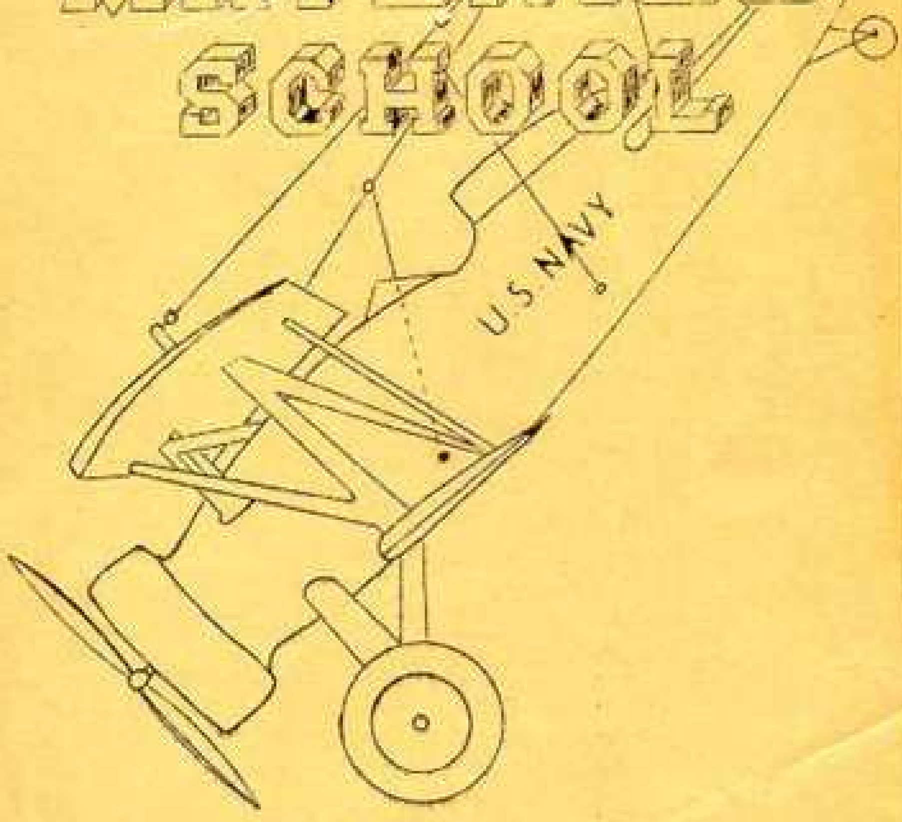
P.R. Schneider

RESTRICTED

RADIO MATERIEL SCHOOL



AIRCRAFT RADIO

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CHAPTER III

AIRCRAFT RADIO DIRECTION FINDERS

40. GENERAL

Reliable radio direction finding bearings taken from aircraft are becoming more and more necessary with the rapid development of aviation in general. Night flying is now routing practice and it is highly desirable that radio direction finders in aircraft be as equally effective and accurate during dark hours as they normally are during daylight. Before this can be realized radical changes must be made to the present type aircraft radio direction finders, or a new type must be developed which will permit reliable night operation. The development of long range patrol aircraft necessitates the use of a radio direction finder capable of taking bearings over much greater ranges than are normally necessary for other types of aircraft. It is desirable that all aircraft be equipped with a direction finder capable of taking bearings, under service conditions, over at least one-half the cruising range of the aircraft.

The general requirements, for what is termed a satisfactory radio direction finding bearing taken from an aircraft while in flight, are not so exacting as are the requirements of bearings taken from surface ships. It is almost impossible, with the small magnetic compasses used in aircraft, to hold the ships head closer than two or three degrees of a desired course although the average of the magnetic errors will give a true heading; also, if the pilot does not know that a bearing is being taken, the error from this cause may be even greater. For all practical purposes, however, a radio bearing taken from an aircraft over considerable distances, which is within three or four degrees of true, after all corrections have been applied, may be considered as satisfactory as this error will decrease with a decrease in distance separating the aircraft and the transmitting station. More accurate bearings are desirable but in actual practice, where these bearings are taken over distances in excess of those at which surface ships normally take bearings, greater error is to be expected.

Both rotatable and fixed type loops are used for radio direction finding in aircraft. The RDF-1 or RDF-1-A rotatable loop direction finder is a standard installation for two and three place aircraft and the RDF-2 remotely controlled rotatable direction finder is used on some patrol type aircraft. Section 51 describes the RDF-1-A equipment in detail and a brief discussion of the RDF-2 is given in Section 52. Bellini-Tosi type fixed loops which have been used successfully for several years on metal hull flying boats are discussed in Section 47. There are several types of small fixed loops which, when installed in the fuselage or in the headrest of aircraft and used with the RU series receivers, will give "homing" direction finding indication. A radio homing device, Type NES-2, involving special principles, is explained in Section 53 in order that the reader may become better acquainted with the different types. An experimental type direction finder, Model AS-101, is discussed in Section 54.

There has been much controversy over the use of a rotatable type loop in lieu of the Bellini-Tosi type loop on patrol aircraft. The fact remains that neither type loop has been developed to its fullest extent and that development should continue with both until there is some conclusive evidence definitely establishing the superiority of one or the other type of loop for particular types of aircraft. In their present stage both types have some advantages and disadvantages. The Bellini-Tosi loop has considerable signal voltage pick-up because of its large size thus permitting bearings to be taken over distances in excess of 500 miles on intermediate frequencies. The RDF-1-A and RDF-2, because of their small size (12 inches), are limited to a range somewhat below this distance. The main objections to the Bellini-Tosi loop are not in its radio direction finding properties, but in its bulkiness, air drag, requirements for special wing and hull fittings and upkeep. A small rotatable loop would be preferable to the Bellini-Tosi loop if designed to give equal range performance. The Bellini-Tosi type loop is an untuned system and is confined to narrow frequency ranges whereas small loops can be tuned to permit their use on both intermediate and high frequencies.

All the present type loop direction finders in use on aircraft are subject to errors due to "night effect" and other causes where the wave fronts of the received signals are abnormally polarized. "Night effect" causes the minima to shift from their true bearings; causes a very broad or indefinite minima or even eliminates any indication of a minimum. Section 41 discusses "night effect" in detail. "Night effect" is most liable to be present at sunset and sunrise and other indefinite times during the night, and for this reason, bearings taken at night should be interpreted with caution. From this discussion it may be seen that even though the present type loop direction finders were developed to perfection, there would always be erratic and inconsistent errors due to "night effect." These errors cannot be eliminated in this type loop as their cause is uncontrollable and the principle upon which this loop works is such that the horizontal polarized component of the radio wave which causes this error cannot be eliminated.

The apparent solution to the elimination or partial elimination of "night effect" and the effects of abnormally polarized wave fronts, permitting satisfactory bearings to be taken at all times on both intermediate and high frequencies, is the possible adoption of some modification of the Adcock (antenna) direction finding system adaptable to aircraft. This seems to be the only solution to the inadequacies of the present type loop direction finders and the Service in general should look forward to its development with interest. At the time this pamphlet was written, there were no such direction finders available for aircraft use but it is believed that in the near future this type equipment will be developed sufficiently to permit experimental tests. The Adcock principle and a possible aircraft installation is discussed in Section 50.

Unsatisfactory conditions of radio direction finding and erroneous bearings are sometimes obtained while aircraft are flying in close formation, especially of other aircraft are between the transmitting station and the aircraft taking the bearing. (This condition is also found with surface ships.) This condition is a result of the radio waves being deflected from their true course or is caused by reradiation from the antennas of the other aircraft and for this reason aircraft taking bearings should detach themselves from the formation.

41. NIGHT EFFECT

"Night effect" is the destruction or shifting of the minimum in a loop direction finder and is caused by down-coming (reflected), horizontally polarized components of the radio waves.

The first accounts of "night effect" in this country were given by Dr. A. H. Taylor in 1919. He first discovered that trans-Atlantic low frequency signals suffered from quite wide changes in bearings at night, showing considerable constancy in the daytime with some variations at sunset and at sunrise. This discovery was the beginning of the investigation leading to our present Heaviside layer refraction theories. The effect was noticed only at night and got its name from that fact. Later the effect was found to exist at the intermediate frequencies. 375 kcs did not show a great deal of it at first, but as other errors in the apparatus were decreased, this particular error became more noticeable and has done considerable harm. Now the 375 kcs frequency, as far as is known, does not show these errors in the daytime (except perhaps at sunset and at sunrise). When we get to 3,000 kcs, however, it is more or less ordinary to notice some of this effect at noon, while from 3,000 kcs up (approximate frequencies only) it may be expected that these effects will be present in the daytime as well as the night. The effect on the direction finder at the low frequencies is generally a shift in the apparent bearing, sometimes accompanied by broad minima. There may be a shift of 30 degrees in a short time, or it may take an hour to swing that far. Going to the other extreme, at noon time, at 3,000 kcs, an ordinary loop may show 5 degrees shift in 15 minutes. At night it is often impossible to take bearings with a plain loop on 3,000 kcs transmission from some distance and the higher frequencies may be increasingly difficult. Those symptoms ordinarily experienced and the following explanation is rather universally accepted.

The "ground wave" follows the shortest path along the earth s surface and direction finding on it is relatively simple along well known lines. The Heaviside layer refracts or bends down some of the waves reaching it. The refracted wave component, known as the "sky wave", may reach the direction finder alone or in conjunction with the ground wave. They may add or neutralize according to phase and relative intensity, sometimes producing fading.

The ground wave gives us good direction finding while the sky wave often does not. Given a ground wave with horizontal magnetic lines, vertical electrical lines, (normally polarized wave) we have receiving conditions such as those discussed in which the loop gives a minimum or zero EMF when the plane of the loop coincides with the plane of the wave front. If that wave in passing over poor conducting surface leans forward a little, no great change in direction finding conditions is introduced. The amount of induction field will be influenced and that is the principle change. If, however, this wave travels up and is refracted back to the earth, it reaches the direction finder with a vertical component of motion. Now if the magnetic lines are still horizontal and the electrical lines are in a vertical plane but tilted forward somewhat, because they descend obliquely, the direction finder will still give good directions on this component of the wave alone.

Polarization refers to the question of the angle at which the forces lie in the wave front. A normally polarized wave has horizontal magnetic fields and vertical electric fields. In terms of ordinary procedure we speak of a vertically polarized wave as one in which the electric vector is vertical. If the wave is spoken of as horizontally polarized it means that the wave front has rotated about the direction of motion as an axis so that the electric vector is now horizontal. Its rotation is similar to a corkscrew effect. Any type of wave polarization may become horizontal after traveling some distance through free space.

A normally polarized ground wave we will call component "A". The normally polarized sky wave which is like a ground wave, merely coming down at some angle, we call the "B" component. We will use the term "C" component for the horizontally polarized sky wave. Any wave received may be resolved into one or more of these components at a given instant. Of course, the conditions change rather rapidly at times. Components "A" and "B" give normal direction finding as long as sufficient signal is received though they might neutralize to cause fading. Component "C" taken alone will give a 90 degree error on a loop.

The "A" component of the wave does not cut the horizontal portion of the loop, and produces no EMF in top and bottom conductors. The same is true of the "B" component. The "C" component of the wave, coming down at some oblique angle cuts the top of the loop, then the bottom of the loop and does not cut the vertical conductors. It follows then that there is a phase difference between these cuttings due to vertical motion and an EMF production in the normal position of the loop. Shifting to the normal maximum position, we find no cutting of conductors by the magnetic lines of force, thus zero reception. That means then that the maximum reception of the loop is at a scale setting 90 degrees displaced from the usual position and similarly for the minimum. This then is the cause of what is properly known as "night effect" better described as heaviside refraction effect. Under these conditions, to get a direction finder independent of refraction effects, we must exclude the "C" component from our reception or exclude the "A" and "B" from our reception. The second case would not work on a ground wave. The method of excluding the "A" and "B" components will work best with high angle reception and moderately high frequencies, not the ultra-high. For the general case we wish to be able to receive the ground wave so that we want a direction finder which will work from the "A" and "B" component. It is pertinent to add at this point that transmission from an aircraft resembles the sky wave from the standpoint of the direction finder. The trailing antenna is neither vertical nor horizontal, furthermore, the height of the aircraft may produce considerable vertical component in the traveling of the wave and we may expect in the received wave front considerable equivalent "C" component and if the distance is relatively short probably very little "A" component or genuine ground wave. At short distance we may consider aircraft transmission to be practically all sky wave.

Under these conditions then we have an explanation for the fairly well known phenomena known as "airplane effect". If an aircraft flies across the line of sight with a trailing antenna at a considerable distance above the ground, the direction finder will normally point behind the aircraft by an angle varying from 0 to 20 degrees. The suggestion has been brought out that the direction finder points to the approximate position where the line of the antenna strikes the ground. That has been an obstacle in Naval maneuvers where bearings of spotting aircraft are desired and interference with correct direction finding for navigational purposes for aircraft. (See Chapter 11 Section 28 for an explanation of trailing wire antenna characteristics.)

42. AIRCRAFT HIGH FREQUENCY DIRECTION FINDING USING TYPE RDF LOOPS

The greatest obstacle to high frequency direction finding in flight is the generally observed regular rythmic fading in and out of signals from an approaching or receding station. This is due to the continuously changing phase relation with change in distance between the direct and reflected or "sky" waves. This regular fading is often noticeable even at short distances while taking minimum bearings due to balancing out by the loop of most of the direct wave while it is still susceptible to a considerable vertical reflection of the high frequency from the Kennelly-Heaviside Layer. This fading interferes with fixed loop "homing", since the pilot cannot readily tell the difference between a minimum due to fading and a minimum due to aircraft heading unless careful average readings are obtained with the aid of an output meter. The best method to obtain definite, although broad, bearing indications under these uncertain conditions is to rapidly and continuously rotate the loop over a period of time with the SELECTOR switch in the "D" position, and to note the average direction of the bright half of the loop for strongest signal during each revolution. This method sometimes suffices to enable rough "homing" at a distance despite insufficient altitude, and it has successfully been used to locate other aircraft in flight even under adverse conditions.

If the transmitter emitting the high-frequency signals employs a vertical antenna bearings generally get sharper as the aircraft approaches it. In the case of other types of antennas, the contrary may obtain. Thus, an appreciable error may result at close range in a bearing taken by one aircraft on another which is transmitting on a fixed antenna with unsymmetrical lead-in. A trailing transmitting antenna would be preferable, however, intermediate frequencies should be employed for most accurate and dependable bearings. In case high-frequency bearings must be followed, be sure of plenty of altitude (At least 2,500 feet for bearings on transmitting stations 50 miles distant and 9,000 feet if the transmitting station is 100 miles distant.) and check direction on "D" setting of the selector switch.

Considerable remains to be learned about the relative value and best methods of high-frequency direction finding and pilots and radiomen are urged to determine its value and limitations by actual tests whenever conditions permit. On the basis of such experience, it is believed that each pilot and radioman, for himself, will learn to discriminate between dependable and doubtful high-frequency bearings. Individuals are warned about accepting enthusiastic reports on high-frequency bearings, taken under what may have been exceptionally good conditions, as being generally true and applicable to high-frequency bearings as a whole.

43. USING BROADCAST STATIONS FOR DIRECTION FINDING

A problem which often besets Naval pilots and radiomen who use radio broadcast stations for direction finding purposes is the lack of information on the exact geographical location of the antennas from which the signals are radiated. This information is available in the Berne List but does not reveal other important characteristics of the station, particularly its susceptibility to interference from stations on the same and adjacent channels.

BROADCAST STATIONS SUITABLE FOR AERONAUTICAL DIRECTION FINDING

LOCATION BY STATES	CALL	FREQ. IN KC.	POWER IN KW.	INTER-FERENCE	ANTENNA LOCATION LONGI-TUDE ° ' "	ANTENNA LOCATION LATI-TUDE ° ' "	APPROXIMATE LOCALITY OF ANTENNA
ARKANSAS							
Hot Springs	KTHS	1060	10	42*	93 02 00	34 28 45	3 mi. s. Hot Springs. 2 mi. e. Airport.
CALIFORNIA							
Belmont (San Francisco)	KPO	680	50	18*	122 14 00	37 32 30	
Buena Park (Los Angeles)	KFI	640	50	30*	118 00 50	33 52 47	20 mi. s.e. Los Angeles
Los Angeles	KNX	1050	50	27	118 28 16	34 07 25	3 mi. s.w. of Van Nuys, California
Oakland (San Francisco)	KGO	790	7.5	32	122 12 20	37 15 54	
COLORADO							
Denver	KOA	830	50	25	104 16 50	39 41 21	12 mi. e. State Capitol Bldg., Denver
CONNECTICUT							
Avon (Hartford)	WTIC	1040	50	32	72 18 20	41 46 35	8 mi. w. Travelers Insurance Tower
FLORIDA							
Gainesville	WRUF	830	5	35	82 20 30	29 38 45	1.5 mi. s.w. Court House Square
GEORGIA							
Atlanta	WSB	740	50	20*	84 15 20	33 50 45	10.4 mi. n.e. center Atlanta
ILLINOIS							
Addison (Chicago)	WMAQ	670	50	C	88 01 23	41 56 01	4 mi. n. Glen Ellyn
Downer's Grove (Chicago)	WLS-WENR	870	50	C	88 00 30	41 44 35	3.5 mi. s. Downer's Grove
Elgin (Chicago)	WGN	720	50	C	88 12 53	42 00 46	
Glenview (Chicago)	WBBM	770	50	S	87 49 46	42 05 42	18.3 mi. n.w. Chicago Loop
Mooseheart (Chicago)	WJJD	1130	20	39	87 37 35	41 53 00	35 mi. w. Chicago Loop
York Township (Chicago)	WCFL	970	1.5	40	87 59 14	41 49 09	
IOWA							
Ames	WOI	640	5(D)	16	93 38 30	42 01 30	2 mi. w. Ames
Des Moines	WHO	1000	50	12	93 20 48	41 39 08	14.9 mi. n.e. Des Moines
KANSAS							
Milford (Abilene)	KFBI	1050	5	17	96 42 49	39 09 10	10.5 mi. n.w. Junction City, Kan.
KENTUCKY							
Jeffersontown (Louisville)	WHAS	820	50	12	85 34 40	38 12 10	12 mi. e.s.e. center Louisville
MARYLAND							
Pikesville (Baltimore)	WBAL	1060	10(D)	42	76 44 08	39 21 40	9.5 mi. n.w. center Baltimore
	WBAL	760	10	S	(Synchronized with WJZ, Bound Brook, N. J. at night)		
MASSACHUSETTS							
E. Springfield	WBZA	990	1	S	72 33 00	42 08 00	3.1 mi. n.n.e. center Springfield
Millis (Boston)	WBZ	990	50	S	71 20 05	42 11 03	18 mi. s.w. center Boston
Saugus (Boston)	WHDH	830	1	56	70 59 40	42 26 15	
MICHIGAN							
Detroit	WJR	750	50	2	83 13 00	42 10 07	16 mi. s. Detroit
MINNESOTA							
Anoka (Minneapolis)	WCCO	810	50	25	93 19 02	45 10 01	2 mi. s.e. Anoka, Minn.
MISSOURI							
Kansas City	WHB	860	1(D)	57	94 33 19	39 07 54	0.25 mi. n. Missouri River
St. Louis	KMOX	1090	50	C	90 20 42	38 27 36	13.7 mi. from City Hall, St. Louis
St. Joseph	KFEQ	680	2.5(D)	11	94 52 10	39 46 32	1.0 mi. n.w. St. Joseph, near Mo. River
NEBRASKA							
Lincoln	KFAB	770	10	S	96 41 48	40 49 41	
NEW JERSEY							
Bound Brook (New York)	WJZ	760	50(D)	25	74 30 50	40 33 20	1.5 mi. s.e. Bound Brook
	WJZ	760	50	(Synchronized with WBAL, Baltimore at night)			
Cartaret (Newark)	WOR	710	50	11	74 14 54	40 35 46	1.5 mi. w. Cartaret on Rahway River
Wayne (New York)	WABC	860	50	23*	74 17 12	40 55 30	6.1 mi. n. w. Paterson, N. J.
NEW MEXICO							
Albuquerque	KOB	1180	10	37	106 37 32	35 11 32	8 mi. n. Albuquerque
NEW YORK							
Bellmore (L. I.) (New York)	WEAF	660	50	20*	73 31 49	40 41 07	
New York City	WNYC	810	1(D)	59	74 03 35	40 42 22	Western end Brooklyn Bridge, N. Y. C.
Rochester	WHAM	1150	50	21	77 26 55	43 00 12	14 mi. s.e. Rochester. 2 mi. n. Victor, N. Y.
S. Schenectady	WGY	790	50	17	74 00 36	42 47 37	4 mi. w.s.w. Schenectady, N. Y.
NORTH CAROLINA							
Charlotte	WBT	1080	50	12	80 53 28	35 07 52	8 mi. s.s.e. Charlotte
OHIO							
Brecksville Vil. (Cleveland)	WTAM	1070	50	11	81 37 22	41 16 50	
Mason (Cincinnati)	WLW	700	500	C	84 19 30	39 21 05	22 mi. from Cincinnati
OREGON							
N. Portland	KEX	1180	5	15	122 41 15	45 36 22	5.5 mi. n. business dist. Portland near Columbia River
PENNSYLVANIA							
Newtown (Philadelphia)	WCAU	1170	50	27	75 24 50	39 58 30	12.8 mi. w. City Hall, Phila.
Saxonburg (Pittsburgh)	KDKA	980	50	C	79 49 00	40 43 53	23.5 mi. n.e. Pittsburgh
Whitemarsh Twnp. (Phila.)	KYW	1020	10	22	75 15 00	40 06 25	
SOUTH DAKOTA							
Sioux Falls	KSOO	1110	2.5	13	96 45 30	43 32 20	3 mi. w. Sioux Falls
TENNESSEE							
Franklin (Nashville)	WSM	650	50	C	86 47 32	35 59 50	
TEXAS							
Dallas	KRLD	1040	10	16	96 51 12	32 54 18	
Grapevine (Ft. Worth)	WBAP-WFAA	800	50	15*	97 01 35	32 55 04	11 mi. n.w. Love Field, Dallas
Selma (San Antonio)	WOAI	1190	50	25	98 18 33	29 34 45	
UTAH							
Saltair (Salt Lake City)	KSL	1130	50	25	112 06 03	40 46 30	
VIRGINIA							
Mechanicsville (Richmond)	WRVA	1110	5	37	77 22 43	37 36 10	5.5 mi. n.e. Richmond on edge Chicahominy Swamp
WASHINGTON							
Seattle	KJR	970	5	31	122 18 30	47 47 15	10 mi. n. Seattle

Notes: **Name of town** is government listing. The symbol **(D)** indicates daytime operation only; all other stations operate more or less continuously from 8:00 A.M. to 12:00 midnight, local time. **Interference:** the higher the interference rating, the more likely the station will be interfered with by other stations on same channel. *Stations having an interference rating higher than 40 should be used with caution.* * indicates no interference at night. **C** indicates no interference (clear channel). **S** indicates this station operates synchronously with another station; *signals from such stations should be used with extreme caution.* **Other abbreviations:** mi. = miles. n. = north. w. = west. s. = south. e. = east.

The pilot needs the following information: The locations (more or less exact) of stations toward which he can aim his direction finder; The degree of reliability with which he can identify the station by its frequency or call letters; and finally, The hours of operation, to guard against a sign-off which would leave him without a signal to follow. He must have some means of selecting stations free from interference since a mixture of two signals, even though differing widely in strength, will so distort the effective wave-front on which his loop is trained that grave errors of direction may, and usually do, result. Simultaneous and synchronized operation of stations must therefore be guarded against. Shared-time operation is also dangerous for in many instances the pilot has no time to wait for station call-letter announcements but must depend on the frequency of a station for its identification. Shared-channel stations do not permit such identification unless the exact schedule of hours taken by each station in the group is known and all changes in this schedule taken into account.

All of the 620 broadcast stations are not equally suitable for direction finding purposes. The problem arises of choosing those stations which are most suitable, making clear that most of the other stations may be used under proper conditions if care is taken to avoid errors. Stations most suited to the purpose are 50 Kw. transmitters operating on channels completely free from interference, i.e., on which no other stations in North America are assigned to the same frequency. If this restriction were to be adopted as final, the list would contain only seven stations, located in five cities (three of these stations serve Chicago). The clear channels listed by the FCC (640-680, 700-720, 740-770, 790-830, 850-870, 970-1000, 1020, 1040-1110, 1130-1190 Kc., inclusive) contain over fifty stations, including all those of 50 Kw. power. These stations experience the least trouble with interference caused by simultaneous operation and in addition there are only one or two cases of shared-time operation among them. Stations having assigned frequencies on these channels were selected, therefore, as the basis of the list. There are undoubtedly many stations operating on other channels which can be used by pilots with complete success, but as no means of distinguishing between such stations and those not suitable was available, the arbitrary restriction to "clear" channel stations was necessarily adopted.

On all but seven of the channels some sort of interference exists, except on seven additional channels which are clear at night. (Daytime operation is of greatest importance to the pilot, since the "night" effect makes direction finding at night less useful). To evaluate the interference probabilities on the remaining channels, it was necessary to make assumptions which would indicate the relative probability of interference. The assumptions are (1) that the signal strength, in voltage, of both the desired and interfering station varies inversely as the square of the distance from the station, and (2) that the stations were operating with an average power output commensurate with their listed power rating. On these assumptions it was possible to evaluate the ratio of signal voltages from the desired interfering stations at any desired geographical point. The point chosen was one hundred miles from the desired station in the direction of the interfering station, or in the case of several interfering stations, in the direction of the station having the most power, and/or being nearest i.e. having the highest potentialities. This point represents approximately the worst condition to be encountered by the pilot, who seldom depends on signals at a greater distance than 100 miles, especially at night. The ratios so calculated were then expressed in DB subtracted from the number 80 in order to provide a positive number whose value increases as the interference increases. The formula actually used can be expressed as:

$$\text{"Interference factor"} = 80 - 20 \log_{10} \sqrt{\frac{P_1\ (d - 100)^2}{P_2\ (100)^2}}$$

Where P_1 and P_2 are the power ratings of the desired and and interfering stations, respectively, and d is the distance between them in miles. No great claim can be made for this factor on the score of predicting interference ratios, especially at night when signal strengths often decrease inversely as the first power of the distance or even more slowly, but it is a good approximation in daylight conditions and will serve for comparison purposes.

The six stations now operating under synchronized conditions are marked "S" and no interference ratio is given for them although it could be computed by the formula. Such stations can produce highly erroneous bearings and should be used with caution.

The table lists the principal radio broadcast stations in the United States indicating their characteristics, correct to January, 1936. All Naval aviators and radiomen should familiarize themselves with those stations within their vicinity.

44. "HOMING"

"Homing" is the principle whereby a fixed loop on an aircraft is used to give a zero degree relative bearing on a transmitting station toward which the aircraft is flying. When an aircraft is pointed directly toward or directly away from a transmitting station, and the radio loop is installed in such a manner that it is thwartship on the aircraft, the signal voltages in the loop will cancel out, giving a minimum signal over a few degrees either side of directly toward or away from the transmitting station. The width of the "minima" is dependent on the distance, power and receiving conditions. The pilot may then weave the aircraft along this course, remaining on a course along this "cone of silence" until he flys over the transmitting station. Any type loop system may be used for "homing". When rotatable loops are used, the loop must be rotated to the thwartship position and secured there during the "homing" process. One of the disadvantages of "homing" with a direction finding loop is that, when flying cross wind, no allowances can be made for drift and the track of the aircraft in strong cross winds will be something like that shown in Fig. 34. It is to be seen that when the aircraft takes its original course towards the transmitting

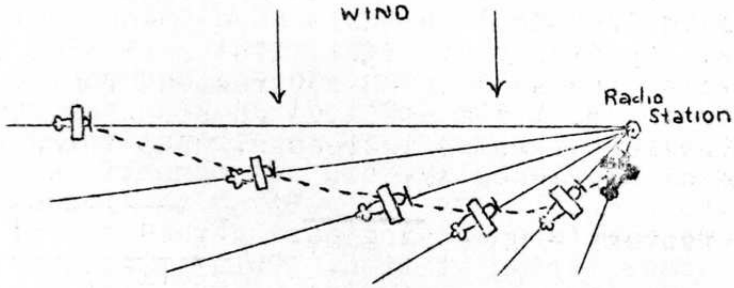


Fig. 34.

station, it would be best for the pilot to alter his magnetic compass course up-wind, to allow for drift, making occasional radio direction finder checks with the "homing" system to assure himself that he is flying towards the transmitting station and is still on the right "track". As is indicated in Fig. 34, should he attempt to "home" all the way back to the transmitting station, the aircraft will fly an arc course and will, by the time it arrives at the transmitting station, have the wind more on its bow.

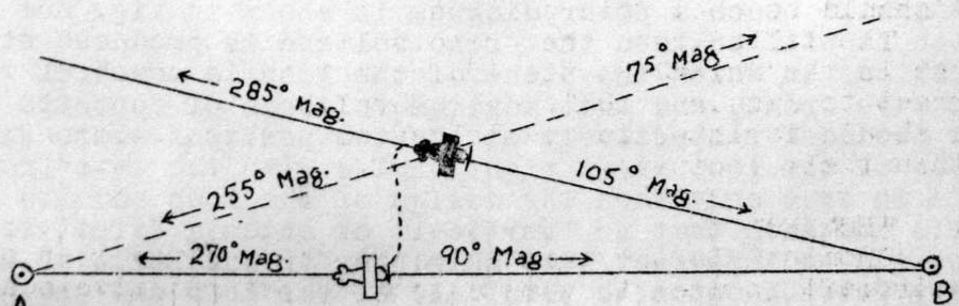


Fig. 35.

When a pilot is in doubt as to whether he is flying towards or away from a transmitting station, he may reduce the receiver volume control until the received signal is barely audible and, if he is flying away from the transmitting station, the signal will soon fade out, whereas, if he is flying towards the transmitting station, the signal will gradually build up in strength. Another method would be to change course 90 degrees for a few minutes and after resuming "homing", check the magnetic compass for the indicated true direction. Fig.35 shows an example of this last system. With reference to Fig.35, assume that the aircraft is "homing" on a magnetic compass course of 90 degrees but the pilot is not sure whether he is flying towards or away from the transmitting station and from indications, the transmitting station could be at either position A or B. The pilot could change course to North or 0 degrees for a few minutes after which he would again "home" on the transmitting station. If he had been flying towards the transmitting station (at B) orginally, his new indicated magnetic compass course would be 105 degrees with both the original and the new courses intersecting at point B, whereas, if the transmitting station had been at point A originally, his new magnetic course would necessarily have been 75 degrees, putting the intersection of the two courses astern and indicating that he was flying away from the transmitting station. This procedure is not necessary with any direction finding equipment having unilateral characteristics but is given as information which will be of use in the event obsolete equipment is used or the uni-lateral characteristics of modern equipment are not satisfactory.

45. FUNDAMENTAL DIRECTIONAL PROPERTIES OF SIGNAL COLLECTORS AS USED ON AIRCRAFT

If a loop collector is connected to the antenna and ground input terminals of a radio receiver, and the voltage induced by a signal from a fixed transmitting station is plotted for various angles as the loop is rotated about its vertical axis, the resultant curve will be a "figure-of-eight." Such a polar diagram is shown in Fig. 36a from which it will be seen that zero voltage is produced at two positions in which the plane of the loop is parallel with the wave front, and that maximum voltages of opposite phase are produced respectively at the two positons where the plane of the loop is at right angles with the wave front. This is true only when the design of the loop and its circuits are such that no "vertical" or antenna effect is present due to imperfect loop shielding or unbalance of capacity between opposite terminals of the loop and ground, and when there is no direct reception or signal pick-up independent of the loop. In other words, a loop collector displays a bi-lateral directional characteristic showing two sharply defined minima of practically zero pick-up essential for obtaining accurate bearings and two relatively broad maxima, these conditions being obtained in alternate quadrants as the loop is rotated through 360° relative to the incoming direction of a received wave.

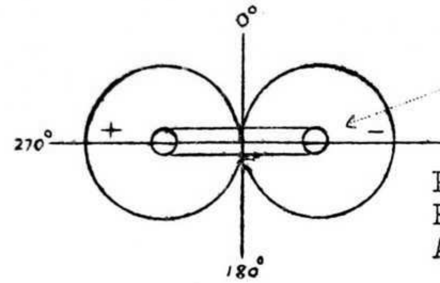


Fig.36a.

Polar Diagram of Reception by a Loop Antenna.

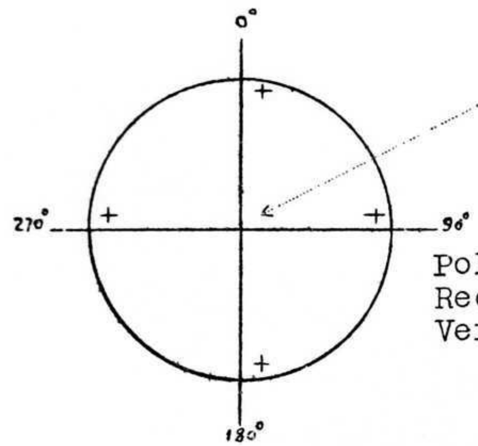


Fig.36b.

Polar Diagram of Reception by a Vertical Antenna

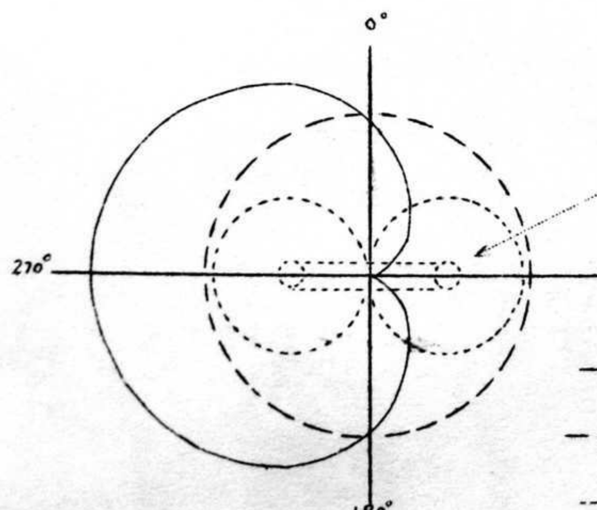


Fig.36c.

Polar Diagran of Reception by a Combined Loop and Vertical Antenna.

—— = Combined Voltage.

— — = Vertical Antenna Voltage.

---- = Loop Antenna Voltage.

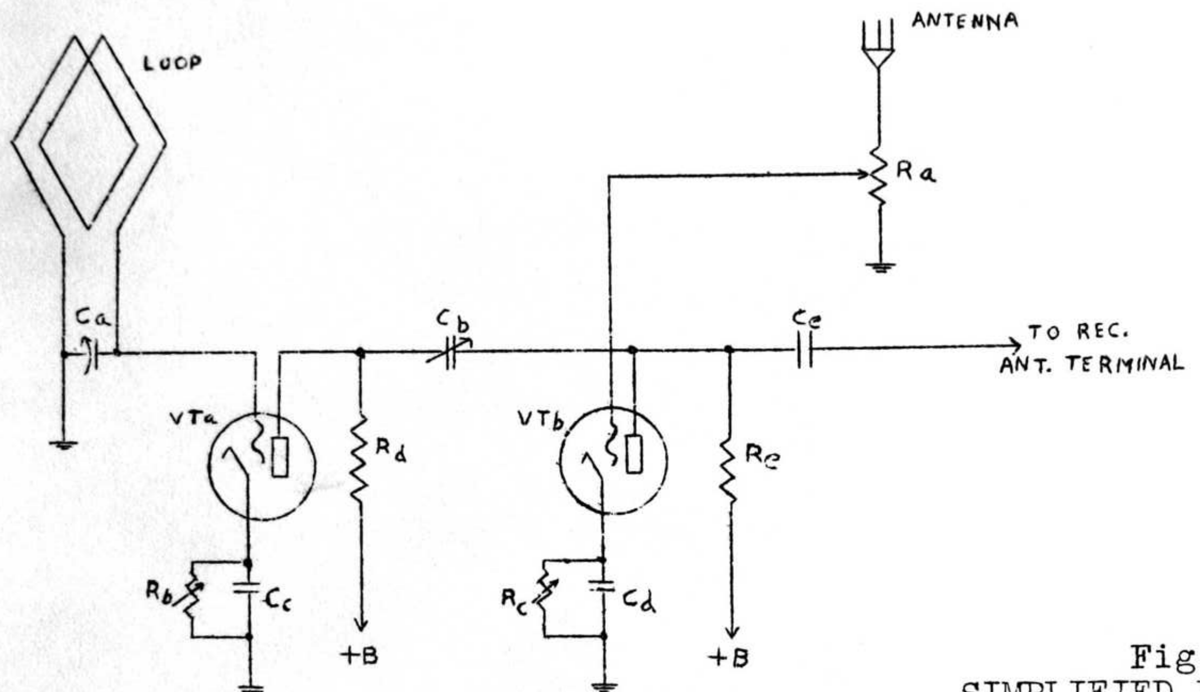


Fig.37.
SIMPLIFIED FUNDAMENTAL
CIRCUIT DIAGRAM
OF
TYPE RDF-1-A
RADIO DIRECTION FINDER

The action of a vertical antenna when connected to the same type of receiver is very different from that of a loop. This could be shown experimentally by moving a transmitter in a complete and true circle about the vertical receiving antenna as a center, and plotting the voltage induced in the antenna against the angular position of the transmitter. The resultant polar diagram would be as shown in Fig. 36b from which it will be seen that the induced voltage is of the same amplitude and phase for all angles. In other words, a vertical receiving antenna displays no directional properties. Likewise, ordinary fixed and downward trailing aircraft antennas are only slightly directional.

If both loop and antenna are now connected to the receiver, and the antenna voltage and phase are adjusted to equality with that obtained at one maximum position of the loop, the resultant output will be twice that obtained for either collector alone. At the opposite loop maximum, the resultant output will be zero since the loop voltage is then equal in amplitude but opposite in phase to that of the antenna. At the two loop minima, the resultant output will be equal of course to that picked up by the antenna alone. Plotting these values in a polar diagram produces a heart-shaped reception pattern, or cardioid, as shown in Fig.36c. It will be noted that the minimum obtained with this combination is not as sharply defined as the two minima obtained with loop reception alone. Morever, if the phasing of antenna and loop is not absolutely correct, the cardioid pattern will be distorted and the position of the minimum will be correspondingly shifted. The most discernable characteristic of the cardioid is the great difference between receiver outputs obtained at or near the two positions where maximum response is obtained with the loop alone. In other words, an antenna-loop combination displays a "sense" characteristic enabling unmistakable determination of the direction to the source of a transmitted wave, but is not capable of the sharply directive bearings obtained with the loop collector alone.

A simplified fundamental circuit diagram of a direction finding equipment, auxiliary to a radio receiver, capable of taking full advantage of all three of these principles is shown in Fig.37. Here, a loop collector is shown provided with a variable resonating capacitor Ca. Voltages built up across Ca excites the grid of vacuum tube VTa. The gain of this tube may be controlled over a wide range by changing the grid biasing voltage through variation of the cathode resistor Rb. Similarily, an antenna collector is shown as exciting the grid of vacuum tube VTb through the adjustable contact of the voltage dividing potentiometer Ra. The amplification of this tube is controlled by adjustment of cathode resistor Rc. Rd and Re are the plate load resistors and Cc and Cd the RF bypass condensers around the cathode resistors of the loop and antenna tubes, VTa and VTb respectively. The RF output of the loop amplifier VTa is fed through the adjustable coupling condenser Cb to combine with that of the antenna at the plate of amplifier VTb, and the resultant "mixed" energy is fed to the receiver through the coupling capacitor Ce.

Thus, with Rb adjusted to a high value, Rc left at normal, and the variable arm of Ra adjusted to the antenna end of Ra, the DC in the plate circuit of tube VTa will bias the loop input grid practically to cut-off, and tube VTb will function as an untuned antenna coupling tube or resistance coupled amplifier enabling non-directional reception of communications through the frequency range over which the receiver can be tuned.

With the movable arm of Ra connected to ground, Rc adjusted to a high value, and Rb returned to normal, the antenna tube VTc will be biased practically to cut-off, and the receiver will respond only to those signals which are tuned in on and collected by the loop. Under this condition accurate bi-lateral bearings can be obtained by swinging the loop to either of the two minima. Also, the equipment can be used as a "homing" device by locking the loop with its plane at right angles to the center-line of the ship (0° or 180° on the azimuth scale) and flying in the minimum signal zone provided it first be known whether the transmitting station is ahead or astern.

This sense or direction is determined with the antenna-loop combination by first reducing Rc to normal amplifying bias, adjusting Ra and possibly Cb to correct amplitude and phase matching, and swinging the loop to the angle of maximum response. The uni-lateral minimum is not used for direction indication because it is often distorted. It should be noted that the proper adjustments of Ra and Cb depends upon the physical characteristics of the antenna and loop collectors involved, and for all practical purposes they are independent of frequency. These two operations therefore become installation adjustments which require no further attention except to correct for any changes that may later be made in the arrangement of the equipment.

46. DEVIATION AND CALIBRATION OF ROTATABLE LOOP TYPE DIRECTION FINDERS

Practically all aircraft radio direction finder installations give definite errors in relative bearings which vary in a regular pattern throughout the 360°, and are known as quadrantal errors or quadrantal deviation. These errors are caused by the effect of the metallic fore-and-aft mass of the fuselage structure, the athwartship mass of the wing structure, and the effect of closed circuits such as represented by wing bays in the case of biplanes or braced monoplanes. If the loop is mounted on the exact centerline of the airplane and its scale has been properly aligned, there is generally no appreciable error on bearings taken dead ahead (0°) or astern (180°). Advantage may be taken of this condition when exact bearings are desired before it has been possible to calibrate the installation, or to determine the exact reference bearing of a station for calibration purposes. It has also been noted, in most installations, that a direction finder is somewhat more sensitive to bearings over the tail than to bearings from ahead due to a slight shielding action of the wing structure if this is ahead of the loop. The poorest bearings are frequently obtained, in the case of biplanes, at angles of around 60 to 70 and 290 to 300 degrees where these bearings pass through the outer wing struts. Since the deviational errors in unfavorable directions are generally on the order of 10 to 20 degrees, and often still greater (especially on the higher frequencies), it is highly desirable to measure such deviations by "swinging the ship", preferably on a compass rose, in a suitable location. The calibration data thus obtained are used to calibrate the various deviations, which may then be transposed and plotted against indicated bearings to form a correction curve. By correction is meant that value which, when algebraically added to the indicated radio bearing (relative to ships heading), gives the actual relative bearing of the incoming signal. Hence, if the actual bearing is numerically less than the indicated bearing, the correction is negative and is preceded by a minus sign (plotted below the zero axis) but when the actual bearing exceeds the indicated bearing the correction is positive, has a plus sign, and is plotted above the zero line. Correction is often confused with deviation, whereas, the former term applies to the indicated while the latter refers to the actual relative bearings. They are numerically equal but opposite in sign.

The deviation generally increases materially in the high-frequency region due to partial resonance of portions of the aircraft. At intermediate frequencies correction curves generally hold good over 150 to 200 Kc from the frequency at which the calibration was made, and at times show only slight change over the entire intermediate-frequency band.

To perform the deviation calibration for plotting the correction curve, proceed as follows:

(a) Visually check the loop alignment.

(b) Select a suitable location for calibration, preferably a compass rose. This should be several hundred feet removed from high buildings, power lines, and other absorbing or conducting metal structures. Also be free from underground pipes or electric cables.

(c) Select a suitable transmitter to calibrate upon. A local transmitter or broadcast station, preferably at a distance between one and ten miles, is satisfactory. Its direction should be exactly known or may be determined with fair accuracy by turning the aircraft to give a zero bearing right over the nose. Calibration at high frequencies (above 3000 Kc) further requires that the transmitting antenna be vertically symmetrical (not a feeder-connected horizontal antenna) and that it be visible from the calibrating location. In absence of a suitable transmitting station, a fair calibration can often be made with a shielded radio-frequency driver provided with a vertical (metal rod or tube) radiator about ten feet high, and placed in the open at as great a distance as the location and receiver sensitivity permit - at least several hundred feet.

(d) Tune in the calibrating signal and adjust the receiver and direction finder. Starting with a head-on bearing, swing the plane by 15 or 30 degree steps until a complete revolution has been made, so that the final observations will serve as a check upon the first set of readings. For greatest accuracy, it is desirable to elevate the tail approximately to normal flight position. A fifteen degree fore-and-aft slope of the aircraft will result in one-degree bearing changes at certain loop positions.

(e) For each 15 or 30 degree heading, record the following data:

1. Actual magnetic heading, by compass rose or by corrected ships compass.
2. Indicated radio bearing relative to ships head.

(f) The deviation is calculated as follows:

1. Add the magnetic heading to the indicated radio bearing.
2. Subtract 360 if the sum obtained in (1) permits.
3. If the resultant of operations (1) and (2) is more than the magnetic bearing of the station, subtract the magnetic bearing. The difference is the plus deviation. For example, if a certain transmitter has a magnetic bearing of 184°, and the ships heading is 225°, the indicated radio bearing might be 340°. The sum, as obtained under (1), is therefore 565; and since this is more than 360, we subtract, as in operation (2), obtaining 205. This resultant is more than the magnetic bearing of the station so the latter is subtracted from the former, as in (3), giving a deviation of +21°.
4. If the resultant of operation (1) and (2) is less than the magnetic bearing of the station, subtract the resultant.

The difference is the minus deviation. Thus, using the same transmitting station (the magnetic bearing of which was 184°) the indicated radio bearing might be 37.5° when the ships heading is shifted to 135°. The sum, as obtained for operation (1), is then 172.5° and since this is less than 360, operation (2) is omitted. However the resultant is now less than the magnetic bearing of the station, so the former is subtracted from the latter, as in operation (4), and the deviation is minus 11.5°.

(g) In all cases, the desired corrections will be numerically equal to the deviations thus obtained, but opposites in sign. For example, a deviation of plus 10° would require a correction of minus 10° to the indicated radio bearing.

(h) When all values for correction have thus been determined, plot the correction curve by showing plus corrections upward, minus corrections downward, and starting with 0° indicated radio bearing at the left, ending with 360° at the right side of the graph sheet. Connect the points by as smooth a curve as possible. If the calibration has carefully been performed, this curve will approximate a "sine wave" having two peaks and two dips through the 360°. If the peaks and dips are not equal, or if the curve does not cross the zero axis at 0°, 180°, and two intermediate points (approximately 90° and 270°) recheck the loop alignment and centering in the aircraft and verify the actual direction of the transmitting station as used in the calculations.

(i) Repeat the calibration for different frequencies, as desired. Do not fail to indicate the calibrating frequency on the different calibration curves thus obtained.

CAUTION: Any metallic masses, structures, or conductors in which circulating RF currents may be induced, if later added, removed, or altered, in the field of the loop, may destroy the accuracy of the calibrations. This applies to the bonding of the aircraft , any change in hood structure, relocation of wiring or of shielding, and spare parts or gear stowed near the loop. Check the calibrations in flight at frequent intervals by taking bearings on stations of known direction. The corrected indicated radio bearing, added to the corrected magnetic heading, should give the actual magnetic bearing to the transmitting station. (Subtract 360° if necessary).

47. BELLINI-TOSI LOOP SYSTEMS ON AIRCRAFT

During the past few years there has been much development of the Bellini-Tosi type loop system for large metal hull flying boats. Satisfactory bearings on transmitters over 500 miles distant are taken regularly on intermediate frequencies and greater distances are quite possible with the sensitive receivers now in use. The Bellini-Tosi system has the advantage, due to the large size of its loops, of being capable of receiving signals over a greater distance and with less deviation than any other systems yet tried. Recent developments, using the hull of the flying boat as part of the fore and aft loop, permits the use of a single wire from the tail section to the center-section being used as the fore and aft loop. This considerably simplifies the installation and causes less interference with gunnery. The objections to the older type systems were that the two fore and aft loops, one on either side of the hull, limited the after machine gun fire to narrow limits and were also a menace to small boats approaching the aircraft. Also, developments with compensator loops within the loop itself has decreased the deviation of this system to a very low value and in some cases deviation may be reduced sufficiently to permit direct uncorrected readings of the bearings taken from the goniometer dial.

The Bellini-Tosi system, although having some advantages at the present time, cannot be accepted as being a completely satisfactory system for patrol type aircraft because of its bulkiness and the large errors introduced into this system by "night effect". Patrol type aircraft are required to do much long distance night flying and Bellini-Tosi type loops cannot be relied upon to give accurate bearings at night. These loops will eventually have to be replaced by some type direction finding system which reduces or eliminates "night effect".

The Bellini-Tosi loop itself is quite a simple affair, consisting of two fixed loops with turns in vertical planes and at right angles to each other. The loops may be composed of single or multiple turns. It is highly desirable that the two loops be symmetrical both electrically and mechanically although in aircraft this is not entirely possible. Compensating loops or correctors must also be applied. These correctors are usually required in the larger athwartship loop and in the single turn loop may consist of wire jumpers, short-circuiting the outer portion of both ends of the athwartship loop. The position of the jumpers must be found by trial and will be that point giving the least deviation on loop calibration.

The physical shape of the loops is determined by the limitations of possible locations on the aircraft and they may be square, rectangular, triangular, or other odd shapes. The shape is not a critical factor. The location of the athwartship loop presents a problem in that it runs parallel to the metal trailing edge of the wing and, unless special fittings are used, quite close to it. It is desirable that the athwartship loop be as far removed from the aircraft structure as possible because of its high capacity effect to the wing structure. The leads connecting the loops to the goniometer should be kept as short as possible.

Loops are installed in such a manner that there is sufficient play for aircraft vibration and tail flutter. It has been found in practice that bowl bulkhead lead-in insulators mounted on a small strip of insulating material secured to the side of the aircraft make best lead-ins. The practice of putting beeswax over these lead-in insulators is detrimental to loop performance. The beeswax, when first put on has very high qualities but after being exposed to salt spray for some time, collects enough salt to make it a high resistance conductor.

The general requirement for most direction finder loops is, not less than two megohms resistance to ground but in the Bellini-Tosi system this should not be tolerated. These loops can be installed in such a manner as to obtain an infinity reading on a megger and are easily kept at that reading. It is good practice to boil any fibre type fittings in beeswax at least twice a year and in doing so, care must be exercised that the fittings do not touch the bottom of the container in which they are boiled. It has been found that good clean insulators or insulators given a high polish with a good grade of auto wax will shed salt water and hold up longer with less loss to ground than those heavily coated with wax compositions.

Unless special loading coils are part of the goniometer unit, it is necessary to make the electrical dimensions of the two loops such that they will resonate to the same frequency. With the use of the loading coils as is found in some types of goniometers, the loops may be brought to resonance by simple adjustment, providing they are not too far apart in frequency.

The goniometer is a very important part of the Bellini-Tosi system and good design is necessary. The Service uses the GI type goniometer, or one patterned after it which has proven to be reliable, but lacks a suitable method of quickly resonating the sense antenna to any desired frequency.

48. CALIBRATION OF BELLINI-TOSI SYSTEMS

The first procedure before calibration is to insure that the loops are free from grounds. The connections to the goniometer will have to be removed for this test. Take only a reading of infinity as being satisfactory for the resistance, loop to ground or loop to loop. After connecting the loops to the goniometer, a small coupling coil should be connected first to one loop and then the other and the number of turns on the loading coils adjusted until both loops resonate to the same frequency. This can be tested by coupling an oscillator up to the coupling coil which has been inserted in the loops.

After the loading coils have been adjusted, the ship should be placed at a known bearing from a certain signal and then the polarity of the loops should be juggled by reversing the leads on the front of the goniometer panel until it gives the correct bearing as indicated by the compass dial. For calibration, the aircraft should be placed on a compass rose, one free from the influence of bent wave fronts caused by nearby structures, hangars, radio towers and underground pipes or cables. Care should be taken to insure that the station used for calibrating is so located that the received signal wave front is not deflected from its true course due to the influence of uneven ground or broken territory of land and water. The separating distance between the aircraft and the transmitting station should be at least five miles. The exact geographical position of the transmitting station should be plotted and the aircraft orientated on the compass rose to the true bearing of it. The bearing of the transmitting station is then zero degrees relative to the aircrafts heading and regardless of the aircrafts position on the compass rose, this position is compass rose zero and the point of reference. If, after the aircraft is headed on the true bearing toward the transmitting station and the "minima" are misplaced, the loops should be compensated for the deviation until the "minima" are well defined when the goniometer dial reads zero. The aircraft may then be turned on the compass rose taking bearings every 10 degrees or so throughout 360 degrees and the radio bearings plotted against relative true bearings. It is to be remembered that all bearings taken are relative to the aircrafts heading. It is then necessary to make a flight test for determining the proper length of trailing wire antenna to use for a "sense" antenna for uni-lateral sense direction. This may be accomplished by tuning in some station on the frequency generally used and with the goniometer dial tuned to "minima" of the signal, rotate the dial to the right 90 degrees, press the sense button on the goniometer and reel out trailing antenna until a point is found where the signal diminishes to a marked degree. (See GI goniometers for an additional goniometer adjustment when using that unit) Check the number of turns reeled out on the counter or put a marker on the wire if no counter is installed. Then rotate the dial back through the "minima" and past it to the LEFT for 90 degrees and the signal should increase when the sense button is pressed. All this is done with the radioman knowing definately the relative bearing of the transmitting station during the process. After the proper length of trailing wire antenna has been determined by this method, the following rule will apply. "WITH THE DIAL TUNED TO THE MINIMA OF A SIGNAL, PRESS THE SENSE BUTTON. IF THE SIGNAL DECREASES AS THE COMPASS DIAL IS ROTATED TO THE RIGHT, AND INCREASES AS THE DIAL IS ROTATED TO THE LEFT, THE BEARING IS CORRECT. IF THE SIGNAL INCREASES AS THE DIAL IS ROTATED TO THE RIGHT AND DECREASES AS THE DIAL IS ROTATED TO THE LEFT, THE BEARING IS 180 DEGREES FROM CORRECT. Fixed type sense antennas may be used but such antennas must necessarily be designed for that purpose and complicate the antenna arrangement of the aircraft.

49. GI TYPE GONIOMETERS

The GI goniometer consists of two field coils (See Fig.38 and 39) wound lengthwise on a cylindrical form, one of these field coils being connected to the athwart loop and the other to the fore and aft loops. Tightly coupled to these field coils and capable of rotating within them, there are mounted two search coils set at approximately 45 degrees with respect to each other. This last mentioned rotating coil system is for the purpose of determining the direction of the magnetic field in the fixed or field coil system. The two magnetic fields of this field coil system produce a resultant field which bears exactly the same space relationship to the axes of the two coils in this fixed coil system as the direction of the received signal does to the planes of the two loop antennas.

It remains then to determine the exact direction of this resulting field. This is done by means of the rotating search coil inside the fixed coils. The voltage induced in the windings of the search coil is proportional to its linkage with the magnetic field of the field coils and therefore as the search coil is rotated in this field, the induced voltage will be minimum when its axis is at

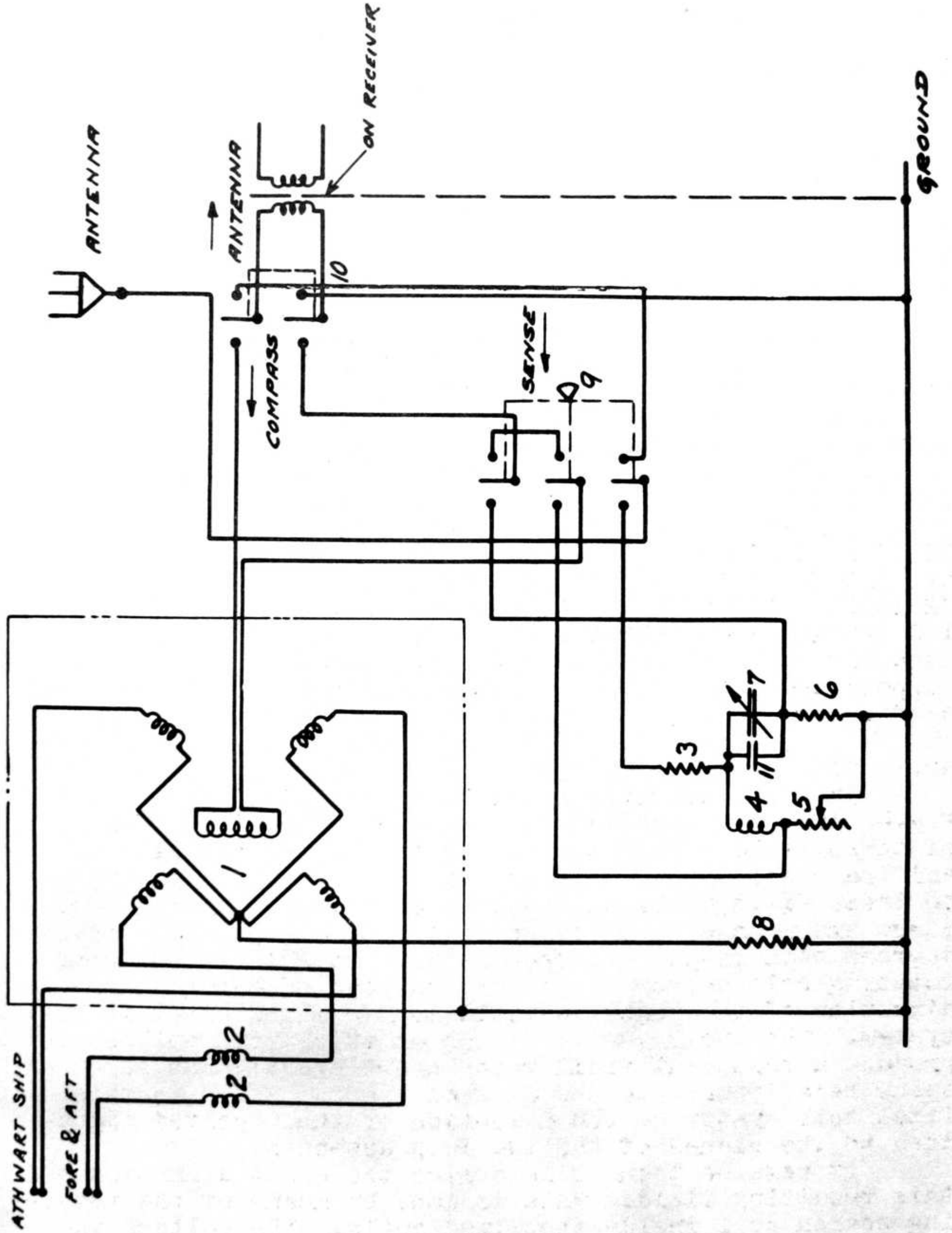

ANTENNA
ANTENNA
ON RECEIVER
10
SENSE
9
COMPASS
GROUND
7
6
3
11
4
5
1
8
2
2
ATHWART SHIP
FORE & AFT

FIG. 38

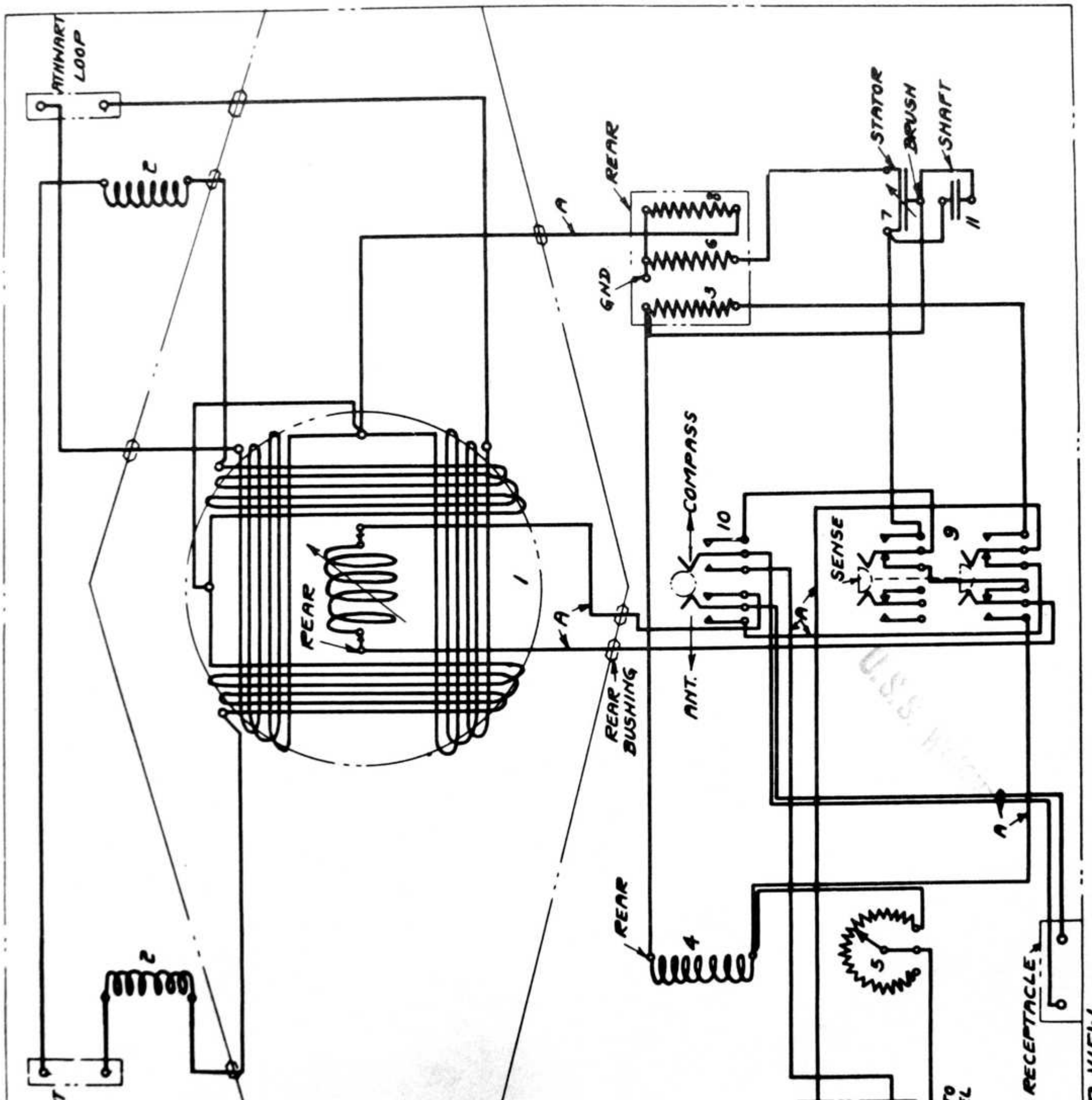

ATHWART LOOP
STATOR
BRUSH
SHAFT
REAR
GND
A
COMPASS
10
SENSE
9
REAR
ANT.
REAR BUSHING
FOR-AFT LOOP
REAR
ANT.
GND.
GND. TO PANEL
RECEPTACLE
REAR VIEW

FIG 39

right angles to the field. It is then obvious that the search coil passes through points of maximum and minimum flux linkage as it is rotated in the field coils and points of maximum and minimum signal strengths are noted 90 degrees apart.

A dial divided into 360 degrees around its circumference is attached to the shaft of the search coil and a reference line is put on the panel so that the direction of the resultant field and hence the incident wave with respect to the bow of the aircraft may be read directly.

It may be seen from the above discussion that any given signal will have two minimum points on the compass dial, one at its true bearing and the other 180 degrees displaced. That is, from the above it cannot be determined whether a signal is directly ahead or astern. To determine the sense or true bearing of the incident wave, provision is made in this radio compass for introducing a non-directional signal pattern on the figure eight pattern. The result is a cardioid or heart shaped pattern from which the true direction of the incoming signal with respect to the fore and aft line of the aircraft may be determined. Thus sense indication is accomplished by pressing the sense button on the panel connecting on to the sense antenna. A trailing wire antenna may be used very effectively for sense if the proper length is determined by experiment. There are two adjustments on the front of the GI goniometer for adjusting sense indication and these should be adjusted until a good sense indication is obtained. There is no excuse for not obtaining good uni-lateral (sense indication) bearings while using the Bellini-Tosi system and the GI goniometer.

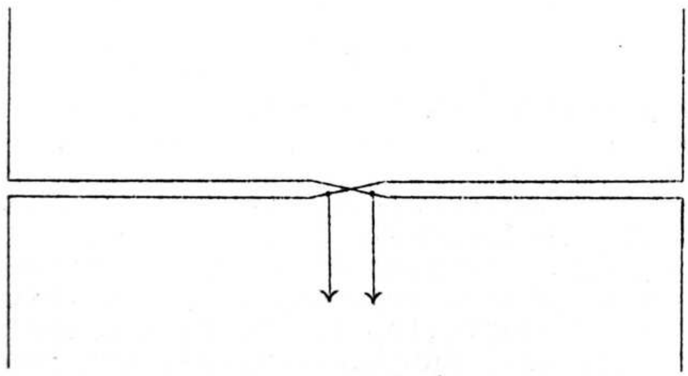
50. THEORY OF THE ADCOCK DIRECTION FINDING SYSTEM AND ITS POSSIBLE USE ON AIRCRAFT

The following is written in view of furnishing some general information necessary to understand the principles involved in the possible adaptation of the Adcock system to aircraft. At the time this pamphlet was written there were no serviceable models of Adcock direction finders available for installation on aircraft but as there has been considerable research work along these lines the Service might expect to see something of it in the near future. It is, strictly speaking, a relatively new field of research and much experimentation and development must be done before some satisfactory installation can be made.

The adaptation of the Adcock type direction finding system for aircraft appears to be inevitable and seems to be the only real solution in eliminating "night effect" and the inconsistencies of present high frequency bearings as is now experienced with the use of the loop type direction finder.

In order that the reader may understand the working principle of the Adcock system it is necessary to understand "night effect" and errors from down-coming waves and their elimination. The bearings obtained by the use of a loop system are accurate only when down-coming horizontally polarized sky waves are absent. Horizontally polarized down-coming waves induce voltages in the top and bottom parts of the loop which give rise to a resultant voltage acting around the loop circuit even when the loop is set for minimum response to vertically polarized waves traveling parallel with the surface of the earth. The result is either that there is no loop position giving zero response, or that the position of zero response represents a false bearing. As a consequence the usefulness of the loop as a means of direction finding is limited almost to the lower radio frequencies, where the waves when observed in the vicinity of the earth are vertically polarized, or when the sky wave is of negligible strength in comparison with the ground wave. Since the sky wave is always strongest at night the errors that result from down-coming horizontally polarized waves are frequently referred to as "night effect" although they are always present to some extent in daytime. (See section 41 for "night effect".)

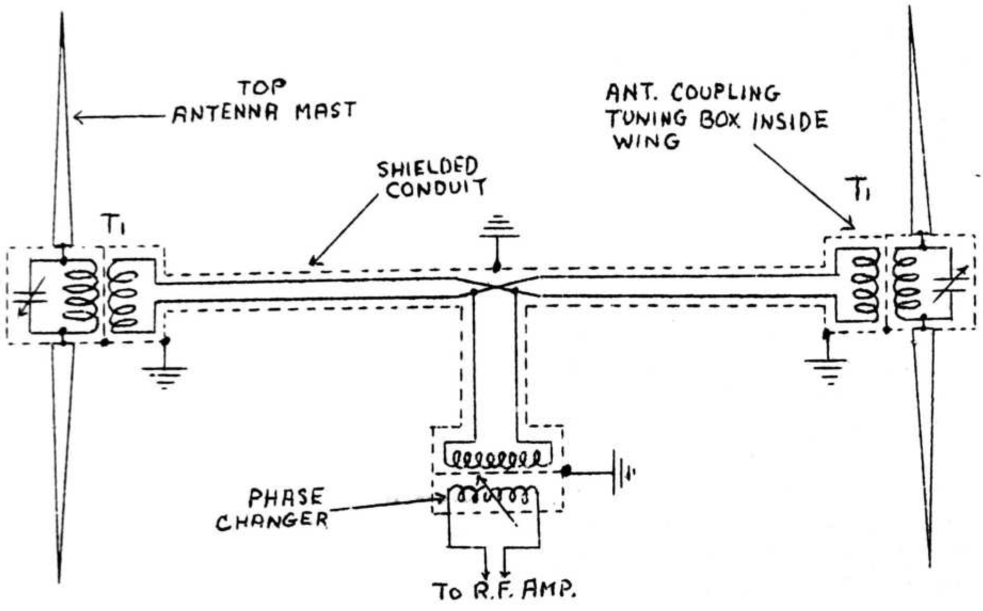
The errors in bearing caused by down-coming horizontally polarized sky waves can be eliminated by replacing the loop system as is now used in aircraft with the Adcock antenna system, which in its simplest form consists of two spaced vertical antennas connected as shown in Fig. 40. The action of



SIMPLE ADCOCK
Fig. 40.

such an antenna as far as vertically polarized waves are concerned is identical with the loop since the resultant current in the output coil of the Adcock antenna is proportional to the vector difference of the voltages induced in the two vertical members, exactly as is the case with the loop. Horizontally polarized down-coming waves do not effect the Adcock antenna, however, since the connections are arranged so that all the voltages induced in the horizontal members balance out each others effects.

Considering the use of such a system on aircraft an arrangement such as shown in Fig. 41 might be used. Such a system could consist of two vertical antennas, each antenna unit consisting of two streamlined stub masts (2 or 3 feet long) connected through a coupling transformer. This transformer



MODIFIED ADCOCK

Fig. 41.

also acts as an antenna loading coil for resonating the antenna to desired frequencies of band operation. As shown by the diagram, the primary of T_1 is tunable by a variable condenser. If wide frequency bands are to be used the antenna should be non-resonant and have a broad frequency response which would necessitate the use of a very low **C** circuit. The two antenna units are coupled together, the secondaries of the coupling transformers being hooked direct to each other through twisted feeder cable run in shielded conduits. From the diagram it will be seen that only the vertical portion of the system, the antennas will be affected by wave fronts as every thing else except the antennas are shielded. The use of electrostatic shields in the coupling transformers reduces capacity coupling between the antennas and other circuits. The receiver coupling transformer transmission line is connected to the electrical center of the antenna feeder cable. This line is also a twisted and shielded feeder cable terminating in the the receiver coupling transformer. This transformer also has an electro-static shield thereby removing capacity coupling between it and the transmission lines. It will be noted that the secondary of the receiver coupling transformer is shown as adjustable. In such a system with the secondary being made adjustable in the form of a variometer, "homing" would be simplified, for, a slight shift of this variometer would change the phasing of the entire system, thereby giving a misplaced "minima". The pilot could tune in a transmitting station on the "dead ahead" "minima" signal, check his magnetic compass course, plot his apparent wind drift and change to the new magnetic course which will give him a true "track" to the transmitting station. This would, of course, take him off the "minima" signal but with the tunable control, he can move a misplaced "minima" over to his new magnetic course and "home" to the transmitting station on it without the usual difficulties usually encountered in "homing" as described in section 44.

Recent developments with vacuum tubes permit isolation of antenna, sense antenna, and receiver both electro-statically and electro-magnetically which will greatly increase the effectiveness of such a system as the Adcock. The antennas themselves will not have as high a voltage pick-up as the large Bellini-Tosi loops but its success lies not so much in the signal voltage as in the difference in phasing due to the large distance separating the antennas. With small coupling losses, a special amplifier unit for isolation and amplification, and the present sensitive receivers, this system should be capable of taking bearings over long distances when used on aircraft.

The antennas would necessarily be installed out on the wing tips of the aircraft, with the antenna coupling box inside the wing itself, and for the large monoplane flying boats this condition would be ideal giving a separation of the antennas of approximately 82 feet. It must be remembered, however, that the above discussion is not that of equipment actually in service use but is more in the nature of information explaining possible application of the Adcock system to aircraft.

With the perfection of an Adcock system for aircraft there will also come more reliable and consistent high frequency radio direction finding.

51. TYPE RDF-1-A AIRCRAFT DIRECTION FINDER EQUIPMENT

The Type RDF-1-A direction finder equipment has been designed to take accurate uni-lateral and bi-lateral bearings when used in conjunction with radio receiving equipment of the RU series. Each equipment consists of the following units:

1 Tyoe L1130-B Direction Finder, weight, including mounting base and tube, 7.5 lbs.

1 Direction Finder - - Receiver Coupling Cable, 24" long, 3/8" diameter, weight, 0.32 lbs.

1 Type A1139 Junction Box, weight, 0.63 lbs. (not used with RU-4 and later type receivers).

2 Power Cable, each, three conductor, 60" long 7/16" diameter, weight 0.94 lbs.

1 Vacuum Tube, Navy Type 38233, Commercial Type RK-33.

Fig.42 shows structural dimensions while Fig.43 shows a schematic circuit diagram.

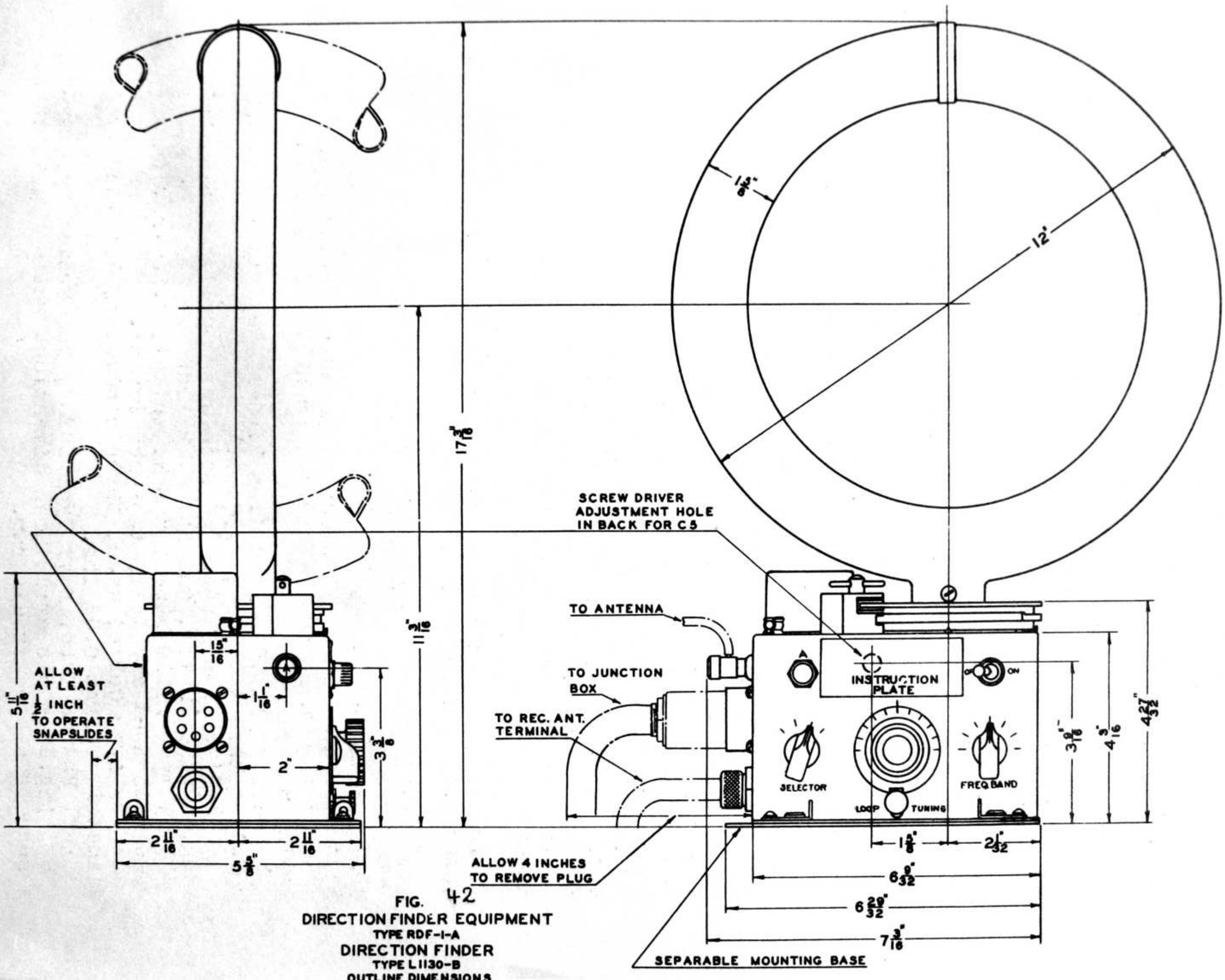


FIG. 42
DIRECTION FINDER EQUIPMENT
TYPE RDF-1-A
DIRECTION FINDER
TYPE L1130-B
OUTLINE DIMENSIONS

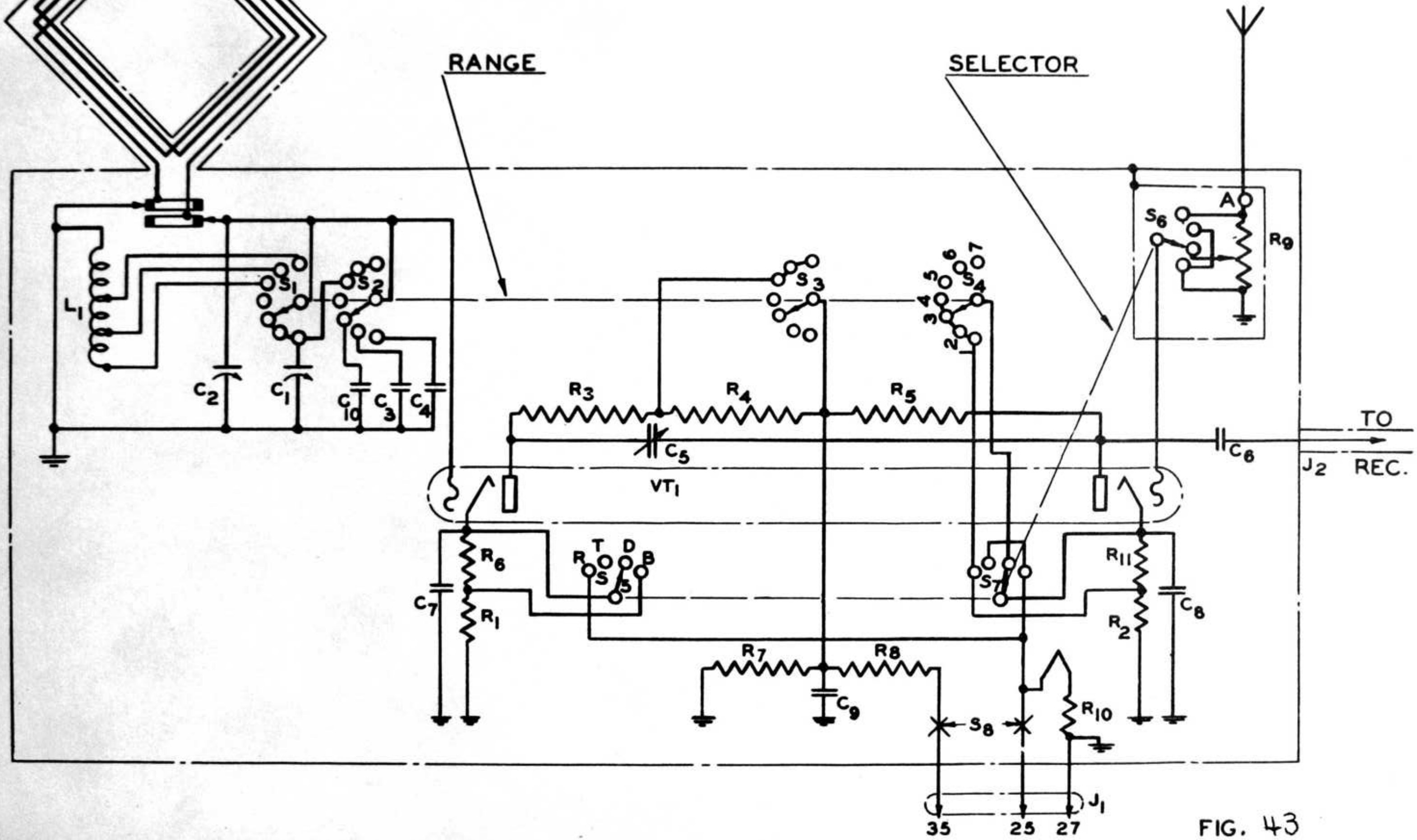


FIG. 43
DIRECTION FINDER EQUIPMENT
TYPE RDF-1-A
DIRECTION FINDER
TYPE L1130-B
SCHEMATIC DIAGRAM

The Type L1130-B direction finder consists of a shielded rotatable loop antenna mounted on a cabinet type base comprising bearings and indicators for the mechanical operation of the unit together with suitable switches, coupling devices and circuits for all of its electrical functions. This unit differs from the L1130-A unit supplied with the Type RDF-1 direction finder equipment mainly in the addition of a separable mounting plate, to which it is normally secured by means of four snap slides.

The direction finder - receiver coupling cable is a low loss shielded transmission line provided for connecting the direction finder output to the antenna terminal of the radio receiver. The 24" coupling cables supplied with Type RDF-1A direction finder equipments are designed for general installations in various types of airplanes where the Type L1130-B direction finder can be mounted in close proximity to the radio receiver. Special coupling cables, of various lengths are supplied with this equipment allowing it to be used in the various types aircraft. Since these special cables have an outside diameter of 5/8" they are supplied with an auxiliary fitting which adapts them to the output bushings on the direction finders. Due to their larger diameter, the capacity of these special cables is of the same order as that of the standard 24" cables, but their weight is increased to 0.66 lbs.

The Type A1139 junction box and the two power cables permit operation of an auxiliary equipment, in addition to the direction finder, from the receiver power supply. One of the power cables may be connected from outlet 74 of the Type CBY-23011-A (or corresponding power outlets of similar junction boxes of the RU series) to any one of the three receptacles of the A1139 junction box, as corresponding terminals of the latter are connected in parallel. With the Type L1130-B direction finder connected to a second receptacle through the remaining power cable, the third receptacle of the A1130 junction box may then be used for a Model LJ or LJ-1 frequency indicator, RH-5 interphone or other equipment.

Beginning with the RU-4 and later type receivers two outlets will be available on the junction box for connection of direction finders, frequency meters and interphone equipment.

The Navy Type 38233 vacuum tube includes two independent heater type triodes in a single envelope, one section being employed to couple the direction finder loop, and the other section to couple the airplane fixed antenna to the antenna terminal of the radio receiver.

In the RDF-1-A direction finder equipment, the foregoing seemingly complicated technique has been reduced to a practical sequence of four successive operations. These operations, which are explained on an instruction plate mounted on the front panel of the Type L1130-B direction finder, are reproduced here for the readers convenience.

R RECEIVE. DO NOT ATTEMPT TO TAKE BEARINGS.

T TUNE LOOP FOR MAXIMUM SIGNAL. DO NOT TAKE BEARINGS.

D DIRECTION. SWING LOOP FOR MAXIMUM SIGNAL. ARROWS WILL POINT TO STATION. ADJUST MASK SO THAT ZERO MARK IS ON INDEX WITH LOOP IN POSITION OF MAXIMUM SIGNAL.

B BEARING. SWING LOOP TO MINIMUM IN UNMASKED PORTION OF DIAL. BEARING IS RELATIVE TO PLANE HEADING.

R, T, D and B are the initial letters of the words naming the particular operations referred to. They are also the designating letters of the four positions of the ganged SELECTOR switch, in each of which the circuits necessary to the designated operations are automatically arranged.

On the R position of the SELECTOR switch, the fixed antenna is coupled to the receiver through one section of the duo-triode RK-33. In effect the arrangement consists of an untuned stage of RF amplification ahead of the receiver. R9 serves as the grid leak and antenna coupling resistor. R5 is the output load resistor, and coupling to the receiver is through C6. The output circuit has been so designed that the receiver antenna trimmer does not need readjustment throughout any one frequency range (plug-in coil range), nor does it require retrimming when the direction finder is used for other modes of operation (T,D or B).

The losses incident to coupling the receiver to the antenna through the shielded lead and C6 are partly compensated for by the amplification obtained in the antenna section of the tube. On intermediate frequencies, the normal signal output will be between 60 percent and 100 percent of that obtained with the antenna connected directly to the receiver.

Since only non-directional reception is desired on the R position, the loop section of the tube is blocked by placing the 12 volt filament supply across its cathode resistor R1,R6, with the negative to ground. The output network, consisting of R3,R4, and C5, remains in the circuit to retain the receiver trimmer adjustment.

The T position unblocks the loop section and blocks the antenna section of the tube through S5,S7. In addition, S6 grounds the antenna section tube grid. The antenna lead-in binding post, R9, and S6, are all enclosed in a separate shielded compartment so that on this position the antenna is completely isolated from the rest of the circuit. The loop energy is coupled through the loop section of the tube, C5 and C6, to the receiver.

The desired frequency range is selected by sections S1, S2 of the frequency band switch. This switch assembly has seven positions, the frequency range for each position being given on a frequency bands chart concealed inside the inner bottom cover plate of the unit. These ranges, and the circuit combinations employed to cover them, are as follows:

STEP	FREQUENCY RANGE	LC COMBINATION
1	500 - 590 Kcs	(Full loop) (C1 + C2 + C4)
2	590 - 700 Kcs	(Full loop) (C1 + C2 + C3)
3	700 -1050 Kcs	(Full loop) (C1 + C2 + C10)
4	1050-1570 Kcs	(Full loop) (C2)
5	1570-3000 Kcs	(Loop shunted by L1) (C1 + C2)
6	3000-5400 Kcs	(Loop shunted by 0.1 L1) (C1 + C2)
7	5400-8000 Kcs	(Loop shunted by 0.01 L1) (C1 + C2)

Successively smaller shunt inductances are required around the loop for steps 5,6 and 7 because the full loop inductance, in conjunction with the residual circuit capacity, resonates at approximately 1600 Kcs. Ganged with S1, S2 are two other switches, S3 and S4. S3 serves to keep the sensitivity of the loop section of the tube at a usable level throughout the frequency range. At the low frequencies, 500-1570 Kcs, the plate load of the loop tube consists of R3 and R4 in series. The plate circuit resistance of the tube is considerably decreased at the high frequencies by S3, which shorts out R4 on all frequency bands above 1570 Kcs. The decrease in plate circuit resistance causes an increase in plate voltage with an attendant increase in sensitivity. S4 serves a similar purpose but in reverse order. At the low frequencies the short fixed antenna is less efficient than at high frequencies; therefore S4, by shorting out R11, decreases bias and increases the sensitivity of the antenna tube section for low frequency operations.

Efficient and complete shielding, together with short leads from the loop to the coupling tube, gives the reception pattern shown in Fig.36c on both the T and B positions. While tuning the loop, it should be swung to a maximum position. Since it is necessary that the loop be correctly tuned for proper operation, the sensitivity of the loop section of the tube on the T position is kept low, making more accurate tuning possible.

The D position is the most important of the four, as a definite indication of the direction to the transmitter is necessary above all else. Since the direction indication is obtained by combining the outputs of both the fixed antenna and the loop, proper phasing and amplitudes are necessary to produce the cardioid pattern shown by the solid line in Fig.36c. The resistance networks in the loop tube plate and cathode have been arranged through actual operating tests to obtain an order of sensitivity which is approximately correct for the average fixed antenna. Specific antenna compensation is obtained at the time of installation by screw driver adjustment of the slider on R9. (Control A) controlling the phase and amount of energy introduced through the antenna section of the tube; and, if necessary, by screw driver adjustment of C5 (Through the rear of cabinet) which controls the amount of energy coupled from the loop section to the antenna section of the tube. Values of adjustment can be found which will give good average results over the entire frequency range.

Two arrows are engraved on the top surface of the azimuth scale which points in the same direction as that half of the loop shield which is finished in bright aluminum, the other half being black. The connections of the loop have been made in such a manner that when the loop is rotated to a D maximum the arrows and the bright half of the loop will always point to the station, the bearing of which (Relative to the plane heading) will be about 90° counter-clockwise from the figure read above the front INDEX pointer. That is, the approximate bearing may be read at the right hand end of the unit.

A mask is provided on the azimuth scale which eliminates the possibility of using the wrong minimum when reading accurate bearings. After pointing the loop in the D maximum position, this mask is rotated so that its zero mark falls above the front index pointer; then the mask opening will be at the right side exposing that portion of the scale in which the true bearing will fall. The mask serves to "remember" that portion for the operator while he is shifting to the B position and swinging the loop to get the accurate bearing.

The B position of the SELECTOR switch arranges the circuits to permit reading accurate minimum bearings. While these are bi-lateral (the loop having the normal figure-of-eight reception characteristic), only the correct bearing with respect to the head of the ship will be readable over the front INDEX pointer. This is because the mask ring was set, in the preceding D operation, so as to cover up the reverse portion of the scale. In the B position, the output of only the loop section of the tube is again utilized as in the T position, but with one important difference. The bias is lowered through the shorting out of R6, raising the sensitivity of the loop section to a much higher value. The effect is to create a signal level in the area of within plus or minus 10° of the minimum which is approximately equal to the signal obtained on the D maximum.

There are several reasons for the changing of sensitivity on the different steps that will become evident during the test operation of this equipment. In the first place, the most accurate bearings of the minimum or bilateral type can be obtained with a high signal level. The high signal level is not unpleasant since the operator need not listen to the maximum; he is concerned only with the minimum signal area. On the contrary, the signal level must be kept to a low level for the determination of the cardioid maximum, since the ears tend to paralyze and become less discriminating in the presence of a loud signal. There is the further possibility that the receiver may become blocked and the maximum be actually not perceptible. In extreme cases it is possible for the blocking on the maximum to become so severe that, due to the receiver characteristics, the maximum would appear as a minimum as the receiver overloaded. These conditions could be overcome by manipulation of the receiver volume control between operations, but it was found that much more satisfactory results were obtained with automatic selection of the proper level. In the equipment as finally developed, the levels are so arranged that when the operator tunes the loop and adjusts the volume to his liking on T, it will not be too loud on the D position; while on the B position he is working near the minimum where the extremely loud "figure-of-eight" maxima do no harm, yet the higher sensitivity increases the sharpness of bearings to a considerable degree.

The use of automatic volume control (AVC) in the receiver is generally undesirable for direction finding as it prevents normal change in signal strength with loop direction. MANUAL volume control should be used. The receiver should also generally be used in the CW position; however, if the incoming signal is strong and has a steady tone modulation, then only may better results be obtained with the receiver non-oscillating, on ICW.

The type L1130-B direction finder should be installed, if at all possible, with the center line of the loop coincident with the center line of the airplane, and with its front panel facing aft. If installed so that the front panel faces forward, the reciprocal (reverse) of all bearings will be indicated, unless the mask is used with the ZERO MARK turned to the rear.

If the direction finder is installed in a position where its loop is surrounded by nearby metallic members such as the braces of a hood enclosure, considerable deviation and loss of sensitivity will be experienced unless undesirable (especially athwartship) circulating currents are eliminated by inserting suitable insulating pieces in the affecting structure. Cockpit enclosing hoods are most suitably broken up electrically by leaving a gap in the top of each of the athwartship metal bows, reinforcing them mechanically with insulating material. Insulation of the hood structure itself from the airplane structure is not desirable.

In bi-planes, the longitudinal members of the fixed cockpit enclosure are not broken. These metallic loops in this class of airplane actually counteract the detrimental effect of the metallic loops in the wing structures and are therefore desirable.

Sufficient clearance to all structures must be left to allow continuous rotation of the loop; also to permit connection and removal of the power and coupling cables, operation of the snapslides, screwdriver adjustment of the loop coupling capacitor at the back of the unit, and to give free access for manipulation of the loop, mask, and all the panel controls. Finally, the direction finder should be mounted close enough to the receiver to allow the connection to be made by means of the two foot coupling cable supplied. This coupling plugs into the fitting in the lower left hand end of the unit, and the bare end connects to the antenna (A) binding post on the receiver. The clamp furnished must be secured under one of the screws holding the front panel of the receiver in place in such a manner that the cable leads directly to the antenna post. The clamp may be secured either on the side or top of the receiver, whichever is the most convenient in the particular installation. The short bend on the one lip of the clamp serves to hold the cable parallel to the front of the receiver.

The type RDF-1-A direction finder is supplied with a separable mounting plate, to which it is secured by four standard snapslides.

After securing the mounting plate, attach the direction finder to it by means of the four snapslides. Now set the loop exactly fore-and-aft, with its bright half forward, and check its alignment by sighting from behind the vertical tail surface of the plane. With the loop carefully set in this position, the directional scale should read 270° (or 90° if the direction finder is mounted with its front panel forward). Any departure from these readings should be corrected by re-setting the directional scale with respect to the loop, proceeding as follows: (a) Clamp the loop in the fore-and-aft position as aligned; (b) Loosen the three screws on top of the directional scale slightly, in no case more than one turn each; (c) Grasp the directional scale itself (not the top plate nor the mask ring) and rotate it to the proper reading as stated above; and (d) tighten the three screws, thus locking the scale in its corrected position.

The type A1139 junction box may be mounted in any convenient location where one power cable will reach the receiver junction box and the other cable will connect to the direction finder. These cables must be bonded to the ship structure; likewise all other cables of the receiver equipment should be thoroughly bonded. In the case of planes where no other equipment requiring power from the receiver supply is installed, the A1139 junction box may be omitted if the receiver junction box is within one cable length (approximately 5 feet) of the direction finder.

The direction finder should be used with a fixed antenna at least five feet in length, extending upward above the airplane and loop as much as possible. The standard fixed airplane antenna installed for operation of the RU series of receiving equipment is usually quite satisfactory if all recommendations of the receiver manufacturer are properly followed. The use of a fixed or trailing antenna extending downward in connection with the direction finder will cause a 180 degree error in indicated direction. The antenna should be connected to the push type binding post at the upper left end of the direction finder.

When making installations, make ground connections as short as possible. If the RDF-1-A direction finder equipment should be installed in any location other than in an airplane, care must be exercised in the selection of a ground. A ground lead of even a few feet in length tends to function as an antenna, and it cannot be isolated from the circuits in the manner in which the regular antenna is controlled. No ground at all is much to be preferred. A counterpoise of metal directly beneath the equipment is satisfactory.

INITIAL ADJUSTMENT AND CALIBRATION.

After installation, there are certain preliminary adjustments that must be made in order to obtain proper operation of the equipment with the particular fixed antenna used. These adjustments are best made as follows:

With the power cable connected, receiver coupling cable in place and properly connected, place the tube in its socket and connect the grid cap, replace the tube shield cap and turn the receiver and the direction finder power switches on. Place the selector switch on R and tune in a signal on the receiver in the 1050-1570 Kcs range. A CW carrier is best. However, a near-by broadcast station supplies an ideal signal when the receiver is on CW, using MANUAL volume control.

Adjust the alignment of the receiver antenna trimmer (antenna-loop switch on A) for maximum sensitivity. Switch to T and tune the loop to resonance, as indicated by the maximum signal obtained. In this position the unit is acting partially as a bi-lateral direction finder, and rotation of the loop will change the signal strength. The loop is most easily tuned in either maximum position, after appropriate adjustment of receiver volume control.

With the loop tuned, switch to D. Remove the knurled cap screwed over antenna phasing control A, on the upper left hand corner of the front panel. Swing the loop to determine whether one or two maxima are obtained. If one maximum is of considerably greater amplitude than the other, set the loop to the weaker maximum, and adjust A with a screwdriver until the signal disappears or reaches a minimum. A rotation of the loop back and forth over twenty or thirty degrees will often assist, since the maximum being worked on is sometimes distorted as it is being balanced out and may shift slightly. Keep the volume control in such a position that the maximum signal made possible by loop rotation is comfortable to the ear.

The small air condenser C5, located under the swinging cover plate on the rear panel, should be left adjusted as near to its maximum capacitance as possible in order to insure greatest sensitivity of loop reception. In this position, the screwdriver slot provided for its adjustment will be straight up-and-down, and (if the vacuum tube is removed) the rotor plates may be seen turned farthest away from the tube opening, i.e. in full mesh with the stator plates. Only in those cases where the balance antenna is very small or so low in effective height that a balance cannot be obtained, the capacitance of C5 should be reduced to decrease the loop reception to a value permitting proper direction indication with the antenna available. To obtain the best adjustment, swing the cover plate to one side and with a screwdriver (preferably with insulated handle to avoid shock) successively turn the condenser about fifteen degrees at a time (in either continuous direction), each time trying various adjustments of the antenna phasing resistor (control A), until a satisfactory direction indication is obtained when the loop is rotated through a complete turn.

The adjustment for control A and condenser C5 may be considered satisfactory when the bright half of the loop turned toward the signal source gives the strongest signal, and only a weak response is obtained when the black half of the loop points toward the station. The use of an output meter will be of considerable help in making these adjustments. In most cases, an output voltage ratio of better than four to one between the maximum direction and its reverse will be obtained. Check the adjustments by tuning in other stations and, if necessary, repeat the procedure until settings are found whereby good ratios are obtained throughout the frequency range.

In case no distinct signal maximum D direction is obtained with the adjustments described above, or in case some sort of maximum is actually obtained, but in reverse direction, the trouble may be due to excessive capacity between the receiving antenna connections (to the direction finder) and the airplane fuselage. To remedy such a condition, it may be necessary to provide a separate short direction finder phasing antenna connected directly to its antenna terminal; or to provide a clip lead for direct connection at the fixed antenna entering insulator, without passing through the break-in relay, while using the direction finder. For proper sense balancing, the phasing antenna should not be less than two feet, nor more than twenty feet in length. A larger antenna (which does not have excessive lead-in capacity within the fuselage) may be used provided a condenser of .00003 to .00005 Mfd is connected between it and the antenna terminal of the direction finder.

Due to local conditions, distance and various other circumstances, it is practically impossible to obtain a perfect "cardioid" pattern on all stations.

When operating properly, a voltage ratio of at least four to one may be obtained on at least 90 percent of the stations throughout the 500-1570 Kcs range. The same is generally true of high frequency stations which are within optical range and which operate into vertical antennas. High frequency signals are much more subject to the shifting and rotation of phase that causes poor bearings. Consequently, operation at the higher frequencies will not be so consistent as at the lower frequencies.

With the direction finder operating in such a manner that unmistakable direction indications are obtained with ease, the clip cover-plate and screw cap may be replaced. No future alterations should be necessary to these adjustments unless the antenna or rigging of the airplane is changed.

NOTE: These adjustments are made on the fixed antenna with the trailing antenna (on airplanes so equipped) in a certain position, and the latter should occupy the same position when the equipment is used at any subsequent time. That is, if the adjustments are made with the trailing antenna reeled in, then it should be reeled in when taking bearings. If this is not desirable, new adjustments should be made in the air with the trailing lead out, but the resultant bearings may not have the same accuracy under these conditions. The trailing antenna (or any other antenna provided in the airplane equipment) may be open circuited, but it should not be grounded to the fuselage while taking bearings. Where a separate antenna is connected to an additional receiver, varying errors may be caused as the tuning of this receiver is changed.

DEVIATION AND CALIBRATION OF TYPE RDF-1-A DIRECTION FINDING EQUIPMENT.

For information on deviation and calibration of this type loop refer to section 46. All conditions as outlined in this section are applicable to the type RDF-1-A system.

OPERATING INSTRUCTIONS

1. INTERMEDIATE FREQUENCY DIRECTION FINDING.

After the completion of initial adjustments and calibration, the successive steps involved in the proper and successful operation of this equipment can be readily acquired from the following brief review of the SELECTOR switch functions:

2. R-RECEIVE (Non-directional).

In this first position, the fixed antenna on the plane feeds through the unit to provide non-directional reception with the receiver. The power switch must be turned ON, since the section of the dual amplifier tube in the direction finder provides the coupling. The receiver is tuned and trimmed as for ordinary antenna reception. The loop should be detuned for best communication; otherwise, through stray couplings, it may produce slight variations of the output.

3. T-TUNE LOOP (Broadly directional).

The loop must be tuned to resonance in order to match the output of the fixed antenna for direction indications. Tuning the loop gives a great increase in sensitivity and reduces the possibility of error. When the loop is improperly tuned, it is impossible to obtain the correct phase relationship with the fixed antenna, and directions cannot be obtained. Rotate loop to a maximum signal while tuning.

4. DIRECTION (Approximate, but uni-lateral).
Rotate the loop for a maximum signal output. The arrows engraved on the top of the dial and the light painted side of the loop always point toward the transmitting station when the maximum signal is being received. When the loop and fixed antenna components are properly matched, the indication of direction will always be unmistakable. Hold the loop in the maximum position and adjust the mask so that the ZERO MARK on the mask is over the INDEX pointer at the front of the unit.

5. B-BEARING (Sharply directional).
Rotate the loop without moving the mask until a minimum is found with the exposed portion of the directional scale over the INDEX pointer. The observed reading over the INDEX when the signal is a minimum is the bearing of the transmitting station, relative to the heading of the airplane. In most cases, the minimum will be less than a degree in width as observed on a meter. The ear may not be able to make so accurate an estimate; so that it becomes necessary to rotate the loop from one definite signal level, through the minimum, to an equal level on the other side. Observe the amount of rotation, and the center of that area is the correct bearing. Note that there is another minimum which may be obtained on the opposite side, but no bearing can be taken since the scale numbers are covered by the mask. Under no conditions should the mask be moved between the time it is set on the D position and the taking of the bearing on the B position. There can be no ambiguity of bearing when the proper procedure, as outlined above is followed.

On both high and low frequency operation, conditions may exist which do not allow good uni-lateral (D) bearings under normal operating methods. The cardioid figure may often be improved under these conditions by a very slight readjustment of the LOOP TUNING dial, generally toward a higher frequency (higher dial reading). The change must be very slight and very carefully made. If it is changed too much, no direction at all will be indicated, the signal being of practically equal intensity at all loop settings.

In some cases, particularly at the higher frequencies, it will be found that accurate bearings may be obtained on the D position. In order to obtain the bearings relative to the plane heading when on the D position, the mask is adjusted, as mentioned above and on the instruction plate, and the bearing is read from the azimuth scale over the pointer on the right hand end of the unit. An even more rapid but less accurate method is merely to note the position of the arrows engraved on top of the scale; or, more easily still, not that the side of the loop painted in the lighter color always points toward the station when the loop is swung to the maximum signal on the D position.

When for any reason broadcast station carriers are being used, care must be exercised in the selection of stations. For complete details on broadcast station selections refer to section 43.

FIXED LOOP HOMING.

In place of operating the equipment as a rotating loop direction finder, it may be used as a fixed loop homing device. For this purpose, adjustments should first be made as with the rotating loop, and the general direction obtained from the maximum with the SELECTOR switch in the D position. The clamping screw should then be tightened to lock the loop athwartship with the directional scale at zero above the INDEX pointer; and, with the SELECTOR switch on B, the airplane is kept headed in the direction giving minimum signal strength.

52. REMOTE CONTROLLED DIRECTION FINDER TYPE RDF-2 FOR LARGE FLYING BOATS

The location of a small rotatable loop direction finder on large flying boats permitting satisfactory bearings with a relatively low degree of deviation, has been a problem for some time. This type of aircraft has an unusual number of closed loops formed by wires and struts which together with the effects of the hull and wing or wings, introduce large deviation effects in the areas generally desired for direction finder installations. Actual tests, using a portable RDF-1-A direction finder, indicate that very few satisfactory locations are available on the large flying boats. The locations considered satisfactory from the standpoint of low deviation effects were found to be as follows; (a) over the pilots cockpit, (b) on top of the center-section wing near the leading edge, (c) on the tail section, (d) on the hull about ten feet forward of the tail. All these positions indicated a possible maximum deviation error of less than 12° without any correction measures taken. The latter position was chosen for an actual service installation on P2Y-3 type aircraft because of its accessability and adaptation to a remote controlled direction finder. (On the PBY-1 type aircraft the RDF-2 loop is installed on top of the main hull just aft of the pilots cockpit, forward of the propellers).

The type RDF-2 direction finding equipment was designed for use on large flying boats and if found sufficiently successful in meeting service requirements, will replace the present Bellini-Tosi loop system now in use on VP type aircraft. It differs from the Type RDF-1-A direction finder in that a special hydraulic mechanical arrangement and autosyn indicator system permits its installation on the hull of the aircraft near the tail. Fig.44 shows the mechanical arrangement of the RDF-2. The complete system weighs only 33 pounds and consists of the following units:

1. 12" loop (Detachable).

2. Hydraulic loop rotator with autosyn motor, type 1 1676.

3. Coupler and indicator Type L 1678 with autosyn motor.

4. Loop hand wheel control Type L 1675.

5. Make-up pump Type L 1677.

6. Junction box Type A 1679.

7. Junction box Type A 1139.

8. Feed lines and cables.

The mechanical and hydraulic arrangement of the system permits rotation of the loop without any actual moving parts linking the control wheel and the loop. A small make-up pump available to the radioman permits the hydraulic system being kept fullof standard hydraulic brake fluid while in use, allowing loop rotation in either direction without noticeable back lash. Two pieces of 1/4" dural tubing are used for the hydraulic feed lines from the hand wheel to the loop rotator.

A special flexable conduit 1 1/4" in diameter and 15 feet long houses the loop transmission line connecting the loop to the coupler and indicator unit. This conduit, even though seemingly large, is very light and 1" isolantite ring insulators spaced periodically throughout its length serve to fix the two transmission wires in the center of the conduit. This arrangement makes a very efficient low loss transmission line necessary for successful operation of any remotely controlled direction finder.

The Type RDF-2 direction finder was designed to operate with the RU series receivers.

While this pamphlet was in the process of being written, the first actual service installation tests with the Type RDF-2 direction finder were being conducted and for this reason it was impossible to give more detailed information on the installation of this equipment in aircraft. However, Fig.44 gives a fairly clear picture of the mechanical and hydraulic principles and as the electrical circuits of the direction finder proper are identical to the Type RDF-1-A, the only other interesting feature is the autosyn motor indicator system permitting the operator to

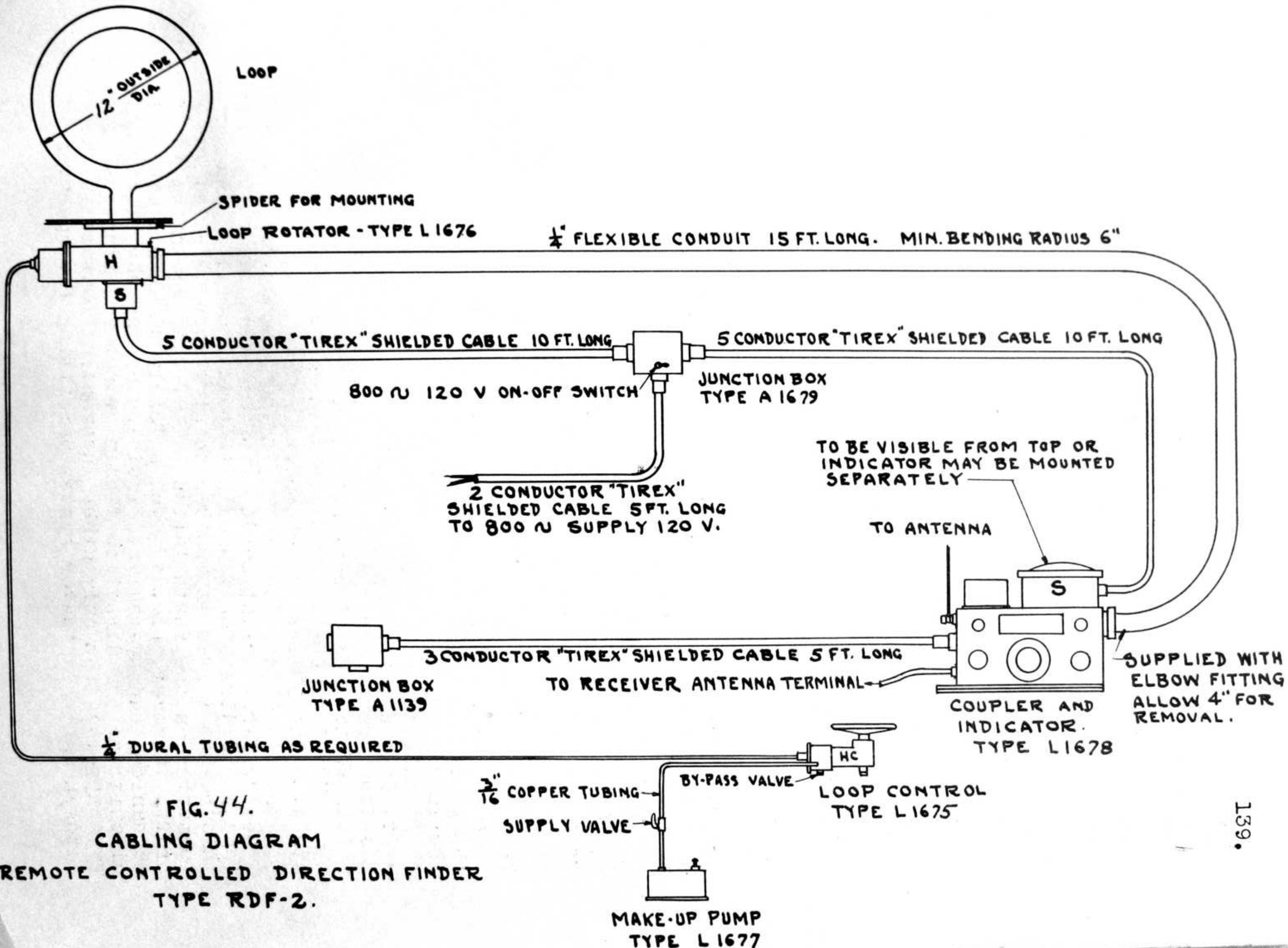


FIG. 44.

CABLING DIAGRAM

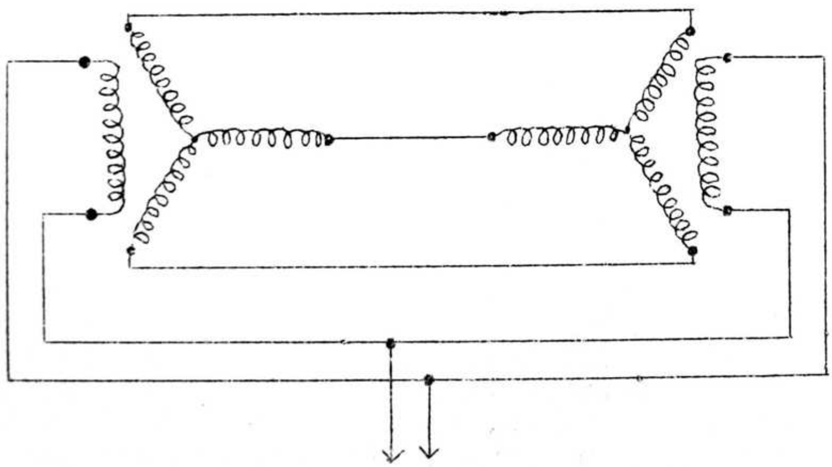
REMOTE CONTROLLED DIRECTION FINDER

TYPE RDF-2.

know at all times the relative position of the loop to the aircraft heading.

Autosyn motor controls and indicator systems are used to some extent in General Service for both radio and sound apparatus but this is the first practical application of its use on aircraft radio, and it is necessary for the reader to understand the fundamentals of such a system to understand its application to the RDF-2 direction finder.

An autosyn motor or generator in physical construction is identical with a three phase alternator. The stator contains a three phase distributed winding which is Y connected. The physical construction of the autosyn is practically the only resemblance that the machine bears to a three phase machine. Three phase voltages and currents do not exist in the autosyn. The exciting flux set up by the anternating excitation induces voltages in the stator winding varying in magnitude according to the physical position of the rotor with respect to the winding. Two of these machines are shown connected together in Fig.45.



A.C. Supply 800 cycle-120volt.
From aircraft radio generator.

Fig. 45.

When the rotors are set in similar positions with respect to the stator windings, the voltages induced in the stator windings are such that no current flows in these windings. Now if one rotor is changed in position, the voltages induced in the stator windings of this machine will not match the voltages induced in the stator windings of the other machine and a circulating current will flow in the stator windings. These circulating currents will cause the space and time phase of the fluxes, existing in the machine. Fig.46 is a vector time diagram of the currents and voltages existing in the rotor and stator of one of the machines shown in Fig.45. Only that component of the circulating current which is in

$T = I_p I_s \sin \theta_s$

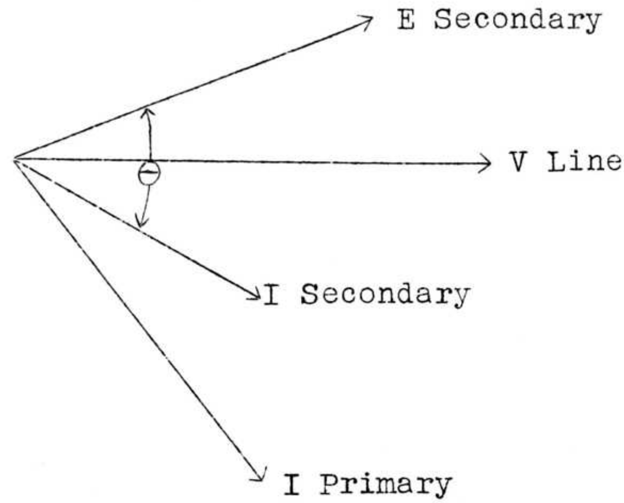


Fig.46.

time phase with the exciting current of the rotor will be effective in producing torque. This torque thus produced will tend to bring the two rotors of the two machines into space alignment, when once again the circulating current will become zero.

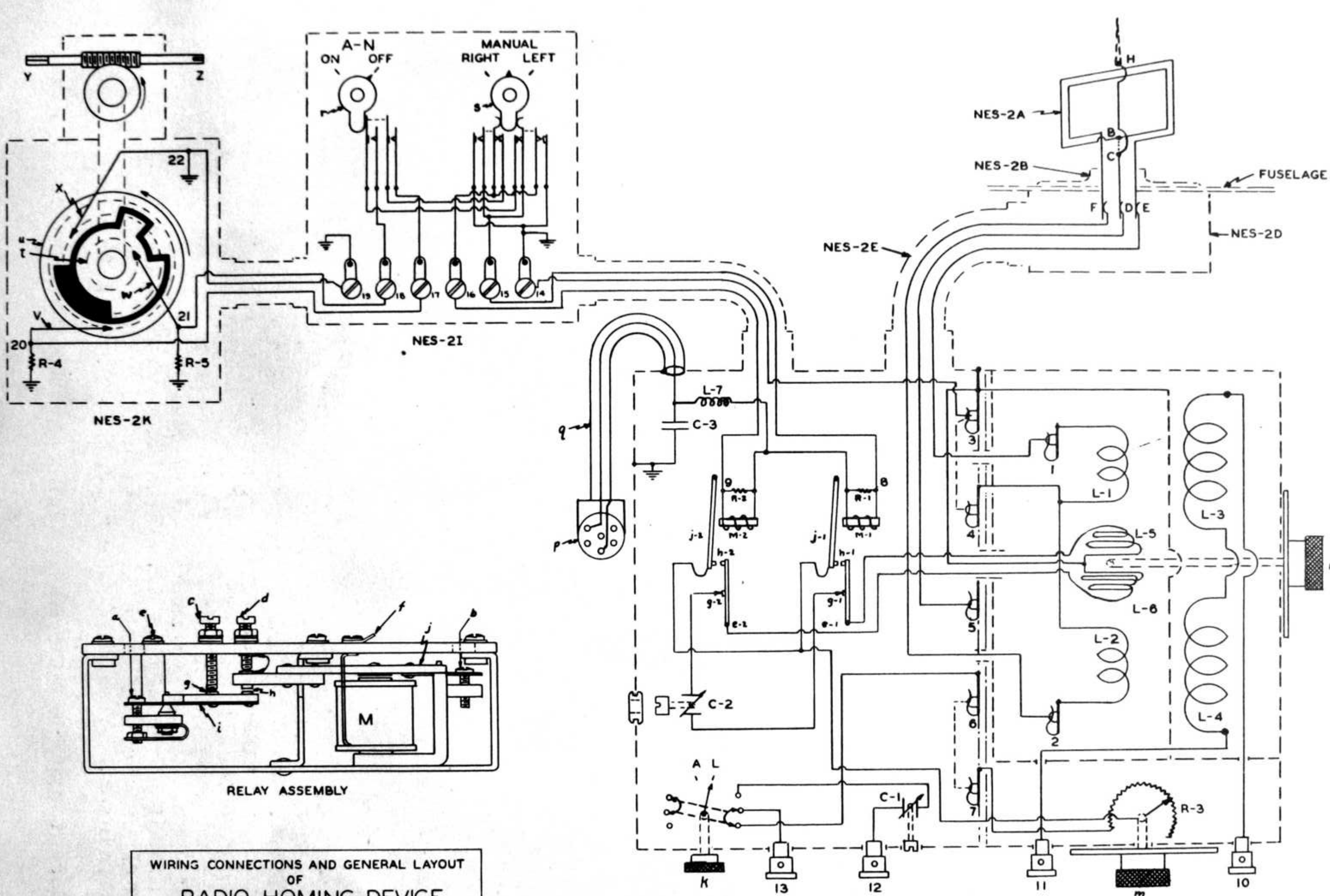
In the Type RDF-2 direction finder we have one autosyn motor directly connected and operated by the loop unit while the other autosyn in the indicator unit is free to follow its movements. If one autosyn is left free to move and the other rotated by mechanical means, the autosyn that is free to move will follow the one that is driven, maintaining the same space position.

Thus it may be seen that with the use of such a system in the remote controlled RDF-2 direction finder, the indicator in the radio cock-pit shows the exact angular position of the loop relative to the aircrafts heading.

53. RADIO HOMING DEVICE. TYPE NES-2

The Radio Homing Device Type NES-2 is a complete equipment designed to aid aircraft in steering a course on signals from any radio transmitting station, within the frequency range from 500 to 1500 Kc. This apparatus is applicable for use in connection with a standard aircraft receiver, of the RU Type. It is especially designed to permit experimental investigation of the direction finding possibilities with various loop and antenna combinations in different types of airplanes. Circuit diagram is shown in Fig.47.

In view of the latitude of adjustment provided for different experimental applications, the equipment is of greater



R.F. COUPLING UNIT, TYPE NES-2F

WIRING CONNECTIONS AND GENERAL LAYOUT
OF
RADIO HOMING DEVICE
TYPE NES-2

FIG. 47.

size, weight and complication than would be necessary for a similar device restricted to a standard use and installation.

In principle, this equipment employs the well-known addition of a properly phased and coupled capacitive antenna circuit to a loop receiving system, in order to render the directional indication of the latter uni-lateral. Its departure from other equipments, employing the same fundamental principle, consists in provisions for continuous aural indication of bearing, rather than visual or manual determination. This aural indication is by means of an interlocking "A" and "N" telegraph signal, produced by means of a commutator driven by the tachometer shaft. The commutator alternately actuates two remotely controlled relays which are located in the RF coupling unit, and which superimpose, in alternate phases, the antenna pick-up upon that of the loop. With proper adjustments, a continuous carrier signal will cause a predominant telegraphic "A" to be produced in the receiver output, when the transmitting station is on the left side of the airplane. A predominant "N" indicates that the signal originates on the right side. A regular repetition of dashes indicates that the transmitting station is in the line of flight. An auxiliary manual control is provided to operate the relays for manual, uni-lateral bearings on signals of an intermittent nature such as telegraphy.

When neither relay is actuated, the device acts as a conventional, bi-lateral loop type of radio direction finder; capable of sharp and consistent bearings because of the statically shielded purely inductive coupling provided between loop and receiver.

In place of the external loop supplied with the equipment, any desirable type may of course be connected. A wide range of flexible adjustment of this equipment renders it particularly suitable for investigations of aural homing, with widely different types of antennas and loops, and in various airplanes.

THEORY OF OPERATION.

If an antenna is coupled to the loop so that the antenna pick-up is superimposed upon that of the loop the resulting pattern will be as shown at "A" Fig.48 and if the antenna is coupled in opposite phase the resulting pattern will be as shown at "B" Fig.48.

Two magnetically operated relays are used to couple the antenna in alternate phases to the loop so that the patterns shown at "A" and "B" Fig.48 are obtained.

The relays are actuated by a commutator which is driven by the tachometer shaft. The commutator has two segments, cut so that they form a telegraphic letter "A" and a telegraphic letter "N" which are interlocked. A developed view of the commutator segments is shown in Fig.49. The black portion represents insulating material, the cross hatched represents the segment that forms the telegraphic letter "N" and the unshaded portion represents the segment which forms the telegraphic letter "A". It will be seen from Fig.49 that when the commutator rotates and the brush marked "X" passes over the "A" and "N" segments the relays will be operated alternately and in turn will shift the pattern alternately from "A" to "B" in Fig.48.

The pattern as shown at "A" Fig.48 is used for obtaining the letter "N" and the pattern at "B" is used for obtaining the letter "A".

When the transmitting station is located to the right of the axis of the loop, as shown in Fig.50 then the strength of the received signal will be the strongest when the relays give the pattern as shown at "A" Fig.48 and weakest when the relays give the pattern as shown at "B" Fig.48. The received signal will be in the form of a telegraphic letter "N" which indicates that the transmitting station is located to the right of the plane.

When the transmitting station is located to the left of the axis of the loop as shown in Fig.51 then the strength of the received signal will be the strongest when the relays give the pattern as shown at "B" Fig.48. The received signal will be in the form of a telegraphic letter "A" which indicates that the transmitting station is located to the left of the plane.

When the transmitting station is located in line with the axis of the loop as shown in Fig.52 the strength of the received signal will be the same with either of the patterns shown in Fig.48 and as the telegraphic letters "A" and "N" obtained with these patterns are interlocked the received signal will be in the form of a series of dashes which indicates that the transmitting station is located directly in the line of flight.

Two methods of obtaining course indications may be used, namely, manual and automatic. Either of the two methods may be selected by means of the two switches on the Control Unit marked "A-N" and "MANUAL". The switch marked "A-N" when in the "ON" position gives automatic course indications and will ONLY give clean cut signals when the receiver is tuned to a transmitting station with key locked or a commercial broadcasting station with carrier on. The switch marked "MANUAL" may be used for obtaining course indications when the receiver is tuned to a transmitting station that is being keyed. When using the "MANUAL" switch for course indications the transmitting station will be located on the right of the plane if the received signal is loudest when the switch is held in the RIGHT position and will be located to the left of the plane if the received signal is loudest when held in the LEFT position.

If the signal is loudest when the switch is held in the RIGHT position then to get on course the pilot must swing the plane to the RIGHT until the received signal is the same strength in either switch position. If the

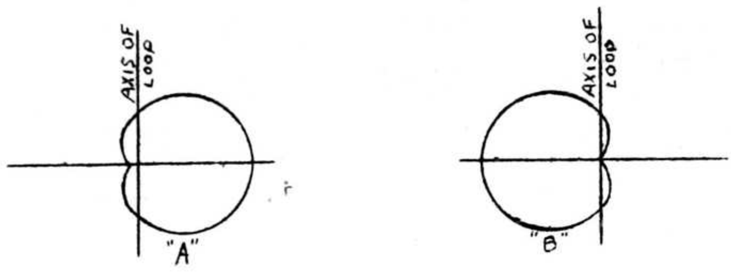


Fig. 48.

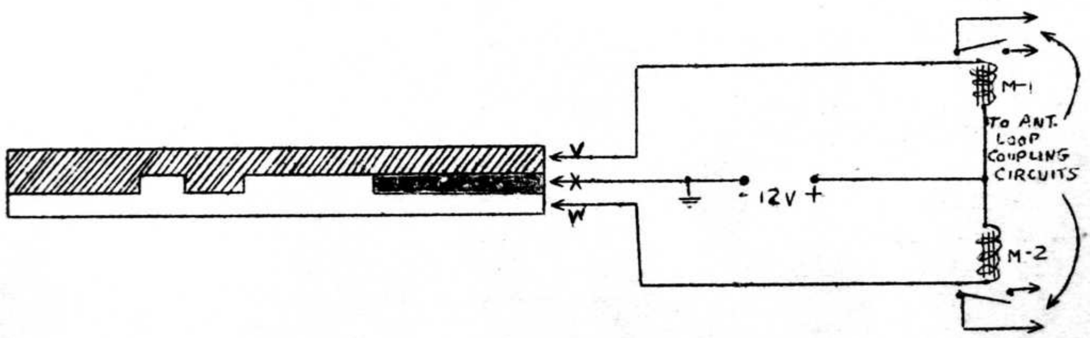


Fig. 49.

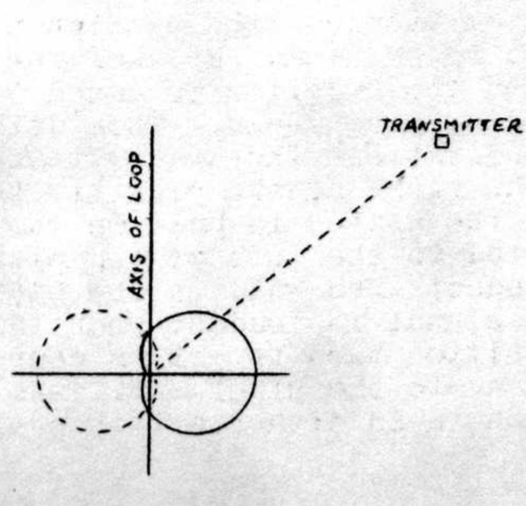


Fig. 50.

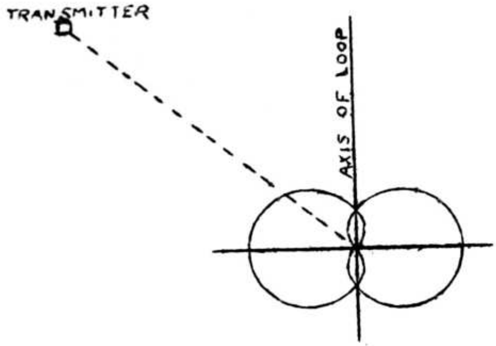


Fig. 51.

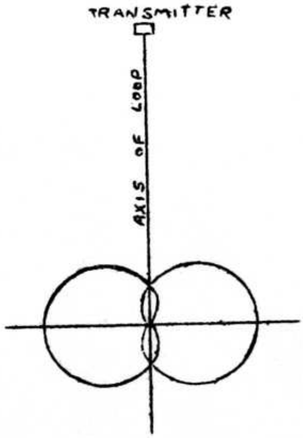


Fig.52.

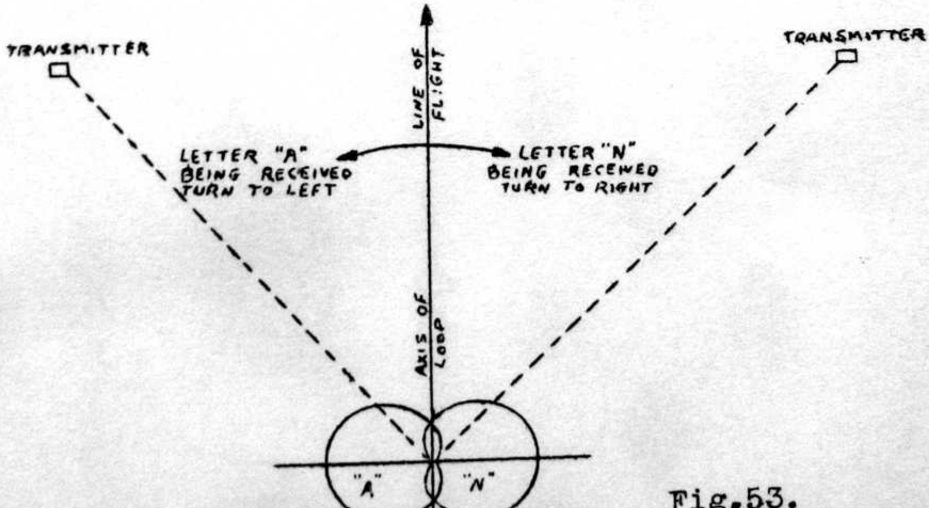


Fig.53.

signal is loudest when the switch is held in the LEFT position then to get on course the pilot must swing the plane to the LEFT until the received signal is the same strength in either position,

Referring to Fig.53 it will be seen that if the letter "N" is being received the transmitter is located to the right of the plane and to get on course the pilot must swing the plane to the RIGHT until a series of DASHES are received which indicates that the plane is on course. Likewise, if the letter "A" is being received the transmitter is located to the left of the plane and to get on course the pilot must swing the plane to the LEFT until a series of DASHES is received which indicates that the plane is on course.

ADDENDA.

The effective range of the Homing Device may be increased by using an UNGROUNDED wing loop in place of the loop provided with the equipment.

The tachometer shaft should be connected to the geared commutator unit so that the commutator rotates with the brushes as shown on the wiring diagram. It is important that this be carefully checked because rotation of the commutator against the brushes will cause excessive wear.

54. MODEL AS-101 RADIO DIRECTION FINDER

The Experimental Model AS-101 radio direction finder provides only the components which must be added to a Model RU-2 or RU-3 Aircraft Radio Equipment, to supply radio direction finder and homing facilities. When used as a radio direction finder, the equipment will indicate the direction of radio stations transmitting modulated or unmodulated signals at all frequencies between 350 and 1330 Kc. When used for homing, deviations from course are visually shown as "LEFT" or "RIGHT" on the indicators. Communication may be obtained from the radio stations toward which the plane of the loop is pointed when the indicator needle is centered on the dial. This allows the airplane pilot to hear weather reports, instructions, etc., without interruption of the direction finding service.

Fig.54 shows a typical cabling of this equipment with parts of Model RU-2 Aircraft Radio Equipment while Fig.55 shows schematic circuit diagram.

The following additional items are necessary to make Model AS-101 Radio Direction Finder completely operative:

(a) One Model RU-2 or RU-3 Aircraft Radio Equipment.
(b) One headset.
(c) Antenna.
(d) Direct current source of power with voltage between the limits of 12 and 14.25 volts.

LOOP TUNING UNIT. TYPE BC-205-A.

Loop Tuning Unit, Type BC-205-A consists of a box in which are located the loop tuning condenser, tube sockets, transformers, relay and cord sockets.

LOOP. TYPE LP-11-A.

The band selector switch 85 for selecting any one of the three frequency ranges (350-545) Kc, 545-850 Kc and 850-1330 Kc) is supported in the loop casting and is controlled by coupling 86. The loop is plugged into the Loop Mounting, type GS-5-A, pin plugs 104 being provided to make the electrical connections.

INDICATOR. TYPE I-58.

Indicator, type I-58, is one of the two meters on which the right and left deviations from the course are indicated. It is supplied with switch 72 which operates relay 53 in the Loop Tuning Unit. It also contains potentiometer 71 used in the bridge circuit for setting the indicators on zero.

INDICATOR. TYPE I-59.

Indicator, type I-59, if the same as Indicator, type I-58 except that potentiometer 71 is omitted.

RECTIFIER. TYPE RA-10.

Rectifier, type RA-10, may be substituted for the VT-84 tube used in the bridge circuit. It consists of a full wave copper oxide rectifier 89 and resistance 90 equal to that of the heater of the VT-84 tube. It should not be used to replace the VT-84 nearest the front panel as loss of sensitivity will result.

OPERATION.

After the direction finder has been installed and all connections made, an operating test should be made on the ground, for which detailed instructions follow:

With either of the control switches 73 on the indicators in "OFF" position make all the customary checks to insure that the receiver is operating normally. The "antenna-loop" switch on the receiver should be in "A" position. The antenna series condenser on the receiver must be readjusted to compensate for the added capacity introduced in the receivers antenna circuit by Cord type CO-86.

Throw both switch knobs 73 to "ON" position. These switches are in series so both must be closed to complete the circuit and operate relay 53 in the tuning unit.

A weak 200 cycle tone will be heard in the phones. With the receivers volume control turned all the way down set the pointers on the indicators on zero by adjusting potentiometer 71 mounted on the back shield of Indicator, type I-58.

Throw switch handle 17 to correspond with the band of the coil set in the receiver and tune the receiver to a station whose geographical position is known. Adjust the receivers volume control (on either "automatic" or "manual") for suitable signal intensity.

Rotate the loop by means of handwheel 16. As the loop is rotated the indicator pointer will swing across the indicator scale. When the pointer is on Zero the loop is at right angles to the direction of the received signal" There will therefore be two readings, 180 degrees apart on the loop scale, for which the pointer will be on zero. One of the readings is the true bearing and the other is its reciprocal. The rule for determining which one of these is the true bearing is as follows:

When on a true bearing rotation of the loop in the direction to increase the scale reading will produce a left scale deflection. This may be stated in other terms: - when the direction finder is used for homing and the station lies ahead of the plane, swinging the ship to left will give a Right deflection. Conversely, when the plane is proceeding away from the station, swinging the ship to the left will give a Left indication. The pilot should visualize the indicator needle as pointing toward the station toward which he is flying. Thus a right deflection would indicate to the pilot to push right rudder to get back on course. If he is unknowingly flying away from the station, the needle will not return to zero but will deflect farther to the right, thus causing the pilot to execute a 180 degree turn before the needle returns to zero and correctly heads him toward the station. If the pilot desires to fly away from a station, he reverses the procedure and presses the opposite rudder to that shown by the Indicator. This procedure is recommended only for very short distances. With the above rules well in mind there will be no uncertainty as to the stations bearing.

The loop mounting is provided with an optional micrometer adjustment for use in making a fine setting on a station. This action is engaged by depressing either of the two clutch handles 21. Rotation of drive 23 will slowly rotate the loop. When handles 21 are down and the micrometer engaged, the loop is effectively and positively locked in position. The usual procedure in operating the loop in observing a bearing will be to rotate the loop directly with the handwheel (with the locking handles up) for a rough zero indication and then get the final setting by depressing the handles and turning the micrometer drive 23. The loop will then remain locked in position after the final adjustment is made. The azimuthal scale is illuminated by a lamp controlled by switch 26.

When flying "on course", that is, with the indicators on zero, the modulated signals will come through undisturbed. When "off course" a distinct 200 cycle tone will be heard in the phones. This aural indication of "off course" deviations will be of assistance in navigating, since the pilot need not always observe the indicators. He may thus give his attention to other matters until the 200 cycle tone warns him that he is off course.

If it is desired to operate the receiver without the direction finder equipment, throw either of the two switches 73 on the indicators to the "OFF" position. The receiver then will be electrically isolated from the direction finder circuit.

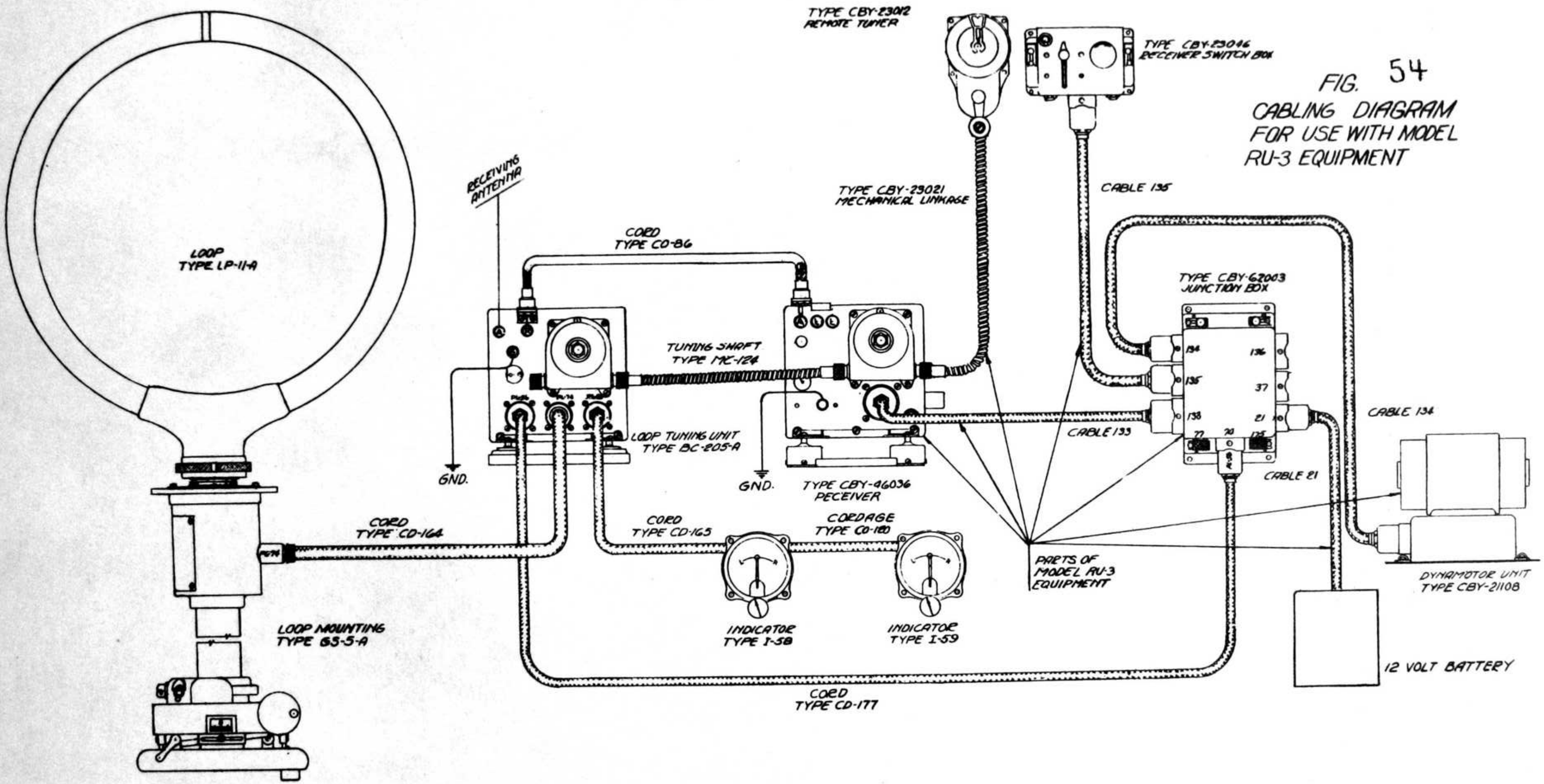


FIG. 54
CABLING DIAGRAM
FOR USE WITH MODEL
RU-3 EQUIPMENT

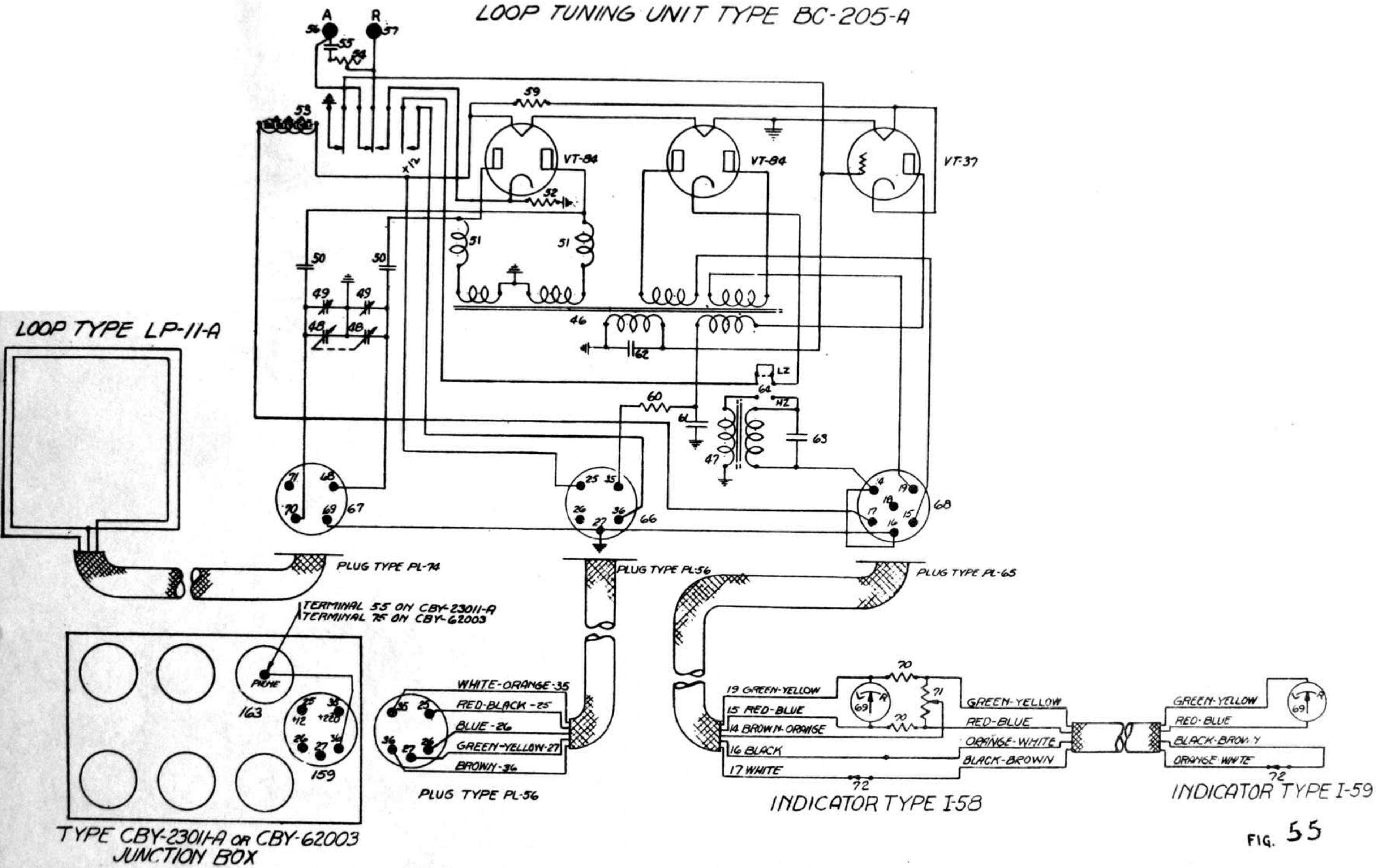

LOOP TUNING UNIT TYPE BC-205-A
VT-84
VT-84
VT-37
LOOP TYPE LP-11-A
PLUG TYPE PL-74
PLUG TYPE PL-56
PLUG TYPE PL-65
TERMINAL 55 ON CBY-23011-A
TERMINAL 75 ON CBY-62003
PHONE
WHITE-ORANGE-35
RED-BLACK-25
BLUE-26
GREEN-YELLOW-27
BROWN-36
PLUG TYPE PL-56
19 GREEN-YELLOW
15 RED-BLUE
14 BROWN-ORANGE
16 BLACK
17 WHITE
GREEN-YELLOW
RED-BLUE
ORANGE-WHITE
BLACK-BROWN
INDICATOR TYPE I-58
INDICATOR TYPE I-59
TYPE CBY-23011-A OR CBY-62003
JUNCTION BOX

FIG. 55