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Pflanz

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[54] **TRANSIENT DAMPING MEANS FOR AN ELECTRICAL INSTALLATION**

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[52] **U.S. Cl.** ..... **333/12;** 333/70 S; 333/81 R; 174/126 CP

[51] **Int. Cl.** **H04b 3/28**

[58] **Field of Search** ..... 333/12, 81 R, 79, 70 S; 174/126 CS, 126 CL, 2; 178/45

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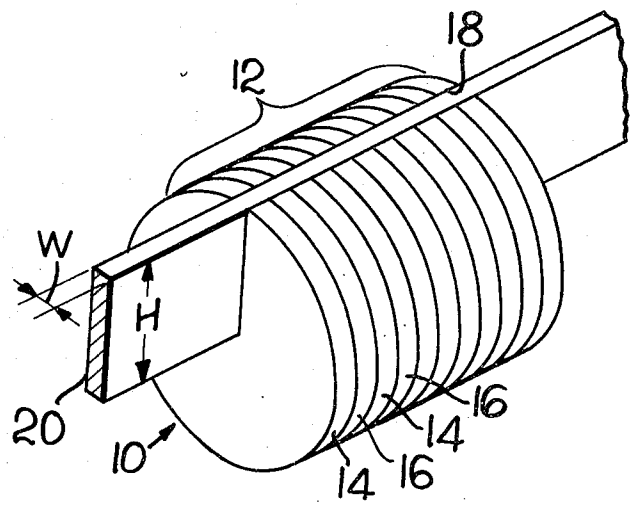
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Assistant Examiner—Wm. H. Punter
Attorney, Agent, or Firm—Robert C. Sullivan

[57] **ABSTRACT**

There is provided in accordance with an embodiment of the invention a wave trap assembly for connection in series with an electrical conductor means such as an electrical power transmission line for the purpose of attenuating or damping transient high frequency phenomena, and comprising a non-magnetic conductor member received in a slot in a stack of magnetic laminations, whereby the inductive effect of the magnetic laminations causes displacement of the high frequency transient currents into a reduced cross-sectional area of the conductor contiguous the outer periphery of the magnetic laminations, to modify the action of the normal high frequency skin effect whereby to more effectively attenuate the high frequency phenomena. The conductor may be cast in the slot. In a modified embodiment, the radially or peripherally outer portion of the conductor lying in the slot of the stack of magnetic laminations may be made of a higher resistance material than the radially inner portion of the conductor whereby to further attenuate high frequency transient currents flowing in the peripherally outer portion of the conductor. In a still further embodiment of a conductor lying in a slot in a stack of magnetic laminations, a radially inner conductor portion of larger cross section may be connected by a narrow cross-section neck portion to a radially outer conductor portion of smaller cross section than the radially inner conductor portion whereby to promote the transfer of high frequency transients to the outer portion. In another embodiment, the wave trap assembly may comprise a plurality of circumferentially spaced conductor members lying in slots in the peripheral surface of a drum-like stack of magnetic laminations. In still another embodiment, a plurality of wave trap assemblies may be supported by stand-off insulators and by conducting spacers in such manner as to be connected in series with each other and in series with the power transmission line.

25 Claims, 14 Drawing Figures



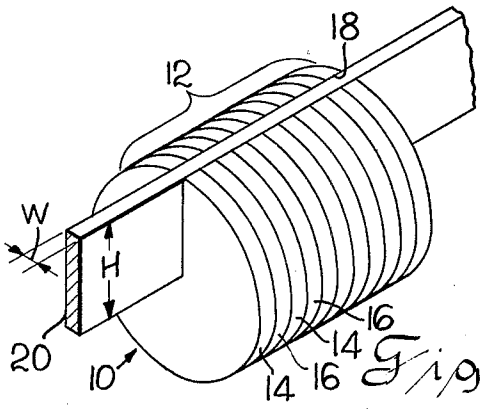


Fig.-1

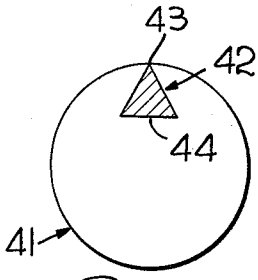


Fig.4a

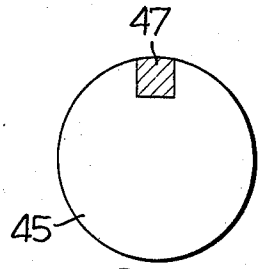


Fig.4b

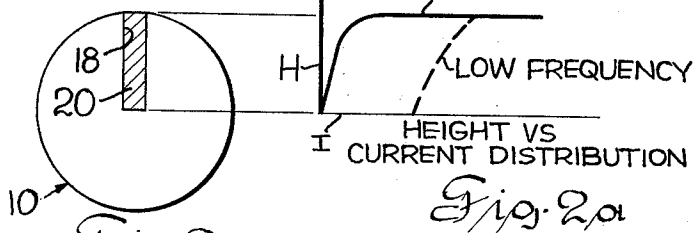


Fig.2a
Fig.2

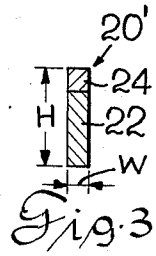


Fig.3

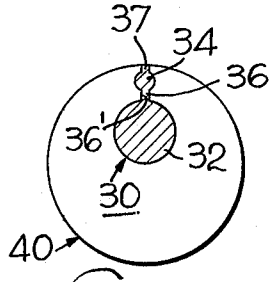


Fig.4

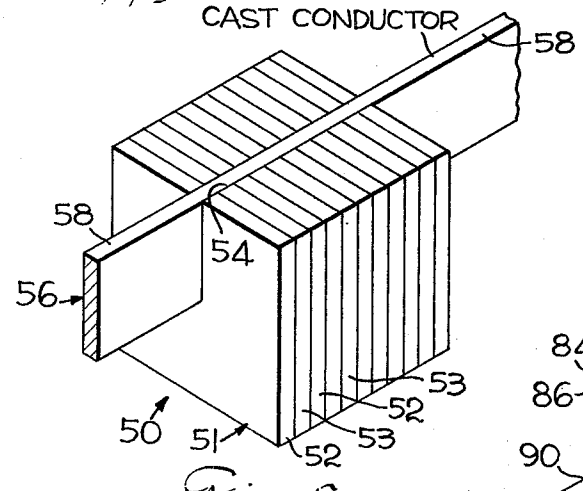


Fig.5

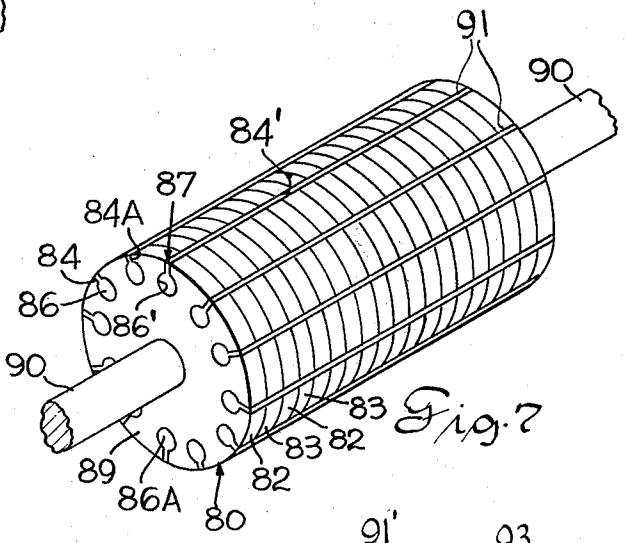


Fig.7

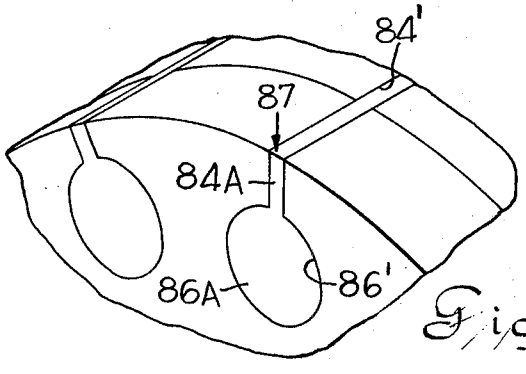


Fig.8

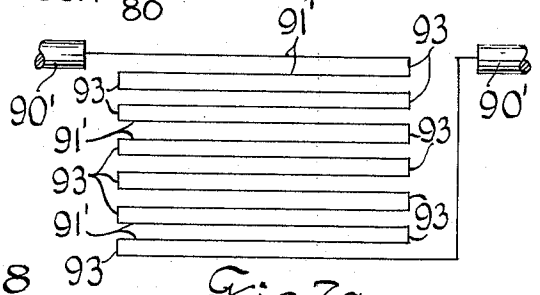


Fig.7a

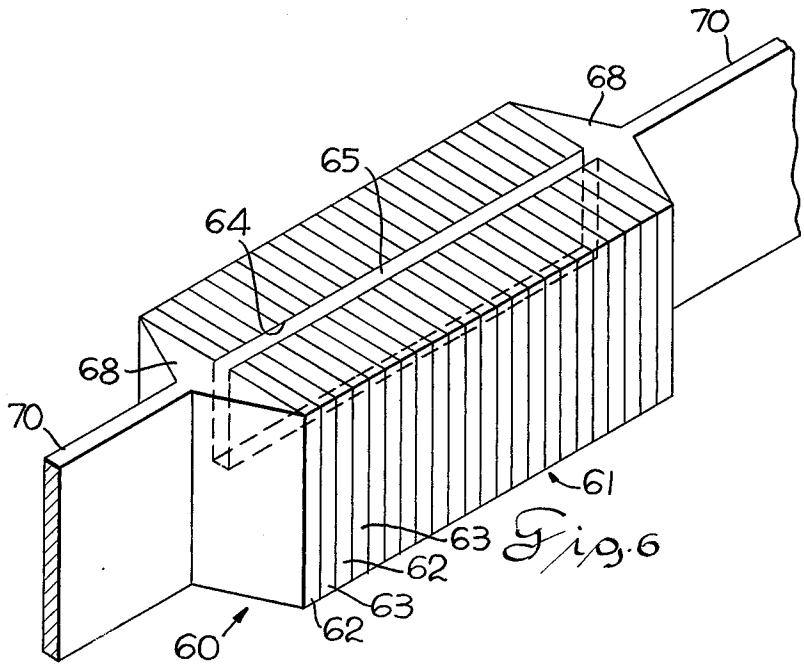


Fig. 6

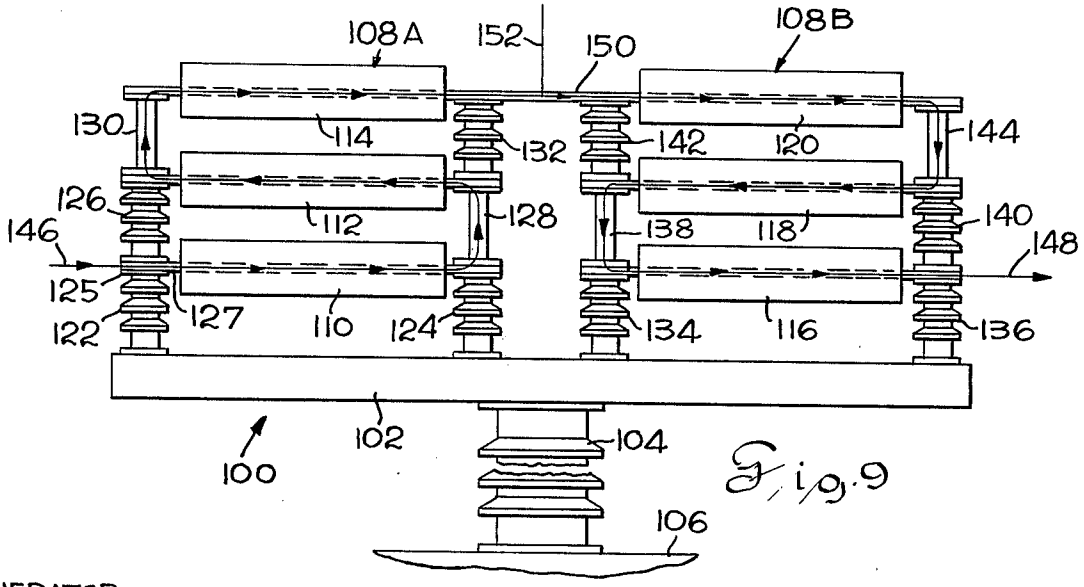


Fig. 9

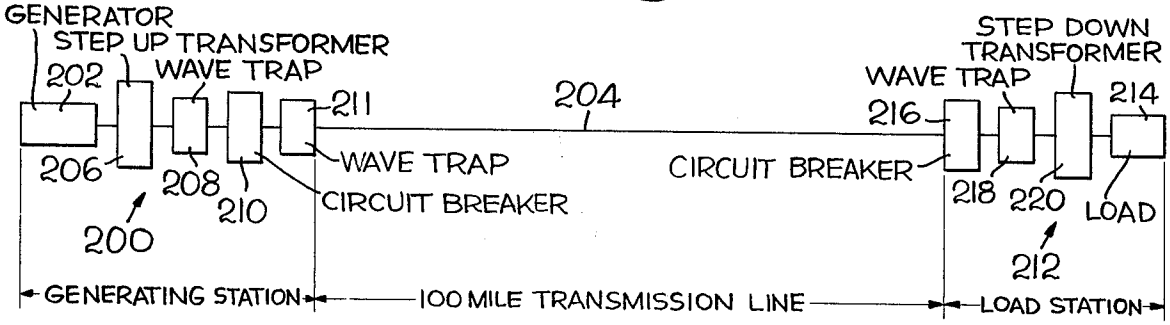


Fig. 10

TRANSIENT DAMPING MEANS FOR AN ELECTRICAL INSTALLATION

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to electrical conductors or electrical transmission lines which have good conductive characteristics for low frequency electrical phenomena, but which present a resistance path for attenuating or damping high frequency phenomena such as switching transients, travelling waves, and lightning surges.

2. Description of Prior Art

When a circuit breaker is closed to energize or reclose a power line, voltage surges of relatively high magnitude and high frequency may be produced. This problem is particularly acute during the switching operation for energizing a capacitor bank when prestriking causes travelling waves which are amplified at a cable line junction and reflect at a transformer terminal and can cause end-of-the-line overvoltages of, for example, several times normal crest voltage. High magnitude, high frequency voltage surges also occur on a transmission line when lightning strikes equipment connected to the line, or, in another example, during a "short line fault."

The high frequency transients of the type which might occur on a high voltage transmission line may have frequencies, for example, in the range 1 Kilohertz to 1 Megohertz (i.e., 1,000 cycles/sec. to 1,000,000 cycles/sec.).

One well-known method of reducing the magnitude of switching surges is to preinsert a resistance of suitable value into the curcuit during the closing operation just prior to the moment at which the main contacts engage. Other methods have involved the use of parallel surge-modifying capacitances in parallel with the transformer terminals; and a third prior art method of attenuating the undesirable high frequency electrical transients in a transmission line or the like has been the use of series inductances in the line. The prior art methods just briefly discussed are undesirable since they are costly, involve high losses, and the resistor insertion method mentioned requires the use of separate switching means for the insertion of the resistor.

It is also known to utilize conductor arrangements for attenuating undesirable high frequency transients which operate upon the principle that high frequency currents tend to flow substantially only in the radially outer peripheral portion of the conductor due to the well-known "skin effect" principle. Prior art teachings of high frequency transient attenuation which show utilization of the skin effect principle include U.S. Pat. Nos. 3,480,382 issued to Herman R. Person; 3,531,264 issued to Herman R. Person; 3,541,473 issued to Heinz M. Schlicke et al.; and 3,543,105 issued to Robert I. Van Nice.

A literature reference relating to a utilization of the skin effect principle for attenuation of high frequency harmonics is provided in an article entitled "High Frequency AC Harmonics on a HVDC Transmission Line Might Be Attenuated by Conductor Design" by John R. Abbott, published in the periodical "Transmission and Distribution," Aug. 1969, pp. 58–60 inclusive.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an

improved electrical conductor arrangement which is a good conductor for low frequencies such as 60 cycle electrical phenomena or for direct currents but which presents a substantial resistance for high frequency electrical phenomena such as switching transients and traveling waves.

It is another object of the invention to provide for insertion in an electrical conductor such as an electrical power transmission line of other electrical installation a "wave trap" which attenuates or damps high frequency electrical phenomena such as switching transients and traveling waves but which presents a good conductive path for low frequency electrical phenomena such as 60 Hz (60 cycle) phenomena, and which wave trap is completely static, self-adjusting to transients and inexpensive to manufacture.

It is a further object of the invention to provide a wave trap assembly for insertion in series with a transmission line for attenuating or damping high frequency electrical transients, but having good conductive characteristics for low frequency electrical phenomena, and which assembly is compact and compatible with existing equipment.

In achievement of these objectives, there is provided in accordance with an embodiment of the invention a wave trap assembly for connection in series with an electrical conductor means such as an electrical power transmission line to attenuate or damp transient high frequency phenomena, and comprising a non-magnetic conductor member received in a slot in a stack of magnetic laminations, whereby the inductive effect of the magnetic laminations causes displacement of the high frequency transient currents into a reduced cross-sectional area of the conductor continguous the outer periphery of the magnetic laminations, to modify the action of the normal skin effect whereby to more effectively attenuate the high frequency phenomena. The conductor may be cast in the slot. In a modified embodiment, the radially or peripherally outer portion of the conductor lying in the slot of the stack of magnetic laminations may be made of a higher resistance material than the radially inner portion of the conductor. In a still further embodiment of a conductor lying in a slot in a stack of magnetic laminations, a radially inner conductor portion of larger cross section may be connected by a narrow cross-section neck portion to a radially outer conductor portion of smaller cross section than the radially inner conductor portion whereby to promote the transfer of high frequency transients to the outer conductor portion. In another embodiment, the wave trap assembly may comprise a plurality of circumferentially spaced conductor members lying in slots in the peripheral surface of a drum-like stack of magnetic laminations. In still another embodiment, a plurality of wave trap assemblies may be supported by stand-off insulators and by conducting spacers in such manner as to be connected in series with each other and in series with the power transmission line.

Further objects and advantages of the invention will become apparent from the following description taken in conjunction with the following drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a "wave trap" assembly for attenuating high frequency transients in accordance with the invention;

FIG. 2 is a cross-sectional view of the wave trap assembly of FIG. 1;

FIG. 2*a* is a graphical representation showing the high frequency current distribution in the conductor and the low frequency current distribution in the conductor relative to the height of the conductor;

FIG. 3 is a view in transverse cross-section of a modified conductor adapted for use in the wave trap assembly in place of the conductor shown in FIGS. 1 and 2, the conductor of FIG. 3 including a high resistance material contiguous the radially outer edge thereof;

FIG. 4 is a view of modified conductor which may be used in place of the conductor shown in FIGS. 1, 2 and 3, and including a small cross-section high resistance path for high frequency currents and a larger cross-section path for low frequency currents;

FIGS. 4*a* and 4*b* are views in transverse cross section of wave trap assemblies using conductors of triangular and square cross section, respectively;

FIG. 5 is a view in perspective of a modified wave trap assembly which is generally similar to the wave trap assembly of FIG. 1 but in which the conductor member such as an aluminum or copper conductor (particularly aluminum) is cast in place in the slot in the magnetic laminations of the assembly;

FIG. 6 is a modified wave trap assembly along the lines of the structure shown in FIG. 5 in which the cast-in-place conductor includes integrally cast end portions which serve to retain the stack of magnetic laminations in assembled relation to each other;

FIG. 7 is a view in perspective of a modified wave trap assembly including a plurality of parallel-connected conductor elements cast in place in circumferentially spaced relation to each other around the periphery of a drum-like structure formed of magnetic laminations;

FIG. 7*a* is a schematic diagram of a modified arrangement in which the conductors on drum 80 are connected in series with each other, rather than in parallel;

FIG. 8 is an enlarged view showing the cast-in-place conductor elements of the embodiment of FIG. 7;

FIG. 9 is a view in vertical elevation of an assembly of a plurality of "wave trap" assemblies such as those shown in FIGS. 1–8, inclusive, connected in series with each other; and

FIG. 10 is a schematic illustration of a typical installation of wave traps in series with an electrical transmission line.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1 there is generally indicated at 10 a wave trap adapted to attenuate high frequency electrical transients and adapted to be connected in series with an electrical transmission line. The wave trap 10 includes a stack 12 of alternate disk-like circular laminations 14 of magnetic material such as soft iron or transformer steel, and laminations 16 of a suitable electrically insulating material. The insulating laminations 16 are normally much thinner than the magnetic laminations 14, but the drawings do not attempt to show this. The function of insulating laminations 16 is to prevent the flow of electrical current through the magnetic laminations 14 lengthwise of the stack. Instead of using insulating laminations 16, as shown, the magnetic laminations 14 may instead be coated with an insulating varnish or the like to prevent the flow of current; or, as a still further alternative, the normal oxides on the surface of the magnetic laminations may serve as an electrical insulating barrier between laminations which prevents the flow of current. It might be noted that upon the occurrence of high frequency electrical transients, the occurrence of eddy currents in the magnetic laminations is not undesirable, since the losses produced by such eddy currents are reflected as a resistance which tends to damp the high frequency transients.

The stack 12 of the alternate magnetic and insulating laminations 14 and 16 is provided with a radially extending slot 18 throughout the entire length of the stack 12, and conductor member 20 of non-magnetic material which is connected in series with the electrical transmission line is received within the slot 18. The conductor 20 is preferably so dimensioned that its height or radial dimension H relative to stack 12 is substantially greater than its transverse or width dimension W. In the example shown in FIG. 1, the conductor 20 is entirely of one material such as copper or aluminum, for example, having good electrical conductive characteristics. As can best be seen from an examination of the graph of FIG. 2*a*, at ordinary low frequency power such as 60 cycles, the current is distributed substantially uniformly over the entire height (H) of conductor 20 along the length of the conductor. However, if high frequency transient electrical currents which may, for example, be anywhere in the range 1 Kilohertz to 1 Megahertz (i.e., 1,000 cycles/sec. 1,000,000 cycles/sec.), are flowing in the conductor 10 as might be due to a switching operation or due to the occurrence of a lightning surge, the high frequency transient currents flow substantially only in the radially outer portion of the height (H) of conductor 20, near the circumference of the circular laminations 14, due to the skin effect principle in accordance with which high frequency electrical currents move to the outer periphery of the electrical conductor, as modified by the fact that the conductor is received in the slot 18 of the stack of magnetic laminations 14.

If the conductor 20 were not received in the slot 18 of the magnetic laminations 14 as shown, the skin effect phenomena would cause high frequency currents to flow in a skin contiguous the entire periphery of the conductor (i.e., along all four edges of the conductor 20). However, when the conductor 20 is received in the slot 18, as shown, in FIG. 1, the inductive effect of the presence of the magnetic laminations 14 will cause the high frequency currents to flow only contiguous the peripherally (or radially) outer edge of conductor 20. The net effect of this is that the area of conductor 20 available for passage of the high frequency transients is substantially less when the conductor 20 is received in the slot 18 of the stacked magnetic laminations, as shown in FIG. 1, than if the conductor 20 were not so located. The skin effect phenomenon in effect reduces the cross-sectional area of the conductor which is available for carrying the high frequency transient currents, thereby increasing the resistance of the conductor to the high frequency transients as compared to the resistance offered by conductor 20 to flow of low frequency power currents, such as 60 cycle currents. The increase in the resistance caused by the reduction in effective cross-sectional area of the conductor 20 available for carrying high frequency transients due to the skin effect phenomena is promoted and enhanced even more by the fact that the conductor 20 is received in the slot

18 of stack 12 of magnetic laminations 14 as just described. As a result of the foregoing, the high frequency electrical transient currents and voltages are more greatly attenuated or damped due to the location of conductor 20 in slot 18 of the magnetic laminations.

As shown in FIG. 3, the conductor generally indicated at 20' may be used in substitution of the conductor 20 and be positioned in the slot 18 shown in FIGS. 1 and 2. The conductor 20' of FIG. 3 is of generally rectangular cross-section, preferably having a relatively large height-to-width ratio including a radially inner (relative to slot 18) conductor portion 22 which may be made of a non-magnetic material having good conductive properties such as copper or aluminum, and a radially outer conductor portion 24 which lies in radially abutting relation to conductor portion 22 and which is made of a higher resistance non-magnetic material such as, for example, (1) lead; (2) tin; (3) aluminum (if conductor 22 is made of copper); (4) fibre metal made of a non-magnetic metal; or (5) foam metal made of a non-magnetic metal. All of the materials just mentioned have a higher resistance per unit length than does the conductive material such as copper of which the portion 22 of the conductor is made. Low power frequencies will flow mostly in inner conductor portion 22. High frequency transients will, due to skin effect as enhanced by the location of conductor 20' in the slot 18 in the stack of magnetic laminations, flow substantially exclusively in the outer conductor portion 24 where the high resistance material, together with the reduced cross sectional area of conductor portion 24 as compared to the substantially larger cross-sectional area of the conductor portion 22, will substantially attenuate the high frequency transients flowing through high resistance conductor portion 24.

For a given material of which radially outer portion 24 of conductor 20 is made, a given frequency of the high frequency transients will flow at a certain depth radially inwardly of the outer periphery of the conductor portion 24. This depth will vary for a given material of which portion 24 is made depending upon the frequency of the transients, the depth of the "skin" in which the current flows decreasing with increase in frequency. In determining the radial depth of high resistance conductor portion 24, allowance should be made for the low end of the range of transient frequencies which it is desired to attenuate.

Referring now to FIG. 4 there is shown a further modification in which a non-magnetic conductor generally indicated at 30 is a composite member including a radially inner portion of larger cross-section 32 and a radially outer portion 34 of small cross-section compared to the cross-section 32. The radially inner and outer portions 32 and 34 of the conductor 30 are connected by a connecting narrow conducting neck portion 36 of non-magnetic material. The composite conductor 30 (formed of portions 32-34-36) is received in a correspondingly-shaped slot in an assembly generally indicated at 40 which may be similar to the stack 12 shown in FIG. 1 and be composed of a plurality of alternately arranged magnetic laminations and laminations of insulating material suitably held together in stacked relation to each other. The slot extends for the entire axial length of assembly 40. Instead of using insulating laminations, the magnetic laminations may be coated with an insulating coating to prevent flow of electrical current along the stack of laminations as previously explained. The radially outer conductor portion 34 may include a narrow projecting neck portion 37 which extends to the outer periphery of assembly 40. Alternatively, the space occupied by projecting neck portion 37 may be left as an air gap. The narrow connecting neck portion 36 may also be left as an air gap for most of the length of the wave trap, the conductor portions 32 and 34 being conductively connected together at each end of the wave trap, thus placing conductor portions 32 and 34 in electrically parallel relation with each other.

The portion 32 of composite conductor 30 in FIG. 4 carries the low frequency currents, such as 60 cycles, (60 Hz) but upon the occurrence of high frequency transient currents, such as during a switching operation or a lightning surge, the high frequency transient currents, due to the skin effect principle, and enhanced by the location of the conductor 30 in the stack of magnetic laminations, move to the outer peripheral portion 34 of the composite conductor. The reduced cross-sectional area of the conductor portion 34, provides a substantially increased resistance per unit length as compared to the resistance of the larger cross-sectional area inner conductor portion 32, with the result that the higher resistance of the conductor portion 34 causes substantial attenuation of the high frequency electrical transients flowing through the portion 34 of the composite conductor 30.

The narrow slot 36' connecting radially inner and outer conductor portions 32 and 34 due to its narrowness provides a gap of decreased dimensions in the magnetic laminations of stack 40, thus increasing the magnetic permeability of the magnetic flux path around lower conductor portion 32, thereby increasing the inductance of lower conductor portion 32. As previously explained, slot 36' receives conductor portion 36 of non-magnetic material, preferably the same material as conductor portions 32 and 34.

The increased inductance of lower conductor portion 32 due to the narrowness of slot 36' promotes the shifting of the higher frequency currents (when these occur) into the smaller cross-section radially outer conductor portion 34, where the increased resistance to high frequency current flow due to the smaller cross-section of conductor portion 34 causes the attenuation of high frequency currents and voltages.

The composite conductor 30 may be made of one non-magnetic metal of good electrical conductive properties such as copper or aluminum, the metal being cast into the slot in the stack of laminations by a die casting process.

There is shown in FIG. 4*a* a stack 41 of magnetic laminations suitable insulated from each other similar to the stacks previously described, and provided contiguous the outer periphery of the stack with a slot of triangular cross-section in which a conductor generally indicated at 42 of a metal such as copper or aluminum is positioned. The apex 43 of the triangular cross-section conductor is positioned at the radially outer portion of the conductor and base 44 of conductor 42 lies at the radially inner portion of the conductor. When power frequency currents such as 60 cycle currents are passing through conductor 42, the current will be distributed substantially uniformly over the cross-section of conductor 42. However, upon the occurrence of high frequency transient currents, such currents, due to skin effect, as enhanced by the location of

the conductor 42 in the stack of magnetic laminations, will tend to crowd into a relatively small cross-section area of the conductor in a region near apex 43, whereby to provide increased resistance to flow of the high frequency transient currents.

There is shown in FIG. 4*b* a stack 45 of magnetic laminations similar to those previously described, and having a slot in which a conductor 47 of square cross-section is positioned. As previously described, high frequency currents will crowd into the radially outer portion of the conductor, whereby the reduced cross-sectional area available for the high frequency transients will increase the resistance to the flow of high frequency transients thereby attenuating or damping the high frequency transients.

Referring now to FIG. 5 there is shown a modified wave trap construction, generally indicated at 50, for connection in series with a power transmission line and including a stack 51 of rectangular laminations 52 of steel or of other suitable magnetic material with insulating laminations or other suitable insulation 53 between adjacent magnetic laminations. The stack 51 of laminations 52 and 53 is provided with a slot 54 extending for the entire length thereof; and an aluminum or copper conductor generally indicated at 56 is cast in the slot 54. Aluminum is preferably used as the conductor metal when the conductor is cast in the slot. The metal conductor 56 includes end portions thereof indicated at 58 which extend beyond the opposite ends of the stack 51. The operation of the embodiment of FIG. 5 is similar to the embodiment of FIG. 1 previously described.

Referring now to FIG. 6 there is shown a still further modified wave trap assembly generally indicated at 60 which is generally similar to the wave trap assembly shown in FIG. 5 and includes a stack 61 of rectangular laminations of magnetic material such as iron or steel indicated at 62 with contiguous magnetic laminations being separated by insulating spacers or laminations or other suitable insulation 63. The assembly or stack 61 is provided throughout its length with a longitudinally extending slot 64 similar to the slot shown in FIGS. 1, 2 and 5 and a conductor member 65 of a suitable non-magnetic conductive material such as aluminum is cast into the slot 64. However, in the case of the embodiment of FIG. 6, the cast material is cast in such manner as to include end portions 68 at the opposite ends of stack 61, which end portions 68 constitute end clamping members for the stack 61 of magnetic and insulating laminations. Conductor lug portions 70 integrally cast with the end portions 68 and with the main conductor 65 extend longitudinally beyond the end portions 68 for connection into the electrical power transmission circuit. The operation of the embodiment of FIG. 6 is similar to the operation of the embodiment of FIG. 1 previously described.

Referring now to FIGS. 7 and 8 there is shown a still further modified form of the invention including a cylindrical drum-like member generally indicated at 80 formed of a plurality of stacked laminations 82 of magnetic material such as iron or steel alternated with laminations 83 of insulating material. Instead of using insulating laminations 83, the magnetic laminations 82 may instead be coated with an insulation material. The laminations 82 and 83 are of circular shape. Each of the circular-shaped laminations 82 and 83 is provided at its periphery with a plurality of circumferentially spaced radially inwardly extending slots 84, each communicating a short distance radially inwardly from the outer periphery of the laminations 82 or 83 with a circular cross-section slot portion 86. When the plurality of laminations 82 and 83 are stacked in assembled relation to each other, they together define a plurality of radially and axially extending slot portions 84′ of rectangular cross-section each communicating at the radially inner end thereof with a generally circular shaped cross-section radially and axially extending slot portion 86′ to define a plurality of composite slots (composite of slot portions 84′ and 86′) each generally indicated at 87 extending for the axial length of the stack assembly. Suitable means, not shown, are provided for holding the stack 80 of laminations in axially assembled stacked relation. Conductor elements 91 of non-magnetic material such as aluminum are cast into each of the plurality of composite slots 87 for the entire axial length of the stack 80. Suitable conductor means such as conducting end plate 89 and a connection stud 90 conductively connected to end plate 89 are provided at each of the opposite axial ends of the assembly 80 for connecting the cast conductors in the plurality of composite slots 87 in parallel relation to each other. The assembly shown in FIG. 7 is connected in series with the transmission line by means of the connection stud 90 at each end of drum 80. The connection studs 90 are only located at the opposite ends of the assembly shown in FIG. 7 and do not extend through the assembly.

When the current flow through the transmission line is of normal power frequency such as 60 cycles per second (60 Hz), the current will flow through the conductor portions 86A in the radially inner larger diameter portions 86′ of the slots. However, upon the occurrence of high frequency transient currents in the transmission line, the skin effect principle will cause the high frequency currents to flow in the conductor portions 84A lying in the radially outer reduced cross-sectional area slot portions 84′. Because of their reduced cross-sectional area, the reduced cross-sectional area conductor portions 84A lying in slot portions 84′ have a higher resistance than the larger cross-section conductor portions 86A, lying in the slot portions 86′ to thereby cause attenuation of the high frequency electrical transients flowing in the reduced cross-sectional area conductor portions 84A.

The conductors carried by the drum-like member 80 shown in FIG. 7 may assume other forms, as for example, the forms shown in FIGS. 1, 3, 4, 4*a* and 4*b*. Also, while the plurality of conductors carried by drum 80 have been shown and described as being connected in parallel with each other, it may instead be desirable as schematically shown in FIG. 7*a*, to connect the plurality of conductors 91′ in series with each other by the use of suitable cross-over end connections 93 and with proper insulation of the conductors 91′ from the stack of laminations (required in the case of a series connection of the conductors), as would be obvious to one skilled in the art. The opposite ends of the series winding of FIG. 7*a* are connected to terminals 90′.

Referring now to FIG. 9, there is diagrammatically shown an assembly of a plurality of wave traps connected in series relation with each other and in series with a transmission line. The assembly of FIG. 9 is generally indicated at 100. The assembly 100 includes a supporting metal frame 102 which is mounted on a suit-

able centrally located stand-off insulator or insulators **104** which, in turn, are supported at the lower end thereof upon a suitable support **106.** The assembly shown at **100** includes a pair of subassemblies respectively generally indicated at **108A** and **108B.** Each of the subassemblies **108A** and **108B** includes a plurality of separate wave traps indicated at **110, 112,** and **114** in subassembly **108A** and at **116, 118** and **120** in subassembly **108B.** Each of the wave traps diagrammatically indicated at **110, 112, 114, 116, 118,** and **120** may be similar to any one of the wave traps shown in any of the previous embodiments. The wave trap **110** is supported upon a pair of stand-off insulators or insulating posts **122** and **124** which, in turn, are supported by metal frame member **102.** The wave trap **112** is supported at the left-hand end thereof relative to the view of FIG. **9** by an insulating post **126** suitably supported on insulating post **122,** and at the right-hand end thereof relative to the view of FIG. **9** by a conductive structural member or conductive spacer **128** suitably supported on insulating post **124.**

As viewed in FIG. **9,** the wave trap **114** is supported at the left-hand end thereof by a conductive structural member or spacer **130** supported by insulator post **126,** wave trap **114** being supported at the right-hand end thereof by an insulator post **132** mounted on conductive spacer **128.**

Each of the stand-off insulators such as **122, 124,** and each of the conductive spacers such as **128** is provided at each end thereof with a flanged sleeve such as those indicated at **125** which is bolted to the contiguous vertically aligned stand-off insulator or spacer, as the case may be, and is also bolted to the projecting conductor member such as **127** of a wave trap, whereby to hold the stand-off insulators, conducting spacer, and wave trap assemblies in assembled relation to each other, as seen in FIG. **9.**

In the subassembly **108B** of FIG. **9,** the wave trap **116** is supported at the opposite ends thereof by insulator posts **134** and **136** mounted on frame member **102.** The wave trap **118** is mounted above the wave trap **116** and is supported at the left-hand end thereof by the conductive structural member or spacer **138** mounted on insulator post **134** and wave trap **118** is supported at the opposite or right-hand end thereof by the insulator post **140** mounted on insulator post **136.** The wave trap **120** is supported above the wave trap **118** at the left-hand end thereof, relative to the view of FIG. **9,** by an insulator post **142** mounted on conductive structural member **138** and is supported at the right-hand end thereof by a conductive spacer or structural member **144** mounted on insulator post **140.**

The total assembly **100** including the two subassemblies **108A** and **108B** is connected in series with the transmission line by a connection at terminal **146** of the wave trap **110** and by a terminal **148** at the right-hand end of the wave trap **116,** relative to the view of FIG. **9.** The two subassemblies **108A** and **108B** are connected in series with each other by conductor member **150** between one end of wave trap **114** and the contiguous end of the wave trap **120.** It can thus be seen that by means of the conductive members **146, 128, 130,** 150, 144, 138 and **148,** the plurality of wave traps **110,** 112, 114, 116, 118 and **120** are connected in series with each other and with the transmission line. A conductive tap member **152** is connected to the conductor member **150** between the two wave trap subassemblies **108A** and **108B** to permit one-half of the total assembly to be connected in the circuit of the transmission line if desired.

Refer now to FIG. **10** which schematically shows a typical installation of wave traps in accordance with the invention in series with an electrical transmission line. There is shown a generating station generally indicated at **200,** including an alternating current generator **202** having its output connected to the transmission line **204** through a step-up transformer **206,** a first wave trap **208,** and a circuit breaker **210.** At the generating station end, preferably another wave trap **211** is interposed between circuit breaker **210** and transmission line **204.** Note that the first wave trap **208** is interposed between the step-up transformer **206** and the circuit breaker **210** and the second wave trap **211** is interposed between circuit breaker **210** and transmission line **204.**

The opposite end of the transmission line **204,** which may be 100 miles long, for example, is connected to a load **214** at a load station generally indicated **212** through a circuit breaker **216,** a wave trap **218,** and a step-down transformer **220.** Note that the wave trap **218** is interposed between the circuit breaker **216** and the step-down transformer **220.** The wave traps **208,** 211, and **218** diagramatically shown in FIG. **10** may be of any of the types hereinbefore described and each may respectively include a plurality of wave traps, as dictated by the requirements of the installation.

While the wave trap assemblies have been described hereinbefore for use in connection with a conductor or transmission line which normally carries alternating current, any of the wave trap assemblies of the invention may also be inserted in series with a conductor which carries direct current, such as, for example, a high voltage direct current (HVDC) transmission line of the type described in the aforementioned article by John R. Abbott, published in the periodical "Transmission and Distribution," Aug. 1969, pages 58–60, inclusive, in which case the wave trap or wave traps would damp or attenuate high frequency transients such as the alternating current harmonics or ripple present on the direct current transmission line.

From the foregoing detailed description of the invention, it has been shown how the objects of the invention have been obtained in a preferred manner. However, modifications and equivalents of the disclosed concepts such as readily occur to those skilled in the art are intended to be included within the scope of this invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents in said circuit, but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, a slot extending inwardly and lengthwise of said body from an outer peripheral surface of said body, and an electrical conductor member of non-magnetic material received in said slot in magnetically inductive relation to said magnetic body, said conductor member extending to contiguous the outer peripheral end of said slot, said conductor member having substantially greater electrical conductivity than

said magnetic material, said conductor member being adapted to be connected in circuit with said conductor means whereby to transmit through said conductor member without substantial attenuation electrical currents of normal power frequency and direct current but with substantial attentuation of high frequency electrical voltages and currents.

2. An apparatus as defined in claim **1** in which said conductor member is of triangular cross section, with an apex of the triangular cross section being located at a peripherally outer portion of said slot, whereby to provide a reduced cross-sectional area and hence higher resistance path in the region of said apex for flow of high frequency currents.

3. An apparatus as defined in claim **1** which said conductor means is an electrical transmission line.

4. An apparatus as defined in claim **1** in which said conductor member is a casting in said slot.

5. An apparatus as defined in claim **4** including end clamping means at each of the opposite ends of said stack, and lug-like conductor means conductively connected to said end clamping means, said end clamping means, said lug-like conductor means, and the conductor member in said slot all being a unitary casting.

6. An apparatus defined in claim **1** in which said body of magnetic material is provided with a plurality of slots each extending lengthwise of said body and each extending inwardly from an outer peripheral edge of said body, said slots being spaced from each other peripherally of said body, and conductor means positioned in each of said slots.

7. An apparatus as defined in claim **6** in which said body of magnetic material is in the form of a cylindrical drum.

8. An apparatus as defined in claim **6** in which the conductor means positioned in the plurality of slots are connected in parallel with each other and in series with the transmission line.

9. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, a slot extending inwardly and lengthwise of said body from an outer peripheral edge of said body, and an electrical conductor member of non-magnetic material received in said slot in magnetically inductive relation to said magnetic material, said conductor member being adapted to be connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and made of material having good electrical conductive properties, and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said second portion being made of a material which is not as good an electrical conductor as the material of said first portion, whereby said second portion serves as a higher resistance conductive path for high frequency currents.

10. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, a slot extending inwardly and lengthwise of said body from an outer peripheral edge of said body, and an electrical conductor member of non-magnetic material received in said slot in magnetically inductive relation to said magnetic material, said conductor member being adapted to be connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion.

11. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, said body of magnetic material being provided with a plurality of slots each extending lengthwise of said stack and each extending inwardly from an outer peripheral edge of said body, said slots being spaced from each other peripherally of said body, a conductor member of non-magnetic material positioned in each of said slots in magnetically inductive relation to said magnetic material and adapted to be connected in circuit with said conductor means, each conductor member including a first portion lying in an inner portion of the respective slot in inwardly spaced relation to the outer periphery of said slot, and a second portion lying in the respective slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion.

12. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, said body of magnetic material being provided with a plurality of slots each extending lengthwise of said body and each extending inwardly from an outer peripheral edge of said body, said slots being spaced from each other peripherally of said body, and an electrical conductor member of non-magnetic material positioned in each of said slots in magnetically inductive relation to said magnetic material, the conductor members positioned in the plurality of slots being connected in series with each other and in circuit with the electrical conductor means.

13. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, a slot extending inwardly and lengthwise of said body from an outer peripheral edge of said body, and an electrical conductor member of non-magnetic

material received in said slot in magnetically inductive relation to said magnetic material, said conductor member being adapted to be connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion, and a narrow neck-like conductor portion connecting said first portion and said second portion along substantially the entire length of said first and said second portions.

14. An apparatus for connection in circuit with an electrical conductor menas to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a body of magnetic material, a slot extending inwardly and lengthwise of said stack from an outer peripheral edge of said body, and an electrical conductor member of non-magnetic material received in said slot in magnetically inductive relation to said magnetic material, said conductor member being connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion, said first portion and said second portion being separated by an air gap along a substantial part of the length of said first portion and said second portion, corresponding ends of said first portion and said second portion being conductively connected to each other.

15. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a stack of magnetic laminations, a slot extending inwardly and lengthwise of said stack from an outer peripheral edge of said stack, and an electrical conductor member of non-magnetic material received in said slot in magnetically inductive relation to said magnetic laminations, said conductor member being adapted to be connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and made of material having good electrical conductive properties, and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said second portion being made of a material which is not as good an electrical conductor as the material of said first portion, whereby said second portion serves as a higher resistance conductive path for high frequency currents.

16. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a stack of magnetic laminations, a slot extending inwardly and lengthwise of said stack from an outer peripheral edge of said stack, and an electrical conductor member of non-magnetic material received in said slot in magnetically inductive relation to said magnetic laminations, said conductor member being adapted to be connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area then said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion.

17. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents in said circuit but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a stack of magnetic laminations, said stack of magnetic laminations being provided with a plurality of slots each extending lengthwise of said stack and each extending inwardly from an outer peripheral edge of said stack, said slots being spaced from each other peripherally of said stack, a conductor member of non-magnetic material positioned in each of said slots in magnetically inductive relation to said magnetic laminations and adapted to be connected in circuit with said conductor means, each conductor member including a first portion lying in an inner portion of the respective slot in inwardly spaced relation to the outer periphery of said slot, and a second portion lying in the respective slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion.

18. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a stack of magnetic laminations, said stack of magnetic laminations being provided with a plurality of slots each extending lengthwise of said stack and each extending inwardly from an outer peripheral edge of said stack, said slots being spaced from each other peripherally of said stack, and an electrical conductor member of non-magnetic material positioned in each of said slots in magnetically inductive relation to said magnetic laminations, the conductor members positioned in the plurality of slots being connected in series with each other and in circuit with the electrical conductor means.

19. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but

which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a stack of magnetic laminations, a slot extending inwardly and lengthwise of said stack from an outer peripheral edge of said stack, and an electrical conductor member of nonmagnetic material received in said slot in magnetically inductive relation to said magnetic laminations, said conductor member being adapted to be connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion, and a narrow neck-like conductor portion connecting said first portion and said second portion along substantially the entire length of said first and said second portions.

20. An apparatus for connection in circuit with an electrical conductor means to substantially attenuate high frequency electrical voltages and currents but which transmits electrical voltages and currents of normal power frequency or direct current without substantial attenuation thereof, comprising a stack of magnetic laminations, a slot extending inwardly and lengthwise of said stack from an outer peripheral edge of said stack, and an electrical conductor member of nonmagnetic material received in said slot in magnetically inductive relation to said magnetic laminations, said conductor member being connected in circuit with said conductor means, said conductor member including a first portion lying in an inner portion of said slot in inwardly spaced relation to the outer periphery of said slot and a second portion lying in said slot outwardly of said first portion and nearer the outer periphery of said slot, said first portion being of substantially greater cross-sectional area than said second portion, whereby the smaller cross-sectional area of said second portion presents an increased resistance to high frequency currents flowing in said second portion, said first portion and said second portion being separated by an air gap along a substantial part of the length of said first portion and said second portion, corresponding ends of said first portion and said second portion being conductively connected to each other.

21. An assembly of damping devices for attenuating high frequency transient phenomena for connection in circuit with an electrical transmission line, each damping device comprising an electrical conductor member extending lengthwise thereof, said assembly comprising a supporting frame member, stand-off insulator means supporting and spacing said frame member relative to a supporting surface, first and second stand-off insulator members positioned in longitudinally spaced relation to each other along said frame member, a first damping device supported contiguous the respective opposite ends thereof by said first and said second stand-off insulator members, means adapted to conductively connect one end of said first damping device in series with said electrical transmission line, said one end of said first damping device being supported by said first stand-off insulator member, a first conductive spacer member, said first conductive spacer member being supported on and substantially in axial alignment with said second stand-off insulator member, a third stand-off insulator member supported on and substantially in axial alignment of the said first stand-off insulator member, a second damping device supported at one end thereof by said third stand-off insulator member and at the opposite end thereof by said first conductive spacer member, the end of said first damping device opposite said one end of said first damping device being conductively connected to said opposite end of said second damping device through said first conductive spacer member, whereby to place said first and said second damping devices electrically in series with each other, and means adapted to connect said one end of said second damping device in circuit with said electrical transmission line, whereby said first and said second damping devices are connected in series with each other and are adapted to be connected in circuit with the electrical transmission line.

22. An assembly of damping devices as defined in claim **21** in which said means adapted to connect said one end of said second damping device in circuit with said electrical transmission line comprises additional damping devices connected in series with said second damping device, the last of said additional damping devices being adapted to be connected to the transmission line, whereby to place said assembly in circuit with the transmission line.

23. An assembly of damping devices as defined in claim **21** in which the respective damping devices are of the type comprising a stack of magnetic laminations and a corresponding conductor member received in a slot in each respecitve stack, the conductor members of the plurality of damping devices being connected in series with each other and in circuit with the transmission line.

24. An assembly of damping devices for attenuating high frequency transient phenomena for connection in circuit with an electrical transmission line, said assembly comprising a supporting frame member, stand-off insulator means supporting and spacing said frame member relative to a supporting surface, and a stack of damping devices supported on said frame member in a plane substantially normal to said supporting surface, said stack comprising first and second stand-off insulator members positioned in longitudinally spaced relation to each other along said frame member, a first damping device supported in spaced relation to said frame member by said first and second stand-off insulator members, means adapted to conductively connect one end of said first damping device in circuit with the electrical transmission line, said stack comprising a plurality of additional damping devices each supported in said plane in stacked relation to said first damping device and to each other by a corresponding additional stand-off insulator at one end of each respective damping device and by a corresponding conductive spacer at an opposite end of each respective damping device, the relative position of the corresponding stand-off insulator and of the corresponding conductive spacer being reversed for successive damping devices in the said stack whereby each corresponding conductive spacer establishes a conductive connection between successive damping devices to place successive damping devices electrically in series with each other, and whereby to place the plurality of damping devices of the stack

in series with each other, and means adapted to connect the terminal end of the last damping device in said stack in circuit with the electrical transmission line.

25. An assembly of damping devices as defined in claim **24** in which the means adapted to connect one end of the stack of damping devices in circuit with the electrical transmission line comprises at least one additional stack of damping devices as defined in claim **18** whereby to place said at least one additional stack of damping devices in series with said first-mentioned stack and in circuit with said transmission line.

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