July 15, 1947. D. C. ESPLEY 2,424,156

APPARATUS FOR TRANSMITTING AND RECEIVING RADIO SIGNALS

Filed Jan. 2, 1942 2 Sheets-Sheet 1

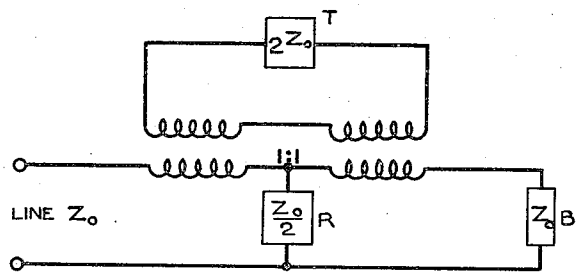


FIG. 1

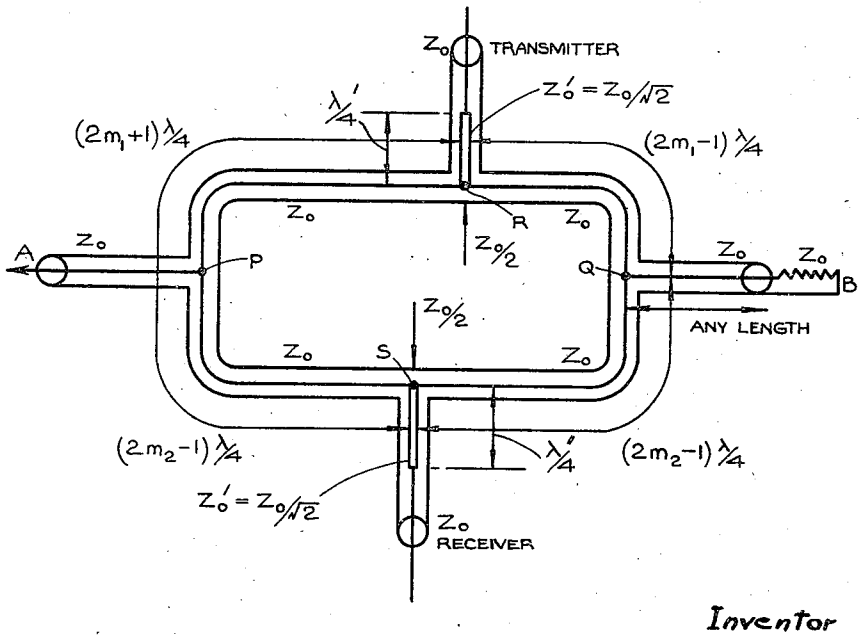


FIG. 2

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FIG. 3

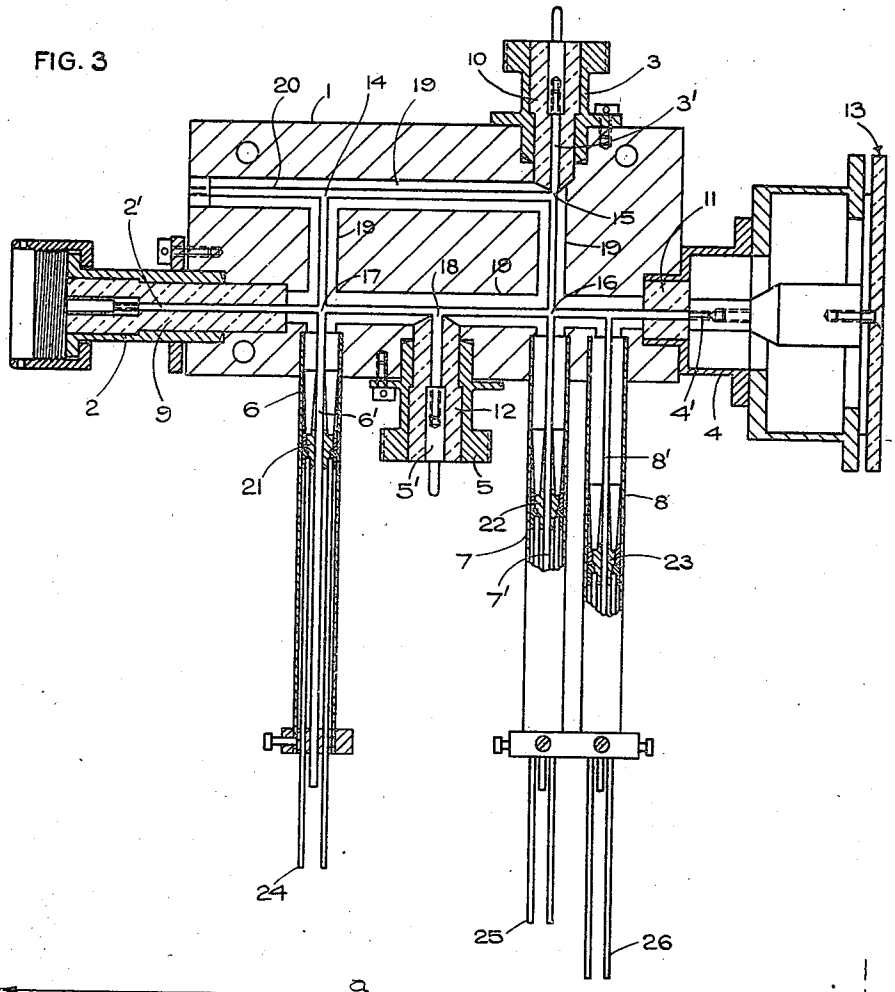
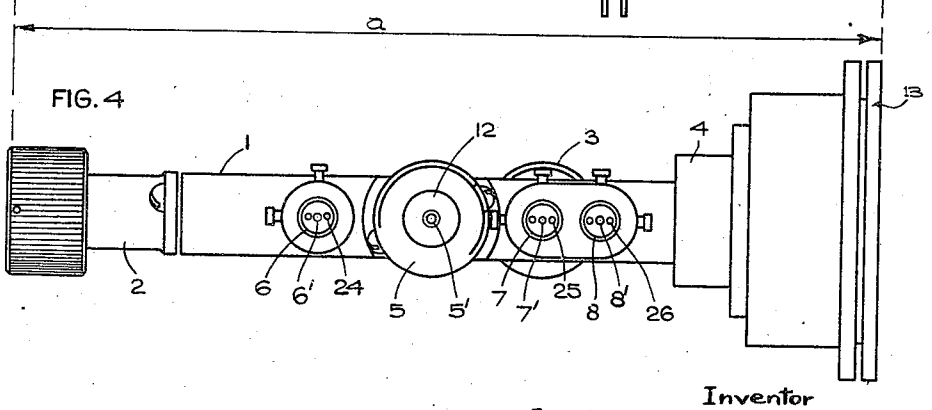


FIG. 4



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APPARATUS FOR TRANSMITTING AND RECEIVING RADIO SIGNALS

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8 Claims. (Cl. 250—9)

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This invention relates to apparatus for simultaneously or alternately transmitting and receiving radio signals of frequency exceeding 100 mc./s., of the type wherein the transmitter and the receiver respectively communicate energy to and receive energy from an aerial common to both of them.

One of the main problems in apparatus of this type is to prevent energy generated in the transmitter from entering the receiver and thus masking the signals arriving from outside that it is desired to receive or even damaging the receiver.

An object of this invention is to provide improved apparatus of the type specified, whereby this problem is overcome.

The invention will be explained with reference to the accompanying drawings, in which:

Figure 1 is a diagram of apparatus used in telephony over wires,

Figure 2 is a diagram of apparatus according to this invention,

Figure 3 is a section of an embodiment of this invention, showing the parts corresponding to those shown in Figure 2, and

Figure 4 is an elevation of the same embodiment, as viewed from the bottom of Figure 3.

A problem analogous to that with which the present invention is concerned occurs in telephony over wires. There it is solved satisfactorily by the use of the well known hybrid coil and balancing network, which is illustrated conventionally in Figure 1. The line has a characteristic impedance Z_0, the transmitter T an impedance $2Z_0$, the receiver R an impedance $Z_0/2$, the balance B an input impedance Z_0. Of the power generated in the transmitter T half goes into the line, the other half into the balance Z_0; of power received from the line half goes into the receiver R, the other half into the transmitter T.

In the arrangement of Figure 1, the transformer consists of lumped inductances. When the frequency is as high as 100 mc./s., distributed impedances are always important and it is difficult or impossible to realise the arrangement of Figure 1. The object of this invention, more specifically stated, is to provide an analogous arrangement in which the lumped impedances of the transformer are replaced by the distributed impedances of concentric lines.

One way in which this object can be achieved is shown diagrammatically in Figure 2. The line leading to the aerial A (which corresponds to the telephone line in Figure 1 and is hereinafter called the aerial line) is a concentric line of characteristic impedance Z_0. At P it branches

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into two concentric lines, each of characteristic impedance Z_0, which re-unite at Q. The lengths of these branches between P and Q are respectively $m_1\lambda$ and $(m_2-\frac{1}{2})\ \lambda$ where λ is the wave-length of the oscillations along the branches and m_1 and m_2 are integers which may or may not be equal. (It is to be noted that, contrary to what might seem to be suggested by Figure 2, the lengths of the two branches are not the same if $m_1=m_2$.) From Q a concentric line, again of characteristic impedance Z_0 but of any length, leads to the terminating balance B of impedance Z_0.

A concentric line from the transmitter is connected as a T-piece to one of the said branches, at a point R whose distance from P is $(2m_1+1)\ \lambda/4$ and whose distance from Q is consequently $(2m_1-1)\ \lambda/4$. The line has a characteristic impedance $Z_0/\sqrt{2}$ for a distance $\lambda'/4$ from the point R, where λ' is the wave-length of the oscillations along this part of the line; for the rest of its length it has the characteristic impedance Z_0; it is terminated by the transmitter which has internal impedance Z_0.

A concentric line from the receiver is connected as a T-piece to the other of the said branches at a point S which is distant $(2m_2-1)\ \lambda/4$ from P and therefore $(2m_2-1)\ \lambda/4$ from Q. This line has a characteristic impedance $Z_0/\sqrt{2}$ for a distance $\lambda''/4$ from the point S, where λ'' is the wave-length of the oscillations along this part of the line; for the rest of its length it has the characteristic impedance Z_0; it is terminated by the receiver which has the internal impedance Z_0. λ' and λ'' may or may not be equal to each other and to λ.

It will now be shown that the arrangement of Figure 2 has certain properties in common with that of Figure 1.

At the outset, it should be noted that the impedance looking into each of the T-pieces from the points R and S is $Z_0/2$. For if Z_c is the characteristic impedance of a line of length $\lambda/4$, if Z_b is the terminating impedance at one end, and if Z_a the impedance looking into the other end then $Z_a=Z_c^2/Z_b$. Applying this to the T-pieces, $Z_c=Z_0/\sqrt{2}$, $Z_b=Z_0$; so that $Z_a=Z_0/2$. The only conditions that the T-pieces need fulfil are (1) that the impedance looking into them is Z_02 and (2) that there is no considerable loss of energy in passing along them from their openings R and S to the transmitter and receiver respectively. Experts will realise that many kinds of transformers could be introduced along the T-pieces

to secure these conditions, even if the internal impedance of the transmitter or receiver or both were different from Z_0. Any modification of the arrangement shown that also fulfils conditions (1) and (2) is therefore equivalent to the arrangement shown for the purpose of the invention.

Again, consider the two branches leading from P to Q. Each of these has a T-piece which will affect the transmission of oscillations along it; but the T-pieces have the same impedance looking into them, and the distance of the T-piece from P (or from Q) along one branch differs from that along the other by $n\lambda/2$, where n is an odd integer. Accordingly the presence of the T-pieces has the same effect on the phase change that the oscillations undergo in travelling along one branch as they have on the phase change that they undergo in travelling along the other; and in considering any difference in the effective length of the branches, the side pieces may be ignored. Similarly, in considering any difference in the effective length of the two paths from R to S, the presence of the T-pieces to that path at P and Q may be ignored; for the impedances looking into both T-pieces are the same and their distances from R differ by $n\lambda/2$.

The common properties of the arrangements of Figures 1 and 2 can now be stated; they will be denoted by I, II, III and IV. Since the arrangement of Figure 1 is known to possess the properties, it is only required to prove that the arrangement of Figure 2 possesses them.

I. No oscillation entering the system from the aerial line reaches B. For the lengths of the two branches between P and Q differ by $n\lambda/2$, where n is an odd integer, so that oscillations starting from A arrive at B in opposite phases.

II. No oscillations from the transmitter can reach the receiver; for the lengths of the two branches between R and S also differ by $n\lambda/2$, where n is an odd integer.

III. The termination of the aerial line has impedance Z_0. For since no energy from P reaches Q, in virtue of property I, the impedance at Q does not affect the value of the impedance of the termination; accordingly the two branches from P may each be regarded as terminated by the impedance $Z_0/2$ of the T-piece. Since the distance between P and a T-piece is an odd multiple of $\lambda/4$ in each branch, the impedance looking into each branch is $Z_0^2/(Z_0/2)=2Z_0$. The termination therefore consists of two impedances, each $2Z_0$ in parallel; the impedance of the termination is therefore Z_0.

IV. Energy entering by the aerial line is equally divided between transmitter and receiver. For the distances of the T-pieces from P differ by $n\lambda/2$ and their input impedances are the same.

Now the properties I, II, III, and IV are those in which the hybrid coil of Figure 1 fulfils its function. Accordingly the arrangement of Figure 2 will fulfil the same function.

However the precision attainable in constructing concentric lines to have a prescribed characteristic impedance is not as great as that attainable in constructing lumped elements of given impedance. Accordingly it is necessary to inquire what effect an error of (say) 1% in the characteristic impedances will have. In virtue of the equivalence of the said Figures 1 and 2, it will be sufficient to inquire into the ratio in Figure 1 between the power emitted by the transmitter and that dissipated in the receiver when the impedances Z_0 are not exactly equal.

Straightforward calculation shows that if the impedance of B is Z_1 the ratio is

$$\frac{1}{4}\frac{(Z_0-Z_1)^2}{(Z_1+Z_0)(3Z_0+Z_1)}$$

If $Z_0-Z_1=Z_0/100$, this ratio is $\frac{1}{32}\times10^{-4}$. Accordingly, even with this error in adjustment, the power from the transmitter reaching the receiver will be attenuated by more than 50 db.

It is known that the hybrid coil of Figure 1 will still perform its main function of preventing energy from the transmitter from entering the receiver, even if there are certain departures from the arrangement shown. Thus the impedance B need not be exactly Z_0. Again, nothing material would be changed if the line to the aerial and the line to the balance were interchanged in position, or if the transmitter and receiver were interchanged in position.

The invention now can be stated generally. According to the invention, apparatus of the type adapted to transmit and receive, simultaneously or alternately, radio signals of a frequency exceeding 100 mc./s. comprises (1) a concentric line of characteristic impedance Z_0 leading from the aerial to a junction P, (2) a pair of concentric lines (branches), each of characteristic impedance substantially Z_0, connecting P to a point Q, (3) a balancing impedance connected to Q whose impedance regarded from Q is preferably Z_0, (4) a line leading to one of the transmitter and receiver connected as a T-piece to one of the said branches at a point R, the impedance of the said line regarded from the point R being substantially $Z_0/2$, (5) a line leading to the other of the transmitter and receiver connected as a T-piece to the other of the said branches at a point S, the impedance of the said line regarded from the point S being substantially $Z_0/2$; the lengths of the paths PR, RQ, QS, SP are so adjusted that the electrical lengths $((PR+RQ)-(PS+SQ))$ and

$$((RP+PS)-(RQ+QS))$$

are both substantially of the form $n\lambda/2$ where n is an odd integer and λ is the wave-length of the oscillations passing along these paths; and the whole arrangement is such that substantially no energy from the transmitter can reach the receiver.

In the embodiment of the invention shown in Figures 3 and 4, the dimension indicated by a is approximately 17.5 cm.; the value of Z_0 is about 75 ohms. 1 is a metal block, made in two parts, from which the unshaded parts 19 have been drilled; it therefore in effect forms a casing surrounding the unshaded parts. From the block project the metal tubes 2, 3, 4, 5, 6, 7, 8, each of which is the outer member of a concentric line, whose inner member is a rod 2', 3', 4', 5', 6', 7', 8' respectively. These rods are connected together, electrically and mechanically, and are supported by the insulating bushings 9, 10, 11, 12 which respectively separate the rods 2', 3', 4', 5' from the tubes 2, 3, 4, 5. These bushings are of the material known by the trade name Distrene. The outer end of the line 2, 2' is shaped so that it is adapted to be connected to a concentric line leading to the aerial; the outer ends of the lines (3, 3') and (5, 5') are shaped so that they are adapted to be connected respectively to the transmitter and receiver; the end of the line (4, 4') is terminated at the outer end by a carbon plate 13, connected between the inner and outer members, and providing the resistance B shown in Figure 2.

In conjunction with subsidiary rods, the rods aforementioned form a rectangular frame within the said casing, whose corners are 14, 15, 16, 17, with at least one of the two sides meeting at a corner prolonged, and with a projection from the mid point 18 of the side (16, 17). This frame, with the block surrounding it as the outer member, constitutes a closed concentric line of characteristic impedance Z_0. Corner 17 corresponds to P in Figure 2, corner 16 to Q, corner 15 to R, and mid point 18 to S. The length of each of the sides (14, 15) and (16, 17) is made equal to $\lambda/2$ at the frequency at which the apparatus is to operate; the length of each of the sides (14, 17), (15, 16) is $\lambda/4$. Then the distance along the frame from P to Q is $\lambda/2$ along the branch (17, 16) and λ along the branch 17, 14, 15, 16. Similarly the distance along the frame from R to S is $\lambda/2$ along the branch (15, 16, 18) and λ along the branch 15, 14, 17, 18. The rod 20 projecting from the corner 14 is the inner member of a quarter-wave-length stub, short-circuited at its far end; its purpose is merely to support the rods at an additional point, while presenting infinite impedance to oscillations that might enter it.

The lengths of the tubes 3, 5 are each $\lambda'/4$, where λ' is the wave-length of the oscillations along the lines (3, 3'), (5, 5'). The dimensions of the members forming these lines are so adjusted with reference to the dielectric constant of the insulation separating them that the characteristic impedance of the lines is $Z_0/\sqrt{2}$.

The concentric lines (6, 6'), (7, 7'), (8, 8') are for adjustment, and each has a bridge 21, 22, 23 connecting the inner and outer member, that can be slid along the line by a handle 24, 25, 26 projecting from the outer end of the line. The line (6, 6') is adjusted so as to eliminate by resonance the electrical effects of the right-angled junctions of the rods forming the rectangular frame. The lines (7, 7') and (8, 8') serve as a transformer and resonator whereby the effective resistance of the carbon plate may be made equal to 75 ohms, without the introduction of reactance by the adjustment.

I claim:

1. Apparatus for transmitting and receiving, simultaneously or alternately, radio signals of a frequency exceeding 100 mc./s., comprising an aerial, a transmitter for communicating energy to said aerial, a receiver for receiving energy from said aerial, a junction P, a concentric line of characteristic impedance Z_0 leading from said aerial to said junction P, a point Q, a pair of concentric line branches, each of characteristic impedance substantially Z_0, connecting said junction P to said point Q, a balancing impedance connected to said point Q, a point R on one of said branches, a line leading to one of said transmitter and receiver connected as a T-piece at said point R, the impedance of said T-piece line regarded from said point R being substantially $Z_0/2$, a point S on the other of said branches, and a line leading to the other of the transmitter and receiver connected as a T-piece at said point S, the impedance of said last-mentioned line regarded from said point S being substantially $Z_0/2$; wherein the lengths of the paths PR, RQ and QS, SP are so adjusted that the electrical lengths $((PR+RQ)-(PS+SQ))$ and $((RP+PS)-(RQ+QS))$ are both substantially of the form $n\lambda/2$, where n is an odd integer and λ is the wave-length of the oscillations passing along these paths, the whole arrangement being such that substantially no energy from said transmitter can reach said receiver.

2. Apparatus for transmitting and receiving, simultaneously or alternately, radio signals of a frequency exceeding 100 mc./s., comprising an aerial, a transmitter for communicating energy to said aerial, a receiver for receiving energy from said aerial, a junction P, a concentric line of characteristic impedance Z_0 leading from said aerial to said junction P, a point Q, a pair of concentric line branches, each of characteristic impedance substantially Z_0, connecting said junction P to said point Q, a balancing impedance which is connected to said point Q and whose impedance regarded from said point Q is substantially Z_0, a point R on one of said branches, a concentric line leading to said transmitter and connected as a T-piece at said point R, the impedance of said T-piece line regarded from the point R being substantially $Z_0/2$, a point S on the other of said branches, and a concentric line leading to said receiver and connected as a T-piece at said point S, the impedance of said last-mentioned T-piece line regarded from said point S being substantially $Z_0/2$, wherein the lengths of the paths PR, RQ and QS, SP are so adjusted that the electrical lengths $((PR+RQ)-(PS+SQ))$ and $((RP+PS)-(RQ+QS))$ are both substantially of the form $n\lambda/2$, where n is an odd integer and λ is the wave-length of the oscillations passing along these paths, the whole arrangement being such that substantially no energy from said transmitter can reach said receiver.

3. Apparatus for transmitting and receiving, simultaneously or alternately, radio signals of a frequency exceeding 100 mc./s., comprising an aerial, a transmitter for communicating energy to said aerial, a receiver for receiving energy from said aerial, a junction P, a concentric line of characteristic impedance Z_0 leading from said aerial to said junction P, a point Q, a pair of concentric line branches, each of characteristic impedance substantially Z_0, connecting said junction P to said point Q, a balancing impedance connected to said point Q, a point R on one of said branches, a line leading to one of said transmitter and receiver connected as a T-piece at said point R, the impedance of said T-piece line regarded from said point R being substantially $Z_0/2$, a point S on the other of said branches, and a line leading to the other of the transmitter and receiver connected as a T-piece at said point S, the impedance of said last-mentioned line regarded from said point S being substantially $Z_0/2$; wherein the electrical length of the path PR is substantially $\frac{3}{4}\lambda$ and the electrical length of the paths RQ, QS, and SP are each substantially $\frac{1}{4}\lambda$, where λ is the wave-length of the oscillations passing along these paths, the whole arrangement being such that substantially no energy from said transmitter can reach said receiver.

4. Apparatus for transmitting and receiving, simultaneously or alternately, radio signals of a frequency exceeding 100 mc./s., including an aerial, a transmitter for communicating energy to said aerial, a receiver for receiving energy from said aerial, an electrical conductor forming a closed loop, a casing comprising two electrically conducting parts assembled face to face, at least one of which parts has in its said face channels accommodating said loop, said casing forming with said loop a closed concentric conductor loop, a concentric line of characteristic impedance Z_0

leading from said aerial to a point P on said concentric loop, a balancing impedance connected to a point Q on said concentric loop, the characteristic impedance of each of the branches of said concentric loop between said points P and Q being substantially Z_0, and two concentric lines leading respectively between said transmitter and a point R on one of said branches and between said receiver and a point S on the other of said branches, the impedance of each of said two lines, regarded respectively from said points R and S being substantially $Z_0/2$, wherein the electrical lengths of the paths are such that

$$((PR+RQ)-(PS+SQ)) \text{ and } ((RP+PS)-(RQ+QS))$$

are both substantially of the form $n\lambda/2$, where n is an odd integer and λ is the wave-length of the oscillations passing along these paths, the whole arrangement being such that substantially no energy from said transmitter can reach said receiver.

5. Apparatus as claimed in claim 4, wherein said closed loop is constituted by a rectangular frame within said casing, at least one of the two sides of said rectangular frame, that meet at each corner, being prolonged and serving to locate said frame with respect to said casing.

6. Apparatus as claimed in claim 4, wherein a branch from said concentric loop is constituted by a quarter-wave-length stub, short-circuited at its far end, and serving to support the inner conductor of said loop with respect to said casing.

7. Apparatus as claimed in claim 4, wherein said aerial, said balancing impedance, said transmitter and said receiver are each connected to said concentric loop by a concentric line with which is associated an insulating bushing serving to support the inner conductor of said loop with respect to said casing.

8. Apparatus as claimed in claim 4, wherein said concentric conductor system is provided with at least one concentric stub the electrical length of which is adjustable.

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