7104 MAINTENANCE

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MAINTENANCE GROUP

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INTER-OFFICE COMMUNICATION

TO: Distribution

DATE:

FROM: Dick Hornicak 74-740

SUBJECT: 7104 Training Information Brochure

The intent of this brochure is to familiarize service technicians with the three unique aspects of the 7104 Oscilloscope System.

A technician who is familiar with the 7000 Series oscilloscopes, should be able to repair and calibrate a 7104 system through use of the service manual and this training information brochure.

This information was provided by a combined effort of the Service Support, Engineering and Maintenance Training groups.

Regards,

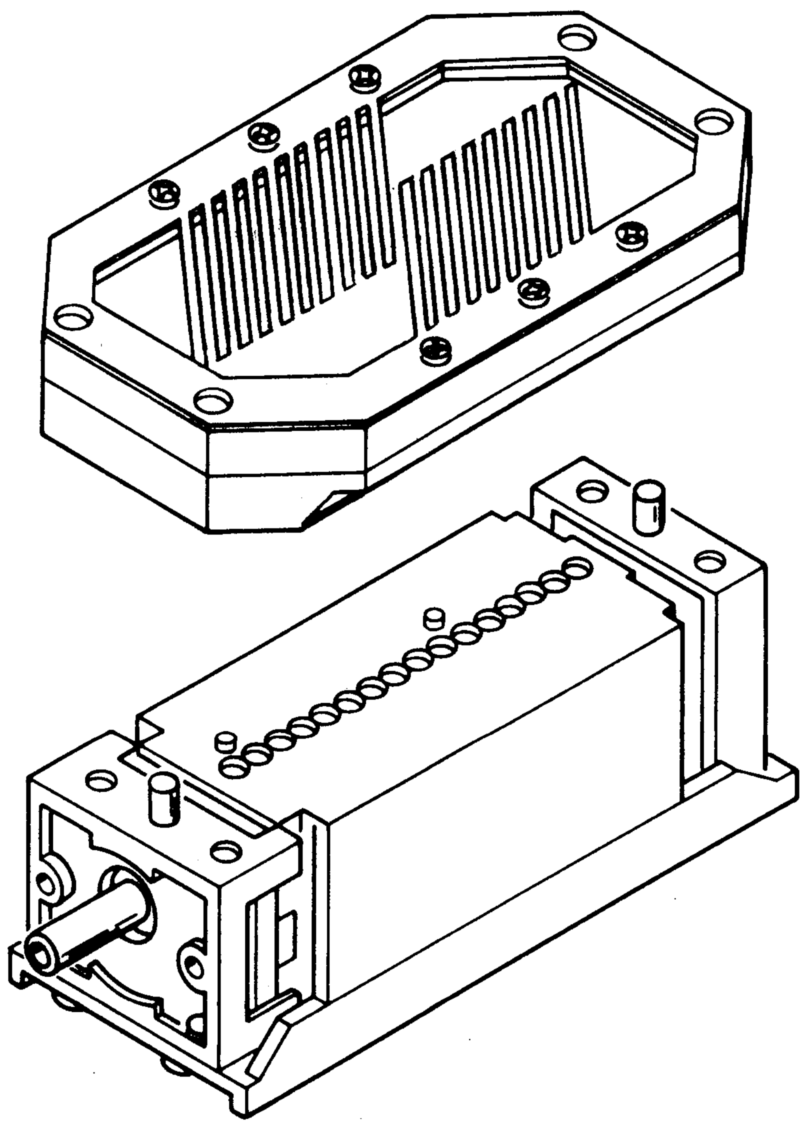
Dick

Dick Hornicak
DH:lam

Distribution

Region Service Managers
District Service Managers

ELASTOMER SWITCHES



Elastomers solve tough problems in high-frequency systems

Elastomer-based contacts set new standards of performance in HF instrumentation and hold promise for use in other HF applications.

William Berg, Ed Strande and **Bob G White,** Tektronix Inc

Happy is the designer who can simultaneously miniaturize a product, increase its performance, maintain its producibility and hold its cost down. Naturally, few such breakthroughs occur in a single design, but three new devices, all using metallized elastomer contacts, illustrate what happens when one does. The first is an improved high-frequency microstripline connector, the second a cam switch and the third a latching relay. Together they constitute quite an improvement in the state of the art, and they will no doubt find use in many high-frequency systems.

The connectors no one made

The microstripline connector proves particularly useful with signals above 100 MHz. Circuit designers have a choice between transmission lines and conventional wiring for signal interconnection at lower frequencies, but above those levels all signal paths function as transmission lines. Thus if you don't follow transmission-line design principles, signal attenuation, reduction in pulse rise times and aberration of pulse wave shapes result.

One type of transmission line, coaxial cable, interconnects black boxes for use at submicrowave frequencies. Inside those black boxes, however, circuitry on etched circuit boards interconnects through microstrip (planar) transmission lines. And while there are coaxial connectors

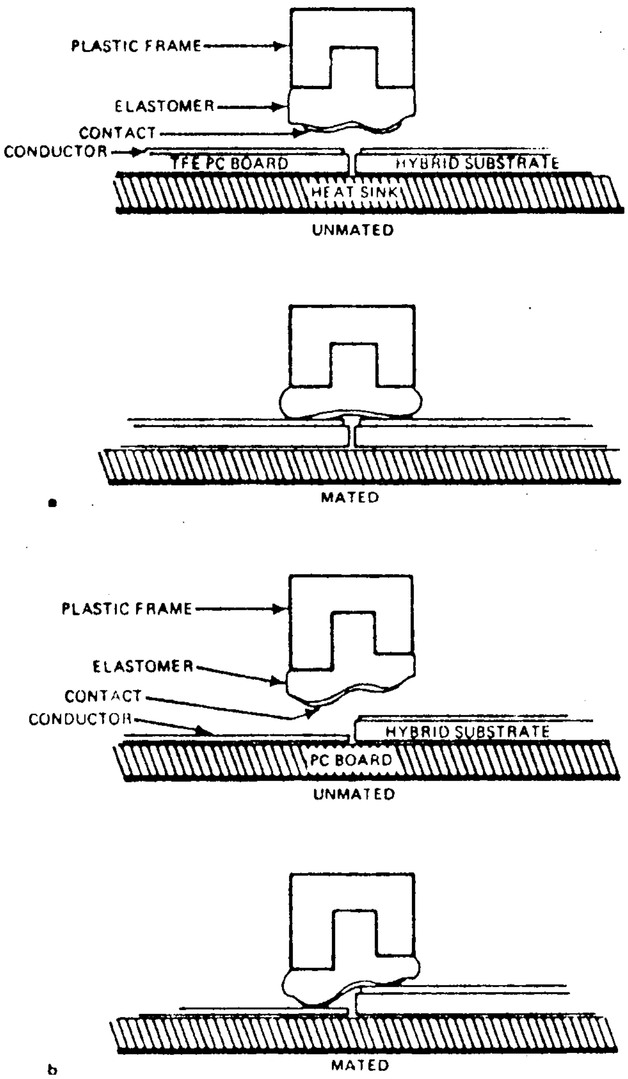


Fig 1—Bridging the gap between high-frequency transmission lines is still the job of a metal contact, but now an elastomer can apply the required pressure. Shown are applications in flat **(a)** and stepped **(b)** microcircuits.

for coaxial cable, there's no commonly available microstrip connector. Why? The pin-and-socket connection techniques that work so well for coaxial-cable connections don't lend themselves to the planar geometry of microstrip lines. What's needed for microstrip interconnection is a planar connector.

Consider how to connect two microstrip lines with their ends separated by a gap. You could solder a thin ribbon across the gap. Ideally this ribbon should be as short as possible to provide a reflectionless junction. Another possibility, the one described here, involves positioning the ribbon over the gap with an elastomer pad and applying pressure.

As with coaxial types, the basic design for such connectors involves keeping the geometry as continuous as possible—for example, by bringing together the edges of two microstrip lines on etched circuit boards and sandwiching them between two metal plates. To achieve this goal, you could replace the metal plane on the signal-line side with a plane of low-dielectric material carrying a small metal ribbon. For best high-frequency performance, the metal ribbon should be thin, short and precisely positioned over the two accurately aligned microstrip lines; the metal plane connecting the ground planes should exhibit low resistance; and the sandwich should be clamped with enough pressure to provide a low-resistance connection.

Hybrid connectors upgrade performance

The basic elements of such a connector for hybrid printed circuits include a shaped metal contact backed with an elastomer to provide resiliency and contact force, a supporting injection-molded plastic frame and a metal sheet that serves as an electrical ground plane and heat sink. Connection between transmission lines occurs through pressure applied by the frame to the elastomer from above **(Fig 1)**. The ground planes of the pc board and the hybrid are shorted together by the metal sheet; heat is removed by conduction through that sheet to the overall system heat sink. The contacts result from a production technique similar to the photographic

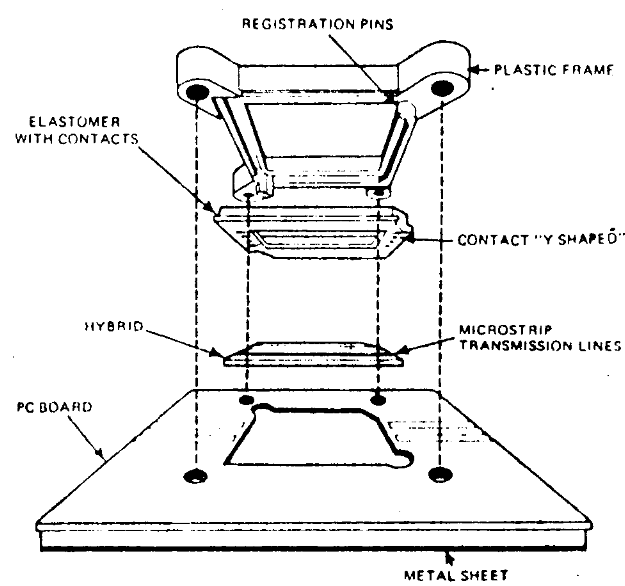


Fig 2—Registration on microstrip lines minimizes misalignment of the elastomer contact; a normal tolerance figure is 0.010 in.

fabrication of pc boards.

The microstrip lines on the pc board are registered (**Fig 2**) to a round hole, while the microstrip lines on the hybrid substrate are registered to the substrate edges; this technique minimizes misalignment of the contact to the microstrip lines. In a worst-case dimensional analysis, tolerance stackup from the contact to the microstrip lines measures <±0.012 in.; normal misalignment, <0.010 in.

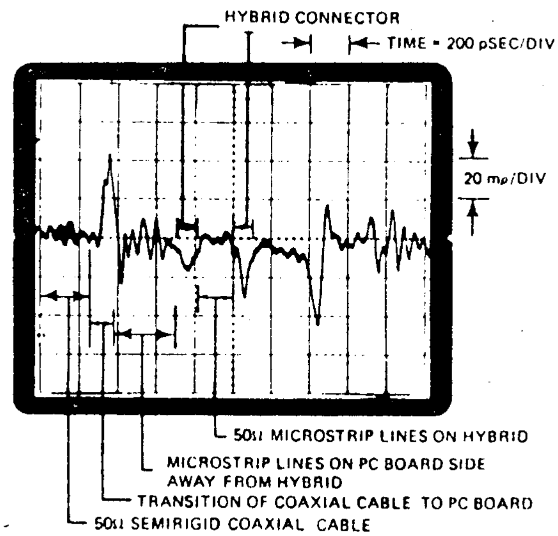


Fig 3—Reflection signature from microcircuit contacts (center) shows the hybrid connector less reflective than the transition from coax to pc board.

A vast performance improvement

Commercial transmission-line connectors are rated by their VSWR and time-domain reflectometer (TDR) characteristics. Because most circuit designers use the latter to identify and locate sources of signal aberrations, that technique also serves to evaluate the performance of the microstrip connections.

Ideally, if the electrical parameters of a lossless transmission line remain constant and you match source and load impedances to the line, that line can transmit a step function, for example, without distortion. Any anomalies along the line, like connectors, reflect energy back toward the source and degrade the signal. Most designers willingly accept aberrations from 3-mm coaxial connectors, the performance goal for the elastomer-backed contact systems was to provide better TDR performance than those devices.

A TDR system for measuring hybrid-connector characteristics has a 50-psec rise time. Specifying

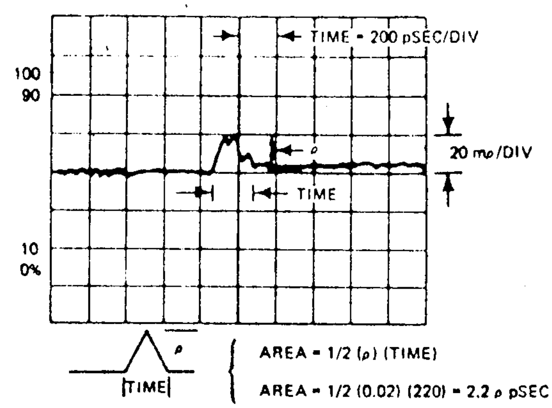


Fig 4—Reflection signature from 3-mm coax connectors measures 2.2ρ psec, compared with 0.9ρ psec for the hybrid connector.

a reflection coefficient (ρ) alone doesn't prove conclusive because that parameter doesn't include the reflection's time and shape. A more definitive description of the reflection considers its total area.

The TDR measurement of reflection from the stripline connector also includes reflection from the launch of the pulse at the coaxial-cable-to-pc-board interface and from impedance variations of the microstrip lines on the pc board (**Fig 3**). The reflection of the contact on the left equals 0.9ρ psec, while the one on the right (purposely misaligned) produces <1.9ρ-psec reflection. By comparison, TDR measurements of 3-mm coaxial connectors attached to semirigid coaxial cable yield a reflection of 2.2ρ psec (**Fig 4**). Only the two center divisions are important for comparing **Fig 3** and **Fig 4**.

Shape determines performance

Overall contact shape depends on the microstrip conductor widths at the interface between the pc board and hybrid. (Conductor width for a given impedance is a function of substrate dielectric constant.) A smooth taper best serves the transition from one width to another. **Fig 5** displays contact dimensions for one set of microstrip line widths. The contact is gold plated to minimize its resistance; gold is used on the conductors of the pc board and hybrid.

Measuring TDR performance vs misregistration with the contact displaced in both the X and Y directions helps optimize contact shape. Sideways displacement either +Y or −Y results in approximately equal reflections, but in the −X direction minimum reflections result with minimum overlap of the contact on the narrower microstrip line.

Typical measurements for well-aligned contacts are <0.8ρ psec, and a ±0.10-in. misalignment of the contact over the microstrip line yields a reflection of <1.8ρ psec. Measurements made at the limit of just barely making contact produce a reflection <2.5ρ psec.

The contact's excellent TDR performance results from its small size and the low-dielectric-constant elastomer that provides the contact force. (Conventional contact systems use metals to provide both the contact medium and the contact force; the latter metals cause parasitic inductance and/or capacitance that lead to undesirable reflections.)

A comparison of 4-point resistance measurements of the connector contacts pressed against a separated microstrip line with the resistance of a continuous microstrip line yields contact resistance <20 mΩ in all cases. This resistance, determined as a function of contact force by

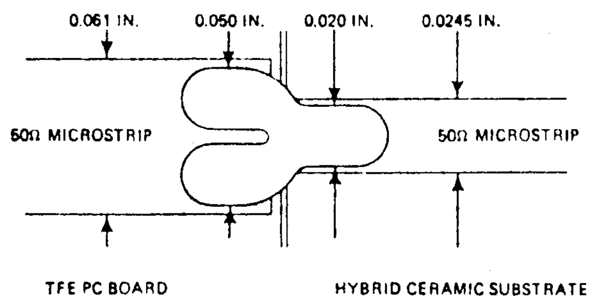


Fig 5—Contact shape for a pair of microstrip transmission lines is determined by the difference in stripline widths.

applying different loads to the connector frame and measuring frame deflection with a transducer, appears in **Fig 6.** The optimum operating range occurs just past the knee in the curve, because further deflection does not greatly improve contact resistance.

Will it take punishment?

The elastomer that provides the contact force has these characteristics:

- Low compression set (<10%) at −55°C to 125°C
- Low dielectric constant (3-3.5)
- High volts/mil breakdown (600-650)
- Adaptability to fabrication by transfer molding (comes premixed with catalyst that reacts at molding temperature)
- Resistance to failure at high and low temperatures (−55 to +125°C)
- Adherability to metals
- Resistance to most chemicals, including acids
- Low outgassing
- Compatibility with other materials
- Good ozone resistance
- Low moisture absorption
- Suitable compression characteristics (50 durometer).

In the connector's mated state, the actual electrical contacts are small areas tangent to the contact's serpentine cross section. The length of these two contact areas measures about 0.05 in. Approximate contact force results from calculating the pressure at the elastomer/hybrid-pc-board interface (approximately 17.5g) and assuming that each contact experiences this pressure.

Improving switch performance

Connectors in HF instruments don't constitute the only potential block to improved performance; switches, too, can contribute a limiting factor. You can compensate for feedthrough holes and corners in the transmission line, but existing switches add significant reflections to a system; if you use several over the length of the signal path, you'll clearly require an improved unit to keep reflection low.

Fig 7 shows a standard switch now used in medium-frequency applications. Its spring member, riveted to the circuit board, is soldered to maintain alignment, and the actual metal contact has two bifurcated fingers to make and break contact with the transmission line. The contact remains insulated from the spring member by a nonconductive plastic cam follower molded between and joining them, an arrangement that minimizes extraneous metal on the transmission line that would lower the coupling capacitance.

At increasing frequencies, some of this switch's shortcomings become apparent. One is the

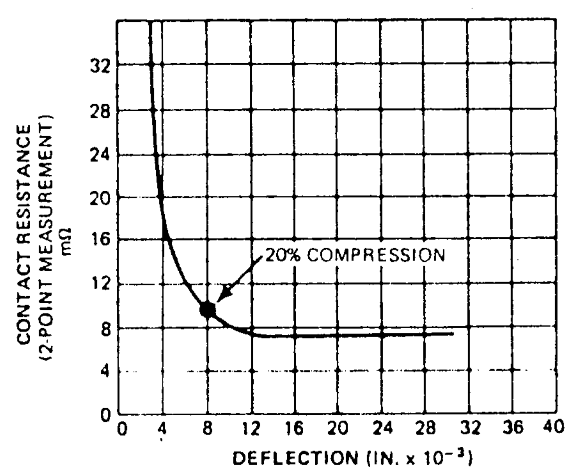


Fig 6—A 20% compression optimizes contact resistance in the hybrid connector.

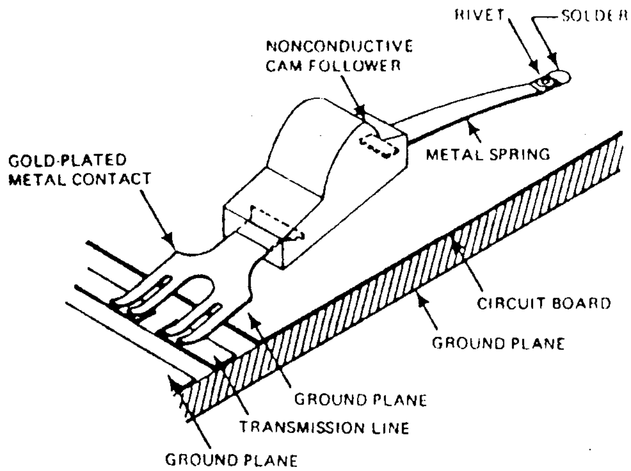


Fig 7—Standard medium-frequency switch incorporates two right-angle turns that add reflection to the transmission line.

reflection caused by a signal's sudden 90° turn in going from the transmission line up the bifurcated fingers, as well as the 180° turn required to return to the transmission line. Another is the capacitive coupling that occurs between the contact and the underlying ground plane, both through air and to the metal spring member through the plastic cam follower.

An "ideal" contact would exploit the same concept as the "ideal" connector: minimum metal placed over the strip line at the break in the path. The problem with implementing this design has been producing a switch to open and close the gaps.

Previous work with silicone elastomer focused on making such elastomer conductive by compounding it with conductive additives. But high frequency matched-impedance requirements can't accept such loaded elastomers because of their high and varying contact resistance. The metal-to-nonconductive-elastomer process allows approximation of an ideal contact, however.

Compatibility with existing systems

Extending these encouraging results requires that the new switches work with existing cam systems. Usable existing cams have a throw or lobe height of 0.034 in.; cam-lobe spacings along the cam's length measure 0.100 and 0.125 in. The maximum distance between the transmission line and the cam in open position equals 0.122 in., and some amount of wipe is required between the mating surfaces. To meet this requirement, the metal is formed in an arch with ends flat or with a slight radius to prevent its digging into and damaging the contact pads. Force must be transmitted through the back of the elastomer, centered over the arch in the metal, and to minimize this required force, a press-together or snap-together assembly is desirable.

A production design **(Fig 8)** has two main parts, both large enough to handle with your fingers, thereby avoiding complex assembly operations.

The switch's hanger forms the frame for the elastomer; it's suspended by slipping it into holes spaced correctly along the length of side rails running alongside a cam drum. A cantilever beam molded in a neutral position is not preloaded against the cam, and the underside of the cam follower contains a locating hole. The locating posts are long and pointed on one side to allow easy insertion in the side rail; they're shorter on the opposite side to allow a snap-in fit in the other side rail with minimum flexing. With the hanger suspended off the circuit board, the valuable unused real estate can accommodate sensitive signal paths or even thin components.

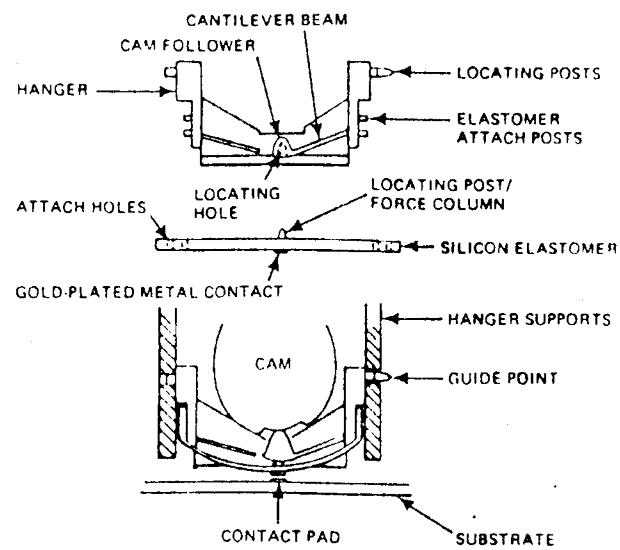


Fig 8—Elastomer-based cam switch minimizes reflection by using a contact to bridge the gap in the transmission line.

The elastomer that carries the gold-plated contact is stretched from both ends rather than cantilevered as in earlier test models; it attaches to and grips two attach posts on each side of the hanger. Directly above the contact's center on its back side sits a molded locating post/force column with a spherical radius to slip into the locating hole and thereby help ensure correct location of the metal contact during operation. This elastomer column provides a much greater compression of the elastomer without the force's

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Some environmental specs

During their development, the connectors underwent several environmental tests. The first series exposed them to environmental conditions imposed on portable oscilloscopes:

- **Ambient temperature.** Operating: −15 to +55°C, storage: −55 to +75°C
- **Altitude.** Operating: to 15,000 ft, nonoperating: to 50,000 ft
- **Vibration.** Operating: 15 min along each of the three axes, 0.025-in. p-p displacement (4 g's at 55 Hz) 10 to 55 to 10 Hz in 1-min cycles
- **Shock.** Operating and nonoperating: 30 g's, 1/2 sine, 11-msec duration, 2 shocks/axis in each direction for a total of 12 shocks
- **Humidity.** Operating and storage: 5 cycles (120 hrs) to 95% relative humidity referenced to MIL-E-16400F (per 4.5.9 through 4.5.9.5.1, class 4).

Additionally, researchers measured contact resistance over 300 cycles of mating and unmating. The average of contact resistance over this period measured 13.78 mΩ with a standard deviation of 0.99 mΩ.

The connectors were also subjected to long-term storage at 50°C and 70% relative humidity. Interestingly, contact resistance generally decreased during the first month of storage, increased slightly during the next four months and then became constant. Average change of contact resistance over 5000 hrs measured 3.13 mΩ with a standard deviation of 1.06 mΩ. In severe tests consisting of 400 g's, 1/2 sine for 1/2 msec, 1 msec and 2 msec in each of the six directions, no failures occurred.

Finally, the connectors underwent a moisture sulfide test, which attempts to accelerate changes in electrical characteristics of metal components that could cause poor electrical connection. Samples were exposed to 24 hrs of high-humidity condition per MIL-STD-202C, Method 106B (omitting steps 7a and 7b), followed by 24 hrs of sulfide atmosphere, followed by 192 additional hrs per MIL-STD-202C, Method 106B humidity conditions and were then allowed to dry at room temperature for 24 hrs. Contact resistance measured before the test and after the drying period showed an average change of 0.87 mΩ with a standard deviation of 0.67 mΩ.

exceeding specified limits. The mild stretch of the elastomer from one side down to the cam follower and up to the other side provides the restoring force required to ensure reaching the full-open position.

Elastomers implement relays, too

A third application of the metal-to-nonconductive-elastomer technique implements a high-frequency, dpdt latching relay used primarily in an attenuator circuit; the attenuator consists of microstrip transmission lines and attenuator elements (resistors) that the relay switches in or out. Electrical data for the cam switch and planar connector contact apply to this design also. Supporting the metal-to-elastomer contacts with a plastic rocker minimizes unwanted metal near the contact area, thereby reducing shunt capacity to ground.

The component parts of the relay include four metal-to-elastomer contacts, two coils in series or parallel, two coil cores (iron), two shaped pole pieces (iron), two bar magnets (alnico), one relay frame (iron), one rocker (plastic), one rocker pin (iron) and one pole-piece separator (brass). These parts assemble as shown in **Fig 9a.**

You switch the relay by applying a magnetic field to repel the permanently magnetized armature from one pole piece and attract it to the other. Opposite-position switching occurs when you reverse the polarity of the voltage; one 0.018 W-sec pulse switches and latches the relay in either position. If you require additional contact pressure, you can energize the coils continuously at up to 0.5W. Switching time equals 2.5 msec.

The relay's armature is really two armatures in parallel; it provides greater efficiency and better balance, both magnetically and mechanically. The rocker pivot pin performs a dual job; it supports the rocker armature to the relay frame, and it completes the magnetic circuit from the relay frame to the bar-magnet ends of the armature. The overall assembly measures 0.650 in. high (minus mounting pins)×0.550 in. wide×0.620 in long.

An elastic future

The nonconductive elastomers, though still new, offer many additional design possibilities, both for designers and end users. To the former,

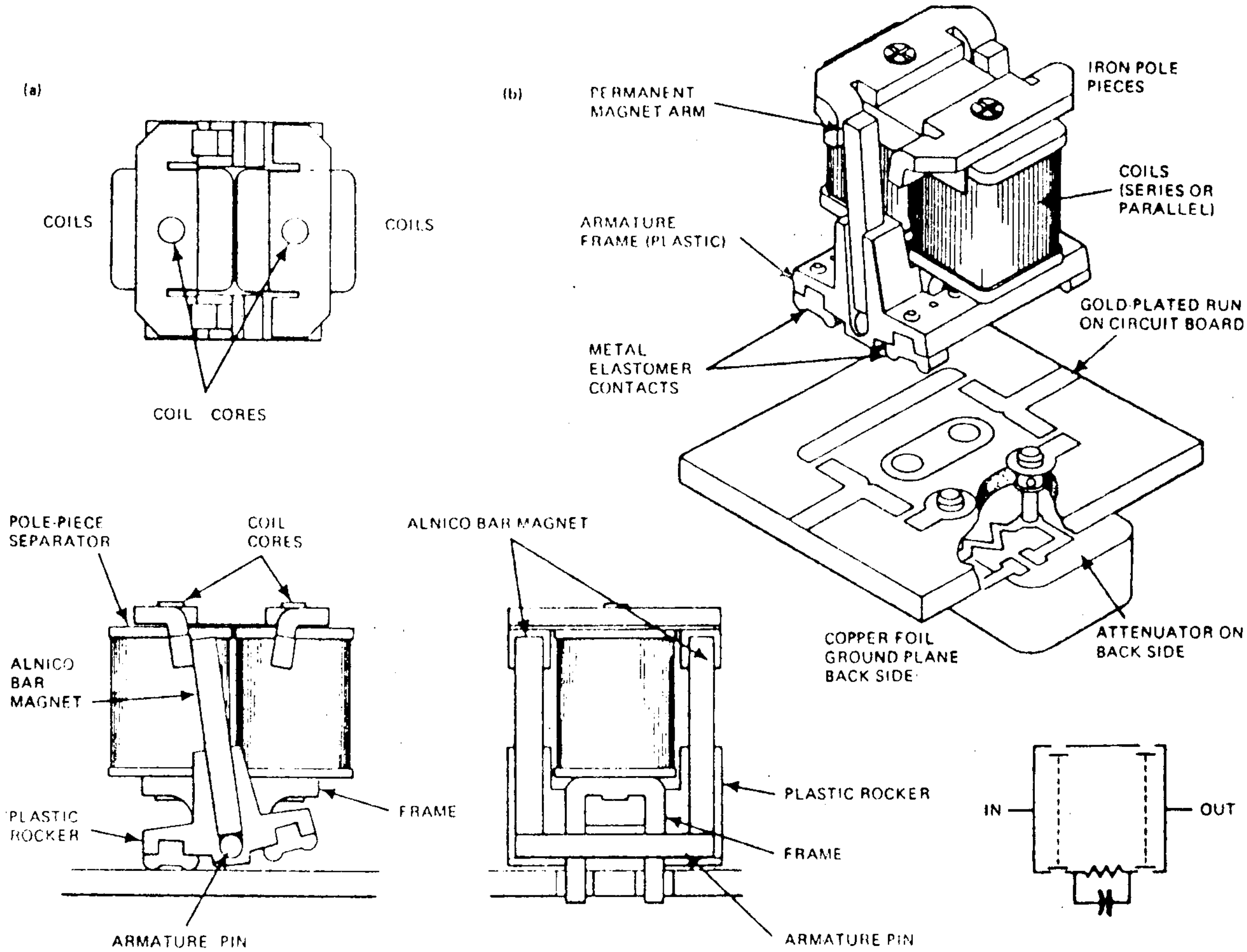

Fig 9—Elastomer-based latching relay switches on a 0.018 W-sec pulse.

they bring solutions to both cost and performance problems that have arisen for years. To the latter, who use new equipment incorporating these solutions, they provide high-performance test instruments with affordable price tags and improved reliability and maintainability. □

ELASTOMER SWITCH FOR 067-0587-02

GENERAL INFORMATION

The elastomer switch assembly is a new and special design peculiar to the instrument. The movable switch contacts are on the opposite side of the board from the cam drum. There are thirty-six (36) movable gold plated contacts that are held in position by thin elastomer strips and actuated in pairs by actuators that extend from the closing spring at one end, through clearance holes in the circuit board, to the cam on the other side of the board. The actuators are positioned at each end by alignment holes in the cover plate and in the board support.

The spring fingers load the actuators so that the contacts are in the "normally closed" position. The cam logic holds the contacts in the open position. There is no actuator under the ninth (from the front) spring finger, so this spring should always rest in a lower position than the others when the switch is installed.

The switch assembly (263-0032-00) has to be assembled using a special fixture to properly hold the eighteen (18) actuators while the cover plate and springs are installed. For this reason the switch itself cannot be disassembled in the field. There are "caution--do not remove" warnings etched into the springs by the 2-56 screws that hold the switch together. Damaged or defective switch assemblies must be replaced with a new unit.

The elastomer/contacts are to be handled with care. Avoid rubbing the contacts against anything during the time that it is not installed to the board. The elastomer strips could be torn if they become caught on other components.

Care must be used to see that the force column (elastomer)

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is properly seated in its socket in the actuator. Rough handling can unseat the post and contact will move out of proper position because the actuators rely on alignment from the board support. When installed, the switch contacts may appear to be slightly out of alignment. This condition also shows up by the cam end of the actuators not all being parallel to each other.

The cleaning called out in the manual must be stressed. Fibers caught on edges of the plated pads or contacts must be removed before reassambly. Also, it cannot be stressed enough that care has to be taken with <u>all</u> switch contact surfaces to see that contaminates are not left on these areas. Soapy solutions (which contain corrosives) can even be transferred from our "dry" hands to the switching surfaces. For reasons like this, the actual elastomer/contacts and switching runs on the circuit board should not be touched. During the wash procedure, be sure that the switching runs on boards are rinsed thoroughly.

When checking the switch contacts, it should be understood that there should be a slight (.004 and .001) concave curve to the metal contact. If a contact somehow gets pinched or loaded in a way other than as designed, a reverse bend could result. This could cause an open condition. Such contacts will require the entire switch to be replaced.

Switches returned from the field are to be sent, along with a written description of the problem to: High Frequency Component Development - Ed Strande - 39/353. Please try to state environmental conditions instrument was used in.

<u>ELASTOMER SWITCH</u>

The TEST switch in the Signal Standardizer is a cam-operated elastomer switch. The cam and the elastomer switch attach to opposite sides of the circuit board.

The elastomer switch can be cleaned or replaced by service personnel. It can be repaired only at the factory because the delicate elastomer/contacts require a highly accurate fixture for reassembly.

To clean or replace the elastomer switch, proceed as follows.

NOTE

Do not clean the elastomer switch while it is assembled to the circuit board.

1. Check for obvious damage or malfunctioning of visible parts - cam, flex coupler, spring fingers, etc.
2. Set the TEST selector to Vert or Horiz GAIN position.
3. Hold the elastomer housing against the circuit board while removing the four 4-40 screws that hold the switch to the circuit board. Do not loosen the six 2-56 screws.
4. Remove the elastomer switch by lifting it perpendicularly away from the board.
5. Loosen the two set screws that hold the shaft in the flex coupling on the cam assembly.
6. Remove the cam assembly.
7. Inspect the switch pads on the circuit board and clean them with a solution of 5% Kelite Spray White, 5% non-soapy non-sudsing ammonia, and water. Then rinse with isopropyl alcohol. Let set for 60 seconds, then blow off with compressed air. Oven dry if required. Do not lubricate the contact pads--they are designed to operate dry. Do not scrub or wipe the contact pads with anything, such as a cotton swab, that could leave fibers caught on the edges of the strip-line. Check the soldered crossover line for continuity and shorting to the line beneath it.
8. Inspect the gold-plated contacts and elastomer parts in the switch housing. If there are any damaged parts, the assembly should be replaced with another assembly, Tektronix Part No. 263-0032-00, because of the assembly fixturing required.

9. Clean the elastomer contacts, if necessary, by very lightly and carefully scrubbing with a small brush and isopropyl alcohol. Do not use anything that could leave fibers or other material on the contacts. Carefully blow off the excess alcohol and allow to dry. Be very careful not to dislodge the elastomer strips from their proper positions by unseating the elastomer force columns from the sockets in the inner and outer actuators.
10. To reassemble, orient the switch so that the numbers 2 and 4 on the end of the spring plate are toward the front of the instrument. As another proof of correct orientation, verify that the two groups of actuator posts (there are groups of eight and ten posts) go into the two groups of holes of the same numbers. (The switch cannot be installed backward.) Be careful not to touch or abrade the elastomer/contacts. Bring the switch housing to the board as perpendicular as possible. If necessary, use a probe from the other side of the board to quide the actuator posts through the holes in the board. Be careful not to damage the elastomers or the actuator posts with the probe.
11. While holding the elastomer switch against the circuit board, position the cam over the locating holes and actuator posts. Push the cam perpendicularly down onto the circuit board. Torque each 4-40 retaining screw to three inch-pounds in the sequence given by the numbers on the metal spring plate.
12. Set the TEST knob to the Vert or Horiz GAIN position, locate the knob about 1/32" from the front panel, and tighten the set screws that retain the shaft to the switch couplet.
13. Rotate the TEST switch to the extremes of its travel to verify that you have properly indexed the knob.

HYPCON CONNECTORS

HYPCON CONNECTOR SYSTEM

INTRODUCTION

Two of the most challenging problems in hybrid design are: a) connection of the hybrid to other circuitry and b) dissipation of heat. This paper describes a new connector system for physically and electrically joining hybrids to circuit boards. It is called a "connector system" because in addition to being an electrical connector, it is also a thermal connector, providing for thermal dissipation by conduction.

DESCRIPTION

Just as in printed circuit board (PCB) technology, the hybrid substrate serves to interconnect passive and active components. One of the main reasons for using hybrids is to reduce the number and length of component leads, thereby reducing unwanted parasitic reactances. However, when one attempts to connect a hybrid to a conventional PCB the problem of unwanted lead parasitics into and out of the hybrid arises once more. Furthermore, the components have been crowded together and the power density has increased. What is needed is a way to connect hybrids to other conventional circuitry such as printed circuit boards while also providing a means of heat removal.

The HYPCON (hybrid-printed-circuit-connector) connector was developed to solve these problems.

Additionally, the HYPCON connector can provide high connection density at low insertion force; is easy to mate and unmate, and is potentially economical to produce.

The basic elements of the HYPCON are: a) a shaped metal contact backed with an elastomer to provide resiliency and contact force; b) a supporting injection-molded plastic frame; and c) a metal

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sheet which serves as electrical ground plane and heat sink. Connection between conductors is made by applying pressure with the frame to the elastomer from above as shown schematically in Figure 1. The ground planes of the printed circuit board and the hybrid are shorted together by means of the metal sheet and heat is removed by conduction through the metal sheet to the ultimate heat sink.

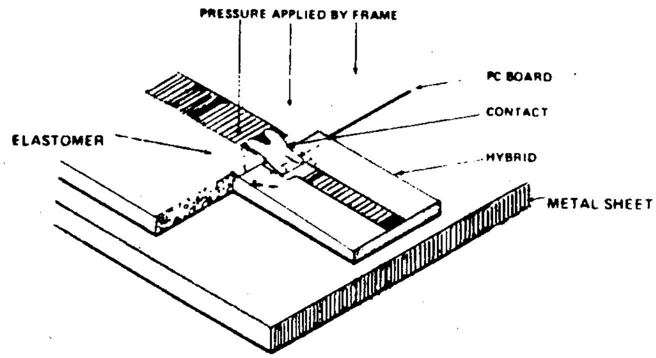

Figure 1. Diagramatic View Of The Flat HYPCON And Basic Elements.

CONTACTS

Contact Fabrication

HYPCON contacts are made using a technique similar to the photographic fabrication of printed-circuit boards. The process steps are:

1. Pattern-plate beryllium copper with gold over nickel to the desired contact shape.
2. Under the correct conditions of time, temperature, and pressure transfer-mold the elastomer and contacts to the desired topology.
3. Chemically etch away the unwanted metal (the gold plating on the contact acts as the resist).

Flat and Stepped Configuration

The HYPCON connector has evolved into two basic configurations. The flat configuration (Figure 2) is for hybrids that have high power densities and thus develop considerable heat that must be dissipated.

Heat is removed from the hybrid by conduction to the metal plate which in turn, transfers the heat by conduction to the chassis or by convection to the surrounding air. The flat configuration requires a square hole in the PCB which must be the same thickness as the hybrid.

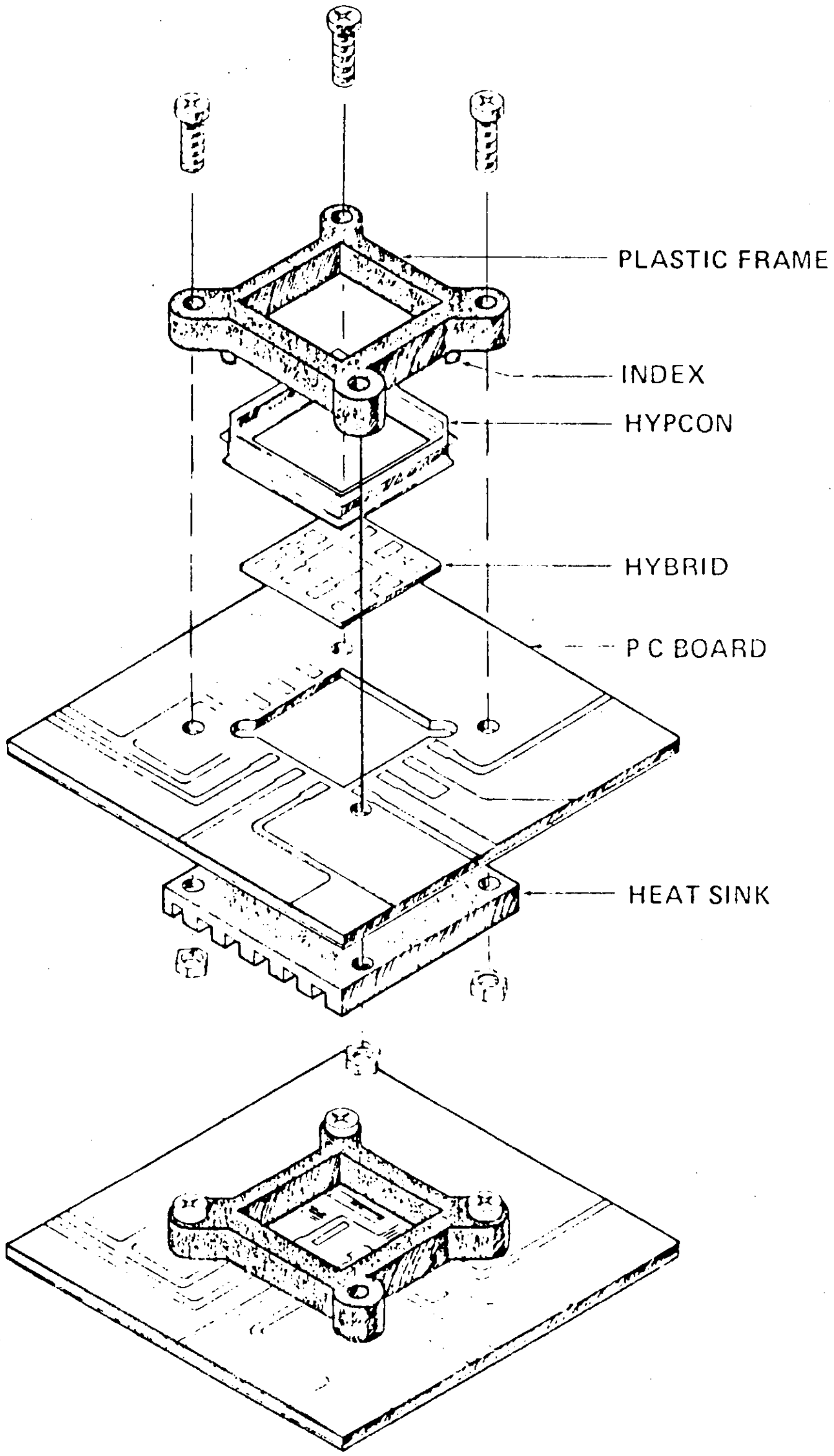

Figure 2. Flat HYPCON Assembly.

In the stepped configuration (Figure 3), the hybrid lays on top of the PCB, which may be of any thickness, eliminating the necessity for cutting a square hole for the substrate. This design is for low power density hybrids. Heat is removed from the hybrid by conduction to the ground plane of the PCB and by convection of the surrounding air.

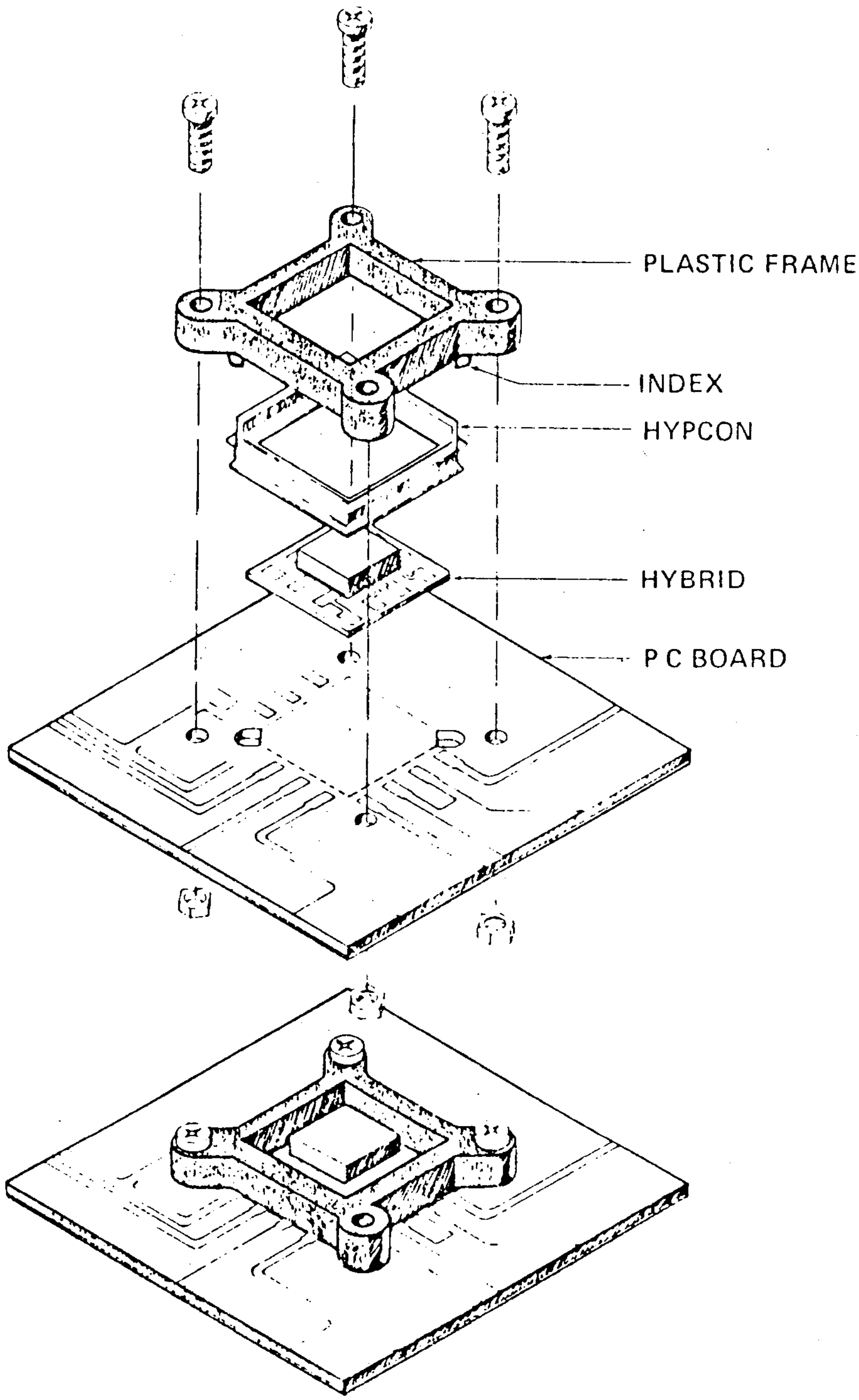

Figure 3. Stepped HYPCON Assembly

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A thermal and reliability analysis of the hybrid halps the designer in detemrining which HYPCON configuration is most suitable for his particular use. In general, the stepped HYPCON configuration is used with hybrids that have less than 1/2 watt power dissipation, and the flat configuration for hybrids of greater than 1/2 watt power dissipation.

Contact Features

Contact shape is dependent on conductor width at the PCB and hybrid. The bifurcated contact shown in Figure 4 is one of many shapes possible. The contact is gold plated and gold is used on the conductors of the PCB and hybrid. The net result is low contact resistance and compatible metal interfaces even in extremely hostile environment.

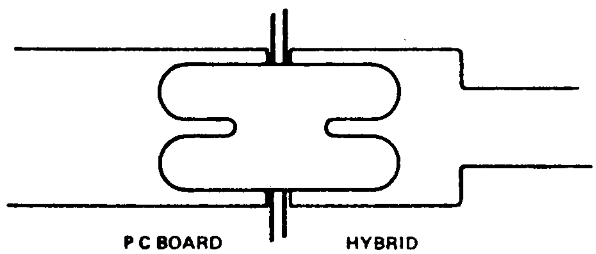

Figure 4. Contact Shape

The serpentine cross section of the FLAT HYPCON contacts (Figure 5) is formed by hydraulic pressure during transfer molding.

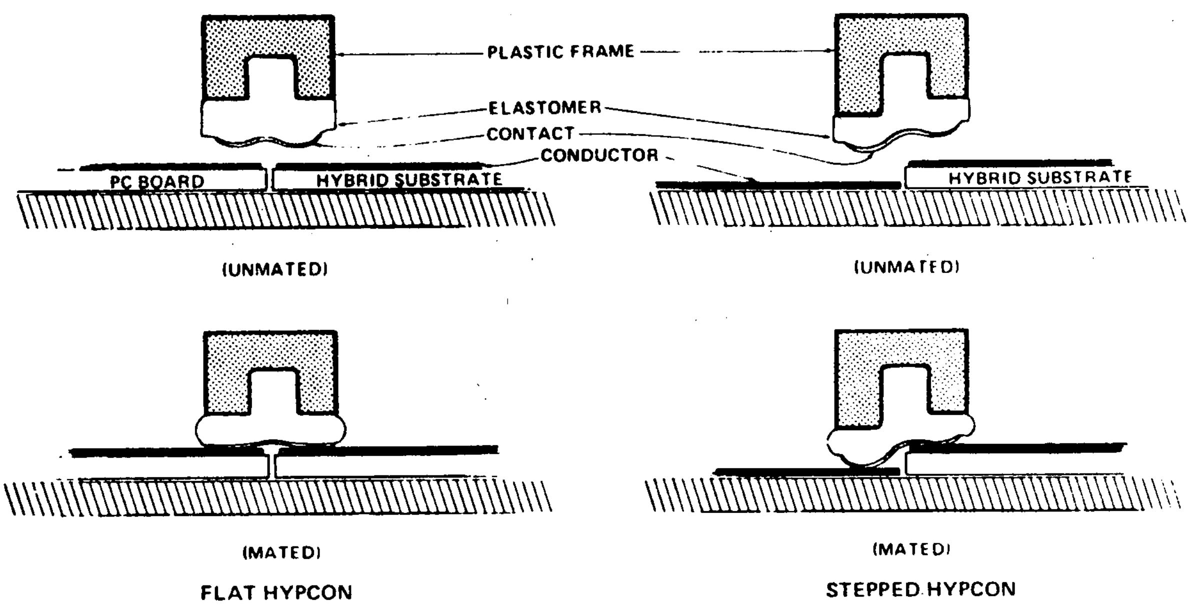

Figure 5. HYPCON System Cross Section

Elastomer Features

In conventional contact systems metal springs provide ocntact force. In the HYPCON system, the elastomer provides the contact force.

The elastomer has the following characteristics:

- Low compression set (10%) at -55°C to +125°C.
- High volts/mil breakdown (600-650).
- Easily adaptable to fabrication by transfer molding. (Comes premixed with catalyst that reacts at molding temperature.)
- Withstands high and low temperatures (-55°C to +125°C).
- Adheres well to metal.
- Resistant to most chemicals, acids included.
- Low outgassing.
- Compatibility with other plastics and materials.
- Excellent ozone resistance.
- Low moisture absorption.
- Suitable compression characteristics (50 durometer).

Contact Resistance

Four-point resistance measurements of the FLAT HYPCON contacts against a separated conductor were compared with the resistance of a continuous conductor as shown in Figure 6. A constant current was injucted at the point marked (I) on the upper pattern and voltage was measured between points A and B with a high-impedance voltmeter. Resistance between A and B was calculated by dividing the voltage by the current. The measurement was repeated on the lower pattern. The difference was taken as the contact resistance. The HYPCON contact resistance was found to be less than 20-milliohms in all cases.

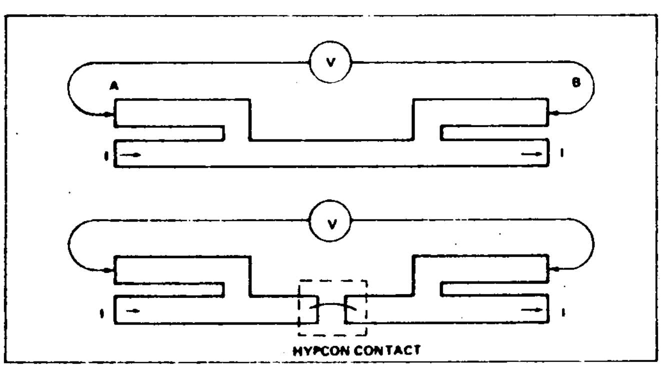

Figure 6. Diagram--Four-Point Resistance Measurement Test Fixture

Because contact resistance is an important property, it was measured as a function of contact force by applying different loads to the HYPCON frames and measuring frame deflection with a transducer. A curve of deflection versus contact resistance was generated (Figure 7). The optimum operating range is just past the knee in the curve since further deflection does not greatly reduce contact resistance.

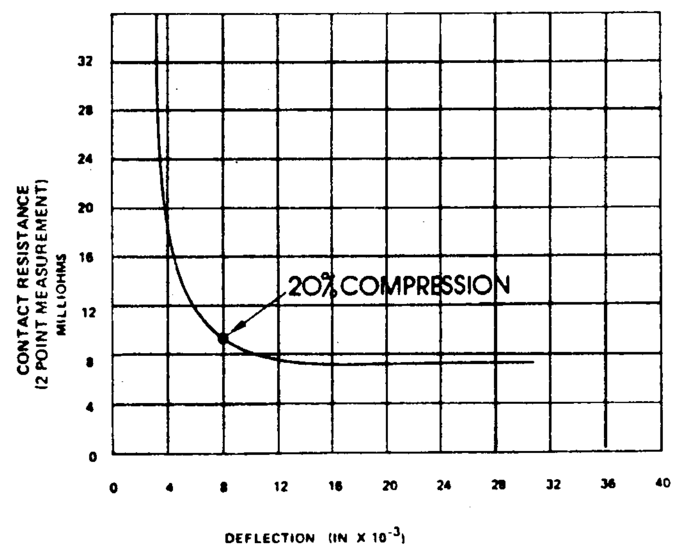

Figure 7. HYPCON. Resistance Versus Deflection.

Contact Force

The elastomer in the unmated state is 0.040-inch thick. In the mated state it is compressed to 0.032-inch, a compression of 20%. With the 20% compression, there are many factors that enter into the determination of contact force. One is the geometric design of the elastomer. The elastomer cross section was designed so the center web is slightly taller but the same width as the slot in the plastic frame it keys into. Thus, when force is exerted in the downward direction at mating, the contact tends to flatten with a wiping action.

Another factor is the contact size. In the mated state, the actual electrical contacts are small areas tangent to the serpentine cross section of the contact. The length of the two electrical contact areas is estimated to be approximately 0.05-inch.

Contact force was approximated by calculating the pressure between the HYPCON/hybrid-PCB interface with the equation shown below, assuming that each contact experiences this pressure.

$$\text{Interface pressure (psi)} = \frac{\text{load (lb)}}{\text{total interface area (in.}^2\text{)}} \qquad (1)$$

The contact force of each contact is then the product of the interface pressure and the individual contact area. With a typical load of 6.0-lb., a 0.1123 inch^2 total interface area and an individual contact area of 7.2×10^{-4} inch^2, the contact force is estimated to be 0.61 ozs. (17.5 gms.).

The plastic frame which provides the contact force, is bolted on through holes in its four corners. Positive stops are provided to give the proper compression to the elastomer-backed contacts and to prevent over-tightening of the mounting bolts.

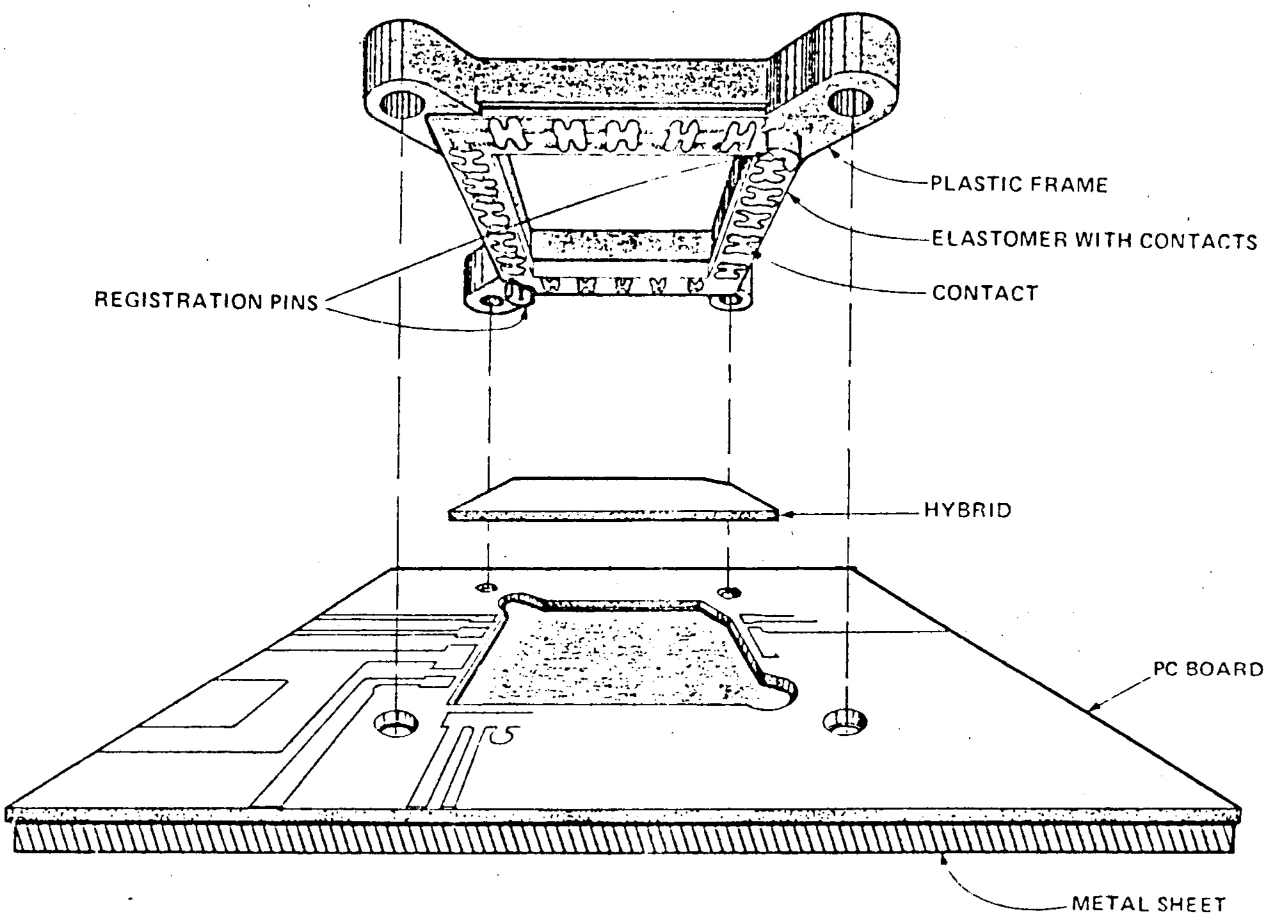

Figure 8. Exploded View Of HYPCON Connector System.

FLAT HYPCON Registration Features

The contacts are registered to the elastomer which is an inverted "T" shape that keys into the plastic frame. The plastic frame has registration pins that key into round holes in the PCB. The pins also key the corners of the square hybrid substrate (Figure 8) which fits precisely into the square hole in the PCB. The assembly mounting screws pass through clearance holes in the plastic frame and do not contribute to registration.

The conductors on the PCB are aligned to the round registration hole and the conductors on the hybrid substrate are registered to the substrate edges.

The above registration features minimize misalignment of the contact to the conductors. In the worst case dimensional analysis, the tolerance stack-up from the contact to the conductors is less than +0.012-inches. The normal misalignment observed is less than 0.010-inches.

Stepped HYPCON Registration Features

The registration scheme is the same as for the flat configuration except that the pins in the corners capture the hybrid and then register the hybrid to the PCB at mating.

Thermal Performance

Thermal predictions and measurements were made for both an alumina and beryllium oxide substrate as shown in Figure 9. The thermal impedance from a semiconductor die to the metal ground plane in the flat HYPCON design depends on die size. The curves in Figure 9 are for substrate flatness of 0.004-inch per inch.

Environmental Performance

During the development state, HYPCON connectors, mated to a PCB and hybrid, were subjected to a number of environmental conditions imposed on portable oscilloscopes as follows:

- Ambient Temperature--Operating: $-15^{\circ}C$ to $+55^{\circ}C$.

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Storage: $-55^{\circ}C$ to $+75^{\circ}C$.

- Altitute--Operating: to 15,000 feet. Non-operating: to 50,000 feet.
- Vibration--Operating: 15 minutes along each of the three axes, 0.025-inch peak-to-peak displacement (4 g's at 55 Hz) 10 Hz to 55 Hz to 10 Hz in 1-minute cycles.
- Shock--Operating and non-operating: 30 g's, 1/2 sine, 11-ms duration, 2 shocks per axis in each direction for a total of 12 shocks.
- Humidity--Operating and storage: 5 cycles (120 hours) to 95% relative humidity referenced to MIL-16400F (par 4.5.9 through 4.5.9.5.1, class 4).

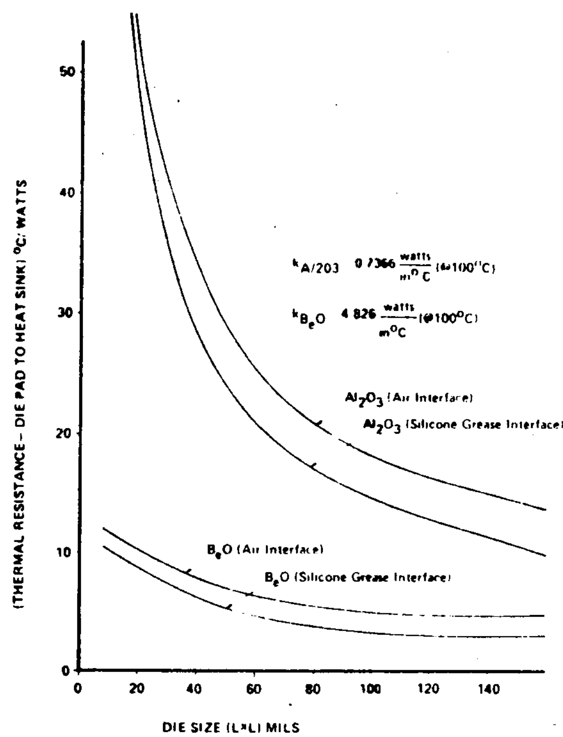

Figure 9. Thermal Resistance Versus Die Size.

Additionally, HYPCON contact resistance was measured over 300 cycles of mating and unmating. The average increase in contact resistance for 300 cycles was 3.78 milliohms with a standard deviation of 0.99 milliohms.

The connectors were also subjected to long term storage at $50^{\circ}C$

and 70% relative humidity. Interestingly, the contact resistance decreased during the first month of storage, increased slightly during the next four months and then became constant. The average increase in contact resistance over 5000 hours was 3.13 milliohm with a standard devistion of 1.06 milliohms.

In an attempt to severely test the connector, it was subjected to 400 g's, 1/2 sine wave for 1/2 millisecond, and 2 milliseconds duration in each of the six directions. No failures occured.

Finally the connectors were subjected to a moisture sulfide test. The purpose of the moisture sulfide test is to accelerate changes in electrical characteristics of metal components which sould cause poor electrical connections. Samples were exposes to 24 hours or high humidity condition per MIL-STD-202C, Method 106B (omitting steps 7a and 7b); followed by 24 hours of sulfide atmosphere; followed by 192 additional hours per MIL-STD-202C, Method 106B humidity conditions; and allowed to dry at room temperature for 24 hours. Contact resistance was measured prior to above test conditions and after the 24-hour drying period. The average increase in contact resistance was 0.87 milliohms with a standard deviation of 0.67 milliohms.

Assembly and Disassembly Features

The fact that no soldering is required for any assembly or disassembly of hybrids when using the HYPCON connector system has many advantages:

- The hybrids do not have any flying leads to become damaged in handling.
- No leads to attach means one fewer assembly step, thus lower overall cost.
- Installation of a hybrid in a PCB is fast because only four screws are involved.
- Field replacement of a hybrid is easy.

CARE AND HANDLING OF HYPCON CONNECTORS

The Hypcon connector is a precision-made connector designed to provide low loss electrical and thermally efficient connection between the printed circuit board and hybrid integrated circuit. Care must be taken when replacing the hybrid IC's not to touch the elastomer gold-plated contacts with the fingers or to use a cleaner which will degrade the conductivity of the contacts. The Hypcon connector and hybrid IC should be removed if it becomes necessary to use a cleaning solvent near the connector when replacing adjacent (within ½") circuit board components. IMPORTANT: Remove all traces of solder flux or foreign material contamination from the circuit board contact area before replacing the connector. Contamination usually takes place during the soldering and cleaning processes. Even when the soldering is done carefully, flux, oil or other contaminants can be carried into these devices during the cleaning operation. When the solvent evaporates, non-conductive contaminants may remain on or near the contact interfaces.

The cleaning process, either hand cleaning with a solvent or machine cleaning in an automatic detergent wash, is not recommended for boards containing Hypcon connectors.

If a component adjacent to a Hypcon connector must be replaced, the following steps are recommended.

1. Remove the hybrid IC and Hypcon connector before any soldering or cleaning and store in a dirt-free covered container. When several hybrids and Hypcon connectors are to be removed, keep parts together and replace as sets. Do not interchange parts.
2. Hand soldering
   a. Use small diameter solder (0.030" - 0.040").

   b. Use low wattage soldeirng irons (25 to 40 watts).
   c. Use care with flux amount and placement.
3. Remove solder flux and contact contamination with isopropyl alcohol.
4. Flush the hybrid and Hypcon connector mounting area with isopropyl alcohol. Do not scrub with a Q-tip, as cotton fibers will adhere to edges and surfaces of contact areas and cause open or intermittent connections. If the etched circuit board surfaces require more cleaning, scrub with a pink pearl rubber eraser and blow or vacuum clean while dusting surface with a small clean brush.
5. If the hybrid IC and elastomer contact holder are contaminated, clean the contact holder and hubrid by flushing or spraying with alcohol and oven dry (100°C). Do not scrub with a Q-tip or similar device. If the contact holder is excessively contaminated, replace it with a new one.

Two inch-pounds of torque should be applied to the coumting screws to secure the Hypcon to the circuit board.

Exercise care when mounting the frame-elastomer connector holder-hybrid IC assembly to the circuit board to prevent misalignment between the connector and board. Grasp the assembly at the hybrid with tweezers to facilitate correct alisnment of the plastic frame projections with the circuit board.

CAUTION

Because of close tolerances involved, special care must be taken to assure correct index alignment of each Hypcon part during reassembly. Failure to do so can result in damage to the parts when they are joined together.

If your instrument contains both the flush and stepped type of Hypcon connector be careful not to mix the elastomer contact holders during reassembly. The flush Hypcon connectors have green elastomer contact holders and the plastic frame is marked "FLUSH". The stepped Hypcons have neutral-colored elastomer contact holders with a slight ridge or step on the contact surface; the large frames are marked "STEPPED". The registration pins on the stepped plastic frame are slightly longer than those on the flush frame. The elastomer contact holder in the small stepped connectors is indexed differently than the large connectors. Look for a small gold arrow in one corner of the holder instead of a flat corner. Match this corner arrow with the pointed corner of the plastic frame. Give close attention to this indexing, as it is easy to insert the elastomer contact holder incorrectly.

Differences also exist between the large flush and large stepped Hypcon circuit board recepticles. The cross-sectional differences must be observed when working with an instrument that contains both types of Hypcon connectors. Damage to the elastomer contact holder can result if the connectors are not mated properly with the board receptacles. When replacing the flush-type hybrid, insert the hybrid in the board opening and then position the Hypcon connector in the board registration holes for perfect alignment. With the large and small-size stepped connector, assemble the connector and hybrid before installing on the circuit board. Use tweezers to hold the assembly by the hybrid "hat" and guide the frame registration pins into the circuit board openings. Avoid touching the hybrid and elastomer contact holder with your fingers; finger oils can degrade conductivity.

MICROCHANNEL PLATE
CRT

NEW ELECTRON OPTICS KEEP CRT'S IN THE FRONT OF THE PICTURE

by Dennis Hall

Predictions of the imminent demise of the crt have been prevalent for a considerable time and while LED, LCD, plasma and EL panels are slowly emerging for certain display applications, the crt continues to be the dominant quality display. This is particularly the case in high frequency, realtime waveform displays. Tektronix' latest contribution to this field is the 7104 general purpose oscilloscope employing a high resolution, high frequency, microchannel plate (MCP) based crt, the T7100. A modification of the crt, the T7101, was developed for the Energy Resource Development Administration (ERDA), to be used in nuclear diagnostic applications. While the MCP, which multiples a single electron entering a channel about one half million times, is the heart of these crt's, they also employ many novel electron optical features. These are the most sophisticated crt's ever committed to mass manufacture and reflect the confidence Tektronix has in the future of crt's.

MICROCHANNEL PLATE (MCP)

The microchannel plate is an assembled structure of microscopic conductive glass channels. The channels are paralled to one another with the entrance to each channel on one side of the plate and the exits on the other (Figure 1).

An electron entering a channel will produce secondary electrons as it strikes the channel walls. When a voltage potential is applied across the two main plate surfaces, that is, across the length of the channels, the secondary electrons will accelerate and themselves collide with the channel walls. This dislodges additional secondary electrons. The process cascades down each channel struck by the crt electron beam and results in a multiplcation of several thousand.

MCP's have been used in second generation image intensifiers for some time. Laboratoires d'Electronique at de Physique Appliquee (L.E.P.) in France has developed two MCP-based, high bandpass crt's, one of which has now been incorporated into a scope by Thompson C.S.F. In the past, MCP's have had short lifetimes. The MCP's in Tektronix T7100 crt's, however, are made using proprietary processes that eliminate this drawback. Rather than decreasing rapidly with usage, the gain of the MCP in these tubes remains constant or actually increases slightly with age. These same manufacturing processes also result in a fifty percent gain increase. The T7100 and T7101 CRT's employ the MCP in the proximity focus mode. The MCP is located about 0.3 cm from an aluminized screen, and with 12 to 15 kV applied across this gap, the spreading of the beam from the MCP is minimized. On the 7104 scope, the INTENSITY control adjusts MCP gain and beam current simultaneously in order to keep a solid trace at all settings. Without this precaution, the trace could take on a granular appearance when beam current was reduced or pushed toward its writing speed limit (3 - 5 GHz) in direct access mode. The graininess results from individual input electron and individual channel gain statistics. That is, at any instant, electrons are not deposited into every channel covered by the beam, and a channel previously excited by an electron will have a considerable gain variation from event to event. In designing a crt, writing speed is but one of the parameters that must be considered. The very large gain in writing speed provided by the MCP is useful in that part of it can be traded off in return for increases in resolution, bandwidth, and deflection sensitivity, and a reduction in unblanking requirements. The writing speed that remains after these trade-offs is still good for use at several Gigahertz.

SCAN EXPANSION LENS (SEL)

The first crt element behind the MCP is a variation on a classic quadripole lens design. The new design offers advantages in terms of both performance and manufacturing cost. The constraint of high bandwidth implies very low sensitivity deflection structures. However, the higher the bandpass of a crt, the more sensitive the deflectors must be. To achieve this, the crt is generally made quite long and the scan relatively small. For the desired scan size and sensitivity of the T7100, the crt, if made this way, would be over seven feet long. Of course this is not acceptable in a benchtop scope. Some novel techniques were used to shorten the actual crt. One was the use of a scan expansion lens. Classic quadripole lenses have been used for scan expansion in several crt's, including the Tektronix T7830. They are particularly advantageous when placed between the deflectors. The chief appeal of this lens is that is can easily be analyzed mathematically. Its liabilities are the need for exacting alignment and dimensional tolerances and the small aberration-free apperature-to-focal length (A/f) ratio off the axes of focus. In the T7100 and T7101, the scan expansion lens is functionally a quadripole lens. Yet by deviating from the classic quadripole architecture, considerable improvements were made. This lens is far less critical with respect to dimensional and alignment tolerances. It has about triple the off-axis aberration--A/f ratio, and allows one to correct a number of gain related geometry defects and to tailor the display linearity to very close specifications (typically one percent versus three percent for most other crt's). The deflection sensitivity in the negative axis of the lens can be adjusted over a range of about 20 percent. Another benefit of the scan expansion lens crt compared to a long crt is that the lens minimizes certain high frequency deflection artifacts stemming from the vertical deflector acting as a linear accelerator at very high frequencies.

The price of this improved capability and versitility is complexity. Whereas in its simplest form, the classic quadripole requires only two potentials, this lens requires up to seven. In operation, the SEL is a strong positive lens in the vertical axis and causes the beam to cross over or invert the vertical deflection (see Figure 2). The vertical scan is expanded four and a half times. In the horizontal axis, the SEL is a negative lens, which merely enhances the deflection of the beam. The horizontal scan is expanded four times (see Figure 3).

DEFLECTORS

The T7100 and T7101 crt's emply traveling wave (slow wave or delay line) deflectors in both axes. These are helical transmission line deflectors where the velocity of the input signals along the helical conductors is equal to the speed of light, but the phase velocity along the length of the helix is nearly matched to the electron beam velocity as it propagates along the helix. The reason for a slight mismatch of velocities is a slight dispersion of the signal in the helix. That is, not all frequencies propagate down the helix at the same speed. To obtain the best compromise in both the time and frequency domains, the beam velocity must be slightly mismatched to the theoretical helix phase velocity (the dispersion of these deflectors is small, resulting in only a two percent mismatch of velocities. The phase velocity and thus the beam velocity is about 0.1c for these deflectors. The helix crosses the beam, not at right angles, but at an angle with a tangent of 1/10. Thus, in the vertical deflector, each side of the beam is deflected by the same potential. As the signal propagates across the beam and in the horizontal deflector, all portions of the vertical scan are deflected equally. If the horizontal helix were not so inclined, there would be a twelve picosecond timing error between the bottom and top of the display, yielding a sweep speed dependent orthogonality error. The inclination of the helix in the vertical deflector eliminates beam defocus which otherwise occurs under high dv/dt conditions. Some high dv/dt defocus remains which is dependent upon the displacement of the beam from the horizontal center screen. This is the result of linear accelerator action upon portions of the beam by the deflectors. The effect is scarcely evident up to the 1 GHz bandpass of the

7104 oscilloscope, but due to the outstanding triggering of the scope, one can observe the effect abote 1.5 GHz.

The horizontal deflector employs much the same construction and impedance compensating techniques as the vertical deflectors of the Tektronix T7900 crt. It also has the same impedance, 365 ohms. The horizontal deflection sensitivity is less than 2 V/div (compared to 3 V vertical and 7 V/div horizontal in the T7900), and the bandpass is greater than 1.5 GHz, allowing 400 MHz response in the X-Y mode of the 7104 (Figure 4). The vertical deflector is a novel embodiment of the internal groundplane structure (Figure 5). This is an extremely rugged, low mass high-percussion design that requires no impedance compensation. The structure can be mounted into an otherwise finished gun and is easily salvaged from rejected crt's. The impedance is 200 ohms, line to line. Deflection factor is less than 1 V/div, and bandpass is about 3 GHz (Figure 6). The vertical deflector and its groundplane are silverplated to minimize skin losses. Connections to the vertical and horizontal deflectors are made through carefully spaced neck pins. The vertical deflector also employs stripline leadins between the deflector and the in/out neck pins. Both deflectors use external terminations.

GUN

While the gun design may appear complex, it is composed of simple parts (Figure 7). First, and immediately upstream from the vertical deflector is the beam limiting sperature. This contains the cross sectional profile of the beam in a field free region, to provide maximum current while minimizing the acceleration effect of the vertical deflector on the beam. Ahead of the aperature, there is a dedicated astigmatism lens. Usually, the astigmatism lens is created by a potential difference between the focus exit (second anode) element and the adjacent deflection plates. But because of the exacting requirements of the intermediate spot images, and because the vertical deflector with its internal groundplanes is not the last of the astigmatic lenses, a special low aberration astigmatism lens was developed. This lens is designed to act as a positive lens in the vertical axis with no effect in the horizontal. This condition of vertical overconvergence results from the requirements of the scan expansion lens. As noted earlier, the SEL is a strong positive lens in the vertical axis and a negative lens in the horizontal. If the beam is to be focused upon the MCP in the vertical axis, a real line image of the crossover must be formed before the SEL. In the horizontal axis, a vertical line image of the crossover is required after the SEL (Figures 2 and 3). Thus the beam is always more convergent in the vertical axis and required only vertical astigmatism control. In spite of considerably different optics in the vertical and horizontal axes, the design maintains the same magnification of the crossover in each axis to maintain a round spot on the screen.

The primary focus lens is of the classic einzel configuration, but considerable effort was made to minimize the aberrations of the lens in this application.

Preceding the focus lens is a stigmator lens, which is an extremely weak lens used to make slight adjustments to the axis of astigmatism. Rotational alignment errors between the deflection axes and the scan expansion lens produces a slight orthogonality error, which is easily corrected by the rotator coil (wound on a form on the crt neck) at the exit of the vertical deflector. Rotator coil correction disturbs the alignment of the axes of spot focus to the SEL, so the stigmator makes correctional rotational adjustments of the axes of focus.

Another device used to shorten the crt is a crossover demagnification lens. This lens produces a real image of the crossover about halfway between the diode and the primary focus lens. The demagnification factor for the T7100 and T7101 crt's are respectively 5 and 6.5 times, and the focus element for each operates at cathode potential. Since this lens operates in a demagnification mode, its aberrations are insignificant, but it has the effect of increasing the magnification of the primary focus lens with the result of roughly doubling the aberration of that lens.

ION TRAP/VACUUM PUMP

The final innovative feature of these crt's--and one which will probably be adopted in time by most crt manufacturers--is an ion trap/vacuum pump feature incorporated into the first anode barrel. Gas ions which might normally damage the cathode are drawn out of the anode and deposited upon a gathering or gas absorbing surface on the grid wafer. Since no change of operating voltage is required, this technique can be incorporated into most crt's. Besides improving cathode performance and life, inclusion of the ion trap/vacuum pump offers longer storage times in mesh storage crt's and improved signal-to-noise ratios in certain signal acquisition devices.

CATHODE

The cathode is a conventional oxide structure with a somewhat smaller than normal grid aperture. This is a proven design which provides more than adequate writing speed with 50 V of unblanking in the T7100 crt. For further writing speed enhancement, the grid may be unblanked to over 70 V as is done in the T7101. For easy reclaimability of the entire crt, the grid, cathode, and heater assembly can be easily removed or replaced intact.

Finally, in addition to the orthogonality coil wound on the neck of the crt, a graticule alignment coils is wound on the envelope of the glass ceramic interface, over the scan expansion lens.

SUMMATION

Far from heading from obsolescence, modern crt's continue to provide design challenges for displays of realtime events at bandwidths beyond one Gigahertz. Recent innovations, such as the improved MCP in the Tektronix T7100 and T7101 help crt's keep pace with advancing technology.

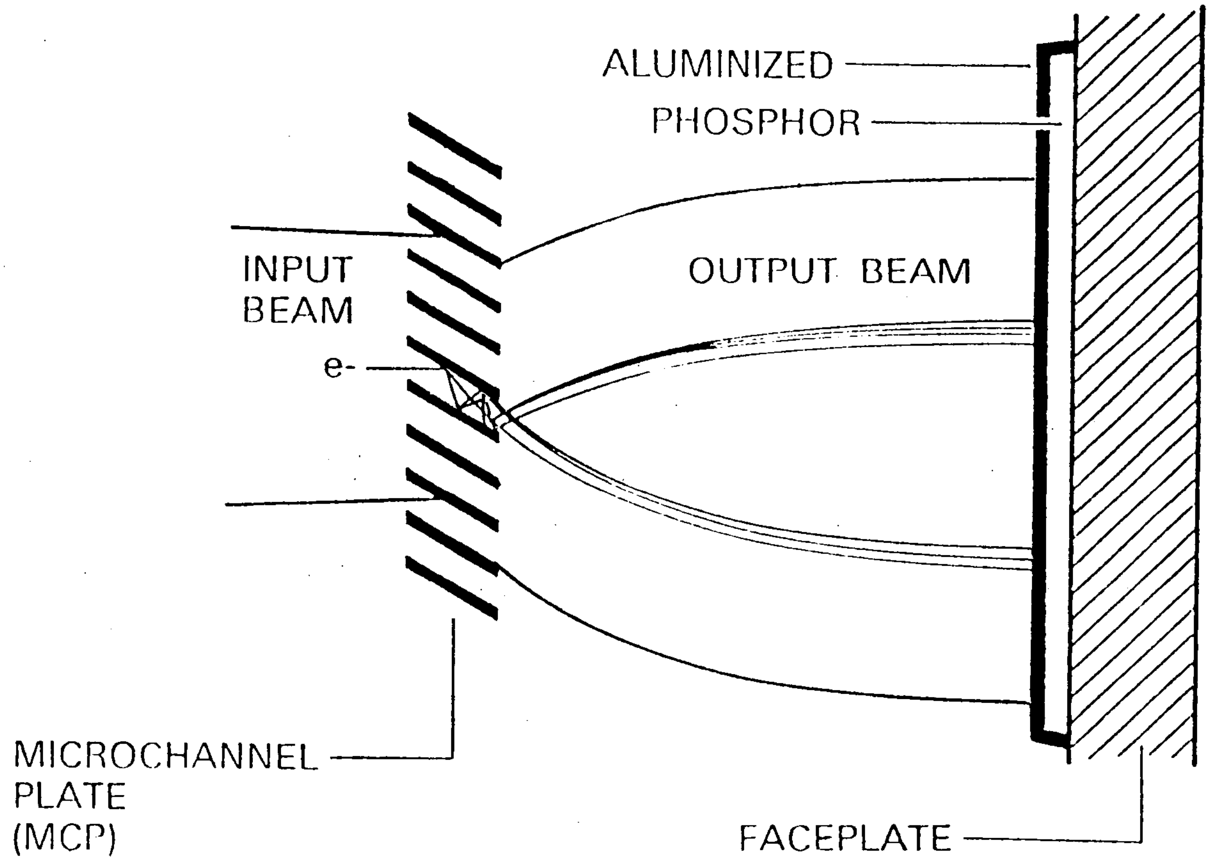

Figure 1. Proximity Focusing Of MCP Beam. The T7100 and T7101 crt employ the MCP to multiply by about 500,000 times the single electron entering a channel. Proximity focusing minimizes parabolic trajectory to limit beam expansion.

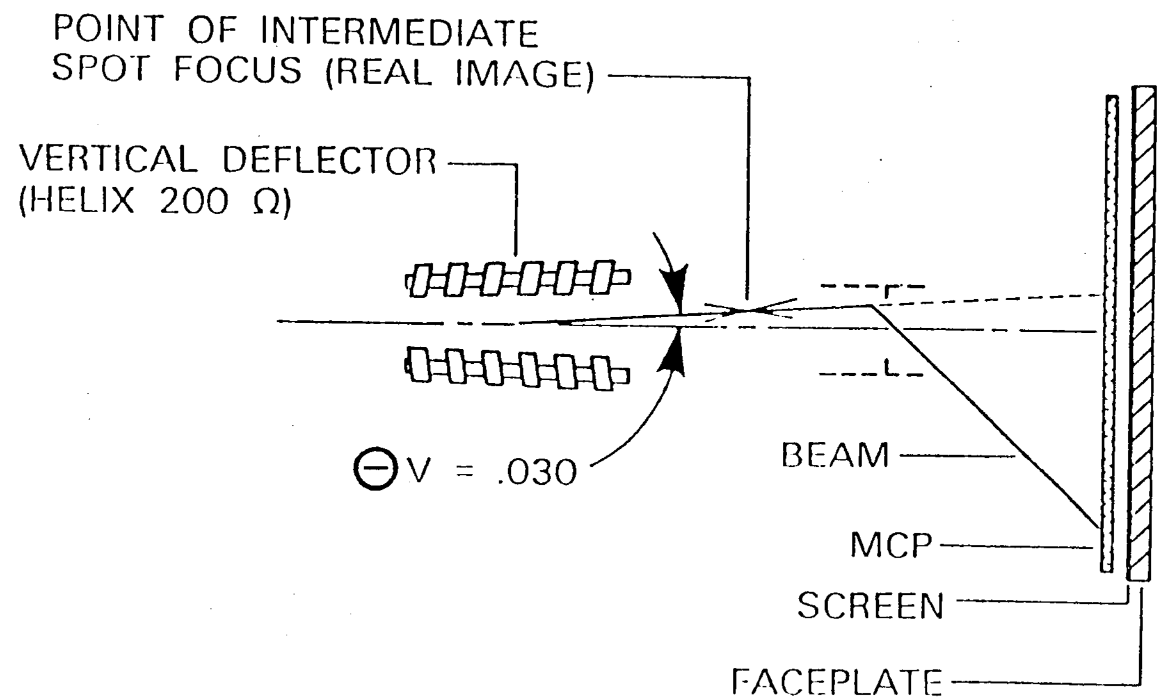

Figure 2. Scan Expansion Lens Vertical Axis. The quadripole positive lens inverts vertical deflection and expands vertical scan $4\frac{1}{2}$ times.

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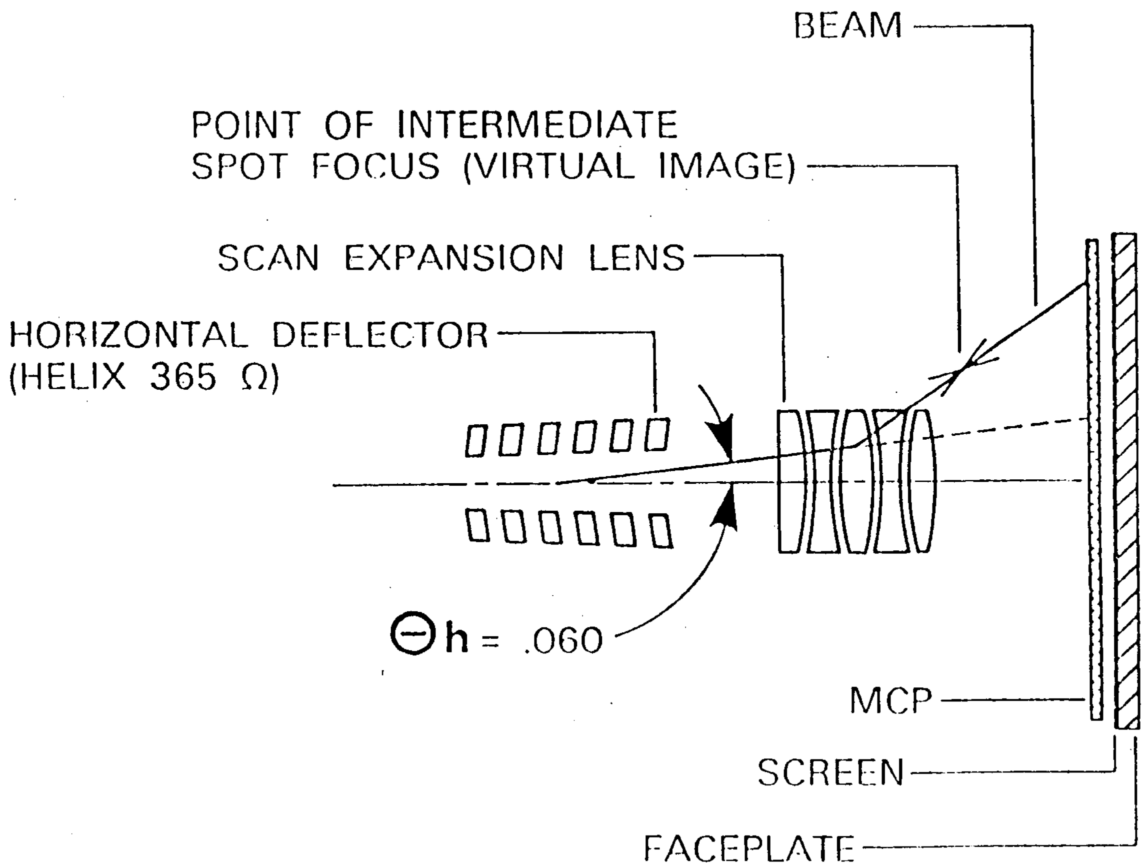

Figure 3. Scan Expansion Lens Horizontal Axis. Horizontal scan is expanded 4 times by this negative lens.

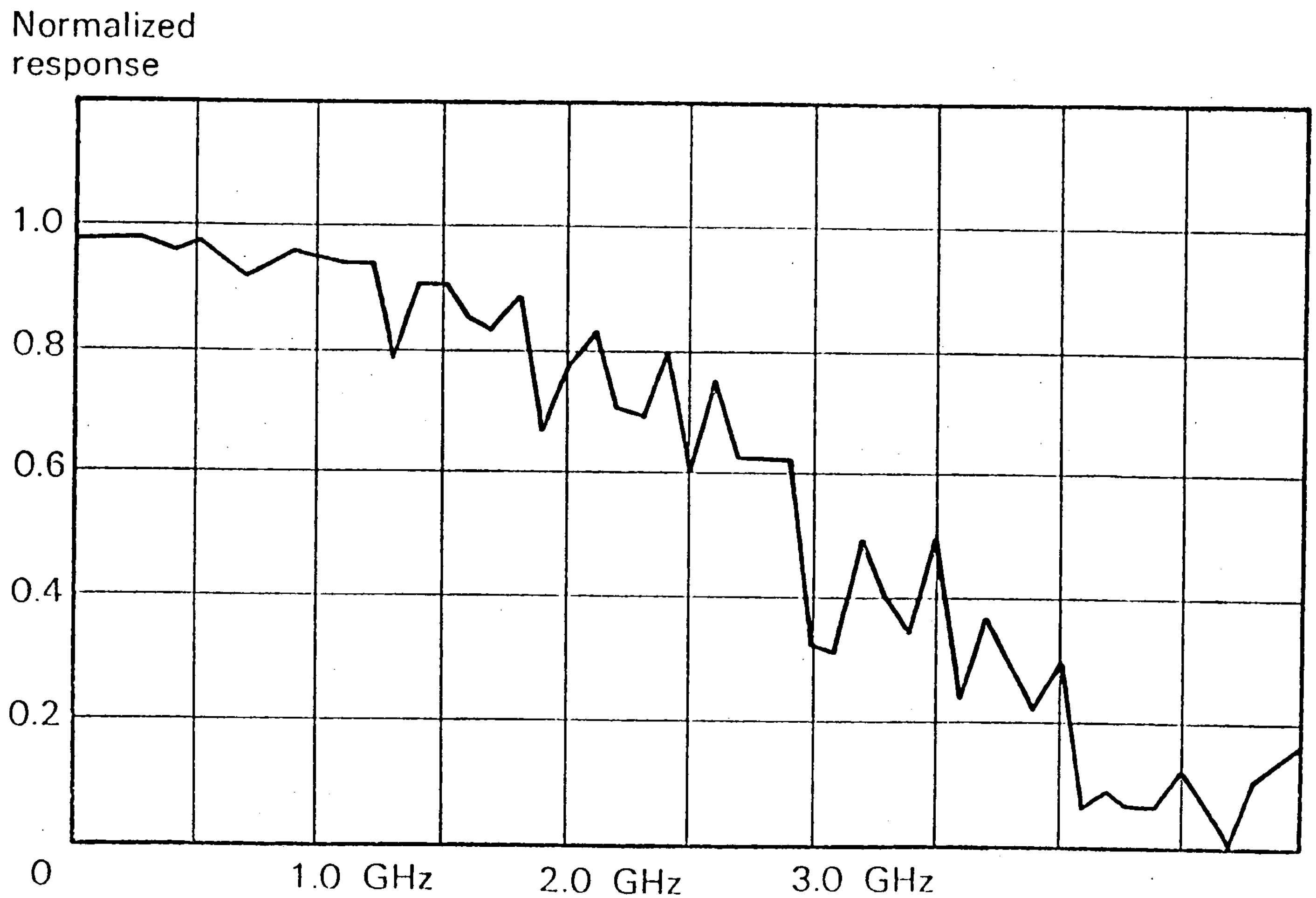

Figure 4. Horizontal Deflector Frequency Response. MCP technology permits a horizontal deflection sensitivity of less than 2 v/div, with a bandpass of much greather than 1.5 GHz.

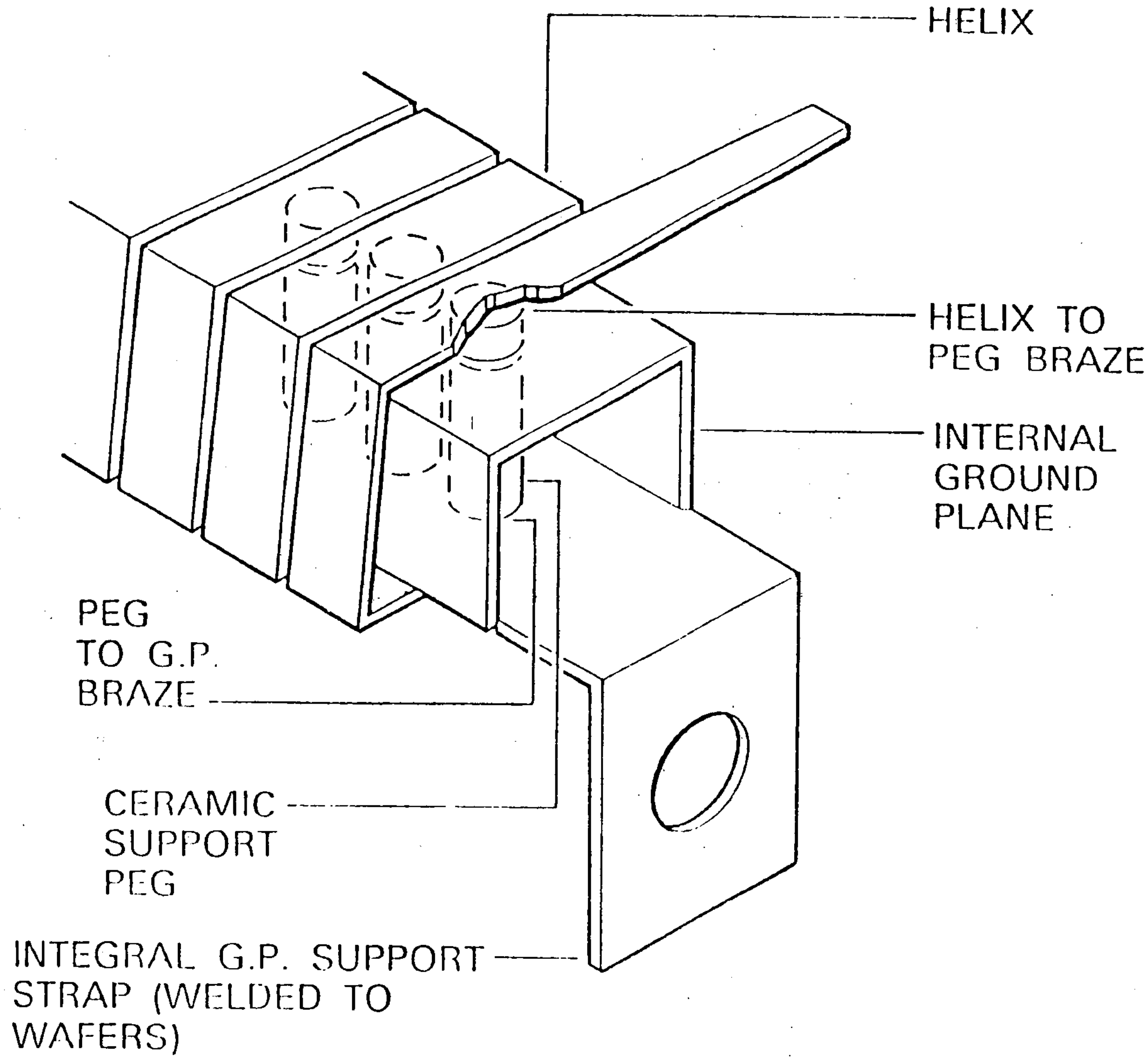

Figure 5. Vertical Deflector. The rugged, novel design of this internal groundplane structure enables mounting the unit into an otherwise finished gun.

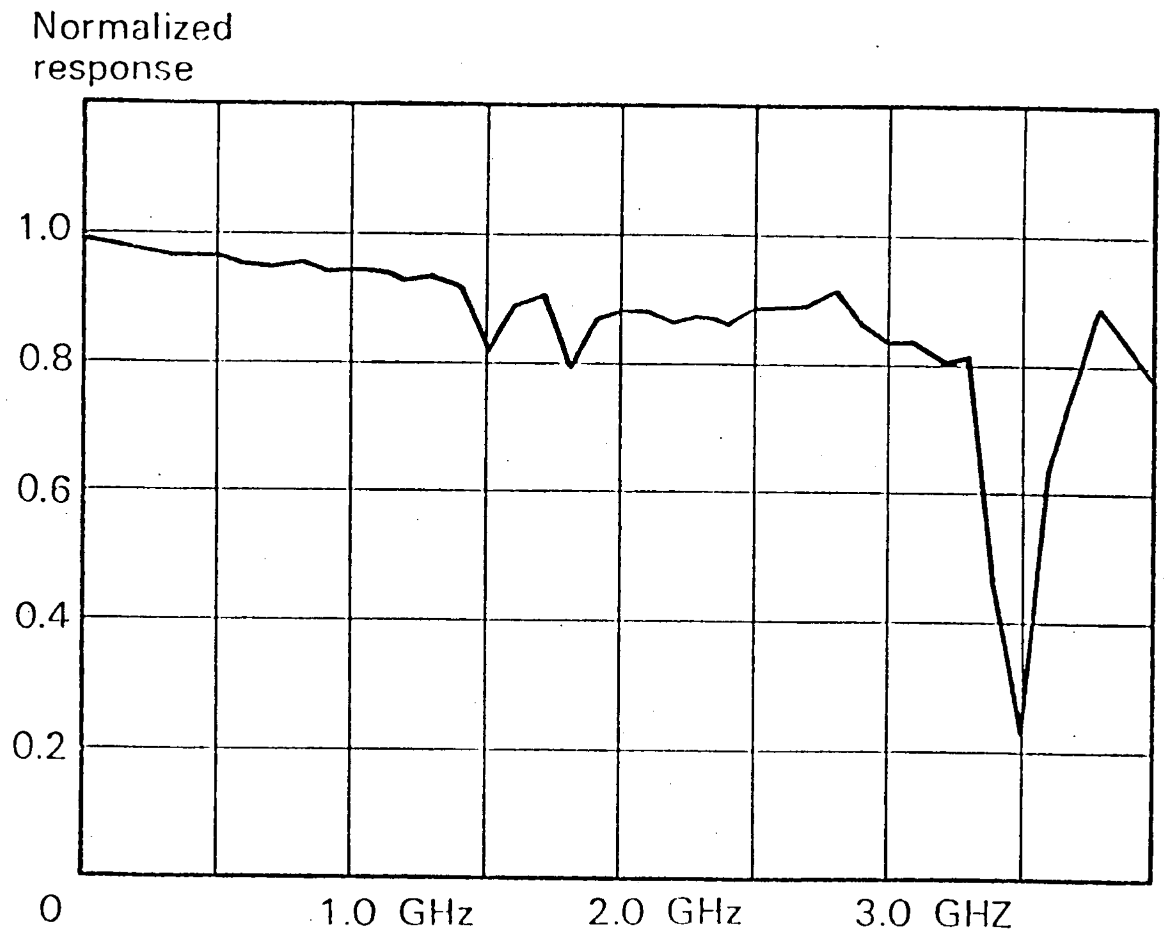

Figure 6. Vertical Deflector Frequency Response. A very good vertical response is produced at greater than 3 GHz. Measurement technique: S_{21} TDM (Time Domain Metrology).

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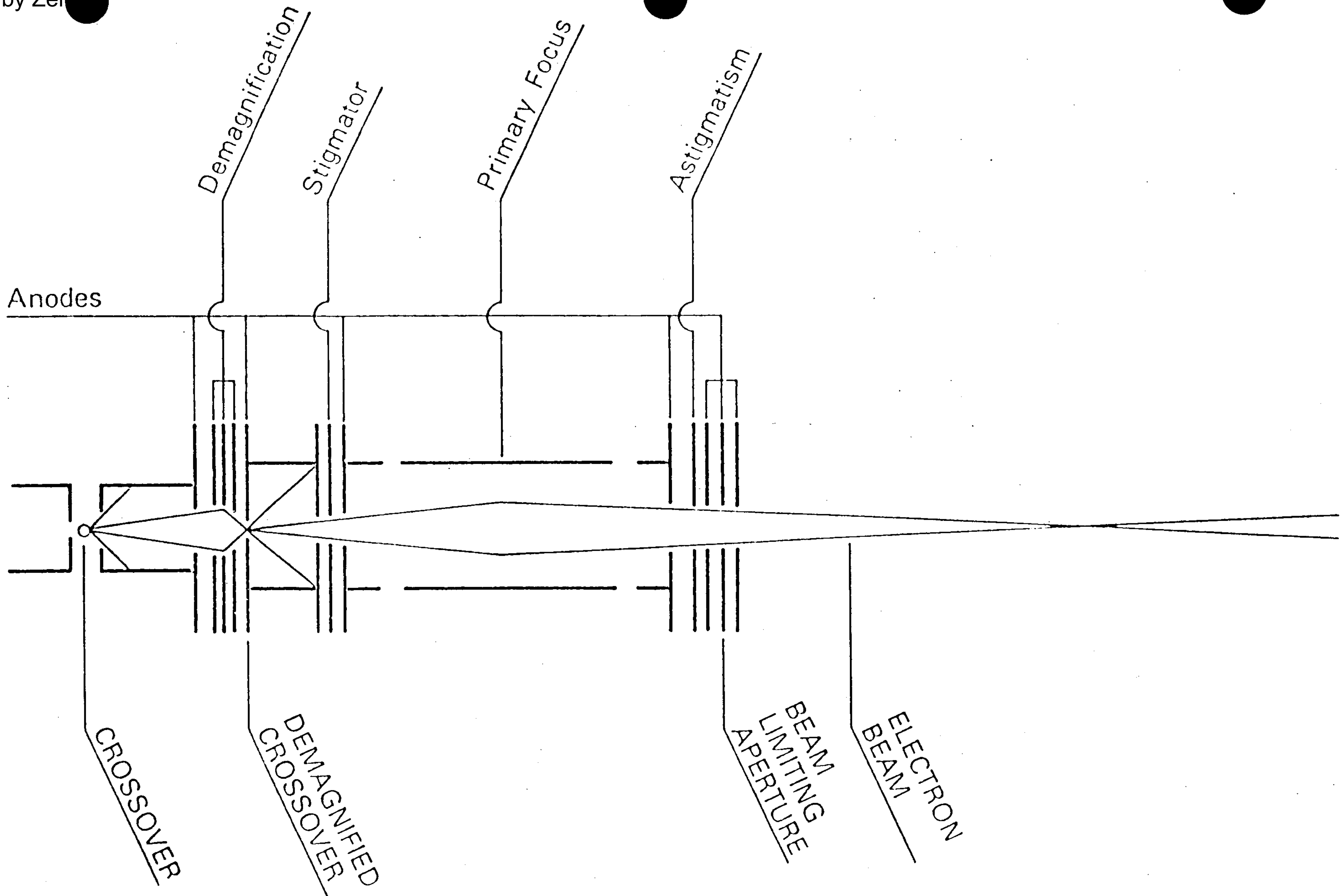

Figure 7. <u>T7100 and T7101 Gun Optics</u>. Electron beam is "measured" far more than in any other crt to maintain high integrity of spot.

MESHLESS CRT SCAN EXPANSION SCHEMES

LOWER POWER AMPLIFIERS

Regardless of what the title says, this report is about power amplifiers, because that is 95% of what crt scan expansion is all about. What we mean by crt scan expansion is increasing the angle between the electron beam and the longitudinal (or z) axis of the crt after it has passed the deflection plates.

BASIC SCAN EXPANSION

In a simple crt with a scan expansion system, the field between the cathode and grid focuses the emitted electrons into a small region called the crossover which is then imaged on the screen by the focus lens and scan magnifier lens. The divergent section of the scan magnifier lens increases the deflection angle generated by the deflection plates. Obviously, the greater the scan expansion by the divergent lens, the smaller must be the applied voltage for a given desired deflection. And the lower the voltage swing in the amplifier, the lower can be the power dissipated in it.

Of course, once the ability to make a low deflection power crt is in hand, it can be traded away for other desirable features such as higher resolution, and greater brightness.

DOMED MESH

The most familiar scan expansion technique at Tektronix, the domed mesh, even goes hand in hand with higher brightness through post deflection acceleration (in which the electrons are sent slowly between the deflection plates for good sensitivity and then accelerated to a high energy to make a bright display).

In figure 1 you can see that the domed mesh shapes the equipotential surfaces so that the electric field rapidly pulls the deflected electrons farther from the Z axis.

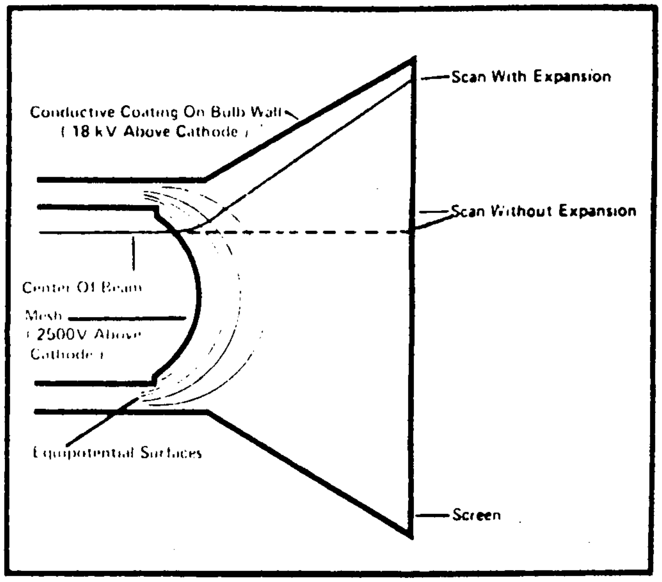

Figure 1. The domed mesh scan-expansion scheme.

Thus the high voltage beyond the mesh creates an exi-symmetric divergent lens which can expand the crt scan typically 2.5 times in the vertical and 2 times in the horizontal.

This system works fairly well and is employed in the crt's of several models of laboratory and portable scopes.

The domed mesh does have some characteristics which keep it from being the ideal scan expansion lens. First, the mesh intercepts 30 to 35% of the beam current thereby reducing brightness.

Second, small lenses formed in the holes of the mesh refocus each portion of the beam, thereby causing an increase in spot size.

Third, the beam knocks secondary electrons from the sides of the holes in the mesh. These secondary electrons reach the screen and form a halo (about 0.5 cm across) near the spot. This mesh halo can be reduced substantially but not eliminated.

Fourth, the mesh lens does nothing to reduce space charge (the mutual repulsion of electrons traveling together in the beam) which makes the spot expand for high beam currents.

Fifth, 2.5 times vertical expansion is nice but more would be better.

Sixth, an important class of storage crt's can not use the domed mesh scheme because it required a very high voltage at the target. (The presence of kilovolts on a storage target precludes economical storage circuitry.)

ELECTROSTATIC QUADRUPOLE

The scan expansion lens which overcomes some of these problems is the electrostatic quadrupole. To see how it is used to achieve scan expansion, let's first look at the simple quadrupole in figure 2. Imagine that we seen here the cross section of four line-charges extending out of the page and arranged symmetrically about the z axis and equidistant from it.

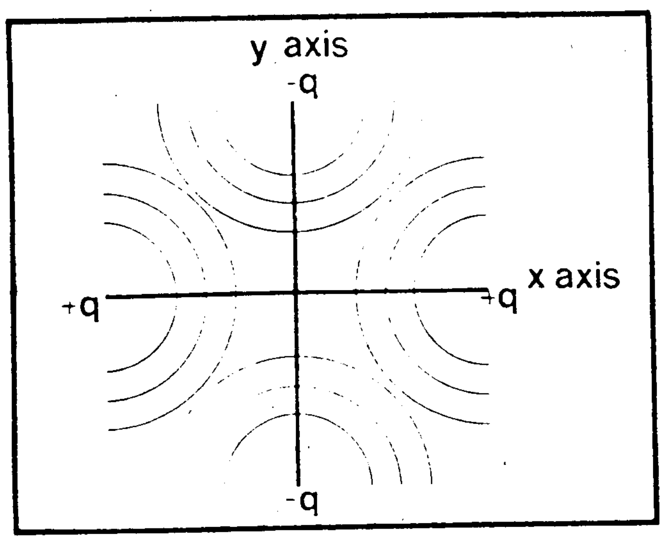

Figure 2. A simple quadrupole.

The four charges are equal in magnitude. The equipotential surfaces between them form two familier of hyperboloids with foci coincident with the lines of charge. If an electron between the charges were displaced vertically from the z axis, it would be pushed toward the x-z plane with a force proportional to its displacement in the y direction. Also the electron would be pulled away from the y-z plane with a force proportional to its displacement in the x direction. For any electron lying in the vertical or horizontal plane of symmetry all forces perpendicular to that plane balance to zero.

The condition of force proportional to displacement is sufficient for an aberrationless focusing field.

Note that if the electrons are not too far from the z axis, we can replace the line charges +q and -q with hyperbolic electrodes carrying the proper voltages. No change in the field near the axis takes place.

THE QUADRUPOLE LENS

<u>Basics</u>

Now we come to the quadrupole lens. In figure 3 we see a quadrupole lens formed by hyperboloids. The voltage V_0 is the voltage on the beam before it enters the field of the lens.

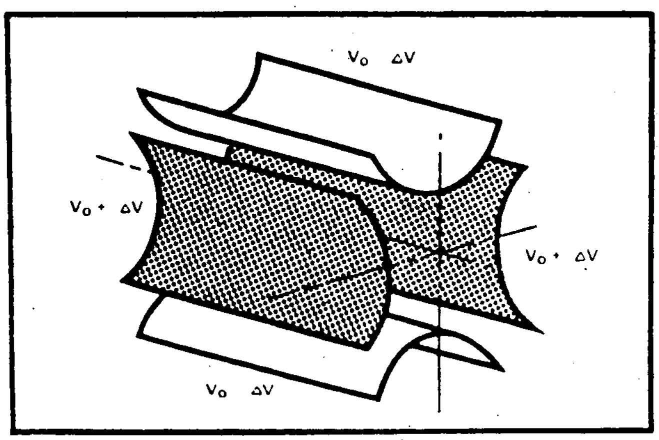

Figure 3. A basic quadrupole lens.

An electron beam entering the lens along the z axis will continue along that axis. A beam that enters the lens parallel to the z axis but displaced horizontally will be bent toward the nearer side electrode, but not at all vertically due to the symmetry of the field above and below. A beam that enters parallel to the z axis but displaced vertically will be bent away from the upper electrode toward the z axis, but due to the symmetry of the field to the left and right it is not deflected sideways. Beams that enter displaced in both the x and y directions will undergo a combination of the two deflections.

So a quadrupole lens is one which converges in one axis to which negative voltage is applied, and diverges in the other axis to which positive voltage is applied. In practice, electrode voltages are typically less than 200 volts away from the beam voltage prior to entering.

Wafers

To make quadrupole lenses that are suitable for crt production, you need three things: some appropriate hyperbolic electrodes, a way to mount them in the gun with precision symmetry about the axes, and low cost for both of the above. The first prototypes were made with machined solid parts. Machined electrodes can be accurate hyperboloids, but they are hard to align accurately in the gun and they aren't cheap. Something that is inexpensive, as well as easy to align, is a wafer with a punched aperture.

If you make wafers like these and stack them alternately, the beam tends to "see" only the hyperbolic lobes sticking in toward the axis. Although the field is weakened slightly by chopping up the electrodes, its quadrupolarity is not appreciably altered. The penalty is that slightly more voltage must be applied. In terms of instrument cost, however, this penalty is more than paid for with lower crt costs.

Applications

Now to the actual application. The simplest approach is to expand just the first axis of deflection, which is usually the vertical. This is done by inserting between the vertical and horizontal deflection plates a quadrupole lens which is divergent in the vertical axis and convergent in the horizontal axis. (This, of course, neither helps nor hinders horizontal deflection.) See figure 4.

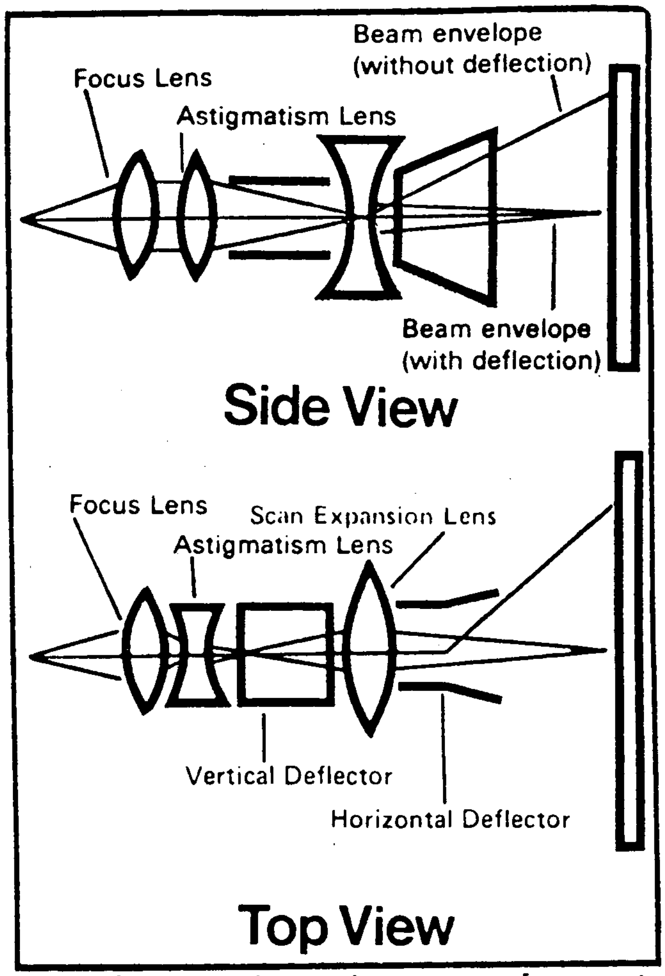

Figure 4. In a quadrupole lens system, focus and astigmatism lenses can be used to precondition the beam to produce a focused round spot.

If nothing further were done, the beam would leave this interdeflection quadrupole with a highly oval shape and arrive at the screen thoroughly defocused. Also shown in figure 4 is the preconditioning of the beam by the focus and astigmatism lenses which produce a focused round spot. Note that the astigmatism lens is depicted with the properties of a quadrupole, which in fact is what it amounts to.

This simple scheme is useful for applications up to 1.2 times

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vertical expansion. Above about 1.25 times, horizontal deflection defocus becomes severe because of the great width of the beam entering the horizontal plates. The spot becomes severely eliptical due to unequal vertical and horizontal merging. Near 1.5 times expansion, the beam can not be focused at all.

THREE QUADRUPOLE WITH VERTICAL EXPANSION

For greater expansion it is better to replace the focus and astigmatism lenses with two successive quadrupoles acting in opposite directions.

This scheme yields round spots at expansions of about 1.8 times in the vertical. It was developed for the tube for the 7834 Fast Storage Oscilloscope. See figure 5.

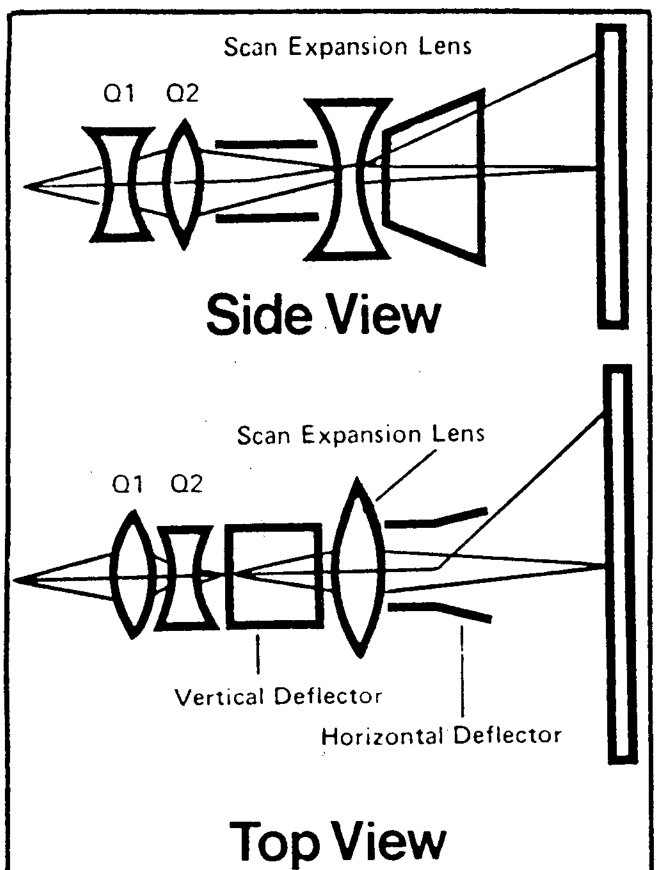

Figure 5. Three-quadrupole scheme, with vertical expansion.

FOUR QUADRUPOLE WITH VERTICAL AND HORIZONTAL EXPANSION

To get expansion in both axes, you can add another quadrupole lens (after the horizontal deflection) which is strongly divergent in the horizontal and strongly convergent in the vertical (see figure 6).

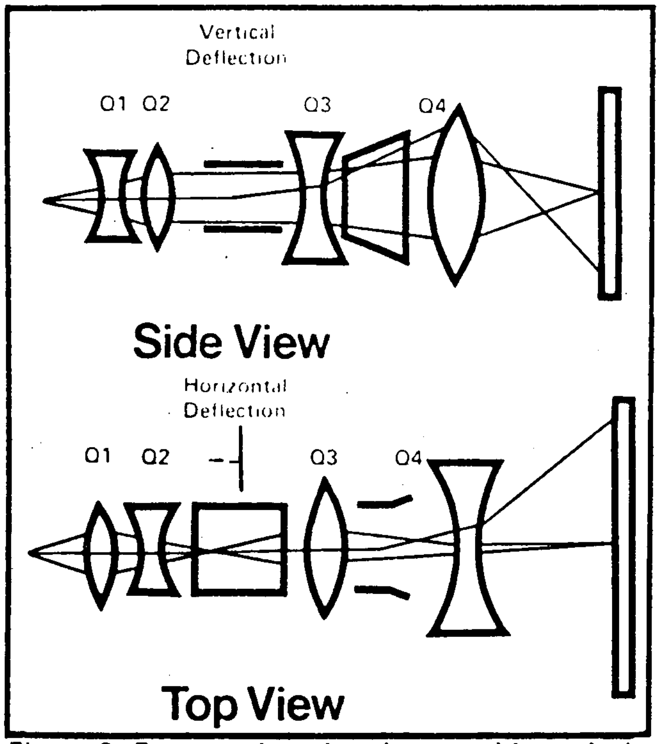

Figure 6. Four-quadrupole scheme, with vertical and horizontal expansion.

Storage CRT Engineering has examined such a lens made from large wafers to pass the larger scan envelope present after the horizontal deflector. Results to date indicate this lens combination may be of benefit only in crt's longer than about 16 inches.

BOX LENS

A lens for which development has passed the design completion milestone in its first application is shown in the crt top view in figure 7.

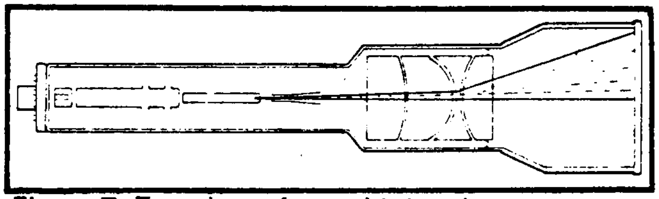

Figure 7. Top view of crt with box lens.

It is called a box lens and will be used in the 7104 1 GHz scope. Although it does not resemble a classic quadrupole lens in construction, its action is similar. In figure 8, the voltages are referenced to the cathode.

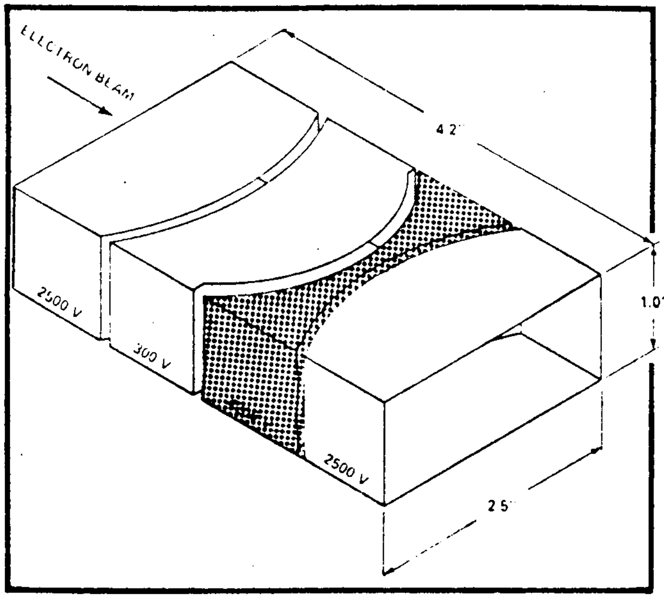

Figure 8. Close-up view of the box lenses shown in figure 7 with voltages referenced to the cathode.

The beam enters and leaves the lens with an energy of 2500 eV. The combination of the D-shaped electrode at negative voltage (with respect to the beam) and the double-convex-shaped electrode at positive voltage (with respect to the beam) causes the beam and the scan to cross over the axis in the vertical and diverge in the horizontal.

The vertical focal length is affected more by the z axis dimension of the D-shaped electrode, and the horizontal focal length is affected more by the x-y aspect ratio of the box. This permits tailoring the box lens to allow the crt to be made with ordinary focus and astigmatism lenses and still have a reasonably round spot for all grid drive levels.

The scan expansions for this lens are 4 times in the horizontal and 4.5 times in the vertical. This nonaccelerating version of the box lens could be of great value in storage crt's if the flood electrons were shielded from the lens field.

An advantage of the box lens is that with a modified design of the cuts in the box lens, it can be made to operate in a PDA mode instead of the nonaccelerating mode.

The voltages (shown referenced to the cathode in figure 8) indicate the bias requirements for PDA operation. In both modes the box lens required an electrode which is operated at a value above the screen voltage. However, the current requirement for that electrode is negligible.

MAGNETIC LENSES

As a parting shot, I would like to mention that quadrupole lenses may be formed with magnetic fields as well as electrostatic fields.

In figure 9, if electrons were moving out of the page through various parts of the field shown by the long curved arrows, they would be diverted from their paths as shown by the short arrows. This action is the same as it is in an electrostatic quadrupole with positive side electrodes. Our research in this area is just beginning. We can probably expect some practical results in 1 to 2 years.

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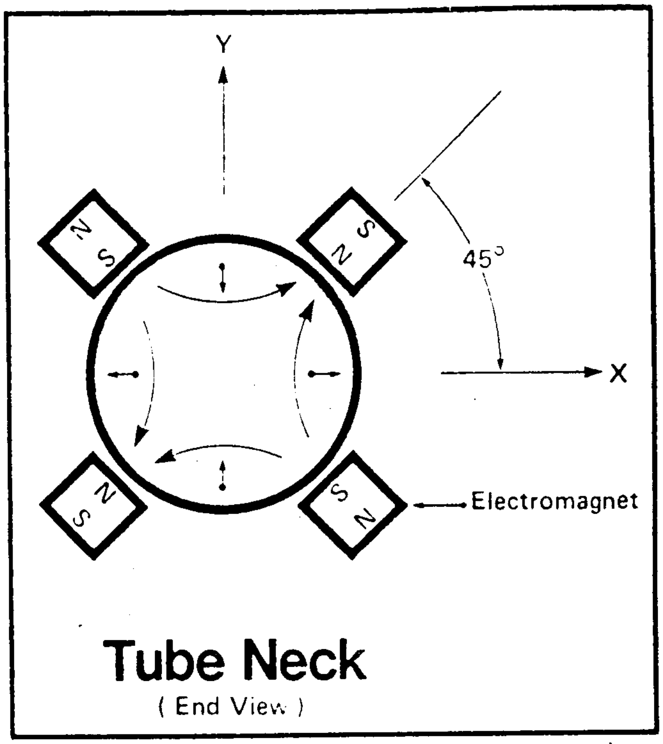

Figure 9. A magnetic quadrupole scan-expansion scheme.

	Vertical Expansion	Horizontal Expansion	Chief Advantage	Chief Disadvantage
Domed Mesh	2.5X	2X	Experience	Lens Let Aberration
3-Quad(vert.)	1.8X	1X	Simplest Mono.	Only 1 Axis
4-Quad(vert.& horiz.)	4X	3X	Storage Compatible	Large Spot Size
Box	4.5X	4X	Mono Or PDA	Bulky
Magnetic Quad	Not Known, Under Evaluation			

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"I need more bandwidth!" is the cry of the oscilloscope user. How does the scope designer go about satisfying his customer's needs?

The standard laboratory oscilloscope has undergone an incredible evolution during the last two decades. Whereas a 30 megahertz bandwidth was considered exceptional in 1955, 350 MHz models are now commonly encountered, and even 500 MHz scopes are found on many laboratory benches. Once we go beyond these limits, however, and wish to look at very-high-speed signals, we leave the domain of the standard model.

Until recently, two types of oscilloscope were commonly used to capture, display, and measure very-high-speed signals: sampling scopes for repetitive phenomena, and recording scopes for single-shot events. To obtain the required combination of brightness and writing speed, the useful screen area of a recording scope CRT is generally rather small. Because of the increasing interest in high-performance scopes with normal-sized screens (60 x 100 or 80 x 100 mm), CRT manufacturers have been led to develop new tubes tailored for this use. Highly sophisticated models that use microchannel plates to intensify the electron beam, thus enhancing writing speed, are now available for bandwidths up to 7 GHz. But, because of the complexity of its design and high cost, oscilloscopes based on this type of tube are specialized instruments and cannot be classed as standard laboratory tools.

Bearing this in mind, engineers at Thomson-CSF's image-tube factory in Grenoble, France, decided several years ago to develop a new, high-performance CRT. Aimed at pushing the practical limit of the standard scope up to the 1 GHz region, the design of the new tube was to be as near-conventional as possible. In this way, it would simplify the scope designer's task, make the final instrument easy to use, and keep costs down—a point always appreciated by customers.

Requirements

Before describing the technology used in this new tube, let's have a quick look at some of the requirements governing its design. Other than obviously wanting his scope to work efficiently at 1 GHz, the user would also like as good a quality display as possible: large screen, bright trace, small spot size, and low geometrical distortion. The scope maker's problem is more complex. Not only does he want a high-performance, good-quality display—he also wants to keep it simple. So, he adds a few requirements of his own, mostly due to the limitations of the electronic components and technology presently available.

For him, the most important additional CRT characteristics are deflection sensitivity, and the characteristic impedance of the "Y" deflection system. The design of high-gain, large-bandwidth amplifiers to feed a deflection system whose impedance may be strongly frequency-dependent (as with conventional plate systems) presents, to say the least, certain problems.

In general, the bandwidth and intrinsic risetime of the CRT should be noticeably better than those of the scope, to make the most of the vertical deflection amplifier's performance.

The deflection sensitivity is less critical along the X axis, but must not be neglected, because high sensitivity leads to a more economical deflection amplifier design.

Another scope maker's headache concerns power supplies. The reliability and cost of scopes depends to a certain extent on the high voltages required by the CRT's electrodes, the accuracy with which they must be regulated, and on the current drawn. Although progress in component technology has greatly reduced this problem, an obliging CRT is always appreciated.

Improving Brightness and Sensitivity

Looking first at a basic CRT (Fig. 1), originally introduced in the 1930s and still in common use to this day, what are the factors that limit its performance?

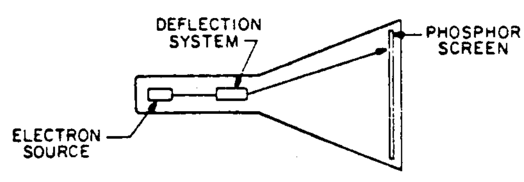

Fig. 1. The simplest CRT, widely used in low-frequency oscilloscopes.

Although these simple tubes are relatively cheap to manufacture, their unsophisticated design means they have a low trace brightness, making them unsuitable for operation above 20 MHz. Since trace brightness depends on the energy imparted to the screen by the electron beam, and hence on accelerating voltage, the only way to increase trace brightness would be to increase accelerating voltage. But this would have an adverse affect on the deflection sensitivity because of the reduction in the electron transit time through the deflection system. Increasing the length of the deflection section to compensate would harm the CRT's high-frequency performance by increasing interplate capacitance.

Early attempts to break this vicious circle consisted of painting a spiral electrode inside the glass bulb. This was used to create an electron-accelerating field *after* the deflection plates. Unfortunately, this post-deflection-acceleration (PDA) technique also bends the beam towards the tube axis, thus reducing the deflection sensitivity.

The next step was to introduce a flat or domed field mesh (Fig. 2) just after the deflection plates, modifying the shape of the PDA equipotentials and producing a deflection magnification effect.

Although such a tube has two of the major requirements of a high-performance CRT, bright trace and enhanced deflection sensitivity, the field mesh diffracts the electron beam, creating a halo around the displayed spot and reducing the spatial resolution.

Quadrupoles

The use of quadrupolar lenses in CRTs was first envisaged by Thomson-CSF in 1967. Since that time, the technique has been continuously developed to create a whole family of tubes, now used by Schlumberger in their top-of-the-range oscilloscopes.

The principle is relatively simple, as can be seen in Fig. 3. A fine beam of electrons from an electron gun is deflected vertically by the incoming signal, applied to the first set of plates. It is then swept horizontally by the time-base voltage. So, effectively speaking, a sheet of electrons now enters the quadrupole lens. Here, deflection magnification is positive in the horizontal sense. The centerline of the sheet remains undeflected whereas the rest is deflected strongly. Deflection magnification in the vertical sense is negative, and the sheet of electrons is very strongly bent in the opposite direction to the original deflection. All electron trajectories pass through the oblong aperture of the slot lens that separates the acceleration and deflection zone from the post-acceleration zone near the screen. Theoretical analysis shows that, so long as certain limits are not exceeded, X and Y deflection magnifications are linear for all input trajectories.

Spatial resolution on the screen is higher than with a mesh-type tube as there is no electron beam diffraction, and deflection sensitivity is noticeably better.

Vertical Deflection with a Delay-transmission Line

Conventional deflection plates are normally considered adequate up to 100 MHz or, if they are very short, 200 MHz. Why this limitation? Their maximum frequency response depends on the time an electron takes to pass between them. If it takes more than an appreciable fraction of the signal cycle time, the net deflection will be either reduced, or even zero. Reducing transit time by shortening the plates or increasing the electron velocity would decrease the deflection sensitivity—a vicious circle. In addition, and of particular importance to the scope maker, the impedance of the plates is inversely proportional to the signal frequency. Designing amplifiers to feed a wide range of loads becomes very difficult, if not impossible, at very high frequencies.

In very-high performance tubes, the plates are replaced by a delay-transmission line system (Fig. 4). Effectively, this is a long line of very short plates, interconnected by inductive/capacitive delay elements, which match the signal propagation time to the electron transit time. The electron is thus constantly deflected during transit. A big bonus for the scope designer is that the impedance of a correctly designed delay-transmission line is frequency-independent.

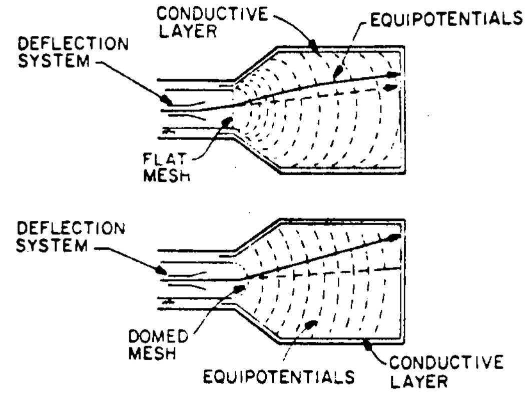

Fig. 2. Flat or domed field meshes alter the profile of PDA equipotentials to provide a deflection magnification effect, but reduce spatial resolution because of electron-beam diffraction.

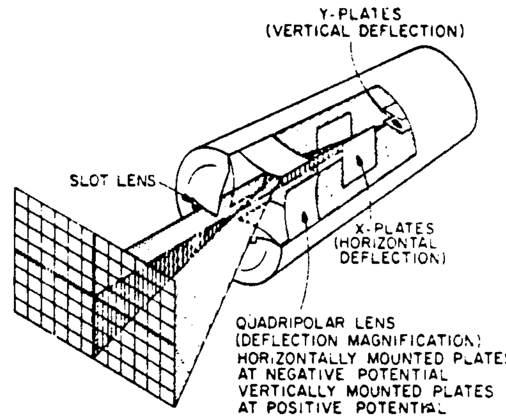

Fig. 3. Using a combination of quadrupole and slot lenses gives deflection magnification and PDA, and avoids the resolution-degrading effects of field meshes.

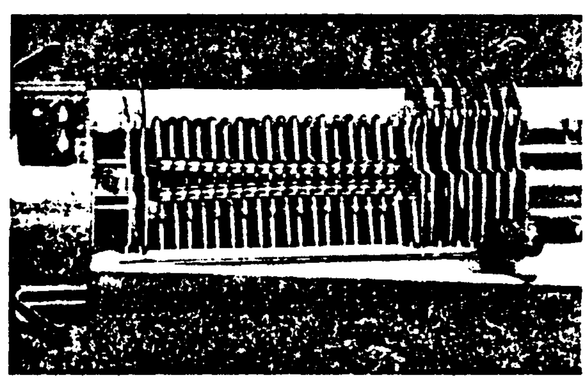

Fig. 4. A delay-transmission line deflection system works at very high frequencies, and its impedance is frequency independent.

Towards the Gigahertz

Using these ideas, we designed the TH 8203, an oscil-

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The tube's near-conventional structure simplifies the scope design.

loscope CRT (**Fig. 5**) whose main characteristics are given in **Table 1**.

The tube is compact and robust, and its near-conventional structure simplifies the scope design task. Its voltage requirements are quite reasonable, and its delay-transmission-line deflection system permits the use of standard deflection-amplifier technology. But the performance of this tube as it stands is still not good enough for a 1 GHz bandwidth oscilloscope, for which the following CRT characteristics are required:

- bandwidth of 1 GHz at less than 1 dB;
- intrinsic risetime of 0.2 ns;
- "Y" deflection factor of 1 to 1.5 V/cm;
- useful screen area of 80 x 100 mm;
- overall length of about 40 cm.

These can be obtained by modifying the standard model, following the indications given in **Table 2**. To the 1 GHz scope designer, such a tube means relative ease of implementation. To the user, it means exceptional high-frequency performance, a bright trace on a large screen, small spot size, and low geometrical distortion.

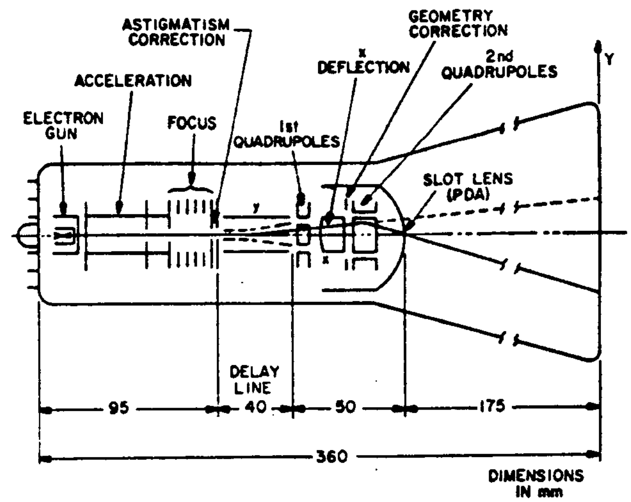

Fig. 5. The TH 8203 uses delay-transmission-line deflection, and quadrupolar-lens deflection magnification.