Jan. 10, 1967 W. M. KAUFMAN ET AL 3,297,969

LOW PASS FILTER WHICH DISSIPATIVELY AND REACTIVELY ATTENUATES HIGH FREQUENCIES

Filed Feb. 12, 1964 2 Sheets-Sheet 1

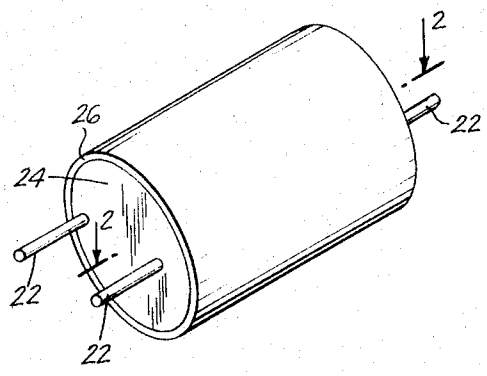


FIG. 1

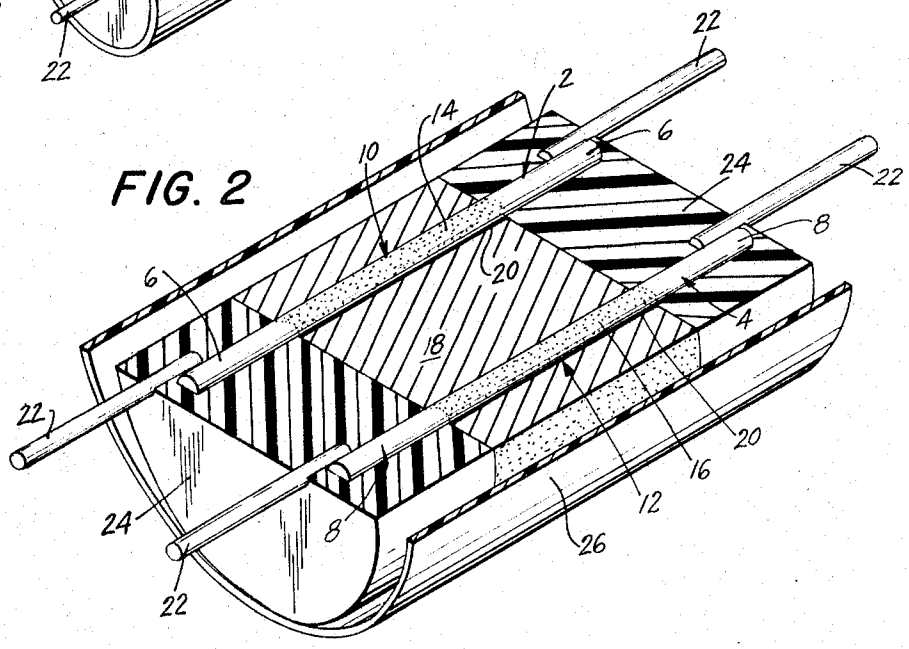


FIG. 2

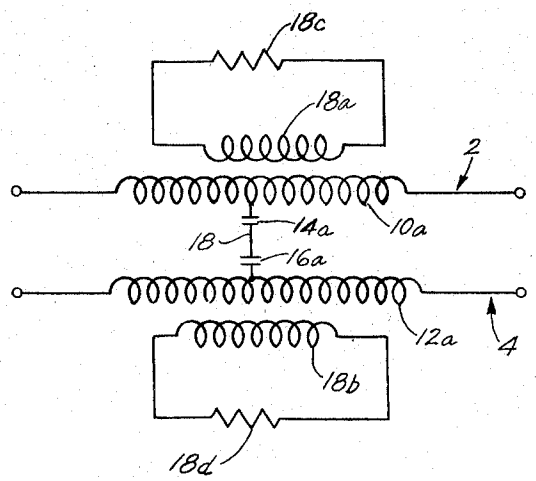


FIG. 3

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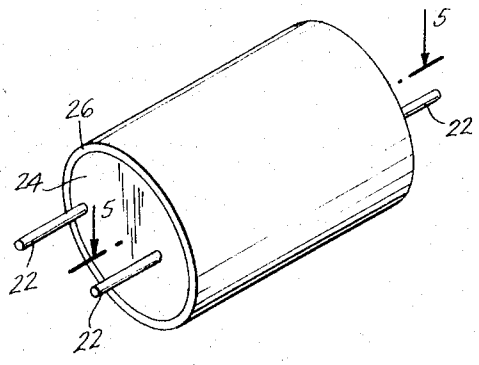


FIG. 4

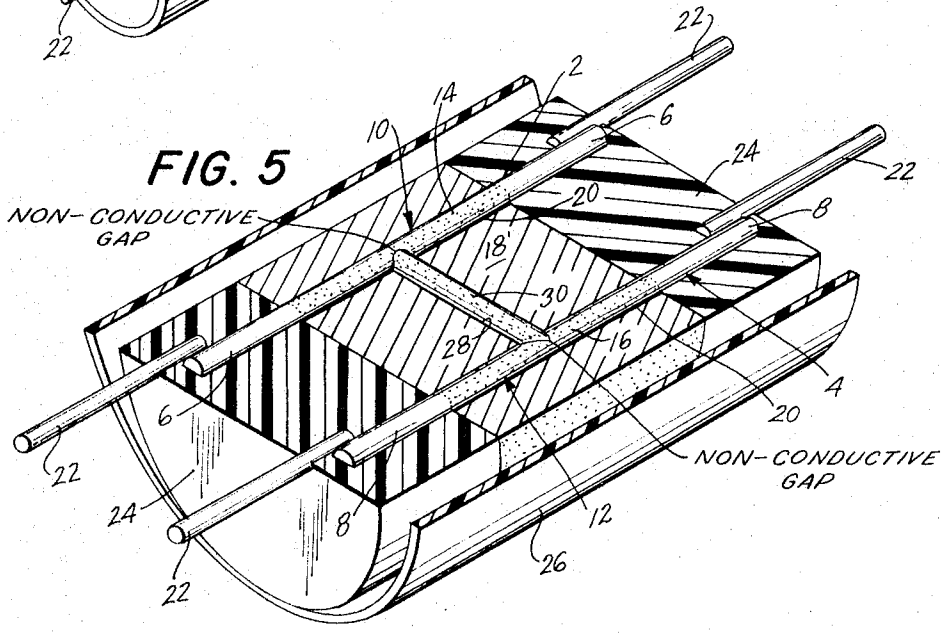


FIG. 5

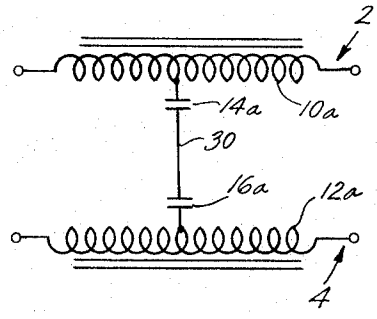


FIG. 6

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LOW PASS FILTER WHICH DISSIPATIVELY AND REACTIVELY ATTENUATES HIGH FREQUENCIES

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The present invention relates to a device for attenuating or filtering electrical signals over a wide frequency range.

Many applications exist where the filtering or attenuation of fluctuating signals is desired, and where the attenuation is to be effective over a wide frequency range. A typical and important such application arises in connection with the electrical detonation of explosives. The detonator is connected by wires to a remote station, and when the switch at that station is closed a direct current passes through those wires, sets off the detonator, and actuates the explosive mass. This type of installation is, however, potentially quite dangerous, since experience has shown that upon occasion radio frequency energy "picked up" by the conducting wires has induced in those wires an alternating current sufficiently great in magnitude to set off the detonator. Such radio frequency energy might be picked up from a short wave radio transmitter being operated in the vicinity, or even by the radiations emanating from certain types of radio receiving sets while they are in operation.

In order to avoid this danger of potentially disastrous consequences, attenuators or filters have been inserted between the detonator and the electrical line to the remote actuating station, these attenuators being designed to cause sufficient weakening of radio frequency currents induced in the lines so as to effectively prevent the detonator from being set off by such currents. While the attenuators known for this purpose have proved effective for relatively high frequency currents such as those on the order of several hundred megacycles per second, the attenuation which they produce at lower frequencies, such as those below a few megacycles per second, have not been satisfactory, and attenuation at frequencies in the upper kilocycle range has been essentially non-existent. Thus the known attenuators improve the safety of the blasting system in which they are used, but they leave a wide area where the risk of accidental detonation still exists.

An important factor in the design of attenuators used for safety purposes in connection with blasting is that the devices involved must be inexpensive, since they are expendable, and are usually destroyed when the explosion takes place. While filtering or attenuating circuits which are effective over a relatively wide frequency range are known, such circuits are generally complex and expensive and involve the use of many circuit components assembled into a bulky unit, thus making them suitable for use in the laboratory or in expensive pieces of electrical equipment but entirely unsuitable for use in applications where portability, inexpensiveness and expendability are present.

It is the prime object of the present invention to devise an attenuator structure which is small in volume, easily and inexpensively manufactured, which is reliable in the type of attenuating effect produced, and which is capable of producing a significant attenuation effect over a much wider range of frequencies than has previously been the case with simple attenuators, and in particular producing significant attenuation in the low megacycle and upper kilocycle ranges.

To accomplish these results we provide an attenuator structure comprising a pair of feed-through conductors arranged in spaced parallel relationship the outer opposed surfaces of which are covered with an insulating dielectric sheath. These wires are closely surrounded by, and preferably embedded in, a body of material which is either highly electrically conductive or highly magnetically permeable. Lead wires are electrically connected to the exposed ends of the feed-through wires, and the entire assembly is encapsulated or otherwise protected by insulating material. When the surrounding body has a highly electrically conductive characteristic, that body is electromagnetically coupled to the feed-through wires, so that any fluctuating current flowing through the feed-through wires will induce a corresponding current in the conductive body, and this transformer effect will, because of the resistance offered to the flow of the induced currents in the conductive body, cause a loss of energy in, or attenuation of, the fluctuating currents. In addition, the feed-through wires are capacitively coupled to one another through the insulating sheaths thereon and through the conductive material which separates them. When the surrounding body has a high magnetic permeability, the inductance of the feed-through wires is increased thereby, thereby attenuating particularly the higher frequencies, as has been known. We provide, in that magnetically permeable surrounding body, a passageway between the two feed-through wires, in which passageway a conductive element, which may be formed of conductive plastic material, is received, the conductive element being electrically connected at its ends to the insulating sheaths on the feed-through wires, thereby producing a capacitive shunt connection between the feed-through wires. It is believed that the existence of this capacitive shunt connection, whether in the transformer-loss embodiment having a highly conductive surrounding body or in the inductive-loss embodiment having the magnetically permeable surrounding body, accounts for the markedly improved functioning of the attenuators of the present invention at low frequencies in the upper kilocycle and low megacycle ranges.

To the accomplishment of the above, and to such other objects as may hereinafter appear, the present invention relates to the construction of an electrical attenuator as defined in the appended claims and as described in this specification, taken together with the accompanying drawings, in which:

FIG. 1 is a three-quarter perspective view of one embodiment of the present invention;

FIG. 2 is a cross sectional view on an enlarged scale, taken along the line 2—2 of FIG. 1 and showing the outer protective sheath partially removed;

FIG. 3 is a circuit diagram illustrating the equivalent circuit of the device of FIGS. 1 and 2;

FIG. 4 is a three-quarter perspective view of another embodiment of the present invention;

FIG. 5 is a cross sectional view on an enlarged scale, taken along the line 5—5 of FIG. 4 and showing the outer protective sheath partially removed; and

FIG. 6 is a circuit diagram illustrating the equivalent circuit of the device of FIGS. 4 and 5.

Turning first to the embodiment of FIGS. 1–3, the attenuator there disclosed comprises a pair of feed-through wires generally designated 2 and 4 formed of any appropriate electrically conductive material, those wires having end portions 6 and 8 respectively and intermediate portions 10 and 12 respectively. The end portions 6 and 8 are exposed, while the intermediate portions 10 and 12 are provided with insulating coatings forming a dielectric sheath therearound. In their preferred form the feed-through wires 2 and 4 are formed of tantalum, and the insulating sheaths on their intermediate portions 10 and 12 respectively are defined by a thin layer of tantalum oxide formed in situ, those insulating layers being shown in FIG. 2 by means of stripping and being identified by the reference numerals 14 and 16 respectively.

The feed-through wires 2 and 4 are arranged in spaced generally parallel relationship with the intermediate portions 10 and 12 thereof opposed to and spaced from one another. Those intermediate portions 10 and 12 are surrounded by, and are preferably embedded in, a body, generally designated 18, formed of material which is a good conductor of electricity. Typical such materials are brass or copper. In order to secure the wires 2 and 4 in place within the body 18, and prevent their longitudinal movement relative thereto, they are preferably bonded to the body 18 in any appropriate manner, as through the use of a layer of highly electrically conductive epoxy resin, identified in FIG. 2 by the reference numeral 20, such as the epoxy resin with silver particles distributed therethrough sold by DuPont Corporation.

The end portions 6 and 8 of the feed-through wires 2 extend out from the body 18, and leads 22 are electrically connected thereto in any appropriate manner. As here specifically disclosed the leads 22 are formed of tinned nickel, and they are welded to the end portions 6 and 8.

The attenuator structure as thus far described is electrically complete. For protective purposes masses of insulating plastic 24 are provided at each end of the attenuator so as to cover the ends of the body 18 and surround, protect and support the end portions 6 and 8 of the feed-through wires 2 and 4, the leads 22, and the electrical connection therebetween, the leads 22 extending out from the insulating masses 24 so that the attenuator may readily be connected in a two-wire electrical circuit. The periphery of the assembly is covered by an insulating plastic film, shell or sheath 26. Insulating epoxy resins may be used for the masses 24, while the outer covering 26 may be formed of Mylar tape.

Because the body 18 is formed of highly electrically conductive material which is insulated from the intermediate portions 14 and 16 of the feed-through wires 2 and 4, the existence of any fluctuating or alternating currents in the feed-through wires 2 and 4 will cause correspondingly fluctuating currents to be induced in the body 18, and the electrical resistance of that body 18 will cause energy losses to occur which will attenuate the original fluctuating signal. It will be recognized that this is the well known "eddy current" phenomenon. Thus, as indicated in FIG. 3, an equivalent circuit representation of the embodiment of FIGS. 1 and 2, the intermediate portions 10*a* and 12*a* of the feed-through wires 2 and 4 respectively are indicated as being transformer-coupled to inductances 18*a* and 18*b* respectively, those inductances in turn being conductively connected to electrical resistances 18*c* and 18*d* respectively. The inductances 18*a* and 18*b* represent those portions of the conductive body 18 which are transformer-coupled to the feed-through wire portions 10 and 12, and the resistances 18*c* and 18*d* represent the electrical resistivity of the body 18 which is active on the currents induced therein.

Also indicated on FIG. 3 are capacitors 14*a* and 16*a* electrically connected in series between inductances 10*a* and 12*a*. These represent, in schematic fashion, the capacitances between the conductive body 18 and the intermediate portions 10 and 12 respectively of the feed-through wires 2 and 4 respectively, the dielectric of those capacitors 14*a* and 16*a* being defined by the insulating sheaths or coatings 14 and 16 respectively on the intermediate feed-through wire portions 10 and 12 respectively.

The transformer coupling and "eddy current" effect will be mainly effective to attenuate high frequency currents on the order of 100 to 200 megacycles per second. As the frequency falls below such values the degree of attenuation produced by the "eddy current" effect will become less. However, at such lower frequencies, on the order of a few megacycles per second or in the upper kilocycle range, the by-pass defined by the capacitors 14*a* and 16*a* will become effective, that capacitive by-pass thus greatly increasing the frequency range of effective attenuation.

The embodiment of FIGS. 4–6 is in many respects

structurally similar with the embodiment of FIGS. 1–3, and the same reference numerals are applied to corresponding structural elements in the two embodiments. The body 18′ which surrounds the intermediate portions 10 and 12 of the feed-through wires 2 and 4 in the embodiment of FIGS. 4–5 is, however, differently constituted from the body 18 of the embodiment of FIGS. 1 and 2. More specifically, the body 18′ of FIGS. 4 and 5 is formed of a highly magnetically permeable material such as ferrite, this being the type of material which has previously been used in low cost attenuators of the type under discussion. Because the material of which the body 18′ is formed does not have a high degree of electrical conductivity, no appreciable "eddy current" effect occurs therein when fluctuating currents pass through the feed-through wires 2 and 4, as was the case in the embodiment of FIGS. 1 and 2. However, because of the highly magnetically permeable nature of the body 18′, the effective inductance of the intermediate feed-through wire portions 10 and 12 is greatly increased, and this in turn adds to the effectiveness of the attenuating action, particularly at high frequencies.

In order to give rise to effective attenuation at lower frequencies, we provide, in the body 18′, a laterally extending passage 28 which extends between the feed-through wire portions 10 and 12. A highly conductive member 30 is received within that passage 28 and has its ends engaging and electrically connected to the insulating sheaths 14 and 16 on the intermediate portions 10 and 12 respectively. The member 30 is conveniently formed of a conductive epoxy resin.

The effect of this conductive member 30 is illustrated in the equivalent circuit diagram of FIG. 6. The ends of the conductive member 30 are capacitively connected to the intermediate feed-through wire portions 10 and 12 by capacitors 14*a* and 16*a*, the dielectric thereof being defined, as was the case in the embodiment of FIGS. 1 and 2, by the insulating sheaths 14 and 16 respectively. Thus a capacitive by-pass is provided between the feed-through wires 2 and 4, which capacitive by-pass becomes particularly effective to attenuate fluctuating currents of lower frequencies which may appear in the feed-through wires 2 and 4.

The attenuators here disclosed represent virtually the quintessence of structural simplicity and reliability and small size. They are susceptible of very inexpensive mass production and therefore are particularly adaptable for applications, such as in the blasting field, where devices must be expendable. They provide greater attenuation at all frequencies of interest (from audio to microwave) than is provided by prior art devices of comparable size. For example, at 500 megacycles per second, the new device of "transformer-loss" type, when compared with either ferrite or powdered iron prior art devices, provides about 18 db more attenuation and at 50 megacycles per second the new device provides at least 28 db more attenuation per centimeter of device length. Although, because of its small size, high attenuation is not obtained at frequencies below 1 megacycle per second, the new devices described here do provide more attenuation per centimeter of device length than do the prior art devices of comparable diameter.

While but a limited number of embodiments of the present invention have been here specifically disclosed, it will be apparent that many variations may be made therein, all within the scope of the instant invention as defined in the following claims.

We claim:

1. An attenuator comprising a pair of spaced feed-through wires extending in substantially the same direction, the ends of said wires being conductively exposed, and opposed intermediate lengths of said wires being provided with an insulating coating, said intermediate lengths of said wires being embedded and supported in a body from which said wire ends axially extend, said

body comprising, in substantially direct engagement with said insulating coating, material for inductively attenuating high frequency currents flowing therethrough, and an insulating outer portion covering the ends and sides of said body, said intermediate wire lengths being cemented to said body by a layer of conductive plastic cement, said body comprising material of high magnetic permeability and low conductivity and having a passage therein extending between said intermediate wire lengths, and a highly conductive member in said passage and electrically connected to the exposed insulated surfaces of said intermediate wire lengths.

2. An attenuator comprising a pair of spaced feed-through wires extending in substantially the same direction, the ends of said wires being conductively exposed, and opposed intermediate lengths of said wires being provided with an insulating coating, said intermediate lengths of said wires being embedded and supported in a body from which said wire ends axially extend, said body comprising, in substantially direct engagement with said insulating coating, material for inductively attenuating high frequency currents flowing therethrough, and an insulating outer portion covering the ends and sides of said body, said intermediate wire lengths being cemented to said body by a layer of conductive plastic cement, said body comprising material of high magnetic permeability and low conductivity and having a passage therein extending between said intermediate wire lengths, and a highly conductive plastic member in said passage and electrically connected to the exposed insulated surfaces of said intermediate wire lengths.

3. An attenuator comprising a pair of spaced feed-through wires extending in substantially the same direction, the ends of said wires being conductively exposed, and opposed intermediate lengths of said wires being provided with an insulating coating, said intermediate lengths of said wires being embedded and supported in a body from which said wire ends axially extend, said body comprising, in substantially direct engagement with said insulating coating, material for inductively attenuating high frequency curents flowing therethrough, and an insulating outer portion covering the ends and sides of said body, said body comprising material of high magnetic permeability and low conductivity and having a passage therein extending between said intermediate wire lengths, and a highly conductive member in said passage and electrically connected to the exposed insulated surfaces of said intermediate wire lengths.

4. An attenuator comprising a pair of spaced feed-through wires extending in substantially the same direction, the ends of said wires being conductively exposed, and opposed intermediate lengths of said wires being provided with an insulating coating, said intermediate lengths of said wires being embedded and supported in a body from which said wire ends axially extend, said body comprising, in substantially direct engagement with said insulating coating, material for inductively attenuating high frequency currents flowing therethrough, and an insulating outer portion covering the ends and sides of said body, said body comprising material of high magnetic permeability and low conductivity and having a passage therein extending between said intermediate wire lengths, and a highly conductive plastic member in said passage and electrically connected to the exposed insulated surfaces of said intermediate wire lengths.

5. An attenuator comprising a pair of spaced feed-through wires formed of tantalum extending in substantially the same direction, the ends of said wires being conductively exposed, and opposed intermediate lengths of said wires being insulated by a thin insulating coating of tantalum oxide formed thereon, said intermediate

lengths of said wires being embedded and supported in a body from which said wire ends axially extend, said body comprising, in substantially direct engagement with said insulating coating, material for inductively attenuating high frequency currents flowing therethrough, said intermediate wire lengths being cemented to said body by a layer of conductive plastic cement, said body comprising material of high magnetic permeability and low conductivity and having a passage therein extending between said intermediate wire lengths, and a highly conductive member in said passage and electrically connected to the exposed insulated surfaces of said intermediate wire lengths.

6. An attentuator comprising a pair of spaced feed-through wires formed of tantalum extending in substantially the same direction, the ends of said wires being conductively exposed, and opposed intermediate lengths of said wires being insulated by a thin insulating coating of tantalum oxide formed thereon, said intermediate lengths of said wires being embedded and supported in a body from which said wire ends axially extend, said body comprising, in substantially direct engagement with said insulating coating, material for inductively attenuating high frequency currents flowing therethrough, said body comprising material of high magnetic permeability and low conductivity and having a passage therein extending between said intermediate wire lengths, and a highly conductive member in said passage and electrically connected to the exposed insulated surfaces of said intermediate wire lengths.

7. An attenuator comprising a pair of spaced substantially parallel feed-through wires, the ends of said wires being conductively exposed and opposed intermediate lengths of said wires having an insulating sheath thereabout, a mass of material of high magnetic permeability closely surrounding and spanning the space between said intermediate wire lengths, said mass having a passage therein extending between said intermediate wire lengths, and a highly conductive member in said passage and electrically connected to the exposed insulating sheaths on said intermediate wire lengths.

8. An attenuator comprising a pair of spaced substantially parallel feed-through wires formed of tantalum, the ends of said wires being conductively exposed and opposed intermediate lengths of said wires having an insulating sheath therearound comprising tantalum oxide, a mass of material of high magnetic permeability closely surrounding and spanning the space between said intermediate wire lengths, said mass having a passage therein extending between said intermediate wire lengths, and a highly conductive member in said passage and electrically connected to the exposed insulating sheaths on said intermediate wire lengths.

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