PATENT SPECIFICATION

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515,684

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PROVISIONAL SPECIFICATION

Improvements in or relating to High Frequency Electrical Conductors or Radiators

I, ALAN DOWER BLUMLEIN, a British subject, of 32, Audley Road, Ealing, London, W.5. do hereby declare the nature of this invention to be as follows:—

This invention relates to high frequency electrical conductors or radiators and is concerned particularly with signal energy carrying or radiating conductors.

High frequency current conductors at present employed commonly consist of metallic conductors air being used as the insulating medium. The object of the present invention is to provide a conductor for magnetic flux for distributing or radiating high frequency electrical power having certain advantages over known forms of conductor.

According to the present invention a conductor or radiator for high frequency electrical power consists of an electrically conducting longitudinal member formed to provide a substantially closed channel for the transmission of magnetic flux and designed to permit energy to be radiated therefrom or to be taken off by inductive or conductive coupling. The conductor may be tubular in shape and in order to prevent metallic short circuit around the surface of the tubular conductor it is formed with a longitudinal slit and the adjacent edges of the slit may be arranged to overlap to an adjustable extent in order to control leakage of magnetic flux, the overlapping surfaces forming a condenser and thus providing with the inductance of the conductor a tuned circuit for controlling the propagation properties of the conductor.

Energy may be fed to the conductor by connections to the opposed edges of the slit or a coupling coil may be arranged to embrace one end of the conductor. Energy may be taken from the conductor by a coil arranged adjacent any suitable point from which magnetic flux is arranged to leak in an adjustable manner.

A conductor designed to operate in accordance with the invention may be employed as a transmitting aerial for short waves or as a feeder.

In order that the nature of the invention may be more clearly understood, some forms of conductor embodying the invention and certain applications thereof, will now be described by way of example with reference to the accompanying drawings in which:

Fig. 1 shows diagrammatically one such embodiment,

Figs. 2, 3, 4 and 5 show diagrammatically cross sections of alternative forms of conductor,

Figs. 6 shows diagrammatically an aerial embodying the invention, and

Figs. 7 and 8 are explanatory connection diagrams.

Referring to Fig. 1 of the drawings, a copper tubular conductor 1 is shown formed with a slit 2 and may be contained within a housing 3. A coil 4 embracing one end of the conductor is fed with signal energy from a source not shown, the signal energy being induced in the conductor 1, or alternatively the energy may be fed directly to the conductor by leads 4*a* shown in dotted lines. The conductor 1 forms a closed channel for the transmission of magnetic flux set up due to the induced signal currents, the flux forming a field at the opposite end of the conductor at which a coil 5 is mounted. The flux induces energy corresponding with the signal energy, in the coil 5.

In Fig. 1 no means are shown for preventing the leakage of magnetic flux through the slit 2 but such means may take various forms. Thus, a plate 6 as shown in Fig. 2 may be arranged to cover the gap formed between the edges of the slit, the position of the plate being adjustable in order to intercept the lines of force. Again the edges of the slit may be arranged to overlap to an adjustable extent, means such as insulated bolts being provided for adjustment purposes as shown in Fig. 3.

The conductor may be composed of two semi-circular sections having their edges overlapping as shown in Figs. 4 and 5.

In order that the action of the tubular conductor as a transmitting channel for high frequency magnetic flux may be understood it may be compared with a tube of similar form but composed of insulating material immersed in a conductive liquid. The copper tube so far as magnetic flux is concerned is analogous to the tube of electrically insulating material and the air within the copper tube and surrounding it so far as magnetic flux is concerned, may be compared with the electrically conductive liquid within and around the insulating tube. The slit in the insulating tube provides a leakage path for current between the liquid within and externally of the tube and in the case of the copper tube the slit forms a leakage path for magnetic flux within and externally of the tube. In the case of an insulating tube in liquid the capacitative currents through the insulator may be balanced against the inductive currents through the slit thus giving no net admittance for one frequency between the inside and outside of the tube.

A tuned circuit may be formed at the slit the resonant frequency of which depends upon the capacity between the overlapping edges of the slit and the inductance. In the case of the copper tube its reluctance to flux passing along the tube may be represented by a series inductance, the reluctance of the slit by a shunt inductance and the capacity of the slit by a shunt condenser. Thus below resonance the equivalent circuit may be represented by distributed series inductance and shunt inductance. At resonance the equivalent circuit may be represented by distributed series inductance and parallel combinations of inductance and capacity. Above resonance the equivalent circuit may be represented by distributed series inductance and shunt capacity. In general the slit may be tuned to vary the propagation characteristic as required.

A half wavelength conductor embodying the invention may be used as an aerial for shortwaves and if vertically mounted will give all round radiation of a horizontally polarised wave.

An application of the invention to an aerial is shown in Figs. 6, 7 and 8 of the drawings.

Referring to these Figures a continuous length of conductor 7 is shown mounted vertically and supported by a hollow metal mast 8 which is connected electrically at intervals by conductors 9 to the electrical centre point of the surface of the conductor 7. Conducting leads 10 and 11 carrying signal currents are led up the mast 8 and brought out at points one half wavelength apart and connected to the conductor 7. Figs. 7 and 8 show the method of connection and it will be seen that these figures differ in that the leads 10 and 11 are oppositely connected. The conductor 7 may be composed of separate lengths connected together but it may be possible so to tune the conductor that the phase velocity is sufficiently high to render the use of separate lengths unnecessary.

In the case of a single half wavelength conductor energy may be fed to it by connections to opposite edges of the slit at one end of the conductor and a short circuit connection may be made at the opposite end in order to give a desired form of flux distribution Alternatively, connections may be made to the opposite edges of the slit at the centre of the conductor, short circuit connections being provided at the opposite ends if desired. Alternatively the radiator may be driven by a coil encircling it.

A length of conductor other than that of a half wavelength may be employed by tuning the slit in the conductor. As shown in Figs. 4 and 5 a composite conductor may be formed by overlapping semi-cylindrical sections tuning being effected as in the case of a single slit.

In order that an aerial conductor designed in accordance with the invention shall be efficient over a wide range of frequencies, it is desirable that it should be of relatively large diameter, diameters of the order of 6 inches to 1 foot being practicable for wavelengths of say 5 metres. While straight conductors have been described it will be understood that the invention is applicable to curved or other shaped conductors and they may be of any desired cross-section.

Dated this 5th day of March, 1938.

F. W. CACKETT,
Chartered Patent Agent.

COMPLETE SPECIFICATION

Improvements in or relating to High Frequency Electrical Conductors or Radiators

I, Alan Dower Blumlein, a British subject, of 37, The Ridings, Hanger Lane, Ealing, London, W.5, formerly of 32, Audley Road, Ealing, London, W.5, 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:—

This invention relates to high frequency electrical power transmitting or distributing apparatus and is concerned particularly with signal energy carrying or radiating conductors such as feeders or aerials.

The object of the present invention is to provide a mechanically simple form of conductor for magnetic flux for radiating high frequency electrical power or for distributing such power over short distances.

According to the present invention a conductor or radiator for high frequency electrical power consists of an electrically conducting tubular member formed to provide a substantially closed channel for the transmission of magnetic flux set up by circulating electric currents, said member being formed with a slit extending therealong and simulating a transmission line having inductive series elements and shunt elements comprising inductance and capacity in parallel, and means for injecting or extracting high frequency power to or from said member. In certain constructions of conductor or radiator embodying the invention, means are provided for effecting adjustment of the width of said slit. In particular forms of conductor or radiator according to the invention, the edges of the slit are arranged so that adjacent cooperating surfaces are provided by, for example, causing said edges to overlap, means being provided for adjusting the distance between the adjacent or the overlapping surfaces or the extent to which said surfaces overlap in order to control the leakage of magnetic flux, said adjacent or the overlapping surfaces forming a condenser and thus providing with the inductance of the conductor a tuned circuit by which the propagation properties of the conductor or radiator may be controlled.

Energy may be fed to the conductor by connections to the opposed edges of the slit or a coupling coil may be arranged to embrace one end of the conductor. Energy may be taken from the conductor by a coil arranged adjacent any suitable point from which magnetic flux is arranged to leak in an adjustable manner.

A conductor designed to operate in accordance with the invention may be employed as a transmitting aerial for short waves or as a conductor of high frequency energy transferring such energy from one coil or equivalent device to another.

In order that the invention may be clearly understood and readily carried into effect, some forms of conductor embodying the invention and certain applications thereof, will now be described by way of example with reference to the drawings filed with the Provisional Specification in which:—

Fig. 1 shows diagrammatically one such embodiment,

Figs. 2, 3 4 and 5 show diagrammatically cross sections of alternative forms of conductor.

Fig. 6 shows diagrammatically an aerial embodying the invention, and

Figs. 7 and 8 are explanatory connection diagrams.

Reference will also be made to the accompanying drawings, the Figures of which are numbered consecutively with the Figures of the drawings accompanying the Provisional Specification, and in which:—

Fig. 9 is an explanatory experimental diagram,

Figs. 10, 11, 12 and 13 are explanatory curves,

Figs. 14 and 15 show circuit equivalents of sections of the conductor, and

Figs. 16 and 17 show forms of connection which may be used in connection with the conductor.

Referring to Fig. 1 of the drawings, a copper tubular conductor 1 is shown formed with a slit 2 and may be contained within a housing 3. A coil 4 embracing one end of the conductor is fed with high frequency signal energy from a source not shown, the signal energy being induced in the conductor 1, or alternatively, the energy may be fed directly to the conductor by leads *4a* shown in dotted lines. The conductor 1 forms a closed channel for the transmission of magnetic flux set up due to the induced signal currents, the flux forming a field at the opposite end of the conductor at which a coil 5 is mounted. Owing to the energy being at a high frequency the flux cannot penetrate the copper (provided this is sufficiently thick with reference to the signal considered) and therefore the flux is constrained to pass along the tube except for a portion which leaks out of the gap. At frequencies of 1 megacycle and 100 megacycles the depth to which the flux penetrates the copper is .007 cm. and .0007 cm. respectively for an attenuation of 1 neper. In order that the leakage due to possible flux penetration may be completely suppressed, the copper must be of a thickness of the order of 10 times or more the depth of penetration of the flux. In actual practice the thickness of the conductor as determined by requirements of mechanical strength is greater than the minimum thickness required in order that undesired flux leakage shall not occur. The gap between the edges of the slit is necessary to prevent the tube forming a short circuited turn which would prevent the flux from entering the tube. The flux induces energy corresponding with the signal energy, in the coil 5.

In Figure 1 no means are shown for adjusting the leakage of magnetic flux through the slit 2, but such means may take various forms. Thus, a plate 6 as shown in Figure 2 may be arranged to cover the gap formed between the edges of the slit, the position of the plate being adjustable in order to intercept the lines of force. Again the edges of the slit may be arranged to overlap, and the distance between the overlapping surfaces may be adjustable, means such as insulated bolts being provided for adjustment purposes as shown in Figure 1.

The conductor may be composed of two semi-circular sections having their edges overlapping as shown in Figures 4 and 5. Again, although no particular form has been illustrated, the extent to which one edge of the slit overlaps the other may be made adjustable, the distance between the overlapping surfaces remaining substantially constant.

In order that the action of the tubular conductor as a transmitting channel for high frequency magnetic flux may be understood, it may be compared with a tube of similar form but composed of insulating material and immersed in a conductive liquid. The copper tube so far as magnetic flux is concerned is analogous to the tube of electrically insulating material and the air within the copper tube and surrounding it so far as magnetic flux is concerned, may be compared with the electrically conductive liquid within and around the insulating tube. The slit in the insulating tube provides a leakage path for current between the liquid within and externally of the tube and in the case of the copper tube the slit forms a leakage path for magnetic flux within and externally of the tube. In the case of an insulating tube in liquid the capacitative currents through the insulator may be balanced against the inductive currents through the slit thus giving no net admittance for one frequency between the inside and outside of the tube. In the case of the copper tube the analogous effect is produced that the inductance of the metal loop formed by the tube may be tuned by the capacity between the two sides of the slit.

The common requirement of a broadcasting aerial that it should radiate equally in all horizontal directions is fulfilled by a vertical antenna radiating vertically polarised waves. Rotation of such an aerial to the horizontal position to cause it to radiate horizontally polarised waves leads to a deep minimum of radiation in the direction of the axis. This may be overcome by employing combinations of dipoles such as a pair of crossed dipoles fed in phase quadrature or a triangle or a square formed of dipoles which are fed in phase.

A simple solution is to use a horizontal loop aerial, a small loop automatically fulfilling the polarisation and directional requirements. An objection to this arises in view of the very small radiation resistance of a small loop leading to excessively high selectivity which may prohibit the use of such an aerial at short wavelengths of the order of those employed in television systems. A section of the cylinder shown in Figure 1 constitutes effectively a small single turn loop of the kind referred to, the above mentioned objection being overcome by reducing the inductance by making the loop in the cylindrical form shown, the length of the cylinder being of the order of one wavelength. The considerable vertical extent of the aerial leads to the further feature that it may have considerable directivity in a vertical plane.

The manner in which an essentially constant circulating current distribution is produced over the considerable length of the aerial may be understood from the following explanation. It is convenient to assume that the cylinder shown in Figure 1 is of copper and is about one wavelength long, the diameter being $\frac{\lambda}{30}$ and that the edges of the slit are adjustably held apart and fed from a high frequency source by conductors as shown in dotted lines at 4*a*.

If the distribution of circulating current is examined along the length by a loop encircling the cylinder and having a measuring instrument connected in it as shown in Fig. 9, it will be found that the current attenuates rapidly from the fed end as shown in Fig. 10. If the edges of the slit 2 are progressively brought together, being finally overlapped with a small clearance, the current distribution changes in the manner shown by the curves in Figs. 11, 12 and 13. The attenuation first decreases as shown in Fig. 11 and a state may be reached when the distribution is uniform over the whole length of the cylinder as shown in Fig. 12 except for a small steady attenuation from the feed point along the cylinder due to radiation and resistance losses, and then a system of stationary waves appears as shown in Fig. 13 the wavelength being at first greater than the wavelength in air, but approaching this value as the gap is closed together.

The sequence of changes in the current distribution may be explained in terms of the capacity between the edges of the slit 2. The portion of the tube in the vicinity of the slit may be regarded as forming the conductors of a balanced transmission line having series inductance and parallel capacity as in the normal case but having in addition a continuous inductive load in parallel with the capacity formed by the body of the cylinder. An elementary section of such a line would thus be represented in the balanced form as shown in Fig. 14 in which an inductance SL is shown in series in each conductor and a parallel combination of inductance IL and capacity C. The unbalanced form would be represented as shown in Fig. 15 by an inductance SL in series in one conductor and a parallel combination of inductance IL and capacity C. When the slit is wide open the shunt capacity is of low value and has a susceptance much less than that of the shunt inductance. Consequently the line has inductance in both series and parallel branches and is highly attenuating as shown in Fig. 10.

Closing the slit progressively increases the capacity and reduces the attenuation until a point is reached at which the shunt inductance and capacity tune. In this condition the line has a very high impedance parallel branch so that the attenuation and phase delay are very low, corresponding with the condition of uniform current distribution shown in Fig. 12. Continued closing of the slit produces still greater shunt capacities which may then neutralise the shunt inductance and forms a conventional transmission line but in which the effective value of the shunt capacity is reduced thus increasing the phase velocity and producing the condition shown in Fig. 13.

All the currents flowing in the cylinder are capable of radiating but those flowing in a lengthwise direction near the slit edges substantially neutralise each others effects so that there remains the radiated field of the currents circulating round the cylinder. Each elementary section of cylinder therefore behaves as a loop aerial and the resulting radiation may be obtained from the summation of the individual effects with due regard to both phase and amplitude. In the case of equal distribution along the length of the cylinder, represented in Fig. 12, the individual currents in the elementary loop sections being of equal magnitude and phase, the radiated contributions add in phase in the equator of the aerial giving a directional maximum in this plane.

Certain experiments have been made with an aluminium radiating conductor of square cross section, one side of which was made adjustable to overlap a turned-in portion of the adjacent side in order to form a long slit. The conductor was of box form, 425 cms. in length, the sides being each of 17 cms. As in the particular mode of use of the conductor the two edges of the slit vary in potential symmetrically with respect to earth, the conductor was fed by balanced feeders connected to the slit edges as shown in Fig. 16. In an alternative case the outer sheath of a concentric feeder was connected to the edge of the radiating conductor diagonally opposite the slit and arranged to make contact freely between that edge and the surface of the conductor between it and the slit, the central conductor of the feeder being connected to the opposite edge of the slit as shown in Fig. 17. Measurements showed that with the axis of the conductor vertical, it radiated a horizontally polarised wave and the horizontal directional diagram was circular.

The effect of adjustment of the width of the slit on the directional diagram in a plane through the axis obtained by placing the conductor horizontally was to produce a poor directional diagram when the slit was open beyond the tuned position. A better diagram was obtained with the slit adjusted to the tuned position producing uniform current distribution and with the slit closed still further to produce the stationary wave condition, the directional diagram presented two lobes having a minimum between them.

At the frequency of 60 Mc. per sec. at which the experiments referred to were conducted, the radiator could be end fed and still produce a maximum of radiation in its equator. At 100 Mc. per sec. however, when the radiator was tuned, the directional diagram was deviated from the equator when end fed. By feeding the radiator at the centre the maximum was restored to the equator. The tilting of the maximum is caused by a phase difference along the length of the radiator, losses in the copper and by radiation producing a propagation constant giving phase shift and attenuation. The propagation constant can be shown to depend on the length of the radiator from the feed point. A long length produces a relatively large phase shift and attenuation and thus a more tilted diagram. To get a symmetrical diagram therefore lengths from feed points must be kept relatively short. As previously indicated, centre feeding of the radiator instead of end feeding may restore the maximum to the equator or more feed points may be employed. Thus at 150 Mc. the tilting phenomenon was more pronounced and five feed points distributed uniformly along the length of the radiator produced a satisfactory directional diagram. The five points were fed by five identical feeders branching from a common point.

In the experiments made favourable gains were obtained compared with a half-wave dipole over a small range of frequencies.

Above the critical frequency, i.e. the frequency above and below which the conditions illustrated in Fig. 12 obtain the propagation velocity is finite, that is to say, there is continuous phase shift along the length of the radiator and there is no attenuation. Thus, unless there is proper matching at the terminations, standing waves will be set up due to reflections. Thus, open ended end fed, or short-circuited end fed quarter wavelength aerials may be employed and desired directional diagrams obtained by suitable combination of quarter wavelength aerials, or of aerials longer or shorter than a quarter wavelength.

Experiments made to investigate the conditions in which standing waves were set up were made at a frequency of about 150 Mc. per sec. with a square section copper radiator, the sides of which measured 17 cm. and which was about 60 cm. in length, which is just over a quarter of a wavelength. The characteristic impedance and propagation constant for a series of different gap widths was measured by the conventional transmission line method of measuring the input impedance with the far end open and short-circuited. A gap of 1.25 cm. was selected as being about the greatest which could be used without approaching the tuned condition too closely. The results obtained were in reasonable agreement with the theoretical values.

An application of the invention to an aerial is shown in Figs. 6, 7 and 8 of the drawings.

Referring to these Figures, a continuous length of conductor 7 is shown mounted vertically and supported by a hollow metal mast 8 which is connected electrically at intervals by conductors 9 to the voltage nodes at the surface of the conductor 7. Conducting leads 10 and 11 carrying signal currents are led up the mast 8 and brought out at points one half wavelength apart and connected to the conductor 7. Figs. 7 and 8 show the method of connection and it will be seen that these Figures differ in that the leads 10 and 11 are oppositely connected. The conductor 7 may be composed of separate lengths connected together, but it may be possible so to tune the conductor that the phase velocity is sufficiently high to render the use of separate lengths unnecessary.

In the case of a single half wavelength conductor, energy may be fed to it by connections to opposite edges of the slit at one end of the conductor and a short circuit connection may be made at the opposite end in order to give a desired form of flux distribution. Alternatively, connections may be made to the opposite edges of the slit at the centre of the conductor, short circuit connections being provided at the opposite ends, if desired. Alternatively, the radiator may be driven by a coil encircling it.

A length of conductor other than that of a half wavelength may be employed by tuning the slit in the conductor. As shown in Figs. 4 and 5, a composite conductor may be formed by overlapping semi-cylindrical sections, tuning being effected as in the case of a single slit. It will be understood that the cross section of the conductor may take various forms and overlapping portions may be arranged to form one or more slits. In addition to the particular forms illustrated in the drawings, for example, a cylindrical conductor may have the adjacent edges turned inwardly towards the centre so that rigid insulating spacers may be clamped in the gap so formed, the whole tube being thus rendered mechanically strong. While in the constructions described with reference to Figures 6, 7 and 8 a central supporting mast is provided, if the conductor is made sufficiently strong mechanically so as to be self-supporting, the mast may be dispensed with.

In order that an aerial conductor designed in accordance with the invention shall be sufficient over a wide range of frequencies, it is desirable that it should be of relatively large diameter, diameters of the order of 6 inches to 1 foot being practicable for wavelengths of say 5 metres. The length of the aerial may be of the order of one wavelength or any of the alternative forms of aerial mentioned above may be adopted. Conductors having diameters greater than 1 foot and provided with more than one longitudinal slit may be used in cases in which it is desired to operate over very wide frequency ranges. While straight conductors have been described, it will be understood that the invention is applicable to curved or other shaped conductors and they may be of any desired cross-section.

As previously indicated, a conductor embodying features of the invention may be employed to transfer high frequency power from one point to another providing the distance separating the points is not so large that radiation from the conductor results in inefficient transfer of energy. In the case of shortwave apparatus, however, an arrangement such as that diagrammatically illustrated in Fig. 1 may be employed. It may be assumed that the coils 4 and 5 are shortwave coils mounted upon the same chassis. As such coils are usually in fixed positions, the adjustment in energy transfer is effected by movement of the tube 1 itself. The tube is preferably earthed in order to eliminate electrostatic couplings.

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 conductor or radiator for high frequency electrical power consisting of an electrically conducting tubular member formed to provide a substantially closed channel for the transmission of magnetic flux set up by circulating electric currents, said member being formed with a slit extending therealong and thereby simulating a transmission line having inductive series elements and shunt elements comprising inductance and capacity in parallel, and means for injecting or extracting high frequency power to or from said member.

2. A conductor or radiator according to claim 1 and provided with means for effecting adjustment of the width of said slit.

3. A conductor or radiator according to claim 1 or 2 wherein the edges of said slit are arranged so that adjacent cooperating surfaces are provided by, for example, causing said edges to overlap, means being provided for adjusting the distance between the adjacent or the overlapping surfaces or the extent to which said surfaces overlap, said adjacent or the overlapping surfaces forming the capacity of said shunt element and thus providing with the shunt inductance of the conductor a tuned circuit by which the transmission properties of the conductor or the radiation properties of the radiator may be controlled.

4. A transmitting aerial for horizontally polarised waves constituted by a conductor or radiator according to claim 1, 2 or 3, and arranged vertically, the constants of which are adjusted so that a uniform horizontal diagram with vertical directivity is produced.

5. An aerial according to claim 4, wherein the width of the slit is adjusted so that the shunt inductance and capacity tune and a condition of substantially uniform current distribution over the length of the aerial is produced with the result that the aerial diagram exhibits a maximum of radiation in a horizontal plane.

6. A transmitting aerial constituted by a conductor or radiator according to claim 1, 2 or 3 and having a length equal to a quarter of the wavelength at the frequency to be transmitted, the ends of the aerial being open or short-circuited.

7. A conductor, radiator or aerial according to any one of the preceding claims, whereby energy is fed thereto or taken therefrom by a directly connected balanced feeder, co-axial feeder or a coupling coil.

8. A conductor or radiator according to claim 1, 2 or 3 and for use with wide frequency ranges, having a cross section exceeding one foot in width or diameter and provided with one or more longitudinal slits.

9. A conductor or radiator substantially as described with reference to any one of Figures 2, 3, 4 or 5 of the drawings filed with the Provisional Specification.

10. An aerial substantially as described with reference to Figure 6, 7 or 8 of the drawings filed with the Provisional Specification.

Dated this 7th day of February, 1939.
F. W. CACKETT,
Chartered Patent Agent.

Leamington Spa: Printed for His Majesty's Stationery Office, by the Courier Press.—1940.

515,684 PROVISIONAL SPECIFICATION

1 SHEET

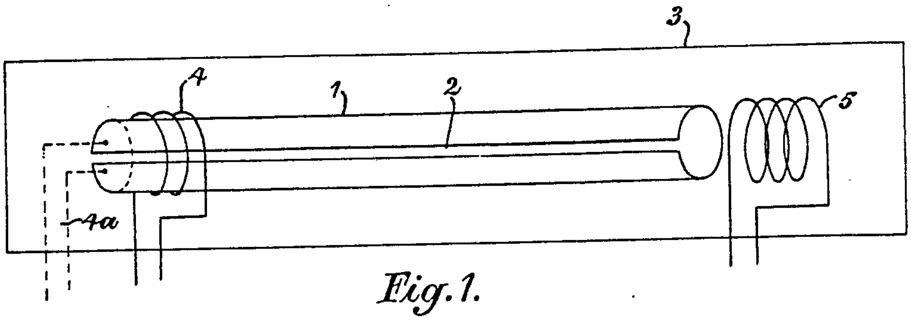

Fig. 1.

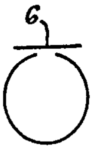

Fig. 2.

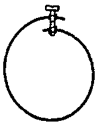

Fig. 3.

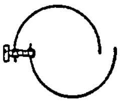

Fig. 4.

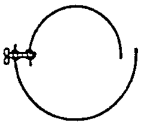

Fig. 5.

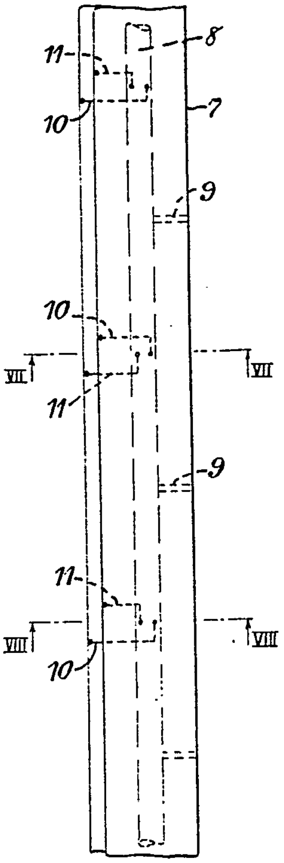

Fig. 6.

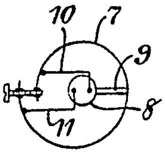

Fig. 7.

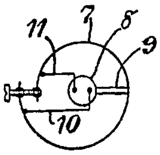

Fig. 8.

[This Drawing is a reproduction of the Original on a reduced scale.]

Malby & Sons, Photo-Litho.