COVER—Advances in state-of-the-art amplifier circuitry is dramatically illustrated in photo showing the output amplifiers for the 7904 and the 517. The 517, for many years, was the high-speed scope standard.

Val Garuts and Thor Hallen discuss operation of the 7904.

a subnanosecond realtime oscilloscope

"The window to electronics" – you have probably heard this phrase used to describe the oscilloscope. Today, we can see more through this window than ever before. The new Tektronix 7904 now expands the real-time horizon from DC to 500 MHz. We have viewed signals of this bandwidth before but with limitations. The signals needed to be several volts in amplitude to drive the CRT directly, or repetitive in nature to permit the use of sampling techniques. With the 7904, fast signals only a few millivolts in amplitude and of single occurrence can be measured.

With the introduction of the 7000-Series instruments in the fall of 1969, Tektronix brought unparalleled versatility and performance to oscilloscope users. The 7904, latest in this series, brings exciting new performance with no sacrifice in versatility. For example, any of the twenty-two 7000-Series plug-ins currently available can be used in the 7904.

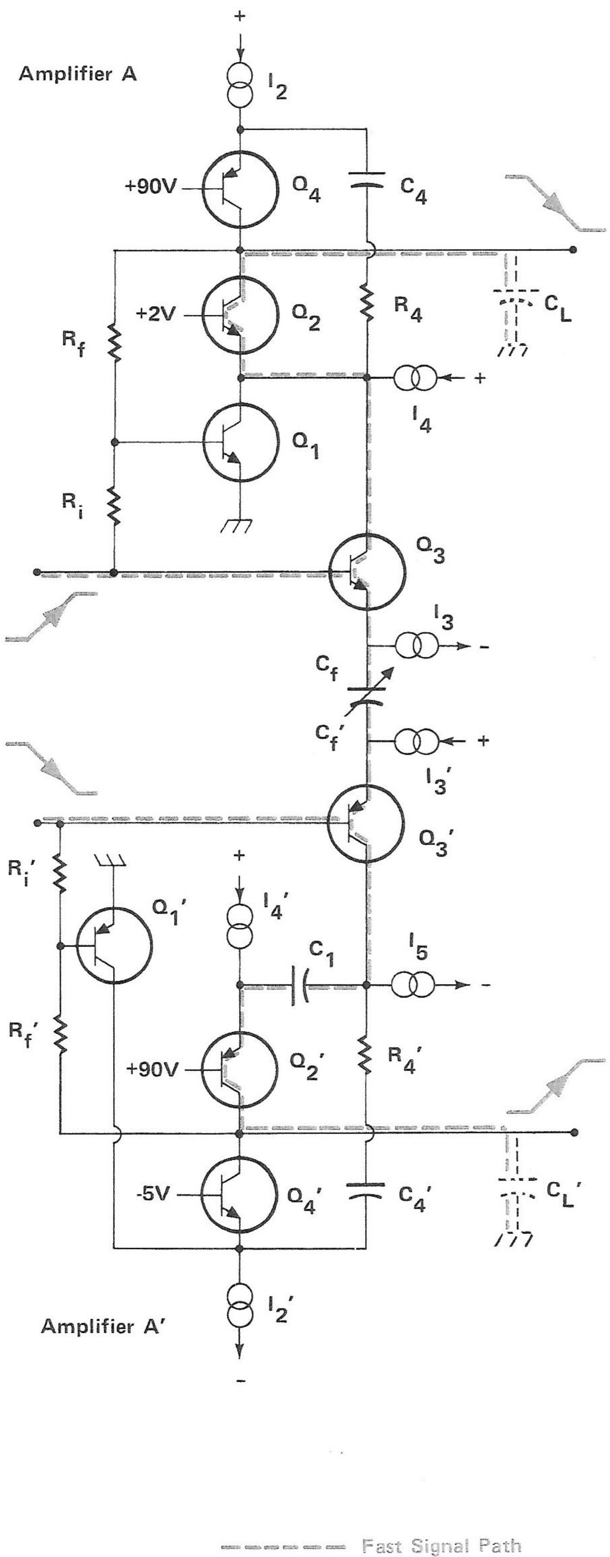
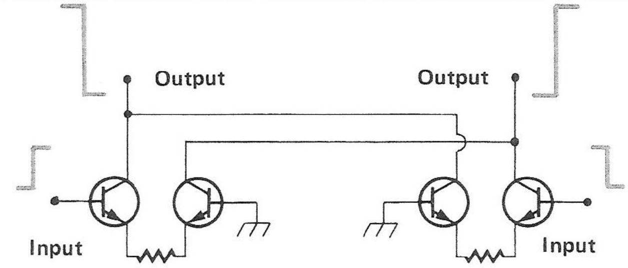


Fig. 1 Simplified schematic of the horizontal output amplifier.



The f_T Doubler Circuit.

The CRT

Design work on the 7904 commenced with development of the cathode ray tube. The goal: a tube with sensitivity and spot size similar to the CRT in the 7704, but having 3 to 4 times the bandwidth and increased writing speed.

The 7704 CRT uses a segmented vertical deflection-plate structure with a top bandwidth of about 500 MHz. To achieve the additional bandwidth needed in the 7904, we selected a helical traveling-wave structure. Similar structures have been used in CRT's for high-speed scopes for several years. Their major drawbacks have been limited scan, low sensitivity, and cost.

The problems of sensitivity and limited scan are overcome by using a dome-shaped mesh electrode between the deflection-plate structure and the post-accelerator field. The mesh effectively shields the beam in the deflection area from the post-accelerator field and shapes the field to achieve a deflection magnification of 2 times in both the vertical and horizontal axis.

The optimum shape for the mesh to achieve good geometry was determined using a computer to plot the fields developed by the mesh, and the path of the electron beam through these fields. The equation producing the desired shape of mesh was then fed into a numerical control machine which made the tool for producing the mesh.

A unique method of fabricating the helical deflection structure yields a vertical scan of 8 cm and bandwidth in excess of 1 GHz. It is also relatively inexpensive to produce.

The CRT uses a ceramic funnel, now standard for most Tektronix CRT's, which permits edge lighting the internal graticule.

The 24 kV accelerating potential applied to the CRT yields excellent visual brightness and photographic writing speeds. Using a C-51-R Camera, P11 phosphor and 10,000 ASA film, the writing speed is 10 cm/ns. Fogging techniques extend this to 20 cm/ns.

THE VERTICAL SYSTEM

Coupled to the advances in CRT design is a vertical amplifier system containing many advances in state-of-the-art amplifier design.

Acquisition and processing of 500-MHz signals requires techniques considerably different from those used to handle signals in the 100-MHz region. In the early planning stages of the 7000 Series, the designers anticipated that bandwidth limits would be continually pushed upwards, and designed the interface between the mainframe and plug-ins to accommodate these greater bandwidths. The characteristic impedance at the interface is 50 ohms, an ideal environment for piping around UHF signals. In the 7904, the signal paths between circuit elements are all transmission lines terminated in their characteristic impedance. The result is a very clean transient response with aberrations typically less than 5%.

A new delay line design avoids preshoot and contributes much to the clean response. Optimized for maximum delay in a minimum volume, and short risetime, the line consists of two parallel solid conductors in a polyethylene dielectric with a foil wrap and extruded polyethylene protective jacket.

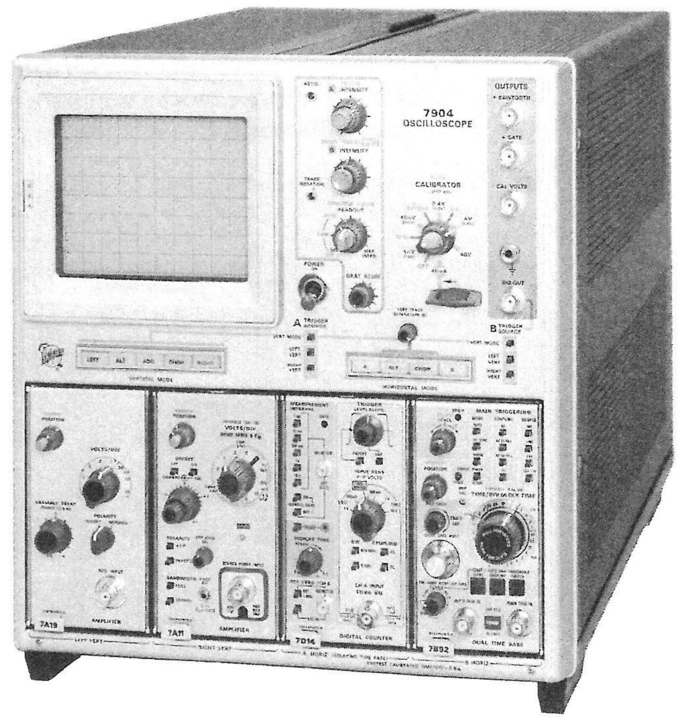
The input impedance of the 7A19 Amplifier Plug-in is 50 ohms. A Tek-made high-frequency cam switch permits input coupling of AC, DC or ground. The signal then passes through a 50-ohm turret attenuator providing deflection factors of 10 mV/div to 1 V/div. Attenuator switching is done ahead of the preamp except for the 10 mV/div position. The basic sensitivity of the plug-in amplifier is 20 mV/div. Since the 50-ohm line carrying the signal from the plug-in to the mainframe is double terminated, switching out the source termination increases the gain by a factor of 2 for a sensitivity of 10 mV/div.

An optional variable delay control permits matching the transit time of two preamps and probes to within 50 picoseconds. The delay is varied by mechanically moving a trombone section of transmission line. Range of delay is ±500 picoseconds.

From the variable delay the signal passes to the first amplifier stage. This is a unique wideband circuit which we call an f_T doubler. The simplified schematic opposite shows the basic circuit. The circuit was originally conceived several years ago by Carl Battjes. Considerable work by Thor Hallen coupled with the development of sophisticated IC fabrication techniques put the concept to practical use.

The f_T Doubler Circuit

f_T is the frequency at which the common-emitter current gain is one. If normal cascading of stages is used, no more than unity current gain can be achieved. The f_T doubler overcomes this limitation by effectively arranging for the base-emitter inputs of four transistors to be in series. The push-pull configuration allows the collectors to be effectively paralleled. At f_T the current gain of this arrangement is approximately two.



The 7904 DC to 500 MHz Oscilloscope System.

The f_T doubler can be thought of as an amplifier building block with twice the f_T of a single device. Using several of these building blocks, an amplifier with significant current gain at f_T can be built.

Once the basic design for the vertical amplifier had been chosen, the next step was to develop state-of-the-art high-frequency IC fabrication techniques to produce the transistors and couple them together. The emitter degeneration resistors were to be processed on the same chip with the transistors. This called for depositing precise amounts of nichrome on the substrate, a state-of-the-art process in itself. Since many critical processes were involved in producing a single f_T doubler stage, we decided to use a separate IC for each stage rather than integrate the entire vertical amplifier on one chip. The mainframe vertical amplifier uses three f_T doubler stages with coupling between stages via 50-ohm transmission lines.

The Output Amplifier

The output amplifier is a hybrid IC with a substrate carrier for mounting five silicon chips. Included on the IC is an f_T doubler, two small chip capacitors and two discrete output transistors.

Considerable design effort was expended in eliminating circuit elements that did not contribute to improving the signal gain. For example, there are no DC level shifting stages in the amplifier. The inductance of bond wires in the IC's, usually a problem in high-frequency design, is used as peaking inductance. There are no high-frequency adjustments in the vertical amplifier in the conventional sense. Transistor leads forming half-turn inductors are adjusted for optimum transient response.

THE TIME BASE PLUG-IN

The 7B92 Dual Time Base Plug-in used in the 7904 system features a fast 500 picosecond/cm sweep which complements the ultra-high bandwidth of the 7904 mainframe.

Delaying sweep measurements are made more convenient by a single front panel control which selects sweep rates for both normal and delayed sweeps, and selects either for display.

A new system of triggering the delayed sweep permits setting the time delay control to zero to view the triggering event on the delayed sweep.

An ALTERNATE sweep mode, available for the first time in a single plug-in, provides essentially dual beam operation for many applications.

Viewing of signals to 600 MHz and beyond is possible using the HF Sync triggering mode. When using an external trigger, either 50-ohm or 1-megohm input impedance can be selected to minimize loading of the trigger source.

THE HORIZONTAL AMPLIFIER

The top sweep rate of 500 picoseconds/cm places some pretty stringent demands on the horizontal amplifier. The CRT horizontal deflection plate sensitivity is 7 volts/cm which means the output amplifier must swing 70 volts in five nanoseconds. Fig. 1 is a simplified schematic of the circuit developed by Val Garuts to provide the fast, large-signal amplification needed in the output amplifier.

The horizontal output amplifier actually incorporates two amplifiers: A and A′. Amplifier A provides drive to the negative-going deflection plate and so is designed to have good performance in the negative direction of output. Amplifier A′ drives the positive-going deflection plate and has good performance for positive-going output signals.

Each amplifier provides two signal paths to its horizontal deflection plate, a high-frequency path using series feedback and a low-frequency path using shunt feedback. The bandwidth of the high-frequency path is 1 MHz to about 200 MHz and that of the low-frequency path is DC to about 30 MHz.

The high-frequency path for Amplifier A is through Q3 and Q2 to C_L, the load capacitance, consisting of the deflection plate, output amplifier and distributed capacitance. The gain of the fast (series-feedback) path is the ratio of the feedback capacitance to the load capacitance (C_f/C_L). C_f is made variable and set for a gain of ten for the high-frequency path.

The low-frequency path is through Q1 and Q2 to C_L. The values of the input resistance and feedback resistance are chosen to give the low-frequency amplifier a gain of ten also.

Amplifier A′ driving the positive-going deflection plate is arranged slightly differently, but the dual-path principle is maintained. The fast path is through Q3′ and Q2′ as before but a coupling capacitor C_1 is inserted between them for DC blocking.

The low-frequency path is through Q1′ and Q4′ (rather than Q2′) because of the DC level at the emitter of Q2′. A gain of ten for both low- and high-frequency paths is selected as in Amplifier A.

An additional fast path is provided in each amplifier by C4, R4 and C4′, R4′ to speed up the positive transition of C_L and the negative transition of C_L'.

The Z-Axis Amplifier

The Z-axis amplifier in the 7904 uses a dual-path amplifier similar to the positive-going horizontal amplifier. The main difference is that the high-frequency path consists of PNP devices and the low-frequency path uses only NPN devices. This provides large output current for a negative-going output, and while the risetime in the negative direction is not as fast as in the positive direction, it is considerably faster than in the configuration used in the horizontal amplifier.

THE POWER SUPPLY

Both the low-voltage and high-voltage supplies in the 7904 are contained in a compact unit weighing just 7½ pounds. The high-efficiency supply provides 150 watts of regulated DC at an efficiency of about 80%.

A considerable savings in cost, weight and space is realized by winding both low-voltage and high-voltage transformers on a common core. The inverter, operating at about 23 kHz, drives both supplies.

Pre-regulation to better than 0.5% is achieved by controlling the inverter conduction time. The control circuitry is designed to switch the inverter transistors off at the zero-voltage point on the sinewave. This eliminates the large amount of EMI normally generated by high-efficiency supplies, and reduces the likelihood of damaging the inverter transistors.

Secondary regulation of the high-voltage supply is achieved using an amplifier to control only the −3 kV section of the supply.

Acknowledgments

Design of the 7904 system was a team effort. Val Garuts was project manager and developed the large signal amplifier circuit used in the horizontal and Z-axis amplifiers. Thor Hallen did the vertical amplifier and John McCormick the horizontal. The trigger and time base were done by Les Larson and Bill DeVey. Bill Peek worked on the Z-axis amplifier and auto-focus, with Hans Springer doing the mainframe interface and channel switching. Joe Burger's work on the power supply, coupled with Joel Swanno's efforts in mechanical design, reduced the weight to only 30 pounds. Ken Hawken did the fine job on the CRT. Certainly much credit is due the IC development team who built the devices that make possible the 7904's 500-MHz bandwidth.