2nd. Edition

PATENT SPECIFICATION

Application Date: Feb. 19, 1943. No. 3212/44.

566,970

(Divided out of No. 566,945).

Complete Specification Left: Feb. 21, 1944.

Complete Specification Accepted: Jan. 22, 1945.

PROVISIONAL SPECIFICATION

Improvements in Alternating Current Bridge Circuits

I, CHARLES GILBERT MAYO, of A55, Du Cane Court, Balham, London, S.W.12, a British Subject, do hereby declare the nature of this invention to be as follows:—

The present invention relates to alternating current bridge circuits for operation at high frequencies.

In Fig. 1 of the accompanying drawing there is shown an admittance bridge comprising an input transformer 4 having one terminal of its secondary winding connected to a tap 5 on the primary winding of a summation transformer 6. The secondary winding of the latter is connected at 13 to an indicating device not shown. The terminal 7 of the input transformer 4 and the terminal 8 of the summation transformer 6 are bridged by standards comprising a variable condenser 9, a conductance decade 10 and the differential variable condenser 1 operating as described in Provisional Specification No. 2816/43 (Serial No. 566,945). The unknown impedance 11 is connected between terminal 7 of the input transformer and terminal 12 of the summation transformer.

In operation a voltage at the required frequency is applied through the transformer 4. The transformer 6 is such that when the bridge is balanced the potential drops between points 5 and 12 and points 5 and 8 are both negligibly small. Thus the standards and the unknown are supplied at the same voltage. When the current to the standards is such a multiple or sub-multiple of the current to the unknown as corresponds to the turns ratio of the windings between points 5 and 8 and points 5 and 12 respectively, the bridge is balanced. In the special case when 5 is the mid-point, the bridge is balanced with equal currents in the standards and the unknown.

When C_1 is a maximum and C_2 is zero, the resistance R of the circuit 1, 2, 3 is effectively in parallel with the standards 9 and 10. When C_1 is zero and C_2 a maximum, the resistance in parallel with 9 and 10 becomes infinite and its effect, therefore, zero.

The decade 10 may, for example, be made in steps of 1 m.mho giving a maximum conductance of 10 m.mho. The resistance 1, 2, 3 would then be designed to give a variation of 1 m.mho and the combination would allow measurements of from 0—11 m.mho. For example if the unknown were 300 ohms or 3.33 m.mho, the decade would be turned to 3 m.mho and the variable resistance 1, 2, 3 adjusted to 0.33 m.mho.

The above assumes that point 5 is the mid-point of the winding. In general, however, if the ratio of the turns between 5 and 8 to those between 5 and 12 be r, then the current through the standards will have in the transformer 6 an effect r times that through the unknown. In this case r may be termed a current ratio and an admittance of g m.mho in the standard will balance an admittance of gr m.mho in the unknown.

The input transformer 4 may, however, also have a tapped secondary winding such that the P.D. across the standard is n times that across the unknown. In this case n can be termed a potential ratio and equal currents will flow in the standard and the unknown when the standard impedance is n times the unknown impedance.

In general it will be preferable for reasons of transformer design to combine current and potential ratios when a substantial bridge ratio is required. A bridge ratio of 9:1 is thus preferably obtained by making r and n both equal to 3 rather than by making either of them equal to 9.

An example of this is shown in Fig. 2 which shows the transformers 4 and 6 of Fig. 1 in modified form. Their connection into the circuit of Fig. 1 will be evident since like references are given to like parts in the two Figures. The arrangement provides two voltages (between 5 and V_{10} and 5 and V_1) in 10:1 ratio, and four current sensitivities through points A_{10}, A_1, A_{-1} and A_{-10} respectively in $\pm 10:1$ ratio. An unknown of very high impedance would be connected across V_{10} A_{10}, giving maximum voltage and minimum current sensitivity, and the standards would be connected across V_1A_{-1}. For a very low impedance unknown, the unknown would be connected across V_1 A_1 and the standards across V_{10} A_{-10}. In the former case the unknown would balance the standard if 100 times greater and in the latter case if 100 times less.

Returning to the arrangement of Fig. 1, in practice for a bridge to work at frequencies of 20 mc/s. and upwards, for example, the condenser 1 may have a total capacity of 60 micromicrofarads. The resistance 3 may have a value 200 ohms when the inductance 2 would have a value about 240 microhenries. K would then have a value of about 0.07 and there would be at 20 mc/s. a magnitude error of about 8.5% and a phase error of about 0.035%. At higher frequencies the errors would be smaller.

In a modification of the arrangement of Fig. 1 for use mainly when point 5 is a midpoint, the part C_1 of the differential condenser is connected to point 12 as shown by the dotted line instead of to point 5. If the ratio of the winding between 5 and 8 to that between 5 and 12 be r and if the range of conductance covered with C_1 connected to 5 be g, then the range of conductance covered with C_1 connected at 12 will be from g to $\frac{-g}{r}$ i.e. equal to a range of $g\left(1+\frac{1}{r}\right)$ When $r=1$ the range will therefore be $2g$.

Dated this 21st day of February, 1944.
REDDIE & GROSE,
Agents for the Applicants,
6, Bream's Buildings, London, E.C.4.

COMPLETE SPECIFICATION

Improvements in Alternating Current Bridge Circuits

I, CHARLES GILBERT MAYO, of A55, Du Cane Court, Balham, London, S.W.12, a British Subject, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The present invention relates to alternating current bridge circuits, especially for operation at high frequencies.

An alternating current bridge circuit has been proposed in which the ratio arms are constituted by two windings of a bifilar inductance coil, the two windings thus having a low series inductance arising from flux leakage between their parts. No input transformer was provided.

It is the principal object of the present invention to provide an improved bridge circuit capable of measuring impedances over a wide range of values with a relatively high degree of accuracy, particularly but not exclusively at very high frequencies.

According to the present invention there is provided a high-frequency alternating current bridge circuit comprising an input transformer whereby a potential difference can be applied across a diagonal of the bridge and an output transformer whose primary winding constitutes the two ratio arms of the bridge, wherein the secondary winding of the input transformer and the primary winding of the output transformer are constructed to have low series inductance arising from flux leakage between their parts and each is provided with tappings such that a plurality of bridge ratios can be obtained by varying the tapping of each of said windings.

Other features of the invention will be apparent from the following description and from the appended claims.

The invention will be described by way of example with reference to the accompanying drawings, in which:—

Fig. 1 is a circuit diagram of an admittance bridge embodying certain features of the present invention.

Fig. 2 shows a modification of the input and output transformers in Fig. 1,

Figs. 3 and 4 are diagrams illustrating how low inductance can be secured in connections in the circuit of Fig. 2,

Figs. 5 and 6 are respectively a diagrammatic elevation, partly in expanded section, and a plan of the transformers shown in Fig. 2, and

Fig. 7 shows a further modification of the transformers of Fig. 1 and illustrating how tappings on the transformer windings can provide the variable ratios according to the invention.

Referring to Fig. 1, there is shown an admittance brigade comprising an input transformer 4 the secondary winding of which is connected to the primary winding of a summation or output transformer 6. The secondary winding of the latter is connected at 13 to an indicating device not shown. The terminal 7 of the input transformer 4 and the terminal 8 of the summation transformer 6 are bridged by standards comprising a variable condenser 9, a conductance decade 10 and the differential variable condenser 1 in series with a parallel arrangement of inductance 2 and resistance 3. The circuit 1, 2, 3 constitutes a variable resistance which forms the subject of co-pending Patent Application No. 2816/43 (Serial No. 566,945). No claim is made in the present application to such a variable resistance. The unknown impedance 11 is connected between terminal 7 of the input transformer and terminal 12 of the summation transformer.

In operation a voltage at the required frequency is applied through the transformer 4. The transformer 6 is constructed, in a manner to be described later, to have a very low leakage inductance between the parts on either side of the tapping 5 such that when the bridge is balanced the potential drops between points 5 and 12 and points 5 and 8 are both negligibly small. Thus the standards and the unknown are supplied at the same voltage. When the current to the standards is such a multiple or submultiple of the current to the unknown as corresponds to the turns ratio of the windings between points 5 and 8 and points 5 and 12 respectively, the bridge is balanced. In the special case when 5 is the mid-point, the bridge is balanced with equal currents in the standards and the unknown.

Where C_1 is zero and C_2 is a maximum, the resistance R of the circuit 1, 2, 3 is effectively in parallel with the standards 9 and 10. When C_1 is a maximum and C_2 zero, the resistance in parallel with 9 and 10 becomes infinite and its effect, therefore, zero.

The decade 10 may, for example, be made in steps of 1 m.mho giving a maximum conductance of 10 m.mho. The resistance 1, 2, 3 would then be designed to give a variation of 1 m.mho and the combination would allow measurements of from 0—11 m.mho. For example if the unknown were 300 ohms or 3.33 m.mho, the decade would be turned to 3 m.mho and the variable resistance 1, 2, 3 adjusted to 0.33 m.mho. The above assumes that point 5 is the mid-point of the winding. In general, however, if the ratio of the turns between 5 and 8 to those between 5 and 12 be r, then the current through the standards will have in the transformer 6 an effect r times that through the unknown. In this case r which is made variable by tappings may be termed a current ratio and an admittance of g m.mho in the standard will balance an admittance of gr m.mho in the unknown.

The input transformer 4 is also provided with a tapped secondary winding so that the ratio n of the P.D. across the standard to that across the unknown is other than 1 to 1. Thus n can be termed a potential ratio and equal currents will flow in the standard and the unknown when the standard impedance is n times the unknown impedance.

In general it will be preferable for reasons of transformer design to combine current and potential ratios when a substantial bridge ratio is required. A bridge ratio of 9 : 1 is thus preferably obtained by making r and n both equal to 3 rather than by making either of them equal to 9.

An example of this is shown in Fig. 2 which shows the transformers 4 and 6 of Fig. 1 in modified form, the bridge being suitable for determining unknowns of very high impedance.

As already stated, the transformer 6 should be such that when the bridge is balanced, the potential drops between points 5 and 12, and between points 5 and 8, are both negligibly small. Thus the standards and the unknown are supplied at the same voltage. This means that the transformer 6 is virtually an ideal transformer or a transformer with very small leakage or series inductance arising from flux leakage between the parts of its primary winding. The secondary winding of the transformer 4 is also designed to have a very small series inductance arising from leakage of flux between its parts.

This feature of low leakage is secured by winding the transformers in such a way that the path of the leakage flux has a very high reluctance. This path has for its length the approximate winding width and for its area the effective distance between the windings concerned, multiplied by the mean perimeter of the windings.

The high reluctance may therefore be secured by winding the transformers with very thin copper tape, relatively wide and with very thin insulation between the windings. In one case the winding is of copper tape 0.001 in. thick, with 0.002 in. insulation and 0.5 in. wide. In another case condenser tissue is used for the winding. In this case the aluminium conductor and the insulation together are only 0.0005 in. thick.

For frequencies higher than a few megacycles not only must the transformers have very low series inductance but the connections between the transformers and the unknown and standards must also have very low inductance. This is secured by, so to speak, extending the transformer low inductance technique to the connectors also. Thus the connections may be made with conductor strip similar to that used in the transformers and so arranged that every current conductor "go" circuit is very close to its return circuit so that the series inductance flux path has a very high reluctance. One way in which this may be done is shown diagrammatically in Fig. 3, which should be read in conjunction with Fig. 2. In Fig. 3 20—28 are copper strips seen edgewise on and in practice about 0.5 in. wide and 0.001 in. thick. The insulation between them may be about 0.002 in. thick. Connections to the input transformer are made by means of strips 20, 21 and 22, and to the output transformer by strips 21 ,25 and 26. Strip 21 connecting to point 5 will be termed the neutral lead. Strip 20 connects the appropriate tapping V_{10} on the input transformer via strip 23 to terminal 31 of the unknown, whilst strip 25 connects unknown terminal 32 via strip 24 to tapping A_{10} on the output transformer. Similarly strips 22 and 26 connect the standard bus bars 29, 30, through strips 27 and 28 respectively, to the appropriate tappings V_1 and A_{-1} on the input and output transformers respectively. The standard bus bars 29 and 30 extend several inches in a direction at right angles to the plane of Fig. 3 and serve for the low-inductance connection of the various standards of resistance and capacity used in the bridge.

The neutral strip 21 may be taken, if desired, to the bus bars between the strips 27 and 28, as shown in Fig. 4, so as to be readily accessible and available for connection to the standards of variable resistance. The current in the unknown connected to the terminals 31, 32 follows a path through strip 20, then strip 23, back through strip 24, along strip 25 and back through neutral strip 21. Thus at all points, including the transformers, the "go" current is very near to the return current so that leakage fluxes are very small. Similarly the standard current path is along strips 22, 27, 28 and 26 and back by strip 21.

Constructional features of the transformers 4 and 6 and their connections, as described with reference to Figs. 2 and 3, are shown in Figs. 5 and 6. The transformer cores are rings wound from strip 0.002 in. thick, and the inner windings are toroidal and covered by screens each consisting of two channel-section rings 31 and 32 placed face to face with the channels opening towards each other. These rings are soldered together round the periphery and there is a gap between their radially inner edges. One end 33 of the inner winding is passed through a hole in the screen and soldered to its outer side, while the other end is brought out through a screened sleeve 34.

Each outer winding is wound on a former consisting of a **U**-shaped piece of sheet insulating material 35 embracing the screen and co-operating with an end of a bridge piece 36 of insulating material. The upper parts of the outer windings are indicated diagrammatically in expanded form in Fig. 5, with their connecting leads, by full lines, the insulation being shown by dotted lines. The several leads are denoted by the references appearing in Figs. 2 and 3. An insulating clamping plate 37 is placed over the connecting leads, packing pieces 38 of insulating material being inserted where necessary, and the assembly is secured by bindings (not shown) passing around the outer windings.

Fig. 7 shows a further modification of the transformers 4 and 6, which is especially applicable to bridge circuits not required to operate at very high frequencies. Their connection into the circuit of Fig. 1 will be evident since like references are given to like parts in the two Figures. The tapping points V_1 and V_{10} serve to provide alternative connections to the unknown and standard impedances in place of the common connection 7 of Fig. 1. The arrangement provides two voltages (between 5 and V_{10} and 5 and V_1) in 10:1 ratio, and four current sensitivities through points A_{10}, A_1, A_{-1} and A_{-10} respectively in $\pm 10:1$ ratio. An unknown of very high impedance would be connected across V_{10} A_{10}, giving maximum voltage and minimum current sensitivity, and the standards would be connected across V_1 A_{-1}. For a very low impedance unknown, the unknown would be connected across V_1 A_1 and the standards across V_{10} A_{-10}. In the former case the unknown would balance the standard if 100 times greater and in the latter case if 100 times less.

In practice, for a bridge to work at very high frequencies of 20 mc/s and upwards, for example, the condenser 1 (Fig. 1) may have a total capacity of 60 micro-microfarads. The resistance 3 may have a value 2000 ohms when the inductance 2 would have a value about 240 microhenries. There would then be at 20 mc/s a magnitude error of about 0.5% and a phase error of about 0.035%. At higher frequencies the errors would be smaller.

In a modification of the arrangement of Fig. 1 for use mainly when the tapping point 5 is near the mid point of the primary winding of transformer 6, the part C_1 of the differential condenser is connected to point 12 as shown by the dotted line instead of to point 5. If the ratio of the winding between 5 and 8 to that between 5 and 12 be r and if the range of conductance covered with C_1 connected to 5 be g, then the range of conductance covered with C_1 connected to 12 will be from g to $\frac{g}{r}$ i.e. equal to a range of $g \left(1+\frac{1}{r}\right)$. When $r=1$ the range will therefore be $2g$.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. A high-frequency alternating current bridge circuit comprising an input transformer whereby a potential difference can be applied across a diagonal of the bridge and an output transformer whose primary winding constitutes the two ratio arms of the bridge, wherein the secondary winding of the input transformer and the primary winding of the output transformer are constructed to have low series inductance arising from flux leakage between their parts and each is provided with tappings such that a plurality of bridge ratios can be obtained by varying the tapping on each of said windings.

2. A high-frequency alternating current bridge circuit according to claim 1, wherein a terminal of the secondary winding of said input transformer is connected to a variable tapping on the primary winding of said output transformer.

3. A high-frequency alternating current bridge circuit according to claim 1 or 2, wherein two conductors forming the connection between said transformers and the unknown impedance are arranged close together throughout substantially their whole length for the purpose of reducing the inductance of this connection.

4. A high-frequency alternating current bridge circuit according to claim 1, 2 or 3, wherein two conductors forming the connection between said transformers and the standard impedance are arranged close together throughout substantially their whole length for the purpose of reducing the inductance of this connection.

5. A high-frequency alternating current bridge circuit according to claim 1, 2, 3 or 4, wherein the said windings are wound with flat tape conductors of width great in comparison with the insulating spacing between turns.

Dated this 21st day of February, 1944.
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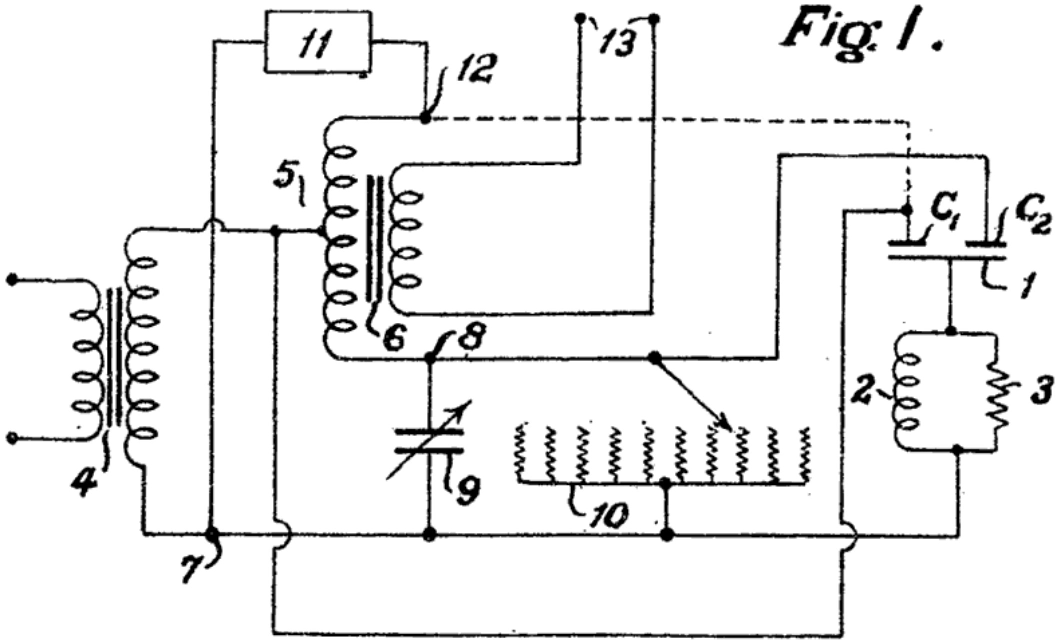


Fig. 1.

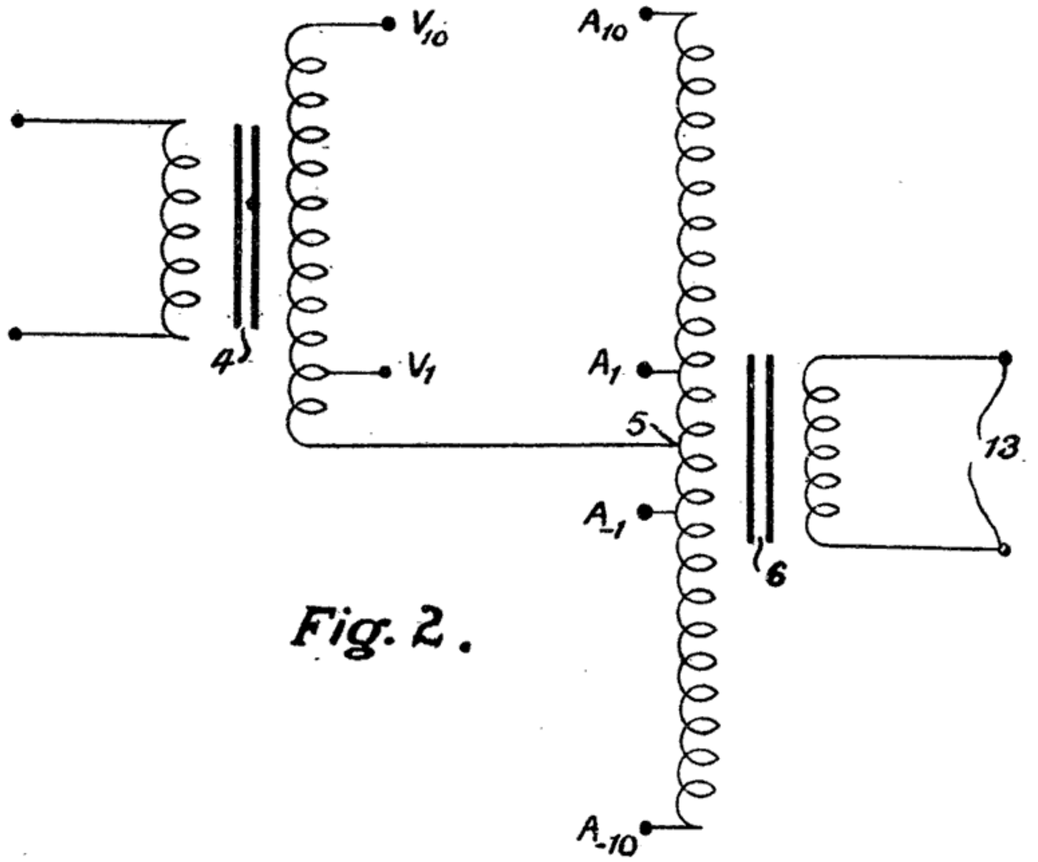


Fig. 2.

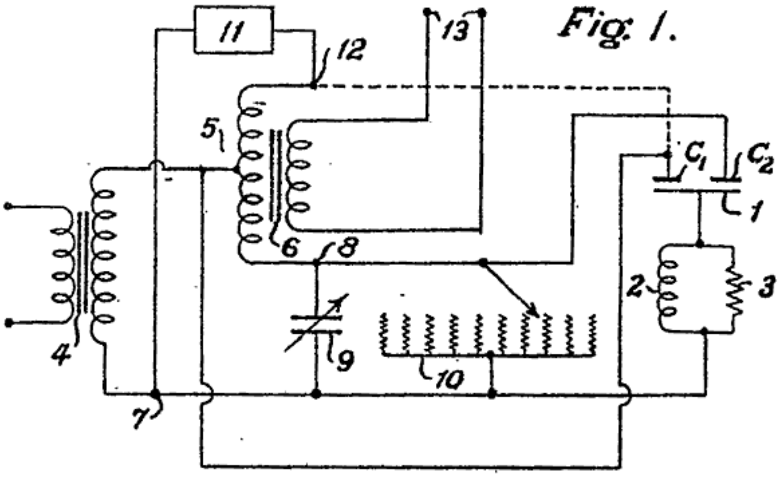


Fig. 1.

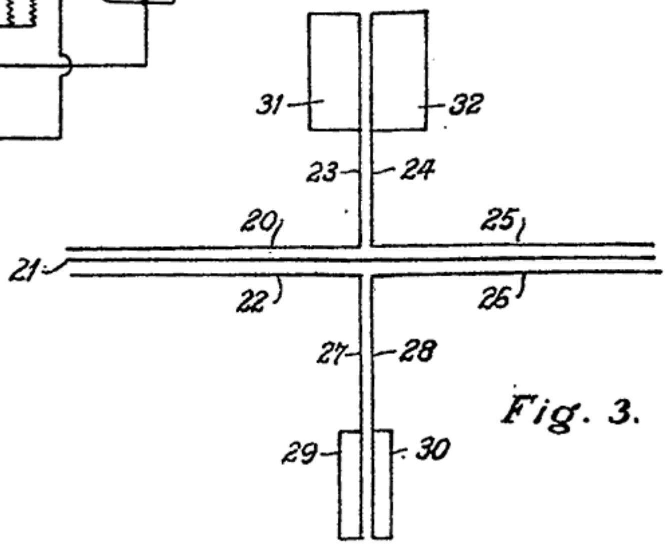


Fig. 3.

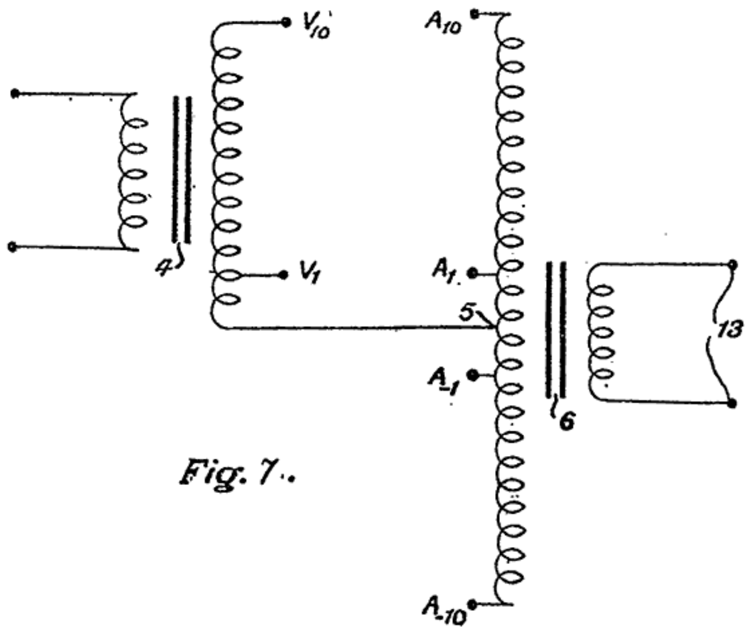


Fig. 7.

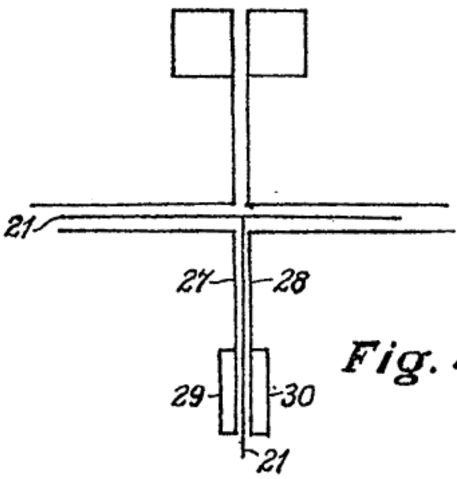


Fig. 4.

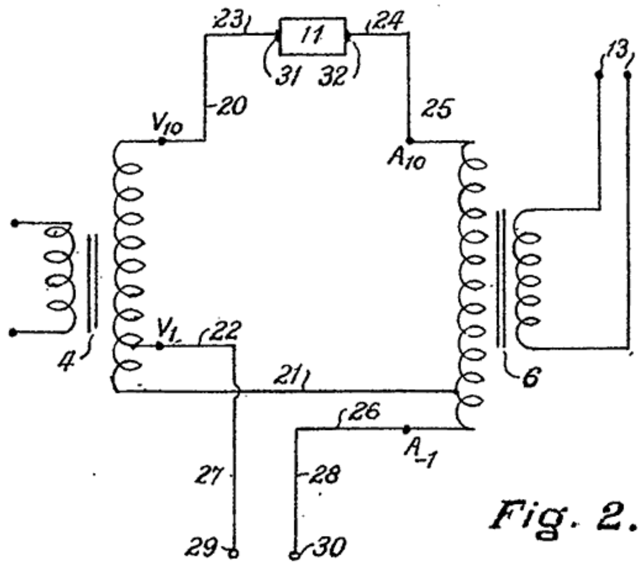
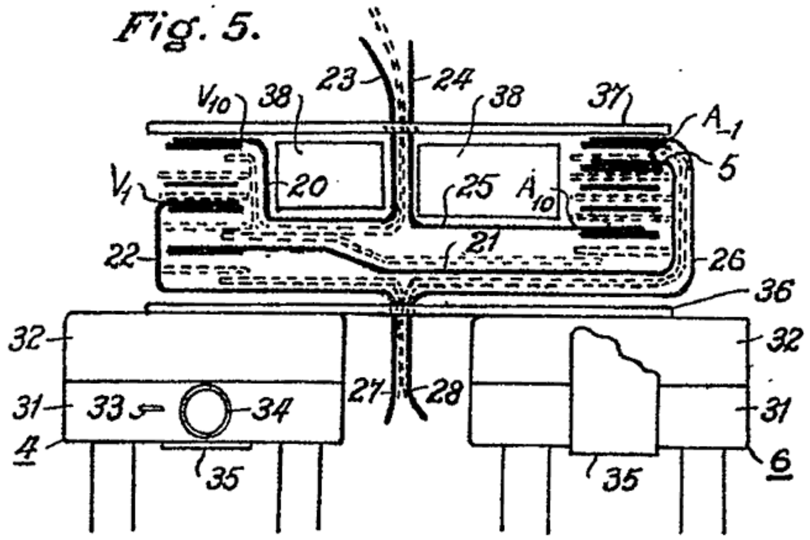


Fig. 2.

Fig. 5.



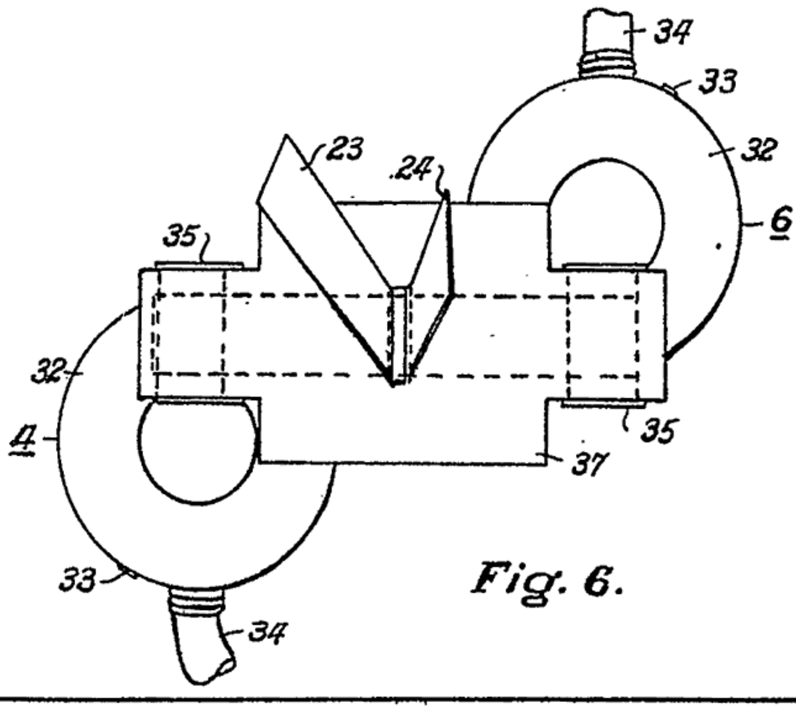


Fig. 6.