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Recorders with Gigahertz Bandwidth

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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 μ m 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 ranges 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 detector¹ 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 detector² 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:

- Self calibration
- Computer control and monitor of essential functions
- 5-10 GHz signal bandwidth
- ≤ 25 ps trigger jitter
- Memory for one or two traces
- Computer interface bus (IEEE-488, Q bus, etc.)
- Signal conditioning (attenuation & equalization)
- 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 XIV³ in Moscow in 1980. The Soviets refer to it as the "LOTOS" system and it is said to have the following specifications:

Soviet System Specification: (LOTOS)

Channels	7
Screen recording area	20 x 40 mm
Spot size	150 μ m
Writing rate	5 x 10 ⁶ 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

Figure 4 - Oscilloscope TSN-660

EXCERPT

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 filter	< 25 ps
Internal step generator risetime	100 ps
Cathode Ray Tube	
Spot size	TMC-4 7400µm TMC-5 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-Comptec (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 (AR 23 MFP)

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

Figure 9 - AR 23 MFP CRT Component Details

Tektronix, Inc. Instruments

Tektronix has an outstanding reputation for providing instruments with high bandwidth recording capability. A bandwidth/sensitivity summary 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 Shiva⁵ facility.

Figure 10 - Tektronix Progression of High Bands MFP 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 features that 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 7912 was a more cost effective solution for our data recording needs.

Figure 15 - Tektronix 7912 Main Frame

The Future

With requests for increased capability at single transient phenomena under the oscillographic waveform by the world community, we will monitor closely the following areas:

- The French work ahead at providing higher bandwidth recording capabilities for their laser fusion research and other scientific work.
- The GGG work design basically by the Los Alamos National Laboratory and the Lawrence Livermore National Laboratory for nuclear weapons diagnostics purposes.
- 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 AA
Spot size	70µm
Screen recording area	10x12cm
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 Hewicon 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 AA PTC CRT

GGG Work

GGG continues their CRT development work at both the Auburn, Massachusetts and in San Jose, California facilities. Their near term development objectives are as follows:

Cathode Ray Tube	213 D3	213 D3
Spot size	70µm	70µm
Screen recording area	10x12cm	10x12cm
Signal impedance	100Ω	100Ω
Sensitivity	1.0 V/cm	1.0 V/cm
Bandwidth (-3dB)	5.0 GHz	5.0 GHz
Internal microchannel plate	Yes	Yes
Mainframe	CS-4000	CS-4000

The CS-4000 will utilize a guard band supporting type deflection structure. This structure reduces the axial 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)

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Figure 16 - Tek Guard Band Serpentine (detail)

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 T41 for the 7104 lab scope we would speculate, based on previous history, that a digital output instrument would be in the offing, in the not too distant future, similar to the 8741/7741/80 concept. This instrument could use a silicon target electron gun instead of another form of electron gun mechanism such as a fibre optically coupled vidicon or CRT mounted internally or externally.

Figure 17 - Tektronix, Inc. 7104 CRT TX 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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