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FINAL REPORT

FOR

UNIVERSITY OF CALIFORNIA (LLL)

P.O. 8699503

LOW-ENERGY X-RAY INSTRUMENTATION

FOR SHIVA

NUCLEAR SCIENCES LABORATORY

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Preface

Presented herein is the final report submitted to University of California (LLL) by the Lockheed Palo Alto Research Laboratory for contractual study under P.O. 8699503.

ABSTRACT

This document reports the results of a study by Lockheed Palo Alto Research Laboratory on the optimization of low-energy x-ray diagnostic instrument for the SHIVA laser facility at the Lawrence Livermore Laboratory. Preliminary outlines for the basic system and several components are presented, experimental considerations and techniques are recommended, and further studies are suggested.

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LOW ENERGY X-RAY DIAGNOSTIC INSTRUMENTATION FOR SHIVA

I. INTRODUCTION

This report presents the Lockheed Palo Alto Research Laboratory (LPARL) conceptual design for a low energy x-ray diagnostic instrumentation system for SHIVA, makes recommendations covering the critical area of calibration procedures and methods, and outlines other areas for further development. With concurrence and assistance of the Lawrence Livermore Laboratory technical staff, changing requirements due to technical advances have been accommodated into the considerations and designs for the final recommendations of this study.

Past LPARL experience has demonstrated the value of a module approach to such instrumentation, so the SHIVA instrumentation should be designed for maximum flexibility and interchangeability of components and channels. Incorporated into the design are some types of equipment and methods developed and employed by LPARL for other projects but with slight modification are well suited for the SHIVA system. The designs and recommendations are divided into five categories. The general system is described in Section II. The mirrors and mirror cassettes are detailed in Section III along with considerations of alignment and standard calibration. The subject of calibration is discussed further in Section IV wherein is presented an alternate calibration system which could provide superior reflectivity measurements. In Section V a beryllium mirror "aging" study is recommended and its considerations outlined. Lastly, in Section VI we describe the LPARL modified 7912 oscilloscope which meets certain requirements of the SHIVA system.

II. GENERAL SYSTEM

The basic configuration is conceptualized in Fig. 1. Flat mirrors and detectors are mounted at the end of a conical vacuum system which is 5 m long by 0.65 m maximum diameter. Such a long flight path provides several advantages, including isolation from target debris, sufficient lever arm for magnetic removal of charged particles, electromagnetic pulse isolation for the detectors, room for anti-scattering baffles to eliminate wall effects and crosstalk, and reasonable area at the end for mounting the mirror cassettes.

The first advantage, isolation from target debris, is achieved by using fast-acting vacuum valves immediately in front of the mirror cassettes. These small valves (one per channel) close in less than one millisecond, before potential contaminants can reach the sensitive mirror, XRD and filter foil surfaces. The ability to achieve stable calibrations and repeatable experimental results (from shot-to-shot as well as over many weeks or months) depends on the ability to protect the sensitive surfaces involved from all potential contaminants; the concept of long flight paths with fast-acting valves is integral to that confidence. By comparison, the gate valve shown near the target in Fig. 1 is slow-acting and used only to isolate the vacuum systems between shots.

Seven energy channels are considered sufficient: five foreground and one background spanning the x-ray energy range from 0.1 to 1.6 keV, and one measuring above 1.5 keV. Each of the five low energy channels will consist of a grazing incidence flat mirror and a vacuum x-ray diode detector, with selective filtering to complement the energy selectivity of the two. For the single high-energy channel, filtering together with the diode response will suffice, without the use of a mirror. Each of the seven detector signals can be recorded using a Tektronix R7912 oscilloscope with a 7A19 vertical amplifier used routinely in the laboratory giving a nominal 1 ns time resolution. In some instances much better time resolution may be required.

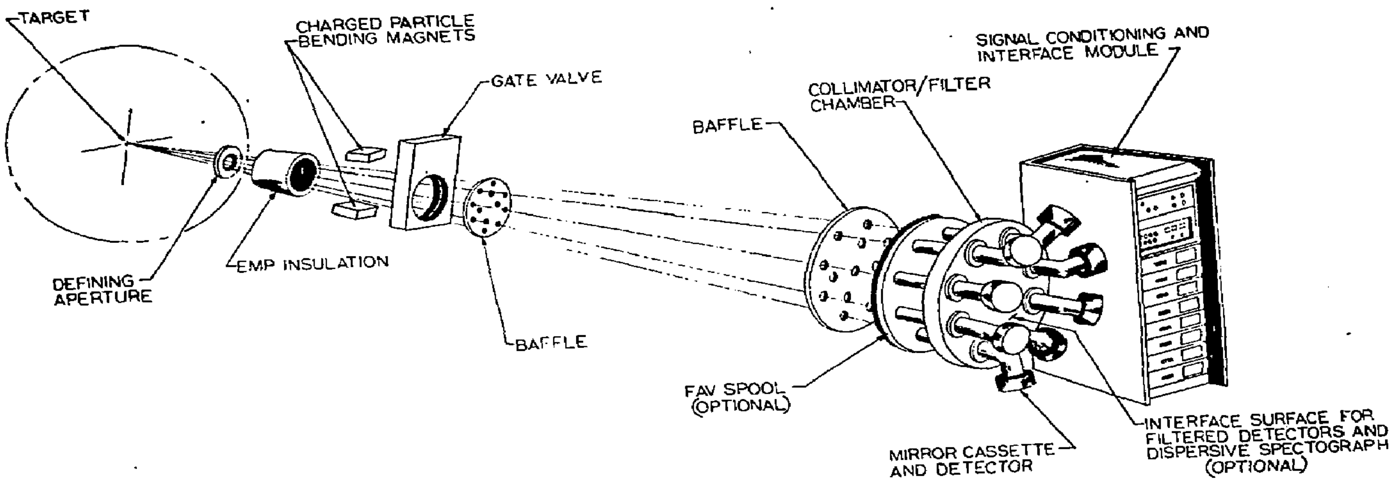

Fig. 1. Conceptual View of Basic System.

A Lockheed modification of the Tektronix 7912 scan converter, elaborated in Section VI below, could provide a time resolution of 115 ps with high signal sensitivity.

The signal conditioning and interface module would contain the 7912 converters, temporary data storage, and all interfacing and monitoring needed to both read out the data via a fiber-optic CAMAC interface and to monitor and set up the experiment manually. Electrical isolation sections are included at both ends of the vacuum system and at the mechanical support stands, to minimize electro-magnetic pulse effects on the detector-recorder systems. For this same purpose, the entire electrical system should be isolated from all power lines and earth ground, double shielded electromagnetically, and powered from an isolated internal source.

Radially outward mounting of the mirror cassettes on a circle about the centerline, as indicated in Fig. 1, ensures that angle corrections are the same for all mounting positions. Since the distance from the source to the mirrors should be variable to accommodate different structural constraints, provision for correction of subsequent changes in mirror angles should be incorporated into the design of the mount for the mirror cassettes. Additional mounting ports can accommodate other diagnostics which may be required to characterize completely the x-ray spectrum in the energy range from 0.1 keV to 2.5 keV (e.g., filtered XRD's, grating spectrographs or total fluence calorimeters).

III. MIRRORS AND MIRROR CASSETTES

Several alternatives are available for partitioning an x-ray spectrum into broad energy bands. For covering the region 0.1 to 1 keV, however, several difficulties arise with most methods. The combination of thin filters and vitreous carbon mirrors has proven highly successful and quite reliable for LPARL measurements at DNA simulation facilities, in UGT at NTS and at the LPARL high-power pulsed laser facility. We therefore recommend their use.

In concurrence with L^3 personnel, five mirror angles 1.3, 1.9, 2.5, 3.5 and 5^o were chosen to cover the required energy band. All the mirrors are made of vitreous carbon with the exception of the 3.5^o mirror which is to be high purity beryllium. A sample calculated filter-mirror response function is shown in Fig. 2 for 2.5^o. (Exact response function requires detailed calibration of each filter-mirror system.) It should be pointed out that the sharpness of the upper-energy cut-off can be enhanced by proper choice of filtering material to take advantage of absorption edges. Calculations of anticipated signal levels have been performed based on the assumption of a 150-μm diameter for the radiating region. The results for 100-, 150-, 200-, 250- and 300-eV blackbody spectra for a wide range of mirror angles are shown in Table 1.

Vitreous carbon provides an excellent mirror material for almost the whole energy range 0.1 to 1.5 keV. For energies just above the carbon K-edge (.277 keV), however, the reflectivity is low. To circumvent this problem, one mirror can be made of beryllium. Theoretical calculations assures that the reflectivity of a beryllium mirror is well suited for this energy range. Uncertainties in its "aging" properties suggest, however, that a further study be carried out to resolve possible difficulties. Considerations for such a study are described in Section V.

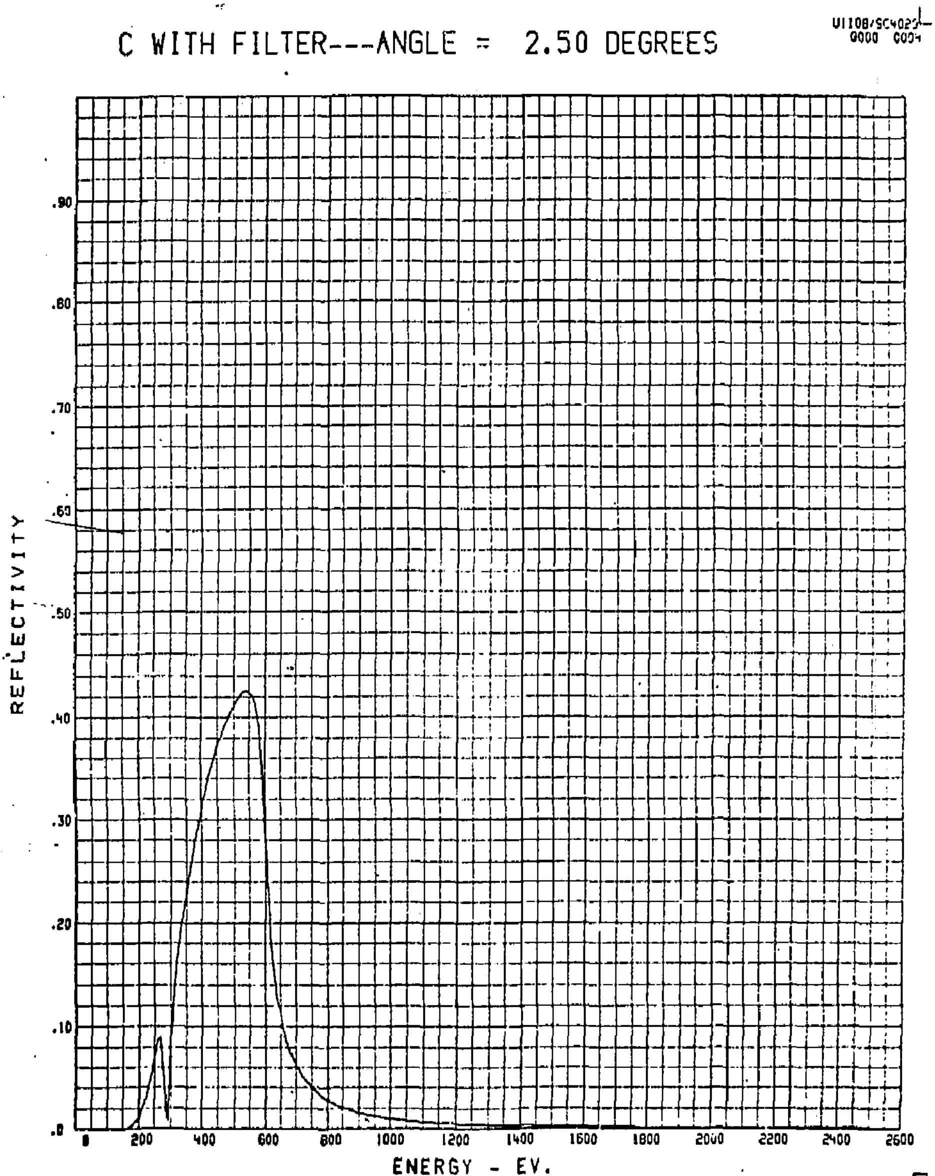

Fig. 2. Calculated Mirror Filter Response Curve.

Table I.

Calculated signal levels (volts) for each XRD channel utilizing typical response functions. The diameter of the radiating region is 150 μm.

Temperature in eV

θ	100	150	200	250	300
7°	2.5	4.7	7.0	9.4	12.0
4	3.6	7.9	13.0	18.0	24.0
3.25	0.5	2.1	4.7	7.9	12.0
2.5	0.5	3.0	8.0	15.0	24.0
2.0	0.7	4.9	14.0	29.0	46.0
1.5	0.7	4.4	15.0	34.0	59.0
1.0	0.05	1.0	4.9	14.0	30.0

Successful use of mirror-filter systems for x-ray diagnostic measurements is critically dependent on alignment and calibration. In the former, several features should be considered in the design of the mirror cassette (mirror holder and enclosure). First, provisions should be made for precision measurement of the mirror angle by optical means. This is typically done at LPARL using a light source set in a geometry similar to the source to be measured. Measurement of the deflected light relative to the undeflected light provides an unambiguous measurement of the mirror angle. A second consideration, measurement of the mirror angle during the shot, typically with x-rays and film, offers a cross-check of both the angle and alignment and increases the confidence in the measurement.

Measurement of the reflectivity of the mirrors as a function of both x-ray energy and mirror angle, particularly in the energy region below 1 keV theoretical calculation, is not sufficient. Standard calibration at LPARL employs a D.C. x-ray source to excite fluorescent radiation from thin foils to provide monoenergetic x-rays. Mirror reflectivity at several energies, typically from the 0.109 keV Be line to the upper energy of interest, and several angles is then measured. Theoretical calculations are then used as a guide to interpolate between the discrete points of the experimental measurements.

IV. ALTERNATE CALIBRATION METHOD

Although the calibration method outlined above has proved sufficient, the small number of fluorescence lines in the 0.1 to 1 keV energy range limits the accuracy of the calibration and, ultimately, the accuracy of the measurements. A different method could provide an almost unlimited number of discrete points over the energy range of interest. The method, which employs curved crystals and laser generated x-rays, has been proven successful at LPARL for the higher energies of interest and could be reconfigured to extend over the entire energy range.

The system, shown schematically in Fig. 3, employs a curved crystal positioned behind the mirror to be calibrated. The laser-generated x-ray source, indicated in the figure, produces a large number of spectrally resolved lines (such spectra are routinely produced at the LPARL Nd-glass laser facility). These x-rays are reflected from the mirror and subsequently from the curved crystal. This results in a line pattern being recorded on the film. A typical film record is shown in the upper part of the figure, with the analysis at a particular angle, θ_1, shown in the lower part of the figure. In a single shot, mirror reflectivity is determined over a wide range in energy and angle by comparing the optical density of the spots at the bottom edge of the film, which are x-rays reflected from the curved-crystal only, with the density of the lines immediately above. A few shots with different crystals suffice to span the entire region of interest. This type of calibration, it may be noted, does not require a calibration standard, but only a knowledge of the relative sensitivity of the recording film. Such a system could, for example, also be employed in the investigation of the "aging" properties of beryllium mirrors.

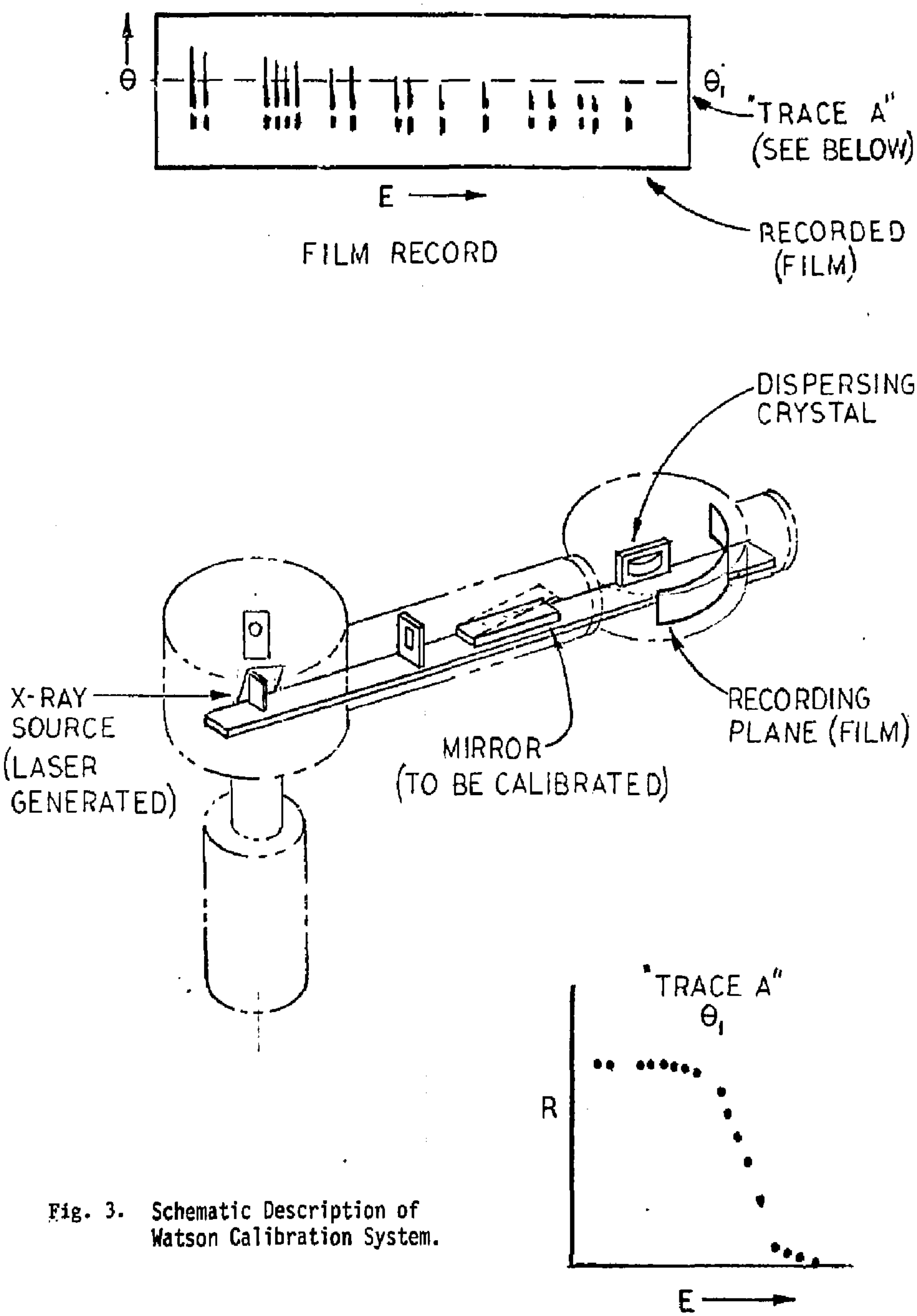

Fig. 3. Schematic Description of Watson Calibration System.

V. BERYLLIUM AGING STUDY

Vitreous carbon mirrors have been used in a wide range of applications and have proven quite stable and, with proper care, immune to debris contamination. Beryllium mirrors, however, have not had similar widespread use. A study should be undertaken to investigate the effects of several "aging"phenomena on the reflectivity of beryllium mirrors. As beryllium is subject to oxidation, one major problem could be reflectivity changes over a long period of time. Second, the effects of the cleaning process should be thoroughly investigated since small amounts of surface contaminants can greatly alter the reflectivity characteristics. Finally, contaminants in vacuum systems could be deposited on the mirror surface; the effect this might have on the reflectivity and how often the mirrors have to be cleaned are unknown. All of these uncertainties need be resolved before one can have good confidence in the experimental measurements carried out with these mirrors.

VI. ENHANCED PERFORMANCE TRANSIENT DIGITIZER, THE LM7912

The Tektronix R7912 transient digitizer oscilloscope is a unique signal recorder, in that it combines an inherently computer-compatible output with a sensitivity-bandwidth product among the highest available. The uniqueness is largely due to its 7910 cathode ray tube, which substitutes a vidicon-like silicon diode target for the conventional phosphor screen; and thereby achieves both an easily-digitized electrical output and rather impressive input characteristics. However, the commercially-available R7912 instrument is not able to exploit fully the CRT parameters, for a number of reasons. Two fast configurations are available, one with 7A19 vertical amplifier plug-in, and one with 7A21N direct access unit. Respective figures of merit are:

	Vertical Bandwidth (GHz)	Vertical Sensitivity (μa/tracewidth)	Writing Speed (tracewidths/ps)
7910 CRT	2.4	400	2
7912-7A21N	1.0	2000	0.4
7912-7A19	0.5	5	0.4

For a number of applications, it would be desirable to achieve (or even exceed somewhat) the full bandwidth and writing speed capability of the CRT, while preserving the sensitivity and digital output characteristics of the standard instrument. This turns out to be quite feasible, as a simple modification. Better matching to the fundamental CRT characteristics produces about a factor of 100 increase in sensitivity-bandwidth product, while maintaining more than adequate writing speed for unambiguous digitization. The resulting LM7912 is used like the standard R7912; but with bandwidth and writing speed somewhat higher than normally associated with the 7910 itself, and sensitivity approaching that of the 7A19 plug-in:

	Vertical Bandwidth (GHz)	Vertical Sensitivity (μa/bit)	Writing Speed (bits/ps)
LPARL-Modified LM7912	3.0	20	>3

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The LM7912 is currently in use at the LPARL Nuclear Sciences Laboratory. Figures 4 and 5 show its performance at different sensitivities. The setting for Figure 4 is typical for large-amplitude use. The input pulse contribution to the displayed risetime is about equal to that from the oscilloscope itself. Figure 5 is typical for a maximum sensitivity setting, approaching the noise limit for 9-bit digitization.

The Mod 1 version of the LM7912 uses the internal 7912 buffer memory in the normal format, so that readout to a central processing unit can be carried out without change. One difference is that with the enhanced circuitry, only one vertical address is possible per horizontal address; so that only one-fourth of the 4096-word memory capacity is used. Alternatively, the format may be changed to eliminate horizontal addresses (using 512 vertical words only), and/or the number of horizontal steps may be increased to a maximum of 4096.

We have also used a Mod 2 version, which eliminates the internal digitization and buffer memory entirely. In this simplest of all forms, the LM7912 operates only as an analog scan converter, with a maximum time expansion ratio of about 10^7. Each fast input waveform produces an equivalent slow output waveform, which is then digitized at the computer input. The advantage is that one ADC can handle several scan converters, with a particularly simple interface.

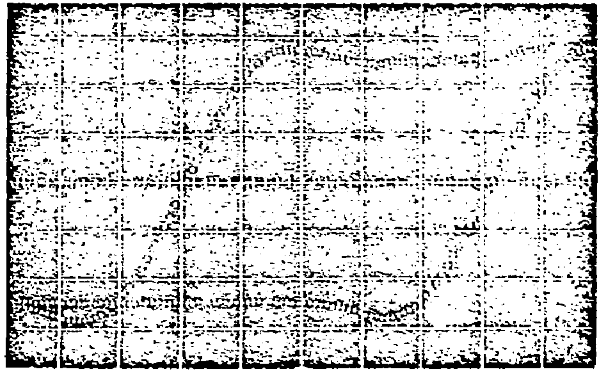

Figure 4

LM7912 RECORDING THE OUTPUT OF A STEP RECOVERY DIODE PULSER

Each of the two input pulses has an amplitude of 7.0 volts and a 10-90% risetime of 120 ps. One pulse is delayed by a calibrated 500 ps with respect to the other, so the scales are 100 ps/div. and 1.4 V/div. A 9-bit word is stored for each 9 ps interval.

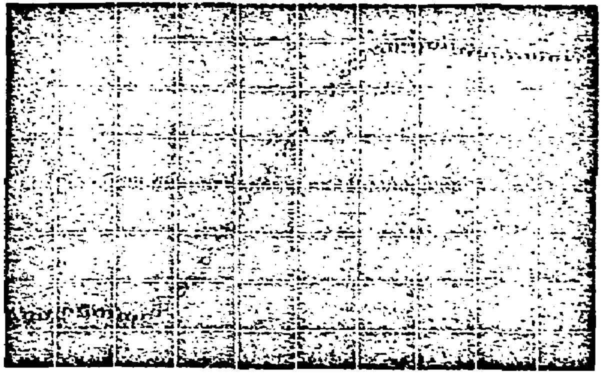

Figure 5

LM7912 RECORDING A 0.2 VOLT STEP

The scales are 40 mV/div. vertically, and 9.6 ps/dot horizontally (or about 70 ps/div.). Each dot represents a 9-bit stored word.