Proceedings of the I·R·E

Bruce.

AUGUST 1939
VOLUME 27 NUMBER 8

Institute of Radio Engineers

Fourteenth Annual Convention

New York, N. Y., September 20–23, 1939

Rochester Fall Meeting

November 13, 14, and 15, 1939

SECTION MEETINGS

CLEVELAND
September 28

DETROIT
September 15

LOS ANGELES
September 19

PHILADELPHIA
September 7

PITTSBURGH
September 19

WASHINGTON
September 11

SECTIONS

ATLANTA—Chairman, Ben Akerman; Secretary, J. G. Preston, 230 Ansley St., Decatur, Ga.

BOSTON—Chairman, H. W. Lamson; Secretary, E. B. Dallin, 64 Oakland Ave., Arlington, Mass.

BUFFALO-NIAGARA—Chairman, H. C. Tittle; Secretary, E. C. Waud, 235 Huntington Ave., Buffalo, N. Y.

CHICAGO—Chairman, V. J. Andrew; Secretary, G. I. Martin, RCA Institutes, 1154 Merchandise Mart, Chicago, Ill.

CINCINNATI—Chairman, H. J. Tyzzer; Secretary, J. M. McDonald, Crosley Radio Corp., 1329 Arlington, Cincinnati, Ohio.

CLEVELAND—Chairman, S. E. Leonard; Secretary, H. C. Williams, Rm. 1932, 750 Huron Rd., Cleveland, Ohio.

CONNECTICUT VALLEY—Chairman, E. R. Sanders; Secretary, W. R. G. Baker, General Electric Co., Bridgeport, Conn.

DETROIT—Chairman, H. D. Seielstad; Secretary, R. J. Schaefer, 9753 N. Martindale, Detroit, Mich.

EMPORIUM—Chairman, R. K. McClintock; Secretary, D. R. Kiser, Hygrade Sylvania Corp., Emporium, Penna.

INDIANAPOLIS—Chairman, I. M. Slater; Secretary, B. V. K. French, P. R. Mallory & Co., E. Washington St., Indianapolis, Ind.

LOS ANGELES—Chairman, F. G. Albin; Secretary, M. T. Smith, General Radio Co., 1000 N. Seward St., Hollywood, Calif.

MONTREAL—Chairman, A. B. Oxley; Secretary, W. A. Nichols, Canadian Broadcasting Corp., 1012 Keefer Bldg., Montreal, Que.

NEW ORLEANS—Chairman, G. H. Peirce; Secretary, D. W. Bowman, 8327 Sycamore St., New Orleans, La.

PHILADELPHIA—Chairman, R. S. Hayes; Secretary, R. L. Snyder, 103 Franklin Rd., Glassboro, N. J.

PITTSBURGH—Chairman, W. P. Place; Secretary, R. E. Stark, 90 Pilgrim Rd., Rosslyn Farms, Carnegie, Penna.

PORTLAND—Chairman, H. C. Singleton; Secretary, E. R. Meissner, United Radio Supply, Inc., 203 S. W. Ninth Ave., Portland, Ore.

ROCHESTER—Chairman, W. F. Cotter; Secretary, H. C. Sheve, Stromberg-Carlson Telephone Manufacturing Co., Rochester, N. Y.

SAN FRANCISCO—Chairman, F. E. Terman; Secretary, L. J. Black, 243-30th St., Oakland, Calif.

SEATTLE—Chairman, R. O. Bach; Secretary, Karl Ellerbeck, Pacific Telephone and Telegraph Co., 612 Northern Life Tower, Seattle, Wash.

TORONTO—Chairman, R. C. Poulter; Secretary, N. Potter, Canadian National Carbon Co., Ltd., 805 Davenport Rd., Toronto, Ont.

WASHINGTON—Chairman, Gerald C. Gross; Secretary, M. H. Biser, 3224-16th St., N. W., Washington, D. C.

Proceedings
of the I·R·E

Published Monthly by
The Institute of Radio Engineers, Inc.

VOLUME 27 *August, 1939* NUMBER 8

Entered as second-class matter October 26, 1927, at the post office at Menasha, Wisconsin, under the Act of February 28, 1925, embodied in Paragraph 4, Section 412 of the Postal Laws and Regulations. Publication office, 450 Ahnalp Street, Menasha, Wisconsin. Subscription, $10.00 per year; foreign, $11.00.

THE INSTITUTE

The Institute of Radio Engineers serves those interested in radio and allied electrical-communication fields through the presentation and publication of technical material. In 1913 the first issue of the Proceedings appeared; it has been published uninterruptedly since then. Over 1500 technical papers have been included in its pages and portray a currently written history of developments in both theory and practice.

STANDARDS

In addition to the publication of submitted papers, many thousands of man-hours have been devoted to the preparation of standards useful to engineers. These comprise the general fields of terminology, graphical and literal symbols, and methods of testing and rating apparatus. Members receive a copy of each report. A list of the current issues of these reports follows:

Standards on Electroacoustics, 1938
Standards on Electronics, 1938
Standards on Radio Receivers, 1938
Standards on Radio Transmitters and Antennas, 1938.

MEETINGS

Meetings at which technical papers are presented are held in the twenty-one cities in the United States and Canada listed on the inside front cover of this issue. A number of special meetings are held annually and include one in Washington, D. C., in co-operation with the American Section of the International Scientific Radio Union (U.R.S.I.) in April, which is devoted to the general problems of wave propagation and measurement technique, the Rochester Fall Meeting in co-operation with the Radio Manufacturers Association in November, which is devoted chiefly to the problems of broadcast-receiver design, and the Annual Convention, the location and date of which are not fixed.

MEMBERSHIP

Membership has grown from a few dozen in 1912 to more than five thousand. Practically every country in the world in which radio engineers may be found is represented in our membership roster. Approximately a quarter of the membership is located outside of the United States. There are several grades of membership, depending on the qualifications of the applicant. Dues range between $3.00 per year for Students and $10.00 per year for Members. Proceedings are sent to each member without further payment.

PROCEEDINGS

The contents of each paper published in the Proceedings are the responsibility of the author and are not binding on the Institute or its members. Material appearing in the Proceedings may be reprinted or abstracted in other publications on the express condition that specific reference shall be made to its original appearance in the Proceedings. Illustrations of any variety may not be reproduced, however, without specific permission from the Institute.

Papers submitted to the Institute for publication shall be regarded as no longer confidential. They will be examined by the Papers Committee and Board of Editors to determine their suitability for publication. Suggestions on the mechanical form in which manuscripts should be prepared may be obtained from the Secretary.

SUBSCRIPTIONS

Annual subscription rates for the United States of America, its possessions, and Canada, $10.00; to college and public libraries when ordering direct, $5.00. Other countries, $1.00 additional.

The Institute of Radio Engineers, Inc.
Harold P. Westman, Secretary
330 West 42nd Street
New York, N.Y.

The Supersonic Light Control and Its Application to Television With Special Reference to the Scophony Television Receiver*

D. M. ROBINSON†, ASSOCIATE MEMBER I.R.E.

Summary—*After the alternative systems of reception are outlined an account of the supersonic light control is given. Its advantages are explained and the optical principles employed for a full exploitation of these advantages are described.*

THIS paper is the first of a series of four giving an account of the Scophony system of television reception. There appears to be a popular misconception that the Scophony receivers represent the application of the mechanical methods used for the low-definition television of a few years ago to modern picture standards. It cannot be emphasized too clearly that the Scophony system is based on the principle of the temporary storage of picture signals, made possible by the supersonic cell, and its conception has nothing in common with the mechanical television of the past.

The best light efficiency at the present time can be obtained with moving scanners, but the use of these is in no way essential to the system, as has been successfully demonstrated by Okolicsanyi[1] of these laboratories.

The method has been developed to the stage where pictures of the highest quality up to fifteen feet wide are available for use in cinemas, while 18- and 24-inch pictures are produced for the domestic market.

It is significant that in a world of television research on electronic lines, Scophony stands alone in using entirely optical methods, and by employing these means it has actually set the pace for large-screen television in England.

In the earlier methods of television proposed in the eighties of the last century, a pencil of light was focused into an area on the screen equal to that of the picture element and was swept over the whole picture field by means of scanners of the Nipkow disk or single-mirror-drum type.

These methods did not involve the conception of storage of picture signals, and since the amount of light concentrated in this single pencil had to be distributed over the total area of the picture reproduced by the receiver, the efficiency obviously decreased in proportion to the increase in definition.

Some forty years later, however, it was found possible, with the aid of improvements borrowed from rapidly advancing electrical and radio arts (such as the high-vacuum valve and the large-area neon lamp) to demonstrate low-definition television, even by using these early crude methods. This line of development had to be abandoned because of the far more exacting requirements of high-definition television.

Meanwhile another development was going on, starting with the invention of the cathode-ray tube at the beginning of this century and with the recognition of the possibility of electronic scanning for television receivers and transmitters.

It was found, at least at the transmitting end, that electrical storage is possible, without auxiliary apparatus as in picture telegraphy or in the intermediate-film recording method, with a suitable design of light-sensitive layer.

The employment of the principle of electrical storage has made possible the remarkable technical achievements on the transmission side known today.

The supersonic light control, by giving us for the first time a practical means of storing picture signals has made possible similar achievements at the reception end.

Before the introduction of the cathode-ray tube for television reception the methods of light modulation used could be divided into two classes.

(a) Those in which the light source itself was modulated by the vision signal, e.g., neon, mercury, or sodium-discharge lamp.

(b) Those in which the light source was of constant intensity but the quantity of light passing to the scanning spot on the screen of the receiver was modulated by some control device, e.g., Kerr cell.

For high-definition television both types of light modulation were impracticable since in either case the quantity of light which could be obtained in the reduced size of spot was entirely inadequate for building up a useful picture. Furthermore the recombination time of the ions in the gas-discharge tube, and the interelectrode capacitance in the case of the Kerr cell resulted in poor high-frequency response or alternatively in the use of unreasonable driving power. The cathode-ray tube had none of these defects, and by its rapid development high-definition television has been made possible. In particular the cathode-ray tube has the advantage of providing both the scanning and the control of the light in one piece of apparatus.

For the smaller pictures for which the fluorescent

---

* Decimal classification: R583×R361. Original manuscript received by the Institute, April 7, 1939.

† Scophony Laboratories, London, England.

[1] "The wave slot," *Wireless Eng.*, vol. 14, pp. 527–536; October, (1937).

screen of the cathode-ray tube can be viewed directly it is doubtful whether any alternative, comparable in cost and simplicity, can be offered. For larger pictures however the image formed on the fluorescent screen must be projected by means of a lens. An *f*.1. lens suitable for the projection is very expensive, and even then collects only about one twelfth of the light from the screen, since the light is emitted fairly equally in all directions, i.e., over a solid angle of 4π stereradians, while an *f*.1. lens can only take the light in unit solid angle (1 stereradian).

The brightness of the fluorescing material cannot be increased beyond the point at which it begins to disintegrate. Different materials vary considerably and the most stable are not necessarily those giving the most acceptable picture color. Moreover the operating voltages have to be very considerably increased and the fact that the scanning and the control of the beam intensity are closely linked may then lead to extra complication rather than simplicity.

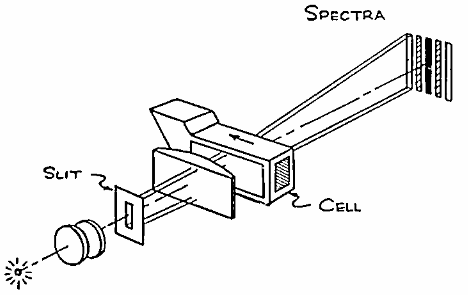


Fig. 1—Diffraction of light by supersonic waves in liquid showing the first-order (shaded) and second-order (unshaded) diffraction spectra, and the normal position of the image of the slit (black).

The demonstration by Debye and Sears[2] of the diffraction of light by supersonic waves in a liquid (see Fig. 1) opened up new possibilities and in 1934 Jeffree[3,4] first showed how this effect could be used as the basis of a light control of negligible inertia and power consumption and with reasonable light efficiency up to the highest picture definition. With this supersonic light control it is possible to modulate a beam of light from an independent light source and the latter, therefore, can be chosen solely on its merit as a bright, efficient, and suitably colored source. Moreover the beam so controlled can be projected directly on to a screen to give large pictures without the necessity for an expensive lens of high aperture. The cell is extremely simple in construction, has unlimited life, is robust and stable, and can be driven from a normal receiver-type output tube, the driving power being independent of the size of the picture.

The supersonic light control consists of a glass-sided cell filled with a transparent liquid with a piezoelectric crystal having a natural frequency between 5 and 30 microseconds immersed in the liquid or inserted in one wall of the cell (Fig. 2). The crystal is provided with electrodes on opposite faces and these electrodes are fed by a high-frequency carrier the frequency of which is approximately that of the crystal, and the amplitude of which may be modulated by the video-frequency signal received from the transmitter.

The electrical excitation at the natural frequency of the crystal causes the latter to vibrate mechanically; it dilates and contracts in the direction of its thickness. These vibrations are transferred to the liquid as a series of compressions and rarefactions which move forward from the crystal at the speed of sound in the liquid, forming a train of supersonic waves. Thus the density of the liquid varies periodically in the direction of travel of the wave train and the index of refraction varies with it. Light passing through the layer of waves perpendicular to the direction of motion of the waves is retarded by the compressive and accelerated by the rarefied half waves and since the supersonic wavelength is small (of the order of 0.1 millimeter) interference of the emergent light takes place and diffraction spectra are produced.

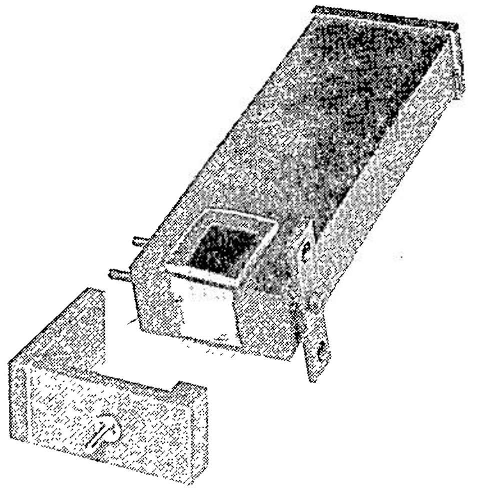


Fig. 2—Supersonic light control with protective base withdrawn to show quartz crystal. The whole of one lens and the edge of the other can be seen.

The intensity of the light deflected from the normal beam into the diffraction spectra is proportional to the amplitude of the high-frequency carrier applied to the crystal. It is a simple matter to arrange that the normal beam shall be stopped out, and the light from the side images utilized on the screen to give an intensity proportional to the received vision signal (Fig. 3).

The capacitance between the electrodes of the quartz crystal is extremely small and forms in any case part of the tuned output circuit. With one or

---

[2] Debye and Sears, "Scattering of light by supersonic waves," *Proc. Nat. Acad. Sci.*, vol. 18, p. 410, (1932).

[3] J. H. Jeffree, French patent No. 786,641, (1935).

[4] J. H. Jeffree, "The Scophony light control," *Television* (London), vol. 9, pp. 260–264; May, (1936).

both of its faces in contact with a liquid the vibration of such a crystal is highly damped and instead of the familiar sharp resonance curve obtained in air or in vacuo we have a broad, low-Q type of frequency response. By choosing a sufficiently high crystal frequency and using a double-peaked output band-pass circuit with additional electrical damping a reasonably flat pass band 5 megacycles wide can be obtained.

The attenuation suffered by the supersonic waves in traveling through the liquid is not very severe and with a suitable liquid the strength of the supersonic waves on reaching the far end of a 5-centimeter long cell is not appreciably different from their original value when just leaving the crystal surface. For a speed of sound in the liquid of 1000 meters per second this journey from the crystal to the absorbent material at the far end of the cell will take 50 microseconds. Thus while the amplitude of the waves immediately adjacent to the crystal has an instantaneous value proportional to the signal received at the antenna of the vision receiver the amplitude at the far end of a cell 5 centimeters long is proportional to the signal which was received on the antenna 50 microseconds earlier.

Thus, if instead of attempting to produce a spot of light of element size on the screen, we form with a lens an image of the light cell on the screen as in Fig. 3 we shall have at the crystal end an amount of light proportional to the instantaneous value of the signal received, and stretched out across the image of the cell we have at any and every instant a complete record, in light, of the signals sent out by the transmitter during the preceding 50 microseconds.

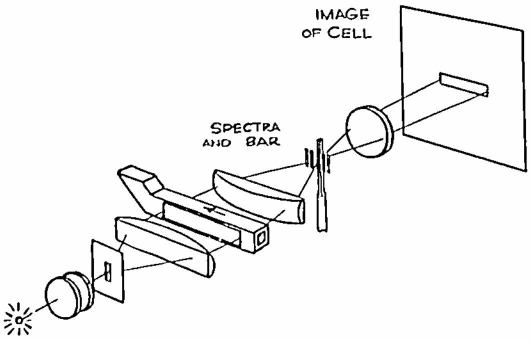


Fig. 3—The supersonic cell as a light control for television. The lens between the slit and cell insures that the light in the latter shall be parallel, while the similar lens on the far side of the cell brings this parallel beam to focus at the bar. The central image is stopped out by the bar and the diffracted light passes on to a further lens, which is arranged so as to form an image of the liquid column on the screen.

The details in light and shade move along the length of this image at a speed corresponding to the velocity of sound in the liquid and are therefore invisible to the eye. If however by means of a mirror polygon the whole image is made to move across the screen at the same speed in the opposite direction (Fig. 4), these details will be "immobilized" on the screen, and will become apparent to the eye. Each picture detail will then be illuminated from the moment the supersonic waves corresponding to it leave the crystal surface, until these same waves pass out of the illuminated portion of the cell at the far end. In the example quoted each picture detail will be illuminated for 50 microseconds. For the 405-line London television standard this corresponds to the scanning time for half a picture line, and means that the length of the cell image or "spot" on the screen will be half the picture width. Put in another way, the picture is reproduced on the screen by a moving line of light which illuminates some 250 picture elements simultaneously, the leading end of the line of light reproduces at every instant a new element of the picture corresponding to the signal just received, and the remainder of the line of light reproduces at the same instant the signals of the previous 50 microseconds, which are present as a record in the form of a supersonic wave train. The liquid of the cell may be compared with a film strip on which new sound track is continually recorded, used for reproduction, and continually wiped out again.

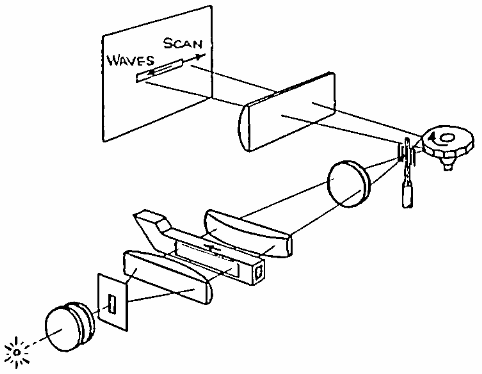


Fig. 4—Immobilization of the supersonic shadows on the screen. A high-speed scanner polygon is placed behind the stop bar and the whole is so arranged that the scan and wave motions cancel each other on the screen. The required width of picture line is obtained by a cylindrical lens which forms an image of the scanner surface on the screen in the direction perpendicular to the scanning direction.

The light efficiency of the supersonic light control does not decrease rapidly as the standard of definition of the picture is increased. This may be explained as being the result of getting more of the picture illuminated simultaneously. More precisely, it is simpler from the optical point of view to project on the screen the long image of a long aperture, than to project an image of element size from the tiny apertures of early light relays. In particular the scanners may be smaller with the supersonic light control.

In the upper diagram of Fig. 5, d represents the aperture of the older type of light relay, e.g., a Kerr cell. Light passes through this aperture to fill the scanner surface of length a at a distance D. The quantity of light is proportional to da/D. In the lower diagram d_1 represents the much greater aperture of the supersonic cell. If the distance D and the quantity of light handled are to remain the same the scanner surface may be reduced to a_1. That is, for the same light, the scanner size may be reduced in proportion to the number of picture elements simultaneously illuminated. Alternatively, for equal scanner size the light handled is increased in proportion to the number of picture elements simultaneously illuminated.

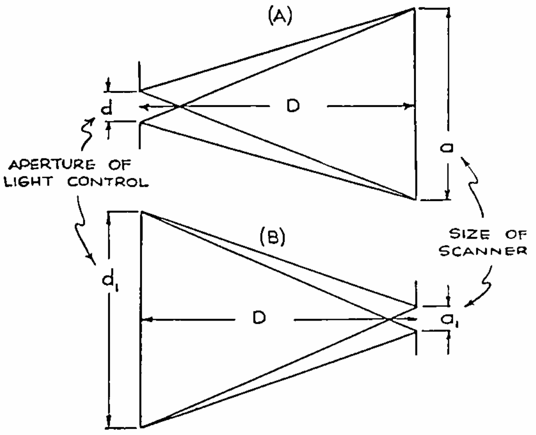


Fig. 5—The advantage of the supersonic light control from the optical standpoint.

The advantage of the supersonic cell from the point of view of the amount of light controlled can only be exploited by the use of cylindrical lenses. For instance, a cylindrical lens is used to produce the line on the screen. The optical magnification required in the direction of the light control length is governed by picture size and the speed of propagation in the liquid. If a spherical lens were used to form this image it would be enlarged the same amount in the other direction, and to obtain a line of the correct width on the screen we should have to stop down the light control to a width of about one-half millimeter. The light passing through it would then be insufficient for a television picture.

Therefore, instead of attempting to form an image of the light control on the screen in the direction of the line width, a greatly reduced image is formed, approximately on the surface of the high-speed-mirror polygon, by means of a powerful cylindrical lens as shown at L_1 in Fig. 6. The faces of the polygon measure 0.125×0.31 inch, the smaller dimension corresponding to the line width and being parallel to the axis of rotation.

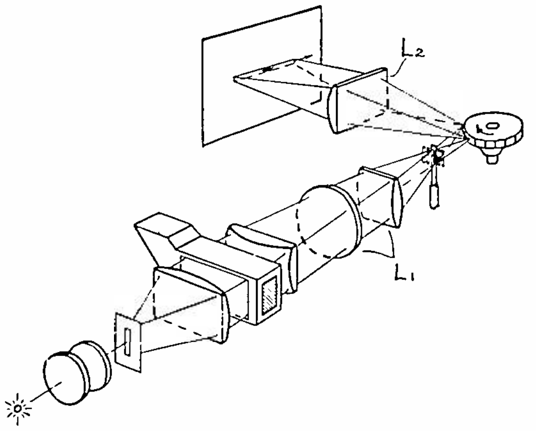


Fig. 6—The use of cylindrical lenses. This drawing does not represent an actual receiver, but has been drawn solely with the object of explaining the functions of the various parts.

A further cylindrical lens L_2 again with its power in the direction of the line width is then arranged to form an image of the illuminated scanner surface on the screen.

The lens L_1 is shown for the sake of explanation as two separate lenses, a powerful cylinder and a much weaker spherical lens. In practice these two lenses are combined into one, the front surface having the cylindrical power and the back surface the spherical power. The cylindrical power converges the light on to the high-speed scanner in the vertical direction, while in the horizontal direction the only power is the spherical power of L_1 which forms a suitably enlarged image of the light control on the screen.

This example of the use of a cylindrical lens as a means of increasing the amount of light that can be dealt with is one case of what has come to be known as the principle of "split focus"[5]; the image planes are different in the horizontal and vertical directions, and can be chosen independently of each other to give the best results.

---

[5] Due to G. W. Walton of the Scophony Laboratories.

The Design and Development of Television Receivers Using the Scophony Optical Scanning System*

J. SIEGER†, NONMEMBER, I.R.E.

Summary—*The practical form taken by the apparatus is indicated by photographs and line drawings. The factors governing the choice of the cell liquid, the crystal frequency, and the lens powers are explained, and a brief description of the electrical apparatus, with circuit diagrams, is given. For the projection of large pictures in cinemas an arc lamp is used but otherwise the optical and electrical components require little modification.*

IN THE development of the Scophony system for commercial use the light control was one of the first problems to be attacked, as the successful operation of this device is connected with so many factors.

It will be seen from Fig. 1 that an image of the plane of the light control is focused on to the screen. When the cell is unmodulated the image of the cell appears on the screen as a faint or "black" image. Any light scattering due to poor lenses, dirt in the liquid, or lenses of a poorly corrected type, will tend to destroy the black level.

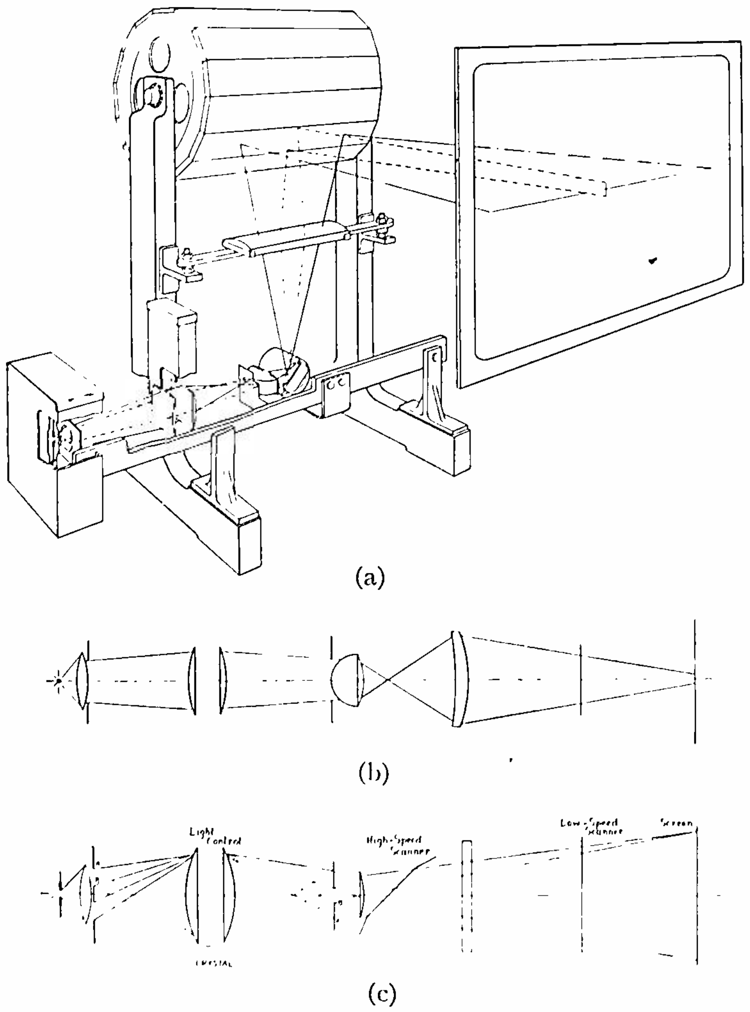


Fig. 1—Optical chassis of home receiver giving a picture 18 inches wide, by back projection.

The length of light cell used corresponds to the length of line simultaneously active on the screen. Any attempt to use a full line, one picture wide, would entail the use of corrected lenses in order to avoid the chromatic aberration, which, if uncorrected lenses were used would tend again to destroy the black level. If the full line were used with corrected lenses it is apparent that attenuation of the supersonic waves in the liquid plays a very important part. A liquid of low attenuation would be necessary. As will be seen from the attenuation characteristics of various liquids (Fig. 2), and as has been found by considerable experimental work, water has the best characteristics from this point of view.

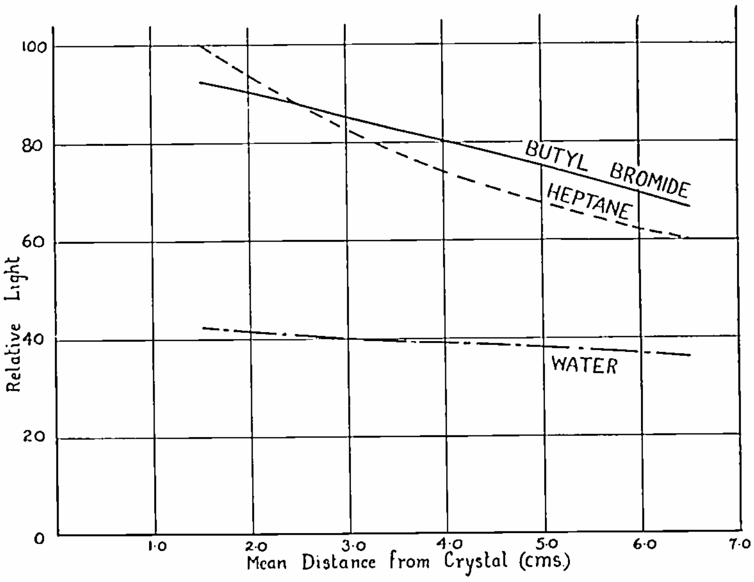


Fig. 2—Attenuation of supersonic waves in liquids. Curves taken with constant voltage applied to the crystal.

Unfortunately it has a considerable disadvantage in that it requires something of the order of three times the power drive on the crystal in order to obtain the equivalent light secured from liquids in the paraffin group. This undesirable characteristic makes it necessary to use valves of the small transmitting type to operate the light control with the resultant increase in cost and energy dissipation.

It will be seen from the same curve that with heptane or butyl bromide the attenuation is very steep but in the first 2 or 3 centimeters of light-control length the light output is quite high.

It was decided under these circumstances that a light control with a liquid column length of about $2\frac{1}{2}$ centimeters using uncorrected spectacle-type lenses would give ample light and good black, and is the type more generally used today in apparatus giving pictures up to about 10 feet wide.

---

* Decimal classification: R583×R361. Original manuscript received by the Institute, April 7, 1939.

† Scophony Laboratories, London, England.

The next step in the light-control design was one of choosing a working frequency for the quartz crystal.

(1) The crystal frequency should be one where the harmonics cannot beat with the carrier frequencies. In England the carrier frequencies of the British Broadcasting Corporation's vision and sound transmitters are 45 and 41.5 megacycles, respectively.

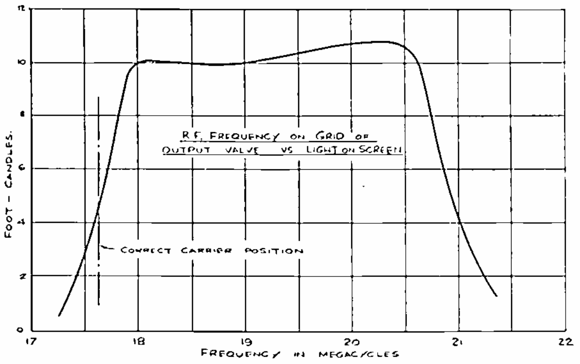


Fig. 3

(2) The attenuation of the supersonic sound waves in the liquid is greater the higher the natural frequency of the crystal.

(3) The higher the frequency used the greater the band width obtainable.

It was first decided to use a crystal of a frequency approaching 10 megacycles. In order to obtain band width a form of mechanical band-pass was tried. This consisted of a crystal of normal thickness (a half wavelength in quartz, for the particular frequency) with a layer of suitable varnish, one-quarter wavelength (in varnish) thick, on the side working into the liquid. The total effective thickness was thus three quarters of a wavelength, and if of one substance throughout, the unit could not resonate. Owing to the greater mass and stiffness of the quartz it still resonates at the quartz frequency, but the reflected out-of-phase wave from the varnish-liquid interface flattens the response curve and can even give a double hump.

The harmonics with sidebands obtained from the 10-megacycle modulated drive oscillator were, however, proved to beat with the incoming carrier frequencies, usually when the drive oscillator was adjusted to give the best picture.

Therefore, it was decided to increase the crystal frequency and as it was already decided to use a short liquid length, the increased attenuation would not matter.

By very simple calculation, a crystal frequency of 18 megacycles was chosen. It was found experimentally that this could be used in an undamped state, which gave higher light efficiency with a relatively flat response curve (see Figs. 3 and 4). The crystal is silvered and copper-plated so that in fixing to the light-control container a low-temperature solder is used and direct contact is made electrically.

Another factor here comes in and is an important one. The length of the optical-assembly base should be preferably short, so that in transport or in general use, no twisting could take place, when a relatively light construction of optical bar was made.

The length is determined by the distance between the light control and optical slit near the high-speed scanner. This distance depends on the speed of the supersonic sound waves in the liquid. In the immobilization of the moving waves in the liquid by the high-speed scanner, it is obvious that the faster the speed in the liquid the greater the distance and vice versa.

Water has a speed of about 1500 meters per second, heptane 1165 meters per second, and butyl bromide 1016 meters per second. The distance of the light control from the slot in centimeters when using a 20-face polygon is given by

$$\frac{\text{liquid speed in centimeters per second}}{4\pi \times \text{motor speed in revolutions per second}}.$$

It will be seen that using butyl bromide in the light control the total distance from slit to slit on the optical bar, including light control, is just over 34 centimeters, which is about 13 inches.

The driving of the quartz crystal by means of a modulated oscillator to the required band width for high-definition response, say five megacycles, was determined after considerable experimental work.

It seemed obvious to us that there was an excellent opportunity of feeding the light control directly from the carrier frequency with a suitable frequency changer. A number of experiments were carried out before we finally used a straight tuned-radio-frequency receiver, demodulating after a level of about two volts and feeding the modulated oscillator with ordinary vision amplifiers.

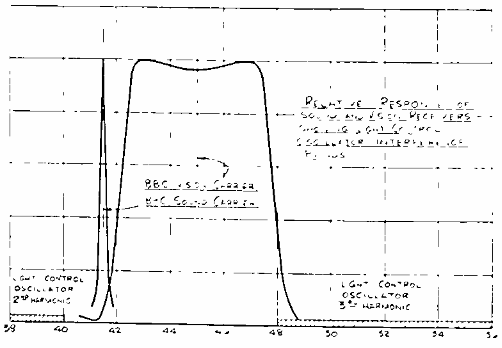


Fig. 4

The disadvantages of the frequency-changer system were manifold. First, carrier amplification from say 1 millivolt input in the antenna to an output of nearly 30 watts driving power to the crystal, apart from suffering from instability unless expensively shielded, was more expensive in valves as more were required. As it is necessary to obtain a synchronizing-signal output from the receiver, demodulation is essential. As this needed a demodulation valve, there was no reason why the signal should not be demodulated also. Second, video-frequency amplification is much higher than carrier-frequency amplification. Third, the frequency-changer system would require a separate oscillator. As there is already a powerful oscillator in the system for the crystal, it is advisable to keep unnecessary sources of interference out. However, experimental work is still going on in this direction.

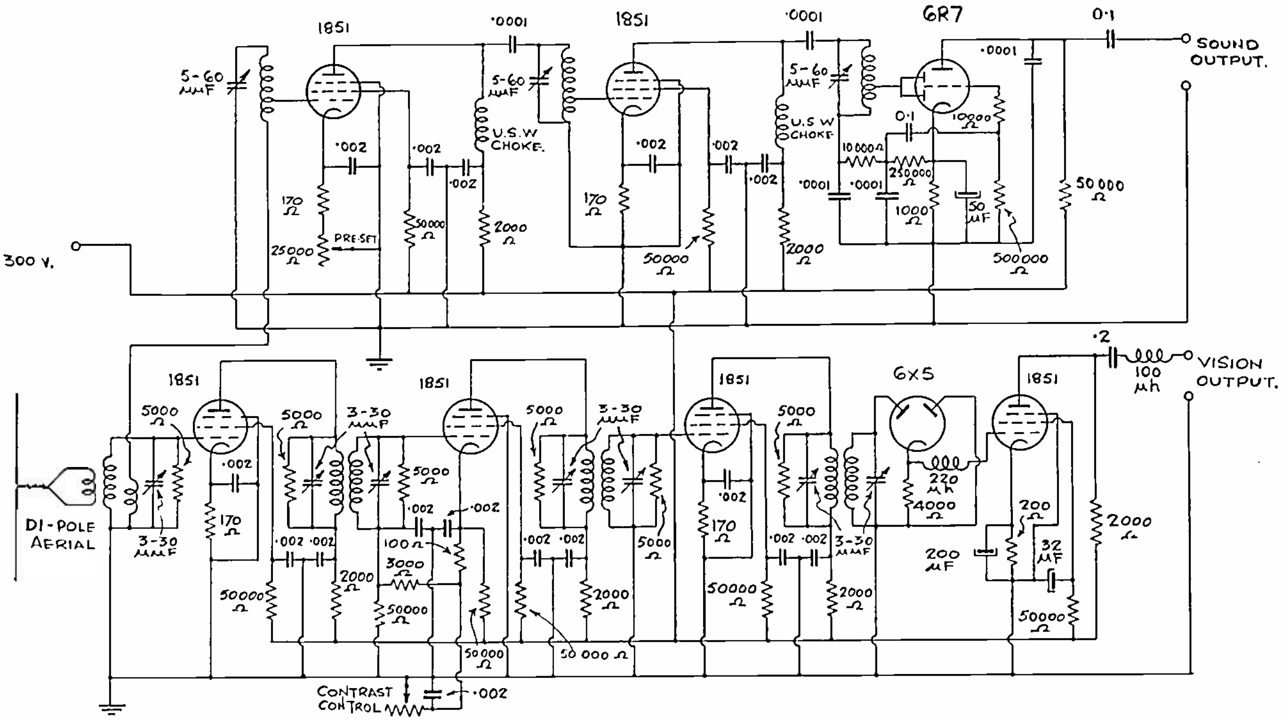


Fig. 5—Vision and sound radio receiver.

Mullard Company. This is a high-frequency pentode using secondary emission and has a lower input capacitance and a working slope of 14 milliamperes per volt compared to 9 milliamperes per volt for the 1851.

Single-sideband working has been adopted on the light control and the relative light to frequency is shown in Fig. 3. The oscillator frequency is tuned to below the fundamental crystal frequency of 18 megacycles and the output circuit is tuned to approximately 21 megacycles. The tuning operations are carried out on an optical bench before being incorporated in a receiver. Only slight readjustment is required afterwards.

From the constructional point of view, the assembly has been simplified by the above design.

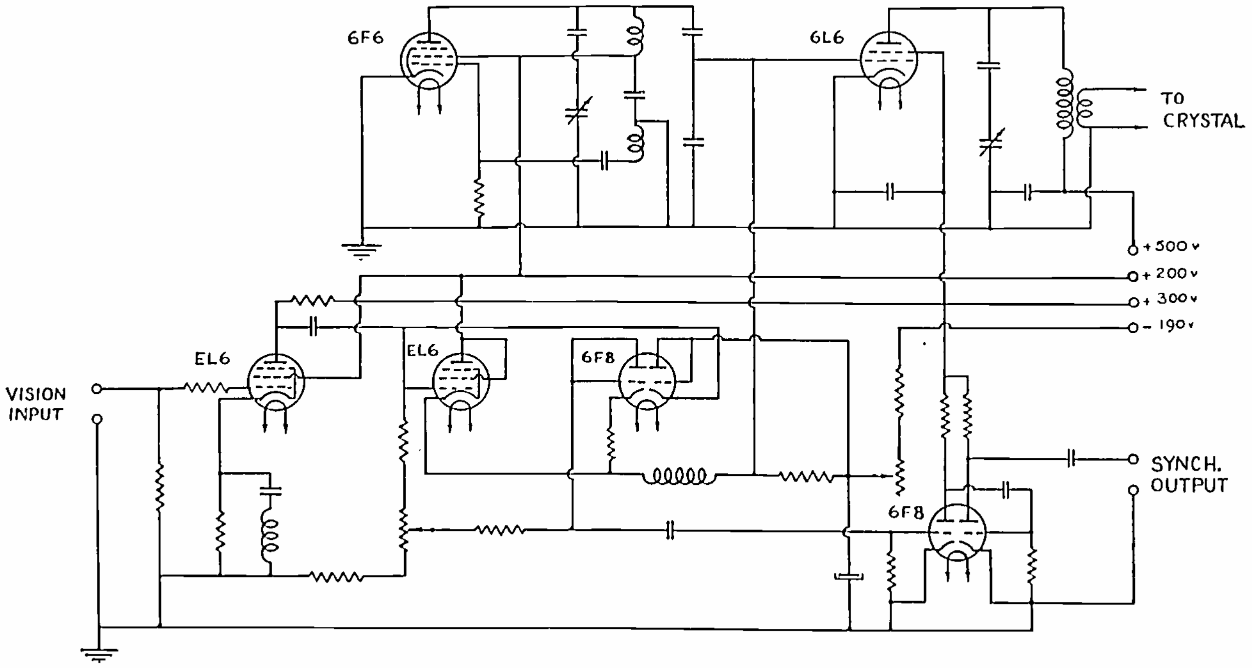


Fig. 6—Modulated oscillator.

The circuit diagram shown of the radio receivers and modulated oscillator in Figs. 5 and 6 are self-explanatory.

It might be mentioned here that the 1851RCA valve used in the present equipment is being superseded by the British valve E.F.50 made by the

Both vision and sound receivers are built in one chasis.

The modulated oscillator and synchronizing-signal separation is built on another chassis and is connected to the radio receiver by a plug and socket so that the two chassis are connected together by simply plugging one into the other. This gives a very short video-frequency lead.

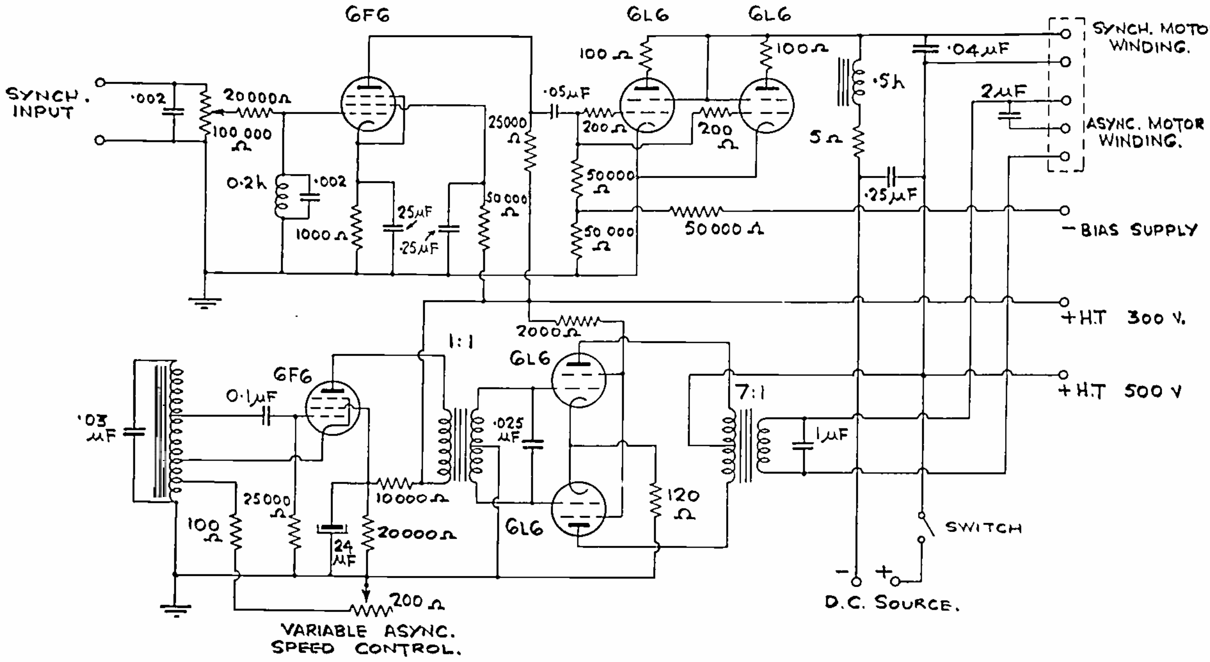


Fig. 7—High-speed drive unit.

The advantage of this system is that both units can be individually tested on the bench and lined up before incorporation in a receiver.

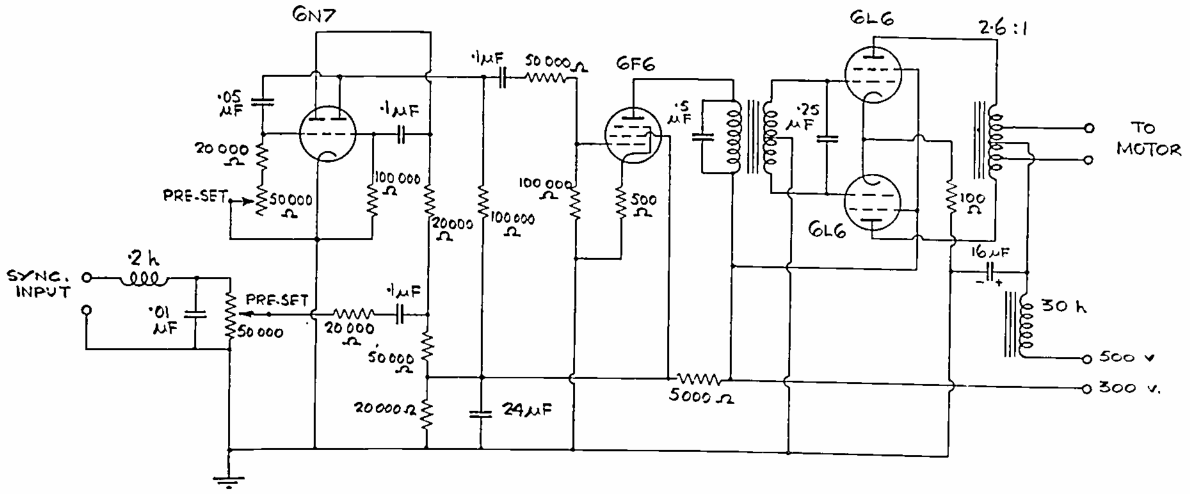


Fig. 8—Low-speed drive unit.

The synchronizing separation is done at high level so that good separation can be obtained even with interference present.

It will be seen from the circuit diagram that a diode valve is used as a direct-current restorer to the picture and synchronizing-signal separation is made after this.

The synchronous drive units are also shown in the circuit diagrams, Figs. 7 and 8. The high-speed motor is driven up to its speed, 30,375 revolutions per minute in the case of a 405-line picture by means of an asynchronous rotor attached to the same shaft as the synchronous rotor. The asynchronous drive unit consists of an oscillator with variable frequency from about 500 to 550 cycles per second, and amplified by means of two 6L6 valves, the output of which is split into three phases. The average running-up time of a motor including valve heating is about 25 to 35 seconds.

The line-synchronizing pulse is amplified and also fed to a pair of 6L6 amplifiers which are impedance-matched to the phonic-wheel winding of the motor. A small amount of direct current is applied in order to lock the motor rigid.

The low-speed scanner consists of an assembled glass polygon driven by means of an ordinary four-pole synchronous motor of standard manufacture running at 1500 revolutions per minute through a single spur reduction gear.

The synchronous pulse is fed directly to a preset multivibrator using a 6N7 valve, amplified by a

6F6 and fed to a pair of 6L6 valves in push-pull connection. The output is fed through a matching transformer and the phase-splitting done by means of condensers.

The phase position of the scanner is adjusted manually on the gear and finally locked. It will be seen that there can be two positions for synchronism, one in frame and the other half a picture out of frame. In order to save mechanical framing nearly every time the receiver is switched on, a push button is fitted to break the supply to the motor. The push button is shunted with a suitable resistor, so that when the button is depressed the reduced power to the motor allows the frame to slip. When the picture is framed the button is released. This operation takes only a second or two.

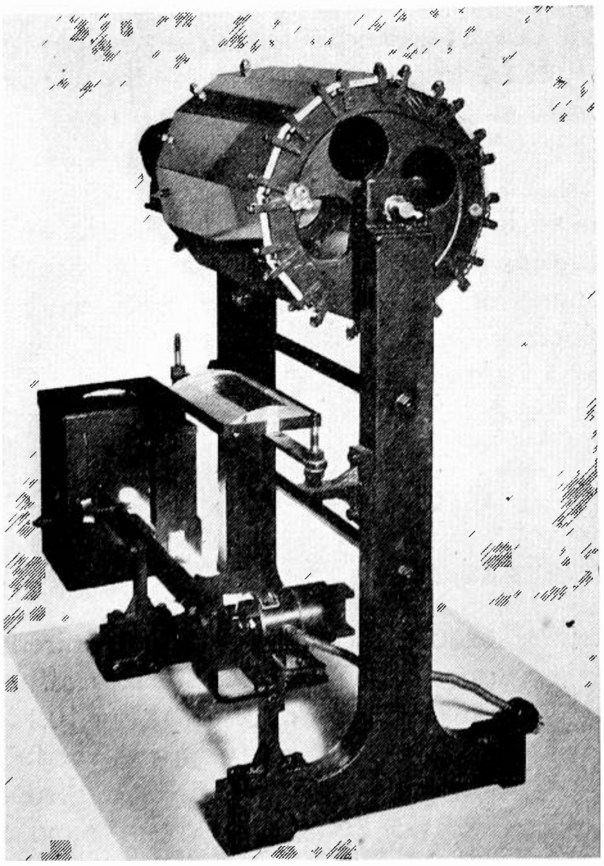


Fig. 9—Optical chassis of home receiver showing high- and low-speed scanners and supersonic light-control cell.

Scophony has developed a home receiver giving a two-foot picture and a picture 18×14 inches for the smaller-size living room. These receivers use a superpressure mercury lamp. This lamp, of the air-cooled type, has been especially developed in the Scophony Laboratories. Its brightness when consuming 300 watts is about 30,000 to 35,000 candles per square centimeter. The brightness of the 18- ×14-inch picture is between 6 and 10 foot-candles measured in the high lights, representing peak white. This brightness is essential for home-receiver requirements, since it may in some cases be desirable for the receiver to be used in a room with a considerable amount of daylight or artificial light. Six to ten foot-

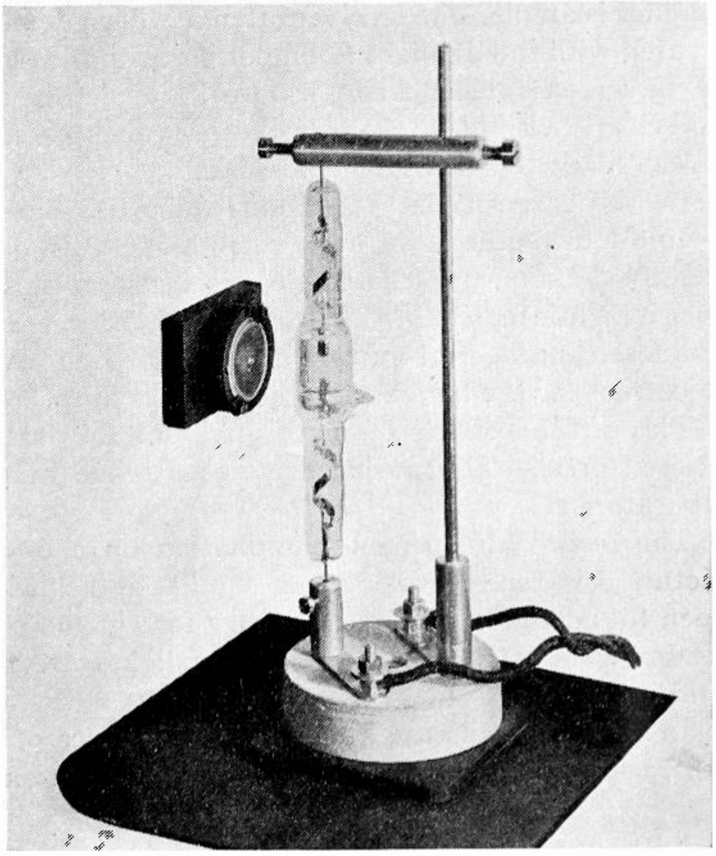


Fig. 10—Superpressure high-intensity mercury-vapor lamp with lens which forms an image of the mercury discharge on the light-control cell.

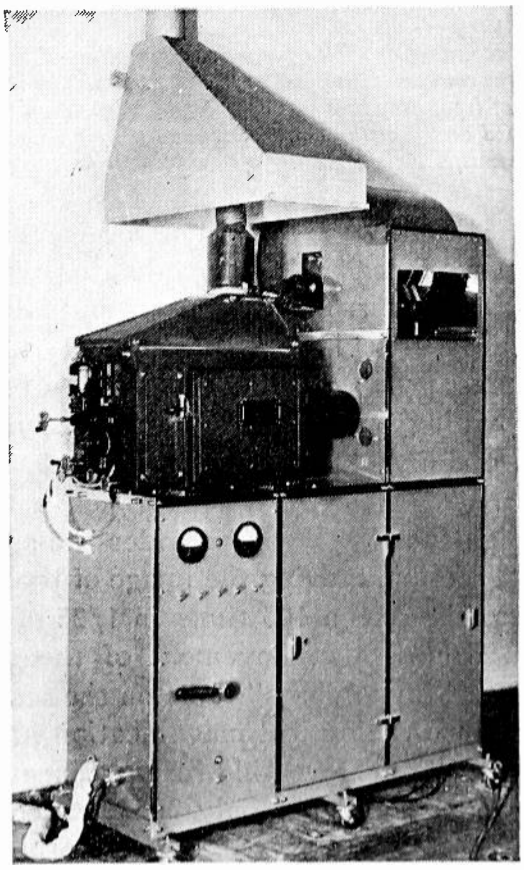


Fig. 11—Television projector installed at the Odeon Theatre, Leicester Square, London. On the left is the normal cinema arc lamp, while on the right some mirrors of the low-speed mirror drum can be seen. The electrical apparatus required, including radio receiver, sound amplifier, light-control modulator, drives for high- and low-speed polygon, is all contained behind the two panels on the right-hand side of the apparatus. The only connections required are the antenna, the alternating-current mains, and the direct-current supply for the arc.

candles is ample. The receiver often has been demonstrated with full daylight falling directly on the front of the screen from a near-by window. The picture was still clearly visible for the translucent rear-projection screen made this advantage possible.

In the large-screen television apparatus up to 6- to 8-foot pictures, for news cinemas, schools, etc., exactly the same optical and electrical system is used with a high-intensity arc lamp as the light source, and a different number of mirrors in the low-speed drum to correct for the increased projection distance.

The screen used is of plate glass suitably sand-blasted or special translucent screens made in the laboratories.

The peak-white screen illumination on a 6-foot picture is in the region of 3 foot-candles and this has been found the minimum necessary for cinema projection where the usual auditorium lights are left burning.

In the larger picture apparatus up to sizes of 15 feet, a screen illumination of 3 foot-candles is retained using improved optical and electrical systems.

The reliability of the apparatus is very gratifying, and the installations carried out at the world's first Television News Theatre at Marble Arch, London, and the Odeon Theatre, Leicester Square, where a 15- by 12-foot screen is used, have been absolutely trouble-free.

American Standard

It may be of interest to state that, although this and other related papers deal with apparatus for the British television standard of 405 lines, 50 frames a second, receiving and transmitting apparatus has already been designed by Scophony for the proposed American standard of 441 lines, 60 frames a second.

Acknowledgment

The author is indebted to S. Dodington and R. E. Duggan for their unfailing co-operation at all times, in connection with the development work herein described.

Synchronization of Scophony Television Receivers*

G. WIKKENHAUSER†, NONMEMBER, I.R.E.

Summary—*Data concerning the size and speed of the high- and low-speed scanners are followed by a description of the motors and the electrical equipment necessary to drive these. The maximum rate of change of frequency that can be followed by the high-speed scanner is mentioned and a method of testing the rate of change of frequency of the transmitter synchronizing pulses is described.*

PRESENT-DAY television receivers using the supersonic cell as light modulator are provided with two mirror polygons on mutually perpendicular axes. The low-speed polygon[1] runs at the speed necessary to give 50 mirror faces per second, thus providing 50 frame scans per second for the British 405-line, 50-frames-per-second interlaced standard.

The high-speed polygon provides the scanning in the line direction, moving the image of the light control across the screen 405 times in 1/25 of a second, and also cancels the movement of the supersonic shadows, or "immobilizes" them on the screen of the receiver, since the optical magnification has been so arranged as to achieve this result. Since the high-speed scanner completes only $202\frac{1}{2}$ traverses of the screen during one traverse of the screen in the vertical direction by the low-speed scanner, spaces are left between the lines, which are filled in during the succeeding 1/50th second; i.e., the required interlacing is produced and registers automatically.

The 405-line picture entails $405\times 25=10{,}125$ lines per second, and this means 10,125 mirror faces per second. The polygon may have anything from 15 to 30 faces, in practice 20 faces has been found to be a useful compromise. The speed of the polygon must therefore be $10{,}125/20\times 60=30{,}375$ revolutions per minute. Obviously, to run at this speed without danger of bursting and with a moderate power consumption, both the polygon and the motor driving it must be of small diameter. The face size of the polygon must also be chosen with reference to the optical design.

The polygons at present used, whether for a 2-foot or 15-foot received picture, are either of stainless steel 2 inches in diameter and 0.125 inch thick, the individual faces being 0.31 inch long, or of glass 1.45 inches in diameter and 0.125 inch thick, the faces being 0.23 inch long. In either case the polygon surfaces are machined, ground, and polished in batches of fifty or more, so that the cost per polygon is nominal, in spite of the great accuracy required. The reflecting surfaces of the glass polygons are rhodium-plated, but the surfaces of the stainless steel polygons are used direct.

A further reduction in the diameter of these polygons is at present uneconomic, as any saving in the drive units is offset by increased complexity of the optical parts.

---

* Decimal classification: R583–R361. Original manuscript received by the Institute, April 7, 1939.

† Scophony Laboratories, London, England.

[1] 15 mirrors each 11×2 inches on a diameter of $9\frac{1}{2}$ inches for the 18-inch picture of the home receiver or 24 mirrors each $11\times 2\frac{1}{2}$ inches on a diameter of $19\frac{1}{2}$ inches for the 15-foot picture.

CHOICE OF MOTOR TYPE

In the early days the low-speed scanner was started by hand spinning and run by a "phonic wheel," i.e., a rotor of mild steel with an appropriate number of teeth cut in its periphery and one or more stator windings carrying alternating current at picture frequency. These were soon abandoned in favor of fractional-horsepower self-starting synchronous motors with suitable reduction gear.

When the pulse generator of the transmitting station is linked to the same supply network as that used at the receiver, the low-speed motor may in some circumstances be run off the mains since the phase shift between the two points is never sufficient to be noticed in the low-speed scanning direction. For outside broadcast work, however, when it is not convenient to run a mains supply, the British Broadcasting Corporation uses a 50-cycle generator driven by an internal combustion engine in one of the outside-broadcast vans, and the frequency and phase of this supply determines the camera scanning and the radiated synchronizing signals. Thus at the receiver it is necessary for the low-speed motor to be driven from an alternating current obtained by amplifying the frame-synchronizing pulse derived from the vision radio receiver.

Two 6L6's in push-pull give sufficient output for self-starting and synchronous running under all conditions.

The high-speed motor was a serious problem. Motors with speeds of the order of 25,000 revolutions per minute were in use for certain purposes, but none of these were of the synchronous type, nor were the bearings or workmanship likely to give the steadiness required. Therefore, the motor had to be developed in the Scophony laboratories. The best solution yet found employs two separate sections built in one case, one section being an asynchronous motor capable of bringing the rotor quickly up to a high speed, while the other section is a synchronous motor of the phonic-wheel type to which the line-synchronizing signals, suitably amplified, are fed from the vision radio receiver. Fig. 1 shows the high-speed motor with the rotor withdrawn. The smaller diameter portion of this rotor is the asynchronous section, of the squirrel-cage type, and situated between this and the polygon is the toothed phonic wheel with the spaces between the teeth filled in with molded material to decrease windage and noise.

Since the size of the high-speed scanner polygon remains the same for all sizes of reproduced pictures, the same motor can be used in all cases.

DRIVE UNITS

The drive unit for the synchronous section of the motor comprises a 6F6 amplifier stage followed by two 6L6's in parallel, while the asynchronous section is provided with an alternating-current supply at about 500 cycles obtained from a 6F6 oscillator, transformer-coupled to two 6L6's in push-pull.

The fundamental sine-wave component of the short-duration line-synchronizing pulse has a perfectly definite phase with respect to that pulse and can be selected by a suitable circuit for amplification to the required strength; i.e., the amplifier is made to have a very low gain at frequencies differing greatly from that of the fundamental, and the output is therefore a fair approximation to a sine wave. The motor running on this output then holds in synchronism with the scanning of the camera, and almost equally important, does not suffer any phase change relative thereto from time to time.

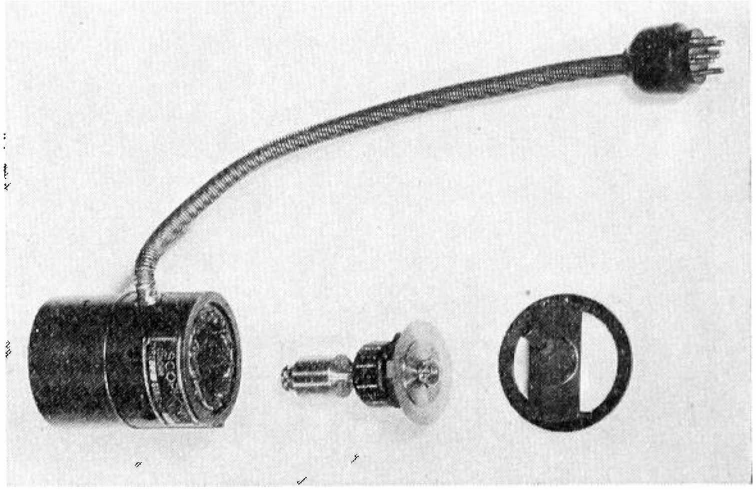


Fig. 1—High-speed scanner unit with rotor withdrawn showing the mirror polygon and the synchronous and asynchronous sections of the rotor.

In order that any residual-hum patterns reaching the screen of a receiver should be as unobjectionable as possible, while at the same time using a reasonably inexpensive design of mains filter in the receivers, it is usual to keep the generator of the synchronizing impulses at the transmitter in synchronism with the supply mains, when this is practicable, i.e., except in the case of outside broadcasts from points where no network connection is available.

Since the supply network is linked up throughout Great Britain this ensures that any such hum patterns will be motionless on the screen.

The high-speed motor together with its drive unit is capable of following satisfactorily a rate of change of frequency of the order of 25 cycles per second per second. The moment of inertia of the rotor and polygon as at present used is 260 gram-centimeters-squared of which the stainless-steel polygon accounts for nearly 140 gram-centimeters-squared.

Owing to the enormous moment of inertia of power-station turbines and turbogenerators compared with any sudden change of load normally occuring on the power station, the maximum rate of change of the supply frequency can be followed by the high-speed motor with the greatest ease, and thus any method of deriving the line-frequency pulses which really linked them rigidly to the mains would be acceptable.

It has been found, however, that some methods of deriving the pulses are susceptible to errors which prevent satisfactory picture reproduction by systems having inertia, and at the same time reduce the definition obtainable on receivers employing cathode-ray tubes. A brief discussion of the methods and some account of the technique of comparing them will not be out of place here.

For testing the behavior of the different frequency generators a magnetostriction oscillator of 10,125 cycles per second (line frequency) is used as a standard frequency, and the time base of a cathode-ray oscilloscope sweeping at half this frequency is arranged to synchronize with it.

The signals from the master generator to be investigated are applied to the vertical deflector plates of the oscilloscope, which then shows a horizontal straight line with two vertical deflections representing successive line impulses. The horizontal line is masked out, leaving two spots of light which remain stationary only so long as the phase of the impulse remains fixed with respect to the magnetostriction oscillator. By moving a film at uniform speed in the vertical direction a record of the movements of these spots can be obtained. Figs. 2 to 7 show the type of records obtained in this way. The vertical ordinate represents time and the horizontal ordinate phase displacement. The close horizontal bands are 1/50-second interval timing, obtained by applying a very slight 50-cycle hum voltage to the vertical deflector plates, and arranging the mask so that sufficient light from the horizontal part of the line passes the edge of the mask once each cycle. The slope of the trace represents the rate of change of frequency. Fig. 8 shows how the quantitative results are obtained, four traces being shown for clarity.

Two methods have been used heretofore to generate the master frequency. In the first a free oscillator is used, automatically tuned so that the frame pulse, obtained by subdivision, remains in constant phase relation with the supply mains. In the second, use is made of an apertured disk with a lamp and photocell, the disk being driven by a synchronous motor from the supply mains.

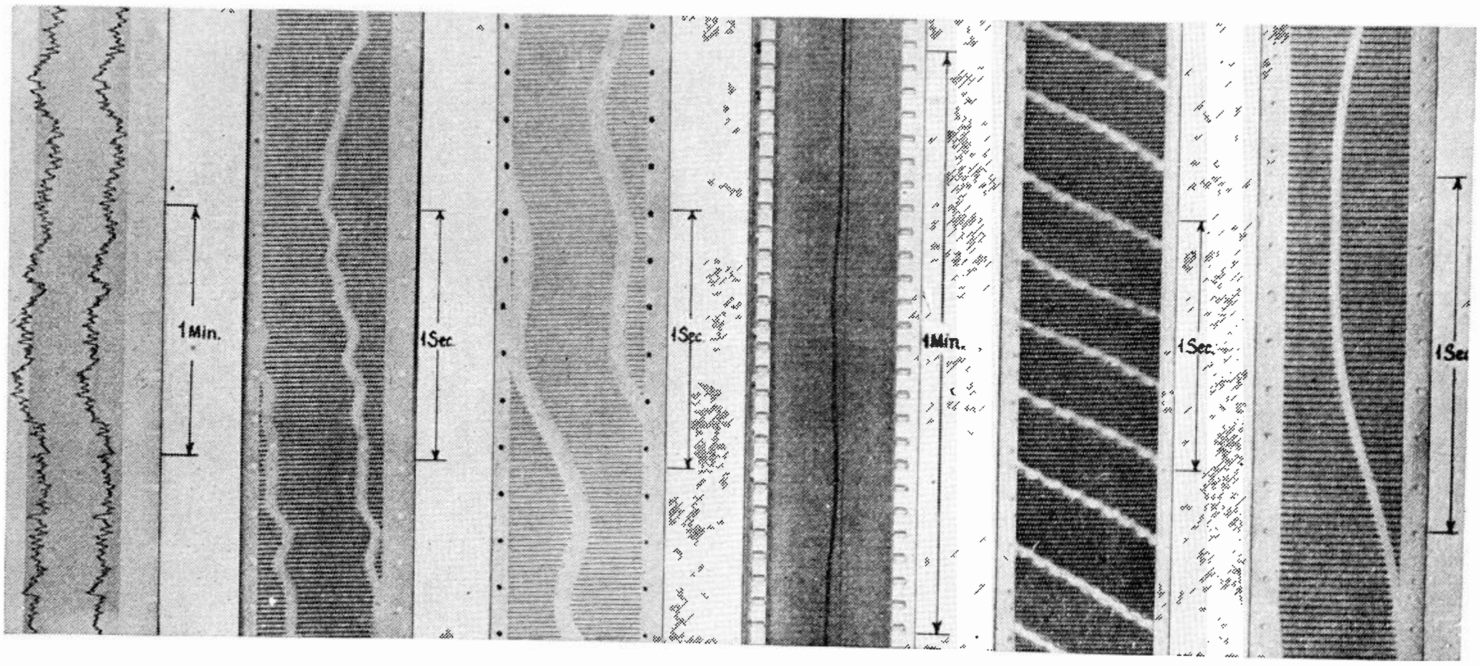


Fig. 2—Electronic generator with "small-time-constant" coupling.

Fig. 3—The same as Fig. 1 on an enlarged time scale.

Fig. 4—Electronic generator with "large-time-constant" coupling.

Fig. 5—Frame impulse drift of Fig. 3 against the mains.

Fig. 6—Apertured-disk master generator.

Fig. 7—Scophony master generator.

Figs. 2–7—Oscillograms of signals obtained from master generators of different types. In taking oscillograms 2 and 5 the oscillograph time base was synchronized to the mains, in the other cases, to the magnetostriction oscillator.

The first, or electronic generator has been used in two distinct forms. In one the time constant of the automatic tuning system is small (of the order of 0.2 second). This results in very fast and erratic phase modulation of the oscillator output. Fig. 2 shows an oscillogram of the output of such a generator. The two lines are traces of successive synchronizing pulses made on moving film. The lateral displacement at any moment indicates the change of phase relative to a standard signal. Measurements of this record show that the maximum curvature of the trace corresponds to a frequency variation of some hundreds of cycles per second per second, and in order to follow such changes a very powerful drive unit would be required.

Fig. 3 is an oscillogram of a generator of the same type on an enlarged time scale.

The origin of this frequency variation is that the automatic tuning system corrects the frequency of the master generator only if the phase difference relative to the mains frequency is of a certain minimum value. The correction is not like a positive drive, but acts only after a considerable displacement has taken place. The change takes place quickly in the form of overcorrection. The frequency then oscillates about a mean position.

In the second form of electronic generator a coupling with large time constant is used. This reduces the frequency variation to about 10 cycles per second per second at the line frequency as shown in Fig. 4 but the phase drift at frame frequency cannot be tolerated. This phase drift is shown in Fig. 5, and results in a slow movement of the picture in a vertical direction. The amount of movement recorded on Fig. 5 would represent at least one fifth of the picture height.

In this case the frequency of swing about the mean position is reduced, but the amplitude is increased.

The mechanical generator using the simple apertured disk suffers from mechanical irregularities in manufacture. For instance a disk having 405 holes designed to rotate at 1500 revolutions per minute requires the angular spacing of the holes to be correct to within ±6.4 seconds of arc for one-element accuracy. Inaccurate placing of the holes would mean that the lines of the picture would be displaced relative to one another.

In addition to this irregular error, regular errors occur if the disk runs eccentrically on its shaft. When such eccentricity is present the small band of frequencies, produced instead of the expected single frequency as a result of the irregular spacing of the holes, will in addition be phase-modulated with a frequency corresponding to the number of revolutions of the disk per second.

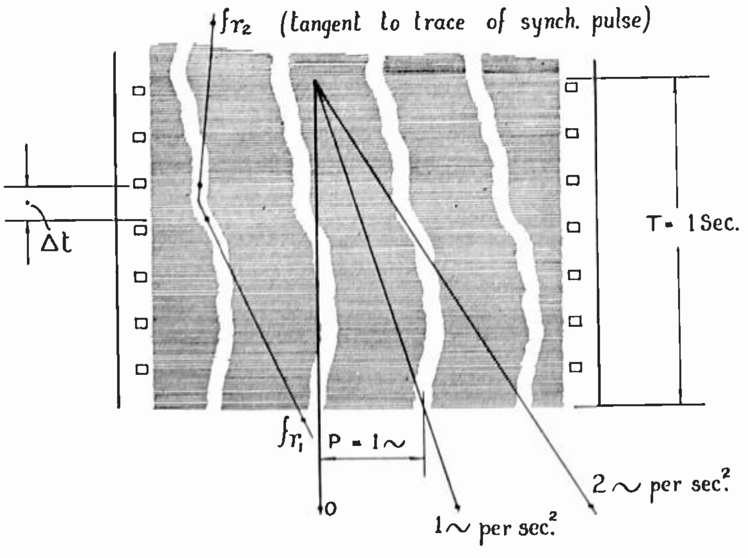


Fig. 8—Rate of change $=(f_{r_1}-f_{r_2})/\Delta t$ cycles^2.

Fig. 6 is a typical example from an unsatisfactory generator of this type; the lines are not sharp, but blurred because of the irregular spacing of the holes and they show regular steps due to the eccentric error.

Any attempt to compensate variations electrically by means of sharply tuned circuits fails as the mains frequency drift is too great.

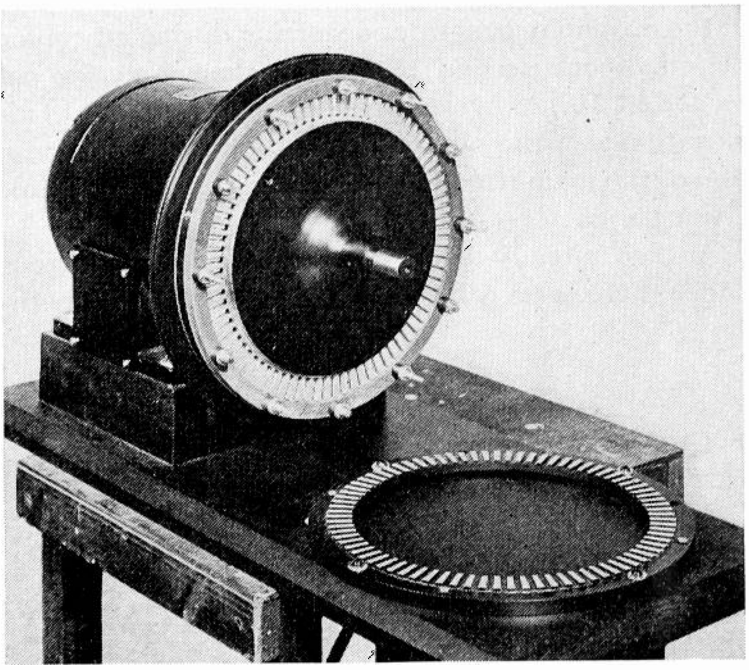


Fig. 9—Scophony master generator.

This problem was of the greatest importance to Scophony as the master generator used for the 405-line standard from the commencement of the British Broadcasting Corporation service was of the electronic type with small time constant. Fig. 1 is in fact a record of the pulses derived from the original British Broadcasting Corporation generator. The British Broadcasting Corporation engineers took steps to reduce the rate of change of the frequency, and from August, 1937, it became possible to obtain steady pictures with the high-speed motor. At the same time, cathode-ray viewers reported improved synchronizing and interlacing. This was particularly noticeable in the outlying, weak-signal districts.

A mechanically driven master generator which appears to offer an entirely satisfactory solution to this problem was developed by the Scophony Laboratories at that period.

It consists of a toothed disk which rotates at 125 revolutions per second between two toothed stator rings (Fig. 9). Use is made of the change in capacitance between the stators when the rotor revolves. The teeth are cut on an optical dividing head to an accuracy of 6 seconds of arc. Owing to the large number of teeth uniformly placed around the periphery of the disk, all simultaneously contributing to the output, angular inaccuracies of teeth cancel out. Likewise eccentricity in the mounting of stators or rotor cannot have any effect on the regularity of the signal. Skewed mounting of stators or rotor cannot have any effect on the signal due to the completely balanced electrical system used.

To compare the maximum frequency variation of the Scophony generator with that of the other generators, tests were made using as a standard a magnetostriction oscillator having a stability of one part in several hundred thousand. Measurements from the photographic records show the maximum variation of the Scophony generator occurring during any given period of one second to be less than 2 cycles per second at 10,125 cycles per second (see Fig. 7). This variation is of the same order as the maximum variation of the mains frequency occurring during the same given period.

As has already been pointed out in a previous paper there is no difficulty in using Scophony methods for the American television standard of 441 lines, 60 pictures per second, and designs for both transmitting and receiving apparatus have already been prepared.

ACKNOWLEDGMENT

The investigations on the synchronizing signals together with the development work on the mechanical pulse generator and the high-speed scanner motor for the receiver have been carried out with the help of my assistant, Mr. A. F. Thomson.

I am indebted to Dr. D. M. Robinson for the preparation of the foregoing paper.

Some Factors Involved in the Optical Design of a Modern Television Receiver Using Moving Scanners*

H. W. LEE†, NONMEMBER I.R.E.

Summary—*The question of optical efficiency is discussed in relation to various forms of scanning. The "split-focus" principle and the smaller size of scanner thereby made possible are described with the aid of perspective drawings. Figures relating to the design of bar and slit sizes for the supersonic cell are given and the method of calculating the light flux on the screen is described. Tolerances on the accuracy of the scanners are discussed and the adjustment for the effect of temperature on the acoustic speed of the liquid is mentioned.*

THE essential parts of an "optical-scanning" television receiver are, (1) optical elements for producing an illuminated area on a viewing screen, which acts as a diffuser to throw light into the eye from any part of its area; (2) means for moving the illuminated area over the screen (known as "scanning," though this term is rightly applicable only to a transmitter); and (3) means for modulating the intensity of the illumination in accordance with that of corresponding areas of the scene to be reproduced.

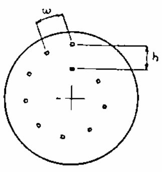


Fig. 1

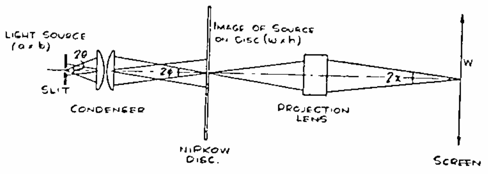


Fig. 2

Scanning can be accomplished mechanically according to two general principles.

(1) A disk may be provided with a number of equidistant apertures in spiral formation and rotated in front of the light source (Nipkow disk, see Fig. 1). Let W = distance between the holes circumferentially and h = pitch of the spiral, then the area scanned by the disk is $W \times h$ and this is enlarged by a projection lens at a magnification m_1 on to the screen; then the screen area covered = $W \cdot h \cdot m_1$. The image of each hole covers the screen in turn so that the number of scanning lines per picture = number of holes. An enlarged image of the light source has to be formed, by a condenser, on the area $W \cdot h$ of the Nipkow disk, (see Fig. 2) and if $a \times b$ = area of the light source (aperture of Kerr cell), since its image has to cover 482×385 apertures in the Nipkow disk, the area of the Kerr cell corresponding to 1 hole $= ab/(482 \times 385)$. (In the British system there are 405 lines in the transmission; 20 lines are used for synchronization, leaving 385 lines for actual picture: the ratio is 5:4 so that there are 482 elements in each line of the picture.) The light flux $= B \times ab/(482 \times 385) \times \pi \sin^2\theta$, B being the brightness of the light source. θ the semiaperture is about 25 degrees with the Kerr cell. B may be taken as 30,000 stilb.[1]

$$a = 0.1 \quad \text{and} \quad b = 0.2 \text{ centimeter.}$$

Hence light flux through one element

$$= \frac{30{,}000 \times 0.02}{482 \times 385} \times \pi \times 0.12. \qquad (1)$$

For a screen picture 10×8 inches the area is then

$$25 \times 20 \text{ centimeters} = 0.05\ m^2. \qquad (2)$$

$$\text{Brightness of screen} = (1) \div (2)$$

$$= \frac{30{,}000 \times 0.020 \times \pi \times 0.12}{482 \times 385 \times 0.05}$$

$$= 0.025 \text{ lux.}^2$$

---

* Decimal classification: R583×R361. Original manuscript received by the Institute, April 7, 1939.

† Scophony Laboratories, London, England.

[1] The stilb is a brightness of 1 candle per square centimeter.

[2] The lux is closely 0.093 foot-candle.

No allowance has been made for light loss by reflection from the lens surfaces. As there will be at least 16 glass-to-air surfaces transmission will be 50 per cent at most. Then there is the efficiency of the Kerr cell to be considered. It is obvious that illumination will not be nearly sufficient, even with a multielectrode Kerr cell.

Apart from light inefficiency the Nipkow disk has other disadvantages. A large number of holes have to be made accurate to size and position; the scanning lines are curved, which leads to distortion of the image, unless the diameter of the disk is large.

(2) The second "classic" method of scanning is to reflect the beam from two revolving mirror drums. (A single drum with mirrors set at different angles is impracticable for high-definition television.) The two drums have their axes at right angles and one scans along the horizontal lines of the picture and the other scans in vertical lines. In the British system of 405 lines scanned 25 times a second (actually half the picture of 202½ lines is scanned 50 times a second), vertical scan, called the picture scan, takes place 50 times a second. If there are n_1 mirrors in the low-speed scanner which produces this scan, the rotational speed will be $50/n_1$ revolutions per second. The line scan takes place in $1/(25\times 405)=1/10{,}125$ second and if there are n_2 mirrors in the drum the speed is $10{,}125/n_2$ revolutions per second. If $n_2=20$ the speed is 506½ revolutions per second. It is obvious that a drum can only be driven at this speed if its moment of inertia, and therefore its size, is very small. The mirrors in each drum must act as an aperture to the beam they are moving, but as each drum is producing scan in only one plane, it need not be an aperture in the plane at right angles, so that the beam in the plane at right angles to its scan can be focused on either mirror drum. This is the principle of the "split focus" of G. W. Walton, which solves the problem of reducing the size of the high-speed drum. The single-mirror drum, used in low-definition television, is an aperture in both planes and so cannot embody this principle and becomes useless for high-definition television. These statements may be illustrated schematically as shown in Fig. 3. In the diagram for the sake of clearness the deviation of the beam by reflection is not shown. O is the light source and A a mirror of the first scanner scanning horizontally over an angle 2θ. B is the mirror of the second scanner scanning vertically over an angle 2ϕ. S is the screen, and L a lens forming an image of O on S. It is seen that A is an aperture limiting the amount of light utilized, also that B has to be of such size as to take in the scan from A as well as the aperture of the beam. Walton's split-focus principle is to replace L by a cylindrical lens forming a horizontal-line image of O on A, as shown in Fig. 4. A second cylindrical lens between A and B forms an image of this line on the screen of a size equal to the line width of the scan. It is seen that now A has been greatly reduced in size, *without altering the aperture of the beam*, in fact since A is now not an aperture in the plane at right angles to its scan the aperture in this last plane can be greatly increased, the only limit being the size of the mirror B of the low-speed mirror drum. As this rotates at a speed of only $50/n_2$ revolutions per second there is no great difficulty about making this fairly large.

The split-focus principle makes possible such a reduction in size of the high-speed scanner that mechanical scanning is possible. Mechanical modulation of the light source, however, is out of the question with a signal frequency of nearly 3×10^6. The Kerr cell was used in the experimental period with low-definition television, but has the disadvantage that it cannot modulate a large light flux, as for efficient working the gap between the electrodes must be small (the beam is of the order of 1×2 millimeters with about 40 degrees angular aperture, though the area was increased by the use of a multielectrode cell somewhat at the expense of the angular aperture), also its rather high capacitance is a grave disadvantage at the high frequencies. The Scophony light control (invented by J. H. Jeffree, British Patent No. 439,236, etc.) employs a cell 2 centimeters wide by 2.5 to 4.5 centimeters long (it can be still further increased) and allows ample light flux, with negligible time lag. Its action is based on the diffraction of light by compressional waves generated in a liquid, which act as a diffraction grating owing to the increase of refractive index at the places of compression. The theory is somewhat involved, but the diffraction spectra are produced at the same positions as they would be if produced by a plane grating having a grating interval equal to the wavelength of the waves in the liquid; hence the diffraction angle for the first order $=\lambda_{\text{light}}/\lambda_{\text{liquid waves}}$ and in order to make this as large as possible the wavelength of the liquid waves must be small. These can be produced by the oscillations of a quartz plate under the action of electric oscillations of the order of 10 to 20 megacycles per second. The speed of mechanical waves in water is 1494 meters per second so that the wavelength is 0.015 to 0.0075 centimeter and thus the angle of diffraction for the first order would be,

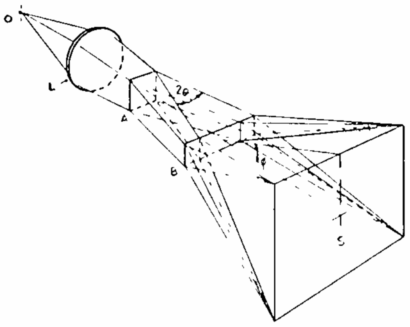


Fig. 3—Scan plane of A is horizontal. Scan plane of B is vertical.

for yellow light, $(0.55\times10^{-4})/(15\times10^{-3})=1/270$ radians for 10 megacycles and 1/135 radians for 20 megacycles.

It is found that the number of diffraction orders and the amount of light diffracted by the supersonic waves (as they are called) in liquid increases with their amplitude and this in turn is proportional to the electrical excitation of the quartz plate. The thickness of the quartz plate is chosen so that the natural frequency is the same as the oscillation frequency (say 10 megacycles per second) of the electric circuit, which is modulated up to 3 megacycles per second by the television signals, the depth of modulation at any instant being proportional to the intensity of the light in that element of the scene which is being transmitted at the time.

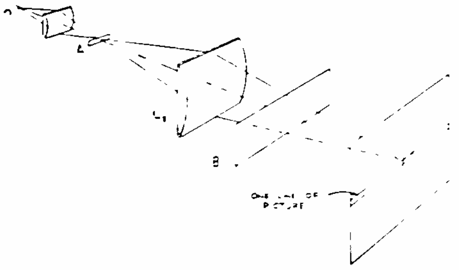


Fig. 4

The amount of light in each diffraction spectrum for different amounts of excitation of the quartz plate has been measured by F. H. Sanders.[3] The total amount of diffracted light, as measured by Sanders, has been plotted against excitation in Fig. 5. It is seen that the curve bears a general resemblance to valve curves and photographic-density-versus-light curves, showing a fairly straight line with a "toe" at the low-intensity end.

The assembly, consisting of liquid in the cell and quartz plate, is called a supersonic cell, and light must pass through the supersonic wave field in a direction parallel to the liquid wave fronts and must, therefore, be a parallel beam. The efficiency of the cell falls off rather rapidly if the direction of the light beam does not coincide with the supersonic wave fronts, a difference of 22 minutes of arc leading to dissymmetry of the light distribution, and at increasing angles the diffraction effect diminishes till it disappears[4] at 2 degrees.

A lens is placed in front of the cell to collimate light from a slit. A second lens placed after the cell focuses an image of the slit on an opaque shield, which cuts off undiffracted light from the screen, and the diffracted light alone passes to the high-speed scanner which is placed at such a distance from the cell that the waves as they travel along the cell are "followed" by the rotating mirrors of the scanner so that the beam of diffracted light is reflected in a fixed direction in space (just as a heliostat mirror follows the sun's motion and reflects its beams in a constant direction to a telescope, spectroscope, etc.). A lens placed close to the scanner forms an image of the cell on the screen. Thus the image of a supersonic wave carrying the correct modulation of a point in the scene transmitted remains on the screen for the time the wave takes to travel through the cell and in effect the image is stored. In a liquid in which waves have a velocity of 1000 meters per second this time is 1/40,000 second for a $2\frac{1}{2}$-centimeter cell and as the time of passage of an element is about $1/(6\times10^6)$ second it is seen that the Scophony light control gives an increase of light, over the single-spot scanning of the Nipkow disk, of the order of $(6\times10^6)/(4\times10^4)=150$ times. For a larger cell (which is easily possible, up to about 10 centimeters) the gain is still greater.

In order to keep the size of the high-speed scanner as small as possible it is advisable to place the shield (which cuts off the zero-order light) as close as possible to it. The "follow-up" distance can be calculated as follows. Since light reflected from a mirror rotates at twice the speed of the mirror we have 2×speed of rotation of scanner×"follow-up" distance = speed of supersonic waves. Now the scanner speed we noticed before was 506.5 2 revolutions per second $=1013\pi$ radians per second for 20 faces, so we get "follow-up" $=10^5/(2\times1013\pi)=15.7$ centimeters. The wavelength for supersonic waves having a speed of 1000 meters per second at an oscillation frequency of 10 megacycles per second is $10^5/10^7=0.01$ centimeter and the diffraction angle $0.000055/0.01=0.0055$ radian so that the displacement of the first order $=0.0055\times15.7=0.086$ centimeter and the shield must not be bigger than 1.72 millimeters if it is to pass *all* the diffracted light which is seen to amount to 94 per cent of the incident light. However, we can get more light at a lower efficiency (i.e., amount of light passing the shield/total amount

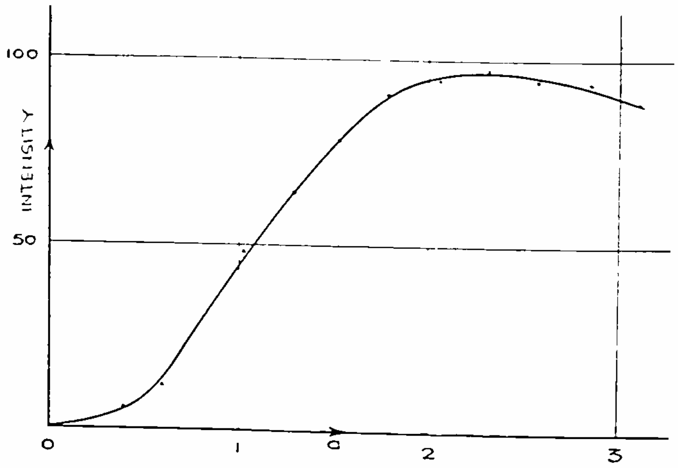


Fig. 5

Ordinates—percentage of incident light diffracted.
Abscissas—$a=2\pi L\cdot\delta n/\lambda$.

---

[3] "Intensity measurements in the diffraction of light by ultrasonic waves," *Canadian Jour. Res.*, vol. 14 (A), pp. 158–171, no. 8, (1936).

[4] Parasarathy, "Diffraction of light by ultrasonic waves," *Proc. Indian Acad. Sci.*, series A, vol. 3, pp. 442–447, no. 5, (1936).

of light incident) by increasing the size of the shield (and of the slot of which it is an image). Utilizing F. H. Sanders' figures we obtain the following table showing the amount of light and the efficiency, with shields of different sizes.

TABLE I

Width of Shield in Millimeters	Amount of Light at Full Modulation	Efficiency in Per Cent	Equivalent Slot at Full Efficiency
0.7	0.544	94	0.66
0.864	0.671	94	0.81
1.0	0.715	86	0.86
1.73	0.944	66	1.14
2.0	0.96	58	1.16
2.59	1.00	47	1.22
3.0	1.0	40	1.22
3.50	1.0	34	1.22

It is seen that there is not much advantage to be gained by increasing the shield beyond about 2 millimeters and none beyond 2.5 millimeters. It must be remembered, however, that the measurements of Sanders were taken with monochromatic light of wavelength 0.000055 centimeter. For red light (for which no figures are available) diffraction angles would be greater, but the amount of light diffracted less. On the whole the theory is in good agreement with practice which finds 2½ to 3 millimeters the maximum useful width of shield.

It will be readily appreciated that the slot and bar can be interchanged, i.e., the bar as the object, illuminated on both sides, and the slot near the scanner. In practice this is the better arrangement as giving a smaller beam with the same amount of light.

We have now examined the optimum conditions for the light-control cell in the plane of the high-speed scanner. The cell does not restrict the light in a plane perpendicular to this in any way as a line image of the light source, which need not be limited by a slot, can be formed on the cell itself, and this again is imaged on the high-speed scanner. Of course cylindrical lenses have to be employed for this. The diameter of scanner, having 20 faces, which will deal with the beam is only 5 centimeters with a length of 3 millimeters. Made in steel it has a moment of inertia of 137 gram-centimeters-squared; in glass this would be about 50 gram-centimeters-squared.

Fig. 6 gives sections of the Scophony optical system (a) in the plane of the line scan, (b) in the plane of the picture scan. Again for the sake of simplicity the change of direction in reflection has been ignored. The light source is a superpressure mercury-vapor lamp, the light from which falls on the lens L_2 after passing the bar B, which is at the focus of L_2 so that parallel beams of light pass through the cell and are focused by L_3 on to the slot S, where the lens L_6 forms an image of the light-control cell on the screen. In the plane at right angles L_1 forms an image of the light source on the cell and L_4 (cylindrical) an image of this on the high-speed scanner. L_6 forms a final image on the screen of line size, which the low-speed scanner moves vertically on the screen. The combined effect of lenses L_6 and L_6 is to form a line image on the screen which carries 150 elements (with a 2.5-centimeter cell).

To calculate the light on the screen with the Scophony system, we shall again suppose a 10- ×8-inch (25-×20-centimeter) screen. The line width will be therefore 0.05 centimeter. If the mirrors of the low-speed scanner are 6 centimeters wide and there are 12 of them the scanning angle will be 60 degrees, the diameter of the drum will be $6/\sin 15 = 23$ centimeters, the distance of the drum from the screen will be $10/\tan 30 = 17.3$ centimeters. As the light is in practice reflected at 90 degrees from the low-speed scanner, the effective aperture of each mirror is 6 sin 45 degrees = 4.25 centimeters, and, therefore, the angular aperture of the beam in plane II at the screen will be $4.25/17.3 = 1/4.07$. The line image being 0.05, if this is formed from a mercury-vapor lamp whose width is 0.15 centimeter, the image has been reduced one third so that the aperture at the lamp in this plane $= 1/(3 \times 4.07) = 1/12.2$.

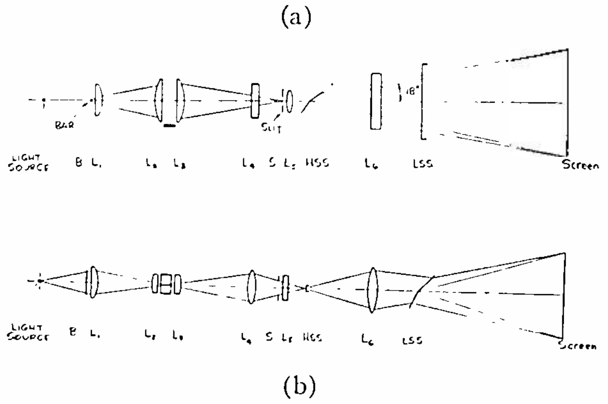


Fig. 6

In the other plane the aperture at the slit is $2.5/15.7 = 1/6.3$. But this has to illuminate two faces of the high-speed scanner to ensure even illumination at the sides of the picture, so the effective aperture is $1/12.6$ and the solid angle of the illuminating cone is $1/12.6 \times 1/12.2$. The slot is 0.3 centimeter wide, but this we saw was equivalent to 0.12 centimeter so the effective area of the light source is $0.12 \times 0.15 = 0.018$ square centimeter. If we take the surface brightness of the mercury-vapor lamp as 30,000 stilb, the candle power of the lamp is $30{,}000 \times 0.018 = 540$ candle power and the flux $= 540 \times 1/12.6 \times 1/12.2 = 3.63$ lumens. This has to illuminate a screen of area 20×25 square centimeters = 0 2 × 0.25 square meters = 0.05 square meters.

$$\text{Illumination of screen} = \frac{5.63}{0.05} = 70.6 \text{ lux.}$$

We have shown 5 lenses, which will have a transmission factor of 0.66 and two reflectors which have reflecting powers of 0.67 and 0.85, respectively (the mirrors of the low-speed scanner are surface rhodium-plated), so that the combined transmission factor is $0.66\times0.67\times0.35=0.375$ and, therefore, the final screen illumination will be 26.5 lux. This is about the illumination actually achieved. It has been found that the line image may be more than the theoretical width (picture height/385), in fact two or three times that amount, without spoiling the definition of the picture noticeably, with the advantage of increasing the illumination on the screen by a factor of 2 or 3.

ACCURACY OF THE SCANNERS

The high-speed scanner is a single piece of steel or glass of small dimensions and so it can be made with optical precision. Since the length is only 3 millimeters a number of these (50 in fact) can be mounted together on a mandrel and worked together so that defects of optical surfacing are divided among 20. The surface of the polygon, since it is an aperture for the detail-imaging lens, must conform to the ordinary standard of optical flatness. The accuracy required for the angles of the polygon can be easily determined from the fact that the angle between consecutive faces is 18 degrees and there are 570 elements in the line; if each face is to stabilize the image within half an element, the angle must be correct to $18/(2\times570)$ degrees $=1$ minute approximately. Twice this limit of accuracy can easily be attained in commercial practice.

Eccentricity will cause a periodic wandering of the image by $2\times\cos 40$ degrees $\times$ eccentricity. Adopting the half-element standard, eccentricity must not exceed $(25\times52)/(2\times471)$ for the 10-×8-inch (25-×20-centimeter) picture, i.e., 0.4 millimeter.

The low-speed scanner face is, as to its width, an aperture in the line-imaging beam. As it has been found that a considerable variation in line width can take place without prejudicing definition, the standard of definition required is not great. The detail-imaging beam has only a small aperture (about 1 centimeter) on the mirrors so that it is sufficient if the mirror does not depart appreciably from optical flatness within that area. This allows quite a large departure for the mirror as a whole. Good-quality plate glass is sufficiently accurate for these mirrors. The thickness is sufficient to prevent fracture by centrifugal force on rotation. The angular displacement must be sufficiently accurate to avoid displacement between successive frames of the picture on the screen, which would lower definition and the mounting must be parallel to the axis. The limit for this can be deduced for the specific case of the 10-×8-inch (25- ×20-centimeter) picture with a 12-mirror drum; the distance of screen from drum was found to be 17.3 centimeters. The size of half an element on the screen $=20/(2\times385)=0.026$ centimeter approximately, so that the permissible error in the mirror, for an image wandering of half an element $=0.026/(2\times17.3)=0.00075$ radians $=2.5$ minutes of arc.

One advantage of the mercury-vapor lamp is the relatively low heat production; however, there is enough heat emission to raise the temperature of the supersonic cell a few degrees in the course of operation and it is well known that the properties of liquids have rather large temperature coefficients. Since the cell is parallel-sided and does no refracting, the temperature change of refractive index is unimportant. However, the velocity of sound waves undergoes appreciable change with temperature. With heptane the coefficient is -4.1 or 0.41 per cent of the actual velocity, so that a few degrees rise produces a change of several per cent, calling for an equivalent alteration in the "follow-up" distance. The imaging of the illuminated slit (or bar) on the bar (or slit) in front of the high-speed scanner is at approximately full size and it is well known that the distance between the object and the image has a minimum value at a magnification of -1, so that it is possible by moving the cell closer to the scanner to adjust for the decreasing speed of the supersonic waves with rising temperature, without upsetting the focus. A small adjustment of the position of the cell is provided for temperature-change compensation.

Notes on the Random Fading of 50-Megacycle Signals Over Nonoptical Paths*

K. G. MACLEAN†, ASSOCIATE MEMBER, I.R.E., AND G. S. WICKIZER†, ASSOCIATE MEMBER., I.R.E.

Summary—To obtain data on the variation of field strength beyond the horizon, simultaneous recordings were made at three locations, one within the optical path of the transmitter, one 700 feet below the line of sight, and one 11,400 feet below the line of sight. All three locations were on the same line from the transmitter. Recordings extended over a two-week period, chosen at a time when atmospheric refraction was likely to be favorable. Analysis of the recorded data indicates several things of interest. The variation of field strength at each location was random and showed no correlation with any other location; the range of field-strength variation exceeded 49 decibels at the most remote location; maximum fields generally occurred at night; and previous data on the rate of attenuation beyond the horizon were confirmed.

THERE has been published a wealth of information, both theoretical and experimental, on the propagation of ultra-high-frequency waves. In general these waves have been shown to follow the known laws of optics. For transmission up to the optical horizon, various investigators have given relations which allow the field strength to be calculated within practical limits.

When the transmission path exceeds the optical distance, however, the theoretical considerations become more complex. While various investigators have arrived at different results, due to differences in setting up limiting assumptions, the properties by which propagation takes place over the horizon have been generally thought to be due to diffraction and refraction. Diffraction is considered to contribute a steady field present for some distance beyond the horizon, while refraction in the lower atmosphere causes the variable, but much greater, fields which have been observed. In some of the published theory, account has been taken of average refraction effects, and agreement has been shown with experimental data. Since the refraction field is often quite variable, short observation periods have proved of little significance.

Recordings of ultra-high frequencies for extended periods have been reported by Ross Hull.[1] He has noted a correlation between temperature inversion in the lower atmosphere and periods of strong refraction fields. Burrows, Decino, and Hunt[2] have reported observations on a 150-megacycle signal over a nonoptical path, for a period of one year. The subject of fading on ultra-high frequencies at distances beyond the horizon was studied by Englund, Crawford, and Mumford.[3]

A more complete knowledge of the magnitude of the refraction field at greater distances is desirable to assist in estimating the service and interference areas of television and other short-range services. The purpose of this paper is to report the results of a series of recordings made at several points beyond the horizon when refraction fields were evident.

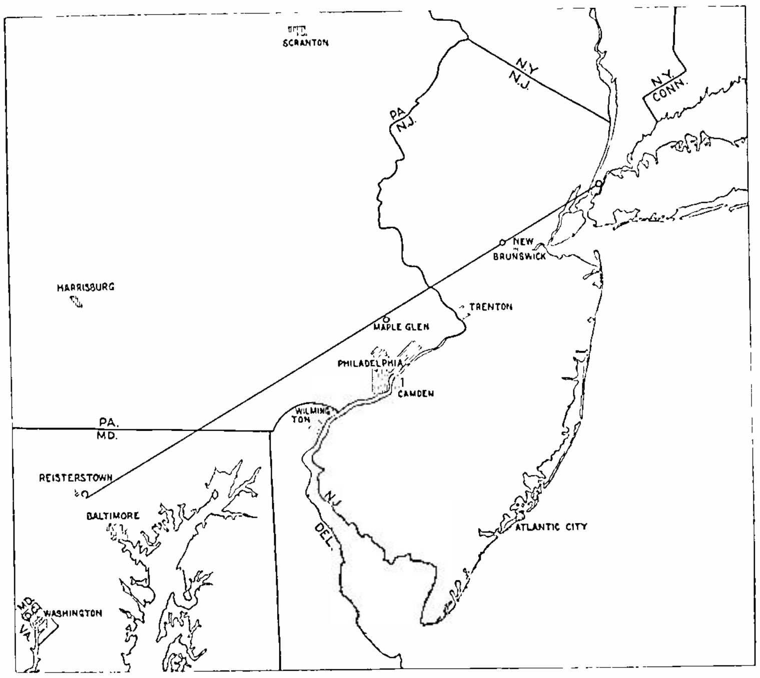


Fig. 1—Map of transmission path.

Transmissions from the National Broadcasting Company television transmitters, located in the Empire State Building in New York City, were observed at three points lying along a common path in the general direction of Washington, D. C. The map of Fig. 1 shows the relative location of the transmitter and the three receivers. The first receiver was located near New Brunswick, New Jersey, a distance of 32 miles, to collect data over an optical path. The second receiver was located north of Philadelphia, near Mapleglen, Pennsylvania, a distance of 72 miles from the transmitter. The most distant receiver was located northwest of Baltimore, near Reisterstown, Maryland, a distance of 172 miles from the transmitter.

The transmitting antenna was a triangular array of stacked horizontal doublets, located on top of the Empire State Building tower, approximately 1300 feet above the ground. The field strength on 52.75 megacycles produced by this transmitting antenna, at low vertical angles, in all horizontal directions, was the same as would be received at right angles to a half-wave horizontal doublet radiating 3.6 kilowatts. Similarly, the field strength on 49.5 megacycles was the same as would be received from 10 kilowatts in a horizontal half-wave doublet, at right angles to the doublet.

---

* Decimal classification: R113.1. Original manuscript received by the Institute, July 15, 1938.

† R.C.A. Communications, Inc., Riverhead, L. I., N. Y.

[1] Numbers refer to Bibliography.

At New Brunswick and Mapleglen, the receivers were triple-detection superheterodynes, operated from alternating-current, regulated power supplies. The outputs of the final diode detectors were recorded on Engelhard recording microammeters. The signal was compared with a standard-signal generator every hour by an automatic switch which connected the signal generator to the receiver input for several minutes. The receiver at New Brunswick was operated with a linear relation between input and output, while the receiver at Mapleglen was operated with logarithmic automatic gain control.

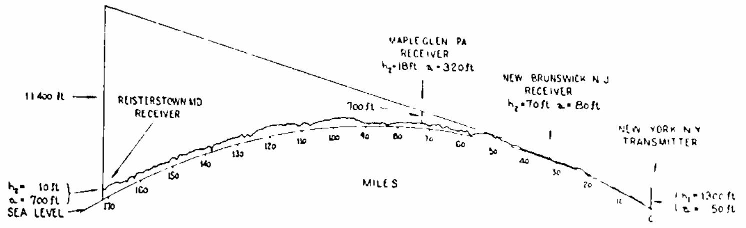


Fig. 2—Profile of transmission path.

At Reisterstown, the same type of receiver was used, although heterodyne reception was necessary, due to the weak fields received. The audio-frequency output from the receiver was fed through a logarithmic audio-frequency amplifier-rectifier unit, and recorded by a Bristol recording milliammeter. This equipment was supplied from 6-volt storage batteries, which operated two 250-volt dynamotors. The receiver was calibrated manually about once an hour, over the range of signal input being recorded. The recorder chart speed was 12 inches per hour, to accommodate the more rapid fading encountered at this location.

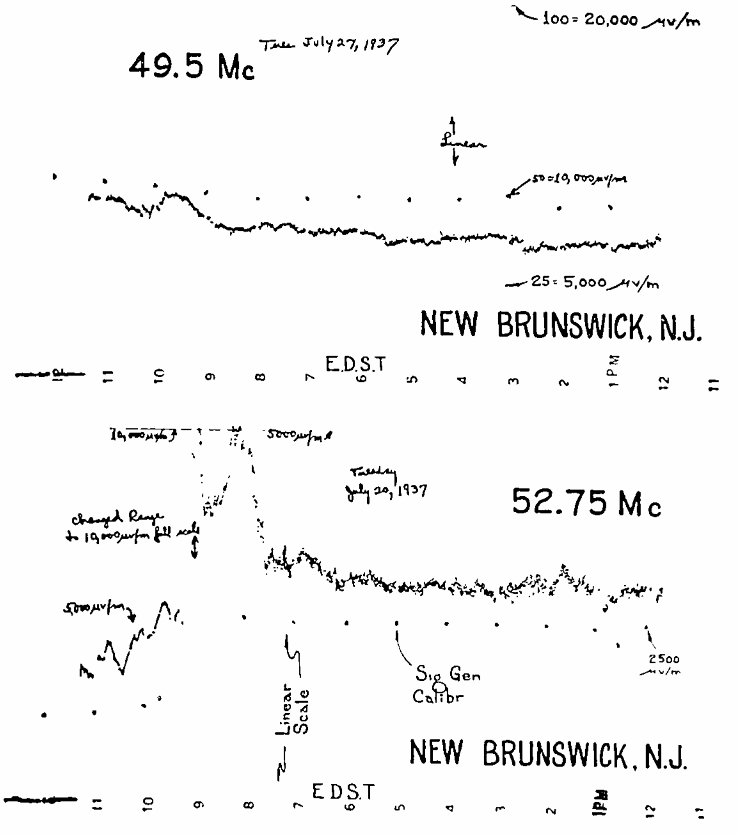


Fig. 3—Sample charts recorded at New Brunswick, New Jersey

All receiving antennas were horizontal half-wave doublets, placed at right angles to the transmitter. The antenna effective height was calculated from the physical dimensions of the doublet, and from a measurement of the transmission-line loss from antenna to receiver.

Recordings were made simultaneously at all three receiver locations during the period July 20 to July 30, 1937. During this time, the 52.75-megacycle transmission was observed on four days, and the 49.5-megacycle channel was observed on five days. The daily schedule was from 12 o'clock, noon, to 10:30 P.M., E.S.T., thus allowing propagation to be studied during daylight and darkness.

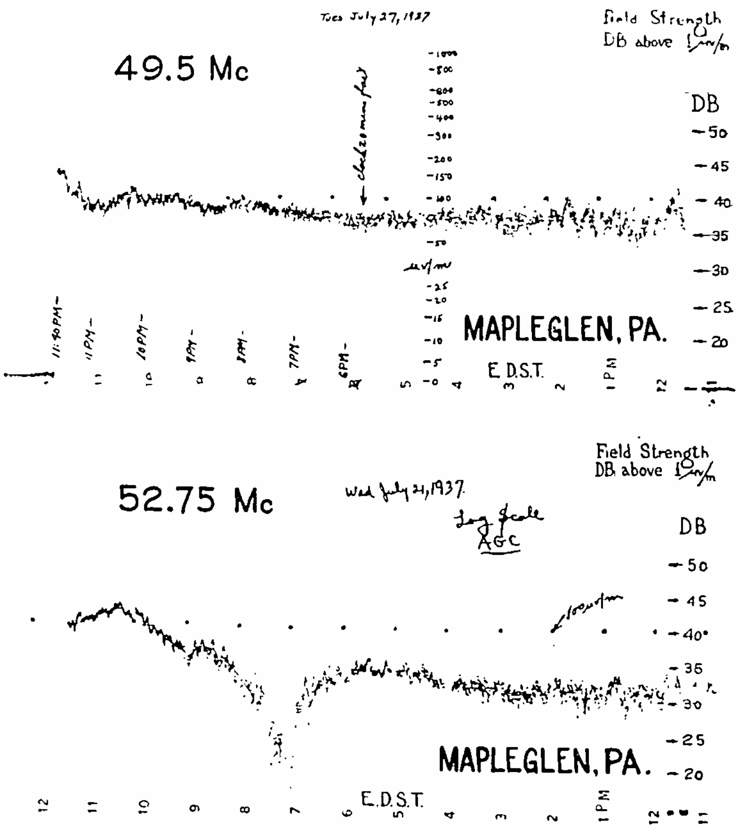


Fig. 4—Sample charts recorded at Mapleglen, Pennsylvania.

A profile drawing of the transmission path has been prepared in Fig. 2. This is merely a graph in which elevations are plotted vertically (to an exaggerated scale), and distances along the earth's surface are plotted horizontally. Antenna heights above ground are denoted by the letter *h*, and ground elevations above sea level are denoted by *a*. The receiver at New Brunswick is within the optical path, although it is not apparent from this drawing.

A number of the original charts are shown in Figs. 3, 4, and 5. Examples of stable and unstable propagation are included, for each receiving location. Each chart in Figs. 3 and 4 is the record for one whole day, while the charts in Fig. 5 are for only 50 minutes each. Variation, even in the daytime, at New Brunswick is apparent in Fig. 3. The two charts of Fig. 5 are interesting, since both are evening records taken on the same frequency. The smooth trace was the steadiest and, except for about a minute, the strongest field received at Reisterstown. The variable trace was taken several hours before a thunderstorm occurred, and is typical of the fading signal received at this location. The differences between the sample charts are caused by varying propagation conditions on different days, and are not due to the slightly different frequencies which were used.

The three records for each day, one from each location, were analyzed and replotted on a single sheet, to compare the field strength at each location simultaneously. The analysis was made on the basis of maximum, minimum, and average values of field strength observed in each half-hour interval. Two striking examples of the random slow fading which was observed at the more distant locations are found in Figs. 6 and 7.

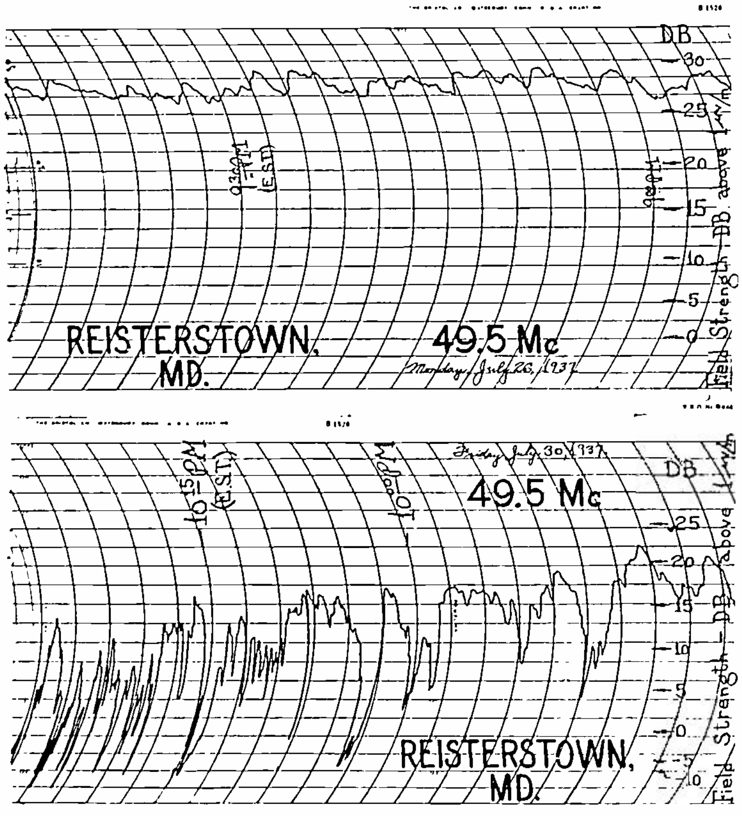


Fig. 5—Sample charts recorded at Reisterstown, Maryland.

All of these daily field-strength curves were examined for possible correlation of fading at Mapleglen and Reisterstown. Since the maximum and minimum values of field strength might occur over a very short period of time at Reisterstown, it was thought that only a change in the average field over an hour period would be representative of a definite trend. With this in mind, a change of 6 decibels in average field strength during one hour was arbitrarily defined as a fluctuation or swing.

Examination of all the curves revealed only one such simultaneous fluctuation in the same direction at Mapleglen and Reisterstown, and two instances of fluctuation in opposite directions. If the definition of a fluctuation be reduced to 3 decibels change in average field during one-half hour, there were two fluctuations in the same direction, and five in opposite directions. Simultaneous recordings were made during 88.5 hours, so the fluctuations, as defined, may be expressed as percentage of the total time. A tabulation of this analysis is shown in Table I.

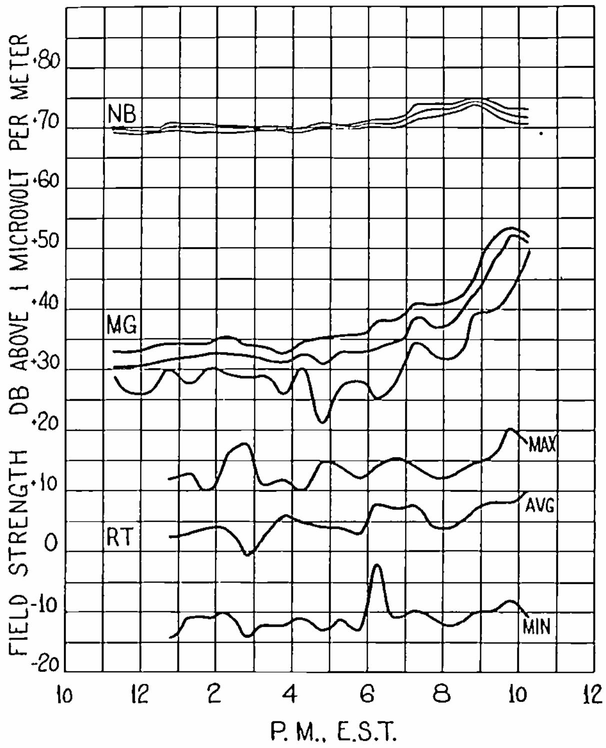


Fig. 6—Analysis of date for July 20, 1937. 52.75 megacycles, 3.6 kilowatts. (Not corrected for receiving antenna heights.)

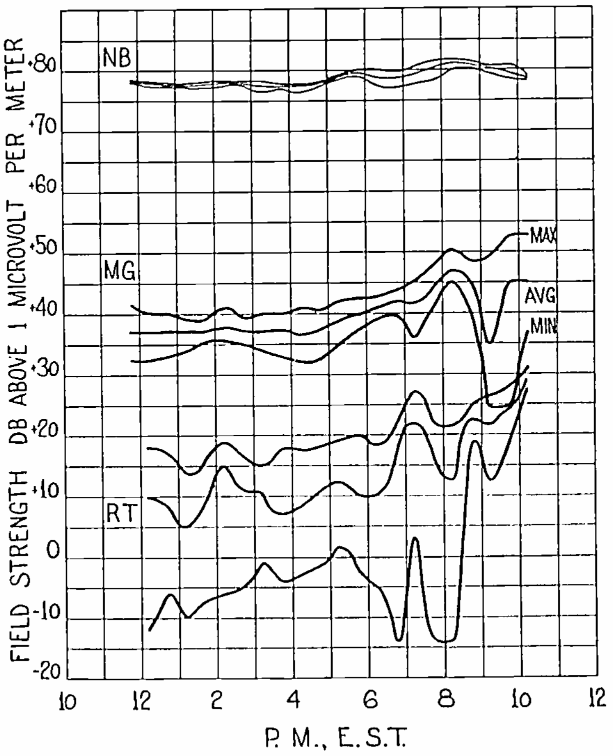


Fig. 7—Analysis of data for July 29, 1937. 49.5 megacycles, 10 kilowatts. (Not corrected for receiving antenna heights.)

TABLE I
FADING CORRELATION

Type of fluctuation (average signal)	Same direction		Opposite direction	
	Number of fluctuations	Per cent of total time	Number of fluctuations	Per cent of time
6 decibels change in one hour	1	1.1	2	2.2
3 decibels change in half hour	2	1.1	5	2.8

From the above tabulation it is apparent that the fading beyond the horizon is very rarely simultaneous at different locations in line with the transmitter.

An additional comparison between signal strength at Mapleglen and Reisterstown is shown in Fig. 8. In this case, the ratio of field strength at the two locations has been plotted for each half hour, over the complete transmission schedule. This graph bears out the lack of correlation of fading at the two locations, and shows the random behavior of the average field strength beyond the horizon.

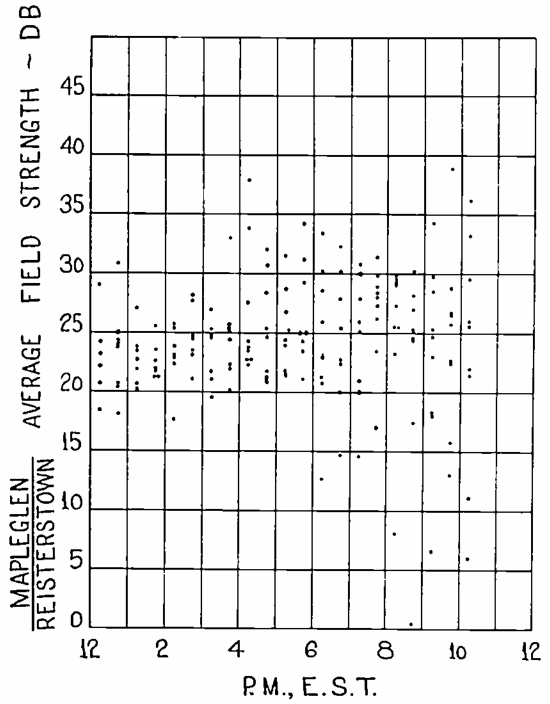


Fig. 8—Comparison of average field strength at Mapleglen and Reisterstown, July 20 to July 30, 1937. (Corrected to receiving antenna height of 10 feet.)

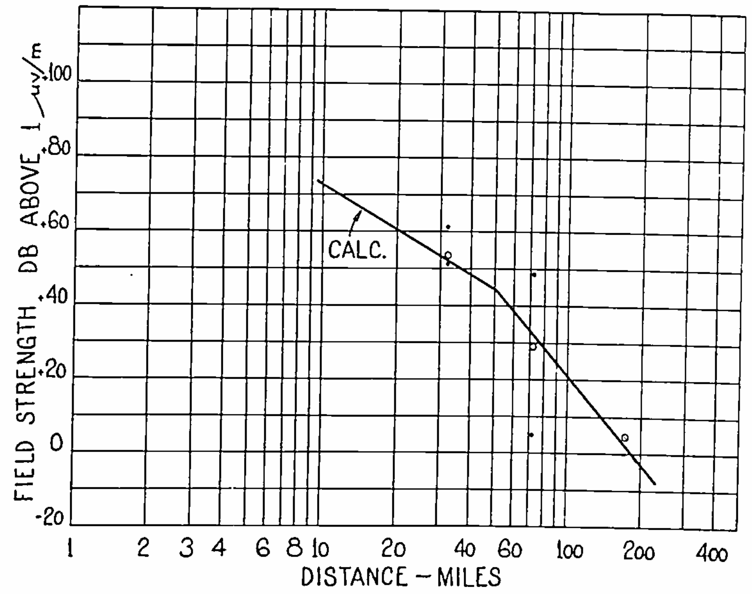


Fig. 9—Comparison of calculated and experimental data. 52.75 megacycles, 3.6 kilowatts.

Table II, showing range of fading at each location, was obtained from inspection of all the daily performance curves. The minimum change in signal level during a half hour and the maximum change in a half hour for both day and night conditions are tabulated.

TABLE II

Range of Fading

Location	Day		Night		Highest to lowest in one day
	Minimum	Maximum	Minimum	Maximum	
	decibels	decibels	decibels	decibels	decibels
New Brunswick	1/2	2	1/2	3	10
Mapleglen	2	17	2	30	35
Reisterstown	15	40+	3	35+	49+

The ratio of the highest maximum to lowest minimum occurring in a single day is also tabulated.

A comparison of calculated and observed field strength on 52.75 megacycles at the various distances is found in Fig. 9. Up to the optical horizon, the solid line has been calculated from the level-ground, grazing-incidence formula.[4] Beyond the optical distance, the slope of the calculated line was obtained from the empirical curve published by H. H. Beverage.[5]

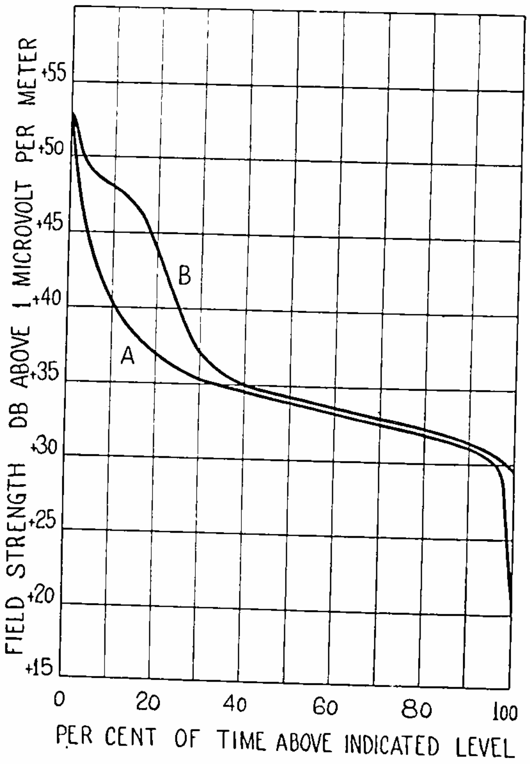


Fig. 10—Time analysis, 52.75 megacycles at Mapleglen.
Curve *A*—Total time, July 20–23, 1937.
Curve *B*—Highest single day, July 20, 1937.

In this graph, the average strength is indicated by the circled points, while the maximum and minimum fields are the plain dots above and below the average points. No minimum is shown for Reisterstown, since at times the signal was inaudible. The agreement between the calculated and observed average field is within 3 decibels.

The increase in field strength at New Brunswick during the evening is interesting, since this location is within the optical distance. The average field was 1.5 to 7 decibels stronger at night than in the daytime, although the fading was not necessarily increased. Comparison of average field strength during the day, with the highest average value observed at night, revealed a mean increase of 3 decibels. An increase of this magnitude is equivalent to doubling the transmitter power for an appreciable time during the evening. Such consistent daily increase in average field would point to a refraction effect, even within the optical distance.

While a knowledge of the upper and lower limits of field strength is important, more complete information is conveyed by associating field strength with relative time. This is done by plotting the per cent of the total time during which the field strength was above various levels. Such curves, for 52.75 megacycles, at Mapleglen and Reisterstown, are found in Figs. 10 and 11. In these graphs, curve *A* represents the analysis for the total time on 52.75 megacycles, and curve *B* is the performance on the highest single day. This type of curve is most useful in predicting field strength from either the service or interference viewpoint.

The curves of Fig. 12 are an attempt to show the variation of field strength at various distances from the transmitter. Certain liberties may have been taken in drawing curves through only one or two points, but it was thought that this relation of field-strength variation with distance would be of interest. Curve *A* represents the maximum variation observed in one day, drawn from data taken at New Brunswick and Mapleglen. Curves *B* and *C* were derived from the time-analysis curve (Fig. 10) when the highest and lowest values of field strength were disregarded.

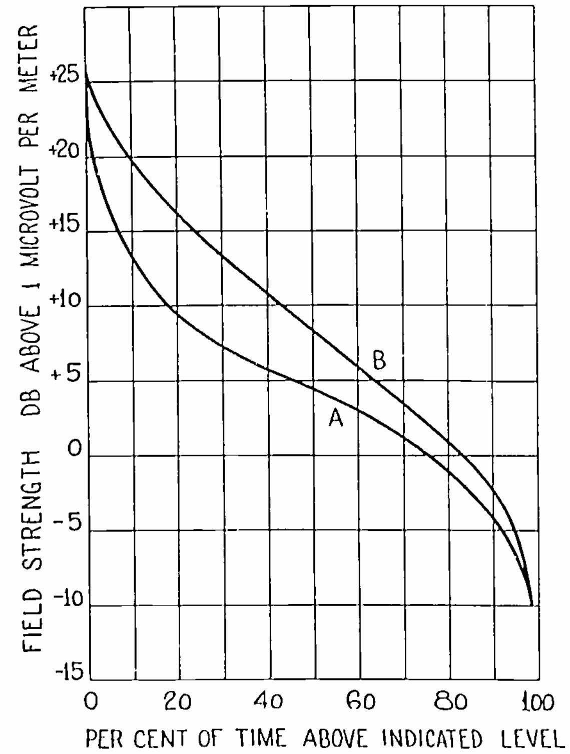


Fig. 11—Time analysis, 52.75 megacycles at Reisterstown.
Curve *A*—Total time, July 20–23, 1937.
Curve *B*—Highest single day, July 20, 1937.

Curve *B* represents the variation when the highest and lowest 5 per cent of the time are neglected, and *C* is the variation when the highest and lowest 10 per cent of the time are neglected.

Conclusions

The rate of attenuation of the average field strength out to the horizon confirmed previous data, decreasing as the inverse square of the distance. Beyond the horizon, the average field strength decreased approximately as the inverse fourth power of the distance. At times, usually at night, large increases in average field took place at all receiving points, attributed to refraction in the lower atmosphere. At both the 72-mile and the 172-mile locations, the maximum field was about 20 decibels greater than the average field. Slow variations in field strength up to 10 decibels occurred within the optical distance, while beyond the horizon, both slow and fast variations were larger in amplitude. Examination of all records revealed no definite correlation of fading at the two locations beyond the horizon, other than a general increase in field strength at night.

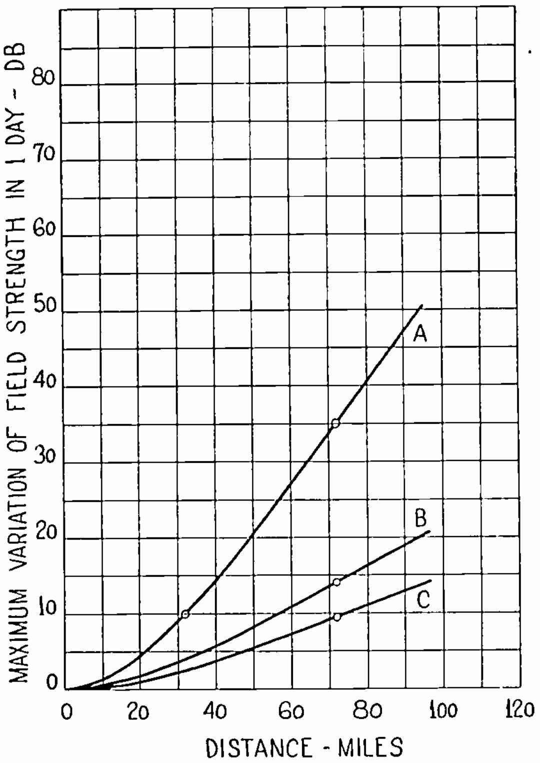


Fig. 12—Field-strength variation at various distances.
Curve *A*—Maximum variation observed in one day.
Curve *B*—Variation neglecting highest and lowest five per cent of time.
Curve *C*—Variation neglecting highest and lowest ten per cent of time.

Acknowledgment

The field work described in this paper was made possible by the co-operation of the Development Group of the National Broadcasting Company, who operated the transmitter throughout the tests.

The investigation was carried out as a continuation of ultra-high-frequency propagation studies being made by the Research and Development Group of RCA Communications, Inc., under the direction of Mr. H. H. Beverage and Mr. H. O. Peterson. The receiving equipment used in the survey work was largely developed by Mr. R. W. George of this group.

Bibliography

(1) R. A. Hull, "Air-mass conditions and the bending of ultra-high-frequency waves," *QST*, vol. 19, p. 13; June, (1935).

(2) C. R. Burrows, A. Decino, and L. E. Hunt, "Stability of two-meter waves," Proc. I.R.E., vol. 26, pp. 516–528; May, (1938).

(3) C. R. Englund, A. B. Crawford, and W. W. Mumford, "Further studies of ultra-short-wave transmission phenomena," *Bell Sys. Tech. Jour.*, vol. 14, pp. 369–387; July, (1935).

(4) B. Trevor and P. S. Carter, "Notes on propagation of waves below ten meters in length," Proc. I.R.E., vol. 21, page 387, March, 1933.

(5) H. H. Beverage, "Some notes on ultra-high-frequency propagation," *RCA Rev.*, vol. 1, p. 76, January, 1937.

(6) L. F. Jones, "A study of the propagation of wavelengths between three and eight meters," Proc. I.R.E., vol. 21, pp. 349–386; March, (1933).

(7) J. C. Schelleng, C. R. Burrows, and E. B. Ferrell, "Ultra-short-wave propagation," Proc. I.R.E., vol. 21, pp. 427–463; March, (1933).

(8) C. R. Burrows, A. Decino, and L. E. Hunt, "Ultra-short-wave propagation over land," Proc. I.R.E., vol. 23, pp. 1507–1535; December, (1935).

A High-Efficiency Modulating System*

A. W. VANCE†, NONMEMBER, I.R.E.

Summary—*This paper describes a new high-efficiency modulating system in which carrier is supplied by a single tube acting as a class C amplifier. This tube drives the load through an impedance-inverting network and becomes, in effect, a constant-current generator. A second tube, working directly into the load, is operated as a class B amplifier, and is excited with a signal consisting of both side bands with carrier suppressed. For upward modulation, the second tube has an output in phase, at the load, with the first and delivers additional current to the load. For downward modulation, the second tube has an output in phase opposition, at the load, to that of the first and absorbs current which would otherwise be delivered to the load.*

The use of biases to improve further the efficiency and to reduce distortion and the use of envelope feedback to reduce distortion are described.

Introduction

DURING the last several years every effort has been made to reduce the first cost as well as the operating cost of broadcast transmitters. Operating costs consist principally of power cost and tube replacements. It is, therefore, desirable to build transmitters with as low a tube and circuit complement as possible, operating as efficiently as possible. Since the average hour-by-hour per cent modulation is quite low, it is desirable that the efficiency for unmodulated carrier be as high as possible.

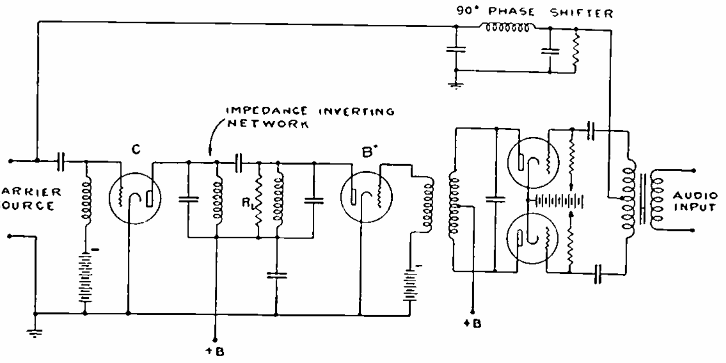


Fig. 1

There are in use in this country at present two high-efficiency systems. One of these is the high-level plate-modulation system. This system permits very high efficiency for unmodulated carrier condition, particularly if the class B modulator tubes are overbiased and the resultant distortion overcome by the use of feedback in the audio-frequency amplifier. It is also extremely stable and simple to maintain in adjustment. It does not easily permit use of feedback. The second system is the high-efficiency linear amplifier developed by W. H. Doherty.[1] This system permits fairly high carrier plate efficiency, although not equal to that of the high-level system and, since it is an amplifier, may be used with low-level modulation and thus avoid a high audio-frequency tube and circuit complement. It is, however, characterized by such nonlinearity as to make the use of feedback almost mandatory. It also requires the critical adjustment necessary in any form of low-level linear-amplifier system.

A new system which combines the advantages of the two systems just discussed has been developed in the electronics research laboratory of the RCA Manufacturing Company and will be herein described.

Theory

In Fig. 1 a simplified circuit is shown which will be used in discussing the theory of the new system. Ideal pentode plate characteristics will be assumed for tube B at this time and the more practical case of typical triode characteristics taken up later. In other words, the plate current of B shall be independent of plate voltage over the operating range. C is a class C amplifier which drives the load R_L through the impedance-inverting network shown. The tank circuits shown across R_L and in the plate of C are tuned such that they present an inductive reactance X_L at the carrier frequency, which is equal to the capacitive reactance X_C of the series capacitance C. It is well known that a class C amplifier, when sufficiently excited, constitutes a nearly constant voltage generator for load impedances sufficient to produce plate-voltage saturation. Therefore, for purposes of explanation it will be assumed that C forces a constant radio-fre-

---

* Decimal classification: R410. Original manuscript received by the Institute, July 21, 1938. Presented, I.R.E. Convention, New York, N.Y., June 16, 1938.

† Electronic Research Division, RCA Manufacturing Company, Inc., Camden, N. J.

[1] For further information see W. H. Doherty, "A new high-efficiency power amplifier for modulated waves," Proc. I.R.E., vol. 24, pp. 1163–1182; September, 1936.

quency voltage E_c across the input to the impedance inverter at all points of the operating cycle. It can readily be shown then that a constant current is forced through R_L, regardless of its value or effective value. The magnitude of this current is E_c/Z_0 where Z_0 is the characteristic impedance of the network, $\sqrt{L/c}$. R_L is set at a value of $Z_0/2$ so that a two-to-one voltage transformation is obtained. The current through the load of course leads the voltage on the input by 90 degrees for a high-pass network as shown. Tube B, in Fig. 1, is a class B, radio-frequency amplifier which is excited by a balanced modulator of a conventional type. The radio-frequency excitation to the balanced modulator is obtained through the phase-shifting network shown from the same carrier source as that which drives C. This network introduces a 90-degree phase shift to compensate for the phase characteristic of the impedance inverter. The network shown gives a 90-degree lag but the only difference between lag or lead would be a reversal in the polarity of modulation. For no modulation, B is biased very near to cutoff and the modulator is in balance, so B draws negligible plate current. Thus, carrier is supplied to R_L at the class C efficiency of C, which efficiency is limited only by the tubes and voltages used, and so may reach high values. A balanced modulator, as shown, produces no carrier output but only the sidebands. One audio-frequency polarity gives one phase of radio-frequency output and the other the opposite phase.

For upward modulation the balanced modulator drives B so it delivers current to the load of like phase to that flowing in it caused by C. As the current in the load increases due to B, C continues to supply the same current as before and so delivers more energy since the same current is driven by C into a higher effective resistance. At 100 per cent modulation upward, B has approached voltage saturation and is delivering a current in R_L equal to that from C, and each is delivering twice the power that C supplied on no modulation. Both tubes are working at relatively high efficiencies since both are at, or near, plate-voltage saturation.

For downward modulation, the audio frequency drives the balanced modulator so it delivers radio frequency to B of such a phase that B delivers current to the load in phase opposition to that flowing in the load due to C. This causes the apparent load resistance to decrease and C delivers less power since it maintains the same current through less resistance. At 100 per cent modulation downward the current from B exactly balances that from C, and the apparent load resistance becomes zero. In this case, C supplies only its circuit losses. B delivers a current of average carrier value into a short circuit, so is subject to considerable instantaneous plate dissipation at this point in the modulating cycle. The average dissipation in B over a 100 per cent sine-wave modulation cycle is not excessive, however. In actual use, with typical program modulation, the dissipation in B is always much less than that in C, and so is of little importance. It is to be noted that as B starts upward modulation, it must start to draw current at minimum plate voltage (approximately equal to one half the direct applied voltage), and as it starts modulation in a downward direction, it must draw current at maximum plate voltage (about equal to one and one-half times the applied direct voltage). Since, in the preceding discussion, ideal pentode plate characteristics were assumed, this variation in plate voltage was of no importance in determining the grid-bias conditions for B. However, pentodes are not available in the high-power ratings, and since the characteristics of those available are not "ideal" anyway, it becomes necessary to consider more practical tubes.

If B is a triode it becomes evident that if the bias is adjusted so that it will absorb negligible power at unmodulated carrier condition, it means that it is biased just at cutoff for maximum plate voltage, and therefore is far beyond cutoff for minimum plate voltage. Thus, a large excitation of the phase which produces upward modulation must be delivered from the balanced modulator before any current is drawn by B at minimum plate voltage, and upward modulation started. Violent distortion results in such circumstances. This distortion can be overcome by reducing the bias of B so that large currents are drawn at maximum plate voltage, and small but definite currents at minimum plate voltage. This causes B to absorb a great deal of power, and thereby greatly reduce the efficiency at the unmodulated carrier condition. It is desirable that B be biased off an equal amount at both minimum and maximum plate voltage. The solution is to supply a radio-frequency bias to B such that the grid voltage is more negative when the plate voltage is maximum, and less negative when the plate voltage is minimum. The procedure is to apply a direct-current bias sufficient to bias the tube off to the desired extent for the applied direct voltage with no radio-frequency voltage present in the plate, and then apply a radio-frequency voltage equal to $-\mu E_c$, where E_c is the normal carrier voltage across the load and μ is the amplification constant of B. The radio-frequency bias is readily obtained by merely applying a direct-current unbalance to the grids of the balanced modulator in the direction of upward modulation, so the normal output at no audio-frequency input is $-\mu E_c$ instead of zero, as was the case of an ideal pentode for B. This radio-frequency bias could, of course, be obtained from any source of excitation, such as from either the grid or plate of C, through appropriate phase-shifting networks in each case. The use of radio-frequency bias on B permits the use of any type tube for B with practically the same efficiency and distortion as would be obtained with pentodes.

Since the impedance facing B varies from a high impedance at 100 per cent modulation upward to zero for 100 per cent downward, it is to be expected, particularly if B is a triode, that the gain of B will be higher for downward modulation than for upward, and thereby tend to produce considerable, even-harmonic, distortion. This is offset by the regulation of the class C stage C. This stage, in practice, is not a constant-voltage generator, as assumed in the previous discussion, so the output voltage will rise as the load impedance increases. From zero modulation to 100 per cent modulation upward, the load varies two to one, while from zero modulation to 100 per cent down, the load may vary 20/1, or more. Therefore, in most cases the output voltage will rise more on the downward modulation part of the cycle than it falls on the upward part of the modulation cycle. This tends to compensate for the increased gain of B on the downward cycle. The actual compensation so obtained will, of course, depend on the tube, the load at no modulation, and the exciter characteristics. This distortion also can be reduced by unbalancing the center tap of the secondary of the audio-frequency input transformer to the balanced modulator, so its output is greater on the upward part of the modulation cycle.

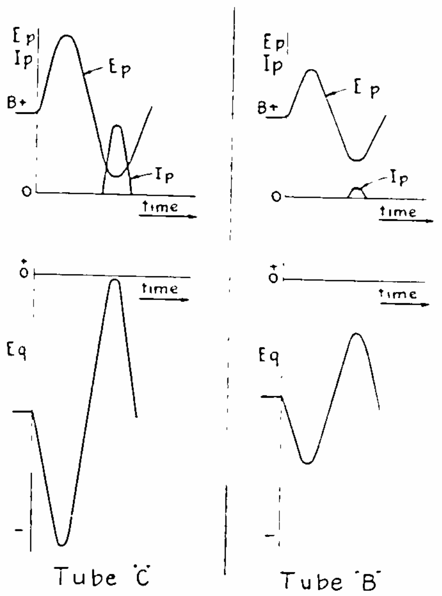


Fig. 2—Unmodulated carrier.

When feedback is used, as is usually the case, the before-mentioned distortion is of little moment since it is of a smooth, low-order character and relatively easily degenerated out. In practice, the zero-signal current of B is kept as low as possible to permit the highest practical efficiency at carrier, and the resultant odd-harmonic high-order distortion removed by the use of feedback, whereupon the distortion due to the varying load on B is removed along with the rest.

The radio-frequency bias may be avoided by the use of two tubes to replace B. One tube may then be used for upward modulation and the other for downward modulation. Then separate plate voltages and direct-current biases may be used for each tube. The downward-modulating tube need only be supplied with enough direct plate voltage to enable it to supply radio-frequency current of average carrier value into a short circuit. The upward-modulating tube would require, as in Fig. 1, the same direct voltage as C. Each tube is, of course, direct-current biased so as to draw equally small zero-signal currents. This system has some merit in that the dissipation at 100 per cent modulation down is greatly reduced. However, the extra tube complement and the necessity for an extra power supply, more than offset the higher efficiency at 100 per cent modulation down since this condition exists a negligible part of the time.

Referring again to the circuit in Fig. 1, it has been pointed out that B should be as overbiased as possible without excessive distortion. Obviously, some current must be drawn by B if any control is to be had at all for small signal inputs. For a given amount of feedback and given distortion, a certain current must be drawn by B. This current may be drawn essentially over the whole radio-frequency cycle and constitutes a pure direct-current loss and so neither absorbs from, nor delivers power to, the load, or it may be drawn at maximum plate voltage and absorb power from the load, or it may draw its current at minimum plate voltage and deliver some power to the load. This latter condition is, by far, the most efficient since plate current is drawn at the lowest possible voltage, and a fair percentage of the power drawn from the plate supply is fed into the load. Efficiency of the order of 30 per cent, or better, is possible for B in such circumstances.

In a typical instance where the efficiency of C is 75 per cent, and B delivers 5 per cent of the total unmodulated carrier power, an over-all efficiency at carrier of about 70 per cent is obtained. If current were drawn at maximum plate voltage, the carrier efficiency would drop to about 63 per cent, and if B drew uniform current and absorbed, or delivered, no radio-frequency power, the efficiency would be of the order of 66 per cent. Thus, the most efficient condition results when a slight excess of radio-frequency bias is used. In Figs. 2, 3, and 4 the grid-voltage—plate-current conditions are illustrated for tubes C and B for unmodulated carrier, 100 per cent modulation down, and 100 per cent modulation up, respectively. All tubes are assumed to be operating in the negative grid region to avoid any complications due to grid currents. In Fig. 2, C is seen to be delivering the major portion of the carrier power with good efficiency since it is working at plate-voltage saturation. B is delivering a small amount of the carrier power at fair efficiency. In Fig. 3, C is seen to be delivering negligible power and is also absorbing little power from $+B$. B is delivering average carrier current into a short circuit. The phase of B's excitation is seen to be reversed in phase from the radio-frequency bias shown on *B* in Fig. 2.

In Fig. 4, representing 100 per cent modulation upward, *C* is delivering its full load and *B* is also delivering its full load at plate-voltage saturation. The load is equally divided and both tubes are operating at high efficiency.

It is of interest to note that if *B* is a triode, (as is the case illustrated in Figs. 2, 3, and 4) at some point between zero modulation and 100 per cent down, no radio frequency at all is applied to the grid of *B*, and it therefore is a simple absorber at this point.

It is also worthy of note that with this system, overmodulation in the downward direction results in a different type of distortion than that ordinarily produced. If the excitation on *B*, of downward-modulating phase, is increased such that *B* delivers more current to the load than *C*, then there results a reversal of phase of the load, or antenna voltage. Since *B* is far from voltage, or emission, saturation at this point it is capable of forcing considerable reversed current through the load.

Thus, overmodulation in the downward direction does not result in distortion in one sense since it represents merely an excessive ratio of sidebands to carrier and not distortion of the modulating wave form. No new sidebands are produced so no interchannel interference is caused, as is the case when ordinary transmitters are overmodulated downward and the downward peaks are sharply cut off. In the upward direction there is no sharp limitation at 100 per cent modulation. The only limitation is that of emission or voltage saturation of the tubes, so the distortion for over 100 per cent modulation upward is decidedly less than that for overmodulation downward in the ordinary case. One hundred per cent modulation upward is an arbitrary value and, by design, the limitation can be set at any figure, 125 per cent, 150 per cent, etc. The new system permits similar control for downward modulation. It is possible to design it so it will overmodulate to almost any desired extent without production of harmonics of modulation frequencies and consequent interchannel interference.

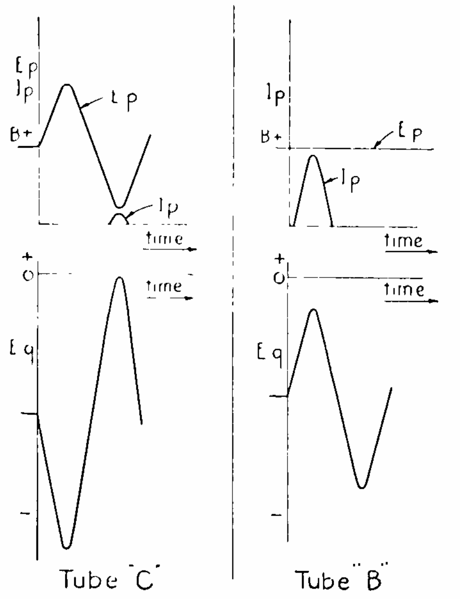


Fig. 3—100 per cent modulation downward.

The distortion produced at the receiver should not be seriously different than that ordinarily obtained except in cases where the selectivity of the receiver is so great as to reduce the per cent modulation such that the carrier envelope applied to the detector is not overmodulated and, consequently, no distortion is obtained. This effect would apply only to overmodulation by high audio frequencies or by sharp peaks of large high-frequency content and so is of little importance.

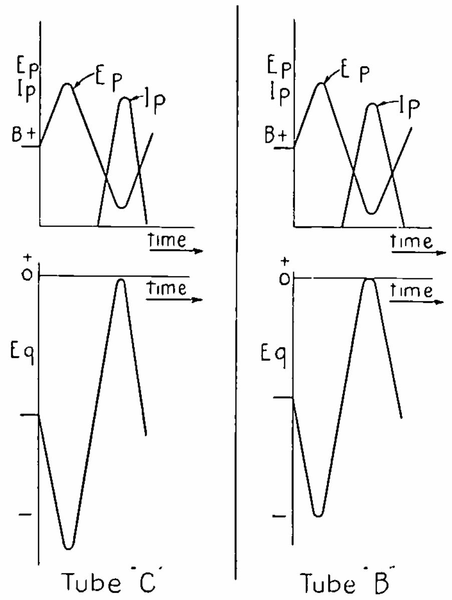


Fig. 4—100 per cent modulation upward.

The problems encountered in the application of feedback to this modulation system are about the same as those encountered with a Doherty linear amplifier, or an ordinary linear-amplifier system. There is, however, one precaution that must be taken which is peculiar to this system. As was pointed out in the previous discussion, overmodulation downward causes reversal of output phase. The detector current at this point starts to rise again for the portion of the wave beyond 100 per cent modulation downward, and the polarity of modulation is effectively reversed at this time. This causes a reversal of feedback phase and serious instability. A solution has been found. A fixed, unmodulated carrier is applied to the feedback rectifier along with the transmitter output, so that the percentage modulation at the rectifier is reduced to the point where saturated transmitter output still represents less than 100 per cent modulation at the rectifier. When this is done the system operates with feedback in the normal manner wherein stability is determined by the phase and gain characteristics around the feed-back loop. Thus, with this system the feedback is effective in reducing any extra sidebands, even when over 100 per cent modulation downward is obtained. This effect is impossible with any other system.

EXPERIMENTAL RESULTS

A small, experimental transmitter was built operating at a low frequency and using receiving tubes operating in the negative-grid region. Feedback was applied so low zero-signal current in *B* could be obtained and, consequently, high carrier efficiencies were possible. The frequency was 200 kilocycles, so chosen to facilitate examination of carrier-frequency wave forms with a cathode-ray oscillograph. Neutralizing was avoided also by the low carrier frequency. The carrier power output was about 5 watts.

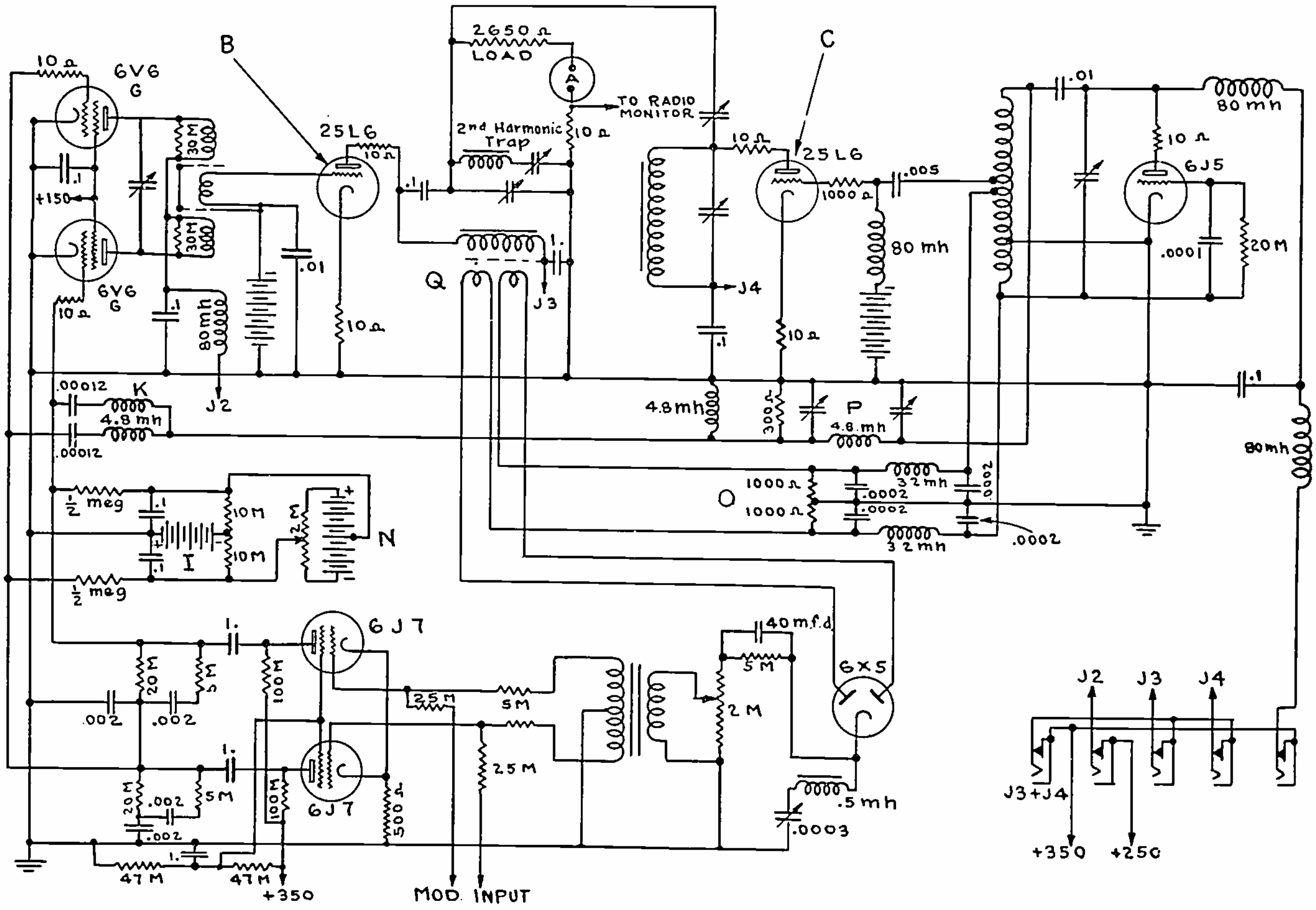


Fig. 5

The experimental results were in no way at variance with the theory and predicted operation. Carrier efficiencies of 80 per cent were obtained with *B* operating as a pentode and 70 per cent was realized with *B* as a triode, with reasonably low distortion for modulating frequencies up to 5 kilocycles. Higher modulation frequencies were considerably distorted due to the phase characteristics of the feedback loop and the low carrier frequency. The efficiency was measured as the ratio of the actual power in the load to the plate input to tubes *B* and *C*. Since circuit losses had to be supplied, the true plate efficiency of the tubes was somewhat higher than the values given.

The circuit diagram of this test transmitter is show in Fig. 5. The 6J5 tube shown in the upper right-hand corner connected as a conventional oscillator, constitutes the carrier-frequency source. The 25L6 class C tube, labeled *C*, is excited through a choke and condenser fed directly from the oscillator. *C* supplies current to the 2650-ohm load through the high-pass impedance inverter shown. Power output is measured by observing the current through the load resistor by means of the thermal milliameter marked *A* in Fig. 5. The 25L6 tube, labeled *B*, is the main modulator and it, of course, drives the output tank and load directly. Good radio-frequency wave form is insured by the use of the series-resonant trap shown connected across the main tank. In practice, its function would be taken over by antenna filters. *B* is driven by the two 6V6G tubes from a balanced and shielded radio-frequency transformer. The two 6V6G's, constituting the balanced modulator, are supplied with carrier excitation from the oscillator through phase-shifting and impedance-transforming network *P* and series-resonant circuits *K*. The common component of direct-current bias for the two 6V6G's is obtained through the one-half megohm resistors shown and the battery *I*. The differential bias for the balanced modulator is supplied by the center-tapped battery *N* and associated potentiometer. This potentiometer is used to set the value of radio-frequency bias output from the balanced modulator and also for applying direct-current modulations to the transmitter for test purposes. Audio-frequency modulating voltage is applied in push-pull to the balanced modulator grids by the push-pull 6J7 pentode stage shown. The resistance-capacitance networks connected across the output of each 6J7 are phase-control circuits which increase the degree of stable feedback obtainable. The audio-frequency input and the feed-back voltage are combined in the grid circuit of the 6J7 stage. The feedback rectifier is the full-wave diode 6X5 which is supplied with transmitter output by the split coupling coil Q, inductively coupled to the main output.

The fixed carrier for reducing the per cent modulation of the signal reaching the diode is inserted between the sections of Q by the push-pull phase-shifting and impedance-transforming network O driven from the oscillator. The 6X5 diode output feeds into the 6J7 grids through the push-pull transformer shown. This transformer is an extremely wide-band affair of relatively low impedance, and so imposes no limitation on the feedback loop. The series-resonant circuit shown across the diode output is tuned to the second harmonic of the carrier to eliminate any possible radio-frequency transmission around the feedback loop. About 30 decibels of feedback at 500 cycles were obtained. The feedback dropped off with frequency reaching unity at about 50 kilocycles.

CONCLUSION

The new system has, under theoretical and experimental examination, been shown to meet all the requirements for high-efficiency broadcast transmitters; namely, it has the (1) highest possible plate efficiency for unmodulated carrier, (2) uses the minimum number of tubes, (3) requires no large or costly audio-frequency components, and (4) permits the use of over-all feedback.

The system is unique in that overmodulation is possible without causing interchannel interference, due to harmonic sidebands.

ACKNOWLEDGMENT

The writer wishes to express his gratitude to Dr. V. K. Zworykin for his invaluable advice and encouragement throughout the progress of this development, and to Mr. J. M. Morgan for aiding in the construction and test of the experimental transmitter.

Contrast in Kinescopes*

R. R. LAW†, ASSOCIATE MEMBER, I.R.E.

Summary—*One of the problems in the art of reproducing a scene by television is to obtain an image with adequate contrast. Although a relatively low contrast range may suffice for the transmission of intelligence, a much greater contrast range is essential for the reproduction of clear, lifelike images.*

The factors harmful to contrast in the kinescope are well known and may be studied in a variety of ways. In the belief that the reaction of the observer is the ultimate criterion for judging the perfection of the image, the author began the present investigation with a series of viewing tests designed to determine the relative psychological effects of the various factors harmful to contrast. On the basis of these tests, it was definitely concluded that halation is far more detrimental to image quality than screen curvature or bulb-wall reflections.

Experimental evaluation of the relative importance of the individual factors harmful to contrast leads to the same conclusion, and it is evident that a considerable improvement in contrast could be effected by reducing halation.

A detailed analytical study of halation shows how it depends upon various parameters. Particularly significant is the conclusion that halation may be reduced several fold by introducing a small amount of light-absorbing material in the kinescope face. According to this analysis, a 10 to 20 per cent absorption should give a three- to sixfold reduction in halation.

Developmental kinescopes made in accordance with these principles give greatly improved contrast. Not only does reduction of halation substantially double or triple the length of the scale available for the reproduction of half tones, but it has a marked effect upon the sharpness of the image.

I. INTRODUCTION

ONE OF the problems in the art of reproducing a scene by television is to obtain an image with adequate contrast. This problem is more significant than it may appear on first inspection, because it involves not only the technical performance of the television system, but also the ability of the observer to see. Seeing, in turn, is an exceedingly complex physiological and psychological process. Among the factors governing this process, contrast occupies an important position.[1]

Contrast, according to the dictionary definition, expresses a state of difference or unlikeness. The differences with which we shall have to deal are differences in brightness. An objective, or brightness, contrast may be defined as the ratio of two brightnesses; or on the other hand, in terms of visual effects, a subjective contrast may be defined as the logarithm of the ratio of two brightnesses. The necessity for taking the logarithm of the ratio of the two brightnesses to obtain the subjective contrast is brought about because, as enunciated by the Weber-Fechner law,[2] a stimulus increasing in geometric progression is required to produce a sensation increasing in arithmetic progression. We shall, therefore, speak in terms of subjective contrast when we consider observer reactions. However, insofar as our photometric measurements are concerned, it will be more convenient to use the objective definition and define contrast as the ratio of two different brightnesses.

Although softness of outline and mildness of contrast have a very definite place in the rendition of

---

* Decimal classification: R583. Original manuscript received by the Institute, July 5, 1938. Presented, I.R.E. Convention, New York, N.Y., June 17, 1938.

† RCA Manufacturing Company, Inc., RCA Radiotron Division, Harrison, N. J.

[1] M. Luckiesh and F. Moss, "The Science of Seeing," D. Van Nostrand, New York, (1937).

[2] J. W. T. Walsh, "Photometry," Constable and Company Ltd., London, (1926).

artistic effects, a television system is also called upon to transmit lifelike, high-definition half tones. In the accomplishment of this end, contrast is significant in several respects. Thus, good half-tone reproduction requires a long scale of tone values which can only be realized with a large over-all contrast range. Then too, in a complex pattern, the apparent, or subjective contrast depends upon the gradient between two areas of different brightness. For this reason, contrast between adjacent picture elements is important. And finally, as is well known in the photographic art,[3] the relative brightnesses of the intermediate tonal values has much to do with the lifelikeness of the reproduction.

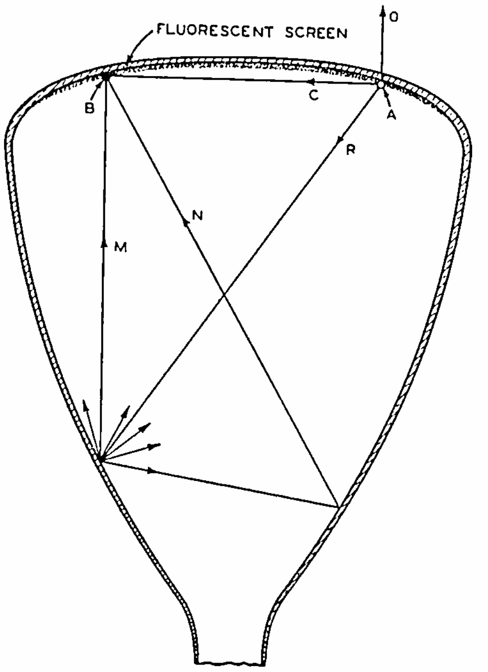


Fig. 1—Schematic diagram illustrating how screen curvature and bulb-wall reflections are detrimental to contrast.

In the present electronic television system,[4] contrast is determined by many factors, both at the transmitter and at the receiver. Although the kinescope[5] does not seriously limit contrast at the present time, a greater and greater burden is thrown on it as the character of the television signal is improved. This paper is intended to report the results of an investigation of the factors limiting contrast in the kinescope itself insofar as they influence the over-all contrast range and modify the contrast between adjacent picture elements.

The factors harmful to contrast in kinescopes are well known.[6] Those familiar with the design of television cathode-ray tubes recognize that halation, curvature of the luminescent screen, bulb-wall reflections, room illumination, and stray electrons influence contrast. By way of review, let us examine these factors briefly to see how each may be detrimental.

In the conventional direct-viewing kinescope, the television picture is reproduced on a fluorescent screen which is deposited on the inner, curved surface of the bulb, as shown in Fig. 1. An examination of typical light-ray paths will reveal immediately how curvature of the screen and bulb-wall reflections are harmful to contrast. Suppose that point A represents a bright region of the image, while point B represents a region that normally would be dark. Inasmuch as the fluorescent screen is substantially a perfect diffusing surface, the light flux from point A is scattered in all directions. A portion of this light flux, represented by the arrow A-O, comes out through the bulb face toward the observer. Another portion, represented by the arrow A-C, travels directly across the curved screen to the dark region B. Still another portion of the light flux, represented by the arrow A-R, impinges on the bulb walls. After successive partial reflections and scatterings, a portion of this light flux, represented by the arrows N and M, finds its way to the dark region. Thus, the degree of darkness in the region B is dependent upon the brightness of other portions of the picture.

To understand how halation comes about, let us examine a section of the kinescope face in more detail. Fig. 2 shows a cross-sectional view of the fluorescent screen and glass face of a typical kinescope. Let us see what happens to the light flux emitted by a small bright area 0. The light ray 0–1 which strikes the glass-air interface perpendicularly will be undeflected and only a small portion, about four per cent, will be reflected. Rays such as 0–2 and 0–3 which strike the interface obliquely will be refracted away from the normal and a small portion, still about four per cent, will be reflected. As the angle of incidence is increased, the transmitted ray is bent more and more away from the normal and somewhat more than four per cent is reflected. However, as soon as the angle of incidence is equal to or greater than the critical angle, not just a few per cent, but the entire amount of the light flux is returned to the fluorescent screen. Thus, in the case of complete optical contact between the fluorescent particles and the glass support, a bright spot would be surrounded by a dark

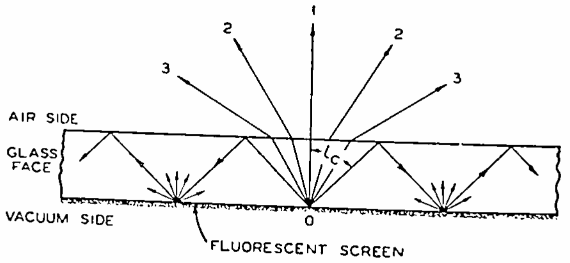


Fig. 2—Cross section of kinescope face showing how total internal reflections produce halation.

---

[3] L. A. Jones, "Contrast of photographic printing papers," *Jour. Frank. Inst.*, vol. 202, pp. 177–207; August, (1926).

[4] V. K. Zworykin, "Iconoscopes and kinescopes in television," *RCA Rev.*, vol. 1, pp. 60–84; July, (1936).

[5] V. K. Zworykin, "Description of an experimental television system and kinescope," Proc. I.R.E., vol. 21, pp. 1655–1673; December, (1933).

[6] I. G. Maloff and D. W. Epstein, "Electron optics in television," McGraw-Hill Book Company, New York, (1938).

circular area and a concentric circle of illumination whose brightness decreases with radial distance. In general, however, the inner glass surface is not entirely in optical contact with fluorescent particles; consequently, only a portion of the light flux enters the particles on its first return to the screen. The remaining portion is again totally reflected and thus gives rise to successive internal reflections. Because of this, the bright spot is usually surrounded by not one, but by a series of concentric circles of illumination of diminishing brightness, as illustrated in Fig. 3. This spurious illumination around the spot is detrimental to contrast.

Room illumination is also important in determining contrast. Although we shall not discuss this problem at the present time, we may reflect that similar difficulties are encountered in the photographic and projection arts and that the corrective methods[7,8] therein developed are applicable to the television problem also.

The effects of stray electrons are of very little importance.[6] Electron-gun design has been so perfected that stray electrons are no longer significant in determining contrast.

So much for the review. Inasmuch as room illumination is external to the kinescope, and inasmuch as stray electrons are unimportant with electron guns of modern design, let us eliminate these two factors. We shall concern ourselves henceforth with the effects of halation, screen curvature, and bulb-wall reflections.

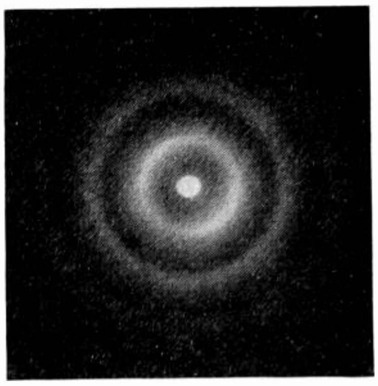


Fig. 3—Appearance of stationary spot on kinescope screen illustrating series of concentric circles of illumination occasioned by halation.

II. Psychological Effects of the Various Factors Detrimental to Contrast

We have seen how halation, screen curvature, and bulb-wall reflections may be detrimental to contrast, and we shall certainly wish to examine the physical aspects of these factors in more detail. However, before we do this, let us take a comprehensive look at the subject as a whole and see if we can get a perspective view of the relative importance of these factors. In the belief that the psychological reaction of the observer is the ultimate criterion for judging the perfection of the image, a logical procedure is a series of viewing tests designed to determine the relative psychological effects of these factors. Such viewing tests are facilitated by an apparatus illustrated in Fig. 4 which permits two images portraying identical subject matter to be compared directly. These images are derived from two substantially identical projectors arranged to project two substantially identical slides on two different viewing screens, one above the other. The only important difference between the two images is occasioned by the unlike viewing screens.

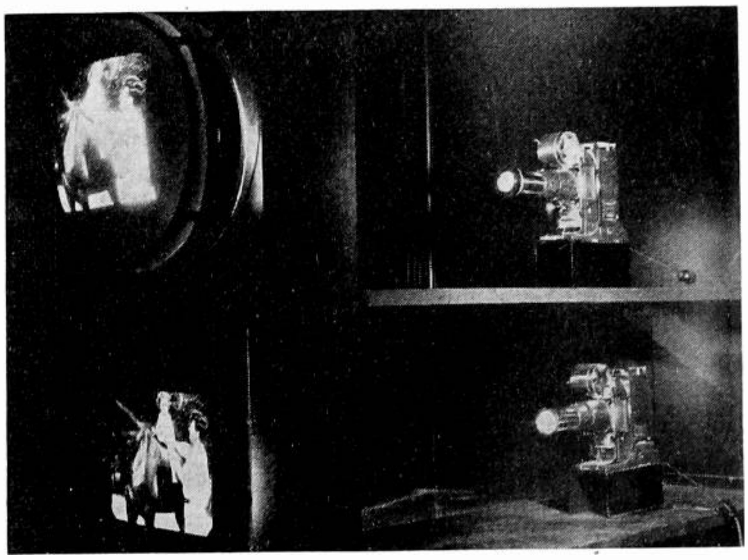


Fig. 4—Apparatus for comparing images reproduced on different screens. Upper image reproduced on conventional kinescope screen. Lower image reproduced on thin mica screen.

Various viewing screens have been used in these tests. The upper image in Fig. 4 is reproduced on a conventional kinescope bulb face coated with willemite in much the usual manner. This screen is subject to the defects of halation and screen curvature. Semireflecting surfaces were introduced behind the viewing screen to simulate bulb-wall reflections. A flat glass plate, of the same thickness as the kinescope face, coated with a suitable layer of willemite, gives a viewing screen free from the defect of screen curvature. A thin, flat, glass plate coated with willemite makes it possible to observe the effect of reducing the spread of the halation bands. And finally, a very thin, flat, mica sheet coated with willemite gives a viewing screen substantially free from halation. The lower image in Fig. 4 is reproduced on this thin, mica, viewing screen.

That the images reproduced on these viewing screens by projection may be made to have the same characteristics as they would have if they were reproduced on similar screens by electronic means is demonstrated in the following manner. Studies of the distribution of light flux emanating from a fluorescent screen when a small area is made luminescent by impinging electrons show that the light distribution obeys Lambert's cosine law. The ratio of for-

---

[7] A. Herz, U. S. Patent 1,614,672, (1927).
[8] A. Herz, U. S. Patent 1,694,706, (1928).

ward to backward light, i.e., the ratio of brightness on the viewing side to brightness on the bombarded side, depends upon the thickness and character of the fluorescent layer.

Similar studies of the distribution of light flux emanating from a willemite-coated glass plate when a small area is illuminated from the willemite side by an external light source show similar results. So long as the willemite coating is sufficiently thick and homogeneous to prevent direct transmission of the incident beam, the light distribution will be found to obey Lambert's cosine law.

Fortunately for the analogy in hand, a fluorescent screen coated with an optimum thickness of willemite for electron bombardment gives substantially the same light distribution irrespective of whether it is bombarded with electrons or illuminated by an external light source. This is not so surprising as it may seem at first sight. Examining the willemite screen in more detail, we see that it is made up of a multitude of very small, irregularly shaped, relatively transparent, crystalline particles of moderately high refractive index. Light rays entering such particles will on the average undergo many internal reflections before they escape. Similarly, light rays produced within the particle as a consequence of electron bombardment will likewise undergo many internal reflections before they escape. In either event the result is the same; each crystalline particle is filled with a substantially homogeneous radiation, the intensity of which determines the brightness of the particle.

Provided then that the willemite layer has a sufficiently good coverage to prevent the direct transmission of light from the projector, and provided also that the ratio of forward to backward light is adjusted to the proper value by using a screen of suitable thickness, an image reproduced by optical means has the same external characteristics as an image reproduced by electronic means. This is a convenient tool. Not only is one enabled to study image characteristics without the attendant electronic equipment, but one can readily obtain images of very high quality.

So much for the justification of the experimental method. As for the results, they would be best presented by a series of photographs similar to Fig. 4. Unfortunately, however, the means of reproduction at our command are not adequate to illustrate the small differences occasioned by screen curvature and bulb-wall reflections. As an alternative, therefore, we must content ourselves with a description of the results.

The reactions and comments of a number of observers may be summarized as follows:

(1) A moderate amount of background illumination arising from semireflecting surfaces introduced behind the kinescope screen to simulate bulb-wall reflections is perceptible, but is not particularly detrimental to the general quality of the image.

(2) The image on the thick, flat, glass screen is somewhat better than the image on the curved kinescope screen. The difference is largely occasioned by the improved detail in the low lights.

(3) The image on the thin, flat, glass screen is somewhat better than the image on the thick, flat, glass screen. The difference in this case also appears to be occasioned by improved detail in the low lights.

(4) However, when we come to compare the image on the thin mica screen with the image on the thin, flat glass screen, the difference is striking. The image on the thin mica screen exhibits a snap and perfection that is entirely absent in the images reproduced on the other three screens.

On the basis of these observations, we may conclude that halation is far more injurious to contrast and image quality than screen curvature or bulb-wall reflections. Not only is halation very important in determining the over-all contrast range, but it has a marked effect upon the sharpness of the image. This sharpening of the image is very instrumental in determining the psychological reaction of the observer.

III. Detailed Study of the Individual Factors Influencing Contrast

Quite aside from the foregoing evidence, we may draw much the same conclusions by a more detailed study of the individual factors influencing contrast. Inasmuch as the regions of light and dark in a television image ordinarily will be arranged in very complicated patterns, our best approach is to analyze one representative case.

A test case readily adapted to analysis is that of a small dark spot in the center of a bright field. This is a very severe test; consequently, the results of the analysis will serve only as a yardstick for the interpretation of other patterns. For a representative image, in which the high lights constitute a relatively small part of the total picture area, the performance will certainly excel that indicated by this example. With such a test pattern in mind, let us now examine the several factors in more detail.

A. Bulb-Wall Reflections

A casual inspection of the mechanism of bulb-wall reflections will convince one that it is impractical to compute the illumination due to bulb-wall reflections for even the most elementary pattern. Referring to Fig. 1, we see that the reflections are of two kinds, direct and diffuse. The reflection coefficients for both direct and diffuse reflections are dependent upon the angle of incidence. Coupling this with the complexities of multiple reflections, the difficulties of possible ray concentrations, and the geometric shape of the bulb, we immediately see the impracticability of an analytical approach.

An experimental approach, on the other hand, is relatively simple. The apparatus illustrated on cross-section in Fig. 5 is well suited to this end. In this apparatus, a projector is arranged to illuminate a rectangular area on the screen, and the light flux contributed by bulb-wall reflections is received on the opal-glass test plate so situated in the opaque tube that it receives illumination only from the bulb walls. The brightness of the opal-glass test plate is measured by sighting the illuminometer on the image of the test plate in the mirror, while the brightness of the field is measured by viewing the screen through the opening at the bulb neck. The contrast ratio, i.e., the ratio of brightness of the field to the brightness of the dark area, is then readily determined if the transmission factor of the opal-glass test plate is known.

The merits of several bulb-blackening materials have been studied in this manner. The results of this study are summarized in Table I.

TABLE I

Effectiveness of Various Types of Bulb Coatings

Type of Bulb Coating	Contrast Ratio as Determined by Bulb-Wall Reflections Alone
Uncoated bulb	4000
Acetylene black	800
E-25B-10 (RCA)	330
Aquadag	220

These results are significant in two respects. First, inasmuch as there is a very good correlation between the observed contrast ratio with a particular type of bulb coating and the diffuse-reflection coefficient for that coating, we are led to believe that the stray illumination occasioned by bulb-wall reflections is largely a consequence of diffuse reflections. This is a tribute to the effectiveness of the bulb shape in preventing direct reflections. Second, and perhaps more significant to the problem in hand, is the relatively large value of the contrast ratio. As we continue with our analysis of the other factors detrimental to contrast, we shall see that the stray illumination arriving by bulb-wall reflections is relatively unimportant. For this reason, the type of bulb coating will have relatively little effect upon contrast.

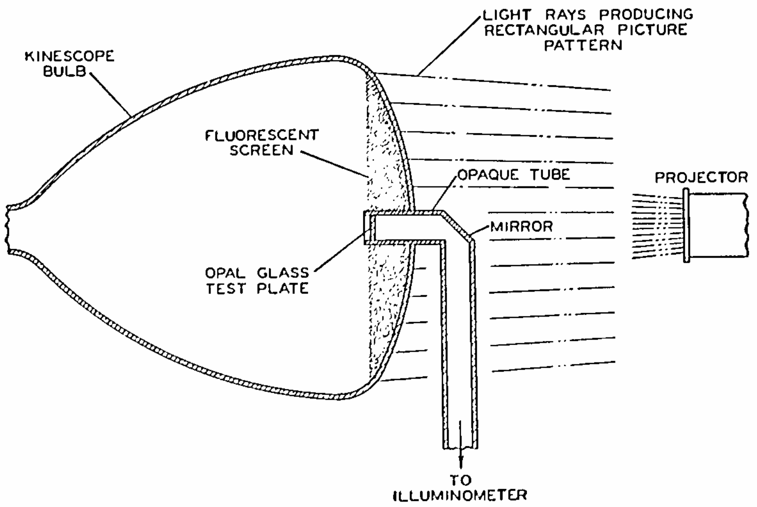


Fig. 5—Schematic representation of apparatus for measuring bulb-wall reflections.

B. Screen Curvature

The effect of screen curvature on contrast is readily determined by analytical methods. In fact, if we wished, we could compute the stray illumination caused by screen curvature quite accurately for any bulb shape. However, in view of the possible wide variations in bulb shape, we shall compromise between rigor of method and adaptability of result by assuming that the image is reproduced on the interior surface of a portion of a sphere.

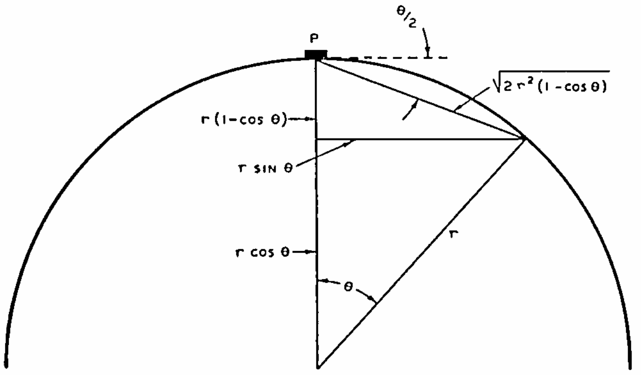


Fig. 6—Geometric considerations relative to the analysis of the effect of screen curvature.

Let us consider a test pattern consisting of a small dark spot in the center of a uniformly bright circular field, as shown in Fig. 6. Let R be the radius of the sphere, α be the angle subtended by the bright circular field at the center of curvature, and let the bright field on the interior surface of the sphere have a brightness B. Assuming that Lambert's cosine law is obeyed at both the emitting area and the receiving area, and that the intensity of illumination varies as the inverse square of the distance, we find the light flux incident on unit area of the interior surface of the sphere in the dark spot will be

$$\phi = \frac{B}{\pi}\,\frac{2\pi R^2}{2R^2}\int_0^{\alpha/2}\frac{\sin\theta\,\sin^2\dfrac{\theta}{2}\,d\theta}{(1-\cos\theta)} \tag{1}$$

or

$$\phi = \frac{B}{2}\left[1-\cos\frac{\alpha}{2}\right]. \tag{2}$$

This light flux will be scattered by the fluorescent particles. A portion of it, namely $T\phi$, where T is the total light-transmission factor of the fluorescent layer, will pass through the screen to the outside of the sphere. In this event, the brightness of the dark spot judged by an observer outside the sphere will be $T\phi$. The brightness of the field, on the other hand, will be $BT/(1-T)$; whereupon, the contrast ratio, i.e., the ratio of brightness of the field to the brightness of the dark spot, will be

$$\text{Contrast Ratio} = \frac{2}{\left(1-\cos\frac{\alpha}{2}\right)(1-T)} \cdot \quad (3)$$

Fig. 7 shows the variation of contrast ratio with the angular size of the bright field computed in accordance with (3) for several values of the screen transmission factor. As is to be expected, we observe that the loss in contrast due to screen curvature may be made as small as desired by flattening the viewing screen. However, in view of the relatively large total pressure exerted on the external surface of a large evacuated bulb by the atmosphere, we are somewhat limited in how flat we can make the screen. In order for the envelope to withstand this pressure better, cathode-ray tubes are customarily made with a face which is quite flat near the center and more sharply curved at the edges. Our foregoing analysis is not strictly applicable to this case, but we may estimate the loss in contrast occasioned by screen curvature. By way of illustration, consider a tube envelope of the shape illustrated in Figs. 1 and 5. This is the shape of a 12-inch developmental kinescope of the type being used in the present RCA television field tests. This kinescope reproduces a rectangular image approximately 10 inches wide by $7\frac{1}{2}$ inches high, and the contrast ratio as determined by screen curvature alone for the case of a dark spot in the center of the bright rectangular field should be about 70 for a conventional willemite-on-glass screen for which the transmission is about 40 per cent.

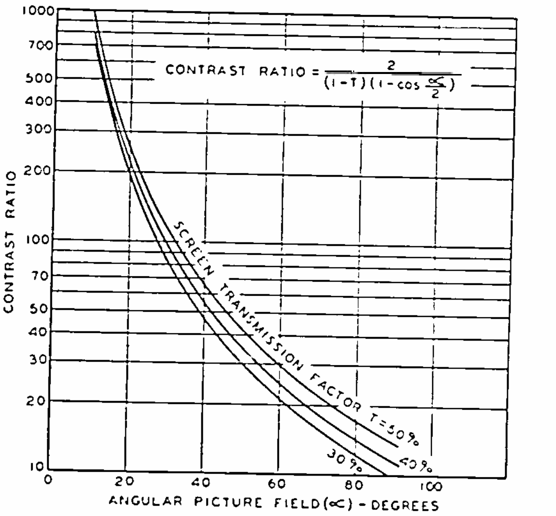


Fig. 7—Dependence of contrast ratio on screen curvature.

This result is checked experimentally. The effect of screen curvature on contrast may be measured in very much the same manner as we have measured the effect of bulb-wall reflections. If the opal-glass test plate of Fig. 5 is moved in flush with the end of the opaque tube and the whole assembly is pushed out even with the fluorescent screen, the test plate will receive illumination by both bulb-wall reflections and screen curvature. With due correction for the relatively small amount of illumination arriving by bulb-wall reflections, the experimentally determined contrast ratio agrees very well with the theoretically derived value.

On the basis of these results, we see that screen curvature is definitely more detrimental to contrast than bulb-wall reflections. However, before we can evaluate the relative importance of either of these factors, we must examine the effects of halation.

C. Halation

The limiting value of contrast as determined by halation may be measured with the arrangement schematically illustrated in Fig. 8. In this apparatus, the field is illuminated by a lamp located sufficiently far away from the screen to give substantially uniform illumination, and the dark circular test area in the center of the field is shielded from direct illumination by a blackened conical light shield which is placed with its open end in contact with the fluorescent layer.

Neglecting diffusion through the fluorescent layer itself, we find that the only light flux reaching the dark test area arrives by halation. The contrast ratio as determined by halation is then simply the ratio of the brightness of the field to the brightness of the dark test area. Measurements of this kind for a conventional willemite-on-glass screen show that the limiting value of contrast ratio, as determined by halation, is about 5 or 6.

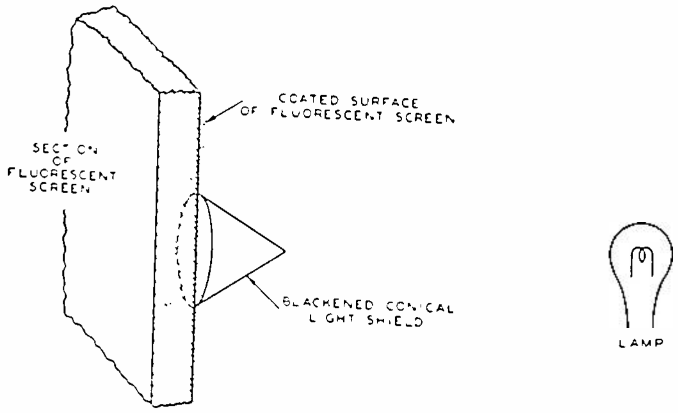


Fig. 8—Schematic representation of apparatus for measuring background illumination occasioned by halation.

Comparing this result with the limiting values determined by screen curvature and bulb-wall reflections, we see why halation is so significant in determining over-all contrast. With this experimentally strengthened viewpoint as to the relative importance of halation, let us study the problem in more detail and see what can be done to minimize halation.

In beginning this study, let us first examine the way in which light flux leaves the fluorescent particles. This is very important, for it is only that portion of the light flux entering the kinescope face through regions of optical contact which is susceptible to total internal reflection.[9,10]

We may determine the relative portion of the light flux which enters the kinescope face through regions of optical contact. A closer examination of the fluorescent layer shows that it is made up of a multitude of very small, irregularly shaped, relatively transparent, crystalline particles of moderately high refractive index. In general, the particles will not be isotropic. However, due to their random orientation, we may suppose that they exhibit some median value of refractive index η_f. In the event that the particles are applied directly to the kinescope face without an intermediate bonding agent, any elementary area on the surface of an individual particle is bounded by one of three media: (1) another particle whose index is η_f; (2) a vacuum whose index is unity; and (3) the kinescope face whose index we shall designate by η. Inasmuch as the light flux within the crystal will on the average undergo many internal reflections before it escapes, we may suppose that each luminous particle is filled with a substantially homogeneous radiation. If we neglect the relatively small portion of the light flux reflected at angles of incidence less than the critical angle, the light flux crossing unit elementary area between a fluorescent particle of index η_f bounded by a medium of index η_x is

$$\Delta\phi = C \int_{i=0}^{i=\gamma} \sin i \cos i \, di \tag{4}$$

where i is the angle of incidence and γ is the critical angle. But

$$\cos^2 \gamma = 1 - \frac{\eta_x^2}{\eta_f^2} \tag{5}$$

whereupon

$$\Delta\phi = C \frac{\eta_x^2}{\eta_f^2} \cdot \tag{6}$$

Applying this to the present case, for the crystal-glass interface, we have

$$\Delta\phi_{\text{glass}} = C \frac{\eta^2}{\eta_f^2} \tag{7}$$

while for the crystal-vacuum interface,

$$\Delta\phi_{\text{vacuum}} = \frac{C}{\eta_f^2} \cdot \tag{8}$$

Let us suppose that the kinescope face is entirely covered with fluorescent particles and D per cent of the kinescope face is in optical contact with these particles. Then, so long as $\eta_f > \eta$, the fractional part of the total light flux entering the kinescope face which will be susceptible to halation is

$$\phi_h = \frac{D\eta^2}{1 + D(\eta^2 - 1)} \tag{9}$$

while if $\eta_f \leqq \eta$, the fractional part of the light flux susceptible to halation is

$$\phi_h = \frac{D\eta_f^2}{1 + D(\eta_f^2 - 1)} \cdot \tag{10}$$

Because, in general, $\eta_f > \eta$, we shall be concerned with the ratio given by (9).

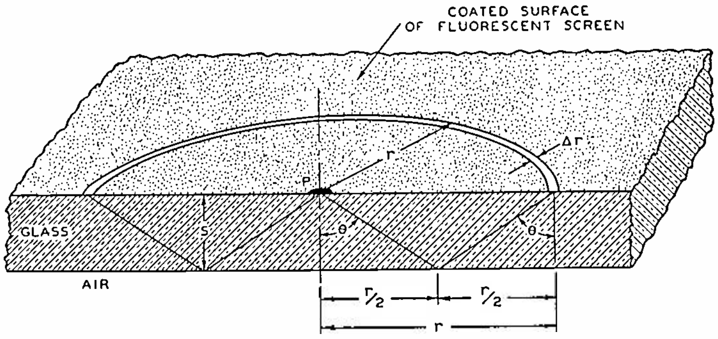


Fig. 9—Geometric considerations relative to the analysis of the effect of halation.

With this knowledge of the fractional part of the light flux that is susceptible to total internal reflections, let us return to our now familiar test case of a dark spot on a bright field. Referring to Fig. 9, let p represent a dark area on a flat, uniformly bright field of infinite extent. Let the glass plate simulating the kinescope face have a refractive index η, and a thickness S. In addition, let us suppose that the glass plate exhibits a neutral light absorption such that if I_0 is the intensity of a light beam entering the material, the intensity I after passing through a thickness x of the material will be

$$I = I_0 e^{-kx} \tag{11}$$

where k is the absorption coefficient. Let the fluorescent layer have a brightness B_0 on the side adjacent to the glass, and furthermore, let us assume that Lambert's cosine law holds, and that the intensity of illumination varies as the inverse square of the distance. If we neglect the relatively small portion of the light flux reflected at angles of incidence less than the critical angle, the light flux incident on unit area of the dark spot from first-order total internal reflections is

$$\phi_{p_1} = \frac{B_0}{2S^2} \phi_h \int_{r=2S/\sqrt{\eta^2-1}}^{r\to\infty} \frac{e^{-2k\sqrt{1+r^2/4S^2}}}{\left(1 + \frac{r^2}{4S^2}\right)^2} r dr. \tag{12}$$

However, of this light flux, only that portion which impinges on the interface at regions of optical contact between the glass plate and the fluorescent particles may enter the particles. The remainder will be again totally internally reflected and will not contribute to

---

[9] M. von Ardenne, "Importance and removal of light disturbances in cathode-ray tubes," *Hochfrequenz. und Elektroakustik*, vol. 42, pp. 113–115; October, (1933).

[10] M. von Ardenne, "The magnitude of the light disturbance in cathode-ray tubes using different fluorescent screen modifications," *Hochfrequenz. und Elektroakustik*, vol. 66, pp. 1–4; July, (1935).

the illumination of the dark area. Neglecting the relatively small portion of the light flux reflected at areas of optical contact, we find that the fractional part of the light flux entering the particles is D, and that the remainder, namely $(1-D)$, is again totally internally reflected. The light flux contributing to the illumination of the dark area is therefore $D\phi_{p_1}$.

The light flux $D\phi_{p_1}$ entering the fluorescent particles is scattered in all directions. A portion $D\phi_{p_1}T$, where T is the total transmission factor of the fluorescent layer, is transmitted through the fluorescent layer, while the remainder, namely $D\phi_{p_1}(1-T)$, is returned. Insofar as first-order reflections are concerned, the resultant brightness of the dark area to an observer viewing the image from the glass side of the screen will be

$$B_{p_1} = \frac{B_0e^{-kS}}{2S^2} D(1 - T)\phi_h \int_{r=2S/\sqrt{\eta^2-1}}^{r=\infty} \frac{e^{-2k\sqrt{1+(r^2/4S^2)}}}{\left(1 + \frac{r^2}{4S^2}\right)^2} r\,dr. \tag{13}$$

For second-order reflections, the limits of integration and the path lengths change; furthermore, the amount of light flux will be decreased by an amount $(1-D)$ due to the intermediate reflection. Consequently, for second-order reflections,

$$B_{p_2} = \frac{B_0e^{-kS}}{8S^2} D(1 - T)(1 - D)\phi_h \int_{r=4S/\sqrt{\eta^2-1}}^{r=\infty} \frac{e^{-4k\sqrt{1+(r^2/16S^2)}}}{\left(1 + \frac{r^2}{16S^2}\right)^2} r\,dr. \tag{14}$$

Similarly, we may write the expressions for the contributions of higher-order reflections. The resultant brightness will be the summation of the individual contributions or

$$B_p = \frac{2B_0e^{-kS}}{S^2} D(1 - T)\phi_h \sum_{n=1}^{n=\infty} \frac{(1 - D)^{n-1}}{(2n)^2} \int_{r=2nS/\sqrt{\eta^2-1}}^{r=\infty} \frac{e^{-2nk\sqrt{1+(r^2/(2n)^2S^2)}}}{\left(1 + \frac{r^2}{(2n)^2S^2}\right)^2} r\,dr. \tag{15}$$

If we make the substitution

$$x = 2nk\sqrt{1 + \frac{r^2}{(2n)^2S^2}},$$

$$B_p = 2B_0e^{-kS}D(1 - T)\phi_h k^2 \sum_{n=1}^{n=\infty} (1 - D)^{n-1}(2n)^2 \int_{x=2nk\sqrt{\eta^2/(\eta^2-1)}}^{x=\infty} \frac{e^{-x}}{x^3}\,dx. \tag{16}$$

By successive integration by parts, we may reduce this to

$$B_p = B_0e^{-kS}D(1 - T)\phi_h\left(1 - \frac{1}{\eta^2}\right) \sum_{n=1}^{n=\infty} (1 - D)^{n-1}e^{-x}\left[1 - x + x^2e^x \int_{t=2nk\sqrt{\eta^2/(\eta^2-1)}}^{t=\infty} \frac{e^{-t}}{t}\,dt\right]. \tag{17}$$

If we now introduce the value of ϕ_h from (9) and adopt the abbreviations

$$C = 2k\sqrt{\frac{\eta^2}{\eta^2 - 1}}, \qquad \text{and} \qquad R = (1 - D),$$

$$B_p = B_0e^{-kS} \frac{D^2(1 - T)(\eta^2 - 1)}{1 + D(\eta^2 - 1)} \left[\frac{e^{-C}}{1 - Re^{-C}} - \frac{Ce^{-C}}{(1 - Re^{-C})^2} + \frac{C^2}{R} \sum_{n=1}^{n=\infty} R^n n^2 \int_{t=nC}^{t=\infty} \frac{e^{-t}}{t}\,dt\right]. \tag{18}$$

Inasmuch as an observer viewing the image from the glass side of the screen will see a field with a brightness B_0e^{-kS}, the contrast ratio, or ratio of brightness of field to brightness of dark area, will be

$$\text{C.R.} = \frac{1 + D(\eta^2 - 1)}{D^2(1 - T)(\eta^2 - 1)\left[\frac{e^{-C}}{1 - Re^{-C}} - \frac{Ce^{-C}}{(1 - Re^{-C})^2} + \frac{C^2}{R} \sum_{n=1}^{n=\infty} R^n n^2 \int_{t=nC}^{t=\infty} \frac{e^{-t}}{t}\,dt\right]}. \tag{19}$$

The value of the integral $\int_b^\infty \frac{e^{-t}}{t}\,dt$ has been tabulated,[11] and we may compute the contrast ratio.

This analysis recognizes four influencing factors: (1) the index of refraction of the kinescope face; (2) the light transmission of the fluorescent layer; (3) the degree of optical contact between the fluorescent

---

[11] E. Jahnke and F. Emde, "Tables of Functions," B. G Teubner, Leipzig and Berlin, (1933).

particles and the kinescope face; and (4) the light absorption of the kinescope face. Of these four factors, the first is least susceptible to independent variation. If we are to use glasses commonly available, the index of refraction of the kinescope face is restricted to a value in the neighborhood of 1.5. We also observe that the light transmission of the fluorescent layer enters our result in a very simple manner. For these reasons, we shall carry out our computations in terms of optical contact and light absorption. Rather than express light absorption in terms of the absorption coefficient *k*, we shall find our results more useful if we express the absorption in terms of the attenuation of the direct rays. Fig. 10 shows the computed variation of contrast ratio with optical contact and attenuation for a particular example where the index of refraction is 1.5 and the light transmission of the fluorescent layer is 0.3.

The results of this computation are striking. Paradoxical as it may seem at first sight, it appears that halation may be reduced by introducing a light-absorbing layer in the kinescope face. This action of the absorbing layer is simply explained. The light rays, which enable us to see the image, pass through the kinescope face once in a nearly perpendicular direction and are attenuated relatively little. On the other hand, the light rays contributing to halation pass through the absorbing layer at least two extra times quite obliquely and are attenuated to a greater extent. Furthermore, with low degrees of optical contact a large part of the light flux contributing to halation arrives by multiple reflections and traverses the absorbing layer many more than three times. Such multiply reflected light rays are greatly attenuated even though the attenuation for the viewed rays is relatively small.

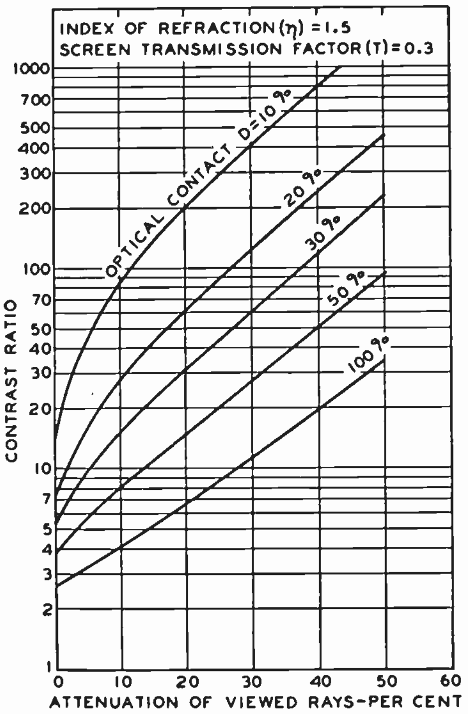


Fig. 10—Influence of various screen characteristics on contrast ratio.

This theory is confirmed by experimental studies. Such experimental studies are simply made, for not only can one determine the contrast but one can evaluate the four factors governing contrast as well. Thus, the index of refraction may be measured with a refractometer. The light absorption and the light transmission may be measured photometrically. And finally, the degree of optical contact may be determined by observing the relative illumination in the successive light bands when a light beam is multiply reflected as shown in Fig. 11.

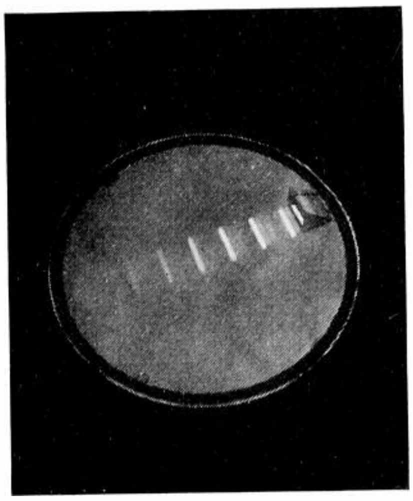


Fig. 11—Illustration showing decrease in intensity occasioned by successive internal reflections.

To illustrate the experimental approach, let us examine a typical kinescope and see how it fits in with the theory. The significant characteristics of a conventional willemite-on-glass screen are approximately: index of refraction, 1.5; screen transmission, 0.3; degree of optical contact, 0.3; and attenuation, zero. With a screen of these characteristics, it is to be expected that the limiting value of contrast as determined by halation should be about 6. This agrees very well with the results of our previously described experimental observations.

We may extend the range of our experimental study in several ways. By using a special viewing screen of cellular form filled with glycerin containing different amounts of a neutral light-absorbing dye, we may vary the attenuation over a wide range. By using various screen materials and also a flashed opal-glass viewing screen which gives substantially 100 per cent optical contact we may extend the investigation over a wide range of optical contact.

In order to interpret these results accurately, we must apply two corrections. First, we must correct for the finite area of the viewing screen, and second, we must correct for the effects of normal reflections. The nature of these corrections will be discussed in more detail a little later.

In this manner, it has been possible to verify the theory in the low-contrast range. Unfortunately, however, it is difficult to correlate experiment and theory in the high-contrast range. There are several reasons for this. From an experimental standpoint, it is difficult to make sufficiently accurate measurements of contrast in this range, and from a theoretical standpoint, it is difficult to compute the corrections with sufficient accuracy. Although the contribution of partial reflections occurring at the glass-air interface for angles less than the critical angle is small, this contribution becomes very important in the high-contrast range.

A computation of the contribution of reflections of this type, which we shall designate as normal reflections, is particularly difficult when we are dealing with an absorbing medium; for, although the reflection coefficient near normal incidence is simply $(\eta-1)^2/(\eta+1)^2$, at angles near the critical angle, Fresnels' equations describing both the parallel and perpendicularly polarized components must be employed. Such a computation is tedious and would need to be carried out for several values of the absorption coefficient. For the purpose of this investigation, it has been considered adequate to carry out this computation for the case of zero attenuation. Obviously, the contribution of normal reflections will be less as the attenuation is increased.

For the case of zero attenuation, a point-by-point computation shows that the effect of the glass-air interface may be approximated by a partial mirror whose reflection coefficient is 0.6 $(\eta-1)^2/(\eta+1)$. By reasoning now familiar to the reader, we find the limiting value of contrast ratio as determined by normal reflections to be

$$C.R._{\text{normal reflections}} = \frac{(\eta+1)^2}{0.6(1-T)(\eta-1)^2}. \tag{20}$$

For a specific case in which the index of refraction is 1.5, the screen transmission is 0.3, and the attenuation is zero, the limiting value of contrast ratio as determined by normal reflections is approximately 60. Although this contribution becomes less at appreciable attenuations, it may still be larger than the contribution of the total internal reflections in the high-contrast range.

When we consider the consequences of a finite-area viewing screen, we encounter even greater analytical difficulties. Looking back over our preceding analysis we see that the computations were greatly simplified by the assumption of an infinite area. By way of illustration, let us consider the case of a small dark area in the center of a uniformly bright circular field of radius R. Returning to (16), we see that although the lower limits of the summation and the integration remain unchanged, the upper limit of the summation becomes

$$n_{\max} = \frac{R}{2S}\sqrt{\eta^2-1}$$

and the upper limit of the integration becomes

$$x_{\max} = 2nk\sqrt{1+\frac{R^2}{(2n)^2S^2}}\,.$$

These limits are seen to depend upon the ratio of screen thickness to screen size, or more properly upon the ratio of screen thickness to the radius of the circular field. The radius of the circular field may in turn be associated with the picture size when the kinescope is used to reproduce a television image. Using these limits, we might proceed to derive an expression of the same general form as (17). With such a relationship, we could undoubtedly compute families of curves of the type illustrated in Fig. 10 for each of a series of ratios of screen thickness to screen size. However, this would be very laborious and does not seem to be justified in the present case. Instead, let us endeavor to get an idea of the effect of varying this ratio by considering a simple example. If we introduce the present limits in our previous equation (15) and assume no attenuation, we obtain

$$P_p = \frac{2B_0}{S^2}D(1-T)\varphi_k\sum_{n=1}^{n=R/2S\sqrt{\eta^2-1}}\frac{(1-D)^{n-1}}{(2n)^2}\int_{r=2nS\sqrt{\eta^2-1}}^{R}\frac{r\,dr}{\left[1+\frac{r^2}{(2n)^2S^2}\right]^2} \tag{21}$$

In this event the contrast ratio may be shown to be

$$\text{C.R.} = \frac{1+D(\eta^2-1)}{D^2(1-T)(\eta^2-1)\displaystyle\sum_{n=1}^{n=R/2S\sqrt{\eta^2-1}}(1-D)^n\left[1-\frac{\eta^2}{\eta^2-1}\left(\frac{1}{1+\frac{R^2}{(2n)^2S^2}}\right)\right]} \tag{22}$$

Fig. 12 shows a plot of this function for several values of optical contact. For a viewing screen of given size, the contrast is observed to improve as the screen thickness is increased. The initial improvement is more rapid as the optical contact is decreased. As the viewing screen is made still thicker, the halation disappears irrespective of the degree of optical contact.

Although this simple example does not close this problem, it does serve to indicate the magnitude of the variation and to show that the correction to be applied for this effect is relatively small so long as the radius of the bright field is large in comparison to the screen thickness.

So much for the analysis of the individual factors contributing to loss of contrast. Let us now see how these results are to be applied to practical kinescope design.

IV. Practical Design of a Kinescope Giving Good Contrast

Preparatory to an application of the results of this detailed analysis to practical kinescope design, let us summarize our findings. For a conventional willemite-on-glass kinescope reproducing a dark spot in the center of a bright field, the limiting value of contrast ratio as determined by each of the individual factors alone is approximately as follows:

Halation	6
Normal reflections	60
Curvature of screen	70
Bulb-wall reflections	200

The net contrast ratio resulting from a consideration of these factors collectively is the reciprocal of the sum of the reciprocals, or about 5.0.

We have already emphasized the importance of halation. However, before we discuss ways and means of reducing halation, let us make a few observations concerning the other factors.

The contribution of normal reflections is relatively small. This is fortunate, for unless we go to an immersion system,[12] there is very little we can do to minimize them. In this connection, it may be well to point out that the safety-glass cover customarily placed over the face of the kinescope in a television receiver has two such partially reflecting air-glass interfaces. The equivalent reflection coefficient of these two surfaces is about three times as great as the equivalent reflection coefficient of the kinescope glass-air interface and such a safety-glass cover is about three times as detrimental to contrast as our so-called normal reflections.

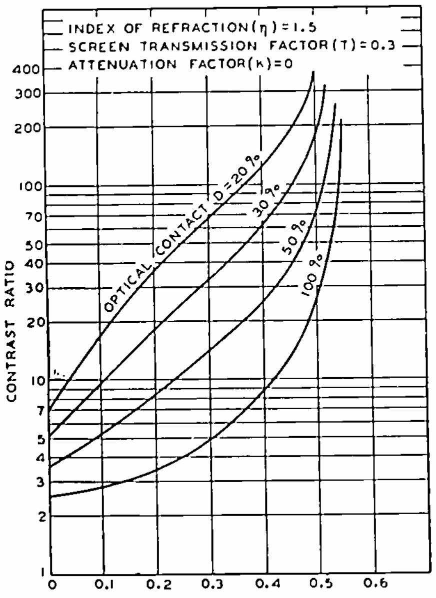


Fig. 12—Influence of picture size on contrast ratio.

The detrimental effect of screen curvature on contrast may be reduced by flattening the screen. However, the contribution of this factor is also small and it is probable that the trend toward a flatter screen will be guided by the demand for a flatter image rather than by a demand for greater contrast.

As for bulb-wall reflections, their contribution to loss of contrast is even less. This is particularly true for a properly shaped uncoated bulb.

Our main avenue to improved contrast, therefore, lies in reducing halation. This may be done in several ways, for although the index of refraction of the kinescope face and the light transmission of the fluorescent layer are more or less fixed, the degree of optical contact, together with the attenuation and the thickness of the kinescope face may be varied over wide limits.

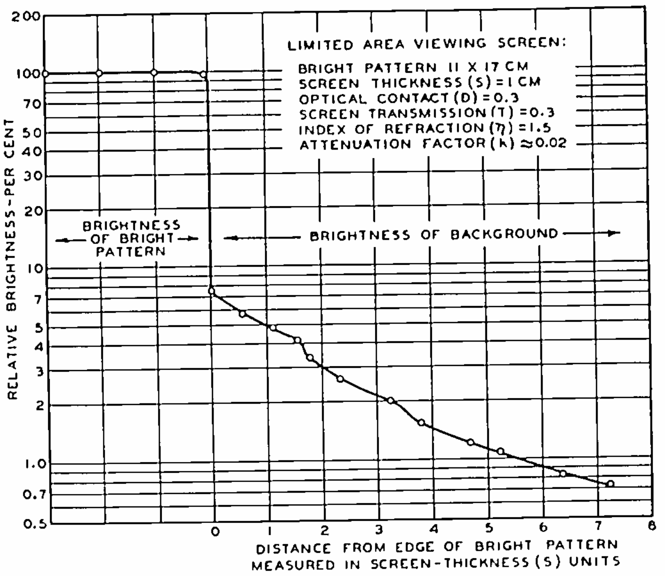


Fig. 13—Results of an experimental determination of the relative brightness of the background adjacent to a bright pattern.

Our theory has indicated that a viewing screen of greater thickness may be advantageous. This statement requires qualification, because so far we have considered only the case of a small dark spot in the center of a uniformly bright field. Such a test object is excellent insofar as the determination of the limiting value of the contrast in the fine detail of the image is concerned, but it does not tell us much about the over-all contrast range when the image contains relatively large dark areas.

To illustrate, let us suppose that one half of the rectangular television image is uniformly bright while the other half is dark except for the stray illumination arriving by halation. The contrast ratio at a point on the axis of symmetry immediately adjacent to the edge of the bright pattern will be just twice as great as that for the case of a small dark spot in the center of a uniformly illuminated field of the same total size. But how does the relative brightness of the background vary as we proceed away from the edge of the bright pattern? This may be determined experimentally. Fig. 13 illustrates the results of such an experimental determination for the case of 11- ×17-centimeter pattern reproduced on a 1-centimeter thick, flat, viewing screen having approximately two per cent attenuation, 30 per cent

---

[12] G. N. Ogloblinsky, "Immersion projection lens," U. S. Patent 2,093,288, (1937).

optical contact, 30 per cent light transmission, and an index of refraction of 1.5. Distance is plotted in screen thickness units (S units). Curve A of Fig. 14 is an enlarged-scale plot of the bottom portion of this curve. The breaks at approximately $1.8S$ and $3.6S$ mark the terminations of the first- and second-order halation bands at the distances $2S/\sqrt{\eta^2-1}$ and $4S/\sqrt{\eta^2-1}$, respectively. The accompanying curves, B and C, are for different conditions. Thus, although we cannot make similar measurements on an infinite-area viewing screen, we can compute the background illumination immediately adjacent to the bright pattern. By analogy with the preceding case, for an infinite-area screen, we would expect the background illumination to vary in somewhat the manner indicated by curve B. Similarly, for an infinite-area screen with 10 per cent attenuation, we would expect the background illumination to vary in somewhat the manner indicated by curve C.

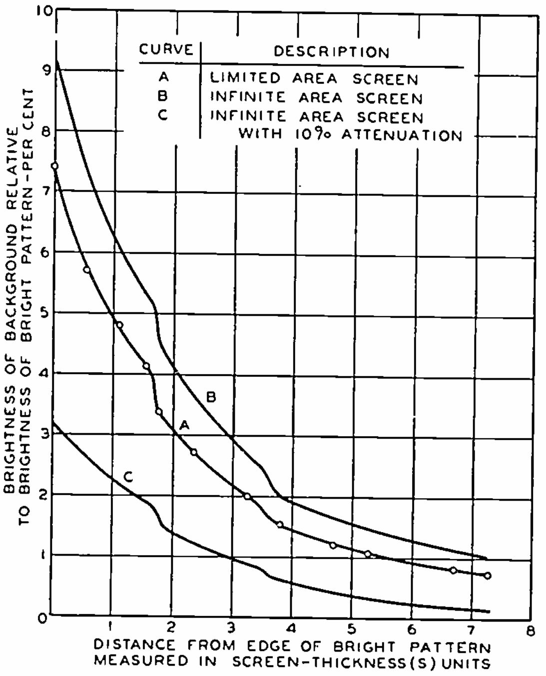


Fig. 14—Relative brightness of the background adjacent to a bright pattern for different types of viewing screens.

We now come to an interesting point. As the viewing screen is made thinner, with a given picture size, the relative size of the bright pattern in S units increases and the background illumination immediately adjacent to the bright pattern increases. These effects are illustrated in Fig. 14 where we find that the background illumination goes from the condition represented by curve A to the condition represented by curve B. However, under certain conditions this shift may not be detrimental to picture quality, for as the screen is made thinner, the halation bands move in closer to the edge of the bright pattern. This is illustrated by the curves of Fig. 15 which show the variation of background brightness with distance from the edge of a bright pattern of fixed size for three different screen thicknesses. If the viewing screen is made sufficiently thin, that is, if the screen thickness is small in comparison to the size of a picture element, the halation bands move in so close to the edge of the bright pattern as to be of no importance. This condition is even more readily attained if the screen is light-absorbing, because the higher-order halation bands are more effectively suppressed. These deductions explain the apparent absence of halation in our previously described, thin, mica viewing screen.

However, in the practical kinescope the situation is quite different. If the fluorescent material is to be applied directly to the bulb face which must necessarily be several picture elements thick, the halation bands can no longer be concealed. Our efforts must, therefore, be directed toward reducing their intensity. In this respect a thicker viewing screen is advantageous. For example, referring to Fig. 12, we observe that increasing the ratio of screen thickness to picture size from 0.05 to 0.15 for the case of 30 per cent optical contact increases the detail contrast by a factor of two. This is not the complete story, however, for this gain is accomplished at the expense of increased background illumination in the relatively large dark areas of the picture.

There are, therefore, two aspects to the contrast problem. First, there is detail contrast, that is, the contrast ratio for the case of a small dark spot on a bright field; and second, there is contrast range, that is, the ratio of the brightness of the brightest part of the picture to the brightness of the darkest part of the picture. A little later, when we come to examine the performance of typical kinescopes, we shall see that the second of these ratios is much larger than the first so that the loss in range occasioned by the thicker screen is more than offset by the gain in detail contrast.

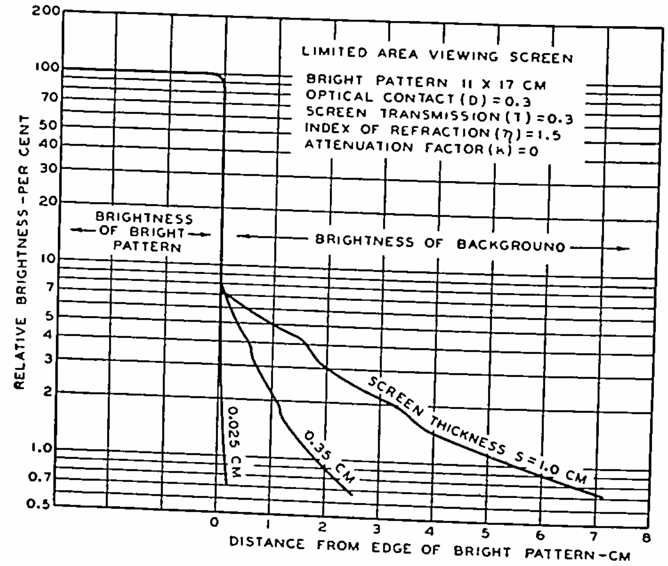


Fig. 15—Relative brightness of the background adjacent to a bright pattern for similar viewing screens of different thicknesses.

So much for the qualification of our original statement that increased screen thickness gives improved contrast. This is but one of the factors governing contrast. Let us now see what improvements can be effected by combining low optical contact with a moderate amount of attenuation.

In practice, optical contact may be varied over wide limits. Conventional, sprayed screens have an optical contact of about 30 per cent. Settled screens, wherein the fluorescent particles are deposited on the kinescope face from a liquid suspension, ordinarily have an optical contact of about 20 per cent. Dusted screens, prepared by air-settling the particles on an an initially tacky binder layer, may have even lower degrees of optical contact. Although the latter type of screen is ordinarily quite transparent due to the relatively low coverage, this does not mean that the transmission factor T in our analysis is increased, for the transmission factor significant in this respect is the transmission of the individual particles rather than the over-all transmission. However, due to the low coverage, the optical contact in such a screen may be very low insofar as multiple reflections are concerned. Furthermore, by controlling the tackiness of the binder layer and the size of the particles, it is possible to control the depth to which the particles imbed themselves in the binder layer, thereby influencing the fractional part of the light susceptible to halation.

Although our theory has not been adapted to fit this case of partial coverage, it is immediately evident that such a screen may have very low optical contact and should, therefore, give appreciably better contrast than sprayed or settled screens. We shall see that this is so when we come to examine the performance of typical kinescopes.

Attenuation may be varied over wide limits also. Insofar as the theory is concerned, the light-absorbing medium may be dispersed in the kinescope face, or it may be disposed in a thin layer located between the fluorescent particles and the bulb face. Thus, the kinescope bulb may be made from a darkened glass, or a thin layer of light-absorbing material may be applied to the bulb face before the fluorescent material is applied. If a binder layer is used to attach the fluorescent particles to the kinescope face, it may be advantageous to incorporate the absorbing material in the binder layer. This comes about because the binder layer ordinarily has a higher index of refraction than the kinescope face, which combination of circumstances gives rise to appreciable halation at the binder-glass interface. The extent of this disturbance is greatly reduced if the absorbing material is incorporated in the binder layer.

The amount of attenuation necessary to give a desired contrast ratio will depend upon the other characteristics of the screen. The optimum attenuation is probably between 10 and 20 per cent. Lesser attenuations would not make possible the realization of the full benefits to be derived by reduction of halation. On the other hand, greater attenuations are not to be recommended because the loss in contrast due to halation becomes about equal to the combined losses due to the other effects and an additional sacrifice in the brightness of the image would not give a corresponding improvement in over-all contrast.

Contrast performance studies have been made on a number of developmental kinescopes of different design. In these studies, the test pattern illustrated in Fig. 16 was used. A uniformly bright rectangular pattern of normal television-picture height and one-half normal television-picture width was displaced horizontally so that the inner vertical edge of the pattern coincided with the axis of symmetry of the tube. The relative brightness of the viewing screen was measured at three positions as indicated in the drawing. Thus,

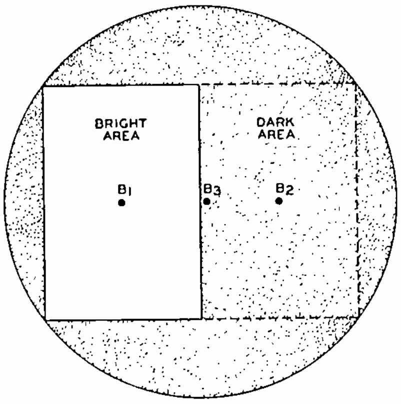


Fig. 16—Test pattern for measuring contrast performance characteristics of kinescopes.

B_1 = brightness at the center of the illuminated pattern

B_2 = brightness at a conjugate point on the dark background

B_3 = brightness of the dark background at a point on the axis of symmetry immediately adjacent to the bright pattern.

From these measurements, two values of contrast ratio were computed.

$$\text{Detail-contrast ratio} = B_1/2B_3$$
$$\text{Range-contrast ratio} = B_1/B_2.$$

As already mentioned, the first of these ratios, the detail contrast ratio, determines the limiting value of the contrast in the fine detail of the picture and is a measure of the sharpness or "clear-cutness" of the image. The second of these ratios, the range-contrast ratio, is an arbitrary measure of the range-reproducing ability of the kinescope.

The general results of this study are shown in Table II.

Viewing tests with representative pictures on screens of these types show that the general appearance of the image is intimately correlated with the detail contrast ratio. Inasmuch as the detail ratio is strongly influenced by optical contact and absorption, the merits of low optical contact and moderate absorption are immediately evident.

TABLE II
CONTRAST PERFORMANCE CHARACTERISTICS OF TYPICAL DEVELOPMENTAL KINESCOPES

Type of Screen	Optical Contact	Absorption	Ratio Screen Thickness to Half Picture Width	Contrast Ratios	
				Detail	Range
	Approximate Per Cent	Per Cent			
Sprayed	30	none*	0.04	6.2	50
		none	0.08	8.9	50
		20	0.04	19	100
Settled	20	none	0.04	10	70
		none	0.08	15	70
		20	0.04	25	100
Dusted	15	none	0.04	18	70
		20	0.04	34	100

* Clear glass.

Although improvement brought about by the use of an absorbing medium necessarily results in a small decrease in the light output efficiency, this loss does not seem to be unreasonable for a gain that contributes so much to the perfection of the image.

Although better contrast is obtained when the lowest optical contact is combined with a moderate amount of absorption we are particularly interested in sprayed screens because of the ease with which they may be applied. Such screens would normally give poor detail contrast because of their relatively large optical contact, but the detail contrast may be appreciably improved when an absorbing medium is introduced. Thus, a 20 per cent absorption makes the contrast performance of a sprayed-screen kinescope better than that of a conventional settled- or dusted-screen kinescope.

V. CONCLUSIONS

The contrast-reproducing ability of kinescopes may be controlled by adhering to specific design principles. Sprayed-screen kinescopes using moderate absorption and a relatively thick bulb face are capable of reproducing images with more than adequate contrast for present needs. For an average picture in which the high lights constitute a relatively small part of the total picture area, the high lights may easily be 50 to 100 times as bright as the low lights; at the same time, the brightness contrast ratio for fine detail in the picture may have a value of at least twenty to one even with a sprayed screen. Such a detail-contrast-reproducing ability gives the kinescope a versatility at least as great as that of photographic printing papers. If greater detail contrast should be required, the demand can be met by combining moderate absorption with lower optical contact. As for the range-reproducing ability of the kinescope, it is probably not below that realized in motion-picture reproduction.

Characteristics of the Ionosphere at Washington, D.C., June, 1939*

T. R. GILLILAND†, ASSOCIATE MEMBER, I.R.E., S. S. KIRBY†, ASSOCIATE MEMBER, I.R.E., AND N. SMITH†, NONMEMBER, I.R.E.

DATA on the critical frequencies and virtual heights of the ionosphere layers during June are given in Fig. 1. Fig. 2 gives the monthly average values of the maximum usable frequencies which could be used during undisturbed periods for radio sky-wave communication by way of the regular layers. Fig. 3 gives the distribution of the hourly values of F- and F_2-layer critical frequencies about the undisturbed average for the month. The ionosphere storms and sudden ionosphere disturbances are listed in Tables I and II, respectively. Table III gives the approximate upper limit of frequency of strong sporadic-E-layer reflections at vertical incidence for the days during which these reflections were most prevalent at Washington. Fig. 4 gives the expected values of the maximum usable frequencies for transmission

TABLE I
IONOSPHERE STORMS (APPROXIMATELY IN ORDER OF SEVERITY)

Date and hour E.S.T. 1939 June	h_F before sunrise (km)	Minimum f_F^x before sunrise (kc)	Noon $f_{F_2}^x$ (kc)	Magnetic character[1]		Ionosphere character[2]
				00–12 G.M.T.	12–24 G.M.T.	
13 (after 1600)	—	—	—	0.2	0.8	0.8
14	342	3900	<5600	1.4	0.9	1.5
15 (until 1600)	338	4100	6800	0.4	0.1	0.7
15 (after 1600)	—	—	—	0.4	0.1	0.8
16	334	3100	6100	1.1	0.4	1.2
17 (until 0500)	316	4200	—	0.0	0.3	0.5
28 (after 1700)	—	—	—	0.2	0.9	1.0
29 (until 2000)	336	4800	6400	1.0	0.7	0.6
2	310	5600	6200	0.8	0.8	0.4
3	340	5400	6100	0.6	0.4	0.5
4	318	5500	6200	0.7	0.5	0.2
5 (until 1800)	332	5400	6400	0.4	0.3	0.3
20	336	4500	—	0.7	0.3	0.6
21 (until 1500)	330	5000	6500	0.7	0.4	0.5
27 (until 0500)	348	5300	—	0.6	0.5	0.2
18 (until 1000)	338	5200	—	0.9	0.7	0.1
19 (0200 to 1000)	322	4800	7600	0.9	0.7	0.1
For comparison: average for undisturbed days	301	5660	8220	0.2	0.2	0.0

[1] American magnetic character figure, based on observations of seven observatories.

[2] An estimate of the severity of the ionosphere storm at Washington on an arbitrary scale of 0 to 2, the character 2 representing the most severe disturbance.

---

* Decimal classification: R113.61. Original manuscript received by the Institute, July 10, 1939. These reports have appeared monthly in the PROCEEDINGS starting in vol. 25, September, (1937). See also vol. 25, pp. 823–840, July, (1937). Publication approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

† National Bureau of Standards, Washington, D. C.

TABLE II

Sudden Ionosphere Disturbances

Date 1939	G.M.T Beginning of fade-out	G.M.T End	Location of transmitter	Relative intensity at minimum[1]
June 24	1301	1320	Ohio, Ont.	0.1

[1] Ratio of received field intensity during fade-out to average field intensity before and after; for station W8XAL, 6060 kilocycles, 650 kilometers distant

TABLE III

Approximate upper limit of frequency of the stronger sporadic-E reflections at vertical incidence

Midnight to Noon

Date	00	01	02	03	04	05	06	07	08	09	10	11
June												
8				4.5	6	8	8	8	8	8	6	6
10	4.5		4.5					8	8	4.5		
11					4.5		4.5	8		6	6	4.5
24						8	8		6	6	6	

Noon to Midnight

Date	12	13	14	15	16	17	18	19	20	21	22	23
June												
4					4.5	4.5	8			4.5	8	
6			4.5	4.5	8	6						
7	4.5	8	8	6	4.5	10	12	10	10	13	15	4.5
8				6	8	4.5	4.5	6				
9		4.5	4.5	4.5	4.5	8	8	6	6	6	6	6
11		4.5	4.5			4.5	8	8			8	
12			8	4.5	6	4.5	6	6	8	8	4.5	
17	8	6	6	4.5								
23						8	8	6	8	8		
25							8	6	8	8	4.5	4.5

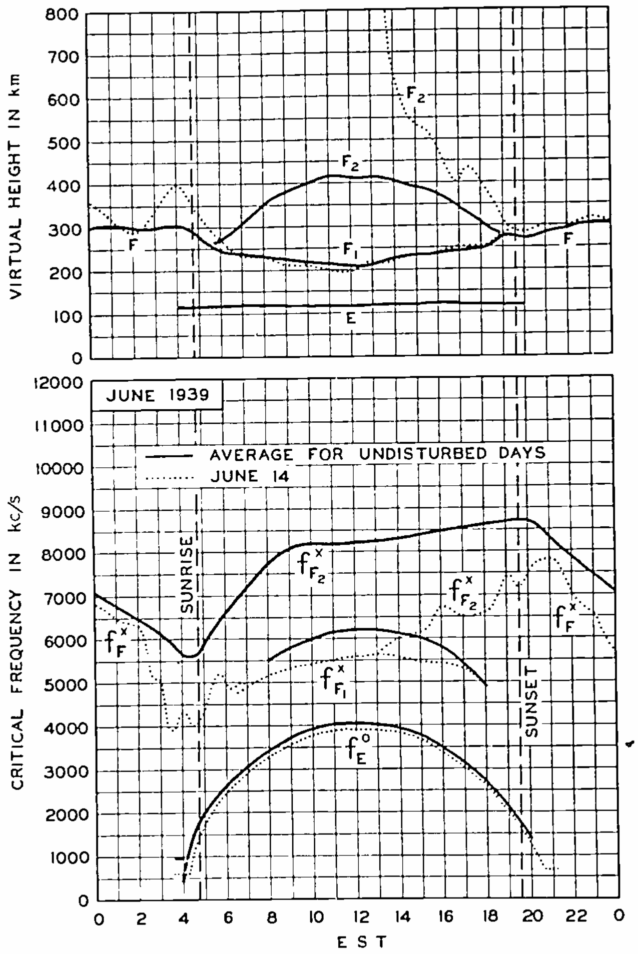


Fig. 1—Virtual heights and critical frequencies of the ionosphere layers, June, 1939. The solid-line graphs are the averages for the undisturbed days; the dotted-line graphs are for the ionosphere storm day of June 14.

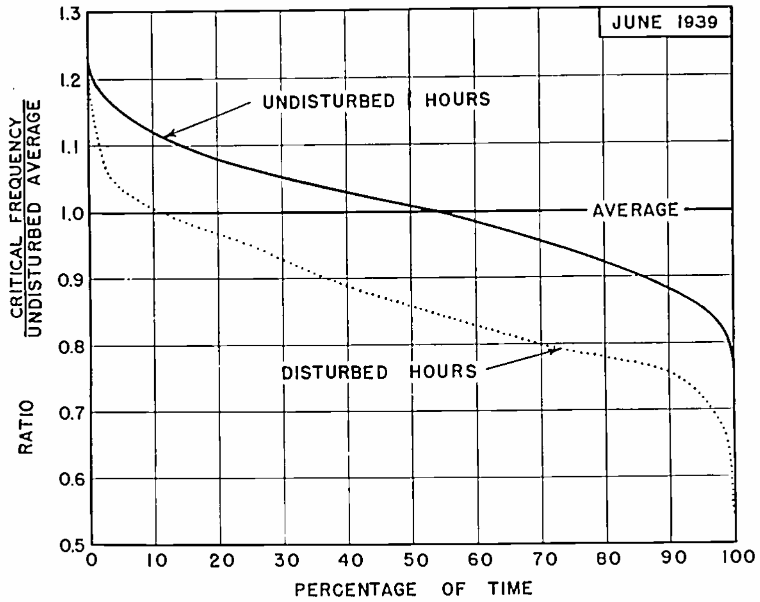


Fig. 3—Distribution of F- and F_2-layer critical frequencies (and approximately of F- and F_2-layer maximum usable frequencies) about monthly average. Abscissas show percentage of time for which the ratio of the critical frequency to the undisturbed average exceeded the values given by the ordinates. The graphs give data as follows: solid line, 414 undisturbed hours of observation; dotted line, 258 disturbed hours of observation listed in Table I.

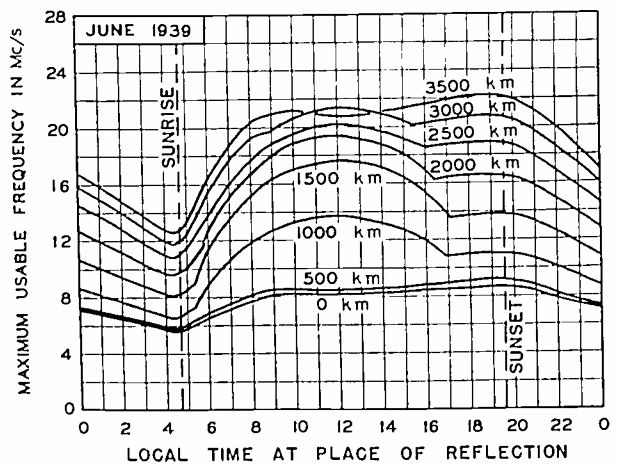


Fig. 2—Maximum usable frequencies for radio sky-wave transmission. Average for June, 1939, for undisturbed days for dependable transmission by the regular E, F, F_1 and F_2 layers. The F layer will ordinarily determine the maximum usable frequencies at night. The effect of the E and F_1 layers is shown by the humps on the graphs during the middle of the day. The values shown were considerably exceeded during irregular periods by reflections from clouds of sporadic-E layer.

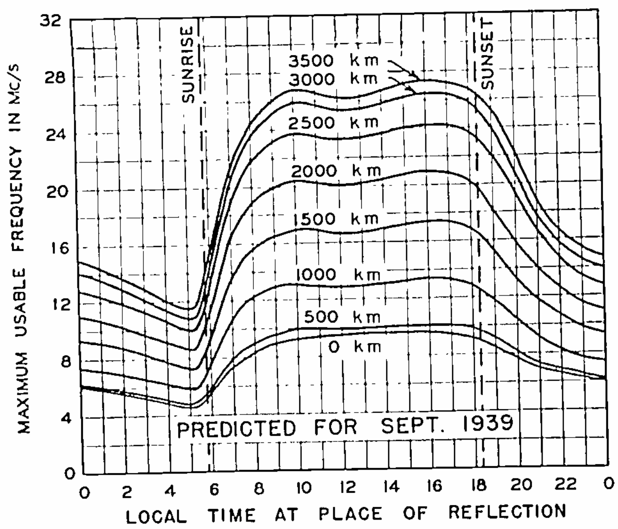


Fig. 4—Predicted maximum usable frequencies for dependable radio sky-wave transmission by way of the regular F and F_1 layers for September, 1939.

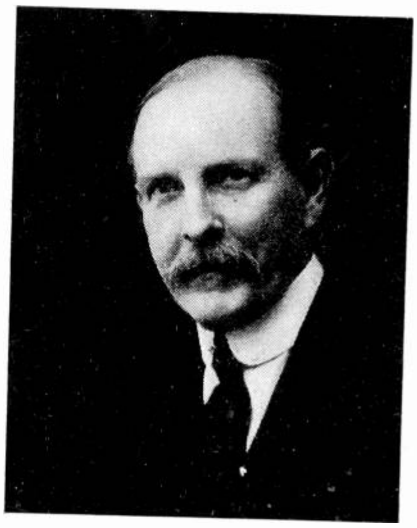
by way of the regular layers, average for September, 1939, for undisturbed days.

The ionosphere storms during June were numerous and prolonged but not very severe. Out of the 672 hours of observation 258 hours were disturbed. The E-layer critical frequency as well as that of the other layers was depressed during the more severe storms as illustrated in Fig. 1. During the night hours of the more severe ionosphere storms the E-layer vertical-incidence reflections at broadcast frequencies, especially those below 1000 kilocycles, were highly absorbed. This effect is probably responsible for weak night sky-wave intensities at broadcast frequencies previously reported for ionosphere[1] storms. As observed during the past two years field-intensity records of European high-frequency stations indicated that the times of beginning and ending of ionosphere storms over the North Atlantic path sometimes differed by several hours from the corresponding disturbances at Washington.

---

[1] T. R. Gilliland, S. S. Kirby, and N. Smith, "Characteristics of the ionosphere at Washington, D. C., May, 1938," Proc. I.R.E., vol. 26, p. 911; July, (1938).

Institute News and Radio Notes



Arthur Edwin Kennelly

1861–1939

'18

Arthur Edwin Kennelly, who died in Boston, Massachusetts, on June 18, 1939, was born in India on December 17, 1861.

He received his early education in England, Scotland, France, and Belgium. In 1895 the University of Pittsburgh awarded him an honorary degree of Doctor of Science. This was followed by an honorary Master of Arts degree from Harvard in 1906, and a Doctor of Science from the University of Toulouse, France, in 1922.

In 1875 he became assistant secretary of the Society of Telegraph Engineers of London, the predecessor of the present Institution of Electrical Engineers. In 1886 he was named senior ship electrician of submarine cables for the Eastern Telegraph Company whose employ he entered ten years before.

From 1887, when he came to America, to 1894 he was the principal electrical assistant of Thomas A. Edison.

In 1902 Harvard University appointed him professor of electrical engineering from which chair he retired as Professor Emeritus in 1930. Additionally, from 1913 to 1924 he was professor of electrical engineering at the Massachusetts Institute of Technology, retiring as Professor Emeritus of that institution also.

Dr. Kennelly was exceedingly active in the engineering and scientific organizations, serving as President of several and holding membership in many.

He was the author of over two dozen books and is credited with the publication or presentation of several hundred scientific and engineering papers. In 1902 he expounded the theory of the influence of a conducting layer in the atmosphere on long-distance radio transmission. The views of Oliver Heaviside having been made known at about the same time, this conducting stratum has been called the Kennelly-Heaviside layer.

Dr. Kennelly served the United States government as a delegate to the International Radiotelegraph Conference in Washington, D. C., in 1927; the Fifth International Congress on Electricity in Paris, 1932; the Eighth General Conference on Weights and Measures in Paris, 1933; and the Third World Power Conference in Washington in 1935.

He was very active in the field of international standardization of electrical terminology and in 1938 was named Honorary President of the International Electrotechnical Commission, which has done much in this field. He also served as Honorary President of the United States National Committee of that organization.

Dr. Kennelly joined the Institute of Radio Engineers as an Associate in 1912, was transferred to Member in 1913, and was made a Fellow in 1928. He served as President during 1916 and received its Medal of Honor in 1932.

Pacific Coast Convention

The Pacific Coast Convention which was held in San Francisco on June 27–30 was attended by 369 of whom thirty-eight were women.

All of the papers listed for the meeting in the June Proceedings were presented and, in addition, a paper on "The Generation of Spurious Signals by Nonlinearity of the Signal Path" by A. V. Eastman of the University of Washington and L. C. F. Horle, consultant, of New York City, was presented by Professor Eastman.

The afternoon session on June 28 was held on Treasure Island after the inspection tour of the clipper ship was completed.

Sections

President's Tour

President Heising visited the Los Angeles, Portland, and Seattle sections of the Institute during June and July, and presented, in addition to a discussion of Institute affairs, his paper on "Radio Extension Links to the Telephone System." His paper is summarized on page 477 of the July, 1939, Proceedings.

Atlanta

Four students of Georgia Institute of Technology presented papers. The first on "The Terrain-Clearance Indicator" was by R. L. Adams. He pointed out first the need for an accurate altimeter to supplement the barometric instruments now used in aircraft. He then described a reflection-type instrument which recent developments in the ultra-high-frequency art have made practical. The method of operation was described and the paper was closed with a discussion of the possible errors and their probable maximum values.

H. H. Hooker presented the second paper which was on "Diode Detectors." After the operation of these devices was described, expressions were derived for rectification efficiency and the magnitude of the load which the rectifier presents to the secondary winding of the intermediate-frequency transformer which supplies voltage to it. He then reviewed the sources of distortion such as nonlinearity, incorrect time constant of the resistance-capacitance combination, and the variation in the value of the load impedance as a function

New York World's Fair, 1939, Inc.

One of the many interesting vistas at the New York World's Fair is the Court of States in the pool of which is reflected a replica of Independence Hall. The Fourteenth Annual Convention of the Institute will be held in New York from September twentieth to twenty-third.

of frequency. The importance of these sources of distortion and other performance characteristics were described.

"Electronic Timers" was the subject of a paper by H. G. Morgan, whose work on this subject was prompted by needs observed while operating X-ray equipment. The circuit diagram of such a device was presented and its operation described. A relatively low-cost device was demonstrated and made available for inspection. Methods of testing the timer on hospital X-ray equipment were outlined.

The concluding paper, "Ionosphere Measurements," was presented by S. T. Smith. The history of ionosphere measurements was first outlined. Important points were the discovery of the existence of the ionosphere by Appleton and the methods of measuring its height which were developed by Appleton and by Breit and Tuve. Modern equipment for such measurement work was described. The paper was concluded with a discussion of the E layer and sporadic E layer and a presentation of typical curves of diurnal variation of layer heights.

As a result of the ballot of the audience and of four judges, the student prize of a year's Associate dues in the Institute was presented to Mr. Hooker.

May 19, 1939, G. S. Turner, vice chairman, presiding.

Chicago

H. C. Vance, manager of the facsimile and communication equipment division of the RCA Manufacturing Company, presented a paper on "Radio Facsimile Transmission" in which he described the present RCA facsimile transmitting and recording equipment. A facsimile scanner was set up in the auditorium and connected to an experimental transmitter on top of the Civic Opera Building. Receivers also located in the auditorium picked up the program and produced records of the material transmitted.

May 19, 1939, V. J. Andrew, chairman, presiding.

This meeting was held jointly with the Western Society of Engineers and the American Institute of Electrical Engineers.

"Some Unusual Features of our Television System" was presented by Albert Preisman, instructor in the RCA Institutes.

He described briefly the operation of a television system recently placed in public operation in this country. An analysis of methods of obtaining odd-line interlacing and its advantage over even-line interlacing was then given. The relation of average brightness to the black level, the need for inserting direct current, and methods of doing so were then considered. The use of shaping circuits for clipping, mixing, differentiation, integration, and keying was described. Multivibrators and time-delay networks were covered. An analysis of counter circuits and their application to the synchronizing generator were given. The advantages of bridge-T networks over other commonly used forms for both transmitting and receiving purposes were discussed. The paper was closed with an analysis of horizontal and vertical synchronizing separator circuits.

June 16, 1939, V. J. Andrew, chairman, presiding.

This meeting was held jointly with the Chicago Section of the Radio Servicemen of America.

Cincinnati

"Development of Modern Television" was the subject of a paper by J. R. Duncan, special television development engineer of the Crosley Corporation.

The speaker outlined first the earliest television experiments which began about 1846 and used selenium as a light-sensitive material. Scanning was proposed around 1875 and the scanning disk developed about 1884. Because of inadequate sources of light for both transmitter and receiver and the absence of effective signal-amplifying equipment, the results were very poor. In 1880, it was announced that "television was just around the corner."

Tube amplifiers developed between 1907 and 1910, helped overcome a number of the problems. In 1907, it was suggested that the cathode-ray tube be used for both pickup and reproduction purposes, the scheme proposed closely approaching our present system. Early systems were designed for 45-line pictures. Later 60 lines were used, and in 1925 several groups began working on 120-line pictures. In 1931 the detail was increased to 180 lines, and in 1933 to 240 lines with 24 frames per second. The iconoscope was introduced at this time. The detail was then raised to 330 lines, interlaced, and projection was at 30 frames per second. By 1936, mechanical moving parts were, in general, eliminated and all-electronic methods employed.

The wave shapes of synchronizing and blanking pulses were demonstrated by using a television receiver. The action of the iconoscope was also described in detail. It was pointed out that the modern television systems reproduce between 10 to 12 shades between black and white. The eye is capable of distinguishing about 100 shades in this range.

The paper was concluded with a demonstration of a modern television system which was held in the Crosley television studios.

June 13, 1939, H. J. Tyzzer, chairman, presiding.

Emporium

G. R. Town, of the research laboratories of the Stromberg-Carlson Telephone Manufacturing Company, presented a paper on "Television Receivers."

Dr. Town pointed out that television transmission requires three basic steps which are the conversion of the picture into electrical energy, the addition to this wave of the necessary synchronizing impulses, and the radiation of this composite signal. In the receiver, the process is reversed. To obtain satisfactory definition, modulation frequencies as high as 4 megacycles are employed. To conserve space in the transmission medium, a major portion of one sideband is not transmitted.

For reception, the superheterodyne system is employed. The chief problem is to obtain flat response with the necessary amplification over a 4-megacycle band. The physical combination of the individual amplifier stages gives rise to difficulties caused by feedback.

June 7, 1939, R. K. McClintock, chairman, presiding.

Los Angeles

A symposium and discussion on "Audio-Frequency Transmission Measurements" was participated in by a number of those present. A. C. Packard, vice chairman of the section, described first the new reference standard and indicating instrument which has been adopted recently by the National Broadcasting Company, the Columbia Broadcasting System, and the American Telephone and Telegraph Company. A reference level which is referred to as zero vu (volume units) results when a sine wave of 1 milliwatt is measured across 600 ohms. This makes unnecessary the specification of reference level when using vu measurements.

E. S. Sievers of the Weston Electrical Instrument Corporation, described the volume indicator which has been agreed upon as a standard instrument for volume-level measurements. Two scales have been adopted. The one preferred by broadcasters for monitoring purposes shows zero to 100 per cent utility of the channel. The other scale is preferred by the telephone system and is calibrated in volume units. Meters using each of these scales were on display.

F. G. Albin of United Artists Studios, presented a brief report on an automatic recorder. It consists of a logarithmic amplifier and an Esterline-Angus recording meter. As the beat-frequency oscillator gives a logarithmic variation of frequency with rotation, the resulting graph gives a logarithmic scale both in amplitude and frequency.

A number of gain-measuring sets were described in a general discussion of this subject which was led by J. N. A. Hawkins of the Walt Disney Studios. Among those who spoke were F. L. Hopper of Electrical Research Products, Inc., Howard Tremain and Mr. Singer of the RCA Manufacturing Company, and C. G. McProud of Paramount Studios.

May 16, 1939, F. G. Albin, chairman, presiding.

Rochester

G. R. Town of the Stromberg-Carlson Telephone Manufacturing Company, presented his paper on "Television Receivers" which is summarized in the report on the Emporium Section meeting of June 7.

This was the annual meeting and W. F. Cotter of the Stromberg-Carlson Telephone Manufacturing Company was elected chairman; H. A. Brown of the Rochester Gas and Electric Company, was designated vice chairman; and H. C. Sheve of the Stromberg-Carlson Telephone Manufacturing Company was re-elected secretary-treasurer.

May 25, 1939.

Washington

"Aircraft Radio Compasses—Principles and Testing" was the subject of a paper by R. J. Framme, associate radio engineer at the Aircraft Radio Laboratory, Wright Field, Ohio.

A description was given of the application of the radio compass to aircraft operation and its importance in the Army instrument landing system. Methods of testing these compasses in shielded rooms and on aircraft were discussed.

The construction of a transmission line for these tests was described. Formulas for calculating the radio-frequency field strength beneath the line were derived. While applicable to any loop or aural null-type radio compass, these tests are particularly interesting when applied to the antenna-loop pickup system. Two voltages ninety degrees out of phase and of different magnitudes must be inserted in the loop and antenna. The antenna pickup is nondirectional while that of the loop is directional. The transmission-line test setup described provides such currents. It has been used extensively for laboratory, factory production, and maintenance testing.

June 12, 1939, Gerald C. Gross, chairman, presiding.

Personal Mention

The following members have recently informed us of changes in their company affiliations or titles to those given below.

Arps, M. W.; Commander, U.S.N.; Naval Radio Station, Annapolis, Md.

Bachman, C. H.; General Electric Company, Schenectady, N. Y.

Briggs, T. H., Jr.; RCA Manufacturing Company, Harrison, N. J.

Comstock, E. E.; Lieutenant, U. S. Coast Guard Cutter *Itasca*, basing at San Diego, Calif.

Francis, O. T.; Captain, U. S. Marine Corps, Post Service Batallion, Renville, Minn.

Friend, A. W.; Cruft Laboratory, Harvard University, Cambridge, Mass.

Hogg, W. S.; Commander, U. S. Navy, Carlsbad, Calif.

Kolar, E. F.; Engineer, Bendix Radio Corporation, Baltimore, Md.

Marriner, A. W.; Major, U. S. Army Air Corps, Wright Field, Dayton, Ohio.

Moseley, F. L.; Aeronautical Radio, Inc., Washington, D. C.

Ports, D. C.; Radio Engineer, Jansky and Bailey, National Press Building, Washington, D. C.

Ryan, C. M.; Lieutenant, U. S. Navy, U.S.S. *Flusser*, basing at San Diego, Calif.

Teaf, J. H.; Mechanical Engineer, Radio Condenser Company, Camden, N. J.

Tucker, D. P.; Lieutenant, U. S. Navy, U.S.S. *Charleston*, basing at New York City.

West, S. S.; Research Department, Baird Television, Ltd., London, England.

ALBERT F. MURRAY

On May 31, Maryville College conferred an honorary degree of Doctor of Science on Albert Francis Murray (A '20, M '26, F '38). Previously Dr. Murray had earned degrees from that college, Harvard University, and the Massachusetts Institute of Technology. Since 1933 Dr. Murray has been in charge of television research for Philco Radio and Television Corporation. He has served the Institute as a member of various committees and as a Director for the past four years.

Membership

The following indicated admissions to membership have been approved by the Admissions Committee. Objections to any of these should reach the Institute office by not later than August 31, 1939.

Admission to Associate (A) and Student (S)

Arechavala, J. M., (A) Ayacucho 2175, Buenos Aires, Argentina.
Born, J. P., Jr., (A) 31-1st Ave., N.E., Atlanta, Ga.
Bunday, W. W., (A) 112 McClelland Ave., East Point, Ga.
Calbick, C. J., (A) Bell Telephone Labs., Inc., 463 West St., New York, N.Y.
Danisch, M. S., (A) Misiones 48, Buenos Aires, Argentina.
Ellory, F. R., (A) 43 North St., Tywardreath, Par Cornwall, England.
Ghosh, P. B., (A) All India Radio, 1 Garstin Pl., Calcutta, India.
Hastings, R., (A) Misiones 48, Buenos Aires, Argentina.

Iglesias, H. V., (A) Luca 2274, Buenos Aires, Argentina.
Jones, G. A., (A) Calle Billinghurst 2224, Buenos Aires, Argentina.
Kotal, J. R., (S) 5540 S. Whipple St., Chicago, Ill.
Kline, L., (A) Carlos Calvo 1152, Buenos Aires, Argentina.
Kobilsky, M. J., (A) Castelli 337, piso 3, Buenos Aires, Argentina.
Krahenbuhl, H., (A) San Martin 329, Buenos Aires, Argentina.
Laconca, F., (A) Benito Perez Galdos 126, Buenos Aires, Argentina.
Mace, J. C., Jr., (A) 404 W. Illinois, Urbana, Ill.
Medina, A. M., (A) Humboldt 2444, Buenos Aires, Argentina.
Milner, C. M., (S) 206 Elec. Eng. Lab., University of Illinois, Urbana, Ill.
Nunez, J. A. R., (A) Av. Pitt 728, Hurlingham Pcia., Buenos Aires, Argentina.
Olson, A. E., (A) Radio Station KIEM, Eureka, Calif.
Ooiman, A., (A) Herrera 527, Buenos Aires, Argentina.
Peschke, F., (A) Acasuso St. 1708, Beccar F.C.C.A., Buenos Aires, Argentina.
Peter, S. S., (A) c.o Peter Isaac, 62 Government Hospital Rd., West Gate, Madura, South India.
Rambo, W. R., (S) 213 Stevens Creek Rd., San Jose, Calif.
Rendell, G., (A) 113 W. 62nd St., New York, N. Y.
Rieke, J. W., (S) Cary Hall, West Lafayette, Ind.
Robb, J. D., (A) Longwood, Mo.
Schwitzer, K. R., (A) 34 Kensington Palace Mansions, London W. 8, England.
Sears, R. W., (A) Bell Telephone Labs., Inc., 463 West St., New York, N. Y.
Shankar, G., (A) 10 Abbott Rd., Lahore, India.
Shukla, R. C., (A) c/o Nanhoo Ram Shukal, P.O. Bisalpur, Dist. Pilibhit, U.P. India.
Siddle, R. W. A., (A) 65 Beech Grove, Whitley Bay, Northumberland, England.
Stewart, F. P., (A) 14 W. 85th St., New York, N. Y.
Stewart, M. J., (A) 570 S. Bryant St., Denver, Colo.
Susmanscky, J., (A) Dean Funer 342, Buenos Aires, Argentina.
Sykes, J. D., (A) Salta 33 V. Ballester F.C.C.A., Buenos Aires, Argentina.
Tulloch, M. M., (A) c/o Chartered Bank of India A & C, 38 Bishopsgate, London E.C. 3, England.
Tysall, F. A., (A) 24 Barford St., Birmingham 5, England.
Van Dyk, T., (A) Guemes 971, Vicente Lopez F.C.C.A., Argentina.
Van Leeuwen, E. G., Jr., (S) 2324 Piedmont Ave., Berkeley, Calif.
Van Spankeren, G. H., (A) Herrera 527, Buenos Aires, Argentina.
Watson, J. R., (A) 306 S. A St., Forest Grove, Ore.
Winter, D. W., (A) 855 Willoughby Ave., Brooklyn, N. Y.
Wixon, G. H., (A) 3657 W. 59th Pl., Chicago, Ill.
Woodward, E. O., (A) 7364 Melrose Ave., Los Angeles, Calif.
Zeile, M. C., (A) Cangallo 3441, Buenos Aires, Argentina.

Books

Einführung in die Funktechnik: Verstärkung, Empfang, Sedung. (Introduction to Radio Engineering: Amplification, Reception, Transmission), by Friedrich Benz.

Published by Julius Springer, Vienna, Germany. 393 pages plus a 6-page subject and name index, 443 figures. Price unbound, RM 15; bound, RM 16.80.

Friedrich Benz who is the head of the Radiotechnical Institute in Vienna wrote this book to serve both as a text and reference book. Its five sections are General Principles (87 pages), Electron Tubes (57 pages), Low-Frequency Amplification, Electroacoustics and their Applications (56 pages), Receivers (107 pages), and Transmitters (78 pages).

The treatment is almost encyclopaedic in nature; a wide variety of topics are covered, each is discussed concisely, and no large amount of space is devoted to any one subject. Fundamentals are emphasized somewhat more than usual, but the viewpoint remains distinctly that of the engineer rather than the physicist.

The author has intentionally omitted certain important special fields of radio engineering, such as television, which is not discussed at all, and radio-frequency measurements. These and other specialized fields, he states, will be covered by a later treatise.

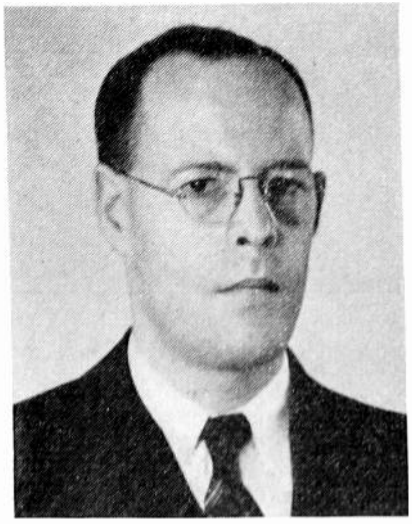
A noteworthy feature is the generous use of simple mathematics. Higher mathematics are avoided. Complex number algebra is explained briefly, and applied to such problems as the calculation of alternating-current impedance, oscillating circuits, transformers, coupled circuits, etc. Differential equations are employed in only a few cases, as in discussing Maxwell's theory, and electrical oscillations.

The usefulness of the book is enhanced by a large number of references to original articles, most of which are in German publications, and frequently employed numerical examples. More attention than usual is given to units, and in the case of most practical formulas the units to be used are frequently explicitly stated. The figures are well chosen and well drawn. The paper and printing are excellent.

Although the material covered is available in American publications, this book should be a useful addition to any radio library.

E. G. Linder
RCA Manufacturing Company, Inc.
Camden, N. J.

Contributors



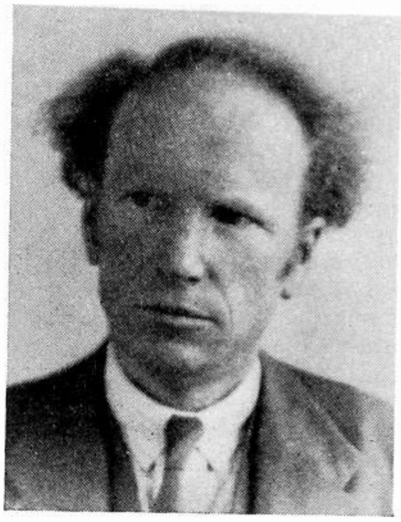
R. R. Law

Russell R. Law (A '35) was born on January 11, 1907, at Hampton, Iowa. He received the B.S. degree in electrical engineering in 1929 and the M.S. degree in 1931 from Iowa State College; in 1933 he received the D.S. degree from the Harvard Engineering School. From 1933 to 1934 he was a research associate in geophysics at Harvard University. Since 1934 Mr. Law has been in the Research and Engineering Department of the RCA Manufacturing Company. He is a member of Sigma Xi and the American Physical Society.

❖

K. G. MacLean

K. G. MacLean (A '30) was born in Boston, Massachusetts, on July 29, 1906. He received the B.E.E. degree from Northeastern University in 1928. In 1928 he was a student engineer with RCA and in 1929 a transmission engineer for the New York Telephone Company. From 1929 to 1931 he was in the Transmitter Development Laboratories of the Radio Corporation of America and from 1931 to 1936 in the Operating Division of R.C.A. Communications, Inc. Since 1936 Mr. MacLean has been with the Receiver Research and Advanced Development Section of R.C.A. Communications, Inc.

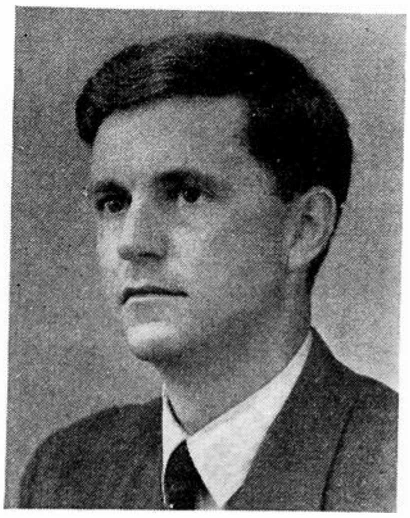

H. W. Lee

◆

H. W. Lee was born in London, England, in 1889. He received the degree of B.A. from Cambridge in 1911. From 1913 to 1936 Mr. Lee was an optical designer to Taylor, Taylor and Hobson, Leicester, England. Since 1936 he has been associated with Scophony, Ltd.

◆

D. M. Robinson (A '36) was born in London, England, in 1907. He received the degrees of B.Sc. and Ph.D. at King's College, University of London, in 1927 and 1929, respectively, and the degree of M.S. at the Massachusetts Institute of Technology in 1931. He then joined the Research Staff of Callender's Cable Company, London, and since 1935 he has been with Scophony, Ltd., of London.


D. M. Robinson

◆

J. Sieger was born in London, England, in 1907. He received his technical training at the Regent Street Polytechnic, London, and joined the development staff connected with *Amateur Wireless* and the *Wireless Magazine* in 1924. In 1931 he became chief engineer of Lotus Radio, Liverpool, and in 1932 joined Scophony, Ltd.


J. Sieger

◆


A. W. Vance

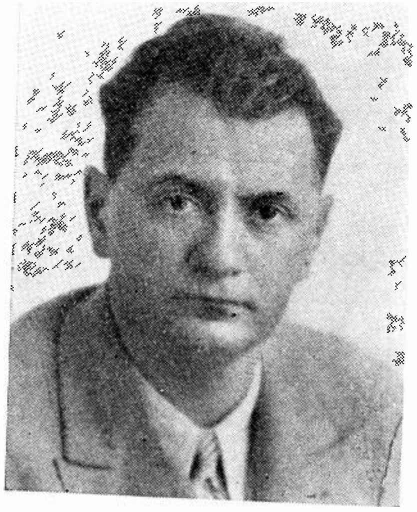
Arthur William Vance was born on July 15, 1904. He was graduated from Kansas State College in 1928 with the degree of B.S. in electrical engineering. From 1929 to 1930 he was a television and facsimile research engineer at the Westinghouse Electrical and Manufacturing Company. Since 1930 he has been employed as engineer in charge of circuit research in the Electronics Research Division of the RCA Manufacturing Company.

Gilbert S. Wickizer (A '28) was born on August 20, 1904, at Warren, Pennsylvania. He received the B.S. degree in electrical engineering from the Pennsylvania State College in 1926. During 1926 and 1927 he was with the Radio Corporation of America, Operating Division, and from 1927 to date he has been with the Receiver Research and Advanced Development Section of R.C.A. Communications, Inc. He is a member of Eta Kappa Nu.


G. S. Wickizer

◆

Gustav Wikkenhauser was born in Budapest, Hungary, in 1901. He received his degree in mechanical and electrical engineering from the University of Budapest in 1926, and was then employed by the A.E.G. in Berlin. In 1929, on the formation of the Telehor Television Company, he was attached to its laboratories in Berlin. Since 1932 he has been with the Scophony Company in London.


G. Wikkenhauser

◆

For biographical sketches of T. R. Gilliland, S. S. Kirby, and N. Smith see the Proceedings for January, 1939.

ERIE CUSTOM MOLDED PLASTICS

Among the very first to specialize exclusively in injection molding, ERIE RESISTOR developed and perfected single operation molding of plastic bezels around spherical glass. Now, ERIE RESISTOR again pioneers by adapting a new plastic material, Bakelite Polystyrene, to video i-f and r-f coil forms for RCA-Victor Television receiving sets.

Characteristically, we are solving problems of design, material and production demands in molded television components just as effectively as we have solved difficulties throughout the whole field of plastic molding. From a smartly fashioned tuning knob, even to television's new coil forms with metal inserts, we set unsurpassed standards to make ERIE RESISTOR PLASTICS a byword in radio circles.

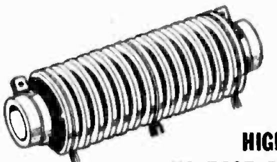
Wherever economical injection molding of parts is feasible, you can profit by the specialized knowledge and experience of ERIE'S design staff.

We would like to have the opportunity to show what we can do for you.

OTHER ERIE PRODUCTS FOR TELEVISION

**ERIE
SILVER MICA
CONDENSERS**

These condensers provide the high tuning stability with low losses so necessary in television receivers. Temperature coefficient is approximately +.000025, Power Factor .04% at 1 megacycle.



**HIGH
VOLTAGE RESISTOR**

A non-inductive multiple ring composition resistor ideally suited for the dissipation of power at high frequencies and voltages.

ERIE RESISTOR CORPORATION, Erie, Pa.

TORONTO, CANADA • LONDON, ENGLAND • PARIS, FRANCE-J.E.CANETTI CO.

MANUFACTURERS OF RESISTORS • CONDENSERS • MOLDED PLASTICS

Commercial Engineering Developments

These reports on engineering developments in the commercial field have been prepared solely on the basis of information received from the firms referred to in each item.

Sponsors of new developments are invited to submit descriptions on which future reports may be based. To be of greatest usefulness, these should summarize, with as much detail as is practical, the novel engineering features of the design. Address: Editor, Proceedings of the I.R.E., 330 West 42nd Street, New York, New York.

●

Molded Silver-Mica Condensers

A new constant-capacitance condenser for use as the tuning condenser in receivers subjected to temperature changes has been introduced by Erie Resistor.* The unit consists of a sheet of clear india-ruby mica to which coatings of pure silver have been intimately bonded. Silver coatings overlap in such a manner that connections can be made on a portion of each coating not in the dielectric field.

The silver plates so applied are so well bonded to the mica that it is practically impossible to remove them from the surface. However, mica itself is naturally laminated and easily split Therefore, if any outward stress is set up tending to pull the silver off the plates (as will occur due to expansion and contraction of any case through wide variations in temperature), the mica will split, separating the two opposite plates of silver and seriously changing the capacitance. To overcome this difficulty, the stack of silvered mica sheets is sandwiched between two "dummy" sheets of mica having no overlapping silver coating. By making sure that no bonding material, such as wax, works in between the "dummy" sheet and the adjacent condenser sheet, no movement tending to split the condenser sheet can be transmitted to it through the blank sheets of mica which are in contact with the case.

The stack of mica plates is clamped to the tinned copper lead wires by two aluminum rivets. Aluminum was chosen because of its softness, so that excessive force would not be necessary in assembly, and because of its ability to retain a set with a minimum of overtravel of the setting punch. These features are important in working with material as delicate as mica. It should be noted that electrical contact is not made through aluminum, but is altogether silver-to-silver, or silver-to-tinned copper. The aluminum rivet is used only as a mechanical fastening device.

The assembly is next molded into a low loss thermosetting plastic case, care being taken in this operation to prevent distortion of the mica sheets. The final manufacturing operation is to vacuum impregnate the condenser with a very highly moisture-resistant wax.

The last operations are those of final test. All condensers are tested for capacitance and power factor at 50 to 200 volts, root-mean-square, 1000 kilocycles. Power factor must be under 0.04 per cent to pass, except in the very small capacitances where distributed capacitance losses in the case make this impractical. All units are also subjected to 1000 volts, direct current, and must show a leakage resistance value in excess of 10,000 megohms.

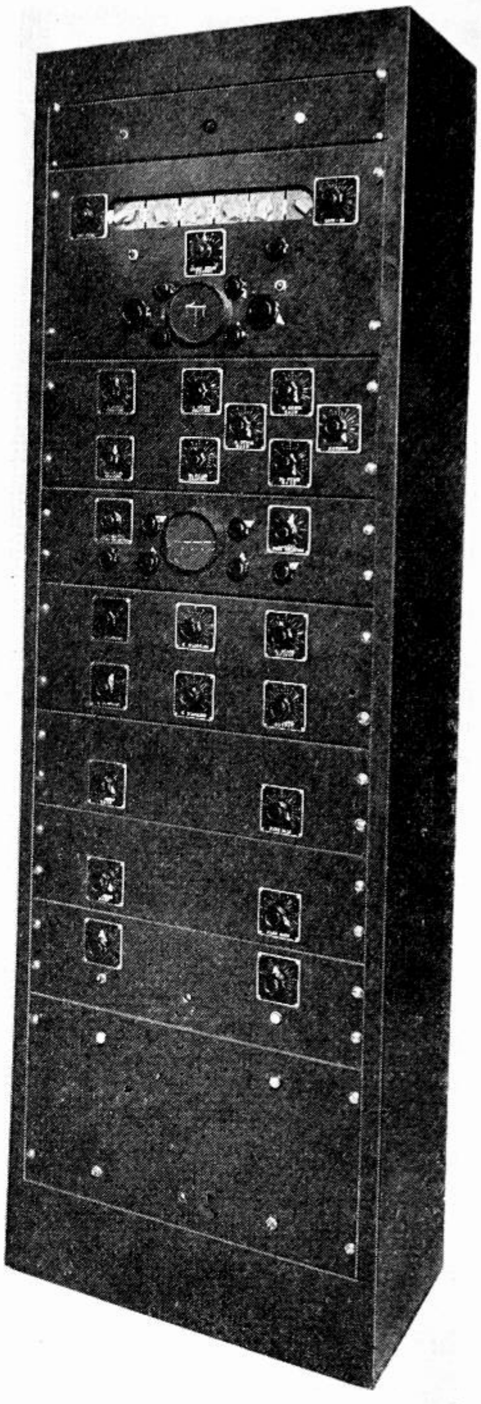
Synchronizing-Signal Generator

A new type of synchronizing-signal generator for supplying the synchronizing, scanning, and blanking waves to a television transmitter is a recent development of the Allen B. Du Mont Laboratories.* The design of the circuits is said to be such that the equipment can be installed and operated by untrained personnel.

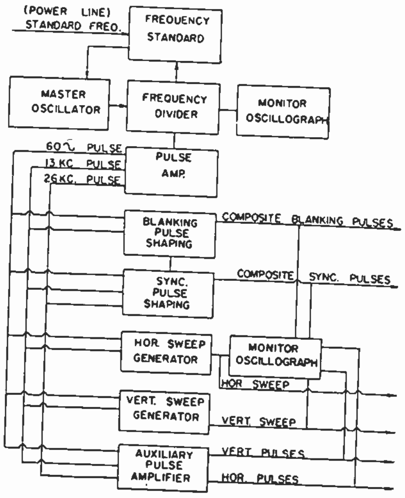
The signal supplied to the transmitter by the assembly conforms to the present R.M.A. television standards, and provision is made for incorporating many of the changes that may be required at some future time.

The operation of the complete system is shown in the accompanying block diagram. The frequency-divider, from which the various timing frequencies are derived, comprises six interlocked relaxation oscillators. Interlocking is accomplished by coupling through buffer tubes. The oscillator plate supply is maintained at a constant voltage by means of a duplex regulator circuit, incorporating both electronic and gaseous types of regulators. The plate supply for the buffer tubes is derived from a similar source so that stable operation of the divider is insured.

The interlocking action of the oscillators has been carefully designed so that frequency variations up to 15 per cent of the master control oscillator can be tolerated before succeeding interlocked stages become unlocked and fall out of synchronism. In many of the divider stages, which have been designed with a low division-factor, variations in frequency much greater than 15 per cent may be tolerated.



The synchronizing signal generator is a rack-mounted assembly equipped with two monitoring oscillographs: one for checking the frequency-divider circuits, the other for checking the various output signals



Functional diagram of the complete synchronizing-signal generator

Provision is made for continuously comparing the frequency of the final divider output with that of the 60-cycle power line, and, an automatic frequency controlled circuit, operates upon the master-frequency sinusoidal oscillator circuit to standardize the divider output frequency. Frequency control of

---

* Erie Resistor Corporation, Erie, Pennsylvania.

* Allen B. Du Mont Laboratories, Inc., 2 Main Avenue, Passaic, New Jersey.

More for your Money!

More output kilowatt hours per dollar with NEW 357A

ANOTHER *New Tube of Radically Improved Design*—the 357A—was shown in Western Electric's latest 1 KW Transmitter at the recent N. A. B. Convention.

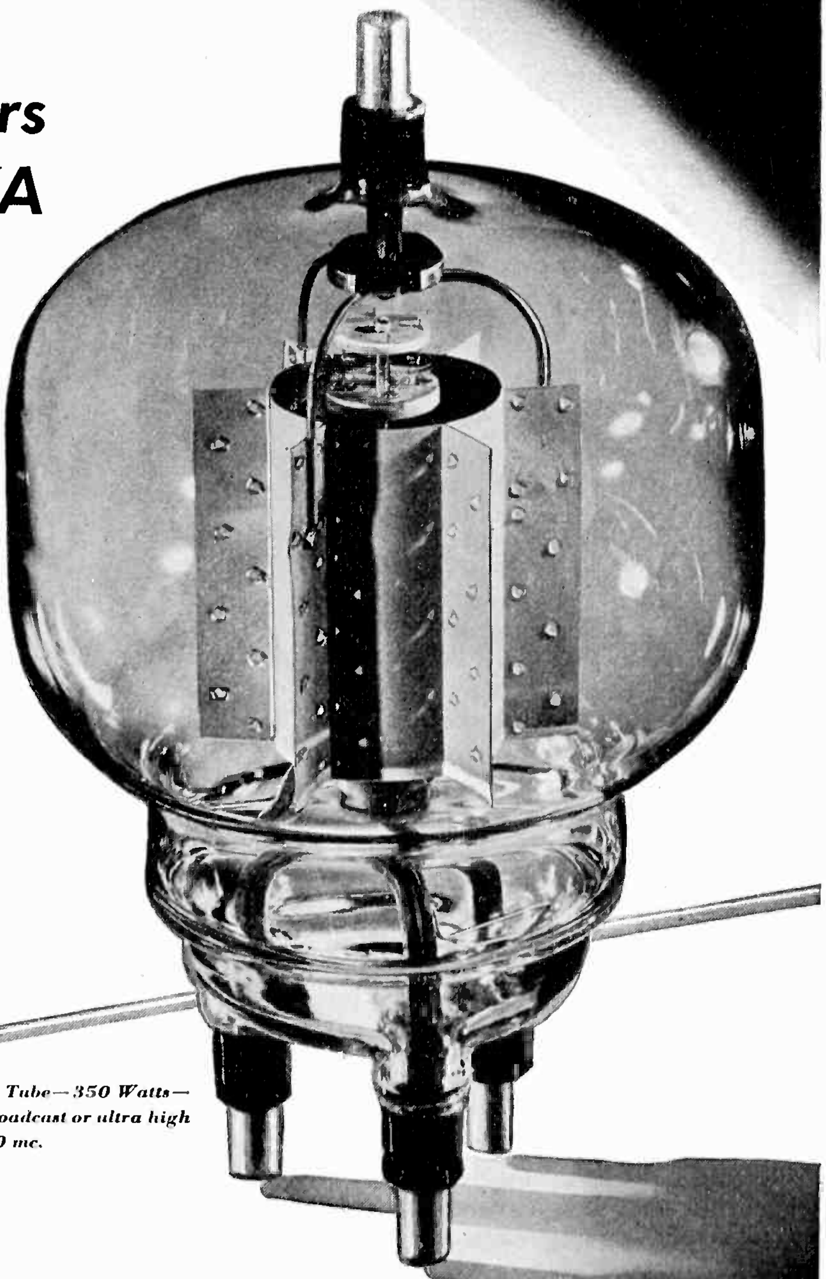
Conservatively rated for Continuous Service, it will be a favorite, both in broadcasting and in ultra high frequency applications.

Five new tube types in the new 1 KW Transmitter join the many others that have already convinced their users of Western Electric's ability to build the longest-lived tubes—affording you the cheapest cost per kilowatt hour of output power!

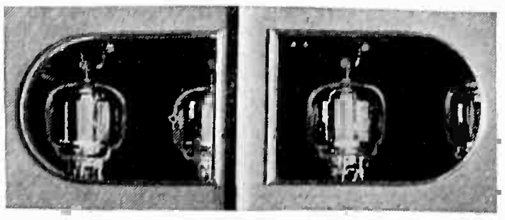
The 357A's outstanding and exclusive features are:

Copper to glass seals which allow heavy leads without cracks; Molded glass with no reentrant stems to give trouble at the higher frequencies; Low-inductance, short heavy leads; Low interelectrode capacity.

These features allow its use at higher frequencies than any other tube of comparable rating. For full details: Graybar Electric Co., Graybar Building, New York.



357A Tube—350 Watts—for broadcast or ultra high to 100 mc.



Four 357A's used in Western Electric's new 1 KW Transmitter.

DISTRIBUTORS: Graybar Electric Company, Graybar Bldg., New York City. IN CANADA: Northern Electric Co., Ltd. IN OTHER FOREIGN COUNTRIES: International Standard Electric Corp.

DESIGN CHARACTERISTICS:

Filament voltage	10 v.
Filament current	10 amps.
Amplification factor	30
Max. Plate Dissipation	350 watts
Max. Plate Voltage	4000 volts
Max. Plate Current	0.500 amps.

INTERELECTRODE CAPACITIES:

P-G	4.25 mmf.
P-F	2.5 mmf.
G-F	9.5 mmf.

Frequency for Maximum ratings 100 mc.

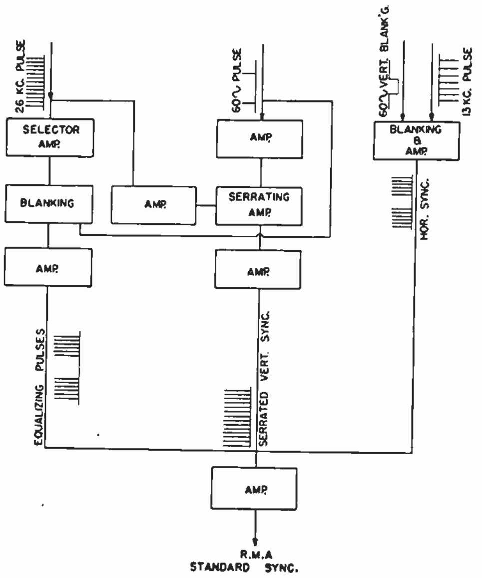
Western Electric

ELECTRONIC EQUIPMENT

Distributed by Graybar Electric Company

(*Continued from page ii*)

the master-frequency relaxation oscillator is accomplished through use of a master sine-wave oscillator controlled by automatic frequency control and to which the master relaxation oscillator is synchronized.



The operation of the synchronizing-pulse-shaping unit can be traced in this functional-schematic drawing

The over-all sensitivity of this frequency control is of the order of 400:1 frequency correction. This correction is more than ample to accommodate any possible variations in either the divider output frequency or the standard frequency. With such sensitivity of frequency control, frequency variations in the equipment during the "warm-up" period are immediately corrected, and the power supply to the unit may be turned on and off at will without fear of prolonging the service interruption due to "warm-up" action.

The functioning of the synchronizing—pulse shaping unit is shown in the second block diagram. The unit operates upon the three types of synchronizing waves so that they are properly shaped, mixed, and transformed to a coaxial output.

The vertical synchronizing pulse is serrated, in this unit, by means of a simple chopping circuit producing a waveshape which is adjusted to conform to the present R.M.A. television standards. By means of a simple adjustment the number of equalizing pulses may be varied.

The horizontal synchronizing pulse wave train is corrected—to allow for insertion of the serrated vertical synchronizing pulses and the equalizing pulses in the mixed composite synchronizing signal.

The entire assembly has its own power-supply system. Two monitoring oscillographs are included. One provides for immediate investigation of the frequency relationships of all frequency-dividing circuits. Ten separate linear sweep frequencies, automatically synchronized and one 60-cycle sinusoidal sweep signal are provided. By means of the second monitoring oscillograph, the operator can check any one of ten waveshapes, some of which are mixtures of two signals, in order to observe the timing of the waves with respect to each other.

A Machinable Ceramic Material

American Lava Corporation* has developed a new ceramic material characterized by the fact that it can be machined after firing. It is an aluminum magnesium silicate in which the raw materials are mixed by well known ceramic methods, shaped into desired forms by pressing or extrusion, and then fired at a temperature of 2500 degrees F. At this high temperature the various ingredients combine in a uniform crystalline mass which has good mechanical strength but is of such a nature that it is still machinable. It has the mechanical strength of fired steatite or "lava" and approaches the physical strength of a commercial dry-press porcelain.

The ability to machine the new material after it has been fired makes it possible to establish the shape and size of a particular unit on an experimental basis once the final design is determined. Other ceramic materials better suited to quantity production can then be substituted. The ability of the user to do his own model work extends beyond the control of cost or of permitting "changes of mind," because of the frequency with which patentable ideas are wanted to be handled confidentially within the premises and organizations of the user.

The fired material can be turned on a lathe or milled like steel. Naturally, it is quite abrasive, and it is necessary to use tools with tungsten-carbide tips. Drilling and tapping can be done with ordinary steel tools, where only a small number of pieces is required, although the tools need rather frequent grinding. For cutting plates, rods, etc., thin carborundum wheels are recommended.

Electrically, the new material is suitable for high-frequency applications if the piece is vacuum impregnated with a moisture repellant substance. It has excellent power factor characteristics at elevated temperatures at high frequencies and is, therefore, suitable for supports and spacers in electronic tubes.

---

* American Lava Corporation, Chattanooga, Tennessee.

Properties of "Alsimag 222"

Specific Gravity (apparent)		2.02
Softening Temperature		1500°C.
Resistance to Heat (Safe limit for constant temperature)		1250°C.
Volume Resistivity in megohms/cm. cube	75°F.	approx. 10^6
	800	1800
	1000	180
	1600	6.5
	1800	.9

	1000 kc	10 Mc
Dielectric Constant	4.5	4.5
Power Factor	.02	.01
Loss Factor	.09	.045

Capacitance Change per degree C. (20°–80°C.) ..... 1.0×10^{-4} mmf/mmf per °C.

One of the many electrolytic forming racks in the new AEROVOX plant. Forming voltages are constantly being checked for uniform electrolytic sections of given voltage ratings.

It's
TEST... TEST... TEST...

in building
QUALITY
into Every
AEROVOX
CONDENSER

● There are no class distinctions among AEROVOX condensers when it comes to routine factory inspection and test. The ten-dollar X-mitting condenser and the ten-cent by-pass tubular are treated alike in safeguarding the good name of AEROVOX.

So it is no idle boast that every AEROVOX condenser is *individually* tested. It would be quicker and cheaper to make percentage tests or even spot tests, whereby units selected at random might answer for the quality and dependability of the entire run.

But AEROVOX, with an experience second to none in the mass-production of quality condensers, prefers to test each unit *individually*. Only in this way can your assemblies be safeguarded against the chance of defective or sub-standard condensers.

Submit Your Problem . . .

Our engineers are ready to collaborate in helping you select the condensers best suited to the other components and circuit considerations. Samples, specifications, quotations, cheerfully submitted.

AEROVOX CORPORATION
New Bedford, Mass.
Sales Offices in All Principal Cities

Current Literature

New books of interest to engineers in radio and allied fields—from the publishers' announcements.

A copy of each book marked with an asterisk (*) has been submitted to the Editors for possible review in a future issue of the Proceedings of the I. R. E.

* IONS, ELECTRONS, AND IONIZING RADIATIONS, Seventh Edition. By JAMES ARNOLD CROWTHER, Professor of Physics, University of Reading. New York: Longmans, Green & Company, February, 1939. xii+341+6 index pages, illustrated, $5\frac{1}{4}\times8\frac{1}{2}$ inches, cloth. $4.00.

* PRACTICAL TELEVISION BY RCA. By Service Division, RCA Manufacturing Company, Inc. Camden: RCA Manufacturing Company, Inc., June, 1939. 40 pages, illustrated, $8\frac{1}{2}\times11$ inches. paper. $0.25.

Booklets, Catalogs and Pamphlets

The following commercial literature has been received by the Institute.

CONDENSERS • • • *Solar Manufacturing Corporation, Bayonne, New Jersey. Catalog 10, 32 pages+cover, $8\frac{1}{2}\times11$ inches.* Specifications on power-type and tuning condensers.

NICKEL • • • *International Nickel Company, 67 Wall Street, New York, New York. Folder, 6 pages, $8\frac{1}{2}\times11$ inches.* Technical data on rolled nickel, monel, and other high-nickel alloys.

TRANSFORMERS • • • *Jefferson Electric Company, Bellwood, Illinois. Catalog 391-R 16 pages, $8\frac{1}{2}\times10$ inches.* Power and circuit-coupling transformers for broadcast, public-address, and television-receiver service.

TRANSMISSION LINES • • • *Isolantite, Inc., 233 Broadway, New York, New York. Bulletin 101-C, 2 pages, $8\frac{1}{2}\times11$ inches.* Specifications on copper coaxial transmission lines and fittings. Outside diameters of $1\frac{5}{8}$, $2\frac{1}{8}$, and $2\frac{5}{8}$ inches.

TUBE DATA (RCA) • • • *RCA Manufacturing Company, Inc., Harrison, New Jersey. Application Note No. 104, 8 pages, $8\frac{1}{2}\times11$ inches.* "A Television Bibliography and RMA Standards," covering recent technical papers and books on television engineering.

TUBE DATA (RCA) • • • *RCA Manufacturing Company, Inc., Harrison, New Jersey. Application Notes Index, 3 pages, $8\frac{1}{2}\times11$ inches.* An index covering all application notes since the first issue in 1933.

TUBE DATA (TUNG-SOL) • • • *Tung-sol Lamp Works, Inc., Newark, New Jersey. Bulletin 39-4, 8 pages, $5\frac{1}{2}\times8\frac{1}{2}$ inches.* "Notes on the Applications of 35Z5GT and 45Z5GT," These tubes are designed for service as combined power rectifiers and pilot-lamp ballast resistors in receivers using 150 milliampere series-operated heaters.

IRE *membership offers many services to the radio engineer*

Proceedings—An outstanding publication in the radio engineering field. Over a quarter of a century of service to the world in publishing important radio engineering discoveries and developments, the PROCEEDINGS presents exhaustive engineering data of use to the specialist and general engineer. A list of its authors is a "Who's Who" of the leaders in radio science, research, and engineering.

Standards—Since 1914 our standards reports have stabilized and clarified engineering language, mathematics, graphical presentations, and the testing and rating of equipment. They are always in the process of revision and thus remain up to date.

Meetings—In twenty-two cities in the United States and Canada, meetings of the Institute and its sections are held regularly. Scores of papers on practically every branch of the field are presented and discussed. Several convention meetings are sponsored by the Institute and add materially to its effectiveness in distributing data of value to engineers.

The Institute of Radio Engineers

Incorporated
330 West 42nd Street, New York, N.Y.

To the Board of Directors
Gentlemen:

I hereby make application for ASSOCIATE membership in the Institute of Radio Engineers on the basis of my training and professional experience given herewith, and refer to the sponsors named below who are personally familiar with my work.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I shall be governed by the Constitution of the Institute as long as I continue a member. Furthermore I agree to promote the objects of the Institute so far as shall be in my power.

....
(Sign with pen)

....
(Address for mail)

....
(City and State)

....
(Date)

SPONSORS
(Signatures not required here)

Mr. ....

Address ....

City and State ....

Mr. ....

Address ....

City and State ....

Mr. ....

Address ....

City and State ....

Associate membership affiliates you with the Institute and brings you the PROCEEDINGS each month as well as notices of meetings held near you.

(Typewriting preferred in filling in this form) No..........

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

Name ....
(Give full name, last name first)

Present Occupation ....
(Title and name of concern)

Business Address ....

Home Address ....

Place of Birth .... Date of Birth .... Age ....

Education ....

Degree ....
(College) (Date received)

TRAINING AND PROFESSIONAL EXPERIENCE

(Give dates and type of work, including details of present activities)

Record may be continued on other sheets of this size is space is insufficient.

Receipt Acknowledged .... Elected .... Notified ....

Requirements—For Associate membership, an applicant must be at least twenty-one years of age, of good character, and be interested in or connected with the study or application of radio science or the radio arts.

Sponsors—Three sponsors who are familiar with the work of the applicant must be named. Preferably these should be Associates, Members, or Fellows of the Institute. In cases where the applicant is so located as not to be known to the required number of member sponsors, the names of responsible nonmember sponsors may be given.

Dues—Dues for Associate membership are six dollars per year. The entrance fee for this grade is three dollars and should accompany the application.

Other Grades—Those who are between the ages of eighteen and twenty-one may apply for Junior grade. Student membership is available to full-time students in engineering or science courses in colleges granting degrees as a result of four-year courses. Member grade is open to older engineers with several years of experience. Information on these grades may be obtained from the Institute.

ENGINEERING DIRECTORY

Consultants, Patent Attorneys, Laboratory Services

BRUNSON S. McCUTCHEN and CHARLES B. AIKEN
Consulting Engineers

Technical cooperation with Attorneys in connection with patent litigation—Design and Development work—Audio and radio frequency measurements—Equipment studies—Receiver and transmitter problems—A well equipped laboratory.

75 West Street
New York City

Telephone
WHitehall 4-7275

W. J. POLYDOROFF
CONSULTING ENGINEER

Design and complete tests of dust core inductors, all frequencies and applications. Research and patent problems in communication art, including television.

2020 ENGINEERING BUILDING
CHICAGO, U.S.A.

Use this directory . . .

when you need consulting services

when you are asked to suggest the name of a specialist on an engineering or patent problem

Consulting Engineers, Patent Attorneys, Laboratory Services . . . Applications for card space in the Engineering Directory are invited. Complete data will be sent on request to

PROCEEDINGS of the I.R.E.
330 West 42nd Street New York, N.Y.

INDEX

DISPLAY ADVERTISERS

POSITIONS OPEN

The following positions of interest to I.R.E. members have been reported as open on July 26. Make your application in writing and address it to

Box No. ......
PROCEEDINGS of the I.R.E.
330 West 42nd Street, New York, N.Y.

Please be sure that the envelope carries your name and address

DESIGN ENGINEERS

The Proceedings is receiving an increasing number of requests from employers for engineers with *commercial—design experience* on various specialized types of radio-communication equipment: receivers and transmitters, audio and video, for the broadcast, police, and aircraft services.

If you are qualified and are interested in openings of this type, we suggest that you file a statement of your education and experience record with I.R.E. headquarters. Write to Box 200 and request a copy of the "I.R.E. Employment Record Form."

TELEVISION RECEIVER ENGINEER

not over 35, with wide background of laboratory experience in modern radio receiver testing and construction. Must possess skill in mechanical layout and know electrical wiring technic at high frequencies as well as at high voltage. Must be able to calculate coils and circuit constants for practical application to television broad band amplifiers. Should be familiar with sweep circuits and synchronizing equipment. Enclose picture and state salary. Box 198.

SOUND-EQUIPMENT DESIGNER

College, or technical school graduate, majoring on subjects associated with electronic tubes and their application, particularly in sound field. Experience should embrace, if possible, sound equipment, phonograph pickups, inter-communicating systems, etc. Our requirements are along lines of design and electrical engineering. Age 25 to 35. Box 199.

Attention Employers . .

Announcements for "Positions Open" are accepted without charge from employers offering salaried employment of engineering grade to I.R.E. members. Please supply complete information and indicate which details should be treated as confidential. Address: "POSITIONS OPEN," Institute of Radio Engineers, 330 West 42nd Street, New York, N.Y.

The Institute reserves the right to refuse any announcement without giving a reason for the refusal

NEW HEAVY DUTY RADIATION-AIR COOLED TUBES

Over-all height 17½ inches Maximum diameter 8 inches

LIST PRICE $300

2000T

Filament voltage	10 volts
Filament current	26 amps
Amplification factor	18.5
Grid-plate capacity	9 mmfds
Grid-filament capacity	13 mmfds
Filament-plate capacity	1 mmfds

MAXIMUM RATINGS

Plate voltage	6000 volts
Plate current	1.75 amps
D. C. Grid current	.2 amps
Plate dissipation	2000 watts

Over-all height 16½ inches Maximum diameter 7 inches

LIST PRICE $225

1500T

Filament voltage	7.5 volts
Filament current	26 amps
Amplification factor	18.5
Grid-plate capacity	7 mmfds
Grid-filament capacity	10 mmfds
Filament-plate capacity	.9 mmfds

MAXIMUM RATINGS

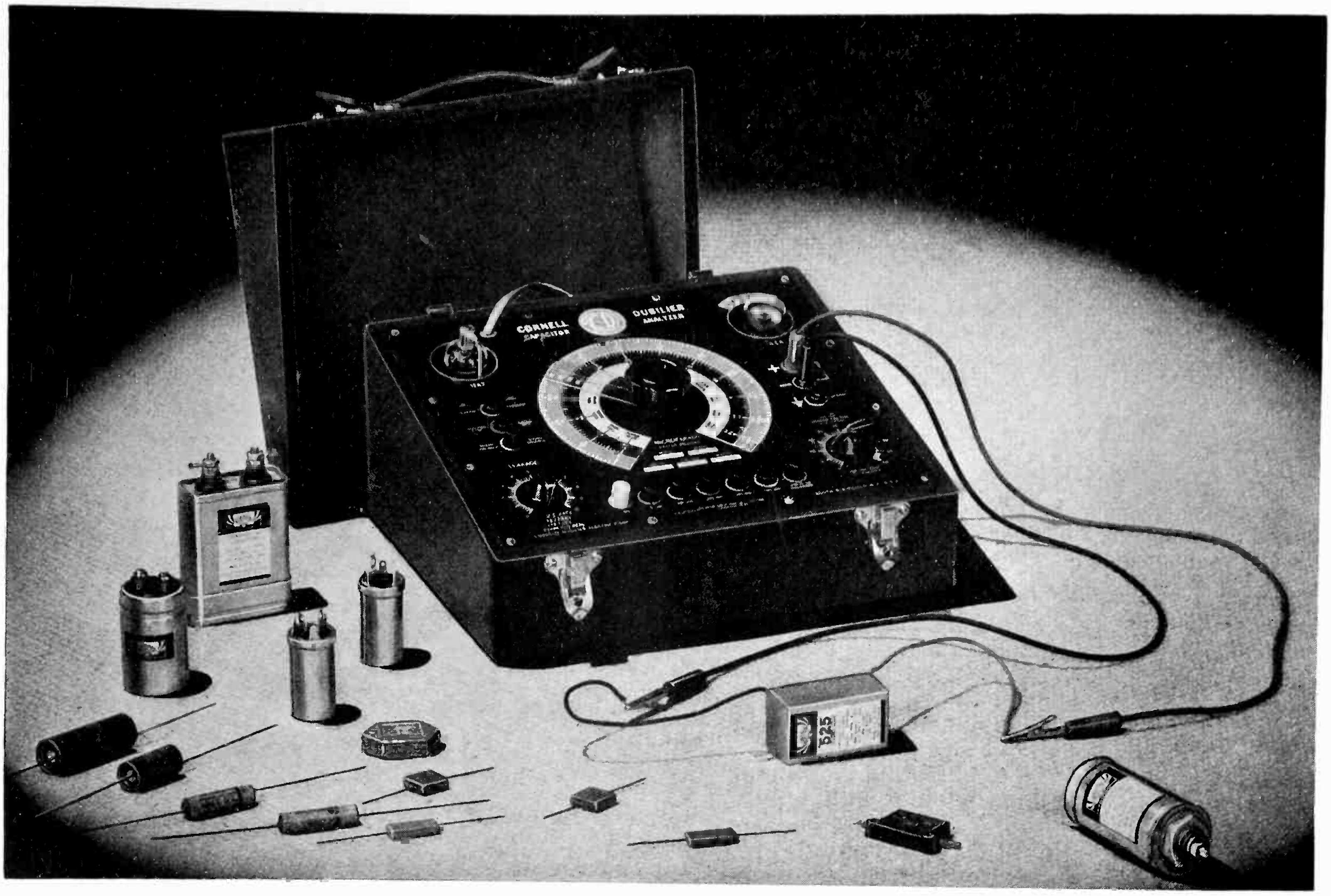
Plate voltage	6000 volts
Plate current	1.25 amps
D. C. Grid current	.175 amps
Plate dissipation	1500 watts

10 TO 15 KW ANTENNA POWER WITH PUSH-PULL RADIATION-AIR COOLED TRIODES.

Here's new economy and greater efficiency for communications companies and broadcasters. Eimac 1500T and 2000T open new fields for the design of commercial transmitters. These new tubes were designed especially for medium high power radio and television transmitters. The unconditional guarantee against failures resulting from gas released internally—the "Eimac-processed" tantalum elements — the extra rugged grid and filament and downright ability to outperform most other vacuum tubes makes them the most outstanding vacuum tube on the market today. Low interelectrode capacities and high electrical efficiency place them "head-and-shoulder" above the old, expensive to operate, water-cooled tube of medium power which is fast disappearing. Immediate recognition by the world's leading radio engineers places the stamp of approval on the new Eimac 1500T and 2000T. Technicians, station owners, manufacturers are invited to write for complete data—*you should have this information.*

Eimac TUBES

Eitel-McCullough, Inc., 768 San Mateo St., San Bruno, Cal.



CAPACITOR ANALYZER

For Laboratory and Shop

The C-D Capacitor Analyzer quickly and accurately measures all important characteristics of paper, mica, oil and electrolytics, including A.C. motor types. It offers the most accurate capacitor test of any instrument of its type, and may be operated on any 110 volt, 50-60 cycle power line.

The analyzer consists essentially of a Wien Bridge connected to a single stage of amplification which operates a "visual eye" for high sensitivity measurements. The degree of leakage is indicated by the "visual eye" making it possible to determine the exact condition of the capacitor under test. A built-in power supply provides 450 volts, D.C. for leakage and insulation resistance measurements. A 12A7 is used as rectifier and amplifier, while a 6E5 is used for bridge detector and leakage indicator. Model BF-50, List Price, *(less tubes)* $41.50

FEATURES

MEASURES CAPACITY. Accurately measures capacity of all types of capacitors from .00001 to 240 mfd.

MEASURES POWER-FACTOR. Measurements of power-factor from 0 to 50% on all types of electrolytic capacitors, including motor starting types.

INDICATES INSULATION RESISTANCE. Insulation resistance measurements of paper and mica capacitors. Also measures many types of insulation.

INDICATES LEAKAGE. Measurements of leakage of electrolytic capacitors by means of built-in direct current power supply.

DIRECT READING LINEAR SCALE CALIBRATION. All scales on panel uniformly spaced, easy to read, thus avoiding possible errors in using multipliers or charts.

PUSH BUTTON SWITCHING. For simplified adjustments, all circuit changes are made by means of push button switches.

SIX COLOR CODED SCALES. Accurately calibrated, six color coded scales, uniformly spaced over total spacing of sixty inches, easy to read. No "blind spots".

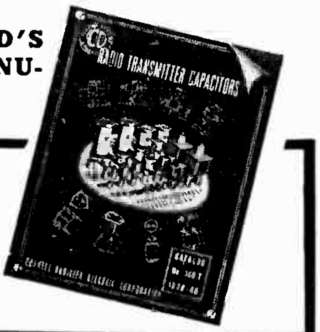
SELF CONTAINED—PORTABLE. An instrument complete in itself, requiring no headphones, meters, etc. Supplied in walnut cabinet, 6½ x 12 x 9¾ inches, with removable cover and carrying handle.

For complete information on the C-D capacitor analyzer, bridge and decades, write for Catalog No. 167-A.

PRODUCT OF THE WORLD'S LARGEST AND OLDEST MANUFACTURER OF CAPACITORS.

CORNELL-DUBILIER
ELECTRIC CORPORATION
1012 Hamilton Boulevard, South Plainfield, New Jersey
Cable Address: CORDU

CATALOG NO. 160-T on
TRANSMITTER CAPACITORS
NOW READY
COPY FREE ON REQUEST



An Open Invitation to all Engineers in Radio and Allied Fields

to attend the I.R.E.'s

1939 RADIO ENGINEERING SHOW

AND

14th ANNUAL CONVENTION

●

HOTEL PENNSYLVANIA, NEW YORK
SEPTEMBER 20-23

No matter where in radio or allied engineering your interests lie, this year's Annual Convention and the Radio Engineering Show will be worth traveling a long way to attend.

There is no easier way of keeping abreast of technical developments in all branches of our rapidly changing industry. And there is no better way of broadening your professional outlook than this 4-day meeting with 2000 other engineers having interests like your own.

NEW YORK IS ALSO THE CENTER FOR OTHER ATTRACTIONS OF ENGINEERING INTEREST

● TELEVISION—Television transmitters are in operation at several points in Metropolitan New York.

● FREQUENCY MODULATION—The new Armstrong wide-band frequency modulation system is now undergoing experimental service tests in the New York area.

● WORLD'S FAIR—A 10-minute, 10-cent ride from the terminal across the street from the Convention Headquarters and the Radio Engineering Show.

● AT THE RADIO ENGINEERING SHOW, 35 leading manufacturers of equipment, instruments, materials and components, exhibit their newest commercial developments. It's your opportunity to see what's new at first hand, to discuss your problems with the manufacturer's engineers.

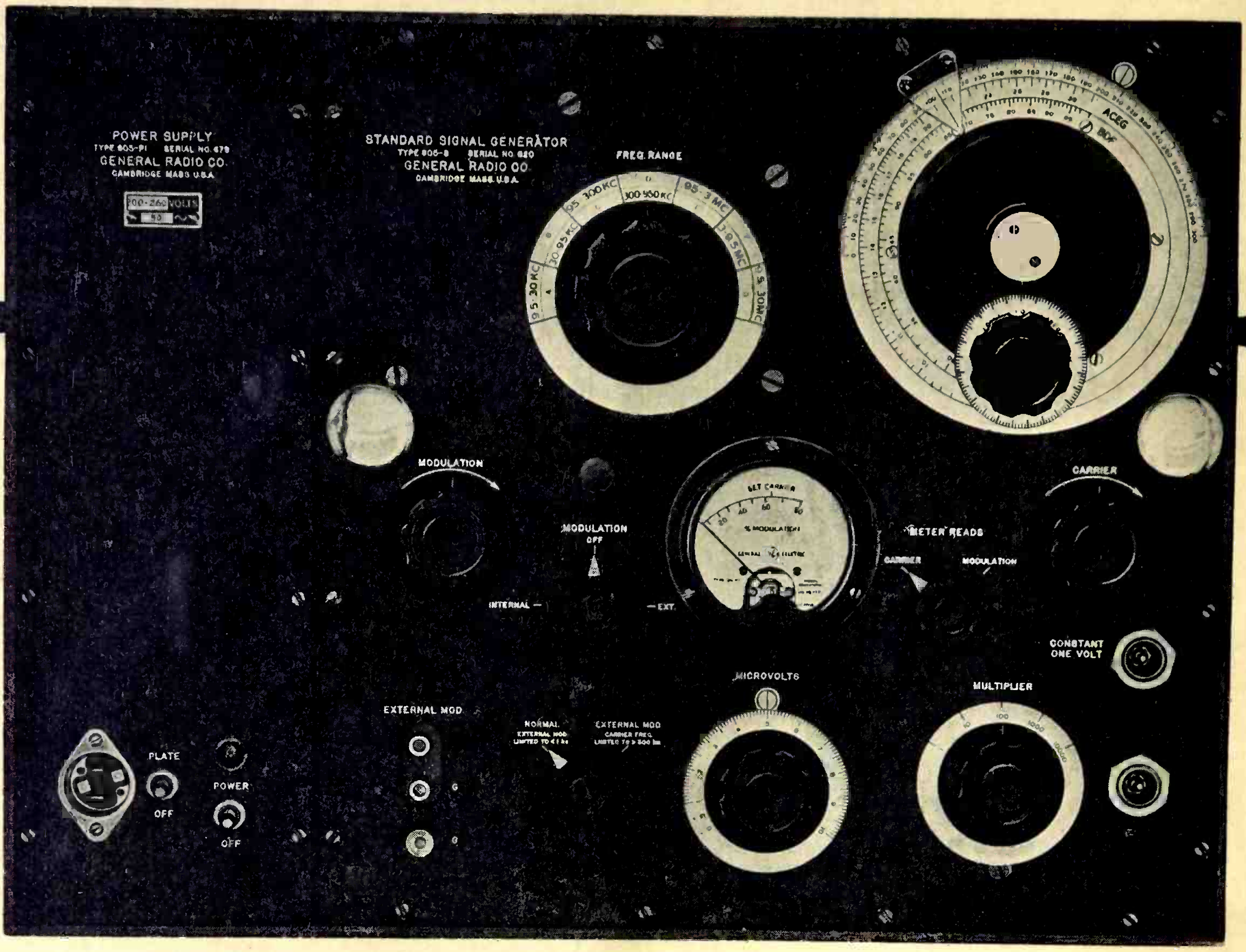
● A TECHNICAL PROGRAM covering all important branches of radio engineering is now in preparation by the I.R.E.'s Convention Committee. For details see the September issue of the PROCEEDINGS OF THE I. R. E.

● THIS INVITATION is extended to all interested engineers and physicists. You will be required to register, but there will be no registration fee or other charge for admission either to the Radio Engineering Show or to the technical sessions of the Convention.

SEPTEMBER 1939

S	M	Tu	W	Th	F	S
*	*	*	20	21	22	23

INSTITUTE OF RADIO ENGINEERS, INC.
330 WEST 42nd STREET NEW YORK, N.Y.



FOR OBTAINING RECEIVER CHARACTERISTICS ACCURATELY • RAPIDLY • CONVENIENTLY

WITH the G-R Type 605-B Standard-Signal Generator you can make the following basic receiver characteristic measurements very simply and quickly:

- **SENSITIVITY**
- **SELECTIVITY**
- **DISTORTION**
- **TUNING RANGE**
- **TUNING CALIBRATION**
- **FREQUENCY RESPONSE**
- **INTERFERENCE**
- **OUTPUT**
- **AVC CHARACTERISTICS**
- **AFC CHARACTERISTICS**

WRITE FOR BULLETIN 456

Many of the design characteristics of the Type 605-B Generator are exclusive. All features of this moderately-priced instrument combine to make it the best signal generator available for obtaining the essential facts about your receiver. PRICE: $415.00

FEATURES

DIRECT-READING CARRIER RANGE: 9.5 kc to 30 Mc
EXTRA CARRIER RANGE: 30 to 50 Mc
LOGARITHMIC FREQUENCY DIAL: with newly designed slow-motion, smooth acting incremental dial reading to 0.02% for selectivity measurements
OUTPUT CONTINUOUSLY ADJUSTABLE: 0.5 µv to 0.1 v
SEPARATE 1-VOLT OUTPUT JACK
MODULATION CONTINUOUSLY ADJUSTABLE to 80%
INTERNAL MODULATION: 400 cycles ±5%
EXTERNAL MODULATION: flat from 30 cycles to 15 kc
NEGLIGIBLE FREQUENCY MODULATION
NO ATTENUATOR REACTION ON FREQUENCY
EXCELLENT SHIELDING
A-C OPERATION with built-in voltage regulator

GENERAL RADIO COMPANY CAMBRIDGE MASSACHUSETTS

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN