TELEVISION APPARATUS

Thesis presented in partial fulfillment
of the requirements for the degree of
Bachelor of Science in Electrical Engineering

by

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May 1930

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Member of Faculty in
charge of the thesis:
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Certification for the
Department of Electrical Engineering

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OBJECT

The theory, design, construction and study of the performance of a television apparatus of new type.

GENERAL CONSIDERATIONS

The process by which television is accomplished nowadays is one of successive transmission and reception of the plurality of details into which any image may be divided. At the transmitting end the image is successively differentiated into those details, and the successive reception of the corresponding electrical impulses is integrated on a screen at the receiving end. The first and principal part, therefore, of any television apparatus, is the device by which the image is traced or "scanned" by a tiny spot of light which is properly focussed on it.

The scanning process is usually accomplished by tracing parallel lines (or practically so) over the image, by means of a spot of light. At any time, therefore, of the process, only one small detail of the image, that one illuminated at the time by the spot of light, receives and reflects light; all other parts of the image are in darkness. Other methods use spiral scanning of the image, but there is no available data relating to the results of such systems of scanning.

Many devices have been proposed for accomplishing the scanning of the image, the most popular of them being that of a rotating disk or system of rotating disks provided with a plurality of small holes on the outer portion of their radii. The scanning device, which is the main object of this thesis, consists of a tiny mirror set into vibration in two directions at right angles to each other, the rate of vibration about one axis being of the order of four to ten vibrations per second, and that about the other axis, of the order of several hundred per second, the latter depending upon the degree of detail or "grain" which is desired to obtain at the received end. In this manner, a beam of light reflected from the mirror, if made incident on the image to be scanned, will trace it in a zigzagging line consisting of thirty or more lines. The number of those lines depends, of course,upon the above rates of vibration, and the width of the lines upon the width of the spot of light that makes the scanning of the image.

Electromagnetic means maintain the mirror in vibration. If the mirror were mounted on a universal joint of the Cardan type, which is the system that most naturally suggests itself, it would be very difficult to avoid the interference of the two motions of the mirror, as the writer convinced himself experimentally. This mounting of the mirror on a universal joint is illustrated in U. S. Patent No. 1702195.

In view of the preceding, another system of mounting the mirror, where the two rectangular motions would not interfere with each other, had to be devised. This is one of the objects of this thesis.

DESCRIPTION OF THE APPARATUS

THE SCANNING DEVICE

This is illustrated in Figure 1. Referring to this Figure:

Numeral 1 represents a frame piece mounted upon a base and thereto rigidly fixed by means of the screws 2. A frame 3, having the general shape illustrated in the Figure, is supported within the framework formed by the frame piece 1 and the base, by means of two tense wires 17 and 18, the ends of which are fixed on the piece 19 and the lower part of the frame 1, respectively.

The frame 3 has two projecting arms 4 which support two rectangular pieces 5 by means of a tightened wire 6 that passes through properly placed grooves at the ends of the pieces 5. Mounted rigidly on the two halves of the wire 6 is an armature 8 which has a mirror 7 fixed to it. The tightening of the wire 6 is done by means of screw 9 which is held in place by means of nuts 11 and 12 on to the pieces 5. The projecting piece 13, of a rectangular shape, is rigidly connected to the frame 3 and the arms 4. In this way, screw 9 is fixed in position by nuts 10 and at the same time holds firmly the pieces 5, 5.

Mounted rigidly on the frame 3 is an electromagnet 21, so placed as to act by its tractive force on the armature 8 which carries the mirror 7.

Held firmly to the frame 3 is a projecting piece 14 which is the armature of another electromagnetic circuit formed by the magnet 15, 16 and the end of the piece 14.

The piece 19 to which the wire 17 is soldered, is fixed to the frame 1 by means of the screws and nuts 20, 20, which permit the tightening of the wires 17 and 18.

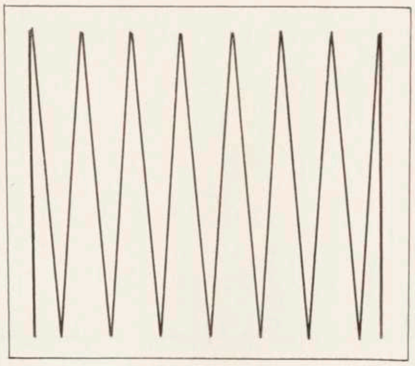
The center of the mirror is placed on the intersection of the planes passing through the wires 17, 18 and the looped wire 6. The mirror is inclined about 15° with the vertical plane, since the plane of the looped wire 6 is so inclined.

MODUS OPERANDI

If a pulsating direct current of several hundred vibrations per second is sent through the coil of the electromagnet 21, and if the wire 6 is properly in tension, the electromagnet 21 will set the armature 8 and the mirror 7 into vibration about a horizontal axis passing approximately through the center line of the rectangle formed by the wire 6.

In a similar manner, if a pulsating direct current of five to ten vibrations per second is sent through the coil of the electromagnet 15, and if the wires 17 and 18 are properly tightened, the attraction of the magnet on the piece 14, will set the system mounted on frame 3 into vibration about a vertical axis that passes approximately through the center line of the wires 17 and 18, and in their plane.

The mirror 7 is thus set into vibration about two rectangular axes, as was desired. A beam of light reflected from it on a screen, will trace a rectangle of light made out of a zigzagging line as shown by the following sketch:



THE TELEVISION APPARATUS

Knowing the manner of operation of the scanning device, I will explain how it can be applied to the art of television. Referring to Figures 2 and 3:

Figure 2 is a transmitting station and Figure 3 represents a receiving station; both of them being diagrammatic.

In Figure 2: 1 is the scanning device at the transmitting end. Through wires 2, pulsating direct current of from five to ten vibrations per second, energizes the side magnet, and through wires 3 pulsating direct current of 400 vibrations per second (larger or smaller frequencies may be used) energizes the other magnet. A local light source 4 sends a thin pencil of light towards the vibrating mirror, which reflects it onto the image 5 which is thus scanned. The photoelectric cells 6 collect the light reflected from the image. The electrical impulses from the photo-cells are properly amplified (by resistance-coupled amplifiers) and sent, by wire or electromagnetic waves, to the receiving station.

In Figure 3: 1 is the scanning device. Wires 2 carry the same electrical impulses that the corresponding wires of Figure 2 carry. The same is true with wires 3 of both Figures. The two pulsating currents, generated at the transmitting end, may be blended into one single electromagnetic wave together with the electrical impulses from the photo-electric cells, in much the same way as explained in the paper presented by V. Zworykin of the Westinghouse Electric & Manufacturing Company, of Pittsburgh, Pa., at the I.R.E. meeting at Rochester, N. Y. on November 18-19, 1929. In this manner the mirrors at both the transmitting and receiving ends are vibrating in synchronism. The received electrical impulses from the photo-cells of the transmitting end are amplified and energize a neon lamp 4 at the receiving end. This neon lamp sends a beam of light onto the vibrating mirror which reflects it onto the screen 5 where, if proper synchronism exists, a duplicate of the image at the transmitting end will appear.

THE OPTICAL ANALOGUE

In order to avoid all the distortion resulting from the use of the interconnecting electrical system between the two stations, I devised an optical analogue of that system. There is some distortion introduced by the optical system, but it is much smaller, of course, than that introduced by the electrical system. This optical analogue was constructed so as to make the experimental demonstration of the apparatus. The schematic representation of the optical analogue is Figure 4.

1 is the scanning device of the transmitter; 2 a local light source; 3 the image scanned and sent to the receiver. A lens 4 collects all the light that passes through the image 3 (only silhouettes are transmitted with this apparatus) and concentrates it on its focus, where a diaphragm 5 of small aperture (or a ground glass in place of it) spreads out the light received. The light thus spread will flicker as a whole as the image is being scanned at the transmitter. Some of the diffused light will be collected by another lens 6 which sends it in parallel rays to the scanning device 7 of the receiving end. The mirror at the receiving end, vibrating synchronously with that of the transmitting end, will reflect the beam of light that comes from 6 onto a screen 8, where a reproduction of the transmitted image will appear.

ELECTRICAL SOURCES AND CONTROLS

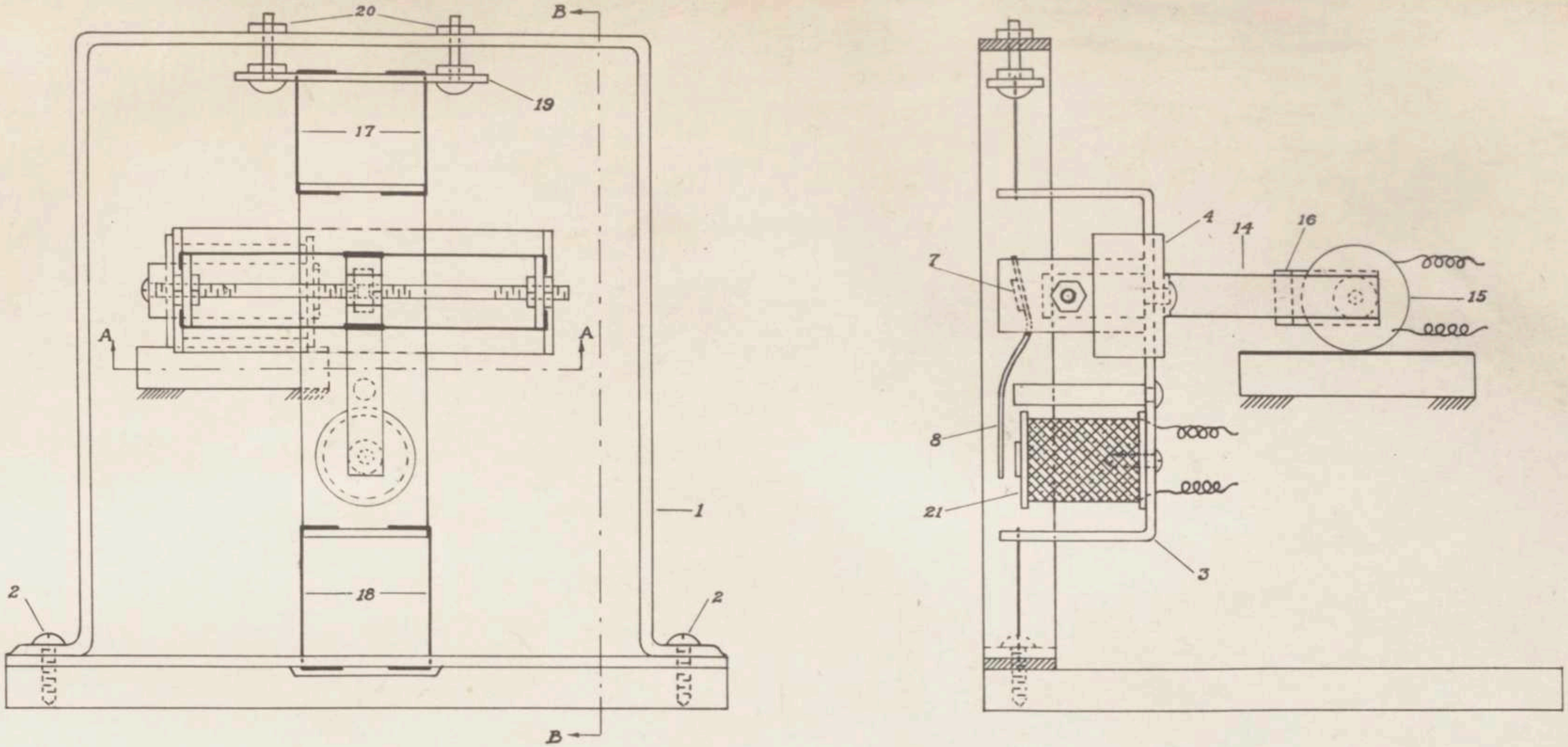
Figure 5 is a schematic representation of the electrical sources of pulsating direct currents and of the system of controls.

1 is a tuning-fork vibrator connected in series with a resistance 2 and a switch 3. In series with the circuit of the vibrator and paralleled in themselves are the resistances and switches 4, 5, 6 and 7,

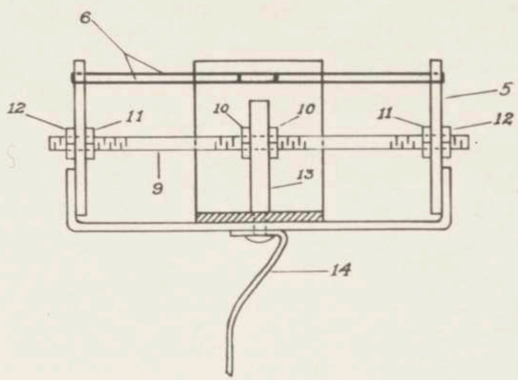
the first two corresponding and in series through binding posts 8 and 9 with one of the magnets for higher frequency in one of the scanning devices; the other two corresponding and in series through binding posts 10 and 9 with the magnet for higher rate of vibration in the other scanning device. This same circuit is arranged for the vibrator of low frequency marked 11. Through binding posts 12 and 13 it energizes the low frequency magnet of one of the scanning devices, and through binding posts 14 and 13 it energizes the low frequency magnet of the other scanning device.

It is possible to use other arrangements, as for instance, a series arrangement with variable resistance by-pass for control of each magnet. The system just described was very satisfactory, nevertheless, and I did not have to use any better system.

By the proper manipulation of the switches and rheostats, the system may be controlled from a central point. Since the corresponding magnets of the two scanning devices are connected themselves in parallel and then in series with the electrical sources of pulsating direct current, it is obvious that if the wires on which the mirrors and their frames are mounted are properly set in tension, both mirrors will vibrate in synchronism. In this manner, therefore, manipulation and exact synchronism are easily attained for the demonstratory experiments of the operation of the scanning devices.



SECTION ON BB



SECTION ON AA

FIG. 1

SCANNING DEVICE	Elec. Eng'g. Dep't. - Mass. Inst. of Tech.	
TELEVISION APPARATUS	Designed by Melchor Centeno V.	THESIS
	Scale: — May-1930	

TELEVISION DEVICE

TRASMITTER & RECEIVER

Elec. Eng'g. Dep't. - Mass. Inst. of Tech.

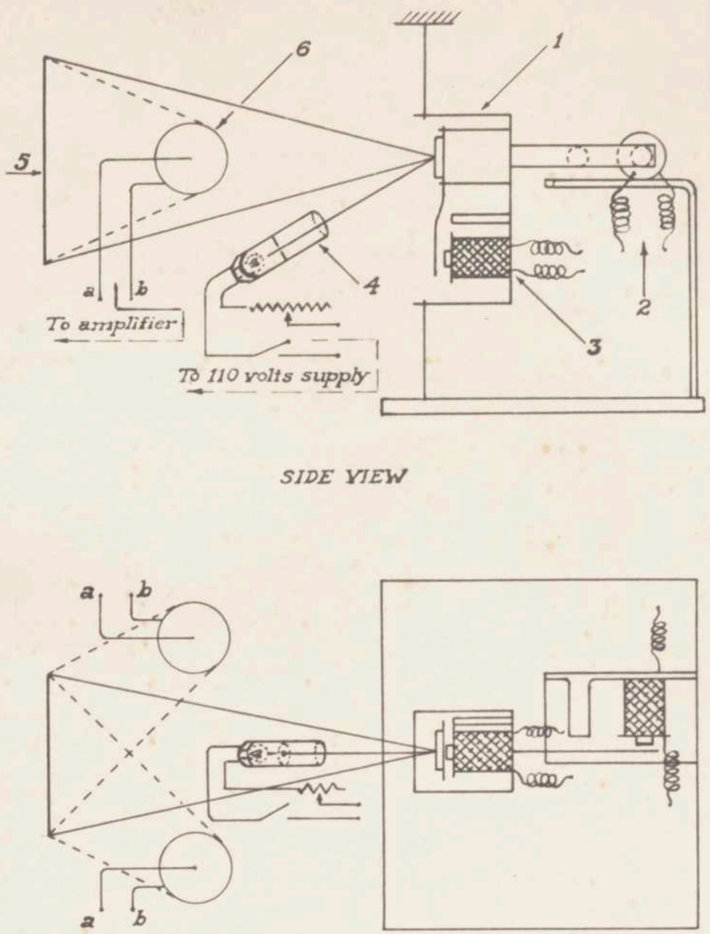
Designed by Melchor Centeno V.

Sketches

May-1930

THESIS

TRASMITTER

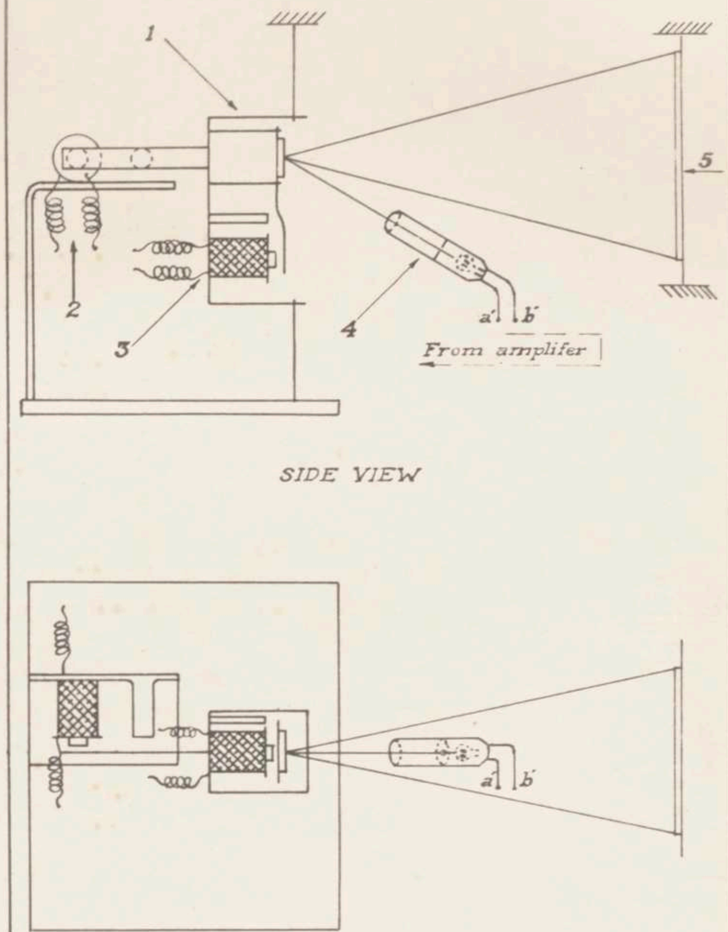


TOP VIEW

Diagramatic Sketches

FIG. 2

RECEIVER



TOP VIEW

Diagramatic Sketches

FIG. 3

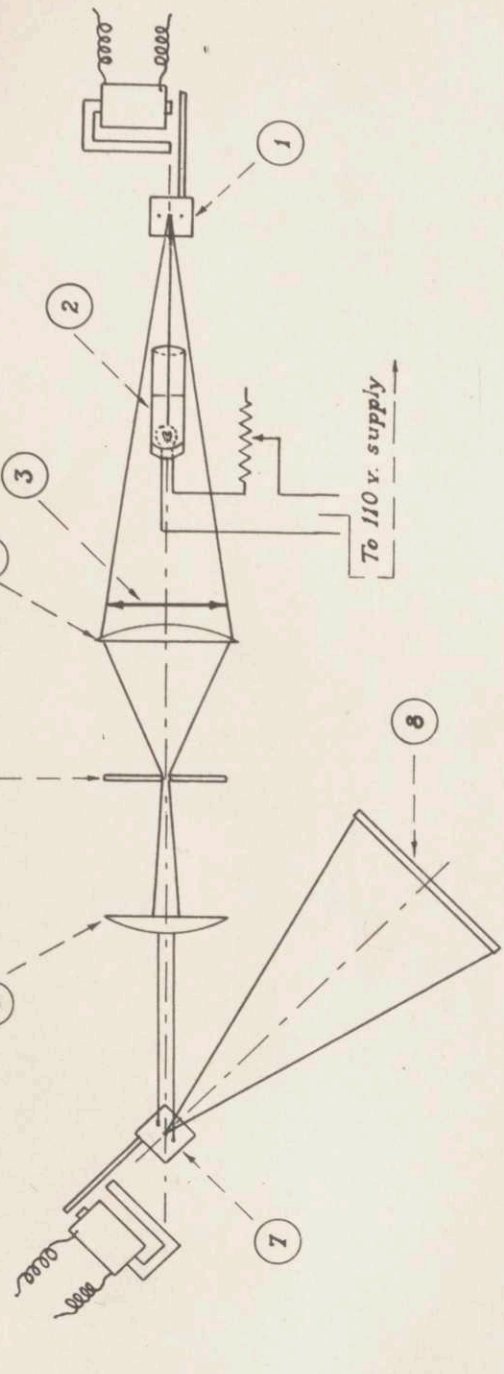


Diagram of the Optical Analogue used in demonstration

FIG. 4

OPTICAL ANALOGUE	Elec. Eng'g. Dep't. - Mass. Inst. of Tech.		
TELEVISION DEVICE	Designed by Melchor Centeno V.		THESIS
	Diagram May-1930		

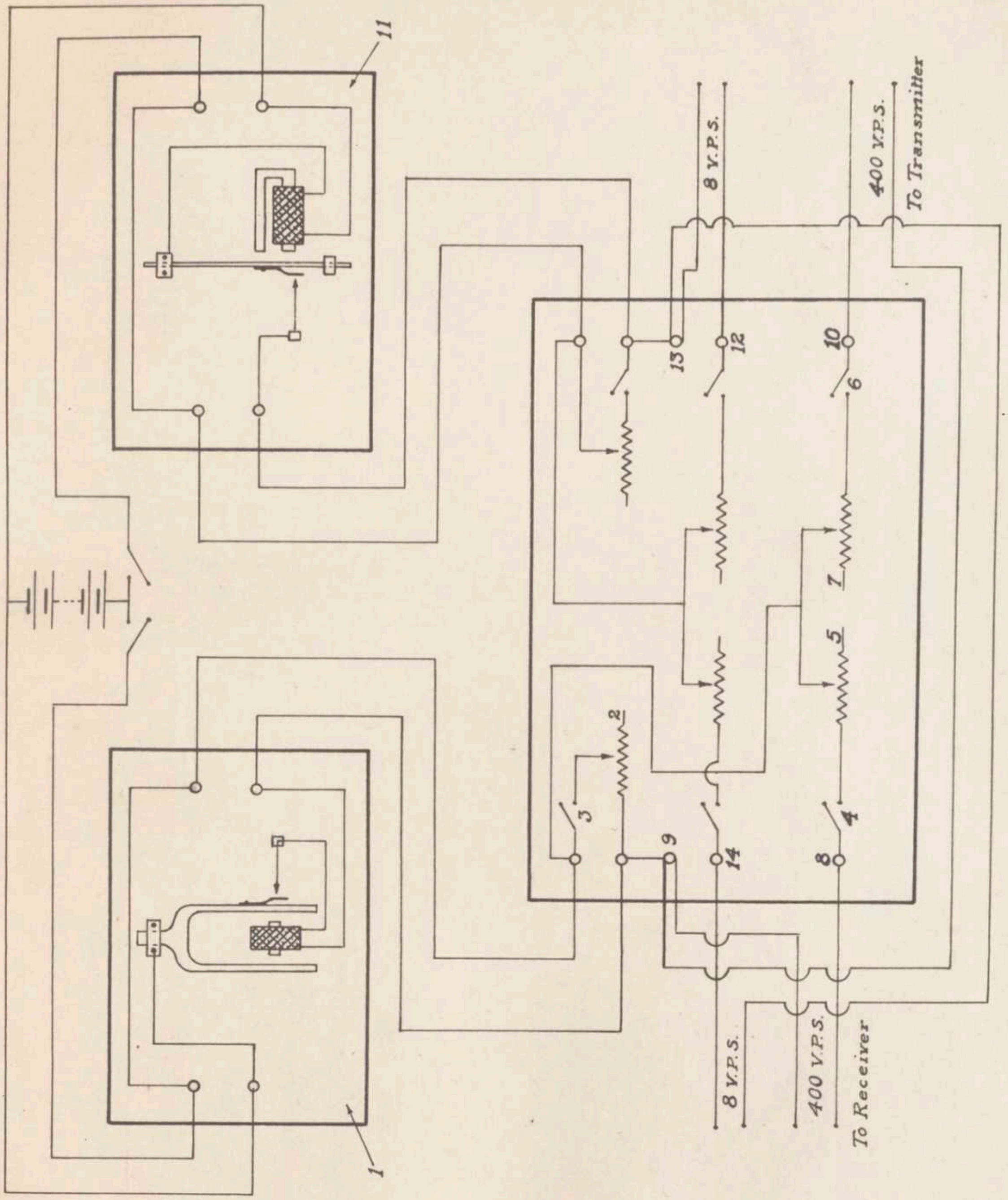


FIG. 5

ELECTRICAL SOURCES & CONTROLS	Elec. Eng'g. Dep't. - Mass. Inst. of Tech.		
TELEVISION DEVICE	Designed by Melchor Centeno		THESIS
	Diagram May 1930		

THEORY OF OPERATION

PERIODIC DRIVING FORCE

The periodic driving forces that maintain the vibrations of the mirror armature and the frame on which the mirror is mounted, are now to be studied mathematically. Since both forms of motion are of the same type, it will suffice to study one of them. For convenience, and because it is the more important of the two motions, the case of the mirror armature will be studied. All the conclusions and formulae derived for this case apply just as well to the case of the motion of the frame, i.e., the low frequency vibration.

The force, since it is produced by a pulsating direct current, is a periodic discontinuous function of finite discontinuities, expressible therefore by a Fourier series of the type

$$f(t) = A_1 \sin \frac{\pi t}{c} + A_2 \sin \frac{2\pi t}{c} + \ldots\ldots\ldots$$

$$+ B_0 + B_1 \cos \frac{\pi t}{c} + B_2 \cos \frac{2\pi t}{c} \ldots\ldots\ldots\ldots$$

Since the inductance of the coils of the electromagnets is small compared to their resistance, we may assume that the current in them is given by Ohm's law,

$$i = \frac{e}{r}$$

where e is the electromotive force applied on the coils.

The flux density in the iron of the magnet cores is given by

$$B = \frac{Ni}{R} \qquad \text{.........................(1)}$$

where N = the number of turns of the magnet coil,

and R = the reluctance of the magnetic path, chiefly made of air.

The force of attraction of the magnets on the armature is given by

$$F = 0.014\ A\ B^2 \text{ lbs.} \qquad \text{....................(2)}$$

where A = the area of the air gap in sq. in.

and B = the flux density in kilolines per sq. in.

Since the reluctance of the iron path is small as compared to the reluctance of the air path, we may neglect the first and we thus have for the reluctance to be substituted in equation (1), the value

$$R = \frac{2g}{\mu A} \qquad \text{.........................(3)}$$

where μ = permeability (unity for air),

g = length of the air gap,

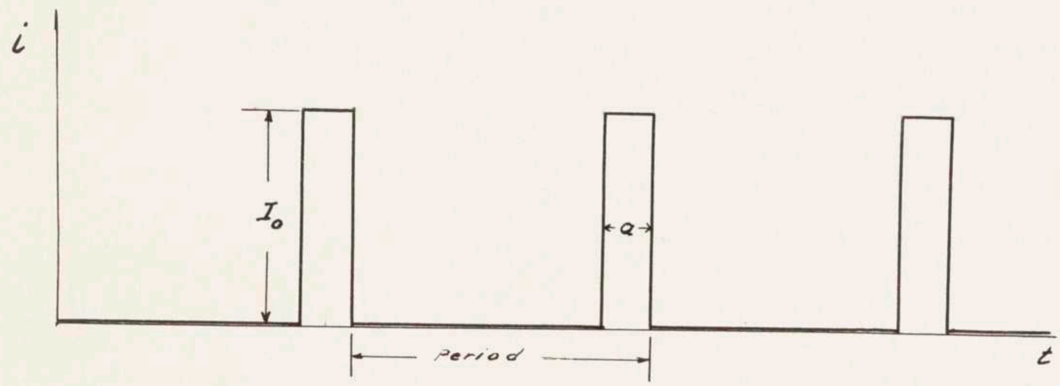
A = area of the air gap.

From (1), (2) and (3) we obtain finally the equation of the force

$$F = k\frac{i^2}{g^2}$$

where $k = \frac{0.014\ A^3\ N^2 \mu^2}{4}$, a constant for all practical dimensions.

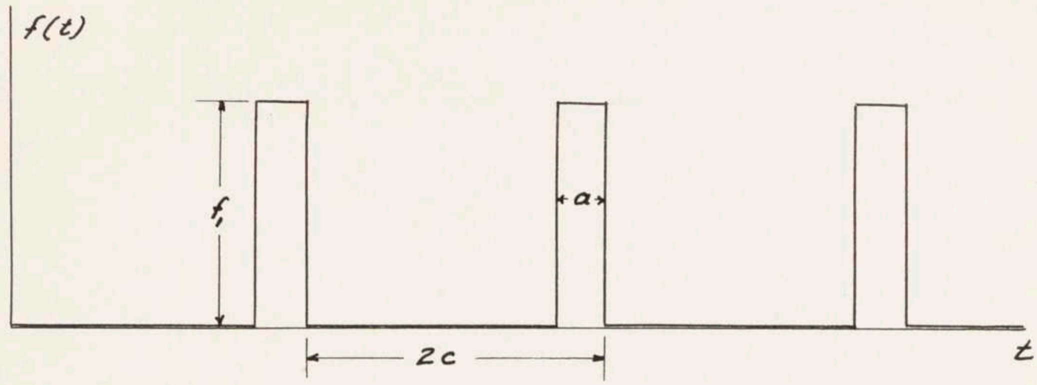
If we neglect the transient distortion during the closing and opening of the circuit of the vibrating sources of pulsating current, the current may be represented graphically by



The value of i to be used in the equation for the force F is I_o of the above figure, which flows during the short part a of a cycle. During the rest of the cycle the current becomes zero and thus the force of attraction is given by

$$F = \frac{K}{g^2}, \text{ where } K = kI_o^2, \text{ a constant.}$$

But since the vibration is small, the air gap does not vary much, and therefore, we may consider that the force is almost constant during the time that the current I_o is flowing. Besides, the time a is small compared to the period 2c of the vibration. Therefore, for all practical purposes we can assume that the driving force varies as shown by the following diagram:



f_1 is the value of the force that maintains the vibration, and the time of action of that force, a, we will represent as a fraction of a whole period, or

$$a = \frac{2c}{N} \qquad \text{(or 1/N of the period)}$$

We will determine a Fourier series representing this function. The boundary conditions are

$$f(t) = 0 \qquad -c < t < 0$$

$$f(t) = f_1 \qquad 0 < t < \frac{2c}{N}$$

$$f(t) = 0 \qquad \frac{2c}{N} < t < +c$$

The coefficients are, therefore, given by the expressions

$$A_n = \frac{1}{c}\int_0^{\frac{2c}{N}} f_1 \sin\frac{n\pi t}{c}\,dt$$

$$B_0 = \frac{1}{2c}\int_0^{\frac{2c}{N}} f_1\,dt$$

$$B_n = \frac{1}{c}\int_0^{\frac{2c}{N}} f_1 \cos \frac{n\pi t}{c}\, dt$$

n is the order of the term.

Evaluating those integrals and substituting the limits we obtain the values

$$A_n = \frac{f_1}{n\pi}\left[1 - \cos \frac{2\pi n}{N}\right]$$

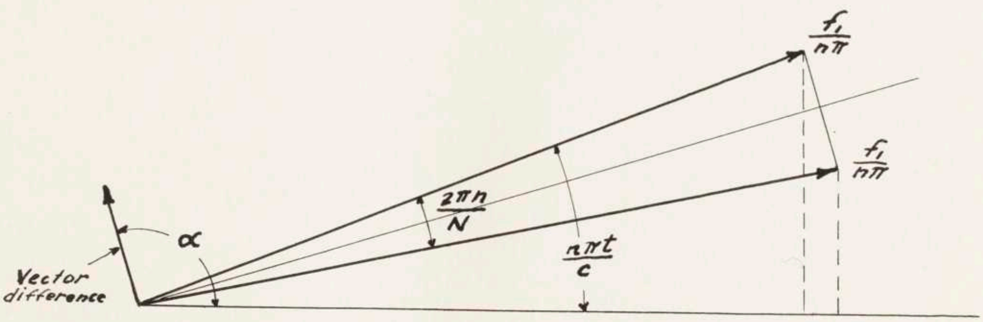
$$B_o = \frac{f_1}{N}$$

$$B_n = \frac{f_1}{n\pi} \sin \frac{2\pi n}{N}$$

The series, therefore, is

$$f(t) = \sum_{n=1}^{n=n} \frac{f_1}{n\pi}\left[\sin \frac{n\pi t}{c} - \sin \frac{n\pi}{c}\left(t - \frac{2c}{N}\right)\right] + \frac{f_1}{N}$$

The two terms inside the summation symbol can be added vectorially in the following manner:



$$\frac{\pi}{2} - \frac{\pi n}{N} + \frac{\pi n t}{c} = \alpha$$

The vector difference is

$$\frac{2f_1}{n\pi}\left[\sin\frac{n\pi}{N}\right]\left[\sin\left(\frac{\pi}{2}-\frac{n\pi}{N}+\frac{n\pi t}{c}\right)\right]$$

and the series becomes

$$f(t) = \frac{f_1}{N} + \sum_{n=1}^{n=n} \frac{2f_1}{n\pi} \sin\frac{n\pi}{N} \cos\frac{n\pi}{c}\left(t-\frac{c}{N}\right)$$

If we make the substitutions

$$Q_1 = \frac{2f_1}{n\pi} \sin\frac{n\pi}{N}$$

$$\beta = \frac{c}{N}$$

$$P = \frac{n\pi}{c}$$

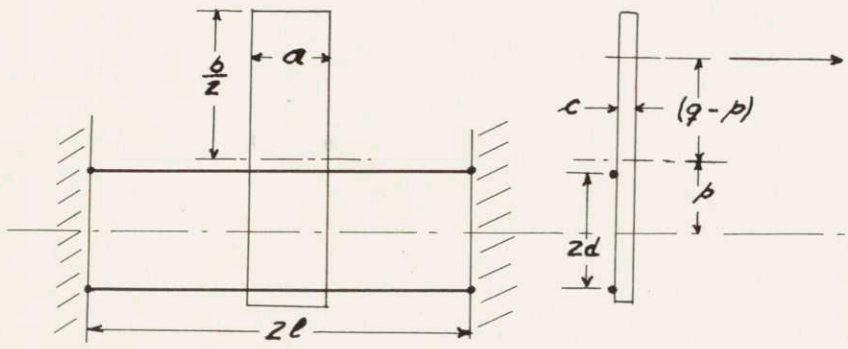
The series simplifies into

$$f(t) = \frac{f_1}{N} + \sum_{n=1}^{n=n} Q_1 \cos P(t-\beta)$$

This is, then, the expression for the periodic driving force that will maintain the vibrations of the mirrors, provided the amplitude of those vibrations is small.

DIFFERENTIAL EQUATION OF MOTION

The following diagram represents the vibrating system we are studying:



The rectangular member of dimensions (a x b x c) is the vibrating member, mounted rigidly on the center of the tense wires of length 2l and 2d units apart. Those wires are fixed at the ends, as shown.

The pulsating force that will maintain, in our hypothesis, the vibration of the system, acts in the direction of the arrow at a distance q from the center line of the wires. Let p, as shown, represent the distance between the center of gravity of the vibrating member and the center line of the wires.

Let also

I = the moment of inertia of the vibrating system,

R = the damping coefficient,

and S = the stiffness coefficient of the wires (in moment units).

Then, if we apply the principle of superposition to this system for an angular displacement θ from mean positive, we have

$$S \times \theta = \text{the restoring moment,}$$

$$V = \frac{1}{2} S \theta^2 = \text{the potential energy at that instant,}$$

$$T = \frac{1}{2} I \dot{\theta}^2 = \text{the kinetic energy at that instant}$$

$$\dot{\theta} = \frac{d\theta}{dt}$$

The total energy at any instant is, therefore, given by

$$E = V + T = \frac{1}{2} (I \dot{\theta}^2 + S \theta^2)$$

If we assume that there is no dissipation of energy inside the system, we will have

$$\frac{dE}{dt} = 0 = I \dot{\theta}\ddot{\theta} + S \theta\dot{\theta} \qquad \ddot{\theta} = \frac{d^2\theta}{dt^2}$$

We may safely assume that the frictional moment is proportional to the angular velocity, or $R \times \dot{\theta}$. Therefore, if the external applied moment is represented by $F(t)$, the equation of motion is

$$I \ddot{\theta} + R\dot{\theta} + S \theta = F(t)$$

where everything is expressed as moments of force. The value of $F(t)$ is given by

$$F(t) = q \times f(t)$$

where q is the moment arm of the driving force.

If we let

$$Q = Q_1 \times q$$

$$M = \frac{f_1 q}{N}$$

$$\text{and } \omega = \frac{n\pi}{c} = P = \text{angular velocity,}$$

the general differential equation for the motion of the system becomes

$$I\ddot{\theta} + R\dot{\theta} + S\theta = M + \sum_{n=1}^{n=n} Q \cos \omega (t - \beta)$$

SOLUTION OF THE EQUATION

The preceding differential equation is an equation of second order with constant coefficients. Its solution consists of a complementary function or transient term, and a particular integral or steady state term.

Complementary Function. Making use of the time differentiator D, our equation becomes, for finding the complementary function ,

$$(I D^2 + R D + S)u = 0$$

Solving for D as an ordinary quadratic equation we have

$$D = -\frac{R}{2I} \pm \sqrt{\frac{R^2}{4 I^2} - \frac{S}{I}}$$

In order that the system may execute natural vibrations, it is necessary for the radical term to be imaginary, so as to have sine and cosine terms in the solution. Therefore,

$$\frac{S}{I} > \frac{R^2}{4\,I^2}$$

Under this condition, the complementary function is

$$u = \varepsilon^{-\frac{R}{2I} \times t} \left[c_1 \sin(n't) + c_2 \cos(n't) \right]$$

$$\text{where } n' = \sqrt{\frac{S}{I} - \frac{R^2}{4\,I^2}}$$

It is more convenient to write this solution as

$$u = A\ \varepsilon^{-\Delta t} \sin(n't + \gamma)\ , \qquad \Delta = \frac{R}{2I}$$

since we can make the substitutions

$$A = \sqrt{c_1^2 + c_2^2}$$

$$\text{and } \gamma = \tan^{-1} \frac{c_2}{c_1}$$

We will determine the particular integral, which will be of the form

$$v = B \sin \omega(t-\beta) + C \cos \omega(t-\beta) + E$$

Operating on this as indicated in the differential equation, we obtain,

$$(BS - C\omega R - IB\omega^2) \sin \omega(t-\beta) + (CS + BR\omega - IC\omega^2) \times$$

$$\times \cos \omega(t-\beta) + SE = Q \cos \omega(t-\beta) + M$$

Therefore, $E = \frac{M}{S}$

$$BS - CR\omega - IB\omega^2 = 0$$

$$CS + BR\omega - IC\omega^2 = Q$$

Solving simultaneously for B and C we obtain

$$B = \frac{\omega R Q}{R^2\omega^2 + (S - I\omega^2)^2}$$

$$C = \frac{-(S - I\omega^2)\,Q}{R^2\omega^2 + (S - I\omega^2)^2}$$

Therefore, making the substitutions and reducing we have for the value of the particular integral,

$$v = \sqrt{B^2 + C^2}\ \sin\left[\omega(t - \beta) + \delta\right] + \frac{M}{S}$$

where

$$\sqrt{B^2 + C^2} = \frac{Q}{\omega\sqrt{R^2 + \left(\frac{S}{\omega} - I\omega\right)^2}}$$

and $$\delta = \tan^{-1}\frac{C}{B} = \tan^{-1}\frac{I\omega - \frac{S}{\omega}}{R}$$

But the impedance of the system is

$$\bar{Z} = R + j\left(I\omega - \frac{S}{\omega}\right)$$

and hence

$$\sqrt{B^2 + C^2} = \frac{Q}{\omega\,|Z|}$$

Consequently, the general solution of the equation is

$$\theta = A\,\varepsilon^{-\Delta t}\sin(n't + \gamma) + \sum_{n=1}^{n=n}\frac{Q}{\omega\,|Z|}\times$$

$$\times\sin\left[\omega(t - \beta) + \delta\right] + \frac{M}{S}$$

We will proceed to study the behaviour of the system as indicated by the preceding equation.

THEORETICAL STUDY OF THE MOTION

I do not intend to make a thorough study of the motion as may be made from the preceding equation, but will limit my study to those points which are of interest in their relation to the scanning device.

The complementary function, first term of the equation, represents the condition of free oscillation of the system, i.e., the equation of the motion once the system has been displaced from its position of equilibrium and then left free to vibrate naturally. As the exponential factor indicates, it represents a transient condition, and it may be called, therefore, the transient state term.

This transient term soon disappears since Δ is comparatively large. Therefore, the only point of interest to us in the transient term is the free frequency of oscillation, which is determined from the equation

$$n' = \sqrt{\frac{S}{I} - \frac{R^2}{4 I^2}} = \sqrt{n^2 - \Delta^2}$$

where $n^2 = \frac{S}{I}$ and $\Delta = \frac{R}{2I}$, as before.

If there were no dissipation of energy to the outside of the system (and none inside of it, as already we have assumed), the free frequency would have been

$$f_o = \frac{n}{2\pi}$$

But since damping actually exists, the free frequency is given by

$$f'_o = \frac{n'}{2}$$

The constant term $\frac{M}{S}$ indicates that due to the one-sided force acting on the system, the axis about which oscillation takes place is displaced by that value in a positive direction. The time axis will be M/S units above (i.e., in the positive direction) and parallel to the time axis were this constant term absent. This term, of course, does not affect the motion itself in any way.

The particular integral is a series consisting of even and odd harmonics, from the first to the nth. It represents the motion of the system once the transient term has disappeared or has become negligibly small. It represents, therefore, the steady state condition, and it is the one of more interest to us.

The angular velocity for any harmonic, such as the nth. is

$$\omega = \frac{n\pi}{c}$$

The amplitude of the motion due to the nth. harmonic is

$$\theta_n = \frac{Q}{\omega |Z|}$$

where the impedance $|Z|$ is for that harmonic.

Q is a measure of the amount of force that the electromagnet exerts on the vibrating system. In order to use a minimum of force for a given amplitude, or, in other words, a maximum amplitude for a minimum of force, we will have to design the system for a maximum value of the amplitude corresponding to any given harmonic, say the fundamental ($n = 1$).

As we see from the preceding equation for the amplitude, the maximum of θ_n occurs when the impedance $|Z|$ is a minimum. Minimum impedance occurs at that frequency which reduces to zero the quadrature component of the impedance. The minimum impedance is, then,

$$|Z| = R$$

For the imaginary term to be zero, it is necessary that

$$I\omega = \frac{S}{\omega}$$

$$\text{or } \omega^2 = \frac{S}{I}$$

Having chosen a given frequency, such as that of the fundamental, it is obvious that S and I can be so chosen as to satisfy the above relation, and thus produce a maximum amplitude at the chosen frequency. We have, therefore, a criterion for the design of the scanning device. The amplitude due to the other harmonics is reduced to a small value, and the motion of the system will approach simple harmonic motion, which is the desired aim.

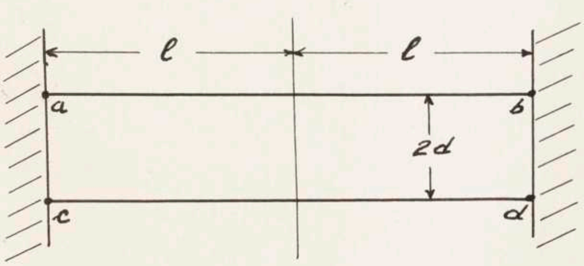
The best frequency to be chosen is obviously the fundamental frequency of the driving force, because it is the lowest frequency available and will permit us to use in the design, lower values of the stiffness coefficient S of the tension wires, which means less tension, and also higher values of the moment of inertia I of the vibrating system. Consequently, we will design the system for the condition of resonance at the fundamental frequency of the driving force.

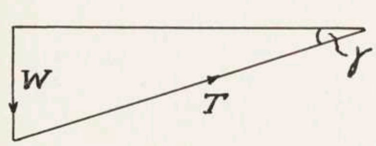
We can conclude from the preceding analysis that the principle of the scanning device is sound, and that if the stated conditions are satisfied in the design, the motions of the mirror will be almost of a simple harmonic nature, since the other harmonics that constitute the driving force will have little effect on the motions, as compared to those produced by the fundamental frequency.

THE COEFFICIENTS I, R AND S

1)- The moment of inertia I is determined from the dimensions of the vibrating system and the materials of which it is made. If the system is sufficiently small in weight, it may be necessary to take into account the weight of the tension wires. It can be shown that the weight due to these which must be included as forming part of the vibrating system, as a weight suspended in the center of the wires, is one-half of the weight of each wire. This correction, nevertheless, does not have to be made for vibrations of low frequency, since we may use heavier vibrating systems than at higher frequencies of vibration.

2)- The stiffness coefficient S of the wires may easily be determined in the following manner. Referring to the accompanying diagram, ab and cd are the tense wires, fixed at the ends. The half-length of each wire is l, as before.





Force triangle.

Since the displacement from equilibrium position is small, the consequent increase in tension due to bending may be neglected. If a force W deflects one wire from its midposition by an amount v_o, the triangle of forces gives

$$W = 2T \sin \gamma \doteq 2T\gamma \qquad \text{(T is tension)}$$

but $v_o = l \times \gamma$

and hence,

$$W = \frac{2T}{l} v_o$$

Therefore, for a deflection of the vibrating system through a small angle θ , we need a torque of

$$\tau = 2d \cdot W = \frac{2T}{l} v_o .2d$$

but $v_o = \theta \cdot d$

and hence,

$$\tau = \frac{4Td^2}{l} .\theta = S . \theta$$

or

$$S = \frac{4Td^2}{l}$$

which is the stiffness coefficient of the wires.

3)- The damping coefficient R is defined as the factor of the angular velocity to produce an opposing torque to the motion. It is commonly assumed, and the assumption has been checked experimentally, that for small velocities up to about thirty feet per second, the resistance to motion due to damping is directly proportional to the velocity. Hence the definition given above.

If we look back at the equation of the transient state of the motion, we see that with the system free to vibrate naturally, the ratio of the displacement at time t and at time t + T_o (T_o = period) is

$$\varepsilon^{+\Delta T_o}$$

If we let

$$\delta = \ln \varepsilon^{\Delta T_o} = \Delta T_o, \quad (\Delta = \frac{R}{2I}, \text{ as before}),$$

we have what is called the logarithmic decrement of the motion.

Let θ_o, θ_2, θ_4, ..., represent amplitudes of successive swings in one direction; we have that

$$\delta = \ln \frac{\theta_o}{\theta_2}$$

If after a complete swings the motion is reduced to 1/b of its original amplitude, it follows by definition, that

$$\delta = \frac{\ln b}{a}$$

Therefore,

$$R = \frac{2I \ln b}{a\, T_o},$$

the damping coefficient. This gives a means of determining the constant R to be used in our equation. I do not intend in this thesis to determine this coefficient, since it is not necessary.

DESIGN

The principal elements to be designed are: the length and cross-sectional area of the wires, their distance apart, the rectangular pieces that support the wires, for the higher period, the size of screw necessary for tightening the latter, and the electromagnets.

1)- CROSS-SECTIONAL AREA OF WIRES

Marks' Mechanical Engineering Handbook gives the following equation for the calculation of the ultimate strength of a steel wire, advising the use of a factor of safety of 3:

$$s_M = \frac{c}{d} + s_o \text{ in lbs. per sq. in.}$$

where $c = 1495$ (a constant),

d = diameter of wire in inches,

and $s = 90{,}600$ lbs. per sq. in. (a constant).

Musical steel wire (hardened) is much stronger than is given by this equation. A test made at the General Electric laboratories on a wire of 0.051 in. in diameter, showed a tensile strength of 321,500 lbs./sq.in., while the equation gives 120,000 lbs./sq. in. for this wire. Consequently, I will use the preceding equation as applied to musical steel wire, and I will not have to use any factor of safety, since the values given by that equation are safe.

2)- DESIGN OF THE WIRES

Referring back to the diagram of page 22, and neglecting the weight of the wires, we obtain for the moment of inertia of the vibrating member, about the center line of the wires,

$$I = \frac{1}{12g} abcs\,(b^2 + c^2) + p^2 abcs \times 1/g =$$

$$\frac{abcs}{12g}(b^2 + c^2 + 12p^2)$$

a = width of member,

b = length of member,

c = thickness of member,

g = acceleration of gravity,

s = weight of member per unit volume.

Substituting values in this equation we obtain the moment of inertia to be used in the fundamental equation of design (p. 29),

$$\omega^2 = \frac{S}{I}.$$

Replacing S by its value already found, we have

$$\omega^2 = \frac{4Td^2}{1.I}$$

From this equation we will determine the different values to be used in the scanning device.

There are so many variables present in that equation, that I have to assume several of them, substituting them into the equation and determine the others. If the values of the latter are reasonable, we have a set of values with which we can proceed to the construction of the apparatus.

I decided first on the frequency to be used: 420 vibrations per second. This gives us the value

$$\omega^2 = 6.96 \times 10^6$$

A compromise had to be reached between the right hand factors of the equation, and many substitutions were made. The final values were:

$$a = 1/8 \text{ in.}$$

$$b = 1 \text{ in.}$$

$$c = 1/32 \text{ in.}$$

$$s = 0.30 \text{ lbs./cu. in. (iron)}$$

$$p = 3/8 \text{ in.}$$

With these values, the moment of inertia is

$$I = 6.79 \times 10^{-7} \text{ lb. in}^2.$$

The next assumption was the tension T per wire. I assumed 25 lbs. Substituting in our equation and reducing, we obtain

$$\frac{d^2}{l} = 4.73 \times 10^{-2}$$

Assuming the half-length <u>l</u> of the wires to be one inch, we obtain

$$2d = 0.436'' \text{ which is very close to } 7/16'',$$

a practical dimension.

The tensile strengtn of musical steel wire #9, of diameter 0.0256", is 150,000 lbs. per sq. in. as obtained from the equation, and this corresponds to a tension of about 70 lbs. But since the wire must be bent in a somewhat sharp angle, the maximum tension will not be that, but less. Using here a factor of safety of 3, we obtain a tension of 23 lbs., i.e., the required tension. Therefore, #9 gauge musical wire will be used as strings.

The practical dimensions are, therefore:

a = 1/8 in.	Musical steel wire
b = 1 in.	#9 gauge. 0.0256" diam.
c = 1/32 in.	Tension T = 25 lbs.
p = 3/8 in.	Length of strings = 2in.
Material: soft iron.	Distance apart = 7/16 in.

Making somewhat the same assumptions, but much less approximate, we obtain, using a tension of 5 lbs. per string, #9 wire, the following values for the low frequency wires:

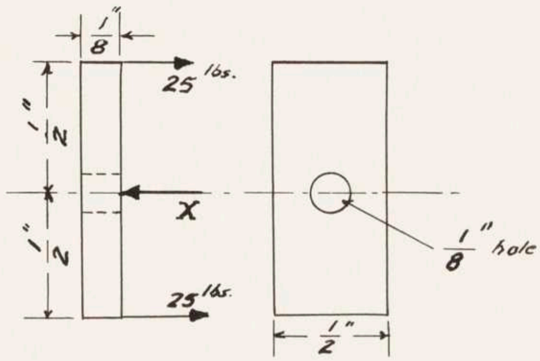
Length of each = 3/4 in.

Distance apart = 3/4 in.

These two values are only rough approximations to the more exact ones, but due to the difficulty in determining the moment of inertia of the vibrating part, I did not consider it necessary to stress more on that point, since the tension of the wires will permit the necessary adjustments.

3)- <u>SUPPORTS</u>

These are the rectangular pieces 5 (Fig. 1), which hold the strings 6 and permit tightening them. They are diagrammatically of the following form:



From the diagram we have:

$$X = 50 \text{ lbs.}$$

Maximum bending moment $= M_o = 25 \times 1/2 = 12.5$ lbs.in.

Assuming an allowable fiber stress of 15,000 lbs./sq. in., and the dimensions shown, we obtain for the section modulus the value

$$S.M. = \frac{2}{3} (1/2 - 1/8)(1/16)^2 = \frac{1}{1024} \text{ (in.)}^3$$

The fiber stress (maximum) will then be

$$1024 \times 12.5 = 12{,}800 \text{ lbs./sq. in.}$$

which is within the limits of our assumption.

4)- <u>THE ELECTROMAGNETS</u>

If it were possible to determine beforehand the value of the coefficient of damping R, it would be possible to calculate the proper number of ampere-turns to be used. But the damping coefficient cannot be determined but experimentally, with the constructed apparatus. Therefore, I will limit myself to the explanation of the method of calculating the electromagnets for an apparatus of this kind.

The maximum amplitude for the condition of resonance is given by the equation

$$\theta_m = \frac{Q}{\omega R}, \text{ since } |Z| = R \text{ at resonance.}$$

We know the desired maximum amplitude and the angular velocity, hence if R were known, the value of Q would be determined. But Q is equal to the product of the moment arm q of the driving force f(t) and Q_1. The value of Q_1 is

$$Q_1 = \frac{2f_1}{n\pi} \sin \frac{n\pi}{N} \quad \text{(p.21)}$$

where n = 1, and $\left(\frac{1}{N}\right)$ isthe fraction of the period during which the force f_1 acts. If we knew this fraction 1/N, we could determine the value of f_1 since Q_1 is known.

Knowing the value of the force f_1, the dimensions of the magnetic circuit (principally of the air gaps), it would be simple to determine the required ampere-turns, as explained in page 18. Unfortunately, the time alloted to the thesis is short and the preceding computations, although interesting, could not possible be carried out.

Therefore, I decided on the use of an electromagnet of good size, with 500 turns of #23 gauge enameled wire, which can safely carry a half-ampere. Obviously, this would more than give the required magnetic pull on the vibrating member. I also decided to use a smaller electromagnet for the lower frequency of vibration. The experiments have shown that these choices were safe, since none of the electromagnets was heated perceptibly, even during runs of more than one-hour's duration.

5)- <u>TIGHTENING SCREW</u>

This is numbered 9 of Fig. 1. The load is X, (see the calculations of the supports) its value being 50 lbs. Assuming an allowable stress of 4000 lbs./sq.in. in the bolts, the diameter is given by

$$\text{Diam.} = \sqrt{\frac{4 \times 50}{4000}} = 0.126 \text{ in. or } 1/8 \text{ in.}$$

CONSTRUCTION

With all the preceding dimensions, I constructed two scanning devices, trying to make them as alike as possible. Made as they were, in a hurry, not much was to be expected from their performance. I also constructed a control board and the electrical sources of pulsating direct current. A tuning fork of 426 2/3 vps. nominal was used for the higher frequency, and a steel rod one foot long, with a sliding weight at its free end was used for the lower frequency. The electrical circuit of the sources is that of an electric bell. Much of the distortion and inaccuracy of the apparatus may be traced back to the mechanical imperfections of these electrical sources, as will be explained later.

The appended photographs give an idea of the experimental set up of the optical analogue used in the tests. The diagram of this optical analogue is that of Fig. 4.

The source of light used was that of a regular Pathe Baby projection camera. It gives a powerful light. I encountered much difficulty in obtaining a thin pencil of light; in spite of all the troubles taken, the beam was not as thin as desired.

The photograph of the scanning device is explanatory in itself, since with the help of the drawings (Fig. 1) it can be understood easily.

Referring to the numerals of the other photographs:

1 is the transmitter's scanning device,

2 is the source of light,

3 is the first lens. Between it and 1, the silhouette to be transmitted was placed.

4 is the control board and aperture of diffusion.

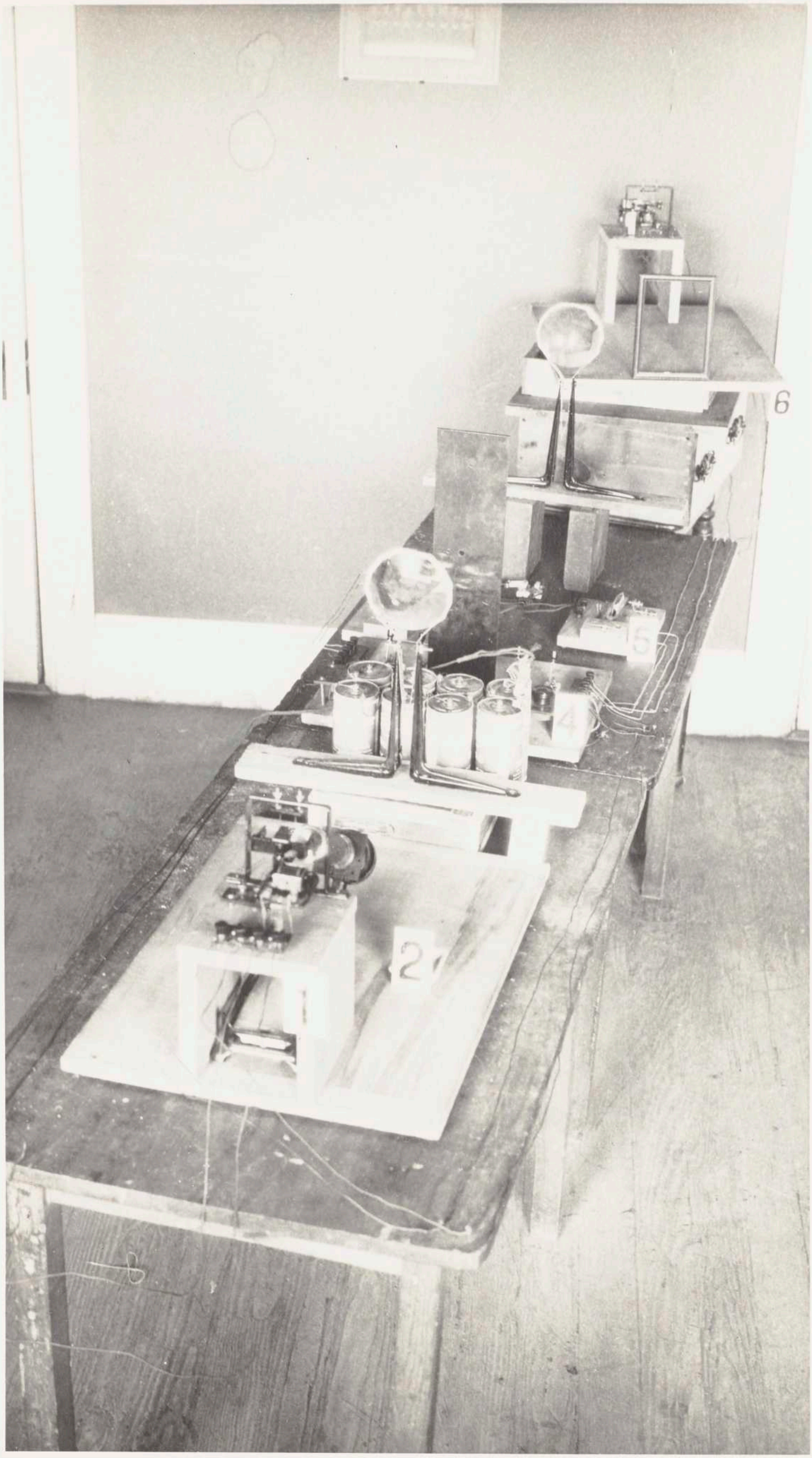
5 are the electrical sources of pulsating direct current; also the second lens.

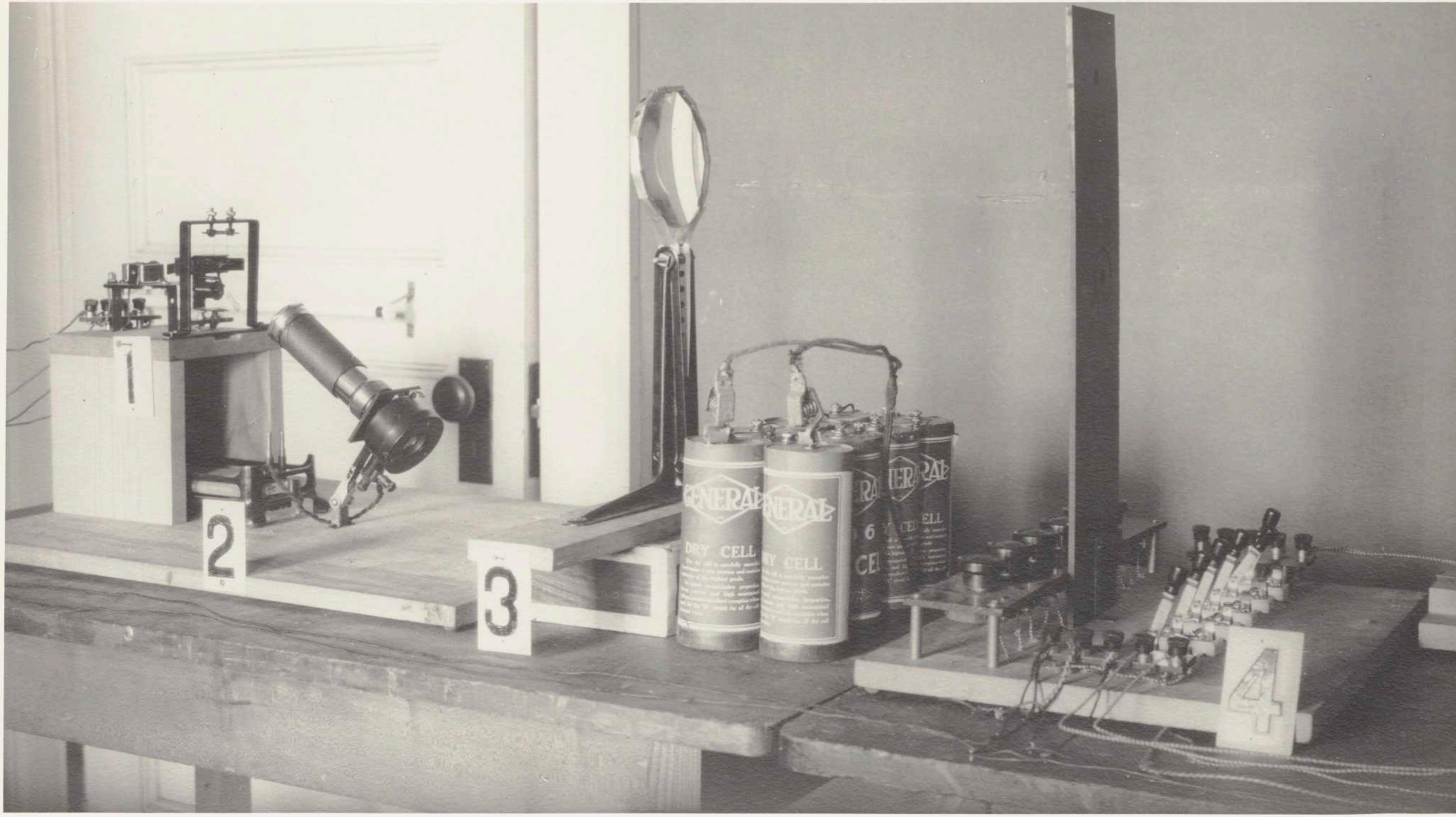
6 is the receiver's scanning device.

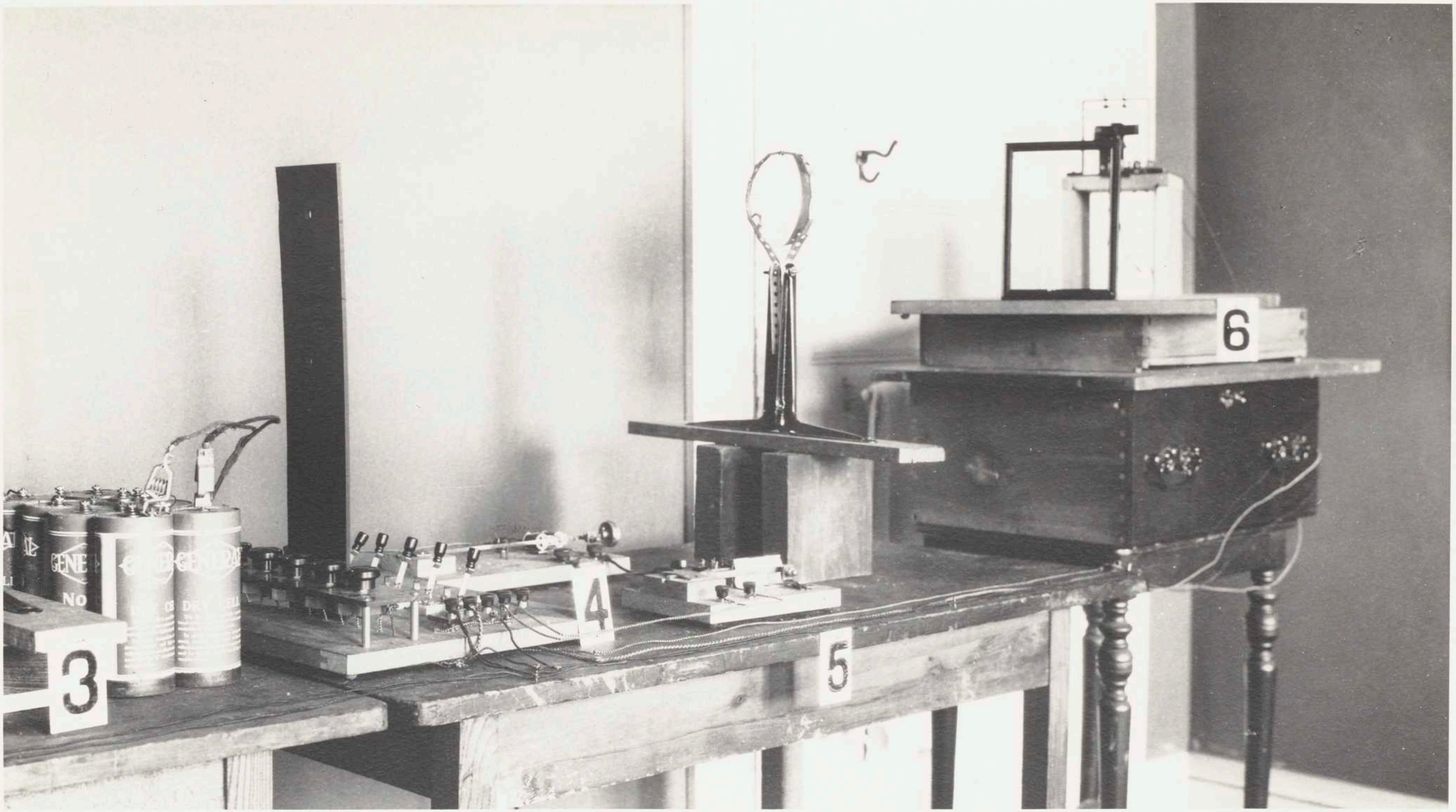
The control board and the sources form a central station from which synchronization of the vibrating systems is obtainable. Four wires run from the central station to each of the scanning devices. Eight dry cells of 1.50 volts each, connected in series, supplied the system. The source of light received its energy from the 110 volt direct current supply line.

The mirrors, 3/16" square, are of silver, with good polish so as to obtain a clear image and a good reflecting power.

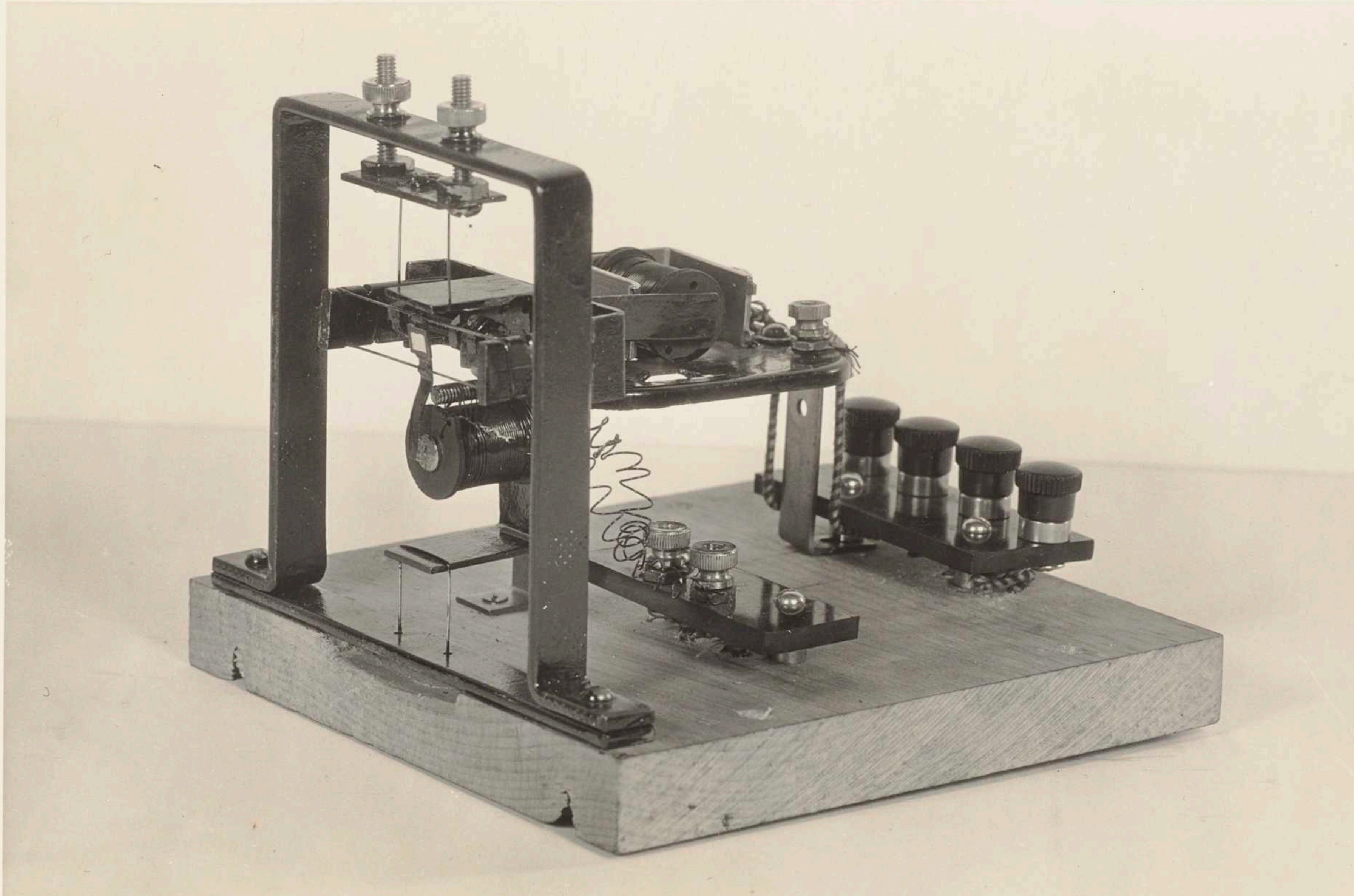

1
2
3
4
5
6


6
5
4
2
1


1
2
3
4
GENERAL
DRY CELL
GENERAL
DRY CELL



94



METHOD OF TEST

CONDITION OF RESONANCE

The first test to be made is that of securing the condition of resonance for the higher and the lower frequencies. This is done in the following manner:

1)- Start the vibrating source of higher frequency, varying its series rheostat until a smooth vibration is obtained.

2)- Close the switch for one of the scanning devices, thus sending current to the electromagnet for higher frequency.

3)- Vary the tension of the wires by means of the tightening screw until the maximum amplitude is secured. This point of maximum amplitude (for that current) is the point of resonance, as may be determined by giving more tension to the wires: if the condition of resonance had been reached by the preceding tuning, the amplitude will be less after the increase in tension.

4)- Repeat 2) and 3) for the other scanning device.

5)- Stop the vibrating source of higher frequency.

6)- Start the vibrating source of lower frequency, adjusting its rheostat until a smooth vibration is obtained.

7)- Proceed as per 2), 3) and 4) for the tuning of the vibrating systems of lower frequency.

TESTING THE OPTICAL SYSTEM

It is obvious that if the size of the aperture is not correct, and if the lenses are not properly focused, only a part of the image to be sent will give light to the aperture. In this manner, at the receiving end we would not receive a complete image. Also, it is necessary to secure the condition of no-motion of the receiving spot of light, with and without the transmitting device working. The last condition is the more important, since from its satisfaction depends the clearness of the received image. Consequently, the following method was followed:

1)- Light the local lamp with direct current.

2)- Adjust the lenses and aperture until a clear spot is obtained at the receiving screen.

3)- Start the scanning device of the transmitting end. If the spot of light at the receiving screen moves, adjust the lenses and aperture until it remains stationary. This is the desired condition for transmitting.

4)- By step 3) we secured the following condition: the image was being traced by the transmitter, i.e., we obtain a rectangle of light at the transmitter's end; at the same time, the spot of light at the receiving screen remained stationary. If, therefore, the scanning device at the receiving end is started, we will also obtain a rectangle of light on the receiving screen.

TEST FOR SYNCHRONISM

If a silhouette is cut out of cardboard and placed at the transmitting end so as to have it "scanned" by the spot of light at that end, and the two scanning devices are in synchronism, we will receive at the receiving screen a duplicate of the silhouette, that is, we have secured actual television with the apparatus.

If no image is received, we have to repeat the tuning of the vibrating systems until the image appears on the receiving screen.

The best way to proceed in the synchronization of the devices is as follows:

1)- Cut out a strip of cardboard wide enough so as to cover about one-third of the rectangle of light at the transmitting end, and place it so as to be scanned in a vertical direction, long dimension horizontal and about in the middle of the rectangle of light.

2)- Stop the vibrating source of lower frequency. On both sides we will have only a vertical line being "scanned."

3)- Adjust the tension of the wires for higher frequency until a black spot appears at the receiving end in the center of the line of light. This secures the synchronization for the higher frequency.

4)- Start the source of lower frequency and energize the corresponding electromagnets at both ends. Stop the other source.

5)- Place the strip of cardboard vertically and about the center of the horizontal line being "scanned" at the transmitting end.

6)- Adjust the tension of the wires for lower frequency until a black spot appears at the center of the horizontal line being traced at the receiving end. This secures the synchronization for the lower frequency.

7)- Start the other source. If any cardboard silhouette is placed at the transmitting end, its image must appear on the receiving screen.

RESULTS

METHOD OF OBTAINING RESULTS

After all the preceding tests were performed to the full satisfaction of the writer, the following photographs were taken by placing sensitized photographic films at two places: just in front of the first lens of the analogue, and in place of the receiving screen. The positive copies of those films are appended and numbered thus:

1)- The spot of light at the transmitting end.

2)- The spot of light at the receiving end (transmitting end working).

3)- Horizontal scanning at the transmitter.

4)- Horizontal scanning at the receiver. (Transmitting end working).

5)- Vertical scanning at the transmitter.

6)- Vertical scanning at the receiver. (transmitting end working)

7)- Rectangle of light at the transmitter.

8)- Rectangle of light at the receiver. (transmitting end working)

9)- Horizontal cardboard strip at the transmitter.

10)- Vertical cardboard strip at the transmitter.

11)- Diagonal cardboard strip at the transmitter.

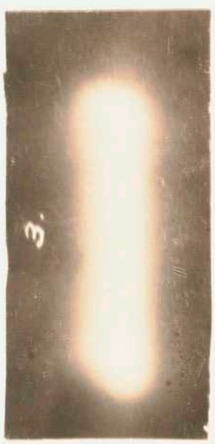
12)- Horizontal cardboard strip image at the receiver.

13)- Vertical cardboard strip at the receiver.
(image)

14)- Diagonal cardboard strip image at the receiver.


4.


8.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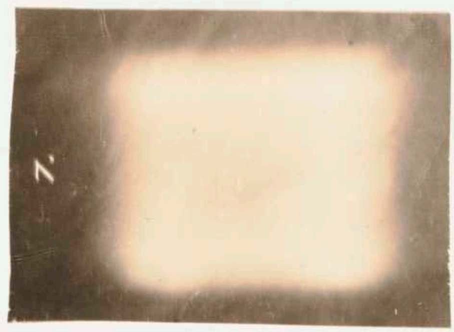
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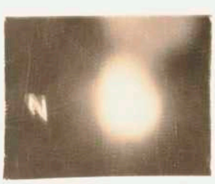
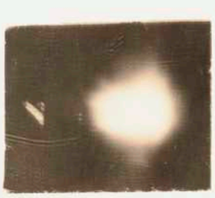

2


6.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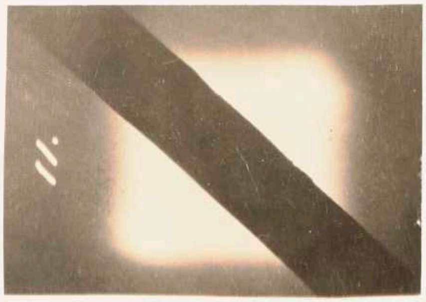
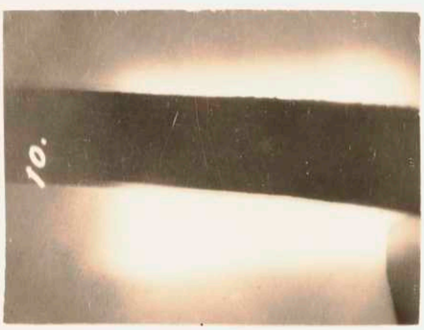
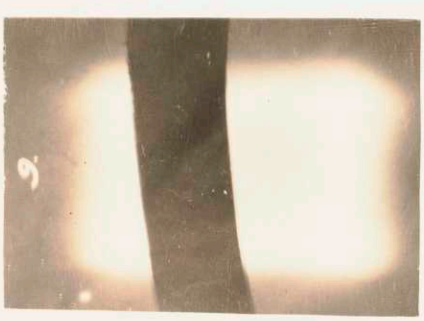

11.


14.


10.


13.


9.


12.

DISCUSSION OF RESULTS

The spots of light at the transmitter and receiver ends are shown blurred in the pictures. There was actually much diffraction and distortion due to the apertures used. Also, as said before, due to the many difficulties encountered in obtaining a small enough spot of light at the transmitter, there was no necessity of obtaining a smaller spot at the receiver. The size of the spots, as shown by the photographs, is somewhat larger, due to over-exposure. In fact, the sensitized films used were Kodak Film Packs Nos. 518 and 520; the time of exposure (determined by experiment) for the photographs at the transmitting end was of from two to four seconds, and for those at the receiving end was of from thirty to forty seconds. The difference of the two times of exposure is due to the small amount of light that reached the receiving screen, since only a small portion of the light diffused by the aperture was reflected by the receiving mirror. Therefore, having no definite criterion I had to determine the times of exposure by trial. It is pardonable, therefore, that some of the photographs resulted overexposed.

The horizontal and vertical scanning lines of both the transmitter and receiver show clearly one phenomenon which permits us to think that the motions were almost of a simple harmonic nature. This phenomenon is the crowding, let me say, of the light towards the ends of the lines. It is manifest in all of them. It is due to the slower velocity of the scanning spot of light at the ends of its travel than at the center of the same. It is a characteristic of all simple harmonic vibrations. In spite of the fact that the driving force was one-sided, the photographs show clearly that at resonance, the motion has simple harmonic characteristics, a fact which is already proved by the mathematical analysis of the motion. I obtained thus an experimental check to my calculations.

The above phenomenon is more clearly seen in the photographs of the rectangles of light at the transmitter and receiver. We can notice it clearly on all four sides of the rectangle, and more particularly at the corners of the same. If the spots of light were smaller in size, the corners would appear just as much illuminated at the sides of the rectangle.

Due to the length of time of the exposures and the many mechanical and electrical imperfections of the experimental apparatus, it is obvious that the "traces" made by the spot of light cannot possibly be noticeable in the photographs. In fact, those imperfections manifested themselves in many ways: difficulties in synchronization, which should be theoretically very simple, had the apparatus been constructed near perfection, i.e., properly balanced and adjusted; difficulties in obtaining constant pulsating frequencies out of the electrical sources; difficulties in adjustment due to the rheostats; extraneous vibrations due to surrounding objects, such as the tables on which the apparatus was mounted. Most of the trouble can be traced back to the irregularity of vibration and of the current in the electrical sources of pulsating direct current; for instance, the ear could clearly perceive the variations in pitch and intensity of the tuning-fork vibrator.

If a sensitized film capable of recording with the light used in the optical analogue, in one-sixteenth of a second were used the traces would be perceptible. But due to the other results obtained, there is no necessity of doing that, since we are convinced by those other results, which are a proof of the performance under actual television conditions, that the scanning was carried out satisfactorily.

The main object of the thesis was to prove experimentally the possibility of television with my scanning device. I desired only to prove that it is not only with the use of disks, bands and the like, driven by synchronous motors (extremely difficult to maintain in exact synchronism), that television is possible, but that with a device of the kind we are studying it is easier to "see through distance". The photographic proofs of horizontal, vertical and diagonal strips of carboard transmitted and received through the optical analogue are a complete satisfaction of my aims in doing this thesis.

I transmitted and received, not only stationary pictures as the ones shown in the photographs, but also silhouettes in motion, such as crosses, pliers, etc... But due to the extraneous vibrations present in the performance, I could not secure good photographs of them. For some time the received image would appear clearly, a few seconds later it would disappear entirely, to appear again after some new adjustments were made, but with such irregularity it was impossible to obtain good photographs.

The proof photographs, due to the time of exposure, appear very much blurred. This is because they show the average of thousands of superimposed pictures that were "scanned" during the time of exposure. The silhouettes were scanned sixteen times per second, the number of "lines" in each picture being about fifty. Since the spot of light was a large part of the rectangle of light, it is obvious that the traces were overlapping each other.

This could not but produce very rough pictures on the receiving screen, as was the case. Neither sharp lines, nor details of smaller size than the spot of light could be received. This is the reason for the indefiniteness of the received images.

CONCLUSIONS

The television apparatus has proven to be a complete success, and constitutes, undoubtedly, a very valuable contribution to the art of television. The form of the device used in the demonstration is very crude and lends itself to many modifications and improvements which can make of it a very practical and simple television apparatus. Several improvements suggest themselves at once.

The system for tigntening the wires may be modified greatly, so as to make the "tuning" of the vibrating systems a simpler matter than it is in the form studied.

A lens may be used to increase the size of the rectangle of light produced by the scanning device, and also to smooth out the edges of the rectangle, by converting the almost simple harmonic motion of the tracing pencil of light into an approximately uniform motion. In this manner, a larger rectangle of light with more uniform illumination is obtainable.

Concave mirrors may be used instead of plane ones, so as to obtain a thinner pencil of light for scanning.

The scanning device itself can be modified so as to use a balanced driving force instead of a one-sided driving force, and thus be able to use alternating currents instead of pulsating direct currents as used in the apparatus studied. By such an arrangement it would simplify the process of synchronization, since the frequencies produced by vaccum tube oscillators can be varied by changing the constants of the circuit, and thus, by varying the driving frequencies and the intensity of the driving currents (by means of a voltage attenuator, for instance) the dimensions of the scanning rectangles of light can be varied at will and exact synchronism attained.

It is possible to televise colored pictures with a device of the kind studied. This may be done as follows: three groups of photo-cells, each of them sensitive to one of the primary colors, receive the light reflected from the image at the transmitter. The electrical impulses from the photo-cells are received by corresponding lamps at the receiver. Each lamp emits light of only one primary color. The light emanating from those lamps is blended into a single pencil of light which is reflected on the mirror of the receiver and traces the image on the receiving screen. This image, of course, will have the colors of the original.

If the number of details is large enough, it is also possible to televise stereoscopic images. There is no need to go into the details of this, since it has been done already with other television devices.

Not only living images, but photographs and moving pictures may be televised by means of the apparatus studied.

Many other modifications and applications are possible with the apparatus studied in this thesis, just as many or more than are possible with any of the television devices known today.

The advantages of my apparatus over the televisors known nowadays are many: much smaller size, fewer moving parts, greater flexibility, use of much smaller amount of light at the transmitter and receiver, facility of synchronization, ease of control, negligible power consumption, simplicity of construction resulting in small cost, etcetera.

The smaller size and the small number of moving parts makes it adaptable to telephone systems in the home. A manner by which this may be accomplished is as follows: the central telephone station has the sources of energy that maintain the mirrors of the subscriber's stations in perfect synchronism. The currents that energize the driving magnets may be sent through a single channel, and separated at the receivers by means of filters. Through this same channel may be sent the electrical impulses from the photo-electric cells, and also the impulses that energize the neon lamps. One single scanning device may serve the purpose of scanning the image to be sent and of tracing the image received; this is simply a matter of sending the beam of light from the local light source (transmitter) and the beam of light from the neon lamp (receiver) at different angles to the same vibrating mirror; of the reflected beams, one goes to "scan" the image and the other to trace the received image on the screen. Simultaneous two-way television is thus possible with just two scanning devices, one at each end. In this manner, any telephone subscriber may see and hear any other telephone subscriber, by a method similar to the one used today on telephone conversations, i.e., communicating with a central telephone station (automatically or not) and this will make the connections.

The greater flexibility of my apparatus manifests itself in the facility with which the rates of vibration may be varied by changing the frequency of the driving currents. The smaller amount of light required at the transmitter and receiver is due to the fact that the beam of light that does the scanning of the images is a concentrated beam, meanwhile in the television systems that use small holes on a disk or bands, it is only the light that passes through those small holes that illuminates the image, that is, a very small amount of the light behind the disk or bands. This alone is a great advantage of my device. This advantage, together with the minute consumption of electrical power add to the feasibility of combining television and telephony in the home. Another advantage that is not to be neglected is the very small cost of my device as compared to all other television apparatuses.

If television is to become an everyday commodity, the apparatus which is to accomplish it must be small, simple and economic. My television apparatus satisfies those three conditions, and represents, therefore, a great stride forward in the solution of the problem of "seeing through distance".

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