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DEVELOPMENT OF A CRANZ-SCHARDIN PHOTOGRAPHIC SYSTEM CAPABLE OF 10^6 FRAMES PER SECOND FOR STUDY OF BUBBLE COLLAPSE AND LIQUID JET IMPACT

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ABSTRACT

The development of a Cranz-Schardin multiple spark source photographic system, with a maximum framing rate of 10^6 frames per second, is described. Major items involved in the system are triggerable air-gap spark light sources, a solid state delay network, a converted portrait camera, associated optics, and mounting methods for the system. The usage and limitation of the system are also described. It is especially adapted to the study of such events as bubble collapse and high-velocity liquid impacts, and can be used in Schleiren or shadowgraph studies.

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I. Introduction

For photographic studies requiring very high framing rates (10^5-10^6 frames per second), the types of cameras available are limited. The most versatile camera in this range is the high speed rotating mirror camera; however, this device requires a high initial investment. The image converter camera has the best light economy, but does not have high resolution. If light intensity is no problem a Kerr-Cell camera may be used[1]. Finally, if the object to be photographed is non-luminous and may be backlighted, as is the case for the study of bubbles, a Cranz-Schardin photographic system[2] may be optimum. This last possibility has the advantage of involving a minimum initial outlay.

Fig. 1 and Fig. 2 show photographic and schematic representations of the specific Cranz-Schardin system described in this report. The major parts of this system are the light sources, the trigger electronics, the field optics, the camera, and the optical bench.

II. Light Sources

The compact light sources (Fig. 3), which are an integral part of the camera, are triggerable air gap sparks with a light output great enough to expose 400 ASA film and a light duration of 0.22 μs. This is the half maximum duration of the pulse as measured by an RCA 7102 photomultiplier. Plexiglas plates, a brass busbar, and a Bakelite strip make up the body of the light source, while the major electrodes are fabricated from mild steel.

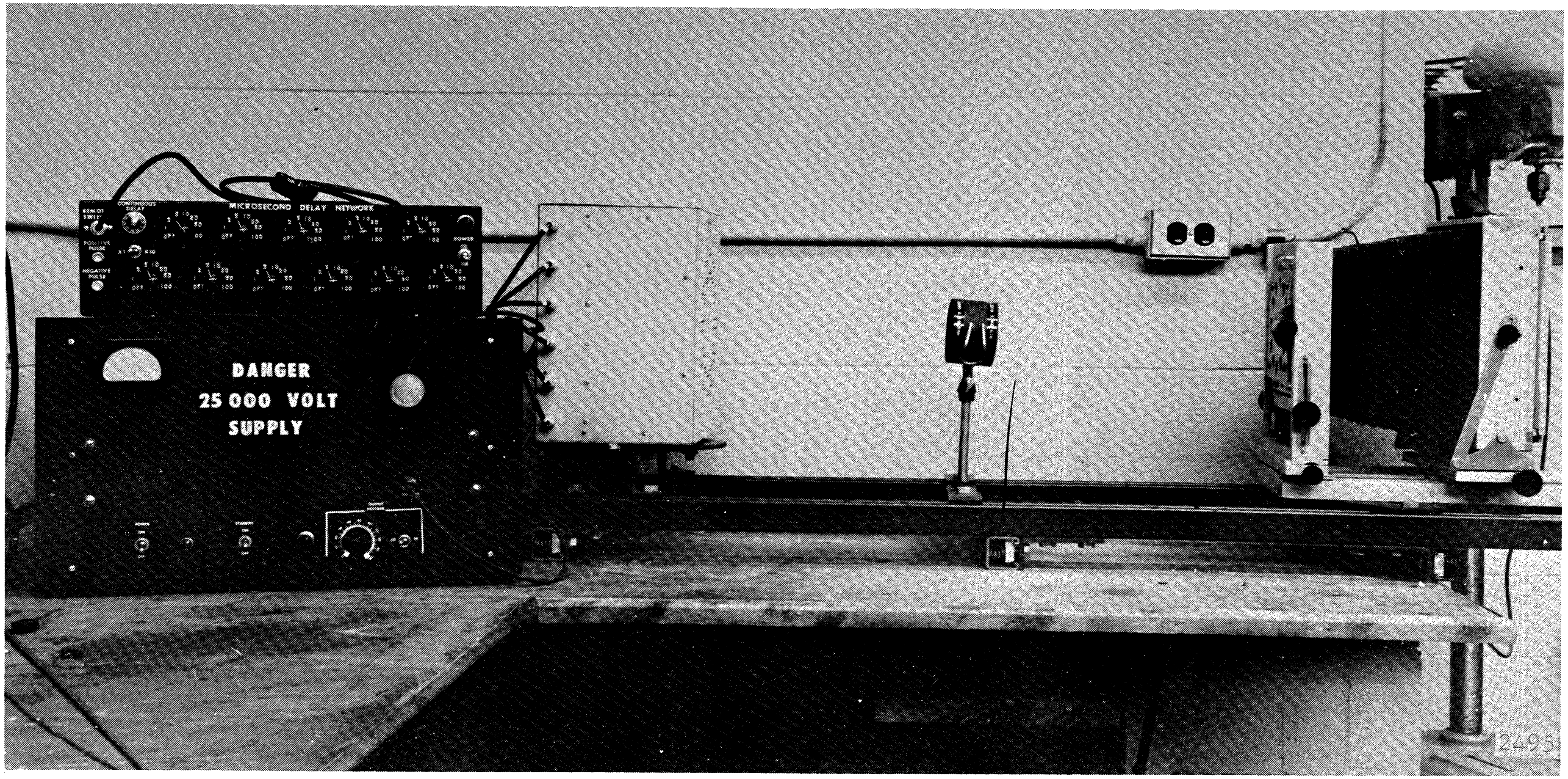


Fig. 1.--Cranz-Schardin System Including Delay Network and High Voltage Power Supply.

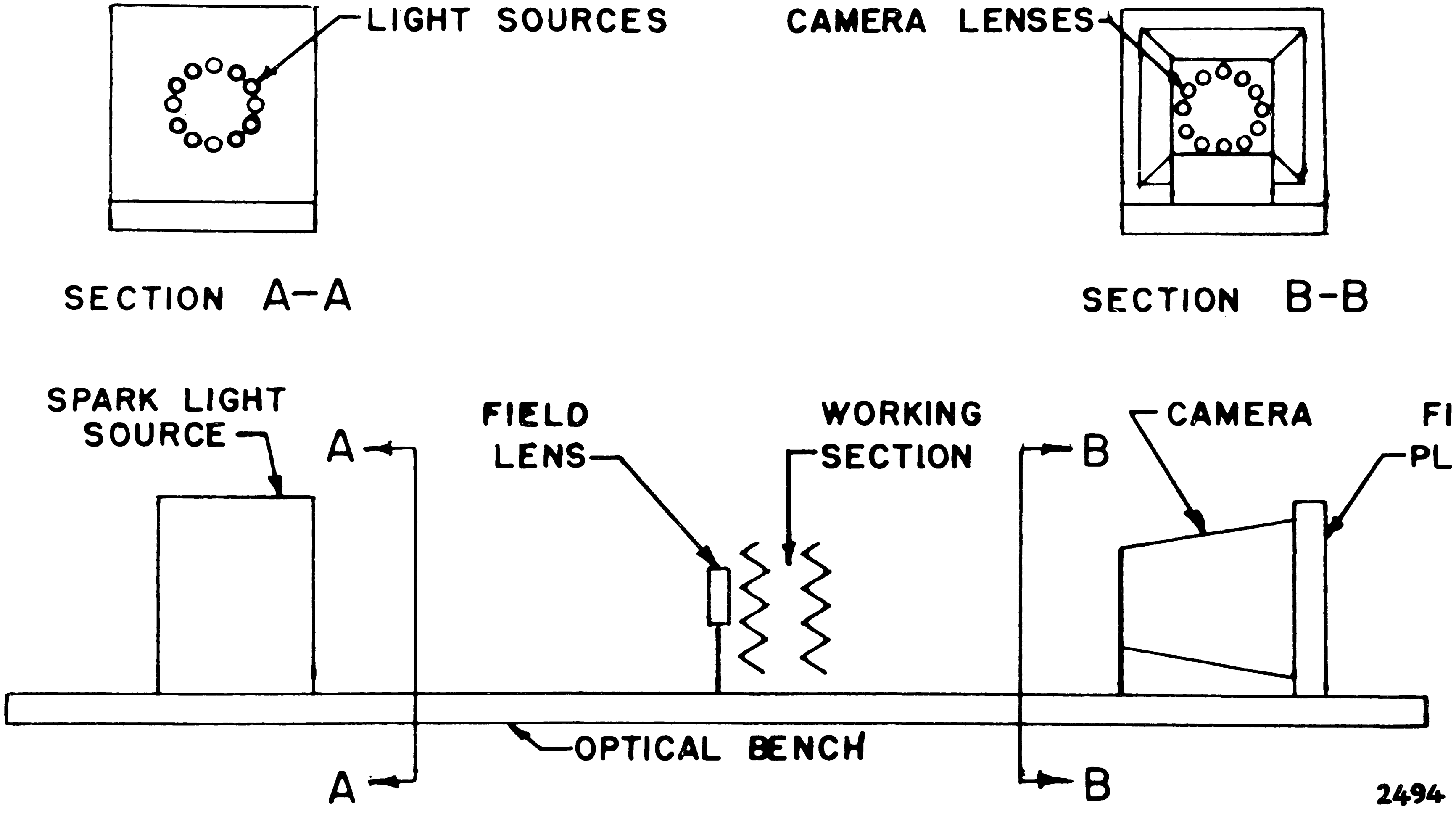


Fig. 2.--Schematic Diagram of Cranz-Schardin System.

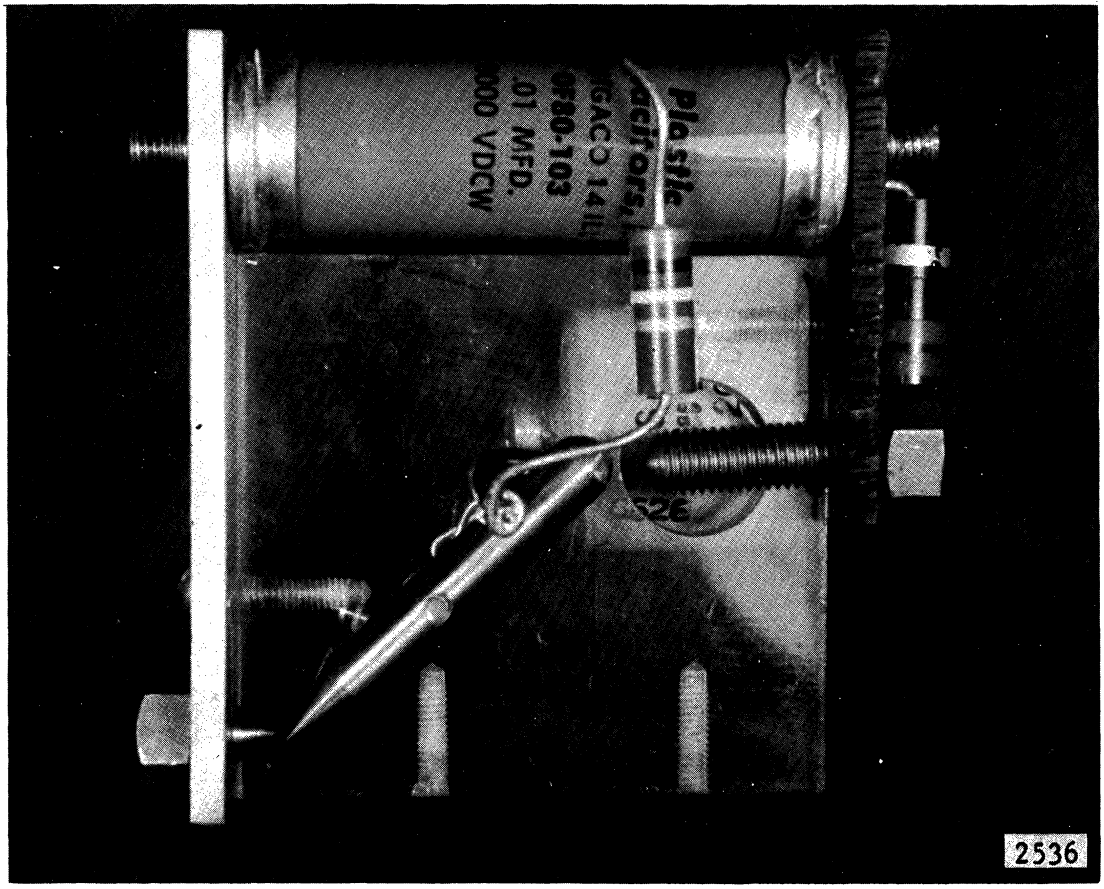


Fig. 3.--Triggerable Air Gap Spark Light Source. (Top plexiglas plate is removed for clarity.)

The two outer electrodes are threaded to facilitate easy adjustment of the gap distances, and the center electrode is drilled to accommodate a concentric trigger electrode of insulated #14 wire.

The operation of the light source is more easily understood by use of a schematic (Fig. 4). The 0.01 μF capacitor is charged to 10kV and the larger gap is set just wider than the breakdown distance. When the trigger pulse (with a 24kV peak and a 10 μs pulse width) breaks down the gap between the trigger electrode and center electrode, the 0.01 μF capacitor discharges across the large and small gaps, and the damping resistor within a few tenths of a microsecond. The damping resistor allows the 0.01 μF capacitor to discharge completely in the first half cycle so that successive light pulses are eliminated. The 500pF, 20kV capacitor aids in the initial breakdown of the larger gap. The smaller gap is used as the light source and may be masked if a smaller light source is required. Twelve of these light sources are mounted on a 5.5 cm radius in an iron box (used to reduce electromagnetic radiation to a minimum). In the interests of compactness a 0.01 μ F capacitor having a rating of only 8kV is used; however, no capacitor breakdown has occurred over a lifetime of several hundred discharges. The jitter time due to gap breakdown is reduced to a minimum by using the above mentioned concentric trigger electrode which allows the larger gap to be as small as possible.

III. Trigger Electronics

A solid state delay network was designed and constructed to produce trigger pulses with 1 to 100 μs delays (i.e., 10^4 -10^6

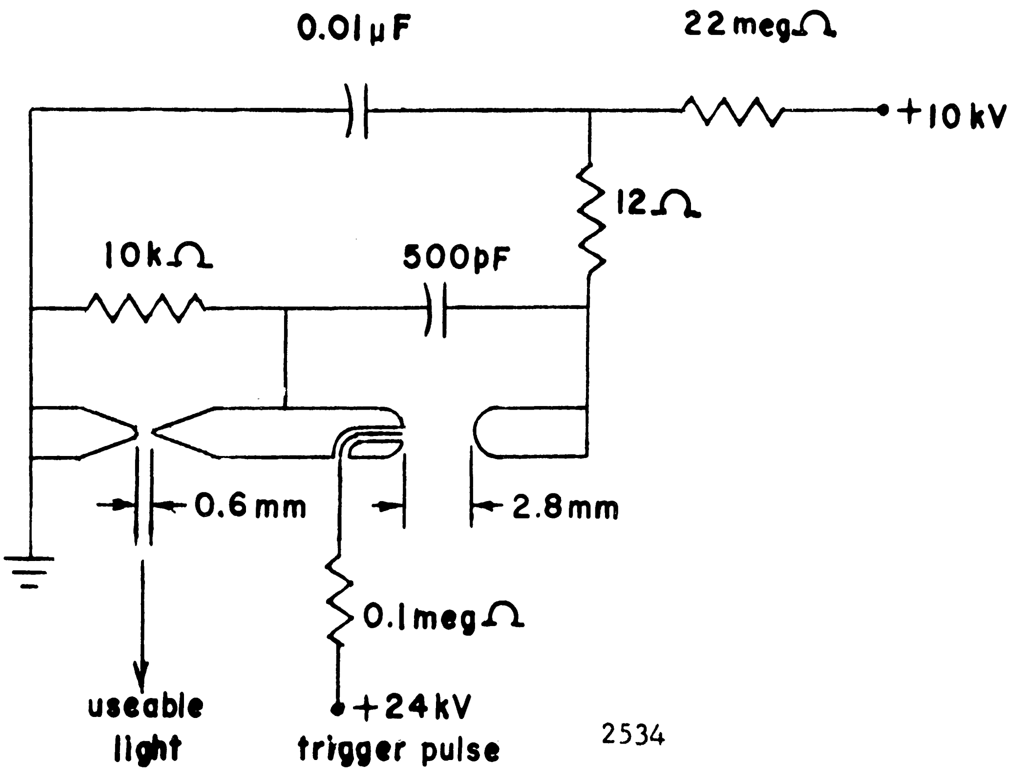
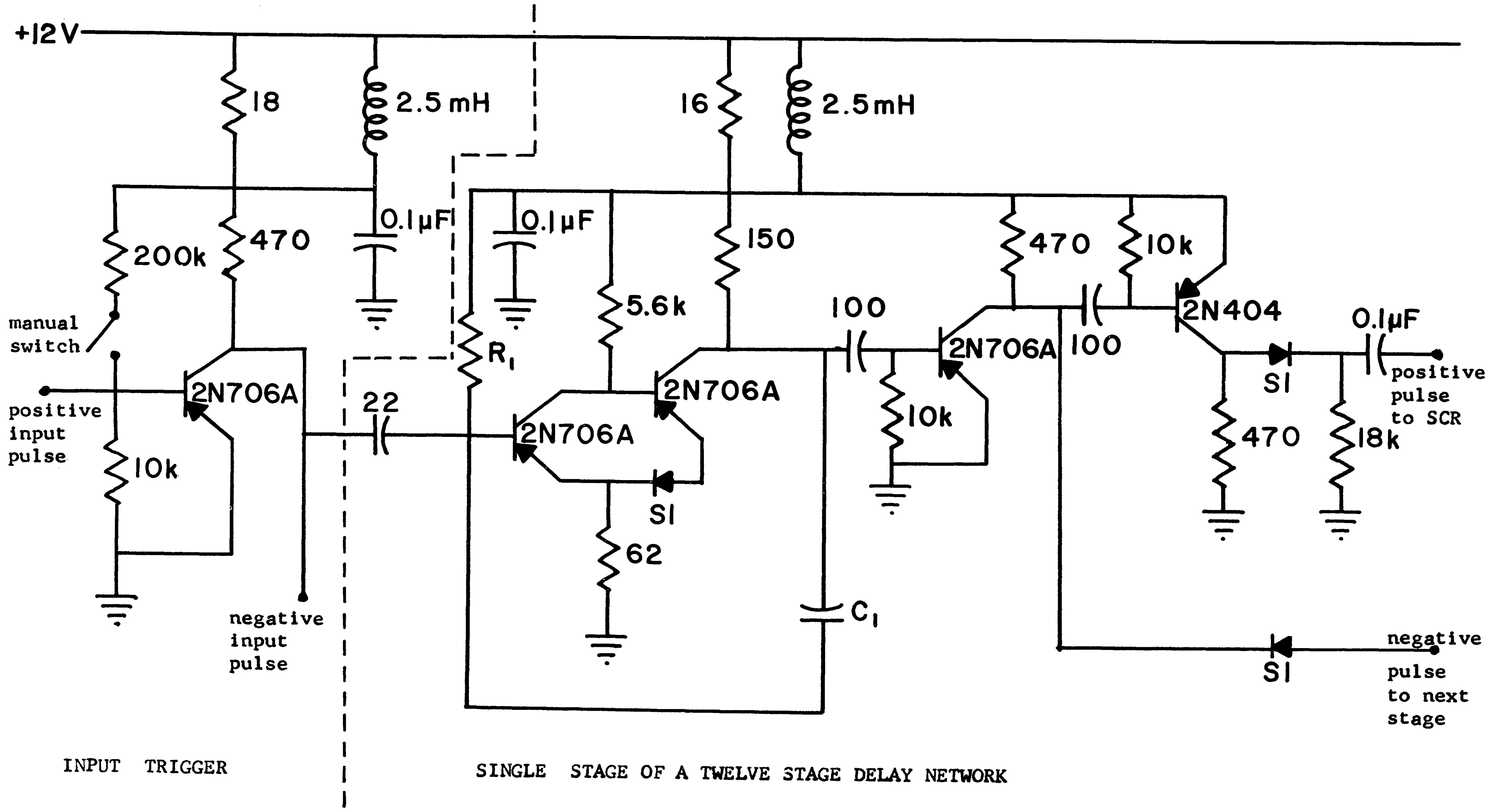


Fig. 4.--Schematic Diagram of Spark Light Source.

effective framing rates) for the light sources. A study of schematic (Fig. 5) shows that provision is made for either a positive pulse, a negative pulse or a manual switch to initiate the delay network. A monostable vibrator with adjustable RC delays forms the main component of each delay stage. The square wave output of each monostable vibrator is differentiated to produce a negative pulse with the proper delay. This pulse is amplified and then inverted. The amplified pulse triggers the next delay stage and the inverted pulse is used to fire silicon controlled rectifiers. The initial delay stage uses a precision 10 turn resistor to obtain a continuously variable delay from 5 to 1,000 μs. Each succeeding pulse may be delayed in steps of 1, 2, 10, 20, 50, and 100 μs. The RC delays for these stages use precision resistors (±1%), and padders (adjustable capacitors) to compensate for variation in self-capacitances. Variations in delay time from one stage to the next are thus reduced to less than ± 3%. Isolation filters are used for each stage of the network in order to reduce feedback and preignition. Also extreme care has been exercised in grounding all components and shielding all pulse carrying wires so that feedback is eliminated.

When an inverted positive pulse fires a silicon controlled rectifier (SCR), a 1.0 μF capacitor discharges across the primary of a trigger transformer producing the trigger pulse (Fig. 6). All of the trigger components (including the SCR, 1.0 μF capacitor, and trigger transformer) are mounted in the same steel box (Fig. 7) as the spark sources. In this way high voltage wiring and



Resistances in OHMS
Capacitances in pF unless indicated
Delay given by approximately $0.7R_1C_1$

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Fig. 5.--Schematic Diagram of Solid State Delay Network.

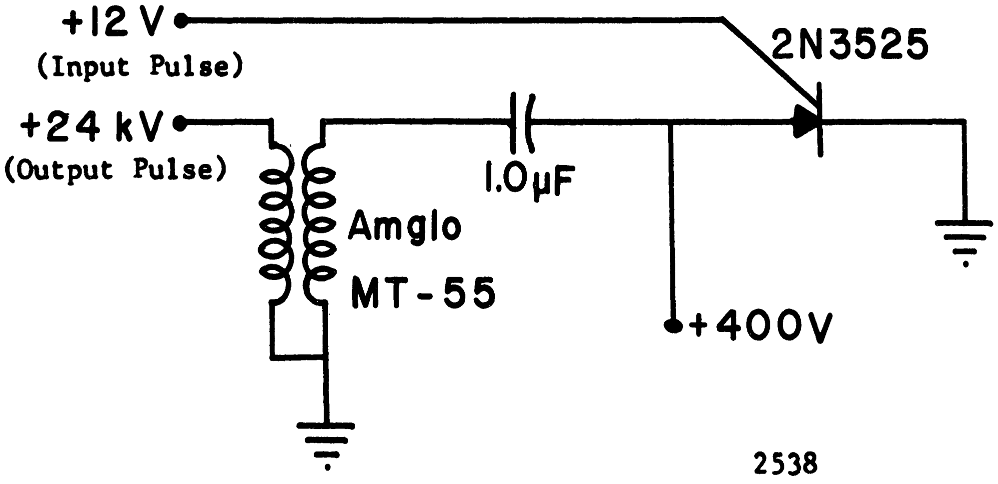

Fig. 6.--Schematic Diagram of Trigger Pulse Network.

electromagnetic radiation are minimized. Since the network uses high speed transistors, the major source of time jitter for the light sources (which totals 0.25 μs) is due to the variable breakdown time of the spark gaps.

IV. Field Optics

The light from each spark source is focused onto a separate camera lens by a field lens. When the twelve camera lenses are mounted on the same 5.5 cm radius as the light sources, the correct field lens imaging is obtained by making the distances between the light sources and the field lens and between the field lens and the camera lenses equal to twice the focal length of the field lens. For working section diameters up to 15 cm, low cost acromatic field lenses of various focal lengths are easily available. Using long focal length field lenses provides nearly parallel light through the working section thus allowing the possible use of shadowgraph or Schlieren methods to measure density gradients in the working section.

V. Camera

The camera for this photographic system is a converted 20.3 cm by 25.4 cm (8 inch by 10 inch) portrait camera. The lens plate of the camera holds twelve acromatic lenses. These lenses, as mentioned earlier, are mounted on a 5.5 cm radius and have an image of the light sources focused on them. In turn, these lenses focus the working section on the film plane. Thus all the light from each of the spark sources that passes through the field lens is used to produce an image of the working section on the film.

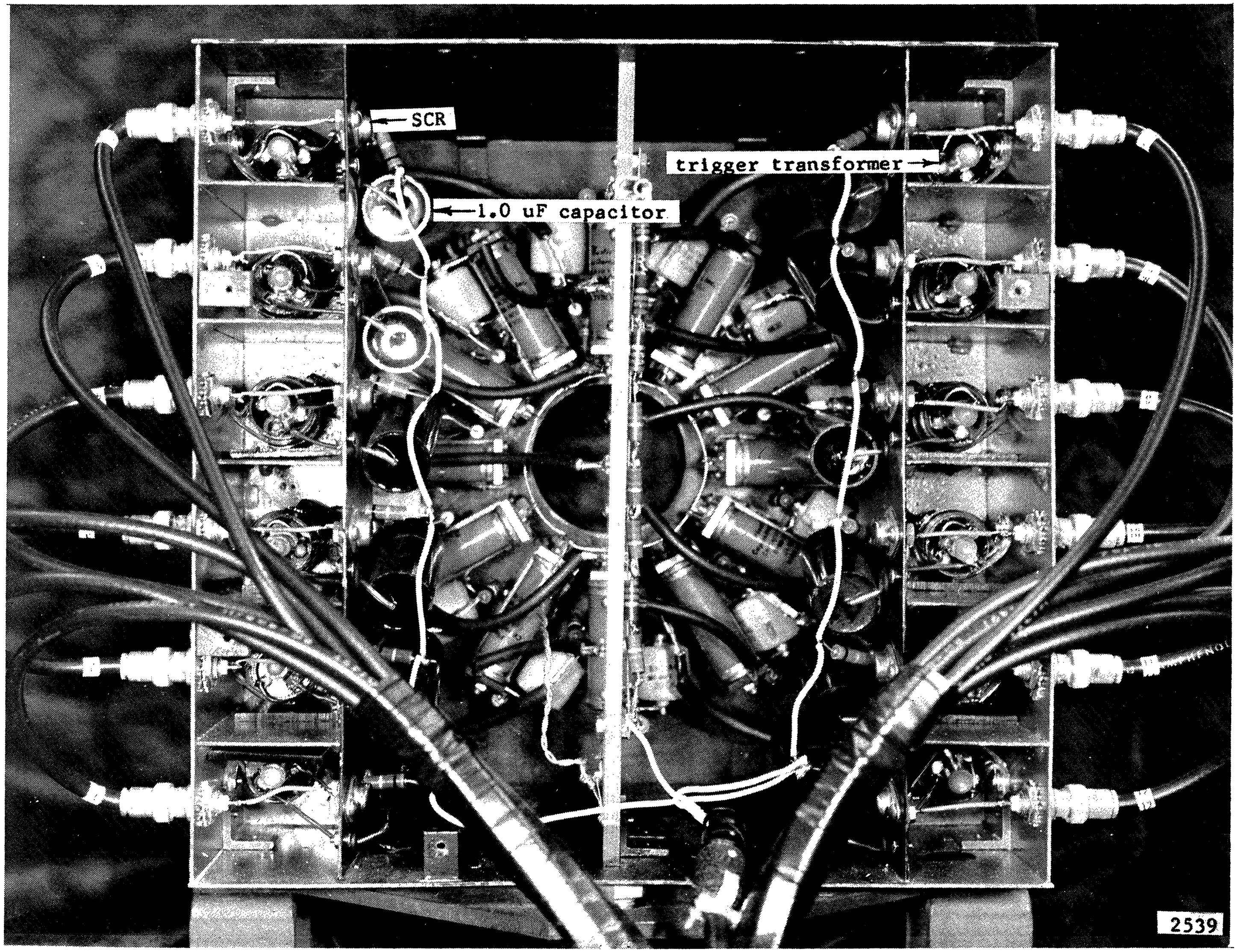

Fig. 7.--Rear View of Spark Light Source Containment with Back Plate Removed.

The resulting circle of twelve images, each up to 3 cm in diameter, are on a radius slightly greater than the radius of the camera lenses.

VI. Optical Bench

All of the systems components are mounted on a rigid platform. This optical bench is designed to be rigid enough to reduce relative movement of the photographic components to less than 0.01 cm so that effective Schlieren work is possible. The optical bench for this system is fabricated of heavy duty Unistrut components well cross braced to insure rigidity.

VII. Operation

Once the photographic system had been constructed, it proved to be easy to align and operate. First, all optical components were mounted in their approximate positions on the optical bench. Then by using a low power continuous light source placed behind the spark sources, focusing of the spark sources on the camera lenses and of the working section on the film plane was done by direct visual means. Once the system has been aligned, only periodic checks are required to insure that proper focusing is maintained.

Unless a fast capping shutter is used over the camera lenses, operation of the system must take place in subdued light to avoid film exposure by extraneous light. The operating procedure is as follows:

1. Film is loaded into the camera.
2. The desired delay sequence is set on delay network.
3. The high voltage supply is turned on (3 second delay

required for spark capacitors to charge to 10kV).

4. The capping shutter is opened.
5. The delay network is triggered either manually or by electronic coupling to the event being photographed.
6. The capping shutter is closed.
7. The high voltage is turned off and the exposed film sheet removed.

VIII Usuage and Limitations

The system was initially used to study high speed water jets impacting on a solid target.[3] At present the system is being used to study the growth and collapse of cavitation bubbles in a cavitating venturi.[4] As mentioned in the introduction, the system may be used to photograph any non-luminous objects that may be backlighted. Major problems inherent in the Cranz-Schardin system are the variable perspective of each image which must be accounted for if quantitative spatial data is to be taken and the low number of frames per sequence (12 in this case). Because this system has continuous access, the second problem may be partially overcome by triggering the system during the critical stage of the event being photographed.

The materials cost for the entire unit was approximately $1,000 and the construction was carried out by the author with the gratefully acknowledged aid of University of Michigan electronic and instrument shops.

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