Proceedings

of the

Radio Club of America

Incorporated

May-1930

Volume 7, No. 5

RADIO CLUB OF AMERICA, Inc.
55 West 42nd Street :: New York City

The Radio Club of America, Inc.

55 West 42nd Street :: New York City

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PROCEEDINGS
of the
RADIO CLUB OF AMERICA

Vol. 7 MAY, 1930 No. 5

A PRACTICAL TELEVISION SYSTEM†

By D. E. Replogle *

THE purpose of this paper is to present the general outlines of a practical television transmission system that is capable of daily service operation, transmitting the best picture obtainable within the limitations of contributing factors. Such a system recognizes and compensates where possible for deficiencies in the contributing elements. Undoubtedly in its present form the means for production of the television signal has progressed beyond the capabilities of the apparatus employed in its propagation.

Considering each component part in a paper would be endless, but a general description of a transmitting system with more or less emphasis on the points found most difficult is believed to be of interest. For this reason I have made but brief mention of the reception of the television signal, leaving that for another time or to some-one else.

No doubt all are familiar with the structure of the image as it is transmitted through space. In brief review it will be necessary only to recall the fact that the frequencies encountered range from the picture frequency, in our case 15 cycles (we are dealing with a 48-line system having a picture frequency of 15 per second) and capable of a horizontal resolution of 64 elements (the actual resolution we attain is greater) up to the highest frequency involved, which is half the number of picture elements multiplied by the frequency of repetition

$$\frac{48 \times 64 \times 15}{2} \text{ or } 23{,}240 \text{ cycles.}$$

There is nothing new in Nipkow's disc nor in the basic methods of scanning employed. There are two main systems used in our transmission of scheduled programs—one employing motion-picture film with film recorded, or disc synchronized sound, and the other a direct pickup arrangement, capable of operation with a normal degree of artificial lighting, or, in the field, with the subject illuminated by sunlight alone, or by scanning the subject with a flying point of light and picking up the reflected light with a multiple bank of photocells.

In the film pickup system as substantially shown in Fig. 1, the film is steadily advanced at a speed of fifteen frames per second and is projected, enlarged to about three times its original size, upon an aperture so adjusted as to represent one forty-eighth of the picture height. This aperture is scanned by a disc rotating at a corresponding rate and slotted with forty-eight narrow apertures. Because of the uniform advance of the film no intermittent action is necessary in the advancing mechanism. In addition it will be observed that the disc turntable for sound synchronized material is geared directly to the drive motor that actuates the film advance.

I would like to stress the importance of a uniform light source. The arc is rather vague as to light frequency values, is prone to the introduction of shifting images of the crater, and is highly unstable in illumination intensity. On the other hand, the incandescent lamp has little radiation toward the low or ultra-violet end of the spectrum where the cells are most efficient. The ideal source is as yet unknown but research points to the ultimate use of a sturdy ribbon filament worked at an extremely high temperature and used in conjunction with a quartz envelope and lenses to conserve all of the ultra-violet possible.

Special Sound Recording

Naturally, the speed of 15 frames per second made it impossible for us to employ standard film and our sound matter had to be recorded specially. The purpose of scanning an enlarged picture, as shown in the sketch, is one of increased resolution, there being a lower limit to the width of scanning aperture which we are capable of accurately producing. By scanning an enlarged picture we were able to produce a scanning element so fine when applied to the picture width as to allow us to attain a horizontal definition of the order of a thousand elements, that is, a degree of excellence far surpassing the capabilities of contributing equipment.

I mentioned before that this system required the use of special film and likewise special recordings. We, therefore, desired to rearrange our equipment to employ standard film at standard speed so as to utilize sound synchronized material of a normal character. It was neither possible to scan the image cast by the ordinary projection machine, due to the intermittent gear, nor was it desirable to increase the speed of our own equipment so as to advance the film at the usual

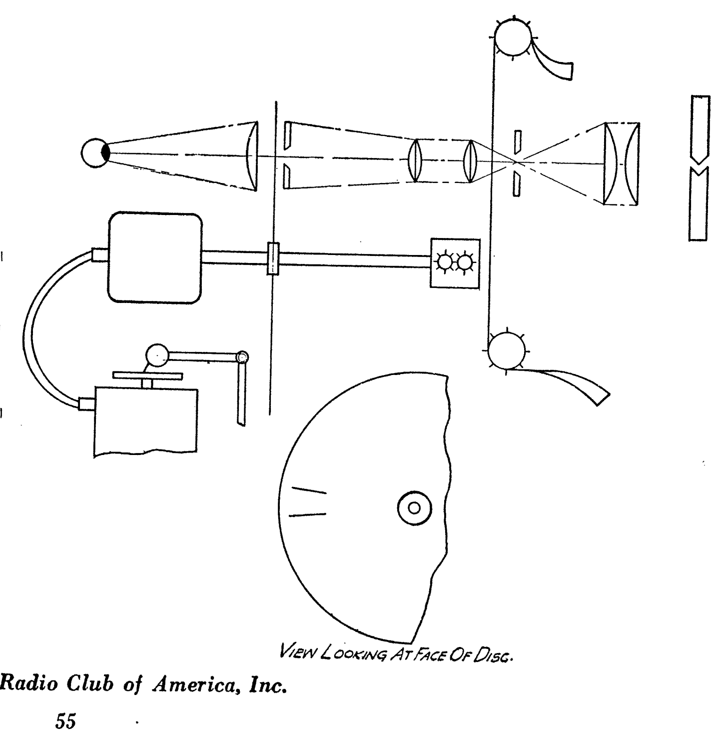

Fig. 1. Schematic of film pickup system.

† *Delivered before the Club, March 12, 1930.*

* *Acting Chief Engineer, Jenkins Television Corporation.*

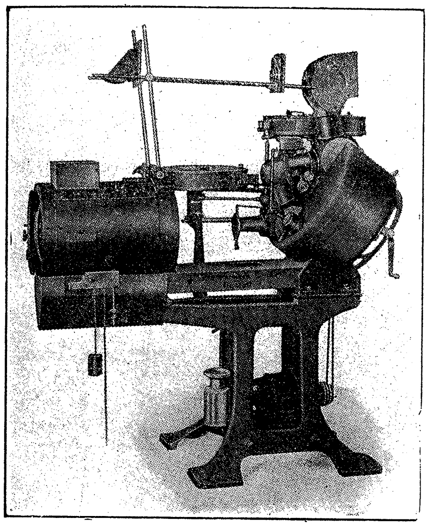

Fig. 2. The Mechau Projector.

rate. This would have increased our frequency band by some fifty per cent. without noticeably improving the character of the picture. The Mechau Projector, a photograph of which is shown in Fig. 2, helped greatly in the solution of this highly complex problem. The horizontal film magazines are readily identified but the principle of the optical intermittent employed is best shown in schematic as in Fig. 3. The figure is, in a large measure, self explanatory. The set of rotating mirrors oscillate in such a manner as to hold each frame stationary on the screen. As one frame fades in intensity the next takes its place. Hence, there is always a picture on the screen and there is no motion of the picture across the field of vision. In order to avoid the use of a spiral disc in scanning the projected image, we employ a rotating multiple mirror to create a steady motion downward, thus obtaining an optical equivalent of the spiral disc.

These projectors fortunately were available at a time when we found it necessary to go "on the air" with standard sound film. Mr. C. Francis Jenkins developed and manufactured a similar and much simplier "optical intermittent" some years ago and this is now undergoing a process of adaptation in the laboratory. This is based on Jenkins' prismatic discs and his prismatic rings of similar character. One of these discs can be rotated so as to follow one frame of a film during its course of motion and thus hold it steadily on the field until it is displaced by the succeeding frame just as in the Mechau system but with vast simplification. As an illustration, Fig. 4 shows two of these discs arranged to function as a spiral scanning mechanism in conjunction with a lens disc. We obtain a steady downward motion of a light beam by means of the rings and throw it across the field by means of the lens disc, thus obtaining another optical equivalent of a physical spiral. This mechanism is adaptable to scanning at the transmitter or to the projection of an enlarged image at the receiving point, in conjunction with a high intensity glow lamp.

These film transmissions are known as radio movies (or radio talkies, as the case may be), as opposed to "direct pickup" where the actual subject (or the projected image) is scanned. There are two possible methods of scanning in this case, either by scanning an image, where the complete illumination of the subject, either by brilliant artificial light or by sunlight, is necessary, or by scanning the subject with a "flying spot" of intense light. The two methods are outlined schematically in Figs. 5 and 6.

Development Difficulties

The principal difficulties encountered in the flying spot system are: first, that a shadow effect giving an unnatural cast to the image is introduced by the spot and by the angle at which the cells are required to work; secondly, that the subject must work in semi or complete darkness and, too, the subject is required to face an exceedingly intense light spot.

The system has the advantage of requiring cells of comparatively low sensitivity and large area and has given fair results with minimum equipment, though with low over-all efficiency.

The direct system had the disadvantages of requiring highly sensitive photocells and noiseless amplifiers together with highly efficient light gathering lenses of high speed. While these disadvantages were great they were offset by advantages and promising possibilities. Under favorable circumstances, a normal degree of light could be employed. Pickup could be made out of doors by sunlight alone. The maximum illumination required could be obtained without discomfort to the subject. By proper lighting values a considerable stereoscopic effect could be obtained. The equipment was efficient and compact, lending itself readily to portability.

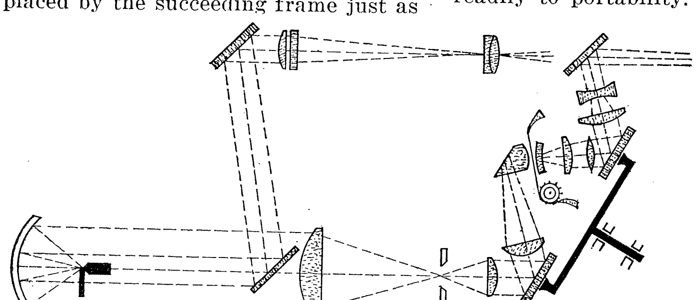

Fig. 3. Illustrating the principle of the optical intermittent.

In the final arrangements incandescent lamps and arcs were unsatisfactory because of troubles arising in film pickup. The best source of illumination seems to be the d-c. mercury vapor lamp, supplied from well filtered sources.

The scanning mechanism is at present an accurate 48-line spiral disc upon which the image is thrown by a camera lens of extremely high speed. Because of the small value of light obtainable it is necessary to effect every possible conservation. This is done through the use of quartz lenses wherever possible. Because of the low input voltage obtained our chief difficulty has been in the construction of amplifiers in which the initial noise level is sufficiently low. We have been able to avoid disturbance from magnetic induction, mechanical vibration and acoustic vibration by proper shielding and suspension. It is necessary to choose the resistances employed with care so as to avoid the trouble encountered through thermal agitation in the resistive material itself.

Improved Photoelectric Cells

In obtaining the photoelectric cells for this work it was necessary to do considerable research in this field. Happily we have been quite successful and have been able to greatly improve picture detail by using the new

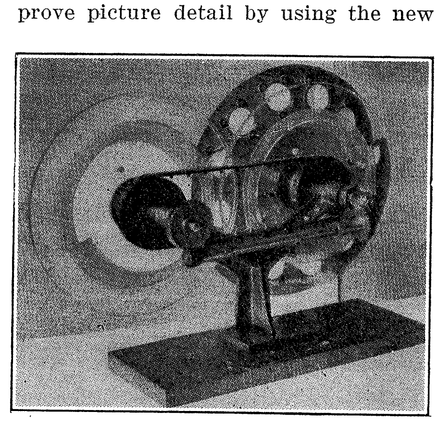

Fig. 4. Two discs arranged to function as a spiral scanning mechanism.

cells which we have developed, two of which are shown in Fig. 7.

While the output from the cell enters into the problem, the other factors are also important. High sensitivity must be coordinated with linear operation, quietness, and freedom from frequency restriction.

The gas filled type of cell has an output greatly in excess of that obtained from the hard vacuum type but suffers from "lag" and excessive frequency restriction at light frequencies beyond 10,000 cycles. We have, therefore, developed a "compromise" cell in which a fairly high degree of sensitivity has been attained together with marked decrease of high-frequency cutoff. Mechanical production difficulties, such as the attainment of a uniform light sensitive surface, have been overcome. These cells employ a

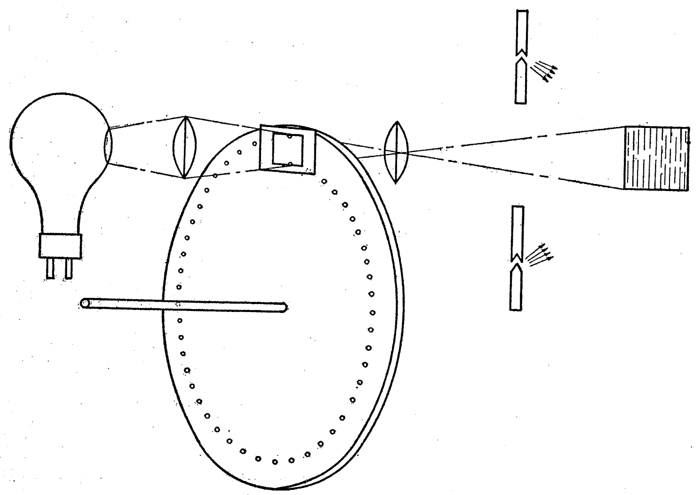

Fig. 5. One method of scanning.

photo-sensitive material sensitive over the entire range of light wavelengths but with a marked peak toward the ultra-violet end of the spectrum. They are exceptionally quiet in operation.

Contrary to first thought, the circuit into which the cell is operated has a marked effect upon the quality of the picture as the dynamic characteristic of the cell exhibits a hyperbolic curvature where impressed light flux is plotted against output. Thus

$$e = \frac{SLZ}{1 - LGZ}$$

L = Light flux
S = Sensitivity (slope of the light flux/anode current curve)
G = Conductance
Z = Load Impedance

—the treatment employed by Metcalf, I.R.E. Vol. 17, No. 11. Therein is given the computations for harmonics present in the output.

To avoid harmonic distortion the load impedance must be kept small, thus lowering the possible output. Capacity effects also require a low resistive impedance if cutoff of the high frequencies is to be avoided.

The best d-c. potential should be ascertained by trial and will be substantially below that at which ionization occurs.

Double Amplifiers

The amplifiers used in feeding the transmitters are constructed in two units; the photocell amplifiers which feed approximately one volt into a 500-ohm transmission line and which are mounted together with the photoelectric cell as a fixed portion of each scanning system, and a main amplifier which feeds the grid of a 1 k.w. modulator tube.

The problems encountered in the design of these amplifiers were many. It was necessary, in order to attain the desired results, to obtain a gain frequency characteristic flat within twenty per cent. from 15 cycles to 50 kilocycles. A curve taken on one of these circuits is shown in Fig. 8.

In the design of an a-f. amplifier for a frequency range of from 10 cycles to 50 kilocycles there are but two considerations which govern the frequency characteristic. First, the low-frequency cutoff is determined by the point at which the voltage across the grid becomes appreciably attenuated due to the grid resistance and the reactance of the coupling condenser being in series.

The high-frequency cutoff is a function of the tube and stray capacitances and is amenable to calculation where they are known. It is necessary only to maintain the active circuit impedances low so that the strays will be negligibly high up to the required high-frequency point. In other words, the chosen circuit parameters must remain constant in value over the required bond. If these requirements are met it may be postulated that the da/dω or "envelope delay" will also not deviate throughout the amplifier circuit. To this end it is important that the active elements in the circuit remain resistive at *all* frequencies and that *no* attempt to equalize internally by minor resonance effects be made.

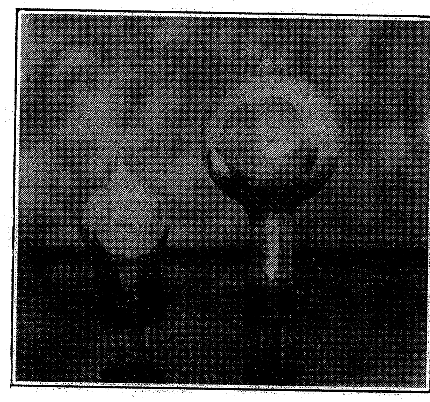

Fig. 7. Photoelectric cells.

Equalization of the transmission line and of the calculated discrimination due to the physical aspects of the scanning system is carried out in each line as is any equalization of phase displacement (da/dω) necessary. It has been found necessary to measure accurately the phase distortion present and to hold the displacement linear to within a few microseconds at the higher frequencies. Figs. 9 and 10 show the distortion evident in the transmission of a simple geometric figure. This particular figure is one which has been used by many investigators and is ideal for observation of improvement of phase and frequency distortion. The measurements of phase distortion are made by the Nyquist method, familiar to most communication engineers and will not be described in detail.

The transmission lines within the plant have not presented any major difficulties. Coupling to the lines is, in most cases, through a transformer designed for the purpose and employing a core of specially rolled 1 mil high permeability core material. The coils are universal wound in pies and are so disposed as to obtain almost perfect coupling. No d-c. is permitted to flow in the primaries and a curve

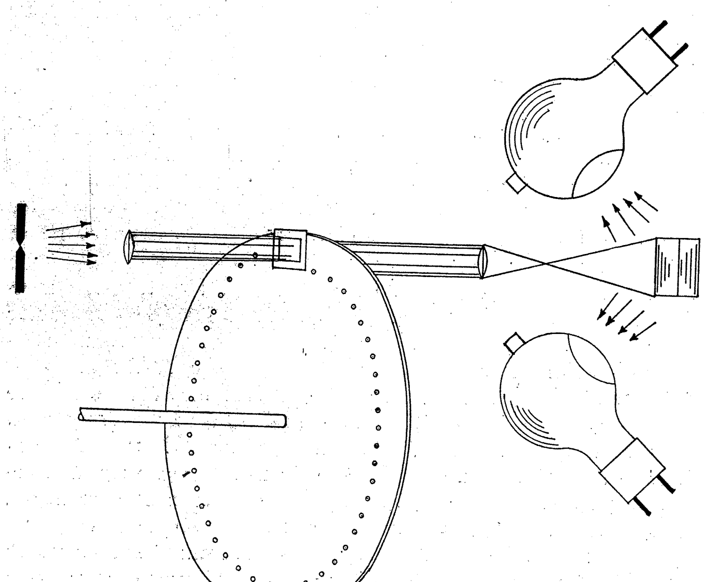

Fig. 6. Scanning by means of intense "flying spot" light.

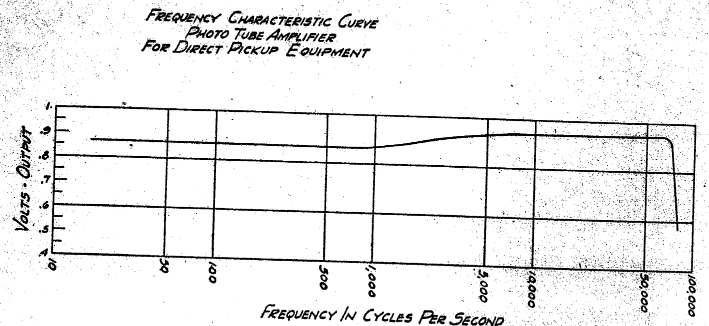

Fig. 8. Important to obtain a gain frequency characteristic flat from 15 cycles to 50 kc.

essentially flat from 15 cycles to 30 kilocycles has been attained. At first we fed these lines out of paralleled output tubes but encountered the classic difficulties of the system. We have had considerable success with special low impedance tubes designed for the purpose, the operating characteristics of which are as follows:

Ep—100 v.
Eg—40 v.

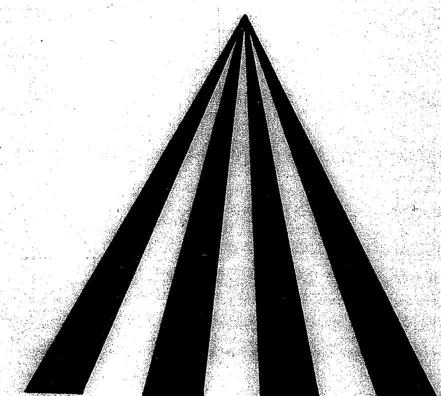

Fig. 9. Simple geometric figure for transmission test

E_f—2.5 v.
Ip—72. ma.
μ—.55
Rp—710
Gm—775

We have also utilized "grid-positive" tubes in this connection with the operating elements so chosen as to give a low output impedance. These tubes are purposely allowed to draw grid current and are current operated rather than voltage operated as in the ordinary case.

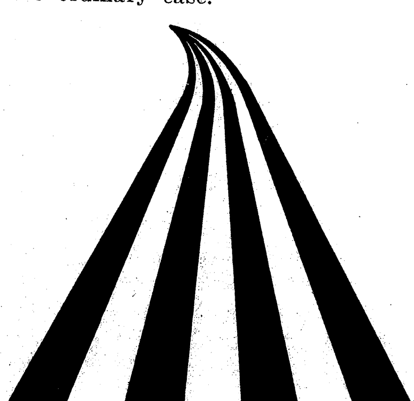

Fig. 10. Evidence of distortion.

In outside operations over a distance of several miles from a studio where permanent setup is possible, we have run into a great deal of trouble which we were able to correct by utilizing specially strung separated lines of large cross section with appropriate delay correction networks.

Impedances Matched

We have been able to reduce reflection with attendant losses and distortion of the picture by carefully matching the line impedances and correction of the delay characteristics. Fig. 11 shows the type of network inserted in the lines to correct for phase distortion. The entire program as transmitted, together with the outgoing speech for synchronizing over a second station, is controlled by a program director, an announcer, one operator who sets up the film pickup machines and operates the main amplifier, and another who controls the carrier. Fig. 12 shows the layout schematically. Periodic runs over these lines serve to keep their frequency characteristics up to normal requirements.

The transmitter proper is similar to any broadcast transmitter of similar capacity except for the fact that the interstage circuits are coupled so as to obtain substantially even modulation up to 30 kc. input. Special modulator circuits are employed with chokes so wound as to affect but slightly modulation at the higher frequencies, and are so designed as to be capable of complete modulation of the carrier when desired. I have shown the circuit employed in coupling the last two stages and the 600-ohm transmission line feeding the antenna in Fig. 13.

There are two basic classes of amplifiers; those which draw grid current and those which must never be permitted to do so. In circuits as we know them today we maintain the grids of a-f. amplifiers always slightly negative to avoid harmonic distortion which is fatal to quality. Our precautions are, however, equally fatal to economy. In our r-f. transmission circuits, though, we employ amplifiers which are fed at an extremely high voltage level. We bias the grids of these tubes to cut off (of plate current) and beyond, and even then drive the grids positive during a fraction of each cycle. While this method is productive of harmonics of the fundamental, it is also highly efficient. In our audio amplifiers we would be unable to filter out and destroy this harmonic distortion, but in r-f. circuits the harmonic frequencies are widely removed from the fundamental and quite amenable to discipline. If the interstage transfer takes place across a capacitance the reactance may be made so low at harmonic frequencies as to effect a virtual short circuit.

Grid Circuit Damped

The fact that these amplifiers draw grid current gives rise to a further distorting effect in that the grid-filament impedance is substantially lowered during a portion of each cycle and precautions must be taken to prevent this change being reacted back into the plate circuit of the preceding stage. To this end, the grid circuits are damped by resistances of such value that the grid-filament impedances will always remain high in comparison.

In a circuit employing 100 per cent. modulation we rate the carrier power at one-fourth the peak power under modulation. The r-f. stages must be so designed as to handle these increases.

The main advances needed for better transmission are along the following lines:

a. Photoelectric cells having a high output with little frequency discrimination, no background noise, and a uniform sensitivity over the color spectrum.

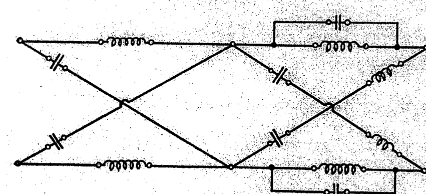

Fig. 11. Type of network to correct phase distortion.

b. A light source, even in distribution and steady in intensity and with emission over the entire spectrum.

c. A scanning method of extreme accuracy and mechanical simplicity.

d. Increased economy of the transmission band through better understanding of transmission circuits.

So far we are able to transmit moving pictures of a standard character and good detail with surprising realism. Certainly some of the subjects, where the conditions of lighting are favorable, are easily comparable with the motion picture of two decades ago. We transmit regularly motion-picture films of prominent personages, vaudeville teams, singers, etc., together with synchronized speech which is fed to a second transmitter over a 20 mile leased line. We transmit

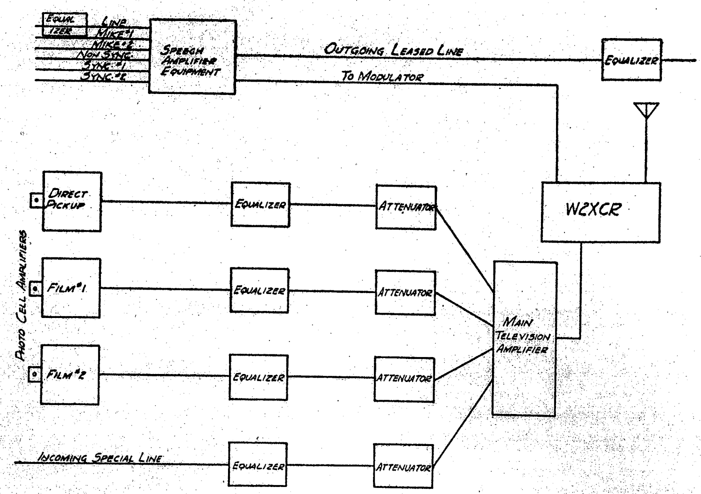

Fig. 12. Hook-up for program transmission.

short, one reel stories in silhouette, showing prize fights and similar action. This paper has not dealt with the problems of reception, but may I say here that these silhouettes are utilized, not because of the incapabilities of the transmission equipment, but because of the fact that few short-wave receivers now in use meet the standards of performance necessary for delineation of half-tone subjects. That is, a fidelity characteristic flat to within a few per cent. from 15

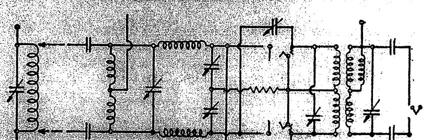

Fig. 13. Coupling to antenna system.

cycles up to 30 kilocycles, with little harmonic distortion at high percentages of modulation. We also transmit, though not yet on our regular schedule, direct pickup subjects, and are planning to add this feature to our daily program within the next few weeks—with sound.

Number of Picture Elements

There has been much said in the press with regard to the number of picture elements necessary to create an image of marked perfection. Some of this publicity has been quite misleading. We know from experience that a picture of 576 elements is of

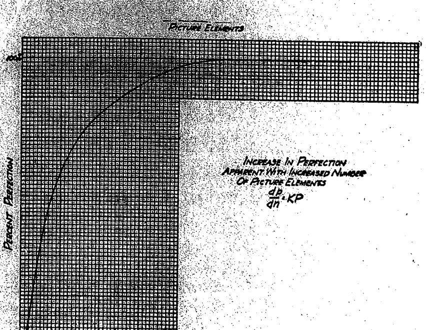

Fig. 14. Picture elements.

interesting detail, that a 900 element image presents a vast improvement over that, and that a picture of 2300 elements (such as we employ), still offers a marked improvement, but the transition from 2300 to 3600 does not give the approach toward perfection that would be supposed. We might, therefore, formulate a law for the variation of apparent perfection obtained by increased number of picture elements where $\frac{dP}{dN}$ = the slope of the curve in Fig. 14 is equal to KP where K must remain a constant as yet undetermined and P and N are respectively the degree of perfection and the number of elements.

$$\frac{dp}{dN} = KP$$

We assume, as you see, that the curve takes on a logarithmic aspect and that the improvement observed, with a vast change in the number of picture elements, becomes slight as we approach the complete perfection only obtainable with an infinite number of elements.

The human senses are readily imposed upon and the power of sight is most fallible. With a knowledge of what has already been done, even with the crude methods now employed it is easy to imagine that an image, but slightly removed from true perfection, can be transmitted without exceeding our present band of 100 kc., provided that that band be subjected to all the rigorous economies of present day communication engineering.

The television image must not be compared with a newspaper half-tone of equivalent definition, as the apparent excellence is enhanced by the added effect of motion and by the addition of sound.

We are prepared to televise with sound, such items as, prize fights, athletic events covering small area, addresses of important personages, etc.

We have recently conducted reliability tests in connection with a public demonstration of synchronized sight and sound in Newark, N. J., and also at the recent Jersey City Radio Show. Those of you who were fortunate enough to witness these demonstrations will no doubt concur with me regarding their success.

▲

Further discussion on the paper published in the April issue: "A Study of Sound Recordings," by C. F. Goudy and W. P. Powers.

P. H. EVANS:

Mr. Powers' paper is exceedingly interesting and very well done. As he points out the amplitude for a given output level is inversely proportional to the frequency and that, therefore, the greatest tendency for cutovers is at the low-frequency end. He also points out that by reducing the amplitude of the low-frequency sounds it is possible to raise the general recording level and thereby improve the ratio between the sound and the surface noise. It is interesting to note that when the frequency characteristic is so modified in order to help the recording, the reproduction actually sounds better in the theatre than when the low-frequency and high-frequency sounds are recorded in their true proportion. At first, this was somewhat baffling. The explanation can be found in the study of theatre acoustics. Measurements show that the period of reverberation is much higher for the first two or three octaves than it is for the last two or three octaves and that, therefore, a smaller amount of energy is required to produce a given volume of sound at the low-frequency end of the sound spectrum than is required at the high-frequency end.

For best results in the theatre it is important, therefore, that an exhibitor when providing acoustic treatment should give special attention to the absorption characteristic of the sound treatment for the first and second octaves, centering at 128 and 256 cycles as this is the frequency range of the average male voice. Many of the absorbing materials on the market at the present time have little or no absorption power in this range. The choice of material is, therefore, of extreme importance and no exhibitor should attempt to specify the acoustic treatment to be used without first consulting an expert in this line who is not associated with the manufacturer of any particular brand of acoustic treatment. The experts associated with the manufacturers of materials which have little or no absorbing power in this range always attempt to convince the prospective customer that this range of frequencies is of no importance. We are convinced, however, that proper attention to this frequency band is essential if the tubby characteristic which is so frequently observed in theatres is to be eliminated.

CLUB NOTES

New Members

(Elected at the March 18th Board meeting.)

Roger Williams
Charles E. Dean
James E. Smith
Walter L. Roe
Col. Nugent H. Slaughter *
C. Winston Haller
Arturo G. Cayetano
Kenneth W. Roy
Joseph Sara

* Elected a Fellow.

Membership News

Willis K. Wing.

Has resigned the editorship of *Radio Broadcast* and is now on the editorial staff of the *New Yorker*.

Julius Weinberger.

Is now connected with the RCA Photophone, Inc. at 153 E. 24 Street, New York City, having left Radio Corporation of America.

Michael I. Pupin.

Was recently elected President of the University Club.

▲

The April issue of the "*Proceedings*" carried the information that A. V. Loughren was connected with the Radio Frequency Laboratories, of Boonton, New Jersey. This was an unfortunate error. Mr. Loughren is still connected with RCA-Victor, at Camden, New Jersey.