Design of Some Coupling Circuits for Aircraft Transmitting Aerials

By W. W. Honnor, B.Sc., B.E.

ABSTRACT. The electrical constants are given of various aircraft fixed and trailing aerials in the frequency range 140-500 kc and of fixed aerials in the frequency range 2-20 Mc. A design is discussed of circuits for coupling a low impedance line to these aerials over the above ranges of frequency. The design for fixed aerials in the high-frequency band employs the device of a single condenser connected either in series or in parallel with the aerial impedance in order to make the combination always capacitive.

1—Introduction

The design of circuits to couple the power amplifier of an aircraft transmitter to aircraft aerials has generally presented some difficulty partly due to the usual restrictions in aircraft equipment of small size, light weight, and the necessity of operating at greatly reduced atmospheric pressures, and partly to the fact that the designer frequently has no precise knowledge of the electrical constants of the aerial, or aerials into which the equipment may be required to work. In the writer's experience, it is seldom that circumstances allow the designer of the equipment to exert any influence on the aerial systems to be employed. In any case, apart from fulfilling its function as a radiator of electro-magnetic energy, the aerial system must meet other requirements; for example, in addition to the restrictions imposed by the size of the aircraft, the aerial must not impose any considerable 'drag' on the aircraft, it must be capable of withstanding vibration and be sufficiently strong not to fail under the stresses imposed by high-speed flight, it must continue to operate under conditions of 'icing' (Haller, 1938 and 1942) and, in the event of a wire breaking, it must not be liable to foul aero-dynamic controls. A general description of the various types of aerials used on aircraft has been given by McGuire and Delmonte (1940). A description of some of the mechanical features of aircraft aerials as used in the Royal Air Force has also been given by Hecht (1939).

In the medium- and high-frequency ranges the aerials used on aircraft for communication purposes, as distinct from aerials used for navigation, may be subdivided broadly into the two classes known as trailing aerials and fixed aerials. The trailing aerial consists essentially of a wire paid out from the fuselage of the aircraft, one end only being attached to the aircraft.

The free end is usually weighted to cause it to assume a more nearly vertical position but, due to wind resistance, the wire assumes a curve, the major part being inclined at about 30° to the horizontal (Eisner, 1932). This effect reduces the effective height of the aerial and for this reason the use of trailing aerials appears to be decreasing as aircraft speeds increase. Trailing aerials are now normally restricted to use in the medium-frequency bands and, for this purpose, lengths of the order 200-300 ft. are used. The fixed aerial consists essentially of a wire or wires attached at both ends to the aircraft by means of insulators, a lead-in being taken off at an appropriate point. Fixed aerials are used on both medium- and high-frequency,

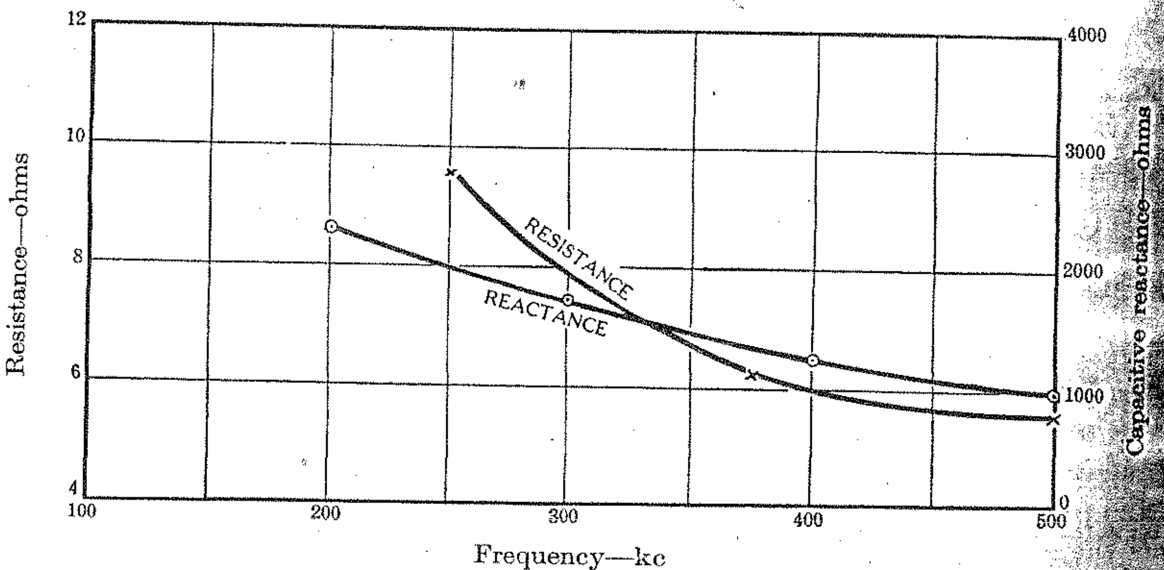


FIGURE 1—Resistance and reactance of a 235 ft. trailing aerial on a Ford tri-motor all-metal aircraft (after Hyland).

although the tendency is to use less and less medium-frequency transmission from aircraft to ground in favour of increased numbers of channels at high- and ultra-high-frequency.

A recent development in transmission from large all-metal aircraft is that of shunt-feeding of the aircraft structure itself. The method is discussed by Haller (1942) and is similar to the well-known technique of shunt-feeding earthed broadcast transmitting aerials (Morrison and Smith, 1937), although the practical difficulties would appear to be greater in an aircraft using a number of frequencies than for an earthed mast used at a single frequency in the broadcast band.

2—ELECTRICAL CONSTANTS OF TRAILING AERIALS

Before circuits can be designed to couple the power amplifier of an aircraft transmitter to the aircraft aerial or aerials at the working frequencies, some knowledge is required of the electrical constants of the aerials under consideration. A number of measurements of these constants for trailing aerials, in the frequency range 140-500 kc, on a variety of aircraft, has been made by Hyland (1929). His method was to energise the aerial by means of a small oscillator coupled through a variable loading coil and variable non-reactive resistance. The loading coil served to resonate the aerial capacitance and the variable resistance was inserted and varied so as to alter the aerial current at resonance by a known amount. Allowance was made for the resistive component of the loading coil. Hyland states that "An interesting fact developed from this study is the negligible effect of

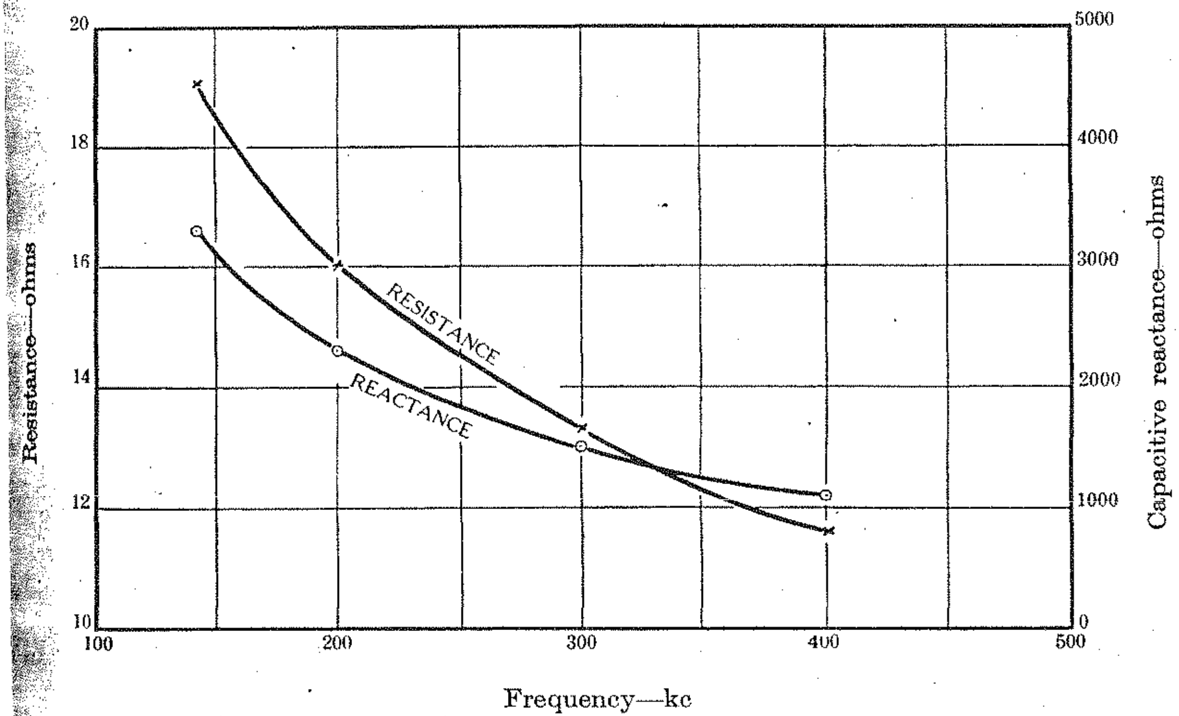


FIGURE 2—Resistance and reactance of a 235 ft. trailing aerial on a medium twin-engine all-metal aircraft.

structural differences on antenna constants. The three structural types—all metal, metal frame fabric covered, and composite wood and wire frame fabric covered—are interchangeable (when properly bonded) insofar as major effect on antenna constants is concerned." Hyland's results of the resistance and reactance of trailing aerials on a Ford tri-motor all-metal aircraft have been interpolated and re-plotted for 235 ft. length of aerial and are shown in figure 1, but the scale of the diagrams in Hyland's paper is small so that the accuracy is not great.

The writer has made some measurements of a 235 ft. trailing aerial of 7 strands of 25 S.W.G. stainless steel wire installed on the medium twin-engine all-metal aircraft of figure 3, and these results are shown in figure 2. The connection between the radio equipment and the aerial winch was approximately 8 ft. long and was included in the circuit when measurements were made. This lead was measured separately and was found to have a capacitance to the aircraft frame of 80 $\mu\mu F$, and also had an appreciable resistive component. The measurements were made using a circuit-magnification- or Q-meter; this consists basically of a tunable radio-frequency oscillator supplying a known current to a low resistance inserted in series with the tuned circuit to be investigated. A self-contained valve voltmeter is then used to measure the voltage magnification (or Q) of the circuit. By measuring the Q of a standard circuit, also contained in the Q-meter, then connecting the aerial across this circuit, retuning to resonance,

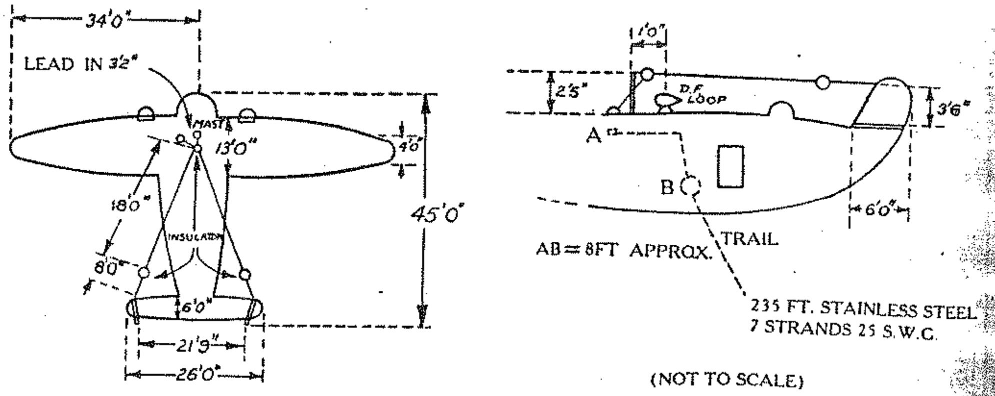


FIGURE 3—Fixed aerial dimensions on a medium twin-engine all-metal aircraft.

and measuring the Q of the combined circuits, it can be shown that the Q of the aerial is given by

$$Q_{AE} = \frac{(C_1 - C_2)\, Q_1 Q_2}{(C_1 + C_0)(Q_1 - Q_2)}$$

where C is the tuning capacity, subscript 1 refers to values at resonance before connecting the aerial, subscript 2 to values after connecting the aerial, and C_0 is the self-capacitance of the coil of the standard circuit. The capacitance of the aerial is given by $C_1 - C_2$ and the resistance by

$$R_{AE} = \frac{1}{\omega Q_{AE}(C_1 - C_2)}$$

where $\omega = 2\pi \times$ frequency.

Comparison of the results of figures 1 and 2 show that the reactances of the two aerials are much the same, but the resistances recorded by Hyland are about half those recorded in figure 2. Hyland makes no reference to the type of wire used for the trailing aerials in his measurements, but the lower values of resistance obtained by him could be accounted for by the use of copper wire as against the stainless steel wire used in figure 2. Haller (1942) gives some results on the measurement of resistance of different types of wires, at radio frequencies, suitable for aircraft aerials, and shows that a copper-clad steel wire is almost as good as a solid copper conductor, and is better than beryllium-copper or phosphor-bronze. The use of stainless steel wire for trailing aerials would seem to be a somewhat one-sided compromise in favour of mechanical strength at the expense of electrical efficiency.

3—The Electrical Constants of Fixed Aerials.

In the case of fixed aerials, prior to 1938 there appears to have been little information published concerning their electrical constants, but in

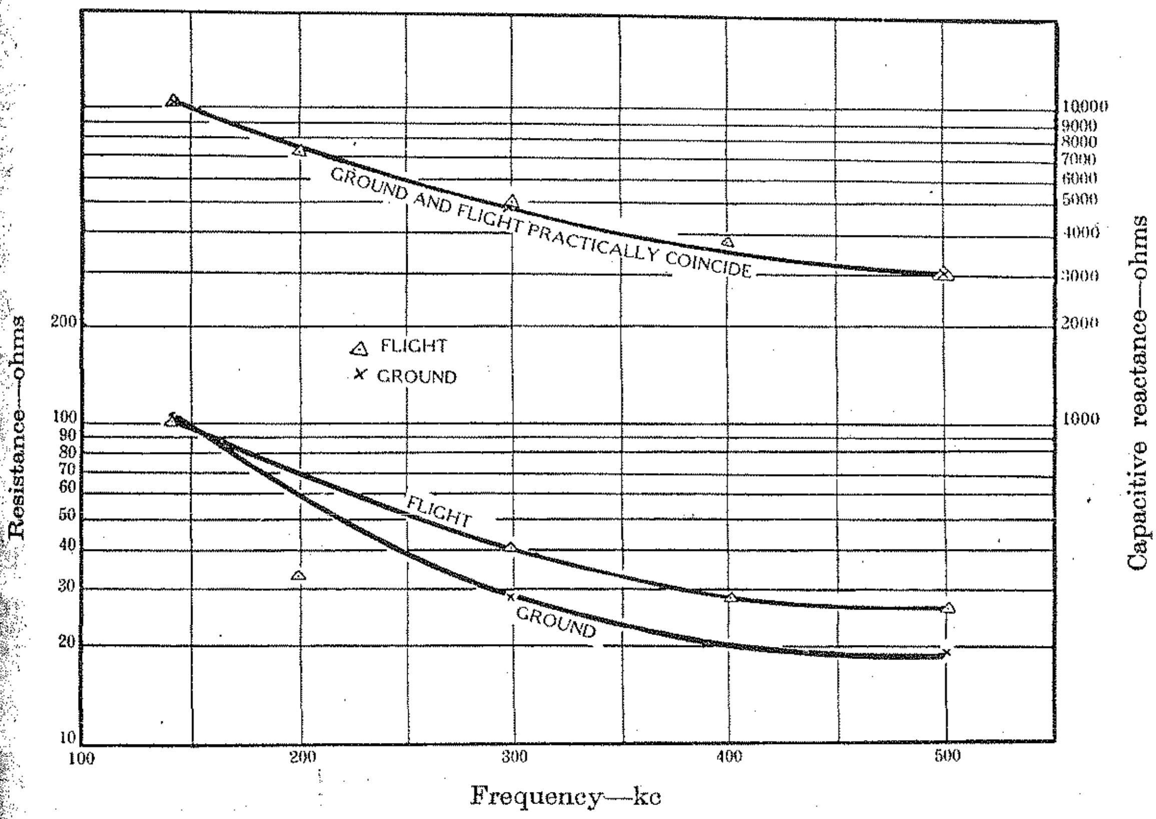


FIGURE 4—Resistance and reactance of the fixed aerial on a medium twin-engine all-metal aircraft.

this year Haller (1938) published a paper on the subject followed by a further paper in 1942 referred to above. Also, Sandretto (1942) has published curves for the characteristics of aerials used on the Douglas DC-3 and Douglas DC-4 aircraft. Haller's results of 1938 were obtained using a Q-meter and cover a frequency range of 3-8 Mc with four different aerial arrangements on a single-engine two-seater fighter aircraft of 48 ft. wing-span and three different arrangements of aerials on a twin-engine bomber of 90 ft. wing-span. Sandretto's results cover the frequency range of 2-6 Mc for the DC-3 aircraft and 2-10 Mc for the DC-4. Both these aircraft have a single aerial wire extending from a short stub-mast over the cockpit to the top of the vertical tail fin. The length of the DC-3 aerial is 45 ft. 6 in. and the DC-4 is about 68 ft., quarter-wave resonance for the DC-3 occurring at 5.1 Mc and for the DC-4 at 8.9 Mc. More recently, Kiernan (1944) has recorded the characteristics of a *V* aerial on a Lockheed 14 aircraft in the frequency range 2-15 Mc.

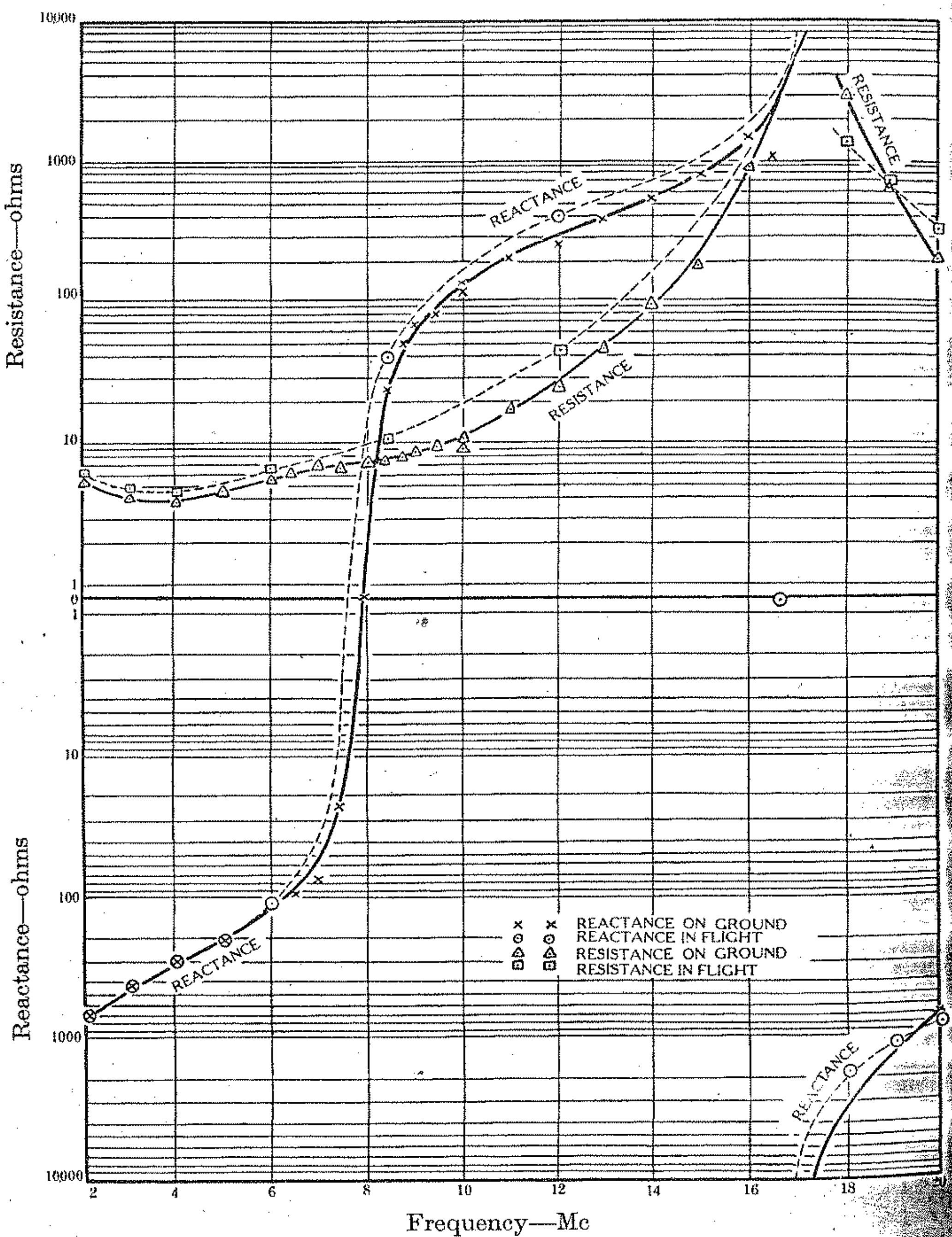


FIGURE 5—Resistance and reactance of the fixed aerial on a medium twin-engine all-metal aircraft.

Measurements on the fixed aerial of a medium twin-engine all-metal aircraft in flight and on the ground have been made by the writer in the ranges 150-500 kc and 2-20 Mc using a Q meter. When using this method near quarter-wave and half-wave resonances it is desirable to insert in the aerial circuit a series condenser of known capacitance and Q to obtain better readings of Q. Allowance can readily be made for the effect of this condenser in calculating the aerial constants. There are some regions where the accuracy of the Q-meter method is not high owing to the comparatively small differences of readings involved in the calculations.

The configuration of the aerial measured is shown in figure 3 and the electrical constants in the frequency ranges 150-500 kc and 2-20 Mc are shown respectively in figures 4 and 5. It will be observed that the difference between grounded and flight conditions is small, except for the value obtained for resistance at 200 kc in flight. It is likely that an error was made in one of the readings for the observation at this frequency.

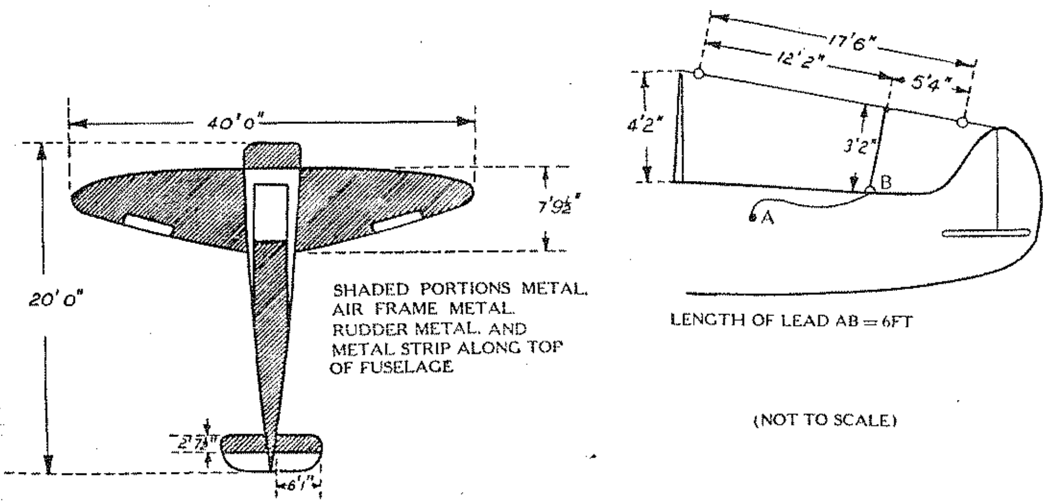


FIGURE 6—Fixed aerial dimensions on a two-seater metal and fabric aircraft.

Some measurements have also been carried out on the fixed aerial of a two-seater aircraft on the ground, in the frequency ranges 140-500 kc and 2,000-20,000 kc, the dimensions of the aerial being shown in figure 6; it will be observed that the measurements included about 6 feet of insulated lead connecting the lead-in insulator to the radio equipment. This aircraft has a metal frame, and uses part metal and part fabric covering. The values of resistance and reactance in the frequency range 140-500 kc are shown in figure 7, and figure 8 shows the results in the range 2-20 Mc.

Measurements were also made on the fixed aerial of a large flying-boat in the frequency range 140-20,000 kc, the majority of measurements being made on the water, but a few check measurements were made in flight. The aerial of the ship, shown diagrammatically in figure 9, was a rather complicated system comprising a horizontal vee, with the apex at the tail and the two arms of the vee spreading out to the wing tips. The vee was fed by a wire connected part way along the starboard arm of the vee and running under the starboard wing to a point about 3 ft. forward of the leading edge of the wing on the hull, and entered the hull through the lead-in insulator, which was about 3 feet above the water-line. Measurements were made on two days on the same aircraft, as the results of the first day's measurements gave a rather low resistive component particularly at the lower end of the medium-frequency band. On the second day the resistive component was found to be very much greater, and it was hoped to take further measurements in order to ascertain the cause of the discrepancy.

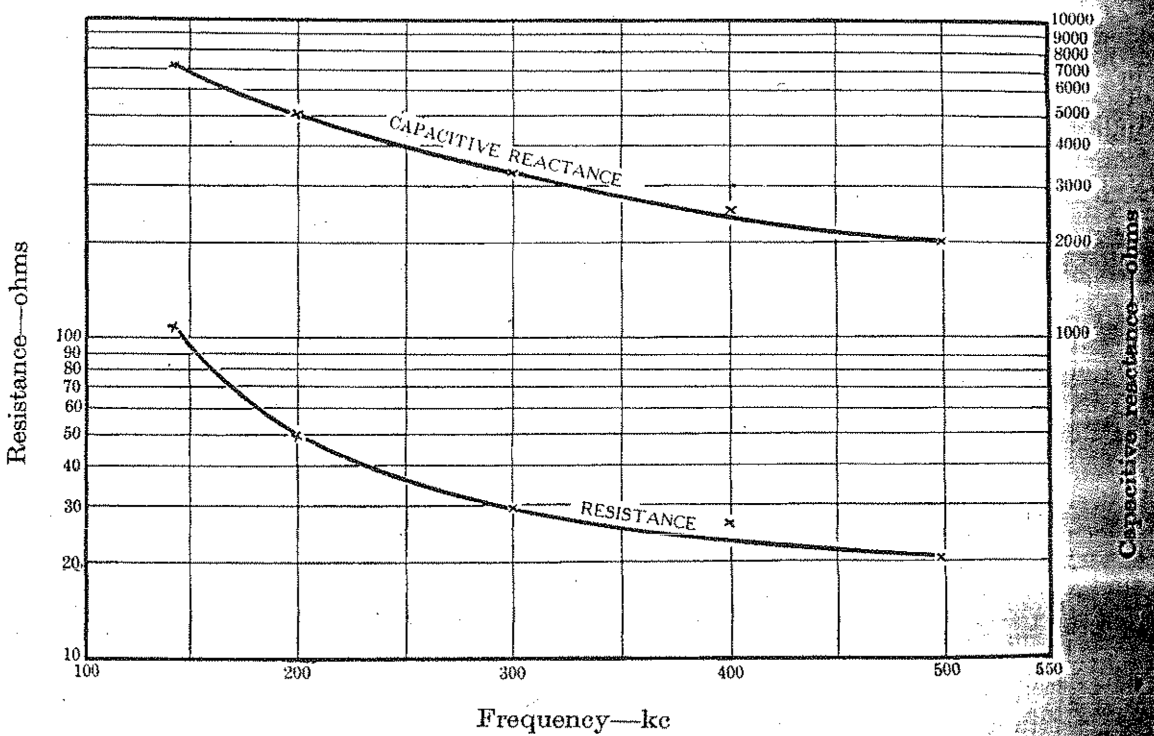


FIGURE 7—Resistance and reactance of the fixed aerial on a two-seater metal-and-fabric aircraft.

Unfortunately, it was not possible to obtain the use of the aircraft for a longer period to enable this to be done. The conditions on the two days were as follows :—

First Day—A hot sunny day with calm sea, the aircraft having been anchored for some considerable time prior to measurements being made. Both 'flight' and 'on the water' measurements were carried out.

Second Day—Warm day, with sufficient sea running to splash water on to the lead-in insulator, and in addition, the aircraft had just landed when measurements were commenced, so that the whole aircraft was covered with salt spray. Only 'on the water' measurements were made. The results of the measurements taken on the two days are shown in figures 10, 11, 12 and 13 ; curves marked A were taken on the first day and those marked B on the second day. No attempt has been made to draw curves in figures 12 and 13, as there appears to be insufficient evidence to indicate where the curve should lie, except perhaps in the region 1-4 Mc.

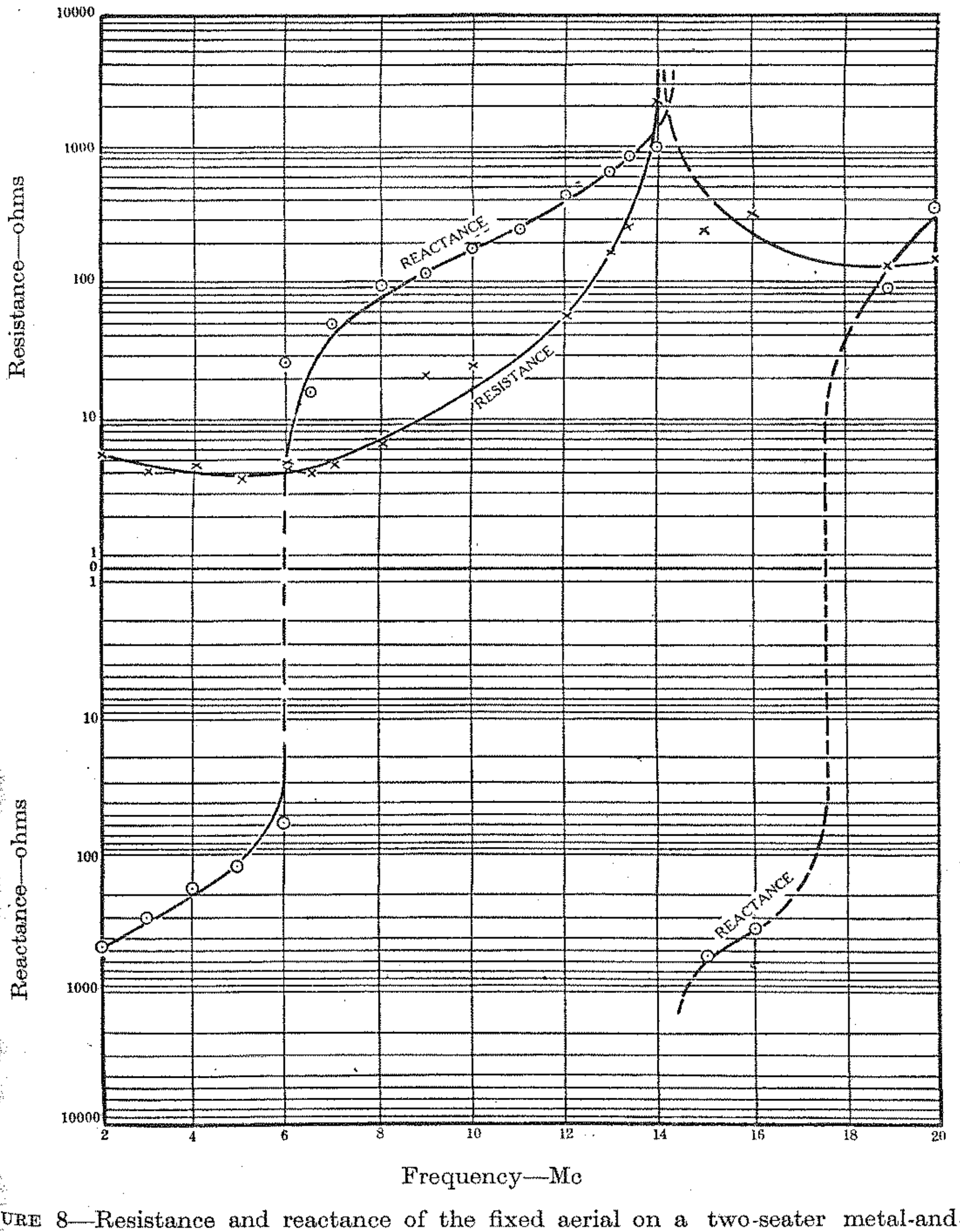


FIGURE 8—Resistance and reactance of the fixed aerial on a two-seater metal-and-fabric aircraft.

Comparisons of the results obtained on the comparatively simple aerials of figures 3 and 6 with those on the aerial of figure 9 indicate, as would be expected, that the simple configurations behave in a manner such that a comparatively few measurements would enable their general characteristics to be determined, but that the complicated configuration of figure 9 produces an aerial with characteristics that are extremely difficult to determine. This, in turn, sets a very difficult problem for the designer of the radio equipment, since, if a number of frequencies are to be employed it might be expected that complicated aerial coupling circuits would be required to make certain that the aerial can be matched over a range of frequencies.

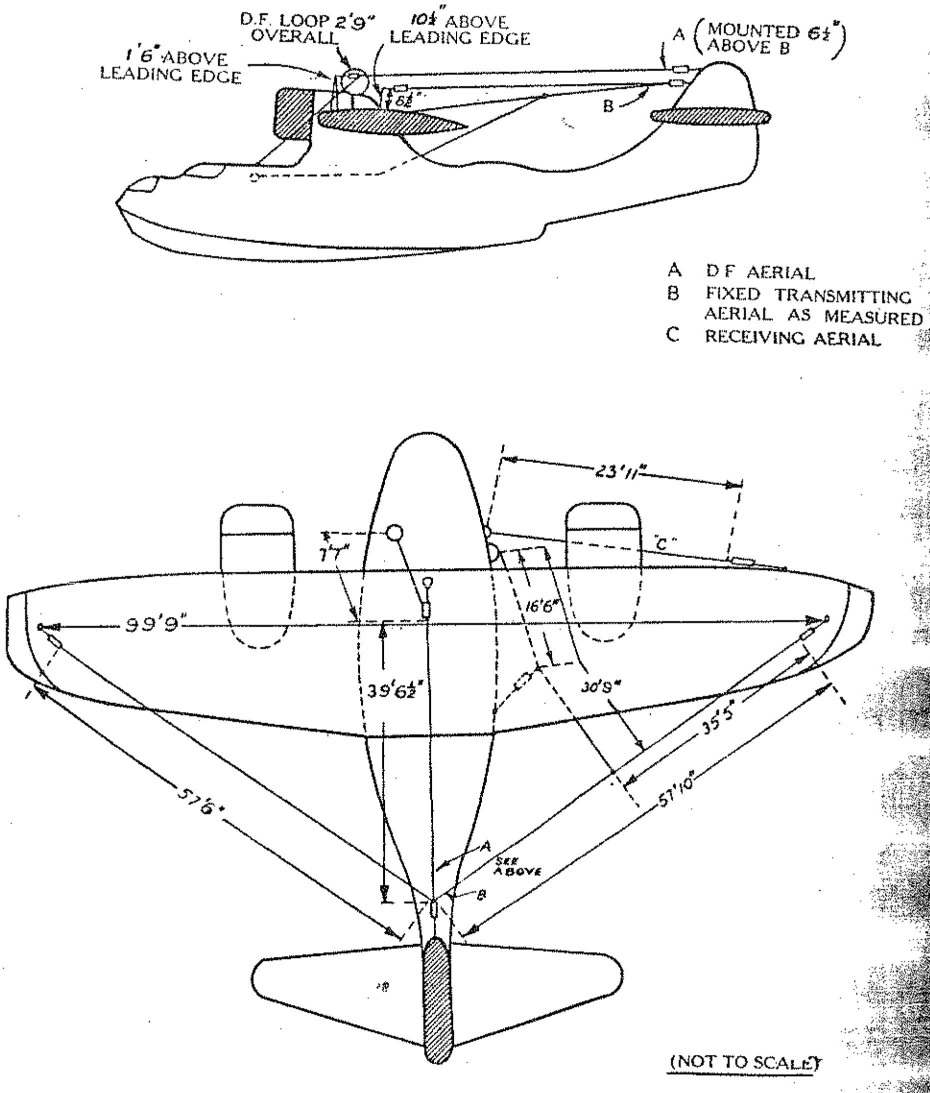


FIGURE 9—Fixed aerial dimensions on a large flying-boat.

The possibility of determining the approximate characteristics of fixed aircraft aerials by measuring their dimensions and making empirical corrections to allow for proximity to the fuselage and the size of the aircraft, has been discussed by Holmes (1942). He uses two charts, the first of which enables the quarter-wave resonant frequency to be determined, knowing the length of the aerial plus length of lead-in. Corrections are plotted for variations in size of aircraft, and for various configurations of aerials such as end-fed single wire, centre-fed vee, etc. Having determined the quarter-wave frequency, the second chart is then used to obtain the resistance and reactance components at any other frequency. As an example, taking the aerial of figure 3, the quarter-wave resonance is obtained as 8.0 Mc, which agrees very well with figure 5. From the second chart the electrical characteristics at 4 Mc and 12 Mc are obtained as 1.8 ohms resistance, 400 ohms capacitive reactance and 40 ohms resistance, 800 ohms inductive reactance respectively. These agree reasonably well

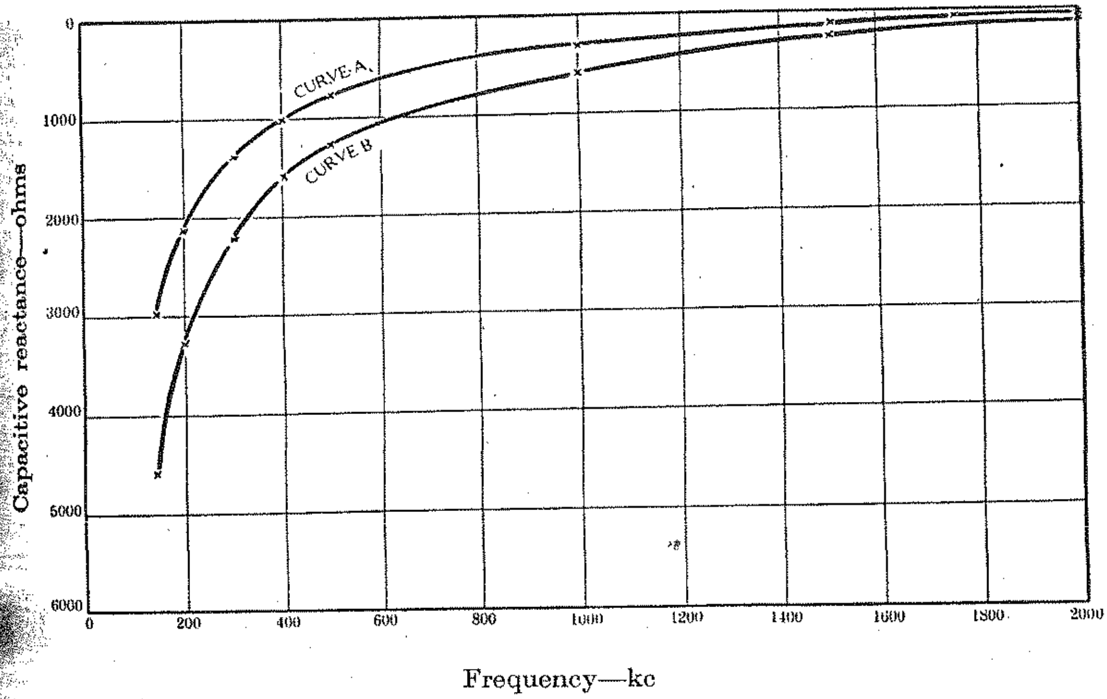


FIGURE 10—Capacitive reactance of the fixed aerial on a large flying-boat.

with the values obtained from figure 5, namely 4 ohms resistance, 300 ohms capacitive reactance and 40 ohms resistance, 400 ohms inductive reactance respectively. In the case of an aerial such as that shown in figure 9, it is clear that the charts cannot be applied at all.

4—Coupling Circuits for Trailing and Fixed Aerials in the Medium-Frequency Band

Before circuits can be designed to couple the power-amplifier anodes of the transmitter to the aerial, a decision must be made as to whether the aerial shall be coupled directly into the power-amplifier tank circuit or whether a low-impedance line shall be taken from the tank-circuit to the aerial coupling circuits housed in a separate unit. Several advantages accrue from this latter solution, including:

(a) The tank-circuit can be calibrated directly in frequency independently of the aerial constants.

(b) The very high R-F voltages produced with electrically short aerials are confined to a separate unit.

(c) It is frequently convenient in some installations to have a small aerial coupling unit to place near the aerial lead-in rather than a larger unit containing the whole transmitter.

Trailing Aerials—Consider now the problem of coupling a 100-ohm line to a trailing aerial in the frequency range 140-500 kc. Since even the largest of aircraft aerials can be represented by a resistance in series with

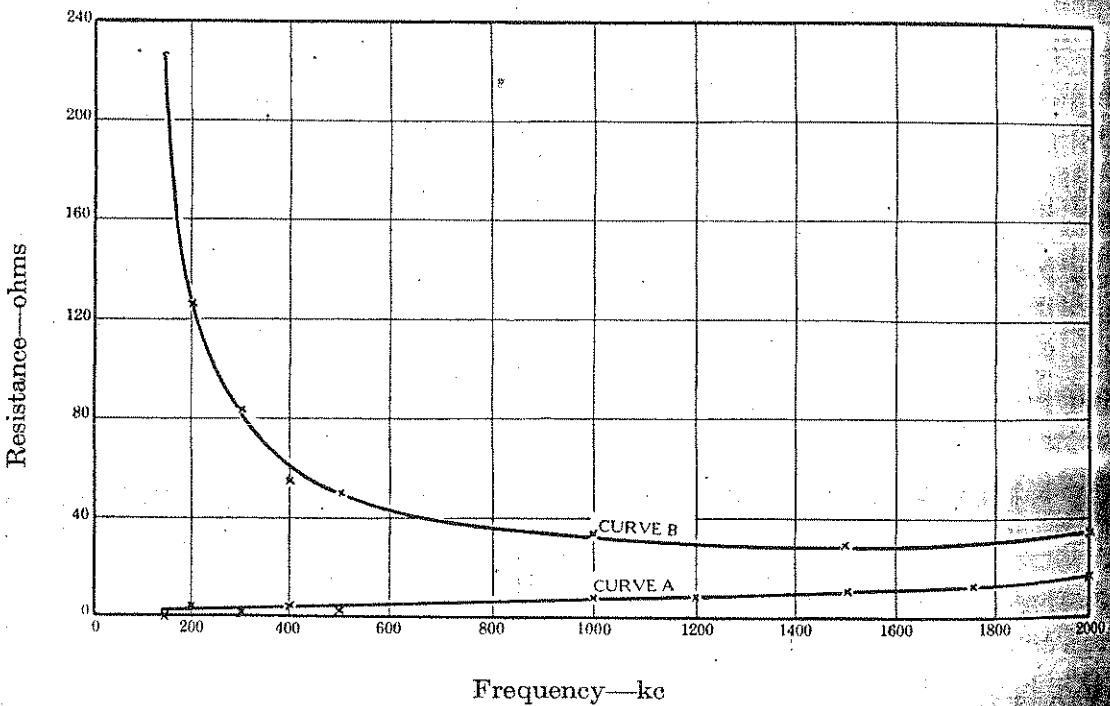


FIGURE 11—Resistance of the fixed aerial on a large flying-boat.

a capacitance, at least two possible matching systems are the π network circuit shown in figure 14 (a), and a circuit in which the coupling element is the inductance L_2 as shown in figure 14 (b). Here C_2 and R_2 are the equivalent series capacitance and resistance of the aerial, and R_G is the impedance of the line from the transmitter. The resistive components associated with C_1 in (a) and L_2 in (b) have been neglected as they are negligible compared with the other resistances in the circuit. Due to the range of frequencies to be covered, it is clear that a coarse and fine control would be required for L_1, so that if at all possible it is most desirable that only one additional control be used for either C_1 or L_2, depending on which system is used.

Referring to figure 14 (a), it is seen that L_1, R_1, C_2, R_2 can be replaced at any given frequency by an equivalent inductance L_0 and resistance R_0 in series, the equivalent circuit then being as shown in figure 15 (a), similarly figure 15 (b) is the equivalent circuit of figure 14 (b), where C_0 and R_0 are equivalent to L_1, R_1, C_2 and R_2.

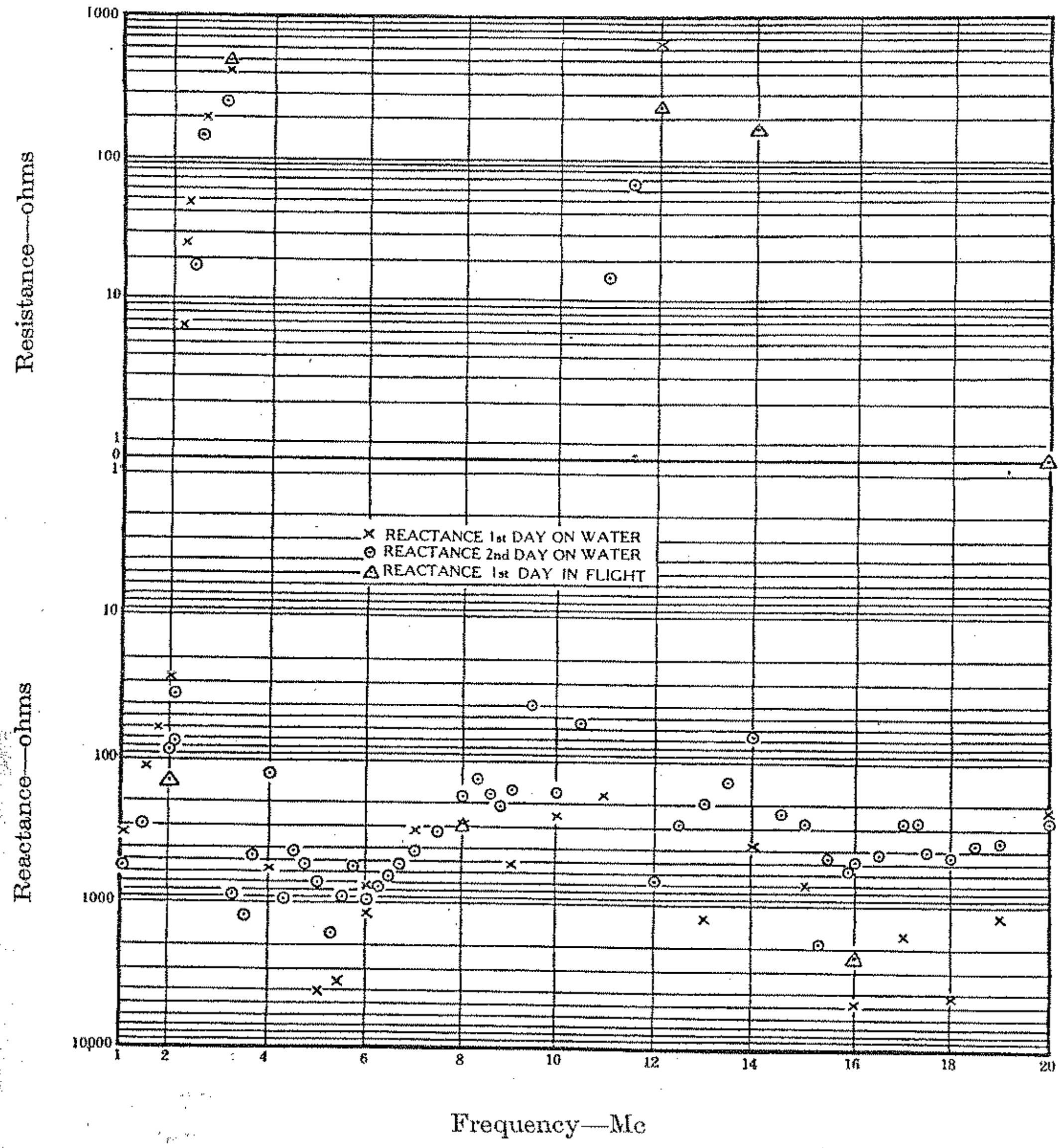


FIGURE 12—Reactance of the fixed aerial on a large flying-boat.

Writing X_L for the reactance of L_0 at the working frequency, and X_C for the reactance of C_1, then Z_{AB}, the impedance across the terminals AB of figure 15 (a), is given by

$$Z_{AB} = \frac{X_L X_C - jR_0 X_C}{R_0 + j(X_L - X_C)}. \tag{1}$$

Rationalising gives the well-known form

$$Z_{AB} = \frac{R_0 X_C^2}{R_0^2 + (X_L - X_C)^2} + j\frac{(X_C^2 X_L - X_C X_L^2 - R_0^2 X_C)}{R_0^2 + (X_L - X_C)^2}. \quad (2)$$

Two conditions must now be satisfied if the 100-ohm line from the transmitter is to be correctly terminated ; (a) The imaginary term must be zero, (b) The real term must have the value 100 ohms. Assuming, as would always be the case in the medium-frequency band, that $X_L \gg R_0$, this immediately gives $X_L = X_C$ and hence $X_C^2/R_0 = 100$.

Taking the values of impedance of a typical trailing aerial at 140 kc and 500 kc as $16 - j3000$ ohms and $10 - j1000$ ohms respectively (see figure 2),

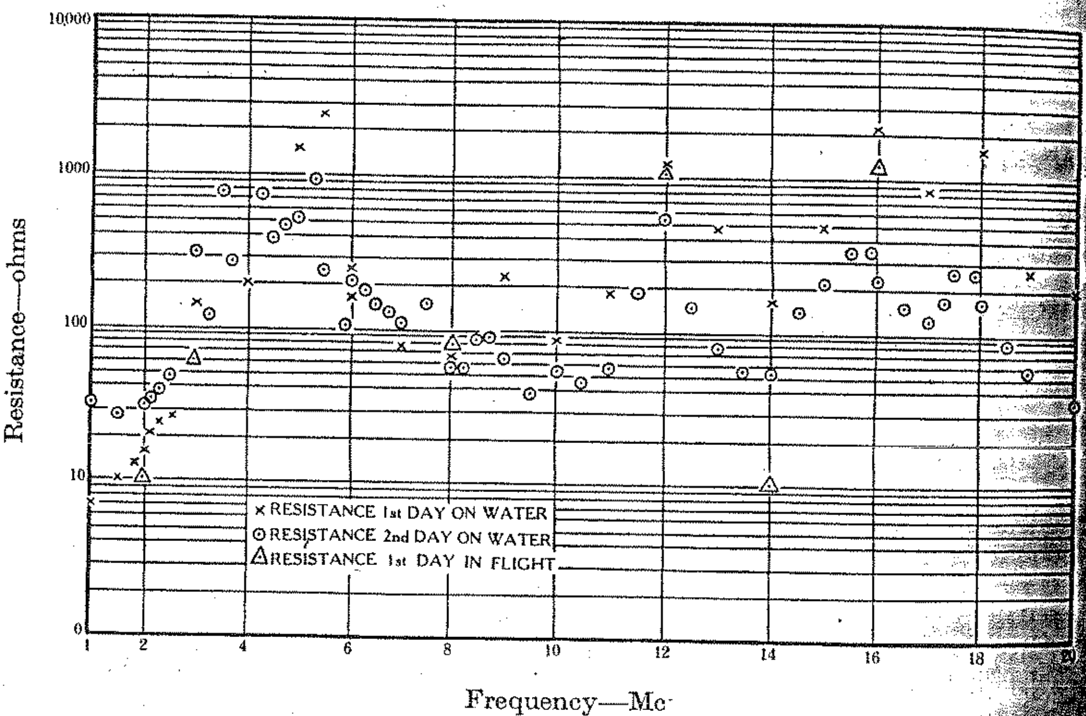


FIGURE 13—Resistance of the fixed aerial on a large flying-boat.

we can now compute the variation required in C_1 and L_1 of figure 14 (b), assuming some reasonable value for the resistance R_1 associated with L_1. We might assume the Q of the loading inductance to be 100, that is, $100 = \omega L_1/R_1$ where $\omega = 2\pi \times$ frequency. We have also

$$X_C = \frac{1}{\omega C_1} = \omega L_1 - \frac{1}{\omega C_2} = X_L \quad (3)$$

and

$$\frac{X_C^2}{R_0} = \frac{1}{(R_1 + R_2)\omega^2 C_1^2} = 100. \quad (4)$$

Substituting the assumed values of C_2 and R_2 and using the relation

$\omega L_1 = 100\ R_1$ in (3) and (4), we obtain the values of C_1 and L_1 at 140 kc and 500 kc as being $0.018\,\mu F$, $3500\,\mu H$ and $0.007\,\mu F$, $330\,\mu H$ respectively.

Without considering the further variation required to cover different trailing aerials, manufacturing variations in the Q of the tuning inductance, or the constants of fixed aerials, it is clear that a variable capacitance with a single control to cover the range of approximately $0.02\,\mu F$ to $0.007\,\mu F$ is impracticable.

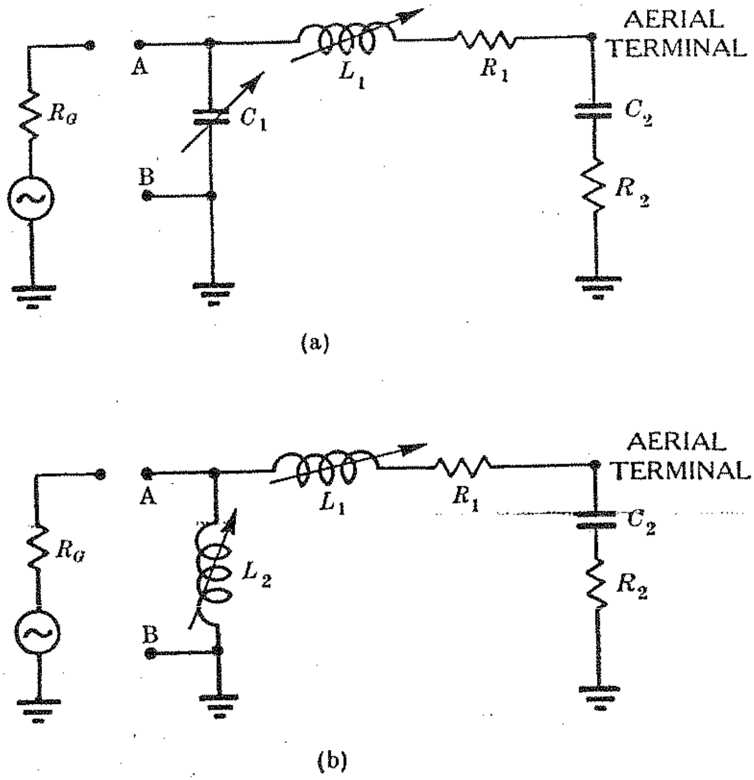


FIGURE 14—Two possible coupling circuits for the medium-frequency band.

Considering figure 15 (b), and writing, at the working frequency, X_L for the reactance of L_2 and X_C for the reactance of C_0, we have

$$Z_{AB} = \frac{X_L X_C + jR_0 X_L}{R_0 + j(X_L - X_C)}. \tag{5}$$

Rationalising (5) gives

$$Z_{AB} = \frac{R_0 X_L^2}{R_0^2 + (X_L - X_C)^2} + j\frac{X_C^2 X_L - X_C X_L^2 + R_0^2 X_L}{R_0^2 + (X_L - X_C)^2}. \tag{6}$$

As before, to meet the required conditions we must have the real term equal to 100 ohms, and the imaginary term zero. Again, $X_C \gg R_0$, hence $X_C = X_L$, and $X_L^2/R_0 = 100$. Taking the same values for the aerial impedance as previously and assuming the Q of $L_1 = 100$, we find that the values required for L_1 and L_2 at 140 kc and 500 kc are 3300 μH, 75 μH and 300 μH, 14 μH respectively.

The problem now is to find a method of obtaining a variable inductance to cover the range 14-75 μH using a single control. This appears to be quite practicable using a variometer, the assumed value of 100 for the Q of L_1 giving a transfer efficiency of about 30 per cent at 140 kc and 50 per cent at 500 kc.

Fixed Aerials—It remains now to see what extension of the ranges of L_1 and L_2 in figure 15 (b) are required to cover fixed aerials over the same range of frequencies. It can be shown that L_2 requires a higher value for increasing values of both C_2 and R_2, the maximum value clearly occurring at the 140-kc point. The aerial of figure 4 would require, by this criterion, the largest value of L_2 of any of the aerials considered. The smallest value of L_2 is required at 500 kc and decreases as both the reactance and resistance

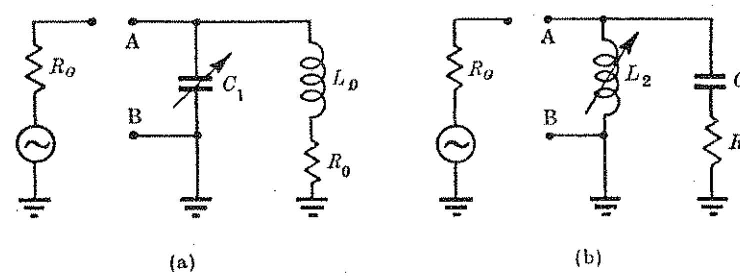
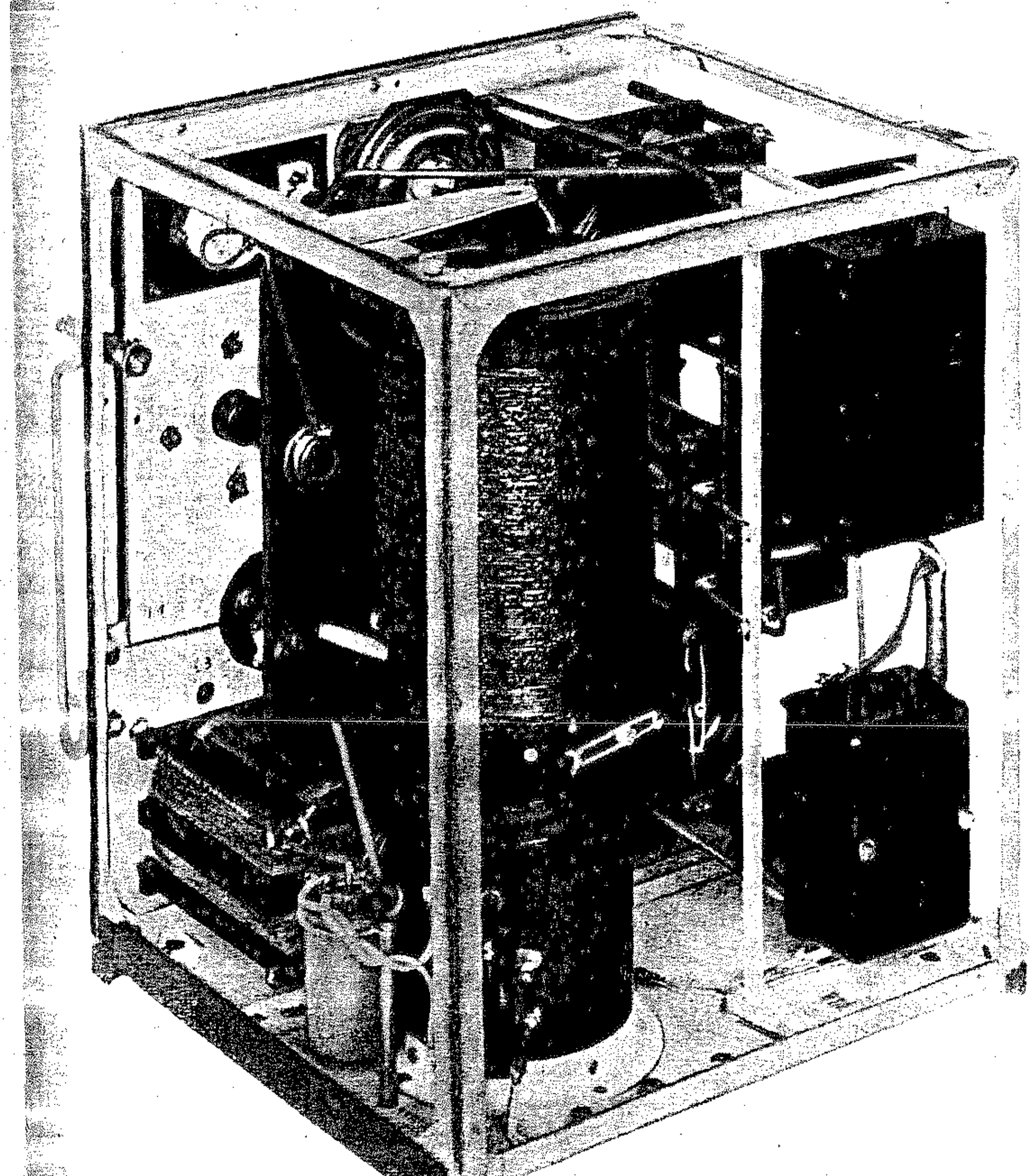


FIGURE 15—Equivalent circuits of figures 14 (a) and 14 (b).

decrease, hence trailing aerials already considered require the minimum value of L_2. Considering the fixed aerial of figure 4, at 140 kc the impedance is $100-j10{,}000$ ohms, and assuming again that the Q of L_1 is 100, the values required for L_1 and L_2 may be shown to be 10,000 μH and 160 μH respectively. With the assumed value of Q of 100 for L_1, the efficiency of transfer is almost exactly 50 per cent. It follows from the above calculations that the ranges of values for L_1 and L_2 to cover both fixed and trailing aerials in the band 500-140 kc are of the order 300-10,000 μH and 14-160 μH respectively, the values depending upon the Q obtained in the coil L_1.

Description of Coupling Unit—Figure 16 shows a view of an aerial coupling unit, with its covers removed, which provides coupling between a 100-ohm line and both fixed and trailing aerials over the frequency range 140-500 kc and for fixed aerials over the range 2-20 Mc. It is capable of handling an input power of the order 50 watts. The variable inductance L_2 of figure 14 (b) takes the form of a variometer and can be seen at the lower left corner of figure 16. The loading coil L_1 is mounted with its axis vertical and can be seen at the back of the unit illustrated in figure 16. Variometer L_1 is approximately rectangular and has a stator inductance



[Fig]ure 16—Internal view of an aerial coupling unit showing the loading inductance L_1 and the matching variometer L_2 of figure 14 (b) for the medium-frequency band.

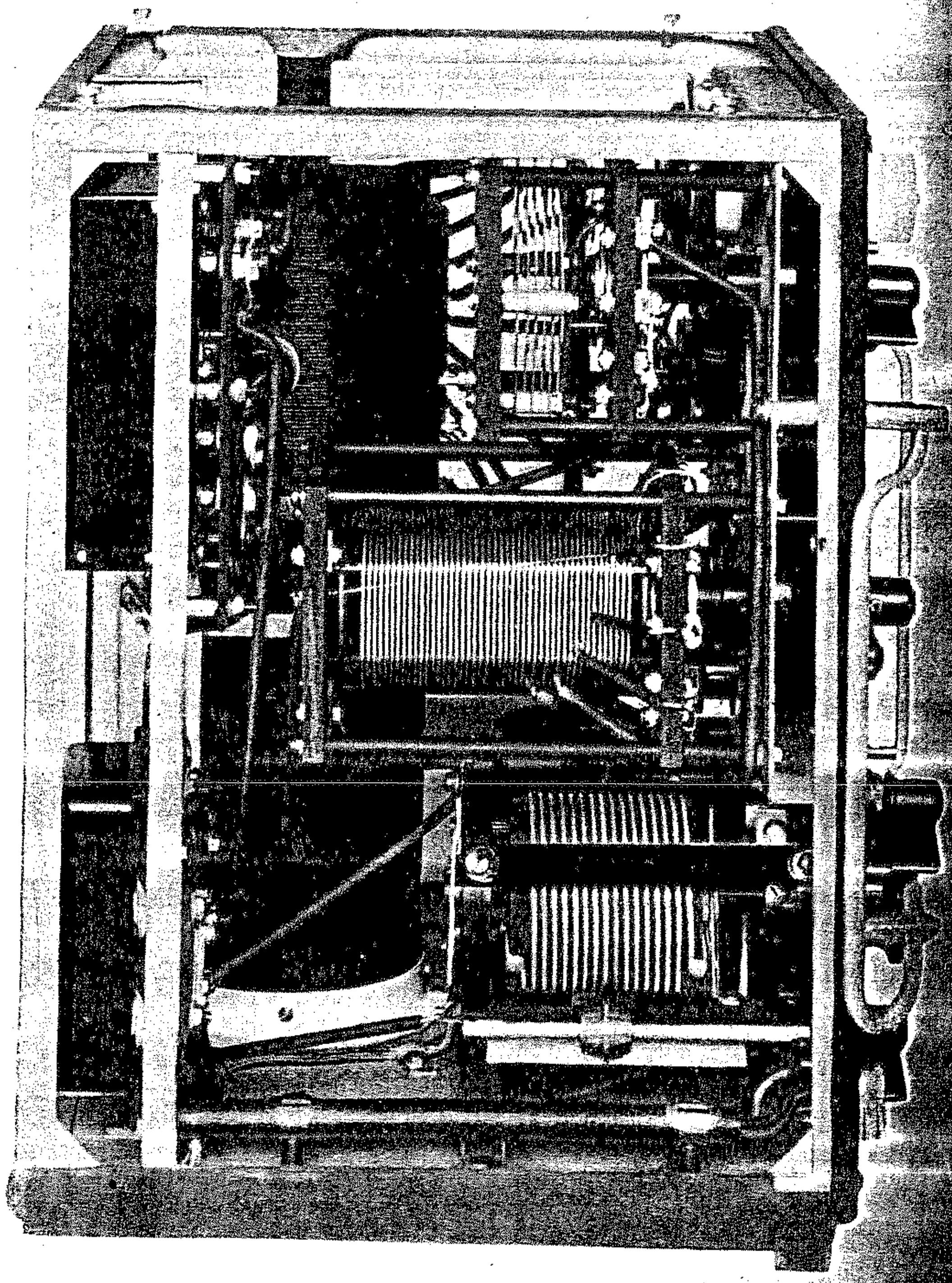


FIGURE 17—Another internal view of the aerial coupling unit of figure 16 showing some of the components for the high-frequency band.

of $54\,\mu H$ and rotor inductance of $47\,\mu H$, with a coefficient of coupling slightly better than 0.8, giving a range of approximately 18-180 μH. The variometer was designed using formula No. 166 of the Circular of the National Bureau of Standards C74 (1937). Despite the slight variation of the variometer from the true rectangular shape, the calculated values agreed very well with measured values. The method used was to calculate the total inductance of the variometer treating it as a single coil, and then calculate the individual inductances of the stator and rotor, so that the coefficient of coupling for a given spacing could be found.

The loading coil L_1 consists of a bank-wound tapped coil wound with Litz wire, variation between the ten tapping points being obtained by a variometer-like arrangement consisting of a rotor coil mounted at the base or ' cold ' end of the main coil, and using the main coil winding as the stator. The Q of coil L_1 varies, with setting of the variometer and the tap selected by the tapping switch, between the limits of 70 and 150. Design of the bank winding requires consideration of the permissible volts per turn, since, for 50 watts unmodulated carrier input to the unit at 140 kc using the aerial of figure 4 and assuming a Q for L_1 of 100 at this frequency, the potential developed at the aerial terminal is readily calculated as 7,000 volts peak value.

5—Coupling Circuits for Fixed Aerials in the High-Frequency Band

It has been shown that, in the medium-frequency band, there appeared to be at least two possible circuits which could be used for coupling a low-impedance line to fixed and trailing aerials, as both types of aerials are always capacitive at these frequencies. The circuit of figure 14 (a) was subsequently abandoned due to the difficulty of providing a variable capacitance of sufficient range for C_1. In the case of fixed aerials in the range 2-20 Mc even the aerials on small aircraft will become inductive within this frequency range. It is clear that the circuit of figure 14 (b) cannot be used as it stands if the aerial is inductive, furthermore, the circuit of figure 14 (a) will also fail if the series inductance of the aerial is sufficiently large to make $L_1 < 0$. In the latter case L_1 would require to be replaced by a variable capacitance. It is, of course, always possible to insert a capacitance in series with an inductance to produce a nett capacitive effect, but in the vicinity of half-wave resonance the capacitance becomes extremely small. For example, at 16.5 Mc the aerial of figure 5 would require a series capacitance of about $5\,\mu\mu F$ to make it capacitive, and for the aerial of figure 8 at 13.5 Mc the capacitance required is $12\,\mu\mu F$. If, however, a capacitance of $80\,\mu\mu F$ is connected in series with the fixed aerial of figure 5 in the region of quarter-wave resonance, and in parallel for higher frequencies, the condenser and aerial combination is found to be always capacitive. Table 1 shows the calculated constants of this combination at various points in the frequency range of 2-20 Mc for the aerial of figure 5 and Table 2 gives similar results for the aerial of figure 8.

Frequency Mc	Aerial Constants.		Position of 80 $\mu\mu F$ Condenser	Equivalent Series Resistance of Combination ohms.	Equivalent Series Reactance of Combination ohms.
	Series Resistance ohms.	Series Reactance ohms.			
2	4.5	−700	Out	4.5	−700
4	4	−310	Out	4	−310
6	6	−110	Out	6	−110
8	8	0	Series	8	−250
10	15	+150	Series	15	−50
12	35	+350	Parallel	31	−326
14	100	+600	Parallel	10.6	−197
16	1000	+1500	Parallel	5.9	−138
17	4000	0	Parallel	3.6	−120
19	700	−1500	Parallel	2.75	−104
19	700	−1500	Out	700	−1500
20	300	−800	Parallel	3.3	−90
20	300	−800	Out	300	−800

TABLE 1—Table showing the transformation of the constants of the aerial of Figure 5 by the use of an 80 $\mu\mu F$ condenser either in series or parallel with the aerial impedance.

From Tables 1 and 2 it is seen that the aerials of figures 5 and 8 may be made equivalent to a resistance in series with a capacitance by the simple expedient of using a single condenser of the somewhat arbitrary value of 80 $\mu\mu F$, and it is believed that this transformation can be accomplished using a value of condenser of this order with almost any aircraft aerial likely to be met with in practice. If it is assumed that the aerial to be coupled to the transmitter can always be made capacitive by means of the above device, then clearly a choice is available of either of the circuits of figures 14 (a) and 14 (b) with the addition of an 80 $\mu\mu F$ condenser and a switch to select the appropriate connection of the condenser. Calculation of the range of values required for L_2 in the circuit of figure 14 (b) for matching a 100-ohm line to the aerials of figures 5 and 8 shows that such extremely small values of inductance are required in some portions of the frequency range as to make the circuit impracticable. The values required of C_1 and L_1 in figure 14 (a), however, are realisable provided that coarse and fine controls are provided for each, making a total of five controls for the high-frequency band of 2-20 Mc.

Frequency Mc	Aerial Constants.		Position of 80 $\mu\mu F$ Condenser	Equivalent Series Resistance of Combination ohms.	Equivalent Series Reactance of Combination ohms.
	Series Resistance ohms.	Series Reactance ohms.			
2	5.5	−500	Out	5.5	−500
4	4	−200	Out	4	−200
6	4	0	Series	4	−340
8	7	+75	Series	7	−175
10	18	+180	Series	18	−20
12	55	+400	Parallel	28	−289
14	2000	+1500	Parallel	7	−152
16	250	−350	Parallel	14.5	−103
16	250	−350	Out	250	−350
17.6	150	0	Parallel	55	−72
20	150	+300	Parallel	33	−183

TABLE 2—Table showing the transformation of the constants of the aerial of Figure 8 by the use of an 80 $\mu\mu F$ condenser either in series or parallel with the aerial impedance.

A practical design of an aerial coupling unit using the circuit of figure 14 (a) with the addition of a selector switch and 80 $\mu\mu F$ condenser is shown in figure 17. This is another view of the unit illustrated in figure 16, the high-frequency band also being capable of handling an input power of 50 watts of unmodulated carrier. The 80 $\mu\mu F$ condenser is air-dielectric and, with its associated switch, is seen at the top of the unit. Inductance L_1 has been divided into a tapped coil of total inductance 50 μH, shown in the centre of figure 17, for coarse adjustment, and a roller coil at the bottom of the unit with a range of 0.5 μH to 10 μH for fine adjustment. Condenser C_1, not shown, takes the form of six mica condensers, each of 350 $\mu\mu F$, additively connected in parallel by a six-position switch, for coarse control, and an air-dielectric variable condenser of range approximately 15-400 $\mu\mu F$ for fine control. The coupling unit illustrated in figures 16 and 17 has been used on a great variety of frequencies within the bands 140-500 kc and 2-20 Mc with all of the aerials shown fitted to the aircraft in figures 4, 6 and 9, and has also been fitted to other types of aircraft. It has also been used in the medium-frequency band with trailing aerials of the constants shown in figure 2 and no case has been found, even with the aerial of figure 9, where satisfactory coupling could not be achieved. In the high-frequency band it has also been used to couple to whip aerials on vehicles with satisfactory results.

ACKNOWLEDGMENT

It is a pleasure to acknowledge the assistance of W. W. Jenvey and A. D. Thomas in taking measurements of the electrical constants of the various aircraft aerials described.

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