A LOW-NOISE DATA COLLECTION SYSTEM FOR THE THOMSON SCATTERING DIAGNOSTIC APPA

G. R. DYER and M. MURAKAMI, Oak Ridge National Laboratory, Oak Ridge, Tenn

Summary

An automated data collection system as designed and built for the ORMAK Thomson scattering apparatus is described here[1]: The system uses both gated photomultipliers and gated integrators; advantages of this approach are discussed. Four electron temperature and electron density measurements can be made during each plasma discharge, with measurements spaced as closely as one millisecond apart. Data are automatically digitized and stored in a computer for processing and display.

System Operation

A block diagram of the complete system is shown in Figure 1. At the beginning of an experiment, the ORMAK master clock triggers the laser firing timer. The laser firing timer triggers each of four capacitor banks at preset times during the plasma discharge to energize a 10-joule, Q-switched ruby laser which illuminates a point in the ORMAK plasma through a quartz optical system. One-half microsecond before each laser pulse, the system photomultipliers are gated on. One photomultiplier measures light in the laser housing to provide a relative power measurement. Ten other photomultipliers measure scattered light from the plasma. This scattered light is collected by a fast lens system, analyzed into ten spectral regions spanning 6943 Å to 5500 Å by a grating spectrometer, and led through acrylic light guides to the ten photomultipliers. The photomultiplier signals are stored in gated integrators, with one data integrator and one background integrator per tube. A fast photodiode in the laser housing provides the signal to initiate the gate pulses for the integrators. After each laser firing, an 8-bit analog-to-digital convertor digitizes the information stored in the 20 gated integrators, and an interface module transfers this digitized information to a PDP-8/E computer. (We plan to use the ORMAK PDP-12 after a time.) The PDP-8/E stores all data for a plasma discharge, processes it, and types out the results. Cycle time for the system from laser firing through data storage in the computer is approximately 700 microseconds. This allows four plasma measurements in under four milliseconds.

Gated Photomultipliers

Detailed functioning of a Thomson scattered apparatus depends a great deal on how photomultiplier gating is done. Gating is necessary because the photomultipliers must be protected during the initial bright light flash as the plasma ionizes, and mechanical shutters are neither fast enough or reliable enough for the job. The data must be gated, since otherwise the faint signal from the light

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enough dynamic range and is very linear, we decided it would be better to eliminate these transients from the data. To do this, we made the gate-on time of the photomultiplier relatively long (two microseconds) and provided for turning the tube on 0.5 microseconds before the laser pulse. This allows time for the turn-on transient to die away and for the tube gain to stabilize before any data are taken. By using gated integrators, both the scattered light data and a background measurement can be acquired during a single photomultiplier gating period. We are also able to observe the photomultiplier signal on an oscilloscope, so that we have two independent measurements of the data in the oscilloscope picture and the digitized data. Since our gate circuit is built up from TTL circuits and normal switching transistors instead of the usual delay-line pulse shaping network and avalanche-mode trigger, we have the additional advantages of smaller size, faster recovery time, and more reliable operation than with delay-line gating.

Photomultiplier Housing

The ten gated photomultipliers are housed in a steel box shielded with 0.5 inch lead and electrically isolated from the spectrometer compartment. Each photomultiplier has an individual magnetic shield, and the steel box provides additional protection against stray magnetic fields. The box also provides electrostatic shielding, and the lead lining prevents unwanted signals from x-rays generated by runaway electrons in ORMAK. This shielding has proven effective against most noise sources. We still have some interference from the Q-switch thyratron, which generates a very steep transient at the time the laser fires. While our data are useable now, we intend to reduce the thyratron interference by more careful cable routing, more isolation in the photomultiplier gate generator, and whatever else we can think of.

Fast Gating

To keep signal-to-noise ratio as high as possible, it is essential to gate the integrators with as short a gate time as practical. The laser pulse is typically 70 nanoseconds wide at the baseline, so we have chosen a 100 nanosecond integrator gate time to be sure we include all of the signal within the gate. The integrator gate signals are referenced directly to the laser firing time by using a trigger pulse from a fast photodiode in the laser compartment. The transit time of the light pulse through the optical train, plasma, photomultipliers and signal cables is approximately 30 nanoseconds longer than the transit time from the photodiode through the trigger cable to the fast discriminator in the trigger generator module. This time difference allows us to adjust the data

processing and display.

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A block diagram of the complete system is shown in Figure 1. At the beginning of an experiment, the ORMAK master clock triggers the laser firing timer. The laser firing timer triggers each of four capacitor banks at preset times during the plasma discharge to energize a 10-joule, Q-switched ruby laser which illuminates a point in the ORMAK plasma through a quartz optical system. One-half microsecond before each laser pulse, the system photomultipliers are gated on. One photomultiplier measures light in the laser housing to provide a relative power measurement. Ten other photomultipliers measure scattered light from the plasma. This scattered light is collected by a fast lens system, analyzed into ten spectral regions spanning 6943 Å to 5500 Å by a grating spectrometer, and led through acrylic light guides to the ten photomultipliers. The photomultiplier signals are stored in gated integrators, with one data integrator and one background integrator per tube. A fast photodiode in the laser housing provides the signal to initiate the gate pulses for the integrators. After each laser firing, an 8-bit analog-to-digital convertor digitizes the information stored in the 20 gated integrators, and an interface module transfers this digitized information to a PDP-8/E computer. (We plan to use the ORMAK PDP-12 after a time.) The PDP-8/E stores all data for a plasma discharge, processes it, and types out the results. Cycle time for the system from laser firing through data storage in the computer is approximately 700 microseconds. This allows four plasma measurements in under four milliseconds.

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Several methods of photomultiplier gating have been reported in the literature[2]. These include gating the photocathode, the focus electrode, one or more dynodes, and the tube signal itself. We found that we could obtain the highest on-to-off ratio by gating alternate dynodes of our 12-dynode RCA 8852 tubes. Figure 2 shows the circuit we finally used. With any method we tried, switching transients comparable to or larger than the signal from the scattered laser light were present in the photomultiplier output. While it is true that the transients are capacitively coupled to the PMT output and should integrate to zero provided the integrator has

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Gated Integrators

The gated integrators are commercial modules[3], with four integrators housed in a two-wide NIM module. Tests indicate that the integrators perform very adequately at the 100 nanosecond gating time we require. We have not yet had time to complete gain normalization and pedestal adjustments under actual operating conditions, since a vacuum problem stopped operation of ORMAK after only a single day's operation of our complete system! We have enough test and actual experimental data to be confident of the system's successful operation, however.

The integrators have a dynamic range of 5 volt·nanoseconds, which means that a 50 millivolt signal will drive the integrators full scale during our 100 nanosecond gate time. This put us in the startling position of having to attenuate our experimental Thomson-scattered signal during our first day's operation!

Digitizing and Data Processing Electronics

After data from a laser shot are stored in the gated integrators, a commercial interface and analog-to-digital convertor digitize the 20 channels in sequence, requiring approximately 35 microseconds for each 8-bit conversion and transfer. A second interface transfers each digital word to a PDP-8/E computer. The total conversion cycle is essentially 700 microseconds long, so consecutive data points closer together than one millisecond are possible. This feature allows good time resolution of fast-changing plasma conditions, as are encountered just after initial ionization or when an instability occurs.

Experimental Results

Due to limited operating time on the actual ORMAK experiment, we have been able to confirm that the gating circuits, integrators, and digital circuitry functions as planned; but we have not completed normalization and pedestal adjustments. Thus we do not have good experimental digital data at this time, although the oscilloscope pictures have yielded very good data. However, Figure 3 is a set of oscilloscope traces which show the quality of signals from the gated photomultipliers. These data indicate a 550 eV electron energy in the plasma. The oscillatory baseline noise comes from the Q-switch thyratron transient mentioned earlier. We are confident that we will be able to reduce this noise and complete adjustment of the digital circuitry shortly.

Conclusion

The design, construction, and preliminary testing of the Thomson scattering apparatus have been completed. The system can make four density and temperature measurements of plasma with an electron temperature range from 50 eV to 2 keV with a time resolution of less than one millisecond. The system automatically digitizes, stores, and processes the data, and prints out or displays the experimental results.

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References

1. For a detailed mechanical description of the ORMAK Thomson scattering apparatus, refer to J. S. Culver and M. Murakami, "Mechanical and Optical Coupling of a Thomson Scattering Laser T_e Measurement to the ORMAK Machine," found in these proceedings.
2. A short discussion of PMT gating methods and a bibliography are given by G. G. Albach and J. Meyer, A Linear Gate for Photomultiplier Signals, Rev. Sci. Instrum. Vol. 44, No. 5, May 1973.
3. Gated integrators and the ADC were obtained commercially from Lecroy Research Systems, West Nyack, New York.

*Research sponsored by the U.S. Atomic Energy Commission under contract to Union Carbide Corporation.

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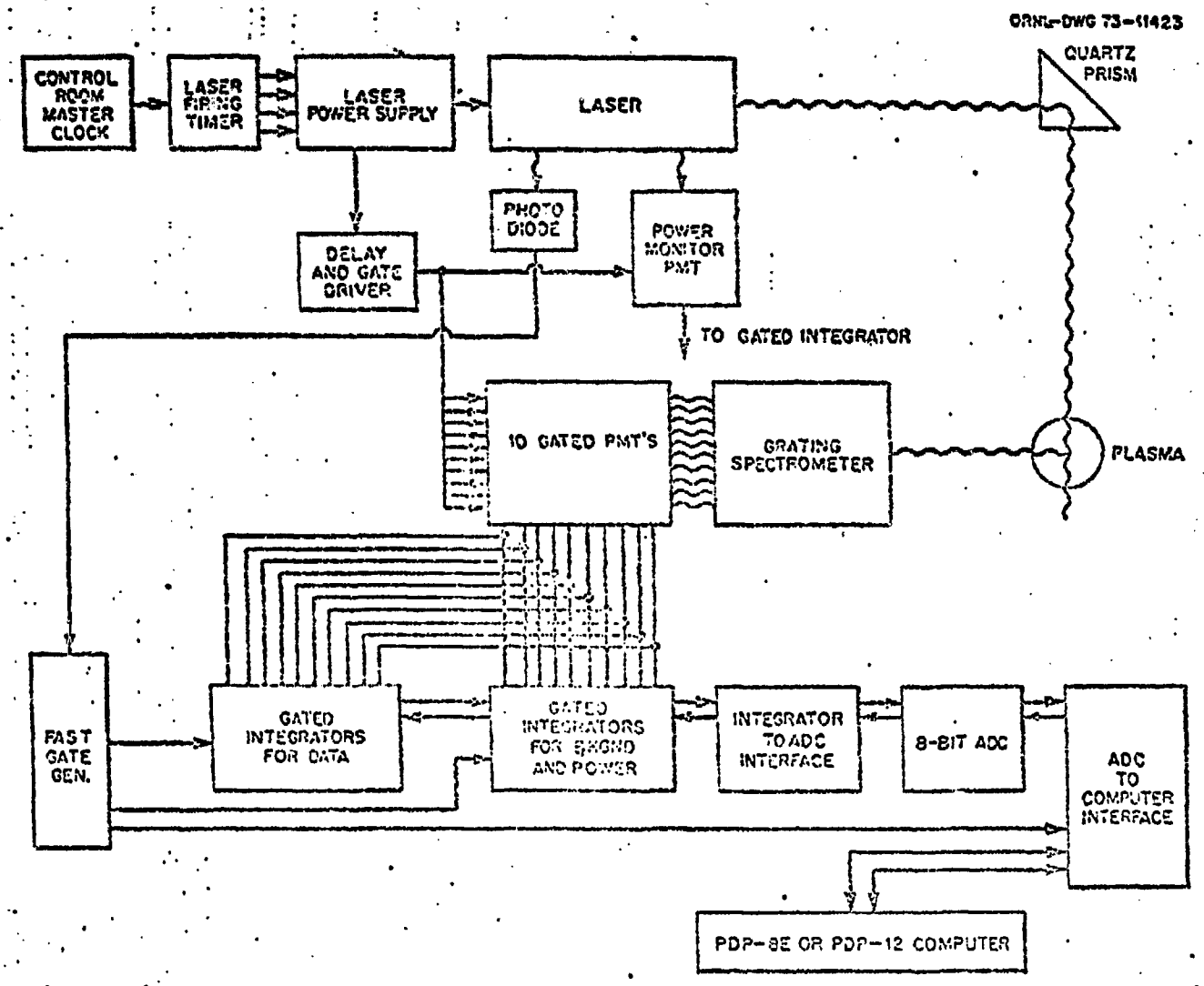
Figure Legends

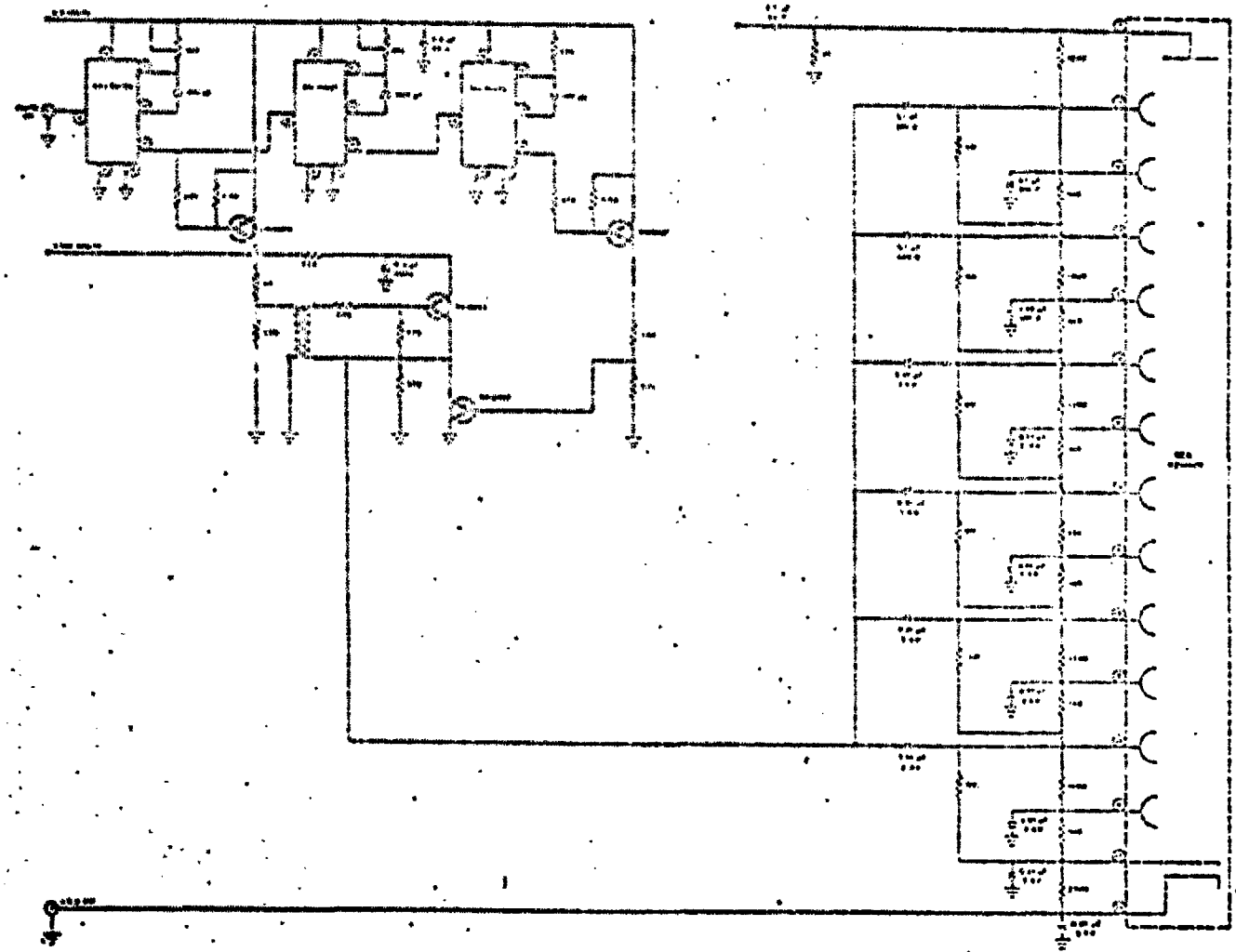
Fig. 1: Block diagram of ORMAK Thomson scattering data collection system.

Fig. 2: Schematic diagram of gated photomultiplier tube used in ORMAK Thomson scattering apparatus.

Fig. 3: Oscilloscope traces of channels 1 through 6 of the Thomson scattering apparatus for a 550 eV plasma.



ORMAK Thomson Scattering Diagnostic Apparatus — Block Diagram.



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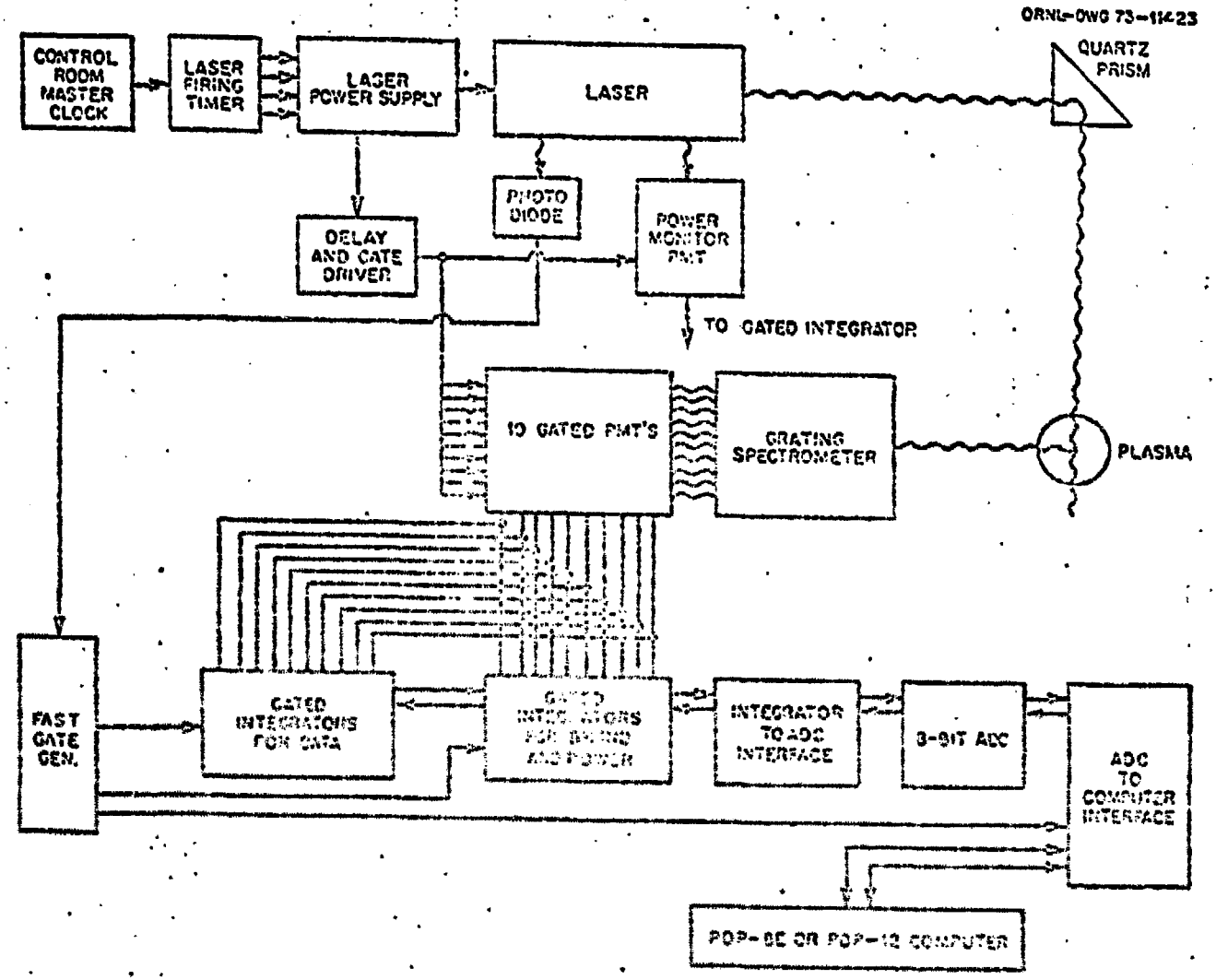

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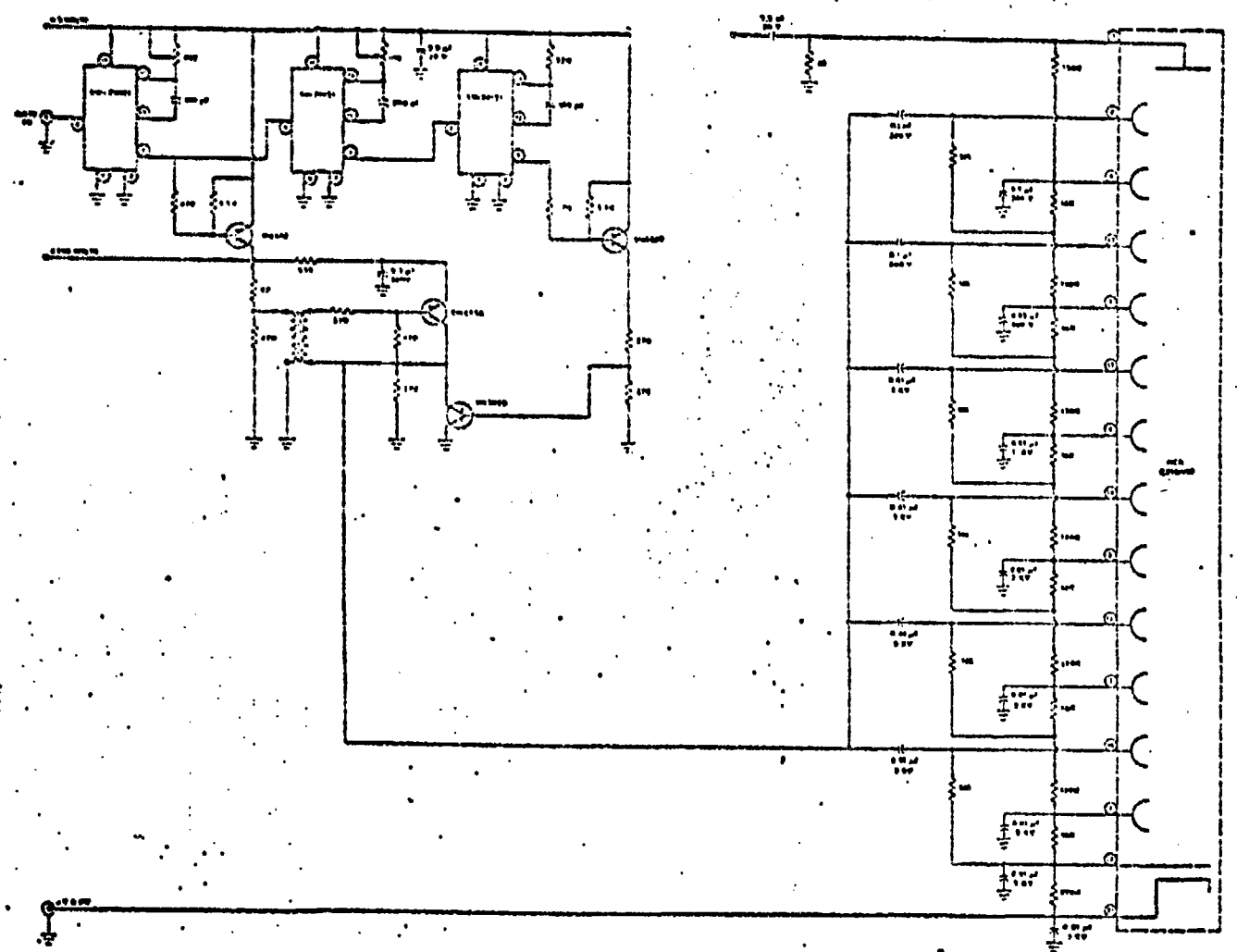

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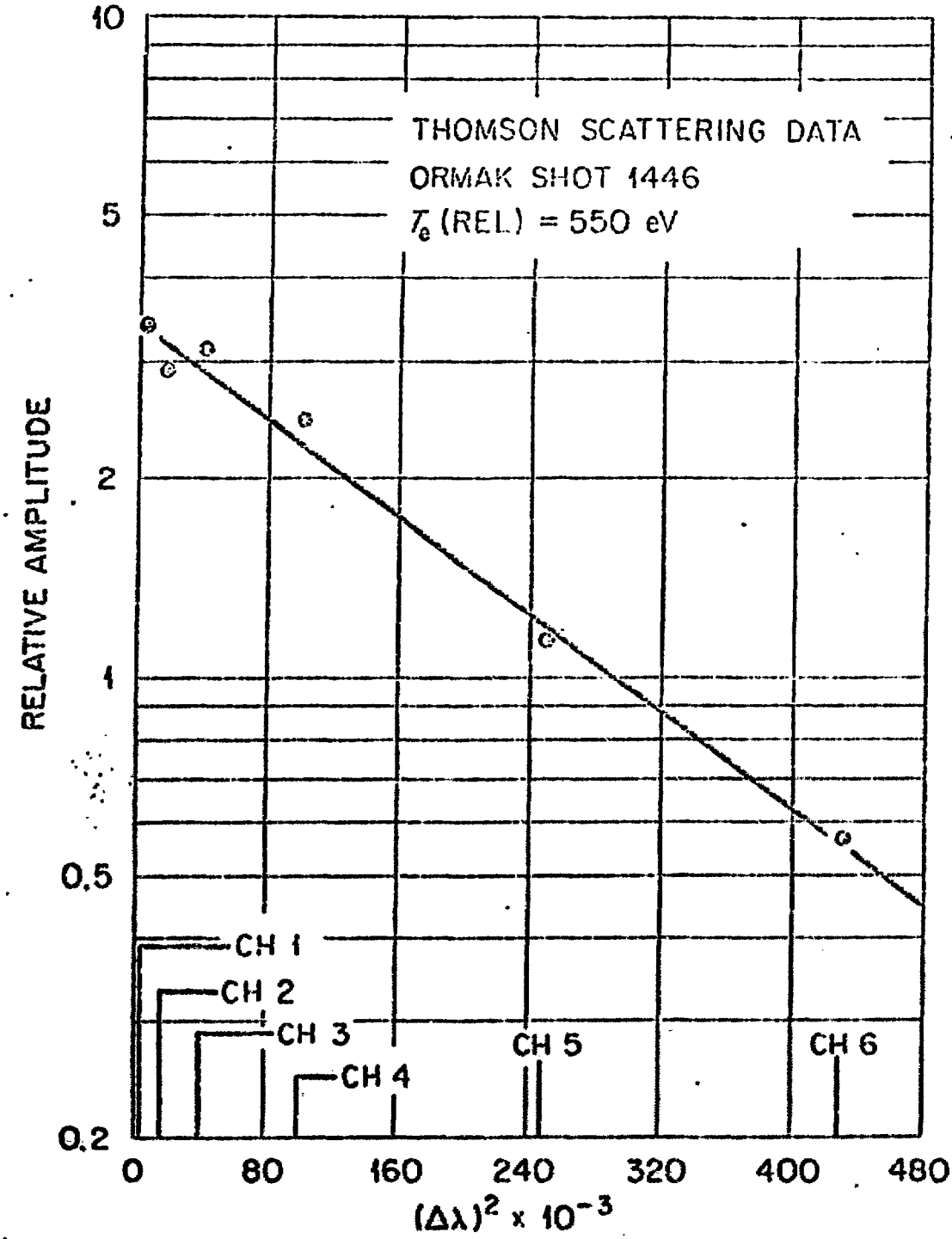

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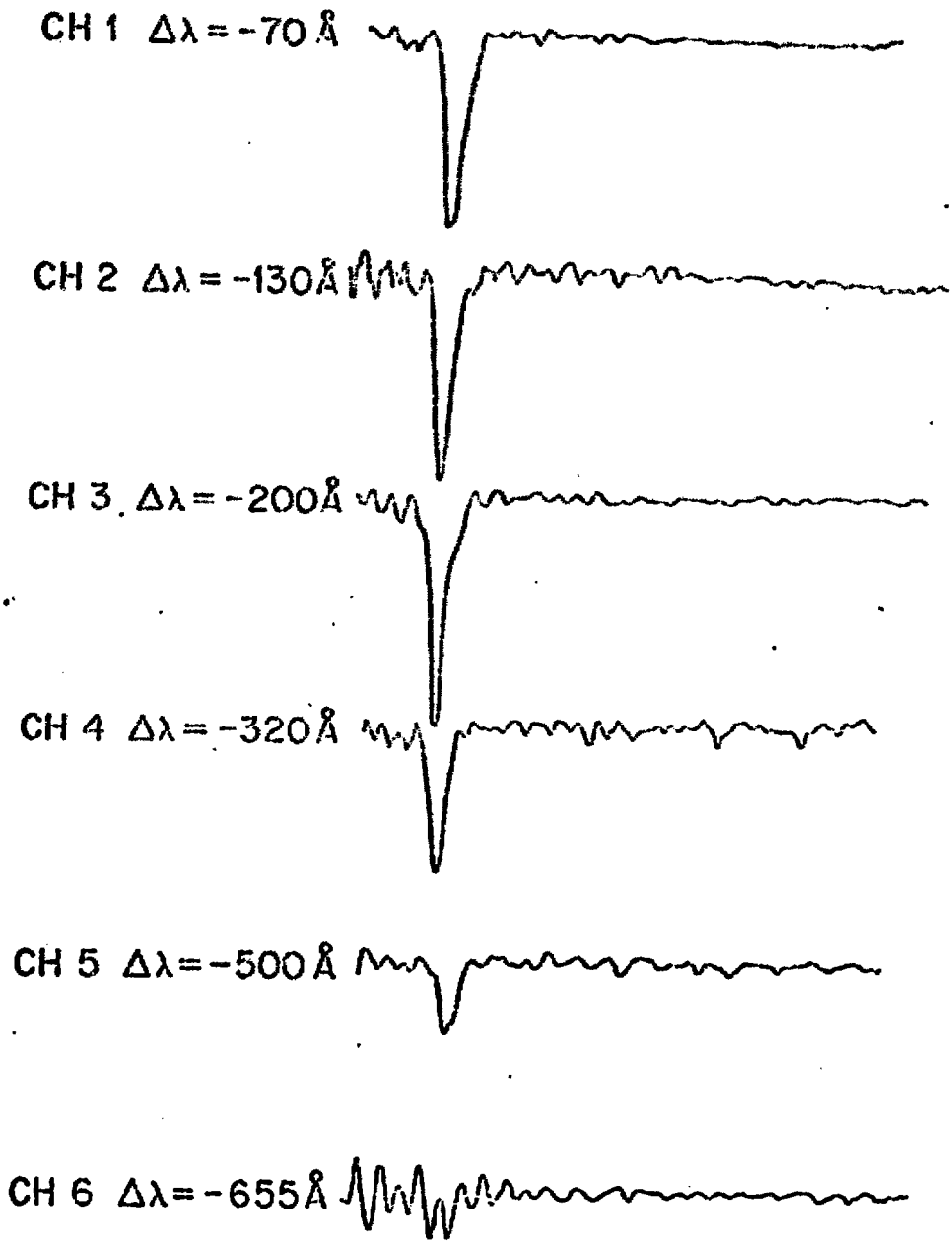

Thomson Scattering Data ORMAK Shot 1446.