Oct. 18, 1955 P. H. NETHERWOOD ET AL 2,721,311

HIGH VOLTAGE LOW PASS FILTERS

Filed March 7, 1950 2 Sheets-Sheet 1

Fig. 1

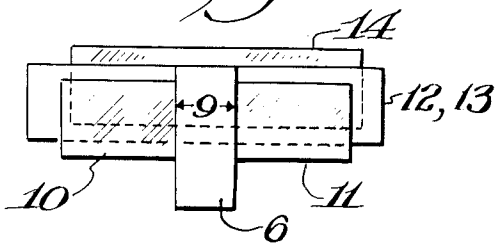


Fig. 2.

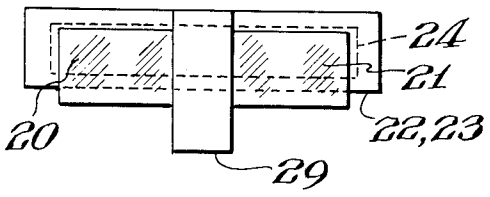


Fig. 3.

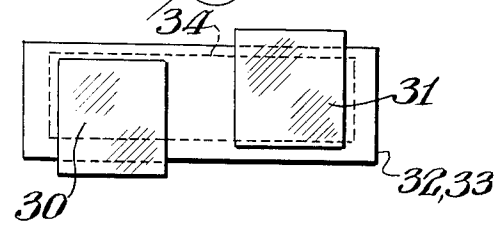


Fig. 4.

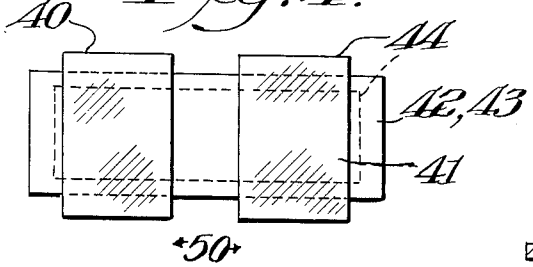


Fig. 5.

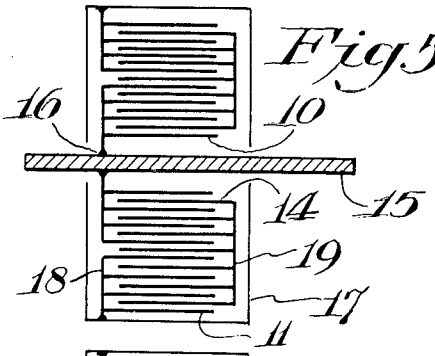


Fig. 6.

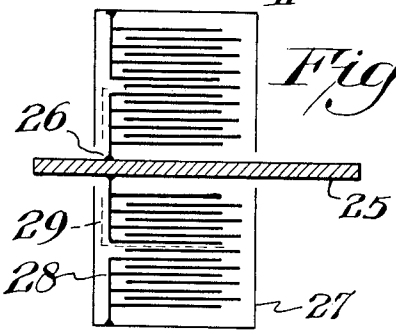


Fig. 7.

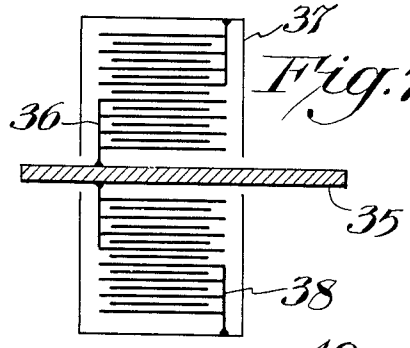
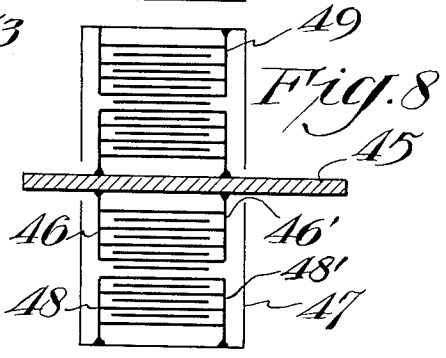


Fig. 8



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Fig. 9.



Fig. 10.

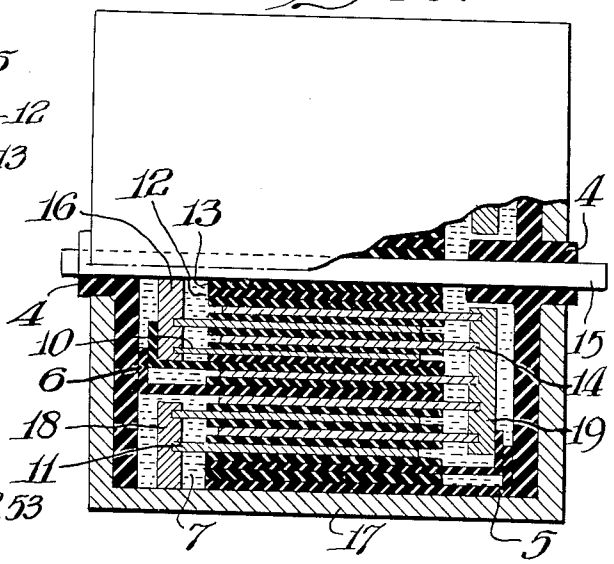


Fig. 8A

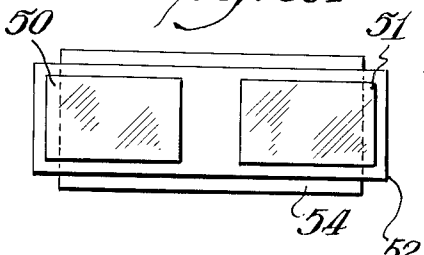


Fig. 8B.

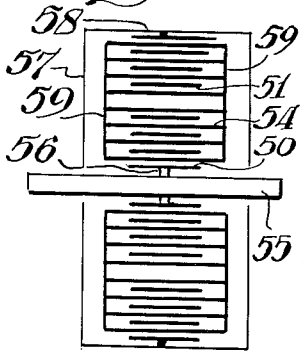


Fig. 11.

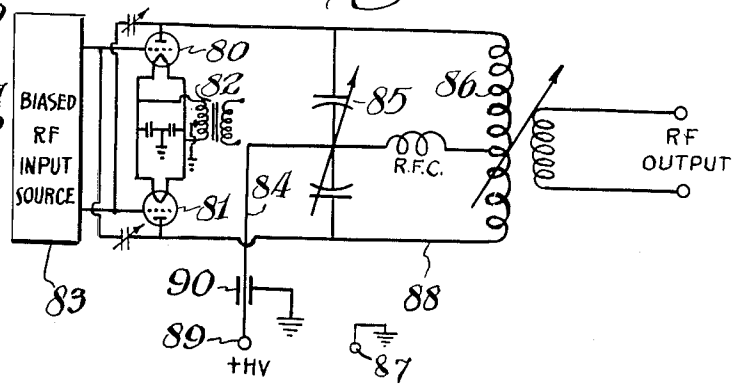


Fig. 12.

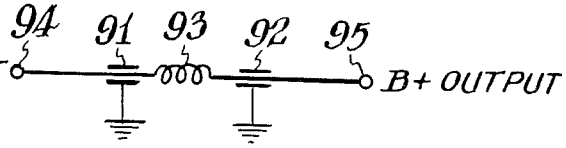
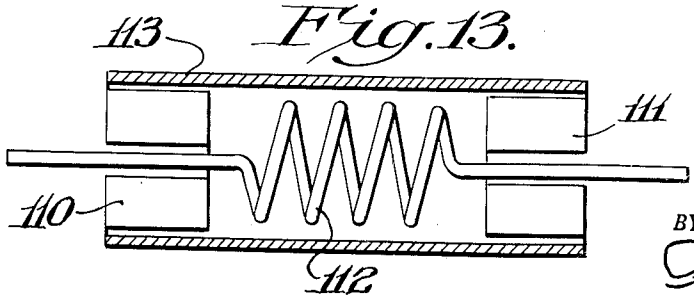


Fig. 13.



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HIGH VOLTAGE LOW PASS FILTERS

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Application March 7, 1950, Serial No. 148,208

2 Claims. (Cl. 333—79)

The present invention relates to new and improved electrical circuits and more particularly refers to high voltage artificial transmission lines having characteristics which are highly desirable, but heretofore have been practically unattainable.

The classical picture of a transmission line is a network of an infinite number of sections, each consisting primarily of a series inductance (corresponding to the inductance per unit length of the wire constituting the transmission line), a series resistance (corresponding to the resistance per unit length of the wire) and a parallel capacity (which is the capacity to ground or between adjacent wires of a unit length of the wire). Such transmission lines are very useful particularly at high frequencies in transmitting or rejecting signals, in matching or transforming impedances, and in delaying and modifying the wave-shape of the signals.

It is well known in the art to make artificial transmission lines with so-called lumped characteristics, that is to say, made up of a finite number of relatively large inductances and capacities, and these artificial transmission lines with lumped parameters have been quite successful. At high frequencies they suffer from the defect, however, that the lumped inductance has a high distributed capacity, and that the lumped capacity has a high series inductance so that it is extremely difficult to obtain the electrical equivalent of the natural transmission line. At the same time the natural transmission line to have useful qualities is so long physically that it is difficult, if not impossible, to make use of it in the lower radio frequencies.

A further difficulty with the known artificial line is that it is impossible to match the behavior of the natural line at the physical start of the line. In the natural line there is actually shunt capacity appearing as part of the line from its very inception. There is likewise series inductance appearing in the natural line upon its inception. With the artificial line a choice must be made between starting with either a series inductance or a shunt capacitance of this choice necessarily makes the resulting network differ from the natural prototype.

In U. S. Patent No. 2,440,652 there is disclosed an artificial transmission line which overcomes the disadvantages of prior artificial lines in a small, unitary assembly. However, it is difficult to produce devices of the type described therein for high voltage service because of the nature of the armature winding. To obtain the relatively large dielectric thickness required for high voltage service, a complicated winding machine for many thicknesses of thin spacing material is necessary, since thick paper or resin spacing layers are not readily wound without wrinkling. Wrinkling unduly increases the condenser bulk and causes the spacers to draw in their side edges thereby reducing the insulation between the oppositely polarized electrode edges.

It is an object of the present invention to overcome the foregoing and related disadvantages of the prior art. A further object is to produce new electrical circuit elements having desirable voltage and frequency characteristics.

A still further object is to produce an artificial transmission line which combines the advantages of prior art transmission lines without at the same time being subject to their disadvantages. A still further object is to produce artificial transmission lines, net-works and filters of simple physical structure which have characteristics greatly desired but heretofore unattainable. Additional objects will become apparent from a consideration of the following description and claims.

These objects are attained in accordance with the present invention wherein there is produced a high voltage artificial transmission line comprising two electrode strata separated by dielectric sheet material and convolutely wound about an electrically conducting core, which projects out from both sides of the wound assembly, the first stratum being transversely divided into inner and outer stratum sections, the inner section being electrically connected at its inner end to the core, and the outer section being electrically connected at its outer end to external terminal structure, one of said strata including side portions projecting throughout substantially its entire length from at least one side of the wound assembly and low-resistance connecting structure electrically connecting said projecting stratum portions.

In one of its limited embodiments, the invention is concerned with a high voltage artificial transmission line comprising the above elements wherein the electrode strata are in the form of one long and two short metal foils, one side edge of said long foil extends beyond the side of the winding and its extended edges are interconnected by a low resistance path, and each of said short foils extend from the opposite side of said winding, the extended edges of the inner of said short foils being connected by a low resistance path to said core, and the outer of said short foils being connected by a low resistance path to a cylindrical metallic housing.

In one of its preferred embodiments the invention is concerned with a high voltage artificial transmission line similar in structure to the above convolutely wound assembly of strata, and having, on each side of the winding, stratum portions that project along substantially their entire length, together with low-resistance connecting structure interconnecting the individual projecting stratum portions.

This invention also refers to a novel, high voltage, filter network comprising two short and one long electrode foils separated by dielectric spacing material and convolutely wound upon an electrically conducting core, said foils being terminated in a manner as immediately above described, wherein said short foils are separated by several turns of the long foil of said winding so as to increase the lumped inner series inductance of the device.

According to the present invention a very wide insulating spacer may be inserted between the divided stratum portions or short foils before winding the device. Upon winding the extended edges of the spacer may be crimped over the extended edges of the inner of said short foils thereby protecting the two series condensers of the device from one another and increasing the corona starting and breakdown voltage of the device.

Reference is made to the appended drawings in which:

Figures 1, 2, 3, 4 and 8A represent plan views of different types of transmission line units of the invention, in unwound condition. The metallic housing and the electrically conducting core are not shown.

Figures 5, 6, 7, 8 and 8B represent simplified axially sectioned views cross-sections of the wound units of Figures 1, 2, 3, 4 and 8A respectively, the dielectric being omitted in the interest of clarity.

Figure 9 is a longitudinally-sectioned view of an unwound unit similar to that shown in Figure 1 but including an additional dielectric insulator.

Figure 10 is a fragmentary detailed cross-section view of a typical transmission line, such as shown in Figures 5 and 9.

Figure 11 shows a typical radio frequency tank (inductance capacitance) circuit that includes the transmission line unit of the invention.

Figure 12 shows a new pi type low pass filter, suitable for use in D. C. power supply circuits, and

Figure 13 shows an exceptionally wide range filter unit incorporating features of the present invention.

Referring more specifically to Figures 1, 5 and 9 it will be noted that conductive strata are here shown as short electrode foils **10** and **11** separated by a distance **9** and extending beyond the same side of superimposed dielectric sheets **12** and **13**, together with a long electrode foil **14** between and extending beyond the opposite side of the dielectric sheets **12** and **13**. The extended edges of short foil **10** ar connected to the electrically conducting core **15** by a low resistance path, as provided by solder **16** or other means, and the extended edges of short foils **11** are soldered to metallic housing **17** by means of solder **18**. The extended edges of long foil **14** are interconnected in a low resistance path by solder **19**.

Figure 10 is a complete fragmentary cross-section of a typical line such as shown in Figures 1, 5 and 9; however, the particular construction shown employs insulating spacers between the condenser sections as illustrated in Figure 9. In Figure 10 the extended edges of short foil **10** are connected to the electrically conducting core **15** by means of solder **16**, while the extended edges of short foil **11** are connected to metallic housing **17** by means of solder **18**. Dielectric spacer **6** is employed to insulate the edges of the short foils one from the other. The extended edges of long foil **14** are interconnected in a low resistance path by solder **19** and are also insulated from housing **17** by means of dielectric spacer **5**. The metallic housing **17** is insulated from conducting core **15** by means of insulating members **4** which have integral bushing portions. Insulating members **4** may comprise a separate ring and bushing, if desired, and usually consist of a material such as, for example, rubber. The entire unit is impregnated with dielectric oil **7**, as by means of an opening in the housing which is subsequently sealed, with solder for example.

Figures 2 and 6 show another preferred embodiment of the invention wherein long foil **24** is completely enclosed by dielectric sheets **22** and **23** and does not have edges interconnected by means of an external low resistance path. Short foils **20** and **21** are terminated by means of the solder connections **26** and **28** as shown. If even higher breakdown and corona starting voltage are desired, an insulating spacer **29** may be wound within the device as shown in these figures.

Another prefered embodiment is shown in Figures 3 and 7. Here short foils **30** and **31** extend from opposite sides of the winding and are linked by the solder connections **36** and **38** respectively to core **35** and housing **37**. Long foil **34** is totally covered by dielectric spacers **32** and **33**.

In Figures 4 and 8, another preferred embodiment is shown. Dielectric sheets **42** and **43** again completely cover a long foil **44**, and short foils **40** and **41** extend from both sides of the winding and the extended edges on both sides are secured to core **45** and housing **47** by means of solder connections **46**, **46'** and **48**, **48'** respectively.

Length **50** between short foils **40** and **41** can be varied as required. The greater the length **50** the greater the inherent series inductance of the filter network.

The construction of Figures 8A and 8B is the converse of that shown in Figures 4 and 8. Whereas in Figure 4 the short foils **40**, **41** extend beyond both sides of the long foil **44** but the long foil extends on both ends, in Figure 8A, short foils **50**, **51** extend beyond the ends of a long foil **54**, and the long foil extends beyond both sides of the short foils. The dielectric spacers are shown at **52**, **53** and sandwich the long foil.

After winding over a conductive core **55**, the inner end of short foil **50** is connected as by the soldered union **56** to the core while the outer end of foil **51** is soldered as shown at **58** to an external conductive housing **57**. The projecting side edges of foil **54** are separately united by solder connection **59** to provide low-resistance connections.

The artificial transmission line devices disclosed herein has many desirable characteristics: it provides a low resistance direct current (D. C.) feed-through path and a low impedance alternating current (A. C.) path from the feed through to an external return conductor such as a ground return for example. This low impedance A. C. path by-passes undesired alternating current, particularly of higher frequencies so that they are not carried along in the feed-through circuit. Figures 11 and 12 show typical circuit applications for the present invention.

Figure 11 shows a radio frequency amplifier to which the transmission line of the invention has been applied. A pair of amplification tubes **80**, **81** are shown in a conventional amplification circuit for operation by high voltage direct currents supplied between the +HV and −HV terminals **89**, **87**. A transformer **82** is connected to heat the filaments of the tubes by alternating current supplied from any convenient source. In operation the tubes are fed radio frequency (RF) signals from an input source **83** which is also connected to bias the input grids of the tubes, as is well known. Amplified currents corresponding to these incoming signals are developed in the output tank circuit **88** composed of inductance **86** and capacitance **85**, and these amplified currents are delivered to the RF output terminals as by the illustrated inductive coupling to the inductance **86**.

For energizing the tubes **80**, **81**, a positive lead **84** connects the +HV terminal **89** to a center tap on inductance **86** through a radio frequency choke (R. F. C.). This completes the direct current circuit to the tube plates.

The above amplifier construction is standard and does a god job of amplifying. However, because of unavoidable nonlinearity, some harmonics of the desired currents are also generated and appear in the tank circuit. These harmonics are of relatively high frequency and have a tendency to be fed back to the amplifier input thereby tending to cause instability and oscillation.

Conventional capacitors are not too effective in by-passing the harmonics away from the high voltage lead **84**. The transmission line of the invention is therefore connected, as shown at **90**, with its feed-through conductor in series in the high voltage lead and the by-pass connection or housing grounded. The by-pass impedance of this connection to the high frequency harmonics is so low that no effective amount of harmonics will pass to the +HV terminal **89**.

Any other type of amplifier construction can be used in place of that specifically shown in Figure 11. Where the amplifier is operated at high power output, the D. C. operating voltage is usually very high, about 5000 volts being not unusual. At this high voltage the transmission line of Patent No. 2,440,652 breaks down readily and cannot be used. The constructions described above however, are quite suitable for such use.

The present device may be employed in connection with a vibrator in a D. C. power supply. If as in Figure 12 a vibrator-supplied B+ input at terminal **94** contains undesired surge pulses and hash due to the irregular wave shape of the vibrator output (not shown) and/or rectifier circuit to which it is connected, the novel pi type filter here disclosed may be used to effectively shunt such undesired waves to ground, and thereby provide a D. C. output at B+ terminal **95**, relatively free of all A. C. ripple. The pi type filter shown consists of artificial transmission line devices **91**, **92**, such as those shown in Figures 1, 2, 3, 4, 8A or 9, and filter choke **93**.

Figure 13 shows a unitary filter assembly that is extremely efficient and compact. It is composed of at least two artificial transmission line devices **110** and **111** constructed according to the present invention and an inductor coil **112** therebetween. Devices **110**, **111** are shown as of the type described in detail in connection with Figures 3 and 7, but any of the other may also be used, the devices being disposed about the inductance coil element **112** in a manner as illustrated, e. g. to provide an annular filter. A ferromagnetic core may be employed with the coil **112** where maximum inductance per unit volume is needed. A single metal housing **113** is employed about the unit to keep current paths at a minimum length and provide a unitary assembly. An extremely efficient unit of the type shown in Figure 13 and described above employs an inductance coil impregnated or potted with a high permeability casting resin consisting of insulated high permeability materials suspended in a resin material such as polystyrene.

It is apparent that numerous modifications may be made of this invention without departing from the spirit and scope thereof. Representative modifications will be discussed in the following paragraphs.

The winding may be made with a number of different conducting layers. For example, paper or a dielectric resin film may be metallized with zinc, aluminum, etc., to provide a very thin conducting layer on the dielectric spacer. Suitable electrode foils include aluminum, copper, silver, lead, tin, etc. When the length of the narrow foil is appreciable, it is generally advisable to make them of a relatively highly conductive metal such as copper, aluminum or silver. Where metallized paper or resin is used, the side edges may be directly soldered or treated as by solvents or burning to remove the paper or resin backing and leave a projecting margin of metal.

The dielectric spacing material may be paper, a resin film, a resin coating on the electrode foil, a flexible ceramic coating on the foil, an oxide film on the foil, or other material which will withstand the operating voltages without breakdown. It is generally preferred to impregnate a dielectric spacer with a dielectric oil, wax or resin. To this end, the impregnation may be carried out either before or after placing the wound assembly in the housing.

The extended edges of the foils may be pressed together, sprayed with metal, soldered, welded, or otherwise interconnected to form a low resistance path to the terminal arrangements from each point in the winding. The housing is generally metal so as to produce a low impedance terminating path to the chassis or other electrical circuit points to which it is to be connected. A metal tube may be spun over the ends of the assembly against the bushing or other insulation on the axial terminal element. Alternately the winding may be wrapped in a flexible foil or provided with a sprayed metal coating. For some applications it is desirable to provide an insulating casing about the transmission line. In such cases a resin may be cast or heat-and-pressure molded about the winding, totally enclosing the latter with the exception of the axial terminal element and a ring or tab terminal from the outermost foil.

The axial terminal element which extends from both sides of the winding may be insulated from the housing by means of a bushing of a plastic material, such as a polyamide, polyethylene, rubber, polysiloxane, etc. In some instances, particularly for low voltage applications, the insulation on the axial element may be simply cotton, silk, or a wire enamel. Where extremely high operation temperatures are to be met, ceramic or polytetrafluoroethylene bushings may be employed.

The width and length of the electrode foils as well as the materials of which they are made can be varied extensively to produce designs particularly adapted to certain applications. Where relatively high distributed inductance is desired, the length of the shorter foils may be increased and the width decreased.

The present invention has been particularly described in connection with transmission lines in the form of conventional, that is paper-type condensers. It is, however, quite possible to produce transmission lines in the form of electrolytic condensers. In such instances one of the electrode foils would be of film forming metal such as titanium, aluminum, or tantalum and its surface would be provided with an insulating oxide film of the metal. Instead of a dielectric spacer an electrolyte-saturated spacer would be employed. The short electrode foils would be suitably interconnected and terminated as previously described or by other known means. The axial terminal rod or core can, if desired, be a film forming metal provided with an insulating oxide film thereon, except for foil contact areas, to lower leakage currents.

The use of cylindrical metal containers for the transmission lines of the invention is by no means critical, as the uncased wound assemblies themselves, with a low impedance terminal, ring or strip to the outer electrode foil, may be employed. Further, the convolutely wound section may be pressed flat or square without any appreciable effect upon the high frequency characteristics. The metal casing adds to the durability of the line, to the simplicity of mounting, and in some cases to the simplicity of electric connection into the circuit. Optimum electrical characteristics, particularly terminal impedance values, are obtained when metal housings are employed.

The artificial transmission lines are usually incorporated in circuits by connecting one end of the core as an imput terminal and the other end of the core as an output terminal for one side of the line. The terminal strap or metal housing for the outer foil serves as both input and output connection for the other side of the line, which, in most instances, is grounded to the chassis or container of the complete circuit assembly. Grounding is preferably carried out completely around the line periphery of the metal casing, rather than at one or two isolated points.

As many apparently widely different embodiments of this invention may be made without departing from the spirit and scope hereof, it is to be understood that the invention is not limited to the specific embodiments hereof, except as defined in the appended claims.

What is claimed is:

1. In a high voltage low-pass filtering unit for transmitting electric currents of low frequency and by-passing undesired currents of high frequency, the combination of an assembly of first and second elongated electrode strata, dielectric sheet material interposed between said strata, said strata and sheet material being convolutely wound together about a central electrically conductive core, said first elongated electrode stratum being separated into an inner and outer section spaced from each other along the length of said dielectric sheet material to thereby provide inner and outer series-connected capacitors in conjunction with said second electrode stratum within said wound assembly, said separate sections of said first electrode stratum being narrower in width than said dielectric sheet material, said second elongated electrode stratum being wider than said dielectric sheet material and projecting axially from both sides of said wound assembly, low-resistance structure separately interconnecting the projecting portions of said second stratum on each side of said wound assembly, a metallic casing enclosing said assembly, and means connecting the outer section of the first stratum to said casing and the inner section of the first stratum to said core.

2. A low-pass filter unit for transmitting electric currents of low frequency and by-passing undesired currents of high frequency, said unit comprising a tubular electrically conductive sheath, an inductor positioned centrally in said sheath and having axially extending input and output terminals projecting therefrom, artificial transmission lines positioned within said sheath about each axially

projecting terminal of said inductor and including an electrical connection to said sheath and a separate electrical connection to the adjacent terminal, said artificial transmission lines each including an assembly of first and second elongated electrode strata insulated from each other by dielectric sheet material and convolutely wound together about its inductor terminal, the first stratum being transversely divided into inner and outer stratum sections of substantially equal length, the inner section being electrically connected at its inner end to the core, and the outer section being electrically connected at its outer end to said sheath, one of said strata including side portions projecting throughout substantially its entire length from both sides of the wound assembly and low-resistance connecting structure separately electrically connecting said projecting stratum portions.

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