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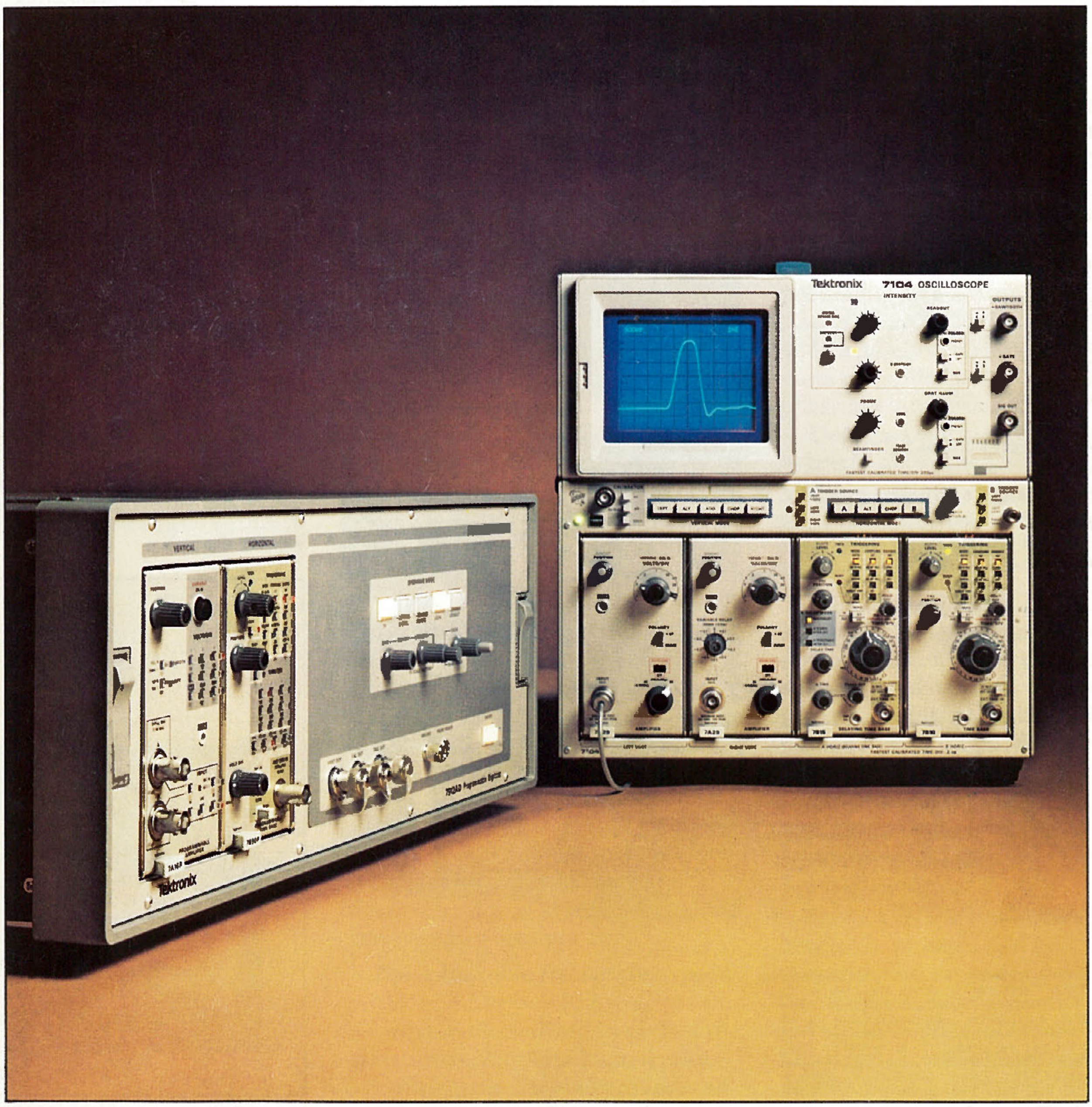
New Products

Volume 11
Number 1

1979

Tekscope



1 GHz at 10mV in a General Purpose Plug-in Oscilloscope

Hans Springer was Project Engineer for the 7104 program. He came to Tek in 1962 from Enschede, Holland following graduation from the Higher Technical School and a brief period of military service. He received his MSEE in 1966 from Stanford University. Hans has contributed to many 7000-Series projects including the 7A14, 7503, and 7904. He also designed the 134 Current Probe Amplifier.

Subnanosecond, single-shot events have been difficult, if not impossible, to view. They required use of a camera with a fast lens, 10,000 speed film, enhancement techniques such as film fogging, P11 phosphor for the crt screen, and a limited-scan display. Such events, thus recorded, left a dim trace at best.

The new TEKTRONIX 7104 changes all of that. Using a microchannel plate cathode ray tube, the 7104 achieves about a thousand-fold increase in single-shot trace brightness over conventional crt's. Individual subnanosecond events can now be viewed directly from the crt screen. Photographic writing speed, rated at 20 cm/ns (6.4 cm amplitude at 1 GHz), is measured using 3000 speed film without film fogging, an f1.9 camera lens with 1 to 0.85 reduction, and standard P31 phosphor. A fine trace width is maintained throughout the intensity range. For example, at full single-shot intensity no trace widening occurs.

Three new plug-ins have been developed to complement the 7104 Mainframe. The 7A29 Vertical Amplifier provides a system bandwidth of 1 GHz at a sensitivity of 10 mV per division. Two new time bases, the 7B15 and 7B10, provide normal or delayed sweep speeds up to 200 picoseconds per division, with triggering to 1 GHz and beyond.

The 7104 incorporates several new technologies to achieve this greatly improved performance. The key element in the system is the new T7100 cathode ray tube. A formidable set of specifications for the new tube called for a bandwidth at least twice that of previous designs, a three-times improvement in deflection sensitivity (over the T7904), writing speed sufficient to view subnanosecond single-occurrence events in normal ambient light, and improvement in spot size.

The solution to the writing-speed problem made possible much of the improvement realized in each of the other areas. A microchannel plate (mcp) structure, which provides an electron gain of about 10,000, is placed just back of the phosphor screen in the crt. Some of this large gain potential in brightness is traded for the improvements in bandwidth, resolution, and sensitivity.

The microchannel plate is an electron multiplier device. Closely spaced across the plate are parallel, 1-millimeter length channels 25 microns in diameter, offset at a slight angle to the electron beam. The channel walls are coated with a material which exhibits secondary emission. Both sides of the plate are metallized so that an accelerating potential (mcp bias) can be established down the length of the channels.

When an electron from the crt beam enters a channel, it strikes the channel wall, dislodging secondary electrons. The secondary electrons are accelerated and collide with the channel walls producing additional secondary electrons. The process cascades down each channel receiving electrons from the crt beam, producing an electron multiplication of about ten thousand. The multiplication is determined by the bias voltage applied across the microchannel plate structure.

Electrons exiting the channels are accelerated by the 12.5 kilovolt potential existing between the mcp structure and the aluminized phosphor screen, resulting in a bright, sharp trace.

The gun structure of the T7100 also includes several innovations. A scan expansion lens was needed to achieve the deflection sensitivity goal of 0.9 volt/division. Both the domed mesh and quadripole lens were considered and found to be less than optimum for our needs. A box lens, which functions similarly to a quadripole lens, proved to be the best solution.

The box lens is less critical with respect to dimensional and alignment tolerances, and also provides a means of correcting geometrical distortions caused by other elements in the gun structure. The lens provides an expansion of 4½ times in the vertical scan and four times in the hori-

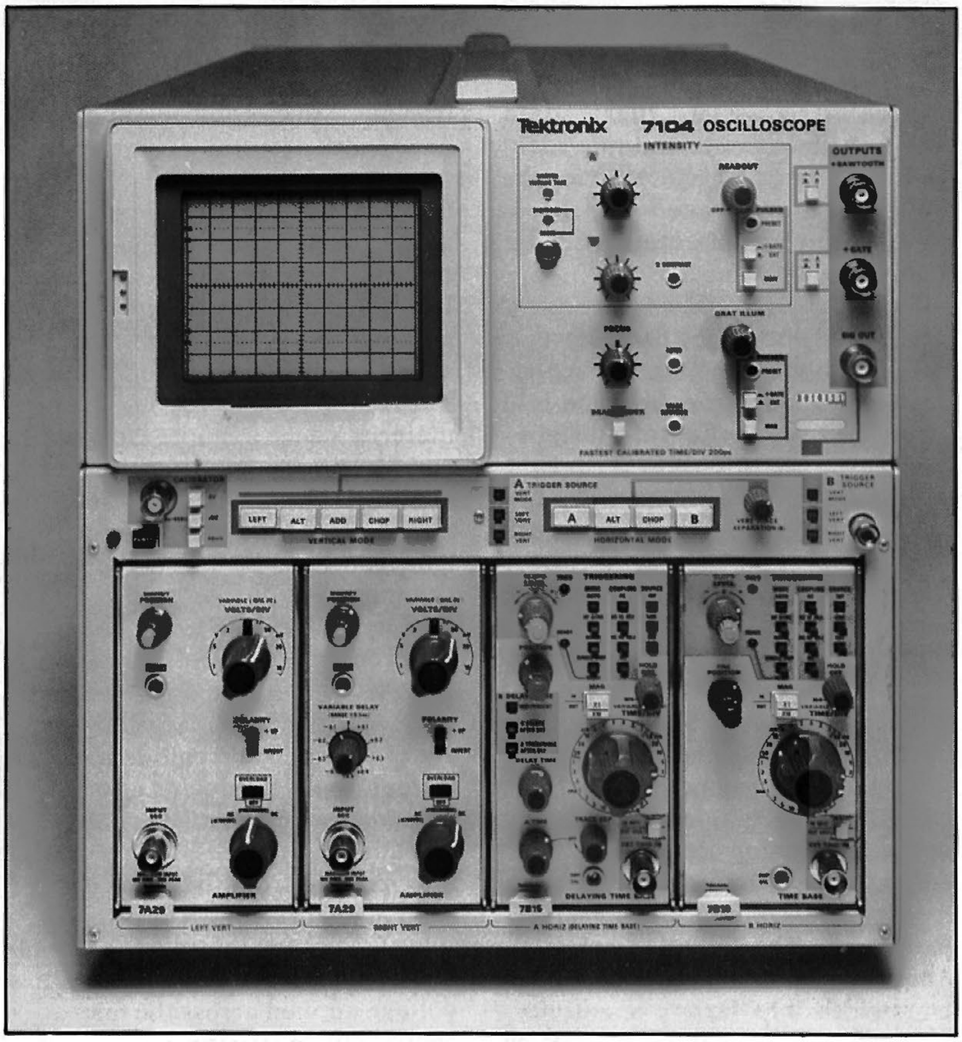


Fig. 1. The 1 GHz 7104 Oscilloscope brings the versatility and operating ease of the 7000-Series to the measurement of single-shot or recurring subnanosecond rise time signals.

zontal scan. It is the last element the electron beam encounters before reaching the microchannel plate.

Both the horizontal and vertical deflectors in the crt are helical transmission line deflectors. The vertical deflector has an internal ground plane structure that yields an extremely rugged, precision design. Vertical deflection sensitivity is ≤1 volt per division (0.85 cm) and bandpass is about 2.5 gigahertz.

The horizontal deflector employs much the same construction as the vertical deflector in the T7904. The deflection sensitivity is ≤2 volts per division and bandpass greater than 1.5 gigahertz, allowing 350 megahertz operation in the X-Y mode of the 7104.

Most of the remaining elements in the crt gun structure are dedicated to minimizing spot size. A crossover demagnification lens serves to shorten the crt. It is interesting to note that a crt using conventional techniques to achieve the same specifications would be over seven feet long.

The vertical system

While design work was proceeding on the cathode ray tube, a parallel effort was under way to develop the high speed circuitry needed to complement the new display capability. Wider bandwidth amplifiers, channel switches, and attenuators, and faster sweep and triggering circuits, were needed. Also, the standard plug-in hybrid package had been pushed to its limit in the 500 MHz 7904. A new packaging and interconnecting system which would allow easy insertion and removal of wide-bandwidth devices was needed.

The answer to this need was development of a hybrid-to-printed-circuit connector system we call HYPCON. The system uses a thin-film hybrid substrate to which integrated circuits are attached, and on which nichrome resistors and precision conductors are deposited. The precision conductors form transmission lines to carry signals from the edge of the substrate to the integrated circuits. The HYPCON is used to mount the substrate to the

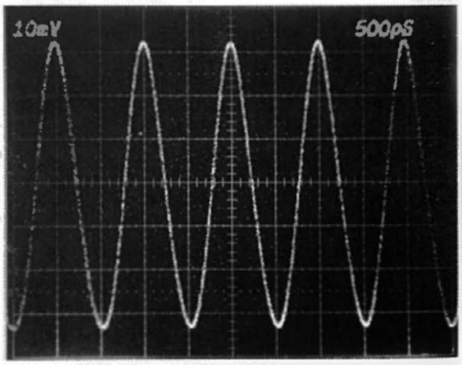


Fig. 2. This single-sweep display of a 1 GHz sine wave shows the high writing rate capability of the 7104.

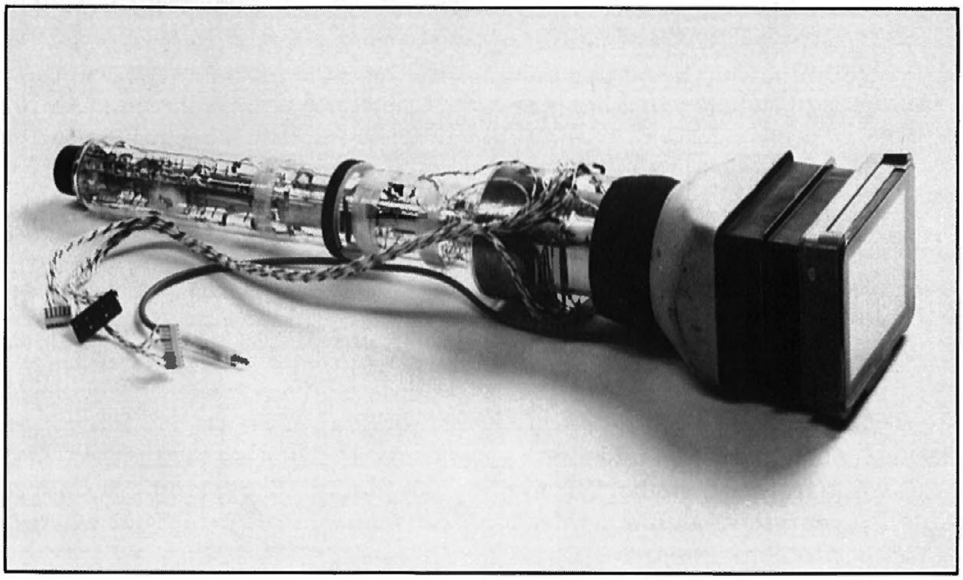


Fig. 3. The T7104 microchannel plate crt is the key to the 7104's performance. A portion of the box lens is visible just to the rear of the large black ring adjoining the funnel section.

printed circuit board and make the necessary connections for signals, control, and power.

The HYPCON connector consists of a plastic frame and an elastomer with gold contacts. The elastomer makes contact between the printed-circuit board and the substrate, and the plastic frame provides contact pressure and assures precise alignment (see Figure 4).

Two different types of HYPCON connectors — the flush and the stepped HYPCON — are used. The flush HYPCON provides better heat sinking since the hybrid substrate rests on a metal plate. This requires a hole in the circuit board. With the stepped HYPCON, the hybrid substrate rests on the groundplane of the circuit board. For most hybrids we use the stepped HYPCON, when the ground plane on the printed circuit board provides adequate heat sinking.

The circuit board material used for high-frequency signal transmission is glass-impregnated Teflon. This material gives lower losses than the standard G-10 glass-impregnated epoxy.

The HYPCON provides a practically reflection-free connection (as viewed on a 5 GHz TDR system), is inexpensive, and permits the hybrid to be replaced in only minutes.

6.5 GHz integrated circuits

To achieve a 1 GHz system bandwidth, the individual components in the system must, of course, have considerably greater bandwidth. The integrated circuit transistors used in the 7104 have a unity gain-bandwidth product in excess of 6 GHz.

A new high-frequency linear IC process we call super high frequency III (SHFIII) was developed specifically for the 7104. The Tek-developed f_T doubler cascode circuit and bridged-T coil peaking are used to achieve the high current gain-bandwidth needed. A novel approach we call "feedbeside" is used to match the low frequency gain to the high-frequency gain, rather than vice versa. Laser trimming with the circuit under power is used to set gain and input impedance to their nominal values.

Wideband delay lines

The delay line in the 7104 provided its share of design challenges. At the frequencies involved, skin-effect losses become a major concern.

Such losses can be minimized by using larger cables; however, there is a practical limit to cable size, especially since the signal delivered to the 7104 Mainframe is differential, requiring two delay lines. As large a cable size as feasible is used to minimize losses and still achieve the required 50 nanosecond delay. (Each cable is 32.5 feet in length). Even so, a passive, frequency-dependent hybrid equalizer is needed to compensate for skin-effect losses. This is accomplished by attenuating the low frequencies to match the high-frequency attenuation. The compensated line is flat within 0.25 dB to 1.5 GHz and has a 3 dB bandwidth of nearly 3 gigahertz.

Smoothing the signal paths

The gigahertz frequencies involved also required special attention be given to the signal and trigger interfaces between the plug-ins and the mainframe. A special "follower board" was developed for that portion of the interface connector which carries high-speed signals.

Precision 50-ohm strip lines are etched on the follower board; then the 50-ohm coaxial cables from the mainframe are soldered to the strip lines. Special contact fingers are soldered to the other end of the strip lines to make contact with the plug-in printed circuit board.

The follower board is held in place by a spring so that it can move lengthwise in the connector. When the plug-in is inserted into the 7104

Mainframe, the plug-in circuit board pushes against the follower board, eliminating the air gap between boards which causes inductive reflections.

As the input signal traverses the forty feet of signal path in the 7104 vertical system, it encounters several kinds of transmission lines — three types of coaxial cable, printed circuit microstrip lines, hybrid microstrip lines, coplanar flexible printed circuit lines, and the crt helical deflector.

Each place the signal makes a transition from one kind of line to another represents a unique interconnect problem. Extensive physical modeling and TDR testing was used to produce a very clean system. The largest single discontinuity occurs at the carefully spaced crt neck pins which provide access to the horizontal and vertical deflectors.

The horizontal system

Handling the fast sweeps needed to display subnanosecond rise times requires a wide bandwidth horizontal system. The T7100 horizontal deflector is a helical deflector similar to that used for the vertical in the T7904. The scan expansion lens provides a four times magnification on the horizontal axis for a sensitivity of 2 volts/division at the crt.

The 7104 horizontal amplifier uses many of the same techniques as the vertical amplifier. Bandwidth with the 7A29 is 350 MHz.

An optional delay line allows phase matching to be obtained at any frequency up to 250 MHz when using a 7A29 with variable delay (Option 04). Phase shift is within 2 degrees from dc to 50 MHz when balanced at 35 MHz.

The 7B10 and 7B15 Time Base Plug-ins feature the same versatile delta delay measurement capabilities introduced in the 7B80 Series. They also use the new sweep circuit developed to replace the traditional Miller integrator. A sweep start gating circuit and a selectable timing current source are used to charge a grounded timing capacitor.

This configuration yields fast sweep speeds with very clean sweep start characteristics, while maintaining good accuracy and linearity. Top sweep speed has been extended to 200 picoseconds per division.

Triggering to 1 GHz

Wide bandwidths, fast sweeps, and a high writing rate crt allow you to see signal jitter that is normally masked in a lower performance system. This places severe requirements on the trigger circuitry of the 7104.

Two new integrated circuits were developed for the trigger using the SHFIII process. The first serves as a trigger amplifier, selects internal or external trigger source, selects the trigger coupling mode, and processes the trigger level input. The second serves as the trigger generator. It contains a trigger amplifier and two ECL latches. The amplifier is switchable to provide slope selection. The two latches operate in series, one arming or enabling the other, to provide a fast,

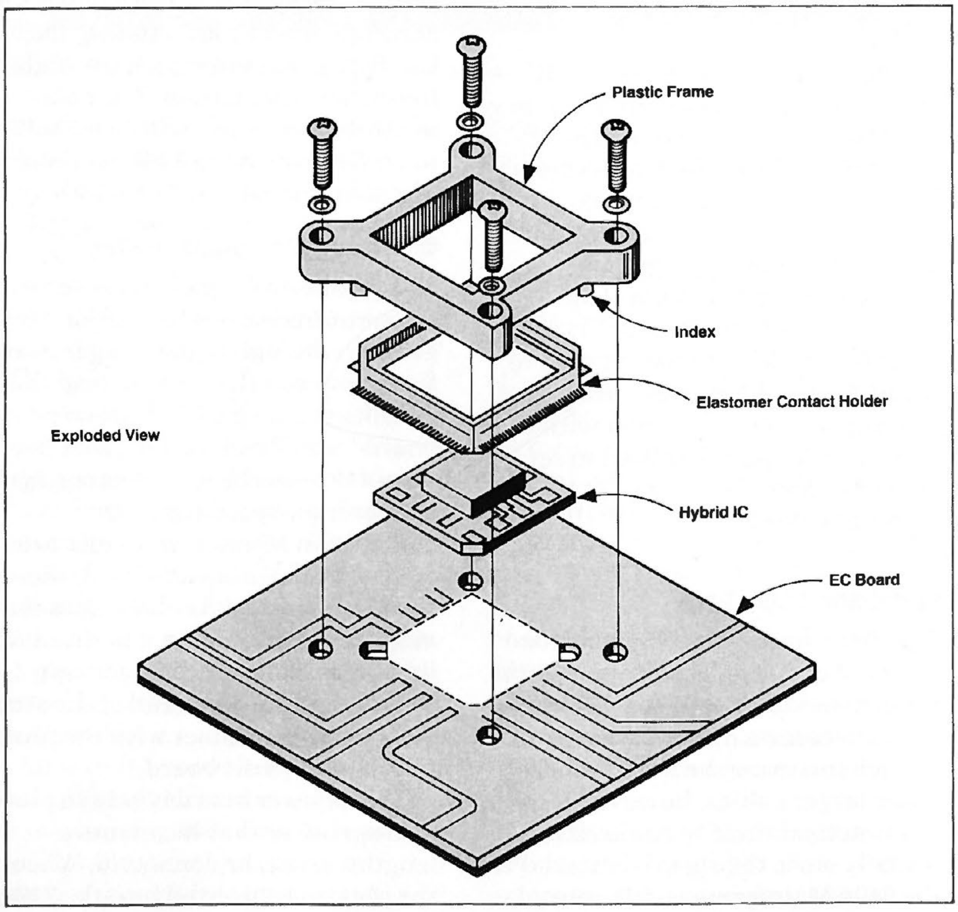


Fig. 4. The HYPCON connector system provides a fast, electrically clean method of mounting high-speed hybrids.

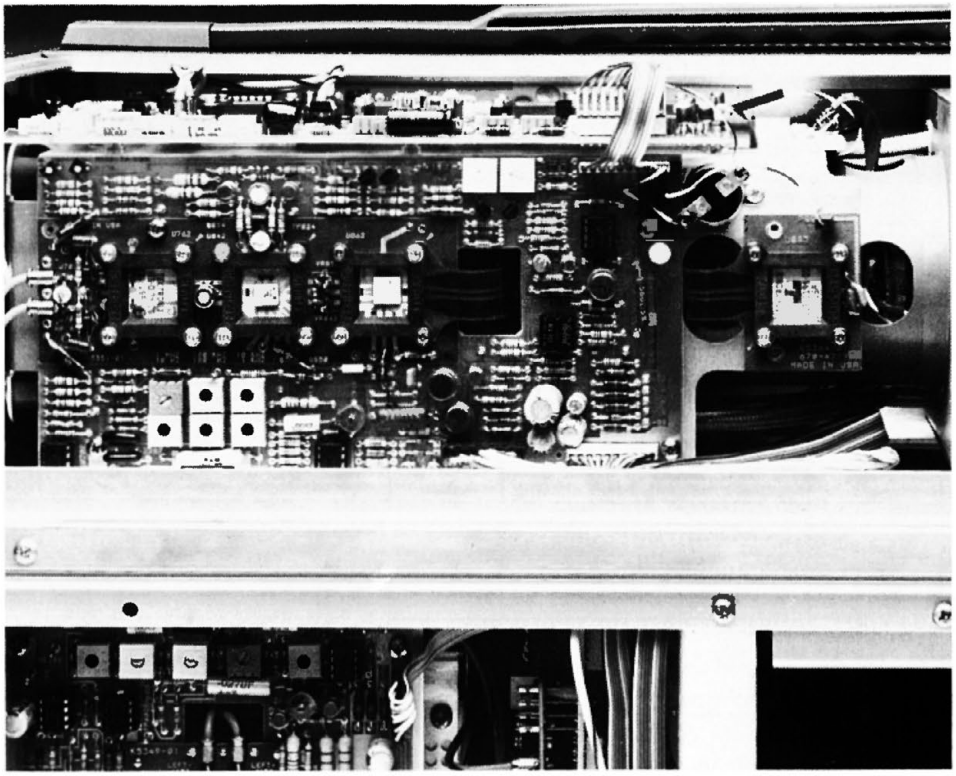


Fig. 5. Photo of vertical amplifier shows clean, open construction afforded by the HYPCON connector system.

clean trigger for gating on the sweep generator.

The latches are also used to produce stable high-frequency synchronization (see Figure 6). In the HF SYNC triggering mode, feedback is applied to the trigger amplifier to force the signals to the latches to be centered regardless of the dc component of the trigger input signal.

The trigger LEVEL control is switched to allow control of the hysteresis width (the voltage difference between the arm level and trigger level of the arm latch and trigger latch, respectively). With the LEVEL control, the hysteresis can be adjusted to zero and below. If the hysteresis is negative and no input signal is present, the dc-centered input at the latches exceeds both the arm and trigger levels and both latches are set when the holdoff signal goes LO. The sweep thus free runs at a frequency determined by the sweep and holdoff times.

When a trigger signal is present and the LEVEL control is used to control the hysteresis width, the trigger level of the trigger latch is moved up and down the signal until a locked or synchronized display is obtained. The characteristics of the circuit have a tendency to "pull" making it easy to produce an exceptionally stable display, even at a gigahertz.

Mechanical design

Many of the challenges facing the 7104 mechanical design team involved creating electrically clean interfaces between hybrids and circuit boards, between circuit boards themselves, and between the mainframe and plug-ins.

Implementing the HYPCON concept for making a low cost, fast, clean, interconnection between high-frequency hybrids and circuit boards was a major contribution to the 7104 project.

The follower board, which provides a clean interface for trigger and signal paths from the plug-ins to the mainframe, while not as extensive an undertaking, was an important one.

A refinement to the Tek-developed Peltola high-frequency connector was made to provide a more precise connection between small coaxial cables and the circuit boards.

Another task involved making a clean transition from the bulky delay lines, to small 50-ohm coaxial lines for connection to the circuit board. This was solved by drilling a small hole in the center conductor of the larger delay line and inserting a small socket to receive the center conductor of the smaller line. A four-piece clamp couples the two outer conductors and provides a secure mechanical bond.

Proper cooling provided its share of challenges. A plenum chamber at the rear of the instrument is used to produce a smooth flow of air across the vertical and horizontal amplifier sections to the exhaust fan.

Ease of maintenance is an important factor in mechanical design and received its share of attention in the 7104. The upper and lower sections of the instrument are hinged at the rear, with a built-in tilt bail provided near the front to keep the sections apart. Access to all of the circuitry is unusually good for an instrument of this complexity. For example, the substantial high-voltage circuitry is just behind a clear cover along the upper right-hand side of the instrument.

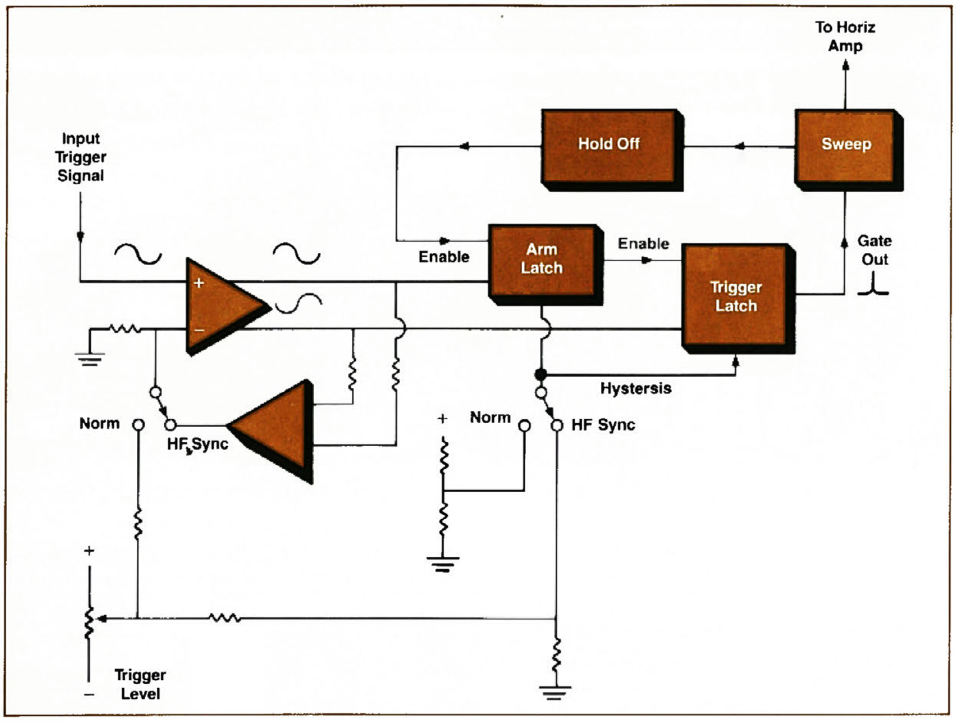


Fig. 6. Dual latch triggering system eliminates traditional multivibrator used as a count-down device. The trigger level adjusts hysteresis between latches to achieve "lock-on" at frequencies to 1 GHz.

Summary

The 7104 and its associated plug-ins are designed to let you view and measure low-amplitude gigahertz signals with the same ease as those in the 1 MHz range. Short pulses and fast rise times occuring at low repetition rates can be viewed directly from the crt. Delta delayed sweeps, crt readout, and other operating features common to the 7000 Series have been retained.

From the operational viewpoint you might say the 7104 is "just another 7000 Series Oscilloscope." But from the measurement capability viewpoint it is a giant leap forward.

Acknowledgements

The 7104 project, spanning some seven years, has been one of the most extensive undertaken by Tektronix. Val Garuts was the original Project Manager, with Gene Andrews taking over about mid-stream. Joel Davis did the early mechanical design with Neal Broadbent taking over the reins and completing the work.

John Addis, Project Engineer on the 7A29, worked out the vertical system design, assisted by Winthrop Gross. Dave Morgan did the mainframe horizontal amplifier, and Art Metz the Z-axis design. The 7B10 and 7B15 Time Base Plug-ins are the work of Art Metz and Bruce Hofer. Art did the trigger design and Bruce the sweep circuit design. Chuck Davis and Ed Wolf are responsible for the 7A29 and 7B10/7B15 mechanical designs, respectively. Bill Berg, Chuck Davis, and John Addis each contributed to the development and implementation of the HYPCON connector system.

Much credit is due Walt Ainsworth, Binoy Rosario, and others in IC Engineering; and Doug Ritchie, Jon Schultz, and the folks in IC Processing, for their contributions.

Dennis Hall was Project Leader for the team that did the outstanding job on crt design.

The 7104 Mainframe prototypes were built by Lois Davis, with Jan Bowden performing a similar function for the plug-ins. Gary Bohms was the technician for the project.

Many others should be included in this list but time doesn't allow. Each can take personal pride for their part in a seemingly impossible task well done.