Back

# Noise Suppression

## by EMI Filtering

EMC Innovative Solutions

# Basics of EMI Filters

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# INTRODUCTION

The need to attain an EMI controlled environment is an important issue for electronic systems. The FCC and other regulatory agencies are enforcing stringent restraints on EMI emissions. This coupled with the growing number of electronic and digital systems industrial, commercial and consumer markets is making electromagnetic compatibility (EMC) a necessity. That is, various system must be able to function in close proximity without either radiating noise or being affected by it. This trend will guarantee that EMI issues will indefinitely continue to gain importance to design engineers.

This text includes the basic principles on noise suppression using filters. It will provide engineers with a general understanding of EMI problems and practical solutions to eliminate these problems using EMI filters.

# 1. Reasons for Noise Suppression

## 1.1. Conditions for Electromagnetic Interference and Future Trends

### Conditions for Electromagnetic Interference and Future Trends

1

There are three conditions or elements required for EMI

- A: EMI generator - a source that emits noise.
- B: EMI receiver - a device that is susceptible to noise.
- C: EMI path - a path for which the EMI generated can reach the EMI receiver.

Future trend of noise problems

There is a continual increase in the density of electronic equipment used in applications where they are affected by each other.

↓ (Solution)

A: Electronic equipment that emits less noise
B: Electronic equipment that is more immune to noise
"A" and "B" shown above are required.

The wide array of electronic equipment available makes our life more comfortable, and such equipment is now essential in our society. The operation of these electronic devices may be disturbed by noise interference which, in many cases, may jeopardize human life. For this reason, it is no exaggeration to say that the prevention of noise interference is an obligation to society.

However, with the increasing amount of electronic equipment being used together in areas where they can affect each other, the probability of electoromagenetic interference becomes higher.

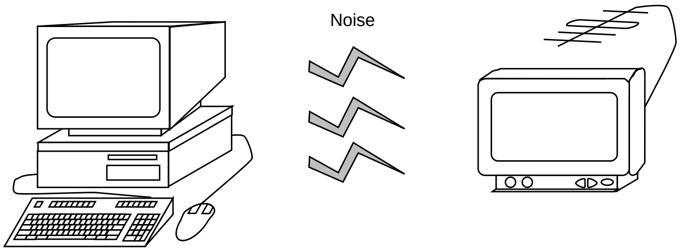
Therefore, electronic equipment that emits less noise and will be  in greater demand.

[Notes]

1. Reasons for Noise Suppression
1.2. Noise Emission and Immunity

## Noise Emission and Immunity

2




| Equipment that emits noise | Equipment that is exposed to noise |
|---|---|
| ⇩ | ⇩ |
| Preventing equipment from emitting noise | Preventing equipment from being affected by noise |
| ⇩ | ⇩ |
| Noise emission suppression | Immunization against noise |

Emission:
: The phenomenon by which electromagnetic energy emanates from a source.

Immunity:
: The ability of equipment to perform without degradation or being damaged by electromagnetic interference.

EMC (Electromagnetic Compatibility):
: The ability of equipment or system to function satisfactorily in an electromagnetic environment without introducing intolerable electromagnetic disturbance to anything in that environment.

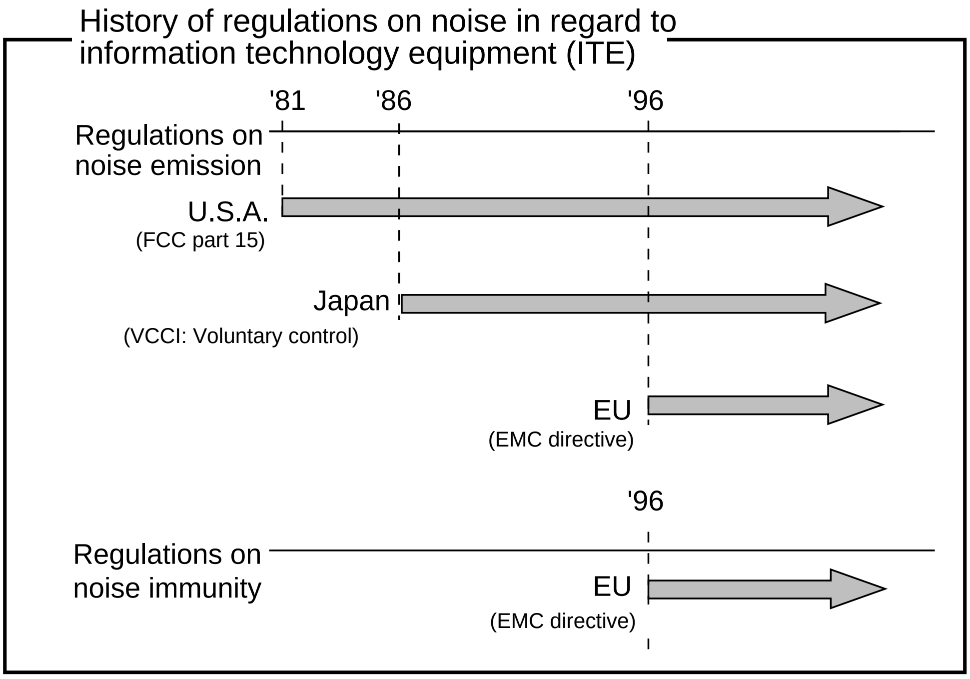
EMI (Electromagnetic Interference):
: Degradation of the performance of equipment, transmission channel or system, caused by an electromagnetic disturbance.

“Preventing equipment from emitting noise” is called “suppression of emission”. “Emission” means “to emit noise from equipment”. “Preventing equipment from being affected by noise” is called “immunization against noise”. “Immunity” means “the extent to which equipment is resistant to noise without malfunctioning (degradation of performance) or being damaged”. Though “EMS” (electromagnetic susceptibility), which refers to the susceptibility of equipment to noise, is also used, “immunity” is generally used as an antonym of “emission”.

“EMC” (electromagnetic compatibility) means “equipment’s or system’s capability to prevent the equipment or system from emitting unacceptable noise externally and from malfunctioning due to noise”. “EMI” (electromagnetic interference) means “decline in the performance of equipment, transmission channels, or systems due to noise (electromagnetic disturbance) when the EMC is unsatisfactory”.

# Noise Regulations

3




Noise regulations are enforced in many countries. Since most of these regulations have become laws, equipment that does not comply with the regulations cannot be sold in the country. Though most of the previous regulations were intended to prevent noise emission, there is an increasing number of regulations dealing with noise immunity.These regulations state that the equipment should not degrade perfirmance due to noise.

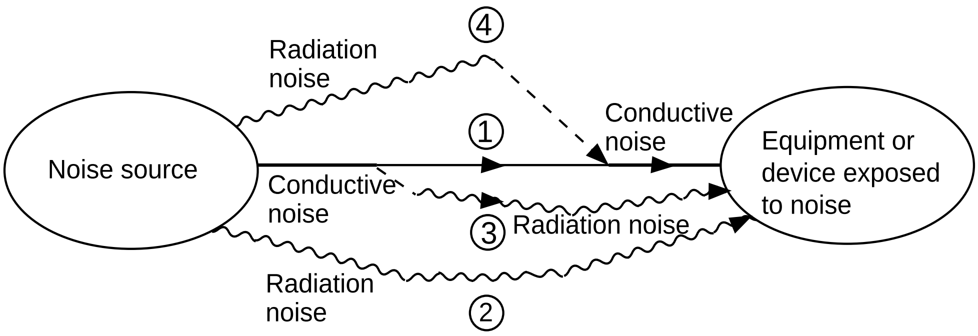
[Notes]

## 2. Noise Transmission Paths and Basic Concepts for Noise Suppression

### 2.1. Principle of Noise Suppression

#### Noise Transmission Paths

4




① Conduction

② Radiation

③ Conduction ——— Radiation

④ Radiation ——— Conduction

Noise emitted from a source is transmitted through many complicated paths, sometimes through a conductor and sometimes as radiation. When it reaches a device or equipment, that equipment is exposed to noise.

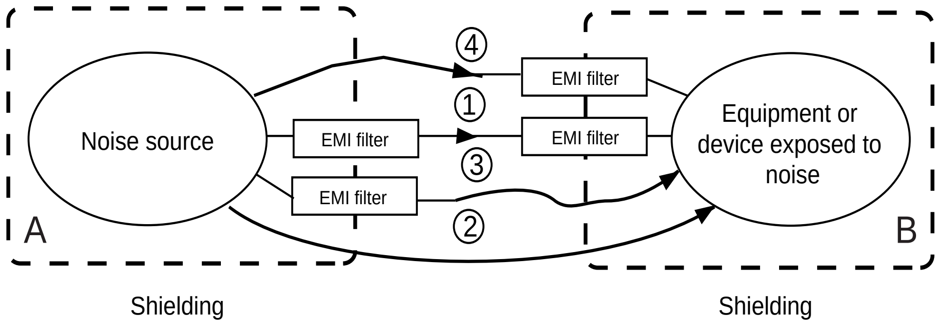
[Notes]

## 2. Noise Transmission Paths and Basic Concepts for Noise Suppression

### 2.1. Principle of Noise Suppression

**Principle of Noise Suppression**

5




| | How to suppress noise (Side A) | (Side B) |
|---|---|---|
| ① Conduction | EMI filter | EMI filter |
| ② Radiation | Shielding | Shielding |
| ③ Conduction → Radiation | EMI filter | Shielding |
| ④ Radiation → Conduction | Shielding | EMI filter |

In order to properly suppress noise, we must know the noise source and how it is transmitted. If the initial check is inaccurate, we cannot judge whether the noise suppression technique has failed or the technique was applied to an incorrect source.

The principle of noise suppression is to use an EMI filter for conducted noise and shielding for radiated noise.

[Notes]

## Methods to suppress noise with EMI filters

6

| Type of Noise | Methods to suppress noise with EMI filter |
|---|---|
| High-frequency noise<br>(Harmonic wave of signal, etc.) | Use different frequencies for signal and noise. |
| Common mode noise<br>(Noise transmitted on all lines, regardless of line types such as a signal line or ground line, in the same direction) | Use a different conduction mode between signal and noise. |
| High voltage surge<br>(Electrostatic discharge, surge, etc.) | Suppress high voltage surges using non-linear resistors (Varistors). |

To suppress noise using EMI filters, the following three methods are available.

1. Using different frequencies for signal and noise.
2. Using a different conduction mode between signal and noise.
3. Suppressing high voltage surges using non-linear resistors (Varistors).

[Notes]

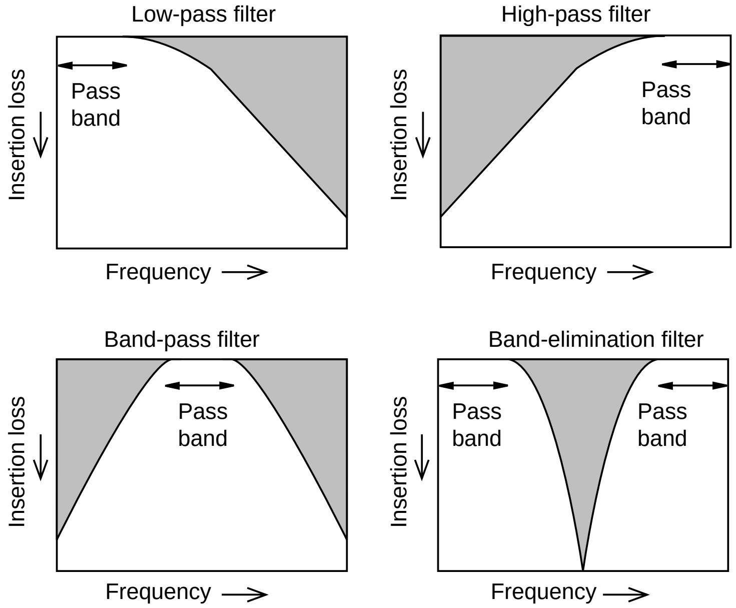
## 3. Noise Suppression by Low-pass Filters

### 3.1. Typical Filters

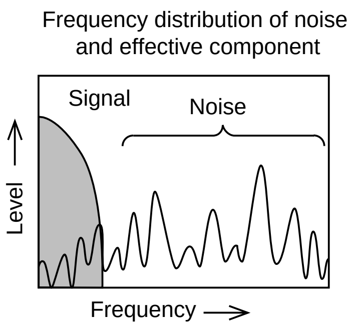
**Typical Filters**

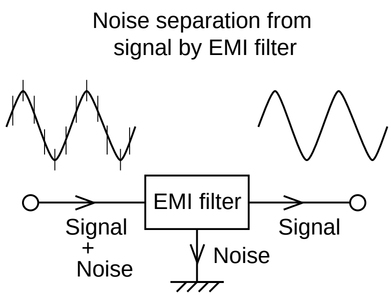
7

■ Typical filters




■ Noise separation by EMI filter




Filters used to pick out the desired signals are classified into the following four types.

Low-pass filter (LPF):

A filter which passes signals at frequencies lower than a specified frequency but attenuates signals at frequencies higher than the specified frequency.

High-pass filter (HPF):

A filter which passes signals at frequencies higher than a specified frequency but attenuates signals with frequencies lower than the specified frequency.

Band-pass filter (BPF):

A filter which only passes signals within a specified range of frequencies.

Band-elimination filter (BEF):

Filter which does not pass signals within a specified range of frequencies.

Most noise emitted from electronic equipment is at frequencies higher than circuit signals. Therefore, low-pass filters, which only pass signals with frequencies lower than a specified frequency and attenuates signals with frequencies higher than this frequency, are generally used as EMI filters.

3. Noise Suppression by Low-pass Filters

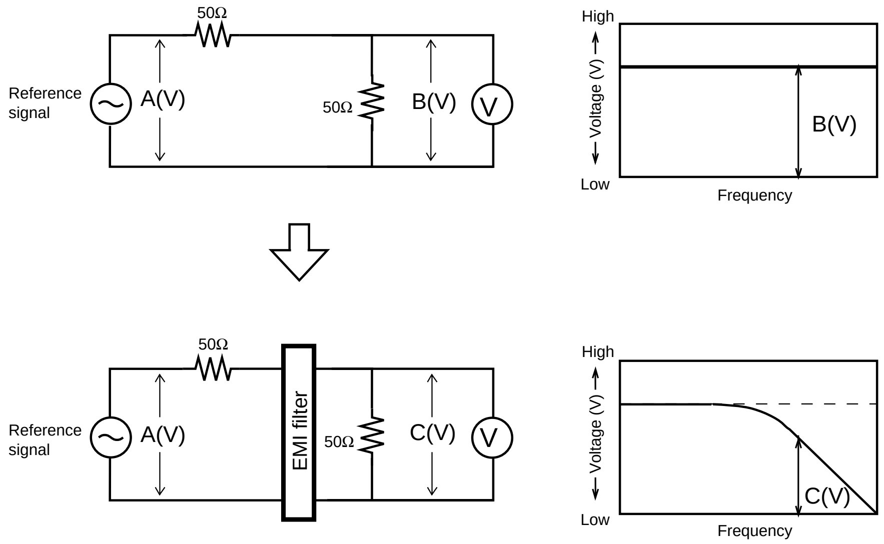
3.2. Insertion Loss

# Insertion Loss

8

Measuring methods of insertion loss( as specified in MIL STD-220 with input and output impedances of 50 Ω.)

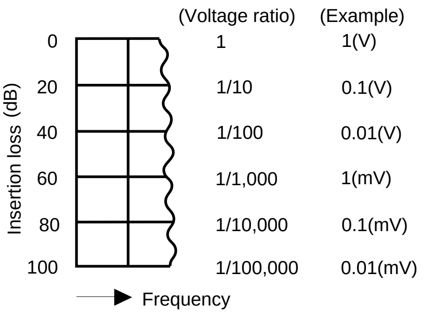
(a) Circuit for measuring insertion loss




(b) Expression to find insertion loss

$$\text{insertion loss} = 20 \log \frac{B}{C}$$

(c) Relationship between dB and voltage ratio




The noise suppression performance of EMI filters is measured according to the measuring method of insertion loss specified in MIL STD-220. Voltage across a load is measured both with and without a filter inserted, and the insertion loss is determined using the expression shown above. The unit of insertion loss is expressed in dB (decibel). For example, when insertion loss is 20 dB, noise voltage is reduced to one-tenth.

This measurement is performed with input/output impedances of 50 Ω (50 Ω system). However, in real-life circuits the input/output impedance is not 50 Ω and so the filter performance will differ from the 50 Ω system.

[Notes]

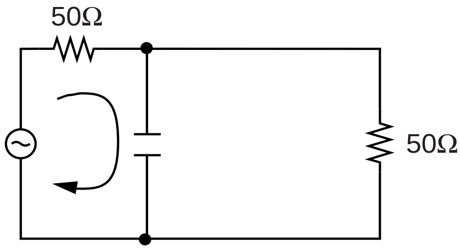
3. Noise Suppression by Low-pass Filters

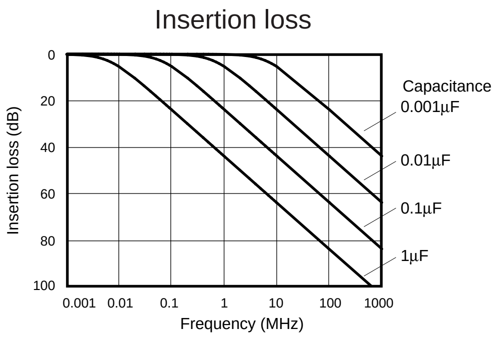
3.3. Low-pass Filters

## Low-pass Filters

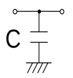
9

### 1. Capacitor



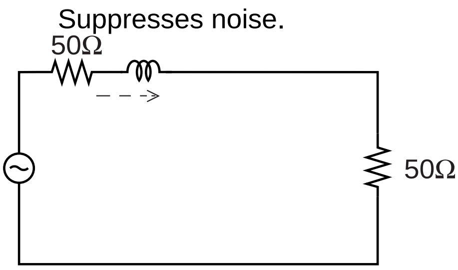

Capacitor

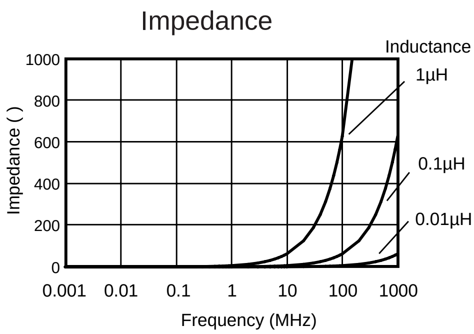



| Z | = 1 / 2 fC

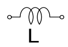
| Z | : Impedance ( )
f : Frequency (Hz)
C : Capacitance (F)

### 2. Inductor




Coil




| Z | =2 fL

| Z | : Impedance ( )
f : Frequency (Hz)
L : Inductance (H)

The most basic low-pass filter includes the following two components.

1. A capacitor installed between the signal line and GND line. (As the frequency becomes higher, the impedance of the capacitor becomes lower. Thus noise is forced to go through bypass capacitors to GND.)
2. An inductor (coil) installed in series with the signal line. As the frequency increases, the impedance of the inductor increases which prevents noise from flowing into the signal line.

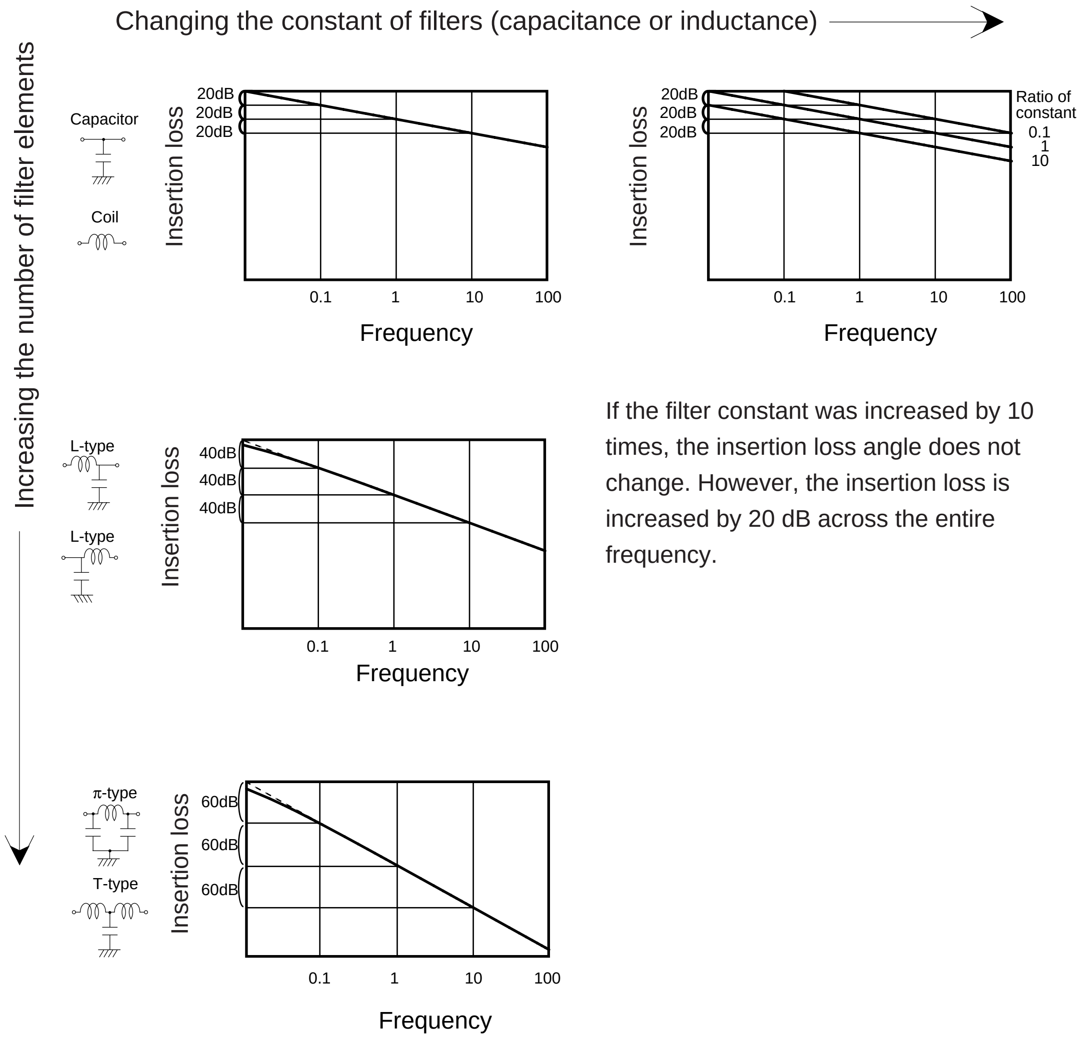
[Notes]

3. Noise Suppression by Low-pass Filters

3.3. Low-pass Filters

## Filter Construction - Constant and Insertion Loss

10




If the filter constant was increased by 10 times, the insertion loss angle does not change. However, the insertion loss is increased by 20 dB across the entire frequency.

The angle of insertion loss increases by 20 dB/decade every time one filter element is added.

In the frequency band where EMI noise problems occur, the insertion loss of filters increases by 20 dB every time the frequency is multiplied by ten.

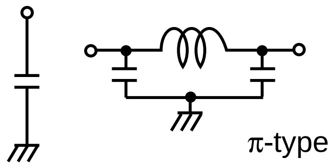
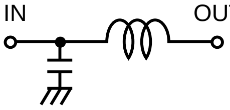
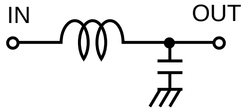
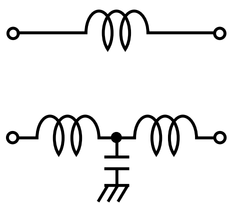
When the constant of filters (capacitor's capacitance or inductor's inductance) is increased, the insertion loss of filters increases by 20 dB every time the constant is multiplied by ten.

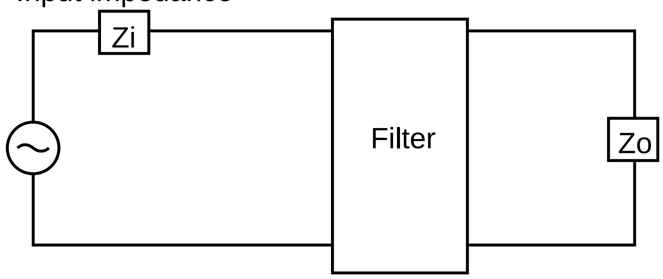
To increase the angle of the insertion loss, filters are used in combination.

[Notes]

## Suitable Filter for Input/Output Impedance

11

| | | Output impedance (Zo): High | Output impedance (Zo): Low |
|---|---|---|---|
| Input impedance (Zi) | High |  Capacitor, π-type |  L-type (IN, OUT) |
| | Low |  L-type (IN, OUT) |  Coil, T-type |




Filter effect varies depending on the input/output impedances.

As mentioned earlier, the insertion loss is measured with input and output impedances of 50 Ω . However, actual circuit impedances are not 50 Ω. Actual filter effects vary depending on the impedances of the circuit where the filter is installed.

Generally, a capacitor is more effective in suppressing noise in high impedance circuits, while an inductor is more effective in low impedance circuits.

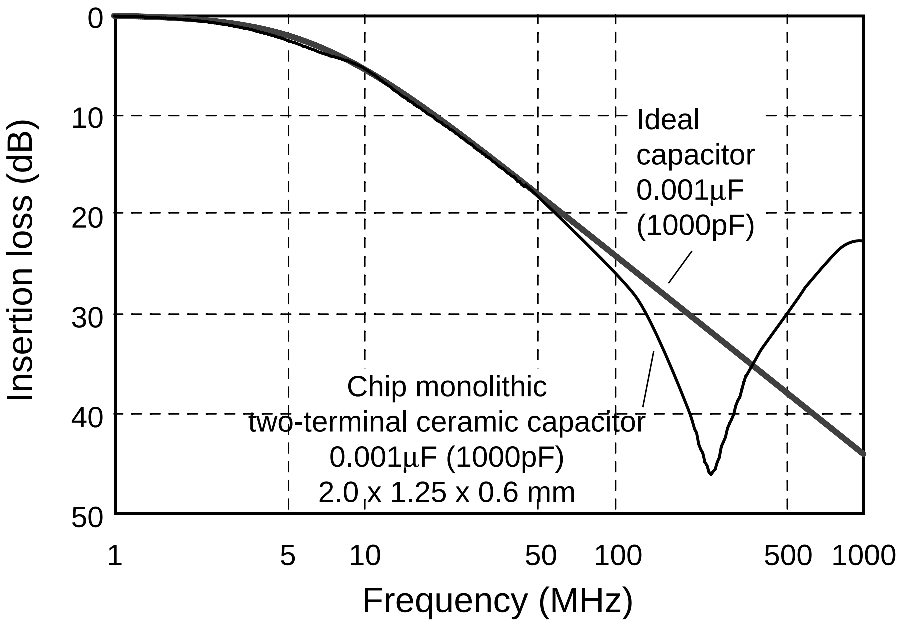
[Notes]

3. Noise Suppression by Low-pass Filters

3.5. The Effect of Non ideal Capacitors

## Characteristic of Capacitors

12




This section and the following sections describe the necessity and performance of capacitor-type EMI filters.

With the ideal capacitor, the insertion loss increases as the frequency becomes higher. However, with actual capacitors, the insertion loss increases until the frequency reaches a certain level (self-resonance frequency) and then insertion loss decreases.

[Notes]

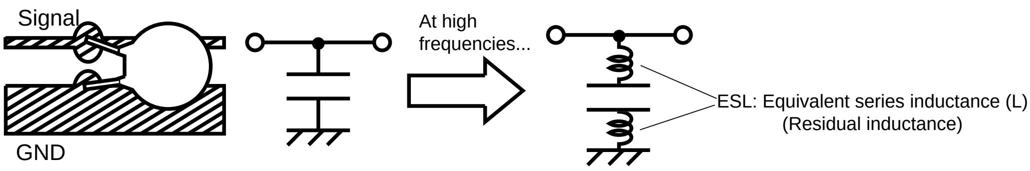
3. Noise Suppression by Low-pass Filters

3.5. The Effect of Non ideal Capacitors

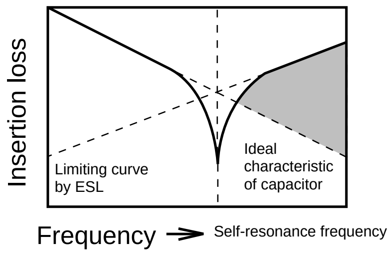
# The Effect of Non ideal Capacitors

13

## (a) Equivalent circuit of capacitor




## (b) Effect by residual inductance




Self-resonance frequency

The frequency  at which resonance occur due to the capacitor's own capacitance, and residual inductance. It is the frequency at which the impedance of the capacitor becomes zero.

From $j2\pi fL + 1/j2\pi fC = 0$,

$f = 1/2\pi\sqrt{LC}$

f: Self-resonance frequency

C: Capacitance

L: Residual inductance

The insertion loss of capacitors increase until the frequency reaches the self-resonance frequency and then  decrease due to residual inductance of the lead wires and the capacitor's electrode pattern existing in series with the capacitance.Since noise is prevent from going through the bypass capacitors  to the GND,the insertion loss decrease.The frequency at wich the insertion loss begins to decrease is called self-resonance frequency.

[Notes]

3. Noise Suppression by Low-pass Filters
3.5. The Effect of Non ideal Capacitors

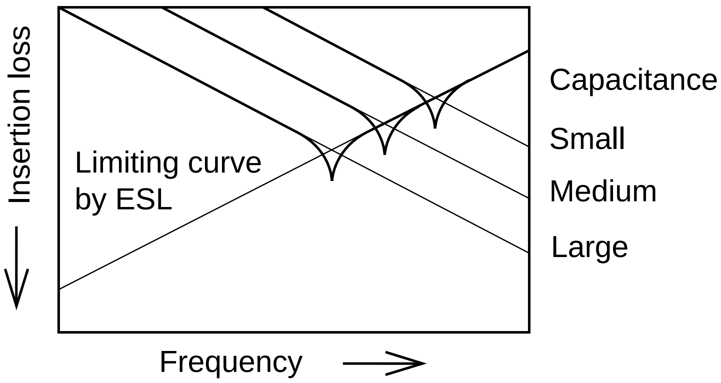
# The Effect of ESL

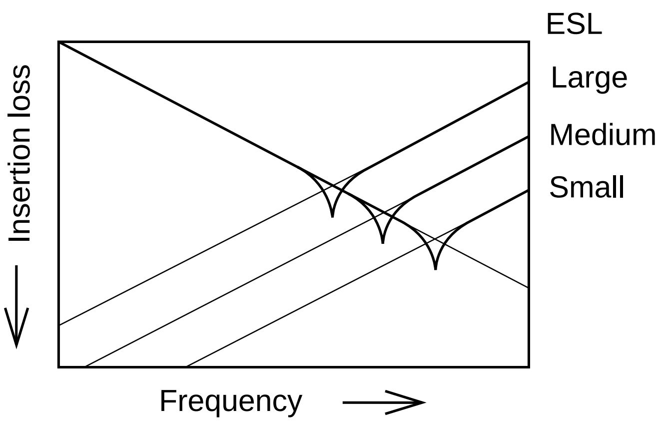
14

At frequencies higher than the self-resonance frequency, the insertion loss does not change regardless of whether the capacitance value is increased or decreased.

⇓

For use in a high-frequency range, a capacitor with a high self-resonance frequency, i.e. small residual inductance (ESL), must be selected.




When the residual inductance is the same, the insertion loss does not change at frequencies above the self-resonance frequency, regardless of whether the capacitance value of the capacitor is increased or decreased. Therefore for greater noise suppression at frequencies higher than the self-resonance frequency, you must select a capacitor with a higher self-resonance frequency, i.e. small residual inductance.

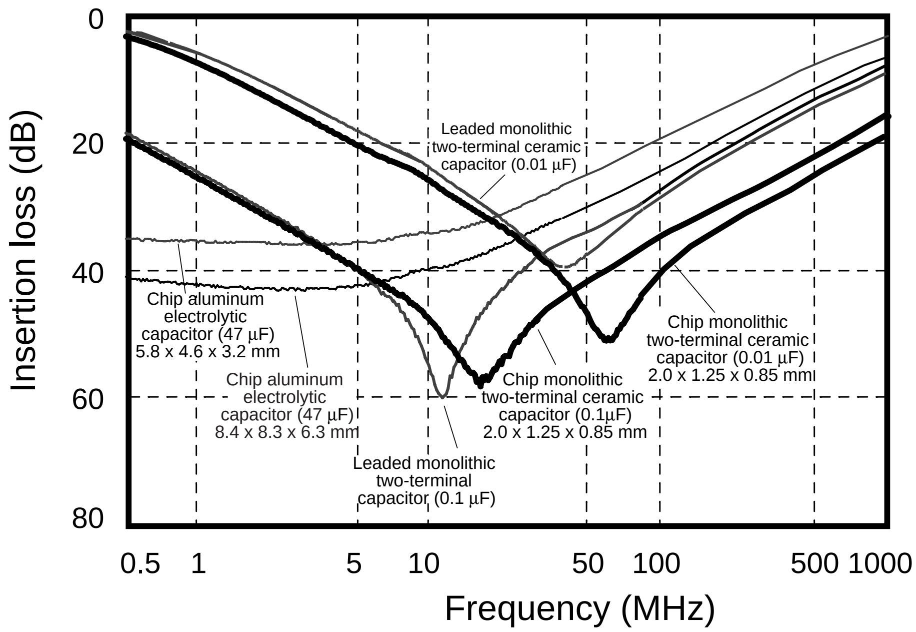
[Notes]

3. Noise Suppression by Low-pass Filters

3.6. Characteristic of Typical Capacitors

## Insertion Loss Characteristics of Typical Two-terminal Capacitors

15




The above drawing shows examples of insertion loss measurements of typical capacitors. For leaded capacitors, the insertion loss is measured with the lead wires cut to 1 mm.

[Notes]

## Typical ESL Values for Capacitors

16

| Type of Capacitor | Residual inductance (ESL) |
|---|---|
| Leaded disc ceramic capacitor (0.01 µF) | 3.0 nH |
| Leaded disc ceramic capacitor (0.1 µF) | 2.6 nH |
| Leaded monolithic ceramic capacitor (0.01 µF) | 1.6 nH |
| Leaded monolithic ceramic capacitor (0.1 µF) | 1.9 nH |
| Chip monolithic ceramic capacitor (0.01 µF, Size: 2.0 x 1.25 x 0.6 mm) | 0.7 nH |
| Chip monolithic ceramic capacitor (0.1 µF, Size: 2.0 x 1.25 x 0.85 mm) | 0.9 nH |
| Chip aluminum electrolytic capacitor (47 µF, Size: 8.4 x 8.3 x 6.3 mm) | 6.8 nH |
| Chip tantalum electrolytic capacitor (47 µF, Size: 5.8 x 4.6 x 3.2 mm) | 3.4 nH |

The above table shows typical residual inductances (ESL) values for capacitors, which are calculated from the impedance curves shown on the previous page.
The residual inductance varies depending on the type of capacitor. It can also vary in the same type of capacitor, depending on the dielectric material and the structure of the electrode pattern.

[Notes]

3. Noise Suppression by Low-pass Filters

3.7. Improvement of High-frequency Characteristic

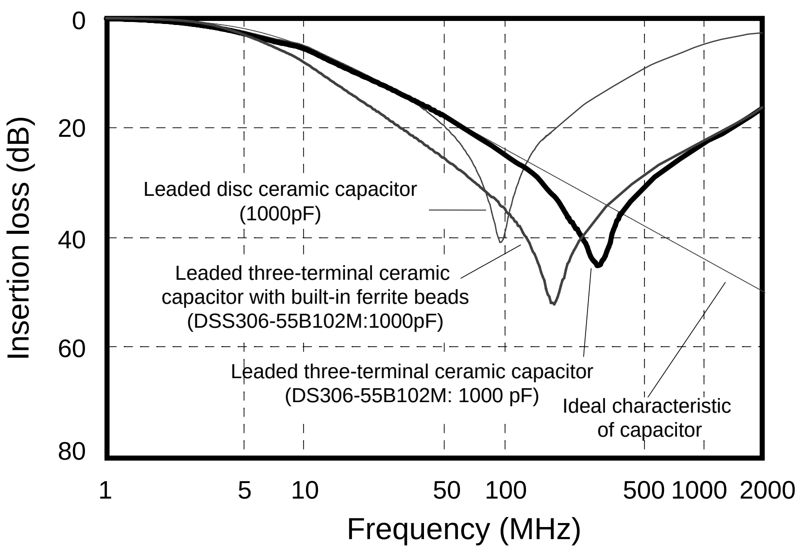
# Three-terminal Capacitor Structure

17

## (a) Structure of capacitors


## (b) Equivalent circuit with considerations for ESL


## (c) Improvement results in insertion loss characteristic




With leaded two-terminal capacitors, the residual inductance is larger because the lead wires work as inductors.

By making the three terminal structure ,the residual inductance in series with capacitance become lower .Therefore the insertion loss is better than two terminal capacitors.

[Notes]

3. Noise Suppression by Low-pass Filters

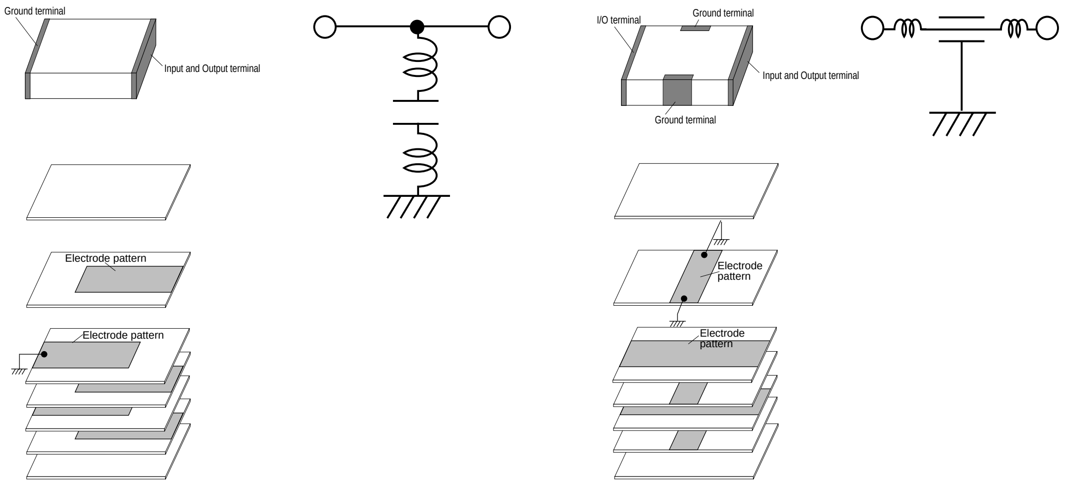
3.7. Improvement in High-frequency Characteristic of Capacitors

# Chip Type Three-terminal Capacitors

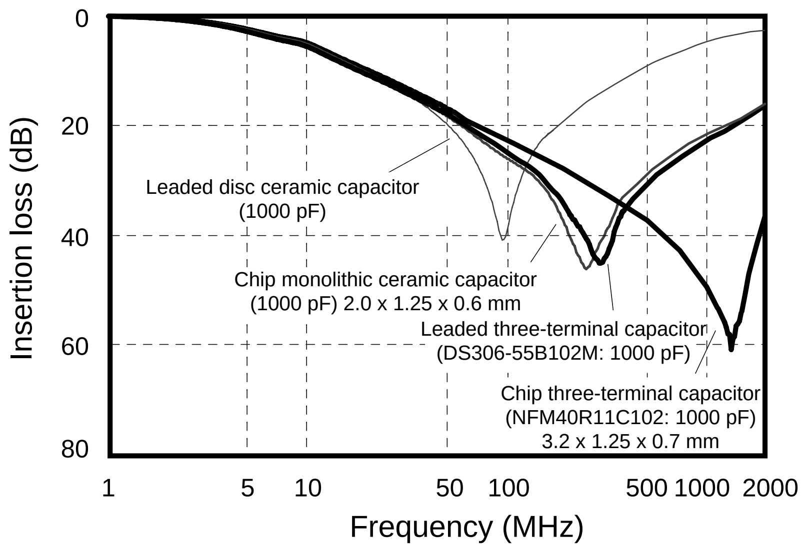
18

## (a) Structure of capacitors

Chip two-terminal capacitor                Chip three-terminal capacitor




## (b) Improvement results of insertion loss characteristic




The structural model of the chip three-terminal capacitor is shown above. An electrode pattern is printed on each dielectric sheet. Input and output terminals are provided on both ends and are connected using the electrode pattern. This structure allows the signal current to pass through the capacitor.The residual inductance on the ground terminal is reduced with ground terminals on both sides.

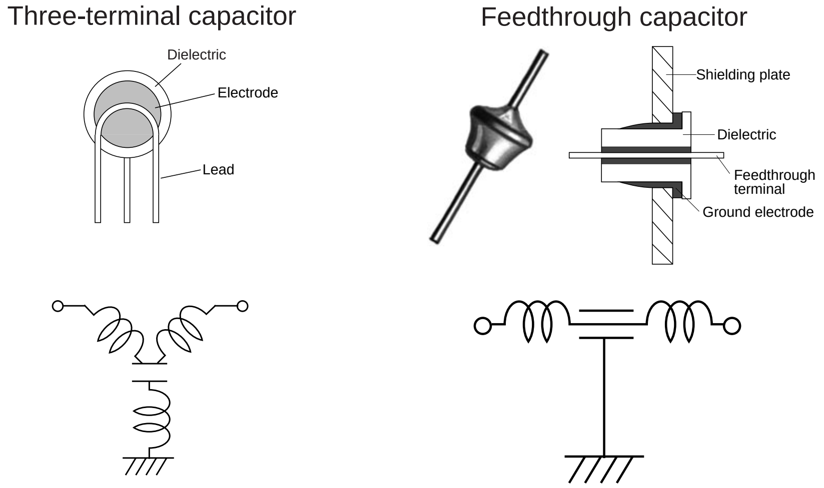
This structure makes an extremely low residual inductance, which provides a higher self-resonance frequency.

[Notes]

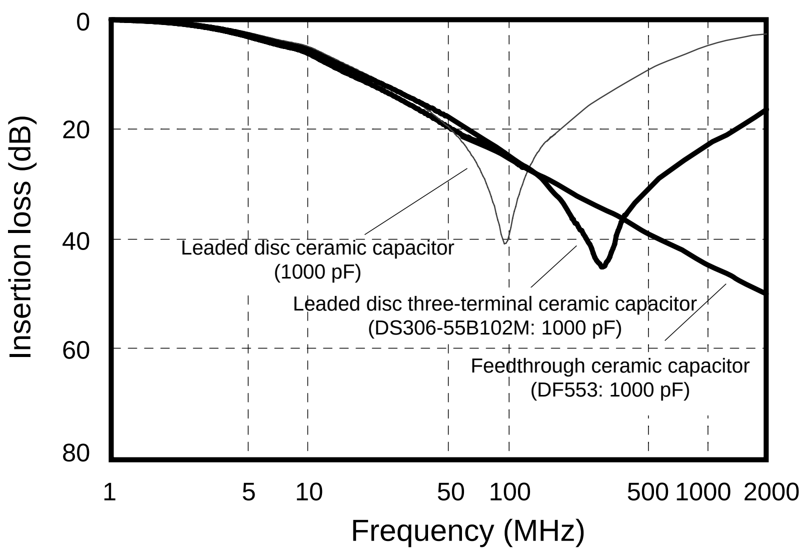
# Feedthrough Capacitors

19

## (a) Structure of capacitors




## (b) Improvement results of insertion loss characteristic




Feedthrough capacitors have a structure in which the ground electrode surrounds the dielectric and the signal terminal goes through the dielectric. Feedthrough capacitors are used by making a mounting hole in the shielding case and soldering the ground electrode directly to the shielding case (plate). Since this type of capacitor has no residual inductance on the ground terminal side as well as on the signal terminal side, it can provide nearly ideal insertion loss characteristics.

[Notes]

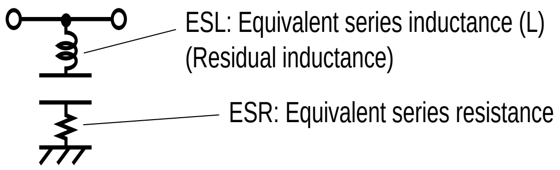
3. Noise Suppression by Low-pass Filters

3.8. The Effect of Equivalent Series Resistance

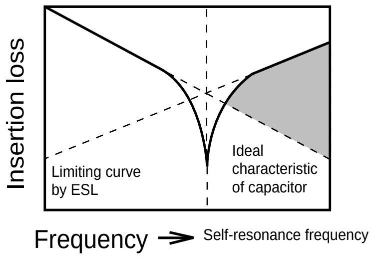
# The Effect of Equivalent Series Resistance

20

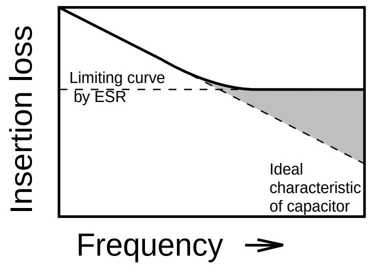
(a) Capacitor's equivalent circuit with ESL and ESR



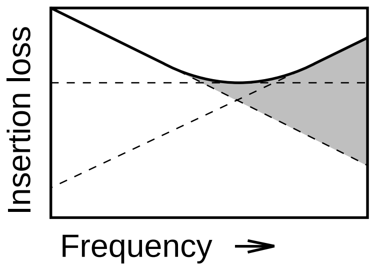

(b) Affect by ESL




(c) Affect by ESR




(d) Insertion loss frequency characteristic of actual capacitor affected by ESL and ESR




The second factor that causes deterioration in the characteristic of capacitors is equivalent series resistance (ESR). The insertion loss will be lower due to ESR caused by the electrode and material.

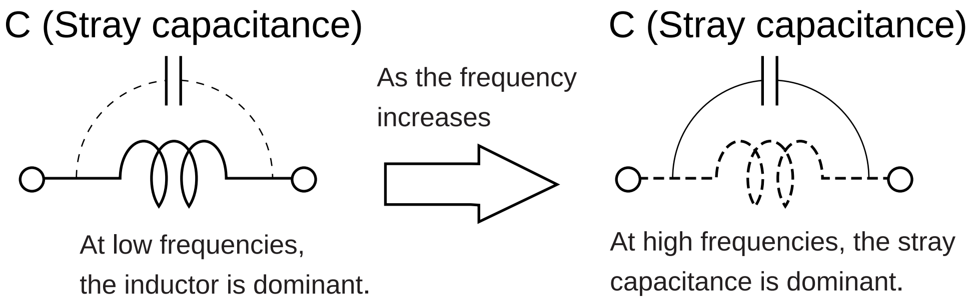
The ESR is very low in ceramic capacitors but higher in aluminum electrolytic capacitors.

[Notes]

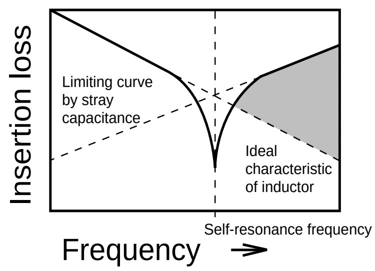
# The effect of Non Ideal Inductors

21

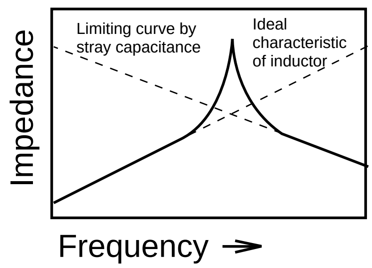
(a) Inductor's equivalent circuit




(b) Effect of stray capacitance




(c) Impedance characteristic




The previous sections have described why the insertion loss of capacitors is not ideal due to the residual inductance and equivalent series resistance. The insertion loss of inductors is also not ideal. The impedance of inductors begins to decrease when the frequency exceeds the self-resonance frequency because as frequency increases, the impedance of the stray capacitance decreases. Hence noise bypasses the inductor.

[Notes]

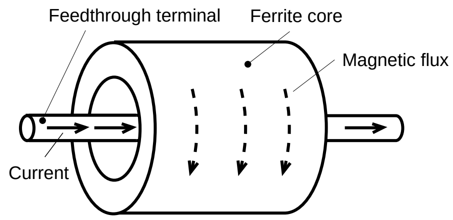
3. Noise Suppression by Low-pass Filters

3.10. Ferrite bead Inductors

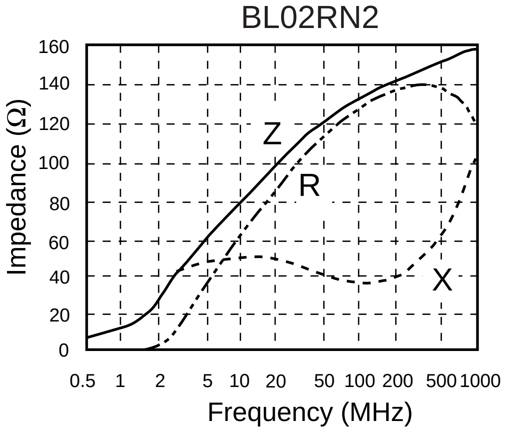
# Ferrite Beads Inducters

22

(a) Structure




(b) Example of impedance characteristic




$Z = R + jX$

$(Z^2 = R^2 + X^2)$

Leaded ferrite bead inductors, which are typical inductor-type EMI filters, have a simple structure in which a feedthrough terminal goes through the ferrite core, allowing reduction of stray capacitance. The above graph (b) shows an example of the impedance characteristic. This graph demonstrates that this type of inductor has an excellent characteristic with a self-resonance frequency of 1 GHz or higher because of small stray capacitance.

[Notes]

3. Noise Suppression by Low-pass Filters

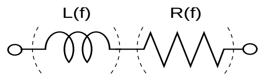
3.11. Understanding Ferrite Bead Inductors

# Understanding Ferrite Bead Inductors

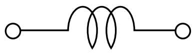
23

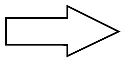
At high frequencies, ferrite bead inductors work like resistors instead of inductors.

Equivalent circuit




In a low-frequency range as frequency increases In a high-frequency range



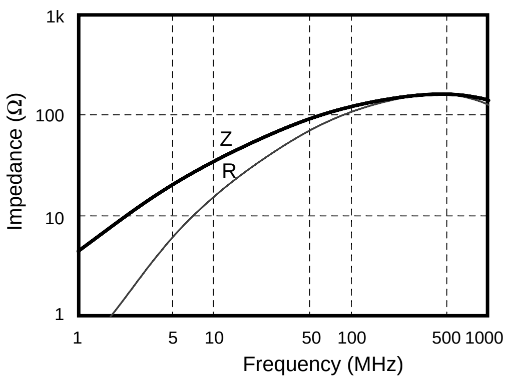


The inductance (L) is dominant.

The resistance (R) is dominant.

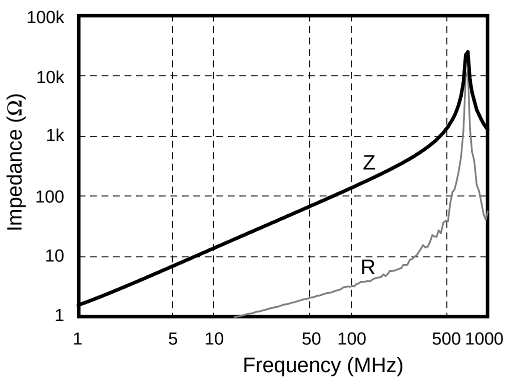
Examples of impedance characteristic

Ferrite bead inductor




Resistance is dominant.
(The loss is high.)

Reference: Coil for high-frequency filter circuits
(Air-core coil)




Resistance is small.
(The loss is low, i.e. “Q” is high.)

In addition to small stray capacitance, ferrite bead inductors have another excellent feature. At high frequencies, this type of inductor works not as an inductor but as a resistor, and dissipates noise in the form of heat.

The above graphs show examples of the impedance curves exhibited by a ferrite bead inductor and coil for high-frequency filter circuits. “Z” shows the impedance and “R” shows the resistance. The “R” is high in the ferrite bead inductor.

[Notes]

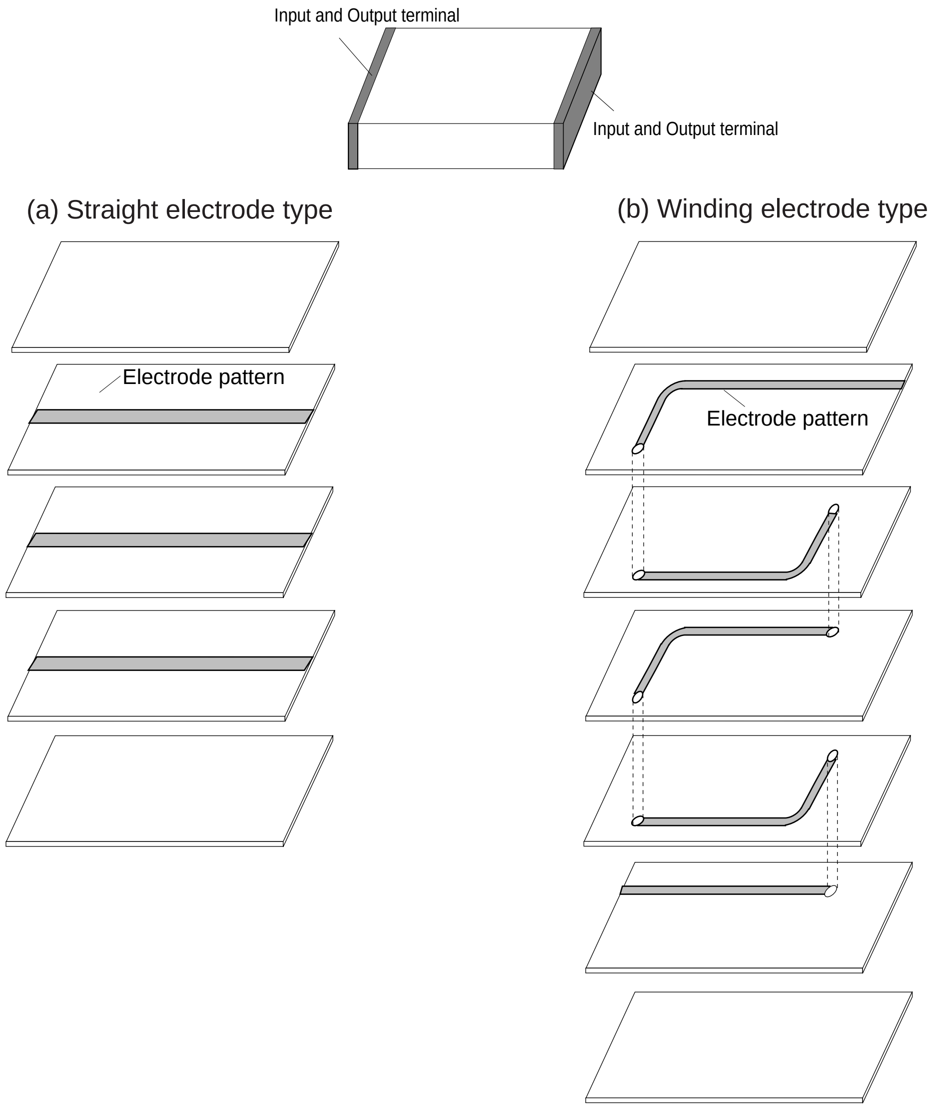
3. Noise Suppression by Low-pass Filters

3.12. Structure of Chip Ferrite Bead Inductors

# Structure of Chip Ferrite Bead Inductors

24

Structure of chip ferrite bead inductors




The above drawings show the structure of chip ferrite bead inductors. An electrode pattern, which forms a feedthrough electrode, is printed on ferrite sheets. These sheets are stacked to form a chip inductor. When larger impedance is required, the electrode pattern on each sheet in connected through the via-holes to form a winding electrode type chip inductor.

Unlike general inductors, both chip types are designed so that stray capacitance is small.

[Notes]

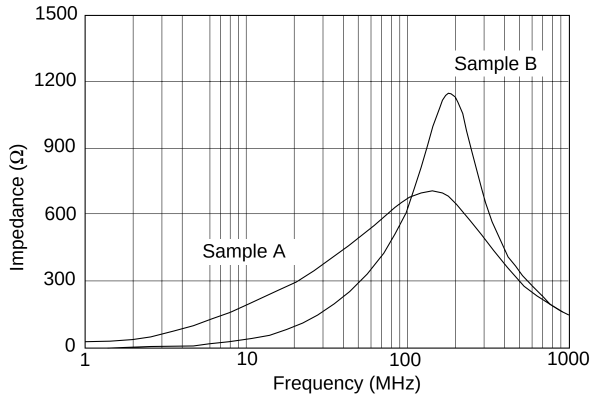
3. Noise Suppression by Low-pass Filters

3.13. Impedance Characteristic

# Impedance Characteristic

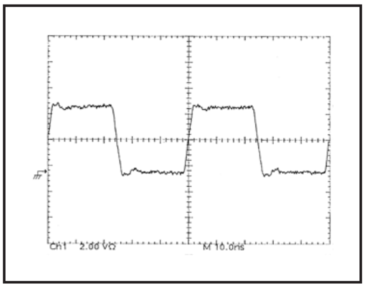
25

Example of different impedance characteristic

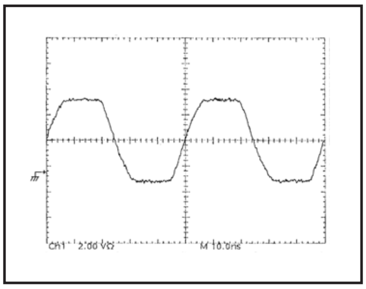



Examples of measured signal waveforms (10 MHz)

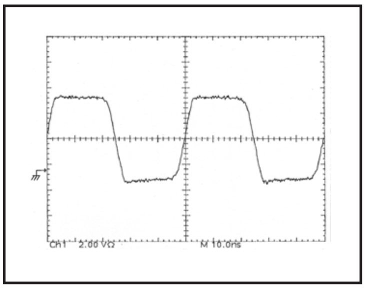
No filter



Sample A



Sample B



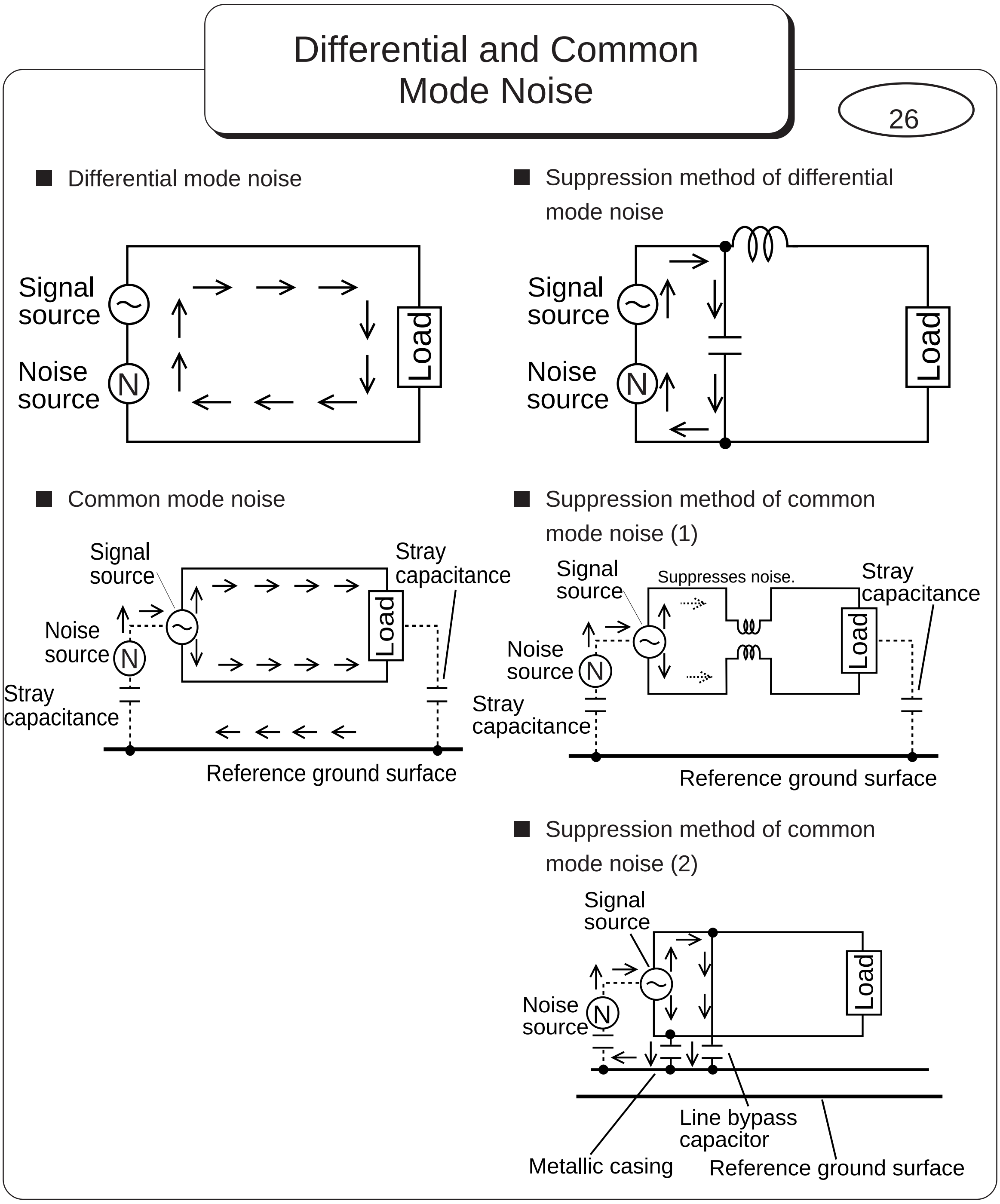
With ferrite bead inductors, the impedance characteristic varies depending on the material and structure. The signal waveform and noise suppression effect vary depending on the impedance.

With ferrite bead inductors the impedance varies depending upon the material and internal structure. The above graphs show examples of signal waveforms varying with impedance. The signal frequency is 10 MHz. When selecting a ferrite bead inductor, it is necessary to consider the impedance in the noise band and also the impedance gradient.

[Notes]

## 4. Other Filters

### 4.1. Differential and Common Mode Noise




Noise is classified into two types according to the conduction mode.

The first type is differential mode noise which is conducted on the signal (VCC) line and GND line in the opposite direction to each othe. This type of noise is suppressed by installing a filter on the hot (VCC) side on the signal line or power supply line, as mentioned in the preceding chapter.

The second type is common mode noise which is conducted on all lines in the same direction. With an AC power supply line, for example, noise is conducted on both lines in the same direction. With a signal cable, noise is conducted on all the lines in the cable in the same direction.

Therefore, to suppress this type of noise, EMI suppression filters are installed on all lines on which noise is conducted.

In the examples shown above, the following two suppression methods are applied.

1. Noise is suppressed by installing an inductor to the signal line and GND line, respectively.
2. A metallic casing is connected to the signal line using a capacitor. Thus, noise is returned to the noise source in the following order; signal/GND lines ➝ capacitor ➝ metallic casing ➝ stray capacitance ➝ noise source.

4. Other Filters

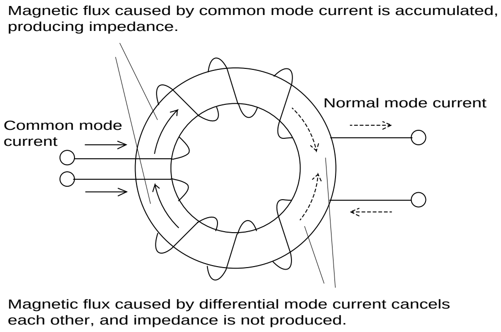
4.2. Noise Suppression by Common Mode Choke Coils

# Noise Suppression by Common Mode Choke Coils (1)

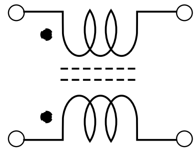
27

Common mode choke coils work as a simple wire against differential mode current (signal), while they work as an inductor against common mode current (noise).

(a) Structure




(b) Equivalent circuit

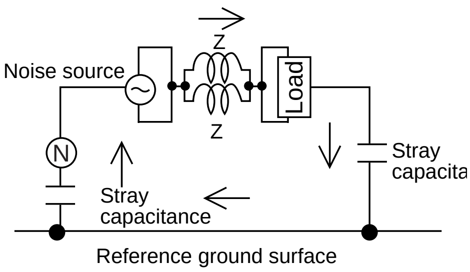


(c) Effect against common mode noise

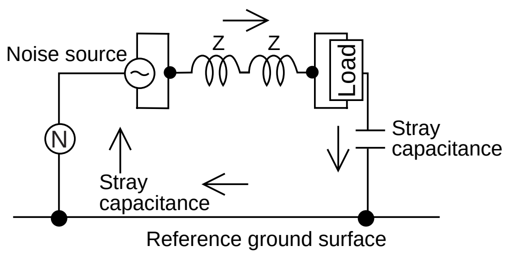
Since magnetic flux caused by common mode current is accumulated, a high amount of impedance is produced.

⇨ Common mode choke coils are suited for common mode noise suppression because a coil with large impedance is easily achieved.

(1) When two normal inductors are used




(2) When a common mode choke coil is used




Common mode choke coils are used to suppress common mode noise. This type of coil is produced by winding the signal or supply wires one ferrite core.

Since magnetic flux flows inside the ferrite core, common mode choke coils work as an inductor against common mode current. Accordingly, using a common mode choke coil provides larger impedance against common mode current and is more effective for common mode noise suppression than using several normal inductors.

[Notes]

4. Other Filters

4.2. Noise Suppression by Common Mode Choke Coils

# Noise Suppression by Common Mode Choke Coils (2)

28

(d) Effect on differential mode current

Since magnetic flux caused by differential mode current cancels out, impedance is not produced.

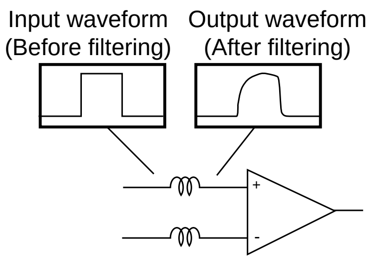
⇨ A decrease in impedance due to magnetic saturation does not easily occur, even if the current flow is large.

Common mode choke coils are suited for noise suppression on lines with large current flows, such as AC/DC power supply lines.

⇨ The distortion of the waveform is less.

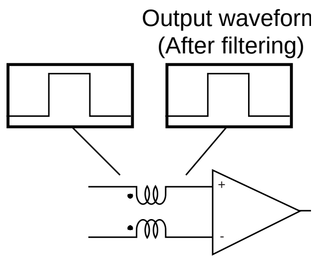
Common mode choke coils are suited for noise suppression on lines where signal waveform distortion causes a problem, such as video signal lines.

(1) When two inductors are used



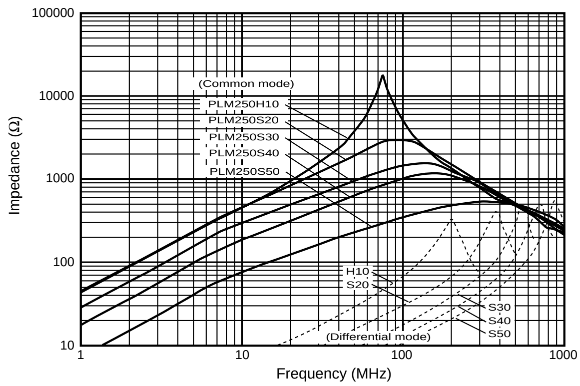

The distortion of the waveform is large

(2) When a common mode choke coil is used




The distortion of the waveform is small

(e) Examples of impedance characteristics of DC common mode choke coils




Since magnetic flux cancels out inside the ferrite core, impedance is not produced for differential mode current. The magnetic saturation problem is small. Common mode choke coils are suited for common mode noise suppression on lines with large current flow, such as AC/DC power supply lines. Since they do not affect signal waveform, they are also suited for common mode noise suppression on lines where signal waveform distortion causes a problem, such as video signal lines.

The above graph shows examples of impedance characteristics of DC common mode choke coils. Actual characteristics also contain differential mode impedance, and this must be considered when using common mode choke coils in circuits where the signal waveform is significant.

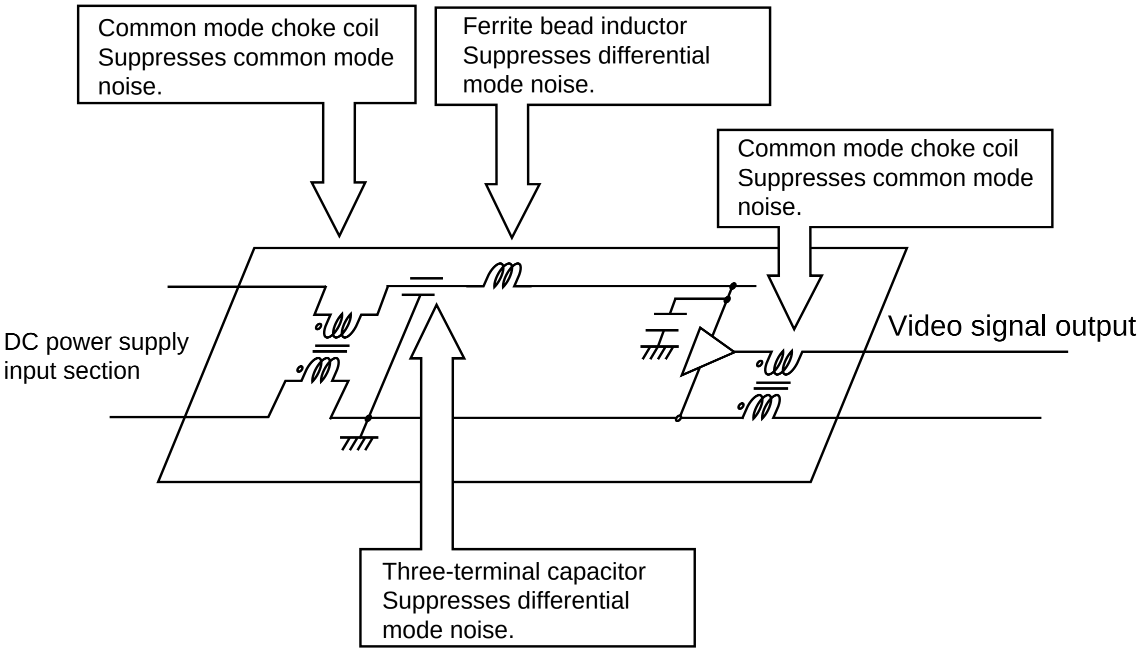
[Notes]

4. Other Filters

4.3. Example of Noise Suppression by using Common mode Choke Coils

## Example of Noise Suppression in DC Circuit

29




The above drawing shows an example of noise suppression in the DC circuit.

DC power supply input section

A common mode choke coil is installed in the input section of the DC power supply line to suppress common mode noise. (This coil can be replaced with two ferrite bead inductors.)

Differential mode noise is suppressed by installing a three-terminal capacitor and ferrite bead inductor in the supply line.

Video signal output section

Common mode noise transmitted to the video signal output section is suppressed by using a common mode choke coil.

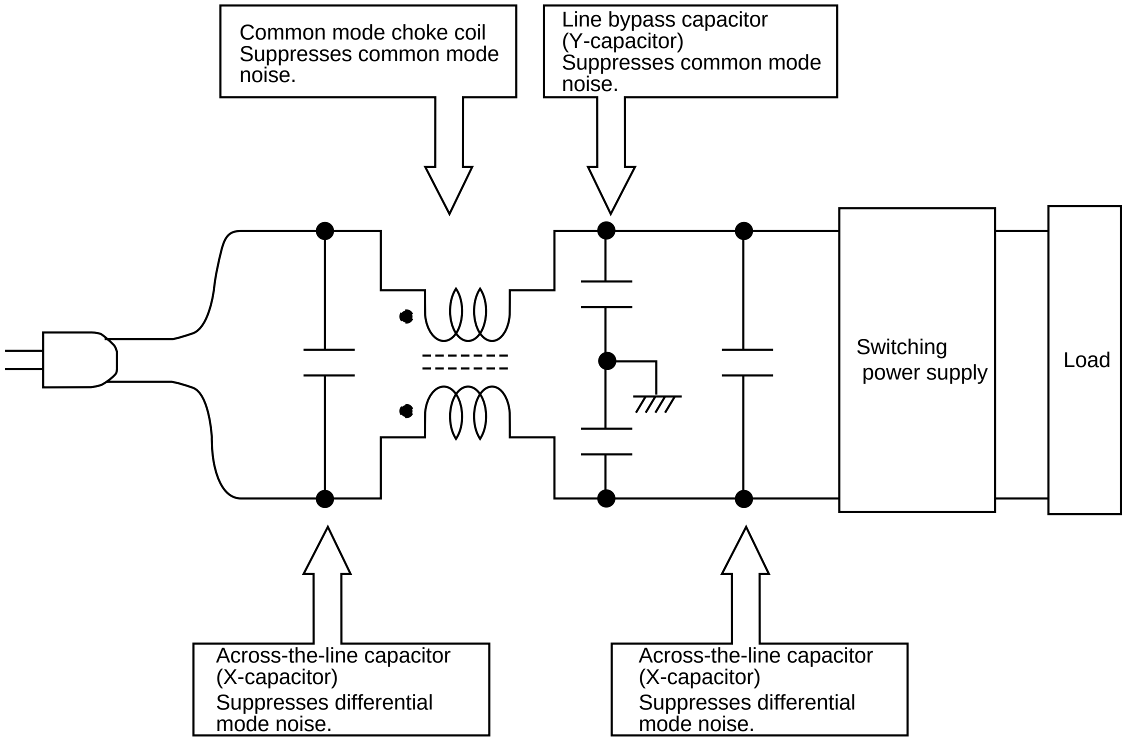
[Notes]

4. Other Filters

4.3. Example of Noise Suppression by using Common mode Choke Coils

# Example of Noise Suppression on AC Power Supply Line

30




The above drawing shows an example of noise suppression on an AC power supply line.
Common mode noise is suppressed by using a common mode choke coil and capacitor (line bypass capacitor or Y-capacitor) installed between each line and the metallic casing. The Y-capacitor returns noise to the noise source in the following order; Y-capacitor → metallic casing → stray capacitance →noise source.

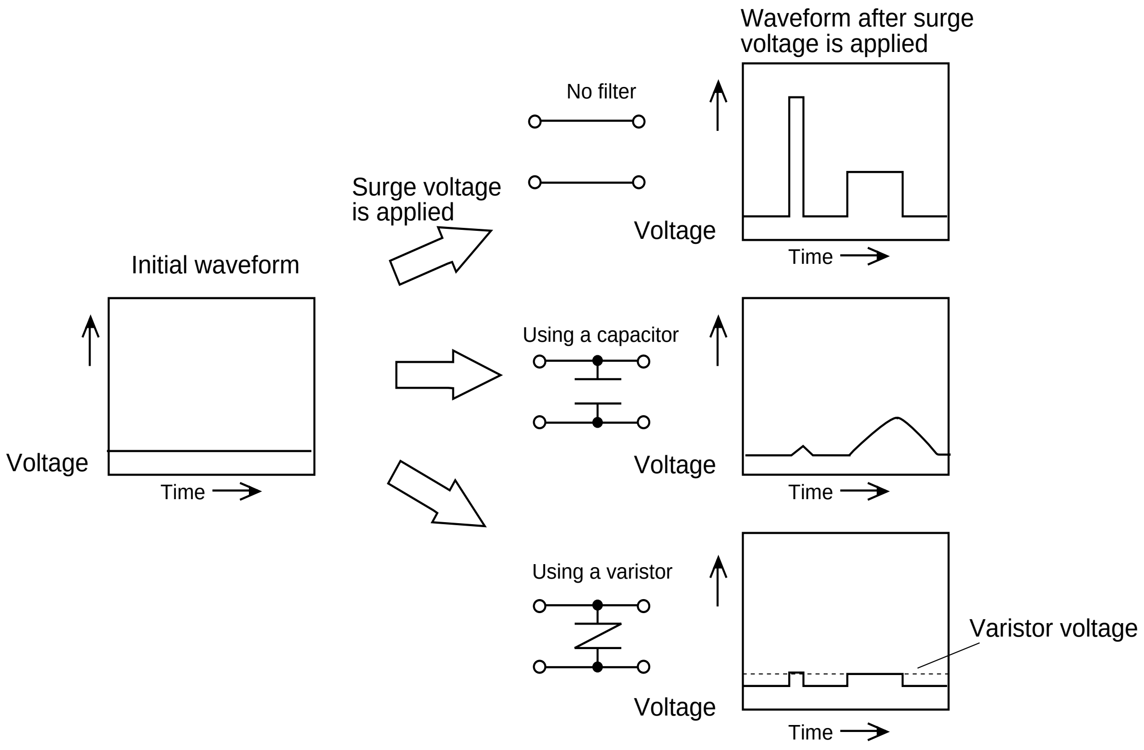
Differential mode noise is suppressed by installing capacitors(X capacitors) across the supply line.

[Notes]

4. Other Filters
4.4. Varistors

# Circuit Protection from Transient Voltage by Varistor

31




Varistors are used to protect a circuit from high voltage surges.
When a high voltage surge is applied to a circuit, the outcome is usually catastrophic to the circuit. A capacitor may be installed across the signal lines. However, this capacitor cannot suppress voltage surges.

Therefore, when circuit protection from voltage surges is required, a varistor is used as a voltage protection device. When a voltage surge exceeding a specified voltage (varistor voltage) is applied, the varistor suppresses the voltage to protect the circuit.

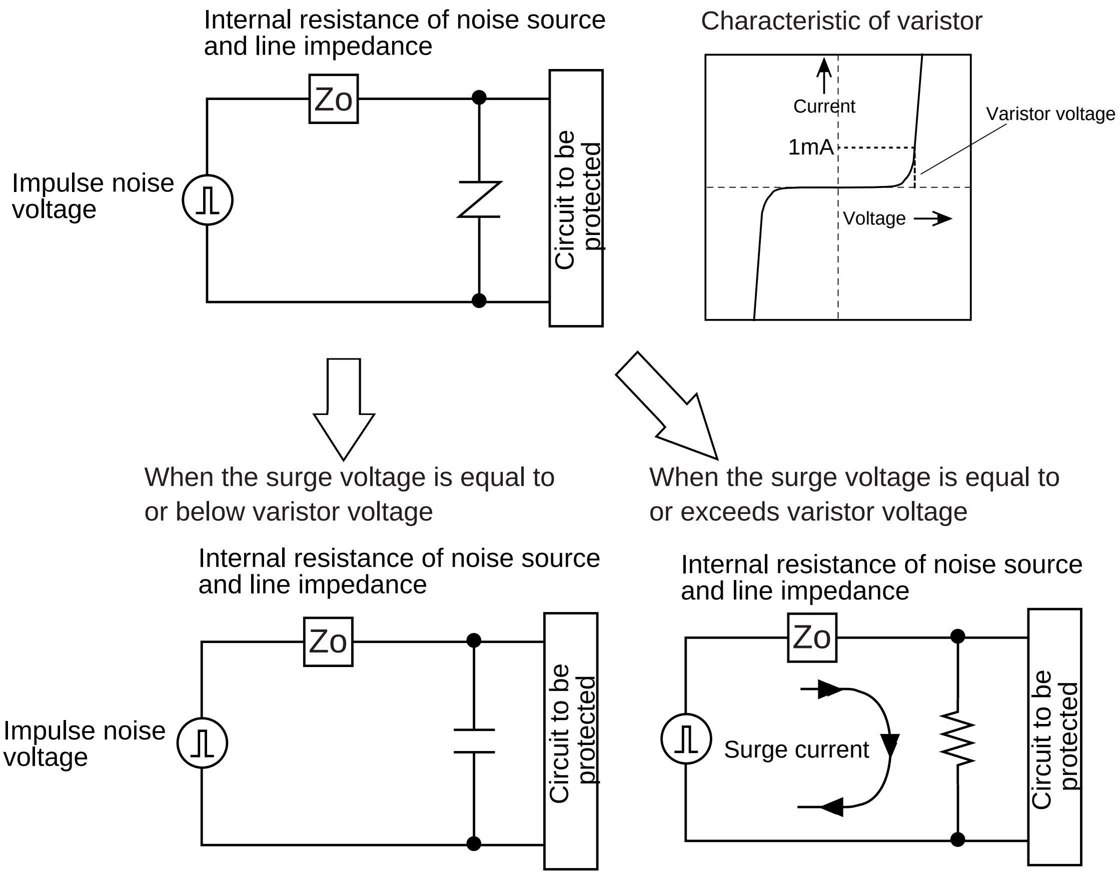
[Notes]

4. Other Filters

4.4. Varistors

## Characteristic of Varistor

32




Varistor voltage

The Voltage applied across the terminals when a current of 1 mA flow through varistor .

Peak pulse current

Impulse current which the varistor can withstand.

When the voltage surge does not exceed the varistor voltage, the varistor works as a capacitor. However, when the surge voltage exceeds the varistor voltage, the impedance across the varistor terminals decreases sharply. Since input voltage to the circuit depends on the varistor internal resistance and line impedance, the decrease in the impedance across the varistor terminals allows surge voltage suppression.

An essential point of varistor selection is that the varistor can handle the peak pulse current. The peak pulse current is the maximum current at which the varistor voltage does not change by more than 10% even if a peak current is applied twice at intervals of 5 minutes(pulse to have a rising pulse width of 8 µs and a half width of 20 µs). If the peak pulse current rating is insufficient,then the varistor may be damaged.

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