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RCA REVIEW

a technical journal

RADIO AND ELECTRONICS
RESEARCH • ENGINEERING

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RCA REVIEW

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INTRODUCTION
to the new
RCA REVIEW

RCA REVIEW is written by scientists and engineers. It speaks the language of the technician and bespeaks his ingenuity and influence upon the world. As an authoritative scientific journal, RCA REVIEW is highly representative of the cooperation and exchange of thoughts so vitally needed in order that science may advance in the "One World" which it so greatly has helped to create.

RCA REVIEW encompasses more than its name implies; it is more than a review of the past. Not only does it relate the achievements of RCA scientists and engineers but it reflects the thoughts of those whose pioneering in research, development and engineering are projecting the present into the future.

Introduced in 1936, RCA REVIEW was discontinued during the war because of security reasons and due to the fact that men of science had little time to record their thoughts and the results of their work for publication. RCA REVIEW now reappears in peacetime to reveal radio-electronic advances in the laboratory and in the field. Through the dissemination of knowledge it will aid industry. In reporting the latest developments in television, radar and all new phases of radio and related fields, it will continue to erect signposts that point into the future so that all who work in radio-electronic research and engineering may draw from it the inspiration and new ideas that will lead them onward across the broad frontiers of science.

David Sarnoff

DAVID SARNOFF, *President*
Radio Corporation of America

FOREWORD

THE purpose of RCA REVIEW is to present the latest available information concerning developments in radio, electronics and related fields to all scientists, engineers, executives and any others who may be interested in the advancement of radio and electronics as a science, an industry, and a service.

Comments on papers or suggestions for additional features or other improvements in RCA REVIEW will be greatly appreciated since they will insure that RCA REVIEW more nearly fulfills the purpose for which it is published.

From time to time this short foreword will be included as a method of presenting information concerning RCA REVIEW which is of interest to its readers. It is in no sense an "editorial", a "news bulletin", or a "sales message"; there are more than sufficient vehicles for such material. Nothing will appear in the foreword that is not considered to be of sufficient interest *and* importance to warrant occupying the time of busy scientists and engineers. Subject matter will include, among other items, announcements of various types as well as any necessary corrections.

All inquiries concerning papers published in RCA REVIEW and any comments or suggestions should be addressed to: Manager, RCA REVIEW, Radio Corporation of America, RCA Laboratories Division, Princeton, N. J.

Manager, RCA REVIEW

IMPROVED CATHODE-RAY TUBES WITH METAL-BACKED LUMINESCENT SCREENS*†

BY

D. W. EPSTEIN AND L. PENSAK

Research Department, RCA Laboratories Division, Princeton, N. J.

Summary—Considerably improved cathode-ray tubes result from the application of a light-reflecting, electron-pervious, thin metallic layer on the beam side of the luminescent screen. Although this has been realized for some time, it is only recently that practical methods for applying such a metallic layer in kinescopes have been developed.

Observations and measurements on such tubes, using aluminum for backing, show that under appropriate conditions such tubes possess many advantages over similar conventional tubes. These are:

1. *Improved efficiency of conversion of electron beam energy into useful light—in other words, more useful light output for a given beam power input.*
2. *Elimination of ion spot—thus making other, generally less direct, means for eliminating the ion spot unnecessary.*
3. *Improved contrast.*
4. *Elimination of secondary emission restrictions—thus permitting the use of high voltages and screen materials with poor secondary emission.*

ONE of the outstanding quests in the cathode-ray tube field has been the search for means of increasing the brightness of the pictures on the face of the tube. Previous methods consisted primarily of efforts to increase beam power—that is, raising the voltage and increasing the current by improvements in electron optics—as well as a search for luminescent materials with greater efficiency in converting beam power into light. The most recent step in increasing light output is the application of a light-reflecting metallic layer on the beam side of the fluorescent screen.

Many practical tubes with metallic layers on the screens were built and used six and seven years ago. However, these tubes were limited to high-voltage operation and the metallic layers did not possess the light-reflecting properties which characterize the new metal films. The advantages of having a thin reflecting layer have long been anticipated and, to a limited extent, observed in the laboratory. It is only recently, however, that methods have been developed which will make such tubes possible and practical.

Before showing how this is accomplished, it is worthwhile to review briefly the pertinent part of the state of affairs at the luminescent

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† Presented at the I.R.E. Winter Technical Meeting, January 24, 1946, in New York, N. Y.

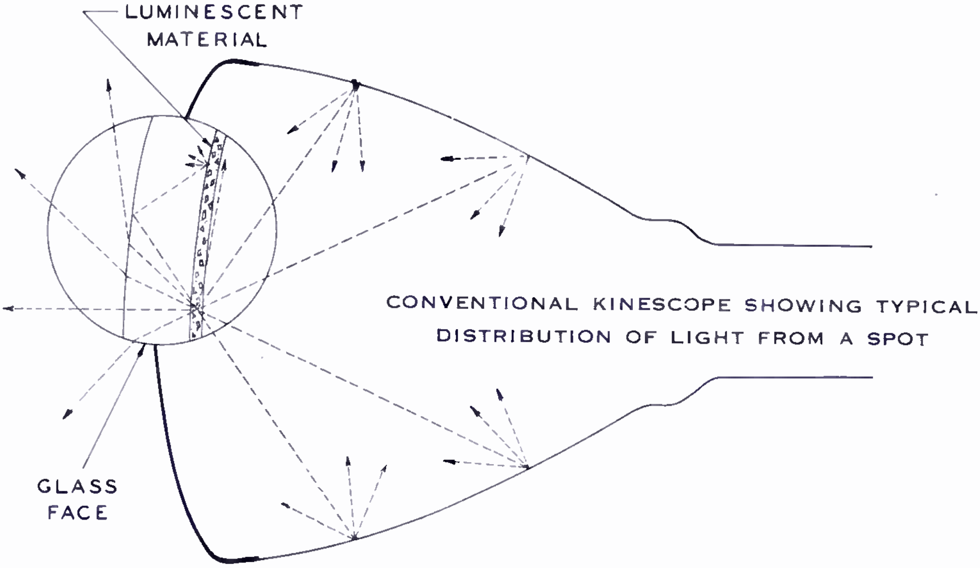
LUMINESCENT MATERIAL
CONVENTIONAL KINESCOPE SHOWING TYPICAL DISTRIBUTION OF LIGHT FROM A SPOT
GLASS FACE

Fig. 1.

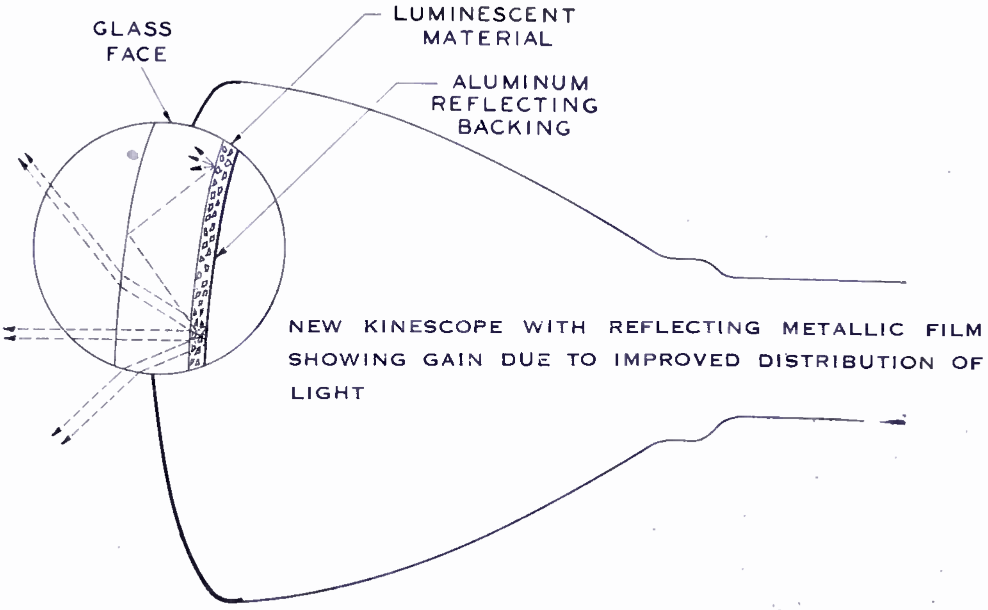
GLASS FACE
LUMINESCENT MATERIAL
ALUMINUM REFLECTING BACKING
NEW KINESCOPE WITH REFLECTING METALLIC FILM SHOWING GAIN DUE TO IMPROVED DISTRIBUTION OF LIGHT

Fig. 2.

screen in a conventional kinescope. This is shown schematically in Figure 1. The region in the circle is a greatly magnified and somewhat distorted diagram of a small section of the tube face of which one element is fluorescing. Generally, at least 50% of the light generated in the screen is emitted towards the electron gun in the tube. Another 15-25% is lost by total internal reflection in the glass of the tube face. Thus only about 25-35% of the total light generated is emitted in the forward direction to constitute the useful light output of the tube. It should also be pointed out here that some of the wasted light is harmful in that it is scattered back onto the screen to set a limit on possible contrast in the picture. There are several mechanisms for this. One is the back-scattering of the light which strikes the inside walls of the tube; although the light is largely absorbed by the blackening on the wall, some of it comes back to the screen. Another is the light from one portion of the screen which can illuminate other regions directly because of the curvature of the face. Some of the totally reflected trapped light in the glass is reflected back onto the screen and is scattered causing what is known as halation.

Figure 2 shows a tube whose screen is covered with an electron-pervious, but light-reflecting, metallic layer. Now it is seen that the light which previously would go towards the rear (electron gun) is reflected forward into the direction of viewing. Thus without an increase of light generated, the efficiency of conversion of electron beam power into useful light has been increased. At the same time, some of the limitations on contrast have been removed, that is, the back-reflected light and the effects due to curvature of the face. Experiments show that the large area contrast is considerably improved by a factor of three to ten times; the detail contrast, being primarily limited by halation, is only slightly improved.

The properties which this metallic layer should possess are: (1) it should be thin enough and of the right kind of metal to cause negligible absorption of the electron beam at the desired operating voltages; (2) it should be opaque, relatively smooth, and highly light-reflecting, so as to act as a mirror; (3) it should have sufficient conductivity to conduct the full beam current; (4) it should be strong enough to withstand the stresses due to effect of the focussed electron beam; (5) it should be durable enough to be able to withstand the necessary subsequent processing of the tube; and (6) it should be of a metal that will not chemically react with the luminescent screen material.

The metal chosen to work with is aluminum, because it combines properties which provide the best compromise in meeting the above conditions. It is easily applied by evaporation and does not affect luminescent screens. Its ability to meet condition (1) is indicated in Figure 3 where are shown a group of calculated curves giving the fraction of electron beam power that is passed by films of various thicknesses, as a function of the initial beam voltage. It will be noticed that a 10,000-volt beam will retain only 15% of its incident energy on passing through an aluminum film 5,000 Å thick. A film 2,000 Å thick will pass fifty-seven per cent and a film 1,000 Å will pass about 77% of the energy. If we assume that the effect of the mirror is to double the apparent brightness, then it is evident that a tube operating at 10,000 volts and with a film about 3,000 Å thick will show no difference from an unaluminized standard tube at the same voltage. It should be noticed, however, that a moderate increase in voltage causes a rapid

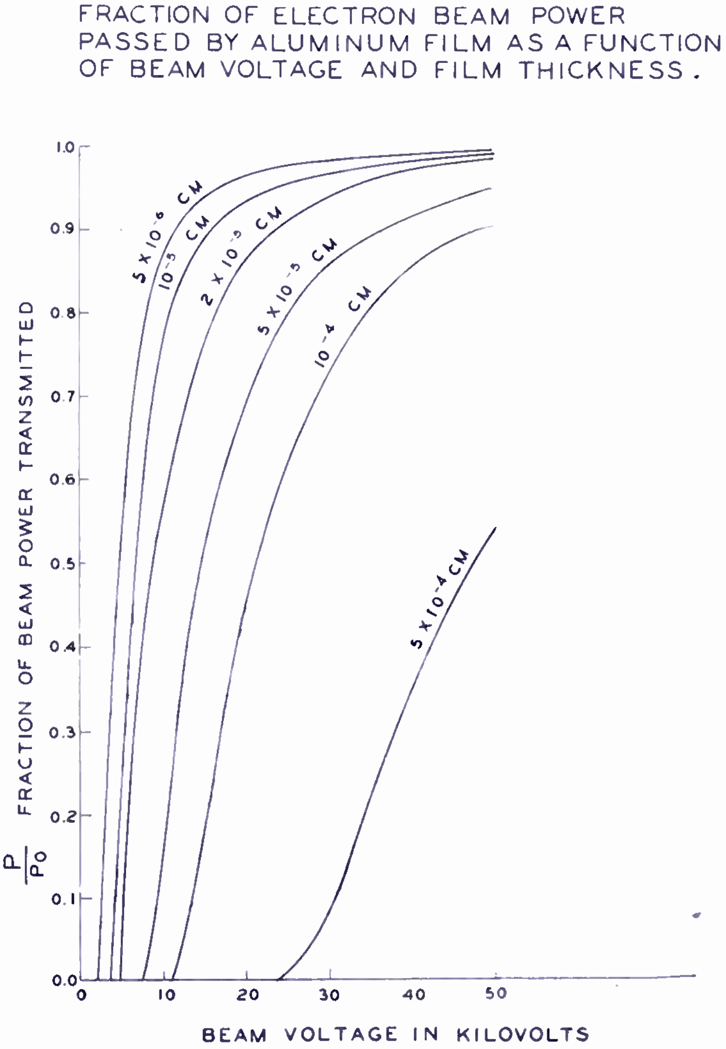

Fig. 3.

decrease in percentage loss of beam energy in the film. Experience has indicated that the most useful range of film thickness is between 500 Å and 5,000 Å.

In order for the film to meet condition (2), "that it be relatively smooth and mirror like", it has been found possible to cover the fluorescent screen with a thin film of organic material stretched over the crystals like a blanket. This provides a smooth surface upon which the aluminum can be evaporated. If such an intermediate film is not present, the aluminum will be broken up on evaporation so that it will not have its reflecting properties nor will it be continuous and conducting in the thicknesses necessary for low voltage operation. In order to obtain conductivity without the organic film, it would be necessary to evaporate five to ten times as much aluminum as is now necessary. This is why previous metallized screen tubes were restricted to high voltage operation.

These earlier tubes were aluminized in order to avoid undesirable effects due to poor secondary emission from the screen. It can readily be shown that if one tries to operate tubes at a voltage such that the secondary emission ratio from the screen is less than one to one, the screen will accumulate sufficient charge to slow up approaching electrons to a velocity at which the secondary emission is unity. This means that the screen is effectively operating at a voltage that may be considerably less than that applied to the tube. This is known as the "sticking" effect and is almost entirely corrected by providing a conducting layer over the screen. The new method of providing an aluminum film makes possible the correction of the effects due to secondary emission difficulties in tubes operating in the voltage range in which kinescopes are now operated. Thus the choice of luminescent materials for the screen is enlarged and improved techniques for applying these screens to the tube face are made available.

This aluminum film also provides a new line of attack on the old television tube problem of ion spot. Ions can be completely stopped by a film of aluminum that will readily pass electrons. Experience with tubes in the laboratory has shown that, with the right set of conditions —such as proper aluminum thickness and reasonably low gas pressure —tubes can be made which will show no ion spot at normal operating voltages.

Among other advantages of the aluminum film are the protection of the phosphor during processing and life and the improvement of the stability of the pattern with regard to displacement due to surface leakages on the face of the tube such as are produced if one touches the face of an operating kinescope.

Figure 4 gives the efficiency in candle power per watt as a function of applied voltage and at a fixed beam current obtained for two laboratory-made 12-inch tubes, identical except that one was aluminized. These curves are typical of measurements made on a number of tubes. It is to be noted that at the lower voltages the unaluminized tube has the higher efficiency whereas above the cross-over voltage the aluminized tube has the higher efficiency. The cross-over voltage which is controlled by the aluminum thickness is primarily dictated by such considerations as operating voltage and ion spot elimination. As seen from Figure 4, the increase in efficiency above the cross-over voltage is quite considerable; for luminescent screens with poor secondary emission characteristics, the gain may be considerably greater than that shown on the figure.

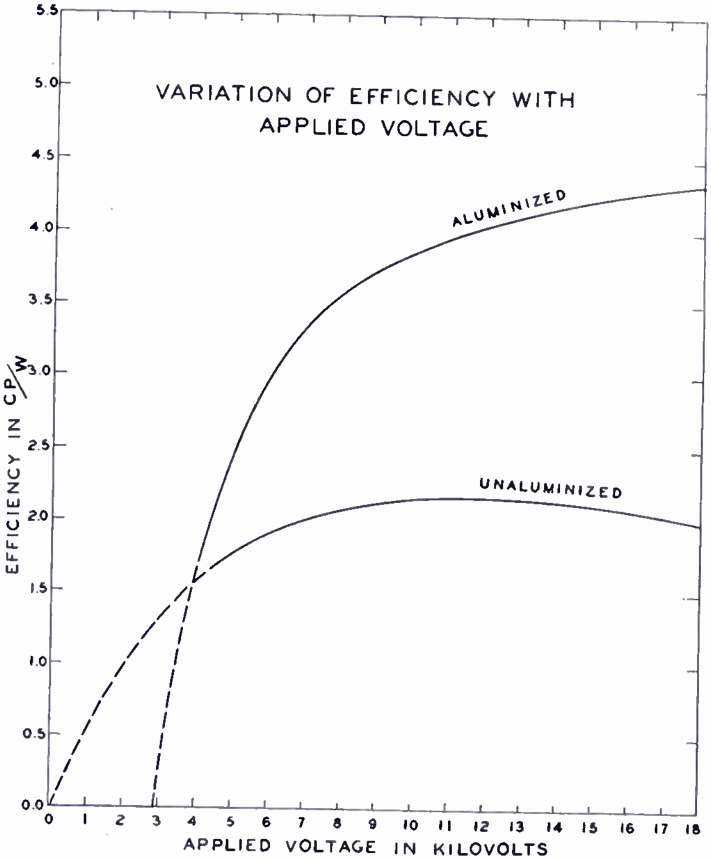

Fig. 4.

OBSERVATIONS AND COMPARISONS ON RADIO TELEGRAPH SIGNALING BY FREQUENCY SHIFT AND ON-OFF KEYING*

BY

H. O. PETERSON, JOHN B. ATWOOD, H. E. GOLDSTINE,
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Summary—Comparisons were made between CW Telegraph (CWT: on-off keying) and Frequency Shift Telegraph (FST) signals received from Bolinas, California at Riverhead, New York. The CWT signals were received with a standard RCA Communications, Inc. three-receiver diversity group and the FST signals were received through a frequency shift adaptor using two receivers of the same diversity group. The quality of the circuit was indicated by error counts on a five-unit start-stop printer, using a recurring series of test words transmitted from a loop of perforated tape at San Francisco, Calif. High speed dots were observed on an oscilloscope. Four-channel multiplex seven-unit printer signals were observed several days in New York.

It was concluded:

1. The FST system (2 receivers) used in these tests gave an equivalent power gain of approximately 11 decibels over the CWT system (3 receivers).

2. It was found that when printer errors are caused by noise, the number of errors per thousand letters is inversely proportional to the 0.75 power of the transmitter power. A field strength of approximately 10 microvolts per meter was required for an accuracy of one error in ten thousand letters on FST with two-receiver diversity, and approximately 40 microvolts per meter were required for the same accuracy on CWT with three-receiver diversity.

3. The gain due to the use of the space diversity principle in the FST unit is approximately 10 decibels where noise is a limiting factor. There is also a considerable diversity gain where multipath distortion is a limitation. This gain cannot be expressed on a power basis since multipath distortion causes errors independent of power.

4. The gain due to three-receiver diversity on CWT was 10.5 decibels.

5. The use of superimposed 200 cycle phase modulation was not found to yield a gain on the FST system when space diversity is provided. However some gain is indicated where a single receiver is used.

6. It was found the FST system would satisfactorily carry a four channel time division multiplex signal operating seven-unit printers. As the signal faded into the noise level the FST system carried the signal longer than the CWT system.

7. Oscilloscopic observation of high speed dots indicated the top speed possible, when limited by multipath effects, would not be greater for FST than for CWT. It is estimated the baud length should not be shorter than 1.33 times the multipath elongation time. In the presence of multipath echo, the results on CWT can sometimes be improved by operating with

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* Decimal Classification: R531.8.

light telegraph bias at the transmitter but for FST the results are optimum when the telegraph bias is neutral at the transmitter.

8. It was determined that multipath distortion is more troublesome when the frequency shift is reduced. It appears a shift of 850 cycles is a good choice for the present system, with anticipated multipath conditions, and a keying speed corresponding to 4-channel seven-unit printer multiplex. A shift on the order of 1400 cycles is indicated for an operating speed corresponding to eight-channel multiplex.

9. It was determined that the four-channel seven-unit printer signal, using FST with 850 cycles shift, can be received with a receiver bandwidth of 1 kilocycle. Eight-channel multiplex would generally be received with the 2 kilocycles receiver bandwidth.

10. It was determined that the length of the propagation path does not vary greatly with time. Over a period of eight hours the maximum variation in time of arrival was approximately two milliseconds. This indicates it should be feasible to use precision frequency standards to maintain synchronism in a time division multiplex system.

INTRODUCTION

THIS paper presents the results of a series of tests which were conducted at the request and with the cooperation of RCA Communications, Inc. to evaluate the benefits to be derived from frequency shift keying. The tests were made over a radio circuit from the transmitting station at Bolinas, California, to the receiving station at Riverhead, New York, during the period from June 27, 1945 to September 1, 1945. These tests were made as a part of a program of research and development in the field of frequency modulation and frequency shift signaling which has been carried forward during the past two decades.

DESCRIPTION OF TEST CIRCUIT

A. *Transmitter*

The transmitter was located at Bolinas, California and a block diagram of the equipment is shown in Figure 1.

The transmitter consisted of a standard RCA Communications 1 kilowatt transmitter as modified for the transmission of frequency shift keying by the addition of the Transmitter Frequency Shift Keying Unit. During the tests, the transmitter output power actually used was varied from 22 watts to several hundred watts. For most of the tests, the transmitter was connected to a horizontal doublet directed towards Riverhead.

The F-S Keying Unit replaces the normal crystal oscillator stage in the transmitter, and should provide average frequency stability comparable to the usual crystal units. A stable 200 kilocycle oscillator is frequency modulated by a reactance tube in accordance with the keying signal applied to the grid of the reactance tube. The output of the

200 kilocycle oscillator is combined with a crystal oscillator in a balanced modulator and the upper sideband (sum of crystal and 200 kilocycle oscillator frequencies) is selected and fed to an amplifier-doubler output stage. The radio frequency output from the F-S Keying Unit is fed to the transmitter by a short length of radio frequency transmission line. A 200 kilocycle crystal oscillator is supplied to provide a means of calibrating the 200 kilocycle frequency shift oscillator.

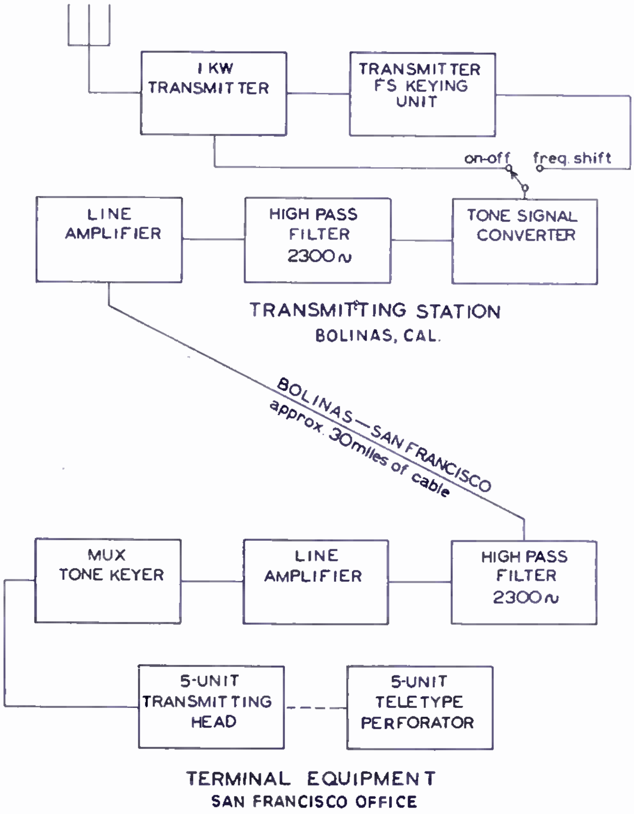

Fig. 1—Functional diagram of transmitting equipment.

B. *Receiver*

The receiver was located at Riverhead, New York, and a block diagram of the equipment is shown on Figure 2.

The receiver consisted of a standard RCA Communications three-receiver diversity as modified for the reception of frequency shift keying by the addition of the Frequency Shift Adaptor. The regular diversity Tone Keyer output was connected to a Line Amplifier-Rectifier which operated a 5-unit Teletype Printer. The inputs to the three receivers were connected to fishbone antennas directed towards Bolinas.

Located in another building at Riverhead was a single receiver which was used to record the strength of one of the signals used in the test. It used a tilted rhombic antenna directed towards Bolinas.

The Frequency Shift Adaptor was designed to adapt either a two-receiver diversity, or any two receivers of a three-receiver diversity, to the reception of frequency shift keying. In the case of a three-receiver diversity, the 50 kilocycle outputs from the intermediate frequency amplifiers of the three receivers are fed to the F-S Keying Unit over three coaxial cables. The selection of which two of the three receivers are to be used is made by means of two switches labeled A and B (Figure 2). Switch A is used to select between receivers one and two and Switch B to select between receivers two and three.

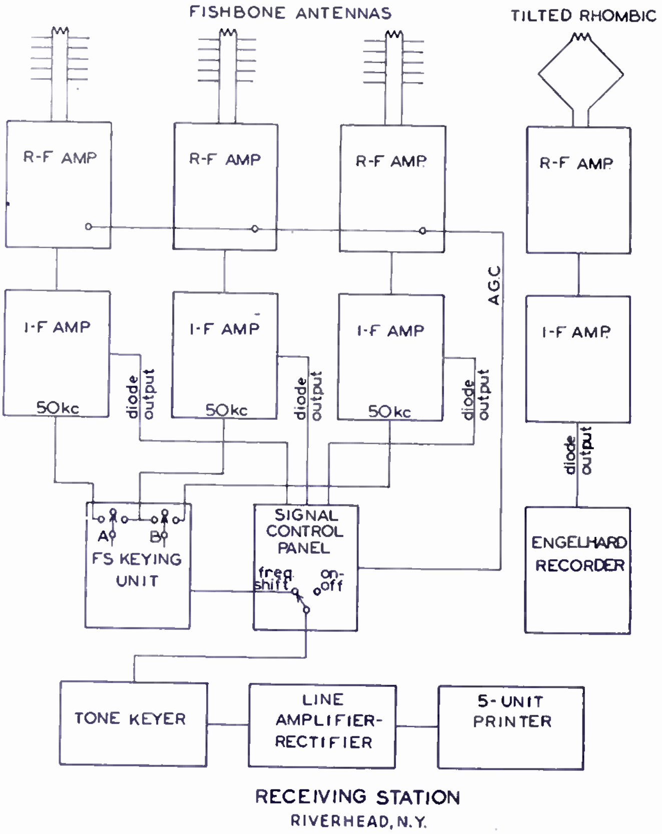

Fig. 2—Functional diagram of receiving equipment.

In the block diagram, Figure 3, the treatment of selected signals A and B is shown. Each signal is separately amplified, limited, fed through discriminators and detected. At this point (6SA7 gates, Figure 3) the unit automatically selects the output of the detector associated with the stronger signal and passes it on to the rest of the circuit.

Due to frequency diversity, the mark and space frequencies will fade at random with respect to each other much of the time on a given antenna. However, due to space diversity, the relative strength of mark or space will probably be different at any given instant on a second antenna. Thus there will be intervals when signal A is stronger than signal B on mark frequency but weaker than signal B on space frequency or vice versa. At such times the automatic selector will choose one detector output during the mark interval and the other detector output during the space interval.

The automatic selector consists of a pair of differentially connected diodes which rectify the 50 kilocycle outputs from the two intermediate frequency amplifiers. The differential voltage developed is used to trip a double trigger which in turn operates a pair of gate tubes having a common plate load and having their grids connected separately to the two detector outputs.

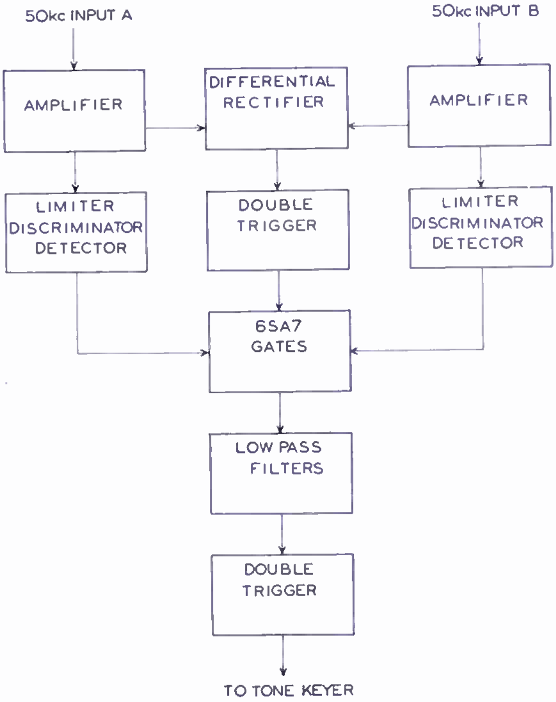

Fig. 3—Functional diagram of frequency shift adaptor unit for the receiver.

The automatic selector will switch from signal A to signal B with a difference in level of about 3 decibels. The actual switching time is about 40 microseconds, but the decision to switch takes about 150 microseconds.

Following the gate tubes, the selected signal goes through either of two low pass filters and a double trigger to the output. This second double trigger squares up the wave form and operates the diversity tone keyer.

Figure 4 shows typical loss vs frequency characteristics of the two low pass filters provided in the unit.

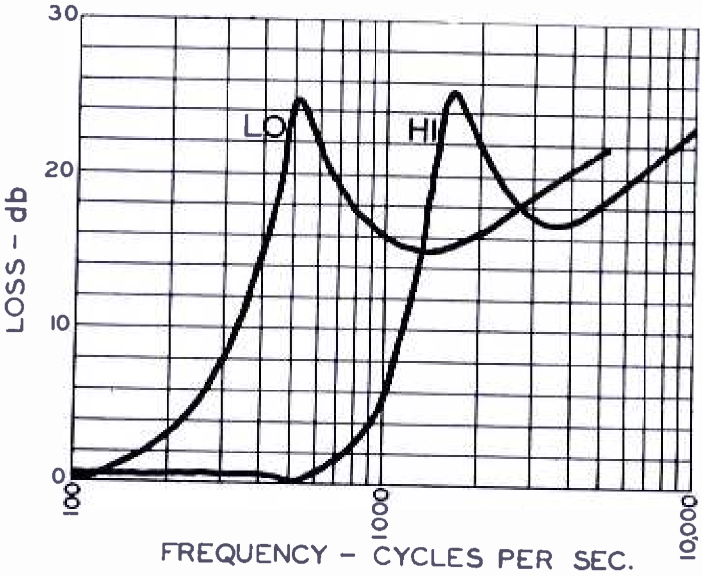

Fig. 4—Attenuation characteristics of the low pass filters in the frequency shift adaptor unit.

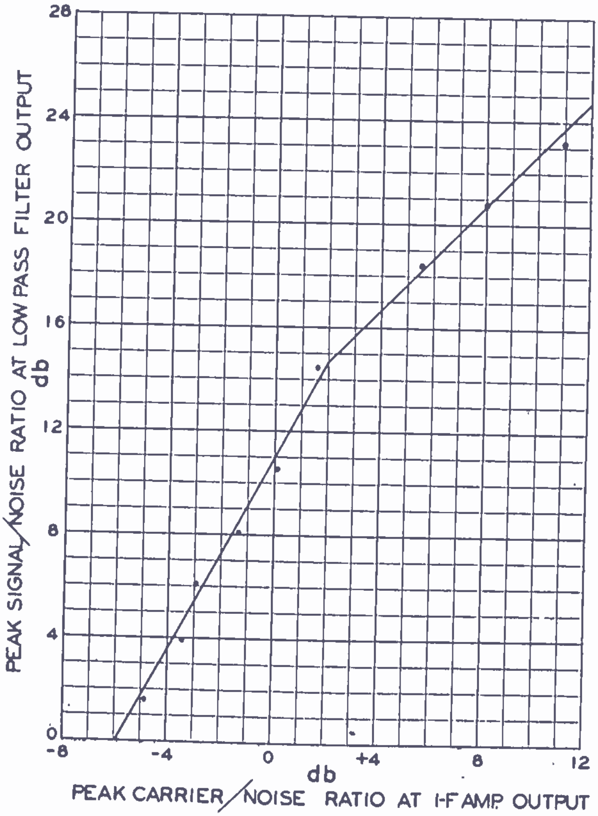

Fig. 5—Signal to noise characteristic of frequency shift adaptor unit for 850 cycles shift, 1000 cycles intermediate frequency bandwidth, 210 cycle low pass filter.

Figure 5 shows the peak signal/noise ratio at the output of the 200 cycle low pass filter plotted against the peak carrier/noise ratio at the output of the intermediate frequency amplifier (1000 cycle bandwidth) using a total frequency shift of 850 cycles.

Figure 6 is a similar curve except that the bandwidth and frequency shift have been cut in half and an additional curve added for a narrower low pass filter.

The curves for both Figures 5 and 6 were taken at the keying speed of a 5-unit start-stop printer, or about 22 cycles per second.

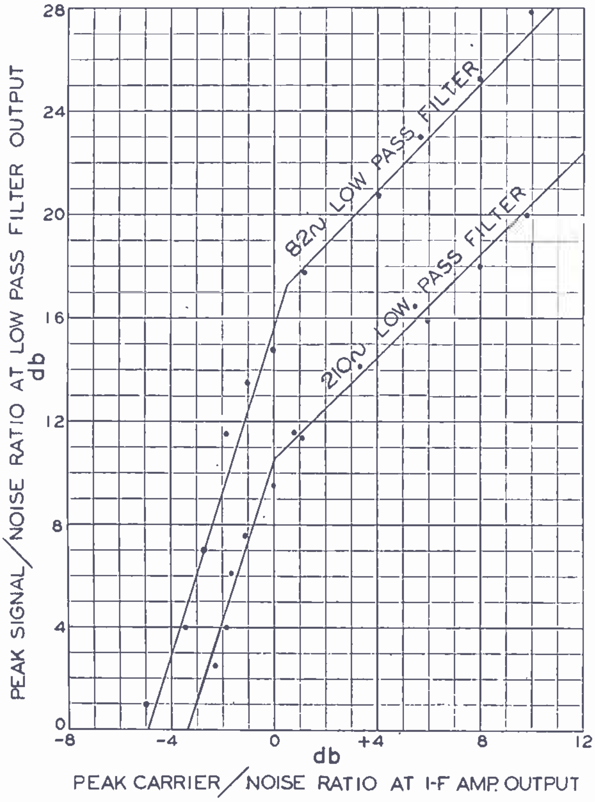

Fig. 6—Signal to noise characteristics of frequency shift adaptor unit for 425 cycles shift, 500 cycles intermediate frequency bandwidth, 82 and 210 cycle low pass filters.

TEST PROCEDURE

The general procedure followed in making these tests was to transmit a repeating tape for a 15 minute interval with the transmitter operating under one set of conditions; for example, on-off keying and a peak power output of 800 watts. For the next 15 minute interval, the transmitter would operate under another set of conditions; for example, frequency shift keying and a peak power output of 200 watts. The transmitter would then keep alternating between the two conditions for the duration of the test period.

At the receiving end, the number of errors made by the printer were counted for each 15 minute interval. At the end of the test period, a comparison was made between the total errors made under each condition. If the two error counts came out the same, then the difference between the two conditions was given by the power ratio used at the transmitter. If they were not the same, the result was used to estimate the power ratio that would be required to produce equality and another run was made using this new ratio. The power ratio used was progressively changed so as to go through the equality point as a further check.

The two test conditions were alternated every 15 minutes in order to average out fading cycles and varying atmospheric conditions. For most of the test conditions, the errors observed were due to atmospheric noise.

Two transmitter frequencies were available: KLR on 10,090 kc and KEM on 15,490 kc. Most of the testing was done using KLR, as observation showed that more significant results would be obtained on the lower frequency. One reason for this was that multipath effects were present quite regularly on the lower frequency and very seldom on the higher frequency. The signal strength of KLR was continuously recorded in order to correlate signal strength against printer errors.

RESULTS

A. *Comparison of Frequency Shift Keying (2 receiver diversity) and On-Off Keying (3 receiver diversity).*

Table I shows the results obtained using a total frequency shift of 850 cycles. The Frequency Shift Adaptor used a 200 cycle low pass filter in the detected output. The intermediate frequency bandwidth for both frequency shift keying and on-off keying was 1 kilocycle. This table shows that frequency shift keying is between 8 and 10 decibels better than on-off keying.

TABLE I.

Transmitter KLR

Peak Power Ratio (on-off = higher power)	*Errors/1000 Characters*		*Approximate no. of Characters/sample*
	Freq. Shift	*On-off*	
6.0 db	0.75	1.25	16,000
7.8 db	3.6	5.1	10,000
10.0 db	2.1	1.2	28,000
12.6 db	3.8	0.66	34,000

Another comparison can be obtained from Figures 7 and 8. For these two curves, the printer errors per 1000 characters are plotted against the field strength at the receiver location in decibels above 1 microvolt per meter. At the speed used in these tests, approximately 10,000 characters were transmitted in one half hour. These curves are a consolidation of all the applicable data obtained during the two months of testing and hence should give a better long term comparison than Table I. It should be pointed out that standard RCA Fishbone antennas were used on the receiver and that their effective height was not measured. These curves would indicate that frequency shift keying (2 receivers) is 11 decibels better than on-off keying (3 receivers).

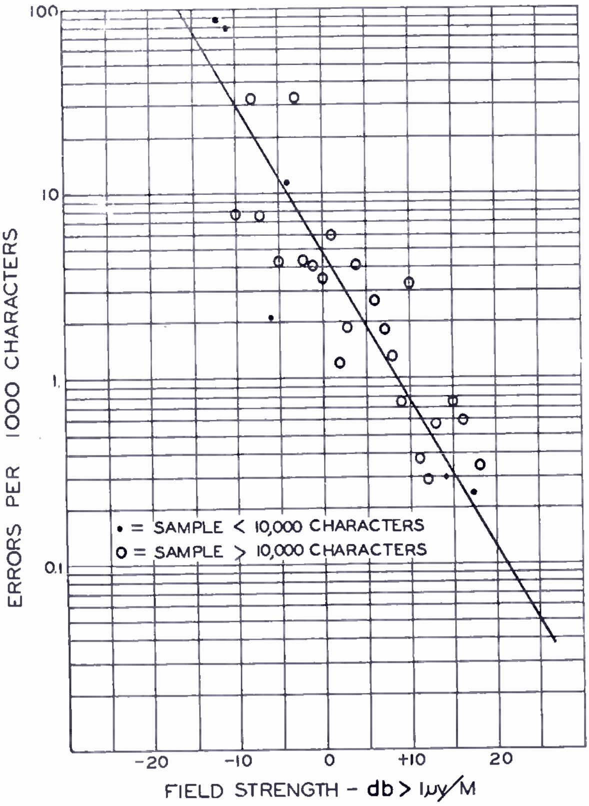

Fig. 7—Errors vs field strength for frequency shift keying using frequency shift adaptor unit with two-receiver diversity on fishbone antennas, 1000 cycles intermediate frequency bandwith, 210 cycle low pass filter, 850 cycles shift, 5 unit start-stop printer. The total number of characters was 700,000.

The slope of the lines drawn on Figures 7 and 8 are also of interest. If we let E represent the number of printer errors per thousand characters, this can be expressed by the relation

$$1/E \propto (\text{Power})^{x}.$$

Figure 7 shows that for frequency shift keying

$$x = 0.8$$

and Figure 8 shows that for on-off keying

$$x = 0.7$$

If a mean of the two is taken, the exponent of the power would be 0.75.

Another comparison between frequency shift keying and on-off keying was made using a total frequency shift of 425 cycles. The Frequency Shift Adaptor used a 70 cycle low pass filter in the detected output. The intermediate frequency bandwidth for both frequency shift keying and on-off keying was 500 cycles. The results are given in Table II below, which shows frequency shift keying (2 receivers) to be 10 decibels better than on-off keying (3 receivers).

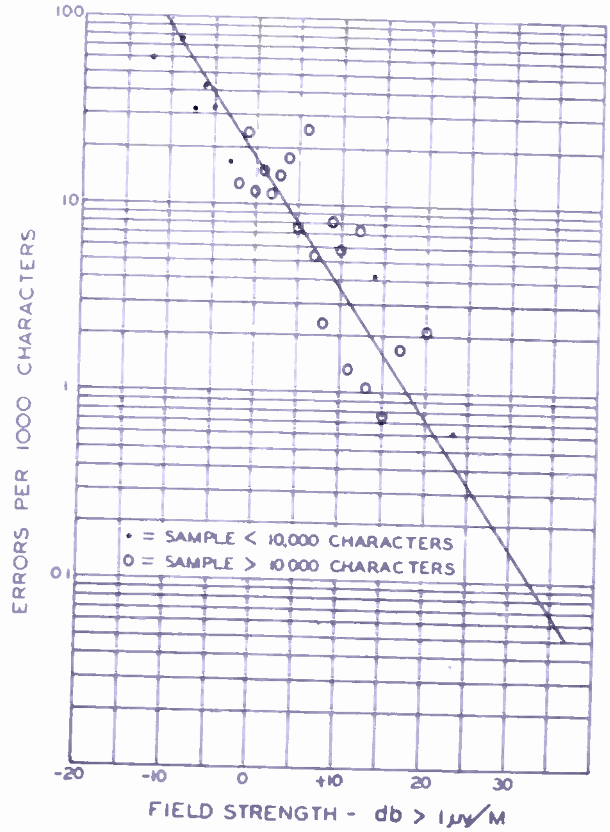

Fig. 8—Errors vs field strength for on-off keying with three-receiver diversity on fishbone antennas, 1000 cycles intermediate frequency bandwidth, 5-unit start-stop printer. The total number of characters was 477,000.

Table II.

Transmitter KLR

Peak Power Ratio (on off = higher power)	*Errors 1000 Characters*		*Approximate no. of Characters/sample*
	Freq. Shift	*On-Off*	
3 db	17	50	9,000
6 db	2.5	5.8	32,000
10 db	3.1	3.1	51,000
14 db	59	35.5	22,000

B. Gain Due to Space Diversity in F-S Adaptor.

Table III below shows the results obtained using a total frequency shift of 850 cycles, an intermediate frequency bandwidth of 1 kilocycle, and a 200 cycle low pass filter in the detected output. Interpolation shows the improvement due to space diversity to be approximately 10 decibels.

TABLE III.
Transmitter KLR

Peak Power Ratio (1 set = higher power)	*Errors/1000 Characters*		*Approximate no. of Characters/sample*
	2 sets	*1 set*	
6.5 db	0.3	2.7	4,000
8.2 db	4.2	4.7	55,000
12.0 db	10.7	8.8	21,000

C. Gain Due to Space Diversity on On-Off Keying Using RCA Communications Diversity Receiver.

A similar set of observations indicated that for on-off telegraph, a gain of 10.5 decibels was realized due to space diversity with the three receiver diversity receiver used in these tests.

D. Gain Due to Fast Time Constant in F-S Adaptor.

The time constant referred to in the heading is that of the automatic selector described in the Receiver Section. As stated there, the selector determines which of the two incoming signals is the stronger. It has a time constant of 150 microseconds. This fast time constant was compared with a medium time constant of 0.2 seconds and a slow time constant of 2 seconds. The intermediate frequency bandwidth was 1 kilocycle and the total frequency shift was 850 cycles. Table IV shows that the fast time constant is less than 6 decibels better than the medium time constant and more than 6 decibels better than the slow time constant.

TABLE IV.
Transmitters KLR and KEM

Peak Power Ratio (Fast = low power)	*Errors/1000 Characters*			*Approximate no. of Characters/sample*
	Fast	*Medium*	*Slow*	
0 db	2.9	7.2	11.7	39,000
6 db	4.4	2.4	7.4	19,000

E. Phase Modulation Superimposed on Frequency Shift Keying.

For this test 200 cycles phase modulation, of one radian deviation, was superimposed on 850 cycles frequency shift keying and this was compared with frequency shift keying without the phase modulation. An intermediate frequency bandwidth of 2 kilocycles was used when the phase modulation was present, and a 1 kilocycle bandwidth when it was removed. To correct for the doubled intermediate frequency bandwidth with phase modulation, the transmitter power was increased 3 decibels when the phase modulation was added. The results are shown below.

TABLE V.
Transmitters KLR and KEM

	Errors/1000 Characters				
	With Phase Modulation		*Without Phase Modulation*		*Approximate no. of Characters/sample*
	2 sets	*1 set*	*2 sets*	*1 set*	
(KLR)	2.1	1.9	2.4	4.2	10,000
(KEM)	2.4	12.9	3.3	6.4	8,000
Combined	2.3	6.9	2.8	5.2	18,000

Since the combined errors per 1000 with phase modulation are somewhat greater than those without phase modulation, it would appear that to produce equality, it would be necessary to increase the transmitter power about 4.5 decibels when phase modulation is added; 3 decibels to correct for the wider bandwidth required, and an additional 1.5 decibels calculated from the slope of Figure 6 to make the errors equal. However, it is noted that in the case of the KLR test considerable improvement is indicated for a single receiver when phase modulation was used. Since the KLR signals were subject to more multipath effects than the KEM signals, this observation is probably significant and suggests that a useful degree of frequency diversity gain can be realized by the use of phase modulation on circuits where space diversity cannot be provided.

Another run was made using equal power and an intermediate frequency bandwidth of 1 kilocycle for the two conditions. This meant that the phase modulation would swing about 125 cycles outside the intermediate frequency filter pass band. For this condition, better results were obtained without the phase modulation.

TABLE VI.
Transmitter KLR

Errors/1000 Characters				
With Phase Modulation		*Without Phase Modulation*		*Approximate no. of Characters/sample*
2 sets	*1 set*	*2 sets*	*1 set*	
0.9	1.9	0	0.9	10,000

F. Comparison of Frequency Shift Keying (2-receiver diversity) and On-Off Keying (3-receiver diversity) Using 4-Channel Multiplex.

The comparison of frequency shift and on-off keying was made in two ways. The first method was quite similar to that used in the preceding comparisons with modifications as required by the use of multiplex. Either KLR or KEM was run dual with the regular multiplex traffic circuit, one channel of which was provided with a repeating tape. No separating equipment was available at Riverhead, so the signal was sent in to New York over the land line and the separation performed there. The transmitter in use alternated 15 minute periods on each type of keying and made power changes as required. A frequency shift of 850 cycles was used and an intermediate frequency bandwidth of 1 kilocycle. Table VII shows the results of these tests which extended over a period of three days.

TABLE VII.

Transmitters KLR and KEM

Peak Power Ratio (On-off = higher power)		*Errors/1000 Characters*		*Approximate no. of Characters/sample*
		Freq. Shift	*On-off*	
(KLR)	0 db	1.0	3.1	47,000
(KLR)	6 db	1.0	3.9	6,500
(KEM)	6 db	0.3	0.5	11,000
(KEM)	9 db	0	0.2	15,000

The difference in the error ratios between KLR and KEM should be noted for the 6 decibels power ratio. On KLR, on-off keying made nearly four times as many errors as frequency shift keying. On KEM, on-off keying made only 1.6 times as many errors as frequency shift keying. This difference can be accounted for by the fact that multipath and high fading ratios existed on the KLR frequency, whereas the KEM frequency was characterized by very slow fading and lack of multipath. Table VII shows that frequency shift keying (2 receivers) is over 9 decibels better than on-off keying (3 receivers).

During this test, it was found that the 4-channel multiplex could be passed satisfactorily through the 1 kilocycle band pass filter in the intermediate frequency amplifier and the 200 cycle low pass filter in the F-S adaptor.

For the second comparison, two transmitters were used. KEM (15490 kc) was used to transmit frequency shift keying with 850 cycles shift and KKL (15475 kc) was used to transmit on-off keying. The two transmitters were run dual and again one channel was provided with a repeating tape and the separating was done in New York. The two transmitters were similar and they used similar antennas. The voltage induced in the receiving antennas was measured from time to time with a signal generator.

This test started at 5 PM one evening and ran to 9 AM the next morning. Both signals faded into the noise at about 4 AM so that the actual available test time was about 11 hours. During this period, simultaneous observations were taken and the results are plotted on Figure 9. It was noted that the FST circuit carried the signal longer than the CWT circuit when the signals were fading into the noise at the fade out period.

G. Oscilloscope Observations of F-S Keying and On-Off Keying Reversals.

A large number of oscilloscope observations were made of 50-50 mark-space keying for the purpose of determining the effect of multipath transmission on the possible keying speed of the circuit. Keying speeds of 60, 120, and 180 cycles were used with frequency shifts varying from 180 to 1360 cycles.

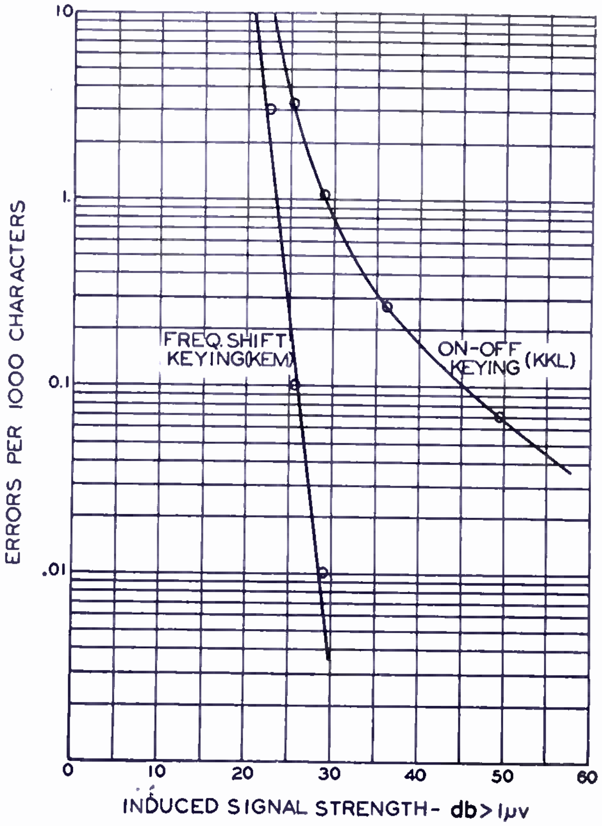

Fig. 9—Errors vs induced signal strength for 4-channel multiplex. For on-off keying, a three-receiver diversity having 1000 cycle intermediate frequency bandwidths was used. For frequency shift keying, a two-receiver diversity having 1000 cycle intermediate frequency bandwidths and a 210 cycle low pass filter was used. The shift was 850 cycles.

The transmissions were synchronized with the sixty cycle power supply at Bolinas. At the receiver, the oscilloscope was synchronized with the local sixty cycle power supply. The two power supply frequencies were near enough so that only a slow drift was observed on the oscilloscope. A few 16 mm moving pictures were taken and Figures 10-25 are enlargements made of typical frames. In examining these prints, the non-linear oscilloscope sweep should be kept in mind. The results obtained using the 120 cycle keying speed were intermediate to those obtained using 60 cycles and 180 cycles and no pictures were taken.

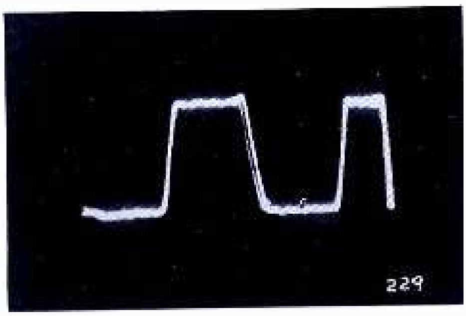

Fig. 10—Gate output using one receiver with 1000 cycle intermediate frequency bandwidth. 60 cycle revs were used with 790 cycles shift.

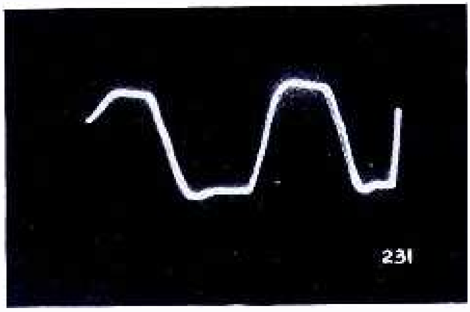

Fig. 11—210 cycle low pass filter output using two-receiver diversity with 1000 cycle intermediate frequency bandwidths. 60 cycle revs were used with 790 cycles shift.

Figures 10-13 show the normal undistorted waveforms appearing at various points in the F-S adaptor.

Figure 10 shows the gate output. Single receiver, 1 kilocycle intermediate frequency bandwidth, 60 cycle reversals, 790 cycles frequency shift.

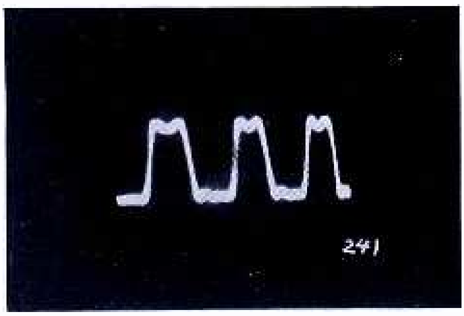

Fig. 12—900 cycle low pass filter output using two-receiver diversity with 2000 cycle intermediate frequency bandwidths. 180 cycle revs were used with 720 cycles shift.

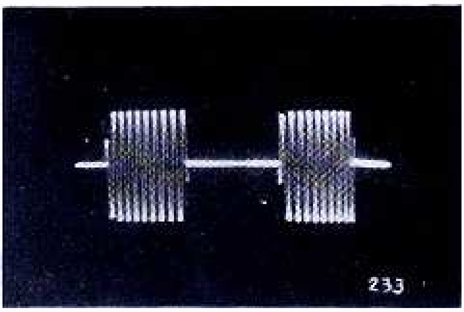

Fig. 13—Tone keyer output using two-receiver diversity with 1000 cycles intermediate frequency bandwidths. 60 cycle revs were used with 790 cycles shift.

Figure 11 shows the output of the 200 cycle low pass filter. Two receivers, 1 kilocycle intermediate frequency bandwidth, 60 cycle reversals, 790 cycles frequency shift.

Figure 12 shows the output of the 900 cycle low pass filter. Two receivers, 2 kilocycle intermediate frequency bandwidth, 180 cycle reversals, 720 cycles frequency shift.

Figure 13 shows the output of the tone keyer. Two receivers, 1 kilocycle intermediate frequency bandwidth, 60 cycle reversals, 790 cycles frequency shift.

Figures 14-18 illustrate transients produced by multipath transmission as observed at the gate output. The time delay due to the multipath causes both mark and space frequencies to be present simultaneously for a short period following the transitions from one frequency to the other. The beat note between the two frequencies causes a transient whose amplitude and direction is a function of the relative amplitudes and phases of the two frequencies.

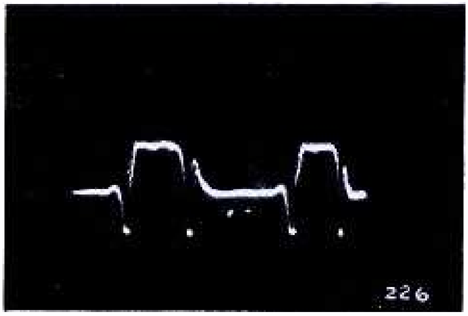

Fig. 14—Gate output using one receiver with 1000 cycle intermediate frequency bandwidth. 60 cycle revs were used with 180 cycles shift.

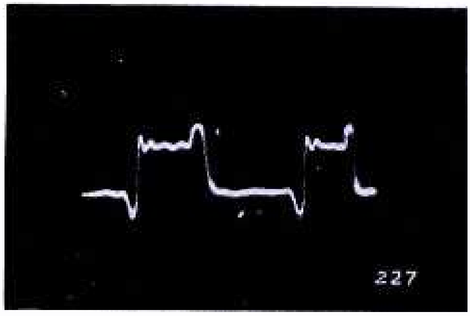

Fig. 15—Gate output using one receiver with 1000 cycle intermediate frequency bandwidth. 60 cycle revs were used with 180 cycles shift.

Figures 14 and 15 show the gate output using a single receiver, 1 kilocycle intermediate frequency bandwidth, 60 cycle reversals and a frequency shift of 180 cycles. The amplitudes of the transients in Figure 14 are about twice the amplitude of the signal.

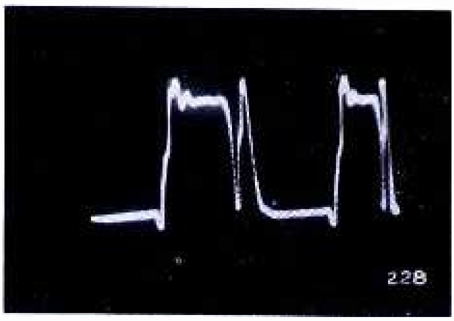

Fig. 16—Gate output using one receiver with 1000 cycle intermediate frequency bandwidth. 60 cycle revs were used with 790 cycles shift.

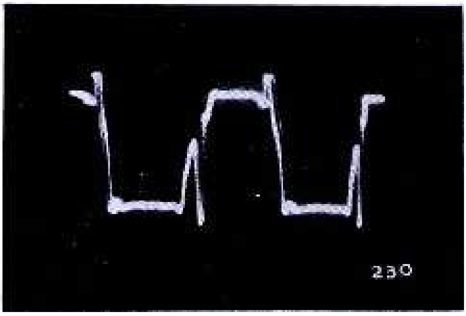

Fig. 17—Gate output using one receiver with 1000 cycle intermediate frequency bandwidth. 60 cycle revs were used with 790 cycles shift.

Figures 16 and 17 were taken under the same conditions except that the frequency shift has been increased to 790 cycles. Here the amplitudes of the transients are only slightly larger than the amplitude of the signal.

There is a small amount of 50 kilocycles present at the gate output and, with fast fading or transients, this appears occasionally as the dotted traces which can be seen in these figures.

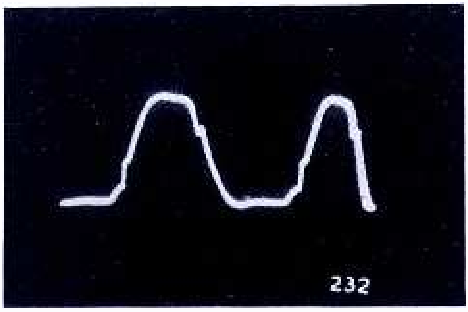

Fig. 18—210 cycle low pass filter output using two-receiver diversity with 1000 cycle intermediate frequency bandwidths. 60 cycle revs were used with 790 cycles shift.

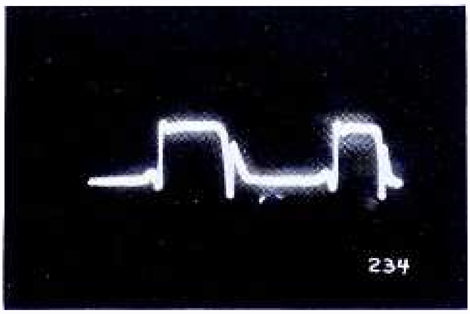

Fig. 19—Gate output using two-receiver diversity with 1000 cycle intermediate frequency bandwidths. 60 cycle revs were used with 790 cycles shift.

Figures 18-21 show typical transients at various points when two receivers are used to obtain diversity. They were all taken under the same conditions; two receivers, 1 kilocycle intermediate frequency bandwidth, 60 cycle reversals, and a frequency shift of 790 cycles. Figure 18 is the output of the 200 cycle low pass filter and Figures 19-20 are of the gate output.

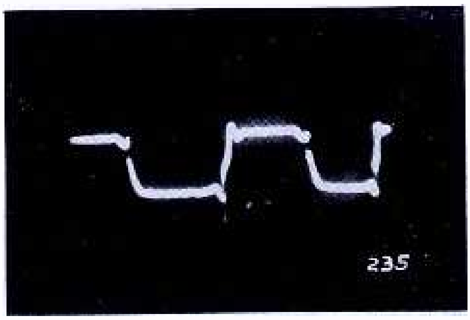

Fig. 20—Gate output using two-receiver diversity with 1000 cycle intermediate frequency bandwidths. 60 cycle revs were used with 790 cycles shift.

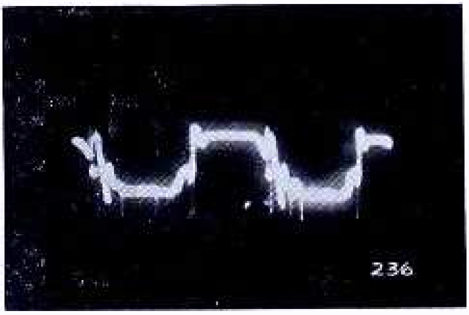

Fig. 21—Gate output using two-receiver diversity with 1000 cycle intermediate frequency bandwidths. 60 cycle revs were used with 790 cycles shift.

The gate switching time can be seen on Figure 20 as a gap in the signal trace.

Figures 22-25 are all of the 900 cycle low pass filter output using a 2 kilocycle intermediate frequency bandwidth, 180 cycle reversals and 720 cycle frequency shift. Figures 22-24 were made using two receivers and Figure 25 with one receiver. The non-uniform mark, most noticeable in Figure 23 was produced by the transmitter. Every third mark character was narrow. This was not a normal condition, and was introduced in some way by the connections used to synchronize the 180 cycle reversals with the 60 cycle power line frequency.

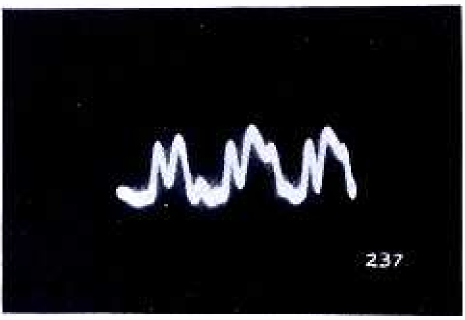

Fig. 22—900 cycle low pass filter output using two-receiver diversity with 2000 cycle intermediate frequency bandwidths. 180 cycle revs were used with 720 cycles shift.

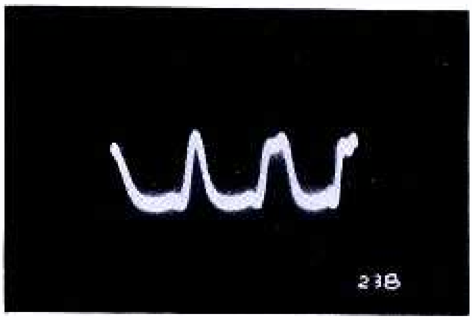

Fig. 23—900 cycle low pass filter output using two-receiver diversity with 2000 cycle intermediate frequency bandwidths. 180 cycle revs were used with 720 cycles shift.

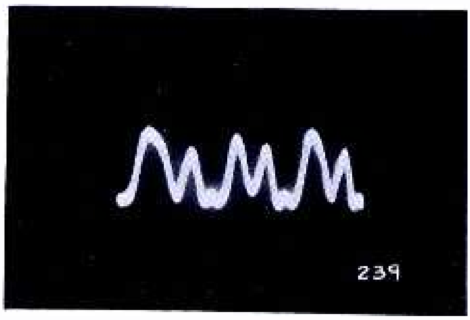

Fig. 24—900 cycle low pass filter output using two-receiver diversity with 2000 cycle intermediate frequency bandwidths. 180 cycle revs were used with 720 cycles shift.

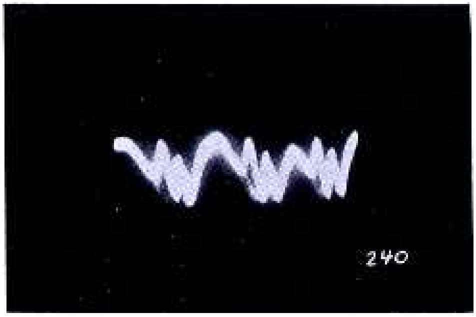

Fig. 25—900 cycle low pass filter output using one receiver with 2000 cycle intermediate frequency bandwidth. 180 cycle revs were used with 720 cycles shift.

Unfortunately, due to wartime conditions, additional film could not be obtained in time to take similar pictures for on-off keying. However, oscilloscope observations of on-off keying (made at the tone keyer grid) showed that with 60 cycle reversals the mark character varied from 50% mark to 70% mark. With 180 cycle reversals, the mark was quite often 70% and there were times when complete fills would occur.

H. *High Speed Reversals Using Quartz Crystal Frequency Standards for Synchronization.*

An experiment was conducted to determine whether the arrival time was seriously affected by short time and diurnal variations in the height of the ionosphere.

The KLR transmitter at Bolinas sent out 50-50 mark-space frequency shift keying at a 100 cycle rate which was locked in synchronism with a precision frequency standard located at the Frequency Measuring Laboratory of RCA Communications at Point Reyes, California. An oscilloscope on the receiver was synchronized with 100 cycles derived from the frequency standard of the Frequency Measuring Laboratory at Riverhead.

It was found that the relative phase drift amounted to 1⅓ milliseconds after 5 hours (starting about 3 AM), which corresponds to a relative frequency stability of 1 part in 13.5×10^6, if we assume the path length remained constant. If we assume the two frequency standards were exactly equal, this observed drift of 1⅓ milliseconds would be due to variations in the ionosphere affecting the path length. The time required for the radio wave to travel from Bolinas to Riverhead was calculated to be approximately 14.5 milliseconds. There was no evidence of large scale rapid fluctuation in the average travel time.

From these observations, which included a period of multipath transmission, it appears feasible to use precision frequency standards (with a very slow acting minor adjustment of phase) for multiplex synchronization.

Since the signal arrives simultaneously over several paths of different lengths, and since the relative strengths of these components vary with time, the instantaneous timing of the bauds coming out of the limiter will fluctuate by an amount equal to the multipath delay time. Both the leading and trailing edges of a baud will fluctuate by this amount. During these observations on KLR, this fluctuation in timing amounted to 2 milliseconds when multipath was most extreme. At other times it was as small as ¼ millisecond.

Figure 26 illustrates the variation of baud timing due to multipath effects in a simplified case.

In this figure, "a" and "b" represent the frequency shift signal on reversals coming in over two paths. The signal over path "b" arrives two milliseconds later than the signal over path "a".

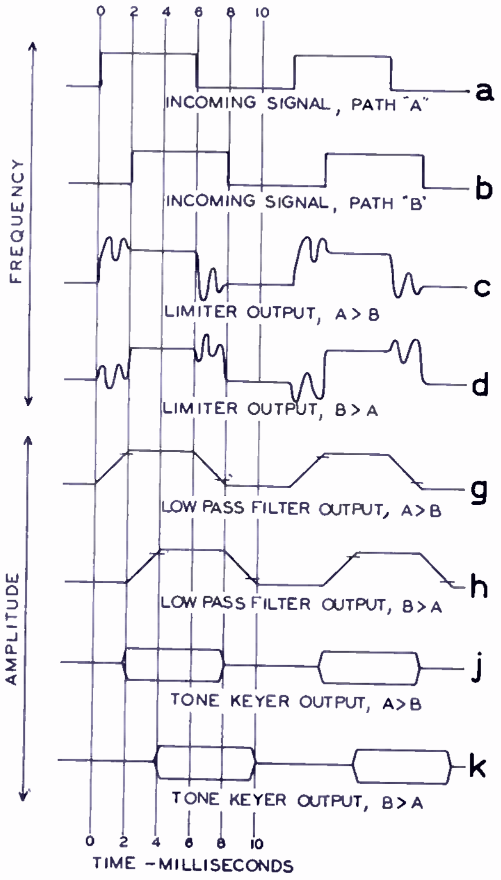

Fig. 26—Frequency shift keying baud timing changes due to multipath.

Both the path "a" and the path "b" signals are present in the receiver, one or the other being the stronger depending on momentary conditions in the two paths. Both signals enter the limiter.

During the indicated time intervals 0 to 2 and 6 to 8 milliseconds, both mark and space frequencies are present in the limiter input. When the path "a" signal is slightly stronger than the path "b" signal, the time-frequency plot of the signal at the limiter output is as in diagram "c". When the path "b" signal is a little stronger than the path "a" signal, the signal at the limiter output is represented by diagram "d".

The limiter output is passed in sequence through a discriminator, a rectifier, and a low pass filter. The output of the low pass filter is represented by diagrams "g" and "h". Diagram "g" represents the condition in which the path "a" signal is stronger and "h" represents the condition in which the path "b" signal is the stronger.

The output of the low pass filter actuates the trigger which in turn controls the output of the tone keyer. The trigger operates when the output of the low pass filter reaches a value about 25% short of the extreme voltage swing, in either direction. This results in a tone keyer output represented by envelope traces "j" and "k". Envelope "j" is the output when the path "a" signal is the stronger and envelope "k" is the output when the path "b" signal is the stronger. The timing of the "j" and "k" bauds differ by two milliseconds in this example.

In this series of diagrams, the requirement of the multiplex timing would be that "contact" be made during the interval from 4 to 8 milliseconds on the indicated time scale. If the duration of "contact" is 10% of a baud, this allows a range of approximately ±1.7 milliseconds for the error of synchronization.

As stated above, this series of diagrams represents a much simplified condition. Under some conditions the baud length will vary. However, the observations indicated that the portion of the baud between 4 and 8 milliseconds, on the time scale of these diagrams, will be reliable.

ACKNOWLEDGMENTS

As may be inferred from a perusal of this report, a rather large number of people, other than the authors, participated either directly or indirectly in the conduct of the tests.

The multiplex test facilities in New York were set up under the direction of Mr. C. W. Latimer. Their operation was attended to by Mr. L. A. Thomas and Mr. A. Sholkin, and the Central Office Multiplex Technicians.

Arrangements for the use of the transmitting and receiving facilities were made by Mr. E. D. Becken.

The field strength recording was done by Mr. A. M. Braaten.

In addition, the conduct of the tests was greatly facilitated by the cooperation and assistance rendered by various members of the RCA Communications staffs at the San Francisco office, the Bolinas transmitting station, the Riverhead receiving station, and the New York terminal.

LOCAL OSCILLATOR RADIATION AND ITS EFFECT ON TELEVISION PICTURE CONTRAST*

BY

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Princeton, N. J.

Summary—The objects of this paper are (1) to investigate the effect on a television receiver of a c-w † interfering signal which lies in the high end of the picture band, (2) to set up a maximum permissible interference level, and (3) to correlate this level with radiation from the local oscillator of superheterodyne receivers.

It was observed that the chief annoying effect of interference at the high end of the video band was a loss in contrast. A strong interference, in fact, caused a complete loss in contrast or even a negative picture. Overall contrast gradation curves were computed theoretically which checked the experimental observations; the observations and computations indicated that a 20 decibels signal-to-interference field strength ratio at the antenna is a minimum satisfactory value. To maintain this ratio in a 500 microvolt-per-meter region of a desired transmitter, nearby receivers must have a radiation below 0.01 microwatts. Pre-war receivers, which used no radio frequency stage, radiated 100,000 times as much as this and were extremely unsatisfactory. A grounded-grid triode radio frequency stage may give a reduction of about 30 decibels or more and a pentode radio frequency stage may be made even better. Other remedies are also discussed but all increase receiver cost somewhat. However, it is made clear that an adequate television service will require suppression of radiation if the frequency assignments are such as to make interference possible.

† Throughout this paper "c-w" indicates "continuous wave".

I. INTRODUCTION

THE interference caused by local-oscillator radiation from superheterodynes has long been recognized as an important problem in receiver design. In spite of this, very few published papers indicate quantitatively how much radiation is present from various receiver circuits or how much radiation might be considered tolerable. In the sound broadcast field, even with the commonly used multi-grid mixers and converters which give partial separation of the local oscillator from the antenna, the radiation problem is serious in the shortwave bands.[1, 2, 3] In television reception, it has been common practice

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* Decimal Classification: R583.15.

[1] R. Moebes, "The Superheterodyne Receiver as a Source of H-F Interference," Telégr.-Fernspr.-Funk-u. Fernschtech., Vol. 29, pp. 199-201, July, 1940.

[2] R. Moebes, "On the Permissible Value of Local Oscillator Voltage at the Antenna of Superheterodyne Receivers," Telégr.-Fernspr.-Funk-u. Fernschtech, Vol. 31, pp. 217-222, August, 1942.

[3] G. S. Wickizer, "Radiation from Superheterodyne All-Wave Receivers," unpublished report of RCA Communications, Inc., April 7, 1937.

to use triode or pentode mixer tubes because of their high signal-to-noise ratio[4] and, when no radio frequency stage is used, the radiation is high. In the New York area, the channel assignments throughout the war were such that, with the usual 12.75-megacycle intermediate frequency, a receiver tuned to channel 1, 50 to 56 megacycles, radiated a local-oscillator frequency of 64 megacycles which lay in the upper video frequencies of channel 2, 60 to 66 megacycles. Post-war frequency assignments and choice of intermediate frequencies will undoubtedly be different but the problem remains and is the reason for the writing of this paper. The work to be described is also applicable to other types of c-w interference (such as sound carriers in the picture channel and harmonic radiation from amateur and other services) and, to a lesser extent, to certain types of noise interference.

To the writer's knowledge, only one study of the interference problem in television has been published to date.[5] This study provided an excellent start, but was made using British television standards, with viewing tubes and picture pick-ups in common use at the time, and was entirely subjective. Furthermore, when c-w interference was studied, the interference was introduced into the video circuit so that an interference pattern might be observed at all light levels. Practically, when the interference comes through a receiver antenna circuit and with light levels such that the picture carrier is of very small amplitude, the interference pattern may not be observable on a kinescope or viewing tube. The U. S. standards, which incorporate negative modulation and vestigial sideband operation, require other special consideration. The present report is intended to treat the problem when U. S. standards are used; the conclusions will be based on objective analysis supported by a subjective study.

In the reception of a television picture, a small interfering signal will give rise to a pattern which can sometimes be observed on the viewing screen at certain light levels. If the interfering frequency is close to the picture carrier, the "beat" interference is of low frequency and gives rise to relatively large vertical or horizontal bars (i.e., large detail patterns). Jarvis and Seaman[5] showed that such a condition is the most annoying to the viewer, particularly when the bars are stationary, i.e., the beat frequency is synchronized with the scanning system. With present U. S. standards, the video channel is about 4

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[4] E. W. Herold, "Superheterodyne Converter System Considerations in Television Receivers," RCA REVIEW, Vol. 4, No. 3, pp. 324-337, January, 1940.

[5] R. F. J. Jarvis and E. C. H. Seaman, "The Effect of Noise and Interfering Signals on Television Transmission," *Post Office E. E. Journal*, Vol. 32, pp. 193-199, October, 1939.

megacycles or more wide so that low-frequency beat interference (under 1 megacycle) is not as probable as higher frequency beats (i.e., small detail patterns). Furthermore, it would be wise to choose an intermediate frequency so that receiver local-oscillator radiation will not produce the most annoying interference, namely, large detail patterns. In the present study, therefore, only higher frequency beats will be considered and, since synchronization with the scanning system is unlikely, it will be less important to consider the annoyance of the possible small-detail fluctuating pattern, and more important to consider other effects due to the interference. The chief one of the other effects is a degradation of picture quality due to a loss in contrast.

II. PICTURE CONTRAST WITH SMALL CONTINUOUS WAVE INTERFERENCE

In order to obtain an understanding of how picture contrast is affected by an interfering c-w signal, let us look at Figure 1. At (a) is shown a typical black-white transition in a simulated television modulated signal with conventional negative polarity (i.e., decreasing carrier for increasing light levels). During the black portion, the transmitter sends out nearly maximum output, increasing to a peak only for the synchronizing and blanking interval. During a white picture, the carrier of an ideal transmitter is very low, substantially zero for the brightest light values; only for the synchronizing pulses is peak carrier amplitude attained.* When such a signal is received, the final detector follows the carrier envelope and the direct current restorer system operates so that black level is set at the point shown. Such a signal will produce maximum light output on the viewing tube (kinescope) for the white part, and minimum light for the black part, the ultimate contrast range being set by the picture viewing tube capabilities, room lighting, etc.

In Figure 1 (b) is shown a similar received carrier combined with an interfering unmodulated carrier whose frequency is assumed to be such that the "beat" is in the high video range. Assuming the black level setting of the viewing tube is unchanged from Figure 1 (a), it is seen that the originally black portion of the signal envelope now has small periodic excursions toward white. If the "beat" is high,† the eye will not observe the checkered nature of the pattern so much as the fact that the general black level illumination has been raised, i.e., the blacks now look grey. With the idealized 100% modulated carrier

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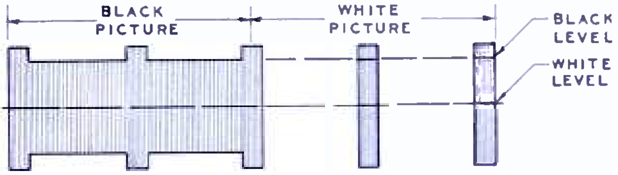
* In practical transmitters, 100% modulation is not always reached so that white level may correspond to a larger carrier than shown on Figure 1. This changes the effects described quantitatively by a small amount but, qualitatively, the idealized 100% modulation herein treated is entirely adequate to explain the behavior.

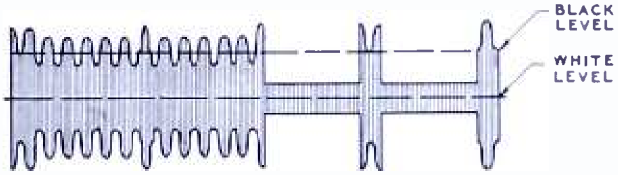
† Or if the viewing distance is sufficiently large.

here assumed, in the white portion of the picture, there is no "beat" since the picture carrier is zero.* The interference, however, causes a spurious carrier to appear at the receiver so that, instead of a completely white output, the brightness is decreased again toward the grey. Thus, both the black and the white portions of the picture are shifted toward each other, i.e., toward a neutral grey. The picture contrast has then suffered.

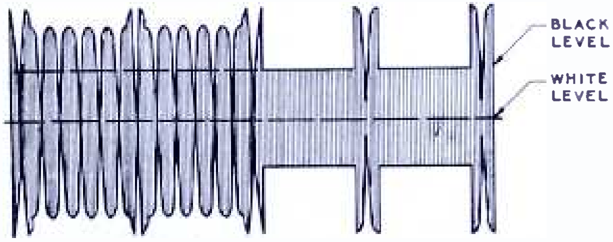
If the receiver controls are readjusted, of course, the over-simplified case of a black to white transition, which we have been discussing, can be corrected while the interference is present. With an actual picture, however, no correction is possible without an almost complete loss of



(a) RECEIVED CARRIER WITH NO INTERFERENCE



(b) SMALL INTERFERING C-W ADDED



(c) LARGE INTERFERING C-W ADDED, APPROX. EQUALLING PICTURE CARRIER

Fig. 1—Received television signals showing how an interfering c-w leads to loss in contrast, even to the point of a negative picture (case c).

the picture tone values at the extremes of brightness; the loss will be particularly serious in the darker portions and can be interpreted as a loss in gradation contrast or "gamma." If the direct current restoring system of the receiver follows the peak values of the "beat" during synchronizing intervals, there is less tendency for the white part to become

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* It should be noted that this condition cannot be duplicated by introducing the interference in the video frequency band as was done by Jarvis and Seaman (Reference 2).

grey but the raised brightness of the black becomes worse. Practically, many present television receivers use a direct current restoring system which will follow the average, not the peak, of the synchronizing pulse whenever the "beat" lies above a megacycle or so. This is caused by the relatively poor high-frequency video response of the restorer input, since high-frequency response is not needed in this circuit. Thus, in these receivers, the interference considered here has no effect on the black-level setting and the observed effects will be substantially as indicated on Figure 1, i.e., the black appears grey and the brightness of the white parts is reduced. Similarly, receivers with a limiter ahead of the peak-operated type of direct current restorer, will operate very much like the average-operated type.

III. THE NEGATIVE PICTURE PRODUCED BY STRONG INTERFERENCE

In conducting experiments on the effect of c-w interference, it was observed that a strong interfering signal gave rise to a picture of reversed contrast, i.e., the dark portions of the original became the light portions of the reproduction and vice versa. Although this phenomena had been observed by others, for example when a strong sound carrier was tuned into the picture channel, it had usually been assumed that overloading occurred, or some other unusual behavior was present. However, the writer's experiments showed that the effect existed when there was no overloading and, indeed, was a straightforward extension of the contrast loss phenomenon described above. In fact, the experiments showed that, as the interfering carrier was increased, the picture contrast steadily decreased until, at a definite point, the picture was substantially "washed out." Further increase of interference gave a negative picture of rather poor contrast and, finally, with interference signals far in excess of the black-level picture signal the picture again disappeared. Synchronization was well maintained throughout, with little or no apparent effect due to the interfering c-w. The scanning return lines are, of course, visible in such a negative picture since there is no blanking.

Figure 1 (c) shows how a large interfering c-w can lead to a negative picture. When the interference approximately equals the picture carrier during black transmission, the "beats" produced alternately raise the received signal to double amplitude and reduce it to substantially zero amplitude. Thus, with a black transmitted picture, the viewing tube has excursions extending to full white, leading to an average brightness well up in the grey region. On the other hand, during white transmission, the transmitted carrier is not present and no "beats" occur. The interfering c-w simply replaces the normal picture carrier and makes the picture appear black. To summarize this, the black transmissions now appear grey and the white transmissions appear black, leading to a complete reversal of contrast (i.e., a negative gamma).

It was here assumed that the direct current restorer of the receiver is unaffected by the interference and, as already indicated, this is typical of the many receiver circuits in which either direct current restoring follows the average of the high video-frequency beat or in which limiters are used. A direct current restorer whose input contained all video components and whose output followed peak amplitude would not lead to a complete washout of the picture or a negative picture, although

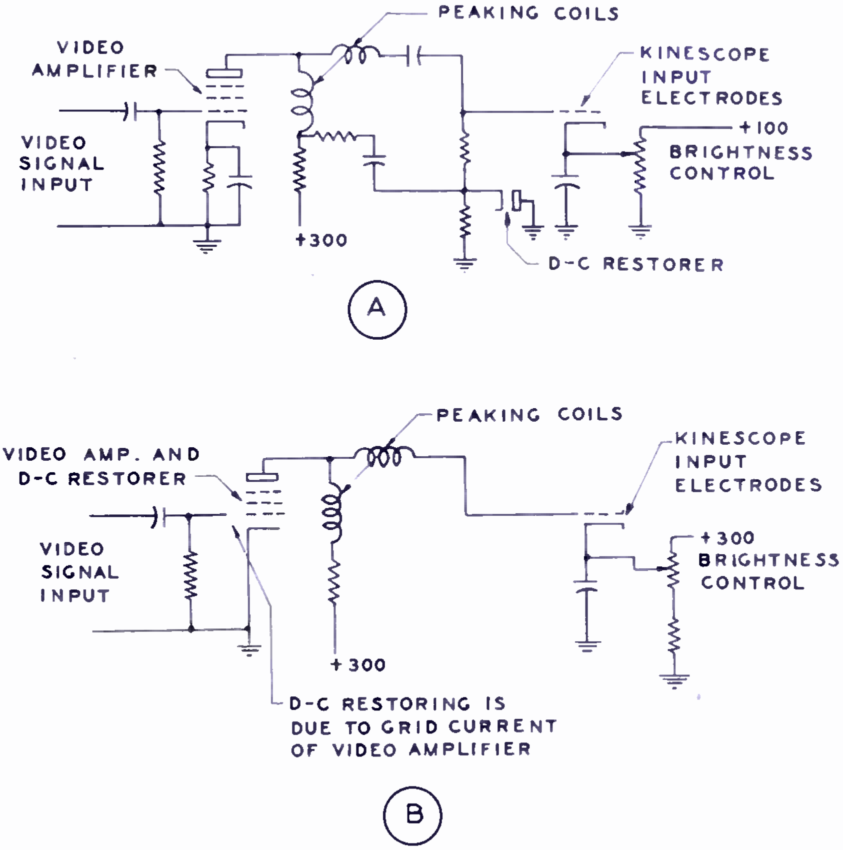

Fig. 2—(A) A direct current restoring circuit which does not follow high video frequencies and so permits strong interference to produce a negative picture; (B) a direct current restoring circuit which operates on the peaks of a synchronizing wave and so does not give a negative picture (unless a limiter precedes the circuit).

the loss in contrast is more serious than with the averaging type of direct current restorer. In this connection, two typical direct current restorer circuits are shown in Figure 2. One of these, Figure 2 (A), is of the averaging type and can give rise to a negative picture while the other, Figure 2 (B), is of the peak type and cannot (i.e., unless preceded by a limiter). In a later section of this paper calculations will be made which show the contrast loss of receivers with each type of restorer as a function of interfering amplitude.

IV. CONTRAST EVALUATION

To evaluate quantitatively the effect of interference on contrast, it is necessary to consider the various ways in which the contrast of a reproduced picture may be expressed. The simplest expression for the contrast is simply the over-all maximum brightness ratio, i.e., the ratio of the light from the brightest portion of the reproduced picture to the light from the darkest portion. In a perfect system, this ratio can be infinite since the darkest portion can be completely black. Maximum contrast ratio has been used to discuss kinescope performance[6] although it is then necessary to distinguish between halation effects and normal large-area contrast ratio. It is often stated[7] that a ratio of 35:1 or more is desirable in a television picture and such ratios are attainable with the best reproducing systems. We shall use degradation in maximum contrast ratio as one criterion for estimating the effect of c-w interference.

In photography, it has long been well known that, even if the maximum contrast ratio is fixed, startling changes in appearance are made possible by difference in the contrast *gradation*, i.e., the way in which various brightness values of an original are interpreted in the reproduction. The same is, of course, true in television. If a curve is drawn of reproduced light values as a function of original light values, complete information on contrast gradation is shown. Furthermore, such a curve may also indicate maximum contrast ratio by the ratio of the maximum to minimum light value at the ends of the curve. The over-all contrast gradation curve is, therefore, an even more significant measure of the degradation caused by an interfering signal; such curves will also be used in this paper.

Practically, whether or not an interfering signal is noticed depends upon the quality of the over-all system when free from interference. There are many grounds for believing that future television pictures will be far superior in their contrast range and low-light tone renditions than those which are presently called high in quality. In considering interference, therefore, it is well to concentrate on the effect which is obtained when the received picture is more nearly ideal, since this will have most value for the future. In this respect, an objective

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[6] R. R. Law, "Contrast in Kinescopes," Proc. IRE, Vol. 27, pp. 511-524, August, 1939.

[7] P. C. Goldmark and J. N. Dyer, "Quality in Television Pictures", *Journ. Soc. Motion Picture Eng.*, Vol. 35, pp. 234-253, September, 1940.

study is at present more valuable than a subjective one made with less-than-ideal viewing tubes, etc.

V. COMPUTED EFFECTS OF INTERFERENCE

This section is concerned with the computation of the over-all contrast gradation curve when interference is present, and assuming an idealized kinescope. The video wave which results from envelope detection of a television signal which includes c-w interference is derivable as follows. If we call the picture carrier, as it arrives at the second detector, $A \sin \omega t$ and the interfering carrier is $B \sin (\omega + p) t$, then the second detector receives an over-all signal of

$$A \sin \omega t + B \sin (\omega + p)\, t = [\sqrt{A^2 + B^2 + 2AB \cos pt}] \sin (\omega t + \beta)$$

where β is a time-variable phase angle which is of no concern here. After detection only the envelope is of interest. It may be written

$$V_c = \sqrt{A^2 + B^2 + 2AB \cos pt} = (A + B) \sqrt{1 - \frac{4AB}{(A+B)^2} \sin^2 \frac{pt}{2}}$$

$$= (A + B) \sqrt{1 - k^2 \sin^2 \phi} \qquad (1)$$

where

$$k^2 = \frac{4AB}{(A + B)^2}$$

and

$$\phi = \frac{pt}{2}$$

The picture carrier amplitude, A, has a maximum value, A_{max}, during the synchronizing interval, and a value ¾ A_{max} at the black level.* With maximum brightness of the original picture, A is reduced to zero when the modulation is complete (100%). For intermediate brightness, and a constant transmitter gamma, A follows the relation

$$A = \tfrac{3}{4} A_{max} \left[1 - \left(\frac{L_T}{L_{\max}} \right)^{\gamma_T} \right] \qquad (2)$$

where L_T is the instantaneous original picture brightness, L_{max} is the maximum brightness and γ_T is the transmitter "gamma," or slope of the modulation characteristic when corrected for negative polarity of modulation and plotted on log-log paper.

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* According to U. S. television standards.

A sufficiently close approximation to an idealized kinescope characteristic is a power law over the range from cut-off to zero bias. We shall assume that the output light is constant for inputs beyond zero bias and zero beyond cut-off. Thus, the kinescope characteristic is represented by Figure 3. Mathematically, the light output is

$$\begin{aligned} L &= K\,(V_{co}+V)^{\gamma_R} \text{ when } O < (V_{co}+V) < V_{co} \\ L &= O \text{ when } (V_{co}+V) < O \qquad (3) \\ L &= K\,V_{co}^{\gamma_R} \text{ when } (V_{co}+V) > V_{co} \end{aligned}$$

where V_{co} is the magnitude of the voltage needed to cut off the tube, V is the applied bias and signal, and γ_R is the exponent of the power law.

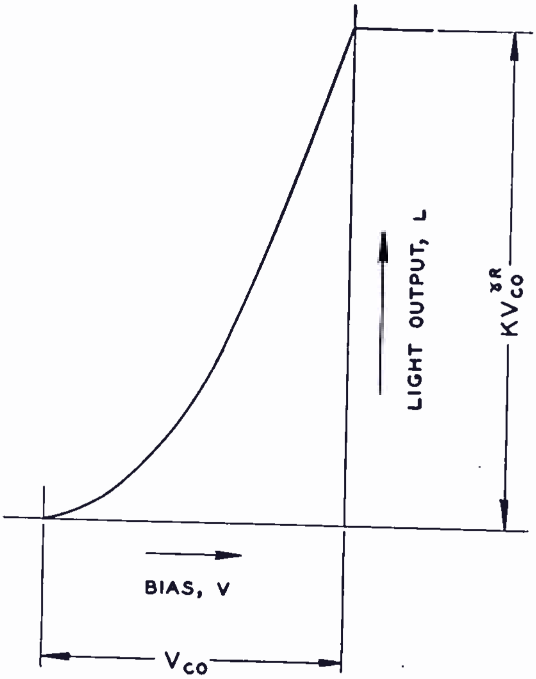

Fig. 3—Characteristic of an assumed power-law kinescope following the equation $L = K\,(V_{co}+V)^{\gamma_R}$

The manner with which the video signal is applied to the kinescope is shown in Figure 4. In Figure 4 (a) is shown the normal, interference-free case. It is seen that the receiver gain control is so adjusted that the range of black to white video signal, which is ¾ A_{max}, equals the assumed kinescope cut-off V_{co}. Furthermore, the direct current restorer, which operates from the synchronizing pulse, together with the kinescope bias control comprise a net bias, $V_{d\text{-}c}$ which sets the black level at cut-off. The difference between A_{max} and V_{co} is shown as ¼ A_{max} on the figure and is adjusted to this value by the bias control (often called the brightness control). The instantaneous video signal is shown as V_c (equation 1).

Figure 4 (b) shows the video signal when a high beat-frequency interference is applied and the direct current restorer is of the type shown in Figure 2 (a), i.e., it operates on the average of the synchronizing video pulse during the fluctuating beat. From equation (1) we find the average to be

$$\overline{V}_c = (A_{max} + \mathrm{B})\,\frac{2}{\pi}\int_0^{\pi/2} \sqrt{1 - k^2 \sin^2 \phi}\; d\,\phi \tag{4}$$

which can be evaluated for various values of B by the usual tables for the complete elliptic integral.[8]

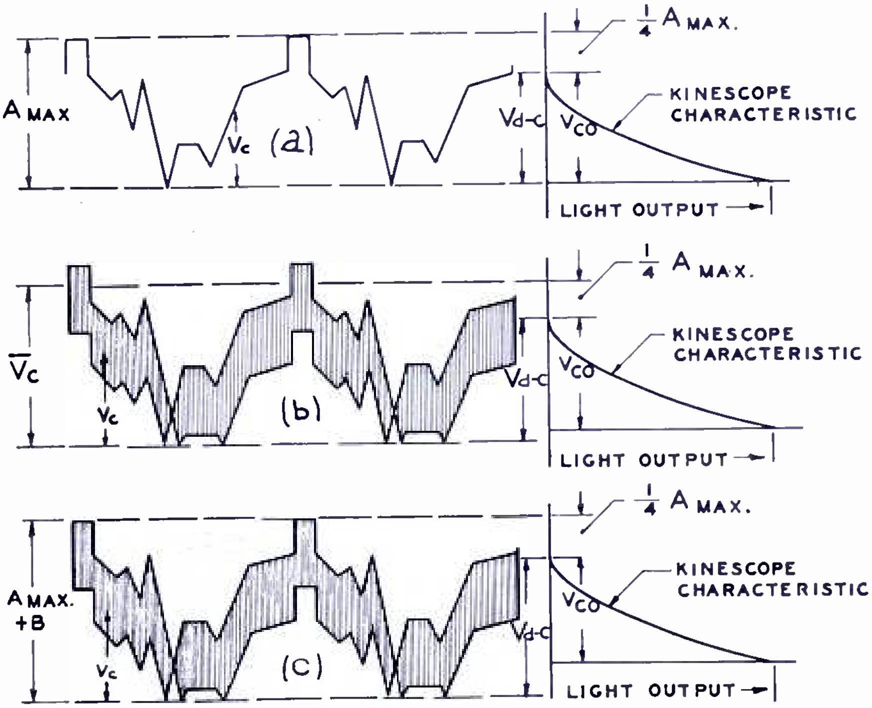

Fig. 4—This figure shows the video signal placement on the kinescope characteristic: (a) with no interference; (b) with high video beat interference and an average-operated direct current restorer; (c) with high video beat interference and a peak-operated direct current restorer.

Figure 4 (c) shows the case when a peak-operated d-c restorer is used without a limiter, such as the one of Figure 2 (b). In this figure, the direct current restorer operates from the peak signal during synchronizing, $A_{max} + B$. When a limiter is used, conditions will be sub-

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[8] B. O. Peirce, "A Short Table of Integrals," p. 121, Third Edition, Ginn and Co.

stantially the same as in Figure 4 (b) since the increased peak values are clipped by the limiter. It is, of course, clear that a manual change of the kinescope brightness control can change the effect of one of the direct current restorers to that of the other. In this analysis, the controls will be assumed to remain at their normal setting when no interference is present.

Putting equation (1) in equation (3) and including the effect of d-c restorer and kinescope bias, $V_{d\text{-}c}$ (Figure 4) we see

$$\begin{aligned} L &= K\,(V_{d\text{-}c} - V_c)^{\gamma_R} \\ &= K\,[V_{d\text{-}c} - (A+B)\sqrt{1-k^2\sin^2\phi}\,]^{\gamma_R} \end{aligned} \qquad (5)$$

where we must remember the limitations imposed on the equation by the cut-off and zero bias points (see equation 3). These limitations are that

$$[V_{d\text{-}c} - (A+B)\sqrt{1-k^2\sin^2\phi}\,] \geq 0$$

and

$$[V_{d\text{-}c} - (A+B)\sqrt{1-k^2\sin^2\phi}\,] \leq \frac{3}{4}A_{max}$$

Each of these limiting conditions may be solved for a value of ϕ which will be needed as an integration limit when finding the average light output. Calling these ϕ_1 and ϕ_2 respectively, we find

$$\phi_1 = \sin^{-1}\sqrt{\frac{1}{k^2} - \frac{(V_{d\text{-}c})^2}{4AB}} \qquad (6)$$

$$\phi_2 = \sin^{-1}\sqrt{\frac{1}{k^2} - \frac{(V_{d\text{-}c} - \frac{3}{4}A_{max})^2}{4AB}} \qquad (7)$$

These angles have limiting values of 0 and $\pi/2$ respectively and these limits are used when the arguments of (6) and (7) are greater than unity or imaginary.

The average light output over the fluctuating beats is then

$$L = \left(1 - \frac{2}{\pi}\phi_2\right) K \left(\frac{3}{4}A_{max}\right)^{\gamma_R} + \frac{2}{\pi} K \int_{\phi_1}^{\phi_2} [V_{d\text{-}c} - (A+B)\sqrt{1-k^2\sin^2\phi}\,]^{\gamma_R}\, d\phi \qquad (8)$$

where the first term gives the light output when the instantaneous bias on the kinescope exceeds zero, and the integral gives the total light output averaged over the normal kinescope range. The integration is straightforward for $\gamma_R = 1$ and $\gamma_R = 2$ although the result involves the incomplete elliptic integral. Since tables for these are available[9], a numerical answer may be obtained, although the calculations are very laborious.

The square law relation, $\gamma_R = 2$, is a far better approximation to an actual kinescope than the linear one. The writer has carried through the calculation of equation (8) to find the over-all contrast gradation curves for different interference levels, using $\gamma_R = 2$ and assuming, in turn, each of the two types of direct current restorer which give

$$V_{d\text{-}c} = \overline{V}_c - \frac{1}{4} A_{max} \text{ (average-operated type)}$$

where $\overline{V}_c$ is found from equation (4), and

$$V_{d\text{-}c} = (A_{max} + B) - \frac{1}{4} A_{max}$$

$$= \frac{3}{4} A_{max} + B \text{ (peak-operated type)}$$

The calculations were made by assuming a complementary gamma at the transmitter of $\gamma_T = ½$ (equation 2). The curves can be corrected for other transmitter gammas by an appropriate compression or expansion of the abscissa scale.

Figure 5 shows the calculated reproduced light as a function of original light at the transmitter, using the average-operated direct current restorer. The curves are largely self-explanatory and show the marked decrease in contrast as the interference level is increased. Because vestigial sideband operation was assumed, it should be remembered that the interfering c-w receives 6 decibels more gain in the receiver than the desired picture carrier. Furthermore, with U. S. television standards, the black-level carrier is 2.5 decibels less than the peak carrier which is used to rate transmitters and field strengths. Thus the curve labeled "interference 8.5 decibels down" means an interfering c-w whose antenna field strength is 8.5 decibels less than the peak of the picture carrier field strength; at the second detector of the receiver, because of the increased amplification for the interference, the inter-

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[9] H. Hancock, "Elliptic Integrals," John Wiley and Sons, New York.

ference is just equal to the black-level picture carrier. From the point of view of interference calculation, of course, it is the value at the antenna which matters, so that the curves are significantly labeled.

The negative picture for the stronger interference levels is clearly indicated by the reversed slope or negative gamma. One of the more striking features shown by Figure 5, is the rapidity with which contrast is lost as the interference level reaches a point 15 decibels below the picture carrier. Between the 14.5 decibels curve shown, which still gives a positive picture, and the 8.5 decibels curve, which gives a negative picture, the original contrast is substantially wiped out. In Figure 7 will be shown curves of maximum contrast ratio as a function of interference level which show that this rapid loss of contrast holds for other kinescope gammas as well.

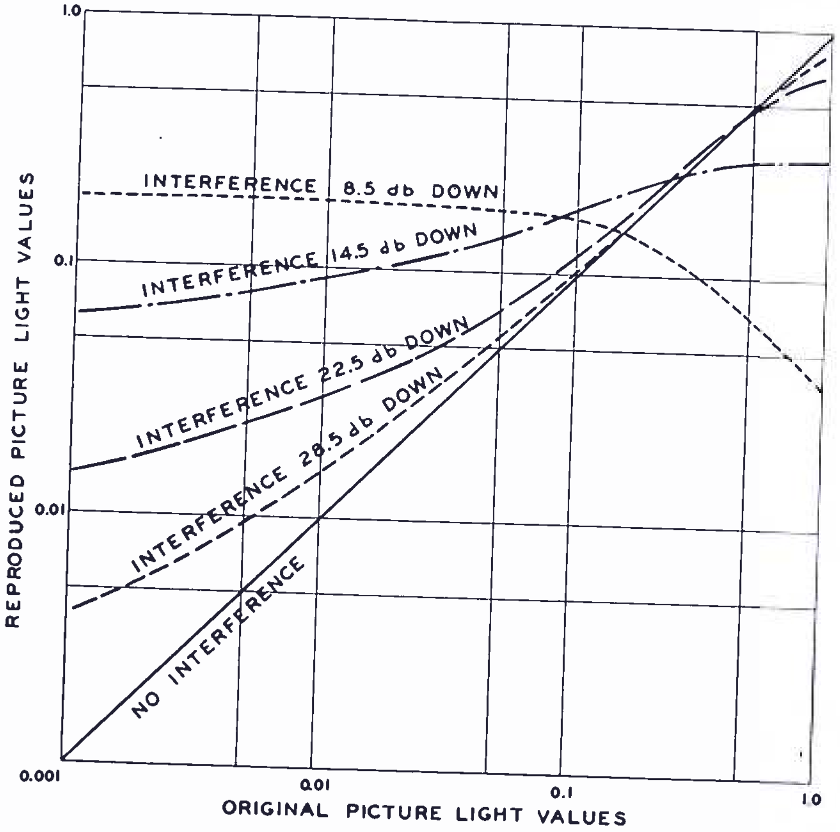

Fig. 5—Effect of c-w interference on television picture contrast using a direct current restorer which follows the average of the synchronizing pulse. Kinescope gamma = 2, transmitter gamma = ½, and vestigial side-band operation using U. S. standards.

Figure 6 shows a set of contrast gradation curves for the other type of direct current restorer (such as that of Figure 2b). It is here found that no reversal of the picture takes place at any interference level, as had been expected. It should be remembered that the difference between the results of Figure 5 and those of Figure 6 lie only in the kinescope bias provided by the direct current restorer. Thus a manual adjustment of the bias control (brightness control) will change either set of curves into the other.

Since the gamma (γ_R) of existing kinescopes is often in excess of two, it is of interest to examine the contrast degradation for $\gamma_R = 3$ and $\gamma_R = 4$. Over-all contrast gradation curves, such as are given in Figures 5 and 6 for the square-law kinescope, are extremely tedious to compute for the higher-power laws. However, there is a simplification in equation 8 when the interference level is small ($B << A_{max}$). If only the end points are desired, i.e., the output light level for a completely black and a completely white transmission, the small-interference approximation is readily usable. Furthermore, for one case of large interference, namely, when $B = \frac{3}{4} A_{max}$, the end points can also be simply evaluated for higher gammas. If only the light outputs for white and also for black transmission are given, their ratio is the most easily understood evaluation of contrast degradation and, as discussed

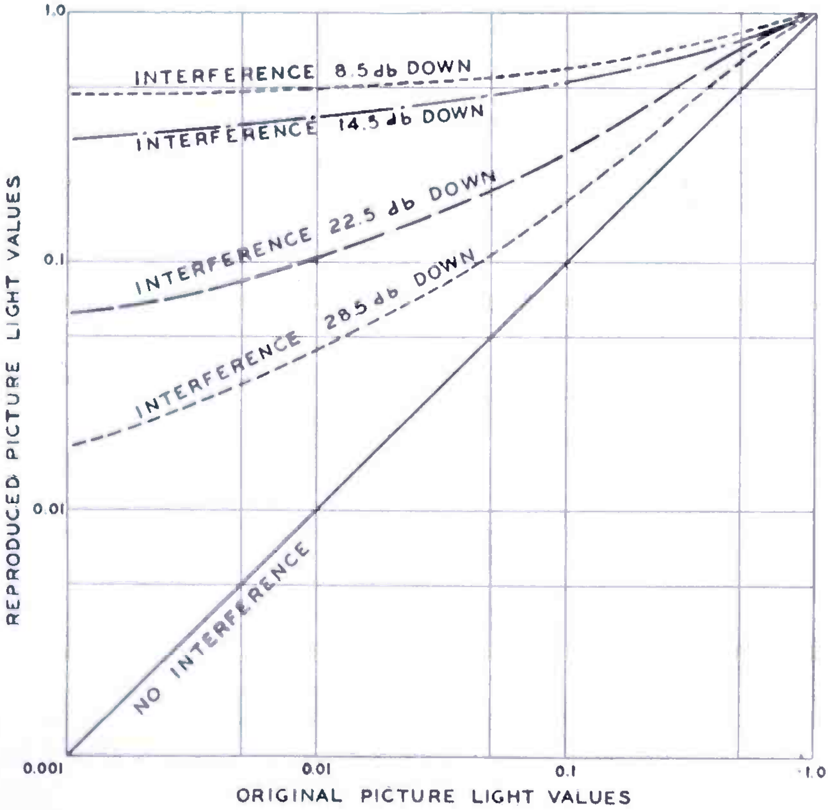

Fig. 6—Effect of c-w interference on television picture contrast using a peak-operated direct current restorer and no limiter. Kinescope gamma = 2, transmitter gamma = ½, vestigial side-band operation using U. S. standards.

in Part IV above, is called maximum contrast ratio. Figure 7 shows curves of the contrast ratio as a function of interference level for kinescope gammas of from 1 to 4, assuming the average-operated type of direct current restorer.

Examining Figure 7, we notice that the interference level at which the picture washes out (contrast ratio of unity) lies between −10 and −13 decibels for all the kinescope power laws, and that the loss in contrast is quite rapid as this point is approached. If we assume a transmitter gamma, γ_T, which is the reciprocal of the kinescope gamma, γ_R, the interference-free picture for each of the assumed kinescopes will be the same. Figure 7 shows, however, that *small* interference has far less effect on the higher-gamma kinescopes. This illustrates the well-known advantage of gamma compression at the transmitter, with corresponding expansion at the receiver, in improving the signal-to-noise ratio. On the other hand, with *larger* interference, the curves eventually cross and the advantage is no longer present.

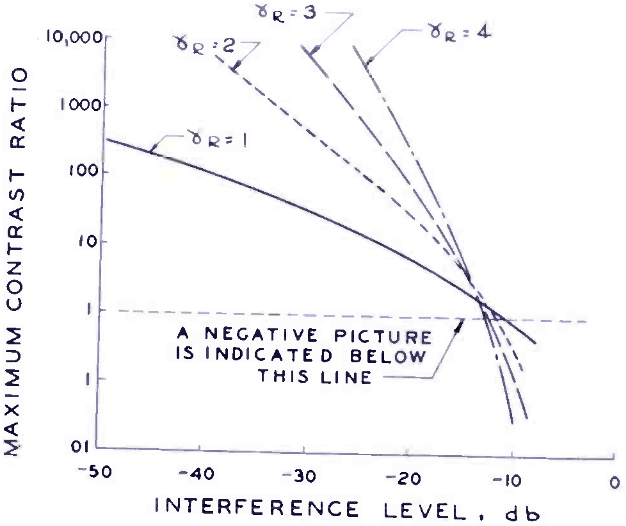

Fig. 7—Effect of c-w interference on ratio of light output during white transmission to light output during black transmission. An average-operated direct current restorer is assumed and the curves show the effect of different kinescope gammas.

VI. Experimental Results and Estimated Tolerable Interference

A television receiver in the writer's home was used to obtain experimental subjective data on the effect of interference. This receiver included the type of direct current restorer shown in Figure 2a except for a modification originally made to reduce possible effects of kinescope grid leakage. Normal program material and the test pattern from the National Broadcasting Company's New York Station, WNBT, was used. A Ferris Microvolter was used as the calibrated source of c-w interference and was connected across the receiver antenna transmission line (100 ohms impedance) through two 500-ohm resistors, so as not to interfere with the input alignment or impedance values. With no television signal present, a response curve of the receiver was measured and the diode second detector current calibrated in terms of the signal generator voltage. In this way, when the television signal came on, its relative magnitude with respect to the signal generator readings could be determined by its second detector current. It was necessary, of course, to use a substantially black picture to calibrate the black-level carrier of the received signal. It was then assumed that the peak carrier was 2.5 decibels higher, corresponding to U. S. standards. A check on this relative calibration of the received television signal was made by using a low-frequency "beat" interference and observing the magnitude of the beats on the synchronizing pulses as viewed on an oscillograph across the kinescope grid. The two methods checked very well.

Although many observations were made using various interfering frequencies, giving beats with the picture carrier from some tenths of megacycles to around 4 megacycles, most attention was given to a beat at 3.7 megacycles, well within the video band but at such a high frequency that the predominant effect was loss in contrast, rather than the very fine-grained pattern. In fact the interference pattern could hardly be observed with the kinescope and viewing distances used and might even pass completely unnoticed if attention was not called to it. The contrast changes, on the other hand, were very marked. In such subjective tests, it is not possible to obtain accurate data as to loss of contrast; fortunately, however, the transition point beween the positive and negative picture was quite clearly defined since it led to an almost complete wash-out of contrast values. The data are presented in tabular form in Table I and represent an average over a number of observations. In every case the receiver controls were set as for an interference-free picture and were left untouched for the observation.

Table I

Interference Beat Frequency	Interference Level, decibels	Observed Results
3.7 Mc	— 28	Barely perceptible loss in contrast
3.7 Mc	— 22	Substantial but tolerable loss in contrast
3.7 Mc	— 16	Intolerable loss in contrast
3.7 Mc	— 10	Completely washed-out picture
3.7 Mc	greater than — 5	Negative picture of poor contrast, return lines visible

From the computed data as presented in Figure 7 it is seen that a completely washed-out picture (contrast ratio = 1) was predicted with an interference of —10 to —13 decibels, depending on the kinescope gamma. Thus the computation and the observed value of Table I are in close agreement.

A comparison with the results of Jarvis and Seaman,[5] in England, is of some interest, in spite of substantial differences between their technique (which introduced the interference in the video channel instead of at the antenna) and even though the criterion they used was the annoyance value of the beat pattern, rather than contrast loss. When 8.5 decibels is added to their figures, to make them comparable with those used here for U. S. standards, the various results appear as shown in Table II.

Table II

Observed Result	Interference Level Using 3.7 Mc Beat and 525 Line System	Seaman and Jarvis Results With 2.0 Mc Beat and 405 Line System
Just visible change	— 28 db	— 26 db
Just tolerable change	— 22 db	— 19 db

On the basis of the calculations, as supported by the experiments, it is clear that relatively small differences in interference level near the critical point will cause rapid deterioration of the picture (see Figure 7). There can be no denying that the permissible interference limit must be below the point at which a complete wash-out of the picture occurs. If the interference is 10 decibels below this limit, a reasonable safety factor is allowed, although a noticeable deterioration of picture quality is still present. On these grounds we may say that the type of interference here considered, i.e., in the high-video range, should be at least 20 decibels below the picture carrier at the antenna. This number will be used as a criterion in the discussion of local-oscillator radiation below.

VII. QUANTITATIVE LIMITS ON RECEIVER LOCAL OSCILLATOR RADIATION

Since the superheterodyne receiver is here acting as an interfering transmitter, it is logical to measure its radiation in terms of the power which the local oscillator delivers to the antenna. With long transmission lines having appreciable loss, the radiated antenna power may be appreciably less than would be measured on a bench test with a receiver connected directly to a calibrated measuring receiver. Although this loss should be considered in special cases, the more general approach should assume no loss in the connection to the antenna, since negligible loss is readily obtained by use of good lines.

The type of interference considered here will be most serious between nearby antennas; thus complications introduced by propagation phenomena need not be considered. It can be assumed that "free-space" propagation will occur.* Thus a receiver radiating W watts into a half-wave dipole will give a field strength at a distance, d, of

$$E_I = \frac{\sqrt{45\,W}}{d}$$

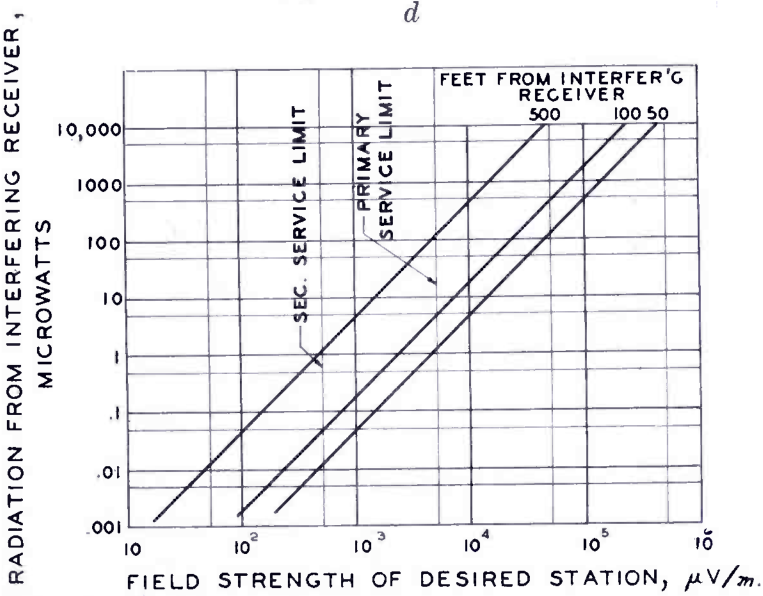

Fig. 8—Permissible radiation from television receiver to give an interference level of –20 decibels. A half-wave dipole is assumed on the receiver causing the interference.

If we consider a nearby receiver, with an antenna so situated as to receive both the interfering radiation and a desired signal from a television transmitter whose field strength is E_s, then, using the 20 decibels criterion,

$$\frac{E_s}{E_I} = \frac{E_s d}{\sqrt{45\,W}} \geqq 10$$

Thus the radiated receiver power should be $W \leqq \dfrac{E_s^2\, d^2}{4500}$ (9)

This equation has been plotted in Figure 8 and shows that, to protect

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* The limiting distance for antennas 30 feet high, within which free space propagation may be achieved (on the average) is some 700 feet at 60 megacycles and greater than this at higher frequencies.

the 500-microvolt/meter area, the radiating receiver should radiate less than 0.01 microwatts if receivers are to be as close as 50 feet. This may be contrasted with prewar receivers using a 6AC7 mixer and no radio frequency stage which radiated in the order of 1,000 microwatts; to avoid annoyance to other receivers at a distance of 50 feet, it is necessary to have a signal of over 100,000 microvolts/meter. Fortunately, channel assignments, station hours, and the small number of existing receivers have been such as not to bring this problem into prominence except under special circumstances.* However, this situation cannot continue and measures should be taken to reduce radiation on all future receivers.

VIII. Receiver Design Considerations

It is, of course, one thing to suggest 10^{-8} watts as a maximum permissible radiation and another to achieve it. A carefully designed pentode radio frequency stage between the antenna and a pentode mixer, together with a reasonably high intermediate frequency (so as to tune the oscillator far away from the band-pass of the amplifier), can be expected to provide enough attenuation.

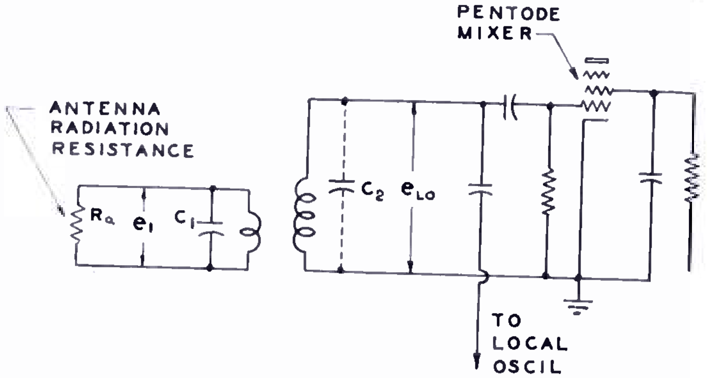

Fig. 9—Typical pentode mixer with double-tuned input circuit. The required local oscillator voltage is indicated as e_{LO}, whereas the resulting antenna voltage is shown as e_1.

To consider further, let us calculate the local oscillator radiation to be expected from the simplest television receiver with good performance, which uses a double-tuned circuit to couple the antenna to a pentode mixer. This type of input was commonly used in prewar receivers and is shown in simplified form in Figure 9. The local oscillator injection must be sufficient to give good results with the mixer, so that the local oscillator voltage across the input circuit, e_{LO} in the figure is fixed. Thus it is clear that the selectivity of the sec-

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* In the New York area, as already mentioned, prewar receivers tuned to WNBT (50—56 megacycles) radiated at 64 megacycles in the WCBW band (60—66 megacycles).

ondary of the double-tuned circuit is not effective in reducing the radiation. It can be inferred, on the same grounds, that a single-tuned circuit would have no selective effect at all on the local-oscillator radiation. In either case, however, the secondary capacitance does affect the radiation since its value determines the antenna-to-grid step-up for a given band width. With the double-tuned circuit, it can be shown that, to a fair approximation, the primary voltage, e_1 of Figure 9, induced by the local oscillator, is

$$e_1^2 \approx \frac{e_{LO}^2}{2} \frac{C_2}{C_1} \frac{1}{1 + 2\left(\dfrac{\omega_{i\text{-}f}}{\Delta\omega}\right)^2} \tag{10}$$

where $\omega_{i\text{-}f}$ is the angular, mid-band intermediate frequency, and $\Delta\omega$ is the 3 decibels down, angular, input circuit band width. This approximation assumes adjustment for a flat-top response curve and a high secondary Q (i.e., the damping is provided entirely by the antenna). Under these conditions the primary Q determines the band width according to the relation

$$Q_1 = \omega\, C_1\, R_a = \frac{1}{\sqrt{2}} \frac{\omega}{\Delta\omega}$$

Solving this for C_1 and putting it into the previous expression, it is seen that the radiated watts are

$$W = \frac{e_1^2}{R_a} \approx \frac{e_{LO}^2}{\sqrt{2}} \frac{\Delta\omega C_2}{1 + 2\left(\dfrac{\omega_{i\text{-}f}}{\Delta\omega}\right)^2} \tag{11}$$

which is conveniently independent of antenna radiation resistance.

Assuming an 8-megacycle circuit band width, which is suitable for the 6-megacycle channel of present U. S. transmissions, and an oscillator excitation of 2 volts, which is satisfactory for the high-transconductance pentodes, Table III was calculated for two currently available tubes.

Table III

Intermediate Frequency	Microwatts Radiated	
	6AC7	6AK5
10 Mc	680	340
20 Mc	210	105
30 Mc	96	48
100 Mc	9	5

Even with an intermediate frequency of 100 megacycles, the local-oscillator radiation is far from the 0.01 microwatts desired.

A grounded-grid triode radio frequency stage, such as the one recently described[10] using a 6J4 or 6J6 tube, requires a slightly different approach. A double-tuned circuit between the triode and the pentode mixer will give slightly less radiation than a single-tuned circuit. With the double-tuned circuit, the local oscillator voltage at the triode plate (a loading resistor for primary damping is assumed) is given by equation (10) above. This voltage reacts on the input antenna circuit only through the plate-cathode capacitance and through the plate resistance, if we may assume good grounding of the grid. Assuming an antenna directly connected to the cathode-grid input circuit, we find an antenna radiation around 30 decibels less than the figures in Table III. Although this is a substantial improvement, it may be insufficient unless a high intermediate frequency is chosen. A pentode radio frequency stage, on the other hand, will have much less output-to-input coupling and may have an additional pair of selective circuits in its input. This should allow such a radio frequency stage to reduce oscillator radiation sufficiently to give satisfactory performance even for lower intermediate frequencies. The use of a mixer with less inherent radiation, such as the cathode-coupled, double-triode mixer (see Figure 13 of reference 10), will decrease the isolation requirements on the radio frequency stage.

Still other arrangements which are possible make use of balanced triode or pentode mixers with the local oscillator driving the tubes in parallel, while the antenna signal drives them in push pull. These circuits must be carefully balanced to give effective reduction of radiation. If combined with a grounded-grid triode radio frequency stage, however, it may be possible to attain the desired 50 decibels or so of radiation reduction. Neutralization of the radiation from a single mixer tube is possible but again, to be effective, is achieved by a rather critical adjustment. Particular methods of operating balanced mixers will give conversion using an oscillator of half of normal frequency. This places the oscillator so far away from the normal signal channel that, when combined with the neutralization due to a balanced oscillator feed and unbalanced signal feed, adequate reduction of radiation may be achieved.

The one solution, which unfortunately cannot be proposed with those tubes which are commercially available on the open market, is the separation of oscillator and signal circuits of the mixer by the

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[10] G. C. Sziklai and A. C. Schroeder, "Cathode-Coupled Wide-Band Amplifier," Proc. I.R.E., Vol. 33, pp. 701-709, October, 1945.

methods used in such low-frequency tubes as the 6L7.[11] The signal-to-noise ratio of this illustrative type of mixer has not been adequate for television service. Thus, if a radio frequency stage cannot be used, the only practicable remedy is the use of additional selective circuits between antenna and mixer, possibly with a rejection band at local oscillator frequency.

In all cases, local oscillator shielding should be employed to prevent direct chassis radiation.

IX. CONCLUSIONS

The tolerable amount of local oscillator interference, or other c-w interference, in a television picture is greater when the interfering frequency is at the high end of the picture band. In this case, the chief annoyance is loss of picture contrast which, for strong interference, can be very bad, even to the point of a negative picture. The transition between a slight loss in contrast and a completely washed-out picture is sufficiently sharp to make a choice of minimum interference level not too difficult. A value of signal-to-interference field strength ratio of 20 decibels may be considered a satisfactory minimum when the interference is near the upper end of the picture band.

On the basis of an interference 20 decibels below a desired carrier, and assuming channel assignments and choice of intermediate frequency so that an interference does take place with another channel, it is found necessary to reduce receiver radiation to 0.01 microwatts to protect the 500 microvolt per meter field strength contour with receivers 50 feet apart. Prewar receivers radiated 10^5 times as much as this and so were extremely unsatisfactory. A grounded-grid triode radio frequency stage is not a sufficient safeguard, though a carefully designed pentode radio frequency stage may be. Other alternatives lie in the use of balanced or radiation-neutralized mixers, or additional selectivity with an oscillator rejection circuit between antenna and mixer.

Although none of the suggested remedies lend themselves to a minimum-cost receiver design, an adequate television service will require substantial suppression of local oscillator radiation if frequency allocations are such as to make interference possible.

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[11] C. F. Nesslage, E. W. Herold and W. A. Harris, "A New Tube for Use in Superheterodyne Frequency Conversion Systems," Proc. I.R.E., Vol. 24, pp. 207-218, February, 1936.

MERCHANT MARINE RADAR*

BY

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Summary—This paper outlines and discusses surface search radar for maritime applications. Such applications require high performance including good bearing and range resolution to pick up buoys, other vessels and shore lines when navigating in restricted waters. Fundamental aspects of transmitter, receiver, indicator, and antenna design are discussed. The effect on range due to reflections from the sea, which produce a lobe structure, are described and the advantages of using very high frequencies to obtain the best performance are pointed out. Range calculations and the importance of adequate power for reliable operation under adverse conditions are considered.

I. INTRODUCTION

IT IS the purpose of this article to examine some of the elements of a radar system when applied as an aid to marine navigation. During the war period radar reached a high state of development as a military device to determine the range and bearing of enemy or friendly vessels, to locate aircraft, to direct gunfire or bombing operations, and in numerous other applications. We are now entering a new phase, peacetime commercial uses of radar, and one of the most important services will be as a navigational device for merchant vessels.

It might be assumed that wartime designs, with minor modifications could immediately be applied to the merchant marine industry. However, from the long range viewpoint, it is necessary to consider the special requirements of peacetime commerce and to avoid, as much as possible, premature standardization in an art which is developing rapidly. By careful attention to the fundamental factors involved and through extensive field tests, it will be possible to protect the inherently complex marine radar installations from early obsolescence.

Bowditch has defined marine navigation as the science which affords the knowledge necessary to conduct a vessel from point to point on the earth's surface and to enable the mariner to determine, with a sufficient degree of accuracy, the position of his vessel at any time. Piloting is usually considered the most important part of navigation, involving as it does, safe movement of a ship along coasts, through channels and harbors and in similar restricted areas where a constant watch must

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* Decimal Classification: R537.

be maintained and frequent references made to landmarks, lighthouses, buoys or other *visible* aids. When visibility is poor, piloting in dangerous areas or navigation on the high seas become more difficult and it is under these conditions that radar is expected to become a valuable aid for the prevention of stranding and the avoidance of collisions.

II. Principal Applications

A shipboard radar installation, well designed and correctly operated and interpreted should provide the navigator or pilot with range and bearing information under the following general conditions:

Object (Target)	Average Range (Nautical Miles)
High coast lines (300 feet or more)	20 to 50 miles
Low coast lines (30 feet or more)	5 to 10 miles
Average cargo ship (400 feet long)	7 to 10 miles
Small fishing vessel (40 feet long)	2 to 5 miles
Average buoy (metal)	1 to 5 miles

It will be evident that large or high targets (because they act as better reflectors) may be detected at greater distances. Since radar operation is more or less governed by line of sight considerations, optical analogies are useful in roughly estimating performance. Small low objects that cannot be sighted under conditions of *good* visibility (as a buoy in a disturbed sea) will likewise not intercept the radar beam and return an echo to the antenna. On the other hand, if the buoy could be seen, except for fog, darkness or other unfavorable factors, then it should be apparent on the radar indicator scope.

III. Government Recommendations

General marine radar specifications for use as a guide by the shipping industry and radio manufacturers have been issued in the United States and Great Britain. The United States Coast Guard has prepared "Minimum Recommended Specification Briefs" for voluntary use by industry, which cover three classes of radar installations. In Great Britain performance specifications for a general purpose radar set for marine transport have been published. The principal objective of the material issued to date is to provide a "starting point". Extensive field tests and the natural development of marine radar must take place before complete and final requirements may be specified. Frequency allocations, under international agreements, are to be determined. Shipboard radars, in the future, should be closely coordinated with radar beacons and the latter must also undergo development and tests. It is anticipated that many of these factors will receive careful attention during the year 1946, while trial installations on various classes of vessels will provide valuable data under practical operating conditions.

The recommended specification briefs, which have been released by the United States Coast Guard, cover three general types of radar equipment. The first type, usually referred to as class A, will operate in the three centimeter band and will be designed to provide a high degree of resolution for navigation in restricted waters. The class B type is intended for less exacting service, with operation in the three or ten centimeter bands, where a fair degree of resolution and fewer refinements for accurate ranging and true north presentation are considered adequate. In the case of the class C radar, the emphasis is on a simplified design as an anti-collision device, with limited utility for general navigation. With respect to the class A radar, it is of interest to consider some of the more important characteristics from the viewpoint of overall design.

IV. TRANSMITTER

The transmitter is recommended for operation in the three centimeter band between 9320 and 9430 megacycles. A peak power output of not less than 15 kilowatts would be obtained from a resonant cavity magnetron oscillator which is pulsed by a suitable modulator. Since the magnetron is the heart of the transmitter, a brief explanation of the power relations is in order. Peak power multiplied by the "duty cycle" determines the average power output. The duty cycle, for conventional rectangular pulses, is equal to pulse length in microseconds multiplied by the pulse repetition frequency in cycles multiplied by 10^{-6}. Thus for the specified maximum pulse length of 0.5 microsecond and minimum repetition frequency of 800 cycles, the duty cycle is 0.0004. With 15 kilowatts peak power output the average value is, therefore, only 6 watts.

The choice of pulse length and repetition frequency involves conflicting factors. For good range resolution and "close in seeing", a very short pulse length is necessary. Short pulses result in low average power output. A pulse of 0.5 microsecond, under ideal conditions, gives a minimum range resolution of about 82 yards, but this low value is not always realized in practice because of the widening of the pulse in receiver and indicator circuits. For a maximum range of say 50 nautical miles, the repetition frequency has a theoretical value of 1630 cycles. However, a lower rate is generally used to permit a more evenly balanced duty cycle—i.e., relationship of peak power to average power. Considering a pulse of say 0.3 microsecond and a repetition frequency of 1000 cycles, the duty cycle is 0.0003. Under these conditions the range resolution will be good, but the performance at maximum distances would be improved if the average power could be increased by the use of a longer pulse with a corresponding reduction in receiver noise band-width. This may be accomplished if provisions are made to shorten pulse length and increase repetition frequency for short ranges and vice versa for greater distances. Such an arrangement maintains the average power and the duty cycle constant, gives high resolution where needed, and high average power for obtaining maximum range.

V. RECEIVER

The receiver used in the class A radar will be designed for high gain and optimum band width with special characteristics to improve performance in marine service. An overall gain of at least 120 decibels and an overall noise not to exceed 15 decibels above $KT\Delta f$ is recommended. Automatic frequency control of the receiver local oscillator, arranged so that the magnetron frequency keeps the receiver in tune, is essential. In order to minimize "sea return" which can obscure targets near the ship, circuits which provide sensitivity time control (STC) and fast time constant (FTC) are effective. STC lowers the receiver sensitivity for nearby targets without impairing response at longer ranges. FTC breaks up the solidarity of the "sea return" on the PPI tube and thus helps make the echo appear through the clutter. Figures 1 and 2 show the clutter due to sea return using two different sweep lengths. Figures 3 and 4 show the improvement due to STC and FTC under the same conditions. (See following two pages.)

VI. INDICATOR

The indicator will be a cathode ray tube, commonly refered to as a PPI (Plan Position Indicator), having a diameter of at least 7 inches. Three or more range scales will permit observation of suitable targets from a minimum of two miles to a maximum of at least thirty miles. In order to measure ranges with accuracy, a variable range marker (adjustable radius range pip) to cover distances between 500 yards and 30 miles is recommended. For determination of bearings with respect to true north, on vessels fitted with gyro compass systems, the PPI tube is to be stabilized from that system. This means that north will always be "up" on the scope, and as the vessel changes course the targets will not shift. A flashing ship's head indicator mark on the PPI will also allow bearings to be observed relative to the bow. For installations where a north stabilized PPI cannot be used, a movable azimuth scale around the edge of the scope may be employed for manual setting to ship's course. It is likely that most designs will provide a

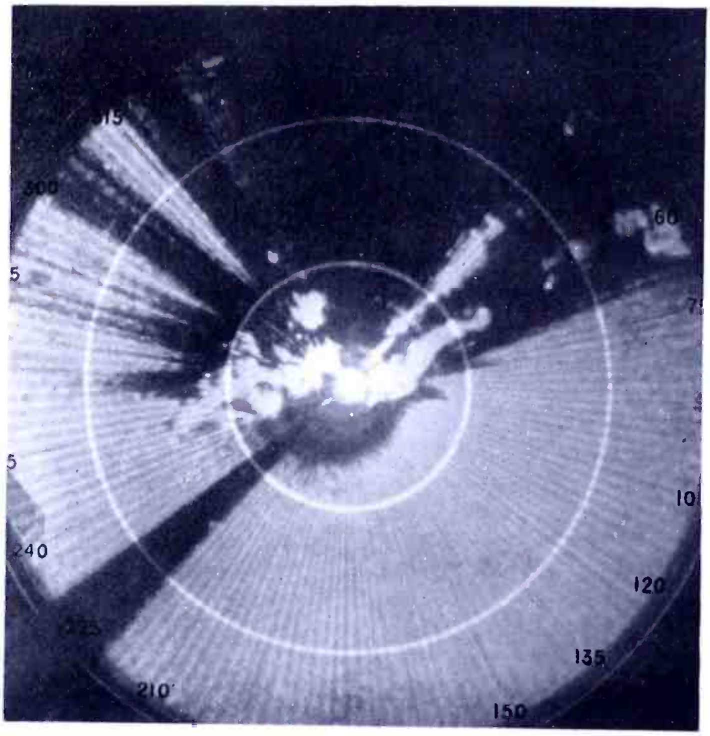

Fig. 1—Sea Return—27 Knot Wind—Normal Gain
Range: 1 mile per Range Ring, Targets generally obscured.

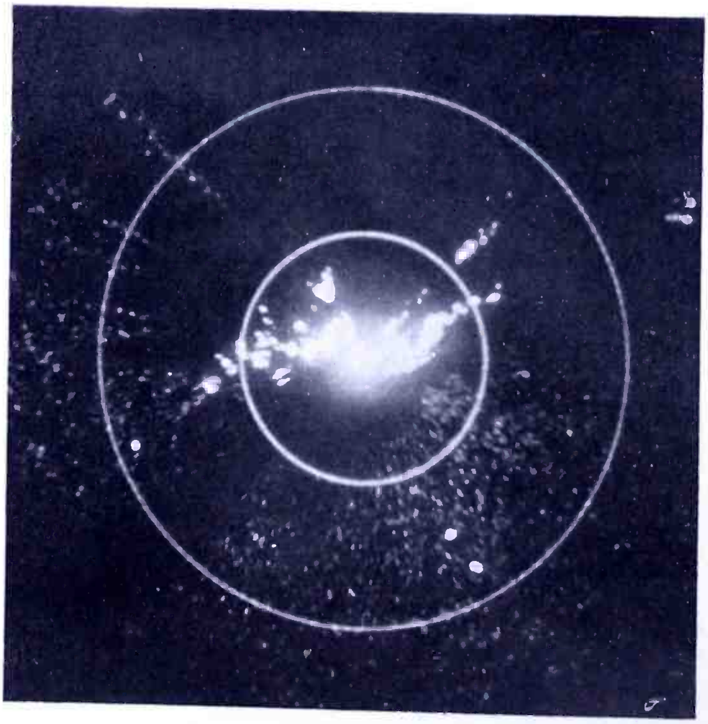

Fig. 3—Sea Return—27 Knot Wind—Using FTC and STC
Range: 1 mile per Range Ring, Targets within both Range Rings visible.

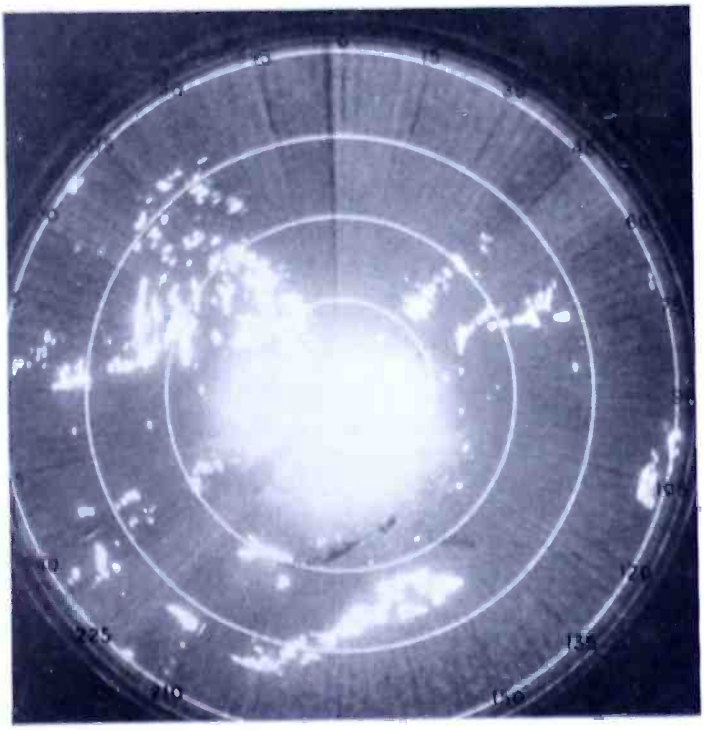

Fig. 2—Sea Return—27 Knot Wind—Normal Gain
Range: 5 miles per Range Ring. Targets obscured below 8 miles.

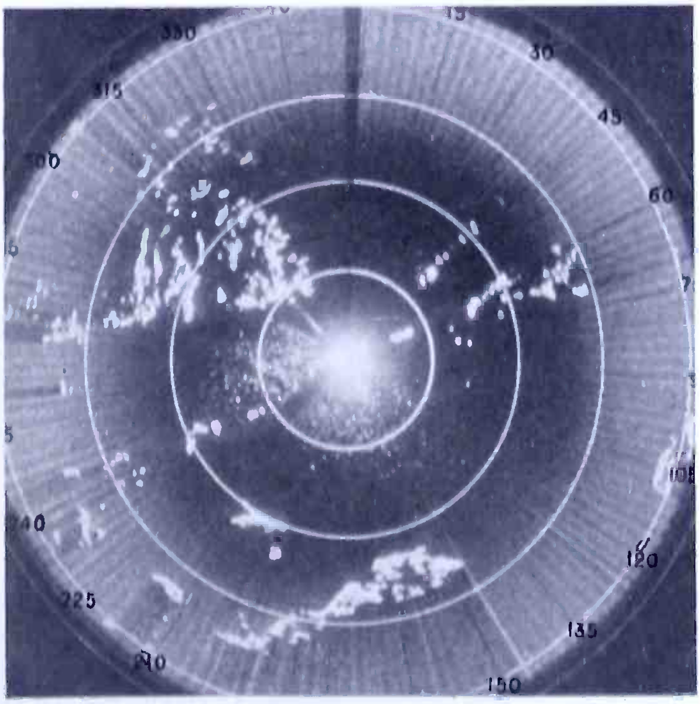

Fig. 4—Sea Return—27 Knot Wind—Using FTC and STC
Range: 5 miles per Range Ring, Targets visible near Ship.

simple switch so that either true or relative bearings may be conveniently selected by the navigator on vessels which are equipped with a gyro compass.

VII. Bearing Resolution

A high degree of resolution for both bearing and range is essential. Bearing resolution is determined primarily by the horizontal beam width of the antenna, two degrees being specified. When two vessels, at the same range, are spaced by more than the horizontal beam width, they will appear as separate arcs on the PPI scope, if viewed on a short range sweep. Using a two degree beam and with receiver gain properly adjusted to permit sharp definition of targets, the following approximate "span" of the beam exists at various ranges:

Range (yards)	125	500	2000	8000	32000	64000
Span (yards)	4.37	17.5	70	280	1120	2240

Thus at a range of 2000 yards two ships separated by say 100 yards will appear as individual targets. To allow for normal pitch and roll of the radar-equipped vessel a vertical beam width of at least 15 degrees is recommended; otherwise the beam may not intercept the target during rough weather. Because of the comparatively large vertical beam, the overall pattern skews to some extent with the motion of the ship and some impairment of bearing resolution is to be expected when navigating in heavy seas. In discussions of beam width it is implied that measurements are taken at the "half power points". Below these values the beam power falls off rapidly with a well designed antenna.

VIII. Antenna System

The design of the antenna system involves electrical and mechanical factors of considerable importance. Since the antenna must rotate continuously throughout the azimuth, the overall size should be kept within practical limits. The largest dimension of the antenna is that determined by the horizontal section of the reflector. For a truncated parabola or a section of a parabolic cylinder, operating in the proposed three centimeter band, the width of the reflector is expressed approximately by:

$$W \text{ (ft.)} = \frac{7.5}{\text{Beam Width (degrees)}}$$

Thus a reflector for a 2 degree horizontal beam would be about 3.75 feet wide in the frequency band 9320-9430 megacycles. If the ten centimeter band were used, a 2 degree beam requires a reflector about 12 feet wide.

The effects of wind resistance and the corrosive action of salt atmosphere and stack fumes require careful attention with exposed antennas. Use of slats in the reflector, rather than solid surfaces will minimize wind resistance. Appropriate metals and finishes are needed to resist corrosion. The antenna drive motor should have adequate power to give constant angular velocity with lash in gearing kept to a minimum to avoid "spoking" on the PPI.

The speed at which the antenna should rotate is governed mainly by the repetition rate, persistence of the PPI, and the relative speed of the ship and targets. A speed between 6 and 15 revolutions per minute is recommended. Enough pulses should strike the target each time the beam sweeps past. A minimum of 25 or so "hits" per beam width is desirable. Assume a scanning speed of 10 revolutions per minute (1 revolution in 6 seconds), a 2 degree beam and a repetition frequency of 1000 cycles. Two degrees represents 1/180 or 0.0055 of 6 seconds = .033 seconds, which is the time the 2 degree beam persists. At 1000 cycles the number of pulses which strike the target are 1000 × .033 = 33. If the target is large compared to the "span" of the beam, then a greater number of pulses will be obtained and the arc on the PPI will be extended accordingly. Too low a scanning rate makes targets appear to move in jumps when viewed at close ranges from a fast ship. Even where speed relative to the target is not a factor, there appears to be operational merit in not requiring the observer to feel that he is "waiting" for the next sweep of the beam.

Spurious emission due to side lobes in the horizontal plane of the antenna must be kept to a level of 25 to 35 decibels below the power in the main beam. The effect of side lobes, particularly at short ranges, is to cause multiple images of individual targets which can lead to confusion in congested areas. Although radiation of side lobes cannot be completely suppressed, the experienced navigator can readily recognize them and by suitable adjustment of gain control, reduce them to a negligible effect.

IX. RANGE CALCULATIONS

The computation of maximum detectable range for various targets on the surface of the sea is complicated due to several conditions. The amount of energy reflected from an object depends upon its size and aspect. The roll and pitch of the ship cause the returned signal to fluctuate. Also the projected area of the target vessel depends on the ship's course. Sometimes a target, for example a small fishing boat or a buoy, may be out of sight in the trough between waves. Similarly the radar set itself may be adversely located. Humidity and temperature also may affect the radar beam, giving ranges shorter or longer than normally expected. By means of a few general rules and some computations a fairly accurate picture can be drawn of what may be expected from a radar set under normal operating conditions.

The radar range equation has been published elsewhere[1] and may take several forms, one of which is as follows:

$$\text{Maximum Range} = \sqrt[4]{\frac{P_t A^2 \rho}{4\pi P_{min} \lambda^2}}$$

where P_t = peak power in watts
A = Effective antenna reflector area
ρ = target effective area
P_{min} = minimum detectable signal in watts
λ = wavelength

Range is given in feet when wavelength, antenna area and target area are expressed in the same units. This formula gives the "free space" range, that is, the range if there are no reflections from ground or sea.

The effective area "A" of the antenna reflector is roughly 0.6 times the projected area. The value for ρ, the effective cross section of the target, is a quantity not too well defined because of the various sized ships and their aspect. The following table will give an idea of values to be expected.

Buoy	10 sq. ft.
Motor Boat	70 sq. ft.
Small two masted vessel	1500 sq. ft.
Freighter or Tanker	25000 sq. ft.

The theoretical minimum detectable power is given by $P_{min} = NKT \Delta f$; where N is the factor by which the practical falls short of the theoretical; K is Boltzman's constant $1.37 \cdot 10^{-23}$ watt-seconds per degree; T is absolute temperature of the crystal (300° Kelvin); and Δf is the receiver intermediate frequency band width in cycles. The optimum band width in megacycles for a given pulse length is approximately $\frac{1.2}{d}$, where d is the pulse length in microseconds.

In a practical radar system, detection falls short of the ideal by about 10 or 15 decibels, that is, it requires about 10 to 31 times as much power as the theoretical value for detection. This is due to TR tube and mixer plumbing losses, intermediate frequency noise, conversion

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[1] D. G. Fink, "The Radar Equation," *Electronics*, Vol. 18, No. 4, pp. 92-94, April 1945.

and noise loss in the crystal, and local oscillator noise. The Coast Guard specification states that these losses shall not exceed 15 decibels for the class A radar. Actually a good radar should have a loss of a few decibels less than this value.

Not included in the above are two other losses which must be considered. One is the loss on transmission and reception in the waveguide. This will probably be about 3 decibels total for both directions of transmission. The other is known as the scanning loss. It is due partly to the small time allowed for signals to "build up" on the cathode ray tube screen and partly to the slow integration time of the human eye. This loss is $\sqrt{\frac{N_{ta}}{N_{tr}}}$ where N_{ta} = number of hits on a target in one pass of the antenna beam and N_{tr} is the number of pulses transmitted in 8 seconds. This loss may be a factor of 10 decibels when PPI presentation is used. Coming back to the quantity N in the range equation

$$\begin{array}{rl} N = & 15 \text{ decibels lack of receiver sensitivity} \\ & \ \ 3 \text{ decibels wave guide loss} \\ & \underline{10} \text{ decibels scanning loss} \\ & 28 \text{ decibels} = \text{a factor of } 630 \end{array}$$

Therefore, $P_{min} = 630 \cdot 1.37 \cdot 10^{-23} \cdot 300 \cdot 2.4 \cdot 10^{6} = 62.5 \cdot 10^{-13}$ watts

The following is a sample computation of the expected free space range on a buoy using 10 kilowatts peak power, an antenna reflector of 6″ × 48″ and $\lambda = 3.2$ cm (receiver intermediate frequency band width used in P_{min} was 2.4 megacycles which corresponds to a pulse width of 0.5 microsecond).

$$\text{Maximum Range} = \sqrt[4]{\frac{10{,}000\ \ (2 \times 0.6)^2\ \ 10}{4\pi\ 62.5 \cdot 10^{-13}\left(\dfrac{3.2}{2.54\ \cdot\ 12}\right)^2}} = 20{,}300 \text{ ft. (approx.)}$$

$$= \frac{20{,}300}{6080} = 3.35 \text{ nautical miles}$$

Under ideal overwater conditions one may expect between 65 and 100 percent greater range; however, this refers to a very exceptional condition which will not generally be encountered. There are two paths on transmission and two on reception, one the direct wave and the other a reflection from the sea. Reflection is almost 100 percent from a smooth sea if the grazing angle is small, and, of course, is less from a rough sea. If the reflection were 100 percent and the two rays arrived at the target in phase the intensity would be doubled. In power this means 4 times the direct energy which is 10 log 4 = 6 decibels gain one way and 12 decibels for two way transmission. A 12 decibel gain in power is equivalent to double the range.

Reflections from the sea reach a point in space either in phase or out of phase, with the line of sight path. This gives rise to a lobe structure which is represented in Figure 5. The first or lowest lobe is the one of main interest to navigation. This lobe is closer to the sea with increasing frequency and, consequently, targets can be seen farther using 3 centimeters, as compared to 10 centimeters, in systems having the same overall performance figure. The increase in range varies with conditions, but can be 50 to 90 percent greater, especially when searching for small low targets.

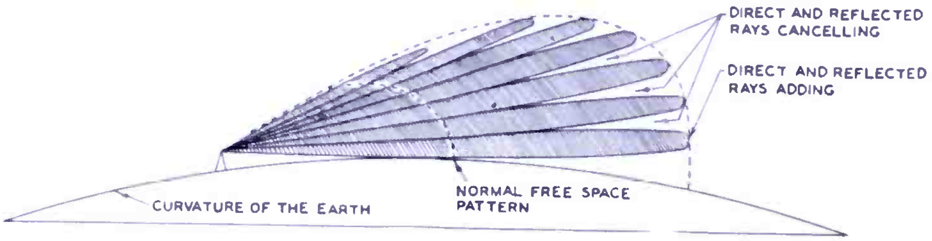

Fig. 5—The reflections from the sea reach a point in space either in phase or out of phase with the direct ray giving rise to a lobe structure as illustrated.

A further analysis of the range equation yields some interesting information. Substituting $\frac{1.2}{d}$ for Δf (bandwidth)

$$\text{maximum range} = \sqrt[4]{\frac{d\ P_t\ A^2\ \rho}{4\pi\ NKT\ 1.2\,\lambda^2}}$$

Thus the range would be increased if the pulse length could be increased with simultaneous decrease in the receiver intermediate frequency bandwidth. In a marine radar short pulses are necessary to have the desired range discrimination; so in order to get more range the peak power is increased. Thus dP_t is a measure of the energy or average power per pulse. Increasing the peak power or the pulse length has the same effect. Therefore, it is the average power per pulse which must be considered and not merely peak power. This was recently demonstrated by the U. S. Army in receiving echoes from the moon. Getting extremely high peak power was impracticable, so moderate peak powers with a very wide pulse and a receiver of narrow band width were used. In this case the energy per pulse was very high and short range discrimination was not a problem.

The range equation is often divided into three parts and each is expressed in decibels.

1. System performance figure $= -10 \log \dfrac{P_t}{P_{min}} \left(\dfrac{G\,\lambda}{4\,\pi} \right)^2$ (λ in meters)

2. Target performance figure $= -10 \log \dfrac{\rho}{4\,\pi}$

3. Attenuation $= -10 \log R^2$ (meters) (One way attenuation). This gives the relative attenuation between one meter and R meters where R is range.

By substituting in the range equation the value of "A" obtained from the equation for the gain "G" of a reflector

$$G = \frac{4\pi\,A}{\lambda^2}\ ,\quad A = \frac{G\,\lambda^2}{4\,\pi}\ ,\ \text{the result is}$$

$$\underset{\text{maximum}}{R^4} = \frac{P_t}{P_{min}} \left(\frac{G\,\lambda}{4\,\pi} \right)^2 \frac{\rho}{4\,\pi}$$

which shows the origin of the above division.

The first equation, the system performance figure, is often used to "rate" a radar system but it must be realized that all the variables are not represented which makes a radar useful, such as range resolution, azimuth resolution, rate of information and the increased range which the 3 centimeter band gives compared to the 10 centimeter band equipment. It will now be demonstrated how this method works by using the example previously employed.

For example, with a peak power of 10 kilowatts, an antenna gain of 1365, a wavelength of 3.2 centimeters, etc., expressing these values in decibels gives the following tabulation. The first five values represent the system performance figure and the last two values the target performance figure over a two way path. The algebraic sum of these values must be divided by 2 when reading the attenuation curve in Figure 6.

1—Peak Power, — db_{P_t} $= -\ 40$
2—Antenna Gain, — db_{G^2} $= -\ 62.66$
3—Wavelength, — $\mathrm{db}\lambda^2$ $= +\ 29.9$
4—Min. Det. Power, + $\mathrm{db}_{P_{min}}$ $= -\ 112.0$
5—Constant, + $\mathrm{db}_{(4\pi)^2}$ $= +\ 21.96$
6—Target Area, — db_{P} $= +\ .3$
7—Constant, — $\mathrm{db}_{4\pi}$ $= +\ 11.0$

$\mathrm{db}_p = -151.5$ decibels two way, –75.7 decibels one way.

The quantity db_p is the intensity at a point in space with respect to the intensity at one meter. Radar range is half that of the total transmission path. One can think of having the square root of the total intensity $\frac{(\text{db}_p)}{(\ 2\ )}$ at one meter and use one way radar attenuation, R^2 instead of R^4 attenuation. For this example one reads from the attenuation curve, Figure 6, a range of 3.35 nautical miles.

Under ideal conditions, one might obtain a range of perhaps 6.5 nautical miles if the target is within the radar horizon, which is 1.22 $[\sqrt{h_a} + \sqrt{h_t}]$ where $h_a =$ height of radar antenna and $h_t =$ effective height of the target. The effective height h_t depends on the construction and aspect of the target. If a ship, the effective height will, of course, not be the height of the top mast, but will perhaps be the height of the decks or lower. Figure 6 also gives the radar horizon for either the target or the radar set. The horizon curve must be applied twice to give the sum of these distances which is the line-of-sight range. Thus the radar would indicate the buoy if the antenna were about 30 feet above the surface of the sea.

Using only enough power for ideal conditions is, of course, dangerous. Under such conditions one does not need radar because the weather is good, the ship is steady, the target is still, the surface of the water is like a mirror and one can see where he is headed. Under adverse conditions, with heavy seas and rain, snow, fog or darkness, then the range will fall short of the theoretical value and ample power provides the necessary safety factor.

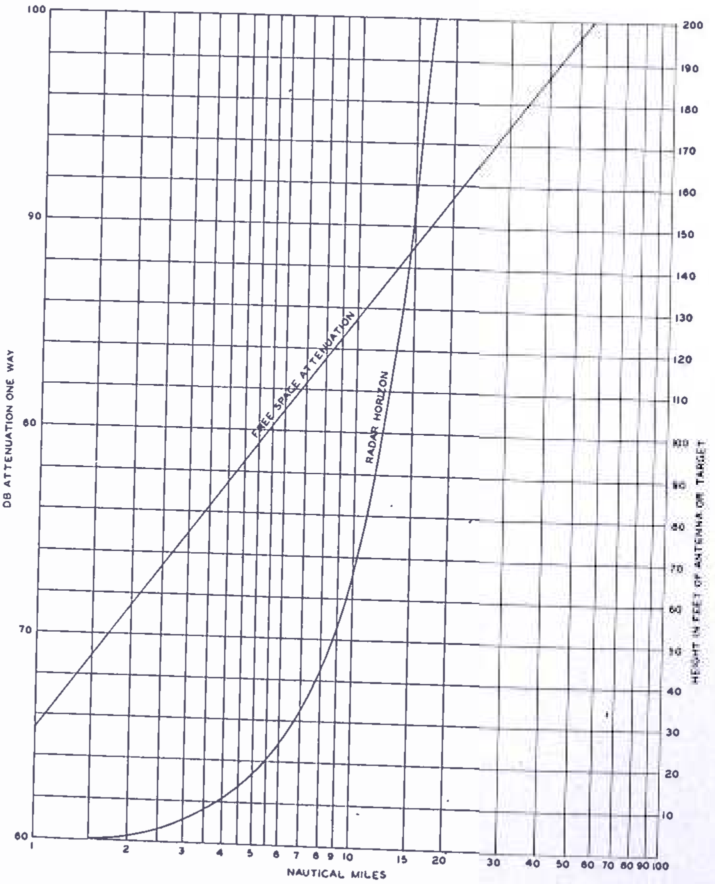

Fig. 6.

IMAGE ORTHICON CAMERA*

By

R. D. Kell and G. C. Sziklai

Research Department, RCA Laboratories Division, Princeton, N. J.

Summary—*One of a series of developmental television cameras using the image orthicon is described. The complete camera weighs less than forty pounds. The input power required by the camera is 300 watts. This power may be supplied by a non-regulated power supply or generator. A unique regulated high voltage supply was developed for the electron multiplier and image section of the camera tube. The camera circuits include the deflection system, voltage regulators, black-level setting, blanking circuits, and video amplifiers. A total of seventeen tubes is used in the camera. An extremely high-sensitivity version of the camera, using reflective optics, is also described.*

I. Introduction

THE development of the image orthicon[1] provided a camera tube for an extremely sensitive television camera. In addition, due to its high output signal level, it permitted a substantial reduction in the number of tubes used in the video amplifier, and thus permitted the incorporation of other circuits within the camera that were built into auxiliary equipments in previous types of cameras. While certain operating features of the image orthicon provide simple blanking and black level setting, the photo-cathode image section and multiplier electrodes require potentials of such values and stability that new circuits had to be designed to permit the incorporation of these supplies in the camera.

II. Resolution

During the early part of the development the major effort was applied to improving the resolution of the image orthicon. In the course of the investigation, it was observed that by scanning only a portion of the target considerably better resolution was obtained than when the whole target area was scanned. In order to determine whether the lack of resolution was due to limitations in the scanning or in the image section of the tube, or possibly in the coupling section between the camera tube and the amplifier, a variable frequency signal was applied to the target. It was found that a 5-megacycle signal was satisfactorily passed by the scanning section and the amplifier, indicating that the limitation was caused by the image section of the tube. The

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* Decimal Classification: R583.12.

[1] Paper on the image orthicon was presented by A. Rose, H. B. Law, and P. K. Weimer, at the IRE Winter Technical Meeting, on January 24, 1946.

fact, however, that scanning a small portion of the target provided a well-resolved picture indicated that the image section itself formed a picture of satisfactory resolution. These experimental results tended to show that an interaction between the scanning and the image section was degrading the picture.

Upon the assumption that the horizontal scanning field was vibrating the electron image on the target, and thereby blurring the picture, a portion of the horizontal deflecting current was applied to an auxiliary coil located over the image section. This current had a direction opposite to that in the deflecting coil in order to cancel the variable component of the magnetic field. The experiment resulted in considerable improvement in resolution.

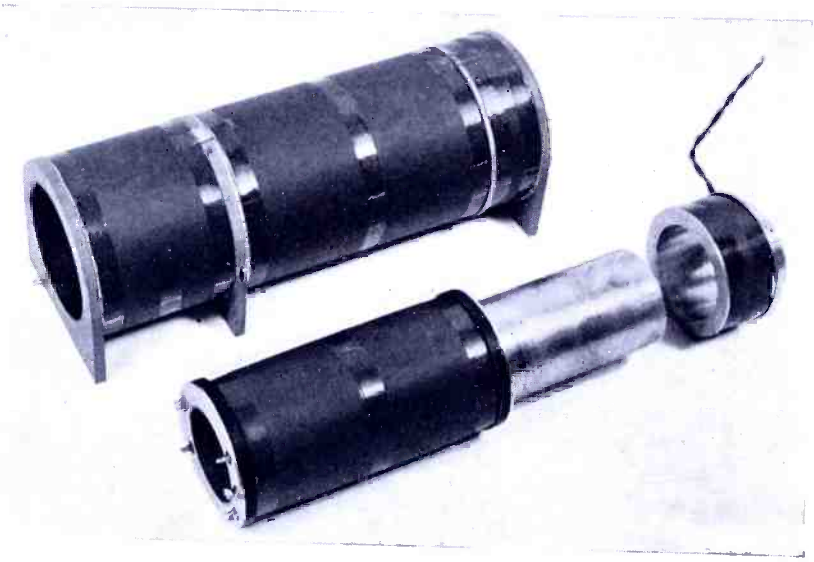

Fig. 1—Focusing, Deflection, and Alignment Coil Assemblies.

As another approach to the problem, this crosstalk effect was reduced by careful shielding. The problem was pursued further, since it was known that a reduction of the deflection power would proportionally reduce the effect. A simple reduction of the focusing field intensity allowed a reduction in deflection power, but it degraded the resolution around the edges of the picture, and hence was not permissible. However, it was found that by reducing the focusing field over the deflection coils and reinforcing it over the gun and the target, better resolution in the corners was obtained because of better electron landings. It was further found that the desired field distribution could be obtained with a uniformly-wound focusing coil and a magnetic shield (of iron wire) over the focusing coil. This method, with the addition of electrostatic shielding, was finally adopted. The arrangement considerably reduced the required deflection power and provided a resolution in excess of 450 lines under high light conditions. In cameras where a maximum resolution is required, the image section bucking coil was also provided.

Figure 1 shows the focusing coil assembly, the deflection coil assembly, and the alignment coil in the usual order with the shields. The shield which extends from the deflection coil over the gun end is to prevent pickup from the deflection coil by the signal lead.

III. THE CIRCUITS

A block diagram of the camera is shown in Figure 2. The video output is taken from the last, or fifth, multiplier of the orthicon across a 33,000-ohm resistor, through which a high potential of approximately 1500 volts is fed to the multiplier. This load resistance is about one-tenth of the conventional value used with iconoscopes. It is permitted by the higher signal current output of the image orthicon. The lower signal output resistance also permitted the use of a correspondingly reduced amount of equalization in the high peaker circuit[2] in the second video amplifier plate circuit. With the five stage multiplier image orthicon, substantially all the noise generated is due to the scanning beam, and with the reduced equalization in the high-peaking circuit there were no noticeable microphonics due to the amplifier system.

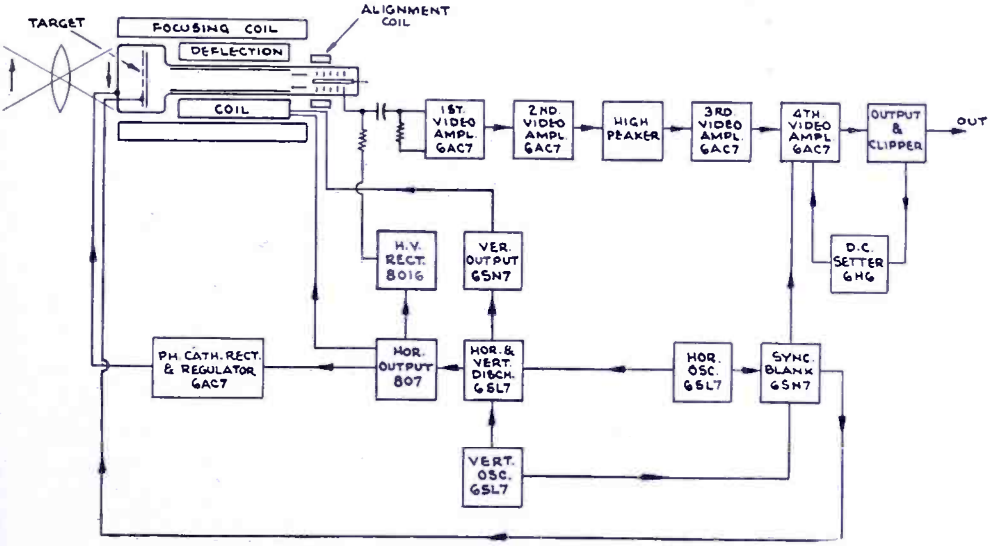

Fig. 2—Camera Block Diagram.

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[2] U. S. Pat. No. 2,151,072—A. V. Bedford, March, 1939.

By using a clamping circuit at the fourth video amplifier stage to reinsert the low video frequencies, further assurance was taken to keep the camera free from microphonics generated in the amplifier.

The clamping circuit is shown in Figure 3, and it functions as follows:[3] At the input to the amplifier the video signal is given a reference level, such as black, during the horizontal return time. This reference level is readily obtained by applying pulses to the target of the image orthicon during the horizontal blanking interval. These pulses cause all of the scanning beam to return to the multipliers. This is a signal which is equivalent to black level. After this reference level is inserted in the signal, the low frequency response of the video amplifier can be reduced to the point where it will just pass a square wave corresponding to line frequency. At a high signal level, where all danger of microphonic disturbance in the amplifier tubes is passed, the signal at the time of the black reference (which has become variable in level due to the presence of picture signal) is again established at a fixed value. With black level representing a fixed bias on the amplifier stage, it follows that the low frequency and direct current component of the signal are again present. Referring to Figure 3, the video signal which has lost the direct current and all low frequency components, passes from the plate circuit of tube A to the grid tube B through the small coupling condenser C. The grid leak on tube B is replaced by the two diodes of the 6H6 type. The push-pull pulses obtained from the tube E are applied to the diodes. The pulses cause both diodes to conduct. This is equivalent to connecting the grid of tube B to the battery through a switch. This makes the potential of the grid corresponding to black equal to the battery voltage.

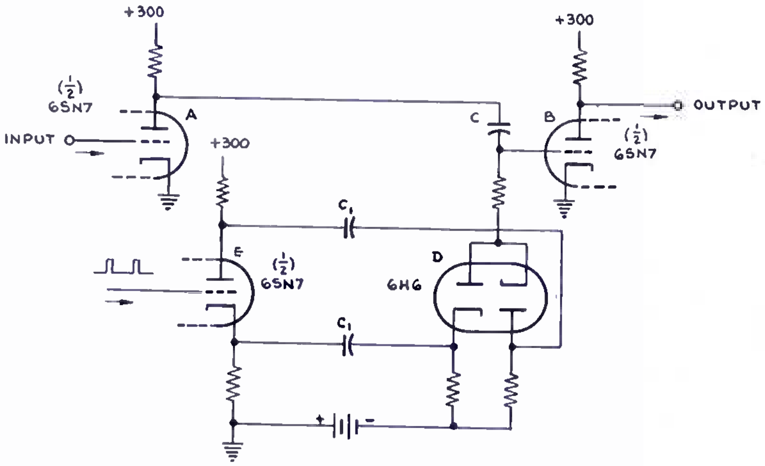

Fig. 3—Direct Current Setting Circuit.

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[3] U. S. Pat. No. 2,299,945—K. R. Wendt, October, 1942.

The reconstructed signal is mixed with a blanking signal in the plate circuit of the fourth amplifier stage, then fed to a cathode follower output stage, which provides a complete video signal of approximately one volt peak-to-peak value.

The deflection circuit consists of the horizontal and vertical oscillators, the two discharge tubes in one envelope, and class A_1 type deflection output stages for both the vertical and horizontal deflection.

The high voltages for the image orthicon were obtained by rectifying the return sweep voltage of the horizontal output stage. Any change in the deflection voltage then tended to upset the operating conditions of the image orthicon tube. Since the photo-cathode voltage, in particular, is very critical, a simple voltage regulator was devised.

Owing to the fact that the current required was exceedingly small, the constant current property of a pentode was considered the simplest method of providing a constant voltage. A further improvement in regulation was obtained by applying a portion of the rectified potential to the control grid of the pentode rectifier and degenerating any change that might occur.

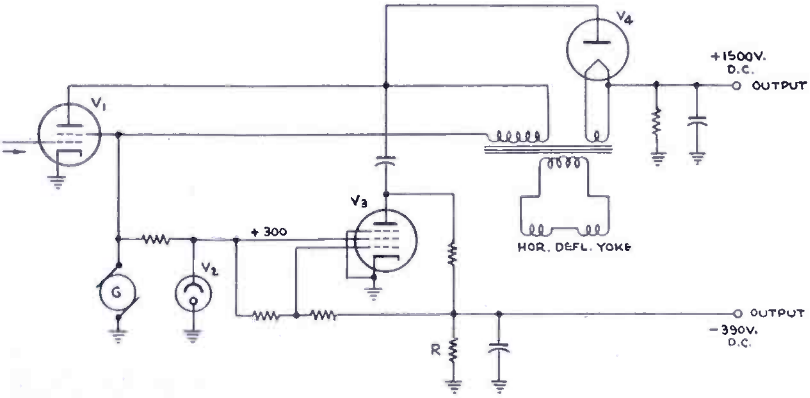

Fig. 4—High Voltage Power Supply and Regulator

The circuit is shown in Figure 4. A portion of the high alternating current pulse voltage across the horizontal deflecting output transformer is rectified by the pentode V3. The useful direct current voltage supply then occurs at the negative terminal shown and is regulated by suitably controlling the grid voltage of the pentode. A portion of the output of the power supply G is regulated by the glow discharge tube V2 and is used for the screen supply to V3. This regulated voltage also serves as a reference potential for the control action, in that a portion of the rectified output voltage is subtracted from it and applied to the control grid. This arrangement will produce a large potential change of the grid voltage with small percentage change of the output voltage. When the negative potential tends to increase across the load resistance R, the grid becomes more negative and the resistance of the circuit increases, thereby reducing the potential across the load. The high voltage for the multipliers is supplied by the rectifier V4. The wall coating and persuader voltages are obtained from the voltage regulator V2 which is actually two VR-150 tubes in series.

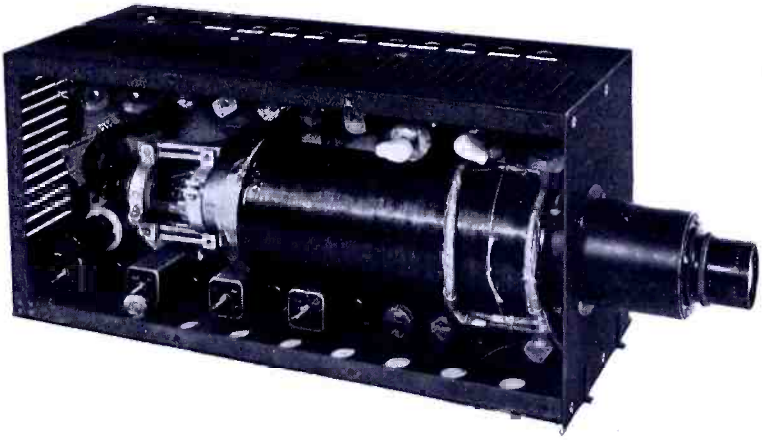

Fig. 5—Top View of Camera Chassis

Figure 5 shows the top of the camera chassis. The high voltage signal coupling capacitor may be seen in the left side of the picture. The video amplifier is located in the bottom row. The voltage regulators, high voltage supplies, and deflecting circuits occupy the top row.

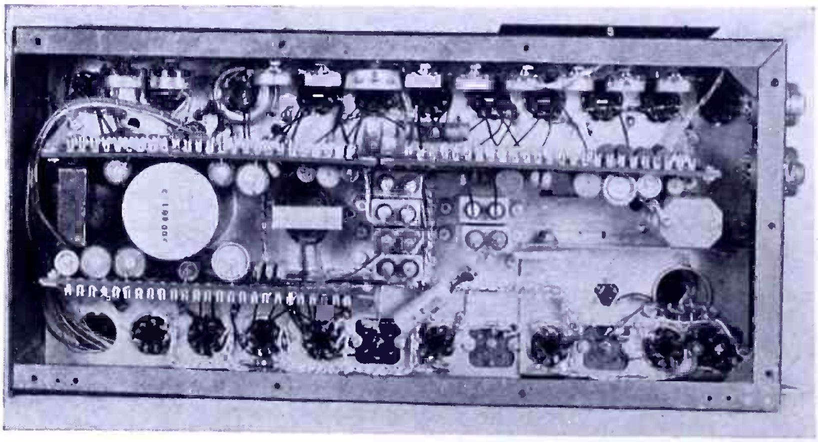

Fig. 6—Bottom View of Camera Chassis

The bucking coil to eliminate the image jiggling is on top of the focusing coil. A bottom view of the chassis, showing the circuit components, is given in Figure 6. The voltage divider for the electron multipliers is at the left side, the potentiometers at the top, and the deflection transformers at the left side of the picture. Four controls, namely, the scanning beam bias, the scanning section focusing control, the image section focusing control, and the amplifier gain control are readily accessible by the opening of a hinged lid. The other controls are normally covered with a plate fastened with screws.

Fig. 7—External View of Camera Assembly with Lens

IV. THE CAMERA ASSEMBLIES

Figure 7 shows an external view of the camera assembled with a 12 cm. f 2.7 lens. Figure 8 shows an image orthicon camera assembled with a reflecting Schmidt optical system. The photo-cathode surface of

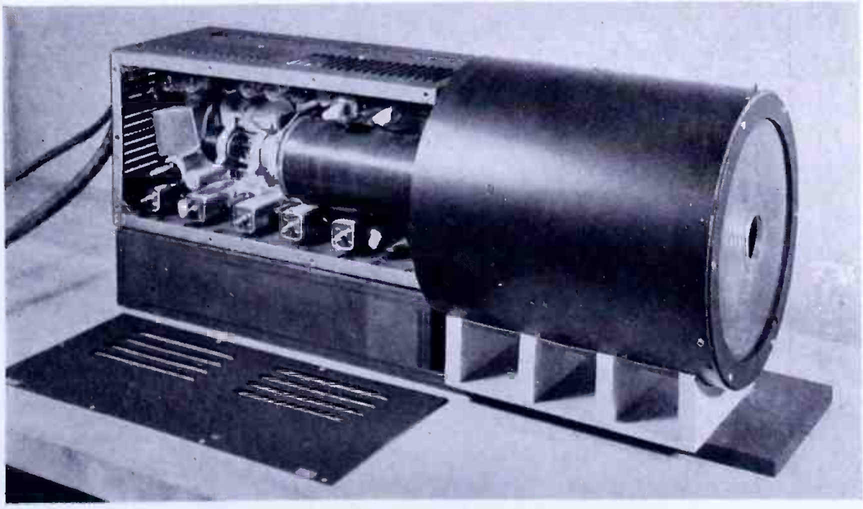

Fig. 8—Camera Assembly with Reflective Optical System

the image orthicon used in this camera was properly curved in order to secure proper focus of the optical image of the entire field of view, and it was placed approximately in line with the spherical mirror. The

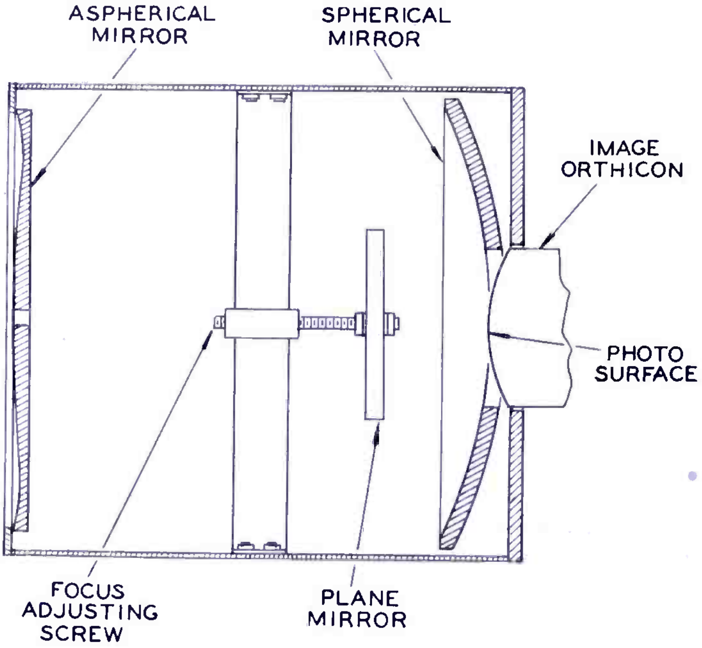

Fig. 9—Construction of the Reflective Optical System

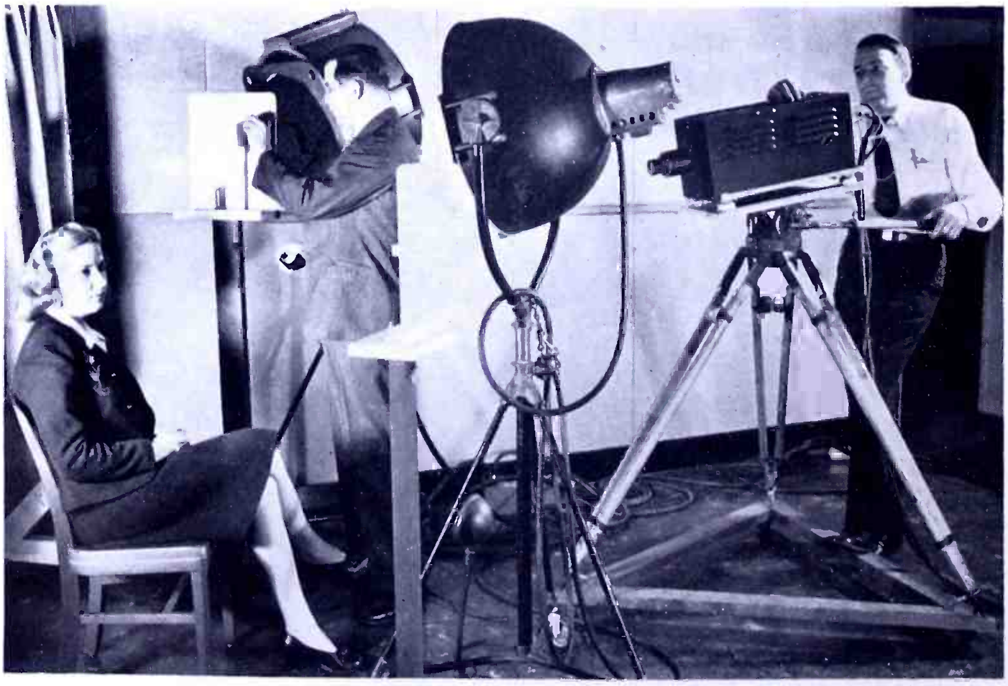

Fig. 10—Camera Demonstration Setup

design of the optical system is shown in Figure 9. A brass barrel provides a rigid structure for the system. The focusing is adjusted by the plane mirror which reflects the image on the photo-cathode of the image orthicon. The system has an (f) power of .7 and an aperture of 10 inches. The completed optical unit has a resolution of better than 1000 lines at the image surface.

Fig. 11—Television Picture Taken with the Subject Illuminated by 3 Kilowatt Incandescent Light.

Fig. 12—Picture with the Subject Illuminated by a 25 Watt Desk Lamp.

Fig. 13—Picture with the Subject Illuminated by One Candle.

V. PERFORMANCE

Figure 10 shows a typical demonstration setup with the image orthicon camera using the f 2.7 lens. Lighting can be provided by the two one-and-a-half kilowatt reflectors, a 25 watt lamp, or by one to four candles. Figure 11 shows a picture taken from a 12-inch direct viewing monitor when the subject was illuminated by the two one-and-a-half kilowatt lights. Figure 12 shows the same subject illuminated with the 25-watt lamp, and Figure 13 shows the same subject with a single candle at a distance of three feet as the only source of illumination. The main difference between the last two pictures is in the noise present, which can not be seen in the photographs due to the inherent integration of the exposure.

The sensitivity of the Schmidt camera was found to be adequate to detect the presence of a test pattern in an incident illumination of 150 microfoot candles. For 200 line resolution of the test pattern, however, 1.5 millifoot candles were required.

ACKNOWLEDGMENT

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FIELD TELEVISION*

By

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Summary—*A resume is given of the history of NBC Field Television Operations. The four periods of this history, corresponding to four major types of pickup equipment, are outlined and the scope of activities possible during each period is described. Special attention is paid to the fourth period, just now beginning, which is characterized by a greatly widened scope of potential field programs made possible by the new Image Orthicon camera. Some of the characteristics of this new camera, as they affect field operation, are discussed and experience in its use is described.*

A recapitulation of NBC television programs reveals that 40% of the program hours broadcast between the opening date of the public service, April 30, 1939, and December 31, 1945 were originated by remote pickup. A total of 1167 program hours were devoted to field events during that period although, because of the war, no activity was recorded for the 16½ months between the middle of May 1942 and the first of October 1943. Television programs originating outside the studio have always been considered to hold an important place in a well-rounded program service, and in television development work early attention was given to providing facilities for originating such programs. Progress in this line of work has been reported from time to time in the technical literature*; therefore the present report will not give the history of these developments in detail. It is intended rather to give an overall picture of the present status with some review of the past work which has lead up to the present state of the art.

Field operations for NBC television broadcasting is divided into four rather distinct periods, determined principally by the characteristics and capabilities of the pickup equipment available during each period. It is true that much progress was continuously being made at all stages in the development of this service on matters of technique and operating procedures, but it is, nevertheless, also true that the characteristics of the pickup equipment were the major factors in determining the scope of field television operation. The four periods referred to above may be characterized as follows in terms of the pickup equipment available in each:

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* Decimal Classification: R583.17.
# See Various Footnotes.

1. Iconoscope Studio Type Equipment permanently mounted in large vehicle.
2. Orthicon Pickup Equipment permanently mounted in large vehicle.
3. Transportable Suitcase Type Pickup Equipment.
4. Equipment Employing the Image Orthicon.

The fourth period is the one which we are just entering and it gives promise of surpassing by far all previous records with regard to the wide variety of events which will become available for television broadcasting.

In addition to the pickup equipment employed in field operation, it is, of course, necessary to provide a suitable means for transmitting the television signal back to the main studios or to the broadcast transmitter. This may be done by either radio relay circuits or wire lines. Both means have been used successfully in the past and there is every indication that we will see the continued use of both means for at least some time to come. Progress made in microwave radio frequency equipment for a variety of uses during the war will undoubtedly lead to substantially improved radio frequency links for this television relay application in the near future. The present paper will be concerned principally with the pickup equipment and the program limitations imposed by it rather than with the problem of the relay link. Each of the four periods of NBC field television operation will now be considered in more detail.

ICONOSCOPE STUDIO TYPE EQUIPMENT PERMANENTLY MOUNTED IN LARGE VEHICLE

Some indication of the rapid development that has taken place in television pickup equipment may be obtained by examining the facilities available for field operation at the beginning of the NBC television public service on April 30, 1939. A large van type of vehicle was necessary to house and transport the studio type equipment—cameras, camera and power cable, microphone cables, interconnection cables, and the large variety of accessories required to do a proper job on a field set-up. Despite the size of these vehicles (a second vehicle of about the same size housed the permanently mounted radio relay transmitter), they were relatively efficient and mobile. (See Fig. 1) Their size and weight did prevent their reaching marshy or sandy locations, and some areas where parking was at a premium were difficult to reach. They were, however, capable of moving normally in city traffic and on the open road. The great disadvantage from an operating standpoint lay in the fact that the equipment was, of necessity, permanently mounted in the vehicles. The cameras were equipped with 250 feet of camera cable and this accordingly was the radius of action from the vehicle housing the control equipment.

The original equipment installed in this large vehicle employed an iconoscope camera and studio type rack-mounted amplifiers, control equipment and synchronizing signal generator. At the time this equipment was built, the iconoscope was (and in some respects still is) the most satisfactory type of direct television pickup tube available. With medium and high levels of illumination, it produced highly satisfactory pictures and for day-time out-door field television operation where the incident illumination did not fall below several hundred foot candles, the results obtained were generally good. In addition to the fact that the pictures obtained under conditions of very low light levels were degraded by excessive amounts of "dark spot" signal, edge flare, and other defects, it was soon found that the iconoscope had additional limitations in field operation which were not serious in its use in the studio. As regards the use of iconoscope cameras, studio operation has, in effect, a threefold advantage over field operation. In the studio, the lighting is under control of the operator and may be modified to suit the needs of the scene being televised; scenery, back-drops and drapes may be employed having light reflection characteristics suitable for

Fig. 1—Telemobile Units in Rockefeller Plaza, New York City, 1939.

the camera; and finally, in studio operation rehearsal will usually have given the operator a knowledge of the shading problem to be encountered as the program progresses. On the other hand, in field operation —especially outdoors—the lighting is generally not subject to any control, and may fluctuate over a wide range; the scene being televised in many instances may have an unfavorable background or direction of the lighting may be unfavorable; and usually the event being televised is spontaneous and unrehearsed so that the operator has little warning of the changes to be encountered in shading. During this period of the NBC field television operation, the fact that peak field program hours occurred between the months of June and September was not because most field events suitable for television pickup occurred during those months, but rather because most of the *outdoor* events of this kind occurred at that time. The field program curve tapered off in November during the football season and took a sharp drop as the gridiron season ended. During the winter months, an occasional outdoor program was originated and a few indoor programs were attempted using added illumination for the benefit of the iconoscope camera. Many events which would have made good television programs could not be transmitted because of the amount of light required by the iconoscope camera.

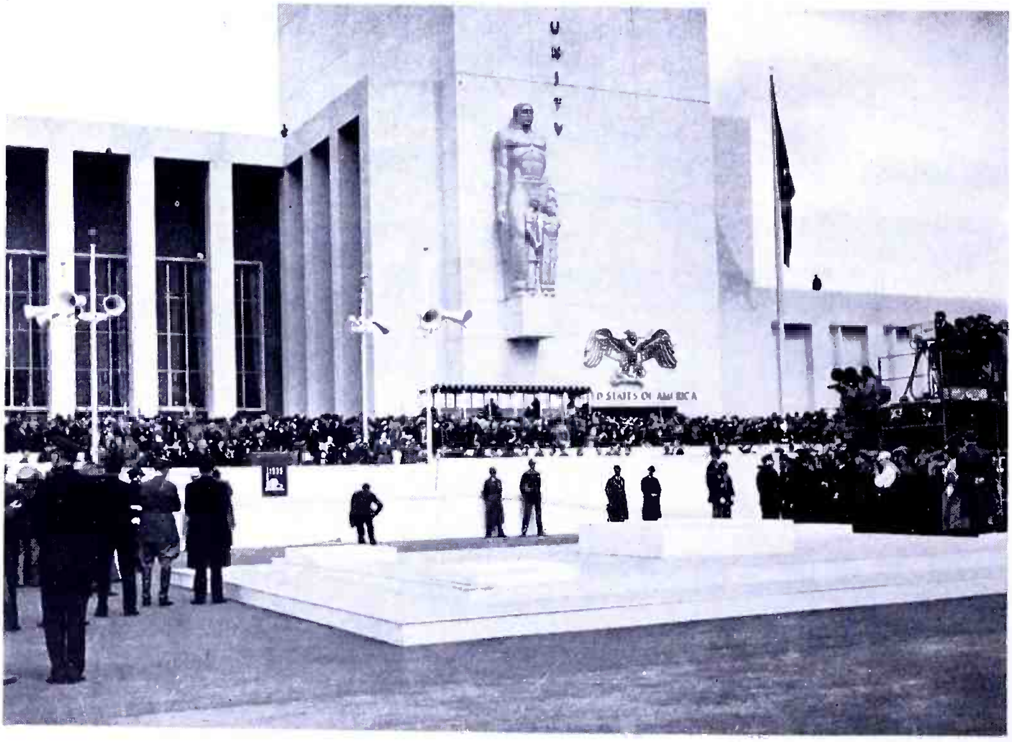

Fig. 2—Ceremonies at Opening of New York World's Fair, April 30, 1939. (Television Camera on Platform at Extreme Right.)

Despite the limitations imposed by the equipment in use, several hundred interesting and timely television programs were presented originating at locations as far as 28 miles from the main studios. Although the iconoscope suffers from relatively low sensitivity in comparison with other types of pickup tubes, when an adequate light level is available, the overall quality of the picture obtained with an iconoscope camera is probably superior to that from any other type of pickup device so far used in the program service.

The outstanding program originated with this first field pickup equipment was the inauguration of the television public service on April 30, 1939 when the late President Roosevelt was televised during the opening ceremonies of the New York World's Fair. (See Fig. 2) A program more typical of field operation with this equipment, however, was the pickups of tennis matches at the Westchester Country Club at Rye, New York during the summer of 1939.

ORTHICON PICKUP EQUIPMENT

A major revision in the field pickup equipment was made during the month of September 1939 when a new camera employing the orthicon type of pickup tube was substituted for one iconoscope camera in the mobile unit. For some time thereafter, the unit was operated with a combination of one orthicon camera and one iconoscope camera. The importance of this change in equipment lay in the relatively greater sensitivity of the orthicon tube. Although a direct comparison in sensitivity between the orthicon and the iconoscope is difficult because of their differing contrast characteristic, the orthicon has an effective sensitivity between 3 and 10 times that of the iconoscope for scenes of low incident illumination. In addition, it is essentially free from spurious signals, such as the "dark spot" in the iconoscope. With the orthicon camera, the scope of television field activity was immensely widened. Many events previously unavailable because of the lighting problem now could be satisfactorily televised. The second halves of football games played in the late Fall were now made entertaining as television program fare whereas with the iconoscope, particularly on overcast days, the pickup had been very unsatisfactory. Even with the orthicon camera, in late November and early December, the light condition near the end of the games sometimes was such that the picture quality was seriously degraded. In some instances, the light level dropped so low that floodlights were turned on for the benefit of the players and spectators and under these conditions the orthicon gave very satisfactory results. Another important advantage of the orthicon, in comparison with the iconoscope, is the smaller mosaic size. The area of the mosaic of the orthicon is only approximately one-fourth that of the iconoscope, and this permits the use of substantially smaller lenses to obtain the same angle of view. This is a fairly important item in field operation where a large assortment of lenses must be provided to obtain various viewing angles depending upon the available camera location and the type of coverage contemplated.

Perhaps the most important class of programs made available for the first time by use of the orthicon camera was the large class of indoor sporting events such as boxing, wrestling, ice hockey, basketball, indoor track, etc. Nearly all of these events are presented under conditions of lighting which are satisfactory for the orthicon camera but too low for useable pictures with the iconoscope camera. The importance to television broadcasting of the availability of events of this kind can hardly be over-emphasized. They have formed an important part of the total television program service ever since the first orthicon camera was placed in service. Figure 3 shows the orthicon camera in use for program pickups that are typical of the enlarged scope afforded television field operation by the use of this important development.

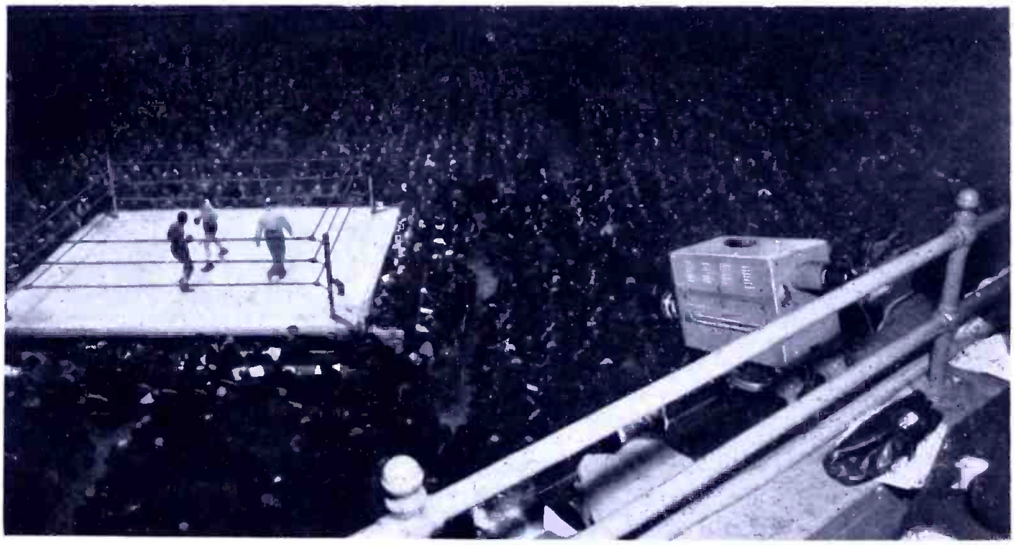

Fig. 3—Orthicon Camera in Use in Madison Square Garden, New York.

Although the orthicon has substantially greater sensitivity than the iconoscope and is essentially free from the spurious "dark spot" signal which plagues the iconoscope, it does have certain disadvantages compared to the earlier, less sensitive type of pickup tube. One of the principal disadvantages is its tendency to "charge up" when subjected to light intensity exceeding a certain threshold value. This phenomenon is due to the inability of the low velocity electron scanning beam to completely discharge areas of the mosaic subjected to high light intensities exceeding a certain threshold value determined by the beam current. This weakness produces especially annoying effects on indoor pickups when photographers' flashbulbs are set off in the field of vision of the camera. This invariably occurs during climactic episodes of the event being televised and frequently portions of the most exciting action are lost to the view of the television audience before stable operating conditions can be re-established in the orthicon pickup tube. Trouble is also encountered in televising outdoor events in bright sunlight when a portion of the scene is in shadow and the rest in sunlight. Changes in the contest being televised which necessitate sudden and rapid panning of the camera from dark shadow to bright sunlight frequently lead to this "charging up" or blocking effect. It is minimized by operation of a special control that temporarily raises the value of the scanning beam current to an abnormally high value in order to dissipate the excessive charge on the mosaic.

The orthicon has a contrast characteristic (frequently referred to loosely as "gamma" characteristic), which is linear over its entire useful operating range. The iconoscope, on the other hand, possesses a contrast characteristic which exhibits a substantial amount of saturation in the higher light ranges and is, therefore, roughly equivalent to a "gamma" of less than unity. This contrast characteristic of the iconoscope complements rather well the corresponding characteristic of the kinescope tube used in most receivers so that the overall contrast characteristic of the system is generally satisfactory. When using the orthicon, however, it is necessary to provide in the video amplifier chains associated with the camera a controllable amount of saturation which will reduce the equivalent "gamma" characteristic to a value more suitable for the kinescope. Generally speaking, the combination of orthicon and its "gamma" correction circuit does not produce quite as satisfactory an overall contrast characteristic as the iconoscope possesses, but it is hoped that future work will improve the "gamma" correction circuits. Despite the previously mentioned fact that the orthicon requires smaller size lenses than the iconoscope for a given angle of view, the sizes of lenses necessary to provide the desired range of camera angles are still substantial. The Type 1850 iconoscope requires a lens of 16″ focal length, when the camera is located 70 feet from a boxing ring, to create images of the contestants which will be large enough when reproduced on the average receiver to provide optimum coverage of a prizefight. A lens of longer focal length and smaller viewing angle makes it difficult for the camera operator to follow the fast-moving contestants about the ring and often results in one of the two fighters being out of the picture. The smaller mosaic in the orthicon tube allows the use of lenses which are approximately one-half the focal length of those used with the iconoscope camera for the same viewing angle. With the orthicon camera, boxing at Madison Square Garden is generally covered with a lens of 8″ focal length, the distance from the camera to the ring being approximately 70 feet. Even with the reduction in lens size made possible by use of the orthicon pickup tube, it has not been considered feasible to attempt the use of lens turrets on these cameras.

TRANSPORTABLE SUITCASE TYPE PICKUP EQUIPMENT

The wider field of television activity permitted by the orthicon camera was still restricted by the limitation due to the location of equipment permanently mounted in a vehicle. The camera cables contained four flexible coaxial cables and thirty-two other electrical conductors and were 1½″ in diameter. Storage and transportation difficulties, plus the need for compensating electrical networks to correct for pulse delay in very long cables were the factors which restricted the length of the camera cables to a practical value of approximately 250 feet. Shorter lengths of 50 feet each were carried for use where the longer lengths were not necessary. The 250 foot radius of activity of cameras was sufficient for most outside pickups when only two cameras were employed. Additional cameras, which would be those located at greater distances, could not readily be accommodated because of lack of space for additional control equipment in the vehicle. Field pickup service was restricted to coverage of events taking place below the fourth floors of buildings. Banquets, important meetings, interesting exhibits and panoramic scenes are among the potential programs which were unreachable with this equipment. The need for portable equipment which could be carried closer to the pickup scene became apparent early in field operations.

The development of the small iconoscope (Type 1848) transportable equipment[1] which was contained in eight boxes approximating the size of suitcases again greatly expanded the scope of the field service. The boxes, weighing approximately 65 lbs. each, were inter-connected on the scene of action to form a complete operating chain of television pickup equipment. This equipment could be used for television pickup either in a vehicle in which it was transported or removed from the vehicle and carried to the upper floors of a building or to other locations inaccessible to the vehicle. (See Fig. 4)

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[1] G. L. Beers, O. H. Schade and R. E. Shelby, "The RCA Portable Television Pickup Equipment", Proc. IRE, Vol. 28, pp. 450-458, October, 1940.

The availability of this transportable type of television pickup equipment again opened up new sources of television programs previously unavailable, and also increased the ease of operation in some cases where television pickups had previously been made with equipment permanently mounted in a vehicle. This type of equipment was used in the Rainbow Room atop the RCA Building in Radio City to televise the New Year's Eve festivities there in 1940. When the Republican National Convention of 1940 at Philadelphia, Pennsylvania was televised and the signals transmitted via coaxial cable to New York for broadcasting, both the transportable type of pickup equipment and the equipment permanently mounted in the mobile unit truck were employed, thus providing a four-camera pickup. The four cameras were used to pick up both wide angle and close-up scenes inside the main Convention Hall, for studio type pickup in a small improvised interview studio and for pickups on the sidewalk in front of the Convention Hall. All sessions of the five-day convention were televised.[2,3]

Fig. 4—Complete Single Camera Iconoscope Type Transportable Pickup Equipment.

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[2] O. B. Hanson, "Televising a Political Convention", RCA REVIEW, Vol. V, No. 3, pp. 267-282, January, 1941.

[3] H. P. See, "Televising the National Political Conventions of 1940, Journal of SMPE, Vol. XXXVI, pp. 82-100, January-June, 1941.

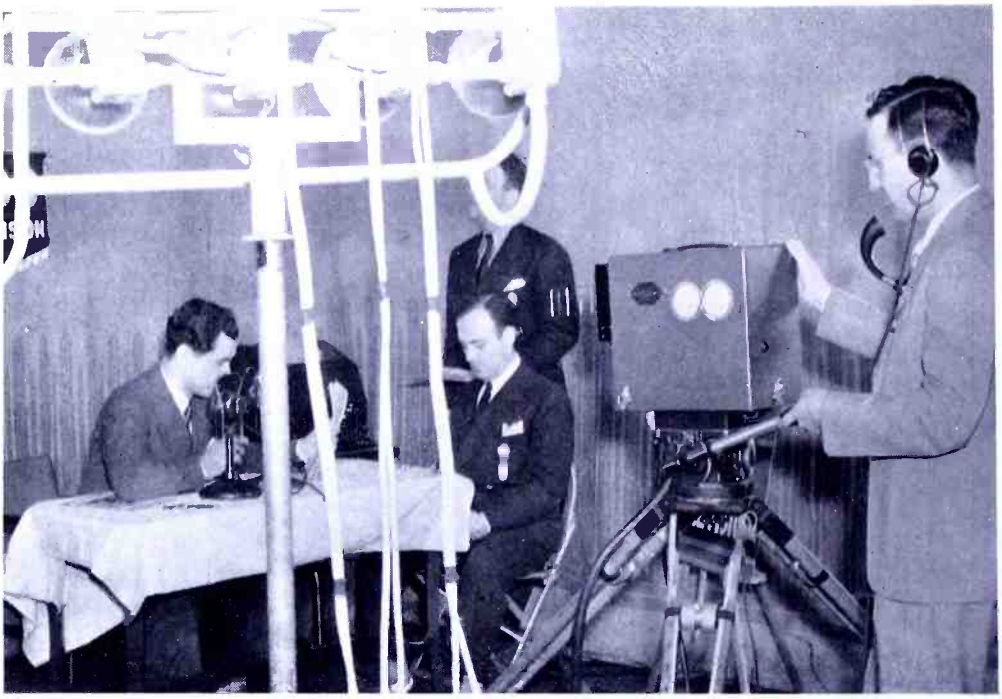

Fig. 5—Transportable Iconoscope Camera in Temporary Studio Set-up at GOP Convention, Philadelphia, 1940.

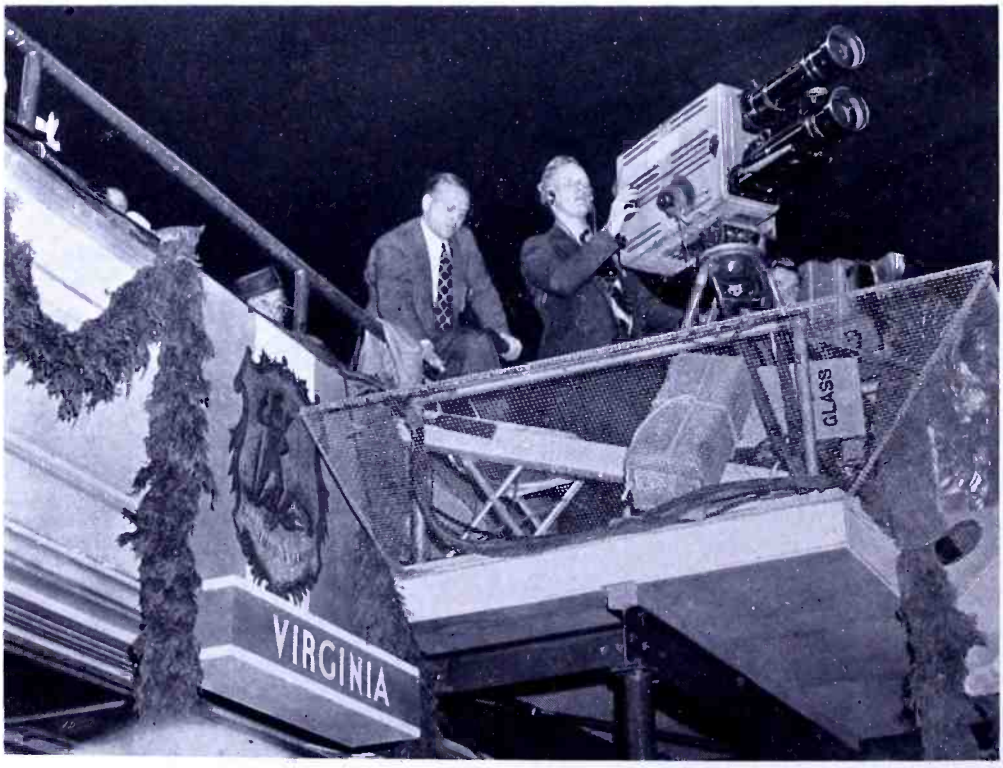

Fig. 6—Televising the GOP Convention, Philadelphia, 1940. (Orthicon Camera in Foreground, Iconoscope Camera on Right.)

The photographs of Figures 5 and 6 show scenes at the Philadelphia Convention pickup.

Transportable equipment employing orthicon cameras[4, 5] became available shortly before the war and a two-camera system of this type has been used for the majority of all NBC field pickups since 1944.[6,7] Figure 7 shows the suitcase type equipment for the orthicon cameras situated on a movable table in a small control room at Madison Square Garden. This is the normal location for the control equipment during the televising of events in Madison Square Garden and its use here illustrates one of the advantages of the transportable type of equipment. Prior to its availability, when televising events in Madison Square Garden, the large mobile unit vehicle was parked at the curb outside the Garden and camera cables and power and communication cables had to be strung in place for each program.

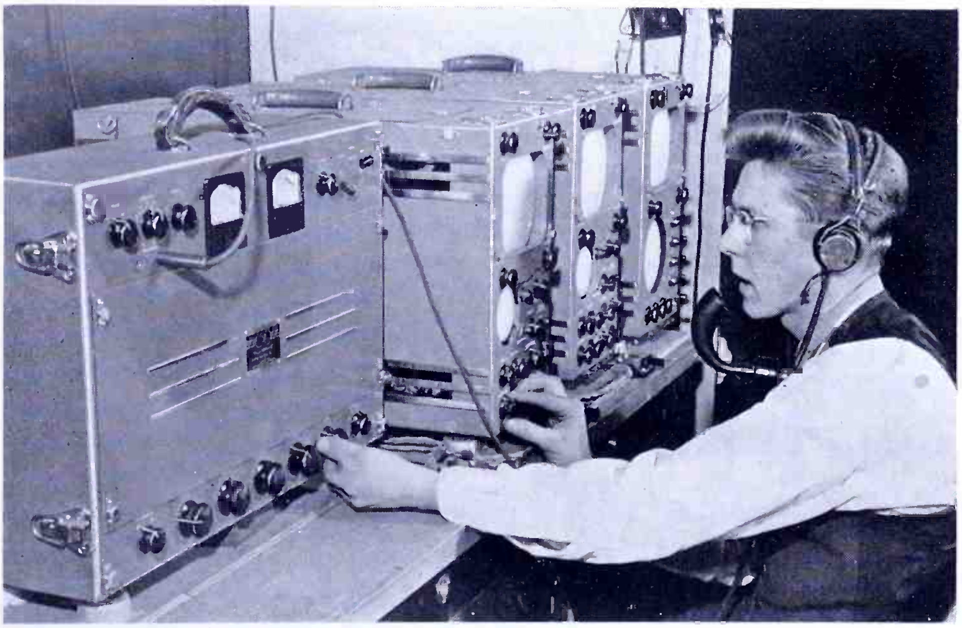

Fig. 7—Television Control Set-up at Madison Square Garden, 1944. (Audio Amplifier on Left, Transportable Orthicon Control Units on Right.)

Although the transportable type of equipment has several distinct advantages, as already indicated, there are some offsetting disadvan-

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[4] Albert Rose and Harley Iams, "The Orthicon, A Television Pickup Tube", RCA REVIEW, Vol. IV, No. 2, pp. 186-199, October, 1939.

[5] M. A. Trainer, "Orthicon Portable Television Equipment", Proc. IRE, Vol. 30, pp. 15-19, January, 1942.

[6] R. E. Shelby, H. P. See, "NBC's Experience with Portable Television Broadcast Equipment", Broadcast News, No. 39, pp. 14-21, August, 1944.

[7] R. E. Shelby, H. P. See, "NBC and Madison Square Garden", Television, Vol. II, pp. 2-3, April, 1945.

tages. In comparison with the older style of rack mounted equipment, the suitcase type of equipment is highly condensed and the components crowded rather closely together. This means that maintenance work and trouble-shooting are sometimes more difficult than in the rack mounted type of equipment. The large number of interconnecting cables with their sockets and plugs increases the chance for contact failure and delays occasioned by loss or damage. The smaller size of the monitoring kinescopes and cathode-ray oscilloscopes is somewhat of a handicap in operations compared to the larger size screens used in the older equipment. Convenient accessibility of operating controls has had to be sacrified somewhat in the interest of portability. In spite of these disadvantages, however, there can be no doubt that this type of equipment provides a substantial net gain in television field operation. It is interesting to note in passing that the extensive amount of work done during the war on highly compact military type of television pickup equipment which had to operate under very rigorous conditions will undoubtedly lead to significant improvements in future designs of transportable pickup equipment for the television broadcasting service.

IMAGE ORTHICON EQUIPMENT

There has recently been announced a new type of television pickup tube known as the Image Orthicon which in comparison with any previously available pickup tube possesses rather startling characteristics, particularly as regards operation at extremely low levels of illumination. Development work on this tube had been started prior to the war but it received its greatest impetus as a part of the war-time research on military television. Technical design details and characteristics of the device have been given in a recent paper[8] by Dr. Albert Rose and these will not be repeated here. Very briefly, however, it consists essentially of an orthicon scanning tube with an image electron amplifier section in front of the mosaic and a multiple stage electron multiplier at the output. It is still smaller in size than the Type 1840 orthicon tube, having a photo-cathode area approximately one-quarter that of the Type 1840 orthicon and one-sixteenth that of the larger iconoscopes. The sensitivity of the tube is such that it will produce satisfactory pictures at illumination levels lower by a factor of about 100 than those required for the iconoscope. In addition, it is much less subject to the "charging up" effect which is so troublesome in the case of the Type 1840 orthicon.

The importance of this new tube in television field pickups is self-

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[8] Albert Rose, P. K. Weiner and H. B. Law, "The Image Orthicon, A Sensitive Television Pickup Tube", presented at the IRE Winter Technical meeting, on Jan. 24, 1946.

evident. It removes all practical barriers with respect to operation at low light levels. It seems safe to state that any event which has illumination adequate for direct viewing by an audience can be televised satisfactorily with the Image Orthicon camera.

The smaller length and diameter of the new tube plus its increased sensitivity and small photo-cathode area result in a camera substantially smaller than the standard orthicon field camera. The standard iconoscope and orthicon cameras in use today are considered too large and heavy for efficient handling in the field. The comparatively large mosaic areas of the iconoscope and orthicon tubes require optical systems of appreciable proportions. In contrast, the optical systems used with the Image Orthicon are about the same as those used on standard thirty-five millimeter motion picture cameras. Whether future camera models incorporate the twin lens optical viewfinder, the kinescope viewfinder or some other view-finding device, the reduction in the size of lens with the introduction of this tube makes practical the use of a lens turret. The sizes and weights of lenses included in the complement for a Type 1840 tube are generally considered to be approximately half those necessary for a Type 1850 iconoscope. The Image Orthicon reduces this by approximately one-half again for the same viewing angles. The lack of a lens turret in some cases in the past has imposed a limitation upon the latitude of operations and programming.

There are characteristics of the Image Orthicon which, at least for the present, partially offset some of its advantages. Its signal-to-noise ratio is not as good as that of the iconoscope under conditions of strong illumination, although at low levels of illumination it continues to produce satisfactory pictures far below the levels at which the signals from the orthicon and iconoscope are completely submerged in noise. The lower signal-to-noise ratio of the new tube is generally not noticeable except on scenes which include relatively large dark areas. Test-chart resolution in excess of 500 lines has been obtained with the Image Orthicon, but it has not yet quite equalled the performance of the better iconoscopes in this respect. Models of the tube produced for military use and early samples available for tests in television broadcasting possess rather high infra-red sensitivity. This necessitates the use of optical filters to attenuate the infra-red light when televising most outdoor scenes in daylight—particularly scenes which include appreciable amounts of living green foliage.

The Image Orthicon is more sensitive to ambient temperature than other types of pickup tubes. It does not give maximum performance until it has warmed up to approximately 100° F., and when used outdoors in cold weather auxiliary heating units are sometimes needed. When the tube is too cold, its resolution may be impaired and retentivity of the electrical "image" on the target will be abnormal, producing excessive smearing in the reproduced picture whenever the camera is panned or when rapid motion occurs in the scene.

One important advantage which the Image Orthicon has over the Type 1840 orthicon is its ability to handle a very wide range of light values. If the various electrode potentials are properly set, a change in the scene from deep shadow to brilliant sunshine in outdoor pickups is readily accommodated without serious degradation in the transmitted picture and without the necessity for instantaneously coordinated readjustment of controls, as in the case of the Type 1840 orthicon. In one outdoor test, the Image Orthicon was adjusted for optimum performance with the iris on the pickup lens set for an opening of f 32. Without changing any other control, the iris setting was then changed to f 8, thus increasing the amount of light on the photocathode by a factor of 16. To the casual observer, at normal viewing distance, there was no appreciable change in the transmitted picture. In an indoor test at Madison Square Garden, it was found that a single suitably chosen setting of all controls would give acceptable results when the Image Orthicon camera was panned from the dimly-lighted outer fringes of the audience to the brilliantly-illuminated boxing ring at the center of the arena.

While it is true, as indicated above, that the Image Orthicon possesses great practical flexibility under varying conditions of illumination, it is also true that *peak performance* will be obtained only when the settings of the iris and other controls are proper for the brightness of the scene being televised. Close inspection of the transmitted picture shows appreciable loss of information in the highlights if the light image on the photocathode is excessively bright, and signal-to-noise ratio will be lowered by operating the beam current at a value greatly above that required to discharge the target. In preparing for a television pickup, after the Image Orthicon has warmed up to normal operating temperature, the entire scene to be televised should be explored with the camera to determine, to the extent possible, the upper and lower limits of reflected light to be expected from the scene during the program. Settings of the iris, beam current, and other controls should be made in the light of this test, and if wide fluctuations in brightness are to be encountered, plans should be made for readjusting beam current and iris opening at proper times during the program.

Television broadcasting experience with the Image Orthicon camera has included the following pickups:

1. *Herald-Tribune Forum, Grand Ballroom of Waldorf-Astoria Hotel.* Moderate illumination as normally used for audience.
2. *Navy League Dinner, Grand Ballroom of Waldorf-Astoria Hotel.* Moderate illumination as normally used for audience.
3. *Army-Navy Football Game.* The day was an unusually bright one for the season, and offered no test of sensitivity, but did afford a good comparison with orthicon cameras under conditions of high-level illumination. (See Fig. 8)

Fig. 8—Image Orthicon Camera Televising Army-Navy Football Game at Philadelphia Municipal Stadium, December first, 1945.

4. *Mayor-Elect O'Dwyer of New York City, from his campaign headquarters in the Commodore Hotel on Election Day.* Illumination provided by two 100 watt lamps in a frosted glass shade, and a 40 watt lamp for relieving shadow areas on faces.
5. *New Year's Eve Celebration in Times Square, New York City.* Illumination as normally present in Times Square at night—from electric signs, street lamps, theatre marquees, show windows, and automobile lights.
6. *Memorial Service at Lincoln Monument, Washington, D. C. on February 12, 1946.* A program originated jointly by stations WABD, WCBW and WNBT and transmitted to New York over the coaxial cable of A. T. and T. to inaugurate television service over this cable.

In addition to the foregoing on-the-air programs originated with the Image Orthicon camera, a number of successful test pickups have been made. These include the following:

1. *Baseball game at Polo Grounds, New York City.* The day was a bright one, and it was found that the minimum lens stop available—*f* 32—gave more than the optimum amount of light. Depth of focus was, naturally, no problem. A filter had to be used to reduce the infrared light reflected from the grass of the playing field. Most observers felt that the Image Orthicon camera had a net advantage over the Type 1840 orthicon camera, which was set up for comparison.

Fig. 9—Image Orthicon Camera (Foreground), in Comparative Test with Orthicon Camera, Televising Rodeo at Madison Square Garden.

2. *Strollers on the Mall at night in Central Park, New York City.* The only illumination was that provided by the normal light fixtures in the park.

3. *Scenes from the Rodeo in Madison Square Garden, New York City.* The dark tan-bark on the floor, and the relatively low light level employed for many events to avoid blinding the contestants, had made this a relatively unsatisfactory program for orthicon cameras. The Image Orthicon camera was able to do an excellent job on all events. (See Fig. 9)

4. *Television Pickup of Standard Sound Broadcast.* No special lighting of any kind was employed, and those in the studio did not even know that the test was being made.

5. *"Stunt" Pickups in the Studio.* Successful pickups were made using only the light of a pocket flashlight, or a single candle, or one match, and also in total darkness, using invisible infra-red illumination.

The importance of the Image Orthicon development to field television broadcasting is emphasized by statistics of operation which show that in the past more than one-half of the seven hundred odd field programs have originated indoors under artificial illumination—despite the fact that many potential indoor programs had to be passed up because cameras were not sensitive enough to give acceptable results with the illumination available. In the future, it is probable that the percentage of indoor programs will go even higher, now that there are virtually no technical limitations on the televising of such events. The economic advantages of the new camera are by no means insignificant, since the cost of providing special illumination for some events televised in the past has been a major item of expense. On the basis of experience to date, it seems safe to say that the Image Orthicon represents the greatest single advancement so far made in field television.

AN OMNIDIRECTIONAL RADIO-RANGE SYSTEM*

By

David G. C. Luck

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NOTE: The first two parts of Dr. Luck's paper appeared in RCA REVIEW in July 1941 and January 1942 respectively. Part III was scheduled to appear in the April 1942 issue but was withheld for security reasons. Although a lengthy period of time has elapsed and great improvements in ultra-high-frequency techniques and airborne applications have occurred during the war, the experimental results and methods of use of the omnidirectional radio-range system are still very timely.

The summaries which appeared with Parts I and II are included herewith for reference purposes. A limited number of copies of the July 1941 and January 1942 issues which contain these papers are still available for those who desire a complete file on the omnidirectional radio-range system.

PART I—PRINCIPLES OF OPERATION

(Reprinted from July 1941 issue of RCA REVIEW*)*

Summary—Radio navigation may be done with direction-finding receivers on mobile craft, with fixed direction finders on the ground or with directional beacon transmitters on the ground. Each method has its unique merits and faults, but the last seems especially suited for aircraft guidance in the United States and has, in the form of four-course radio "range" beacons, rendered outstanding service. The disadvantages of limited choice of courses and of difficulty in definitely determining on which course a craft may be, inherent in the present four-course ranges, may be avoided by rotating a transmitted radio beam and timing its passage over the receiving craft, to determine uniquely the bearing of that craft from the known location of the beacon transmitter.

A rotating beam, of figure-eight shape, may be produced without mechanical motion by setting up two fixed antenna systems, having figure-eight directivity, at right angles and feeding them with radio-frequency signals modulated at the desired rotation frequency, the modulation of the separate supplies to the two crossed antennas being in phase quadrature. Unmodulated carrier, to resolve the ambiguity of the figure-eight beam by changing its shape to a limaçon, is radiated from a non-directive antenna, and a timing reference is provided by interrupting all transmission momentarily just as the beam points north.

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* Decimal Classification: R526.1.

The audio output from a receiver tuned to this beacon comprises a sine wave produced by the sweep of the beam and a train of impulses produced by the reference keying. The sine component is filtered, split in phase and used to drive a cathode-ray beam in a circle, in step with the rotation of the transmitted beam. The impulses are used to slow up the beam electrons momentarily, marking the swept circle with an outward jog and so indicating receiver bearing directly. The impulses also actuate a zero-center meter, while the sine wave renders this meter insensitive at a certain moment of the cycle and oppositely sensitive just before and just after that moment. By adjusting the sine wave phase, the meter may be centered when the receiver is on any desired bearing, and thereafter will indicate any departure from that bearing. A special broadcast transmission may be used to check adjustments of receiving indicators.

Certain conditions as to modulation phases and amplitudes, antenna-current phases and amplitudes, antenna geometry and cathode-ray indicator voltage phases, amplitudes and tube geometry must be fulfilled if accurate bearings are to be obtained. Study of these conditions shows all adjustment tolerances to be of reasonable magnitude, though considerable care in antenna construction is necessary to insure adequate symmetry of antenna-current phase.

PART II—EXPERIMENTAL APPARATUS

(Reprinted from January 1942 issue of RCA REVIEW*)*

Summary—*Experimental omnidirectional ranges have been developed and tested in flight at frequencies of 6425 kilocycles per second and 125 megacycles per second. In each case, a radiating system consisting of five vertical antennas and a metallic ground mat was used. Each transmitter was of a normal radio-telephone type, supplemented by a pair of balanced modulators, an impulse keyer, and a set of modulation controls. Full monitoring of the effect of all transmitter adjustments was provided. Essentially normal aircraft receivers and antennas were employed. Both cathode-ray azimuth indicators and pointer-type deviation from course indicators were provided.*

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There follows the concluding paper in this series: Part III—Experimental Results and Methods of Use.

The Manager, RCA REVIEW

PART III—EXPERIMENTAL RESULTS AND METHODS OF USE

Summary—*Tests of experimental omnidirectional ranges have been made at 6425-kilocycle and 125-megacycle operating frequencies. Ground measurements at the higher frequency showed directive-pattern shapes to be imperfect but acceptable and showed overall instrumental errors of indicated azimuth averaging less than one degree. Flight tests at both frequencies showed considerably larger errors, apparently related to terrain or transmitter-site characteristics. Sky-wave operation at the lower frequency was found fairly satisfactory in the absence of violent fading. Standing-wave effects were sought but not found in the ultra-high-frequency field. Trouble* *was experienced in the higher-frequency flight tests with spurious modulation of received signals produced by spinning propellers and imperfect structural bonding of aircraft, as well as with ignition interference. Behavior of the experimental equipment itself was on the whole satisfactory. Omnidirectional ranges may be used to fly straight radial courses to or from range stations, in which service the technique of their use is rather similar to that employed with other visual course-type ranges, or they may be used for general cross-country navigation following a uniquely simple technique. Omnidirectional ranges lend themselves well to safe air-traffic control.*

1—INTRODUCTION

"OMNIDIRECTIONAL radio range" is a term used to denote a system of apparatus for radio guidance in which signals from a special fixed transmitter are received on mobile craft and there caused to indicate directly and automatically the bearing of the craft from the transmitter. In a previous section of this paper, the place of such a device in the field of radio guidance was indicated and the principles of operation of one version of it were described in detail. A further section described experimental transmitting and receiving apparatus with which the operation of omnidirectional ranges was tested. The purpose of the present and final part of the paper is to set forth the results obtained in these tests, including general comments on the behavior of the equipment, and to describe methods of use of such a system in actual guidance of aircraft. Familiarity with the previous sections[1] will be assumed in what follows.

2—EXPERIMENTAL RESULTS AND OPERATING EXPERIENCES

A—*Local Ground Tests*

Because of numerous obstructions at distances of the order of a very few wavelengths from the range antennas, ground tests at the medium frequency used in the earlier tests, 6425 kilocycles, gave results that were clearly unreliable, and were seldom even consistent; these will not be described here. At the ultra-high frequency of the later tests, 125.0 megacycles, while obstructions were still too near for comfort, they were several wavelengths removed from the range antennas and it was possible to get significant measurements in the region between the antennas and the nearest obstructions.

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[1] "An Omnidirectional Radio-Range System," by David G. C. Luck.

"Part I. Principles of Operation", RCA REVIEW, Vol. VI, No. 1, p. 55, July 1941.

"Part II. Experimental Apparatus", RCA REVIEW, Vol. VI, No. 3, p. 344, Jan. 1942.

These will be referred to as I and II.

a—*Antenna Directive Patterns*

Measurements were first made of the shape of the patterns radiated by the three ultra-high-frequency antenna systems separately. Several measuring instruments were tried, the most consistent results being obtained with one similar to the monitoring pickups. The device finally used employed a small, unbalanced tuned loop with a shielded acorn-type diode rectifier. It was arranged for plug-in connection at 24 equally spaced points around the edge of the ground disc of the range-antenna system. This unit may be seen in place in the photograph of the ultra-high-frequency antenna system.[2] Detector output was fed through a carefully grounded and shielded cable to a microammeter located at the transmitter, an arrangement permitting readings to be made without an observer on the roof and thus avoiding disturbance of the radiated field during the measurements. Data were taken by exciting a single pattern at a time without modulation, and taking readings with the loop-pickup unit set up successively at each of its 24 fixed stations. Of course, transmitter output and distance from range antennas to measuring unit were held accurately constant during each set of measurements.

Early pattern measurements showed very poor minima. The cause was found to be slight bending of the antenna rods during their installation and adjustment. Non-conducting guys to adjust the antenna rods to their exact positions provided a solution for the difficulty. Within the accuracy of the observations, the radiated field was always found to have pure vertical polarization. Best adjustment of antenna feed circuits and antenna rod positions gave the patterns shown in Figure 1. It will be seen that good minima were produced, but that appreciable pattern deformation appears to have been associated with a brick chimney, the nearest obstruction.[3]

Deformation of the broadcast, or circular, pattern is not directly harmful, but departure of the figure-eight pattern lobes from their ideal circular form does give rise directly to errors of indicated bearing. If the independently measured patterns are corrected for relative amplitude, these errors may readily be calculated. Adjusted for equality of north and west pattern maxima, the data for Figure 1 show a maximum bearing error of 2¾ degrees at an azimuth of 345 degrees, and an average error of 1 degree for all 24 observed points. These errors are, of course, entirely independent of range transmitter or

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[2] II, Figure 5.

[3] II, Sect. 2B(a), p. 352.

receiving indicator; they may have been due partly to imperfect antenna feed, but are more likely to have been caused mainly by the imperfect symmetry of the antenna site. The broadcast pattern was found to depart from the circular form by as much as +7 per cent and −9 per cent at azimuths of 45 degrees and 180 degrees, respectively. Remarkable concordance of results obtained for the broadcast pattern on different days and with different measuring instruments indicated that distortions of the radiated field were real and permanent.

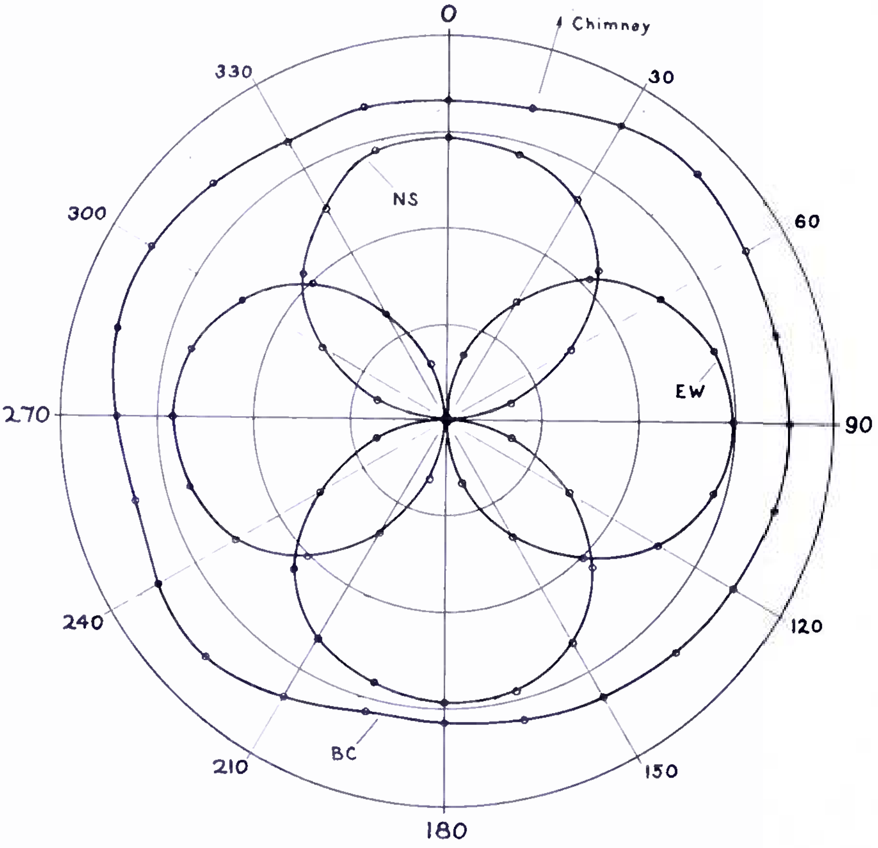

Fig. 1—Directive patterns of ultra-high-frequency omnidirectional range antennas.

b—*Overall Calibration*

Overall performance of the range transmitter and cathode-ray indicator in operation was checked by a modification of the technique developed for measuring the individual pattern shapes. The complete transmitter was operated in entirely normal omnidirectional-range fashion. The shielded output cable from the detector in the movable pickup on the roof was connected, not to a microammeter, but in place of the second detector of the regular test receiver. Thus, the audio-frequency amplifier of the receiver and the complete cathode-ray azimuth indicator were operated entirely normally. All apparatus-error sources of the complete range system, except possible misalignment of the radio circuits of the receiver, were therefore present and fully effective, but the vagaries of radio-wave travel over long paths were eliminated from the measurements. Readings of indicated azimuth were taken with the roof pickup in each of its 24 positions of accurately known azimuth. Sometimes transmitter and indicator were completely readjusted for each reading and sometimes no readjustment was made during an entire run.

The result of such a calibration is shown by Figure 2, in which the straight line representing equality of true and indicated bearings typifies ideal operation and the plotted points represent the measurements made. The greatest error was 3 degrees and the average of the absolute magnitudes of the errors found at the 24 points, taken without regard to sign, was ±⅔ degree. A number of similar calibration runs gave results entirely comparable with these, the maximum error being only 2 degrees on one run which was carried out with no intermediate readjustment of any controls.

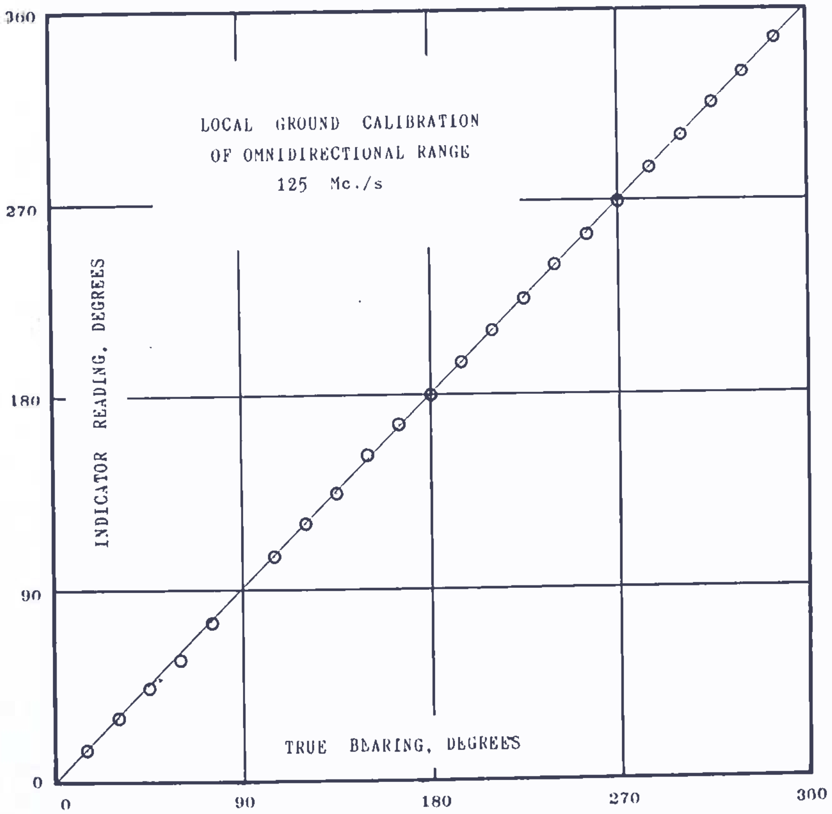

Fig. 2—Calibration of complete system.

On another occasion, a somewhat variable error was observed in one sector, sometimes reaching a value as great as 5 degrees. Whether the variation was caused by changing properties of the lines of the antenna-feeding and stabilizing system, which were not sealed against atmospheric changes, or was the result of electrical changes in nearby obstructions, we were unable to determine. Tests with a removable obstruction, a metal pole about 50 feet from the range antennas, showed this alone to be capable of producing a one-degree change in the errors observed at certain azimuths.

In any case, the results of these local overall apparatus calibrations show that this type of omnidirectional range is capable of an all-around accuracy which is quite adequate for most uses. There seems every reason to hope that a better site, some refinements in design details and more operating experience would lead to still better and more reliable performance. In particular, the fact that the monitoring and adjusting system worked out for transmitter and indicator was consistently able to maintain a useful level of all-around instrumental accuracy is worthy of note.

A number of ground measurements were also made, at distances from 2 to 30 miles, with the complete ultra-high-frequency aircraft equipment[4] mounted in a station wagon. Wherever the signal was sufficiently strong to provide adequate indicator input, the indications observed with the truck stationary were generally of the same quality as those obtained from the roof pickup distant one wavelength from the range antennas. Passing aircraft, however, occasionally disturbed the field sufficiently to cause a slight flutter of indicated bearings. In view of the necessarily unruly condition of the ultra-high-frequency field near the ground, the accuracy and stability of the indications found is surprising: errors in excess of 5 degrees were the exception rather than the rule and errors exceeding 10 degrees were quite rare. Ignition interference made observations impossible with the truck motor running; a test while coasting showed marked standing-wave variations of signal strength, but practically unimpaired stability of azimuth indications.

B—*Local Flight Tests*

a—*At 6425 Kilocycles Per Second*

Flight calibrations of the range and indicator were made by reading indicated azimuth when flying directly over prominent landmarks; the true bearing of each landmark from the transmitter was determined from an accurate map. Figure 3 shows the results of three such flights made during the early work. The frequency was 6½ megacycles and the points observed were distant 10 to 30 miles from the range. It will be seen that, in general, there was some spread in the results

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[4] II, Figures 15 and 16.

for the three flights, though at several of the chosen points the three readings checked exactly. Despite the spread, a definite trend is evident from the figure: northeastward of the range, azimuths indicated were too high, while in a southerly sector indications were consistently too low. It is also evident from the figure that northwesterly readings were markedly more consistent than others, especially than northeasterly ones. This difference was quite noticeable while making the observations. We incline to attribute the effect to the different soil properties of Pennsylvania, northwest of the range, and southern New Jersey.

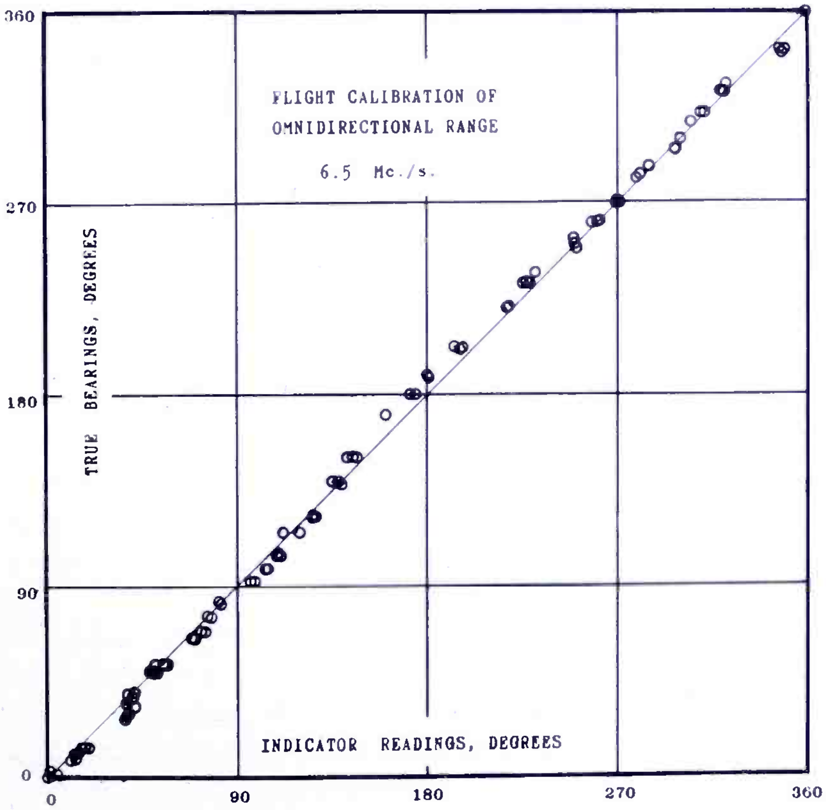

Fig. 3—Flight results at medium-high frequency.

Other peculiarities of indication were also noticed in flight. For example, during steady flight in a circle around the range, the azimuth indication was sometimes observed to move for a while markedly faster or slower than its normal rate, and even occasionally to reverse its travel and move backwards for a moment. The last manifestation, with the same azimuth indicated successively at three different true bearings, obviously corresponds to the well-known "multiple course" phenomenon observed with long-wave course-type ranges. However, with the omnidirectional range the possibility of following a false course until it fades out, and then finding oneself off the true course with no convenient way to return to it, does not exist. Extra fast or slow rates of variation of indicated bearing also correspond, respectively, to the less well-known, but equally real phenomena of excessive narrowness or broadness of courses sometimes observed with course-type ranges. In our flights, the occurrence of these effects could often be correlated with the proximity or branching of water-courses. Some dependence of indicator reading on ship's heading was observed in the first flights made, but this effect was completely overcome by providing adequate magnetic shielding for the cathode-ray indicator. Results obtained in four different airplanes, at the 6½-megacycle frequency, differed only in the level of ignition interference encountered.

In low-altitude flights out to the limit of ground-wave transmission and back, observations at the lower frequency were made at a large number of points in a narrow sector to the northeast of the range and, also, in one to the northwest. For the northeasterly sector, the average of 26 observations indicated that a correction of −2.8 degrees should be applied to readings of 50 to 60 degrees. After such correction, the largest error of a single reading of this set was 2.2 degrees and the average error magnitude of the 26 readings was ±1¼ degrees. For 15 points between 310 and 320 degrees, a region in which consistently accurate performance had been found, the average correction to be applied to readings as made was found to be +1.2 degrees; the maximum error after correction was 1.3 degrees and the average error magnitude for the 15 points was only ±¾ degree. These results imply that the scattering of points in Figure 3 results largely from strictly local effects near the particular landmarks used.

Most of the readings so far discussed were taken at low altitudes, from 1500 to 3000 feet. Altitude effects, both over a point southeast of the range which had given erratic results and over a stable and accurate point to the northwest, were checked in a flight to 9000 feet. Over the erratic point, the indicated bearing changed by 8 degrees between 1500 and 3600 feet and thereafter held constant within ±1 degree up to 9000 feet, but remained considerably displaced from its true value. Over the reliable point, all ten readings taken between 9000 and 1500 feet were equal and correct within the accuracy of readings, about ±½ degree.

A very sharp, deep signal null or "cone of silence" over the transmitter was indicated by collapse of the luminous circle on the indicator face. Subsidiary nulls and high-angle signal lobes accompanied the main null; these were probably caused by reradiation from power lines near the range. Noise, giving transient marks on the bright indicator circle, was easily distinguished from the steady mark showing the desired indication, so long as the noise was not overwhelmingly intense. Indications obtained at the lower frequency were, in general, steady and easy to read, though the variation in reference-impulse strength from north to south gave rise to an annoying variation of indicating-spot width and so occasioned the use of an impulse equalizer in the later work.

b—*At 125.0 Megacycles Per Second*

The method of obtaining flight calibrations of the ultra-high-frequency system was the same as that used in the earlier, lower-frequency work. The results of a number of flights are shown in Figure 4.

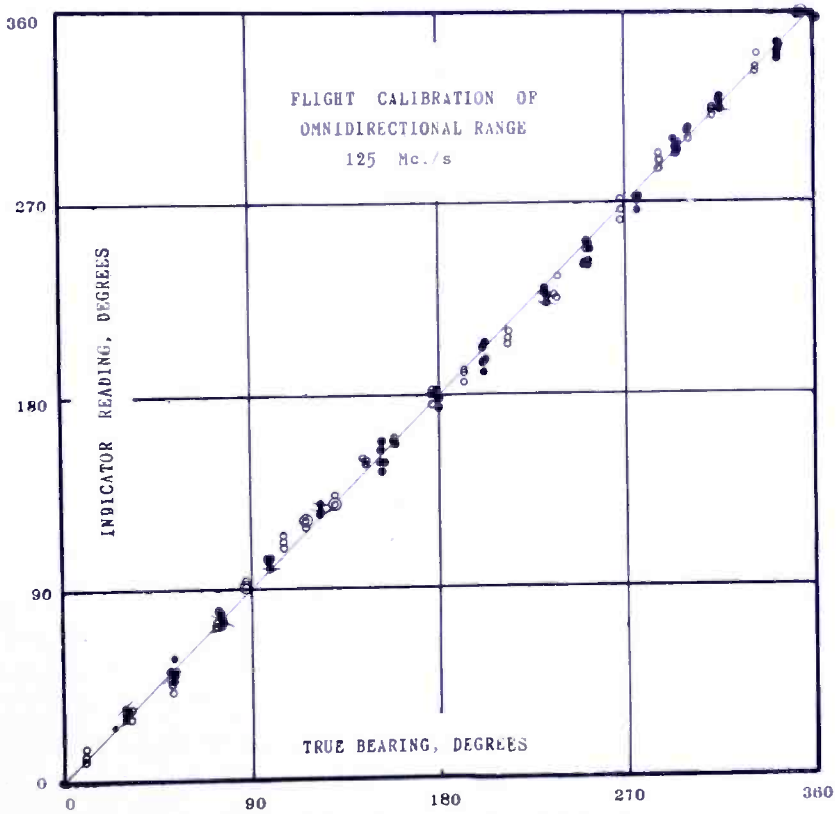

Fig. 4—Flight results at ultra-high frequency.

Check points lying roughly on circles, of 20 and 50 miles diameter, centered at the range transmitter were used for these observations, which were made at an altitude of 3500 feet. In the figure, the open circles represent points 25 miles from the transmitter and the full dots, points 10 miles from the transmitter. Scatter of the readings was obviously greater than at the lower frequency, but again a definite trend of errors is evident. Readings tended to be high to the southeast of the range, low to the southwest and quite accurate to the north.

The largest error ever observed in flight, when all equipment was fully adjusted for normal operation, was 10½ degrees, and the average error magnitude for all the observations represented in Figure 4 is about ±3½ degrees. The difference between these values and corresponding ones of 5 degrees and ±1 degree for close-in observations on the ground is an indication of the vagaries of ultra-high-frequency wave travel and of other disturbances to be discussed later. There were no definite signs of multiple courses or of unduly fast or slow motion of the indicating jog during the ultra-high-frequency work. On an altitude test, the indicated bearing changed by 4 degrees from 1000 to 2000 feet and thereafter remained fairly constant. It showed a maximum deviation of 2 degrees and an average deviation of ±1 degree from the average of 11 readings taken between 2000 and 10,000 feet.

No dependence of indicator reading on aircraft heading was observed, the indicator used in the ultra-high-frequency tests being well shielded magnetically, but large variations of signal strength with heading, caused by undesired directivity of the combination of receiving antenna and aircraft structure, were quite annoying. With the vertical-rod antenna protruding from the bottom of the Ford transport in which most test flights were made, signal was lost entirely whenever a landing wheel and its structure crossed the line of signal arrival. When the antenna was transferred to the top of the airplane[5], its sensitivity to signals from the ground decreased markedly, but became a great deal less dependent on heading, though the signal was still practically lost in steeply banked turns whenever the uptilted wing crossed the direct signal path.

The loss of sensitivity with the antenna on top of the airplane was not serious, because the pickup of signal and of ignition interference, which always set the limit of useful sensitivity, decreased by about the same amount when the antenna was moved up. Very intense ignition interference was always encountered at the ultra-high frequency, but repeated tests showed that it never reached the receiver except by way of the regular antenna, along with the desired signal. Improvement would therefore only have been possible by a thorough revision of the airplane ignition system, which was not felt to be justified for the omnidirectional range tests.

Directly over the range antennas, a deep cone of silence was observed. This was accompanied by three subsidiary nulls on all sides, perhaps caused by the energy which was intentionally reflected upward to prevent an obstruction[6] from upsetting measurements in the vicinity of the antennas. Pilots testing the range liked this supposed defect of multiple high-angle signal lobes, as the repeated collapse and reap-

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[5] II, Figure 15.

[6] II, Sect. 2B(a), p. 352.

pearance of the bright indicator circle gave a very striking indication of passage over the range. The 180-degree shift of indicated bearing accompanying such passage made the indication completely definite and not to be counterfeited by mere fortuitous variations of signal strength.

On early flights with the ultra-high-frequency equipment, the indications were violently unsteady, as was even the circular pattern itself. Flight with all ignition off, but with motors "windmilling", gave some improvement, but indicated nevertheless that ignition interference was by no means the sole cause of the trouble. Even after careful attention to the condition of the experimental equipment and its bonding to the aircraft, there remained a smooth swinging of the indication, of variable and sometimes quite appreciable extent, which did not seem to interfere particularly with reading. There was also an occasional rapid bouncing of the indication and of the circle; this was of rather small extent, and though quite annoying was not too serious. These residual effects were ascribed to: spurious modulation of the incoming signal by the whirling propellers near the receiving antenna, modulation by poor bonding of the vibrating aircraft structure and, especially, disturbance of the wave field itself by reflections from and shadows of trees, buildings and similar objects. It was sometimes found that, with decidedly unsteady indications, the use of strong automatic gain control was definitely harmful, the time-constant of the automatic gain control evidently interacting with the period of the unsteadiness to give a regenerative effect on the latter.

Brief tests made, late in the investigation, in a Douglas DC2 transport, through the courteous cooperation of Mr. D. S. Little of American Airlines, gave indications so violently unsteady as to be practically useless. This reopened the question of the causes of such unsteadiness. The temporary receiving antenna for these tests in the DC2 was mounted on the pilots' escape hatch and was rather fully exposed to both propellers, but this did not appear likely to be the entire cause of the poor performance of our experimental equipment in that ship. Increased speed of motion through standing-wave patterns which disturbed the radiated field of the range was thought also to be contributing to the poor results observed, so a careful attempt to investigate the extent of standing-wave phenomena was decided upon.

For this purpose, a flight was made in a small Goodyear dirigible. The ability of such a craft to drift with machinery shut off made it possible to avoid all propeller modulation and mechanical vibration effects. To our surprise, no unsteadiness at all was ever observed during this flight, except in the following case. When the dirigible was maneuvered to bring the signal directly through the spinning propellers, a slight slow swinging of the indication was induced if the propeller speed was carefully regulated to beat with the range modulation. In particular, all our efforts to find appreciable standing-wave effects were in vain, although we did confirm the existence of the previously inferred high-angle radiation lobes adjacent to the cone of silence.

Readings were made in the dirigible when over a few of the previously used check points. The errors found were remarkably small, not exceeding 2 degrees at any positively identified point. It is regrettable that it was not feasible to make a full calibration circle in a craft so well suited to separating the actual apparatus performance and wave-propagation effects from extraneous disturbances. As the dirigible attained a ground speed of almost half that used in the Douglas, and since no standing waves were observed, it seems safe to assume that the relatively slow speed of the dirigible was not the direct reason for the good results obtained with it.

Finally, some ground tests in a vibration machine disclosed unsuspected mechanical resonances in the receiver which were capable of causing much of the disturbance found in the Douglas. These particular responses had evidently happened to be excited by the vibration characteristic of the Douglas, but not by that of the Ford or the dirigible. Ground tests using a fan to simulate propeller modulation indicated that this also could, as had been suspected, cause some of the observed behavior.

These results were important because, had the behavior found in the Douglas been an inevitable result of rapid motion through a disturbed wave-field, it might have been necessary to discard entirely the notion of an ultra-high-frequency omnidirectional range. Actually, thoroughly satisfactory and unexpectedly accurate ultra-high-frequency omnidirectional-range operation was obtained in an aircraft in flight, and a field surprisingly free of disturbances was found. However, ultra-high-frequency operation in aircraft requires very careful attention to such details as receiver microphonics, thorough bonding of aircraft structures, and antenna placement to minimize propeller modulation.

c—*Distant Tests*

Like any ultra-high-frequency signal, that from the 125-megacycle omnidirectional range was limited in its coverage to essentially line-of-sight distance. Since this limitation avoids interference between widely separated stations, it is not wholly a misfortune. One flight, at 10,000 feet altitude, was made out to a distance of 90 miles, with continuous observation of the ultra-high-frequency range signal. No novel effects were observed, except that the swinging of the indication often associated with local flight diminished appreciably at distances over 30 miles. Up to 60 miles satisfactory operation was obtained. Bearings showed the errors normal in the sector involved, but were consistent among themselves. Beyond that distance, ignition interference became increasingly annoying, until finally, 90 miles out and over Baltimore, Maryland, no bearing could be read. The signal at that distance was amply strong to give a satisfactory indication, but the interference was very much stronger still.

More interesting results were found on a similar flight made earlier, with the 6½-megacycle system. Then also, a strong, steady noise-free direct-ray signal was obtained out to 50 miles. Beyond that distance, a sky-wave became increasingly evident; it produced a second, intermittent indicating mark about 15 degrees later than the normal one. The origin of this mark was confirmed by the fact that the apparent reflecting-layer height, calculated from its delay, agreed quite well with the published average for the month of the noon E-layer height over Washington. At greater distances, noise and multipath effects became stronger until, over Baltimore, 4 echoes were prominent, about 8 more were discernible and the signal was fading markedly. Even at 100 miles, when the return flight was begun, though the indication was jumping somewhat and swinging about ±1 degree, it was still readable through the noise and the bearing indicated was still correct. At this distance, transmission was evidently predominantly by sky wave.

Another test made at the lower frequency was from the range at Camden, N. J., to the receiver and indicator on the ground at Cambridge, Ohio, 350 miles away and almost due West. During the day and early evening, fairly stable multipath propagation with from 1 to 4 indications visible was the rule, although there were occasional brief periods of violent fading, "hollow" signal tone and extreme multiplicity of indications. The indications, both on calibrating and directive signals, swung fairly slowly and smoothly over an arc of ±10 degrees and sometimes as much as ±30 degrees. With some care, readings could be estimated within ±2 or 3 degrees. They were usually correct, but sometimes as much as 5 degrees high. Late at night, a weak, hollow-sounding, violently-fading signal was the rule, with such a multiplicity of wildly swinging marks that no readings at all were possible. The results of the Camden-Cambridge transmissions represent only a brief test and, of course, reflect only one set of propagation conditions, but they indicate that fairly reliable sky-wave bearings may be transmitted over moderate distances at medium-high frequencies, when propagation conditions are such as to provide an ordinarily good signal.

C—*General Comments on Observed Behavior of Equipment*

Experimental operation, with frequent minor changes in apparatus, gave ample opportunity to check the ability of the monitoring system to give warning of breakdowns or other faulty operation. With the aid of two-way communication facilities, it was found that the system gave such warnings successfully. The communication facilities were necessary so that, if the observer at the receiving end suspected trouble, he could request a check of transmitter operation and, if that was normal, could obtain a calibrating transmission of adequate duration for a complete check of his own equipment. Whenever such an overall check showed normal operation throughout, the bearings indicated were considered (and always appeared to be) reliable to the accuracy characteristic of the system.

When a fault developed in the transmitter, it was always quite evident to the transmitter operator, either from the behavior of the usual plate current meters or from error indications, on the monitoring meters, which could not be corrected by the normal adjustment procedure. When a fault developed in the receiver or azimuth indicator, it was always made evident by distortion, instability or complete disappearance of the bright circular pattern. The most frequent and annoying difficulty in flight testing consisted of failure of the auxiliary channel for communication from airplane to ground. In the case of faults in the experimental apparatus, such failure made it difficult for the observer in flight to determine whether the trouble lay in the aircraft or on the ground. In normal test operation, communication failure prevented the flight observer from requesting and obtaining a complete calibration when he desired to check the accuracy of an observed bearing.

Occasional very slight variations of transmitted bearings were, as noted earlier, shown by ground calibrations, but not by the monitoring instruments. This, together with the successful operation of the field-pickup portion of the monitoring apparatus that we have used, indicates that a monitoring system actuated entirely from the radiated field, rather than mainly from modulation circuits in the transmitter, might be a desirable further development. With such a method of monitoring, slight modulation of the broadcast pattern, adjustable as to phase and amplitude, could be used to correct some of the bearing errors found in ground calibrations and, thus, to provide better all-around accuracy of bearing indication. The monitoring system used in our tests was designed to be easily adaptable to the automatic control of the transmitter adjustments. Such equipment could, therefore, maintain accurate operation without the intervention of an operator. This possibility suggests another line for further development, particularly appropriate for inaccessibly located range transmitters.

While no tests of prolonged routine operation were made, it was found that the normal day-to-day readjustment of the transmitter required to maintain correct operation, when no changes were made in the apparatus, was very slight. It was also found that the transmitter readjustment necessary to maintain all-around accuracy during long flights was slight, and could usually have been omitted had we not been seeking to obtain the limiting accuracy of the system. Similarly, while it was our custom to check repeatedly and thoroughly all indicator adjustments during flight, the smallness of the readjustments generally required indicated that this also might be a superfluous precaution in normal use of the equipment. The tests gave no reason to suppose an omnidirectional range to be any more likely than any other type to develop faults in routine operation. However, the ready availability of a complete checking method is an added assurance of reliability even in regular service.

The difficulty mentioned in a previous section, that a receiver reasonably free from microphonics when tested in one aircraft may be sufficiently affected by the different vibration typical of another craft to impair seriously the indications given, has been largely overcome by the advances made in airborne ultra-high-frequency technique since the tests. The other difficulty also mentioned there, that of propeller modulation, was unwittingly exaggerated by the use of 60-cycle power from the supply lines to modulate the ranges. Two-bladed aircraft propellers customarily rotate at a speed not markedly different from 1800 revolutions per minute and, therefore, have a blade frequency of approximately 60 per second. Three-bladed propellers are geared down to rotate at speeds near 1200 revolutions per minute, again giving a blade frequency of 60 per second. The remedy to be applied in the design of an omnidirectional range is again obvious, but it must be remembered that the directional modulation used should be below the frequency band required for voice communication. Mention should be made here of the fact that the presence of the low-frequency directive modulation did not seriously impair speech intelligibility. Nor did speech, so long as overmodulation was avoided, impair the accuracy of the bearing indications.

Strong ignition interference encountered in the ultra-high frequency tests permitted some interesting observations of the effect of noise on the indications. When the range signal was considerably stronger than the interference, the only effect of the latter was to produce momentary, rapidly moving extra marks on the indicator pattern, which were easily distinguishable from the steady true mark. This effect increased as the signal grew weaker until, when the interference was decidedly stronger than the signal, the extra marks became very annoying and the true mark itself unsteady. Finally, with the signal very much weaker than the noise, the whole circular pattern became violently unsteady and a reading was practically impossible.

The pulse-comparing deviation indicator was much more seriously affected by moderate amounts of interference than was the cathode-ray indicator, which is not surprising. A skilled operator can, by ear, pick out a desired signal successfully from a very strong background of noise. This advantage of human perception and judgment is lost when all information is condensed into the position of a sluggish meter needle, but is, to a large extent, regained when signal and interference are fully exposed to view on the face of a cathode-ray tube.

As no tests were made with horizontally polarized transmission, no information as to the effect of polarization on omnidirectional range accuracy was obtained. However, the complete absence of marked standing waves and the remarkable accuracy of the few bearings taken in flight when unnecessary extraneous disturbances were known to be absent, imply that little improvement could be had by a change of polarization. The antenna and antenna-feeding system used have the definite advantage of simplicity of design, construction and adjustment. With an adequate ground plate they provide rather pure vertically polarized radiation.

Omnidirectional ranges should be neither better nor worse than others, at any given frequency, with respect to terrain effects producing bent or multiple courses. The continuous, quantitative indication provided by the omnidirectional range, however, prevents such effects from ever becoming seriously confusing and facilitates determination of their magnitude and extent. The omnidirectional range principle is, of course, not restricted to use at any particular radio transmission frequencies, but is of quite general applicability.

3—METHODS OF USING OMNIDIRECTIONAL RANGES IN FLIGHT

A—*The Omnidirectional Azimuth Indicator*

The omnidirectional range system as tested culminates in a standard A-N size face in the instrument panel before the pilot. This instrument has the appearance shown in Figure 5. The bright circle with the marking jog appears in green light against a dark-green background, the position of the jog being read against a white 0-to-360-degree azimuth scale. In function, the instrument is as different from others as it is in appearance. It may be thought of as a protractor, centered at the location on the ground, or on the map, of the range beacon that is tuned in. The jog points out, definitely and automatically, the line of position of the receiving ship from that range.

This instrument is a true position indicator and its reading does not depend at all on the heading of the receiving ship. Figure 6 shows three ships, all headed in different directions. The position of each ship bears 240 degrees true from Philadelphia. Therefore each, tuned to an omnidirectional range at Philadelphia, will receive the 240-degree azimuth indication shown in Figure 5. Even if one of the pilots tries spinning his ship, he will find his azimuth reading unchanged, because the ship is still in the same place over the ground.

Fig. 5—Face of omnidirectional-range azimuth indicator. A bearing of 240 degrees is indicated.

Suppose a pilot, getting a 240-degree reading from Philadelphia, tunes over to a range at York, Pennsylvania and reads a bearing of 120 degrees. He may transfer both readings directly to his map with a protractor, as the lines of position drawn in Figure 6, and locate himself at their intersection, at the head of Chesapeake Bay. Wherever two omnidirectional ranges can be heard, a complete radio position fix may be obtained in this easy way. Any chosen cross-country course may thus be followed by means of cross bearings, even if no radio facility is available anywhere along it.

Referring again to Figure 6, suppose that the pilot of the outbound ship, near Wilmington, wants to go to Baltimore. He need only hold his omnidirectional-range azimuth reading constant, at the 240 degrees true from Philadelphia of Figure 5, and this one instrument will then take him straight to his destination regardless of wind. In a cross-wind, he will merely find his compass heading "crabbed" away from his range bearing, as shown in the figure. Referring now to the inbound ship shown in the figure at Baltimore, we note that its pilot need only fly so as to hold his bearing from Philadelphia constant at 240 degrees in order to come straight in to Philadelphia. When he gets there, the bright circle will begin to jump and then will collapse, while still indicating 240 degrees, as he enters the cone of silence over the Philadelphia range. The circle, still jumpy, will reappear reading 60 degrees as he emerges from the far side of the cone after passing over the range. Thus, he gets a very striking and positive cone of silence indication. Should he miss the cone slightly, the circle will not collapse, but the jog will run rapidly halfway around it as he passes the range, always indicating the bearing of his ship from the range and so showing on which side of the range he has passed.

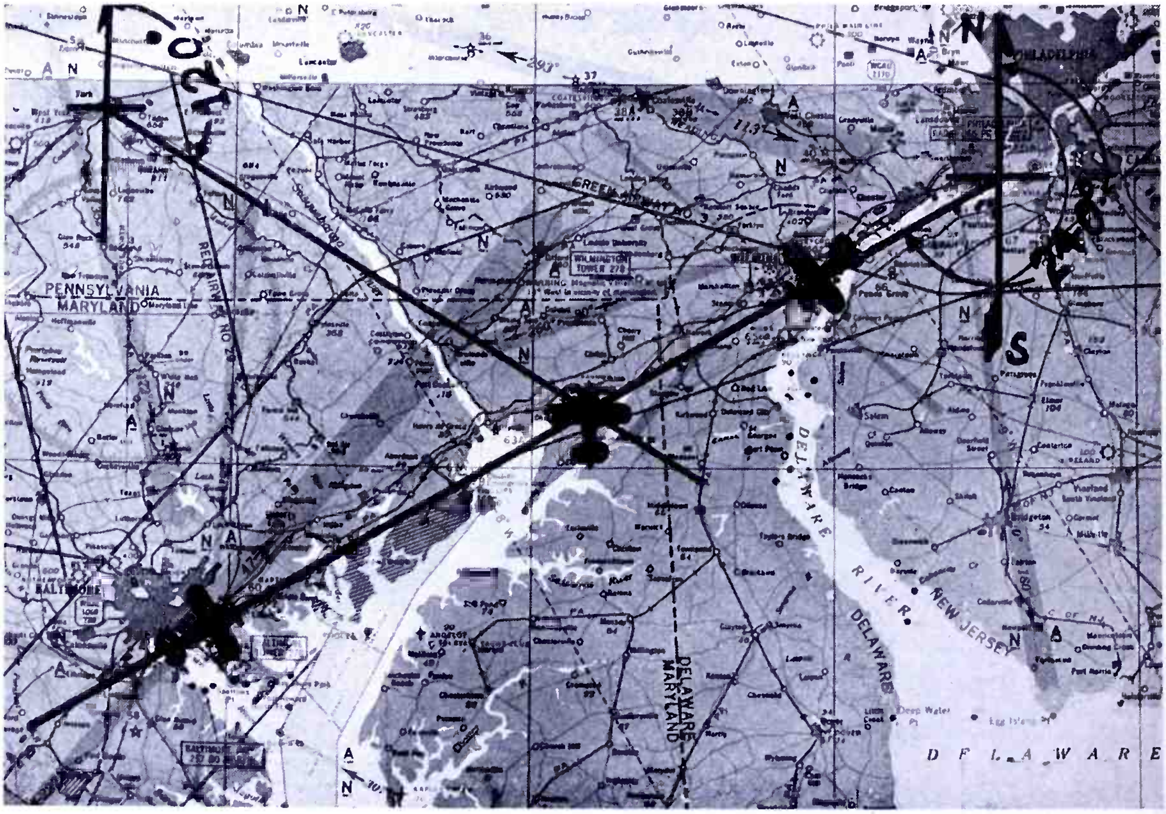

Fig. 6—Three airplanes on true bearing of 240 degrees from Philadelphia. All receive the same indication, shown in Figure 5.

Ranges know only position over the ground, but in trying to hold a constant bearing a pilot flies by his right and left. Now, a ship due north of a range and outbound—northbound—has east on its right, while another ship in the same place but inbound—southbound—has east on its left. This reversal is not a fault of the range, but is inherent in our world and we cannot escape it, so we must always allow for it. Inbound, one must veer to the right to decrease his bearing or to the left to increase it. Outbound, these rules are just reversed. Following a radial course by the azimuth indicator is easier when a movable lubber-line, which may be set to mark the chosen course, is provided on the instrument face. Of course, the range does not tell whether a ship is outbound or inbound without maneuvering. The magnetic compass supplies that information. If compass card and range indicator read alike, you are outbound; if they read reciprocally, you are inbound. Indicators may be set up to read true or magnetic bearings, directly or reciprocally. If direct-reading in true bearings, as described above and used in our tests, they show the real relationships of aircraft to terrain especially clearly.

B—*The Deviation Indicator*

Intuitive application of the above rules for right and left to bearings which may be anywhere around the azimuth-indicator face requires considerable practice. Concentration of the full 360 degrees in one small scale makes slight bearing changes inconspicuous. So we also provided, for the pilot's convenience in holding a constant bearing while flying a radial course, a zero-center pointer instrument which gives magnified and correctly sensed indications of small deviations from a chosen course.

To use this, a course-setting control knob is turned to read, against a rough scale, the bearing from the range of the chosen course. The pilot flies to intersect that course. When appearance of the desired reading on the azimuth indicator shows that he is on his chosen course, he trims the control-knob setting to center the deviation indicator and turns to head along that course. The deviation indicator thereafter shows direction and amount of any lateral drift.

Almost every instrument pilot is now familiar with the radio-compass right-left indicator and its immediate response to changes of heading. Only a few, however, have had occasion to fly visual-indicating radio ranges which, because it takes time for a plane to travel from one place to another, respond only slowly. To avoid confusion, the experimental deviation-indicator face was therefore arranged to look as different from radio-compass indicators as possible and to portray its actual function as graphically as possible. The face bears fixed representations of an airplane and a radio range, the latter centered over the meter pivot. The meter needle represents a straight course, emanating from the range, on which the airplane is to be kept centered.

Provision must be made for the inbound-outbound reversal, and this might be done in several ways. In the experimental deviation indicator, we carried out the idea of graphic portrayal by using two similar instruments. On the face of one, the airplane flies directly in toward the range, while on the other the airplane flies straight away from the range, as Figure 7 shows. In our tests the unused instrument was covered to avoid confusion. The pilot knows whether he wants to fly to or from the range and chooses his instrument and procedure accordingly. Of course, a single instrument could be designed to show either picture at will.

The deviation-indicator needle swings across the small pictured airplane, when drift occurs, just as the real course swings across the real airplane. If the chosen course happens, for example, to parallel a railroad, the pilot may look out the window of his ship and see the railroad drifting off to his right. Or he may look at his deviation indicator and see its needle drifting off to the right of its little ship. In either case, he changes heading a little to the right to check the drift and waits for the change to affect his position. The indicator is so arranged that a pointer motion of about 8 degrees results when the azimuth of the ship changes by 2 degrees.

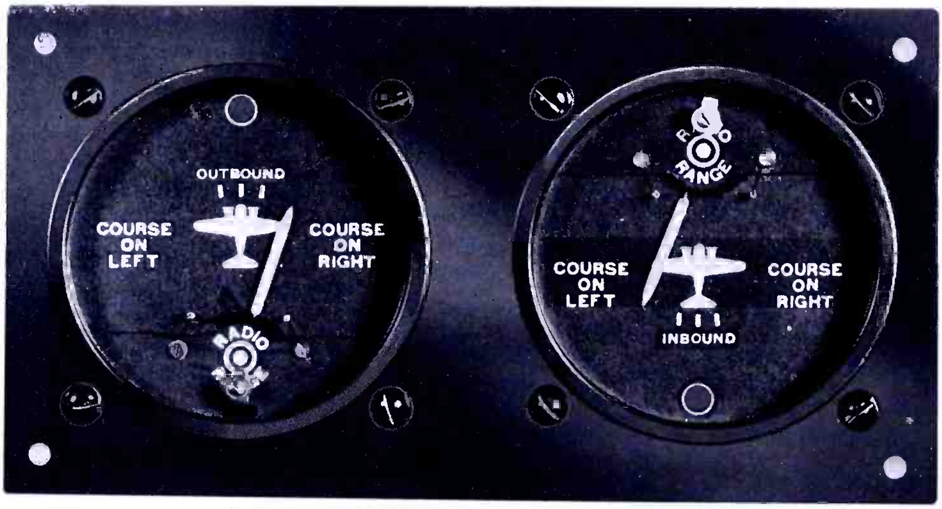

Fig. 7—Face of experimental deviation-from-course indicator.

Far from the range, a given change of bearing corresponds to a large change of position, while close in, the same bearing change is accomplished in a small distance. Therefore the omnidirectional range, like any other, gives courses which seem very broad far out from the range and very sharp close in. While the deviation indicator may be used directly as a flight instrument when close to the range, it is too sluggish farther away, where it serves preferably to establish the compass heading to be held to keep on course. The right heading is found by bracketing, or successive approximation by flight on a series of trial headings, as with present ranges. Outbound, a pilot can start, when on course, with a compass heading roughly equal to the indicated bearing, inbound with a compass heading roughly reciprocal to (180 degrees different from) it. But his flying is of course neater, and needs fewer trial headings in bracketing, if he starts with a true heading accurately equal, if outbound—or reciprocal, if he is inbound—to the indicated true bearing, and corrects it for known cross-wind. A tendency to make additional changes of heading without waiting for the altered drift resulting from a previous change to become slowly apparent seems universal and must be guarded against, as it leads to overcorrection.

C—*General Procedures*

As an example of traffic control with omnidirectional ranges, Figure 8 shows a two-lane direct airway between Philadelphia and Washington. Northbound traffic is ordered to hold 60 degrees from Washington until bearing 180 degrees from Philadelphia, then to turn left and hold 180 degrees until arrival at Philadelphia. Southbound traffic holds 240 degrees from Philadelphia until bearing zero degrees from Washington, then turns left to hold the latter bearing until arrival over the Washington range. These courses, not being single straight lines joining the terminal points, are not the shortest routes possible, but some practical compromise between economy and safety is necessary in deciding upon the best course to follow. In present practice, each pilot flies in the "twilight zone" to his right of the range course he is following, changing course slightly as he tunes from one range to another when about half-way between them. Thus, inbound and outbound craft on a single range course are laterally separated by the width of that course, a difference in bearing from the range of perhaps 2 to 4 degrees. Because of the acuteness of this angle, oppositely bound craft have little lateral separation for a considerable distance from the range; Figure 8 shows a safer situation than that now customary. Two-lane airways using duplicate, parallel lines of course-type ranges have been proposed to give just the condition shown in Figure 8.

The omnidirectional range may be used in three main types of flight. Direct radial flight outward from the range to any chosen destination within reach of its signals may be accomplished by circling the range to reach the azimuth of the desired destination and then holding that azimuth until the destination is reached. No computation whatever is necessary, though for especially precise work correction for known terrain error of the range may be advantageous.

Also, as mentioned earlier, correction of the initial trial compass heading of the aircraft for compass errors and known cross-wind is a refinement likely to be used.

As the second type, radial flight inward to the range from any point within reach of its signals is accomplished simply by holding constant one's indicated azimuth, while heading in a roughly opposite direction. No computation, except a rough determination of the heading reciprocal to the indicated bearing, is necessary. No terrain correction is justified, but compass and wind corrections are attractive refinements. In these two radial types of flight, the deviation indicator or an index movable around the azimuth-indicator dial will be used to aid in holding the fixed bearing required. The omnidirectional range when so used functions simply as a course-type range, distinguished by the features that there is always a course just where one is wanted and that no ambiguity of position can ever arise.

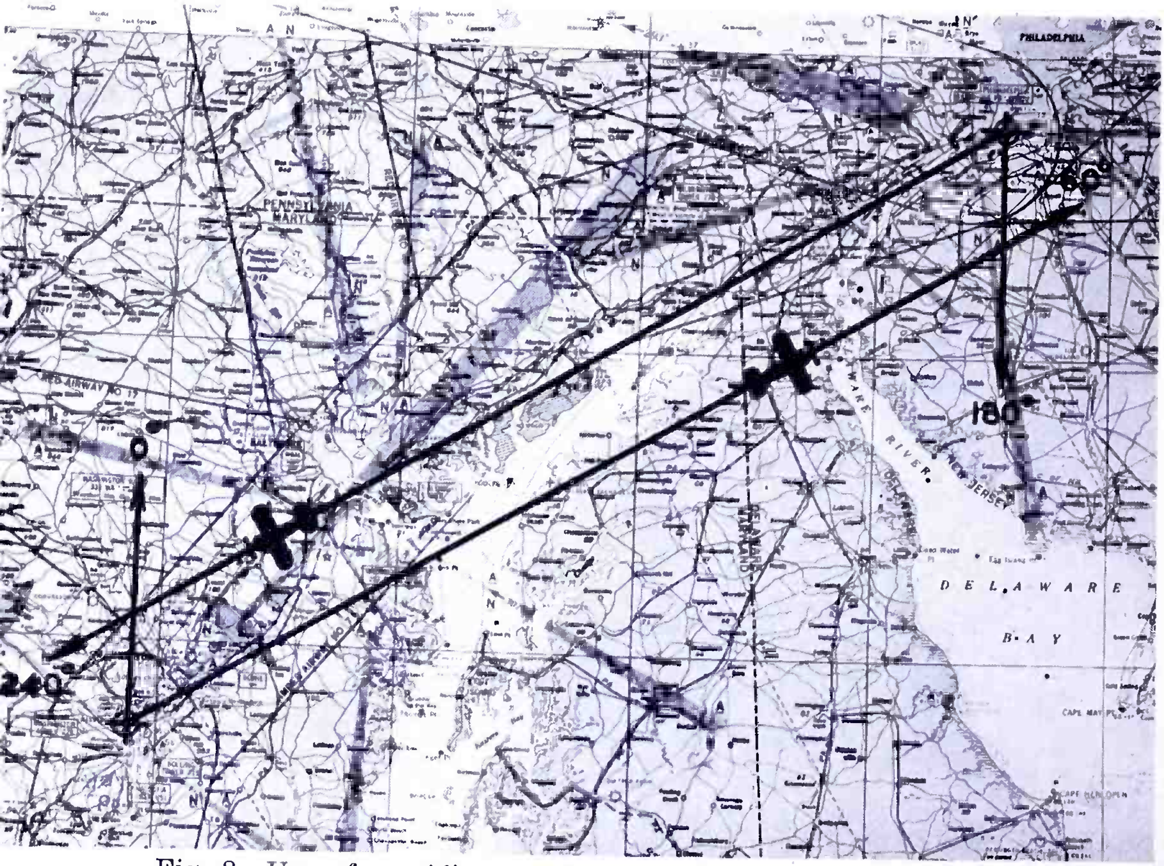

Fig. 8—Use of omnidirectional ranges for air traffic control.

General cross-country flight is a third type, which may be accomplished throughout any region in which two or more omnidirectional ranges can be heard. Azimuth readings from two ranges can be transferred directly to a map to give a complete position "fix" whenever required. Again, no computation whatever is necessary, but for special precision work terrain corrections may be useful. Heading is not significant in obtaining the fix, so no compass or wind correction is involved. This use of the omnidirectional range is one for which course-type ranges are not at all fitted.

As cross-country flight requires quick availability of two range signals on different channels, a receiver suitable for this use should be designed to permit tuning to both chosen channels, so that one or the other could be instantly selected by a switch. Maps for use with these ranges would be overlaid with azimuth scales centered on the range locations, just as present maps are overlaid with range course data; the scales could be corrected for any permanent terrain errors, if desired. With such a map, complete position-finding equipment would consist of a pair of straight-edges which would be pivoted, for example by thumb-tacks, so as to be rotatable about the map locations of the pair of ranges tuned in. Lacking space in an aircraft to use a map, one might substitute a narrow chart prepared for a chosen cross-country course. This would be a curved line drawn on a coordinate set of bearings from the pair of ranges to be used, after the fashion of the Napier chart for compass corrections.

So far as is known to the writer, there is no flight application of a course-type radio range for which an omnidirectional range will not serve equally well. On the other hand, the course-type range may not happen to have courses where they are required for a particular radial flight and such ranges are seldom directly useful, as ranges, in general off-airway, cross-country flying. The few courses of a course-type range can all be accurately adjusted to chosen bearings, while an omnidirectional range will ordinarily be adjusted for the best all around average accuracy. However, omnidirectional ranges may also be adjusted so that indications will have maximum accuracy in five chosen directions.

4—ACKNOWLEDGMENTS

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A NEW EXCITER UNIT FOR FREQUENCY MODULATED TRANSMITTERS*

By

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Summary—*This paper describes an exciter unit for use in frequency-modulation transmitters. The new exciter unit is capable of producing a frequency modulated carrier of excellent linearity and low noise level. The carrier frequency is automatically maintained to an accuracy close to that of a crystal-controlled oscillator, the frequency of the latter being used as a reference.*

THERE are two systems now in general use for producing a frequency modulated signal which meets the Federal Communications Commission's requirements for frequency modulation broadcasting. One method, making use of phase-shift modulation, was developed by Major E. H. Armstrong. The operation of this system is shown in schematic form in Figure 1.

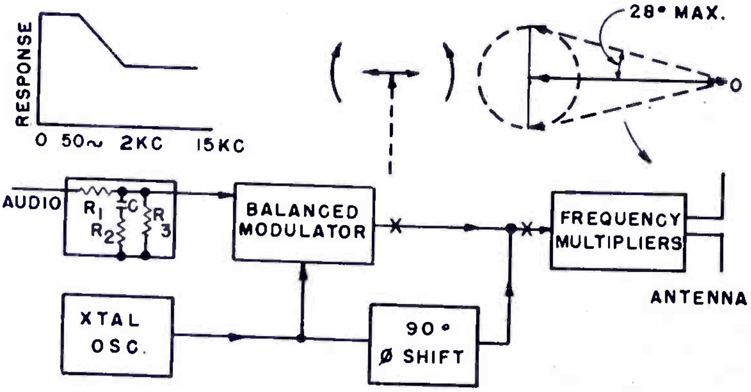

Fig. 1—Operation of Phase-Shift Modulator, Armstrong Type FM Transmitter.

The crystal frequency and the audio input are fed to a balanced modulator. The balanced modulator is so constructed that only the sidebands appear in its output. The sidebands are pictured at the output of the modulator as two small vectors rotating in opposite directions. The relation of the carrier, although not actually present, is

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* Decimal Classification: R423.8

shown dotted in the proper phase relation. A portion of the output of the crystal is shifted in phase by 90 degrees, and added to the sidebands, as shown in the top right of the illustration. The effect of the sidebands is to advance and retard alternately the position of the carrier vector. The whole picture rotates about the point *O* at an average angular velocity determined by the crystal frequency. The magnitude of frequency modulation produced depends on the modulating frequency, and on the amplitude or length of the sideband vectors relative to the reintroduced carrier. It can be seen that, if the length of the sideband vectors is fixed, the frequency modulation will increase six decibels per octave as the modulation frequency is increased.

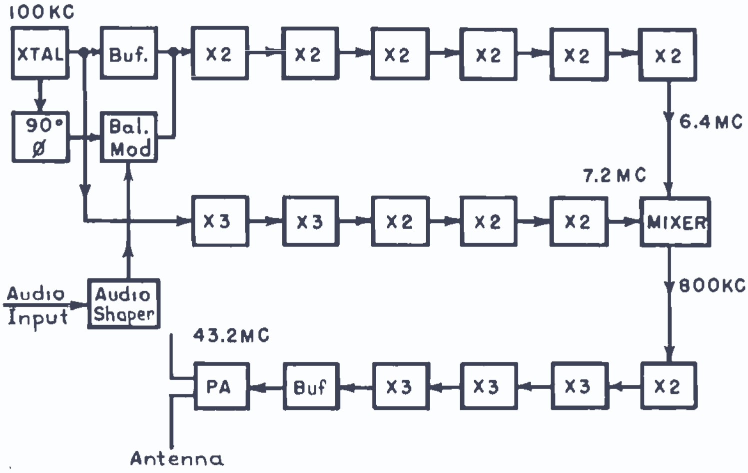

Fig. 2—Block Diagram of Armstrong Type FM Transmitter.

In order to obtain pure frequency modulation it is necessary to decrease the amplitude of the audio input six decibels per octave, with rising frequency. This is shown in the response curve, at the upper left, in the modulating frequency range from 50 to 2,000 cycles. The audio response is flat for frequencies above 2,000 cycles. This means that the frequency-modulated output increases at six decibels per octave above 2,000 cycles, to give the 75 micro-seconds standard pre-emphasis of high frequencies agreed upon by the Radio Manufacturer's Association, as a measure to improve signal-to-noise ratio at the receiver. The receiver has a corresponding drop in response above 2,000 cycles to produce a flat response for the overall system. The audio response is again flat for frequencies below 50 cycles, resulting in six decibels per octave drop in frequency-modulated output below 50 cycles. This restriction is imposed by the fact that the distortion in the frequency-modulated output is five per cent, when the phase displacement is plus or minus 28 degrees, and increases rapidly with greater phase shifts. These representative figures call for a frequency multiplication of about 3,000 to produce a frequency swing of plus or minus 75 kilocycles at 50 megacycles.

Figure 2 is a more complete block diagram of an Armstrong type of transmitter making use of an arrangement to minimize radio carrier drift.

A second method of producing a frequency modulated signal employs a reactance tube to produce a direct change in the frequency of a master oscillator. The basic circuit is shown in Figure 3. The oscillator circuit is illustrated at the right and the reactance modulator is shown at the left. The plates of the two tubes are tied together. The grid of the reactance tube is driven from the plate circuit, but is 90 degrees out-of-phase with it. The plate current of the reactance tube is therefore 90 degrees out-of-phase with respect to the plate voltage. The tube reactance becomes either capacitive or inductive in nature, depending on whether the 90-degree shift in grid excitation leads or lags the plate voltage. The audio voltage changes the bias of the reactance tube grid in accordance with the signal voltage. As the reactance tube is a pentode, this change in bias causes a corresponding change in mutual conductance of the tube. The net result is that the reactive current of the tube varies as the impressed audio signal. In a high-fidelity circuit it is customary to use two reactance tubes, one acting as a capacitive reactance and the other as an inductive reactance, in order to obtain maximum frequency stability and linearity of response. The circuit is capable of a frequency swing of more than plus or minus 10 kilocycles at 5 megacycles so that very little frequency multiplication is required to obtain a plus or minus 75 kilocycles swing.

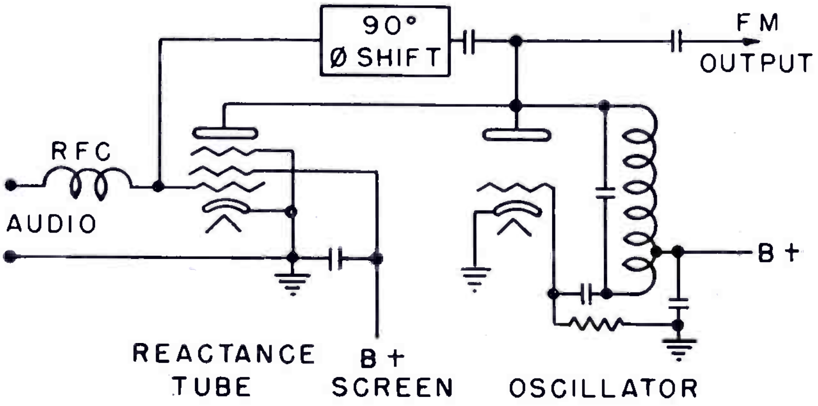

Fig. 3—Reactance Tube.

Because of the advantages of the reactance tube modulator, considerable effort has been devoted towards obtaining such an exciter unit that would also have excellent frequency stability. The frequency correction should be effected independent of the modulation process, and, if possible, provision should be made to correct frequency manually if there should be a failure of the automatic frequency control. A good crystal-controlled oscillator should be used as a standard reference frequency source for the automatic frequency-control circuit.

One type of frequency modulation exciter (illustrated by the block diagram of Figure 4) beats the master oscillator frequency down to one megacycle, using a crystal oscillator as the beat-frequency source. The one-megacycle beat frequency acts on a discriminator to provide a direct current control potential which is applied to a reactance modulator tube grid so as to compensate any drift of the master oscillator frequency. The time constant of the correction is of sufficient duration to prevent it responding to modulation.

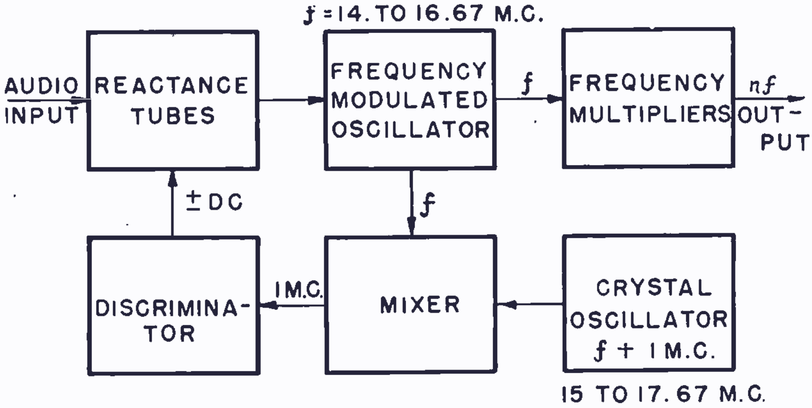

Fig. 4—Reactance Tube FM Exciter.

Certain points, in regard to this method of frequency control, however, should be mentioned. There is fluctuation in the direct current control potential from the discriminator caused by variations in contact potential in the diodes. Circuit components change in value with changes in temperature; therefore the discriminator circuit and reactance tubes have to be placed in an oven, as illustrated in Figure 5, to provide an accurately controlled temperature. The functions of modulation and frequency control are performed by the same reactance tubes, which does not allow optimum adjustment of the reactance tubes for minimum distortion. If the modulating signal is unsymmetrical, there is a change in control potential from the discriminator, causing a shift in oscillator frequency. The frequency correction is degenerative in action, and therefore acts only to reduce the magnitude of frequency drift of the master oscillator.

Data on many other circuits intended to accomplish automatic frequency control have been published. A number of these make use of the scheme shown in Figure 6. The signal from the oscillator to be controlled is fed to two amplitude-modulation detectors or mixers. The signal from the crystal-controlled reference oscillator is also fed to the detectors, but through circuits that shift phase so that there is a 90-degree displacement of the reference frequency between the two detectors. The resulting beat frequency of the two oscillators will appear in the output of each detector, and because of the 90-degree phase shift of one of the exciting frequencies, the beat frequencies will also be displaced by 90 degrees. The interesting feature of the circuit is that, as the frequency of the oscillator, being compared to the frequency of the crystal, is caused to change through the synchronous or zero-beat condition, there is a reversal in phase of one beat-frequency output with respect to the other.

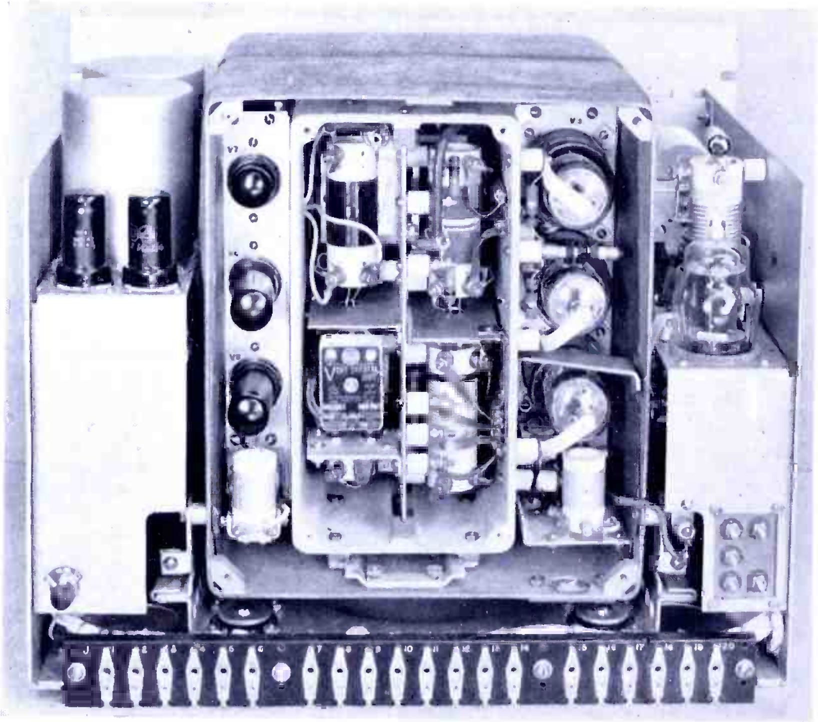

Fig. 5

There are many ways in which to make use of this phase reversal to provide an indication as to whether the controlled oscillator frequency is high or low. Several methods were investigated. The most promising idea was to make use of the fact that the two beat notes displaced by 90 degrees constitute a source of two-phase power and could, therefore, be used to set up a rotating magnetic field in an induction motor. Inasmuch as one phase reverses when the controlled oscillator frequency passes through zero beat, the rotation of the field

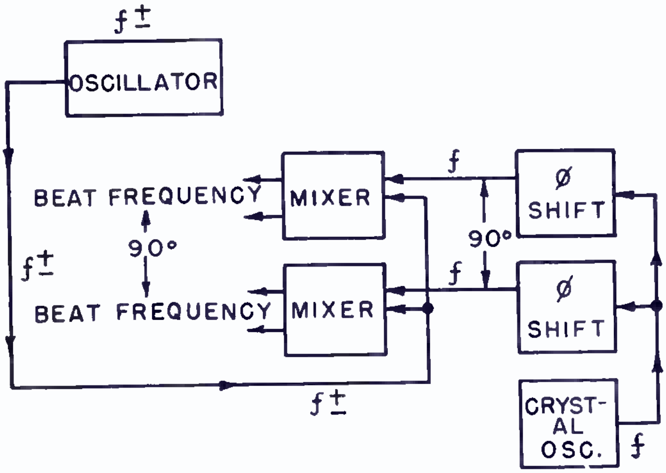

Fig. 6—Fundamental Frequency Control Circuit

and therefore of the motor, will reverse. The motor can be used to drive a variable condenser or other tuning means to bring the controlled oscillator in step with the crystal oscillator as shown in Figure 7. This

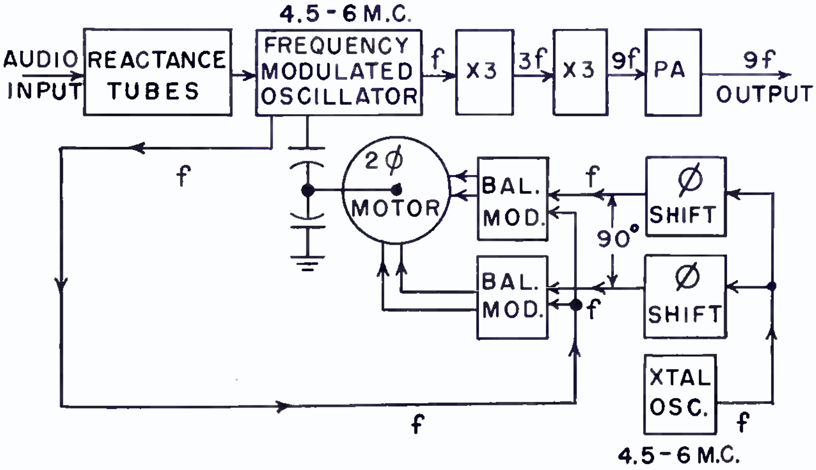

Fig. 7—Preliminary Frequency Control FM Exciter

scheme was tried in just this form. The induction motor developed torque enough to run well at frequencies from a few cycles per second to two or three hundred cycles per second. This does not constitute a very wide range of control at five megacycles. On a cold start it was necessary to change the frequency of the controlled oscillator so that the beat frequency would fall in the range where the motor had torque enough to take control. Frequency modulation of the controlled oscillator had no apparent effect on the motor except to reduce its torque. The system was operated with program modulation from a local broadcast station and ran for several days without once losing control. There was, however, a constant danger that a sudden jump in oscillator frequency, especially in the presence of modulation, might cause loss of control. Some improvement could be obtained by speeding up the rate of frequency correction. In these first tests it had been necessary to drive the control condenser through a gear train so that the frequency correction would be gradual and without overshooting, which would result in hunting.

The slow speed of the motor, added to the backlash and friction in the gear train, gave rather poor performance in following minor departures in frequency. To eliminate some of these troubles, the condenser was mounted directly on the motor shaft as illustrated in Figure 8. The tendency to hunt was eliminated by fitting a dash-pot to the opposite end of the motor shaft. The friction of the tuning condenser bearings was avoided by using a split stator condenser with the rotor on the motor shaft and insulated therefrom. One set of stator plates was grounded and the other set was connected to the plate of the controlled oscillator. This procedure eliminated all friction save that in the ball bearings of the motor. The range of operation was, thereby, extended at both high and low frequencies, the motor being able to take control at 1,000 cycles above or below zero-beat. The oil damping gave much more rapid control action without causing trouble from hunting. These changes yielded an enormous improvement in the operation of the frequency control.

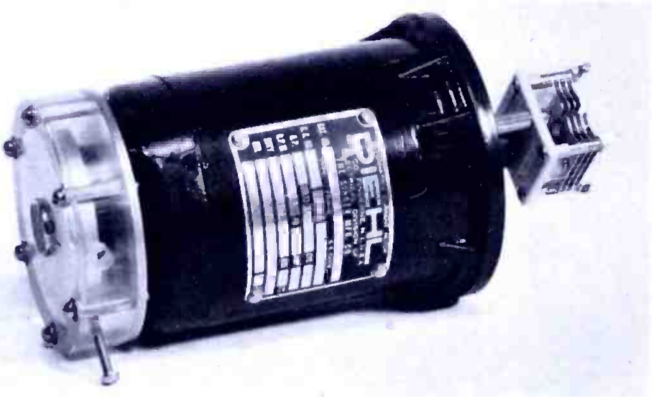

Fig. 8

Since the limit of the control range is the high-frequency-response limit of the motor, an increase in the range of control can be obtained by dividing the modulated oscillator frequency, so that it could be compared to a crystal oscillator at a lower frequency. The range of control would thus be increased by a factor equal to the division in frequency. An exciter unit, such as described by J. F. Morrison in his U.S.P. #2,250,104, accomplishes this by using ten stages, each divided by two, yielding a total division of 1024. Each divider stage is a duplication of the one schematically shown in Figure 9. The circuit employs the principle of regenerative-modulation whereby a subharmonic is obtained by a modulation process. Since the output energy is obtained by a modulation process involving both the input and output waves, the output wave will appear only when an input wave is applied, and bears a fixed frequency ratio with respect to it. The circuit makes use of copper-oxide modulators and the output circuit is tuned to one-half the input frequency. The tuned circuits are made sufficiently broad to permit substantial output voltage over a frequency range of ± 1.5 per cent. While the circuit is rather complicated and expensive, the output waveshape is good and the fact that there is no output wave when there is no input signal, might prove to be of value. The division per stage is low, although division ratios greater than 2 are possible under special circumstances.

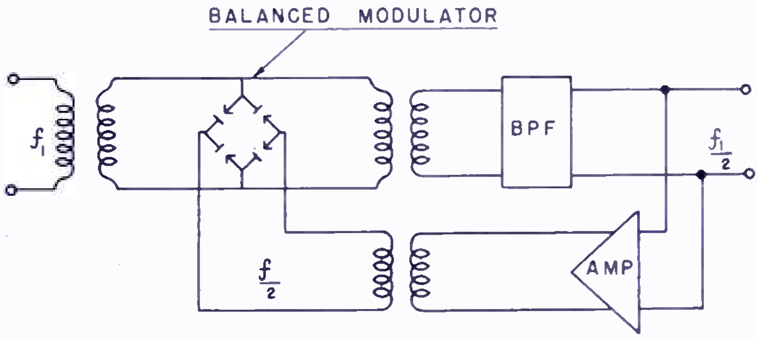

Fig. 9—Frequency Division Pat. By. R. L. Miller 2,159,595

Another possible way to obtain frequency division would be to make use of multivibrators. The waveshape would not be good, but it would be possible to get higher division per stage.

The circuit finally adopted for use in the new exciter unit is shown in Figure 10. This circuit minimizes the number of divider circuit components. The waveshape of the output of the divider, described in greater detail by G. L. Beers in his U.S.P. #2,356,201, has been found to be entirely satisfactory for automatic frequency control purposes. The circuit can be tuned over the required range by means of an adjustable iron slug located within the field of the coil. The lock-in range may be as high as plus or minus five per cent. Division ratios as high as 12 have been successfully obtained.

Having selected a circuit for frequency division the next consideration was to fix the frequency at which the comparison of frequencies was to be made. A crystal and holder with excellent performance designed to operate in the frequency range of 90 to 125 kilocycles is used as the frequency standard for the exciter units.

A preliminary test of the performance of the frequency control with frequency comparison, made at 100 kilocycles, gave excellent results except for a loss of control in the presence of tone-frequency modulation when the modulating frequency was below 100 cycles. A fundamental characteristic of frequency modulation is that the energy in the modulated signal does not change with the degree of modulation. However, as the amount of modulation is increased from zero, there is a transfer of power from the carrier to the sidebands lying above and below the carrier frequency. This effect continues with increasing modulation until a point is reached at which all the energy is in the sidebands and there is no power in the carrier. With further increase in modulation, or frequency swing, the carrier again reappears. With the ± 75-kilocycle swing of frequency, used for broadcasting, there are several cycles of this effect at low modulating frequencies. In the first experiments, where the frequency comparison was made at five megacycles, this phenomenon was detected only in a loss of torque in the tuning motor.

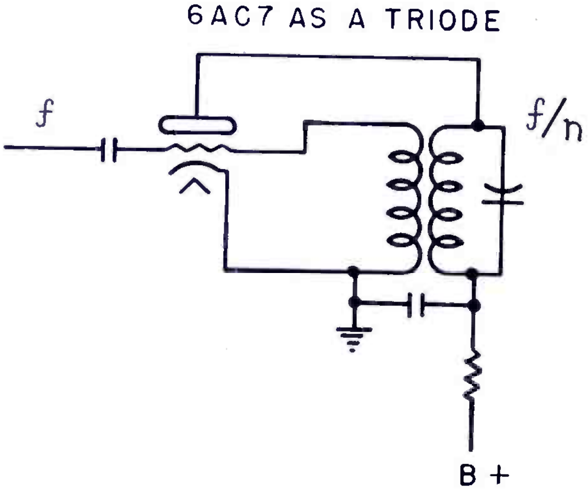

Fig. 10—Locked-In Oscillator Frequency Divider

Theoretically, it should have been possible to find conditions of modulating frequency, and degrees of modulation, where there was no torque. Actually, these points were so critical and so sharply defined that it required considerable patience to find them. In actual operation, with program modulation, the condition of no torque would not exist long enough to lose control.

The effect of frequency division is to reduce the swing of frequency with modulation, along with the reduction of carrier frequency. This is carried far enough when the frequency comparison is made at 100 kilocycles so that carrier loss occurs only at frequencies of modulation below 100 cycles and, for 100-cycle modulation, only with full frequency swing or 100-per-cent modulation. This effect was not serious in program modulation, but in taking performance data on a transmitter, with tone modulation, it would be readily apparent. An additional division by five, to 20 kilocycles, eliminates this problem except for modulation below 20 cycles, which appears low enough not to be a source of complaint.

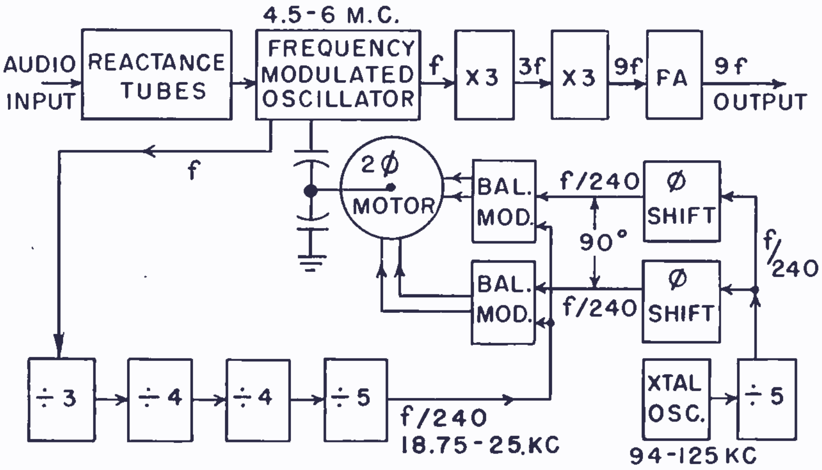

Fig. 11—New FM Exciter

The circuit of the current model of the exciter unit is illustrated in Figure 11, as a block diagram. The items in the top row are (from left to right) the reactance tubes, a modulated oscillator, a frequency tripler, a second tripler, and a power amplifier. The power amplifier is used to obtain sufficient power to feed the main transmitter through a transmission line. The output frequency will fall in the range of 40.5 to 54 megacycles. Multiplication by two, in the main transmitter, gives a possible output frequency range from 81 to 108 megacycles.

A lead shown at the left of Figure 11 serves to conduct a synchronizing voltage from the modulated oscillator to the first divider at the lower left. The dividers are arranged as shown, with four stages, giving a total division of 240. This places the output frequency of the last divider in the range of 18.75 to 25 kilocycles. The output of the last divider is connected directly to the two balanced modulators. The crystal oscillator shown at the lower right may operate at any frequency between 94 and 125 kilocycles. The crystal output synchronizes a divider at one-fifth the crystal frequency. This frequency is also fed to the balanced modulators, but in this case a phase-shifting network is included in the lead to each modulator, adjusted to maintain a 90-degree displacement in-phase between the modulators, over the range of frequencies involved.

Each balanced modulator has a pair of 6L6 tubes biased to cut-off, and connected in push-pull. An induction motor with high-impedance center-tapped windings on each phase is used in the plate circuit of the modulator tubes, the use of matching transformers then being unnecessary. In this way the motor receives full voltage to direct current beat-frequency. The need for this is evident when one considers that the motor must respond to a beat-frequency lower than one part in a million at 20 kilocycles, which is .02 cycles per second or 1.2 cycles per minute. This rather phenomenal performance from an induction motor is largely made possible by the elimination of any load on the motor. The absence of gearing and the use of viscous damping establishes a condition in

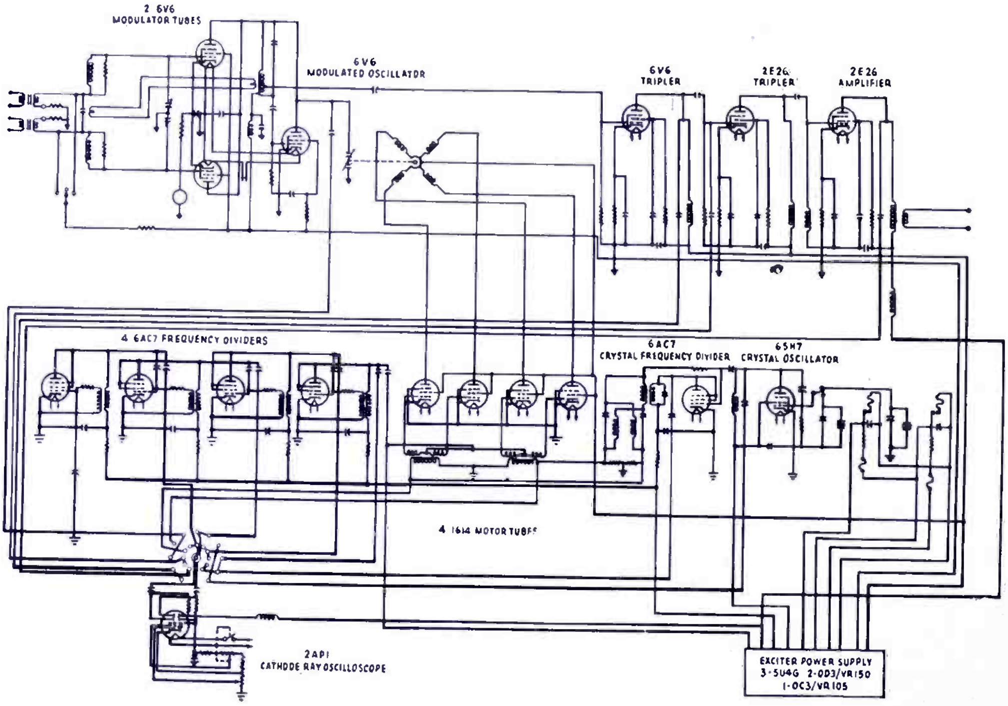

Fig. 12

which there is little or no resistance to slow rotation of the motor shaft. This motor responds on application of voltage to frequencies up to 1000 cycles.

In order to make tuning and performance checking of the frequency control simple and rapid, the necessary test equipment is built into the exciter. A cathode-ray oscilloscope, with the required switching mechanism, is provided. By selecting the proper switch position it is possible to check the division in each divider and also the tuning and multiplication of the tripler stages, by means of Lissajous figures.

The accuracy of the frequency control is so exact that it is limited by the heat cycle of the crystal oven. During test, this effect produced a regular variation of ± 40 cycles at 100 megacycles as the thermostat of the crystal oven went on and off. The control action is smooth and rapid. There are no critical adjustments. The range of control can be as high as ± 1000 cycles at 20 kilocycles—that is, ± 5 per cent. At 100 megacycles this amounts to ± five megacycles. In case of failure of the frequency control during a program, operation can be continued with manual frequency control by locking the motor shaft and adjusting the frequency with a vernier tuning control located on the master oscillator tank coil.

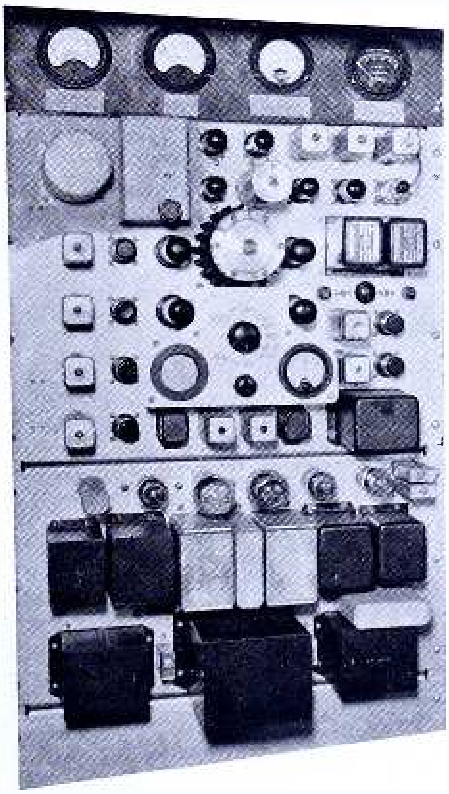
Fig. 13

The distortion in the frequency-modulated output of the exciter is of the order of 0.5 per cent for modulating frequencies from 30 cycles to 15,000 cycles. The noise level in the output is 74 decibels below 100-per-cent modulation.

A schematic diagram of the new exciter unit is shown in Figure 12. Figure 13 is a front view of the new exciter unit with the major components and controls identified. Figure 14 is a rear view of the exciter unit.

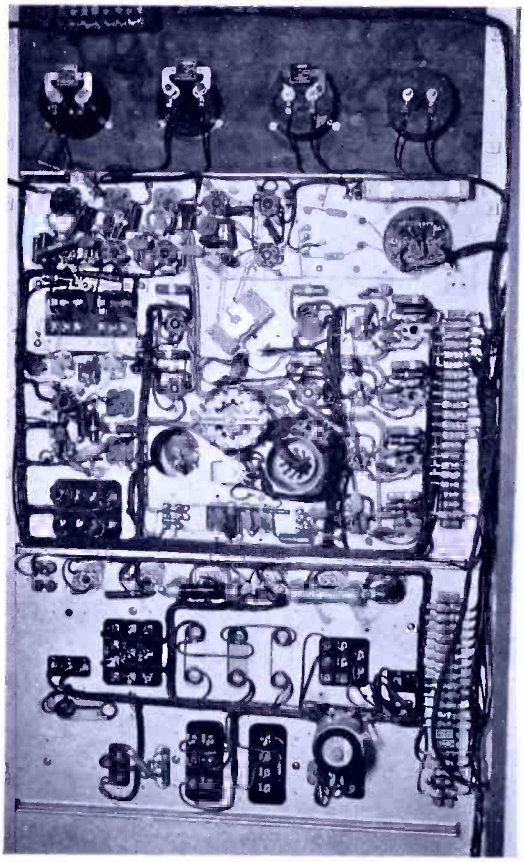

Fig. 14

In summary, the principal advantages of this new exciter unit are:

(1) Its relative simplicity of circuit design.

(2) Use of a minimum number of tubes.

(3) Accurate frequency control.

(4) Reliability of operation.

(5) Excellent performance characteristics.

(6) Ease of maintenance and service.

CONTRIBUTORS TO THIS ISSUE

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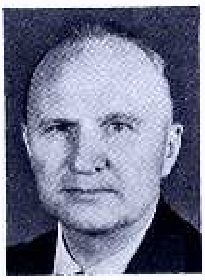

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Robert E. Shelby received his B.S. degree in electrical engineering and B.A. and M.A. degrees from the University of Texas. He joined the National Broadcasting Company, Inc., in 1929 in the Engineering Department, serving in various positions connected with television. He is now the Director of Technical Development on all technical phases of the company's activities in AM and FM sound broadcasting, transcription recording, acoustics and television. He is a member of Tau Beta Pi and Phi Beta Kappa, and associate member of Eta Kappa Nu and Sigma Xi, a Senior Member of the Institute of Radio Engineers, and Member of the American Institute of Electrical Engineers and of the Society of Motion Picture Engineers.

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TECHNICAL ARTICLES BY RCA AUTHORS

Commencing with the June 1946 issue of RCA REVIEW, this section will include a list of all technical papers published or presented by RCA Authors in technical journals or at technical meetings. The June issue will include all papers published or presented in 1946 up to and including June 30. Subsequent issues will cover papers appearing in the quarter ending with the month of issue.


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