Title
Indirect Electrical Stimulation of the Visual Apparatus

Authors
Budinger, Thomas F
Huen, Anthony

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INDIRECT ELECTRICAL STIMULATION OF THE VISUAL APPARATUS

Thomas F. Budinger
Donner Laboratory of Medical Physics and Biophysics,
and Lawrence Radiation Laboratory,
University of California,
Berkeley, California

and

Anthony Huen
Lawrence Radiation Laboratory
Livermore, California

DISCLAIMER

A B S T R A C T

Subjective sensations of light flashes can be generated in humans by means of 0.3 mA current across the head (rise time of about 100 msec.). The flash sensation (phosphenes) can be induced by exciting the retina, the optic nerve, or the brain cortex, and has some promise as an aid to the visually impaired patient. Preliminary experiments with normal but blindfolded subjects and children with partial visual impairment or complete enucleation show that fuller development of a head-mounted photodetector system using external electrodes has promise as a visual aid for many blind patients. This paper is a review of the world literature and presentation of our experiments.

INTRODUCTION

Visual impressions can be produced in blind patients by electrical or electromagnetic stimulation of the visual apparatus without the use of internal electrodes. Many environmental sensors and aids for the blind are available which use tactile or auditory pathways as the mode of information input to the brain (Bach-y-Rita, 1967; Benham, 1963; Bliss, 1967; Shrager and Süsskind, 1964; Zahl, 1922); however, electrical stimulation of the visual apparatus, although a procedure of some antiquity, has not been incorporated in research toward extending human perceptive abilities until recently. This report presents a survey of the progress in the field of indirect electrical stimulation of the visual cortex with some simple experiments which show that light flashes can be induced in blind patients by external-electrode electrical stimulation.

BACKGROUND

Some of the earliest experiments with electricity on the human body and the first cautious suggestion that the use of electrical stimulation might relieve blindness were made by Benjamin Franklin in 1751 (Watson, 1751-2). A few years later LeRoy (1755) reported the induction of flashes in a blind patient by using a Leyden jar discharge. The electrophysiology associated with electrical stimulation of the visual apparatus was studied by Volta (1796), who experienced a flash-like sensation of light (known as Purkinje patterns or, more commonly, as phosphenes) when a small potential difference was induced between his eyelids and some other part of his body. During the nineteenth century the phenomenon of pressure (deformation phosphenes) (Brindley, 1967) or electrically induced flashes was investigated by Brennan, Du-Bois-Reymond, Finkelstein, Helmholtz, Müller, Purkinje, Ritter, and others (e.g., see Finkelstein, 1894; Müller, 1897). The phenomenon of flash sensation was also elicited by using induction coils not touching the head (d'Arsonval, 1896), and later independently by Thompson (1910). Since these discoveries, a few careful investigations of electrical (Barlow et al., 1947b; Bogoslowski and Ségal, 1947; Motokawa and Iwama, 1950; Bouman, 1935; Brindley, 1962, 1964; Müller, 1897) and magnetic (Barlow et al., 1947a; Becker, 1963; Beer, 1902; Dunlap, 1911; Magnusson and Stevens, 1911; Valentinuzzi, 1962) stimulation of man's visual apparatus have been made. Radiophosphenes induced by X-ray machines, gamma rays and beta particles from Radium (Brandes and Dorn, 1897; Edison, 1896; Giesel, 1899) received much attention during the late nineteenth century.

The flash sensation phenomenon has been generally accepted as the result of retinal stimulation by a current emanating radially from the electrode through the eye globe (Brindley, 1955). The conclusion that electrically induced phosphenes are mediated solely by the retina should be qualified.

Russian workers demonstrated in the 1930's that phosphenes can be electrically induced in patients after enucleation but before optic nerve degeneration (Bogoslovsky, 1934; Gersuni et al., 1935; Vishnevskii, 1939). This is not true for radium gamma ray or beta ray phosphenes, which through experiments with patients after globe removal were found to react with retina and not the optic nerve (Godfrey et al., 1945). Only with an intact retina do the thresholds of electrical sensitivity remain normal, and only with a well preserved, attached retina are the normal adaptive changes in electrical sensitivity present (Bogoslovskii and Ivanova, 1941). Fortunately, even if the retina were necessary for the induction of phosphenes, most blind patients have intact retinas and might benefit from a device which along with normal head scanning proprioception produces a pattern of light suggestive of the shape of objects in the environment. Atrophy of the retina of an eye with severe visual defect might be circumvented by periodic electrical stimulation.

The direct approach to stimulation of the visual cortex by implanted electrodes was suggested by the pioneering work of Penfield and Rasmussen (1950), and implemented in an attempt to build a visual prosthesis by Button and Putnam (1962) and others (Marg and Dierssen, 1965; Shaw, 1956; Shipley, 1963). This approach had some success, as has electrode implantation in the eighth cranial nerve for auditory stimulation (Simmons et al., 1965). Brindley and

Lewin (1968) have recently confirmed and extended these results by producing phosphenes using radio-receivers connected to electrodes in direct contact with the visual cortex.

Other than Barnard's suggestion in 1947 (Barnard, 1947), little has been reported regarding the practical use of electrical stimulation of the visual apparatus, and there has been little active research until recent years. In 1964 Barraquer discussed the phenomenon of phosphene production by inducing alternating current in the head, and suggested that a transistorized photodetector device might be used as an aid for the blind. Such a system has been developed independently by us and, prior to our efforts, by Polish researchers (Starkiewicz and Kuliszewski, 1963; Starkiewicz, 1967), and a group at the University of Mexico. These recent investigations have raised the question of whether the sensation of light produced in either blind or normal subjects is entirely phosphenes or might be mediated by a pathway from the supra- or infraorbital branches of the trigeminal nerve to the visual tract, perhaps via the reticular formation (Hernández-Peón, 1961). There is no convincing evidence of any trigeminal nerve mediation.

The fact that visual impressions can be produced in blind patients with some intact retina prompts us to report our studies in children with retrolental fibroplasia and some facts and ideas which might lead to the practical implementation of electrical and electromagnetic stimulation of the visual cortex.

METHODOLOGY

The sensation of light flash is elicited by application of 2 to 4 volts potential difference across the head using a 1-cm metal disk electrode on a ciliary arch or the forehead and a similar electrode placed on the back of the neck (Fig. 1). Electrolyte paste or sodium chloride solution is used to establish less than 10,000 ohms (usually about 4,000 ohms) resistance across the head. Use of small sponges soaked in salt water and electrode paste and attached to 1-cm diameter platinum disks on a supporting frame is a very convenient alternate approach. A sensation of "flash" is generated on making or breaking the circuit (rise time should be less than 100 msec.). A flicker phenomenon can be generated by pulse trains or ac stimulation (fusion cannot be obtained at 60 Hz--normal upper limit for photic stimulation fusion); chronaxie is about 1 msec. (Gersuni _et al._, 1935). The intensity of the flash is a function of current (usually about 0.3 mA), rise time, repetition rate, past stimulation experience, concomitant auditory noise and even time of day. The sensitivity of the eye to electrical stimulation has a circadian rhythm (Bogoslovskii, 1937). Rise-time dependency might be more an electrode counter-EMF phenomenon than a characteristic of phosphene generation, as may be optimum repetition rate. Theoretically waveform should be important, particularly in color production, as early experiments demonstrated that different colors could be elicited depending on whether the anode or the cathode was nearer the eye being stimulated. The spatial identification of the flash is a function of the location of electrode application on the forehead or face; e.g., an electrode applied over the right temporal area gives an impression of flash, usually a bluish-white crescent or flicker like lightening in a cloud bank off to the right, a few meters above and to the right of the subject, and an electrode placed on the forehead midline will give a sensation in both eyes of a flash located centrally a few meters ahead of the subject spatial location. Experiments have not been conducted with multiple electrode systems using intensity and delay combinations.

A simple device (Fig. 1) weighing one kilogram was made using two photodetectors mounted on ordinary glasses frames and two independent amplifying systems, one connected to each photodetector, with a common electrode to the neck. The system shown in schematic fashion (Fig. 1) was designed to deliver 0 to 10 volts, depending upon the luminosity of the light at which the sensor is "looking". The device has been used in the pulse mode wherein the experimental subject interrogates the environment either on the left and right by manually depressing buttons and a flash is detected when the luminosity "seen" by the photodetectors changes. Electrode polarization and skin resistance problems are still troublesome. An automatic pulsing circuit with rise time (Fig. 2) or current intensity dependent upon light luminosity "seen" by the photodetectors is a better environment sensor. The use of an electromagnet induction coil and appropriate circuit might enable one to achieve similar results without the cumbersome electrodes.

RESULTS

Experiments were conducted, using the simple device of Fig. 1, with the purpose of ascertaining whether phosphene generation is a practical means of transferring information about the environment to the visually impaired. As shown in Table 1, the experimental subjects have been children with retrolental fibroplasia or retinal blastoma. The results indicate that a device as simple as that illustrated by Fig. 1 would allow some visually impaired children to navigate in areas where the light-dark contrast is great. Children having no memory of light as a sensation characterize the impulse as something new, describing it as a "bong" or "tap". Voltage threshold for pain is only slightly higher than the electrical phosphene threshold. Therefore, the responses of subjects with poor or no light memory are hard to interpret. Further, some aphasia or other difficulty in communicating with the subjects made it impossible to quantitate the results. Experiments with enucleated patients have been inconclusive, but promising. A trigeminal to visual cortex pathway might have an anatomic basis, but production of phosphenes via this route seems physically untenable.

Two children with severe visual impairment were able to navigate better than usual using natural light following use of the device. This suggests that electrical stimulation of the defective retina might effect a lowering of the threshold to natural photic stimulation; however, navigation enhancement is often the case after a training session with other prosthetic devices.

DISCUSSION

Extension of these experiments to blind adults with and without intact retinas is indicated.

Our experiments and similar investigations by the University of Mexico team indicate a visual prosthesis using phosphene production has promise for some blind patients. The hypothesis that color is a function of waveform and the relationships between flash intensity, voltage, and rise time (dv/dt) need further investigation. If these questions are resolved, pattern development might be implemented by an array of photodetectors connected to a multielectrode system on the forehead or eyeball as suggested some years ago (Barnard, 1947) and recently implemented by Starkiewicz (1963, 1967). Results of our studies and the phosphene pattern studies using normal adults (Höfer, 1963; Kellogg et al., 1965; Knoll and Kugler, 1959; Knoll, 1962) suggest that subjective abstract light patterns can be controlled by waveform, repetition rate, electrode placement, and current. Thus, the information capacity of the phosphene mode might be much greater than is apparent on cursory examination.

The development of a system using photodetectors or even infrared sensing devices, sonar, or Gunn Effect radar is dependent on improvement in the electrode coupling. One of the most promising approaches is an electromagnetic coupling system between the environmental sensor and the brain. Using magnetic field fluctuations of about 1000 oersteds with coils about 2 mm from the head, one can induce the flash sensation through the phosphene-retinal pathway. Caution should be exercised in experimenting with static fields over 80 oersteds, as a depression of cellular respiration has been reported (Pereira et al., 1967).

A device based on the concepts discussed here might provide a practical means of transferring information about the environment to the visual cortex without interfering with other sensory modalities. It remains to be seen whether the practical embodiment of electrical or electromagnetic stimulation of the visual apparatus can provide a more useful prosthesis than tactile and auditory feedback devices now being investigated. At present the cane remains the superior aid for the blind. The author shares other workers' reservations about the supposition that induced phosphenes can transfer sufficient information to materially aid the blind.

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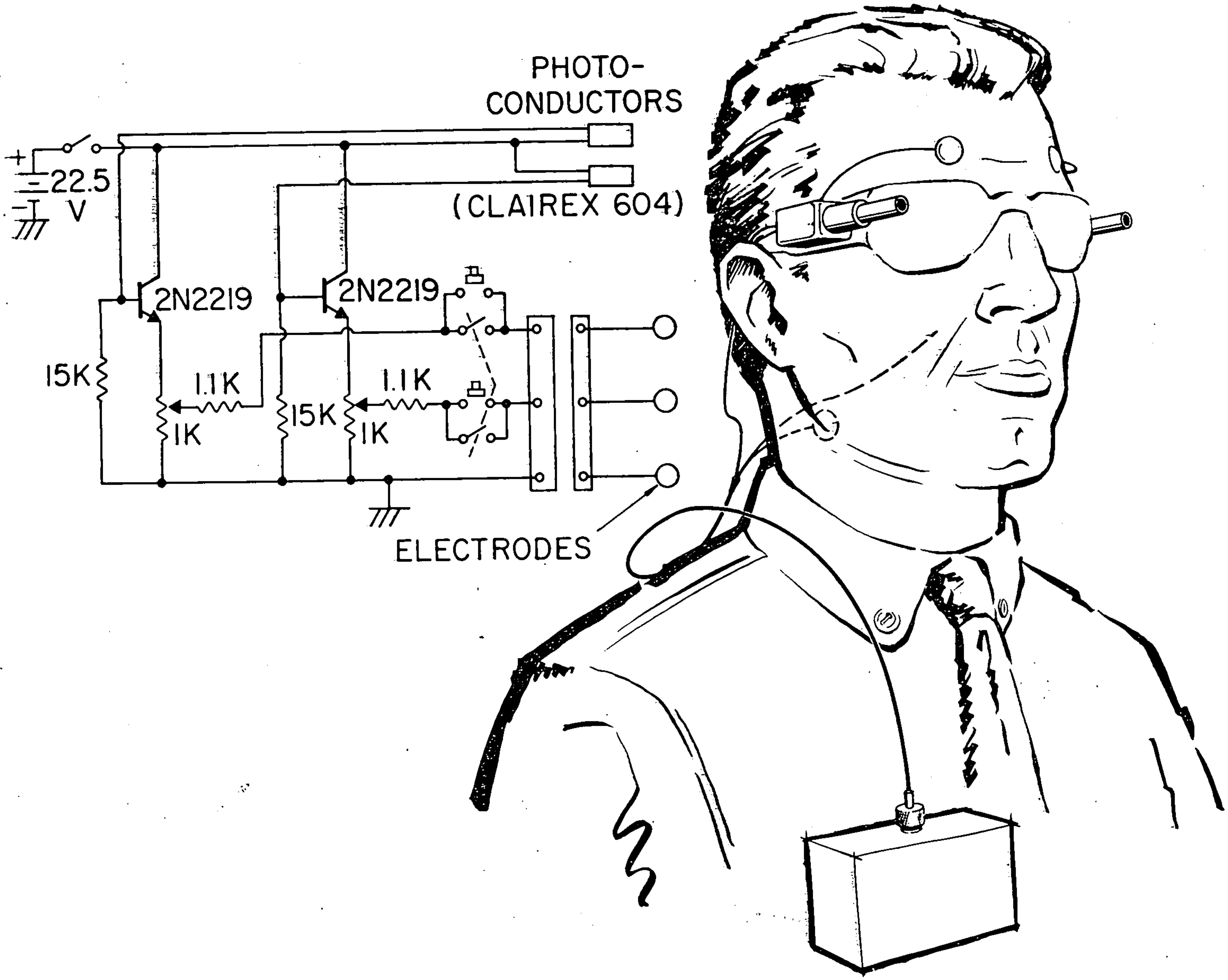
Table 1. Results of tests with device shown in Fig. 1

Patient	Age (yrs.)	Sex	Disease	State	Results
J.T.	16	M	Retinal blastoma	Enucleation	Distinguished "like a tap" from high voltage pain "sting".
D.T.	14	M	Retinal blastoma	Enucleation	Distinguished "impulse" from high voltage "sting".
J.M.	16	M	Retrolental fibroplasia	Slight light perception	Distinguished phosphene from high voltage "sting" as "volts man volts". Unequivocal.
R.M.	12	F	Retrolental fibroplasia	No vision since 6 years old	Distinguished "shock" from "sting". Equivocal
F.B.	14	M	Retrolental fibroplasia	Light perception only	Very positive results with patterns of light fingers and shadows. Saw "sparks" and "shocks".
H.M.	13	F	Retrolental fibroplasia	O.D. light perception, O.S. blind	Saw light circles and lines O.D. $>$ O.S.
A.R.	14	M	Retrolental fibroplasia	Blind (aphasic)	"Stinging" only.
W.R.	14	M	Retrolental fibroplasia	Blind (aphasic)	Reported "motion". Equivocal results.
J.M.	14	F	Retrolental fibroplasia	Blind	Distinguished "bong" or "tap" from high voltage "sting".
C.C.	16	F	Probably hysterical blindness	Subjective blindness	No results to above pain threshold impulses
20 normal adults		M,F	Normal	Blindfolded	Blue-white or yellow crescents and spots or like "lightening masked clouds".



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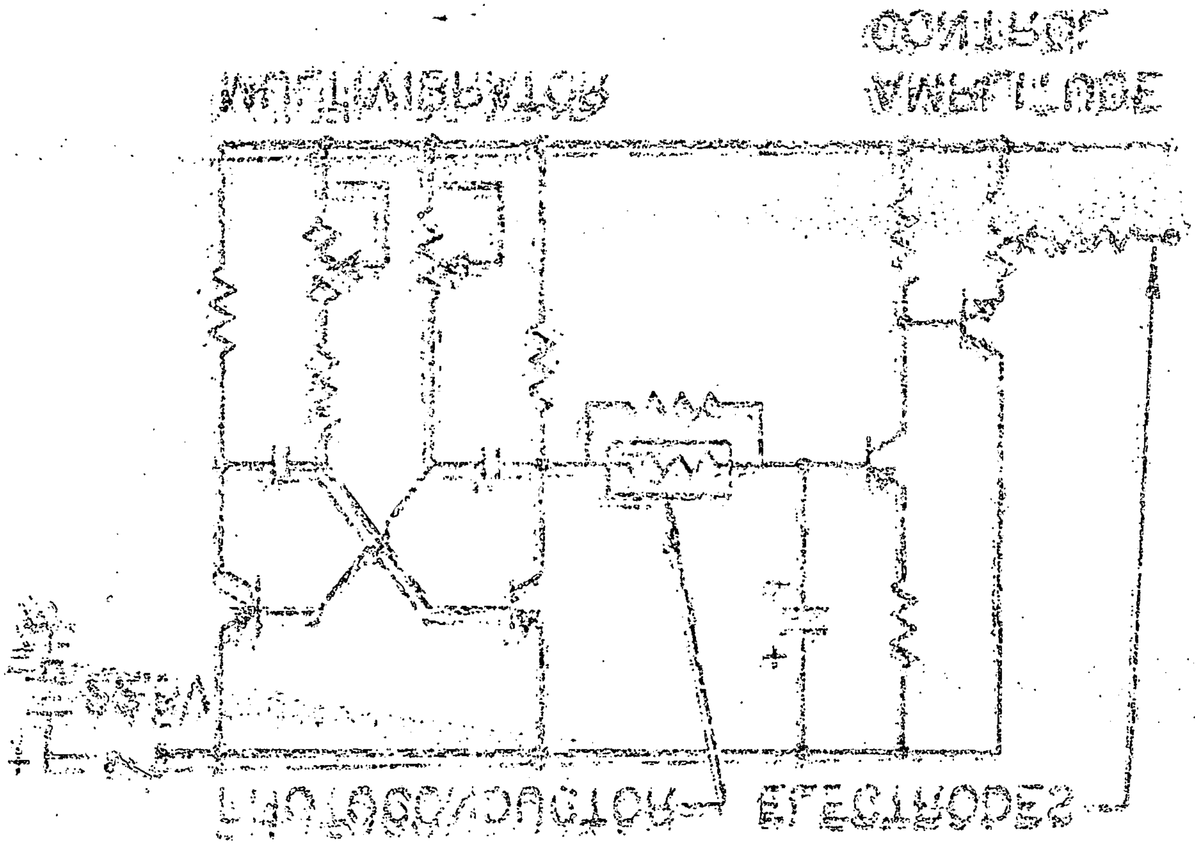

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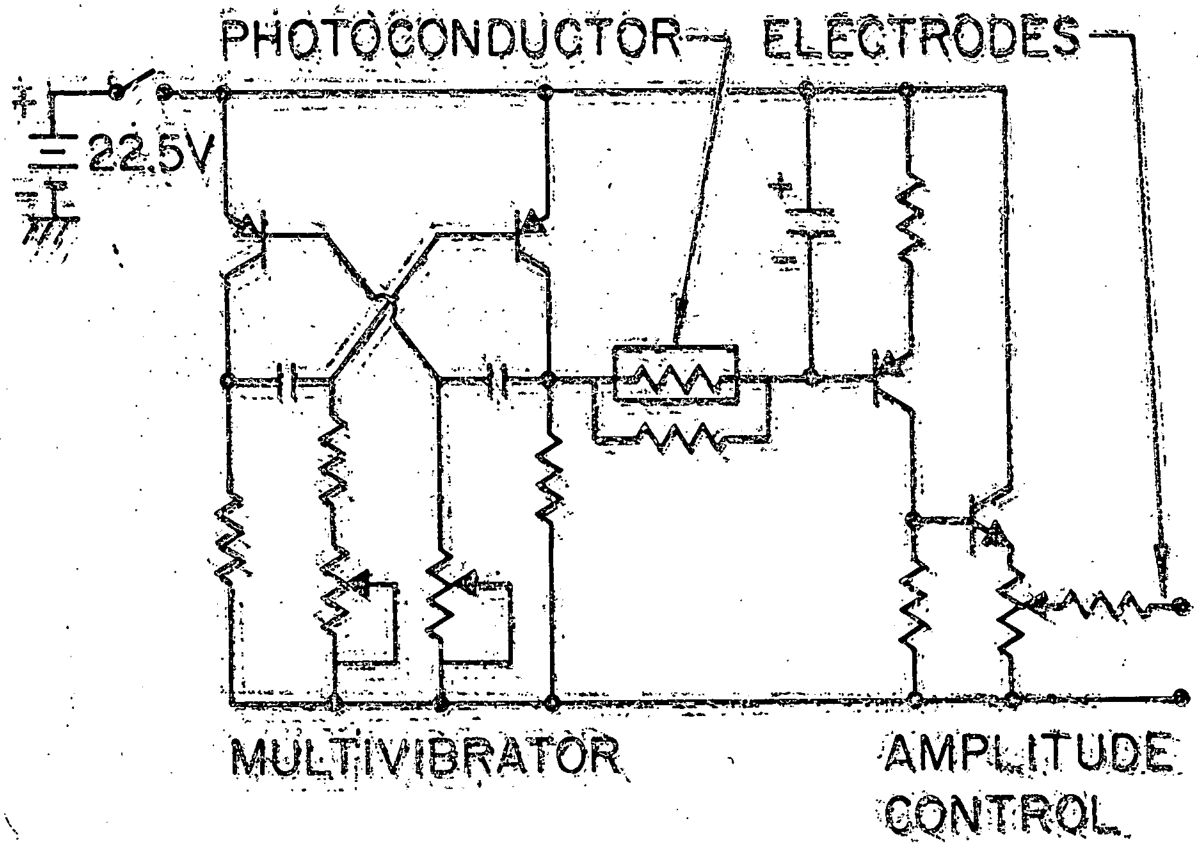
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