Feb. 21, 1939. A. ALFORD 2,147,809

HIGH FREQUENCY BRIDGE CIRCUITS AND HIGH FREQUENCY REPEATERS

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FIG. 1.

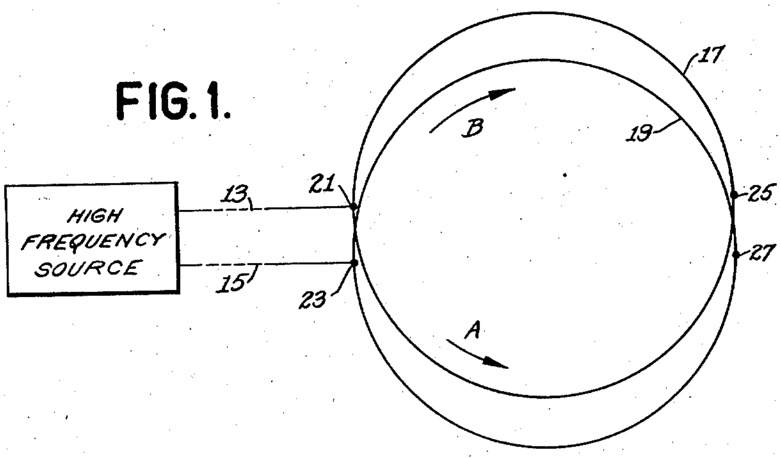

FIG. 2.

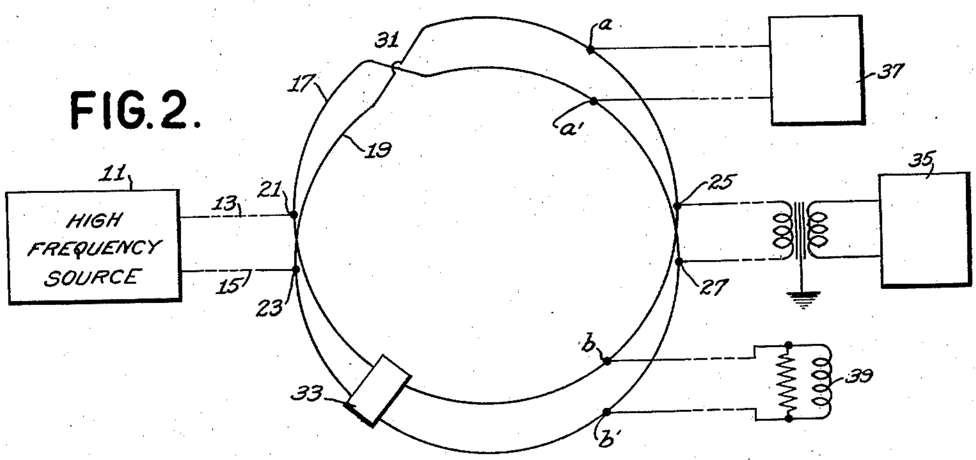

FIG. 3.

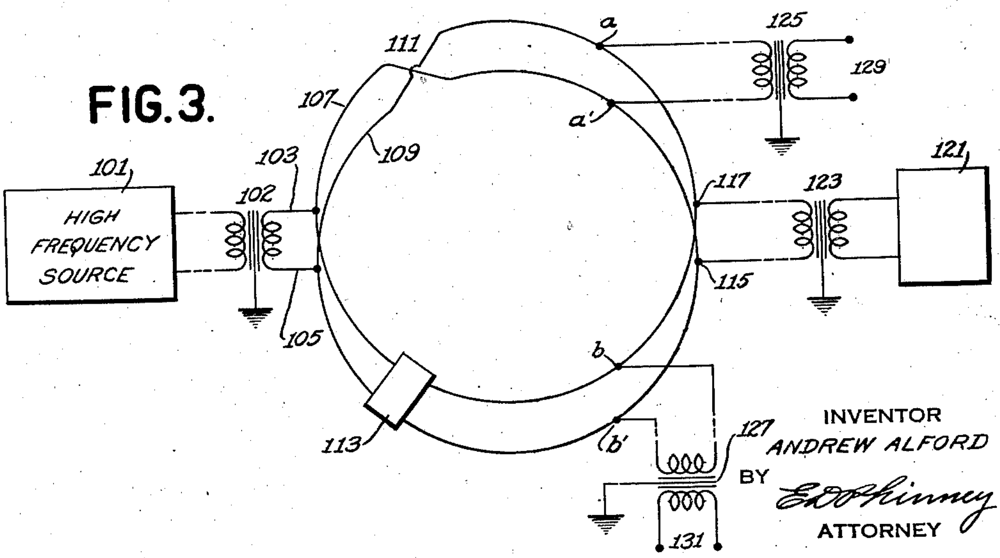

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FIG. 4.

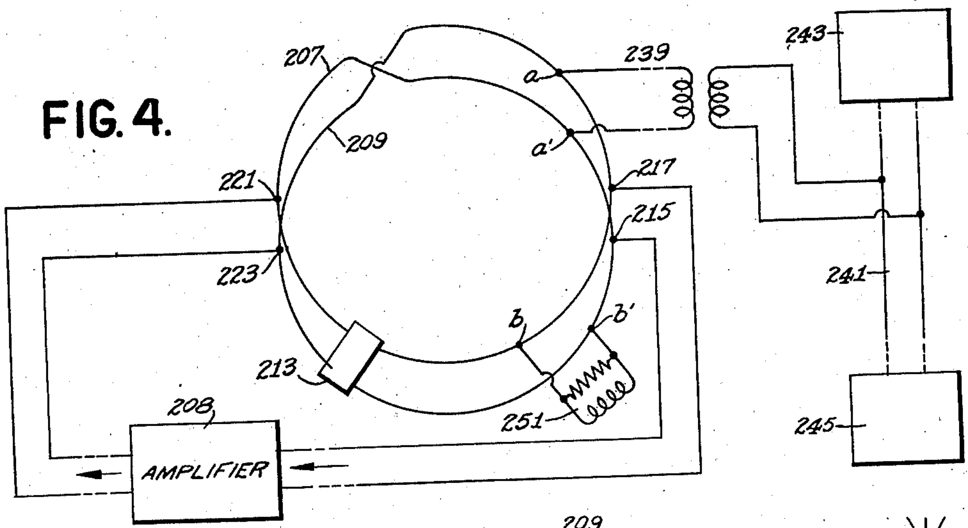


FIG. 4A.

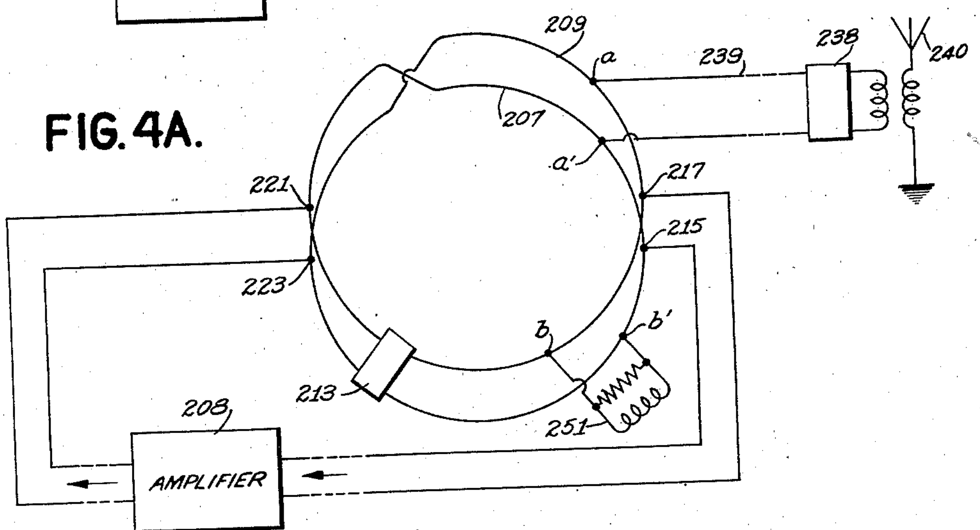
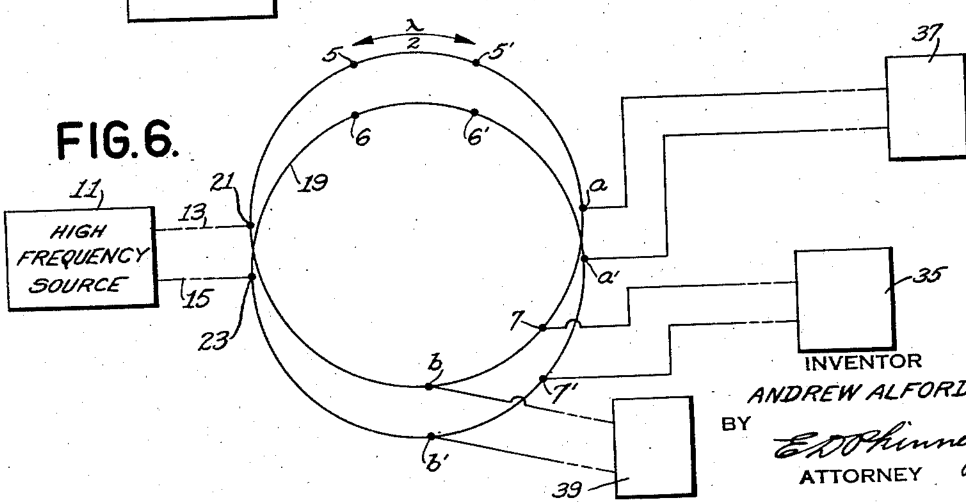


FIG. 6.



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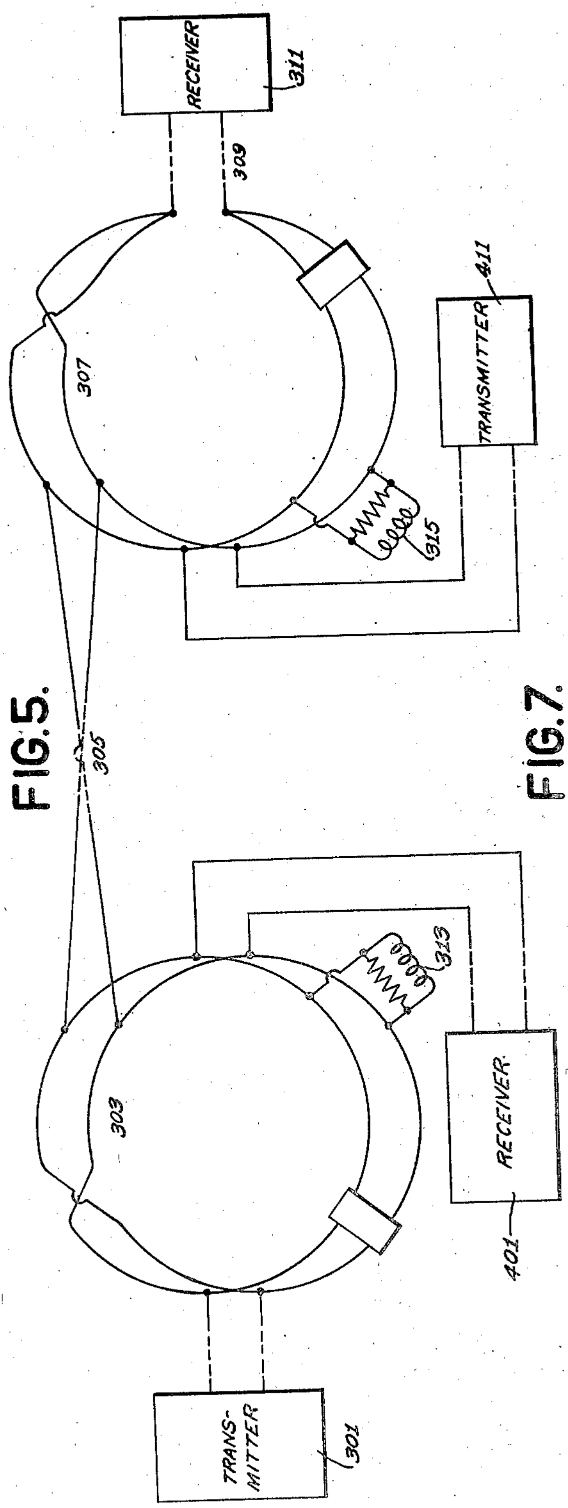

FIG. 5.

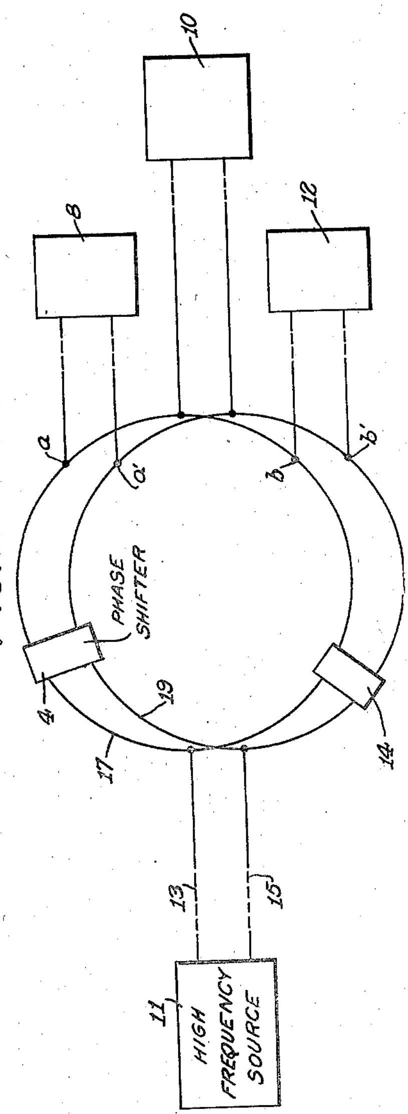

FIG. 7.

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2,147,809

HIGH FREQUENCY BRIDGE CIRCUITS AND HIGH FREQUENCY REPEATERS

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Application May 4, 1937, Serial No. 140,594

20 Claims. (Cl. 250—6)

My invention relates to high frequency units particularly for use as high frequency bridge circuits and in high frequency repeaters. Because of the extreme simplicity of the system and the ease with which very accurate adjustment may be made, this system is particularly useful when dealing with extremely high frequencies, for example in the neighborhood of 20 megacycles.

My invention makes use of reentrant loop circuits, and in its broadest form comprises a reentrant loop circuit coupled to some source of high frequency so that at points on said loop there may be produced voltage nodes or current nodes which may be used as points for coupling to the desired apparatus or circuit. Such reentrant loop units may be then used for extremely accurate comparison of impedances or for coupling together circuits in conjugate relation in a manner similar to that used in the conventional hybrid coil circuits. It is an object of my invention to provide such a unit which may be used readily in bridge circuits and other high frequency apparatus.

It is a further object of my invention to produce an extremely accurate impedance bridge circuit.

It is a further object of my invention to provide a high frequency repeater system in which amplification and reenforcement of high frequency waves may be accomplished readily by providing a bridge circuit for connecting such high frequency repeater systems to a line in a very simple and easily adjusted manner.

It is a further object of my invention to provide a two-way high frequency communication system between two points in which system interference between the transmitter and receiver is prevented by use of reentrant bridge circuits.

Other objects and uses of my invention will be suggested by the particular description made in connection with the accompanying drawings, in which

Figs. 1 and 2 illustrate a simple form of the network particularly for explaining the theory thereof,

Fig. 3 illustrates an embodiment of my invention particularly adapted for impedance measurement,

Fig. 4 illustrates an embodiment of my invention which comprises a high frequency repeater system,

Fig. 4A illustrates a modification of Fig. 4 adapted for use as a radio repeater,

Fig. 5 illustrates an embodiment of my invention applied to a two-way communication system,

Figs. 6 and 7 illustrate modification of the circuit shown in Fig. 2.

For a more complete development of the formula applicable to bridges and reentrant loops, than is set forth in this specification, reference is made to my application, Serial No. 118,866, filed January 2, 1937.

Referring more particularly to Fig. 1, 11 represents a source of radio frequency energy connected by transmission lines 13, 15 with reentrant loops 17, 19 at junction points 21, 23. Points 25, 27 represent points along loops 17, 19 respectively, which are separated equal electrical distances from the corresponding junction points 21, 23. In the loop circuit 17, 19 there then exist two traveling waves, each of which start forwardly from junction points 21, 23 as indicated by arrows A and B, and which after passing each other at 25 and 27 become back waves. The two halves of loops 17, 19 are assumed to be identical in all respects, including attenuation. Since these traveling waves travel equal distances to junction points 25, 27 and are of equal amplitude at the starting points 21, 23 they are in phase and still of equal amplitude at points 25, 27. Since the voltages are of equal amplitude and are in phase at points 25, 27 they add, forming a voltage loop, but the currents are in phase but in opposite directions and consequently cancel, producing an absolute current node. It can thus be seen that this circuit provides a very readily constructed means for obtaining an absolute current node.

Fig. 2 is substantially the same as Fig. 1, with the exception that the loops are transposed at point 31. As a consequence of this transposition the currents in this circuit add at points 25, 27 and the voltages cancel, producing an absolute voltage node. Since the transmission lines in Fig. 2 are assumed to be equal in all respects, as stated in connection with Fig. 1, the voltage across the line at 25, 27 would be precisely zero if there were no reflection at the point of transposition 31. However, since there always exists a certain amount of reflection due to any irregularity in a transmission line, and since a transposition results in such an irregularity, there will be a small residual voltage at 25, 27 unless some compensating means is used to correct for this irregularity. Accordingly, some such compensating means is indicated at 33, which may for example consist simply of a small capacity connected across the line. This compensating means together with a slight increase in the length of the arms completely compensate for the transposition. It should be further noted that any inequality in the attenuation in the two arms of the bridge circuit may be compensated by means of suitable attenuators added to the line circuit.

With the circuit constructed as described above and the compensating means **33** properly adjusted, the voltage across points **25**, **27** is extremely small compared to the voltage across points *a*, *a'*, *b*, *b'*, which are spaced a distance equal to a fraction of a wavelength from points **25**, **27**. It is this phenomenon which renders this circuit particularly useful as a bridge.

If a sensitive meter such as, for example, a vacuum tube voltmeter, is connected across points **25**, **27** through a suitable balanced transformer, the voltage indicated by meter **35** will be very small, substantially zero. However, if a load such as **37**, having an impedance Z_1, is connected across the line at points *a*, *a'* spaced from the points **25**, **27** the balance of the bridge will be upset due to reflections along the arms **27**, *a*, **21**. Accordingly, meter **35** will show a material increase in indication. However, if a second load **39** is connected across the line at points *b*, *b'* spaced an equal distance on the opposite side of points **25**, **27** from points *a*, *a'*, said second load having an impedance Z_2 equal in every respect to impedance Z_1, then symmetry of the circuit will be restored and the voltage node again established at points **25**, **27** and the meter will again indicate a minimum reading. For this to be the case, the load Z_2 must be equal in every way to the load Z_1 i. e. in reactance and resistance. Thus it will be seen that the reentrant loop circuit shown behaves in much the same manner as the ordinary impedance bridge.

If the impedance Z_1 of load **37** is high, the load should be connected at a point distant a substantial fraction of a quarter wavelength from the voltage nodal points **25**, **27**. In fact, it may be noted that as the distance between the voltage nodal points **25**, **27** and points *a*, *a'* is gradually increased from zero with a corresponding and opposite increase of distance between the voltage nodal points **25**, **27** and *b*, *b'*, the voltage across the line at points *a*, *a'* gradually increases. Since points **25**, **27** represent a voltage node, the voltage across a point a small distance from this node will be small and consequently a very small amount of current can be diverted into the high impedance load **37**. As the distance is increased the voltage across the line at points *a*, *a'* increases and consequently the current diverted into the load also increases with the result that a larger meter reading is noted at **35** with a given amount of unbalance. The loop circuit **17**, **19** however, is not most sensitive with respect to unbalance when the distance between the load and the voltage nodal points **25**, **27** is equal to a quarter wavelength. The reason for this is that when the load is located at a quarter wavelength from the voltage nodal points, such a large amount of current is diverted into the load that only a small fraction is able to penetrate as far as the points **25**, **27** across which the meter **35** is connected. For this reason there is a certain distance for every value of impedance Z_1 of the load **37** at which the loop circuit will be most sensitive. The larger the impedance Z_1 of the load **37** the greater is the distance for maximum sensitivity. Only in cases in which the load impedance Z_1 is of very large value, is the maximum sensitivity obtained when the spacing is nearly a quarter wavelength. The actual distance at which the given impedance should be connected to obtain maximum sensitivity of the loop is not very critical, however, so that exact location of the load with respect to the bridge voltage node is not necessary.

In Fig. 3 is illustrated an application of this reentrant loop bridge circuit for impedance measurement. Because of the extreme simplicity and accuracy of this bridge particularly in the higher radio frequencies, this device is a useful tool for measurements of all kinds. In Fig. 3, **101** represents a radio frequency source connected through transmission lines **103**, **105** to a bridge loop arrangement **107**, **109** constructed in substantially the same manner as that described in connection with Fig. 2. A suitable sensitive voltmeter **121** is coupled over balanced transformer **123** to the voltage nodal points **115**, **117** of the loops **107**, **109**. The loops **107**, **109** are shown as transposed at **111** and provided with an impedance **113** to compensate for the reflection at the transposition point. Connected across loops **107**, **109** at points *a*, *a'*, *b*, *b'* equally spaced from points **115**, **117** are two identical shielded transformers **125**, **127** through which the various elements to be tested may be coupled. The loop bridge as shown may then be used for comparing any desired impedances, such as variable or fixed condensers, tuned circuits or any other equipment. For example, equal lengths of identical cables **129**, **131** may be connected to the transformer and may be employed for comparing two grounded impedances, one or both of which may be at substantially large distances from the loop bridge.

Another application of a somewhat different character of the loop circuit is shown in Fig. 4. In this circuit the loop is used somewhat in the manner of a hybrid coil for coupling a repeater amplifier to a transmission line. In this figure the reentrant loop circuit comprises two loops **207**, **209** constructed in the same manner as that shown in Fig. 2. An amplifier **208** is coupled with its input across points **215**, **217** which represent the voltage nodal points of the loop system, and with its output coupled to the points **221**, **223**. It can thus be seen that in this circuit any feedback from the output of the amplifier to the input cannot take place as long as the bridge is maintained in balance. Across two points on the bridge, *a*, *a'* is connected a transmission line **239** which is coupled across the line **241** connected between stations **243** and **245**. This line then presents a definite impedance Z_1, and in order that the value of this impedance will not be momentarily disturbed this line should be made reflectionless by the use of well known matching devices. Across the loop at points *b*, *b'* spaced from points **215**, **217** a distance equal to *a*, *a'* is an impedance element **251** which has an impedance Z_2 equal to Z_1. It can be seen that in this system energy from line **241** may be transmitted over line **239** to the input of amplifier **208**, and the amplified energy transmitted back over **239** to **241** in amplified form. Due to the loop bridge **207**, **209** none of the energy from the output of amplifier **208** can be transmitted back to the input. Accordingly, a repeater amplifier coupling is made in the line **241**. Such an amplifier is particularly useful in high frequency circuits since it is capable of easy construction and accurate adjustment. It is clear that the desired and necessary connection of the load to the proper points on the loop and the proper impedance load may be readily chosen to adapt the system to any circuit in which it is desired to use this type of repeater connection.

An adaptation of the loop repeater circuit of Fig. 4 to a radio repeater is illustrated in Fig. 4A.

Parts of this circuit are identical with those of Fig. 4, and accordingly the same reference characters are used to designate the similar elements. In this figure however, the loads represented by the elements 241, 243 and 245 are replaced by the antenna 240 which is coupled to the line 239. A suitable impedance matching means should preferably be included in line 239, to prevent reflections therein. This may be a separate matching device as indicated at 238, or the transformer may be suitably designed for this purpose. It can be readily seen from the description given above in connection with Fig. 4, that signals received upon antenna 240 may be amplified in 208 and reradiated from the antenna at increased strength. The conjugate bridge circuit prevents undesirable feedback and consequent building up of oscillations in the amplifier.

If antenna 240 is mounted at a suitably isolated location so that its field is substantially free from disturbing foreign objects, the retransmission may be made at the same frequency as the reception without creating any difficulties. However, it has been found that changes and movements about the antenna in the vicinity thereof may produce an unbalance in the bridge and a consequent feedback to amplifier 208 which produces undesirable howling and distortion. To avoid this difficulty the amplifier 208 may incorporate therein a frequency changer so that the frequency retransmitted differs from the frequency received by a fixed amount, preferably above audibility. The amplifier 208 then will serve to prevent this undesirable feedback through the proper construction and tuning of the circuit. The frequency difference between the signals received and transmitted need not be large, and may be such that both signals may be ordinariily received and detected on the same receiver.

The radio repeater circuit illustrated in Fig. 4A is particularly useful where coverage of territory around a fixed reception point with broadcast signals is desired. The amplifier 208 may be so sensitive as to readily receive rather feeble signals and retransmit these signals at a substantially increased energy level for more ready general reception by less sensitive receiving sets.

Another application of the use of this loop bridge circuit as a conjugate coupling means is illustrated in Fig. 5, which shows two such bridge circuits used in a two-way high frequency communication system. In this system a transmitter indicated at 301 is coupled over a bridge circuit shown generally at 303, through a transmission line 305, a second bridge circuit shown generally at 307, and a transmission line 309 to a receiver 311. At the same station with transmitter 301 a receiver 401 is coupled to bridge circuit 303 at the voltage nodal point of the loop bridge. Accordingly, signals transmitted from 301 cannot interfere with the reception at 401. An impedance 313 is bridged across loop circuit 303 at a point spaced from the voltage nodal point a distance equal to the distance from said nodal point to the junction of line 305 with said bridge circuit. The impedance element 313 is made equal in every respect to the impedance of the circuit coupled through line 305 to the bridge. At the station at which receiver 311 is located, a transmitter 411 is coupled across the voltage nodal points of loop bridge 307, and an impedance balancing unit 315 is provided across loop bridge 307, said impedance being equal to the load connected across the transmission line 305, and spaced a distance from the voltage nodal points of the loop bridge circuit equal to the spacing of line 305 therefrom.

It can readily be seen that with this arrangement communication between 301 and 311 may be carried on without any effect upon the receiver 401 or the transmitter 411, and likewise communication may be carried on between transmitter 411 and receiver 401 without affecting transmitter 301 or receiver 311. Of course, in this system the two bridges must be properly designed and the impedances properly matched for the desired frequency which it is contemplated using for communication. Likewise if desired, two transmitters may be provided in one circuit such as at 301, 401 and two receivers may be provided at 311, 411 to permit transmission of two messages in one direction. However, in this latter case, the frequencies should be slightly different to prevent interference between signals at the two receivers. The approximate conjugate relation between the circuits aids in discrimination so that the receivers need not be so precisely tuned. It thus appears that these impedance bridge units formed by the simple method of the use of reentrant loop structures provide an efficient, easily constructed and adjusted conjugate coupling circuit readily applicable to any high frequency circuits in which the conjugate relation may be found useful.

The compensating devices used to compensate for the reflection at the transposition point as illustrated in Figs. 2–5 may be omitted in many cases since the reflection due to transposition is normally rather small and may be compensated for almost completely by slight changes in physical length of the two arms of the loop bridge structure. In fact, the compensating devices need only be used when extremely fine adjustment of the loop is desired.

Furthermore, other means of obtaining the desired space relation between the two arms of the bridge may be used in place of the transposition as shown in Figs. 2–5. For example, in place of the transposition a half wavelength of the frequency being used may be inserted in one arm of the bridge as shown in Fig. 6. In this figure a section of transmission line indicated at 5, 5′ and 6, 6′ is shown inserted in one side of a bridge loop circuit similar to that shown in Fig. 1. With this arrangement the voltage nodal point will occur at a different point in the bridge as indicated at 7, 7′. The operation of this bridge circuit is substantially identical with that shown in the other figures. However, in this case the load impedances will be inserted at points spaced from the points 7, 7′, which are not at the apex of the loop, since the added half wavelength has been inserted in lieu of the transposition.

The loop bridge circuit may likewise be constructed with any desired form of phase shifting unit used in place of the transposition. Fig. 7 illustrates a system in which a phase shifter shown generally at 4 is inserted in one side of the loop. This phase shifter may be of any form but should be made so as to produce a 180° phase shift at the desired working frequency. With this system circuit connections may be made substantially identical with those shown in the other figures. However, a transposition of the line is unnecessary and accordingly the loops have the same general appearance as those shown in Fig. 1. A load 8 may be connected at a point on the bridge spaced relative to the voltage nodal point shown connected to the meter 10, and a balancing impedance equal to the load 8 may be connected across the loop as indicated at 12, to produce the desired balance relation. In the circuit shown in Figs. 6 and 7, means for compensating reflection may not be necessary as the irregularities are not present in the line. However, if any such reflections occur in Fig. 7 due to the phase shifter 4, a compensating means 14 may be provided to correct for such reflections.

Although in each of the embodiments illustrated the loop circuit has been shown as comprising simple wire lines, it is to be understood that any desired type of line may may be used in this system. For example, the loop may be made of concentric cable conductors, or of insulated twisted pairs, or any desired known type of structure.

Furthermore, the operation of the system does not require that the loop be of some particular shape since any reflections caused by any sharp angles or irregularities in the line may be compensated for by other means inserted in the loop. Moreover, the loops may be constructed so as to include a part of a normal transmission line already in use, for a portion of their length, as suggested in my prior application, Serial No. 118,866, referred to above.

What I claim is:

1. A conjugate bridge circuit comprising a reentrant loop circuit, means coupled to said loop at a first point, other means coupled at a point on said loop substantially 180° different in distance electrically in opposite directions from the coupling point of said first named means, and substantially equal impedance means coupled to said loop on opposite sides of said second named point and at equal distances therefrom.

2. A circuit in accordance with claim 1, in which said first named means comprises a high frequency transmitting means, said second named means comprises a high frequency receiving means, and said impedance means comprises a transmission line circuit and a matching impedance, respectively.

3. A circuit in accordance with claim 1, in which said first named means comprises a source of energy, said second named means comprises a sensitive measuring device, and said impedance means comprises a standard impedance and a load impedance to be measured.

4. A circuit in accordance with claim 1, in which said first named means comprises the output of an amplifier, said second named means comprises the input of an amplifier, and said impedance means comprises a transmission line circuit and a matching impedance, respectively.

5. A circuit in accordance with claim 1, in which said first named means comprises the output circuit of a radio frequency amplifier, said second named means comprises the input circuit of said amplifier, and said impedances comprise a transmission line coupled to a radio antenna and a matching impedance, respectively.

6. A high frequency communication system comprising a high frequency transmitter, a reentrant loop circuit coupled to said transmitter, a receiver coupled to said reentrant loop circuit at a point spaced equal electrical distances from said transmitter, a second reentrant loop circuit, a second transmitter and receiver coupled to said second loop circuit in conjugate relationship, a transmission line coupled to both said reentrant loop circuits at points on the loops between said receiver and transmitter, and balancing networks coupled to each reentrant loop circuit at points located symmetrically with respect to said transmission line coupling point.

7. A high frequency communication system comprising a pair of reentrant loop circuits, high frequency apparatus coupled to each of said reentrant loop circuits at conjugate points thereon, a transmission line connected to said reentrant loop circuits at points between said coupled apparatus, and balancing networks coupled to said loop circuits at points on the loop circuit symmetrically arranged with respect to the connection point of said transmission line.

8. A high frequency bridge circuit comprising a high frequency source, a reentrant loop circuit coupled to said source, apparatus coupled to said loop circuit at a point equi-distant electrically from said transmission source, and means for establishing a voltage node at the point of connection of said apparatus, by introducing a phase shift of 180° in one arm of said loop.

9. A high frequency circuit according to claim 8, further comprising two substantially equal impedance means coupled to said reentrant loop circuits at points arranged symmetrically with respect to said apparatus coupling point.

10. A repeater circuit comprising an amplifier having an input and an output, a reentrant loop circuit, means to couple said amplifier at substantially conjugate points on said loop, a transmission line for transmitting signal energy, means for coupling said transmission line to a point on said loop intermediate said amplifier connections whereby energy may be conducted to and conducted from said amplifier, and means cooperating with the opposite side of said loop from that to which the transmission line is coupled, for maintaining the conjugate relation of said circuit.

11. A repeater circuit in accordance with claim 10, in which said transmission line is coupled between two communicating stations.

12. A high frequency bridge circuit comprising high frequency apparatus, a reentrant loop circuit coupled to said apparatus, means coupled to said loop circuit at a point such that the two arms of said loop circuit between said point and the junction point of said loop circuit with said apparatus present equal electrical lengths, a load coupled to said bridge circuit at a distance from said means coupling point to provide for maximum energy transfer from said bridge, and a second means spaced at a distance equal said first named distance and on the opposite side of said coupling point, said second means presenting an impedance substantially equal to that of said lead.

13. A bridge circuit comprising a source of high frequency energy, a reentrant loop circuit coupled to said source so as to produce a voltage nodal point in said loop circuit, a load circuit coupled to said loop at a distance from said voltage nodal point, and means presenting substantially the same impedance as said load coupled to said loop at a distance equal to that of the load from said voltage nodal point and on the opposite side of said voltage nodal point.

14. A high frequency bridge, comprising a reentrant loop, means coupled to said loop to introduce energy therein, said loop being so constructed that energy introduced therein produces a definite node at a point in said loop, means for coupling a load to said loop intermediate said first named means and said nodal point, and means

in said loop on the other side of said nodal point to compensate for said load and maintain the nodal point in its initial position.

15. A high frequency bridge as claimed in claim 14, in which the load coupled to the loop circuit comprises a high frequency transmission line.

16. A high frequency repeater comprising a reentrant bridge arrangement, means for coupling a repeating means to said bridge, the input of said repeating means being connected to a point on the bridge which is at a voltage node with respect to the output of said repeating means, and means coupled to said bridge between said voltage nodal point and the output of said repeating means, for introducing energy to the input of said repeating means and receiving the repeated energy from the output of said repeating means.

17. A repeater as claimed in claim 16, further comprising means in said loop circuit on the side of said voltage nodal point opposite said coupled means, for compensating for said coupled means to maintain the loop in stable condition.

18. A bridge circuit comprising energy supply means, means associated with said energy supply means for transmitting energy therefrom in two paths to a common point, said two paths being so proportioned that a voltage node is produced at said common point, a load circuit coupled to one of said paths at a distance from said common point and means presenting substantially the same impedance as said load coupled to the other of said paths at a corresponding distance from said common point.

19. A bridge circuit in accordance with claim 18, in which said utilization means comprises two substantially equal impedance means coupled on opposite sides of said common point.

20. A bridge circuit in accordance with claim 18, in which said common point is coupled to an amplifier, and the output of said amplifier comprises the energy supply means.

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