DESCRIPTION OF EXPERIMENTAL TELEVISION TRANSMITTING APPARATUS

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Summary*—A description is given of an experimental television transmitter. This equipment was installed in the Empire State Building and was used in making practical tests on an experimental television system. The installation included facilities for radiating sound and picture signals from studio and from motion picture film. The general considerations underlying the design and performance of television terminal and transmitting apparatus for this experimental system are reviewed.

Theoretical Considerations

The utilization of that part of the radio-frequency spectrum in the vicinity of 50 megacycles has removed from television the limitations of a narrow communication channel. The remaining question to be answered before an experimental system could be decided upon was how great a resolution of the picture would be practicable with the available terminal equipment. In the resolution of the picture, the limiting factor was found to be in the quantity of light available for scanning in the studio. In other words, as the picture resolution is increased with a corresponding decrease in the scanning spot size, the signal-to-noise ratio reaches a value beyond which the television signals are unusable. A ratio of ten to one has been found by experience to be about the limit of usefulness. From measurements on 48-, 60-, and 80-line television studio pick-up equipment, it was determined that with a light source of the highest intrinsic brilliancy available, the ratio of signal to noise would approach the limiting ratio of ten to one with 120-line mechanical scanning.

The terminal equipment developed for use at the transmitter consists of the usual photo-electric tubes with their associated amplifiers and scanning disk, using modified forms of the conventional type. At the receiver, a special cathode ray tube replaces the well-known scanning disk with its associated neon lamp. The scanning beam is made to move across the fluorescent screen of the receiving tube in synchronism with the scanning spot at the transmitter by means of special deflecting circuits.

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The scanning spot produced at the transmitter moves with constant velocity across the object being scanned. To produce an undistorted image of the object on the cathode ray tube, the scanning spot at the receiver must also move at constant velocity. After tracing a line across the screen, the beam must return before it can start the scanning of the next horizontal line. The scanning beam is often spoken of as being inertialess, which should allow its return across the screen in zero time. This is practically true, but the inertia of the deflecting circuits is such that approximately one tenth of the scanning time is required for the return of the scanning beam across the screen. To allow for this at the transmitter, the spacing of the apertures in the scanning disk is such that for ten per cent of the time there is no scanning spot on the object. Fig. 1 shows the useful picture

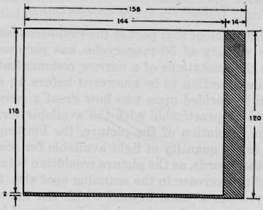


Fig. 1

area plus the shaded area which is that lost due to the time required for the return of the scanning beam. The dimensions shown are in picture elements, which in the vertical direction corresponds with the number of horizontal scanning lines.

The theoretical elements shown in the shaded area at the side of the useful picture area are to allow sufficient time for the horizontal return. The two lines at the bottom of the picture, likewise, allow sufficient time for the vertical return. The total theoretical number of elements which must be transmitted for the production of a picture of 144×118 or 16,992 elements, is found to be 120×158 or 18,960, which is a loss of 1968 elements due to the time required for the horizontal and vertical return of the scanning beam. The highest theoretical frequency required of the system may be simply arrived at by assuming that the maximum frequency is produced when alternate elements are black. This produces 18,960÷2=9480 cycles per picture. At 24 pictures per second, the top frequency is then 9480 × 24=227,-520 cycles.

The lowest frequency that may be produced in the scanning of a stationary object is produced when the scanning field is half black and half white about a horizontal axis. For a scanning speed of 24 pictures per second, this lowest frequency is 24 cycles per second. These frequencies, 24 and 227,520 cycles, define the frequency band required for the production of a 120-line picture.

The synchronizing signals, to be sufficiently accurate for a picture having as many as 17,000 elements, must be supplied to the receiver directly from the transmitter. The use of even a common power supply for synchronizing the transmitter and

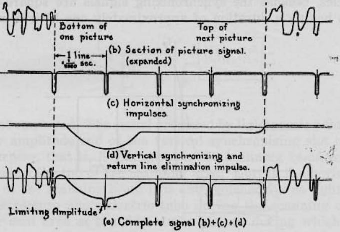


Fig. 2

receiver introduces difficulties when such a great number of picture elements are used. The horizontal synchronizing signals must have a frequency at least equal to the line frequency of the picture if the synchronizing is to be sufficiently accurate in a horizontal direction. A second frequency is required to frame the picture properly in the vertical direction. This also must be supplied from the transmitter.

Because of the time required for the scanning beam to return across the screen at the receiver, a loss of 1968 picture elements per picture is unavoidable. The use of this lost time for transmitting the synchronizing signals seemed, if possible, to be the most desirable solution of the problem. The system developed makes use of this time during which no picture is transmitted for the transmission of both horizontal and vertical synchronizing signals. The first advantage of this is that it is possible to mix the synchronizing and the picture signals at the transmitter, and utilize them for their distinctive purposes at the receiver without the use of filters. The second advantage is that no additional width of frequency band is required for the synchronization of the picture.

At 24 pictures per second, the vertical synchronizing signal is 24 impulses per second and the line frequency of a 120-line picture repeated 24 times per second is $120 \times 24 = 2880$ impulses per second. These then are the two impulse rates that must be transmitted to the receiver for the proper synchronizing and framing of the picture. The term "impulse" is used here instead of cycles, because the synchronizing signals are square-topped waves having a duration of approximately one fiftieth of their

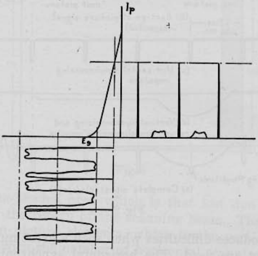


Fig. 3

repetition rate. Fig. 2 shows the general shape of the impulses and their relation to the picture signal. These impulses are generated at the end of each scanning line and last for 10 microseconds. They are produced by means of an auxiliary set of slits in the scanning disk at the transmitter through which light is directed into a photo-electric tube. At the end of each scanning of the picture, or every 24th of a second, a vertical synchronizing impulse, lasting for 350 microseconds, is produced by means of a longer slit passing between the same lamp and photo-electric tube as used for the production of the horizontal synchronizing impulses. These synchronizing impulses are mixed with the picture in such a phase that all synchronizing signals are in the same direction as picture signals produced by the scanning of black, that is, all synchronizing impulses extinguish the scanning beam at the receiver. The vertical synchronizing impulse causes the scanning beam at the receiver to start its return to the top of the picture for the next vertical scanning. The beam moves from bottom to top across the scanning area on its return path, and would produce a bright diagonal line across the picture if some means of extinguishing the scanning beam during its return path

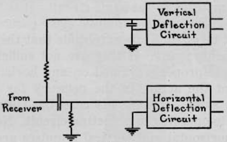


Fig. 4

were not employed. The signal produced by light passing through the low amplitude end of the vertical synchronizing slot serves this purpose, that is, it extinguishes the scanning beam until it has reached the top of the scanning area. During the horizontal return of the scanning beam it is extinguished, as no light falls into the picture photo-electric tube during the scanning of the ten per cent area at the side of the picture during which time the receiving beam is returning. The horizontal and vertical impulses are so adjusted as to have the same amplitude. Also, the picture signal level is maintained at such a value that it never exceeds the synchronizing impulses in amplitude. This allows the use of "amplitude selection" in the receivers to separate the synchronizing from the picture. Fig. 3 shows the condition of operation of the final synchronizing amplifier tube in the receiver, for selecting between the picture and synchronizing signals by amplitude selection. The grid bias is adjusted to such a value that the picture signal causes practically no change in plate current, and only the synchronizing impulses are amplified. The selection between the horizontal and vertical synchronizing impulses depends upon the difference in steepness of the wave front of the two impulses. We have termed this method of separating the impulses "wave front selection." Fig. 4 shows the arrangement of the synchronizing circuits for making the selection between the horizontal and vertical synchronizing signals. In selecting the vertical impulse, the voltage across the condenser which is in series with a resistor is used. The values of condenser and resistor are such that the impedance presented by the condenser to the steep wave front of the horizontal synchronizing impulses is low, while its impedance is high to the gradual slope of the vertical synchronizing impulse. As a result, in the output of the network, the vertical impulses as applied to the vertical deflecting unit have approximately ten times the amplitude of the horizontal synchronizing impulses in the same circuit. It is important that the horizontal synchronizing impulses after passing through the selecting circuit be of such low amplitude that they do not affect the vertical synchronizing. If they are not sufficiently low, the picture may be improperly framed on any horizontal impulses. The principle of the action in the network for the horizontal selection is the same. But in this case the voltage across the resistor is used to operate the deflecting circuit. No serious harm is done if the horizontal and vertical impulses are mixed in the input to the horizontal deflecting unit, because during the vertical synchronizing impulse there is no picture on the receiving screen.

Mechanical Design of Film Scanner

Fig. 5 is a photograph of the motion picture film scanner designed and constructed for our television experiments. This scanner consists of the conventional scanning disk having apertures equally spaced around its periphery and on equal radii. The apertures in the disk are illuminated by a standard motion picture projection arc. Fig. 6 shows the optical system employed. The image of the scanning aperture is focused on the film by means of a projection lens placed at twice its focal length from the disk, so that its dimensions will be the same as the aperture in the disk. Ordinarily, when a photo-electric tube is placed behind the film, the scanning spot which moves across the film also moves across the cathode of the photo-electric tube. The result is undesirable variations in the photo-electric current due to the nonuniform sensitivity of portions of the cathode. To overcome this difficulty, a second lens was placed behind the film in such a position as to image the projection lens on the photo-electric tube.

This causes the light passing through the film to fall in a small stationary spot on the cathode.

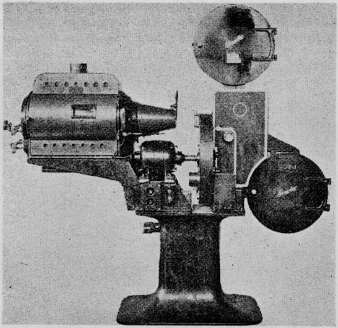


Fig. 5

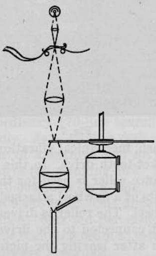


Fig. 6

Fig. 7 is a photograph showing the arrangement of the gates and sprockets in the motion picture scanner head. The path of the film is over a pull-down sprocket and through the picture gate. In order to insure an absolutely constant speed of film through the picture gate, it is necessary that some form of mechanical filter be provided to eliminate slight variations in speed intro-

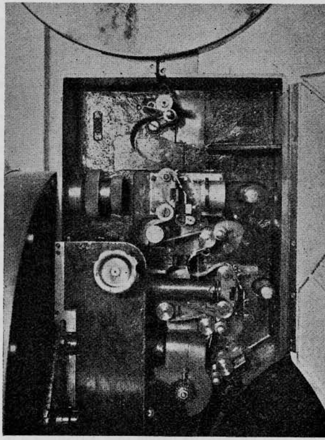


Fig. 7

duced by gear backlash, mechanical vibration, and the jerky feed inherent with sprocket-tooth drive. In this mechanism a device known as an impedance roller is used for this purpose. The impedance roller consists of a flywheel attached to a roller about the size of a sprocket wheel. The roller is driven by the film passing around it and is not connected to the drive mechanism in any other way. The film after leaving the picture gate passes over the roller to the constant speed sprocket. The inertia of the roller serves to prevent any variations in the linear speed of the film, and causes the film to be drawn through the gate at an absolutely constant speed. The vertical framing of the picture is accomplished by manually adjusting the position of the film in the picture gate with respect to the vertical synchronizing aperture so that the vertical synchronizing impulse comes just as the scanning of a picture frame is completed. To make this adjustment, the impedance roller next to the picture gate is moved by means of the framing knob so as to vary the length of the film between the pull-down sprocket and the picture gate.

Fig. 8

Tests with the ordinary 120-line scanning disk proved it to be large and unwieldly. As a result a disk was used having half the required number of apertures and driven at double speed. Fig. 8 is a photograph of the scanning disk. Each of the 60 square apertures measures 0.006 inch on a side. The chordal distance between apertures is 0.926 inch. This dimension is the width of the picture (0.875 inch) plus ten per cent. The additional ten per cent is to allow the scanning beam to return across the screen at the receiver as already described.

Fig. 9 is a photograph showing the arrangement of the incandescent lamp and photo-electric tube used for obtaining the synchronizing signals from a second set of apertures in the disk having the same angular spacing as the picture scanning apertures, but on a shorter radius. The horizontal synchronizing apertures are 0.100 inch in length and 0.010 inch in width, while the vertical synchronizing slot is 2.8 inches in length and 0.100 inch in width at its widest part. The shapes of these two types

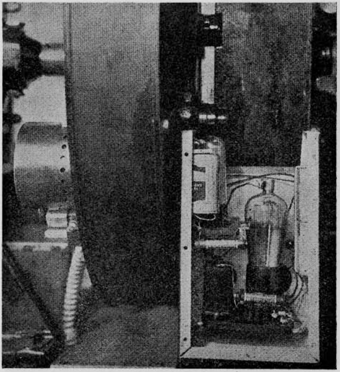
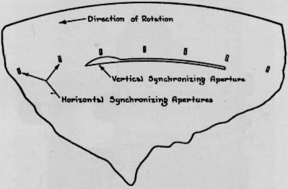


Fig. 9

of synchronizing apertures are shown in Fig. 10. An exciter lamp is used with a lens system arranged to place an image of the filament on the synchronizing apertures.

The position of the synchronizing lamp is such that the light passes through the horizontal synchronizing apertures and into the photo-electric tube just as the corresponding picture aperture moves from the edge of the picture into the ten per cent area in which no light falls on the picture photo-electric tube.

Fig. 11 shows the arrangement for securing the vertical synchronizing signal. A rotating shutter containing a slot is driven through a gear train so that at the completion of each picture the aperture for producing the vertical synchronizing impulse is uncovered. The gearing between the scanning disk and the film



Broken Section of disc.
Fig. 10

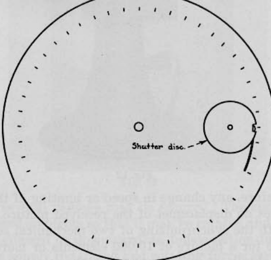


Fig. 11

drive sprockets is so arranged that two revolutions of the scanning disk (the passing of 120 apertures across the film) occur while the film moves one frame. With the disk running at 2880 revolutions per minute, the film runs at 24 frames per second, the standard sound film projection speed. A four-pole synchronous motor operating from a 96-cycle power supply gives the required disk speed (2880 r.p.m.) without the use of gears between the disk and driving motor.

Any fairly constant speed drive would be suitable because receiver synchronization depends directly upon the scanning disk

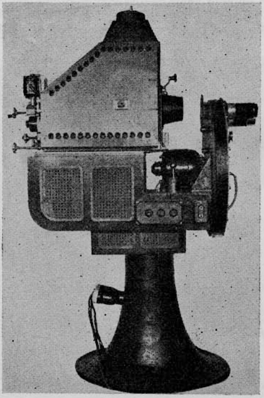


Fig. 12

speed; therefore, any change in speed or hunting of the scanning disk produces no displacemet of the received picture. This is in contrast with the synchronizing of two mechanical scanning devices, where for a picture of 10,000 elements or more it is very difficult to obtain a speed control at the receiver sufficiently accurate to prevent appreciable shifting of the received image, due to hunting.

MECHANICAL DESIGN OF THE STUDIO SCANNER

Fig. 12 is a photograph of the studio scanner. A high intensity arc with a condensing lens system is used to illuminate the rectangular picture aperture. Three lenses of different focal lengths are mounted on the disk housing in such a way that they may be changed back and forth with little effort or delay during a program, so that a quick change in the size of the scanning field in the studio for the transmission of either close-ups or of scenes

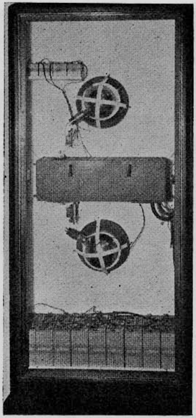


Fig. 13

containing several persons may be secured. The complete scanner is mounted on pivots so that it may be rotated and at the same time tilted upward or downward, to follow action in the studio. Two motors supply the tilting and rotating forces through reduction gears. These motors are both controlled by a special four-position toggle switch located near the monitor, so that the monitoring operator can easily keep the scanning field in the desired position in the studio. A duplicate toggle switch is placed in the studio, enabling the studio director also to control the position of the scanning field if desired.

Studio Pick-Up Equipment

When a picture of 17,000 elements is to be transmitted from a studio, the photo-electric pick-up equipment must be capable of: (a) As great a ratio of picture signal to noise as possible; (b) uniform response to light variation up to 225,000 per second;

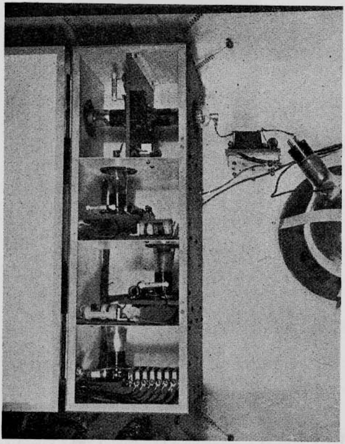


Fig. 14

and (c) arrangement permitting satisfactory close-ups and long-distance views.

For studio work spherical photo-electric tubes of caesium oxide, gas-filled type are used, two tubes forming a pick-up unit. Between each pair of photo-electric tubes is placed a shielded amplifier which may be seen in Fig. 13, a photograph showing the rear view of one of the units with the back removed. Fig. 14 shows the arrangement of the picture amplifier.

THE PRODUCTION OF THE TELEVISION SIGNALS

The photo-electric tubes used in the studio and in the film scanner are gas-filled and have appreciable time lag. Fig. 15 shows a typical frequency response curve of the tubes with different polarizing voltages. The response is seen to increase

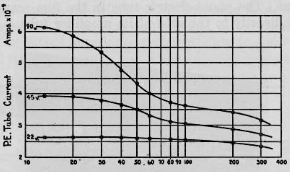


Fig. 15

quite rapidly with increased polarizing voltage at the lower frequencies, but above 60 kilocycles only a small increase in response is secured by increasing the polarizing voltage. The maximum polarizing voltage that is practicable with this type

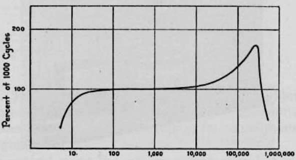


Fig. 16

of tube when working at frequencies above 200 kilocycles is 45 volts. When sufficient light is available to secure satisfactory signal-to-noise ratio, an operating voltage of 22 is preferable.

The capacity across the load resistance at the input to each amplifier stage is very important in determining the frequency characteristic of the system, and must be kept as low as possible if the output voltage to the amplifier is to remain practically constant up to 225 kilocycles. At this frequency 10 micromicrofarads have an impedance of only 70,000 ohms. The photo-electric tubes in the studio pick-up units are connected directly to the grids of special screen-grid tubes, with the shortest possible connections. The photo-electric tube in the film scanner is also connected directly to the grid of its amplifier tube.

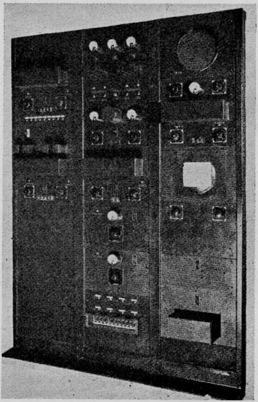


Fig. 17

The amplifiers make use of special coupling circuits to produce the desired frequency characteristic. The plate circuit of each voltage amplifier contains an inductance having a value such that the tube and stray capacity across the coil produce a parallel resonant circuit having a natural period well above the working range of the amplifier. This method of coupling between stages makes possible an amplifier having practically any desired characteristic over a wide band of frequencies. Actually the ampli-

fiers are designed to have a rising characteristic such that the response at 200 kilocycles is approximately twice that at 1000 cycles as shown in Fig. 16. This rising characteristic compensates electrically for the decrease in light change at both the transmitter and receiver when the width of the detail being scanned approaches the width of the scanning spot.

The amplifiers in the film scanner and in the studio pick-up units have an output impedance sufficiently low to allow the transmission of the signal over special low capacity cable to the con-

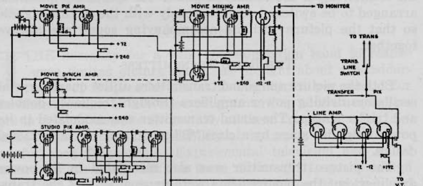


Fig. 18

trol room. The output from the synchronizing amplifiers on both the studio scanner and the film scanner are transmitted to the control room over low capacity cable in the same manner as the picture signal.

In the control room the synchronizing signal is mixed with the accompanying picture signal in an arrangement of two amplifier tubes having a common plate resistor. The synchronizing signal is applied to the grid of one and the picture signal to the grid of the other. The combined signal is then amplified to give approximately 2 volts (peak) across 1000 ohms, after which it is applied to the line amplifier. This amplifier consists of a group of low impedance tubes in parallel and has a voltage amplification of unity. Its output impedance is sufficiently low to allow the transmission of the television signals over special low capa-

city cable to the radio transmitter without objectionable attenuation of the high frequencies. Fig. 17 is a photograph showing the general arrangement of the amplifier racks. Fig. 18 is a schematic diagram showing the complete amplifier layout of the installation in the Empire State Building. The switching is so arranged that the signals from the film scanner or the studio may be passed through the line amplifier to the radio transmitter. The picture monitor may be connected to either the output of the picture amplifier or to a radio receiver, which makes possible the monitoring of the radiated signals. All speech equipment is arranged to be switched simultaneously with the picture signals so that the picture with its accompanying sound are always together.

The Radio Transmitters

Both the picture and sound transmitters utilize quartz crystal oscillators driving power amplifiers through frequency doubler and tripler stages. The sound transmitter was modulated in its power amplifier stage by a class "B" modulator of conventional design.

The picture transmitter was also modulated in its power amplifier, but the requirements were unusual in that the transmitter had to be capable of being modulated uniformly by frequencies from 24 cycles to 225,000 cycles. To accomplish this, the power stage was modulated by means of two UV-848 modulator tubes. The modulation reactors were of special design having very low distributed capacity. The voltage amplifiers preceding the UV-848 tubes have circuit constants such that practically constant response is obtained over the desired frequency range. The adjustment of the modulation at the transmitter is unusual in that amplitude distortion of the synchronizing signals is purposely permitted in order that these signals produce over one hundred per cent modulation. The polarity of modulation is such that the synchronizing impulses drive the plate current of the modulator practically to zero, causing the radio-frequency output to increase. So far as the radiated picture signals are concerned, this means the black portions of the picture correspond to an increase in amplitude of the radio-frequency carrier. The advantage of this method of operation is that the carrier may be driven to one hundred and twenty-five per cent modulation on the synchronizing impulses, thus permitting one hundred per cent modulation for the picture signals.