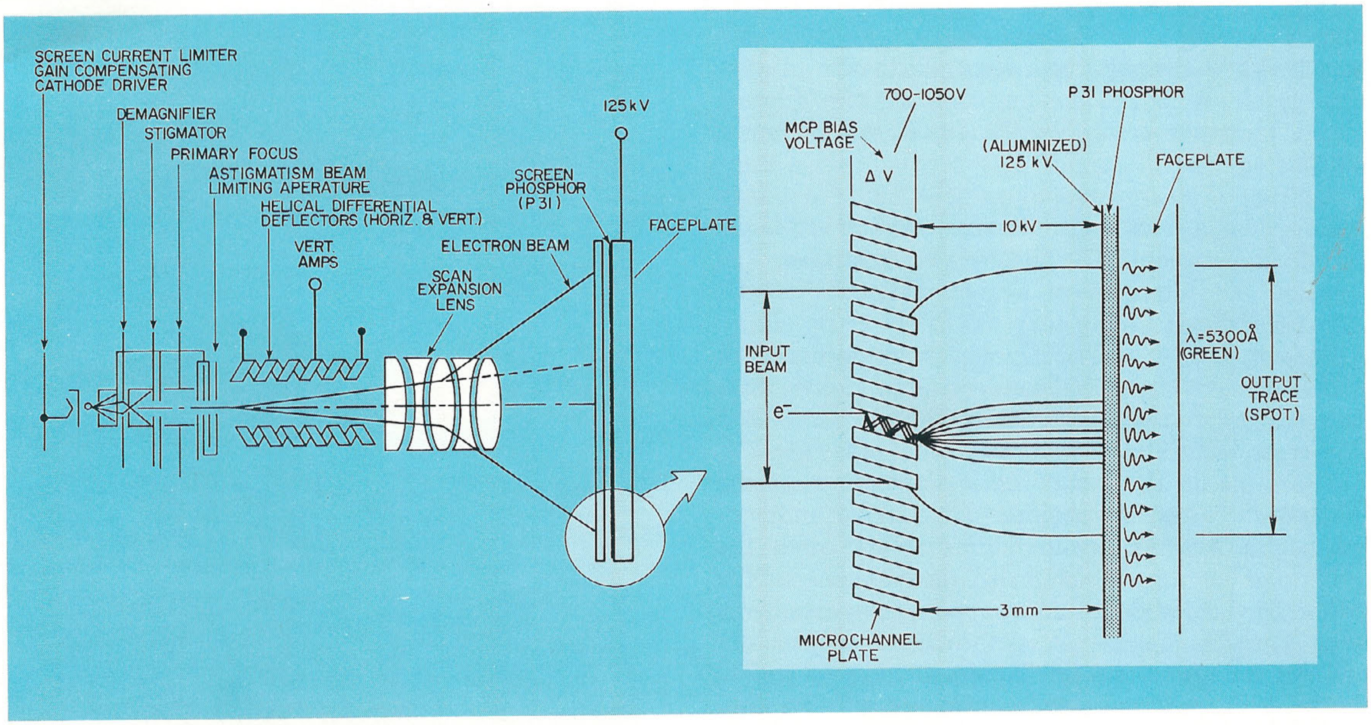
multiplier at a point slightly ahead of the CRT faceplate (Fig. 2). Parallel channels, 25 μm in diameter, are closely spaced across the plate, and offset at a slight angle to the beam. The channel walls are coated with a conductive material that exhibits secondary emission. To establish an accelerating potential down the length of the channels, called the MCP bias voltage, both sides of the plate are metalized and insulated from each other.

From the lens to the plate

When an electron beam sweeps the plate, individual electrons enter the channels and strike the coated walls. This creates secondary electrons which, in turn, collide with the walls causing further electron multiplication. The amount of plate multiplication is a function of MCP bias voltage, and can reach several tens of thousands.

Proximity focusing is achieved at the CRT graticule by placing the microchannel plate within 3 mm of the phosphor-coated faceplate. A potential greater than 10 kV applied across this gap accelerates electrons toward the phosphor with minimum dispersion. Spot size comes to less than 0.015 in., and writing speed is sufficient to observe a full-screen, single-shot, 1.5-GHz sine wave with the naked eye.

The microchannel plate is the key element in the CRT's design. It restores the beam current that is traded for deflection sensitivity, bandpass and screen resolution. The scan-expansion lens, which magnifies the spot size by about four times, is partly responsible for that trade-off. To counter the lens' effect, the size of the beam-limiting aperture must be reduced, caus-



2. **A microchannel-plate CRT and scan-expansion lens** form the "focus" of a key design effort. The object—produce a 2.6-GHz bandpass and 30 cm/ns writing rate in a practical production tube.

ing the loss of considerable beam current. A high-speed defocusing effect, one that depends on the amount of the horizontal deflection and vertical speed, requires an even narrower aperture along the vertical axis.

Beam current was traded off by incorporating a spot demagnification lens to reduce the spot size by a factor of 2. By lengthening the first anode structure, the same could have been accomplished, so in effect, the spot demagnification lens shortens the CRT. Increased deflection sensitivity and bandpass slow a beam and reduce its current. Beam current is also traded off in the triode design to obtain an almost fixed spot size with the cathode drive. (Usually the spot size increases with cathode drive.) Yet, in spite of all the tradeoffs, writing rate remains excellent.

Both the beam current and MCP bias voltage are carefully controlled to achieve a pleasing, continuous display at all sweep speeds and repetition rates. MCP bias voltage increases proportionally with intensity control settings, starting at about midrange.

At high sweep speeds and low repetition rates, both the MCP bias and the beam current are maximized, causing the trace to appear somewhat granular. Under these circumstances, the beam can move laterally across the microchannel plate *at speeds exceeding the velocity of light (30 cm/ns).*

Some channels in the beam path may not receive electronics, so that not every channel is excited. Moreover, gain statistics of the individual channel become evident. But even at this limit, a single-shot event occurring at 200 ps/div. is clearly visible to the naked eye.

The CRT's P31 phosphor coating emits a rather pleasing green light at a wavelength close to the middle of the visible spectrum—350 nm. Although Type 47 film's sensitivity to P31 isn't optimal, the microchannel plate still provides plenty of writing speed.

In a wideband scope system like the 7104, all signal paths from the input connector to the CRT graticule must exhibit exceptionally good frequency response. If they don't, minimum signal distortion cannot be achieved. To maintain bandwidth and still get minimum signal aberrations requires high-quality transmission lines for all signal paths.

Signals encounter a variety of lines in the 7100 system: three types of coaxial cable, printed-circuit microstrip lines, hybrid microstrip lines, the CRT helical deflectors and neckpins, and coplanar flexible printed-circuit lines (Fig. 3). Each signal path is optimized to very close tolerances with time-domain reflectometry (TDR) techniques. No easy task with signal paths *over 40-ft. long.*

Different lines, different problems

Conventional PCB edge connectors are inadequate for gigahertz transmission between plug-in and mainframe because of inductive losses and reflections. Vertical, horizontal and trigger signals must exit the plug-ins and enter the mainframe on 50-Ω lines. A plug-in interface, called a follower board, solves the interface-connector problem (Fig. 4).

The board fits into the mainframe interface connector and contains 50-Ω coaxial cables soldered to one end of 50-Ω strip lines. Soldered directly to the other end of the lines are contact fingers. Held in place with just a spring, the board moves, or "follows," lengthwise within the connector. With the plug-in module circuit board pushing against the follower board, inductive reflections caused by air gaps are eliminated.

Another problem overcome in the high-frequency system design involves the interconnection of planar striplines between PCBs and hybrid substrates. The solution: an interconnect system called HYPCON (Hybrid Printed Connector).

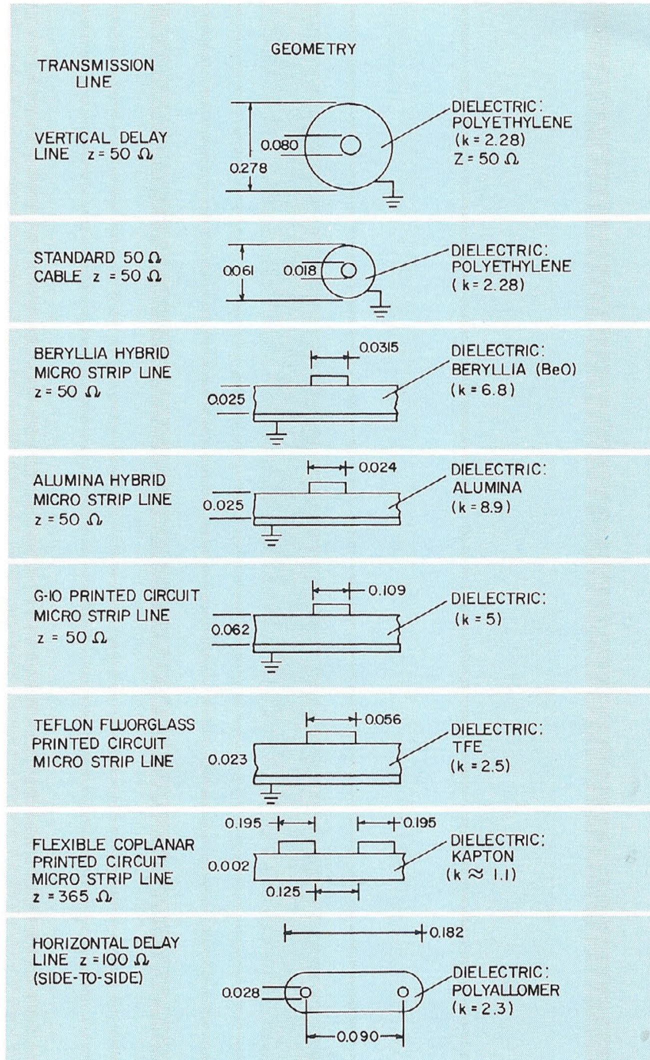
Consisting of a plastic frame, an elastomer with contacts and a metal plate, the system makes what is essentially a sandwich including the board and substrate, which are of identical thickness (see Fig. 5). Both sit on the metal plate—the bottom of the sandwich. The plate provides heat sinking and connects the backside groundplanes. Next come the elastomer contacts, which bridge the gap between the PC and hybrid striplines. The top of the sandwich is the plastic frame, which holds the elastomer, provides contact force and aids in alignment.

The Y-shaped micro-strip transmission line contacts provide a gradual transition from the wide PC line to the narrow hybrid line. Minimum signal reflection at the interface, however, depends on close alignment. Tight tolerances and alignment pins deliver very clean signal transitions, as measured with TDR. HYPCON not only outperforms the popular 3-mm coaxial connectors, it gives significant cost savings as well.

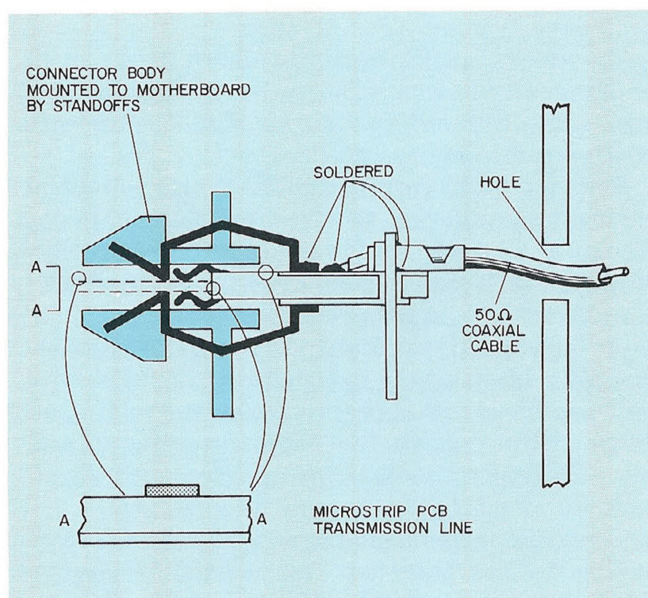
Usually high-frequency paths demand double-terminated—forward and reverse—transmission lines. Amplifier inputs and outputs must match the characteristic impedance of the transmission lines. The reverse termination at the beginning of each line absorbs reflections from the receiving end. Doubling terminations, however, requires doubling amplifier gain, and that results in a loss of over-all bandwidth.

The 7A29 plug-in has an input impedance of 50 ohms for compatibility with the 50 ohm environment used in most high frequency work. Deflection sensitivity is 10 mV/div. The input amplifier is protected by a fast diode bridge, which disconnects inputs under overload conditions. The 50 ohm input attenutor is protected by a special IC developed to perform an RMS conversion on the input signal. The integrated RMS value is proportional to power in the attenuator—excess power causes a relay to disconnect the input signal from the attenuator.

The input amplifier in the 7A29 converts the input signal from single ended to push-pull. Differential signals are hence used throughout the remainder of the vertical system. An output amplifier delivers the signal to the mainframe. A trigger signal is tapped from the 7A29 output amplifier and fed via a trigger amplifier to the mainframe trigger selection circuitry. The trigger signal is screen related and contains information about signal positioning, polarity, and gain. The vertical signals enter the mainframe on 50 ohm transmission lines and are fed via the vertical



3. **High-frequency signal paths take many forms** within the scope system, depending upon signal environment. TDR ensures high-quality lines.



4. **A particularly sticky problem** is connecting the plug-ins and mainframe. The solution: a follower board with micro-stripline edge connectors. The board moves, or follows, within the connector, minimizing air-gap losses or reflections.

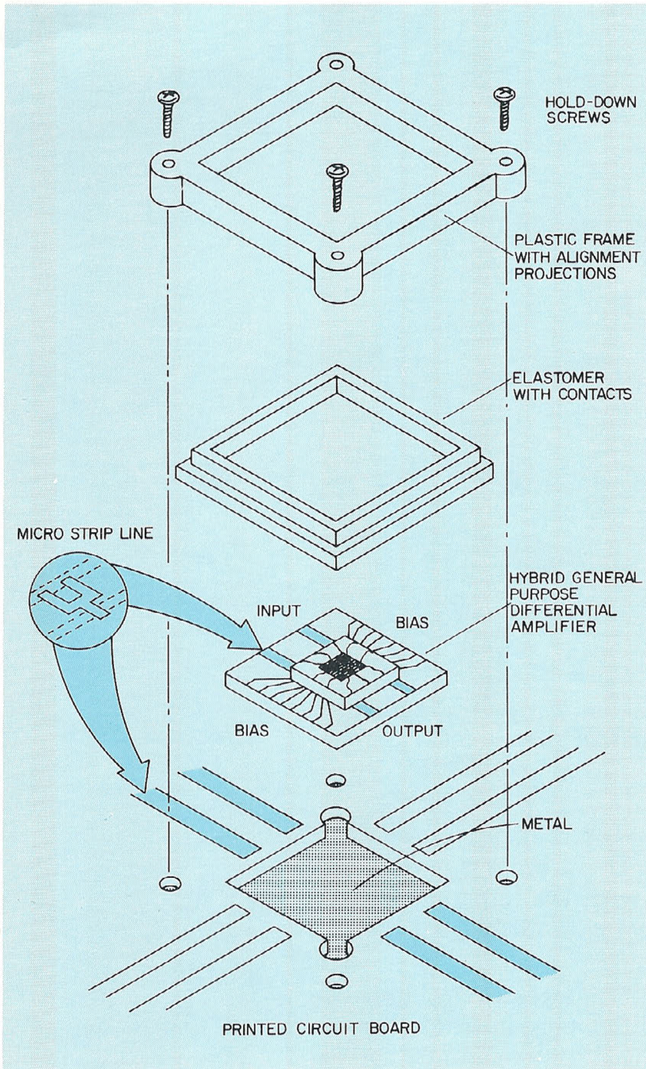
channel switch to the vertical delay line.

Delay lines are used in oscilloscopes to enable viewing of the triggering event. To provide for propagation delays in the trigger selection circuitry and other signal paths within the mainframe horizontal section, the 7104 delay line length is 50 ns. Since the signal to be delayed is differential, two lines were required, with side-to-side matching within 20 picoseconds.

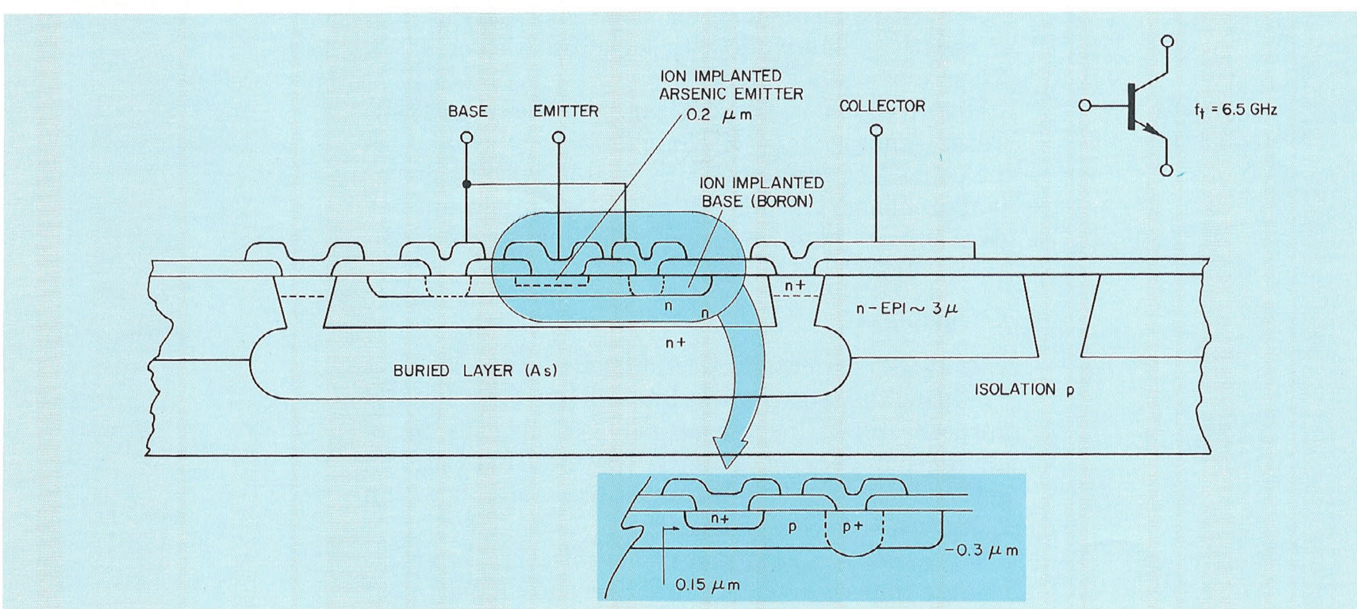
Skin effect losses are a major concern in delay line design. Minimum skin effects can be obtained only with relatively heavy and bulky coaxial cables. The best lines for the task must have an outside diameter as large as possible while maintaining TEM mode of propagation over a wide bandwidth.

Skin effect losses of the delay line are compensated by means of a passive, frequency dependent, hybrid attenuator network. This RLC network has four pole-zero pairs positioned such that the frequency response is inversely matched to the response of the delay line. At low frequencies the attenuation is about 4.8 dB, while at high frequencies no losses occur. The signal from the delay line compensation network is further amplified by a hybrid amplifier before the signal is delivered to the CRT driver amplifier. These hybrid amplifiers provide enough drive to deflect the beam more than eight divisions at the required bandwidth. A wide dynamic range minimizes vertical positioning effects on the step response. The output of the vertical system is differential (push-pull) with a characteristic impedance of 100 ohms per side. The output signal from the reverse terminated vertical amplifier is launched toward the CRT on a 200 ohm flexible PC coplanar transmission line. While deflecting the beam the signal travels along the vertical deflector, exits the CRT via another coplanar line and is terminated in a 200 ohm resistor.

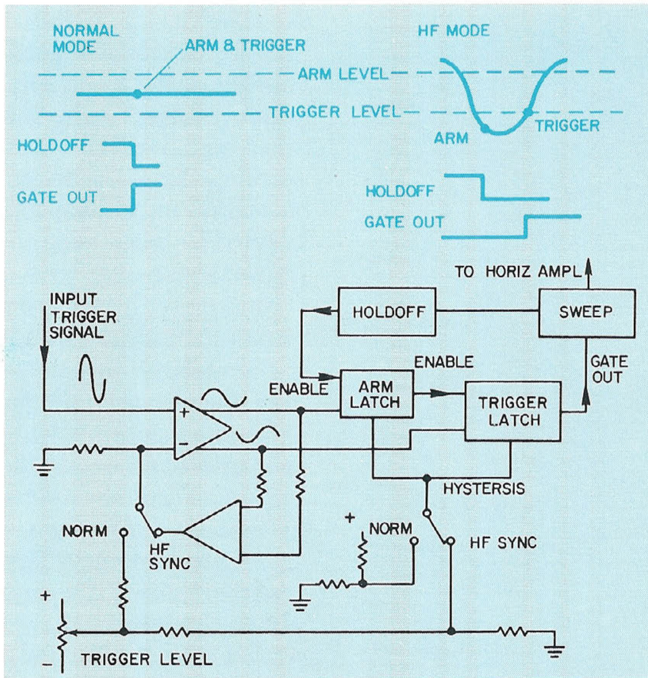
The required vertical sensitivity and performance



5. **Another problem—connecting printed circuits** to hybrid micro-strip transmission lines, without producing reflections. A hybrid PC connector, called Hypcon, does the job inexpensively.



6. **High-frequency response** needed by the vertical and horizontal amplifiers comes by way of a new IC process. Submicron, ion-implanted diffusions and a 1.7-μ emitter achieve an f_T of 6.5 GHz.



7. **Triggering out to 1500 MHz** took a new trigger amplifier and generator system. The final design locks-in easily and provides a rock-stable display.

are possible thanks to a new Tektronix IC process called Super-High III (Fig. 6). The process combines extremely shallow diffusions with ion implantation to make transistors with usable gain (beta-1) all the way to 6.5 GHz.

One new IC, a trigger amplifier, processes the input signal from the vertical amplifier plug-in and helps select the trigger source and coupling modes: ac, ac l-f reject, ac h-f reject and dc. Another IC forms the basis of the trigger-generator circuitry (Fig. 7). A trigger pulse must be delivered precisely at the moment that the input signal reaches a certain level for each horizontal sweep. In addition, the trigger generator must be switchable for slope selection (positive or negative), and work with logic levels from 800 to 600 mV.

High-frequency synchronization of the trigger generator—another new technique—neatly eliminates the usual free-running multivibrator, with its attendant problems. The new design's differential amplifier gives precise high-frequency synchronization.

X-Y displays

The 7104 horizontal deflection system has a 350 MHz bandpass and is extremely linear. Most other general purpose scopes limit practical X-Y displays to an upper frequency of 1 MHz. On the 7104 with an optional horizontal delay line the phase shift is within 2 degrees from dc to 50 MHz.

With a vertical amplifier in one horizontal compartment, a time-base plug-in in the second compartment controls the z-axis. The vertical signal triggers the base, and the sweep-speed control selects the z-axis turn-on window. ■■