RP513

THE CAUSE AND ELIMINATION OF NIGHT EFFECTS IN RADIO RANGE-BEACON RECEPTION

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ABSTRACT

A new antenna system is described for use at radio range-beacon stations which eliminates the troublesome night effects hitherto experienced in the use of the range-beacon system. Considerable data, comprising ground and flight measurements, are given on both aural and visual type range beacons using the present loop transmitting antennas, which show the severity of the night effects encountered. Because of the magnitude of these effects, particularly in mountainous country, the range-beacon course often becomes of no value beyond about 30 miles from the beacon station. With the new antenna system developed, referred to as the transmission-line antenna system, the beacon course is satisfactory throughout its entire distance range, the night effects becoming negligible. Experimental data are given comparing the performance of the transmission-line and loop antenna systems under nearly identical conditions.

The paper also includes a theoretical analysis explaining the occurrence of night effects with the range-beacon system when using loop transmitting antennas. The analysis shows that the night effects are produced by horizontally polarized components in the sky wave which are radiated from the horizontal elements of the loop transmitting antennas. The transmission-line antenna system employs four vertical antennas placed on the corners of a square; two of the antennas on the diagonal corners working together to replace one of the loop antennas of the present range-beacon stations, while the other two replace the other loop antenna. The principle upon which the antenna system is based has been the subject of considerable experimentation in England for some time. The arrangement employed differs in important particulars from ones previously used, and is the result of trial of a number of expedients. The significant element of the system consists of the use of transmission lines for confining the radiation to the four vertical antennas.

CONTENTS

I. INTRODUCTION

During the past year, the research division of the Aeronautics Branch, Department of Commerce, located at the Bureau of Standards, has carried on an extensive research program on the problem of night effects; that is, the course variations occurring in the use of the radio range-beacon system at night. The characteristics and cause of the night effects have been determined, and a new transmitting antenna system has been developed for the range-beacon stations which eliminates these troublesome effects. For reasons which will become apparent from the description of the new antenna system, it has been named the transmission-line antenna system (abbreviated TL-antenna). This paper presents a theoretical analysis of the phenomena underlying the occurrence of night effects with the range-beacon system and gives full details of the new transmitting antenna, including the experimental work leading up to its development. In addition, the results are given of a large number of measurements on range-beacon stations using the present loop-antenna system and on two experimental installations using the new transmission-line antenna system. The data include measurements at night at varying distance from the respective beacon stations, both on the ground and in the air, and give comparative results under nearly identical conditions for the conventional loop antenna system and for the new TL-antenna system.

1. NATURE OF NIGHT EFFECTS

Night effects are inherent in practically every system of radio direction determination which makes use of the directional properties of the loop antenna, and have been the subject of considerable study and experimental work for some time, notably in England. Night effects in connection with the use of the radio range-beacon system in the United States were first observed by Pratt,[1] in 1927, in night flights on the aural type beacon at Bellefonte, Pa. With the radio range beacon these effects take the form of rapid and irregular variation of the indicated beacon courses, so that an airplane following the true course will receive, in varying amounts, off-course indications to the right, off-course indications to the left, and on-course indications. When the fluctuations of the indicated course are less than about $\pm 10°$, it is feasible for the pilot to follow the true course by averaging a large number of successive course indications, but only with a fair degree of accuracy. When the course variations exceed 10° by an appreciable amount, it is not possible for the pilot to follow the true course, even by the averaging process. Such large night effects are common in mountainous country, beginning at distances from 20 to 50 miles from the range-beacon station. Beyond about 30 miles the beacon course becomes of no value. These facts, definitely established by the research work of the past year to be characteristic of range beacons employing the present loop antenna system, indicated clearly that the range beacons would be of little use at night in mountainous terrain, where they are most needed, unless means could be developed to elminate these errors.

[1] H. Pratt, Apparent Night Variations With Crossed-coil Radio Beacons, Proc. I. R. E., vol. 16, pp. 652–657, May, 1928.

2. FACTORS INFLUENCING MAGNITUDE OF NIGHT EFFECTS

It has been found that the magnitude of the night effects is greatest during winter nights, next during summer nights, next during winter days (particularly within a few hours of sunrise and sunset), and, finally, is least during summer days. Because of the negligible occurrence of course variations obtained during the daytime, the term "night effects" has been applied to this phenomenon. Other factors, in addition to time and season of the year, have considerable influence upon the magnitude of the night effects. Some of these are: Nature of the terrain over which the range-beacon wave is transmitted, location of the transmitting and receiving points, distance of the receiving location from the transmitting station, and form of the receiving antenna. A qualitative measure of the degree of influence of these factors will appear from the data given in this paper. In general, the night effects are most pronounced over mountainous terrain, and the magnitude of the course variations increases with distance of the receiving point from the transmitting station. The influence of time of day, season of year, nature of the terrain, and distance from the transmitting station is about the same as in radio direction finding, thus bearing out conclusions by Smith-Rose [2] on the reversibility of night effects in directional reception and transmission.

It is interesting to note that the type of signal used for the course indications has no bearing upon the magnitude of the night effects. A series of ground measurements made on the Washington and Bellefonte aural beacons and the College Park and Bellefonte visual beacons, at distances from the respective beacon stations ranging from 35 to 100 miles, showed the magnitude of course variations with the two types of beacons to be the same. Full corroboration of these results was later obtained in a large number of night test flights on the range beacons located on the Midcontinent Airway between Albuquerque, N. Mex., and Los Angeles, Calif. The range beacons were tested under identical conditions, first using aural and then visual operation, and the average night effects obtained were the same with both. In addition, a special test was carried out to examine the phenomena underlying the night effects. This test showed that the night effects were due entirely to the type of transmitting antenna employed, and were therefore the same for the two types of beacons, since they employ the same antenna systems.

Typical data which lead to the conclusions outlined in the foregoing discussion on the properties and behavior of night effects are given in the next section.

II. DATA ON NIGHT EFFECTS FOR RANGE BEACONS USING LOOP TRANSMITTING ANTENNAS

1. GROUND AND FLIGHT OBSERVATIONS ON AURAL AND VISUAL TYPE RADIO RANGE BEACONS

The data given in Figure 1 (*a*) to (*d*), inclusive, represent typical night effects obtained during ground observations on the Washington (D. C.) aural and the College Park (Md.) visual radio range beacons.

[2] R. L. Smith-Rose, Radio direction Finding by Transmission and Reception, Proc. I. R. E., vol. 17, pp. 425–478, March, 1929.

Figure 1 (*a*) and (*b*) are for the aural beacon and Figure 1 (*c*) and (*d*) for the visual beacon. The beacons were operating on 272 and 290 kc, respectively. The receiving point was, respectively, at 60 and 95 miles from the beacon stations, being chosen so that at least one mountain range lay between the receiving and transmitting points. A large number of observations of this type were taken on

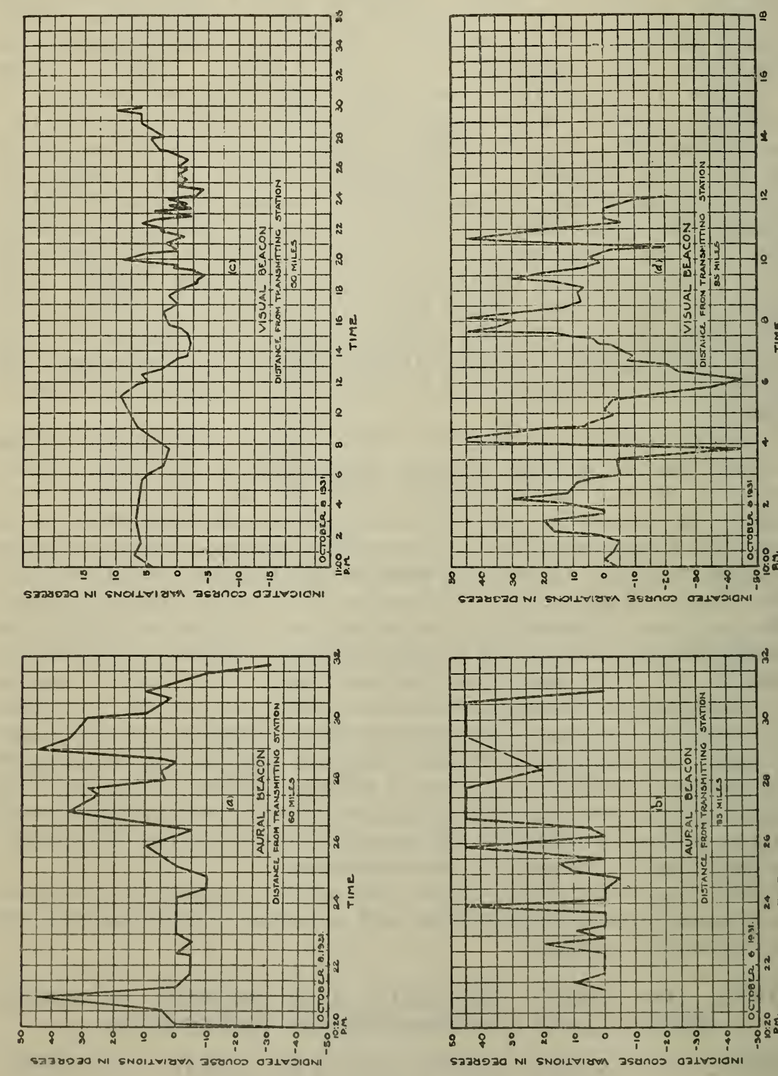

FIGURE 1.—*Night effects from the Washington (D. C.), aural and College Park (Md.) visual radio range beacons when using loop antenna transmission*

the two beacon stations mentioned and also on the aural and visual type beacons at Bellefonte, Pa. (284 and 326 kc respectively), to secure information on the magnitude of the night effects to be expected with the two types of beacons at varying distances from the stations. Measurements were made at distances ranging from 30 to 100 miles. These measurements showed that the night effects for the two types of beacons, although apt to be quite different over a short interval, became very nearly equal when averaged over a longer period of time. Also the magnitude of the night effects increased with increasing distance from the transmitting stations.

Additional data for night effects from both types of beacons over mountainous terrain are given in Figure 2. The measurements were taken at St. Thomas, Pa., chosen because of its location in the Allegheny Mountains and because the courses from the four stations could be made to intersect at that point without interrupting service from the aural beacons. St. Thomas is about 70 miles south of Bellefonte and 80 miles northwest of Washington.

A study of Figures 1 and 2 shows that the average night effects are very nearly of the same magnitude for either aural or visual type beacons. As will be shown later in this paper this is in strict accordance with the theoretical considerations of the problem. Corroboration of this conclusion was had from the results of night flight tests on the

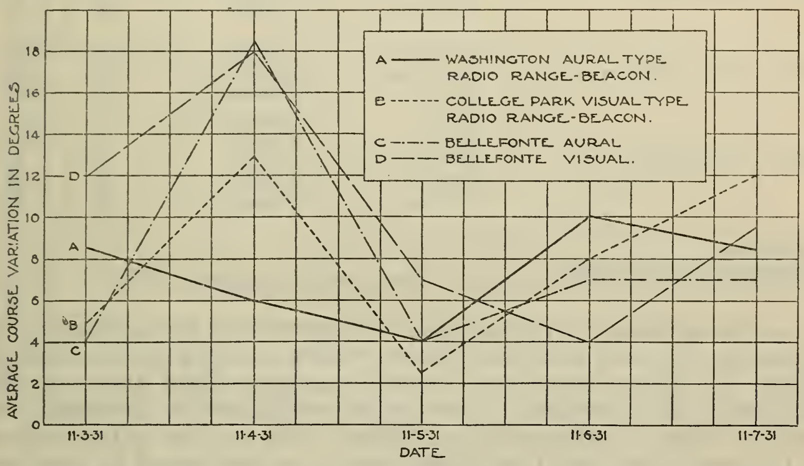

FIGURE 2.—*Summary of data on the Washington aural beacon, the College Park visual beacon, and the Bellefonte aural and visual beacons taken at St. Thomas, Pa., 70 miles south of Bellefonte and 80 miles northwest of Washington*

Courses from all the beacons intersected at this point.

radio range beacons between Albuquerque, N. Mex., and Fontana, Calif., on the Midcontinent Airway. The tests on each of these range beacons comprised four complete night flights, two of which were with aural and two with visual operation. The procedure was to follow the west course of each beacon away from the station using aural operation, return using visual operation, follow the east course away from the station using visual operation and return again to the station using aural operation. In this way the behavior of the night effects with each type of operation under nearly identical conditions could be determined. The essential results obtained are given in Table 1. Referring to Table 1, the distance of no night effects was considered to be that in which the variation of the indicated beacon course was less than ±3°. The limit of useful distance range of the course was determined on the basis of two criteria; first, that the course variations exceeded ±12°, and secondly that off-course excursions of 6 to 8 miles produced no apparent change in the average course indication.

TABLE 1.—*Representative results of night flights on Midcontinent Airway radio range beacons showing night effects as a function of type of beacon operation (aural or visual) and of distance from the beacon station*

Date	Range-beacon station	Course	Type of operation	Distance of no night effects	Limit of useful distance range
				Miles	*Miles*
1932 Mar. 28	Albuquerque, N. Mex	West	Aural	25	40–45
		do	Visual	25	40
		East	Aural	20	40
		do	Visual	20	40
Apr. 4	Winslow, Ariz	West	Aural	30	[1] 70
		do	Visual	30	[1] 70
		East	Aural	30	70
		do	Visual	30	70
Apr. 13	Kingman, Ariz	West	Aural	15–20	35–40
		do	Visual	15–20	35–40
		East	Aural	10	35
		do	Visual	10	35
May 3	Daggett, Calif	Southwest	Aural	15	[2] 40
		do	Visual	15	[2] 40
		Southeast	Aural	15	[1] 70
		do	Visual	15	[1] 70
May 15	Fontana, Calif	West	Aural	6	([3])
		do	Visual	6	([3])
		East	Aural	6	15
		do	Visual	6	15
		North	Aural	10	20
		do	Visual	10	20

[1] Estimated.
[2] Course ends at Mount Baldy.
[3] Multiple and bent course effects too severe to permit estimate of night effects.

Further evidence of the increase of magnitude of night effects with increasing distance from the beacon station is given by the data in Figure 3. These data were secured in night flight tests on the Bellefonte visual beacon. The course variations are averaged for each 10 miles of flight from the station. The method of test was to fly the true course over the lighted airway (as determined by previous flight tests during the daytime) and to record departures of the course indications from an "on-course" reading. Readings were taken only for each change in course indication. The number of readings for a given 10-mile period therefore serves as a measure of the frequency of occurrence of the night effects.

2. VARIABLE NATURE OF NIGHT EFFECTS

Besides showing the relation between magnitude of night effects and distance from the station Figure 3 also indicates the difference in the magnitude of night effects obtained on different nights. Table 2 gives a summary of measurements on the College Park visual beacon over a period of about a month. Most of the measurements were made at Front Royal, Va., located 65 miles due west of College Park beyond the first ridge of the Blue Ridge mountains. The time of each test was from about 8 p. m. to midnight except where otherwise stated in Table 2. During six of the tests simultaneous measurements were made (on a 90° course of the College Park beacon) at Richmond, Va., about 105 miles south of College Park over flat terrain. The third column of Table 2 gives the average of all the course variations observed during a given night's test. The number of readings taken during each test is given in the fourth column. The fifth column gives the percentage of these readings

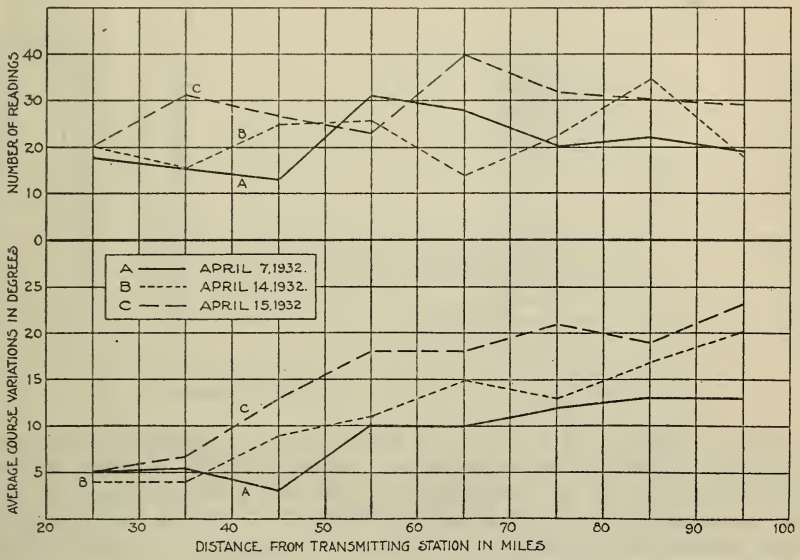

FIGURE 3.—*Summary of night observations in an airplane on the night effects from the Bellefonte visual radio range beacon using loop transmitting antennas*

These graphs show the average course variations as a function of distance from the beacon station.

for which the course variations were ±45°. The third, fourth, and fifth columns combine to give a fair picture of the severity and frequency of occurrence of the course variations. The 45° readings represent the maximum course variations observed; being the maximum off-course indication which can be read with either the aural or visual type beacon. With the radio range-beacon system, a swing off-course greater than 45° by a given amount gives the same course indications as a swing less than 45° by the same amount. Thus, for example, a 60° swing is of necessity recorded and plotted as a 30° swing.

TABLE 2.—*Summary of measurements taken at Front Royal and Richmond, Va., on College Park visual radio range beacon*

Front Royal is 65 miles due west of College Park beyond the first range of the Blue Ridge Mountains, while Richmond is 105 miles south of College Park over flat terrain.

Date	Receiving location	Average course variations (in degrees)	Total readings	45° readings
1932				*Per cent*
Jan. 2	Front Royal, Va	14	243	8.6
Jan. 7	do	26	225	27.5
Jan. 8	do	20	350	20.3
Jan. 13	do	21	420	16.0
Jan. 14	do	24	290	15.0
Jan. 15 [1]	do	18	198	19.2
Jan. 15 [2]	do	29	262	44.3
Feb. 2	do	10	383	2.9
Feb. 3	do	8	301	.3
Feb. 4	do	10.5	191	2.6
Feb. 5	do	14	415	10.3
Feb. 6	do	14	351	10.8
Feb. 9	do	7	286	0
Feb. 2	Richmond, Va	3.7	216	0
Feb. 3	do	25	312	23.0
Feb. 4	do	23	66	16.7
Feb. 5	do	12	167	11.4
Feb. 6	do	11	416	6.5
Feb. 9	do	8	311	1.6

[1] 8.38 to 9.52 p. m. [2] 10.10 to 11.25 p. m.

From a study of Table 2 it is seen that at a given location the magnitude of night effects varies from night to night, or even during different periods of the same night. (See the data for January 15.) It is interesting to note that on the whole the average magnitude of course variations at Richmond was not the same as at Front Royal on corresponding nights.

A summary of similar data for the Bellefonte visual beacon, using loop antennas, is given in the third and fourth columns of Table 5. The receiving point was at Sunbury, Pa., about 50 miles east of Bellefonte and separated from Bellefonte by several mountain ranges. The variability of the magnitude of the night effects from night to night is again evident. In interpreting the data given in the tables, particularly with regard to the numerical average of the course variations for a given run, it should be remembered that course variations greater than 45° by a given amount are recorded as variations less than 45° by the same amount. In this way the value of the average given for nights having large night effects is smaller than the true average. A special test was made to determine the extent of course variations exceeding 45°. The data obtained is plotted in Figure 4, and was secured by orienting the beacon space pattern so that the receiving point was 45° to one side of a true course. On-course indications then corresponded to 45° variations and off-course indications (to the other side of the course) corresponded to variations greater than 45°. Obviously, 90° variations were the maximum that could be secured with this test. As will be seen from Figure 4, a number of such variations were observed.

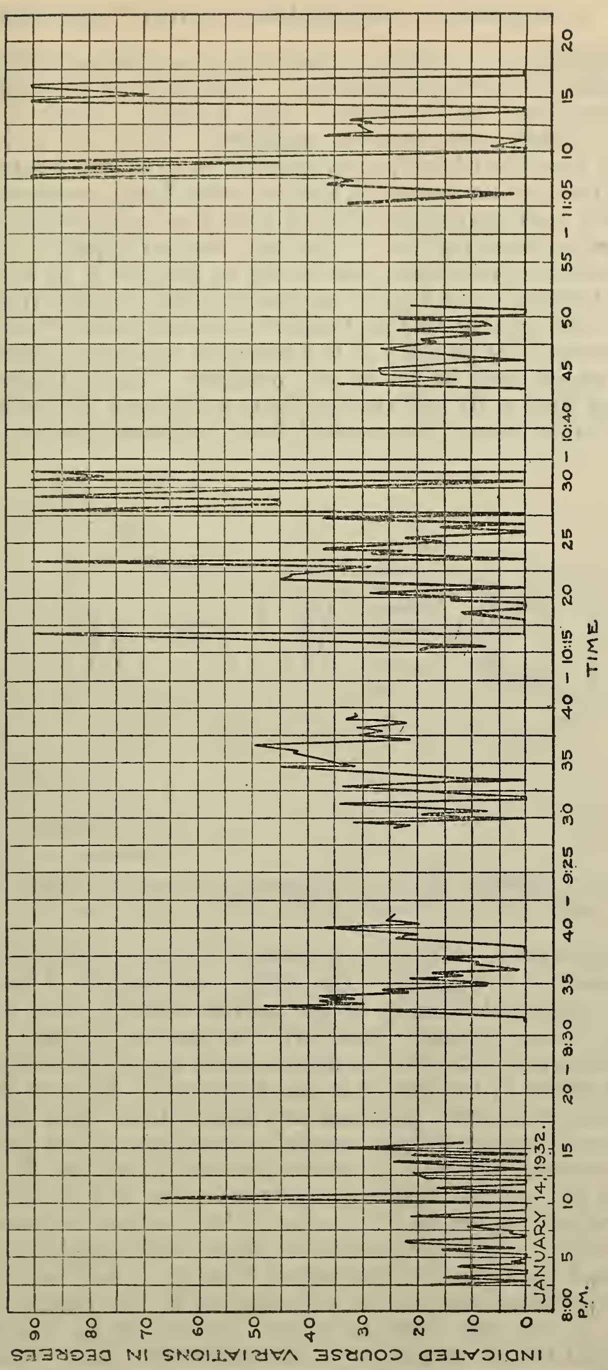

FIGURE 4.—*Graph showing 90° night course variations*

Observations taken on College Park visual radio range beacon at receiving point 65 miles west of College Park

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3. AUTOMATIC RECORDING OF NIGHT EFFECTS

The data on night effects at Sunbury, Pa., were secured by the use of automatic recording equipment. This method is applicable only to measurements on the visual type beacon. Figure 5 shows the electrical circuit arrangement employed. A Leeds and Northrup frequency recorder of the proportional step type was adapted for this purpose, the galvanometer of this recorder being operated from the output of a reed converter which in turn was connected in the output of a beacon receiving set. The set was equipped for automatic volume control operation. Referring to Figure 5, R_1 is a 200-ohm resistor attached to the wheel in the recorder which drives the pen. The movable contact to this resistor is at its center when the pen is at the center of the paper. R_2 is a 400-ohm resistor also with a sliding contact, which may be set in any position. The galvanometer field is supplied from a 10-volt storage battery through a 100-ohm resistor, and the bridge circuit is supplied from the same battery through a

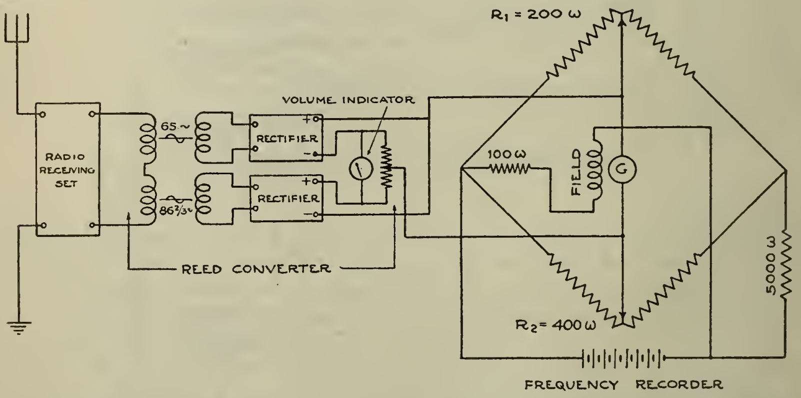
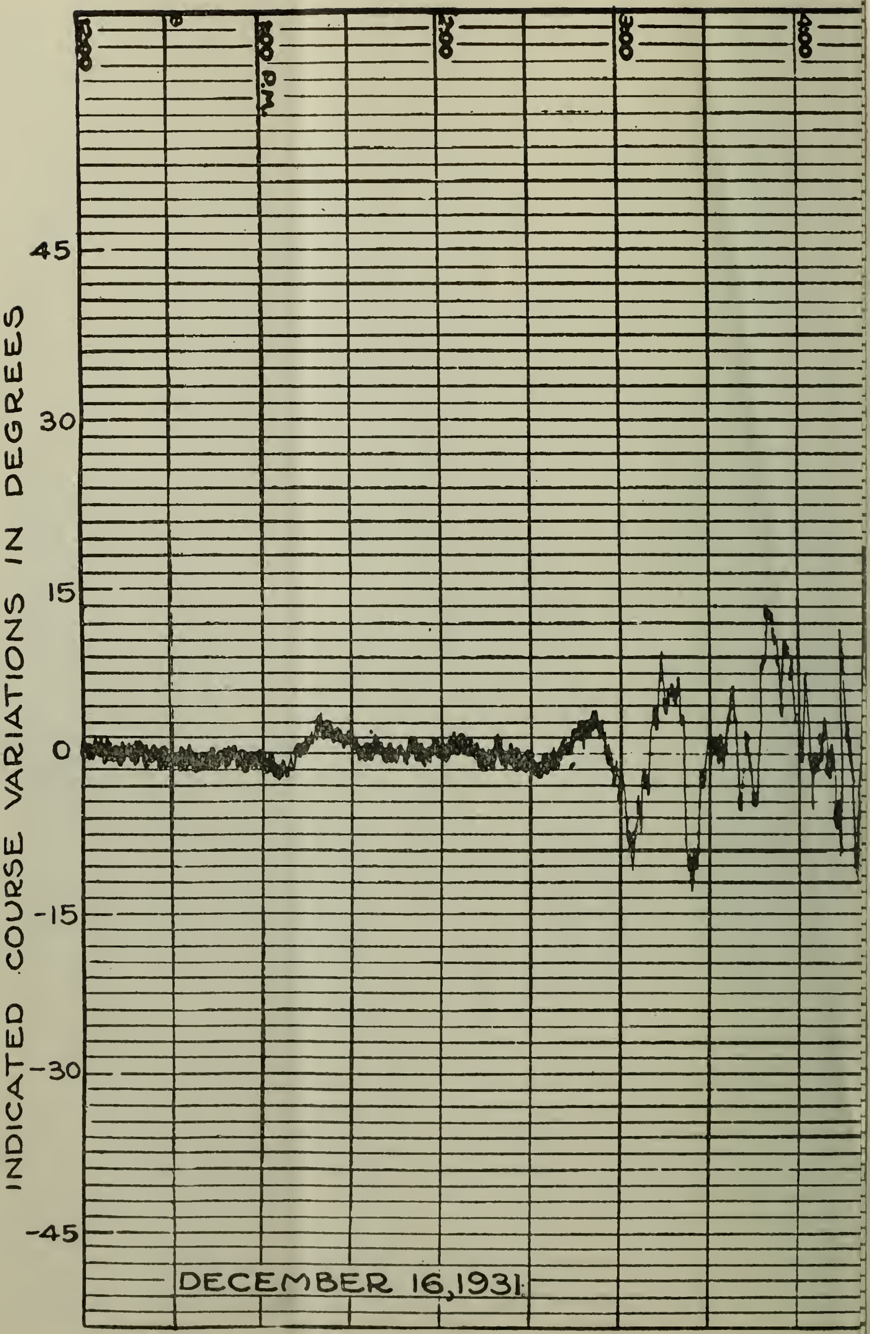


FIGURE 5.—*Electrical circuit arrangement for securing automatic records of night course variations with the visual type radio range beacon*

5,000-ohm resistor. The tap on resistor R_2 is set so that the pen runs at the center of the paper. The differential output of the reed converter is connected directly to the galvanometer, which replaces the course indicator normally used with the reed converter. When the input to the reed converter is an on-course signal, the output is zero, and the balance of the bridge is not disturbed. As soon as the input to the reed converter becomes anything other than an on-course signal, the converter output causes a deflection of the galvanometer and the recorder operates to move the tap of resistor R_1 to a point such that the voltage across the galvanometer due to the unbalance of the bridge is equal and opposite to the voltage impressed by the reed converter. The galvanometer than comes back to its normal position and the motion of the tap on R_1 stops. As the pen is carried by the same wheel that controls the tap on R_1, the record will show a deflection of the pen from its center position by an amount that is proportional to the output from the converter. The volume indicator used in conjunction with the reed converter serves as a check of the degree of automatic volume control attained with the receiving



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set, so that the record may be corrected for changes in volume if found necessary.

A typical record obtained with this arrangement is shown in Figure 6. The record represents a continuous 24-hour run on the Daggett (Calif.) range beacon taken on December 16 to 17, inclusive, 1931. The receiving station was at Kingman, Ariz., about 175 miles from Daggett. This record is of interest in that it shows the magnitude of the course variations as a function of time of day (during the late fall season). Note that the night effects begin about two hours before sunset and occur throughout the night until about one hour after sunrise.

III. THEORY OF NIGHT EFFECTS

The theory underlying the production of night effects with the radio range beacon system using loop transmitting antennas will now be briefly outlined. The three component electric fields radiated from a loop transmitting antenna are:[3]

(*a*) Vertically polarized electric field

$$E_1 = E_0 \cos\alpha\cos\beta \tag{1}$$

(*b*) Horizontally polarized electric field, in plane of propagation of radio wave

$$E_2 = E_0 \cos\alpha\sin\beta \tag{2}$$

(*c*) Horizontally polarized electric field, perpendicular to plane of propagation

$$E_3 = E_0 \sin\alpha\sin\beta \tag{3}$$

In these equations α is the angle between the plane of propagation and the plane including the loop antenna, while β is the angle of elevation. The plane of propagation is the vertical plane containing the transmitting and receiving points. As will be shown, it is the horizontally polarized electric field component (E_3) perpendicular to the plane of propagation, which is responsible for the production of night effects. It is important to note that this component is produced entirely by radiation from the horizontal wires of the transmitting loop antenna.

Consider now the electric field received at a distant receiving point having substantially zero angle of elevation with respect to the transmitter. In the daytime, the first component only is received. This is the ground wave. The voltage induced in a vertical receiving antenna by the ground wave is given by

$$E_A' = K_0 E_0 \cos\alpha\cos\omega_0 t \tag{4}$$

where K_0 is a factor incorporating the efficiency of the receiving antenna and attenuation of the ground wave and $\omega_0 = 2\pi \times$ frequency. At night, in addition to the ground wave, an indirect wave reflected from the Kennelly-Heaviside layer is received. This wave contains all three component electric fields. It is well known, however, that the state of polarization of the electric field in the indirect wave received may be different from that for the field transmitted by the

[3] W. H. Murphy, Space Characteristics of Antennas, J. Frank. Inst., vol. 201, p. 424, 1926.

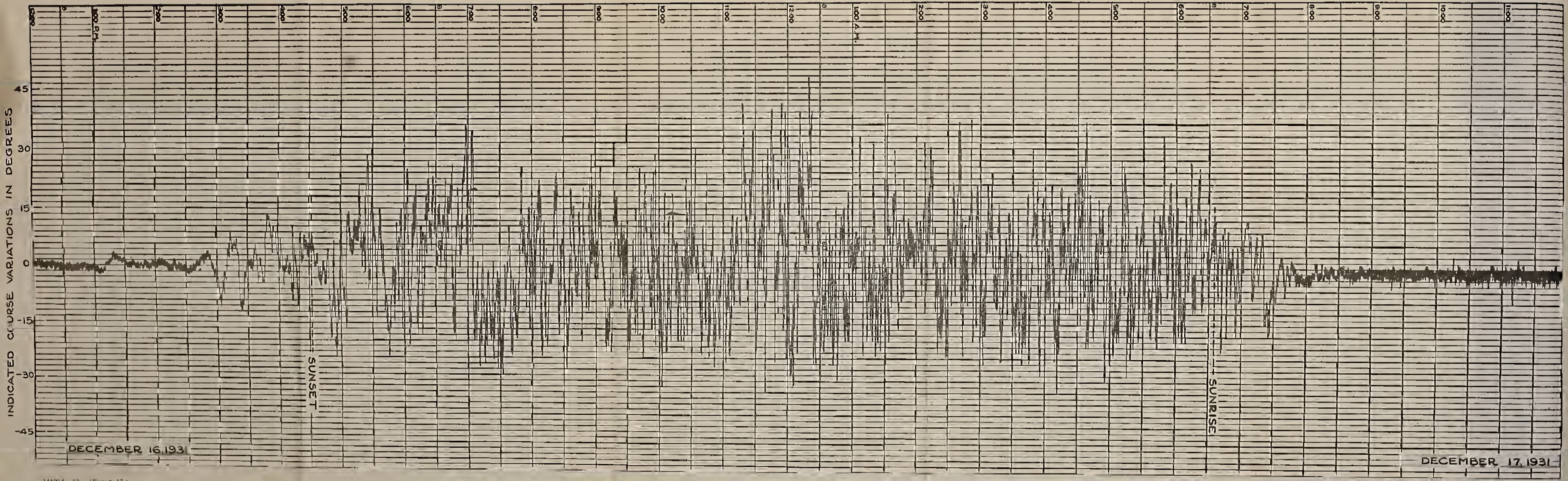

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FIGURE 6.—*Automatic records of the indicated beacon course corresponding to a 24-hour run on the Daggett (Calif.) visual type radio range beacon using loop antenna transmission*

Receiving station at Kingman, Ariz., approximately 175 miles from Daggett.

loop antenna, rotation of the plane of polarization taking place during reflection from the ionized layer. Let us now consider the voltage induced in a vertical receiving antenna by the indirect wave. We will assume that the rotation of plane of polarization occurs about the line indicating direction of propagation of the wave as an axis. Voltage is then induced in the vertical receiving antenna not only by the portion of the first electric field component still remaining vertically polarized but also by the portions of the second and third components which have become vertically polarized due to the rotation of the plane of polarization. The induced voltage becomes:

$$E_A'' = E_0(1+\rho_v)\{K_1 \cos\beta + K_2 \sin\beta\}\cos\alpha\cos(\omega_0 t+\varphi) + E_0(1+\rho_v)\{K_3\sin\beta\}\sin\alpha\cos(\omega_0 t+\varphi) \quad (5)$$

where

ρ_v = coefficient of reflection at the ground for vertically polarized waves arriving at an angle of incidence $(90° - \beta)$.

K_1, K_2, and K_3 are factors by which the original electric field components must be multiplied to obtain the portions remaining in or rotated into the vertical plane. These factors also include the effect of attenuation.

ϕ = time phase angle between indirect and ground waves.

The total induced voltage in the vertical receiving antenna produced by the ground and indirect waves is therefore

$$\begin{aligned} E_A = {} & K_0E_0\cos\alpha\cos\omega_0 t \\ & + E_0(1+\rho_v)\{K_1\cos\beta + K_2\sin\beta\}\cos\alpha\cos(\omega_0 t+\varphi) \\ & + E_0(1+\rho_v)\{K_3\sin\beta\}\sin\alpha\cos(\omega_0 t+)\varphi \end{aligned} \quad (6)$$

Similarly, the voltage induced in a vertical receiving antenna by a second loop transmitting antenna crossed at right angles to the first is given by equation (7).

$$\begin{aligned} E_B = {} & K_0E_0\sin\alpha\cos\omega_0 t \\ & + E_0(1+\rho_v)\{K_1\cos\beta + K_2\sin\beta\}\sin\alpha\cos(\omega_0 t+\varphi) \\ & - E_0(1+\rho_v)\{K_3\sin\beta\}\cos\alpha\cos(\omega_0 t+\varphi) \end{aligned} \quad (7)$$

Equations (6) and (7) represent the two voltages induced in a vertical antenna by the wave radiated from a radio range-beacon station. A beacon course is produced when the two induced voltages are equal. During the daytime (since only the ground wave is received) this occurs when $|\cos\alpha| = |\sin\alpha|$ or at $\alpha = 45°$, 135°, 225°, and 315°. At night, courses occur when the right-hand sides of equations (6) and (7) are equal. Assuming values of

$$\beta = 60° \qquad K_0 = 1 \qquad E_0 = 1$$
$$1+\rho_v = 1.9 \qquad K_1 = K_2 = K_3 = 0.5$$
$$\varphi = \pi$$

we obtain

$$E_A = -0.3\cos\alpha - 0.82\sin\alpha \quad (8)$$

$$E_B = -0.3\sin\alpha + 0.82\cos\alpha \quad (9)$$

Solving for $|E_A| = |E_B|$ gives

$$\alpha = 25°,\ 115°,\ 205°,\ \text{and } 295° \quad (10)$$

The effect of the indirect wave is thus to cause a virtual rotation of the beacon space pattern. The rotational effect is obviously produced by the third terms of the right-hand sides of equations (6) and (7). These correspond to the electric field components which were originally horizontally polarized perpendicular to the plane of propagation when transmitted from the loop antenna, but which have been rotated in part into the vertical plane through rotation of the plane of polarization of the total electric field. The degree of rotation of the beacon space pattern will obviously depend upon the magnitudes of these components in relation to the other components represented in equations (6) and (7), and will vary irregularly as this relation changes. Such change occurs whenever the indirect wave changes in magnitude, phase, or state of polarization, all of which depend upon the refractive properties of the ionized layer.

It is to be noted that the above conception of a rotating or swinging beacon space pattern is not strictly correct, since it requires that the conditions governing the reflection of the sky wave at the ionized layer be the same in all directions about the range-beacon station. However, the analysis outlined gives a fair conception of what occurs in so far as a given receiving point is concerned.

IV. EXPERIMENTAL WORK ON SPECIAL TRANSMITTING ANTENNAS

Since it is apparent from the above analysis that the night effects are produced by the horizontally polarized electric field components radiated from the horizontal members of the transmitting loop antennas, the indicated cure is to eliminate or neutralize such radiation.

1. EARLY WORK

The influence of the horizontal elements of a loop antenna upon the production of night effects was determined a number of years ago in application to direction finding systems using loop antennas for reception. An antenna having the same directional properties as the loop antenna but free from the effects of the horizontal elements was described in a British patent [4] issued to R. E. Ellis in 1919. The principle involved has also been variously attributed to F. Adcock and T. L. Eckersley.[5] Adcock was apparently the first to make experiments based on the principle. The application of the same principle to directional transmitting antennas appeared in a British patent [6] issued to J. Robinson, H. L. Crowther, and W. H. Derriman in 1923. Considerable study and experimental work on the development of this type of antenna system for direction finding purposes [7] and for use with the rotating beacon transmitter [8] have been carried on by Smith-Rose and Barfield since 1926. The antenna system described in this paper is based on the same fundamental principle. However, the arrangement employed differs in important particulars from ones previously used and is the result of actual trial of a number

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[4] British patent 130490.
[5] T. L. Eckersley, The Effect of the Heaviside Layer on the Apparent Direction of Electromagnetic Waves, Radio Review, vol. 2, pp. 60 and 231, 1921.
[6] British patent 198522.
[7] R. L. Smith-Rose and R. H. Barfield, The Cause and Elimination of Night Errors in Radio Direction-Finding, J. I. E. E., vol 64, pp. 831–838, 1926. R. H. Barfield, Recent Developments in Direction Finding Apparatus, J. I. E. E., vol. 68, pp. 1052–1069, 1930.
[8] R. L. Smith-Rose, A Theoretical Discussion of Various Possible Aerial Arrangements for Rotating Beacon Transmitters, J. I. E. E., vol. 66, pp. 270–274, 1928.

of expedients. Several of the older arrangements were tried and found unsuitable.

2. SPECIAL TEST

Before beginning a detailed account of the experimental work leading up to the development of the new antenna system, it is of interest to describe a special test from which representative results are shown in Figure 7. This test was devised to determine whether other factors in addition to the rotational effect described in Section III contributed to the production of night effects, particularly with the visual type beacon. It was considered necessary to prove that the influence of selective audio fading, phase distortion, and other similar phenomena was negligible before proceeding with the problem of eliminating the radiation from the horizontal elements of the loop transmitting antennas. The test consisted of observing the apparent

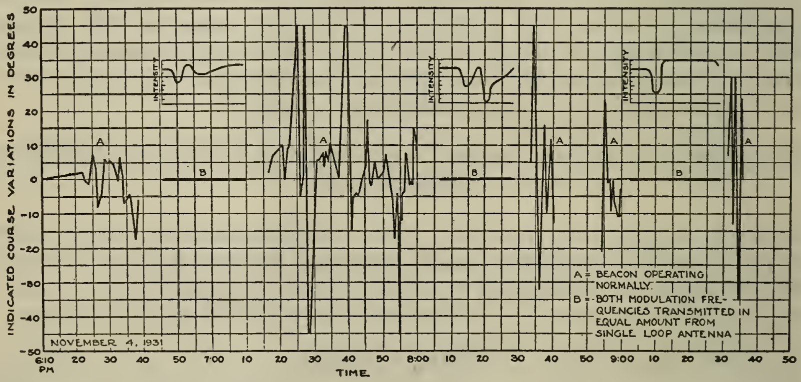


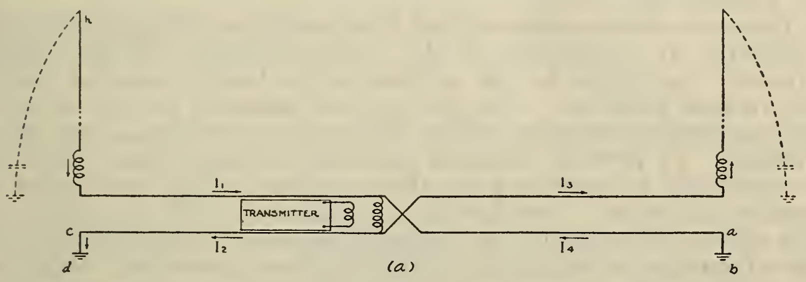
FIGURE 7.—*Special test showing negligible influence upon the production of night effects of all factors other than the rotational effect described in Section III*

Observations taken on College Park visual radio range beacon at receiving point 80 miles northwest of College Park

beacon course produced at a distant receiving point when only one loop antenna was being used for transmission, the loop antenna current being modulated in equal amounts at the two beacon modulation frequencies. For this condition an on-course reading should be obtained at the receiving point at all times (night or day), unless selective audio fading or some other similar factor entered into the picture. Rotation of the figure-of-eight transmission characteristic could result only in equal changes in the intensity of the two audio-frequency signals received, the two signals remaining equal to each other throughout. The results obtained indicated definitely that the rotational phenomenon was the only factor of importance in the production of night effects. The recording of night effects (with the beacon operating normally) immediately before and after this special test insured that the test was being carried on under conditions conducive to the production of night effects. The presence of fading of the received signal intensity during this test (see fig. 7) corroborated this conclusion.

3. EXPERIMENTAL WORK ON EARLY ARRANGEMENTS

The two principal older arrangements which were considered for possible use with the radio range beacon are shown in Figure 8 (*a*) and (*b*). In each case only one-half of the complete antenna system required for a range-beacon installation is shown, and thus corresponds to one loop antenna of the present range-beacon installations. Figure 8 (*a*) represents the original antenna of Adcock except that loading coils are inserted in each vertical antenna circuit to resonate it to the radio-frequency of the transmitter. It will be observed that the two vertical antennas are so coupled to the transmitter that the current in one antenna is in opposite direction to the current in the other



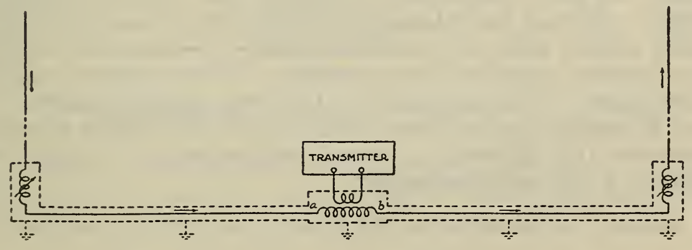


FIGURE 8.—*Early transmitting antenna arrangements tried at College Park, Md., but found unsuitable*

(*a*) Adcock arrangement; (*b*) Marconi adaptation of Adcock antenna

antenna. This corresponds exactly to the conditions in the vertical wires of the loop antenna. The electric field components radiated from this antenna are given by equations (11) and (12) and correspond to the components E_1 and E_2 for the loop antenna. (See equations (1) and (2).)

$$E_1 = E_o \cos \alpha \cos^3 \beta \tag{11}$$
$$E_2 = E_o \cos \alpha \sin \beta \cos^2 \beta \tag{12}$$

The horizontal component E_3 is not transmitted with much intensity, since the currents in the horizontal wires nearly cancel each other, as may be seen by reference to Figure 8 (*a*). Consequently, the presence of the indirect wave at the receiving point no longer produces rotation of the transmission characteristic. It is interesting to note that not only is the component field which produces night effects eliminated with this antenna arrangement, but the other component fields are reduced in the indirect wave (as compared with loop antenna transmission) in the ratio $\cos^2 \beta$. One of the cosine factors results from the directivity in the vertical plane of a single vertical antenna and the second cosine factor from the differential action of the two vertical antennas acting together. An antenna of the type shown in Figure 8 (*a*) was constructed at College Park, Md., but was not used extensively because of difficulties of adjustment. In order that $I_1 = I_2$, and $I_3 = I_4$, it was necessary to insert balancing impedances in the ground leads *ab* and *cd*. The procedure required for determination of the correct values for these impedances was considered too difficult for practical use.

The next antenna arrangement tried is shown in Figure 8 (*b*) and represents an adaptation of the Adcock antenna by the British Marconi Co., except for the addition of the loading coils for tuning the vertical antennas. The two vertical antennas are fed in series by means of the coupling coil *ab*, which may be the goniometer rotor winding. To prevent radiation from the horizontal lead, this lead is completely inclosed in a metallic conductor which is grounded at regular intervals. Considerable experimental work was done on this antenna arrangement at College Park, since it appeared to afford the advantages of simplicity of adjustment and operation. In actual use, the adjustment was found more difficult than expected, particularly in the tuning of the two vertical antennas of each pair to the frequency of the transmitter. Tuning one vertical antenna by adjusting its loading inductance would not only change the resonance frequency of the pair, but would also alter the relative voltages of the two vertical antennas above ground. This in turn would result in a departure of the currents in the two vertical antennas from equality in magnitude and from their proper 180° phase relationship. To overcome this difficulty it was found necessary to tune the two antennas of a pair simultaneously.

4. NIGHT OBSERVATIONS ON MARCONI-ADCOCK ANTENNA

Three series of measurements on night effects with this antenna system were made. In the first tests, the horizontal lead was supported on short posts 3 feet high. The shielding arrangement comprised 4 wires placed along a cylinder 1 foot in diameter, with the horizontal lead along the axis of the cylinder. The shielding wires were connected together at each 10-foot interval and were grounded at the two ends and at the center to the station ground wire system. To secure an idea of the reduction in night effects obtained, the measurements made included periodic observations on the College Park service beacon which uses loop transmitting antennas. A summary of the comparative night effects observed is given under Test I of Table 3. In the second series of tests, the horizontal feeder was inclosed in a lead sheath laid along the ground and connected at its two ends and center to the station ground wire system. The results obtained, in comparison with loop antenna transmission, are given under Test II of Table 3. In the third series of measurements, the station ground wire system was extensively improved. The normal station ground system consisted of two concentric circles, 75 and 150 feet in diameter, interconnected by eight radial spokes which joined directly underneath the central beacon tower. Three additional circles, 40, 120, and 180 feet in diameter and eight additional spokes were added. Also, ground rods were provided at 10-foot intervals along each lead sheath, the lead sheath being connected to these ground rods as well as to the improved ground system. The results obtained are tabulated under Test III in Table 3. In consequence of the lack of improvement in freedom from night effects, it was concluded that a totally different arrangement, other than shielding, would be required for eliminating radiation from the horizontal elements of the transmitting antenna.

Table 3.—*Summary of night effects observed on Marconi-Adcock antenna system in comparison with the conventional loop antenna transmission*

The transmitting stations were located at College Park, Md., and the receiving point at Front Royal, Va., 65 miles due west of College Park.

Test	Date	Type of antenna	Average course variations (in degrees)	Total number of readings	45° readings
	1932				*Per cent*
I	January 2	Marconi-Adcock	6.5	238	0
		Loop antenna	14.0	243	8.6
II	January 7	Marconi-Adcock	11.0	218	.5
		Loop antenna	26.0	225	27.5
	January 8	Marconi-Adcock	7.0	205	0
		Loop antenna	20.0	350	20.3
III	January 13	Marconi-Adcock	14.0	407	10.0
		Loop antenna	21.0	420	16.0
	January 14	Marconi-Adcock	13.3	384	5.0
		Loop antenna	24.0	290	14.5
	January 15	Marconi-Adcock	13.2	359	10.0
		Loop antenna	24.0	460	33.5

V. TRANSMISSION-LINE ANTENNA SYSTEM

The antenna arrangement finally adopted is illustrated in Figure 9. As in Figure 8 (*a*) and (*b*), only one-half of the complete transmitting

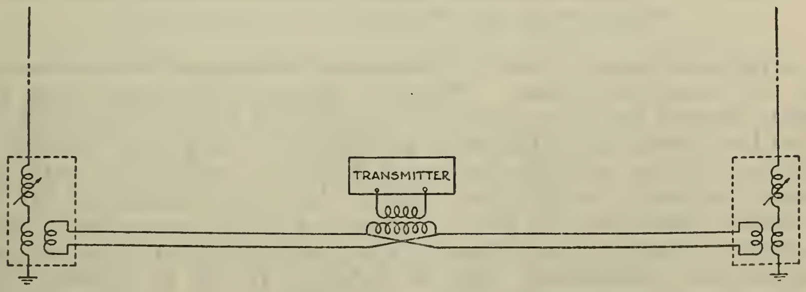


Figure 9.—*Transmission-line antenna developed at College Park, Md.*

antenna system is shown. The significant element of the system is the particular means employed to confine the radiation to the vertical antennas. A 2-wire parallel-conductor transmission line is used to feed power from the goniometer to each vertical antenna, these transmission lines being of such a nature as not to radiate. The efficient means for eliminating horizontal radiation thus provided makes it feasible to reduce the residual errors to much smaller values than was possible with any of the early arrangements. The use of transmission lines also affords efficient transfer of power from the goniometer to the vertical antennas.

1. ELECTRICAL CIRCUIT ARRANGEMENT

Each transmission line is coupled to its vertical antenna by means of an impedance-matching transformer. The secondary winding of this transformer is tapped to permit accurate matching of its input impedance to the surge impedance of the transmission line. In this way reflection from the load end and consequent radiation from the line are minimized. The manner of connection of the input ends of the transmission lines to the range-beacon transmitting set is indicated in Figure 10. The transmitting set and goniometer are unaltered. The change lies in the addition of means for transferring

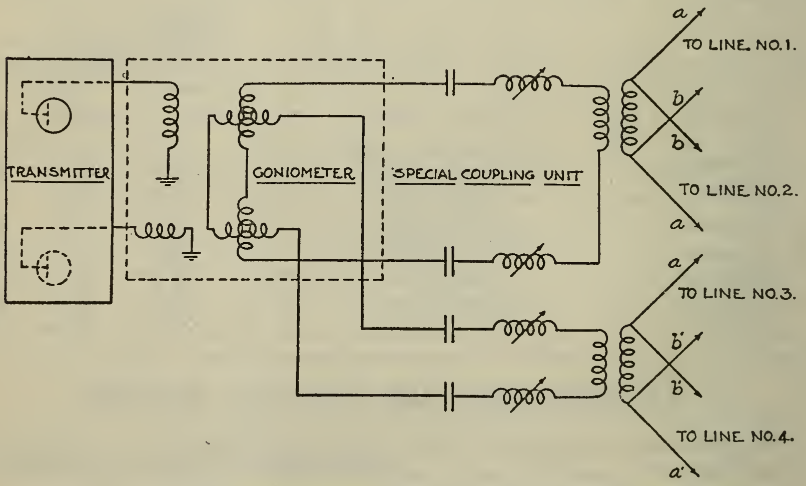


Figure 10.—*Circuit arrangement showing electrical connections of the transmission lines to the radio range-beacon transmitting set*

the radio-frequency power from the rotor windings of the goniometer to the transmission lines. (With the present loop transmitting antenna system each rotor winding is connected directly to one of the two loop antennas.) Referring to Figure 10, each rotor winding is connected in a tuned series circuit which, in conjunction with the radio-frequency transformer shown, has two functions: (*a*) To transfer power from the rotor winding to a pair of transmission lines, and (*b*) to match the impedance of the rotor winding to the impedance of the two transmission lines in parallel. It will be observed, by reference to the letters *a*, *b*, etc., on the leads to the transmission lines that, for each pair of lines, the connections of one transmission line to the radio-frequency transformer are reversed with respect to the connections for the other transmission line. This insures that the currents in the vertical antennas of a pair flow in opposite directions.

2. EXPERIMENTAL INSTALLATIONS

Two experimental installations of the transmission-line antenna system were made and thoroughly tested, one at College Park, Md., where it was developed, and the second at Bellefonte, Pa. The latter installation afforded an opportunity to test the operation of the system in mountainous terrain. A perspective view of the installation at Bellefonte is given in Figure 11. The four vertical antennas shown are spaced at the corners of a square, the pair (*1*, *2*) working together in place of one loop antenna of the present range-beacon antenna system and the pair (*3*, *4*) in place of the second loop antenna. Special attention is paid to increasing the effective capacitance of each vertical antenna to ground, thereby securing as great an antenna current as possible. To this end, each vertical antenna consists of six vertical wires arranged as elements of a cylinder 4 feet in diameter. The vertical antennas are approximately 75 feet high, the two an-

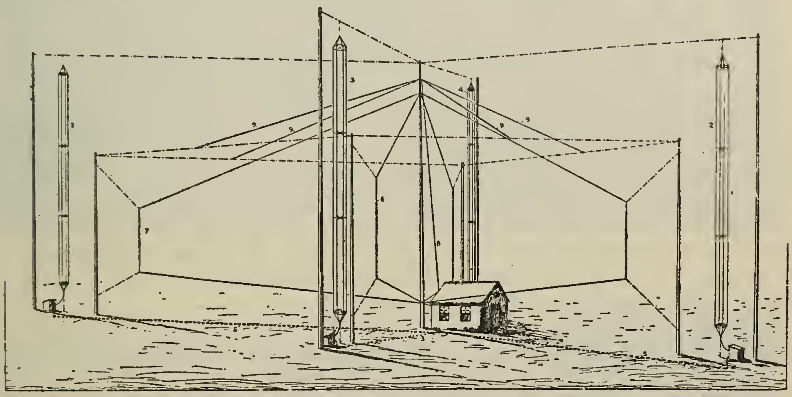


FIGURE 11.—*Perspective view showing the experimental transmission-line antenna installation at Bellefonte, Pa., and also the old loop antenna system, together with its central course-bending antenna*

This installation provided means for measurements of night effects alternately from the two antenna systems. The numerals *1*, *2*, *3*, and *4* designate the four vertical elements of the TL-antenna system; *5*, the transmission lines feeding these antennas; *6* and *7*, the loop antennas; *8*, the down lead of the course-bending antenna; and *9*, the flat-top elements for this antenna.

tennas of a pair being spaced 400 feet apart. To insure a fixed low ground resistance, an individual ground wire system (not shown in fig. 11) is provided at the base of each vertical antenna. Each ground system consists of two concentric circles, one 75 feet and the other 150 feet in diameter. The two circles are interconnected by eight radial spokes which join directly under the vertical antenna. With this set-up, approximately 4 amperes was obtained at the base of each antenna, the radiated field intensity being approximately 75 per cent of that obtained with the conventional loop antenna. To secure greater field intensity and also a more permanent antenna structure, installations of this antenna system on the airways will employ insulated steel towers, 125 feet high and spaced 500 feet apart.

The tuning boxes which house the antenna loading coils and the transmission line coupling transformer are located each near the base of one vertical antenna and are provided with complete shielding to preclude the possibility of stray radiation. The transmission lines consist of ordinary 2-conductor 600-volt cable with a lead sheath, and are buried about 18 inches below the ground surface. The lead sheath provides mechanical protection. Special care must be taken that the lead sheath (particularly that portion near the antenna end) is not electrically connected to the ground wire system, except by way of its continuous connection with the earth; otherwise ground return currents concentrate along the lead sheath thereby reintroducing some night effects.

In addition to the transmission-line antenna system, Figure 11 shows the old loop antenna system, together with the central course-bending antenna which were employed at the Bellefonte visual range beacon station. This installation was left intact to facilitate comparison of the night effects produced by the loop and transmission-line antenna systems. Means were provided for rapid switching of the goniometer output circuits to either antenna arrangement.

Figure 12 shows in greater detail the arrangement employed for supporting the vertical antennas and also (at the left of the photograph) the means for suspending the loop antennas at their far ends. The shielded house containing the tuning and coupling equipment for the vertical antenna is also shown in Figure 12. An interior view of the shielded house is given in Figure 13. The antenna tuning coils are shown at (*a*) and the impedance matching transformer for coupling the vertical antenna to the transmission line is shown at (*b*); (*c*) and (*d*) correspond, respectively, to a terminating resistor and a switch used for test and adjustment purposes. This use will be fully explained in connection with an outline of the electrical performance of the system to be given later. The ammeter shown at (*e*) is used for reading the transmission-line current.

3. ELIMINATION OF NIGHT EFFECTS WITH TRANSMISSION-LINE ANTENNA SYSTEM

An idea of the effectiveness of the transmission-line antenna system in eliminating night course variations may be had by reference to Figures 14 and 15, which represent data secured on the Bellefonte range beacon. Figure 14 (*a*) corresponds to a 24-hour record at Sunbury, Pa., 50 miles east of Bellefonte, loop antenna transmission being employed at Bellefonte. Figure 14 (*b*) is a similar record for the transmission-line antenna system. While these runs were taken on successive nights, they may be used for a direct comparison of performance of the two antenna systems, since other observations (on the Bellefonte aural beacon) showed that the night effects were of about the same magnitude and duration on both nights. Figure 15 shows the results of measurements taken in a night flight on the two antenna systems, and is typical of the results obtained in a large number of similar flight tests. Figure 15 (*a*) is for the outgoing trip during which loop antennas were used at the beacon station, while Figure 15 (*b*) is for the return trip during which TL-antenna transmission was employed. The airplane followed as closely as possible the route marked out by the beacon course during a day flight. The variations shown for the first 18 miles are departures of the airplane from the straight course, not night effects. A comparison of the results with the two antenna systems shows that, while the beacon course became of no further value beyond 45 miles from the station when using loop antenna transmission, it was perfectly satisfactory

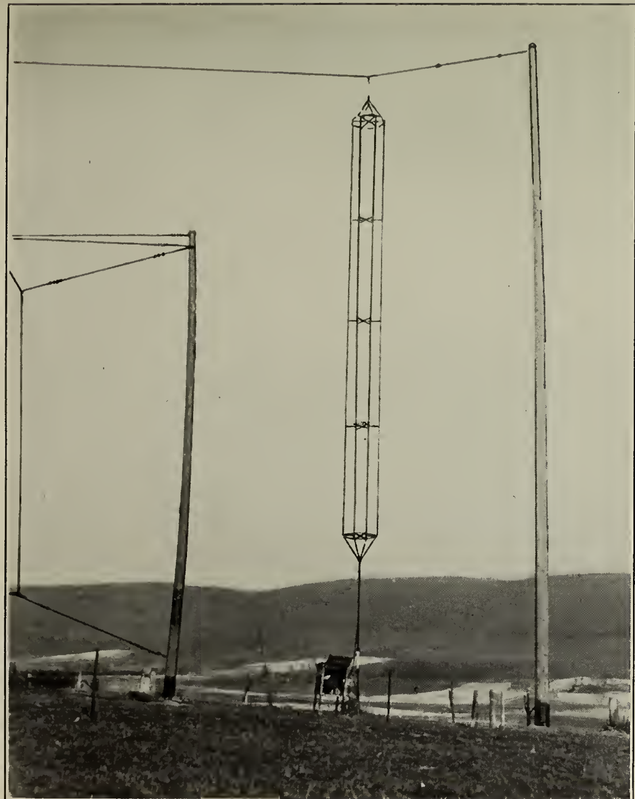


FIGURE 12.—*Manner of suspending the vertical antennas*

One end of loop antenna suspension is also shown (at the left).

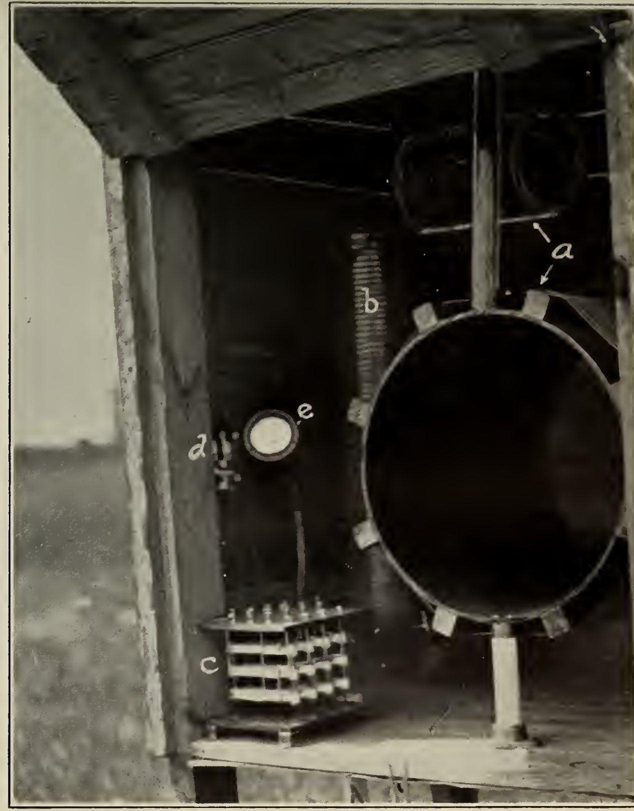


FIGURE 13.—*Interior view of tuning box*

a, Antenna loading coils; *b*, antenna coupling transformer; *c*, terminating resistor for use in testing and adjusting for proper transmission-line termination; *d*, switch; *e*, ammeter for reading line current. The use of *c*, *d*, and *e* will be explained in connection with Figure 18.

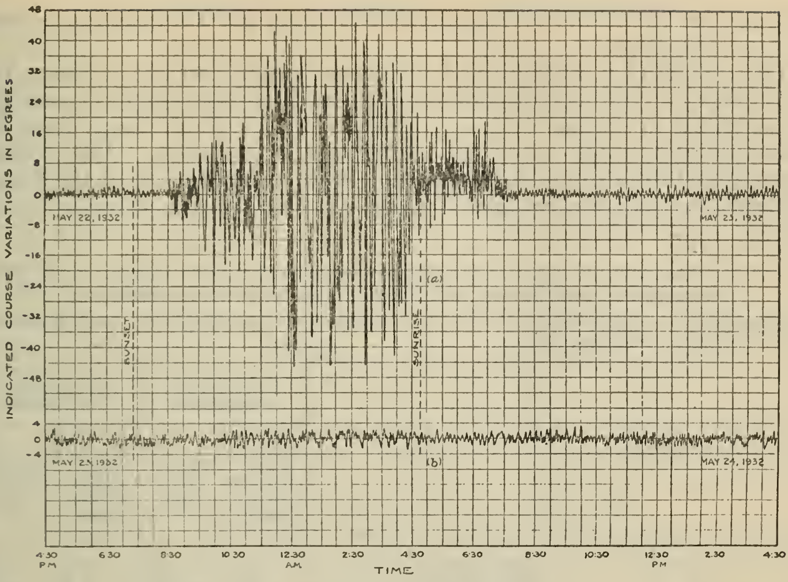


FIGURE 14.—*Twenty-four hour records showing comparative course variations with loop and transmission-line antenna systems at Bellefonte visual radio range beacon station*

(*a*) Loop antenna transmission; (*b*) TL-antenna transmission.

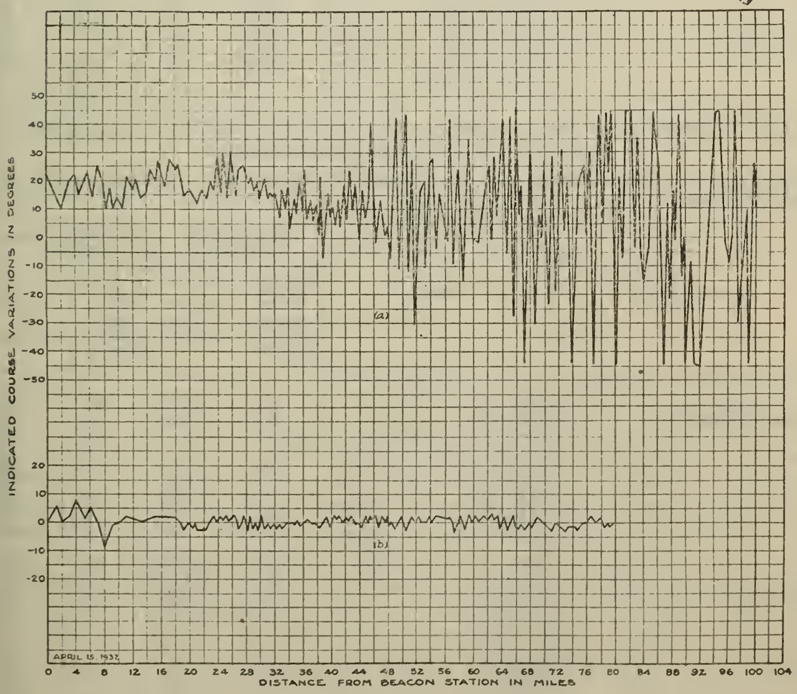


FIGURE 15.—*Night observations in an airplane on comparative night effects with loop and transmission-line antenna systems at Bellefonte visual radio range beacon station*

(*a*) Loop antenna transmission; (*b*) TL-antenna transmission.

throughout the whole distance traveled when the TL-antenna system was in operation.

The results of a large number of measurements on the comparative night effects with the transmission-line and loop-antenna systems are summarized in Tables 4 and 5. Table 4 is for the College Park installation and Table 5 for the Bellefonte installation. The almost complete elimination of night effects obtained by the use of the transmission-line antenna system is quite evident from a study of these tables.

TABLE 4.—*Summary of comparative measurements made on the College Park, Md., visual radio range beacon with TL and loop antenna transmission*

The receiving points were located at Front Royal, Va. (65 miles west of College Park), and at Richmond, Va. (105 miles south of College Park).

Receiving point	Date	Loop antenna transmission		TL-antenna transmission	
		Average course variations (in degrees)	Number of readings	Average course variations (in degrees)	Number of readings
Front Royal, Va	Feb. 2, 1932	10.0	383	2.4	192
	Feb. 3, 1932	8.0	301	2.1	141
	Feb. 4, 1932	10.5	191	2.0	70
	Feb. 5, 1932	14.0	415	1.7	285
	Feb. 6, 1932	14.0	351	1.5	247
	Feb. 9, 1932	7.0	286	1.9	196
Richmond, Va	Feb. 2, 1932	3.7	216	2.4	134
	Feb. 3, 1932	25.0	312	2.3	262
	Feb. 4, 1932	23.0	66	2.5	387
	Feb. 5, 1932	12.0	167	1.7	314
	Feb. 6, 1932	11.0	416	.8	286
	Feb. 9, 1932	8.0	311	2.3	191

TABLE 5.—*Summary of measurements on Bellefonte, Pa., visual radio range beacon using TL and loop antenna transmission*

Receiving points at McConnelsburgh, Pa. (70 miles south of Bellefonte), and at Sunbury, Pa. (50 miles east of Bellefonte).

Receiving point	Date	Loop antenna transmission		TL-antenna transmission	
		Average course variations (in degrees)	Number of readings	Average course variations (in degrees)	Number of readings
	1932				
McConnelsburgh, Pa	Feb. 24	13.0	188	2.1	126
	Feb. 25	26.0	231	2.4	150
	Feb. 27			2.1	340
Sunbury, Pa	Apr. 1	9.0	97	1.0	388
	Apr. 11	8.8	113	1.5	80
	Apr. 12	5.1	219	1.2	148
	Apr. 14	4.5	84	1.6	124
	Apr. 15	9.0	96	1.6	159
	Apr. 18	7.0	175	1.3	258
	Apr. 19	15.5	167	1.1	168
	Apr. 20	8.5	265	1.0	297
	Apr. 21	7.5	146	1.2	115
	Apr. 22	2.5	151	1.2	114
	Apr. 23	3.0	141	1.1	109
	Apr. 24	4.0	159	1.2	129
	May 13	13.1	85	1.5	104
	May 14	7.4	93	.6	138
	May 15	9.1	264	.8	219
Average		9.0		1.4	

4. POLARIZATION OF WAVE AT RECEIVING POINT

A series of special tests were made at Sunbury, Pa., on the transmissions from the Bellefonte set-up, to determine the state of polarization of the received wave at Sunbury. In addition to the receiving set, reed converter and automatic recorder for taking records of the indicated beacon course, a second receiving set, reed converter, and two automatic recorders were provided for taking the polarization data. The two recorders were connected each to the output of one of the units of the reed converter, so that one recorder measured the intensity of the received 65-cycle signal and the second recorder the intensity of the received 86⅔-cycle signal. The receiving set was connected to a loop receiving antenna, the plane of which was oriented perpendicular to the direction of the range-beacon station. The received signal was therefore zero in the daytime. At night, however, the horizontally polarized electric field present in the downcoming sky wave affected the horizontal elements of the loop receiving antenna. The recorders thus took separate records of the instantaneous intensity of the horizontally polarized components present in the received wave and modulated respectively at 65 and 86⅔-cycles.

A discussion of the records taken with this arrangement, together with a complete theoretical analysis explaining the results, will be given in a forthcoming paper in this Journal. It is of interest to summarize here briefly some of the results obtained. When loop antenna transmission was employed, the records showed that night variations in the indicated beacon course were invariably accompanied by horizontally polarized electric field components in the received wave. When the transmission-line antenna system was employed, practically no horizontally polarized components could be detected in the received wave, the received signal intensity being at all times lower than the prevailing noise and "static" level. This is in accordance with the theoretical analysis given in Sections III and IV, since the horizontally polarized electric field component (E_3), most readily detected with the receiving set-up employed, is completely eliminated in TL-antenna transmission, and the other two components (E_1 and E_2) in the indirect wave, which might affect the receiving antenna after changes in their polarization, are materially reduced.

5. ELECTRICAL PERFORMANCE OF TL-ANTENNA SYSTEM

The use of the transmission-line antenna system involves the problem of accurate control of the time phase angle between the currents in the two vertical antennas of each pair. When the time phase angle is 180°, a true figure-of-eight space pattern is obtained; when it is 180° minus the space phase angle between the two vertical antennas, a cardioid is obtained. For phase angles intermediate to those two values, a space pattern intermediate to the true figure-of-eight and cardioid results. This affords a convenient means for alignment of the four beacon courses with airway routes converging on an airport at arbitrary angles. Altering the space pattern radiated by one or both of the directional antennas changes the points of intersection of the two patterns and, in consequence, the angular direction of the four equisignal zones or courses. The requirement for a central open-type course bending antenna, such as is employed with the loop antenna system, is thus obviated.

The use of this method of altering the angular direction of the beacon courses in order to align them with airway routes at arbitrary angles is clearly shown in Figure 16. The space pattern for one directional antenna is successively shown as *A*, *B*, and *C*, corresponding to a time phase angle between the currents in the two vertical antennas equal to 180°, 165°, and 150°, respectively. The angular alignment of the four beacon courses produced by the intersection of this pattern with the space pattern *D* for the second directional antenna (indicated by *1*, *2*, *3*, *4*; *1'*, *2'*, *3'*, *4'*, and *1''*, *2''*,

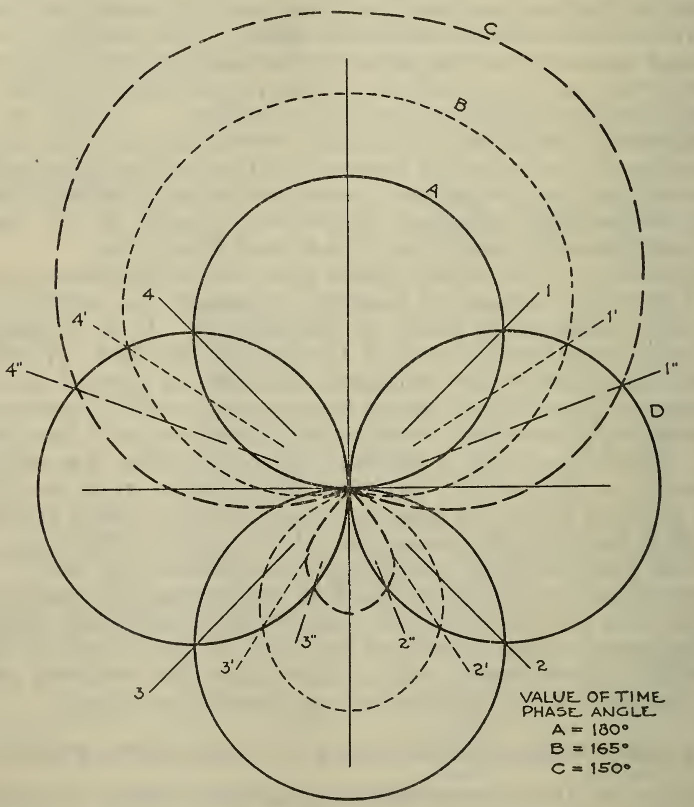


Figure 16.—*Polar pattern illustrating effect of changing the time phase angle between the currents in the two vertical antennas of a pair upon the angular direction of the four beacon courses*

3'', *4''*) is seen to be different for each of the three conditions assumed. The means available for altering the time phase angle between the currents in the two vertical antennas of a pair are quite simple, consisting either of slightly detuning one antenna or inserting a condenser or inductor in series with the input of one or both of the transmission lines. In Figure 17 is shown a polar diagram for the Bellefonte installation which was altered in the manner just described so that courses *A* and *B* coincided with the airway routes to New York and Cleveland, respectively. These routes intersect at Bellefonte at an angle of 166°.

The property of the new antenna system which permits alteration of its radiated space pattern, while thus seen to be of technical and economic advantage, also imposes a special operational requirement on the system. Obviously, the phase angle between the currents in the two vertical antennas of a pair must be kept constant within rather close limits, or the angular direction of the beacon courses will vary from time to time. This requires special design of the vertical antennas, the antenna tuning and coupling units, the transmission lines and the means for transferring power from the goniometer to the transmission lines. The use of tightly coupled impedance-matching transformers at both ends of each transmission line obviates any difficulty from variable phase relationship in any of the equipment excepting the antennas. In the latter, an unbalanced change in tuning for any reason, such as the effect of nearby poles, faulty insulators, etc., during wet weather, will result in a change in

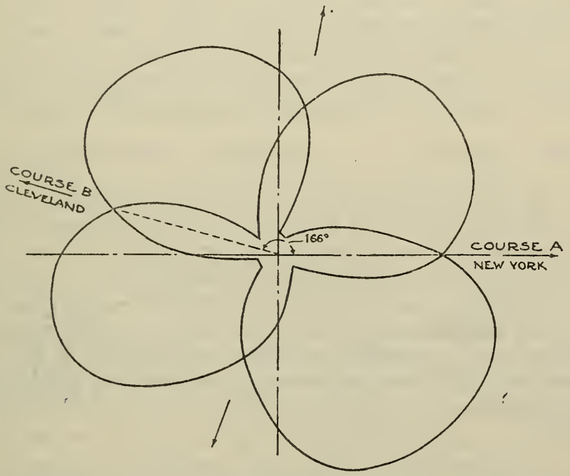


Figure 17.—*Polar diagram for Bellefonte TL-antenna installation showing alignment of the east and west courses with the airway routes to New York and Cleveland*

phase angle between the two antenna currents. Care in installation of the antenna system is required to prevent unbalanced detuning. In the experimental installation at Bellefonte the maximum effect of such detuning over a period of several months was found to be about 5°. The use of insulated steel towers as the vertical antennas, with the consequent absence of wooden poles and suspension wires, is expected to improve the electrical performance of the system in this respect. Complete elimination of this problem of operation is looked for as a result of experimental work now in progress on an arrangement for securing automatic compensation for any change in phase angle. This method utilizes the transmission lines themselves for securing the desired interlocking of phase.

Of interest is the method adopted for tuning the two vertical antennas of a pair, securing the proper phase angle between their currents, and at the same time insuring proper termination for the

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transmission lines so that they will not radiate. Referring to Figure 18, a switch S is provided at the load end of each transmission line so that the line may be terminated either by the primary of the antenna transformer T or by a resistor R equal to the surge impedance of the line. During the adjustment of each vertical antenna, the transmission line to the second antenna of the pair is terminated by the resistor R. The switch S is thrown so that the antenna transformer T is excited, and the loading coil L_1 and the fine tuning coil L_2 adjusted for maximum antenna current I_A. The line current I_L'' at the receiving end of the line is then recorded and compared with the reading corresponding to resistance termination. These two readings are generally not the same at the beginning of an adjustment. The tap on the secondary winding of transformer T is then changed in small steps, the antenna being retuned to maximum current for each step, and the line current I_L'' recorded. The adjustment is

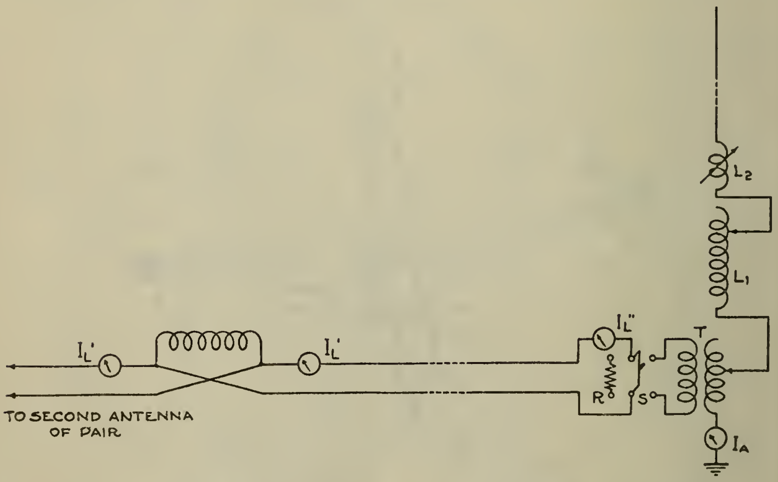

Figure 18.—*Circuit arrangement illustrating method of adjusting the TL-antenna system for proper tuning, phase angle and transmission-line termination*

chosen for which I_L'' reads the same whether the transmission line feeds into the transformer T or the resistor R. This is, however, still not the proper condition of adjustment; it corresponds to an input transformer inpedance equal in magnitude but not in phase to the surge impedance of the line. Reflection along the line still occurs as may be seen from the fact that the input current to the transmission line, I_L', is not the same for resistance and transformer termination. The next step is to detune the antenna slightly by adding inductance in L_1 or L_2 until I_L' reads the same whether the transmission line is terminated by the resistor or by the antenna transformer. The apparent input impedance of the antenna transformer is now a pure resistance equal to the characteristic line resistance. The same series of adjustments is repeated for the second antenna of the pair, the transmission line to the first antenna being now terminated by the resistor provided. After this adjustment is completed, the two antennas may be excited together without disturbing the adjustment of either.

It is next necessary to determine the phase angle between the currents in the two antennas and to adjust it to the desired value. This is accomplished by removing the voltage from the pair of antennas not under test and inserting a milliammeter in one of these antennas. To insure that this antenna remains in tune, the voltage is removed from the input end of the transmission line feeding it and a resistor connected across this end equal to the characteristic line resistance. This antenna being equidistant from the pair of antennas under test, the current induced in it from the pair depends upon the time phase angle between the currents in the two antennas of the pair. For 180° phase angle, the induced current is zero; the greater the departure from 180°, the greater the induced current. The milliammeter reading this current may be calibrated directly in phase angle. If desired, this reading may be made within the beacon house rather than at the antenna by measuring the voltage across the resistor terminating the transmission line coupled to this antenna. This method of measuring the phase angle may be combined with the arrangement for controlling the phase angle (which consists of inserting a condenser or inductor in series with the input end of one or both of the transmission lines feeding the two antennas under test) to give rapid means for periodic phase checking and correction for slight variations.

6. OBSTRUCTION LIGHTING OF TL-ANTENNA SYSTEM

One of the incidental problems which came up during this development was the provision of obstruction lights for the TL-antenna system. Because of the high poles employed and because of the location of the beacon near an airport, it was necessary to install an obstruction light at the top of each of the four outer poles. The problem involved was to run the lighting wires up these poles without at the same time absorbing power from the vertical antennas only 20 feet away. Besides absorption of power and consequent loss in efficiency, it was feared that the induction of radio-frequency currents in the lighting wires would serve to detune the vertical antennas, perhaps in uneven amounts, thereby disturbing the phase relationships of the system; and also to produce radiation from the horizontal wires of the lighting circuits thereby affecting adversely the degree of elimination of night effects. The problem was solved by inserting radio-frequency choke coils in the lighting wires at the base of each pole and providing by-pass condensers on the power side of the choke coils. The arrangement proved quite satisfactory, the presence of the lighting cable having no effect upon the tuning of the system or upon its operation in eliminating night effects.

In the case of obstruction lighting of the insulated steel towers intended for use on the airways, the problem is very similar. The tower itself may constitute one of the lighting wires, while the other wire is kept at the same radio-frequency potential as the tower by means of radio-frequency by-pass condensers. The choke coil and condenser arrangement described above is then also suitable for use with the insulated tower system.

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