A Review of Single Transient Oscillographic Recorders with Gigahertz Bandwidth

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In laser driven inertial confinement fusion research, at Livermore, we are diagnosing many phenomena that occur in a time frame that exceeds the capabilities of even the most advanced, present day oscillographic recording instruments. The high power laser systems used in our experiments have a temporal duration of approximately one nanosecond and a 1.06 µm wavelength. The laser output is optionally multiplied to 2 ω_0 or 3 ω_0 and is then focused on to a small fuel pellet (target). Many of the by-products of the interaction between the laser beam and fuel pellet are monitored to determine the specifics of the fusion process.

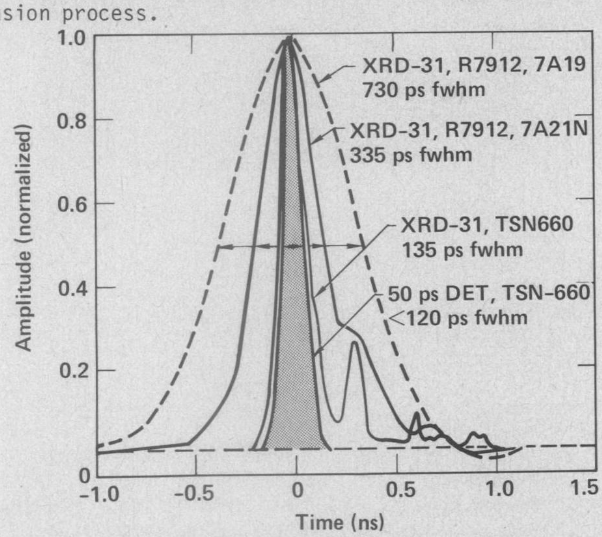

Figure 1 - System Impulse Time Responses Including XRD, Cable, and Oscilloscope

By the use of appropriate detectors, we convert the information contained in the radiated by-products to electrical signals which are recorded on high bandwidth oscillographic recorders. Our present range of recording capabilities for one x-ray diagnostic measurement in use at Livermore is shown in figure 1. A commonly used configuration consists of an XRD-31 x-ray detector[1] connected to a direct access Tektronix R7912 transient digitizer using 1/2" diameter air dielectric coaxial cable. This configuration gives a system fwhm of approximately 335 ps. Our "premier" configuration, on the other hand, consists of an improved response detector[2] and a French Thomson-CSF TSN-660 oscilloscope with a shorter length of coaxial cable (typically 20 feet). The system fwhm in this case is less than 120 ps which is our fastest oscillographic recording system at the present time. Based on our requirements to observe fine structure detail more precisely, a system response of 50 ps or less could be justified if it were available.

The Ideal Oscillographic Instrument for Fusion Experiments Use

Figure 2 is a block diagram of a recording instrument with performance features desired for laser driven ICF experimental work. Features include:

a. Self calibration
b. Computer control and monitor of essential functions
c. 5-10 GHz signal bandwidth
d. $\leq$25 ps trigger jitter
e. Memory for one or two traces
f. Computer interface bus (IEEE-488, Q bus, etc.)
g. Signal conditioning (attenuation & equalization)
h. A precision time base.

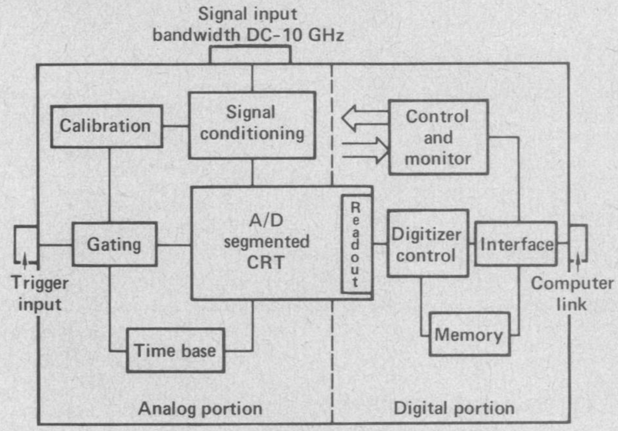

Figure 2 - The Ideal GHz Recording Instrument for Fusion Experiments Use

Countries Manufacturing GHz Single Transient Recorders

At the present time, the USSR, France, and the USA are the only known countries manufacturing GHz bandwidth single transient recording instruments.

USSR

The system shown in figure 3 was displayed at the High Speed Photography Conference XIV[3] in Moscow in 1980. The Soviets refer to it as the "LOTOS" system and it is said to have the following specifications:

Soviet System Specifications (LOTOS)

Channels	3
Screen recording area	20 x 40 mm
Spot size	150 µm
Writing rate	5 x 10^5 Km/s (50 cm/ns)
Signal impedance	50 Ω
Sensitivity	15 V/cm
Bandwidth	7 GHz

Figure 3 - The USSR "LOTOS" Three Channel Single Transient Recording System

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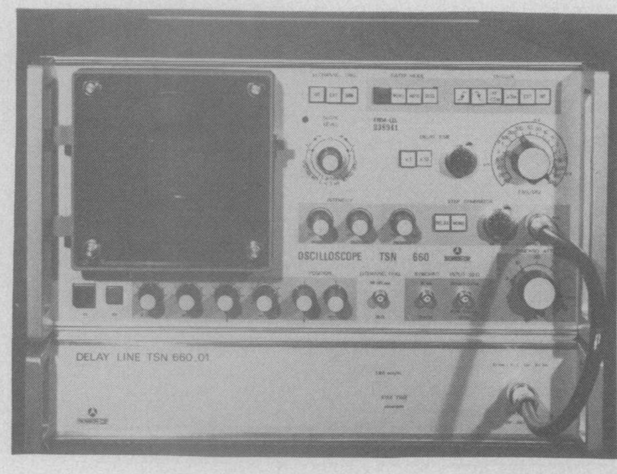

Figure 4 - Oscilloscope TSN-660

FRANCE

An instrument that we have been using in our diagnostic work since 1979 is shown in figure 4, the Thomson-CSF TSN-660 manufactured in France. We have purchased five of these instruments for our diagnostics work with excellent results. The first unit purchased (1979) has recently had a CRT failure (MCP) after a lifetime of over 9000 hours. This instrument is available with a choice of CRT's as follows:

Thomson-CSF TSN-660 Specifications

Mainframe		
Sweep rate	100 ps/cm to 1 ms/cm	
Trigger jitter		< 25 ps
Internal step generator risetime		100 ps

Cathode Ray Tube	TMC-4	TMC-5
Spot size	~400µm	100µm
Screen recording area	40x70mm	40x40mm
Signal impedance	50Ω	50Ω
Sensitivity	150mV/cm	2V/cm
Bandwidth (-3dB)	5 GHz	4 GHz
Internal microchannel plate	Yes	Yes

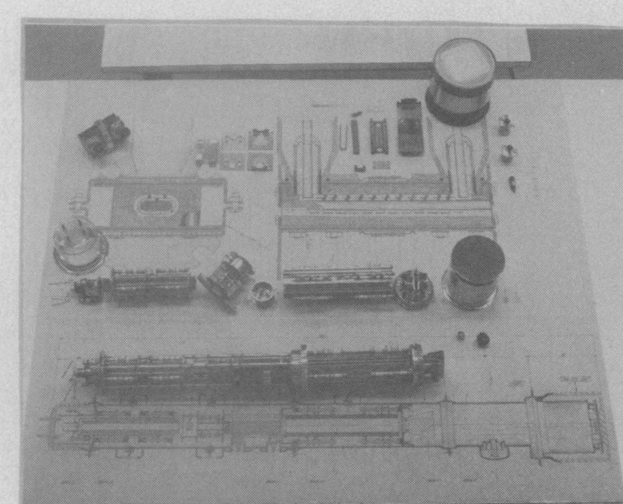

Figure 5 - TMC-5 Details

All five of our instruments utilize the TMC-5 CRT manufactured by La Radiotechnique-Compelec (RTC). The details of this sophisticated CRT are shown in figure 5. An assembled tube with its shield and cabling is shown in figure 6.

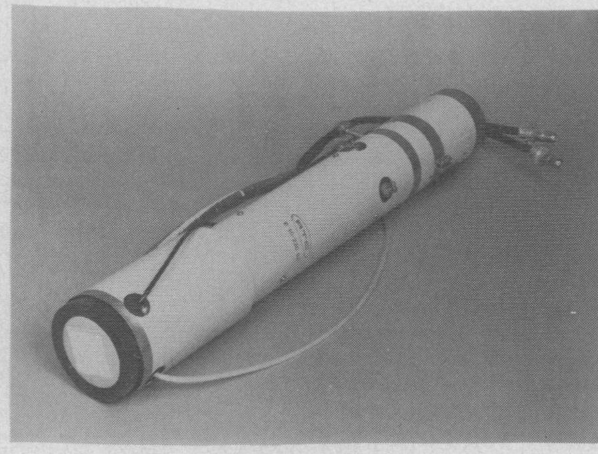

Figure 6 - TMC-5 Assembled with shield and cabling

USA Manufacturers

The manufacturers of instruments with single transient GHz recording capabilities in the USA are EG&G and Tektronix, Inc.

EG&G Instruments

A photograph of the EG&G OS-40A oscilloscope is shown in figure 7. This instrument is used primarily for the recording of diagnostics data from nuclear weapons tests. It is very ruggedly designed.

Presently available CRT's for use in this and other EG&G mainframes are as follows:

EG&G Cathode Ray Tubes

Cathode Ray Tube	KR23 MCP	KR3 MCP
Spot Size	125µm	150µm
Screen recording area	20x33mm	25x33mm
Signal impedance	100Ω	100Ω
Sensitivity	16 V/cm	2.9 V/cm
Bandwidth (-3dB)	2.2 GHz	0.9 GHz
Internal microchannel plate	Yes	Yes
Mainframe	OS-40A	3344

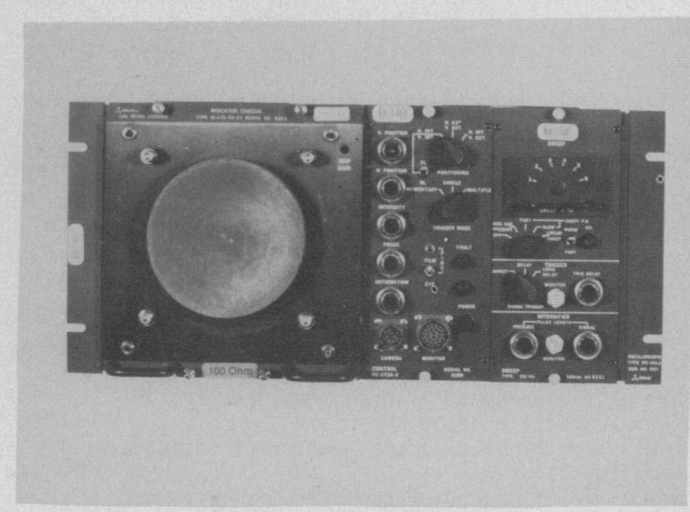

Figure 7 - OS-40A Photo

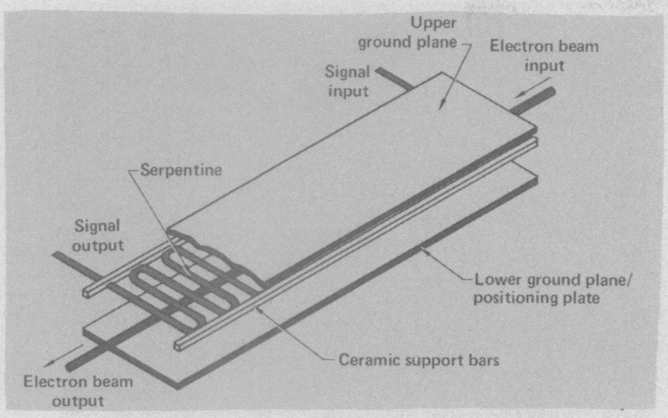

Figure 8 - EG&G Travelling Wave Structure (KR 23 MCP)

The higher bandwidth CRT, the KR-23 MCP, uses a single ended meander line type signal deflection structure. This structure is pictorally shown in figure 8. A detailed photograph of the CRT components is shown in figure 9.

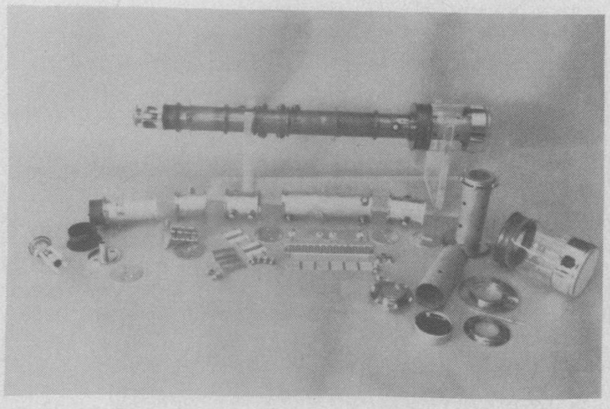

Figure 9 - KR 23 MCP CRT Component Details

Tektronix, Inc. Instruments

Tektronix has an outstanding reputation for providing instruments with high bandwidth recording capability. A bandwidth/sensitivity summary versus catalog year of introduction is shown in figure 10. Two of these instruments, the R7912 and 7912AD, have a digital output representing an array of the points written on by the CRT electron beam. A silicon target with individual diode elements replaces the conventional phosphor screen and is read out with a built in electron beam read gun.

A detailed progression (in block diagram form) of instruments type R7903, R7912, and 7912AD is shown in figures 11, 12, and 13 respectively. The R7903 is a rack mounted version of the earlier 7904 lab scope. It has proven to be a very reliable instrument for our recording needs. In our newest laser facility, Novette,[4] the R7912 is used almost exclusively for our high bandwidth fusion experiment requirements and the digital output capability is in high demand by the scientific experimentalists. These same units have previously provided a large quantity of important data at our now retired Shiva[5] facility.

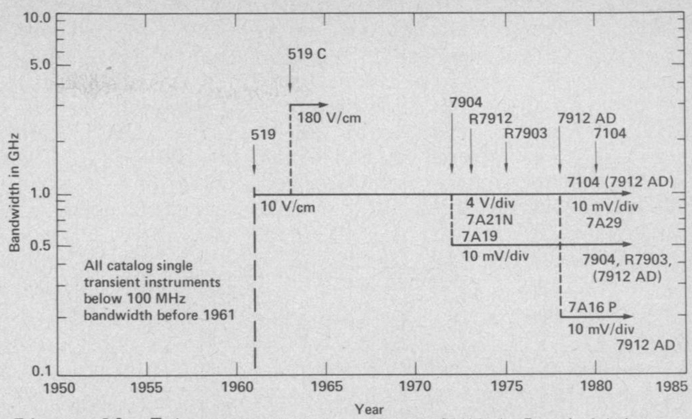

Figure 10 -Tektronix Progression of High Bandwidth Oscilloscopes

We are just beginning to obtain system experience with the 7912AD instruments. These use a different output interface bus format (IEEE 488). We have been hesitant to implement these newer instruments as the R7912 has been so well suited to our application. From our point of view, the R7912 comes closest to the ideal instrument for our recording purposes. The

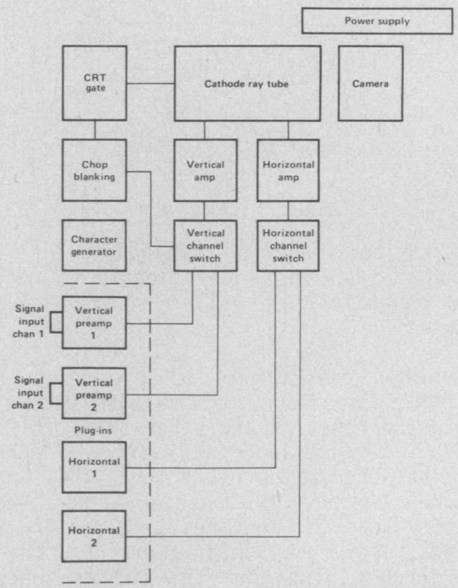

Figure 11 - Tektronix R-7903 Block Diagram

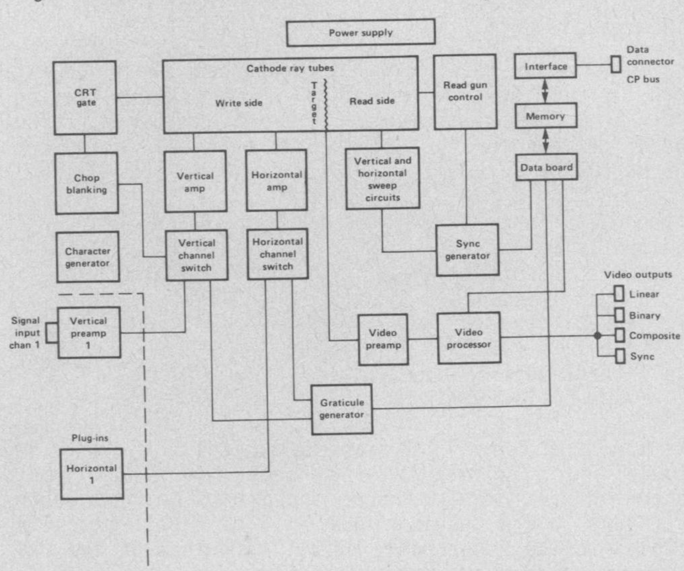

Figure 12 - Tektronix R-7912 Block Diagram

7912AD has many featuresthat we may not find to our advantage to incorporate. The instruments are nearly identical in their maximum bandwidth capabilities. The programmable vertical sensitivity however on the 7912AD is only functional when using the 7A16P vertical plug-in with a bandwidth of 200 MHz. The older, and no longer manufactured R7912 was a more cost effective solution for our data recording needs.

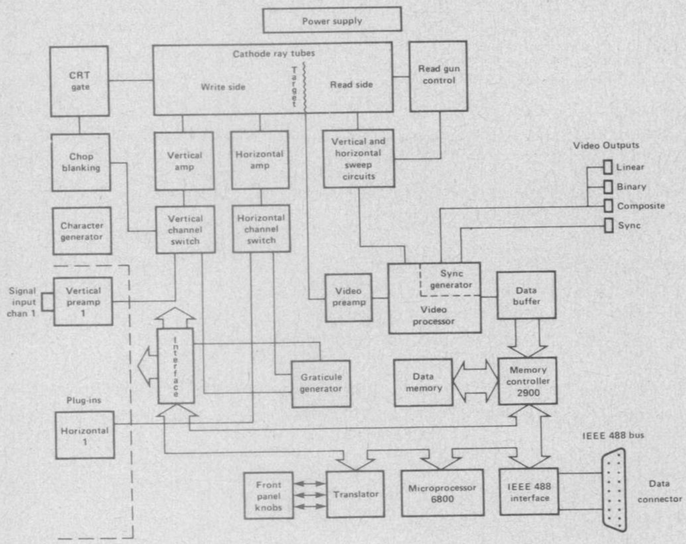

Figure 13 - Tektronix 7912 AD Block Diagram

The Future

With regards to increased capability of single transient gigahertz bandwidth oscillographic recorders by free world countries, we will monitor closely the following sources.

a. The French work aimed at providing higher bandwidth recording capabilities for their laser fusion research and other scientific work.
b. The EG&G work driven basically by the Los Alamos National Laboratory and the Lawrence Livermore National Laboratory for nuclear weapons diagnostics purposes.
c. Tektronix, Inc. in their work to remain a leader in providing state of the art recording instruments to the scientific community.

French Work

The French have formally announced their newest work in this area in a recent press release stating that a 7 GHz instrument has been developed. The specifications for the CRT used in this new instrument are as follows:

Cathode Ray Tube	213 D3 KA
Spot size	70μm
Screen recording area	10x12mm
Signal impedance	50Ω
Sensitivity	5 V/cm
Bandwidth (-3dB)	7 GHz
Internal microchannel plate	Yes
Fiber optic faceplate	Yes

A photograph of the assembled CRT is shown in figure 14. The mainframe concept for this 7 GHz recording instrument will be approximately that shown in figure 15. A Newvicon tube will be fiber optically coupled to the fiber optic output faceplate of the CRT and the readout will be digitized and stored in a local memory. This instrument comes very close to the ideal instrument for our recording needs.

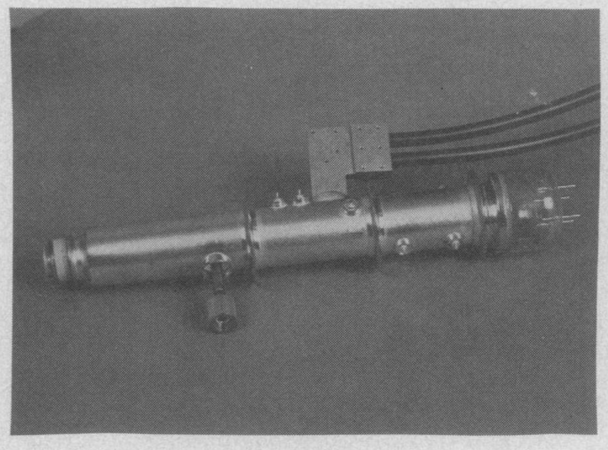

Figure 14 - The 213 D3 KA RTC CRT

EG&G Work

EG&G continues their CRT development work at both the Woburn, Massachusetts and San Ramon, California facilities. Their near term development objectives are as follows:

Cathode Ray Tube	KR-27	KR-30
Spot size	90μm	75μm
Screen recording area	33x33mm	15x38mm
Signal impedance	100Ω	100Ω
Sensitivity	2.8 V/cm	1.77 V/cm
Bandwidth (-3dB)	3.0 GHz	1.0 GHz
Internal microchannel plate	Yes	Yes
Mainframe	OS-40A-2	OS-50

The KR-27 will utilize a guard band serpentine type deflection structure. This structure reduces the mutual coupling between deflection element segments. The details of this structure are shown in figure 16.

Tektronix Work

A photograph of the deflection structure of the CRT used in the 7104 oscilloscope is shown in figure 17. In previous travelling wave type CRT's short lengths of wire were used to connect the travelling wave structure input and output segments to the glass feedthrough pins on the tube body. The newer design maintains a transmission line structure to the tube body feedthroughs. The new structure also contains an internal ground reference for each of the two helical elements of the travelling wave structure.

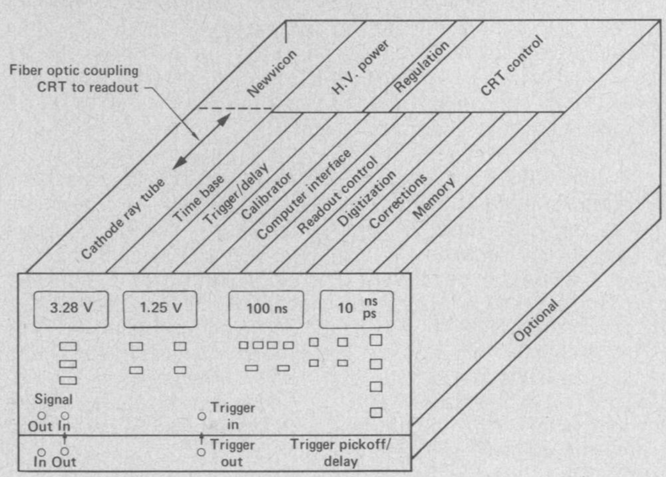

Figure 15 - French Main Frame (Concept)

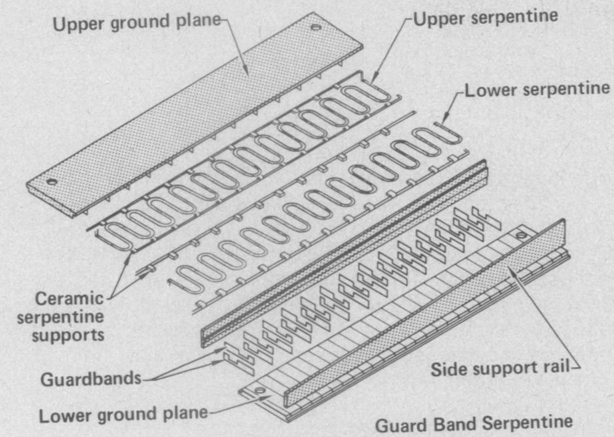

Figure 16 - EG&G Guard Band Serpentine Details

Referring again to figure 10, the progression of past Tektronix instruments, we can speculate what the future may bring in the way of new instruments. In light of the greatly improved travelling wave structure used in the CRT for the 7104 lab scope we would speculate, based on previous history, that a digital output instrument would be in the offering, in the not to distant future, similar to the R7912/7912AD concept. This instrument could use a silicon target electron gun readout or another form of readout mechanism such as a fiber optically coupled vidicon or CCD mounted internally or externally.

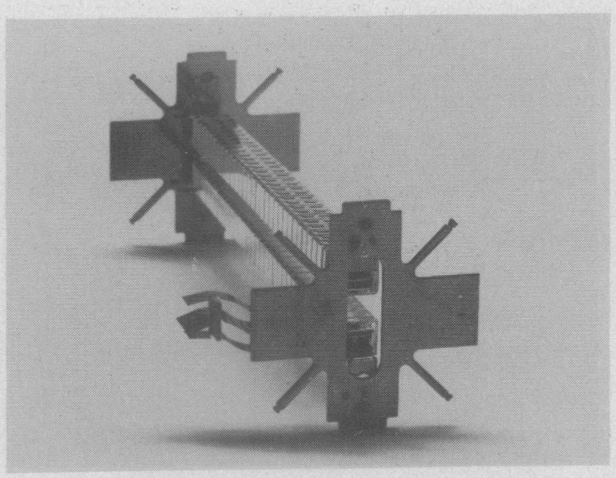

Figure 17 - Tektronix, Inc. 7104 CRT TW Structure Details

Summary

This paper has reviewed the status of gigahertz bandwidth single transient oscillographic recording instruments and their CRT's. I would like to emphasize again the ideal recording instrument from a fusion experiments, target diagnostics, point of view shown in figure 2. The French work appears to be addressing this concept most closely. We are waiting to see and evaluate the actual recording instruments that emerge during the next few years.

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5. Laser Program Annual Report, UCRL-50021-80, Volume 1, Section 2.