United States Patent

Kobayashi

[15] **3,683,271**

[45] **Aug. 8, 1972**

[54] **POWER SUPPLY FILTER FOR NOISE SUPPRESSION**

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[21] Appl. No.: **49,119**

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July 17, 1969	Japan	44/67413
July 17, 1969	Japan	44/67414
Sept. 30, 1969	Japan	44/92781
Sept. 30, 1969	Japan	44/92782

[52] **U.S. Cl.** **323/76,** 333/78, 333/81, 336/181

[51] **Int. Cl.** **G05f 3/04,** H03h 7/00

[58] **Field of Search** .....323/60, 76, 83, 88; 333/70 S, 333/77, 78, 79, 81; 336/181, 188

[56] **References Cited**

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Primary Examiner—Gerald Goldberg
Attorney—Burgess, Ryan & Wayne

[57] **ABSTRACT**

The invention provides a power supply filter for noise suppression in which the windings of a plurality of lines for supplying a power supply voltage and current of a predetermined frequency are so wound around same magnetic core that the sum of the magnetic fluxes produced by the windings may become zero, thereby providing an inductance element. This inductance is almost negligible to a power supply frequency component while it is high to a high frequency noise component, so that the power supply frequency component is not attenuated while the high frequency component superposed upon the power supply frequency component is attenuated to a greater extent. A power supply filter for noise suppression which is compact in size and having a large current may be provided.

7 Claims, 17 Drawing Figures

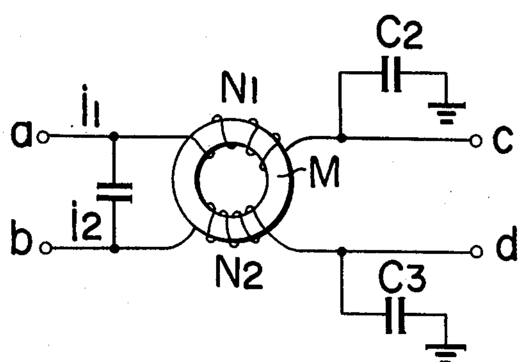


FIG. 1 PRIOR ART

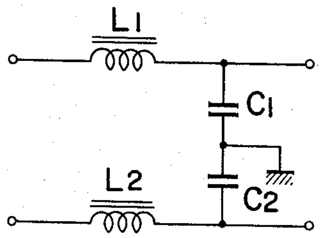


FIG. 2 PRIOR ART

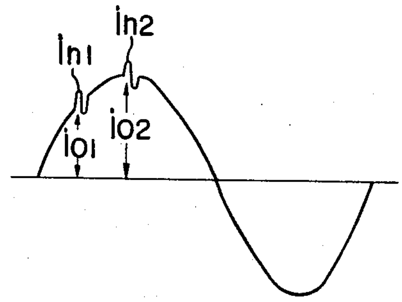


FIG. 3 PRIOR ART

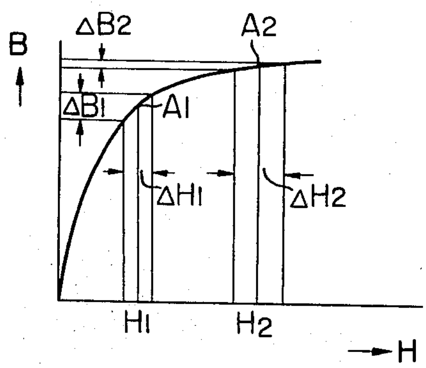


FIG. 4 PRIOR ART

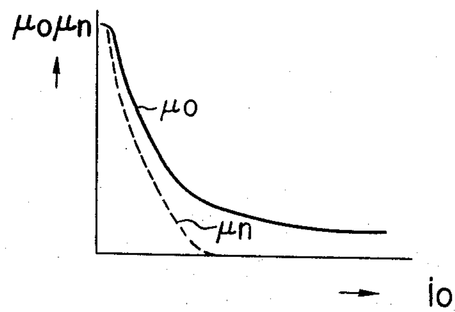


FIG. 5

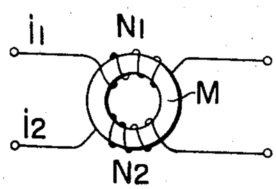


FIG. 6

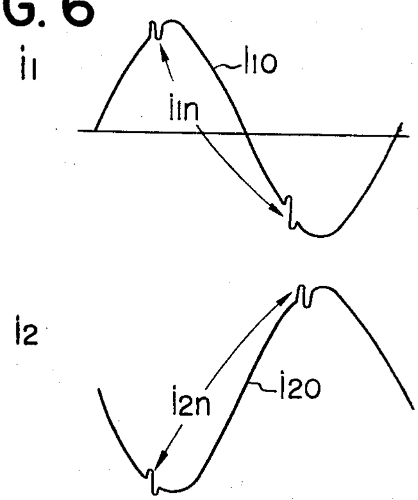


FIG. 7

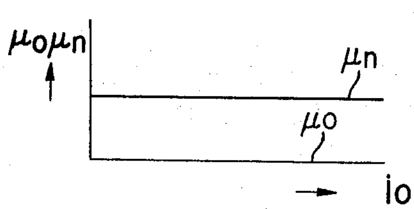


FIG. 8a

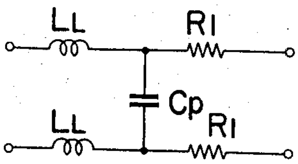


FIG. 8b

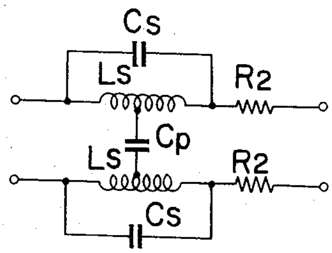


FIG. 9

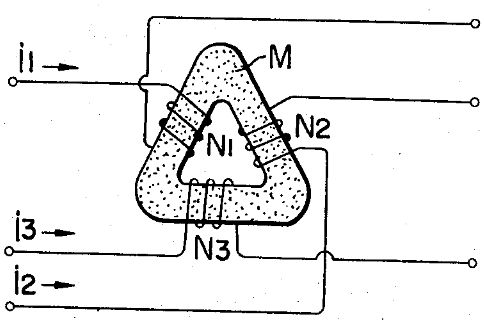


FIG. 11

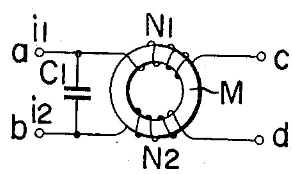


FIG. 12

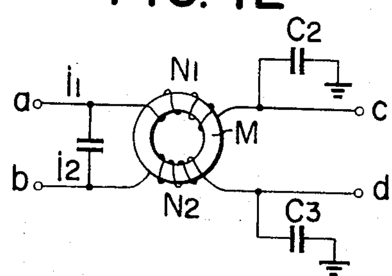


FIG. 10

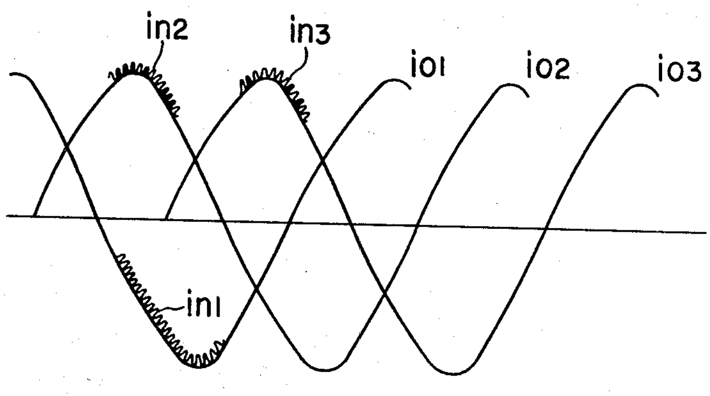


FIG. 13

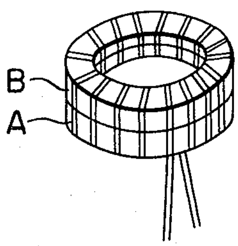


FIG. 14a

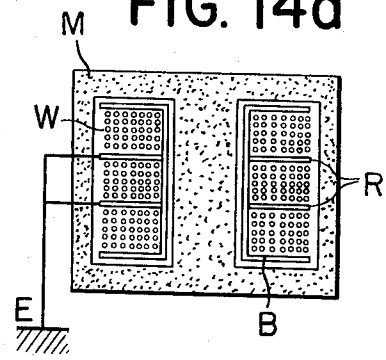


FIG. 14b

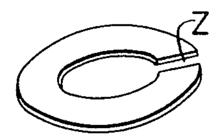
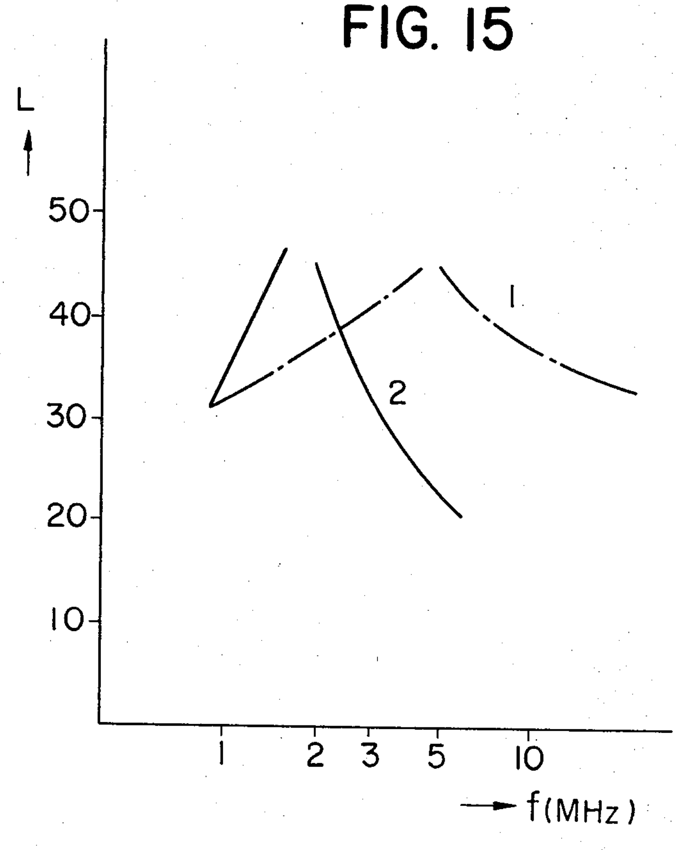


FIG. 15



POWER SUPPLY FILTER FOR NOISE SUPPRESSION

BACKGROUND OF THE INVENTION

The present invention relates to a power supply filter for noise suppression and more particularly a power supply filter for noise suppression especially adapted to suppress the noise in a high frequency band.

Substantial noise sources are devices such as electric instruments or machines and noise originated from these sources may be classified as follows:

1. noise originated from spark discharges in apparatus utilizing high frequency sparks, thermostats, vibrators, relays, interrupters, etc.

2. noise originated from both of spark discharges and sliding contacts in series motors used in electric drills, electric hair-clippers, electric mixers, etc.

3. noise originated from corona discharge in power transmission lines, ozonizer, etc. and

4. noise originated from glow discharge in fluorescent lamps, neon signs, mercury arc rectifiers, etc.

Random and nonrandom noise originated from these noise sources is radiated through the space as electromagnetic waves or may travel along power supply lines so that the electric machines and equipment are adversely affected in operation.

In order to eliminate noise, there are various methods such as electrically shielding the noise sources so as to prevent the leakage of the electromagnetic waves which cause the interference; incorporating a filter circuit and resistor in a power circuit of a noise source so as to eliminate the noise current leaking from the noise source; and/or incorporating a filter circuit in a power circuit of an equipment whose function is adversely affected by noise. A filter circuit or a power supply filter for noise suppression must be compact in size, light in weight, inexpensive and simple to manufacture and having a current rating suitable for a given load.

The inductors used in the conventional power supply filter for noise suppression comprise, for each phase, ring-shaped (toroidal), U-type and E-type magnetic cores made of ferromagnetic materials and a few turns of winding wound around these cores so as to obtain a desired inductance in conjunction with capacitors. However, the effective permeability of a magnetic core varies depending upon the load current, that is magnetizing field strength applied to the core of the filter, because the magnetization curve of the magnetic core has a saturation value. That is, both of the effective permeability for the power supply frequency component and to the high frequency noise components are reduced as the lead current is increased.

In order to avoid the reduction in effective permeability, that is inductance, in the conventional inductor an air gap is provided in a magnetic path of a magnetic core so that the applied magnetic energy may be absorbed in this air gap, thereby suppressing the saturation. Therefore, the effective permeability of the magnetic path is exponentially reduced as the length of the air gap is increased, so that a number of turns must be increased in order to obtain a desired inductance, thus resulting in increase in size of a magnetic core, in cost and in resistance of DC winding and temperature rise due to unsatisfactory heat dissipation.

SUMMARY OF THE INVENTION

In view of the above, the present invention provides a power supply filter for noise suppression, compact in size yet with a higher current capacity which attenuates greatly the high frequency components superposed upon a power supply frequency component but will not attenuate the latter. The present invention contemplates to eliminate especially the noise which is superposed on zero-phase component upon the power supply voltage and current.

The present invention is characterized by the fact that a power supply filter for noise suppression comprises one magnetic core or magnetic path and the windings of a going-and-return line wound around the magnetic core or path. The magnetic fluxes produced by the power supply frequency components in the going and return lines are 180° out of phase from each other so that they are cancelled by each other. In consequence, the inductance to the power supply frequency component becomes zero. On the other hand, the magnetic core exhibits constantly a higher effective permeability to the high frequency noise components so that they are greatly attenuated.

The present invention is further characterized by the fact that each winding of a poly-phase circuit is wound around the same magnetic core or path, thereby providing an AC power supply filter for noise suppression. As in the case of the going-and-return line, the magnetic core or path exhibits a negligible inductance to the poly-phase power supply frequency component but a higher inductance to the higher frequency noise components, whereby a poly-phase power supply filter for noise suppression may be provided.

Furthermore, according to the present invention a capacitor or capacitors may be connected to the input terminals and/or output terminals of the filters of the character described above so that slight unbalances in phase and amplitude of high frequency components superposed upon the power supply frequency component may be matched.

According to the present invention, the magnetic core may be a laminated composite magnetic core consisting of a plurality of magnetic cores having different permeability vs. frequency characteristics so that the high frequency noise components in wide frequency band may be greatly attenuated.

According to the present invention, metallic spacers are interposed between the windings of the filters of the character described above and grounded so that a wide band filter for effective frequency may be provided.

The present invention will become more apparent from the following description of the embodiments thereof taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a circuit diagram of one example of the conventional power supply filter;

FIG. 2 depicts a waveform of current applied to a power supply filter;

FIG. 3 is for explanation of magnetization of a core used in a power supply filter;

FIG. 4 is a graph of permeability vs. load current of an inductor used in the conventional power supply filter;

FIG. 5 is a diagram of one embodiment of the present invention;

FIG. 6 depicts a waveform of current applied to the power supply filter illustrated in FIG. 5;

FIG. 7 is a graph illustrating the relationship between permeability and load current of the filter in accordance with the present invention;

FIG. 8 depicts equivalent circuits of the filter in accordance with the present invention;

FIG. 9 is a circuit diagram of a second embodiment of a three-phase AC power supply filter in accordance with the present invention;

FIG. 10 depicts waveforms of currents applied to the filter shown in FIG. 9;

FIGS. 11 and 12 depict variations of the power supply filter shown in FIG. 5 in which a capacitor or capacitors are interconnected;

FIG. 13 is a perspective view of a filter in accordance with the present invention for attenuating the high frequency noise components in a wide frequency band;

FIG. 14-*a* is a cross sectional view of a filter in accordance with the present invention for attenuating the high frequency noise components in a wide band;

FIG. 14-*b* is a perspective view of a spacer in accordance with the present invention used in the filter shown in FIG. 14-*a*; and

FIG. 15 is a graph of attenuation vs. frequency characteristic of the filter shown in FIG. 14.

PRIOR ART

FIG. 1 depicts an example of the prior art power-supply filter which is an L-type high-pass filter consisting of inductors L_1 and L_2 each consisting of an iron core and a winding wound around it a few turns, and capacitors C_1 and C_2. When the load current i consisting of a power frequency component i_o plus superposed high frequency component i_n (See FIG. 2) is applied, the core made of a ferromagnetic material has a H-B curve as shown in FIG. 3. The magnetic field strength H_1 will be

$$H_1 = (4\pi N\, i_{01}/10l) \text{ (oersted)}$$

where N = a number of turns;

i_{01} = a current at an arbitary point of power supply frequency; and;

l = a magnetic path length.

Therefore, the magnet core is magnetized to the point A_1. When the high frequency component i_{n1} is superposed, the magnetic field strength fluctuates at an amplitude of ΔH_1 from the point A_1. Thus, the magnetic core has an effective permeability of $\Delta u_{n1} = (\Delta B_1/\Delta H_1)$ for the high frequency component i_{n1}. When i_o is increased further to i_{o2} so that the magnetic core is saturated, the effective permeability $\Delta u_{n2} = (\Delta B_2/\Delta H_2)$ reaches almost zero. That is, the effective permeability of the magnetic core for the high frequency component superposed is varied depending upon the magnitude i_o of the power supply frequency component. The permeability for i_n becomes lower as i_o is increased.

FIG. 4 shows the relationships between the power supply frequency component i_o and the high frequency component i_n and effective permeability μ_o and μ_n respectively.

In order to avoid the decrease of the effective permeability, that is inductance, the prior art provides an air gap in the magnetic path of the magnetic core of an inductor so that the applied magnetic energy may be absorbed in this air gap, thereby suppressing the magnetic saturation. Therefore, the effective permeability is exponentially decreased as the length of the air gap is increased so that a number of turns must be increased in order to obtain a desired inductance. The increase in number of turns results in the bulky magnetic core, the increase in cost and resistance of the DC winding and the temperature rise due to unsatisfactory heat dissipation.

When the reactance is increased in order to decrease the high frequency noise component so as to meet the increase in power supply load, the impedance to the power supply frequency component is also increased so that the power supply voltage to be applied to the load becomes exceedingly unstable.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 5 depicts a power supply filter for noise suppression in accordance with the present invention. Two windings N_1 and N_2 are wound on a magnetic core or magnetic path M in such a manner that the magnetic fluxes produced by the currents flowing through the windings N_1 and N_2 may be cancelled by each other. Thus, an inductor element is provided.

FIG. 6 depicts the waveshapes of the currents i_1 and i_2 flowing through the windings N_1 and N_2 of the inductor shown in FIG. 5. These currents i_1 and i_2 consist of the power supply frequency components i_{1o} and i_{2o} and the high frequency components i_{1n} and i_{2n} superposed thereupon. The magnitude of the magnetic flux induced by the power supply current i_{1o} flowing through the winding N_1 is same as that induced by the current i_{2o} flowing through the winding N_2, but the currents are 180° out of phase. Therefore, the fluxes are cancelled by each other so that the magnetic core does not exhibit any flux variation, whereby the inductance remains zero. For the high frequency components i_{1n} and i_{2n}, the magnetic core or toroid has high effective permeability, that is inductance so that the high frequency components are attenuated to a greater extent.

As seen from FIG. 7, the filter in accordance with the present invention exhibits low impedance for the power supply frequency component but has a high impedance to the high frequency components. Furthermore, the same characteristics may be maintained constantly even when the winding current is increased. The arrangement of the windings N_1 and N_2 based upon the above-described principle cancels the flux produced in the magnetic core by $N_1 \times i_{1o}$ and $N_2 \times i_{2o}$ within a power supply frequency range in which i_{1o} and i_{2o} are symmetrical, so that i_{1o} and i_{2o} may have any frequency including DC.

Furthermore, the effective permeability in the magnetic path may be made greater in practice, so that a number of turns of coil may be reduced and the distributed capacity of the coil may be also reduced. Therefore, the self resonance frequency may become higher compared with the conventional filter and the filter of the present invention may be operated even when an air gap is provided. The filter of the invention is effective especially when the amplitude of the noise current component i_n is greater.

FIG. 8 is an equivalent circuit of the inductance element shown in FIG. 5. FIG. 8-*a* is an equivalent circuit for the power supply current in which L_L designates the leakage inductance due to the mismatching between the coils N_1 and N_2; C_p, a coupling capacitor between the windings; and R_1, a resistance of the winding.

FIG. 8-*b* is an equivalent circuit for the high frequency noise component superposed upon the power supply current in which L_s designates a self-inductance of the winding; C_s, a distributed capacity; R_2, a DC resistance of the winding plus the high frequency loss of the magnet core; and C_p, a mutual capacitance between the windings which may be equal to C_p in FIG. 8-*a*.

From these equivalent circuits shown in FIGS. 8-*a* and 8-*b*, the characteristics of the high frequency noise filter may be analyzed as follows:

1. L_L must be made as smaller as possible in order to suppress the effective magnetization of the core;
2. The magnitude of C_p is preferably made greater for matching the zero-phase noise;
3. R_1 must be smaller so as to avoid the temperature rise due to the ohmic loss;
4. L_s must be increased in order to increase the effective filtration impedance so as to improve the filtration characteristics;
5. C_s must be made as smaller as possible in order to minimize the leakage of the high frequency component; and
6. It is preferable that R_2 which is dependent upon the magnetic material is greater so that a suitable material must be selected.

An ideal filter which can satisfy the above-mentioned conditions may be provided in a manner to be described hereinafter. That is, to reduce L_L and C_s and to increase C_p, a pair of windings to be wound around the core are made of two insulated conductors which are twisted with each other and then made into unitary construction by applying a suitable insulating paint having a suitable dielectric constant. Alternately the two insulated conductors may be wound in the form of honeycomb coil so that C_s may be reduced. According to these methods, the relative position of the winding to the core may be maintained constant so that L_L may be exceedingly reduced and a space factor in the bobbin of the winding may be also reduced, whereby C_s may be also exceedingly made smaller.

For example, a pair of magnetic wires insulated with polyurethane plastic coatings and 0.5 mm in diameter were wound 30 turns on an E-type core with a straight bar having a length of 30 mm and made of a ferrite having an initial permeability of 2,000, L_L was 8 micro-henrys and C_s was 10 pF. According to the present invention, L_L and C_s may be reduced to 0.7 micro-henrys and to 2.5 pF respectively. Thus, the characteristics may be greatly improved.

Two insulated winding wires may be disposed in side-by-side relation and made integral by applying an insulating paint having a suitable dielectric constant. In this case, the characteristics may be sufficiently improved even though they are somewhat inferior to those attained by the above described methods.

The power supply filter in accordance with the present invention may be employed not only in a two-wire line but also in a poly-phase-wire line. FIG. 9 depicts a three-phase AC power supply filter for noise suppression. The windings N_1, N_2 and N_3 are so wound around the magnetic core or magnetic path M that the fluxes produced may be cancelled by each other. The currents i_1, i_2 and i_3 flowing through the windings N_1, N_2 and N_3 consist of the fundamental waves i_{o1}, i_{o2} and i_{o3} of the power supply frequency components and high frequency components i_{n1}, i_{n2} and i_{n3}. That is, $i_1 = i_{o1} + i_{n1}$, $i_2 = i_{o2} + i_{n2}$, and $i_3 = i_{o3} + i_{n3}$.

The power supply frequency components i_{o1}, i_{o2} and i_{o3} are out of phase by 120° with respect to each other as shown in FIG. 10 so that the magnetic induction in the magnetic core is cancelled. Therefore, the magnetic core is not magnetized normally and no electromotive force is induced. That is, the windings N_1, N_2 and N_3 have no inductance for the power supply frequency components i_{o1}, i_{o2} and i_{o3}.

The magnetic core has high permeability to the high frequency components i_{n1}, i_{n2} and i_{n3} because the core remains demagnetized. Thus, the magnetic core has no reactance for the power supply frequency components but have a high reactance for the high frequency components so that the latter are attenuated.

FIG. 11 depicts the filter similar to one shown in FIG. 5 except that a capacitor C_1 interconnects the input terminals *a* and *b* so that the inductance for the power supply high frequency component reaches zero while the inductance for the high frequency component becomes higher. Furthermore, the capacitor C_1 serves to match slight unbalances in phase and amplitude of the high frequency component so that the above-mentioned effect is further improved.

FIG. 12 depicts a modification of the filter shown in FIG. 11. In addition to the matching capacitor C_1, a series circuit of filter capacitors C_2 and C_3 is connected to the output terminals c and d in parallel and the junction of the capacitors C_2 and C_3 is grounded. The capacitor C_1 serves to match slight unbalance in phase and amplitude of the high frequency component while the filter capacitors C_2 and C_3 by-pass the leakage high frequency component.

In a filter for suppressing the high frequency noise, a wide band from a lower frequency range to a higher frequency range must be attenuated to a great extent. The highest frequencies range from 20 to 100 MHz or over.

In the embodiment shown in FIG. 13, the magnetic core A is made of a magnetic material having a high permeability while the magnetic core B, of a magnetic material having a relatively lower permeability but an improved permeability vs. frequency characteristic and a higher resistivity. The permeability of the magnetic cores A and B are so selected that the resultant impedance vs. frequency characteristic may be within a predetermined range or only the thicknesses of the cores A and B are suitably selected.

For example, the magnetic core A was made of a Mn-Zn-series ferrite of an initial permeability of 5,000 while the magnetic core B, Ni-Zn series ferrite of an initial permeability of 500. The outer diameter was 15 mm, the inner diameter was 7 mm and the height was 4 mm. These cores are in the form of ring or toroid.

Fifteen turns of wire 0.4 mm in diameter were wound around the laminated magnetic cores A and B. The inductance was 800 μH at a lower frequency of 100 KHz and 30 μH at a higher frequency of 20 MHz with a distributed capacitance of 1.5 pF.

When the magnetic core assembly consisting of the cores A and B made of different magnetic materials are used, the lower frequencies are attenuated to a greater extent by the magnetic core A while the higher frequencies are greatly attenuated by the core B so that the frequencies in a wide band may be effectively attenuated.

The same effects will be attained when the magnetic core assembly consist of more than two magnetic cores made of different materials or when E-type and U-type magnetic cores are used with or without straight bars.

The embodiment shown in FIG. **14** also serves to attenuate the frequencies in a wide band.

In general, the distributed capacitance between the windings of the high frequency inductor, is increased in proportion to a square of a number of turns. When the high frequency current flows through this inductor, a parallel circuit of a capacitance and inductance is formed through the distributed capacitance produced in parallel with the main inductance so that the high frequency component leaks through the capacitance component. In a frequency region higher than a self-resonance frequency which is determined by the main inductance and the distributed capacitance, the impedance is gradually reduced, so that noise may not be attenuated over a wide band.

Referring to FIG. **14**-*a*, the winding W is wound around a bobbin B and is divided by spacers R which are grounded. The spacer R has a slit Z as shown in FIG. **14***b*. The embodiment shown in FIG. **14** serves very effectively not only to increase the capacitance between the winding W and the earth and but also to reduce the parallel distributed capacitance. The shape of the spacer R may be varied depending upon a core and bobbin to be used, but it must have a slit as shown in FIG. **14**-*b* so that the short-circuit may be prevented when it functions as a secondary. This slit also serves to pass the wire in winding.

FIG. **15** shows the relationship between the attenuation and frequency characteristic of a filter in which three wires 0.3 mm in diameter were wound 50 turns in parallel with each other around a pot core having an initial permeability of 2,500 and an effective permeability of 200 and one spacer was used.

From FIG. **15**, it is seen that the self-resonance frequency becomes about 2.7 times while the equivalent distributed capacitance is reduced to 0.95 pF from 6.2 pF.

In case of the pot core having an initial permeability of 500 and an effective permeability of 350, the self-resonance frequency was increased about two times compared with the case employing the conventional spacer.

The same effects would be obtained when ring-shaped, E-type or U-type magnetic cores with or without straight bars are used. Furthermore, the same effects will be attained even when a bobbin is not used.

What is claimed is:

1. A noise suppressing power supply filter comprising a plurality of lines for supplying power supply voltage and current of a predetermined frequency component, said voltage and current including high frequency noise components, and

a magnetic core having at least one magnetic path, all of said plurality of lines being wound around said one magnetic path forming an inductance element with said core,

said inductance element having a pair of input terminals connected to said plurality of lines;

and capacitor means connected across said input terminals for adjusting imbalances in the phases of said high frequency noise components,

said inductance element having a negligible inductance to said power supply frequency component and a high inductance to said high frequency noise component which is superposed on the power supply frequency component.

2. A filter of the character defined in claim **1** wherein said plurality of lines are two going and returning lines.

3. A filter of the character defined in claim **1** wherein said plurality of lines are poly-phase AC lines.

4. A filter of the character defined in claim **1** wherein each winding of said plurality of lines consists of a plurality of insulated conductors twisted together or disposed in side-by-side relation with each other.

5. A filter of the character defined in claim **1** wherein said magnetic core comprises a plurality of magnetic cores each having a different permeability vs. frequency characteristic.

6. A filter of the character defined in claim **1**, wherein said inductance element has output terminals connected to said plurality of lines, and a grounding capacitor connected to said output terminals.

7. A filter of the character defined in claim **1** wherein the windings wound around said same magnetic core are divided by spacers made of a conductor whose surfaces are sufficiently insulated and which are grounded.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,683,271 Dated August 8, 1972

Inventor(s) Tatsuo Kobayashi

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

The first page of the patent is to indicate the assignment to E. R. D. Corporation of Tokyo, Japan recorded as Reel 2628, Frame 392 on June 23, 1970.

Signed and sealed this 13th day of March 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

1770-206

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,683,271 Dated August 8, 1972

Inventor(s) Tatsuo Kobayashi

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

The first page of the patent is to indicate the assignment to E. R. D. Corporation of Tokyo, Japan recorded as Reel 2628, Frame 392 on June 23, 1970.

Signed and sealed this 13th day of March 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents

1770-206

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