Title: ACTIVE COMMON MODE EMI FILTER MITIGATING CONDUCTED ELECTROMAGNETIC INTERFERENCE

Abstract: The present invention relates to an active common-mode EMI filter which is capable of using low-voltage amplifier devices by using a separate amplifier dc source unrelated to the system operating voltage and also is capable of circulating the leakage current within the system by coupling capacitors that operate for the filter circuit to be separated at low frequency and form the closed circuit with the main circuit of the system at high frequency. As a result, it is possible to use fast active devices than the filter circuit of prior art regardless of the operating voltage of the target system. The present invention can solve the prior art’s problem that transistors with higher voltage rating should be used in order for bipolar transistors to withstand the total dc voltage of the system while using a method for detecting and compensating the high-frequency common-mode current.
ACTIVE COMMON MODE EMI FILTER MITIGATING
CONDUCTED ELECTROMAGNETIC INTERFERENCE

TECHNICAL FIELD

The present invention relates to an active common-mode EMI (Electromagnetic Interference) filter mitigating conducted EMI, more particularly to the active common-mode EMI filter for detecting and compensating the common-mode current which is capable of using low-voltage amplifier devices by using a separate amplifier dc source unrelated to the system operating voltage and circulating the leakage current within the system by coupling capacitors which operate for the filter circuit to be separated from the main power circuit at low frequency and provide the low impedance path between the filter circuit and the main power circuit for the high-frequency common-mode current generated by the system.

BACKGROUND ART

A high frequency common-mode current generated by the system not only affects other electronic equipments that are connected to the point of the common coupling by an conducted EMI, but also generates radiated EMI because the circulating path of a high frequency leakage current between the source and the system is relatively large and can be an antenna for the radiation.

Firstly, the high-frequency leakage current generated in electronic system is described by an example, and prior arts to eliminate the leakage current are described.

Fig. 1 is for the description of a high-frequency leakage current generated by PWM (Pulse Width Modulation) inverter system that is connected to a single-phase ac
input. In Fig. 1, a PFC (Power Factor Corrector) is usually used with a front-end single-
phase diode-bridge rectifier in order to meet the harmonic regulation. An ac motor is
used as a load machine of PWM inverter. In the motor drive system, the PWM inverter
is generally operated at 1~20kHz of the switching frequency and FETs (Field Effect
Transistor) or IGBTs (Insulated Gate Bipolar Transistor) are used as power switches.
Fast switching of FETs or IGBTs generates high frequency voltage and current coupled
with system parasitic components. More particularly, by the fast switching of FETs or
IGBTs, high voltage pulse waveform exists in ‘a’ point, ‘b’ point and ‘c’ point. In Fig.
1, the ac machine is connected to ground ‘g’. High frequency leakage current is
generated in case that a high voltage with fast transient is applied to the motor and it is
transmitted through parasitic capacitances (for example $C_{lg}$, $C_{sg}$) between the system
and the ground and is returned to the source. In Fig.1, the voltage between neutral point
of motor ‘s’ and earth ground ‘g’ is measured as $V_{sg}$ in Fig. 2 and the corresponding
leakage current is measured as $i_{sg}$ in Fig. 2.

As a prior art for suppressing such leakage current, a passive common-mode
filter of Fig. 3 has been used at the input or output of the system. The common-mode
choke of Fig. 3 increases the series impedance of the common-mode current path, and
$C_Y$ provides a path with low impedance for the high frequency leakage current
circulating within the system. In order to increase the attenuation of the passive filter of
Fig. 3, LC value of the filter should be increased. However $C_Y$ value is limited for the
safety reason. In this case, inductance of common-mode choke should be increased
instead of increasing $C_Y$ value to increase the attenuation of the filter, which leads to the
increase of cost and volume of the whole system including filter stages.

In order to solve the problem of the passive common-mode EMI filter, there
have been several researches on active common-mode EMI filters.

Fig. 4 shows conceptual structures of a prior active EMI filter. The active EMI filter is for suppressing the ripple voltage or current generated by the switching source. In the active EMI filter, high-frequency current or voltage signal is detected and 'A' gain is multiplied to compensate high-frequency current or voltage, which results in suppression of the high-frequency ripple signal at the source. Although active EMI filter was implemented for normal-mode noise, this idea can be also applicable to the suppression of the common-mode noise in the similar manner.

Fig. 5 shows active common-mode EMI filters for the PWM inverter system.

Fig. 5a and Fig. 5b show active common-mode EMI filters for detecting and compensating common-mode voltage, and Fig. 5c shows an active common-mode EMI filter for detecting and compensating common-mode current.

Fig. 5a and Fig. 5b are circuits that detect the common-mode voltage of the PWM inverter and add it onto output voltages using the common-mode transformer and the push-pull amplifier, which results in the suppression of the common-mode voltage at the motor terminal.

However the filter circuit of Fig. 5a is connected to the dc bus of the PWM inverter and its implementation could be difficult because the bipolar transistor should withstand the whole dc bus voltage. Fig. 5b solved this problem using a separate dc source (50V) but it requires higher current rating of bipolar transistors than that of Fig. 5a.

Fig. 5c is a circuit that detects and compensates the leakage current using push-pull amplifier connected to the dc bus of the PWM inverter. Fig. 5c has the same problem of the voltage rating of the bipolar transistor as in the case of Fig. 5a.
Generally speaking, if transistors with higher voltage rating were used, then the current rating and the applicable bandwidth of the filter circuit would be limited.

**DISCLOSURE OF THE INVENTION**

The present invention has a purpose of providing an active common-mode EMI filter for suppressing the common-mode current that is capable of using low voltage devices regardless of the system operating voltage.

Another purpose of the present invention is to provide a common-mode EMI filter of detecting and compensating common-mode current regardless of the system operating voltage.

In order to attain above-mentioned purposes, the present invention's active common-mode EMI filter comprises: a common-mode inductor that is connected to a main source, offsets the magnetic flux in case that a current with different direction (normal-mode current) flows in each winding, and operates as an inductor in case that a current with same direction (common-mode current) flows; an auxiliary winding which is installed in the same magnetic core to detect the flow of the common-mode current from the source; an amplifier of which the input stage is connected to the auxiliary winding; an amplifier dc source separated from the main source as a biasing source of an amplifier stage; an output capacitor which is installed between an output of the amplifier and the ground; and coupling capacitors, that are installed between the amplifier dc source and the main power circuit, operate for the filter circuit to be separated from the main power circuit at low frequency and constitute the closed circuit with the main power circuit at high frequency.
BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is for the description of a leakage current in PWM (Pulse Width Modulation) inverter system which is connected to a single phase ac input,

Fig. 2 shows waveform of \( v_{sg} \), which is voltage between motor neutral point ‘s’ and the ground, and \( i_{ag} \) which is the leakage current according to the \( v_{sg} \),

Fig. 3 shows a concept of the prior art’s passive common-mode filter,

Fig. 4 shows conceptual structures of a prior active EMI filter,

Fig. 5 shows active common-mode EMI filters for PWM inverter system, Fig. 5a and Fig. 5b show an active common-mode EMI filter for detecting and compensating the common-mode voltage, Fig. 5c shows an active common-mode EMI filter for detecting and compensating the common-mode current,

Fig. 6 shows a conceptual diagram according to the present invention’s active common-mode EMI filter,

Fig. 7 shows an example of the filter of a single-phase ac system or dc system, as an example of the implementation of the active common-mode EMI filter according to the present invention,

Fig. 8 is another example of the filter of the ac or dc system as an example of the implementation of the active common-mode EMI filter according to the present invention,

Fig. 9 shows an example of the filter of the 3-phase ac system, as an example of the implementation of the active common-mode EMI filter according to the present invention,

Fig. 10 shows another example of the filter for 3-phase ac system, as an example of the implementation of the active common-mode EMI filter according to the
present invention,

Fig. 11 shows an example of the auxiliary output filter for the present invention,

Fig. 12 shows PWM inverter system used in the present experiment,

Fig. 13 shows the active common-mode EMI filter of the present invention used in the present experiment,

Fig. 14 shows a DMRN (Differential Mode Rejection Network) to measure the conducted common-mode EMI separately in the present experiment,

Fig. 15 shows the conducted EMI spectrum and waveform of the leakage current without the active common-mode EMI filter of the present invention,

Fig. 16 shows the conducted EMI spectrum and waveform of the leakage current where the amplifier circuit is excluded and only the common-mode inductor $L_{CM}$ is added in the active common-mode EMI filter of the present invention,

Fig. 17 shows the conducted EMI spectrum and waveform of the leakage current where the active common-mode EMI filter of the present invention is installed.

**BEST MODE FOR CARRYING OUT THE INVENTION**

Detailed explanation of the present invention’s active common-mode EMI filter is provided in the following with references to the attached drawings.

Fig. 6 shows a conceptual diagram according to the present invention’s active common-mode EMI filter.

In Fig. 6, $L_{CM}$ offsets magnetic flux by installing 2-line (single-phase ac or dc), 3-line (3-phase ac) or multi-input winding in the different direction, and is a common-code inductor operating as an inductor in case that a current with the same direction flows. A separate dc source ($V_0$) is used as the biasing source of the amplifier. Coupling
capacitors ($C_0$) installed between the amplifier source ($V_s$) and the main power circuit, operate for the active filter circuit to be separated from the main power circuit by disconnecting circuit at low-frequency signal and constitute the closed circuit between the filter circuit and the main power circuit at high frequency. The output of the amplifier is connected to the ground through the output capacitor ($C_o$).

More specifically, $L_{CM}$ operates as an inductor only when common-mode current flows, and magnetic flux proportional to the common-mode current is induced in its magnetic core. This magnetic flux causes the electromotive force to auxiliary winding installed in the same magnetic core, and this electromotive force drives the input of the trans-conductance amplifier. The output of the amplifier provides the compensation current to the ground according to the detected common-mode current through output capacitor ($C_o$).

Coupling capacitors ($C_0$) make the low impedance path for the high frequency common-mode current; hence the active filter circuit is connected electrically to the main power circuit at high frequency. In addition, the common-mode inductor increases the series impedance of the system; hence the inductor inhibits the flow of the high frequency current from the source. As a result the high-frequency common-mode current generated by the system circulates only within the system through the amplifier, coupling capacitors ($C_0$) and the output capacitor ($C_o$), which results in the suppression of the high-frequency common-mode current withdrawn from the source ($V_s$).

Fig. 7 to Fig. 11 shows the detailed example of the implementation of the active common-mode EMI filter according to the present invention.

Fig. 7 shows an example of the filter of a single-phase ac system or dc system, as an example of the implementation of the active common-mode EMI filter according
to the present invention. The common-mode inductor \(L_{CM}\) is installed between the source input and the system, coupling capacitors \(C_0\) are installed between the amplifier dc source and the input stage of the system, the output of the amplifier is connected to the ground through the output capacitor \(C_e\), and the system is connected to the ground. The active common-mode EMI filter of the present invention detects the flow of the high-frequency common-mode current through the inductor \(L_{CM}\), and circulates the leakage current (generated by the system) only between the filter of the present invention and the ground of the system by enabling the amplifier to generate the compensation current reverse to the direction of the detected common-mode current through coupling capacitors \(C_0\) and output capacitor \(C_e\); hence it suppresses the flow of the high-frequency common-mode current from the source. Coupling capacitors, between the system input and the dc source of the amplifier, separate the amplifier source from the system at low frequency providing high impedance and while they constitute the closed circuit for the high-frequency common-mode current (generated by the system) providing low impedance path.

Fig. 8 is another example of the filter of the ac or dc system as an example of the implementation of the active common-mode EMI filter. That is, Fig. 8, as is the same case with Fig. 7, is an example of installing the active EMI filter according to the present invention to the input stage of the single-phase ac or dc system. In Fig. 8, coupling capacitors \(C_0\) are installed between the amplifier dc source and the dc bus stage next to the front-end rectifier (or converter) in the system. The common-mode inductor \(L_{CM}\) is installed between the ac or dc source input and the front-end rectifier (or converter), another ac/dc or dc/dc load system is connected to the dc bus stage expressed as \(V_{dc}\), and this is connected to the ground. The output of the amplifier is
connected to the ground through the output capacitor \((C_{e})\). The circuit shown in Fig. 8 detects the flow of the high-frequency common-mode current through the inductor \(L_{CM}\), and circulates the high-frequency leakage current (generated by the system) only between the filter of the present invention and the ground by enabling the amplifier to generate the compensation current reverse to the direction of the detected common-mode current through coupling capacitors \((C_{0})\) and output capacitor \((C_{e})\); hence it suppresses the flow of the high-frequency common-mode current from the source. At this time, coupling capacitors \((C_{0})\) separate the amplifier source from the dc bus stage providing high impedance at low frequency, while they constitute the closed circuit for the high-frequency common-mode current (generated by the system) providing low impedance path.

Fig. 9 shows an example of the filter of the 3-phase ac system, as an example of the implementation of the active common-mode EMI filter. That is, Fig. 9 is an example of the implementation of the active common-mode EMI filter according to the present invention to the input stage of the 3-phase system. In Fig. 9, coupling capacitors \((C_{0})\) are installed between the amplifier dc source and the each phase of the 3-phase line in order to make the short connection between 3-phase source and amplifier source at high frequency. The inductor \((L_{CM})\) is installed between the source input and a front-end rectifier (or converter) in the system, and the system is connected to the ground. The output of the amplifier of the present invention is connected to the ground through the output capacitor \((C_{e})\). The high-frequency common-mode current generated by the system is circulated only between the ground of the system and the filter of the present invention by detecting the flow of the high-frequency common-mode current through the inductor \(L_{CM}\) and enabling the amplifier to generate the compensation current.
reverse to the direction of the detected current through coupling capacitors \( (C_o) \) and
output capacitor \( (C_e) \). Therefore the flow of the common-mode current from the source
is suppressed. At this time, coupling capacitors \( (C_o) \) separate the amplifier dc source
from the 3-phase input source providing high impedance at low frequency, while they
constitute the closed circuit for the high-frequency common-mode current (generated
by the system) providing low impedance path.

Fig. 10 shows another example of the filter for 3-phase ac system, as an
example of the implementation of the active common-mode EMI filter according to the
present invention. Fig. 10, as is the same case with Fig. 9, is an example of the
installation of the active EMI filter of the present invention for the 3-phase ac system.
In Fig. 10, coupling capacitors \( (C_o) \) are installed between the amplifier dc source and
the dc bus stage (next to the 3-phase rectifier or converter) of the system. The inductor
\( L_{CM} \) is installed between the source input and the front-end rectifier (or converter),
another ac/dc or dc/dc load system is connected to the dc bus stage expressed as \( V_{dc} \).
The load system is connected to the ground. The output of the amplifier is connected to
the ground through the output capacitor \( (C_e) \). The flow of the high-frequency current
through the inductor \( (L_{CM}) \) is detected and the amplifier generates the compensation
current reverse to the direction of the detected current through coupling capacitors \( (C_o) \)
and output capacitor \( (C_e) \); hence the leakage current (generated by the system) is
circulated between the ground of the load system and the filter circuit of the present
invention, and therefore the flow of the high-frequency common-mode current is
suppressed. At this time, coupling capacitors \( (C_o) \) separate the amplifier dc source from
the dc bus voltage providing high impedance at low frequency, while they constitute
the closed circuit for the high-frequency common-mode current (generated by the
system) providing low impedance path.

Fig. 11 shows the auxiliary output filter for the active common-mode EMI filter of the present invention. If the input signal is so fast that the amplifier might generate incorrect compensation current out of phase with the detected common-mode current, then the EMI could become worse even with the active common-mode EMI filter of the present invention. In this case this high-frequency compensation current above the bandwidth of the amplifier should be suppressed. As an example, Fig. 11 shows one example of the suppression of the high-frequency compensation current using \( L_c \) and \( r_c \). These passive filtering elements can be applicable to circuits in Fig. 7 ~ 10 of the present invention.

An experiment of applying the active common-mode EMI filter to the concrete system is described in the following as an example.

Fig. 12 shows the PWM inverter system used in this experiment. The system is a compressor-driving unit for an air conditioner and the input EMI filter has been modified and added for the conducted EMI analysis. Fig. 13 shows the active common-mode EMI filter of the present invention used in this experiment. Parameters and operating conditions of the experimental system are described in the following Table 1.

<table>
<thead>
<tr>
<th>Main source</th>
<th>Single-phase, 220V</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWM inverter</td>
<td>60Hz fixed output frequency, Discontinuous PWM with 2.5kHz switching frequency.</td>
</tr>
<tr>
<td>Switching device</td>
<td>Mitsubishi DIP-IPM PS21205</td>
</tr>
<tr>
<td>Load machine</td>
<td>3-phase 3.7kW induction motor</td>
</tr>
<tr>
<td>PFC</td>
<td>Line frequency switching for harmonic reduction</td>
</tr>
<tr>
<td>Common-mode</td>
<td>( L_{CM}: 2mH, N=13, ) ferrite torroid</td>
</tr>
<tr>
<td>Component</td>
<td>Details</td>
</tr>
<tr>
<td>-----------</td>
<td>---------</td>
</tr>
<tr>
<td>Inductor (choke)</td>
<td>7.5(\mu)H of leakage inductance</td>
</tr>
<tr>
<td></td>
<td>(L_{CM2}: 6mH, N=27), ferrite toroid, 35(\mu)H of leakage inductance</td>
</tr>
<tr>
<td>Y-capacitor, output capacitor, coupling capacitor</td>
<td>High voltage capacitor (2kV)</td>
</tr>
<tr>
<td></td>
<td>(C_y: 2.2 , nF)</td>
</tr>
<tr>
<td></td>
<td>(C_a, C_b: 10 , nF)</td>
</tr>
<tr>
<td>X-capacitor</td>
<td>Polypropylene capacitor</td>
</tr>
<tr>
<td></td>
<td>(C_{X1}, C_{X2}, C_{X4}: 470nF)</td>
</tr>
<tr>
<td></td>
<td>(C_{X3}: 680 , nF)</td>
</tr>
<tr>
<td></td>
<td>(C_{S1}: 100 , nF)</td>
</tr>
<tr>
<td>Push-Pull amplifier</td>
<td>NEC 2SC3840(pnp), 2SA1468(npn)</td>
</tr>
</tbody>
</table>

The active common-mode EMI filter of the present invention shown in Fig. 13 is based on the ripple current elimination technique for detecting the source ripple current and compensating the high-frequency ripple current. In order to minimize the phase delay caused by the filter circuit, the single-stage amplifier using bipolar transistors was used, and an 12V dc voltage source was used as the amplifier biasing source. The dc bus voltage of this system is 370V when the source voltage is 220V and PFC is operating.

The flow of the common-mode current to the system makes the high frequency ripple flux in the common-mode choke shown in Fig. 13, which makes the high-frequency voltage at an auxiliary winding. The high-frequency voltage is then converted to the high frequency current signal by the external resistor and the input impedance of the push-pull amplifier. The amplifier provides the compensation current of the reverse direction to the detected common-mode current through the output capacitor; hence the low-impedance path for the high-frequency current (generated by the PWM inverter) is provided with the aid of the active common-mode EMI filter of the present invention. In order to make the closed circuit between the filter circuit and
the dc bus stage of the PWM inverter at high frequency, two coupling capacitors (C₁) are used as shown in Fig. 13. These coupling capacitors should be selected to be small enough to separate the filter circuit from the dc bus stage at low frequency. As mentioned above, because the path is disconnected by the coupling capacitor at low frequency the common-mode current of the low frequency is not suppressed in the filter of the present invention. The output capacitor (Cₑ) also blocks the path of the low frequency signal and connects the filter output and the ground at high frequency.

The attenuation effect of the conducted EMI is described in the following.

In the measurement of the conducted EMI, one of 50Ω resistors in the Fig. 12 is a dummy resistance and the other is used as an input impedance of the spectrum analyzer. Because the total conducted EMI is the sum of the normal-mode EMI and the common-mode EMI, a DMRN (differential mode rejection network) is used in order to measure the conducted common-mode EMI separately from the total conducted EMI as shown in Fig. 14.

Fig. 15 shows conducted EMI spectrums without the active common-mode EMI filter of the present invention. Fig. 15a shows the total (including normal-mode and common-mode) conducted EMI spectrum, Fig. 15b shows the common-mode EMI spectrum, and Fig. 15c shows the waveform of the motor leakage current generated by the PWM inverter. Because the total EMI is slightly greater than the common mode EMI, the mitigation of the conducted EMI cannot be solely done without considering the mitigation of the common-mode EMI in this stage.

Fig. 16 shows conducted EMI spectrums where the amplifier circuit is excluded and common-mode inductor L_CM is added in the active common-mode EMI filter of the present invention. Fig. 16a shows the total (including normal-mode and
common-mode) conducted EMI spectrum, Fig. 16b shows the common-mode EMI spectrum, and Fig. 16c shows the waveform of the motor leakage current generated by the PWM inverter. In comparison with Fig. 15, although total EMI has been decreased slightly, the attenuation is not same as the case of the common mode. In the case of the common-mode EMI, as the impedance of the current path has increased, the peak value of the leakage current has been decreased and the waveform has become more sluggish as shown in Fig. 16c. Normal-mode EMI spectrum is also decreased due to the leakage inductance of the common-mode inductor but not as much as common-mode EMI spectrum shown in Fig. 16b. As the difference between the total EMI and the common-mode EMI is less than 10dBμV, it is not enough to separate the mitigation effort of the normal-mode EMI from that of the common-mode EMI.

Fig. 17 shows conducted EMI spectrums where the active common-mode EMI filter of the present invention is installed. Fig. 17a shows the total (including normal-mode and common-mode) conducted EMI spectrum, Fig. 17b shows the common-mode EMI spectrum, and Fig. 17c shows the waveform of the motor leakage current generated by the PWM inverter. The common-mode EMI in Fig. 17b has been decreased by at least more than 10dBμV compared with Fig. 16b. Most of the high-frequency component of the leakage current has been disappeared from the common-mode current returning to the source and only low-frequency component remains. Comparing Fig. 17a with Fig. 17b, the magnitude of the common-mode EMI spectrum at over all range (Fig. 17b) is definitely smaller than that of total EMI (Fig. 17a), thus normal-mode EMI determines the level of the total EMI spectrum of the system in this stage.
INDUSTRIAL APPLICABILITY

As explained above, in the present invention's active common-mode EMI filter, it is possible to use low voltage amplifier devices because the separate dc source unrelated to the system operating voltage is used. The amplifier generates the compensation current for the flow of the common-mode current from the source through coupling capacitors and output capacitor. Therefore the high-frequency leakage current (common-mode current) is circulated within the system. Coupling capacitors separate the filter circuit of the present invention from the main power circuit at low frequency and provides low impedance path for the high-frequency leakage current generated by the system. As a result, the use of faster device rather than those of devices used in the filter circuit of prior arts and the active common-mode EMI filter of the present invention can be applicable regardless of the operating voltage of the system. The present invention can solve the prior art's problem that transistors with higher voltage rating should be used in order for bipolar transistors to withstand total dc voltage of the system while using a method for detecting and compensating high-frequency common-mode current.
WHAT IS CLAIMED IS:

1. An active common-mode EMI filter comprising;
   a common-mode inductor which is connected to the main source, offsets the magnetic flux in case that a current with different direction (normal-mode current) flows in each winding, and operates as an inductor in case that a current with same direction (common-mode current) flows;
   an auxiliary winding which is installed in the same magnetic core in order to detect the flow of the common-mode current at the source side;
   an amplifier of which the input stage is connected to the auxiliary winding;
   a amplifier dc source separated from the main power circuit as the source of an amplifier stage;
   an output capacitor which is installed between the output of the amplifier and the ground; and
   coupling capacitors which are installed between the amplifier dc source and the main power circuit, separate the filter circuit from the main power circuit at low frequency, and provides low-impedance path between the filter circuit and the main power circuit for the high-frequency common-mode current generated by the system.

2. An active common-mode EMI filter according to claim 1, wherein an auxiliary output filter which is installed in series with the output capacitor in order to suppress higher frequency compensation current than the bandwidth of the amplifier.

3. An active common-mode EMI filter according to claim 1, wherein the active
common-mode EMI filter is installed in an input stage of a single-phase ac or dc system.

4. An active common-mode EMI filter according to claim 3, wherein the common-mode inductor is installed between the main source and the system, one side of coupling capacitors is connected to the input stage of the system, the other side of coupling capacitors is connected to the amplifier dc source.

5. An active common-mode EMI filter according to claim 3, wherein the common-mode inductor is installed between the main source and a front-end rectifier (or converter) in the system, one side of coupling capacitors is connected to a dc source stage next to the front-end rectifier or converter in the system, the other side of coupling capacitors is connected to the amplifier dc source.

6. An active common-mode EMI filter according to claim 1, wherein the active common-mode EMI filter is installed in an input stage of a 3-phase ac load system.

7. An active common-mode EMI filter according to claim 6, wherein the common-mode inductor is installed between the amplifier dc source and a 3-phase front-end rectifier or converter in the system, coupling capacitors are Y-connected to each phase of the 3-phase line behind the common-mode inductor and their mid-points of Y-connections are connected to the amplifier dc source.
8. An active common-mode EMI filter according to claim 6, wherein the common-mode inductor is installed between the amplifier dc source and a front-end rectifier or the converter in the system,

one side of coupling capacitors is connected to the dc bus stage next to the front-end rectifier or converter in the system, the other side of coupling capacitors is connected to the amplifier dc source.
Fig. 3

*Common-mode Choke*

![Diagram of common-mode choke with inductors and capacitors labeled as $C_X$ and $C_Y$.]
Fig. 8
Fig. 13
Fig. 14
Fig. 15c
Fig. 16c
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC7 H03H 7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC7 H03H 7/00, H03H 7/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
<thead>
<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>A</td>
<td>EP A, 0 151 803 (TELEFONGYAR) 21 Aug. 1985 See page 1 ~ 7, fig. 2, 3, 4</td>
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<tr>
<td>A</td>
<td>US 5 408 193 (Trimble Navigation Limited) 18 Apr. 1995 See col. 1 ~ 4, fig. 3, 4, 5</td>
<td>1 - 8</td>
</tr>
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</table>

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'A' document defining the general state of the art which is not considered to be of particular relevance

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'P' document published prior to the international filing date but later than the priority date claimed

'T' later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

'X' document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

'Y' document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

'&' document member of the same patent family

Date of the actual completion of the international search

Date of mailing of the international search report
27 APRIL 2002 (27.04.2002)

Name and mailing address of the ISA/KR

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Authorized officer

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Telephone No. 82-42-481-5673

Form PCT/ISA/210 (second sheet) (July 1998)