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A. E. Huston and K. Helbrough

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The Synchroscan picosecond streak camera system

By A. E. Huston and K. Helbrough
Hadland Photonics Ltd, Bovingdon, Herts. HP3 0EL, U.K.

The Synchroscan system has been developed to meet the need for a picosecond streak camera that could record repetitively at the pulse recurrence frequencies commonly available in laser systems.

The technique was first tested on lasers producing short trains of pulses, and, having shown promising results, was then applied to the recording of short weak pulses of Čerenkov radiation induced by a repetitively pulsed beam of particles.

With the development of continuous wave (c.w.) mode-locked dye lasers there has been an increase of interest in the Synchroscan method, and the system has been developed into a commercially available accessory for the Imacon 675 streak camera. Results are presented illustrating the various stages of the development.

Introduction

Streak cameras capable of time resolution in the picosecond region were developed in the early 1970s (Arthurs *et al.* 1972; Butslov *et al.* 1972; Thomas *et al.* 1972) and were commercially available (John Hadland (P.I.) Ltd, Imacon 600 camera, 1972). These cameras operated by producing a single linear streak on receipt of a synchronizing trigger pulse, enabling a record to be obtained of the light received during a time period of 10^{-9} to 10^{-8}s. At about this time, however, lasers were being developed (Shank *et al.* 1972) that produced a continuous train of pulses, the interval between pulses being of the order of nanoseconds and the pulses themselves being of the order of picoseconds in duration. Work was begun on the design of a camera that could streak repetitively, at the same rate as the repetition frequency of the laser pulses, enabling a streak record to be obtained for every pulse emitted by the laser. The aim was to achieve this with such consistency and lack of jitter that the recorded pulses could be superimposed accurately on the screen of the image tube, a feature permitting the recording of very weak pulses which would be quite unrecordable on a single-shot streak camera. The result of this work was the Synchroscan streak camera system.

Description

Figure 1 shows the original scheme of Synchroscan. It consisted essentially of an oscillator–power amplifier combination, coupled to the deflector plates of a streak type of image converter tube, via a suitable matching network. The resonant frequency of the circuits of the oscillator and amplifier could be tuned to match the repetition frequency of the laser, and sufficient output could be generated to produce a sinusoidal deflexion of over 100 mm (peak-to-peak) on the screen of the tube. The central 50 mm or so of this deflexion is sufficiently close to a linear sweep to be usable for repetitive streak photography.

The power amplifier was fed from a driver stage that could be operated either as an oscillator or as an amplifier, depending on the way that the system was synchronized to the experiment, e.g.:

(1) where a continuous electrical signal was available, this was simply amplified in the driver stage to a level sufficient to fully load the output stage;

(2) where a continuous optical signal was available (i.e. a continuous train of light pulses) a photodetector (vacuum diode or PIN diode) was used to produce an electrical signal which is then used as in (1);

(3) where only a 'burst' of optical pulses was available, the photodetector output was used to pull into synchronism the driver stage now operated as an oscillator and adjusted as closely as possible to the correct frequency.

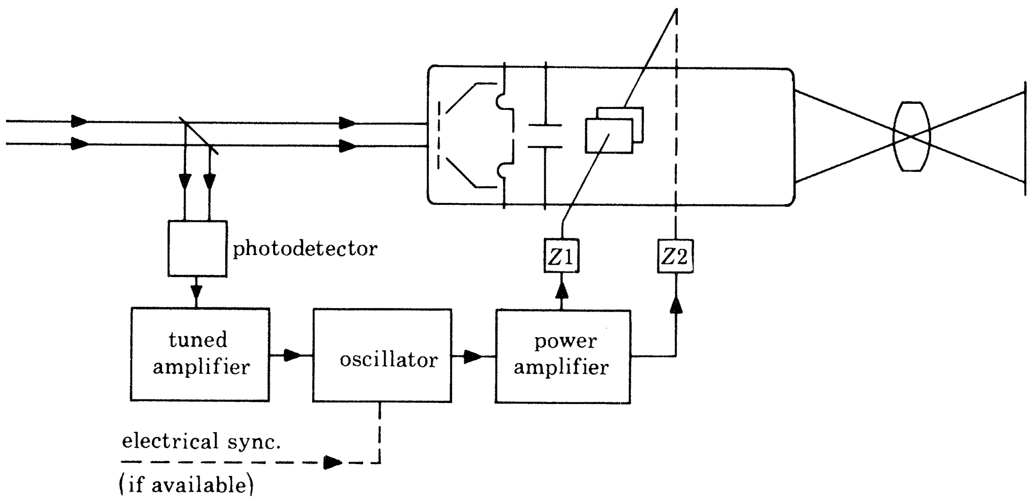

Figure 1. Scheme of Synchroscan camera.

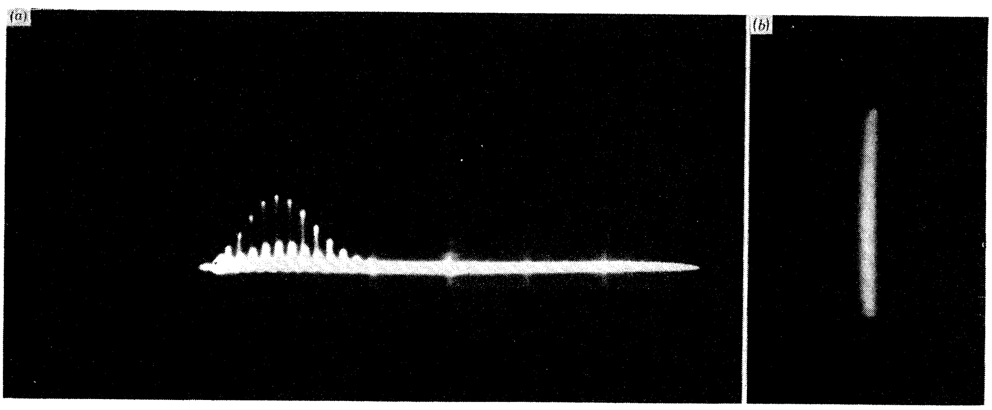

Figure 2. Records taken with Nd–YAG laser. (*a*) Train of pulses recorded by photodiode; time intervals between pulses are *ca.* 8.2 ns. (*b*) Synchroscan record of pulse train; pulse width *ca.* 30 ps.; scan speed 42 mm/ns.

Initial tests

At the time when the first Synchroscan system was assembled (late 1973), a laser producing a continuous train of pulses was not available for carrying out full tests, and it was therefore decided to attempt the apparently more difficult task of synchronizing to a short burst of pulses. An Nd–YAG laser was used which produced a train of pulses at intervals of 8.2 ns, corresponding

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to a frequency of 122 MHz, the pulses being of the duration of approximately 30 ps. Figure 2*a* is an oscilloscope record of a typical pulse train, recorded by a vacuum photodiode picking up a proportion of the laser output (Hadland *et al.* 1975).

Figure 2*b* shows the single 'bar' record from a Synchroscan camera, obtained by taking the output from the photodiode and applying it to the driver stage of the system. The sweep speed in figure 2*b* is 42 mm/ns, and to obtain sufficient image intensity for photographic purposes, the output of the streak tube screen was optically coupled to a three-stage magnetically focused intensifier, the output image in turn being optically coupled to film.

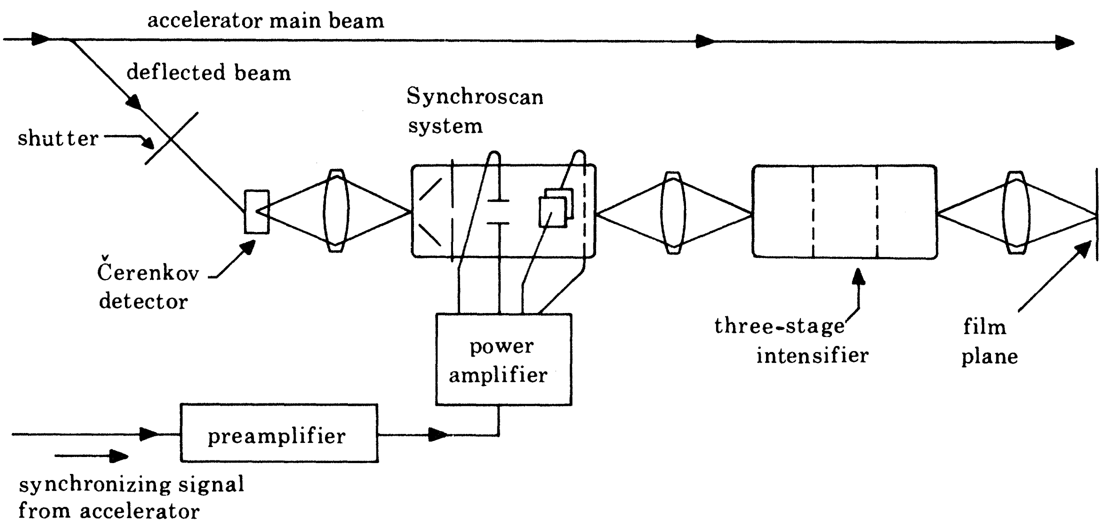

FIGURE 3. Scheme of circular scan Synchroscan camera for recording Čerenkov radiation.

TIME RESOLUTION OF ČERENKOV RADIATION

A non-laser use for the Synchroscan system appeared during 1974. An experiment was being carried out by Rice University of Houston, Texas, at the linear accelerator facility at Los Alamos, New Mexico. An instrument was required that could time resolve Čerenkov radiation produced in a detector by a beam of pions. The beam was pulsed at a repetition frequency of 201.25 MHz, and the light produced in the detector was of very low intensity. It was required to record this light on a circular rather than a linear time base, so that the timing of the light pulses could be observed at whatever point in the cyclic time they appeared. The special system set up for Rice University is shown in figure 3.

The circular scan was produced by generating a quadrature component in the power amplifier stage and applying it to a second pair of deflector plates in the image tube, the plane of deflexion being orthogonal to the plane normally used for streak photography. No optical pick-up device was needed for synchronization, as a suitable electrical signal was available at the facility.

Figure 4 shows the results obtained. Figure 4*a* shows circular deflexion at 201.25 MHz, obtained by illuminating the centre of the photocathode with a fine light spot. Figure 4*b*–*d* shows the recorded Čerenkov light obtained at different points in the cycle depending on the experimental conditions. Each of these records required a total exposure duration of 10 s, so that they represent no less than 2×10^9 superimpositions of the image of the Čerenkov light.

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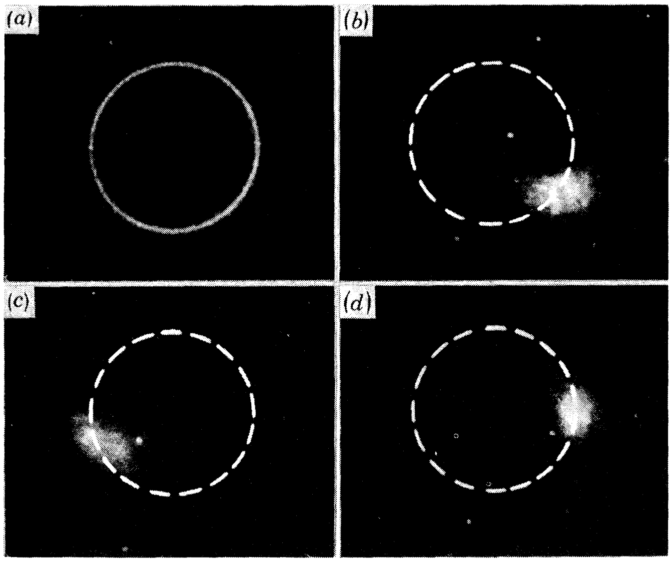

FIGURE 4. Records taken with circular scan Synchroscan. (*a*) Test record showing circular deflexion at 201.25 MHz, with continuous illumination. (*b–d*) Recorded Čerenkov light showing variation of timing obtained by altering the experimental conditions.

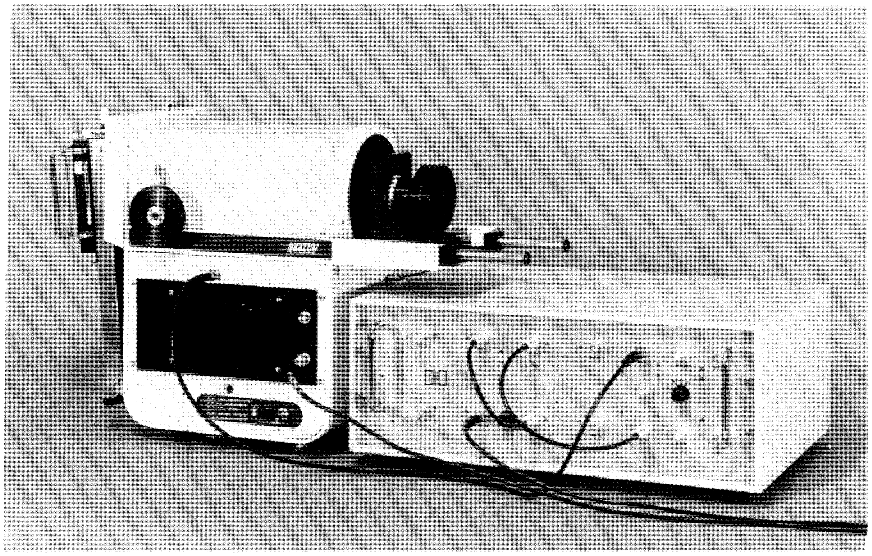

FIGURE 5. Imacon 675 camera with separate Synchroscan drive unit.

APPLICATION TO MODE-LOCKED C.W. LASERS

Much interest has been shown in recent years in the use of ultra-fast streak cameras to study fluorescence, or other luminous phenomena, on a picosecond time scale. This has been done with mode-locked flashlamp pumped dye lasers, but it is preferable to use low-intensity pulses from c.w. dye lasers to avoid nonlinear effects (Adams *et al.* 1978), and the Synchroscan technique, exploiting the repetitive nature of the pulses, has shown promising results (Hadland *et al.* 1978).

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The system has also been developed in engineering terms, and a Synchroscan drive unit coupled to an Imacon 675 camera is shown in figure 5. A power of 18 W is delivered to the streak tube, producing a deflexion amplitude of about 15 cm peak-to-peak. This is much greater than the diameter of the tube screen but only the central portion of the deflexion sinusoid is used for repetitive streak photography.

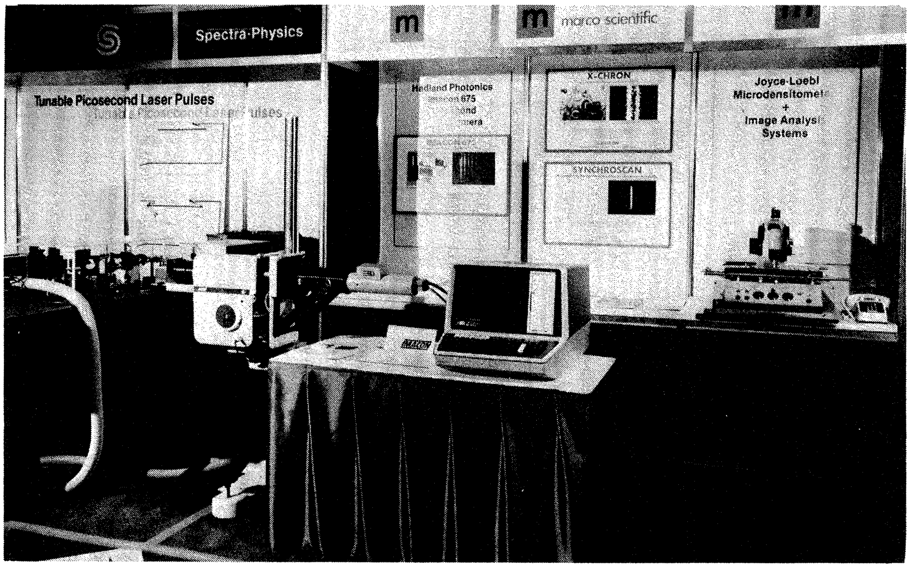

FIGURE 6. Synchroscan system, consisting of Spectra-Physics mode-locked c.w. laser, Imacon 675 Synchroscan camera, and OMA2 analysis equipment.

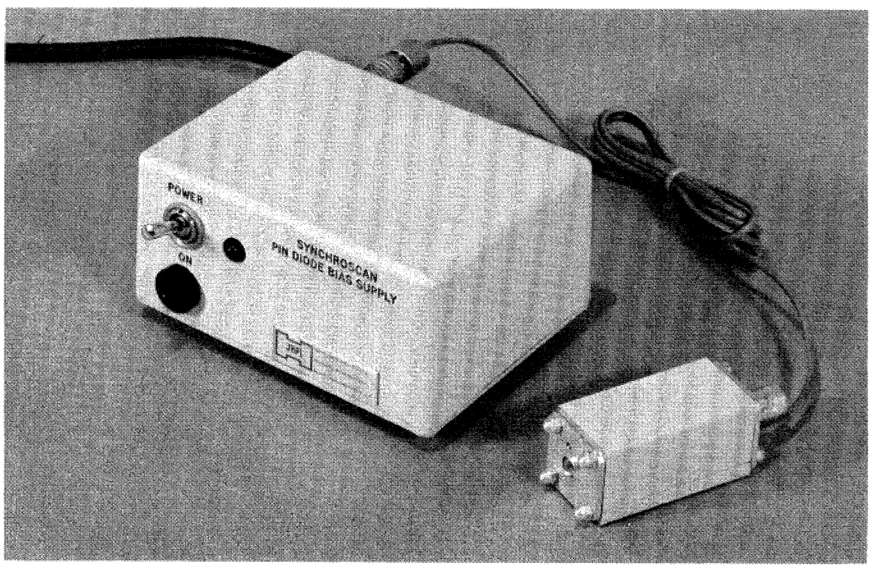

FIGURE 7. PIN diode head and power supply unit, used for synchronizing purposes.

Figure 6 shows a complete system, consisting of a Spectra-Physics mode-locked c.w. laser, Imacon 675 Synchroscan camera, and OMA Mk 2 analysis equipment, on exhibition at the International Quantum Electronics Conference in Atlanta, Georgia, June 1978. In this demonstration, Synchroscan was operated at the fundamental frequency of the laser, 81.8 MHz, and a short gating time of 0.5×10^{-6}s was used, so that about 40 light pulses were superimposed

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in the record. The OMA equipment was calibrated to display a resolution of 4 ps per information line, and the pulse displayed covered 3–4 lines f.w.h.m., indicating a pulse width of 12–16 ps. Synchronization to the laser was effected by the use of a PIN diode detector unit, depicted in figure 7. The pick-up head shown includes a multistage wideband amplifier which delivers a suitable synchronizing signal into a 50 Ω cable.

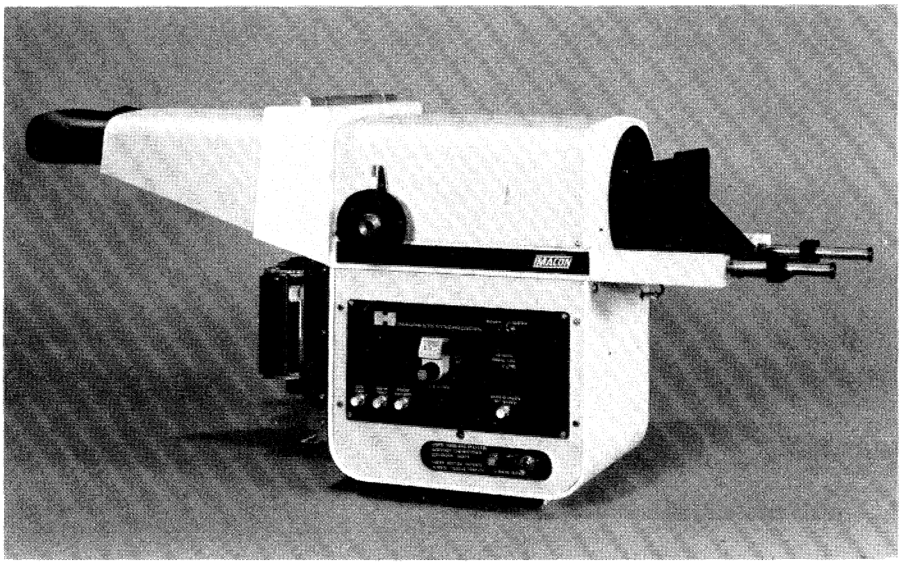

Figure 8. Imacon 675 Synchroscan camera complete.

A synchroscan of integrated design

It is now possible to convert an Imacon 675 camera to Synchroscan operation by direct substitution of the electronic drive chassis, which now appears as shown in figure 8. Included in the unit is a gating pulse generator, allowing the sampling time of the system to be preset. The range of adjustment is from 0.5 to 100 μs, enabling the operator to reduce the effect of jitter in the laser-produced pulses by using a short sampling time. The Synchroscan system itself is virtually jitter-free, owing to the high Q of the resonant circuits used.

With the addition of the PIN diode detector unit of figure 7, this forms a complete Synchroscan camera system ready for use. The camera can be designed for any repetition frequency from 70 to 170 MHz, and the central panel control provides a fine adjustment of frequency, the range covered being nominal frequency $\pm 5\%$.

The authors wish to acknowledge the considerable help given by Professor S. A. Ramsden and Dr R. J. Dewhurst of the University of Hull, in providing and operating a laser on which the initial tests were made, and the valuable discussions with Professor D. J. Bradley, Dr W. Sibbett and Mr M. C. Adams of Imperial College, which resulted in much interchange of ideas.

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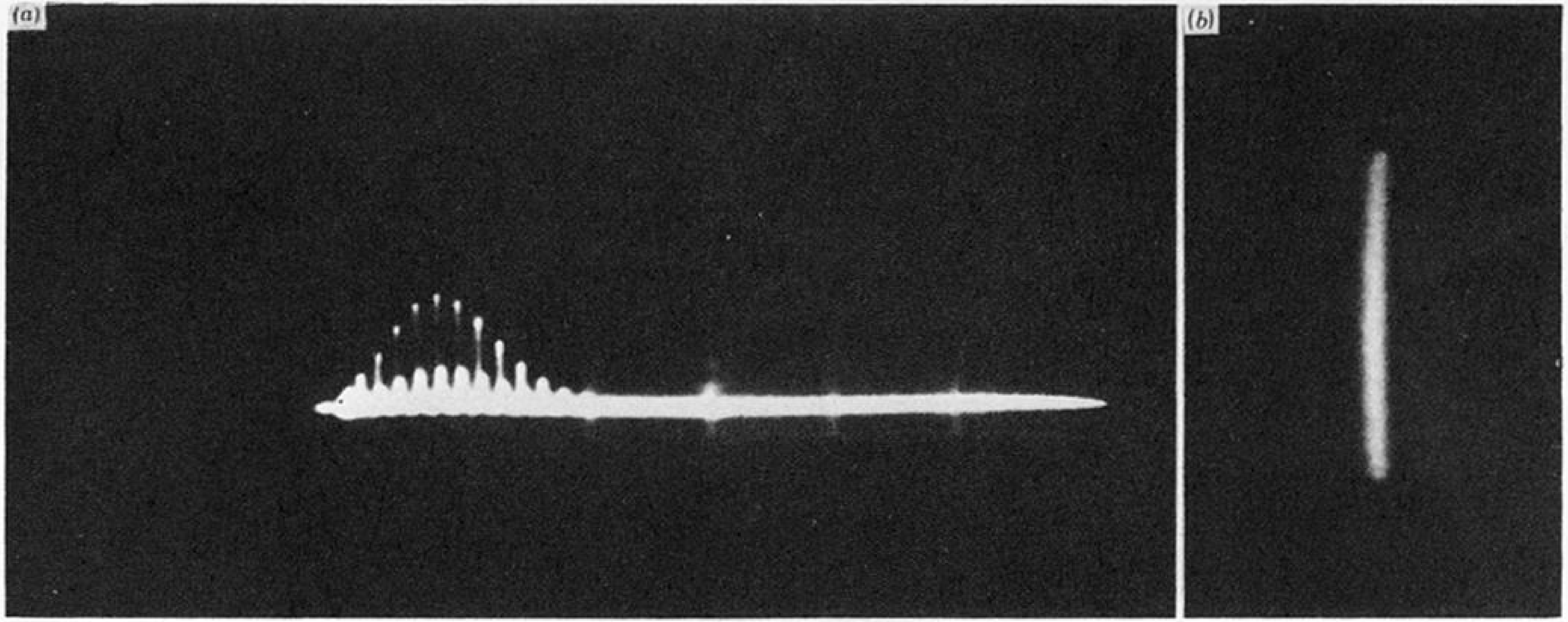

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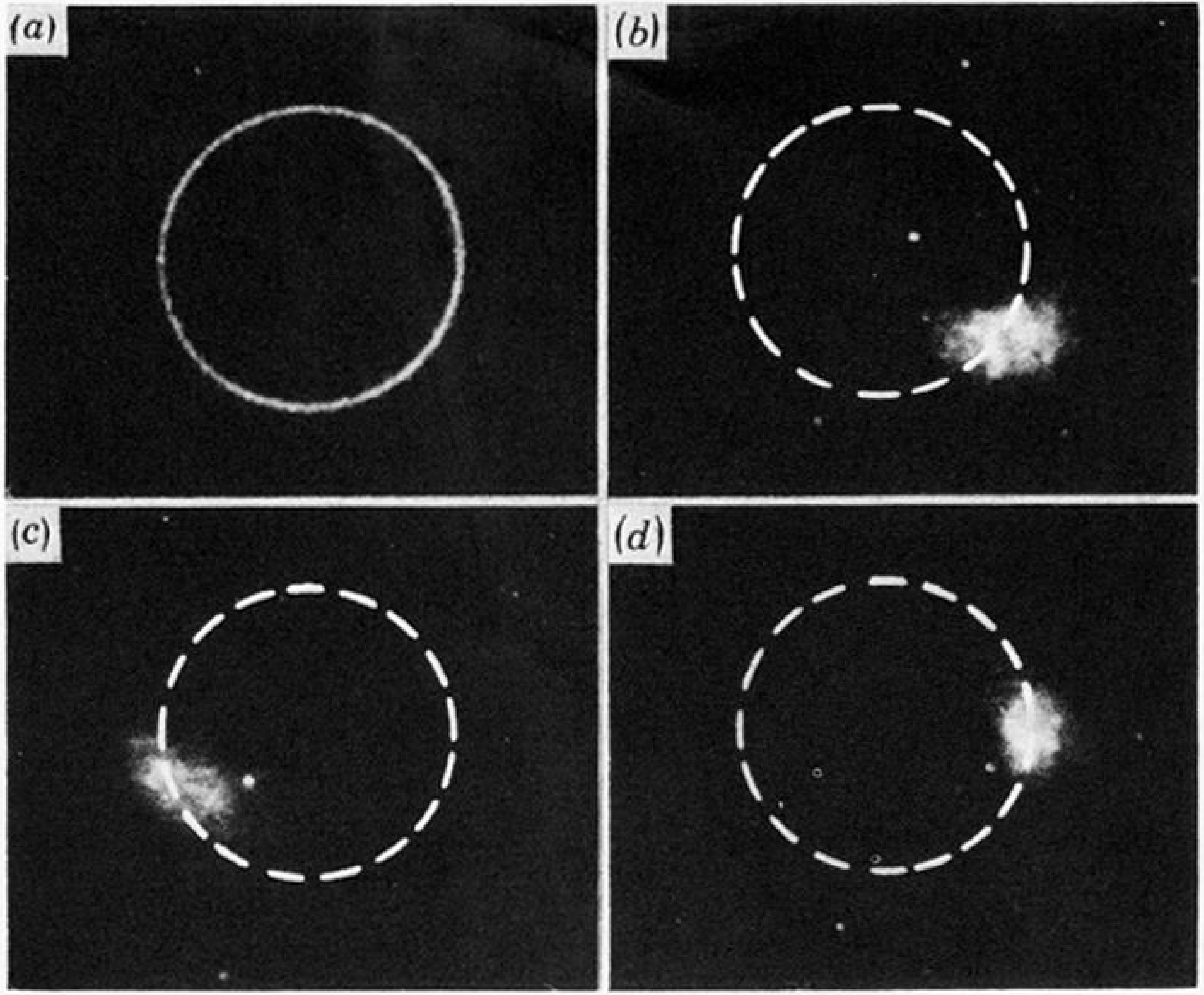

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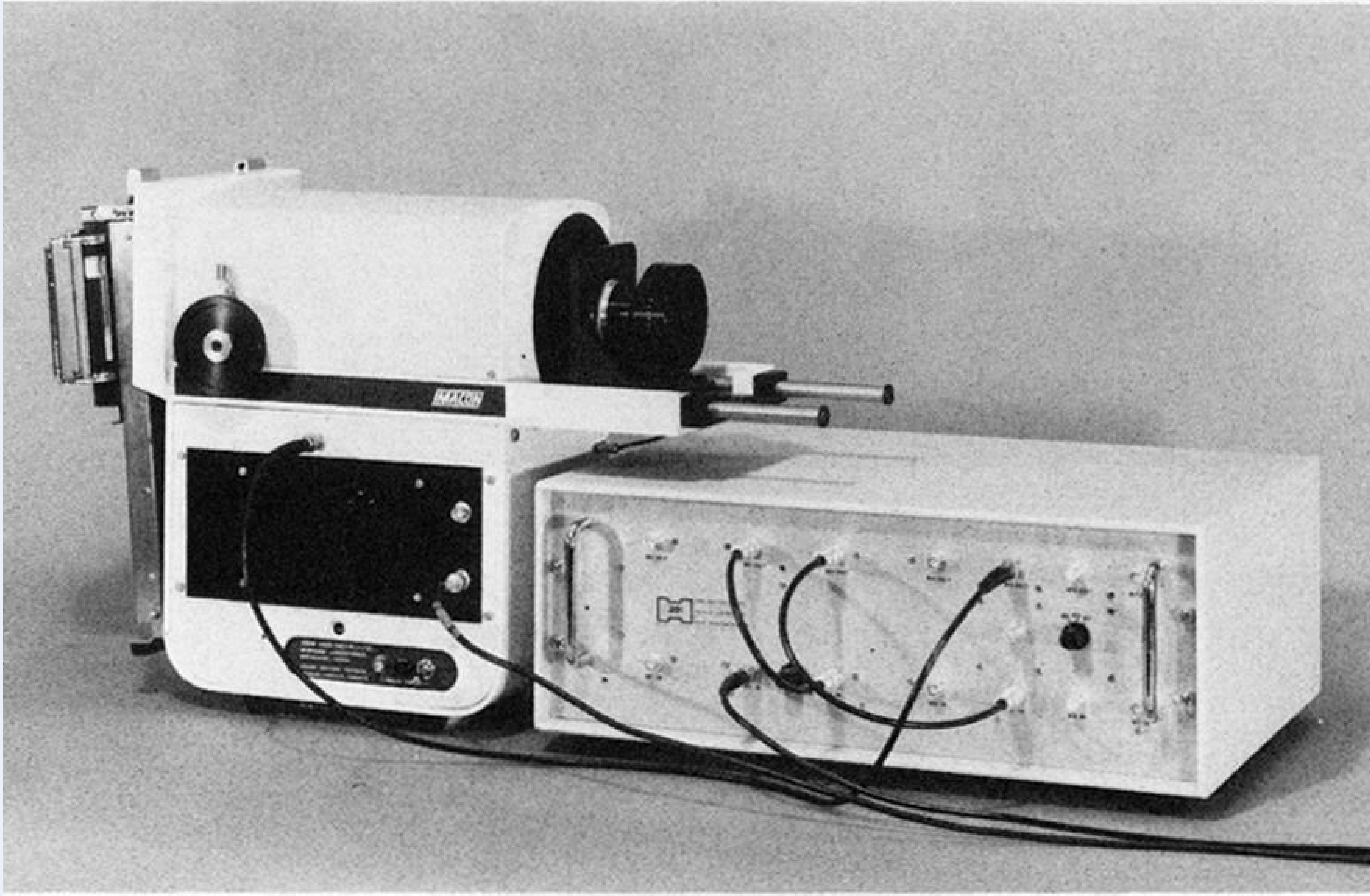

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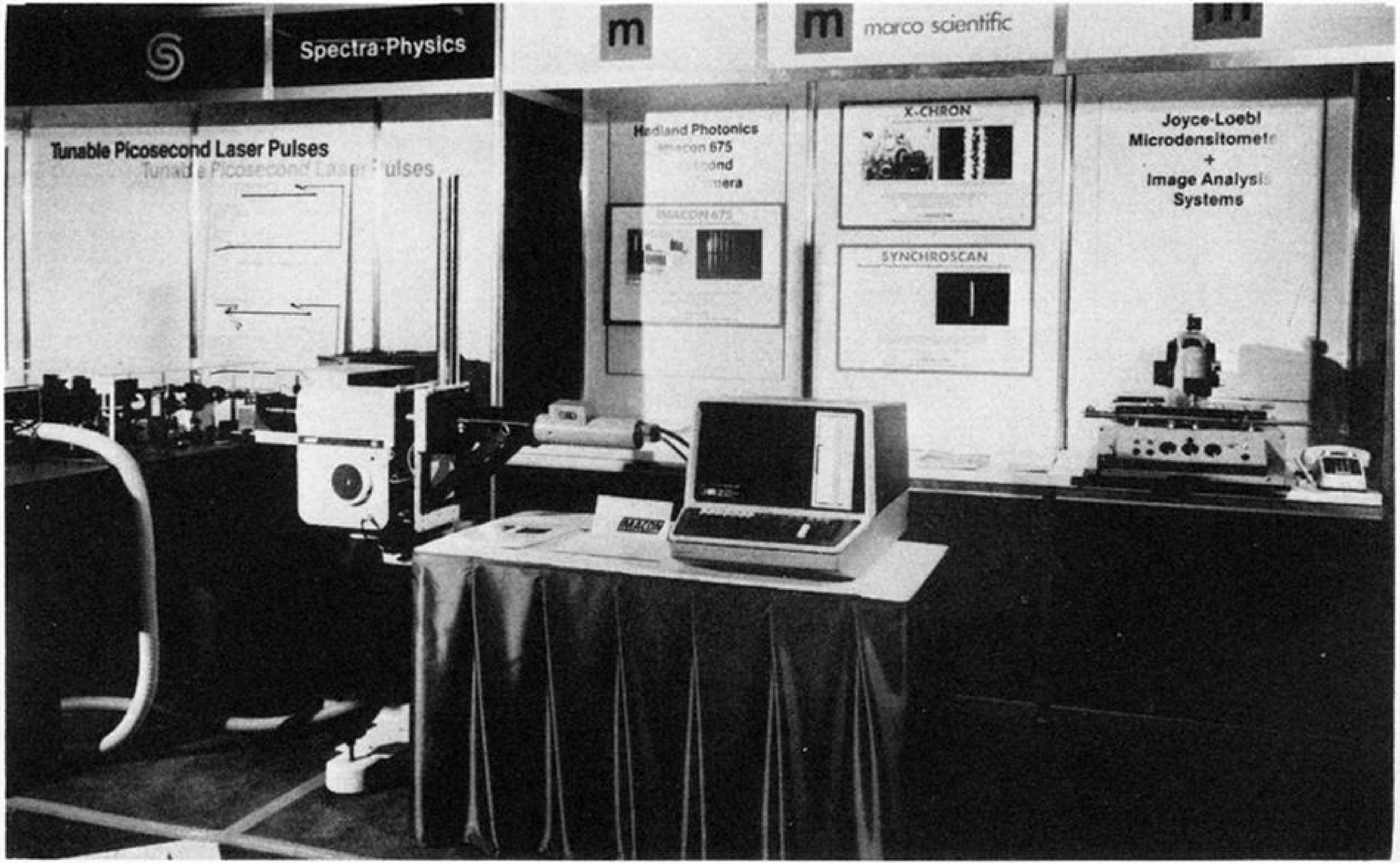

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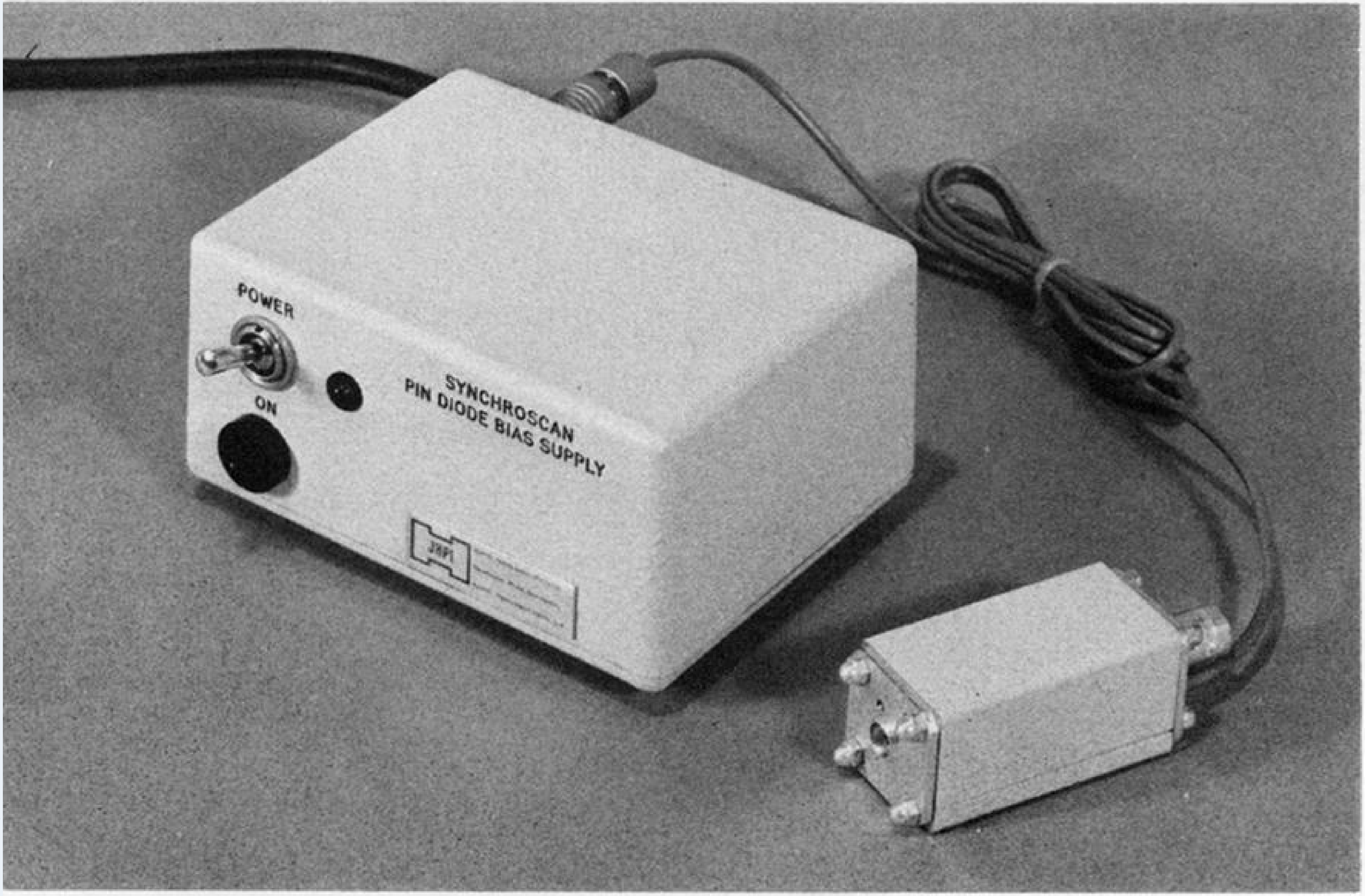

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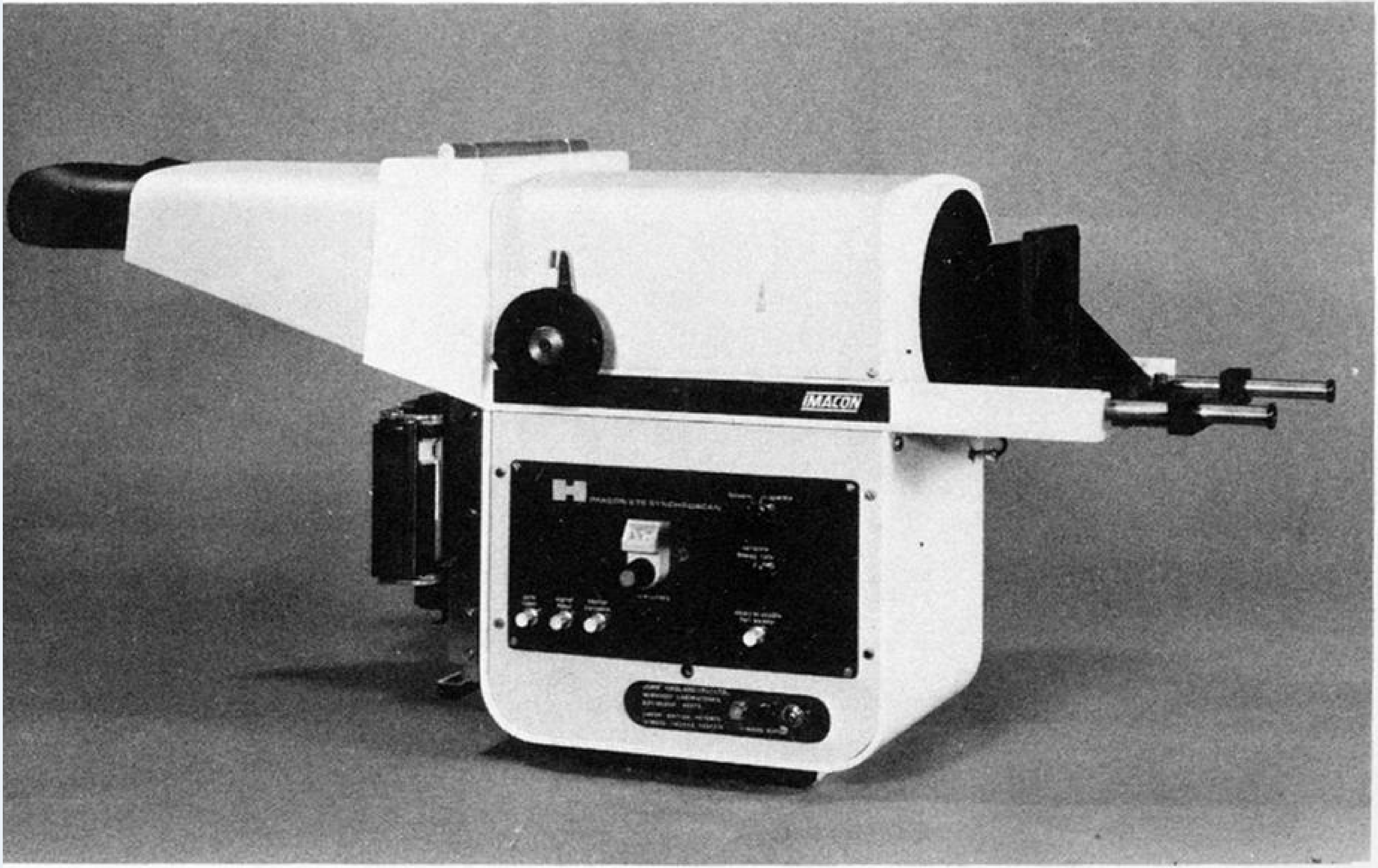

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