TDK EMC TECHNOLOGY

GUIDE BOOK FOR EMC

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Outline of EMC Design Methods

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1 What is EMC Design?

This chapter outlines the latest EMC design methods for electronic circuits. As the basics described in references [1] to [4] are still current, many areas of EMC design have not changed, but because frequency bands have increased in width, more attention needs to be paid to further details (see [5]). Because EMC phenomena are complicated part of the EMC problem has not been clarified sufficiently. Therefore, people often attempt to explain invisible things as if they had really seen them or explain them with personification. EMC engineers are required to judge whether an explanation is reasonable (whether it has enough evidence to support it) and whether the explanation can be applied to their individual situation. These requirements may be the very heart of the EMC problem.

In order to reduce malfunctions and the performance deterioration of electronic devices caused by noise, measures need to be taken by both noise generators and noise receivers. A measure for suppressing noise emitted from a generator or a damage-causing system is called a “countermeasure against emission” and a measure for decreasing entries of noise into a receiver or a damage-suffering system and preventing malfunctions caused by noise that has entered is called a “countermeasure for immunity” (Figure 1). The term “EMC (Electro-Magnetic Compatibility)” [*1] means that these two measures need to be simultaneously and effectively applied at the same time, and that a system with no failure must be realized in any environment.

Figure 1 Classification of EMC Countermeasures

2 Countermeasures for Immunity

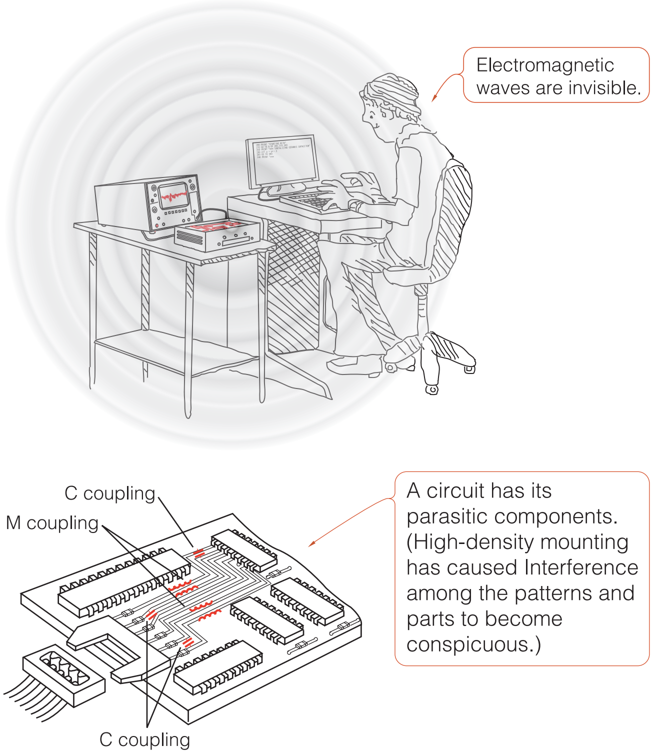
From the viewpoint of noise resistance, circuits that handle faint analog signals, such as sensors, are most in need of countermeasures for immunity. Generally, analog circuits are easily damaged by noise and digital ones are not. This means ironically that digital signals have high-frequency components as their harmonics and they can be noise sources. Therefore, analog circuits need to be placed away from digital and switching circuits. In addition, normally, the same grounding cable should not be used for the three types of circuits. On the other hand, as their drive voltage lowers digital circuits also tend to be affected by noise and therefore malfunction easily.

Recently, as electronic devices have become lighter, thinner, and more compact, they are touched more by users and the problem of static electricity has become a focus for countermeasures for immunity. Countermeasures against static electricity are described in a later chapter.

3 Countermeasures against Emission

Because conduction noise has a low frequency, a relatively conventional measure such as the insertion of a filter to prevent the noise being conducted can be applied. Emission noise however, is difficult to deal with because electromagnetic waves are invisible (Figure 2) and difficult to measure. Furthermore, because emission noise has a high frequency, parasitic

Figure 2 When a Frequency Becomes Higher



Electromagnetic waves are invisible.

A circuit has its parasitic components. (High-density mounting has caused Interference among the patterns and parts to become conspicuous.)

[*1] There is a similar term “EMI (Electro-Magnetic Interference),” which was formerly called “RFI (Radio Frequency Interference.)” EMI refers to problems caused by electromagnetic noise. Countermeasures against EMI, EMC, and general noise can mean much the same, but the term “EMI” is sometimes used to mainly mean emission.

components[2] and resonance become conspicuous, which makes it difficult to find the reason for the emission noise being generated. However, there are some ironclad rules to observe in handling emission noise. The following explains how to handle noise from the viewpoints of (1) noise-generating source, (2) transmission route, and (3) antenna (for emission noise).

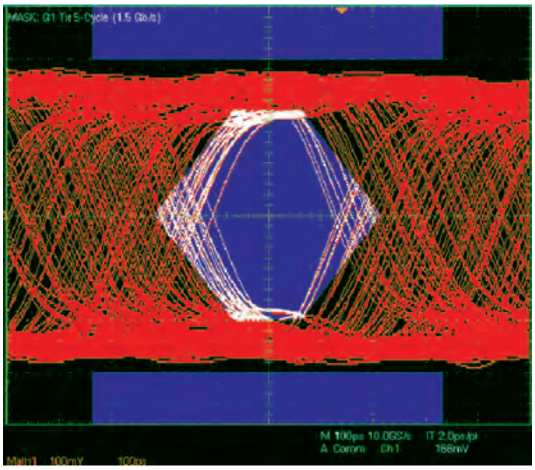
● Measure to be Taken at a Noise-generating Source

The best measure is to ensure the generation of no noise. But, normally, this is not very easy to do. One man's signal is another man's noise. Therefore, as second best, a measure needs to be taken near a noise-generating source and such methods are listed in the next section (transmission route).

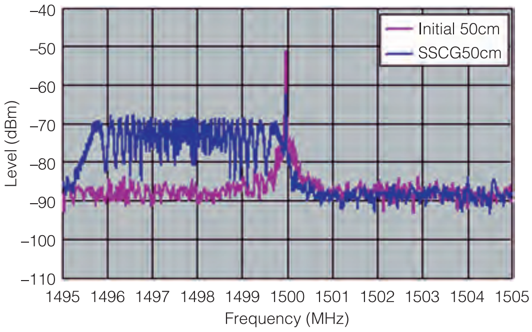
An entirely different method than those mentioned above that may be used for a noise-generating source is Spread Spectrum Clocking (SSC). This method handles a digital signal by introducing a degree of jitter that does not affect the operation of the circuit (Figure 3). Due to the jitter, the signal spectrum becomes wider, which reduces concentration on a single frequency. Of course, the total noise amount has not decreased, but, if a specific frequency is causing a problem, the problem is solved to some extent.

Figure 3 What is Spread Spectrum?

The Eye-pattern of a signal to which SSC has been applied has jitter.



The spectrum of a signal to which SSC has been applied has become wider.

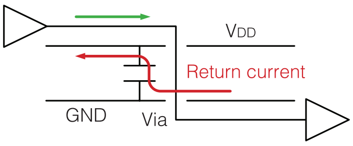


● Measures to be Taken on a Transmission Route

As measures to be taken on a transmission route, four major elements in EMC designing are available: patterning, grounding, filtering, and shielding.

Problems in patterning and grounding (GND) often include the following: (1) when the parallel wiring is long, crosstalk noise increases, (2) unless characteristic impedance is controlled and appropriate terminal processing is performed, reflection arises, and (3) unless an appropriate return path is secured, signals are disturbed. These are simultaneous problems with EMC and SI (Signal Integrity). It is no exaggeration to say that patterning and grounding are both aspects of the printed-circuit board design itself. For example, when wiring passes through from the surface to the back by vias as shown in Figure 4, the return path needs to be made in the same way. Return paths need to be connected by vias when the same potential is applied between grounding wires and by a capacitor (AC coupling) when different potentials are applied to the power supply and grounding wire (see [6]). If this connection of return paths is not made appropriately, signals not only deteriorate but signals that have passed through a part where return paths are connected by vias may also excite the power supply and the grounding surface, and affect power integrity (from SI to PI).

Figure 4 Securing of a Return Path



PI is as important as or even more important than SI. This is because some of the clock frequencies of digital ICs reach GHz order and the conventional careless placement of bypass capacitors of 0.1 μF no longer works. However, basic procedures, such as placement of a bypass capacitor very close to an IC, have not changed (see [7]). Recently, bypass capacitors have started to be installed on ICs, interposers, and printed-circuit boards. Such bypass capacitors have a role of localizing noise made from an IC (and supplying voltage to an IC, to put it the other way around). This is why bypass capacitors are also called decoupling capacitors. Because electrostatic capacity values differ, depending on the size of each IC, it cannot be generally said what value is most suitable. However, with clock acceleration, the ESI (Equivalent Series Inductance) required tends to be lower.

On the other hand, an EBG (Electro-magnetic Band Gap) structure, which is a completely different method, has recently been paid attention to as a measure for PI. In an EGB structure, by incorporating a periodic structure, which includes repeated pattern forming, into the power supply or the GND face (Figure 5), transmission of the electromagnetic waves of specific frequency bands may be prevented (see [8] - [10]). An EBG structure is one type of band rejection filter that has been developed mainly with a longstanding method that was used in waveguide filters (Figure 6).

Now, let's think about shielding. It can be easily imagined that a metal shield cuts off electromagnetic waves and reduces emission noise. However, if the metal shield has a hole in it, its emission noise-reducing effect decreases by half.

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[2] Parasitic components include reactance, etc. that are not shown in the circuit diagram. ESL of a capacitor and coupling among patterns are also parasitic components (Figure 2).

The hole functions as a slot antenna and can be a secondary emission source.

Figure 5 EBG Structure

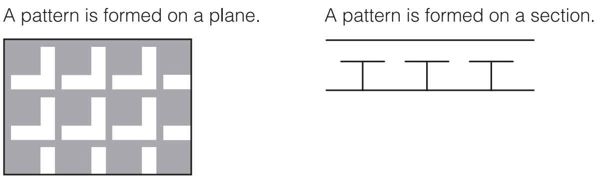


Figure 6 EBG Structure's Propagation Characteristic

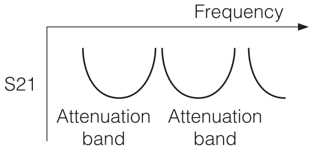
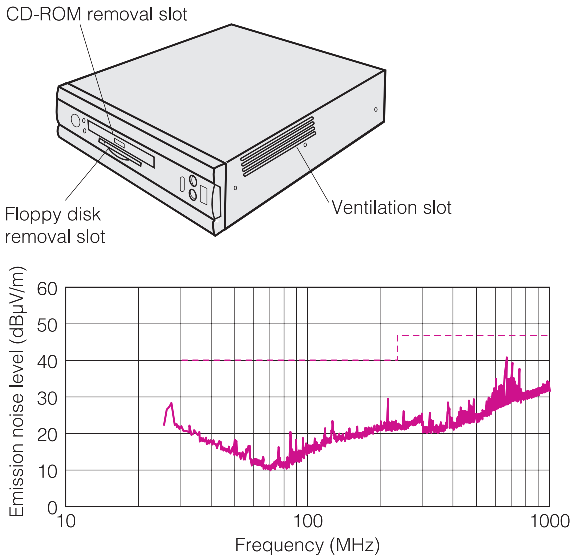


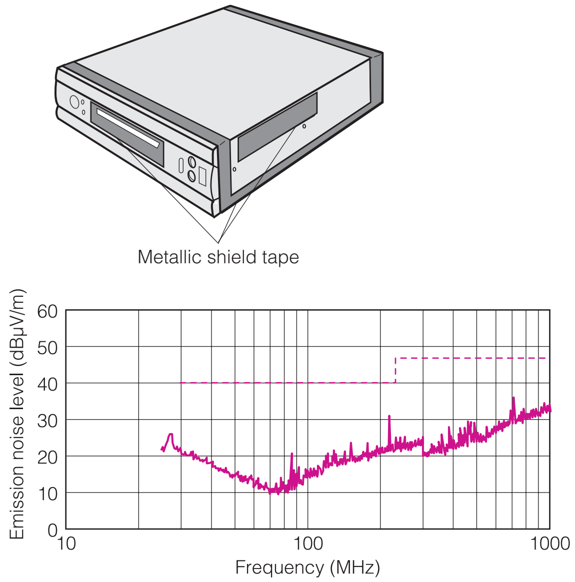
Figure 7 shows the result of an experiment conducted with a personal computer (see [11]). After the holes or openings were covered with metallic shield tape, the noise level around 550 to 750 MHz improved by about 10 dB.

Figure 7 Effect of a Shield

(a) With openings



(b) With no opening



A magnetic sheet has an effect similar to that of a metallic shield. A magnetic sheet cuts off electromagnetic waves and absorbs them with the help of ferrite (see a later chapter).

● Measure to be Taken against Antennas

Emission noise is also called unnecessary emission and is an electromagnetic wave emitted from an unintended antenna. A candidate for such an antenna is something long or big in terms of radiation efficiency. In many cases, cables connected to equipment can be unintended antennas.

In handling cables so that they do not become unintended antennas, it is common practice to insert a filter to prevent noise from being put onto the cables rather than to apply a direct measure to the cables themselves. Generally, it is not possible to know how a cable, particularly an interface cable is used (whether it is bent or not) or what is connected to the end of the cable. Therefore, a filter is needed to ensure safety. In addition, it is necessary to take into consideration the function of a cable as a receiving antenna. Because an antenna is a reversible passive part, an antenna that easily emits electromagnetic waves can also easily receive them (see [12] and [13]). In such a situation, the role that a filter plays as a countermeasure for immunity is very important. Suppressing noise that enters from a cable is another role of a filter.

A printed-circuit board is the second candidate for an unintended antenna. The areas of the power supply and the GND face in particular are large, and their function as a radiation antenna has recently been regarded as a problem. This is what is called the board resonance problem (see [14] and [15]). As a measure against resonance, there is a method of moving a resonance frequency by changing the position or capacitance value of a bypass capacitor to remove it from the clock harmonics. On the other hand, a more fundamental and effective measure against resonance is to introduce a loss component to a circuit to damp the resonance (see [7]). There are various ways to introduce a loss component, and ESR (Equivalent Series Resistance) of a bypass capacitor is one of them. It appears that an electrolytic-system capacitor often plays such a role although you may not be aware of this function. Recently, the Controlled ESR Capacitor, which is one type of ceramic capacitor, has appeared and plays its part in introducing a loss component (see a later chapter). These capacitors help suppress resonance in circuits that have feedback, such as a switching power supply.

In board resonance, when noise that has been put onto the GND face reaches other circuits, such as other ICs or cables (=antennas) on the same board, it affects them as common mode noise[*3]. Therefore, these components need to be given special care when used in transmission routes (from PI to SI).

Recently, radiation from an IC itself has attracted attention (see [16]). Because the area of an IC on a board is not small, the effect of the IC cannot be underestimated.

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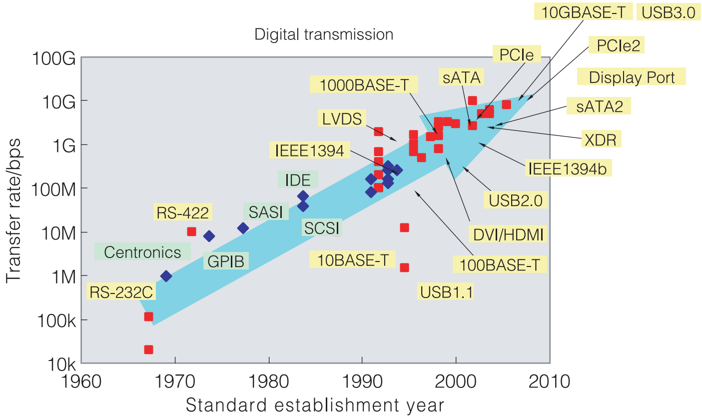
*3 Generally, because the return path of noise is far away in the common mode, the loop area tends to be larger. Therefore, the noise is regarded as a major cause of emission noise (see [3]).

Differential Transmission

In recent years, as a digital signal transmission method, differential transmission (also known as balanced transmission) has been considered. Although the differential transmission method was established a long time ago, recently it has been given more attention with clock acceleration (Figure 8).

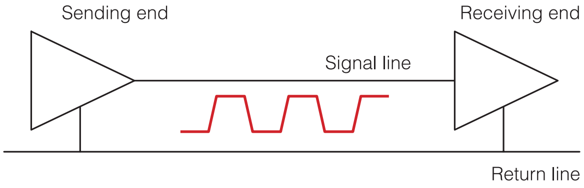
Figure 8 Accelerated Digital Transmission



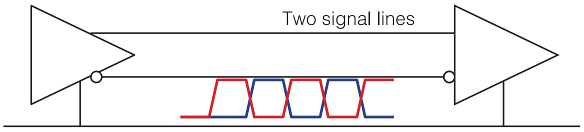
In normal data transmission, the sending and receiving ends are connected by one line, but because one line is needed also for the return path, two lines in total are needed, and high/low voltage is sent. In differential transmission, two lines are used and three lines in total are needed with one line acting as the return path, and two kinds of voltage (high/low and its opposite-direction low/high) are sent (see Figure 9).

Figure 9 Signal Transmission Methods

(a) Normal transmission



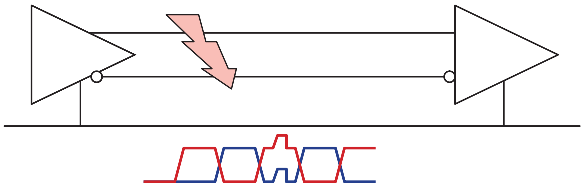
(b) Differential transmission



The receiving side detects only the difference between the two kinds of voltage. At this time, because the receiving side only notices the difference, the information amount of the two lines is the same as that of a single line. Therefore, it seems to be uneconomical to have included an additional line, but in this inefficiency, the strength of the differential transmission is hidden (see [17]). In most cases the two lines used in differential transmission are close to each other (for cables, a twisted pair line is often used), and, therefore, when exogenous noise appears, the noise induced in one line is the same in volume as that induced in the other (Figure 10). Therefore, the receiving end is not affected by such noise. Thus, even with a lower amplitude, signals can be sent safely and securely. On the other hand, from the viewpoint of noise radiation, differential transmission is effective. In differential transmission, an electric current is sent and returns along two lines that are very close to each other. Therefore, when seen from a distance, it appears that no current is run because the two lines offset each other.

In addition, because of the two lines, the low amplitude is reduced by half and the differential transmission's resistance to exogenous noise helps reduce the amplitude and gives an advantage over noise.

Figure 10 Differential Transmission Resistant to Exogenous Noise



The differential transmission method that is resistant to noise in this way can be said to be a type of EMC design. However, such differential transmission is not perfect.

If asymmetric factors (any of signals, wirings, and parts) exist in a circuit system, a part of the differential signals is converted into the common mode components (see [18] and [19]). The effect of the conversion appears as signal skew and amplitude variation (SI problem) and it can develop into the EMC problem. Controlling such common mode components is a role of the Common Mode Filter (CMF). While CMF does not stop differential signals from passing, it can reduce common mode components. Using CMF appropriately can help solve the above problems (see [20]). For details of measures for high-speed interfaces, see a later chapter.

References

[1] Michio OKAMURA, “Noise Mechanism Analysis”, CQ Publishing Co., Ltd., 1987

[2] Yukio SAKAMOTO, Hidetoshi YAMAMOTO, “Measures against Noise in the Field Q&A”, The Nikkan Kogyo Shimbun, Ltd., 1993

[3] Clayton R. PAUL (author), Risaburo SATO (editorial supervision), Akihisa SAKURAI (translation supervision), “Introduction to EMC”, Mimatsu Data System, 1996 (The first edition of the original text (Introduction to Electromagnetic Compatibility) was published in 1992, and the second edition in 2006.)

[4] Shigeki MATSUNAGA, “Measures for and Design of EMC for Printed-Circuit Boards”, Electronics Mounting Technology, vol.12, No.1, pp.66-72, January 1996, vol.12, No.2, pp.73-77, February 1996, vol.12, No.3, pp.62-66, March1996

[5] Yoshikazu FUJISHIRO, Masaaki TOGASHI, Masao UMEMURA, Seiji KONISHI, Harushige URATA, Hidetoshi HATTORI, “Basics of Noise Suppression Parts and How to Choose Them”, Separate-volume supplement of the May 2006 Issue of Transistor Technology, CQ Publishing Co., Ltd., 2006

[6] Hiroshi WABUKA, “PI and EMI Design for Printed-circuit Boards”, EDA Solution Conference 2008 (held by CYBERNET SYSTEM CO., LTD.), December 12, 2008

[7] Yoshikazu FUJISHIRO, Masaaki TOGASHI, Katsuji YASUDA, Hitoshi KUDO, “EMC Measures for Power Supply and Power-supply Line”, EMC, No.158, pp.75-94, June 2001 Issue

[8] Ramesh ABHARI, George V.Eleftheriades, "Metallo-dielectric electromagnetic bandgap structures for suppression and isolation of the parallel-plate noise in high-speed circuits", IEEE trans. MTT, vol.51, No.6, pp.1629-1639, June 2003

[9] Shawn D. ROGERS, "Electromagnetic-bandgap layers for broad-band suppression of TEM modes in power planes", IEEE trans. MTT, vol.53, No.8, pp.2945-2505, August 2005

[10] Yoshitaka TOYOTA, ENGEN Arif Ege, SWAMINATHAN Madhavan, Kengo IOKIBE, Ryuji KOGA, “Miniaturization of planar EBG structure formed in power/ground plane of printed circuit board to suppress EMI and electromagnetic noise”, IEICE TRANSACTIONS on Fundamentals of Electronics, Communications and Computer Sciences, B, vol.J90-B, No.11, pp.1135-1142, November 2007

[11] Hisashi NAGATA, “Noise Behavior Seen through Experiments and Basics of Measures against Noise”, pp.165-175, October 2001 Issue of Transistor Technology, or “All of Practical Noise Suppression Techniques”, Transistor Technology SPECIAL No.82, pp.10-22, Transistor Technology SPECIAL Editorial Department, CQ Publishing Co., Ltd., 2003

[12] Yoshio KAMI, Risaburo SATO, “Radiation from a Transmission Line”, IEICE Technical Research Report EMCJ, pp.9-13, December 1990 (EMCJ90-72)

[13] Yoshio KAMI, “Transmission-Line Circuit Theory in EMC and Its Development”, IEICE TRANSACTIONS on Fundamentals of Electronics, Communications and Computer Sciences, B, vol. J90-B, No.11, pp.1070-1082, November 2007

[14] Takashi ITO, Yoshio KAMI, “Radiated Emission by Resonance of Power/ Ground Layers: Study on Reflection Coefficient and Magnetic Near Field”, IEICE Technical Research Report EMCJ, pp.7-12, July 1996 (EMCJ96-18)

[15] Kenji NAKAMURA, Jianqing WANG, Osamu FUJIWARA “Relationship between Frequency Characteristics of Radiated Emission and Input Impedance of Power-Ground Planes of PCB”, IEICE Technical Research Report EMCJ, pp.19-23, March 2002 (EMCJ2001-117)

[16] Osami WADA, Atsushi NAKAMURA, “Measurement Methods of Electromagnetic Emission and Immunity of Semiconductor Devices”, Journal of Japan Institute of Electronics Packaging, vol.6, No.3, pp.217-221, 2003

[17] National Semiconductor, "LVDS Owner's Manual", 2000 (second edition), 2004 (third edition), 2008 (fourth edition)

[18] Yoshikazu FUJISHIRO, “Analysis on a common mode filter using S-parameters”, IEICE Technical Research Report EMCJ, pp.25-30, September 2000 (EMCJ2000-60)

[19] Yoshikazu FUJISHIRO, Tetsuya UMEMURA, “Blind spot in evaluation of noise suppression and noise suppression parts of IEEE1394 and USB”, Nikkei Electronics, No.784, pp.214-220, December 4, 2000 Issue and No.785, pp.218-223, December 18, 2000 Issue

[20] Yoshikazu FUJISHIRO, “Evaluation of electronic parts using S-parameters”, TDK Application Note AN-SP06A001_ja, 2006 (http://www.tdk.co.jp/tvcl/spara/an-sp06a001_ja.pdf)

Classification of EMC Countermeasure Components and Their Roles

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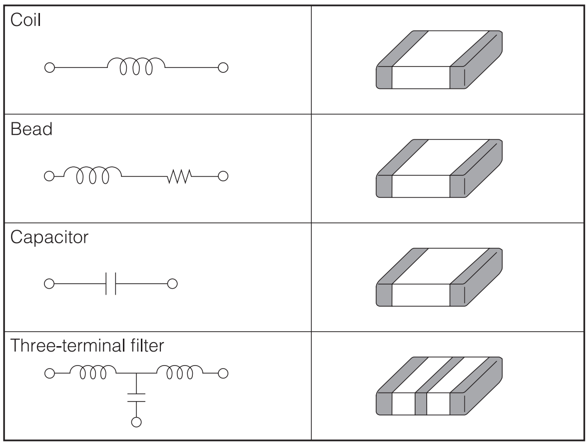
1 What are EMC Countermeasure Components?

■ EMC Countermeasure Components as Filters

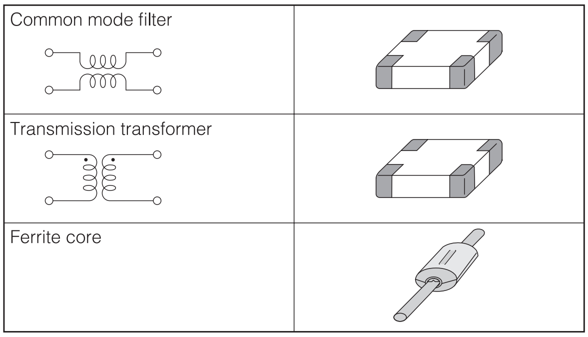
EMC countermeasure components are electronic components used for EMC countermeasures against noise. Specifically, they are components, such as capacitors and filters, as shown in Figure 1, and the phrase “EMC countermeasure components” is generally used to describe them. Therefore, there are no specific objects called EMC countermeasure components. In addition, among the EMC countermeasure components, there are general-purpose components that are used for other purposes than EMC countermeasures, such as capacitors and coils. However, many of the components are used only for EMC countermeasures. Other than the components shown in the figure, in a broad sense a dumping resistor and a clamp diode can be referred to as EMC countermeasure components. However, because they are used mainly for SI (Signal Integrity), they are not described here.

Figure 1 Various Types of EMC Countermeasure Components

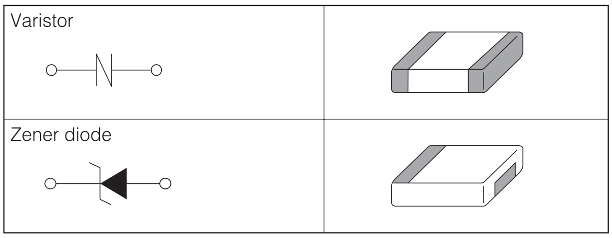
(1) Components that separate signals according to their frequencies



(2) Components that separate signals according to their modes



(3) Components that separate signals according to their amplitudes



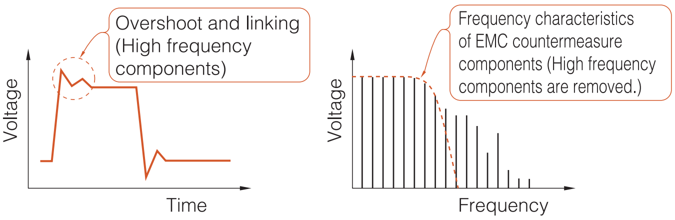
Generally speaking, EMC countermeasure components are regarded as “filters” for separating necessary signals (information) from unnecessary signals (noise). These filters are divided into several types according to their different characteristics.

● Separating Signals according to Their Frequencies

Generally, noise has high frequency components (see a later reference [1]), and, therefore, it can be separated by making use of this characteristic (Figure 2). An EMC countermeasure component in this case can be called an LPF (Low Pass Filter). In Figure 1, a coil, a bead, a capacitor, a three-terminal filter, etc. are classified as LPFs. Because they are LPFs, when they are used a coil and a bead are inserted into a series circuit and a capacitor into a shunt circuit. For obtaining sharper attenuation characteristics, a three-terminal filter can be made by combining a coil, bead, and a capacitor, and an RC filter can be made by

Figure 2 Components that Separate Unnecessary Signals (noise) according to their Frequencies

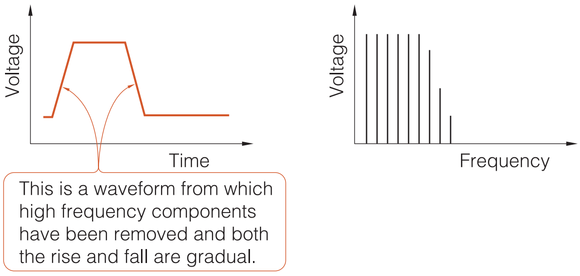
(a) Without EMC countermeasure components



Overshoot and linking (High frequency components)

Frequency characteristics of EMC countermeasure components (High frequency components are removed.)

(b) With EMC countermeasure components



This is a waveform from which high frequency components have been removed and both the rise and fall are gradual.

combining a resistor and a capacitor (which are both cheap). A filter for an AC power line is typical of such filters, and it can be made by combining a capacitor (X capacitor or Y capacitor) and a common mode filter, which can be replaced by a coil.

Although there is no clear difference between a coil and a bead, a bead becomes lossier in a high frequency band. Because in many cases lossiness works favorably (energy absorption, etc.) as an EMC countermeasure, a bead is preferred, but because a coil causes high inductance, it is used in a relatively low frequency band and in a location where an absolute value is needed.

● Separating Signals according to Their Modes

When the transmission mode of noise is different from that of information (necessary signals), noise and information can be separated from each other according to the difference in their mode. For example, in differential transmission, necessary signals are in the differential mode, and, normally, unnecessary components are in the common mode (information may be put in the common mode, depending on standards.) A common mode filter (CMF), ferrite core[*1] (including a clamp filter), and a transmission transformer[*2] are components for suppressing such common mode components. They use magnetic coupling in an effective way so that they do not affect the differential mode and act only on the common mode. These components are inserted into series circuits.

● Separating Signals according to Their Amplitudes

A varistor and a zener diode do not act on signals with low amplitudes, but they transform themselves into an extremely low resistance when high voltage (noise) occurs, and they prevent the noise from being transmitted. They exert an effect on sudden noise, such as static electricity. These parts are inserted into shunt circuits.

■ Classification not Based on the Function of Each Component

Mentioned above is classification based on the function of each EMC countermeasure component, but it is also important to take into account whether the components can be attached additionally. From such a viewpoint, clamp filters, magnetic sheets, etc. are convenient to use. Electronic components, such as beads and CMFs, can be used as necessary if a land is provided beforehand (they need to be connected with a jumper wire when no EMC countermeasure component is used).

In addition, an important point to consider is whether grounding is needed or not. Because a three-terminal filter has a grounding terminal, to deliver its maximum performance it needs to be grounded in the shortest distance to the earth. A capacitor, varistor, and zener diode also need grounding when they are used in shunt circuits. In addition, grounding is often used, although indirectly, for a transmission transformer with an intermediate tap.

Explanations for each component have been omitted here because of space limitations. For more information, see a later chapter or references [2] to [5].

2 | Methods of Evaluating EMC Countermeasure Components

■ Evaluation Parameters

How do EMC countermeasure components actually have an effect? This chapter describes methods of evaluating them.

The characteristics of a two-terminal component can be expressed as impedance between its terminals as shown in Figure 3 (a). The characteristics of a three- or more-terminal component can also be expressed as impedance if its terminals are connected appropriately so as to be two terminals.

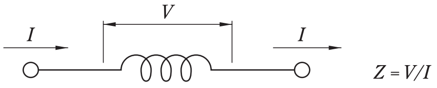
A common mode filter (CMF) is such a filter. The characteristics of a common mode filter are expressed as several types of impedance when its terminals are connected differently (Figure 3 (b)).

Because the characteristics of a component that needs grounding (GND) are difficult to express as impedance, an S parameter is used. The S parameter is used for the three-terminal filter in Figure 1 (Figure 3 (c)). The characteristics of components other than three-terminal filters can be expressed with S parameters if GND is provided appropriately. In this case, attention needs to be paid to the arrangement of components. Coil-system components, such as a bead and a CMF, need to be inserted into series circuits and a capacitor into a shunt circuit (state in which C or L of the three-terminal filter in Figure 3 (c) has been removed) so that their characteristics can be measured.

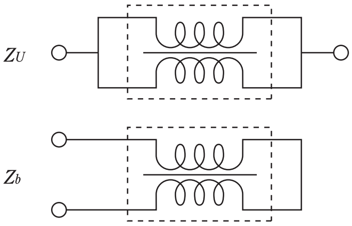
Described below is the outline of impedance. S parameters are explained in another chapter.

Figure 3 Evaluation Parameters of EMC Countermeasure Components

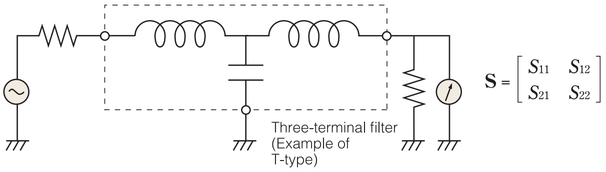
(a) Two-terminal components are evaluated with impedance.



(b) CMFs are evaluated with balanced/unbalanced impedance.



(c) Three-terminal filter is evaluated with S parameters.



■ Impedance

For a component that separates signals according to their frequencies, the frequency characteristic of its impedance is significant. It is important to see how the component's impedance changes between the noise's frequency and the (necessary) signal's frequency (Figure 4 (a)).

At this time, the absolute value of the impedance

[*1] A ferrite core can be seen as a half-finished product, for example when it has a conducting wire passed through it, it becomes a CMF or a bead.

[*2] The role of a transmission transformer should be regarded not as a control of the common mode but as insulation. A transformer converts electric energy into magnetic energy once and converts it back into electric energy again, thereby interrupting an electrical path.

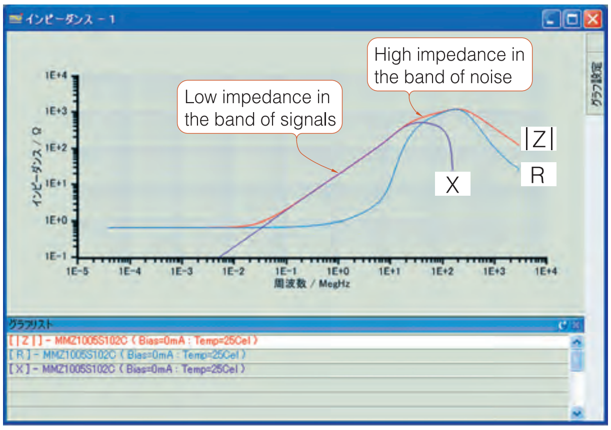
$|Z| = \sqrt{R^2 + X^2}$ is important, but the ratio of R to X of lossy components, such as a bead, needs to be considered. While the ration of R to X of a lossy component changes according to frequencies, it is safe to think that the pattern of the component is almost unique to its material (magnetic permeability frequency characteristic). Therefore, it is important to select an appropriate magnetic material (product series) to be used in the beads. When ringing is to be suppressed, it is better to select a material that becomes lossy from relatively low frequencies; when high speed is regarded as important, the opposite type of material needs to be used.

On the other hand, the performance of a less lossy component is characterized with reactance X (or susceptance B), and the value obtained from division of the reactance X or susceptance B by the angle frequency ω is often used. In other words, inductance L for a coil and capacitance C for a capacitor are often used. These values are constant, not dependent on frequencies, and therefore, they can be expressed not by a graph but by numerical values (in nH or pF). However, both components have self-resonance (changed from being capacitive to being inductive, and vice versa), and, therefore, when high frequencies are handled, impedance (and its frequency characteristic) needs to be considered again. ESL may sometimes be used as an indicator of self-resonance for capacitors.

For a component that separates signals according to their amplitudes, the voltage or current characteristic (not frequency characteristic) of its impedance is important. However, for varistors, etc., "voltage vs. current" is graphically displayed conventionally (Figure 4 (b)). In this case, the curves on the graph shows impedance (resistance).

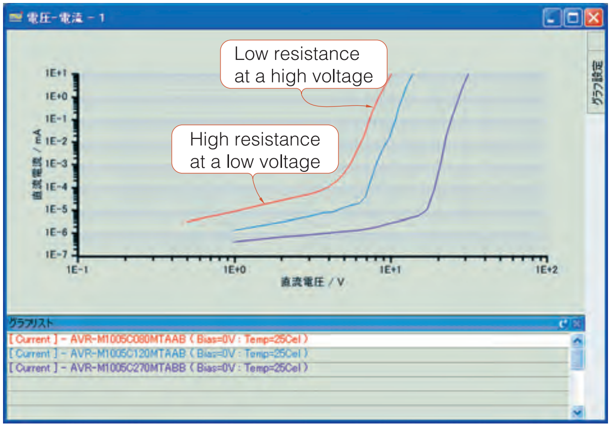
Figure 4　Impedance Characteristics

(a) Example of a bead



[|Z|] - MMZ1005S102C (Bias=0mA : Temp=25Cel)
[R] - MMZ1005S102C (Bias=0mA : Temp=25Cel)
[X] - MMZ1005S102C (Bias=0mA : Temp=25Cel)

(b) Example of a varistor



[Current] - AVR-M1005C080MTAAB (Bias=0V : Temp=25Cel)
[Current] - AVR-M1005C120MTAAB (Bias=0V : Temp=25Cel)
[Current] - AVR-M1005C270MTABB (Bias=0V : Temp=25Cel)

3 Points to Note When Selecting an EMC Countermeasure Component

The previous section has described methods of evaluating EMC countermeasure components. This section mentions some points to note when selecting an EMC countermeasure component to be used with a method. Concerning whether an EMC countermeasure component is actually effective, other than the characteristic of the component, the following four items are related: (1) Termination condition, (2) Mounting position and mounting state, (3) Radiation mechanism of radiation noise (from where and how it is radiated), and (4) Surrounding environment including thermal coupling and magnetic coupling.

Therefore, even if you use a good performance component, whether the component has an effect depends on how you use it. Considered here are (1) and (2) of the above four items.

(1) Termination condition

Parameters for evaluation, such as impedance and S Parameter have the following characteristics:

- Impedance shows the characteristic of a single component (on the assumption that it is sufficiently away from the GND). Therefore, whether the component is effective depends on a relative evaluation of the terminating impedance. In other words, an absolute judgment cannot be made for such questions as whether the component is effective when its impedance equals or exceeds a certain number of ohms, or whether the component is not effective when its impedance is less than the value. However, it is useful to know the following tendencies: In a high-impedance environment, insertion of a capacitor into a shunt circuit is effective[*3]. The reason why this is effective is that a relatively large inductance value is needed in order to produce a similar effect when a coil is inserted into a series circuit. Conversely, in a low-impedance environment, insertion of a coil into a series circuit is effective. In addition, when a component is used in low frequencies, its consonants (L value, C value) need to be relatively large. Therefore, the shape of the component tends to be larger. When a component is used in high frequencies, the situation will be reversed.
- On the other hand, when an S Parameter is used, a termination condition is taken into account. However, normally, this is a characteristic when the purely resistant termination is 50 Ω (CISPR17: 1981 and MIL-STD-220B: 2000). Of course, it will be a rare case if the termination is exactly 50 Ω[*4], and reactance components also exist.

Then, how can a component's effect on noise be measured directly? If resistive termination is allowable, the S Parameter when the termination is other than 50 Ω can be calculated from the S Parameter when the termination is 50 Ω. Therefore, when the calculated S Parameter is used, the attenuation effect on

---

[*3] In this instance, resistive termination is assumed. Another assumption is described later.

[*4] A matching circuit of differential transmission, etc. is one example of such a rare case, and the S Parameter value itself shows the behavior of a circuit. Therefore, for example, it is an important indicator of the behavior that, in a CMF for high-speed differential transmission, the cutoff frequency of the differential mode (frequency of $|S_{dd21}| = 3$ dB) is sufficiently high and the characteristic impedance Z_{0d} is matched.

any (resistive) termination can be estimated. For a concrete calculation method, see the chapter on S Parameter.

If the termination is not resistive, there is no way other than to examine the effect under actual use conditions. Of course, there will be no error if an actual component is soldered and the effect is observed. On the other hand, in a circuit simulation, the effect can be clarified to some extent (in this case, information of impedance and S parameter[*5] is used).

Figure 5 shows the effect of an EMC countermeasure component measured in a simplified simulation with the "SEAT" software that TDK provides for free. The figure shows a case where, because a reactance component exists in I/O, the attenuation effect that may be expected from an S Parameter when termination is 50 Ω has not been obtained. In such a case, by making the best use of easily repeated trial and error in a simulation, the search for an optimum component can be narrowed down.

(2) Mounting position and mounting state

Basically, an EMC countermeasure component must be inserted into a noise occurrence location. This will easily produce the expected effect (see [6]) and reduce the risk that noise will diffuse because there is no distance between the component and the location. Concerning static electricity countermeasure components, such as a varistor, it is important to place them as near to the route by which noise enters as possible.

In addition, the I/O position relationship of a component and the way GND is provided also affect the characteristic of the component. It is an ironclad rule that input and output must not be close to each other, and that a component must be grounded within the shortest distance.

References

[1] Clayton R. PAUL (author), Risaburo SATO (editorial supervision), Akihisa SAKURAI (translation supervision), "Introduction to EMC", Mimatsu Data System, 1996 (The first edition of the original text (Introduction to Electromagnetic Compatibility) was published in 1992, and the second edition in 2006.)

[2] Hisashi NAGATA, "Special TOPIC: Noise Countermeasures with No Sanctuary", pp.159-240, October 2001 Issue of Transistor Technology, or Transistor Technology SPECIAL Editorial Department, "Comprehensive Guide to Practical Noise Suppression Techniques", Transistor Technology SPECIAL No.82, CQ Publishing Co., Ltd., 2003

[3] Yoshikazu FUJISHIRO, Masaaki TOGASHI, Masao UMEMURA, Seiji KONISHI, Harushige URATA, Hidetoshi HATTORI, "Basics of Noise Suppression Parts and How to Choose Them", Separate-volume supplement of the May 2006 Issue of Transistor Technology, CQ Publishing Co., Ltd., 2006

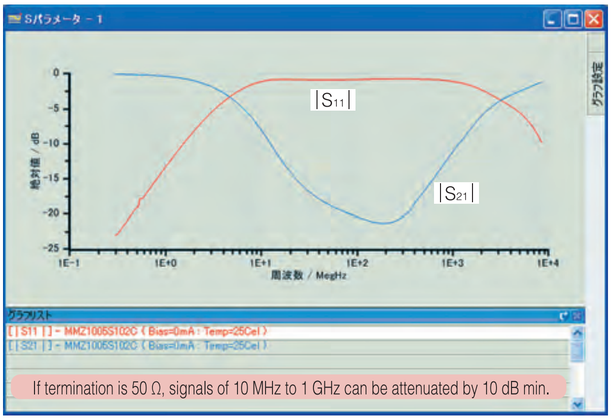
[4] Yukio SAKAMOTO, Hidetoshi YAMAMOTO, "Measures against Noise in the Field, Q&A", The Nikkan Kogyo Shimbun, Ltd., 1993

[5] Yukio SAKAMOTO, "Noise Countermeasure Components and EMC Design", Kogyo Chosakai Publishing, Inc., 2005

[6] Hidetoshi YAMAMOTO, Shinichi SHINOHARA, Risaburo SATO, "Predictions of the Effect of a Noise Suppression Device on Radiated Interference Suppression from Printed Wire", IEICE Technical Research Report EMCJ, pp.21-26, January 2000 (EMCJ99-116)

Figure 5 Case showing that Insertion of an Inappropriate Component causes a Disordered Waveform.

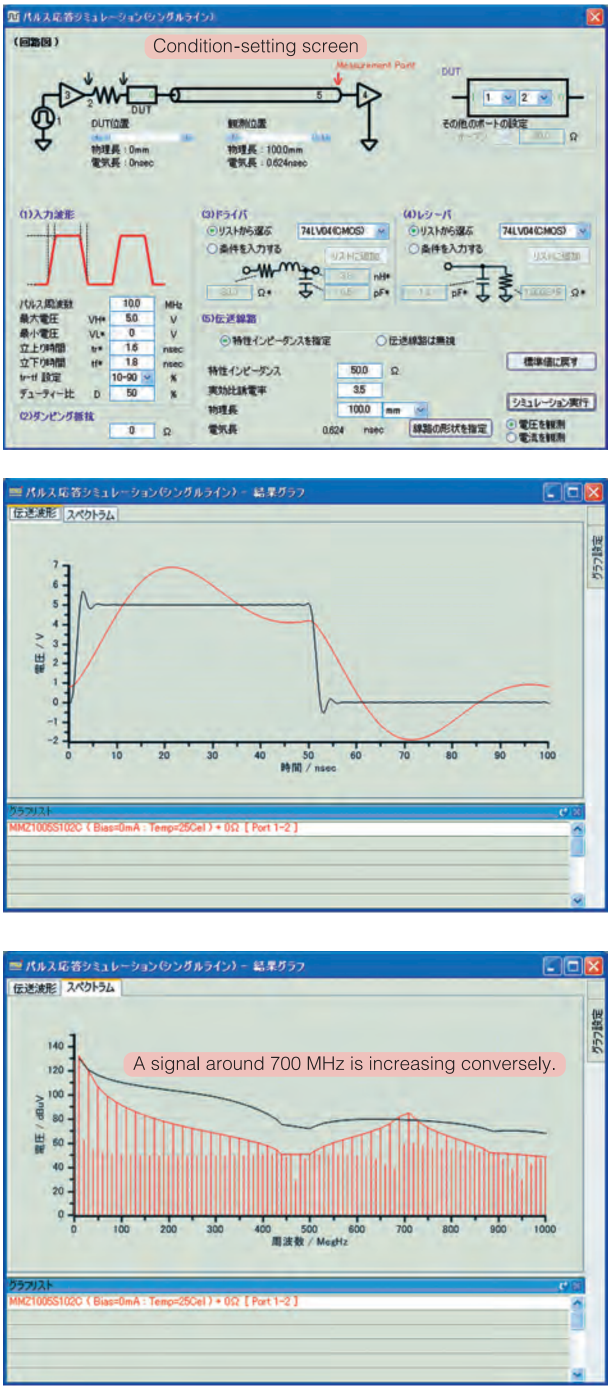
(a) S parameter



[| S11 |] - MMZ1005S102C (Bias=0mA : Temp=25Cel)
[| S21 |] - MMZ1005S102C (Bias=0mA : Temp=25Cel)

If termination is 50 Ω, signals of 10 MHz to 1 GHz can be attenuated by 10 dB min.

(b) Simplified simulation with "SEAT"



Condition-setting screen

DUT位置
物理長 : 0mm
電気長 : 0nsec

観測位置
物理長 : 100.0mm
電気長 : 0.624nsec

(3)ドライバ
◉リストから選ぶ 74LV04(CMOS)
○条件を入力する

(4)レシーバ
◉リストから選ぶ 74LV04(CMOS)
○条件を入力する

(1)入力波形
パルス周波数 10.0 MHz
最大電圧 VH* 5.0 V
最小電圧 VL* 0 V
立上り時間 tr* 1.6 nsec
立下り時間 tf* 1.8 nsec
tr-tf 設定 10-90 %
デューティー比 D 50 %

(2)ダンピング抵抗 0 Ω

(5)伝送線路
◉特性インピーダンスを指定 ○伝送線路は無視
特性インピーダンス 50.0 Ω
実効比誘電率 3.5
物理長 100.0 mm
電気長 0.624 nsec

◉電圧を観測
○電流を観測

MMZ1005S102C (Bias=0mA : Temp=25Cel) + 0Ω [Port 1-2]

A signal around 700 MHz is increasing conversely.

MMZ1005S102C (Bias=0mA : Temp=25Cel) + 0Ω [Port 1-2]

[*5] While recent circuit simulators can handle S Parameter more easily, many of the SPICE-series simulators are unable to handle them with no trouble. If your SPICE-series simulator cannot handle S Parameter, either, see PSPICE's Application Note "Create a S-Parameter Subcircuit for Microwave and RF Applications."

Taking Advantage of S-Parameter

TDK Corporation Application Center
Yoshikazu Fujishiro

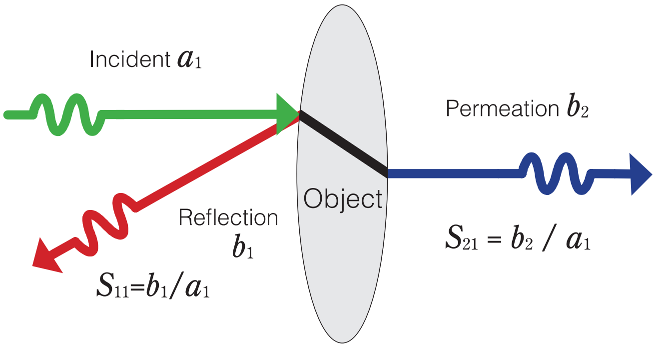
1 What is the S-Parameter?

As the speeds of electronic circuits are increasing, the analog characteristics in digital circuits are becoming ever more critical. Therefore, S-parameters, which are treated differently from other parameters, are now becoming an increased center of attention again. The purpose of this chapter is to give an overview of S-parameters.

■ Definition of the S-Parameter

The S-parameter (Scattering parameter) expresses circuit characteristics using the degree of scattering (i.e. reflection back to the source and transmission to other directions) when an AC signal is considered as a wave. "Degree" means how much a wave (= signal) is attenuated or amplified, while the wave is transmitted through the circuit to be evaluated. The input and output ports of a circuit are numbered, and the S-parameter that is "Incident at port j –> Detected at port i" is described as S_{ij}. If $i = j$, the wave is the reflection. If $i \neq j$, the wave is the transmission. Figure 1 shows this concept by taking the light that passes through a lens as an analogical example. For more detailed definitions, please refer to the textbooks [1-6].

Figure 1 Conceptual Diagram of S-Parameter (Optical Analogy)



The term "insertion loss", which is often used to describe the filter characteristics, can be considered almost the same as $|S_{21}|$. The value of insertion loss and $|S_{21}|$ will be different if the input and output terminal conditions don't match. Even though, the insertion loss can be converted to $|S_{21}|$ by calculation, and furthermore, this situation (= different terminal conditions) doesn't occur very often. The one thing that needs to be paid attention is that the sign must not be ignored. While the S-parameter is defined as "target/reference", the insertion loss is defined as "reference/target"; which means that S-parameter and the insertion loss are reciprocal. Therefore, in logarithmic expression (dB unit), these values must have the opposite signs (i.e. if $|S_{21}|$ =–20 dB, the insertion loss is +20 dB). By definition, the negative sign is usually not used with the insertion loss value. On the other hand, S-parameters can be expressed with both positive and negative signs; the positive sign expresses the amplification, and the negative sign expresses the attenuation.

■ Characteristics of the S-Parameter

Since the S-parameter is a ratio of electrical power (to be exact, a square root of the electrical power), it is basically a non-dimensional parameter (no unit). However, when describing the magnitude of the S-parameter, the unit "dB" is usually used with a common logarithm [*1]. Table 1 shows some typical values for your reference. When the S-parameter is $1\sqrt{2}$ (i.e. half of the electric power is transmitted or reflected), the value in logarithmic expression is –3 dB.

Table 1 Typical S-Parameter Values

$\lvert S_{ij}\rvert$	$20\log\lvert S_{ij}\rvert$
1	0 dB
$1/\sqrt{2}$	–3 dB
1/10	–20 dB
1/100	–40 dB
1/1000	–60 dB

The major characteristics of the S-parameter are as follows:

▶ In 2-port passive circuit, $|S_{11}|^2 + |S_{21}|^2 \leqq 1$.
Therefore, the S-parameter of the passive device does not exceed 1 (0 dB).
If the device is lossless, we have equality (Feldtkeller's formula). There is no loss, so the total amount of the scattering should be 100%.

▶ If a device is reciprocal (e.g. for passive devices, a non-unidirectional component such as an isolator or circulator), $S_{21} = S_{12}$.
Generally, $S_{ij} = S_{ij}$ (the S-matrix is symmetric). Similarly, in mixed-mode S-parameters (see the next section), $S_{cc21} = S_{cc12}$, $S_{dc11} = S_{cd11}$, $S_{dc21} = S_{cd12}$.

[*1] To avoid complexity, the assumption "the absolute value of S_{21} (or, S_{21}) is ○○ dB", is used here. To be exact, it should be explained as "20log$|S_{21}|$=○○ dB". It is implied that the value with the unit dB is the value that neglected "20log" (in some cases, "10log"). For your information, the terms with "loss" (e.g. insertion loss), "attenuation", "–loss" (e.g. LCL) are originally defined as the parameters that use the unit dB. These values are not expressed in antilogarithms.

Recently network analyzers are generally used to measure S-parameters. If the data may be transferred or used for simulation using the parameters as numeric values, it is convenient to save the data in a Touchstone format text file (see Figure 2 for an example).

Figure 2 Example of Touchstone File

```
# MHz   S   MA    R 50
0       0.005    0       0.994    0        0.994   0        0.005   0
0.300   0.999   –0.037   0.002    89.72    0.002   89.72    0.999   –0.023
0.315   0.999   –0.037   0.002    89.87    0.002   89.87    0.999   –0.023
   . . . . .
6000    0.178   –107.7   0.972   –16.48    0.972   –16.48   0.182   –101.8
```

2 | Using the S-Parameters

Reference Impedance

Reference impedance is an important concept for understanding and using S-parameters. The following explains the overview of the reference impedance:

Usually we simply state that S_{21} is ○○ dB. However, to be exact, it should be stated that "S_{21} is ○○ dB when △△ Ω is used as the reference impedance". Since the reference impedance is usually 50 Ω, the abbreviated expression can be used. Still, it is important to keep in mind that the S-parameter is a relative value depending on a certain reference value. In other words, the reference impedance is always necessary for acquiring S-parameters (whether by actual measurement or by simulation).

The following describes what "reference" means taking 1-port S-parameter (i.e. reflection coefficient) as an example. The relationship between the reflection coefficient and the impedance Z can be expressed as follows:

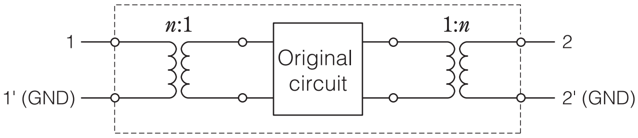
$$\Gamma = \frac{Z - Z_0}{Z + Z_0}$$

"Z_0" in this formula indicates the reference impedance. For example, assume that there are two resistors, 50 Ω and 200 Ω. When 50 Ω is converted into the reflection coefficient using the reference impedance of Z_0=50 Ω, we have Γ=0. Similarly, when Z=200 Ω, Γ=0.6. If the reference impedance of Z_0=200 Ω is used, we have Γ=–0.6 for Z_0=50 Ω and Γ=0 for Z_0=200 Ω. In summary, the 50 Ω resistor doesn't reflect when the reference impedance is 50 Ω (matched, Γ=0), and the 200 Ω resistor doesn't reflect when the reference impedance is 200 Ω. This means that the reflection coefficient is a relative value that varies depending on the conditions. The reference impedance is the reference value used for calculating this relative value. Non-1-port devices can be considered the same way, but the calculation is more complicated [5, 6].

Since 50 Ω is only a reference value, there are other S-parameters than 50 Ω (as described in the example above). The reference value can be changed. Suppose that you have the S-parameter already determined for 50 Ω, it is possible to transform it to a different S-parameter using a reference impedance other than 50 Ω (Note: The original S-parameters require all (S_{11}, S_{21}, S_{12}, and S_{22}) parameters even when you want to know only S_{21}.). The calculation is difficult, but you can use the tools such as high-frequency simulators to obtain the calculation result easily. You can also use TDK's "SEAT" for this calculation. Figure 4 shows S-parameters of the bead with serieS-thru configuration using three reference impedances of 10, 50, and 100 Ω. The smaller the reference impedance, the higher the attenuation is. The shunt-thru capacitors, which are not shown in the figure, give the opposite, namely the bigger the reference impedance, the higher the attenuation.

Figure 3 Varying the Reference Impedance

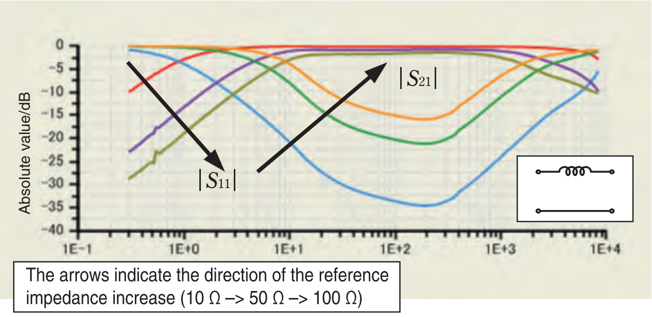
– Simulate the following circuit at the terminal Z_0.
– The ideal transformer multiplies the impedance by constant (n^2).
– Some simulators can vary the terminal impedance freely
  and in such a case this workaround is not needed.



$$n = \sqrt{Z_0 / Z'_0}$$

Z_0 is the original reference impedance (normally 50 Ω).
Z'_0 is the target reference impedance.

Figure 4 S-parameter of Bead with Various Reference Impedances



The arrows indicate the direction of the reference impedance increase (10 Ω –> 50 Ω –> 100 Ω)

Mixed Mode S-Parameters

This section discusses mixed-mode S-parameters.
A differential transmission system is a system that uses different modes such as the differential mode and common mode (refer to the column of the last page). The S-parameter for this system needs to be handled according to the modes, which is referred to as a mixed-mode S-parameter (or modal S-parameter). The normal S-parameter (referred to as a single-ended S-parameter or nodal S-parameter) indicates the response for each port. On the other hand, a mixed-mode S-parameter indicates the response for the sum of two signals (common mode) or the response for the difference of two signals (differential mode).

A mixed-mode S-parameter can be obtained from a single-ended S-parameter (Figure 5). The calculation formula is complicated, but you can use the simulators or other tools to obtain the mixed-mode S-parameter (Figure 6, [7]). Recently there are a lot of network analyzers that can read the mixed-mode S-parameter directly. The obtained mixed-mode S-parameters have the following meanings. See the reference [6, 8] for details.

- S_{ccij}: Common mode response
- S_{ddij}: Differential mode response
- S_{dcij}, S_{cdij}: Mode conversion between differential mode and common mode

The mode conversion (S_{dcij} or S_{cdij}) can be used as the symmetric property index of the system [9, 10]. If the device has good symmetry, the mode conversion should be zero, which means that each mode is independent. LCL[*2] can be calculated using the S-parameter as follows [7, 11, 12]:

2-port circuit $LCL_1 := -20\log|2S_{dc}| = -20\log|S_{11} - S_{21} + S_{12} - S_{22}|$

4-port circuit $LCL_2 := -20\log|2S_{dc11}| = -20\log|S_{11} - S_{31} + S_{13} - S_{33}|$

Figure 5 Mixed-Mode S-Parameter Can be Converted from Single-Ended S-Parameter

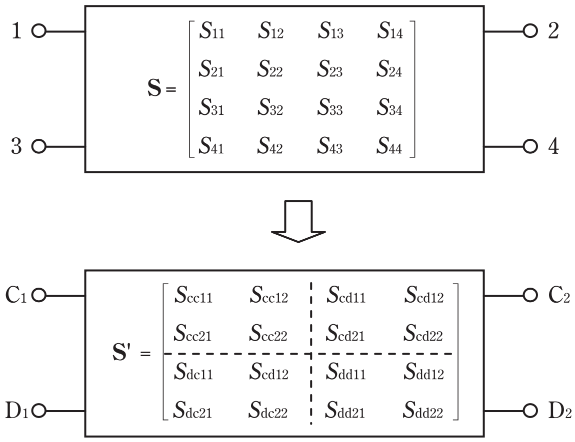
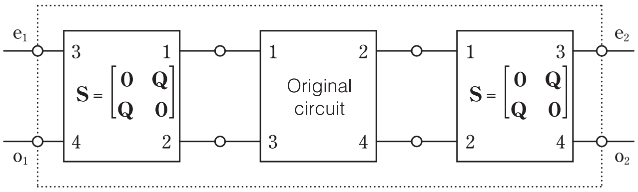


Figure 6 Calculation of Mixed Mode S-Parameter

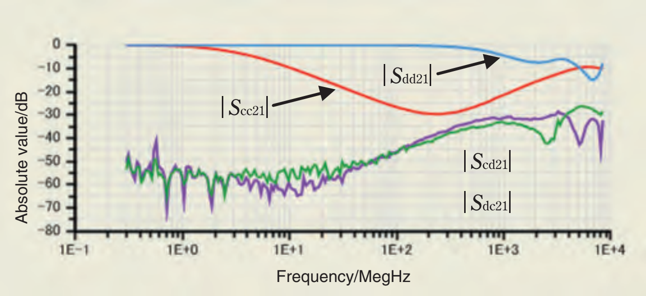
- Simulate the following circuit at the terminal Z_0.
- The circuits on the right and left sides convert from the single-ended to the mixed-mode (and vice versa, because the circuit is symmetric).
- Since this is an "ideal magic T" conversion circuit, it can be expressed using the ideal transformer network (hybrid coil) [7].



$$\mathbf{Q} := \frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

Figure 7 shows an example of actual measurements for a common mode filter (CMF). It can be seen that this CMF attenuates the common mode signal around 100 MHz ($|S_{cc21}| = -30$ dB), but transmits the differential mode signal with little loss ($|S_{dd21}| = 0$ dB).

Figure 7 Example of CMF Mixed-Mode S-Parameter



References

[1] Isao OHTA, "Expressions and basic characteristics of electromagnetic wave circuit by using S-parameters", MWE (Microwave Workshops & Exhibition) '97 Digest, pp.427-436, 1997 December

[2] Kiyomichi ARAKI, "Analysis and design of electromagnetic wave circuits based on S-parameters", MWE (Microwave Workshops & Exhibition) '97 Digest, pp.437-445, 1997 December

[3] Hidetoshi TAKAHASHI, Yasushi FUJIMURA, "Hidetoshi TAKAHASHI's Physics Lecture", Maruzen, 1990

[4] Masamitsu NAKAJIMA, "Microwave engineering" Morikita publishing, 1975

[5] Kaneyuki KUROKAWA, "Power waves and the scattering matrix", IEEE Trans. MTT, vol.MTT-13, No.2, pp.194-202, 1965 March

[5] Yoshikazu FUJISHIRO, "Evaluation of electronic components using S-parameters", TDK Application Note AN-SP06A001_ja, 2006 (http://www.tdk.co.jp/tvcl/spara/an-sp06a001_ja.pdf)

[7] Yoshikazu FUJISHIRO, Tatsuya FUKUNAGA "Multi-port measurement for electronic components/Modeling of EMC countermeasure components for high-speed digital circuits" MWE (Microwave Workshops & Exhibition) 2007 Digest, pp.193-198, 2007 November (Note: The LCL calculation formulas (4) and (7) in this draft contains errors. This paper corrects these errors and gives the correct formulas.)

[8] David E.BOCKELMAN, William R.EISENSTADT, "Combined differential and common-mode scattering parameters: Theory and simulation", IEEE Tarns. MTT, vol.43, No.7, pp.1530-1539, 1995 July

[9] Yoshikazu FUJISHIRO, "Analysis of common mode filters using S-parameters", Shingaku Gihou EMCJ, pp.25-30, 2000 September (EMCJ2000-60)

[10] Yoshikazu FUJISHIRO, Tetsuya UMEMURA "IEEE1394 and USB's countermeasures against noise: Evaluation of countermeasure components containing blind spots" Nikkei Electronics, No.784, pp.214-220, December 4, 2000, and No.785, pp.218-223, December 18, 2000 (Serial in two installments)

[11] Yoshikazu FUJISHIRO, "Evaluation of common mode filters using S-parameters", 9th Nikkei Board Information Forum, "EMC design, measurement, and evaluation technologies for electronic devices of the GHz era", held on February 13, 2002

[12] K.Yanagawa, J.Cross, "Modal Decomposition (Non-Balun) Measurement Techniques: Error Analysis and Application to UTP/STP Characterization to 500MHz", International Wire and Cable Symposium Proceedings, pp.126-133, 1995 November

[13] Clayton R. PAUL (Author), Risaburou SATO (Supervisor), Akihisa SAKURAI (Translation supervisor), "Introduction to EMC" Mimatsu Data System, 1996; Clayton R. PAUL, "Introduction to Electromagnetic Compatibility", John Wiley & Sons, 1992 (First edition), 2006 (Second edition)

[*2] In ITU-T Recommendation G.117-1996, "Transmission aspects of unbalance about earth", LCL is defined for 2-port and 4-port circuits. (In the Standard, 2-port and 4-port circuits are referred to as 1-port and 2-port, respectively.) To avoid confusion, LCLs for 2-port and 4-port circuits are referred to as LCL_1 and LCL_2, respectively. LCL_2 is equal to LCL_1 at the non-target port terminated with reference impedance. Since LCL uses the signal source voltage as its reference, the difference between LCL and S-parameter is 6 dB (double). The calculation formulas in this chapter reflect this difference.

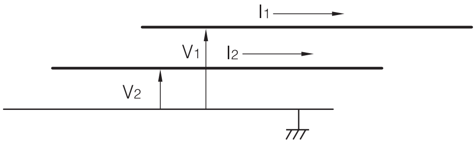
About Common Mode

"Common mode" is one of the keywords for EMC countermeasures. This section gives details about the common mode.

Definition of Common Mode and Differential Mode

Suppose there are two conductors (and a GND conductor) that are parallel to each other (e.g. a differential transmission system). When the voltage and the current for each conductor are named as V_1, I_1 and V_2, I_2 (see Figure 1), the common mode voltage V_c and current I_c and the differential mode voltage V_d and current I_d are defined as the following (IEC technical vocabulary, IEC60050-161:1990, JIS C0161: 1997).

Figure 1 Two Parallel Conductors



- Common mode voltage Vc: Average voltage for each conductor
  $V_c = (V_1+V_2)/2$
- Common mode current Ic: Total current for each conductor
  $I_c = I_1+I_2$
- Differential mode voltage Vd: Voltage between two conductors
  $V_d = V_1-V_2$
- Differential mode current Id: Half of the current difference for each conductor
  $I_d = (I_1-I_2)/2$

The common mode represents the sum of signals, while the differential mode represents the difference between signals. The current in differential mode flows backwards (anti-phase) through two conductors. Therefore, GND is not directly connected (for that reason, it is referred to as normal mode). On the other hand, the current in the common mode flows in the same direction (in-phase) through two conductors. Consequently, the current flows through the GND conductor (or through another area) and then returns (hence this is referred to as an earth circuit).

The common mode is also referred to as asymmetrical (or vertical, as in vertical electrical current) or longitudinal, and the differential mode is also referred to as being symmetrical (or horizontal).

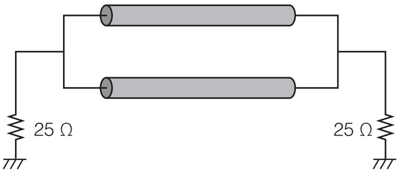
Other Modes

The even and odd modes are similar to the common and differential mode. Like common and differential modes, even and odd modes represent the sum of signals and the difference between signals, respectively. The difference between them is the coefficient. In the calculation formula,

- Even mode voltage Ve, Current Ie:
  $V_e = (V_1+V_2)/\sqrt{2}$
  $I_e = (I_1+I_2)/\sqrt{2}$
- Odd mode voltage Vo, Current Io:
  $V_o = (V_1-V_2)/\sqrt{2}$
  $I_o = (I_1-I_2)/\sqrt{2}$

Compared to the common mode, the even mode voltage is x$\sqrt{2}$, and the current is x1/$\sqrt{2}$. For example, if I_1 = 1 A and I_2 = 1 A, the current is I_c = 2 A in the common mode expression and $I_e = \sqrt{2}$A in the even mode expression. Both the common mode and even mode represents the sum of signals, which means that they are qualitatively the same but quantitatively different. Different voltage and current makes the impedance (i.e. ratio) different. Since the voltage is x$\sqrt{2}$, and the current is x1/$\sqrt{2}$, the impedances (i.e. ratio) differ by two times. (Note: The electrical power (obtained by multiplication) remains the same; $\sqrt{2}$x1/$\sqrt{2}$ = 1.) Therefore, 50 Ω in the even mode equals to 25 Ω in the common mode. The relationship between the odd mode and the differential mode is the same: 50 Ω in the odd mode equals to 100 Ω in the differential mode. The reason why the impedance is 25 Ω (half) in common mode is that the common mode represents the parallel connection by definition. For example, the common mode characteristics for the two symmetrical transmission lines can be expressed as shown in Figure 2. Because 50 Ω lines are connected in parallel, the total impedance will be 25 Ω. Likewise, the definition of the differential mode represents the serial connection.

Figure 2 Two Symmetric Transmission Lines



These modes, which are slightly different from each other, have their own advantages and are used appropriately. Because the impedances do not change in the even and odd modes even after conversion, the use of these modes simplifies the theory construction. Therefore, even and odd modes are widely used in the microwave fields. On the other hand, because even and odd modes contain irrationals such as $\sqrt{2}$, they are a little more difficult to handle. Consequently, the common and differential modes are more popular in practical use. For example, if the characteristic impedance of a balanced cable is expressed as 100 Ω, it indicates the characteristic impedance in differential mode, not in odd mode.

Common Mode is a Source of Radiative Noise

The current in differential mode is a reciprocal current in two conductors, and the backward route is positioned adjacent to the forward route (i.e. the loop area is small). Therefore, when viewed from a distance, forward and backward lines seem to compensate each other and no current flows. On the other hand, as mentioned above, the backward line of the current in the common mode is indeterminate and may be far from the forward line. Therefore, the loop area may be large and tend to be the source of radiative noise [13].

The common and differential modes are defined for systems such as two parallel conductor systems. Therefore, these modes can not be used for other situations such as the current distribution on a surface. However, in general, the term "common mode" may be used for expressing those situations in which due to the similarity the current deviates from the ideal reciprocal current (i.e. the loop area is large and can be the source of radiative noise). The "common mode" used in those situations is not defined clearly, and needs to be handled carefully to avoid misunderstandings.

Basic Knowledge of EMC Standards

TDK Corporation Application Center
Masao Umemura

1 Introduction

This chapter summarizes basic information about EMC standards, including:

- What are EMC standards?
- Why EMC standards are so important and must be complied with?
- What types of EMC tests are being conducted?

2 Beginning of EMC Standards

In order to put an electrical or electronics device on the market, the device is required to comply with EMC standards during its development, design, and manufacture. The EMC standards define the frequency range and limit of unnecessary radiation to prevent telecommunication and broadcasting devices (such as those that use an assigned frequency range for radio communication) and electrical/electronics devices from being interrupted, causing interference, or other similar problems.

Frequency range assignment is critical for ensuring important radio communication (e.g. fire services or police radio) and TV broadcasting, and preventing radio interference. The EMC standards play an important role in adjusting the frequency range assignment.

Another purpose of the EMC standards is to protect electrical/electronics devices from being subject to various interferences (including lightning surges and static electricity) or damage, by minimizing hazards found in their operating environments.

3 Classification of the Standards

(1) International Standards: ISO, IEC/CISPR, etc.
(2) Regional Standards: EN, ASEAN, etc.
(3) National Standards: JIS, BS, ANCI etc.
(4) Industrial Standards: JEITA, SEMI, etc.
(5) Form Standards: Bluetooth, USB, HDMI, etc.

The important thing to note is that international standards are developed by the organizations that meet the commercially agreed principles of the WTO (World Trade Organization) (i.e. to ensure transparency, openness, impartiality and consensus, effectiveness and relevance, coherence, and to address the concerns of developing countries). These above mentioned organizations include ISO, IEC, and ITU.

Regional standards are developed to ensure impartiality in trade, imports and exports to/from the relevant region. The EN standard is a typical example.

National standards are established when a country needs to have customized standards that suit the actual situation in the country. Such national standards may be incorporated in laws and regulations, and operated along with penalties.

Industrial standards may define codes and standards for issues such as inter connectivity between devices. Usually, these codes and standards do not involve legal actions. The USB and HDMI standards are famous examples.

It is important to note that the compliance with the standards is related to commerce and trade issues. Consequently the systems to ensure measurement methods and accuracy (e.g. ISO7025: management system of testing and calibration laboratories) play as important a role as the designated limit values and frequency ranges in the operation of these standards.

The standards and operating rules are created and operated globally. This movement is based on the idea that "radio waves used as the means of information-communication play an extremely important role in the fields of national security, economic activity, and social activity."

4 IEC Standards

The major international standards for the EMC sector are IEC (International Electrotechnical Commission) standards and CISPR (Comité international spécial des perturbations radioélectriques) standards. In the U.S., IEEE standards are more popular and used as the international standards in the field, e.g. antenna calibration tests. The procedures for establishing an IEC or CISPR standard include a conference of representatives from various countries. An IEC or CISPR standard is usually reviewed and revised once every 5 years, in order to keep its technological level equal to the current situation.

5 Hierarchy of Standards

Most international standards such as IEC are maintained systematically. For example, EMC standards are systematized as follows:

(1) Basic EMC publications/Technical report
These standards describe the general EMC specifications that are not limited to specific product or product families.
(e.g. Terms: IEC61000 series, CISPR16)

(2) Generic EMC standards
These standards are applied to products that are not subject to any specific product/product family EMC standards.
(e.g. IEC61000-6 series)

(3) Product family EMC standards

The standards comprehensively applied to similar products are referred to as product family EMC standards. These standards define test, operating, and installation conditions, and so on.

(4) Product EMC standards

The standards applied only to the specific product are referred to as product EMC standards.

The standards of (4) have the highest priority and those of (1) have the lowest priority. Products are required to comply with the standards according to this priority.

6 CISPR Standards

The CISPR standards are employed as national standards in various countries, and considered to be the global standard. Japan is way behind in shifting to international standards as compared with other countries. For example, JIS standard may still be based on CISPR standard of 10 years ago. In the future, Japan needs to employ the international standards pro actively to take advantage of them to help in trade negotiations, to further her international contributions, and help solve environmental problems, and thus play a leading role in Asia.

Table 1 shows a list of CISPR standards. If you check this list considering the above mentioned standard system, you will see that some of these standards assume state-of-the-art products with future technologies.

Table 1 List of CISPR Standards

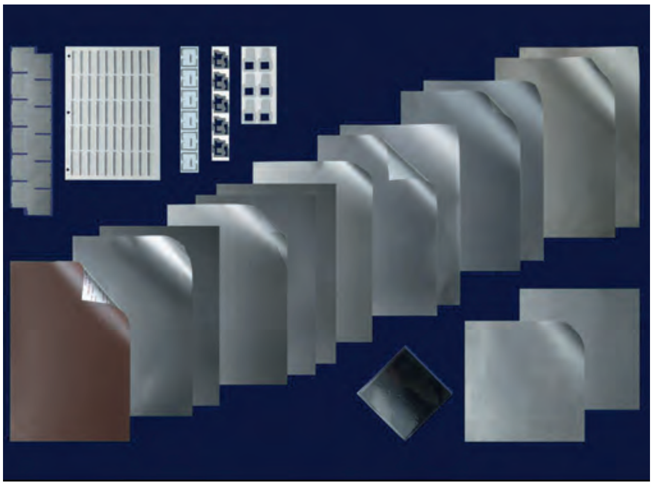
Standard No. (Rev.)	Contents	Issued (Year)
CISPR 11, Rev. 4.1	Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement	2004
CISPR 12, Rev. 5.1	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers	2005
CISPR 13, Rev. 4.2	Sound and television broadcast receivers and associated equipment – Radio disturbance characteristics – Limits and methods of measurement	2006
CISPR 14	Electromagnetic compatibility (EMC): Requirements for household appliances, electric tools and similar apparatus	
14-1, Rev. 5.0	Part 1: Emission	2005
14-2, Rev. 1.1	Part 2: Immunity	2001
CISPR 15, Rev. 7.1	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment	2007
CISPR 16	Specification for radio disturbance and immunity measuring apparatus and methods	
CISPR 16-1	Part 1-1: Radio disturbance and immunity measuring apparatus	
16-1-1, Rev. 2.1	Measuring apparatus	2006
16-1-2, Rev. 1.2	Ancillary equipment – Conducted disturbances	2006
16-1-3, Rev. 2.0	Ancillary equipment – Disturbance power	2004
16-1-4, Rev. 2.0	Antennas and test sites for radiated disturbance measurements	2007
16-1-5, Rev. 1.0	Antenna calibration test sites for 30 MHz to 1 000 MHz	2003
CISPR 16-2	Part 2: Methods of measurement of disturbances and immunity	
16-2-1, Rev. 1.1	Conducted disturbance measurements	2005
16-2-2, Rev. 1.2	Measurement of disturbance power	2005
16-2-3, Rev. 2.0	Radiated disturbance measurements	2006
16-2-4, Rev. 1.0	Immunity measurements	2003
CISPR 16-3, Rev. 2.0	Part 3: CISPR technical reports	2003
CISPR 16-4	Part 4: Uncertainties, statistics and limit modelling	
16-4-1, Rev. 1.1	Uncertainties in standardized EMC tests	2005
16-4-2, Rev. 1.0	Uncertainty in EMC measurements	2003
16-4-3, Rev. 2.0	Statistical considerations in the determination of EMC compliance of mass-produced products	2004
16-4-4, Rev. 1.0	Statistics of complaints and a model for the calculation of limits (Technical report)	2003
16-4-5, Rev. 1.0	Conditions for the use of alternative test methods (Technical report)	2006
CISPR 17, Rev. 1.0	Methods of measurement of the suppression characteristics of passive radio interference filters and suppression components	1981
CISPR 18	Radio interference characteristics of overhead power lines and high voltage equipment	
18-1, Rev. 1.0	Part 1: Description of phenomena	1982
18-2, Rev. 1.0	Part 2: Methods of measurement and procedures for determining limits	1986
18-3, Rev. 1.0	Part 3: Code of practice for minimizing the generation of radio noise	1986
CISPR 19, Rev. 1.0	Guidance on the Use of Substitution Method for Measurement of Radiation from Microwave Ovens for Frequencies Above 1 GHz	1983
CISPR 20, Rev. 6.0	Sound and television broadcast receivers and associated equipment – Immunity characteristics – Limits and methods of measurement	2006
CISPR 21, Rev. 2.0	Interference to Mobile Radio Communications in the Presence of Impulsive Noise: Method of Judging Degradation and Measures to Improve Performance	1999
CISPR 22, Rev. 6.0	Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement	2008
CISPR 23, Rev. 1.0	Determination of Limits of Radio Interference for Industrial Scientific and Medical Equipment	1987
CISPR 24, Rev. 1.0	Information technology equipment – Immunity characteristics – Limits and methods of measurement	1997
CISPR 25, Rev. 2.0	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers	2002
CISPR 28, Rev. 1.0	Industrial, scientific and medical equipment (ISM) – Guidelines for emission levels within the bands designated by the ITU	1997
CISPR 29, Rev. 1.0	Television broadcast receivers and associated equipment – Immunity characteristics – Methods of objective picture assessment	2004
CISPR 30, Rev. 1.0	Test method on electromagnetic emissions from elecronic ballasts for single- and double-capped fluorescent lamps	2001
CISPR 31, Rev. 1.0	Database on the characteristics of radio services	2003
IEC 61000-4-20, Rev. 1.0	Testing and measurement techniques – Emission and immunity testing in transverse elctromagnetic (TEM) waveguides	2003
IEC 61000-4-21, Rev. 1.0	Testing and measurement techniques – Reverberation chamber test methods	2003
IEC 61000-6-3, Rev. 2.0	Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments	2006
IEC 61000-6-4, Rev. 2.0	Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments	2006
IEC pas62437, Rev. 1.0	Radio disturbance characteristics for vehicles and boats—Limits and methods of measurement—Specifications for active antennas	2005

Basics of the Magnetic Suppression Sheet, Flexield

TDK Corporation Magnetics Business Group
Hidetomo Hattori

1 Overview of the Magnetic Suppression Sheet

The magnetic suppression sheet (TDK's trade name: Flexield) is a noise suppression sheet made of soft magnetic material and resin.



The soft magnetic materials contained in the sheet convert electromagnetic waves to thermal energy by natural resonance, and thus prevent electromagnetic waves from being transmitted through the shield, or the waves are reflected internally.

Flexield is mainly used for suppressing unnecessary radiation from ICs, FPCs, and the LCDs of such densely packed devices, as mobile phones, digital still cameras, and notebook PCs.

The sheet can be applied to the source of unnecessary radiation or to those components that are subject to unnecessary radiation.

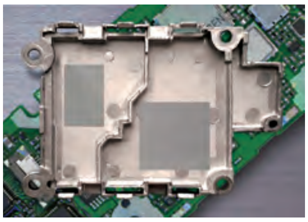
Table 1 Subjects of Noise Suppression Sheets (= Types of noises viewed from the equipment itself)

	Noise Type	Summary	Evaluation Method
1	Emission noise suppression (Equipment -> Outside object)	Regulated by the industrial standards (CISPR, Product Safety Electrical Appliance & Material).	Noise emission evaluation in an anechoic chamber
2	Internal interference suppression (Equipment -> Equipment itself)	Conduction/emission noise from LSI/LCD/ flexible cables cause malfunctions.	Measurement of radiation electromagnetic field during replaying videos

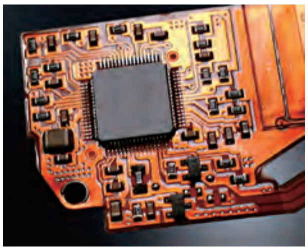
The application examples are:

(1) Prevention of internal interference and unnecessary radiation by attaching the sheet to the enclosure
(2) Prevention of unnecessary radiation from the noise source (IC)
(3) Set the sheet between two boards to prevent one board from being affected by the noise from the other board.
(4) Prevention of unnecessary radiation from the cables when connecting board-to-board or board-to-component.

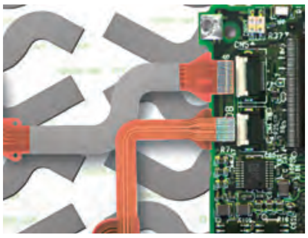
Application example (1)



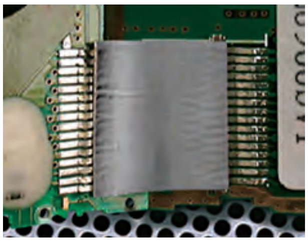
Application example (2)



Application example (3)



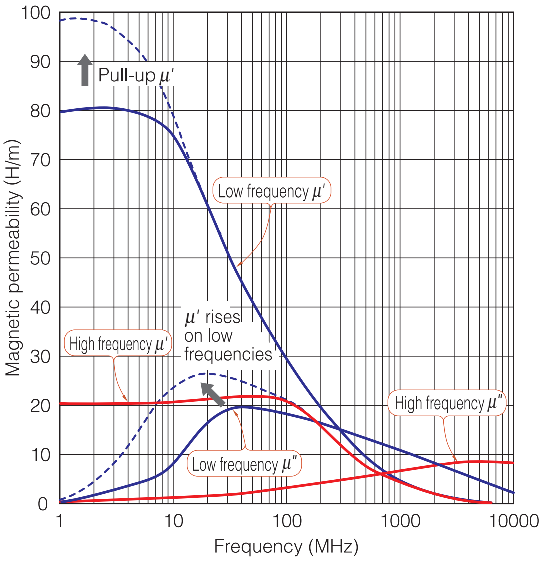
Application example (4)



As mentioned above, the magnetic suppression sheet is a soft magnetic sheet-type material.

The soft magnetic material features low coercive force and high magnetic permeability. The absorption performance of this material can be expressed by the magnetic permeability μ (Flux density (B)/Magnetic field intensity(H)), which is an indication of the ease of magnetization when a magnetic field is applied to a magnetic object.

Figure 1 Magnetic Permeability Frequency Characteristics



In principle, a material with higher magnetic permeability magnetizes more easily.

When the field intensity changes in an alternate-current magnetic field, the flux density can not keep up with the change, and creates a magnetic field wave delay phase. Therefore, the magnetic permeability is expressed as $\mu = \mu' - j\mu''$, where μ' is the real number term (= ease of magnetization) and μ'' is the imaginary term (= degree of phase shift = degree of magnetic loss). Both μ' and μ'' are frequency dependent. The larger the value of μ'', the better the noise absorption performance.

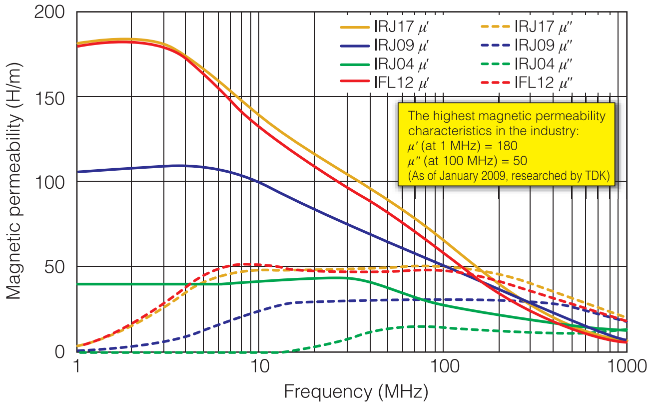
TDK provides:

Thin, halogen-free type: IFL12

Flame-retardant type in various thicknesses: IRJ17, IRJ09, IRJ04

Customers can select the best type taking into consideration thickness restrictions, flame retardation and halogen requirements.

Figure 2 Magnetic Permeability Frequency Characteristics of Flexield



The highest magnetic permeability characteristics in the industry:
μ' (at 1 MHz) = 180
μ'' (at 100 MHz) = 50
(As of January 2009, researched by TDK)

Table 2 Flexield Product Portfolio

Item	IRJ17 (New product)	IRJ09	IRJ04	IFL12 (New product)
Recommended frequency range	10 MHz to 3 GHz	10 MHz to 3 GHz	50 MHz to 10 GHz	10 MHz to 3 GHz
Operating temperature range (°C)	–40 to +85	–40 to +85	–40 to +85	–40 to +85
Magnetic permeability (at 1 MHz)	180	100	40	160
Resistivity (Ω/square)	≧1 M	≧1 M	≧1 M	≧100 k
Thermal conductivity (W/m·K)	1.7	1.5	1.5	1.6
Environment	Conforming to RoHS Directive	Conforming to RoHS Directive	Conforming to RoHS Directive	Conforming to RoHS Directive Halogen-free
Flame-retardant	UL94-V0	UL94-V0	UL94-V0	—
Standard sheet dimensions (mm)	300×200	300×200	300×200	300×200 Can be rolled
Standard sheet thickness (mm)	0.1, 0.2, 0.3, 0.4	0.1, 0.2, 0.3, 0.4, 0.5	0.1, 0.25, 0.5	0.05 to 0.15

2 Evaluation of Basic Characteristics of Noise Suppression Sheet

As mentioned above, the larger the loss (μ''), the better the noise attenuation performance. This can be expressed as follows:

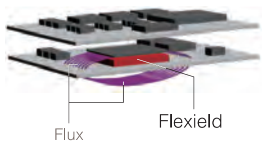
Amount of noise attenuation [dB] $R_{tp} \propto \mu'' \cdot (t / \lambda)$

μ'': Magnetic permeability imaginary part
t : Thickness
λ : Wavelength

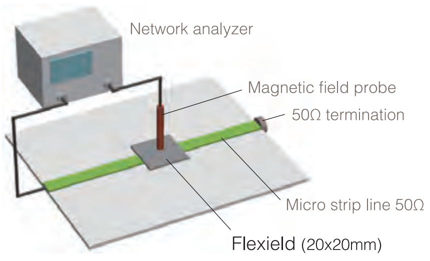
TDK evaluates the effect of its noise suppression sheets using the following measurement methods:

2–1 Decoupling Effect

This reduces the opposite line of high frequency magnetic-field elements occurring due to signal lines and ICs located inside devices, and reduces the inductive coupling of cohesive units.



The micro-strip line's reduction effect against neighboring magnetic fields is measured using the following model:

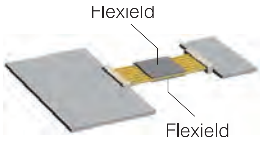


Attach the test sample (20 mm□) on the micro–strip line and evaluate the attenuation ratio of the neighboring magnetic fields on the test sample.

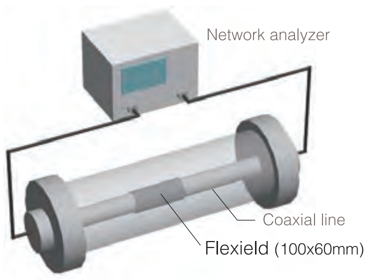
* Attenuation ratio (dB) = Level when test sample is not attached (dB)
– Level when test sample is attached (dB)

2–2 Common Mode Electrical Current Reduction Effect

This reduces the common mode electrical current elements superposed in the flexible cables connecting high-speed circuits and the like.



The attenuation effect of the transmission signals on coaxial lines is measured using the following model:



Evaluate the attenuation ratio of the transmission signal when the test sample (100 mm × 60 mm) is attached to the central conductor of the coaxial line.

* Attenuation ratio (dB) = Level when test sample is not attached (dB)
– Level when test sample is attached (dB)

Figure 3 Decoupling Effect
IRJ17 vs. Existing model (IRJ09)

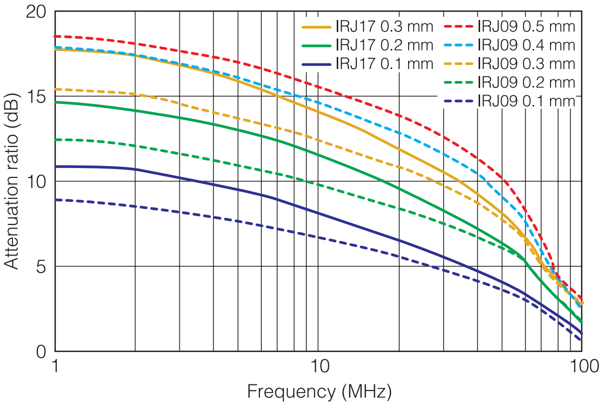
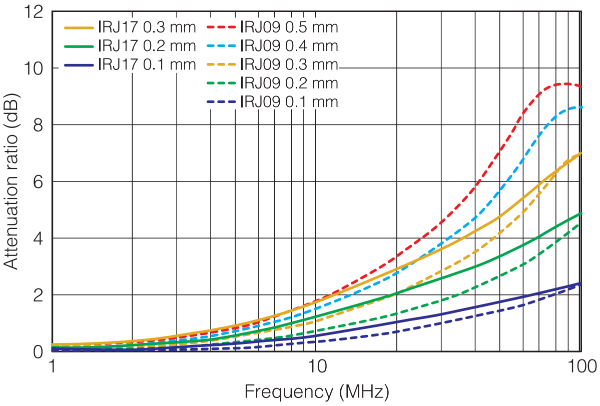


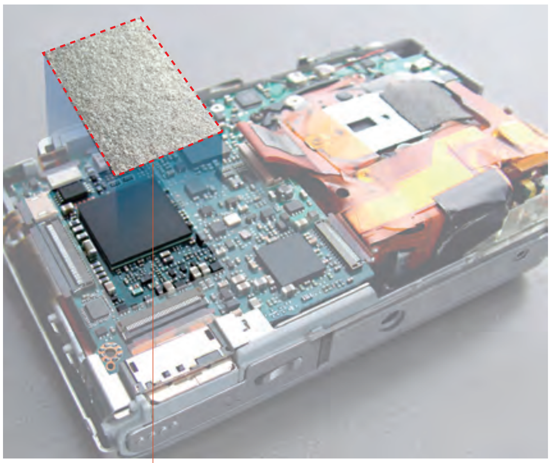
Figure 4 Common Mode Electrical Current Reduction Effect
IRJ17 vs. Existing model (IRJ09)



3 Characteristic Evaluation Verification of Noise Suppression Sheets Using an Actual Device

We evaluated the noise suppression effect when noise suppression sheets were applied to an actual DSC (digital still camera). First, we applied another company's noise suppression sheet available in the market ($\mu = 100$, $t = 500\ \mu m$) to a DSC, and conducted the following evaluations:

- 3-1&3-2 Evaluate the intended use of the noise suppression sheet
- 3-3 Compare the noise suppression effect of the TDK product and another



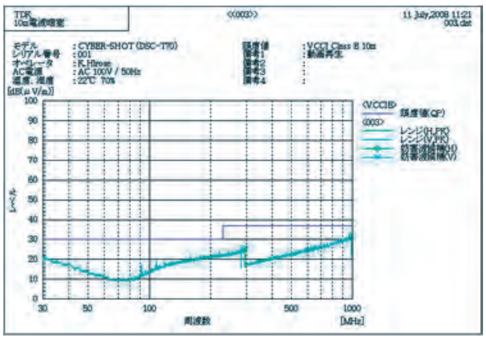
Apply the noise suppression sheet to the target area (Image).

DSC's board and noise suppression target area (Peripheral circuit around the image processing, controller, and SDRAM integrated IC)

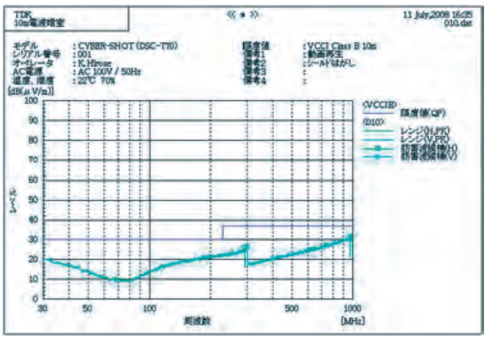
3–1 Noise Radiation Evaluation (Anechoic Chamber)

The noise radiation levels with and without the noise suppression sheets are measured for comparison (measured in a 10m anechoic chamber). In this evaluation, the specified noise radiation level was satisfied even without the noise suppression sheet; therefore, it was confirmed that the noise suppression sheet was not used for the suppression of noise radiated from the source.

During image replay
With the noise suppression sheet

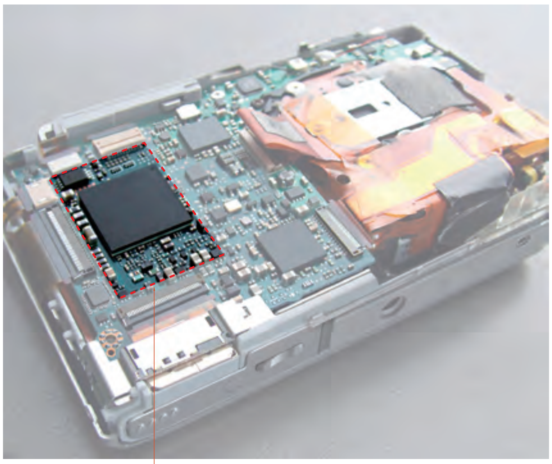


During image replay
Without the noise suppression sheet

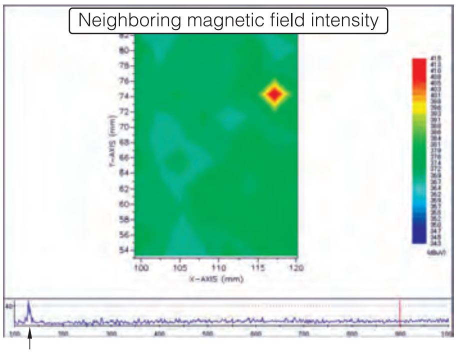


3–2 Neighboring Magnetic Fields Mapping (Internal Interference Suppression)

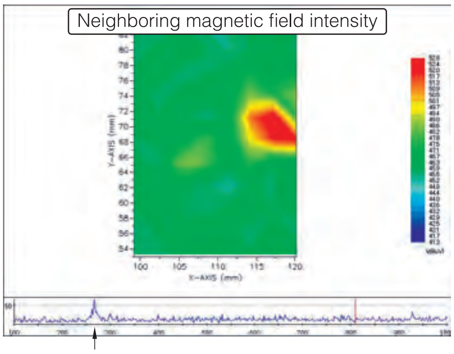
Next, using an electromagnetic field probe, we conducted mapping measurements for the DSC during operation. In this measurement, we found a noise (possibly the clock noise) on the LSI. This noise ranged from 132 MHz to 1.5 GHz, and was higher than the 10th harmonic. It is considered that the noise suppression sheet is mounted as a countermeasure against this noise.



Scan this area.



132 MHz



264 MHz

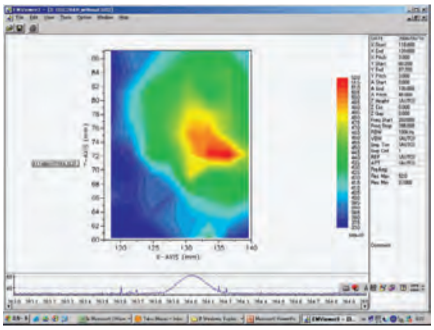
Evaluation method: Mapping using an electromagnetic field probe
Measurement frequency: 100 MHz to 1 GHz
Operation mode: Image replay

3–3 Comparison between the TDK Product and the Other Company’s Product

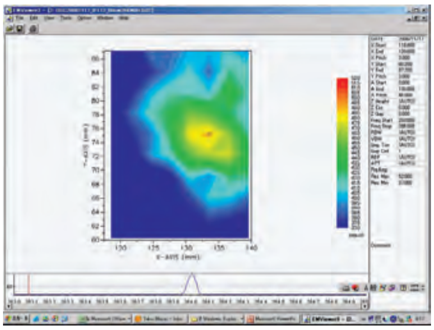
Since noise was found, we measured the noise suppression effect of TDK’s and the other company’s products, applying each noise suppression sheet on the LSI of the DSC.

Chip area (264 MHz)

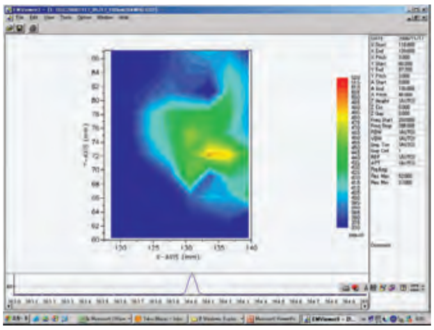
Without sheet



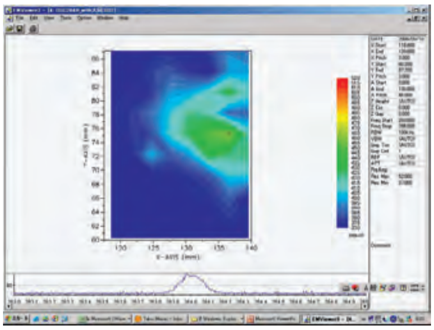
IFL12 t=50 μm



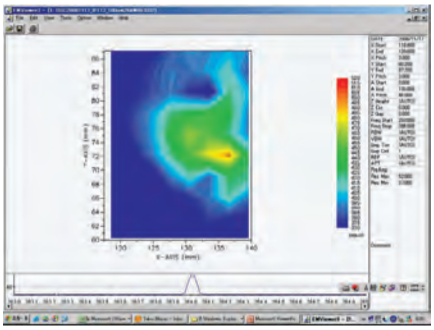
IFL17 t=100 μm



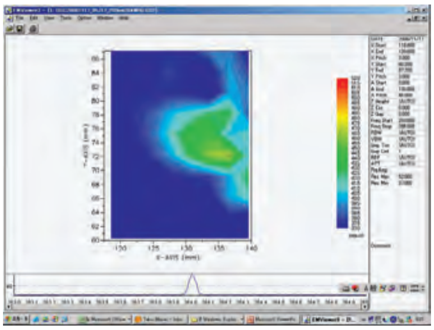
Other company’s product μ=100, t=500 μm



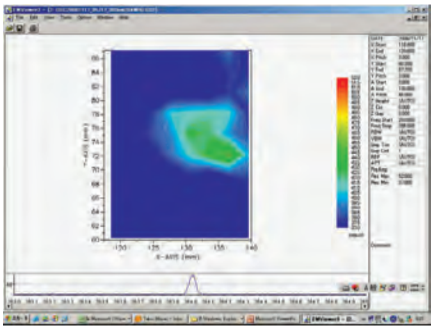
IFL12 t=100 μm



IFL17 t=200 μm



IFL17 t=300 μm



With this evaluation, we confirmed that the TDK’s IRJ17(μ =180) with a 300 μm thickness achieved a noise suppression effect equal to or better than the other company’s product (μ =100) with a 500 μm thickness.

4 Introduction to Ferrite Plate IBF10&IBF20

TDK provides a thin ferrite product that can be used for the same purpose as the noise suppression sheet but with a different magnetic permeability from the noise suppression sheet.

Table 3 Specification of IBF10 and IBF20

Product name		IBF10	IBF20
Material		Sintered thin ferrite plate	
μ” applied frequency		20 MHz to 3 GHz	5 MHz to 3 GHz
at 10MHz	μ” typ.	100	225
	μ’ typ.	1.2	45
at 13.56MHz	μ” typ.	105	200
	μ’ typ.	3	80
at 100MHz	μ” typ.	41	50
	μ’ typ.	45	70
Basic specifications			
Resistivity (Ω/square)		1 G min.	
Operating temperature range (°C)		–40 to +85	
Thermal conductivity (W/m·K)		6 (Ferrite plate), 0.1 (PET and adhesive layer)	
Flame-retardant		—	
Environment		Conforming to RoHS Directive	

Figure 5 Magnetic Permeability Frequency Characteristics of IBF10 and IBF20

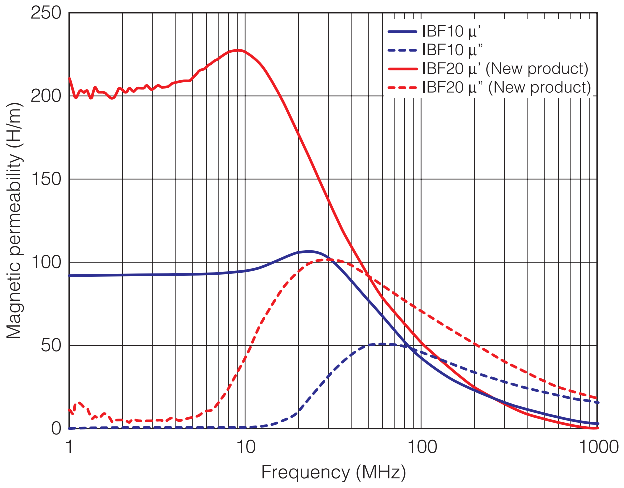
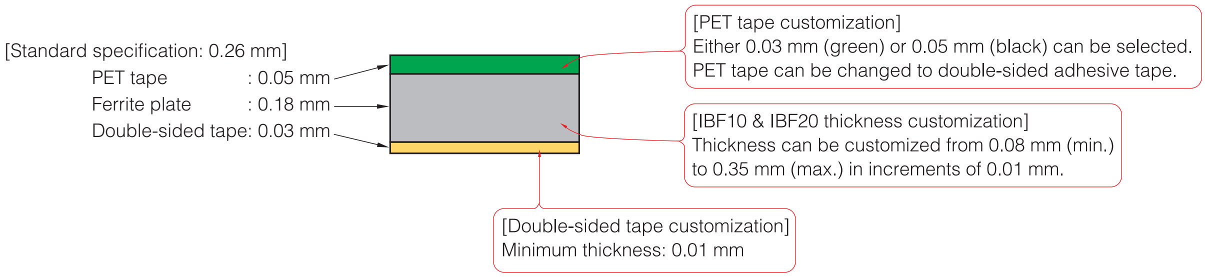


Figure 6 Structure of IBF10&IBF20

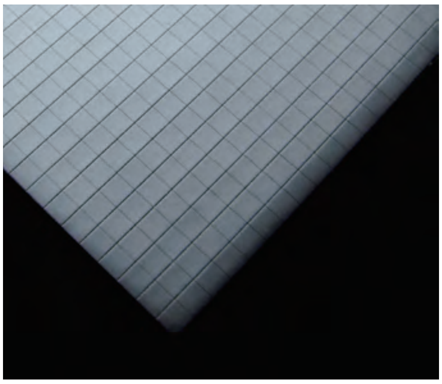
For IBF10&IBF20, “PET tape” is attached to one side of the ferrite plate, and “double-sided tape” is attached to the other side.



[PET tape customization]
Either 0.03 mm (green) or 0.05 mm (black) can be selected.
PET tape can be changed to double-sided adhesive tape.

[IBF10 & IBF20 thickness customization]
Thickness can be customized from 0.08 mm (min.) to 0.35 mm (max.) in increments of 0.01 mm.

[Double-sided tape customization]
Minimum thickness: 0.01 mm



◆The ferrite plate has multiple slits (2 mm apart). After being laminated, the ferrite plate is cracked along these slits to add flexibility.

With an extensive portfolio of materials that meets the intended use and target frequency, we propose Flexield and ferrite plates as one solution to the problem of noise suppression.

Basics of Ferrite and Noise Countermeasures

TDK Corporation Magnetics Business Group
Shinichiro Ito

1 What is Ferrite?

Ferrite was invented by Dr. Kato and Dr. Takei in 1930 and is an oxide magnetic material whose main ingredient is iron (Figure 1) Ferrite is classified into soft ferrite (magnetic core material) and hard ferrite (magnet material). TDK was established for producing soft ferrite in 1935.

Figure 1 The First Ferrite Core in the World

Firstly, differences between soft ferrite and hard ferrite will be explained.

Figure 2 B-H Curve of Magnetic Material

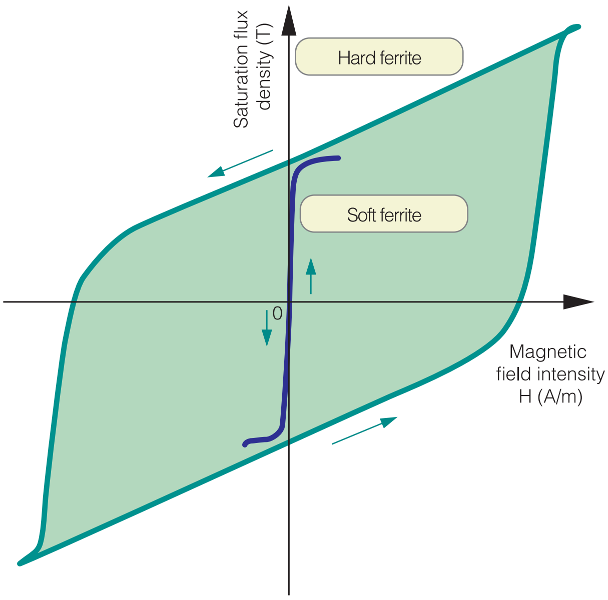


Figure 2 shows what is called the B-H curve (magnetic history curve) of magnetic material, showing the flux density B that flows in a magnetic material when a magnetic field H is applied. It is easy to understand if the magnetic material is imagined as an electrical conductive material, the magnetic field as an electric field, and the flux density as an electric current. When a voltage is applied to the common electrical conductive material, a current flows in proportion to the voltage; then, if the voltage is decreased, the current decreases in proportion to the voltage (Ohm's Law). In the case of the magnetic material, the flux density non-linearly increases against the magnetic field. If the magnetic field is decreased after being increased, the flux density decreases while drawing a different curve from that obtained when the magnetic field is increasing. Therefore, the curve is called a history curve (hysteresis curve).

In the case of hard ferrite, when the magnetic field first increases the flux density does not change so much, however, when the magnetic field becomes extremely strong, a sudden flux density flows to create a magnet. Under such circumstances, a magnetic field in the reverse direction would not restore the original conditions. Such a property is called magnetically hard. The stronger the magnetically hard property, the more stable the magnet, as it would not be easily restored by an external magnetic field and would thus make an excellent magnetic material.

On the other hand, with soft ferrite, when the magnetic field is increased, the flux density immediately starts to flow and magnetization occurs. However, when trying to restore conditions by applying a magnetic field in the opposite direction, the original conditions will be easily restored. Such a property is called magnetically soft. When used as a transformer or a coil, the stronger the magnetically soft nature, the higher the performance, as the magnetic core with even a small change in the magnetic field experiences a large change in the flux density, again making an excellent magnetic material.

2 B-H Curve of Soft Ferrite

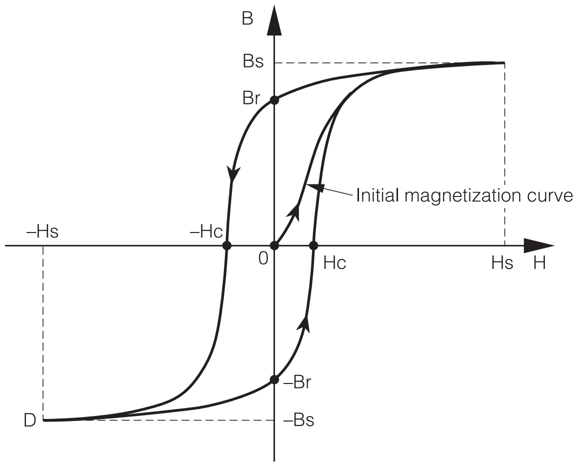
Let's enlarge the B-H curve of soft ferrite again (Figure 3). Just after the ferrite is produced, no external magnetic field is applied to the ferrite, and it is under a state with no magnetization (origin O). As the external magnetic field H is increased, the flux density B flows (magnetized) by the magnetic field in the ferrite along a curve called an initial magnetization curve. When H is increased up to a point where B no longer increases (not correct, strictly speaking), the maximum B is called a saturation flux density Bs, denoting a maximum flux density for the magnetic material flow.

Now, H is decreased from the state of Bs. As explained before, B decreases while drawing a different curve from the initial magnetization curve. B does not return to the original condition even when H becomes zero and magnetism remains in the ferrite. The value of B then is called residual magnetization Br.

H then begins to be applied in the reverse direction from the state of Br. When B is restored to the state of zero, H is called a coercive force Hc.

As H is continued to be applied, this time B reaches Bs in the opposite direction, and later as H is reduced, Br appears in the opposite direction. When H is applied in the initial direction, B reaches Bs after H passes Hc.

Figure 3 B-H Curve of Soft Ferrite



When using soft ferrite as a magnetic core, since in most cases it will be used with an alternative current, the core may generally be considered at the origin of the B-H curve. When applying an alternating magnetic field to the core, the alternating B-H loop becomes large along the initial magnetization curve. Next, descriptions will be given for permeability μ using the initial magnetization curve.

3 Initial Magnetization Curve and Permeability

When using the ferrite for noise countermeasures, permeability μ will be very important characteristics. The relation among permeability μ, magnetic field H, and saturation flux density B is represented by the following formula.

$$B = \mu_{ab} H = \mu_0 \mu H \text{ ....[formula (1)]}$$

where,

μ_{ab}: absolute permeability [H/m]

μ_0 : permeability in vacuum ($4\pi \times 10^{-7}$ [H/m])

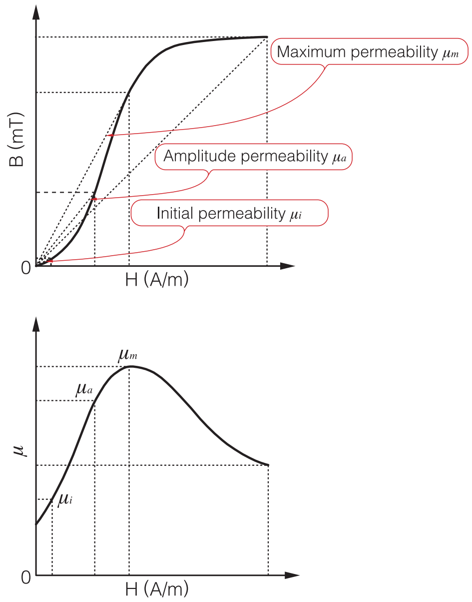
μ : relative permeability

As shown by formula (1), μ is a gradient of the B-H curve. In the world of physics, μ is usually represented by absolute permeability. However, it is practically convenient to be represented by relative permeability. Therefore, when talking of μ, the value represents the relative permeability in general. Relative permeability denotes how many times the magnetic material allows magnetic flux to pass more easily than a vacuum (the air).

Let's consider using the initial magnetization curve of Figure 4. The permeability at the start part (very close to an origin O) of the initial magnetization curve is called initial permeability μ_i.

In many cases, permeability denotes this value. The value on a catalog of ferrite materials denotes initial permeability.

Figure 4 Initial Magnetization Curve and Permeability of Soft Ferrite



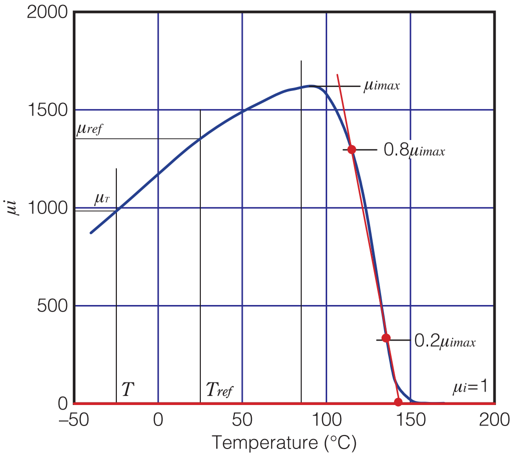
As magnetic field intensity H is increased from an initial permeability area, flux density B increases along the initial magnetization curve. When fully driving a magnetic core by an alternating current (uniformly between a plus side and the minus side across the origin O), the permeability has a gradient connecting the point on the initial magnetization curve with the origin O. Such permeability is called amplitude permeability μ_a. The initial permeability mentioned above can be described as amplitude permeability at the time of significantly small amplitude.

Amplitude permeability μ_a generally increases as H increases, and after reaching a local maximum (maximum permeability μ_m) to decrease again. Therefore, it is necessary to recognize that the permeability of ferrite materials is not constant μ_i, but changes according to the magnitude of the excitation.

4 Temperature Change of Permeability μ and Curie Temperature

The permeability of ferrite changes according to temperature. The permeability of ferrite usually increases as temperature rises. After reaching a local maximum at a certain temperature, the permeability of magnetic materials disappears (comes to be equal to the permeability of the air, $\mu = 1$) as the temperature rises further. The temperature at which the magnetic property disappears from magnetic materials is called the Curie temperature. The Curie temperature of ferrite is usually obtained from the temperature when μ_i becomes 1 on a line, which is obtained by connecting a point where the temperature characteristics of μ_i drops from a local maximum μ_{imax} to a point of 80 % of μ_{imax} with a point of 20 % of μ_{imax} (refer to Figure 5).

Figure 5 Temperature Change of Permeability and Curie Temperature



The temperature change of permeability depends on the kind of ferrite. To use ferrite over a wide temperature range, stable characteristics can be obtained by selecting a ferrite with little change in permeability by temperature. As an index of temperature change of permeability, temperature coefficient α_μ and relative temperature coefficient α_F of permeability are cited, being described as such in the catalog.

$$\alpha_\mu = \frac{(\mu_T - \mu_{ref})}{\mu_{ref} \times (T - T_{ref})} \quad \text{.................................[formula (2)]}$$

$$\alpha_F = \frac{(\mu_T - \mu_{ref})}{\mu_{ref}^{\ 2} \times (T - T_{ref})} \quad \text{.................................[formula (3)]}$$

where,

μ_{ref} : permeability at a reference temperature T_{ref}

μ_T : permeability at temperature T

As the reference temperature T_{ref}, 25 °C is recommended. The temperature T is decided by a temperature zone where the core is used, being selected from –40 °C, –25 °C, + 5 °C, + 55 °C, + 85 °C in general

5 Core Constant

Descriptions will be given to the relation between permeability, and inductance and impedance, however, knowledge about the core constant is needed beforehand.

When calculating electric circuit values (L, R, Z, i, v) from magnetic materials values (μ, B, H), a cross-section area A (the area where the magnetic flux passes) and a magnetic path length l (the distance in which the flux flows) of the core need to be calculated. As for the core in actual use, it is necessary to obtain an effective cross-sectional area A_e, and an effective magnetic path length l_e in consideration of such a factor as the difference in cross-sectional area for each part of the core. In the catalog of ferrite cores, these A_e and l_e are described. These values are available and they can be calculated as follows.

$$C_1 = \sum \frac{l}{A} \quad \text{...[formula (4)]}$$

$$C_2 = \sum \frac{l}{A^2} \quad \text{.......................................[formula (5)]}$$

$$A_e = \frac{C_1}{C_2} \quad \text{..[formula (6)]}$$

$$l_e = \frac{C_1^{\ 2}}{C_2} \quad \text{..[formula (7)]}$$

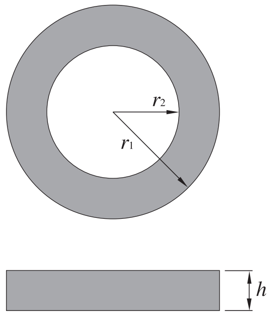
where,

C_1, C_2: core constant

Even for a core with a complicated shape we can calculate an effective cross-sectional area A_e and an effective magnetic path length l_e of the entire core in consideration of dividing each part of the core to totalize the cross-sectional area A and magnetic path length l by formulas (4) and (5).

In the case of a ring-shaped core, A_e and l_e can be calculated by the following formulas.

Figure 6 Dimensional Drawing of a Ring Core



$$C_1 = \frac{2\pi}{h \ln \frac{r_1}{r_2}} \quad \text{.......................................[formula (8)]}$$

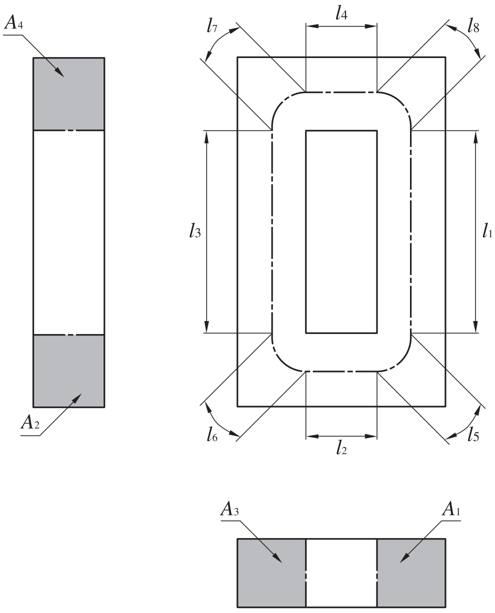
$$C_2 = \frac{2\pi \left(\frac{1}{r_2} - \frac{1}{r_1} \right)}{h^2 \left(\ln \frac{r_1}{r_2} \right)^3} \quad \text{..........................[formula (9)]}$$

$$A_e = \frac{C_1}{C_2}$$

$$l_e = \frac{C_1^{\ 2}}{C_2}$$

In the case of a rectangular (picture frame shape) core, the next formula can be used.

Figure 7 Dimensional Drawing of Rectangular (Picture Frame Shape) Core



In Figure 7,

$$C_1 = \sum_{i=1}^{8} \frac{l_i}{A_i}$$

$$C_2 = \sum_{i=1}^{8} \frac{l_i}{A_i^2}$$

However,

$$A_5 = \frac{A_1 + A_2}{2}$$

$$A_6 = \frac{A_2 + A_3}{2}$$

$$A_7 = \frac{A_3 + A_4}{2}$$

$$A_8 = \frac{A_4 + A_5}{2}$$

6 Permeability and Inductance

A relation between permeability and inductance is given by the following formula.

$$\mu = \frac{l_e}{\mu_0 A_e N^2} \times L_{\text{measured}} \text{ ....[formula (10)]}$$

where,

A_e : effective cross-sectional area (m^2)

l_e : effective magnetic path length (m)

μ_0 : permeability in vacuum = 4π×10^{-7} (H/m)

N : Number of turns of measurement coil

$L_{measured}$: measurement inductance (H)

The magnetic field intensity H applied to the core (or flux density B) can be decided by the current flowing through the measurement coil (or the voltage across the coil).

A relation between the current i flowing through the coil and the magnetic field intensity H is given by the following formula.

$$H = \frac{Ni}{l_e} \text{ ....[formula (11)]}$$

where,

l_e : effective magnetic path length (m)

N: Number of turns of measurement coil

i : electric current flowing through measurement coil (A)

Beware that H is in proportion to i. When applying an alternating magnetic field to a core, the magnetic field intensity to be applied is usually represented by a zero-to-peak value. Accordingly, the current also has to use $I_{0\text{–}P}$ value. For example, current values displayed in such devices as an LCR meter are an effective value, therefore, in order to obtain $I_{0\text{–}P}$, it is necessary to multiply by $\sqrt{2}$ (when the applied alternating magnetic field is a sinusoidal wave).

A relation between the voltage e across a coil and the flux density B is given by the formula as follows.

$$B = -\frac{1}{NA_e} \int e\,dt \text{ ....[formula (12)]}$$

where,

A_e: effective cross-sectional area (m^2)

N : Number of turns of measurement coil

e : voltage across a measurement coil (V)

When an alternating magnetic flux flows in the core, magnetic flux B is usually represented by a zero-peak value as well as the magnetic field intensity H. In this case, however, since flux density is an integral of voltage, it is necessary to calculate an integral value of voltage. When the voltage is sinusoidal, the following formula can be used for calculation.

$$B = \frac{V_{rms}}{4.44\, fNA_e} \text{ ....[formula (13)]}$$

where,

A_e : effective cross-sectional area (m^2)

N : Number of turns of measurement coil

f : frequency (Hz)

V_{rms} : effective voltage across measurement coil (V)

Initial permeability μ_i is permeability of a minute excitation level. At which level the measurement is performed is specified in the standard (IEC 60401-3 and JIS-C-2560-1)(B<0.5 mT). In the measurement, output of the LCR meter is adjusted so as to be a specified excitation level.

7 Complex Permeability and Impedance

Winding and excitation by the alternative current cause core loss in actual magnetic materials. In terms of an electric circuit, L-element is connected with R-element in series, the impedance being represented by $R + j\omega L$. This relation will be applied to permeability and such complex permeability is considered as follows.

$$\dot{\mu} = \mu' - j\mu'' \text{ ....[formula (14)]}$$

In this formula, μ' is a real part, denoting an inductance component, and μ'' is an imaginary part, denoting a resistance component, respectively. μ' is the same as permeability explained in the section 6 "Permeability and Inductance". $|\dot{\mu}|$, μ', and μ'' can be obtained by formulas as follows.

$$|\dot{\mu}| = \frac{l_e}{\mu_0 A_e N^2} \times \frac{|\dot{Z}_{measured}|}{2\pi f} \quad \text{.......................[formula (15)]}$$

$$\mu' = \frac{l_e}{\mu_0 A_e N^2} \times L_{measured} \quad \text{............................[formula (16)]}$$

$$\mu'' = \frac{l_e}{\mu_0 A_e N^2} \times \frac{R_{measured}}{2\pi f} \quad \text{........................[formula (17)]}$$

where,

A_e: effective cross-sectional area (m^2)
l_e : effective magnetic path length (m)
μ_0: permeability in vacuum = $4\pi \times 10^{-7}$ (H/m)
N: Number of turns of measurement coil
f : frequency (Hz)
$|\dot{Z}_{measured}|$: measurement impedance (Ω)
$L_{measured}$: measurement inductance (H)
$R_{measured}$: measurement resistance (Ω)

Then, tangent $\tan\delta$ of a loss angle is represented by formula (18), therefore, a relation of formula (19) exists between the real and the imaginary parts of the complex permeability and $\tan\delta$.

$$\tan\delta = \frac{R_{measured}}{2\pi f L_{measured}} = \frac{1}{Q} \quad \text{.........................[formula (18)]}$$

$$\tan\delta = \frac{\mu''}{\mu'} \quad \text{..[formula (19)]}$$

This $\tan\delta$ is called a loss factor, representing a loss of magnetic materials. A relative loss factor $\tan\delta/\mu_i$ is obtained by dividing $\tan\delta$ by μ_i, being used as an index representing the loss of magnetic materials, as well.

$$\tan\delta/\mu_i = \frac{\tan\delta}{\mu'_i} = \frac{\mu''_i}{{\mu'_i}^2} \quad \text{.............................[formula (20)]}$$

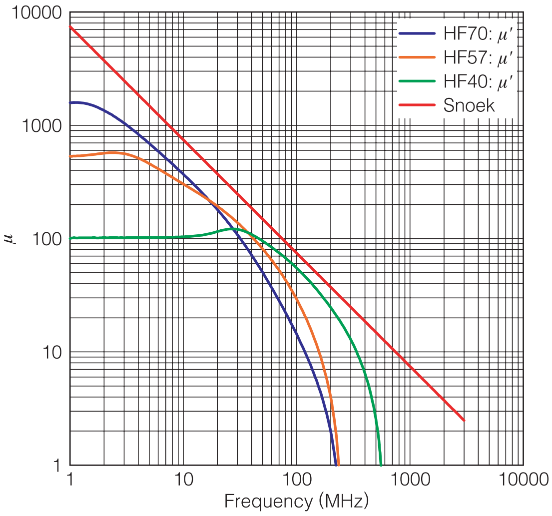
8 Frequency Characteristics of Permeability and Snoek's Limit

The permeability of ferrite remains constant up to a certain frequency. When the frequency becomes high, however, B can not follow the change in H, causing a phase lag. Because of this, L-component (μ') begins to decrease and R-component (μ'') begins to increase.

Then, ferrite exhibits a phenomenon that the higher the permeability of the material, the earlier μ' drops. This is called Snoek's limit. It is desirable that ferrite material having high permeability be used for a high frequency. However, because of the Snoek's limit, ferrite materials have to be selectively used according to the frequency range in use.

Figure 8 shows frequency characteristics of initial permeability of ferrite materials having different initial permeability and Snoek's limit line. In consideration of noise removal, however, this phenomenon is not always wrong, which will be described later.

Figure 8 Frequency Characteristics of Ferrite μ_i and Snoek's Limit



9 Kinds of Ferrite

The chemical formula of ferrite is $MO \cdot Fe_2O_3$, where M denotes a divalent metal ion. Metal ions such as Fe, Mn, Zn, Ni, Mg, Co, and Cu can be substituted for M and ferrite materials having a variety of characteristics are obtained based on the kinds and ratios of the metal ions. Mn-Zn ferrite and Ni-Zn ferrite are typical ferrite materials.

Mn-Zn ferrite has excellent magneto-electrical characteristics because μ_i and Bs are high and the core loss is low.

On the other hand, since low specific resistance (volume resistance) is a weak point, direct winding to the core is not possible but an insulative bobbin or case has to be interposed, resulting in a large shape. Because of high permeability, usable frequency is limited about 1 MHz or less due to Snoek's limit, therefore, as a noise countermeasure Mn-Zn ferrite is used for a common mode line filter choke of a power source line.

Compared with Mn-Zn ferrite, Ni-Zn ferrite has low μ_i and Bs, having a large core loss, however, specific resistance is high and almost regarded as an insulator. Accordingly, direct winding on the core is possible and no bobbin is required. Ni-Zn ferrite is used for small coils and chip inductors, and for noise countermeasures being frequently used for bead core and clamp filters (refer to Figure 9).

10 Characteristics of Ferrite Material for Noise Countermeasures

Tables 1 and 2 show a characteristic table of noise-countermeasure ferrite material by TDK. Ferrite materials of Table 1 are mainly Ni-Zn series, being used for round-type cables (including bead core), flat cables, and connectors (refer to Figure 10). Ferrite materials of Table 2 are mainly Mn-Zn series, being used for common mode chokes (refer to Figure 11).

Figure 9 Characteristics of Mn-Zn and Ni-Zn Ferrite

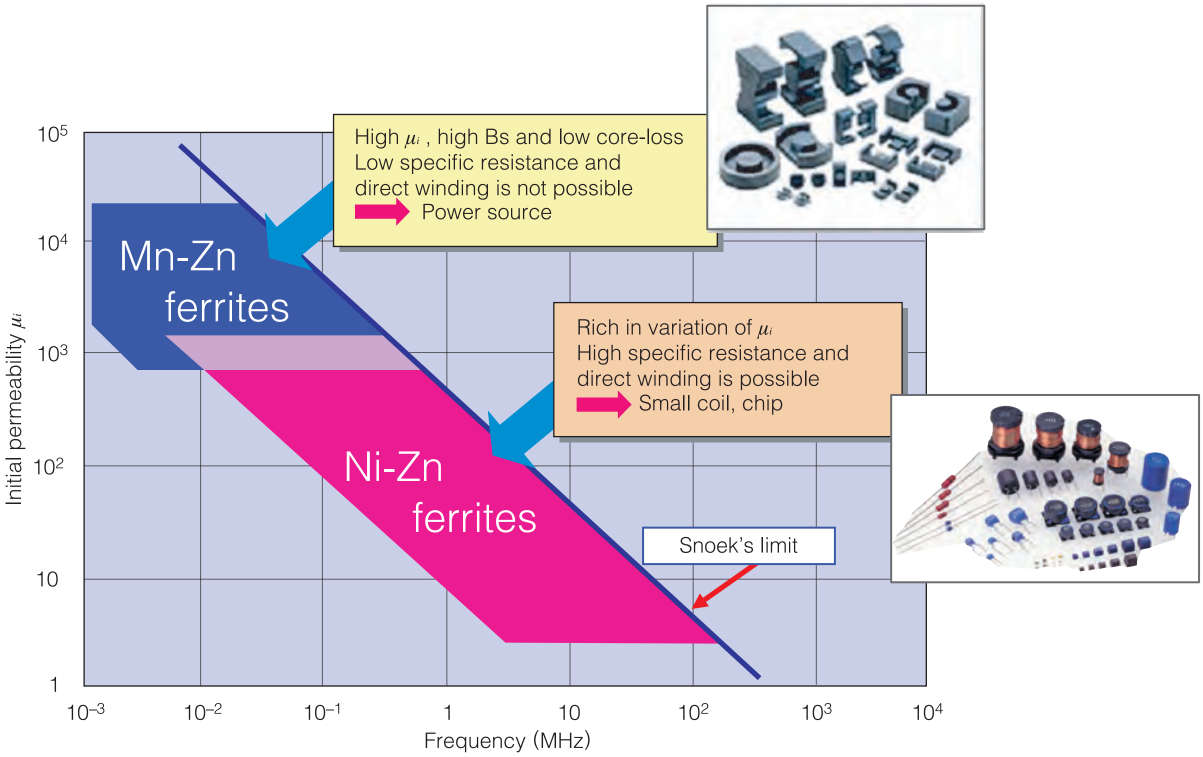


Table 1 Material Characteristics of Noise-Countermeasure Ferrite (round-type and flat cables, and connector)

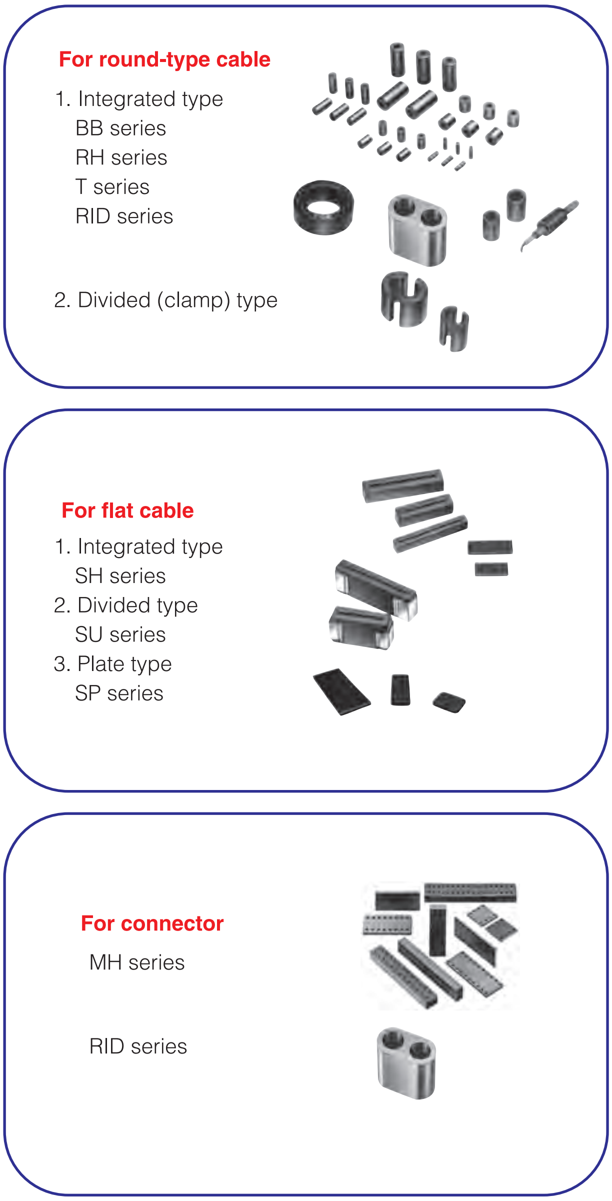
Material name		**HF90**	**HF70**	**HF57**	**HF40**	**HF30**
Material series		Mn-Zn	Ni-Zn	Ni-Zn	Ni-Zn	Ni-Zn
Initial permeability	μ_i	5000	1500	600	120	45
Relative temperature coefficient	α_i (x 10^{-6}/°C)		1~3	3~5	8~18	5~15
Curie temperature	T_c (°C)	> 180	> 100	> 180	> 250	> 300
Saturation flux density	B_s (mT)	480	280	400	410	320
Volume resistivity	ρ (Ω·m)	0.3	10^5	10^5	10^5	10^5
Density	d_b (x10^3kg/m^3)	4.8	5.0	5.0	5.0	5.0
Applied frequency*		~ 1 MHz	~ 500 MHz	~ 500 MHz	~ 600 MHz	~ 1 GHz
Main countermeasure usages		Noise terminal voltage Noise voltage	Radiation noise Noise terminal voltage Noise voltage	Radiation noise	Radiation noise	Radiation noise

*:Frequency band to be applied is a rough estimation

Table 2 Material Characteristics of Noise-Countermeasure Ferrite (for common mode choke)

Material name		**HS52**	**HS72**	**HS10**
Material series		Mn-Zn	Mn-Zn	Mn-Zn
Initial permeability	μ_i	5500	7500	10000
Curie temperature	T_c (°C)	> 130	> 130	> 120
Saturation flux density	B_s (mT)	410	410	380
Volume resistivity	ρ (Ω·m)	1	0.2	0.2
Density	d_b (x10^3kg/m^3)	4.9	4.9	4.9
Main countermeasure usages		Common mode choke	Common mode choke	Common mode choke

Figure 10 Core Shape for Round-type and Flat Cables, and Connector



For round-type cable

1. Integrated type
   - BB series
   - RH series
   - T series
   - RID series
2. Divided (clamp) type

For flat cable

1. Integrated type
   - SH series
2. Divided type
   - SU series
3. Plate type
   - SP series

For connector

MH series

RID series

Figure 11 Common Mode Choke Core Configuration

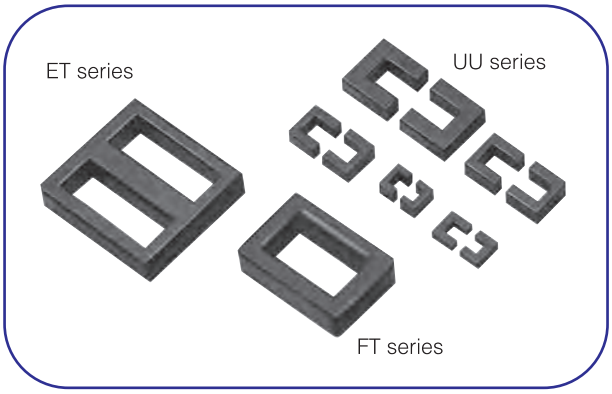


Figure 12 shows frequency characteristics of μ' and μ'' of materials cited in Table 1.

Pay attention that μ'' attains a peak value near the frequency at which μ' begins to fall for all characteristics.

Figure 12-1 Frequency Characteristics of μ HF90 Materials

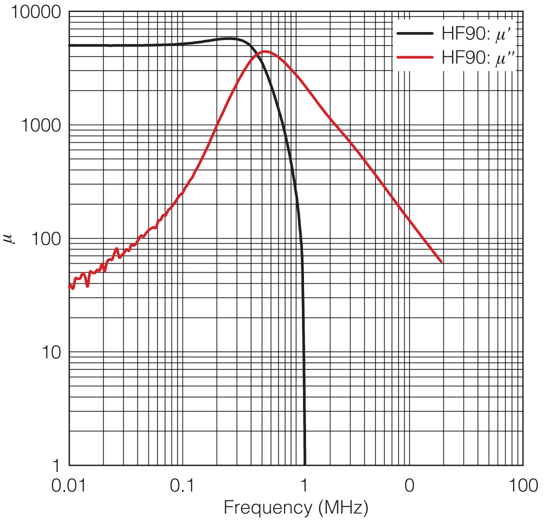
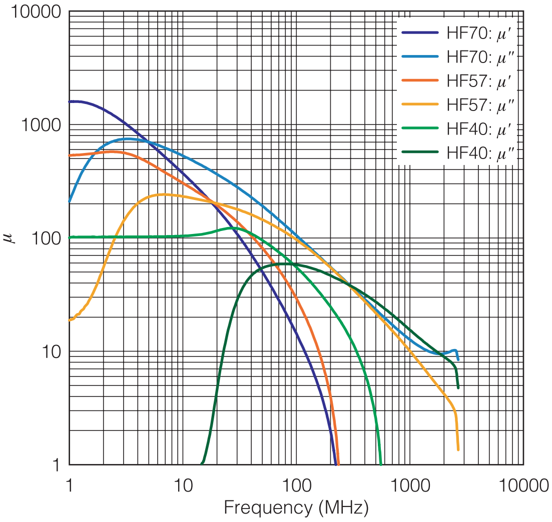


Figure 12-2 Frequency Characteristics of μ HF40, 57, 70 Materials



11 Principle of Noise Countermeasures by Ferrite

Ferrite cores are used for a variety of noise countermeasures, being largely classified into such categories as:

1. inductance element for configuring a filter,
2. to cut off noises by impedance,
3. to absorb noises (transform into heat) by R-component, and
4. shielding.

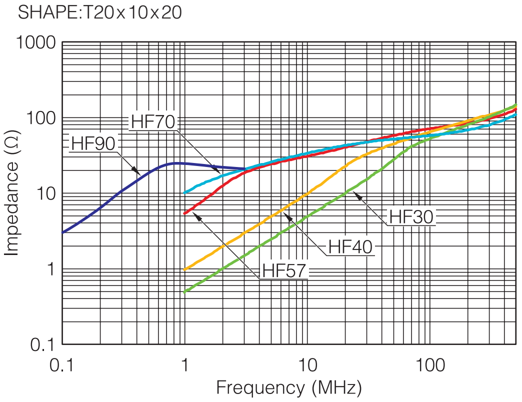
When using the ferrite core as the inductance element, it is used as an L-component. Therefore, it is important to use the ferrite material in a frequency band where μ' does not decrease.

Noise countermeasure ferrite cores are most commonly used to cut off noises by impedance. In this case, to select a ferrite material, a core configuration, and the number of turns is important, so as to acquire impedance large enough to obtain a sufficient noise prevention effect in the frequency band of noises to be prevented.

Frequency characteristics of impedance by each material and shape are described for your reference in the catalog. The catalog is downloadable from the URL as follows.

http://www.tdk.co.jp/tefe02/emc.htm

Figure 13 Frequency Characteristics of Impedance Described in the Catalog



Noises are blocked by impedance, however, it should be noted that since reflection occurs at the edge of the impedance element, noises will not disappear.

A usage to absorb noises by R-component is similar to the usage to block noises by the above-mentioned impedance. The difference is that a μ'' component is positively used instead of a μ' component. As explained before, since μ" is an R-component, when using ferrite in a frequency band where μ" is high, noises can be transformed into heat by R to be absorbed without reflecting noises.

A small ring core called a bead core is a typical product for this type of usage. Ferrite for a radio wave absorber also utilizes this principle. Figure 14-1 shows frequency characteristics of R, X, and |Z| of the beads core. While in the low frequency region, reactance X is dominant and noises are reflected, when the frequency gets higher, X intersects R at a certain frequency. After the reversal, R becomes dominant. In order to absorb noises, it is necessary to select the frequency band where R becomes dominant. The frequency at which X and R intersect depends on the ferrite materials.

Figure 14-1 Frequency Characteristics of Beads Core

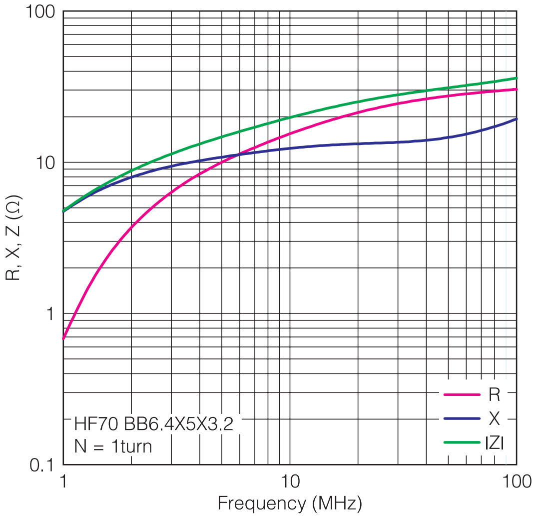
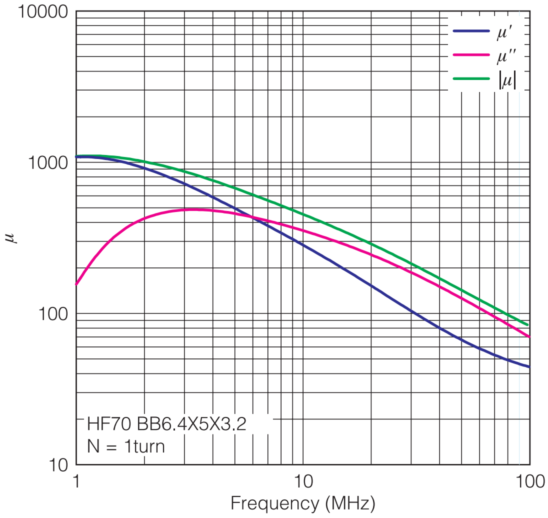


Figure 14-2 shows frequency characteristics of μ', μ'', and $|\mu|$ calculated from impedance characteristics of the bead core. The above mentioned formulas (15), (16), and (17) are used. It will be understood from these formulas and the graph that there are relations between μ' and L(X), μ'' and R, and $|\mu|$ and | Z |, respectively.

Figure 14-2 Frequency Characteristics of μ Beads Core



Accordingly, in order to select a ferrite material suitable for the frequency band to absorb noises, the material may be selected so that μ'' becomes high at the frequency to absorb noises in the graph of Figure 12.

Using ferrite as a shield takes advantage of a principle that fluxes flowing in the space are guided into the ferrite because of the high permeability of the ferrite. As explained in the above, permeability expresses how easily fluxes flow compared with the air. Some ferrite material exhibits high permeability, from as high as several thousands to several tens of thousands, making them suitable for use as a shield.

In that case, μ' becomes important. It is necessary to select a material having μ' as high as possible at the frequency of the noise to be shielded.

Beware that when shielding using ferrite, the flux by the noise only changes paths dependent on the ferrite but does not disappear. Therefore, when a component easily subjected to noises is located near a noise source, a ferrite plate is attached to the side of the component to avoid the concentration of noises.

Although not really needed, descriptions will be given for a method of shielding without using ferrite. It is shielding by conductors in the form of a metal shielding case. The metal must not be composed of magnetic materials.

When an alternating magnetic flux intersects with a metal, an eddy current flows in the metal and generates a magnetic flux in the direction needed to cancel the alternating magnetic flux. Because of the magnetic flux, the alternating flux is cancelled and disappears. Accordingly, in order to prevent flux caused by noises from going outside, it is effective to attach a metal plate near the noise source or to surround it by a metal case.

However, the eddy current is generated at a relatively higher frequency and the generated frequency depends on the conductivity and thickness of the conductor, therefore, it is necessary to know them in advance. In some cases, no eddy current is generated by a magnetic flux of low frequency. In such a case, a further effect may be obtained in combination with shielding by permeability.

Low-ESL Multilayer Ceramic Capacitors

TDK Corporation Capacitors Business Group
Masaaki Togashi

1 Effects of ESL

Decoupling capacitors or bypass capacitors are connected near power supply terminals of LSI (large-scale integration) circuits, and they supply the RF current necessary for operation. In many cases, multilayer ceramic capacitors (MLCCs) are used; however, since the operating frequencies of LSI circuits are getting higher, general-purpose MLCCs are becoming inadequate, since ESL (equivalent series inductance), a parasitic element of capacitors, affects the current supply capacity in high frequency regions (Figure 1). A pulse transient current is generated at the power source of an LSI circuit as it operates. A pulse current is high-frequency and wide-ranging, as it contains the operating frequency of the circuit and its harmonic components. If the ESL of a capacitor is large, much of the high-frequency current discharged from the capacitor will be reflected by ESL, and an insufficient high-frequency current will be conducted through the power supply or GND line, and will cause voltage fluctuations, generating logic errors or becoming common mode noise that is discharged outside the device, and will cause electromagnetic interference.

In order to suppress noise and to stabilize operations in an LSI circuit that operates at a high frequency, a capacitor with a low ESL is suitable. In this chapter, a low-ESL MLCC will be introduced.

Figure 1 Decoupling Capacitor

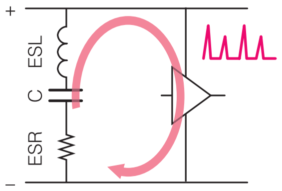


Figure 2 Low-ESL MLCCs

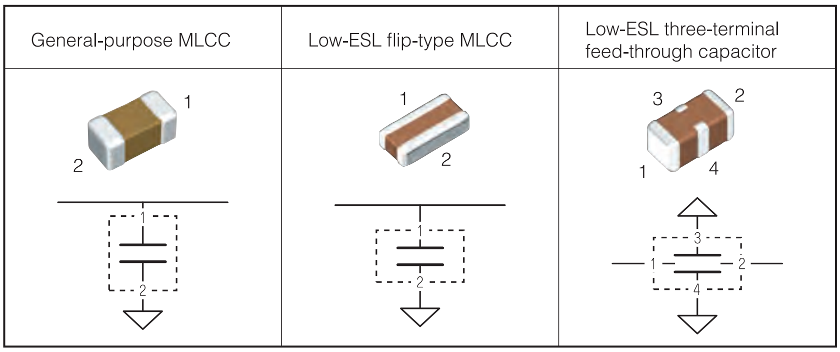
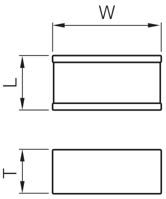


Table 1 Product Lineup of Flip-Type MLCCs

Type [EIA standard]	Dimensions (mm) L×W×T max.	Temperature characteristics	Rated voltage (V)	Capacitance (μF) 0.01 0.1 1 10
C0510 [0204]	0.5×1.0×0.35	X6S	4	0.22μF
		X7S	4	
C0816 [0306]	0.8×1.6×0.6	X7R	16	0.1μF
		X7R	6.3	0.22μF
		X7S	4	2.2μF
	0.8×1.6×0.35	X6S	4	0.47μF



2 | Low-ESL Multilayer Ceramic Capacitor

Flip (LW reverse) Type

By reversing the length and width dimensions of an MLCC, inductance of the internal conductor is reduced. The product lineup (Table 1) and frequency characteristics (Figure 3) are shown. Since characteristics that are equivalent to those of four general-purpose products mounted in parallel can be achieved, a reduction in the number of parts or mounting space will become possible. Additionally, products with a thickness of 0.3 mm have been made available as low-profile products.

A C0816 (0.8 × 1.6 mm) type product with a thickness of 0.35 mm (max.) is shown in Figure 4. These low-profile type products are effective for application as decoupling capacitors in ball grid array (BGA) packaging, as well as in low-profile electronic devices.

Figure 3 Frequency Characteristics of a Flip-Type Capacitor

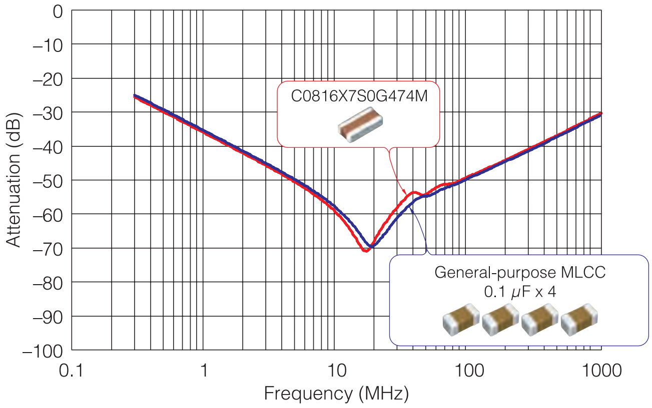


Figure 4 Low-Profile (t = 0.35 mm max.) Flip-Type Capacitor

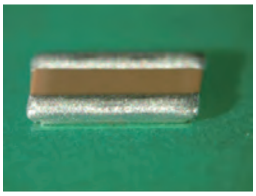
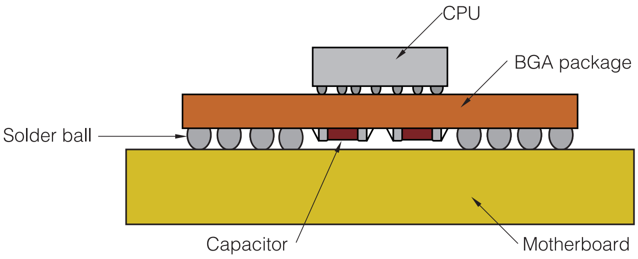


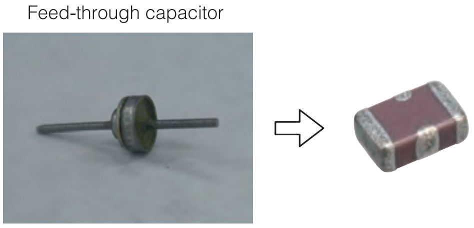
Figure 5 Applications Example of Low-Profile Flip-Type Capacitors



Three-Terminal Feed-Through Multilayer Ceramic Capacitors

The structure of a feed-through type capacitor was applied to MLCCs to reduce ESL (Figure 6). Three-terminal feed-through type products have smaller ESL and superior noise removal performance, compared to flip-type products, and are capable of reducing multiple noise suppression components.

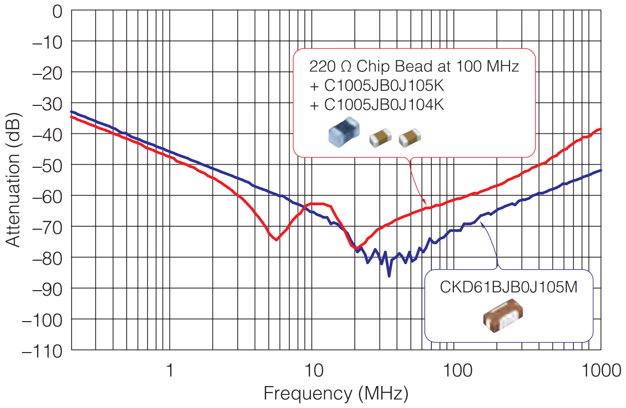
Figure 6 Feed-Through Capacitor and Three-Terminal Feed-Through MLCC



The attenuation characteristics of one CKD610JB0J105M element and of three elements: a 220 Ω chip bead, a 1 μF MLCC and a 0.1 μF MLCC, are shown in Figure7.

The figure indicates that the CKD610JB0J105M shows higher attenuation characteristics at frequencies over 30 MHz.

Figure 7 Frequency Characteristics of a Three-Terminal Feed-Through MLCC



An example of noise reduction effects is shown in Figure 8. A gate IC was driven at 40 MHz, and noise was superimposed on the power line, and the noise reduction effects were observed and compared when a single CKD610JB0J105M was used and when three elements, consisting of a 220 Ω chip bead, a 1 μF MLCC and a 0.1 μF MLCC, were used.

It was shown that a greater noise reduction effect was obtained when the CKD610JB0J105M was used. The product lineup of the three-terminal feed-through type capacitor is shown in Table. 2. A 22 μF large capacitance product is available, which is effective for application in output filters for switching regulators or as decoupling capacitors of high-power LSI circuits.

Figure 8 Example of Effects of a Three-Terminal Feed-Through Capacitor

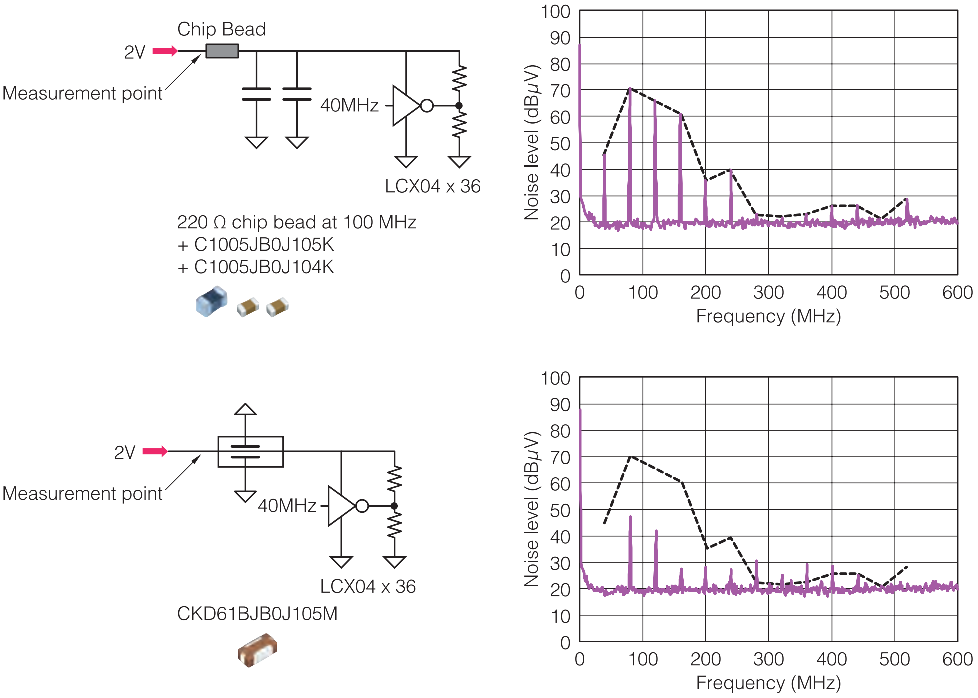
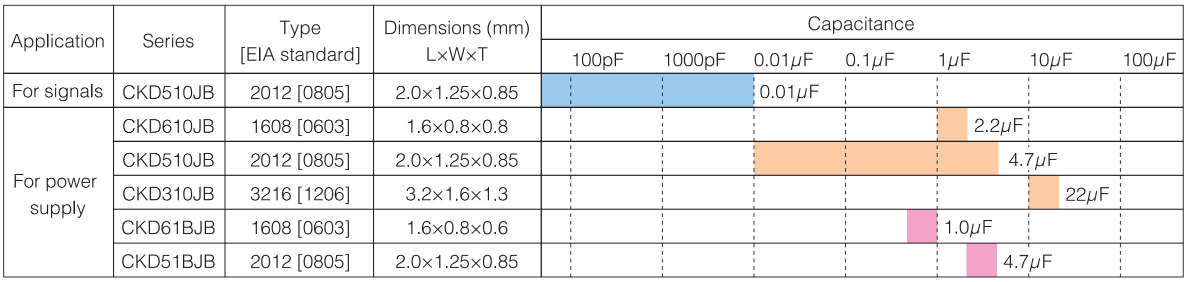
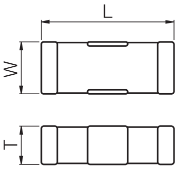


Table 2 Product Lineup of Three-terminal Feed-through MLCCs



Application	Series	Type [EIA standard]	Dimensions (mm) L×W×T	Capacitance (100pF, 1000pF, 0.01μF, 0.1μF, 1μF, 10μF, 100μF)
For signals	CKD510JB	2012 [0805]	2.0×1.25×0.85	0.01μF
For power supply	CKD610JB	1608 [0603]	1.6×0.8×0.8	2.2μF
	CKD510JB	2012 [0805]	2.0×1.25×0.85	4.7μF
	CKD310JB	3216 [1206]	3.2×1.6×1.3	22μF
	CKD61BJB	1608 [0603]	1.6×0.8×0.6	1.0μF
	CKD51BJB	2012 [0805]	2.0×1.25×0.85	4.7μF



ESR Control Multilayer Ceramic Capacitors

TDK Corporation Capacitors Business Group
Masaaki Togashi

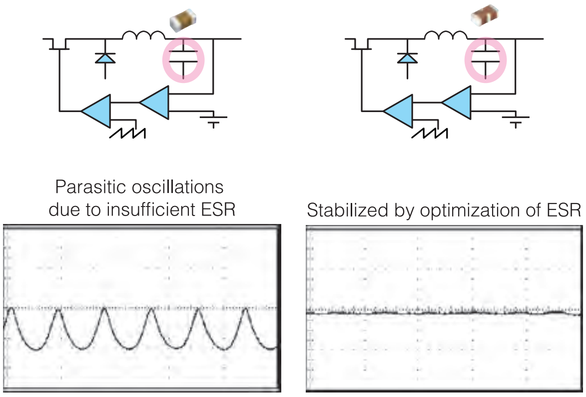
1 Product Overview

Conventional multilayer ceramic chip capacitors (MLCCs) possess some negative effects, due to their small ESR (equivalent series resistance) (Figure 1).

For instance, when MLCCs are used for output decoupling of switching power sources, deterioration of responsiveness or parasitic oscillations will easily occur due to phase delay of the feedback circuit, although they exert a good ripple rejection effect. For this reason, there is a need to perform phase compensation using complicated circuit networks, which in turn requires more components.

Figure 1 Negative Effects of Insufficient ESR

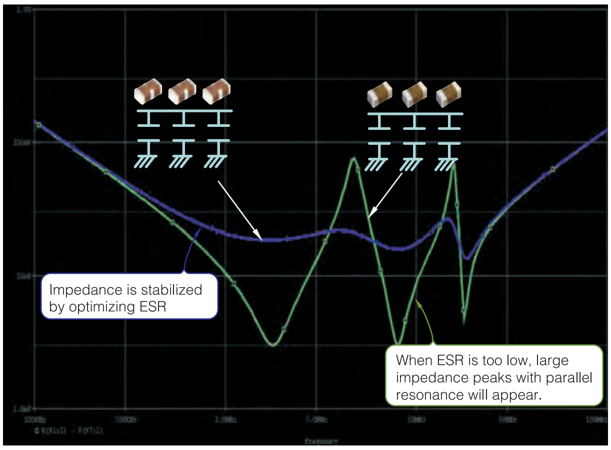
Decoupling of a switching power source



Parasitic oscillations due to insufficient ESR

Stabilized by optimization of ESR

Decoupling of a circuit with large current / low voltage



Impedance is stabilized by optimizing ESR

When ESR is too low, large impedance peaks with parallel resonance will appear.

In addition, insufficient ESR has a negative effect on decoupling capacitors of CPUs, which operate at low voltages and large currents. Multiple capacitors with different self-resonant frequencies (SFRs) are used for CPU decoupling circuits to achieve low impedance over a wide frequency band and to control voltage variations in response to high frequency currents. When the ESR of a capacitor is extremely low, a strong impedance peak occurs due to parallel resonance between capacitors. When a high-frequency current flows that is equivalent to that of the frequency, the power supply voltage can change suddenly, causing malfunctions.

In order to resolve problems such as the above, these products have adopted a newly-developed electrode structure that allows for arbitrary ESR design while maintaining long life and high integrity, which are characteristics of ceramic capacitors. These products allow for the selection of ESR values that are suitable for each application.

In a switching power source, the compensation circuit can be simplified and operations can be stabilized without increasing ripple voltage by moderately increasing the ESR of the MLCC. In a decoupling capacitor for a CPU, flatter impedance characteristics, which suppress voltage fluctuations of the CPU, can be realized by optimizing the ESR.

2 Electrical Characteristics

The equivalent circuits and electrical characteristics of the products are shown in Figure 2 and Figure 3. At present, the 1608 and 2012 type products are commercially available. The capacitance of the 1608 type product is a maximum of 1 μF, and the capacitance of the 2012 type product is 10 μF. A dielectric material with X5R temperature characteristics (±15% at –25 to +85°C) is used for both of them.

Figure 2 Structure and Equivalent Circuit

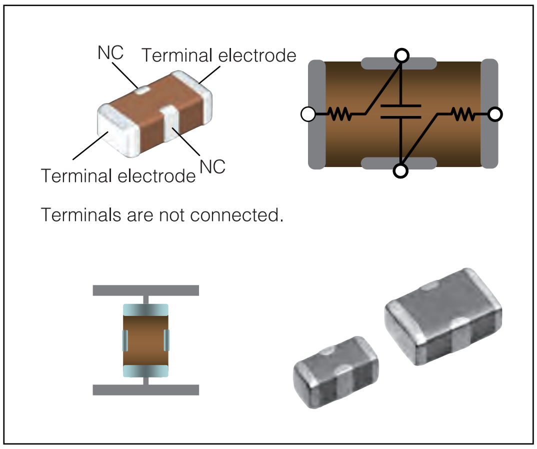
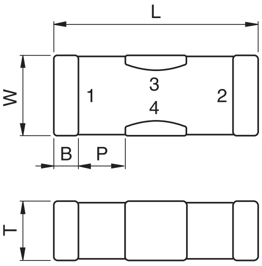
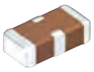


Figure 3 External Appearance, Dimensions, and Electrical Characteristics



Type	CERB (1608)	CERD (2012)
L	1.60±0.20 mm	2.00±0.20 mm
W	0.80±0.10 mm	1.25±0.20 mm
T	0.80±0.10 mm	0.85±0.15 mm
B	0.10 mm min.	0.30±0.20 mm
P	0.20 mm min.	0.20 mm min.

CERB = 1608
CERD = 2012



Electrical characteristics

Part No.	CERB□□*X5R0G105M	CERD□□ *X5R0G106M
Capacitance	1μF	10 μF
Capacitance tolerance	±20%	±20 %
D.F.	10% max.	10 % max.
Insulation resistance	100 MΩ min.	10 MΩ min.
Rated voltage	DC 4.0 V (0G)	DC 4.0V (0G)
Temperature characteristics	X5R (±15%)	X5R (±15%)
Temperature ranges	–55 to +85 °C	–55 to +85 °C
ESR	10 to 1200 mΩ	10 to 500 mΩ

*□□ in the product names are the ESR codes.

The impedance frequency characteristics are shown in Figure 4 and Figure 5. The CERD1CX5R0G106M, CERD1JX5R0G106M and CERD2AX5R0G106M are 2012 type products with a capacitance of 10 μF and ESR values of 20 mΩ, 50 mΩ and 100 mΩ respectively. The CERB2CX5R0G105M, CERB2MX5R0G105M and CERB3UX5R0G105M are 1608 type products, with a capacitance of 1 μF and ESR values of 200 mΩ, 650 mΩ and 1200 mΩ respectively.

These products make it possible to design ESR values at predetermined values, since their ESL (equivalent series inductance) has a smaller increase than existing MLCCs. By selecting optimum ESR values according to application, it will be possible to improve electrical characteristics, reduce mounting space, and increase reliability.

Figure 4 Impedance Frequency Characteristics

CERB series

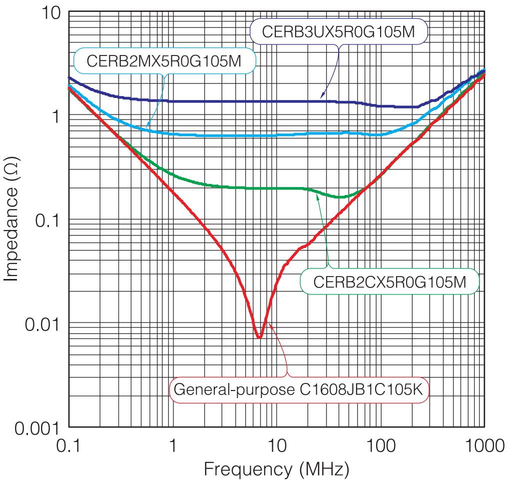
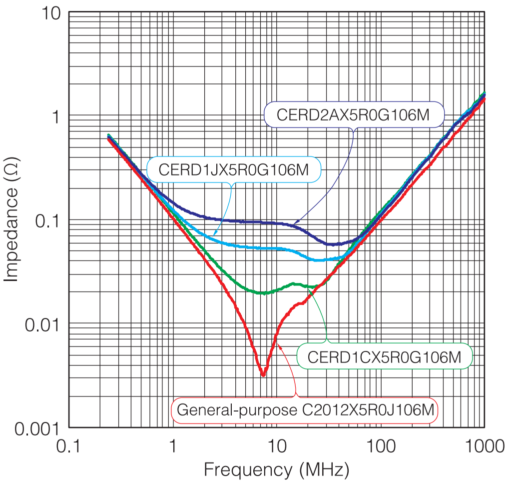


Figure 5 Impedance Frequency Characteristics

CERD series



3 Example of Effects of the Products

As an example of the effects of the products, the power circuit and decoupling capacitors of a CPU were converted into equivalent circuits, and the source impedance and voltage fluctuation were simulated. Two conditions were provided for the decoupling capacitors; condition 1, under which the existing 2012 type MLCCs with a 10 μF capacitance and 1608 type MLCCs with a 1 μF capacitance (30 pieces of each) were used, and condition 2, under which CERD1FX5R0G106M ESL control MLCCs (2012 type/10 μF/ESR=35 mΩ) (30 pieces) were used , as is shown in Figure 6.

The results of the frequency analysis are shown in Figure 7. Under condition 1, a large impedance with anti-resonance appeared due to the small ESR. Under condition 2, no significant impedance peak was observed, and impedance characteristics were flatter, compared to those noticed under condition 1. Furthermore, a current variation of 30 A to 90 A at 370 kHz was provided under both conditions 1 and 2, and then the time axis of the power source voltage was analyzed. The simulation results are shown in Figure 8. The voltage fluctuation was smaller under condition 2, compared to that noticed under condition 1, showing that selecting ESR values optimum for the decoupling capacitors is effective for ensuring power integrity and reducing the number of parts.

Figure 6 Decoupling Capacitors Used in Simulations

Condition 1

	Capacitance / piece (μF)	ESR / piece (mΩ)	ESL / piece (pH)	Quantity (pieces)
Polymeric aluminum electrolytic capacitor	820	7	4000	8
2012 type / 10 μF	8	4.5	218	30
1608 type / 1 μF	0.8	9	258	30

Condition 2

	Capacitance / piece (μF)	ESR / piece (mΩ)	ESL / piece (pH)	Quantity (pieces)
Polymeric aluminum electrolytic capacitor	820	7	4000	8
CER1FX5R0G106M	8	35	210	30

Figure 7 Results of Frequency Characteristics Analysis

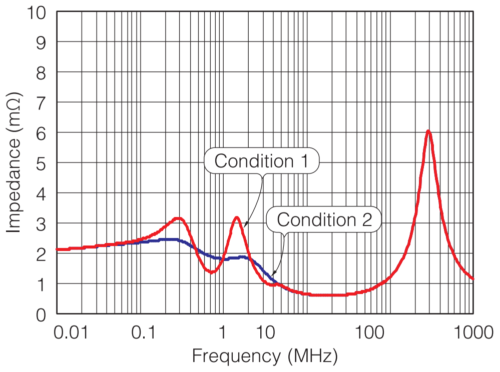
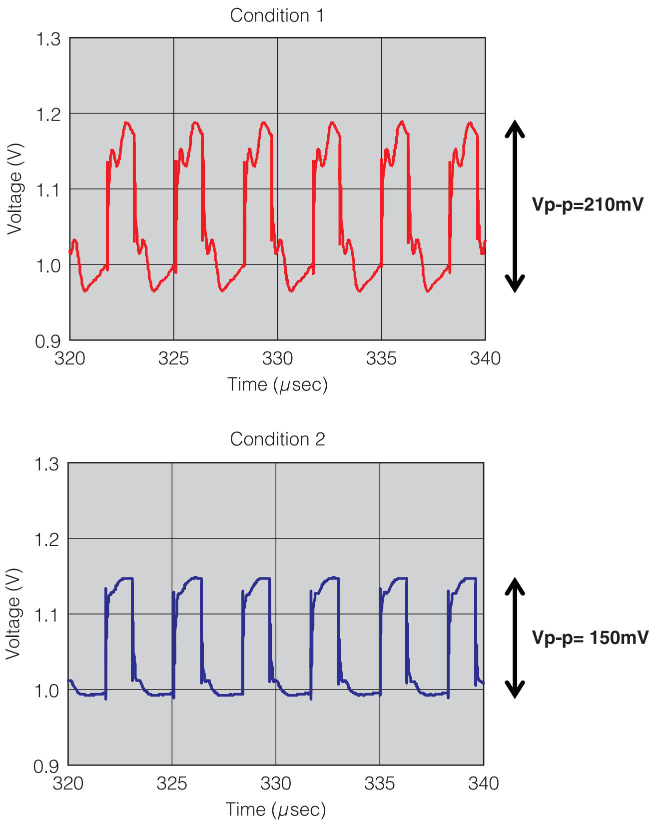


Figure 8 Results of Power Supply Voltage



Chip Beads that Reflect and Absorb Noise

TDK Corporation　Capacitors Business Group
Makoto Yoshino

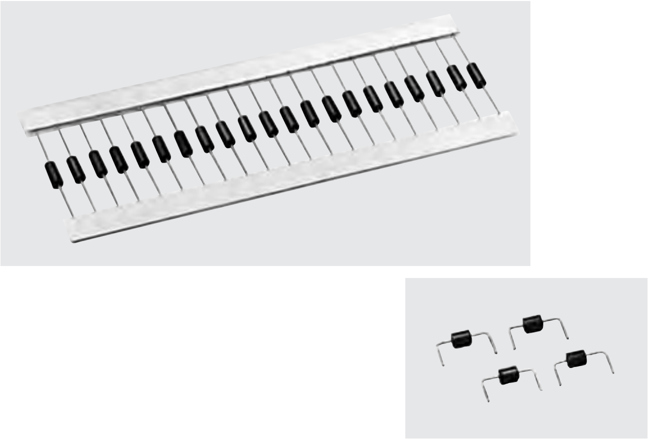
1 Chip Beads that Can Easily be Used by Series Insertion into Circuits

Chip beads can be used in either signal circuits or power supply circuits. They are convenient components, which exert effects as noise suppression measures by simply being inserted into circuits in series. Unlike bypass capacitors, they are not affected by the conditions of ground patterns.

As is shown in Photo 1, a chip bead has a structure in which a conductive wire is passed through a toroidal ferrite magnetic body. It is an inductance element with the simplest structure, in which a conductive wire is wound once around a toroidal core.

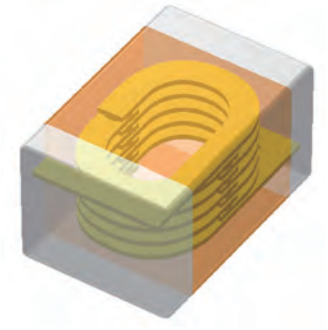
They are called “beads” since their appearance is similar to beads used for accessories such as necklaces.

Photo 1　External Appearance of General Chip Beads BH and BT Series



At present, multilayer chip beads, in which ferrite sheets or ferrite paste and conductive paste are layered, are commonly used. An image of the internal structure of a multilayer chip bead is shown in Figure 1. As is shown in the figure, the conductor forms a coil.

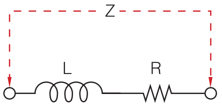
Figure 1　Diagram of the Internal Structure of a Multilayer Chip Bead-1



2 Different Though Having the Same Nominal Impedance

As is shown in Figure 2, the equivalent circuit of a chip bead is denoted by the reactance component X and the resistance component R, and its static characteristics are expressed by the frequency characteristics of the impedance Z, which is the combined impedance of X and R. Generally, the nominal value of the static characteristics of a chip bead is the impedance value at 100 MHz.

Figure 2　Equivalent Circuit of a Chip Bead



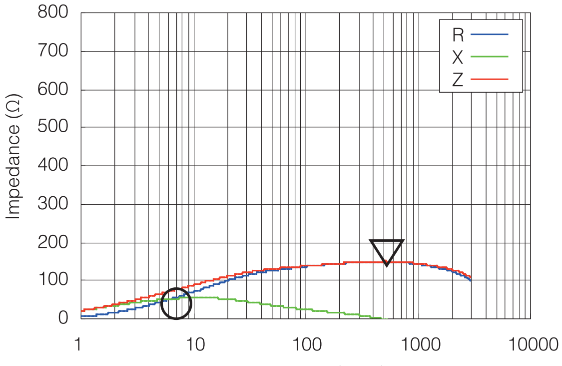
$X = \omega L = 2\pi fL$　f: Frequency

The impedance characteristics of five typical multilayer chip beads with different ferrite compositions are shown in Figure 3. Their impedance values at 100 MHz are approximately the same. Although their impedance values are the same, their frequency characteristics vary; therefore, it is necessary to select a bead that is suitable for the circuit to be used.

In addition, even among chip beads using ferrite bodies with a ferrite composition, some of them have different frequency characteristics depending on their internal conductor structures. The frequency characteristics of two chip beads are shown in Figure 4. The chip bead in Figure 4 (a) has the structure described in Figure 1, whereas the chip bead in Figure 4 (b) has the structure shown in Figure 5, causing the peak point of the impedance to become higher and to shift toward the high frequency side.

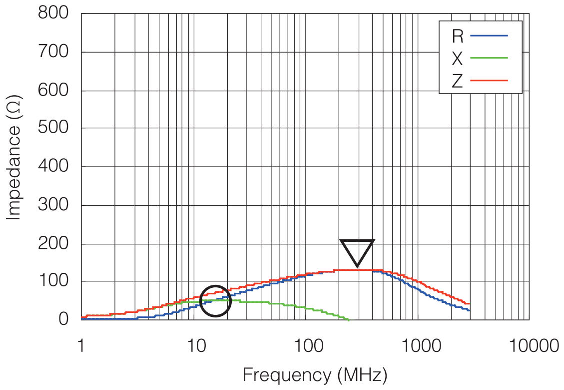
Figure 3　Comparison of Impedance Frequency Characteristics (Uniform impedance at 100 MHz)

(a) MMZ1608B121C

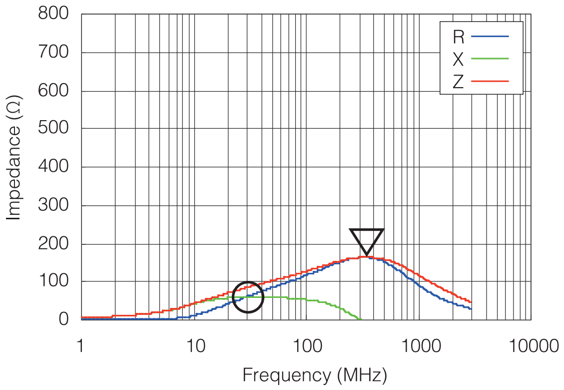


○ : Intersection of R and X
▽ : Peak point of R

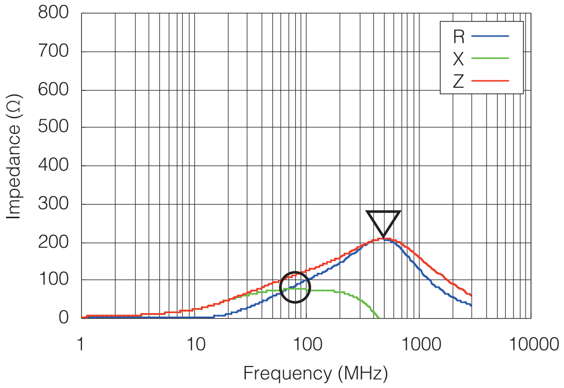
(b) MMZ1608R121A



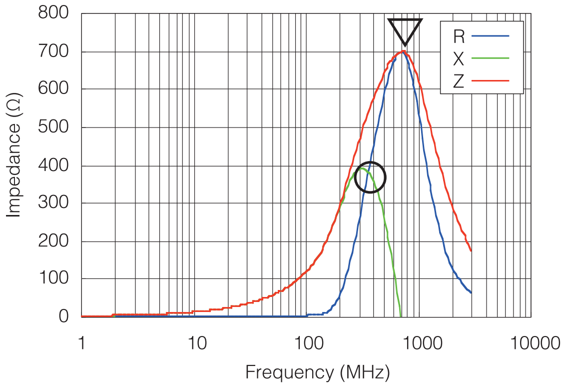
(c) MMZ1608S121A



(d) MMZ1608Y121B



(e) MMZ1608D121C

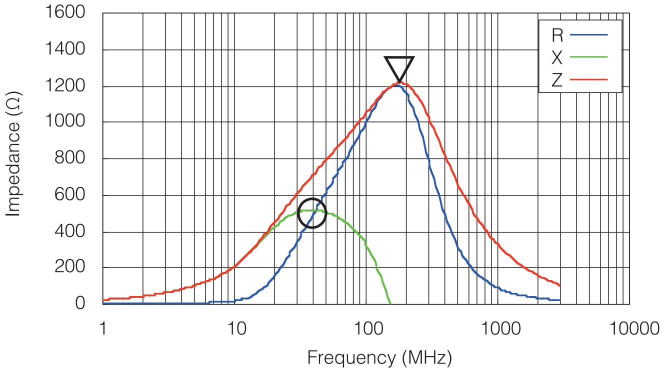


○ : Intersection of R and X

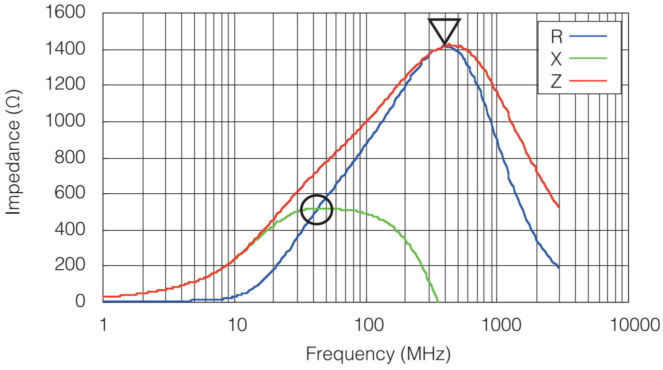
▽ : Peak point of R

Figure 4 Comparison of Impedance Frequency Characteristics (Uniform impedance at 100 MHz)

(a) MMZ1608R121A



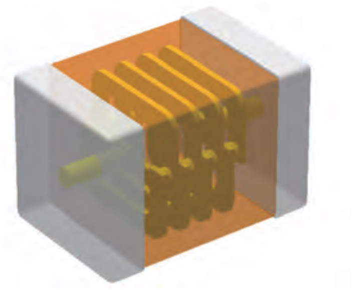
(b) MMZ1608R121A



○ : Intersection of R and X

▽ : Peak point of R

Figure 5 Diagram of the Internal Structure of a Multilayer Chip Bead-2



3 Reflection and Absorption

Let us look into the frequency characteristics of chip beads in a greater detail. The X component is dominant in the low frequency range, and the bead functions as an inductor that reflects noise. In the high frequency range, the R component becomes dominant, and the bead functions as resistance that converts noise into heat (absorbs noise). These functions switch at the frequency where the R component and X component become equal. This frequency is called the R – X cross point.

As the frequency becomes higher, the impedance becomes higher; however, when the frequency reaches a certain point, the impedance suddenly begins to decrease. This frequency is called the self-resonance frequency. Self-resonance is a phenomenon that occurs because the bead functions as a capacitor at frequencies higher than the self-resonance frequency. Based on these factors, in order to select a proper chip bead, the frequency of the noise that needs to be suppressed should be between the R – X cross point and the self-resonance frequency, and the impedance of the bead should be low at frequencies of signals that are necessary.

4 Additional Role of Chip Beads

Chip beads have an effect of improving pulse waveforms.

The effect of chip beads on pulse waveforms was examined using the test circuit shown in Figure 6. The five beads shown in Figure 3 were used in the test.

The test results are shown in Figure 7. As is clear in the figure, less ringing and waveform distortion were observed when the R – X cross point frequency of the beads was lower. Waveform distortion can become a cause for malfunctions of a digital circuit. Although it depends on the frequency of the digital circuit, using a chip bead that has as low R – X cross point as possible will lead to the prevention of malfunctions.

5 Consideration of DC Resistance Levels

DC resistance is another important characteristic. If DC resistance is high, the power consumption will become greater, and the signal levels will also decrease. It is desirable that DC resistance be as low as possible.

By selecting chip beads that are suitable for the circuits to be used based on an understanding of these characteristics, more effective EMC countermeasures will become possible.

Figure 6 Chip Bead Operation Test Circuit

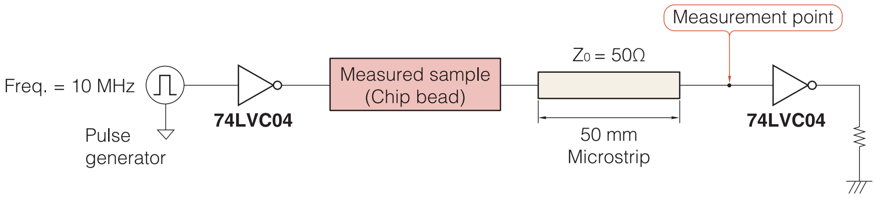
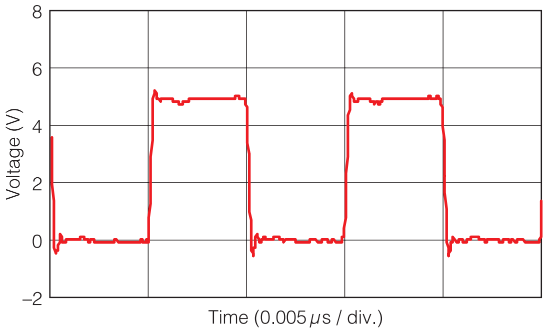
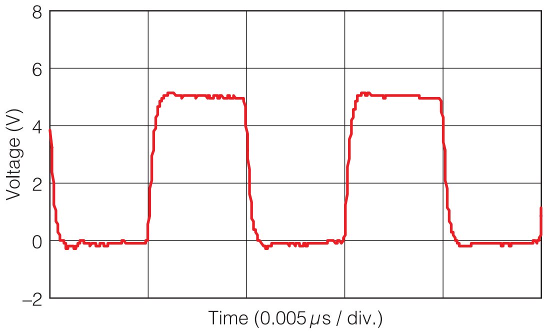


Figure 7 Chip Bead Operation Test Results

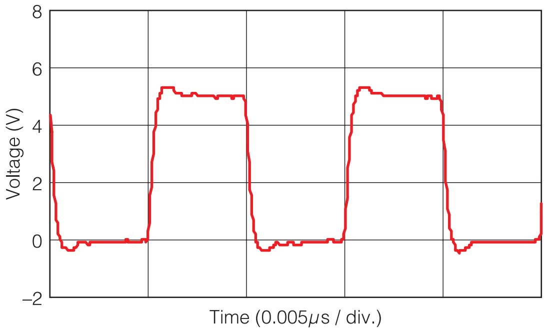
(a) No beads (through)



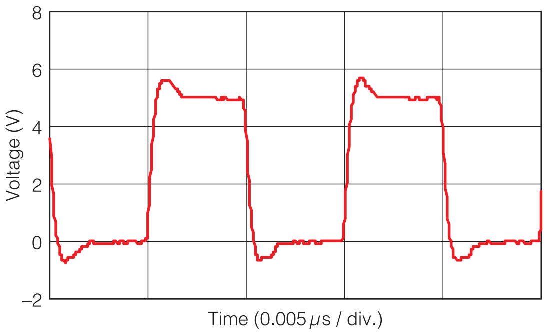
(b) MMZ1608B121 (Cross point : 5MHz)



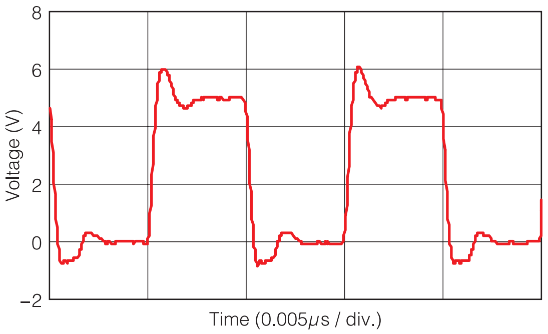
(C) MMZ1608B121 (Cross point : 15MHz)



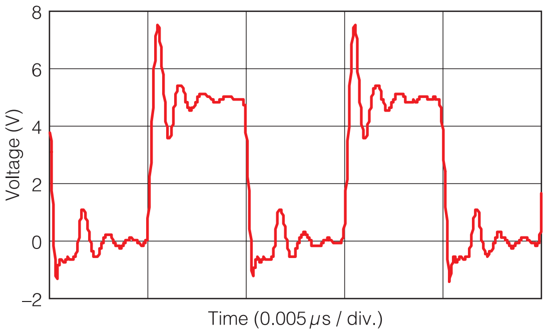
(d) MMZ1608B121 (Cross point : 25MHz)



(e) MMZ1608B121 (Cross point : 80MHz)



(f) MMZ1608B121 (Cross point : 400MHz)



Three-Terminal Filters with Steep Attenuation Characteristics

TDK Corporation　Magnetic Business Group
Yutaka Abe

1 LC Filters with Good Attenuation Characteristics

Three-terminal filters come into play when noise cannot be sufficiently reduced using capacitors or inductors. Three-terminal filters derive their name from the fact that they have three terminals, an input terminal, an output terminal, and a ground terminal.

Three-terminal filters are high-level LC filters in which a capacitor and an inductor are combined to form one chip, and they exhibit greater attenuation characteristics than filters made using a single capacitor or inductor. The inductor has high impedance at high frequencies and suppresses noise, and the capacitor has low impedance at high frequencies and transfers noise to the GND terminal.

2 Types of Three-Terminal Filters

The attenuation characteristics of LC filters become greater as the number of capacitors and inductors increases; however, they cause ringing, overshoot, and undershoot to appear in digital pulse waveforms. To ensure the appropriate use of three-terminal filters, it is necessary to select filters according to the application or noise generation status.

As is shown in Figure 1, there are several different types of three-terminal filters.

▶ T-type filter

This is the most typical third-order LC filter. This type is used when noise cannot be eliminated using a single ferrite bead. It has relatively low impedance (several tens of Ω or smaller), and is inserted into a signal line for which waveform quality is considered important.

The attenuation characteristics of the MEM2012S T-type filter series are shown in Figure 1 (a).

▶ π-type filter

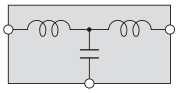
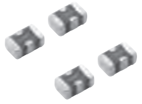
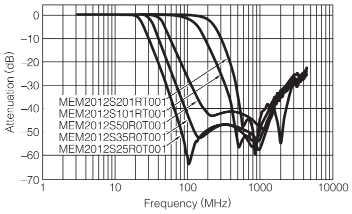
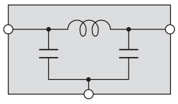
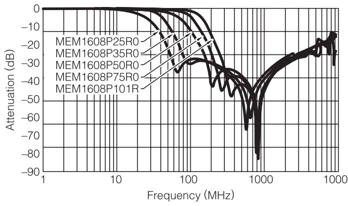
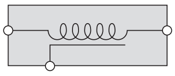
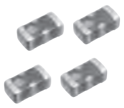
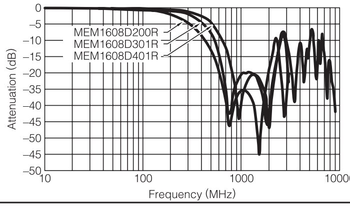
This is a third-order LC filter. This type is used into lines for which capacitors for high-frequency bypass capacitors are not sufficient, or into lines with relatively high impedance (several hundred Ω or greater), e.g., an IC power line.

The attenuation characteristics of the MEM1608P small π-type filter series are shown in Figure 1(b).

▶ Pulse response filter

A tree-terminal filter in which capacitors are disposed to face the inductor.

Figure 1　Types of Three-terminal Filters

Type / dimensions		Series / appearance	Part No.	Cutoff frequency (MHz)	Attenuation characteristics
(a)	T-type filter L2.0 × W1.2 mm 	MEM2012S series 			
			MEM2012S25R0	25	
			MEM2012S35R0	35	
			MEM2012S50R0	50	
			MEM2012S101R	100	
			MEM2012S201R	200	
(b)	π-type filter L1.6 × W0.8 mm 	MEM1608P series 			
			MEA2010P25R0	25	
			MEA2010P35R0	35	
			MEA2010P50R0	50	
			MEA2010P75R0	75	
			MEA2010P101R	100	
(c)	Pulse response filter L1.6 × W0.8 mm 	MEM1608D series 			
			MEM1608D201R	200	
			MEM1608D301R	300	
			MEM1608D401R	400	

Since the transmission characteristics attenuate smoothly near the cutoff frequency, almost no distortion, such as overshoot or ringing, appears in the pulse response characteristics.

The attenuation characteristics of the MEM1608D small pulse response filter series are shown in Figure 1 (c).

3 Space-Efficient Three-Terminal Filter Array

As is shown in Figure 2, array type products containing 4 three-terminal filters in one package are also available.

These types can be mounted in a space-efficient manner in places where there are multiple parallel digital signal lines.

Among small-sized filter arrays, the MEA2010L series is available for general signal lines.

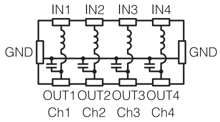
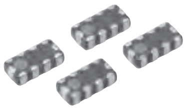
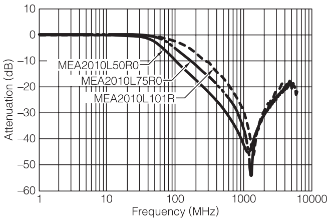
The attenuation characteristics are shown in Figure 2 (a).

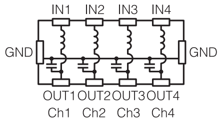
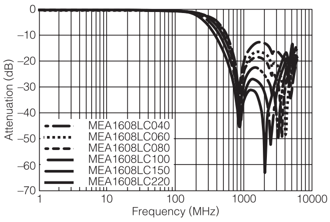
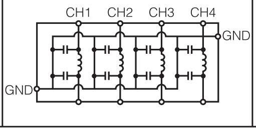
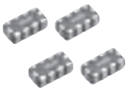
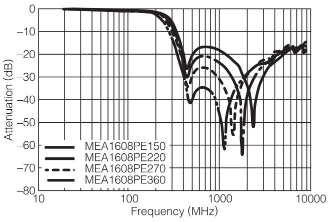
For LCD and camera signal lines, the MEA1608 series is available.

Among the small-sized 1608 type products, there are filter arrays containing L-type circuits and filter arrays containing π type circuits that have different functions.

The attenuation characteristics of the MEA1608LC series for mobile phones are shown in Figure 2 (b), and the attenuation characteristics of the MEA1608PE series for devices that are compatible with terrestrial digital television broadcasts are shown in Figure 2 (c).

Figure 2 Types of Three-Terminal Filter Arrays

Type / dimensions		Series / appearance	Part No.	Cutoff frequency (MHz)	Attenuation characteristics
(a)	L-type filter array L2.0 × W1.0 mm 	MEA2010L series 			
			MEA2010L50R0	50	
			MEA2010L75R0	75	
			MEA2010L101R	100	

Type / dimensions		Series / appearance	Part No.	Capacitance (pF)	Attenuation characteristics
(b)	L-type filter array L1.6 × W0.8 mm 	MEA1608LC series 	MEA1608LC040	4	
			MEA1608LC060	6	
			MEA1608LC080	8	
			MEA1608LC100	10	
			MEA1608LC150	15	
			MEA1608LC220	22	
(c)	π-type filter array L1.6 × W0.8 mm 	MEA1608PE series Compatible with terrestrial digital television broadcasts 			
			MEA1608PE150	15	
			MEA1608PE220	22	
			MEA1608PE270	27	
			MEA1608PE360	36	

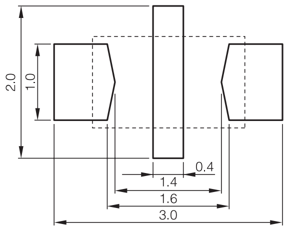
4 Recommended Land Patterns

The recommended land patterns for each three-terminal filter are shown in Figure 3.

In order to achieve sufficient a noise reduction effect, it is necessary to reduce the impedance of the ground pattern as much as possible. Through holes should be made near the elements and should connect the elements to the ground layer.

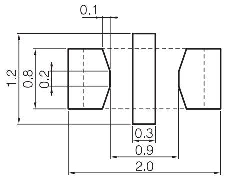
Figure 3 Recommended Land Pattern for Three-Terminal Filters and Filter Arrays

2012 type three-terminal filter



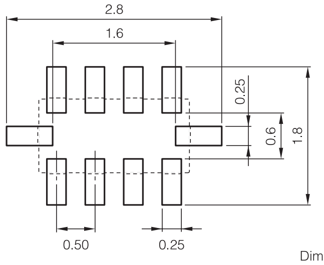
Dimensions in mm

1608 type three-terminal filter



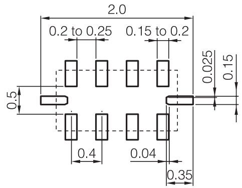
Dimensions in mm

2010 type three-terminal filter array



Dimensions in mm

1608 type three-terminal filter array



Dimensions in mm

Common Mode Filters that Eradicate the Causes of Emission Noise without Affecting Signals

TDK Corporation Magnetics Business Group
Toshio Tomonari

1 Differential Mode Current and Common Mode Current

As is shown in Figure 1, currents that flow through two parallel cables that transmit signals are divided into differential mode currents and common mode currents.

▶ Differential mode currents

These are the signal components that are intended for transmission. Since currents with equal amplitudes flow in opposing directions, the radiated electric fields have opposing directions and cancel each other out. Though the two conductors are not described as having no space in between in the actual PCB, most of the generated magnetic fields will be canceled out. As a result, the radiated electric fields will become relatively small.

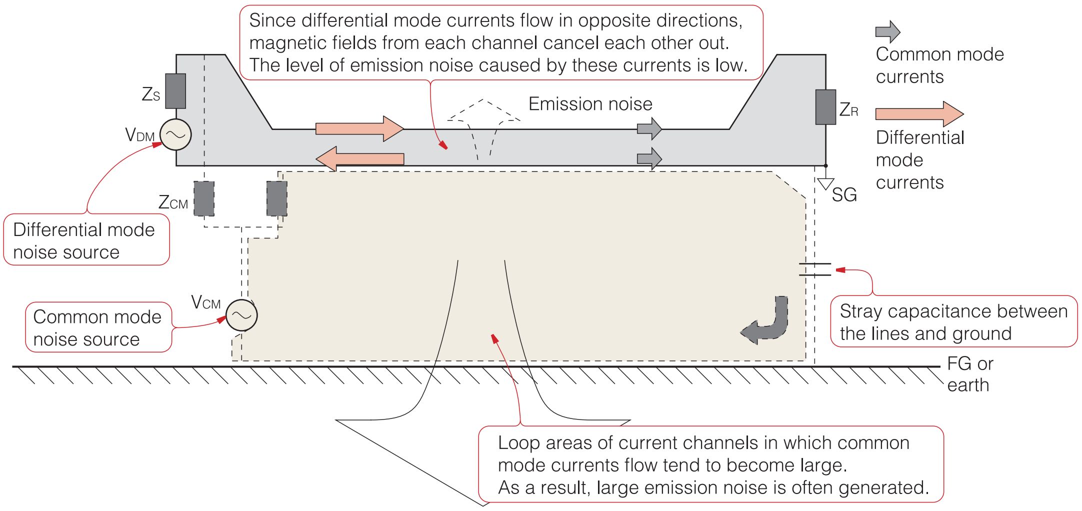
▶ Common mode currents

These are currents with the same amplitude flowing in the same direction. They are unnecessary currents that are caused by coupling between the cables and the ground due to parasitic capacitance or electromagnetic induction. Although they are very small, when compared to differential mode currents, they cause large radiated electric fields since they flow in a large loop. It is no exaggeration to say that the main cause of emission noise is common mode currents.

2 Eliminating only Common Mode Noise

Chip beads are often used as components for emission noise countermeasures; however, as they attenuate both common mode currents and differential mode currents, they might attenuate signal components that are necessary for operations. Common mode filters (hereinafter referred to as CMFs) can solve this problem. CMFs reduce only common mode noise, without affecting differential mode currents at all.

Figure 1 Channel in Which Common Mode Currents and Differential Mode Currents Flow



Since differential mode currents flow in opposite directions, magnetic fields from each channel cancel each other out. The level of emission noise caused by these currents is low.

Differential mode noise source

Common mode noise source

Stray capacitance between the lines and ground

Loop areas of current channels in which common mode currents flow tend to become large. As a result, large emission noise is often generated.

3 | Split Winding and Bifilar Winding Methods

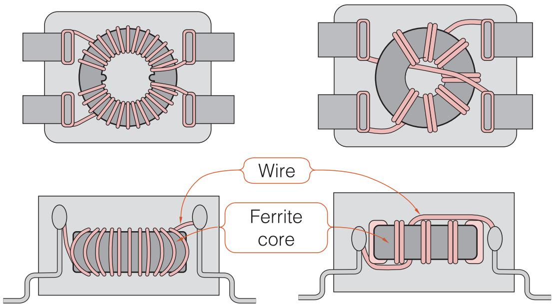
CMF structures can be divided into the following two types, according to the method of winding.

- Split winding
- Bifilar winding

As is shown in Figure 2, CMFs are made by winding conductive wire around a toroidal core or an EI core. The coupling coefficient or frequency characteristics of CMFs vary according to their winding methods or core types. The leakage flux is 0, i.e., all magnetic flux passes through the core, and the coupling coefficient of a CMF in which all the magnetic flux passes through the wire is 1. This is an ideal CMF that does not affect the differential mode current in any way.

Figure 2 Two Types of Winding Structures for Common Mode Filters

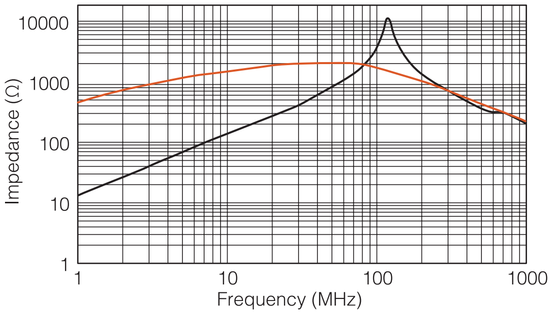
(a) Split winding (b) Bifilar winding



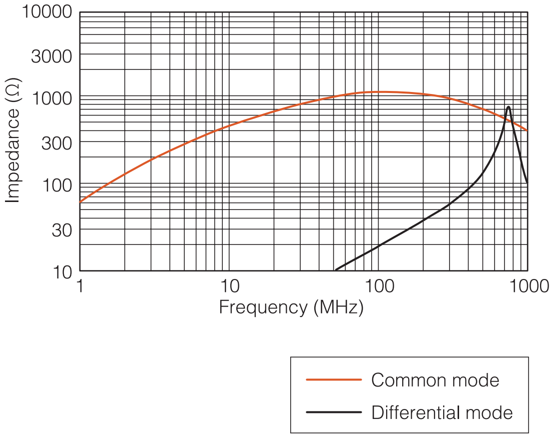
The impedance frequency characteristics of a CMF with a split winding structure and a CMF with a bifilar winding structure are shown in Figure 3.

Figure 3 Impedance Frequency Characteristics of CMFs

(a) Split winding



(b) Bifilar winding



As is clear from Figure 3, a coil with a split winding structure has a relatively large differential mode impedance; therefore, it will attenuate not only noise but signal components as well. Although it is not ideal as a CMF, it is more advantageous than a coil with a bifilar structure in terms of heat resistance or pressure resistance. Therefore, it is suitable for applications in which differential mode impedance is not very important, e.g., application in a DC power line containing no signal components. A split winding structure is employed to improve heat resistance against large currents or to achieve high pressure resistance between lines. There are filters that positively utilize differential mode impedance (two-mode filters).

In a CMF with a bifilar winding structure, coupling between two wires is high and differential mode impedance is small. CMFs with this structure are suitable for high-speed signal transmission lines, since they do not affect the waveforms of transmitted signals.

● Application of each CMF

The types of CMFs for signal lines or DC power lines and their main electrical characteristics are shown in Table 1.

In CMFs for signal lines, large common mode impedance and small differential mode impedance are required. These types of CMFs adopt a bifilar winding structure, and are used for high-speed interfaces, such as USB, IEEE1394, HDMI and DisplayPort.

In CMFs for DC power lines, not only a bifilar winding structure but a split winding structure is employed, as large differential mode impedance does not cause problems as long as the cores do not become saturated.

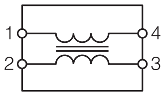
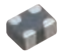
As for onboard applications, “CAN” and “LIN”, which are common standards for communications between ECUs, and the next-generation onboard LAN standard “FlexRay”, are examples in which CMSs (CAN/FlexRay) or LC filters (LIN) are used as EMC countermeasure components. Their aim is to provide radiation noise countermeasures and immunity against external noise to onboard equipment. In order to apply CMFs to components of onboard equipment, it is necessary to meet the demand for reliability under severe environments in vehicles. TDK provides CMFs that satisfy the reliability requirements even under high temperature loads from –40°C to +150°C.

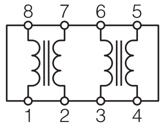
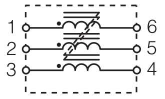
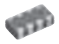
Photo 1 is a CMF for AC power supplies. This type of CMF can reduce conducted noise between 150 kHz and 30 MHz. Even if the differential mode impedance is high, it can be used without problems as long as the core does not saturate; that is to say, it can positively be used as a countermeasure against differential noise.

Clamp filters, which will be described another chapter, are categorized as CMFs. They are mounted onto cables, which are a major cause of emission noise.

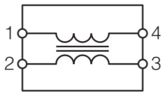
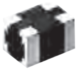
Table 1 Types and Main Electrical Characteristics of CMFs for Signal Lines and DC Power Lines

(a) CMFs for signal lines

Equivalent circuit							
Type	TCM0605	TCM0806	TCM1210 TCM1210U	ACM2012 ACM2012H	ACM2520	ACM3225	ZCYS1512 ZCYS8684 ZCYS9058
Common mode impedance [100 MHz]/ Inductance [100 kHz]	30 to 90 Ω	35 to 90 Ω	12 to 300 Ω	90 to 1000 Ω	300 to 1000 Ω	1000 Ω	0.47 to 20 mH
Rated current (A)	0.05 to 0.1	0.1	0.05 to 0.1	0.1 to 0.3	0.2 to 0.4	0.2	0.2 to 0.4
Rated voltage (V)	5	5	10	50	20	50	80
Number of lines	2	2	2	2	2	2	2
Appearance							
Target set	Portable devices	Portable devices game machines, etc.	AV equipment, PCs, game machines, etc.	AV equipment, PCs, game machines, etc.	AV equipment, PCs, game machines, etc.	AV equipment, PCs, game machines, etc.	Modems
Application	USB2.0 LVDS HDMI (C connectors), etc.	USB2.0 LVDS HDMI (C connectors), etc.	USB2.0 LVDS HDM/DVII SATA/SAS D-Port, etc.	USB2.0 LVDS HDM/DVI SATA/SAS D-Port Ethernet, etc.	Audio lines, Ethernet, etc.	Audio lines	xDSL

Equivalent circuit				
Type	TCM1608	ACM2520-3P	ACM4532-3P	ZCYS51R5
Common mode impedance [100 MHz]/ Inductance [100 kHz]	35 to 200 Ω	800 Ω	1000 Ω	400 Ω
Rated current (A)	0.05	0.15	0.2	0.5
Rated voltage (V)	5	20	50	50
Number of lines	4	3	3	4, 6
Appearance				
Target set	AV equipment PCs	AV equipment PCs	PCs	AV equipment PCs
Application	LVDS USB 2.0 HDMI, etc.	Audio lines, etc.	Audio lines, etc.	RGB lines, etc.

(b) CMFs for power lines

Equivalent circuit							
Type	ACM3225-601	ACM4532-601/801	ACM4520	ACM7060	ACM9070	ACM1211	ACM1513
Common mode impedance [100 MHz]	600 Ω	600 to 800 Ω	100 to 1400 Ω	300 to 700 Ω	700 Ω	700 to 1000 Ω	550 Ω
Rated current (A)	1	1.5 to 2.0	1.5 to 6	4 to 5	5	6 to 8	10
Rated voltage (V)	50	50	50	50	50	50	50
Number of lines	2	2	2	2	2	2	2
Appearance							

(c) CMFs for onboard applications

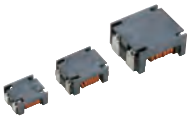
	On-board LAN					Signal lines	Power lines
Type	ACT45S	ACT45B	ACT45R	ZJYS81R5	ZJYS90V	ACM2012	ACM70V/90V/12V
Common mode inductance [100 kHz]/ impedance	22 μH	11 to 100 μH	100 μH	1000 to 2000 Ω [10 MHz]	100 μH	90 to 360 Ω [100 MHz]	700 Ω [100 MHz]
Winding method	Split winding	Bifilar winding	Bifilar winding	Split winding/ Bifilar winding	Bifilar winding	Bifilar winding	Split winding
Rated current (A)	0.2	0.2	0.2	0.5	0.5	0.22 to 0.4	4 to 8
Rated voltage (V)	50	50	50	50	50	20	80
Operating temperature range (°C)	–40 to +150	–40 to +150	–40 to +150	–40 to +125	–40 to +125	–40 to +105	–40 to +125
Appearance							
Application	CANBUS	CANBUS FlexRay	FlexRay	CANBUS	FlexRay	LVDS	Power lines

Photo 1 Examples of CMFs for AC Power Supplies

UF2327L type

HF2018R type

LH series (Gear-wound products)

Clamp Filters that Suppress Emission Noise Provide Immunity Against Surge Noise

TDK Shonai Corporation
Satoru Saito

● Reduce Emission Noise from Cables

Even if an electronic device is designed taking noise into consideration, taking into consideration element locations, the ground or filtering on a PCB, it might generate a high level of noise or become susceptible to noise when it is connected to another device with an interface cable. In particular, cables are components in a system that are long and have a large surface area; therefore, they may radiate or receive large electromagnetic waves.

The external appearance of a clamp filter is shown in Photo 1. It consists of two semi-circle cores, and can be easily mounted onto a cable in a single operation, without cutting the cable. Since it can be mounted after the device is assembled, it becomes useful in cases such as when noise problems occur just before shipping products. Photo 1 (b) is a type that is mounted onto a cable inside of a device.

A clamp filter consists of a ferrite core that is divided into two parts, contained in a plastic case that has elasticity and durability. There are various types of products available, according to the diameters of the cables.

● A Type of Common Mode Filter

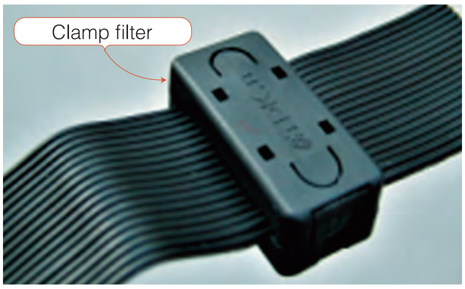
When many people think of common mode filters (hereafter referred to as CMFs), they might imagine a component that is mounted onto a PCB. However, a clamp filter is also a type of common mode filter. It only eliminates common mode noise flowing in interface cables, without attenuating differential mode currents.

Compared to a CMF in which conductive wires are wound, a clamp filter causes small, almost negligible, stray capacitance or electromagnetic coupling; therefore, differential mode impedance is kept low over a wide range of frequencies, and signals are hardly affected at all. Although clamp filters have relatively low common mode impedance, they exhibit stable impedance characteristics, since there are no effects from distributed stray capacitance caused by wound wire and, therefore, self-resonance does not occur even up to approximately 1 GHz.

Photo 1 External Appearance of Clamp Filters

(a) ZCAT2436-1330A-BK

(b) ZCAT3618-2630D-BK



● Adjusting the Amount of Winding

When winding a cable to a clamp filter on two or three times, effective impedance will be enhanced, leading to higher attenuation characteristics. However, as the amount of winding increases, stray capacitance or electromagnetic coupling becomes larger. The most effective amount can be found through trying out various amounts of winding.

1 Confirming the Effect of Reducing Emission Noise through Experiments

In addition to AC power adapters, various peripheral devices, such as digital still cameras or mobile phones, are connected to mobile terminals represented by mobile PCs through various interface cables. In this section, clamp filters will be mounted to these interface cables and their noise reduction effects will be tested.

● Connecting an AC Power Cable

The spectrum of emission noise from a mobile phone before and after mounting a ZCAT1518-0730 clamp filter to the power cable is shown in Figure 1. In this test, a cable was wound twice around the filter.

The measurement results are shown in Figure 2. Before mounting, noise was emitted at frequencies from 250 to 600 MHz, barely satisfying the VCCI class B standard. After mounting the clamp filter, noise was relatively reduced by approximately 5 to 10 dB.

● Connecting a Mobile Phone

As is shown in Figure 3, a mobile terminal was connected to a mobile phone with an exclusive cable, with a ZCAT1518-

Figure 1 Experimental System for Examining Changes in Emission Noise when Mounting a Clamp Filter onto an AC Power Cable

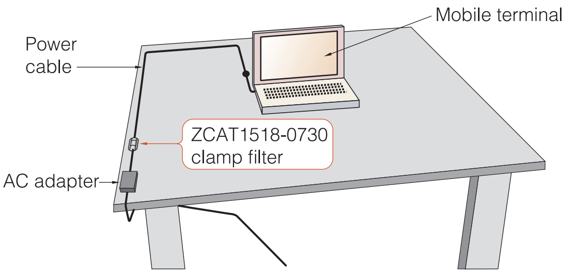
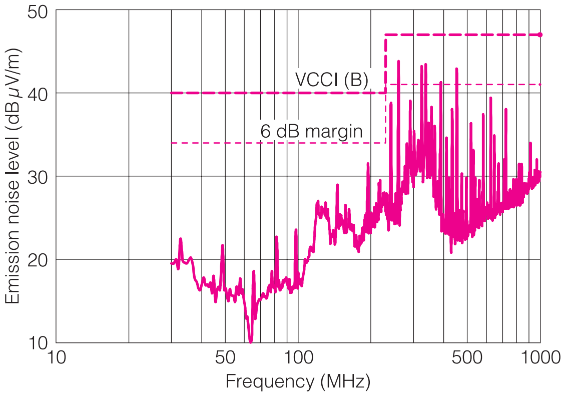
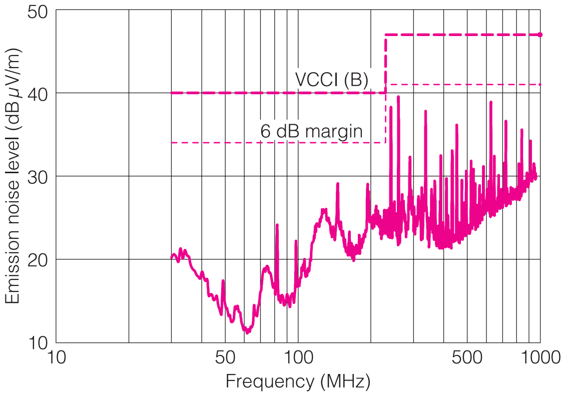


Figure 2 Noise Reduction Effect of a Clamp Filter on Emission Noise from an AC Power Cable

(a) Before mounting the clamp filter



(b) After mounting the clamp filter



0730 clamp filter connected to the power cable.

The measurement results are shown in Figure 4. Before mounting the clamp filter, noise was emitted at a broad frequency band from 100 to 600 MHz. As in the case of the previous test, after winding the exclusive cable twice around the clamp filter, noise was relatively reduced by 5 to 10 dB. Noise at frequencies of 600 MHz or higher, which did not change after mounting the clamp filter, seemed to be emitted from sources other than the cable.

2 | Clamp Filters Improve Immunity to Electrostatic Discharges

When a clamp filter is mounted, not only is emission noise reduced, but errors due to external noise, such as surges or static electricity are also reduced. An ESD (electrostatic discharge) test based on the international standard IEC61000-4 for immunity testing was conducted to examine the frequency or level change of errors before and after mounting the clamp filter.

Figure 3 Experimental System for Examining Changes in Emission Noise when Mounting a Clamp Filter onto an Exclusive Cable for Connecting a Mobile Phone

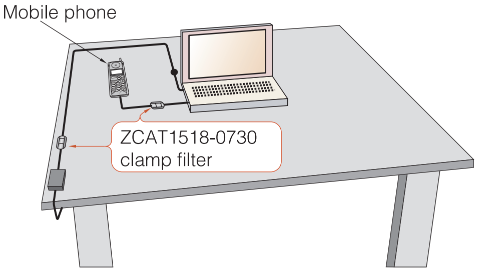
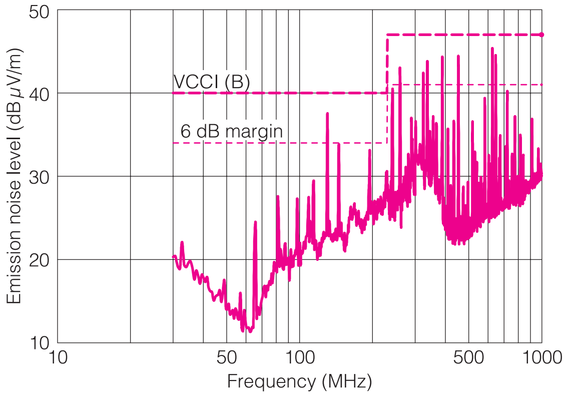
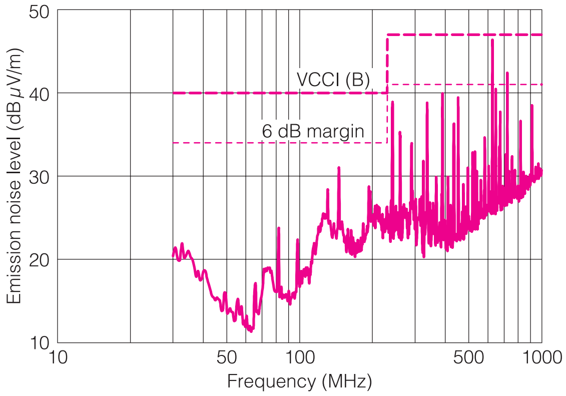


Figure 4 Noise Reduction Effect of a Clamp Filter on Emission Noise from an Exclusive Cable for a Mobile Phone

(a) Before mounting the clamp filter



(b) After mounting the clamp filter



ESD is a phenomenon that occurs when the electric charge accumulated on a body due to causes such as friction with clothes is discharged when the body touches the housing of an electronic device, etc. Immunity means resistance against external noise.

● Testing Method

As is shown in Figure 5, a mobile terminal under operating conditions and a printer were connected. Static electricity was discharged onto the mobile terminal, and the conditions of errors were recorded. ESD was applied to the connector plug shell on the mobile terminal side of the connector cable 10 times with one second intervals. The discharge method was pursuant to the contact discharge method provided in the international immunity standard IEC61000-4-2. The electrostatic pulse waveform for testing specified in IEC61000-4-2 is shown in Figure 6. The levels of discharges were 2 kV, 4 kV and 6 kV.

Figure 5　Experimental System for Examining the ESD Noise Suppression Effect of a Clamp Filter

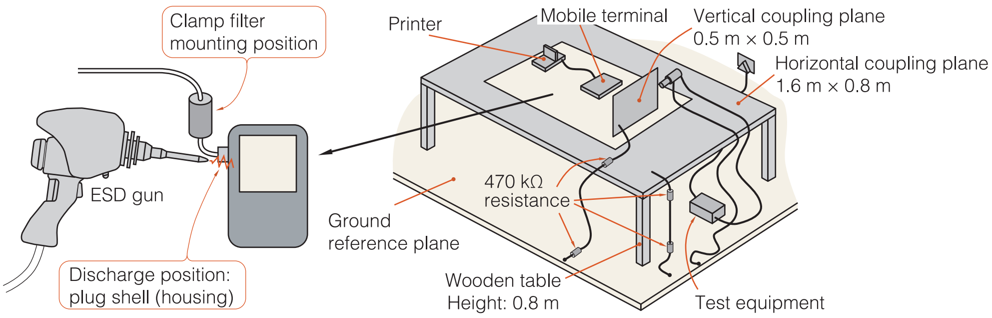
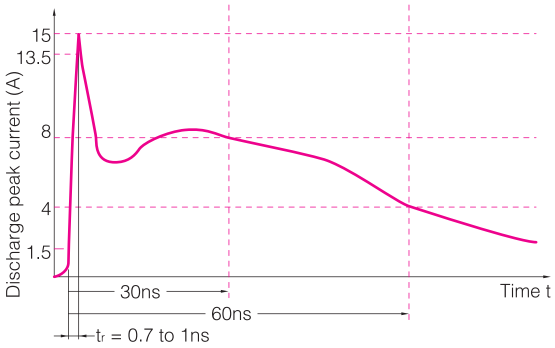


Figure 6　Electrostatic Pulse Waveform Provided in IEC61000-4-2 that is to be Applied to the Mobile Terminal



Test Results

The test results are shown in Table 1.

When no clamp filter was mounted, errors such as stopping of printer operations were observed even at 4 kV. At 6 kV, the printer stopped completely.

When one ZCAT2035-0930A clamp filter (wound once) was mounted, there were no problems in operations at 4 kV, and few errors occurred even at 6 kV. When winding was performed twice, no errors were observed.

The ESD waveforms before and after mounting the clamp filter are shown in Figure 7. Winding was performed twice. ESD was significantly attenuated by the clamp filter. The waveforms were observed at a position near the clamp filter on the cable between the clamp filter and the printer.

Table 1　Improvement of ESD Noise Immunity after Mounting a Clamp Filter

(a) Discharge level: 4 kV (IEC level 2)

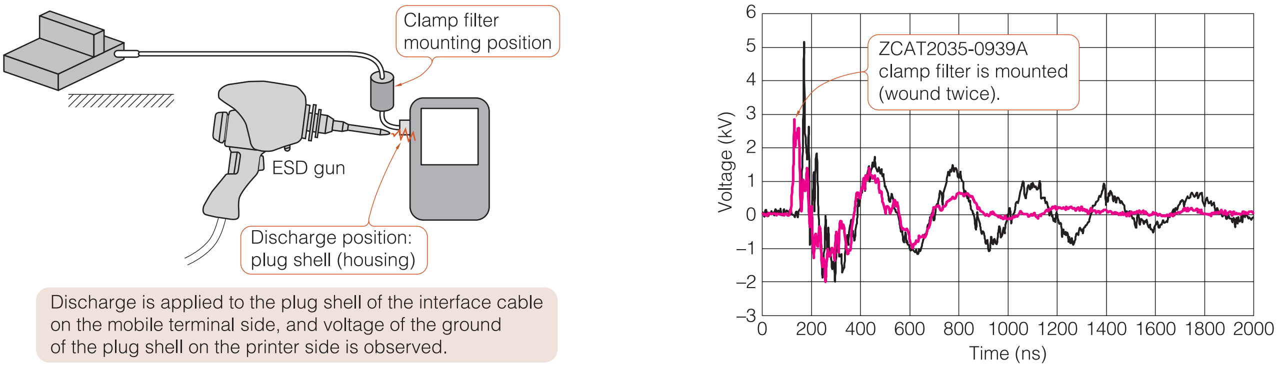
Errors, etc. / Number of discharges	No clamp filter	With a clamp filter
1	◎	◎
2	◎	◎
3	◎	◎
4	△	◎
5	◎	◎
6	◎	◎
7	◎	◎
8	△	◎
9	◎	◎
10	◎	◎

(b) Discharge level: 6 kV (IEC level 3)

Errors, etc. / Number of discharges	No clamp filter	With a clamp filter	
		Number of windings: 1	Number of windings: 2
1	△	◎	◎
2	△	◎	◎
3	△	◎	◎
4	△	△	◎
5	△	◎	◎
6	△	◎	◎
7	△	◎	◎
8	△	◎	◎
9	△	◎	◎
10	△	◎	◎

◎ : No abnormality　○ : Self-recovering errors　△ : Errors requiring system reset　× : Unrecoverable due to function damage

Figure 7　Noise Reduction Effect of a Clamp Filter on Emission Noise from an AC Power Cable



3 ESD Noise Suppression Effects in a Parallel Two-Wire Line

The ESD noise suppression effect of a clamp filter when it is mounted onto a parallel two-wire line was evaluated by an experiment. A comparison was made with the previously-described onboard type CMF.

Figure 8 Measurement System for Examining the ESD Noise Suppression Effect of a Clamp Filter when it is Mounted onto a Parallel 2-Wire Line

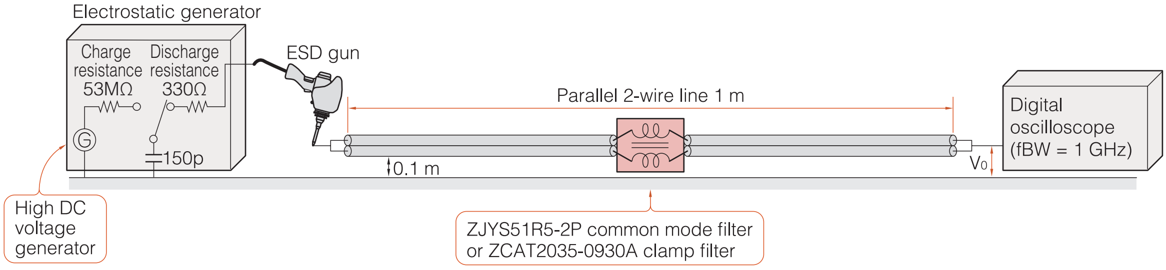
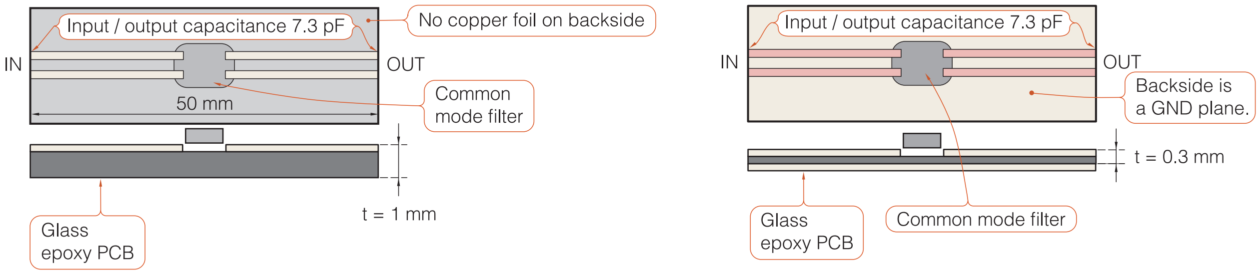


Figure 9 Two PCBs for Mounting Common Mode Filters Used in the Measurement


(a) No copper foil on backside (PCB [A])

(b) GND plane on backside (PCB [B])

● Measurement System

The measurement system is shown in Figure8. Two parallel wires with a length of 1 m were placed at a height of 0.1 m from the ground plane. 6 kV of static electricity generated by an electrostatic generator was applied by an ESD gun to the input side of the line. The ESD and the line were brought into contact with each other. The waveform of static electricity generated by the electrostatic generator was a high speed, spike voltage with a rise time of between 0.7 to 1 ns.

A ZCAT2035-0930A clamp filter (hereinafter referred to as ZCAT) and a onboard type CMF ZJYS51R5-2P (hereinafter referred to as ZJYS) were inserted into the halfway point of the parallel wires, and changes in the ESD waveform were observed on the output side. As is shown in Figure 9, two types of PCBs were prepared onto which ZJYSs were mounted; one was a PCB with a thickness of 1 mm, having no copper foil pattern on the back side (PCB)), and the other was a PCB with a thickness of 0.3 mm, with the entire backside being a ground plane (PCB).

● High Surge Noise Suppression Effect

The waveforms observed at the output terminal are shown in Figure 10.

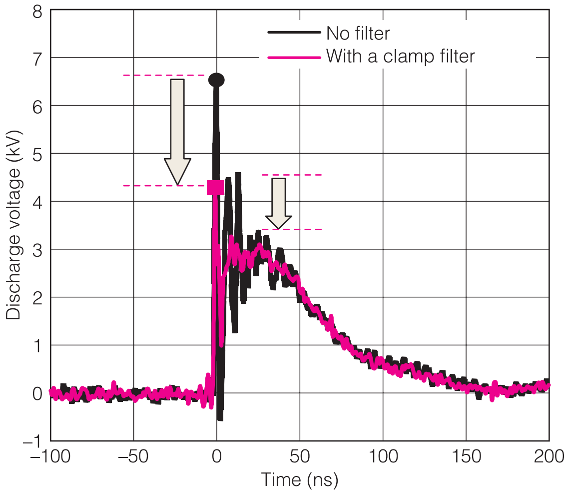
From Figure 10 (a), it is clear that approximately 40% of noise was attenuated after the clamp filter was mounted. Ringing immediately following the voltage rise was also attenuated.

In Figs. 10 (b) and (c), the waveforms in the cases where ZJYSs were mounted show that ringing was attenuated to the same extent as ZCATs, but that the spike voltage at the rise time was not attenuated. In particular, there was almost no attenuation in the PCB [A]. In order to examine the cause, the input/output capacitances of the PCB [A] and PCB [B] were measured using a capacitance meter. As a result, the capacitance of the PCB [A] was approximately 0.1 pF and the capacitance of PCB [B] was 7.3 pF. It seems that in the PCB [B], large stray capacitance existed between the copper foil on the component surfaces and that electrostatic noise escaped to the output side through this capacitance, as is shown in Figure 11. As a reference, the impedance frequency characteristics of the clamp filter, the PCB [A] and PCB [B], which were used for the experiments, are shown in Figure 12.

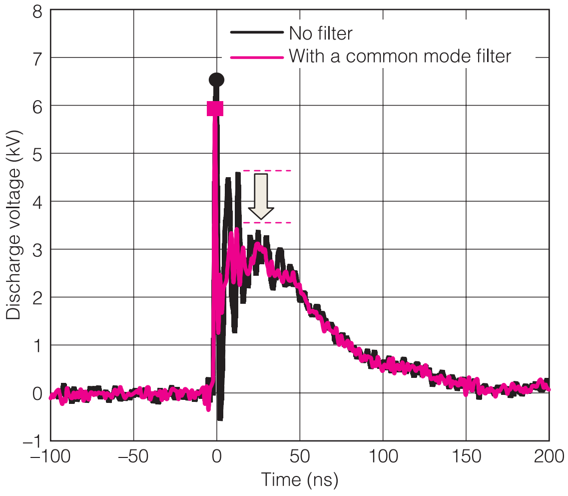
From these experimental results, it is clear that clamp filters exhibit higher surge voltage suppression effects than onboard type CMFs. This is because their ferrite cores do not easily become saturated even when high surge voltage is applied, due to their large physical capacities. Since they are not mounted onto PCB boards, it is not necessary to take into consideration capacitance coupling between inputs and outputs.

Figure 10 ESD Noise Suppression Effect of a Clamp Filter and Common Mode Filters Mounted onto a Parallel 2-Wire Line

(a) ESD suppression effect of a clamp filter (wound once)



(b) ESD suppression effect of a common mode filter (PCB [A])



(c) ESD suppression effect of a common mode filter (PCB [B])

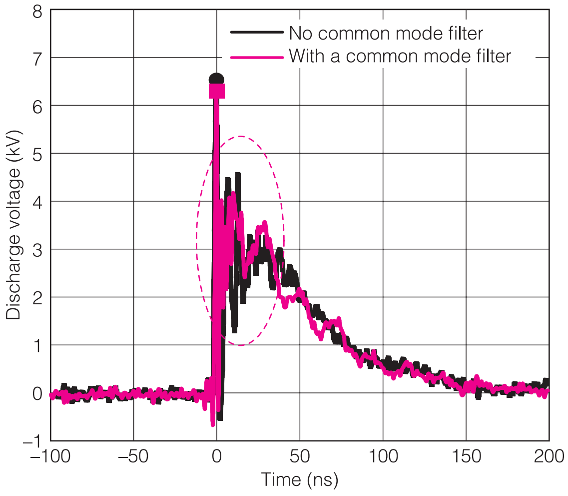


Figure 11 ESD Noise Goes Escapes to the Output through Capacitance Existing on the Front and Back sides of the PCB

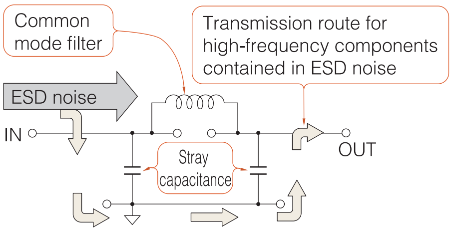
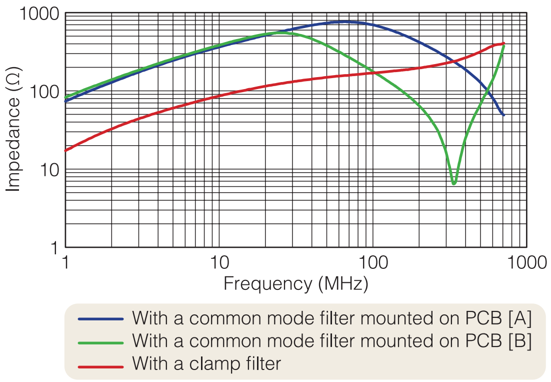


Figure 12 Frequency Characteristics of Input/Output Impedance of the Clamp Filter and Common Mode Filters Mounted onto PCB



Various Product Lineup

Lastly, the product selection chart for TDK clamp filters is shown in Table 2. TDK provides various series of products covering a wide range of applications, from application in general-purpose cables to application in flat cables.

Table 2 Selection Chart by Cable Type

Application	Type	Applicable cable diameter (mm)	Part No.	External photo
Cables	Self-holding	2.5 to 4.0	ZCAT1525-0430AP (-BK)	
		3.0 to 5.0	ZCAT1325-0530A (-BK)	
		4.0 to 7.0	ZCAT1730-0730A (-BK)	
		6.0 to 9.0	ZCAT2035-0930A (-BK)	
		8.0 to 10.0	ZCAT2235-1030A (-BK)	
		10.0 to 13.0	ZCAT2436-1330A (-BK)	
		3.0 to 6.0	ZCAT2506S-01 (-BK)	
		7.0 to 9.0	ZCAT3209S-01 (-BK)	
		10.0 to 13.0	ZCAT3513S-01 (-BK)	
	With fixed band	7.0 max.	ZCAT1518-0730 (-BK)	
		9.0 max.	ZCAT2017-0930 (-BK)	
		9.0 max.	ZCAT2032-0930 (-BK)	
		11.0 max.	ZCAT2132-1130 (-BK)	
		13.0 max.	ZCAT3035-1330 (-BK)	

Application	Type	Product height (mm)	Part No.	External photo
Flat cables	20-flat cable	12 max.	ZCAT3618-2630D (-BK)	
	26-flat cable	13 max.	ZCAT4625-3430D (-BK)	
	40-flat cable	17 max.	ZCAT6819-5230D (-BK)	
	Low-profile for FPC	2.3 max.	ZCAT07R2-F-BK	
		2.3 max.	ZCAT10R2-F-BK	
		2.3 max.	ZCAT15R2-F-BK	
		5.8 max.	ZCAT25R2-F-BK	
		5.8 max.	ZCAT30R2-F-BK	
		5.8 max.	ZCAT40R2-F-BK	

Chip Varistors that Absorb Static Electricity

TDK Corporation Sensors and Actuators Business Group
Takeshi Yanata

1 Necessity of ESD Countermeasures

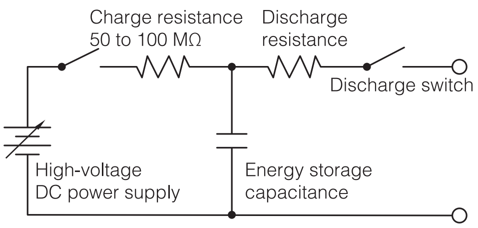
As miniaturization and reduction of power consumption of electronic devices progress, more emphasis is placed on immunity to static electricity. Static electricity enters devices through input or output buttons or gaps in device housings and causes errors or serious problems such as the destruction of internal circuits. For this reason, there have been more regulations regarding immunity to Electro-Static Discharge (ESD) for general electronic devices or automobiles, and countermeasures using ESD protection components, such as chip varistors or zener diodes, have become necessary.

2 What is Static Electricity?

ESD Test Model

An ESD test model is shown in Figure 1.

Figure 1



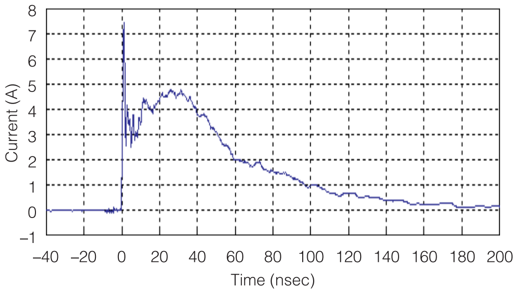
In the human body model, energy storage capacitance: 150 pF, discharge resistance: 330 Ω

First, the left side switch is closed to store electricity in the capacitor. Next, the right side switch is closed (by opening the left side switch) and the energy stored in the capacitor is discharged to simulate ESD. As for combinations of energy storage capacitance and discharge resistance, there are various models according to the assumed amount of ESD. As a human body model, IEC61000-4-2 provides the values of 150 pF for energy storage capacitance and 330 Ω for discharge resistance. Each manufacturer also sets their own ESD test specifications, and there are various requirements concerning ESD charge voltages or the number of times to apply ESD. In addition, as the relationship between humidity and ESD charge voltage is shown in IEC61000-4-2, environments differ between the manufacturing process and the market, and it is necessary to provide models and conditions that are appropriate for each environment and to conduct evaluations.

Characteristics of EDS Waveform

A typical ESD waveform (a human body model with a 2 kV charge voltage) is shown in Figure 2.

Figure 2

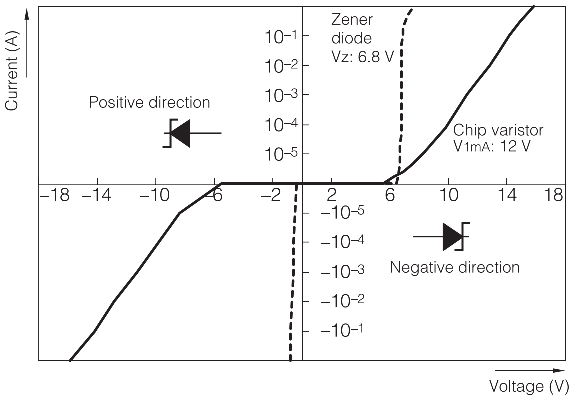


The rise time is as fast as less than 1 nsec, and the peak current is as large as 7.5 A.

3 Chip Varistor's Characteristics

The current-voltage characteristics of a chip varistor and a zener diode are shown in Figure 3.

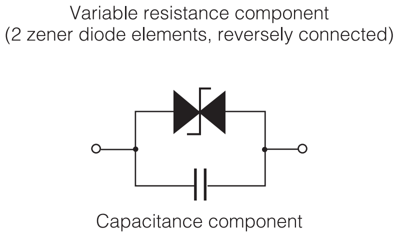
Figure 3 Current-Voltage Characteristic Examples



These elements have nonlinear characteristics; utilizing the characteristic that the resistance of the elements themselves changes according to the amount of voltage applied to the elements, they let noise escape to the ground and protect the subsequent stage circuits. In circuits, they are placed between the line and GND.

The equivalent circuit of a chip varistor is shown in Figure 4.

Figure 4 Equivalent Circuit of a Varistor Element



In this circuit, two zener diode elements that have been reversely connected in series and a capacitance component are connected in parallel. In a steady state (when the resistance of the path on the zener diode side is very large), it behaves as an element having electrostatic capacitance like a chip capacitor, but the resistance of the path on the zener diode side switches to a low resistance and clamps ESD voltage when ESD is applied. When the current-voltage characteristics of the zener diode and chip varistor in Figure 3 are compared to each other, their rise characteristics (curves) vary widely. However, steep current-voltage characteristics do not always mean superior ESD clamping performance. When comparing zener diodes and chip varistors, it is necessary to evaluate the clamp characteristics exhibited when ESD is actually applied.

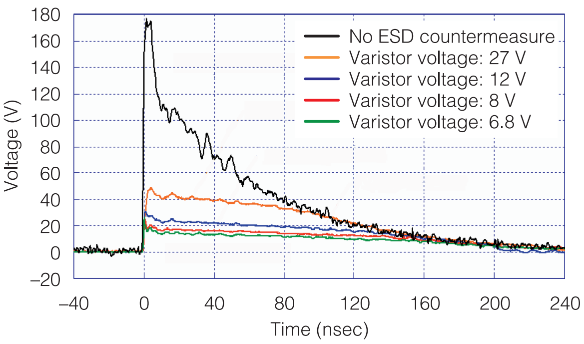
4 How to Select Chip Varistors

Selection based on Varistor Voltage

Reminders and key points in selecting chip varistors are provided in the following.

The primary purpose of using a chip varistor is to increase the immunity of devices against ESD. A key point for selecting varistors is to select items with the lowest varistor voltage possible with respect to the voltage of the circuit that must be protected. TDK offers chip varistors with low varistor voltages as low as 6.8 V. The ESD clamp characteristics according to varistor voltage are shown in Figure 5.

Figure 5 Measured Waveform (ESD voltage = 1 kV)

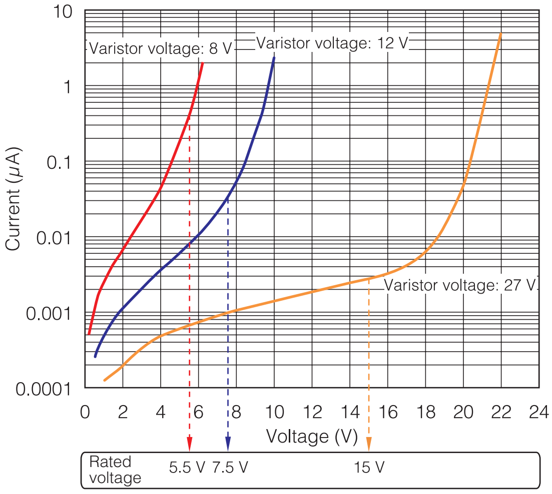


Generally, items with low varistor voltages have a higher ESD clamp effect, and items with larger capacitance have a higher ESD clamping effect when they have the same the varistor voltage. It is clear that voltage is suppressed by the use of varistors, compared to cases in which no ESD countermeasures are applied.

Selection based on Leakage Currents

The second reminder in selecting chip varistors is to select items with low leakage currents in circuits. One of the reasons for the increase in the necessity of ESD countermeasures is the increase of mobile electronic devices and their miniaturization. At the same time, requirements concerning leakage currents on the component level are becoming stricter, to allow the devices to be used for as long a time as possible with batteries mounted inside. A key point in making selections is to select items that provide higher rated voltages (maximum allowable circuit voltage) than the voltages of the circuits to which the varistors are applied. The current-voltage characteristics according to varistor voltage are shown in Figure 6.

Figure 6

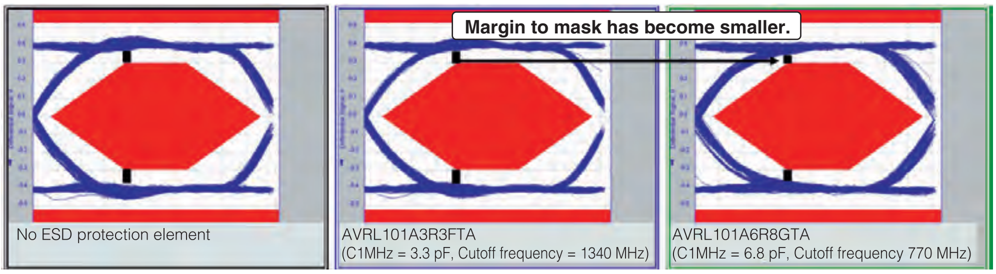


In general, items with lower varistor voltages have lower rated voltages and cause larger leakage currents. Selections based on leakage currents require caution as they have a tendency that is contrary to that of the previously-described selection of items with good ESD clamp characteristics.

Selection based on Capacitance

The third reminder in selecting chip varistors is to select items that take into consideration impacts on transmitted signals. In cases where countermeasures are applied to high-speed signal lines such as USB, it is necessary to select items that have a small impact on signal quality. A key point in making selections is to select items that have cutoff frequencies that are approximately at least three to five times higher than the signal frequencies. Generally, it is said that signal quality has no problem if it can be transmitted at the fifth harmonic frequency, and this is why such a standard was established; however, in actuality, characteristics required for components may become higher due to impacts from output waveforms of ICs, PCBs or connectors. This key point also requires caution, as it has a tendency that is contrary to that of selecting items with good ESD clamp characteristics, as was previously described. The transmission waveforms according to cutoff frequency (size of capacitance) are shown in Figure 7. The original waveform is of a high-speed USB 2.0 (480 Mbps). With the item having a cutoff frequency at the fifth harmonic frequency or higher, almost no changes were observed in the signal waveform, compared to items with no ESD protection elements. However, for items with a cutoff frequency that was lower than the fifth harmonic frequency, the signal waveform had a smaller margin to the mask.

Figure 7



No ESD protection element

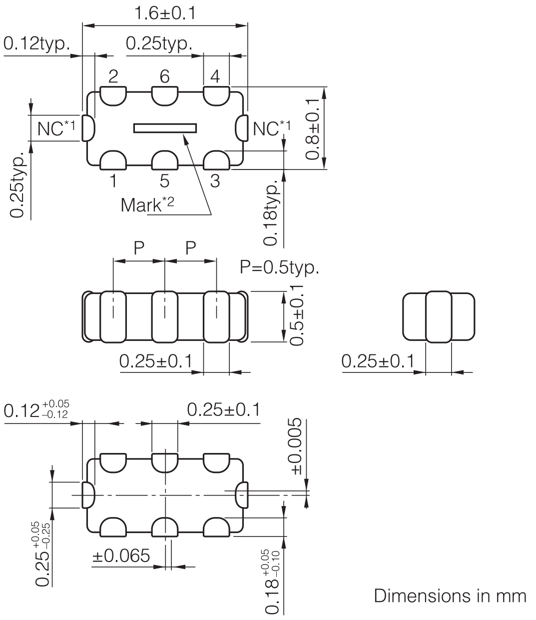
AVRL101A3R3FTA
(C1MHz = 3.3 pF, Cutoff frequency = 1340 MHz)

AVRL101A6R8GTA
(C1MHz = 6.8 pF, Cutoff frequency 770 MHz)

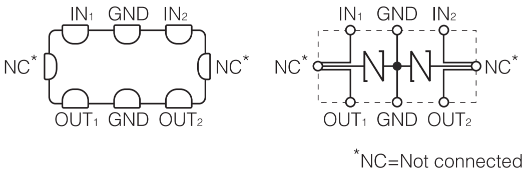
5 Varistors for High-Speed Signal Lines

Due to the material characteristics of chip varistors, varistor voltages tend to become higher, i.e., ESD clamping effects tend to become weaker, in varistors with low capacitance, such as 1.1 pF. In the AVF16C2 series, shown in Figure 8, the capacitance component of the varistors is cancelled out by constructing a matching circuit using the internal element pattern, in order to allow them to be used in high-speed signal lines. The capacitances calculated from the cutoff frequencies are 0.6 pF for the AVF16C212A000F205 and 0.3 pF for the AVF16C225A000F405, and the varistor voltages are 12 V for the AVF16C212A000F205 and 25 V for the AVF16C225A000F405. Compared to TDK's single-type varistors with a 1.1 pF capacitance and a 39 V varistor voltage, low capacitance and low varistor voltage have been realized in these two items. They have also realized compatibility with high-speed signal lines, together with a dramatically improved ESD clamping effect.

Figure 8 Shapes and Dimensions / Circuit Diagrams



Dimensions in mm



*NC=Not connected

Part No.	AVF16C212A000F205	AVF16C225A000F405
Varistor voltage V_{1mA}	12 V	25 V
Rated voltage Edc	5.5 V	5.5 V
Cutoff frequency [Sdd21 at −3dB]	2 GHz min.	4 GHz min.
ESD charge voltage [IEC61000-4-2]	8 kV [10 times]	8 kV [10 times]

[1] Do not solder the terminal NC (not connected) with land etc.
[2] Mark is unrelated to the polarity (directionality) of the terminal.

AC Power Line EMC Filters that Prevent Noise Infiltration and Leakage

TDK Corporation Magnetics Business Group
Suguru Masaki

1 Confirming the Emission Noise Reduction Effect Through Experiments

On AC power lines, various types of noise are superimposed. When classifying noise according to voltage level and rise time, it can be divided into three categories, as shown in Table 1.

▶ High-frequency noise

This mainly consists of the harmonic components of switching frequencies of computers or switching power sources, etc. Generally, EMI noise refers to this type of noise. Its voltage level is relatively low, from several mV to several tens of mV.

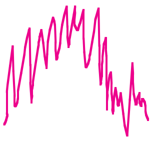
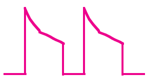
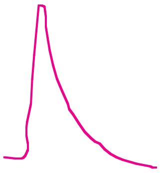
▶ Impulsive noise

This noise generates at the time of switching of relays or induction motors. Its voltage level is high, and the peak voltage may reach several thousand V.

▶ Surge noise

This noise generates in power lines by induced lightning, etc. This type of noise has a large amount of energy as well as very high voltage and current. The peak voltage may reach several tens of kV.

Table 1 Three Types of Conducted Noise

	High-frequency noise	Impulsive noise	Surge noise
Voltage level	- Several V	- Several kV	- Several 10 kV
Rise time	–	1 ns max.	0.5 μs max.
Energy	Several mJ	Several 100 mJ	Several J – several kJ
Waveform			

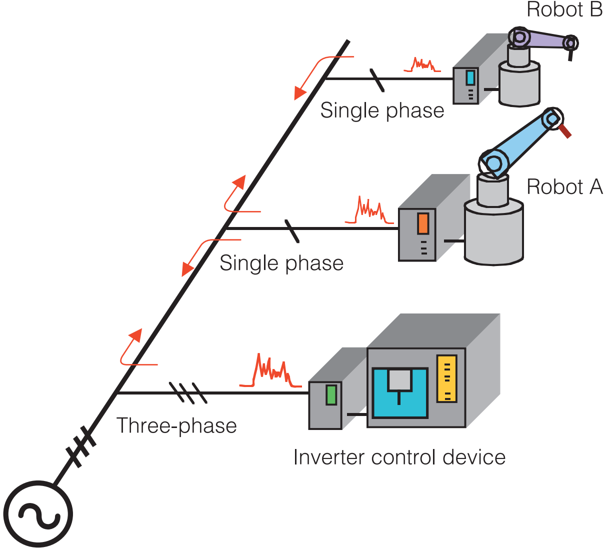
2 Prevents Noise Infiltration from AC Power Lines and Noise Leakage From Devices

As shown in Figure 1,since each device is connected to a common power line, one device may have errors due to noise generated in other devices, or may cause errors in other devices.

The AC power supplies of the devices are entrances for noise energy, in addition to being an exit for noise generated in each device. By mounting an EMC filter to an AC power line, infiltration of external noise and noise leakage into the power line can be reduced.

In every country around the world, immunity against external noise or limits for leakage noise are provided, and devices need to conform to these. EMC filters for AC power lines are used in order to meet such standards.

Figure 1 Noise Generated in each Device is Transmitted Through the AC Power Line



3 Classifications and How to Select Filters

Concerning built-in type EMC filters, the classifications of filters for AC power lines are shown in Table 2, and the appearances of the actual products are shown in Photo 1.

The built-in type filters are directly built into the AC power supplies of electronic devices, and there are various types of appearances and user terminal structures. When using these filters, it is necessary to check that they conform to the noise regulations and safety standards of the countries where the filters are used, in addition to the electrical characteristics of the devices, such as rated values or attenuation characteristics.

Photo 1 Appearance of EMC Filters for AC Power Lines (photos)

1) Three-phase filters (general use):
RTEN series

2) Three-phase filters (wide-band, high attenuation):
RTHN series

3) Three-phase filters (wide-band, high attenuation):
RTHC/RTHB series

4) Single phase filters (general use):
RSEN series

5) Single phase filters (wide-band, high attenuation):
RSHN series

6) Compact type single phase filters:
RSEL-W/RSEL-A series

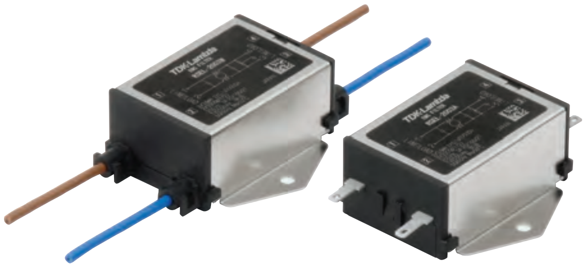


Table 2 Selection Chart by Target

Target set	Power supply	Performance	Type	Series	Rated current (A)	Safety standards UL	Safety standards CSA	Safety standards EN
General-purpose inverters AC servos, etc.	Three-phase	General use	Low profile	RTEN	6 to 300	✓ (to 150 A)		✓
		Wide-band, high attenuation	Low profile	RTHN	6 to 1000	✓ (to 150 A)		✓ (to 300 A)
		Wide-band, high attenuation	Cubic	RTHC	6 to 300	✓ (to 150 A)		✓
		Wide-band, high attenuation	Book	RTHB	6 to 150	✓		✓
	Single phase	General use	Low profile	RSEN	3 to 300	✓ (to 60 A)	✓ (to 60 A)	✓ (to 60 A)
		Wide-band, high attenuation	Low profile	RSHN	3 to 300	✓ (to 60 A)	✓ (to 30 A)	✓ (to 60 A)
Large-sized machine tools	Three-phase	General use	Low profile	RTEN	6 to 300	✓ (to 150 A)		✓
		Wide-band, high attenuation	Low profile	RTHN	6 to 1000	✓ (to 150 A)		✓ (to 300 A)
		Wide-band, high attenuation	Cubic	RTHC	6 to 300	✓ (to 150 A)		✓
		Wide-band, high attenuation	Book	RTHB	6 to 150	✓		✓
Medical equipment	Three-phase	General use	Low profile	RTEN	6 to 300	✓ (to 150 A)		✓
		Wide-band, high attenuation	Low profile	RTHN	6 to 1000	✓ (to 150 A)		✓ (to 300 A)
		General use	Low profile	RTAN	6 to 60	✓		✓
		Wide-band, high attenuation	Low profile	RTMN	6 to 60	✓		✓
	Single phase	General use	Small	RSEL	0.5 to 6	✓	✓	✓
				RSAL	0.5 to 6	✓	✓	✓
		General use	Low profile	RSEN	3 to 300	✓ (to 60 A)	✓ (to 60 A)	✓ (to 60 A)
		Wide-band, high attenuation	Low profile	RSHN	3 to 300	✓ (to 60 A)	✓ (to 30 A)	✓ (to 60 A)
Semiconductor manufacturing equipment Robots	Three-phase	General use	Low profile	RTEN	6 to 300	✓ (to 150 A)		✓ (to 300 A)
		Wide-band, high attenuation	Low profile	RTHN	6 to 1000	✓ (to 150 A)		✓ (to 300 A)
	Single phase	General use	Low profile	RSEN	3 to 300	✓ (to 60 A)	✓ (to 60 A)	✓ (to 60 A)
		Wide-band, high attenuation	Low profile	RSHN	3 to 300	✓ (to 60 A)	✓ (to 30 A)	✓ (to 60 A)
Amusement machines	Single phase	General use	Small	RSEL	0.5 to 6	✓	✓	✓
				RSAL	0.5 to 6	✓	✓	✓

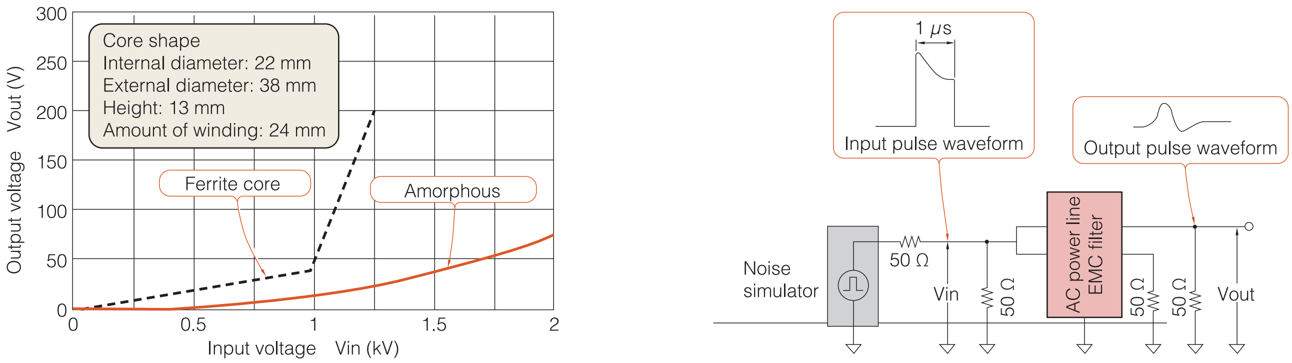
● Reminders in Selecting Filters

If high energy noise, such as impulsive noise or surge noise, enters into an AC power line EMC filter, the core of the coils used in the filter may become saturated and cause a significant decrease in the noise attenuation characteristics. When selecting a filter, it is necessary to check the attenuation characteristics of the core for impulsive noise. Amorphous cores do not easily become saturated even when a high energy surge voltage is applied.

Amorphous materials have excellent permeability and frequency characteristics. Compared to ferrite cores of an equivalent shape and amount of winding, amorphous cores exhibit much greater attenuation characteristics over a broader input voltage range, as shown in Figure 2, since their cores have higher saturation flux densities.

In areas including the Hokuriku area (Japan) in winter, surges exceeding 1 kV occur in power lines several times a year. In such cases, it is effective to apply surge absorption elements such as varistors or lightning arresters to the power input sides of EMC filters.

Figure 2 Example in Which an Amorphous Core is more Resistant to Saturation than a Ferrite Core


(a) Attenuation characteristics

(b) Measured circuit

EMC filters for AC power lines are connected to the primary sides of electronic devices; therefore, a high level of safety is required in order to prevent the occurrence of electrification, smoke or fire. Safety standards as shown in Table 3 are provided in each country. It is necessary to select filters that are approved in the safety standards of the country where the filters are used.

Table 3 Safety Standard of each Country

Country	Organization	Standard
United States	UL	UL1283
Canada	CSA	CSA C22.2 No. 8
Germany	VDE/TÜV	EN60939
Norway	NEMKO	
Sweden	SEMKO	
Finland	FIMKO	
Denmark	DEMKO	
Switzerland	SEV	
Japan	Japan Electrical Testing Laboratory	Product Safety Electrical Appliance & Material

References

Tim Williams, EMC for Product Designers, Second Edition, Newnes, 1996

TDK EMC Technology **Practice Section**

EMC Design for High-Speed Digital Circuits

EMC Design for Power Lines

TDK Corporation Capacitor Business Group
Masaaki Togashi

1 Noise Behavior on Power Lines

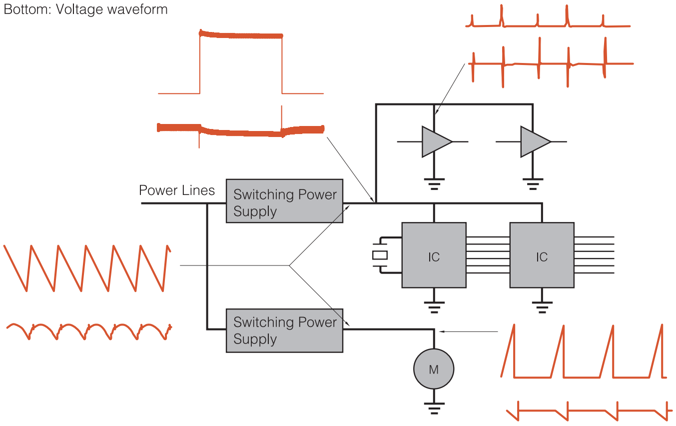
Arithmetic elements such as digital ICs and operational amplifiers, and actuators such as motors have power lines for supplying the power needed for operation. The load on power lines for ICs and motors occasionally becomes unstable due to changes in power consumption. Power lines are the circuits for transmitting constant voltage and direct current voltage, so fluctuations in the power indicate changes in the current of the load and indicate the transient current. Power lines do not have obvious fluctuations in voltage as is the case with digital signals, but a synchronized transient current flows to the control signal. Most noise generated on power lines is due to this transient current.

The transient current that flows on power lines causes voltage fluctuation due to the parasitic inductance (L) on the power line, or due to resistance (R). When the transition speed of the transient current is expressed as di/dt, voltage equivalent to L×di/dt is induced to the power lines, so voltage fluctuation occurs between the power line and GND. When the voltage fluctuation exceeds the noise margin, a problem occurs. In addition, the transient current of the power source can cause emission noise on the loop between the power line and GND, and the harmonic component of the transient current is transferred and radiates on signal lines and cables, which can cause electromagnetic wave interference.

Transient current behavior differs according to the portion of the circuit. Figure 1 shows the power supply configuration, and shows the voltage fluctuation caused by the transient current.

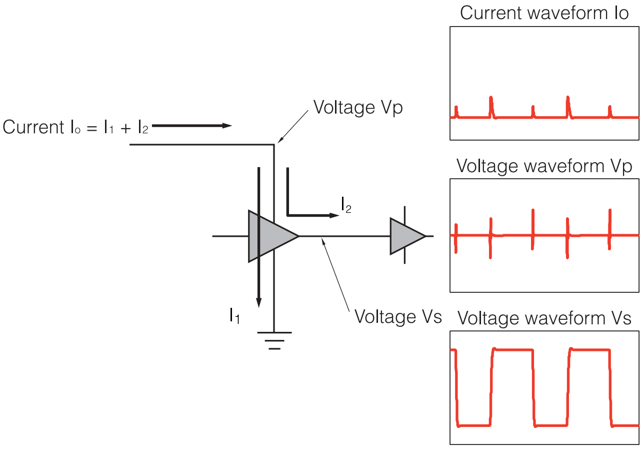
Figure 1 Transient Current and Voltage Fluctuation on Power Lines

Top: Current waveform
Bottom: Voltage waveform



On the gate IC, transient current surges that are synchronized with the clock signal flow to the power supply pins. Figure 2 shows an example of a transient current flowing on a CMOS gate.

Figure 2 CMOS Gate Power Supply Noise



When the clock signal becomes a high-frequency wave, the transient current also becomes a high-frequency wave. Therefore, harmonics increase in the high-frequency band. On an LSI equipped with over 10,000 gates, a large transient current flows temporarily to the power supply terminal at the moment that a program is processed. In addition, when one power line is shared by multiple LSIs and they begin operating at the same time, a larger current flows to the power line, causing voltage drops.

On the other hand, the power line source contains a stable power supply, which generates a predetermined amount of power. Usually, switching power supplies are used. The output from switching power supplies generates a ripple current. The ripple current becomes direct current due to the charge and discharge of the smoothing capacitor, but when the performance of the smoothing capacitor is insufficient, it flows to the power line.

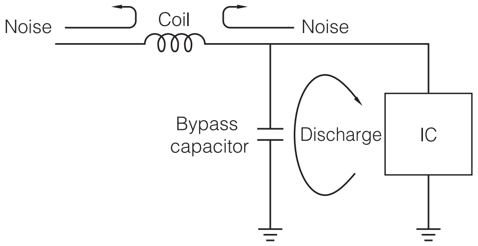
It is important to understand the behavior of transient currents that occur on power lines in order to suppress noise on power lines. Noise countermeasures are implemented through wire design and passive components such as capacitors and coils, while trying as much as possible to localize (seal) the transient current to the load side such as on ICs and actuators.

2 Necessity of IC Bypass Capacitors

Power Supply Bypass Capacitors

Bypass capacitors must be installed on power supply terminals where transient current flows. Bypass capacitors are also called smoothing capacitors and decoupling capacitors. As shown in Figure 3, bypass capacitors are installed according to the shunt direction to the GND for power lines. Because of this layout, bypass capacitors supply the transient current, which is generated by the operation of the IC, by the electrical charge stored in the capacitor. As a result, the transient current flows through the bypass capacitor and is almost completely stopped from flowing to external power lines. When the bypass capacitor is installed near the power supply pins, the transient current can be localized to a small current loop.

Figure 3 Power Line Noise Countermeasures



Bypass Capacitor's Capacitance

Bypass capacitors supply the transient current needed for operating the IC by discharging stored electricity to prevent voltage drops. Therefore, a sufficient electrical charge (Q) must be stored to prevent voltage drops after discharge. When the transient current is expressed as i(t), and the bypass capacitor supplies the whole transient current (i(t)), the electrical charge lost through discharge for the bypass capacitor (Qc) is $\int i(t)\,dt$, so the voltage drop (Vc) between the bypass capacitor terminals is expressed according to the following.

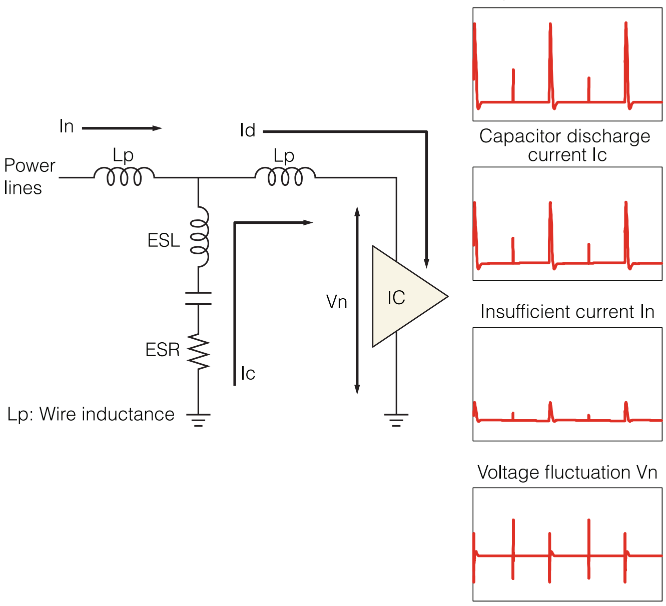
$$V_c = (1/C)\int i(t)dt$$

Capacitors need to be selected based on the calculated capacitance (C) so that the voltage drop (Vc) is within the noise margin.

Dangers Related to ESR and ESL

ESR (Equivalent Series Resistance) and ESL (Equivalent Series Inductance) are parasitic capacitor components. The bypass capacitor supplies necessary transient current for operating the IC, but sufficient current cannot be supplied when the ESR and ESL are large. This is because the ESR and ESL increase the impedance inside of the bypass capacitor, which interrupts discharging. Figure 4 shows this behavior. Insufficient current flows on external power lines, which causes voltage fluctuation or emission noise by propagating to a peripheral circuit. Capacitors with low ESR and ESL need to be selected for bypass capacitors when the IC operates at a high-frequency range because they have a high di/dt, and contain high-frequency harmonics.

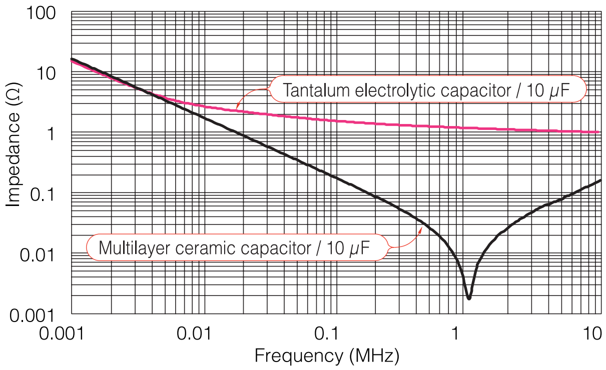
Figure 4 Power Supply Bypass Capacitor and Current Waveform



Multilayer Ceramic Capacitors for Bypass Capacitors

There are various types of capacitors, and generally, tantalum electrolytic capacitors and multilayer ceramic capacitors are used for small type SMD products. Figure 5 shows their respective impedance characteristics. Multilayer ceramic capacitor are effective for bypass capacitors because they have low ESR and ESL, they are compact, and are inexpensive.

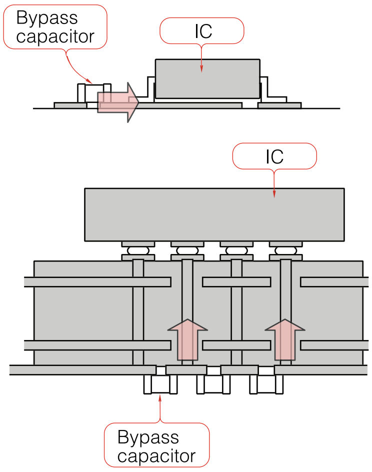
Figure 5 Inductance Characteristics



Bypass Capacitor Layout

Bypass capacitors are usually placed at the inlet of the transient current, which is the source of the noise, where it is closest to the power supply terminal. Figure 6 shows a sample layout. Wires between the power supply terminal and GND pattern, which is the discharge route for the bypass capacitor, should be as short as possible so that the inductance of the wires can be small and the discharged current can be supplied efficiently. This efficiency decreases when the wire inductance is large even if capacitors with low ESR and ESL are used.

Figure 6 Bypass Capacitor Layout Sample



Examples of Bypass Capacitor Efficiency

Figure 7 shows a circuit that is used for evaluating noise suppression efficiency with a tantalum electrolytic capacitor and with a multilayer ceramic capacitor as bypass capacitors. Figure 8 shows the measurement results. The voltage fluctuation was smaller when the multilayer ceramic capacitor was used as the bypass capacitor than when the tantalum electrolytic capacitor was used. Harmonics were also low over a wider band with the multilayer ceramic capacitor, making it more effective.

Figure 7 Evaluation Circuit

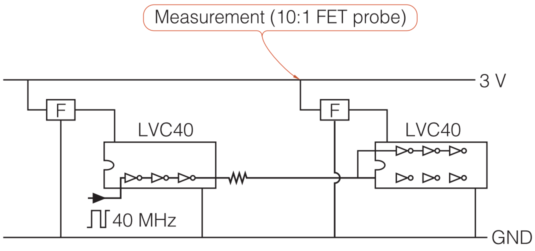
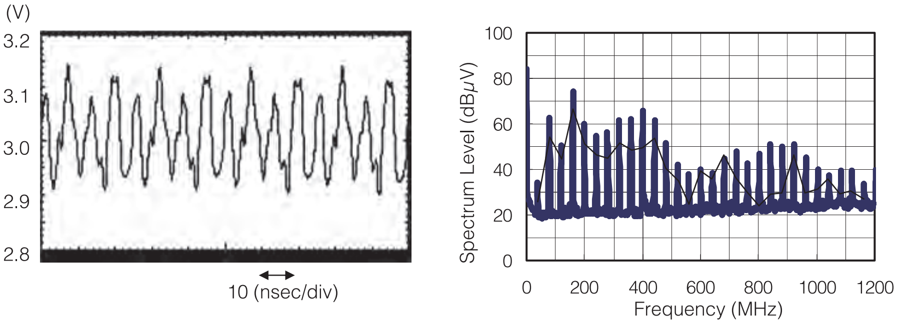
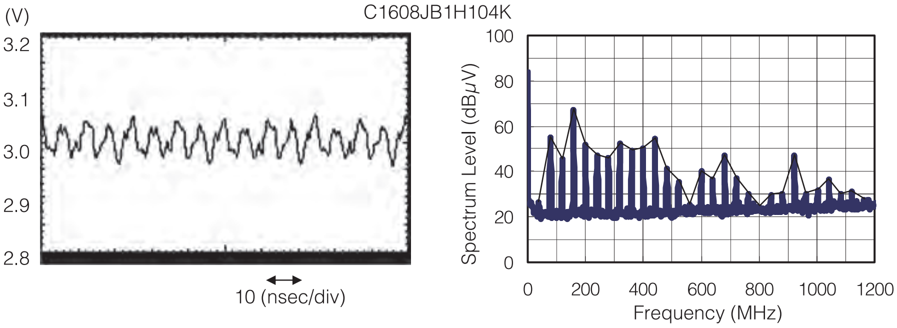


Figure 8 Measurement Results

F: Tantalum electrolytic capacitor / 1 μF



F: Multilayer ceramic capacitor / 0.1 μF
C1608JB1H104K



References

[1] Controlling Radiated Emission by Design, Michel Mardiguian / Mitsutoshi Hatori (Editor) / Takehiko Kobayashi (Translator) / Maruzen Co., Ltd.

EMC countermeasures for High-Speed Differential Interfaces

How Do Common Mode Filters Suppress EMI in Differential Transmission Circuits?

TDK Corporation Application Center
Masao Umemura

1 High-Speed Interfaces

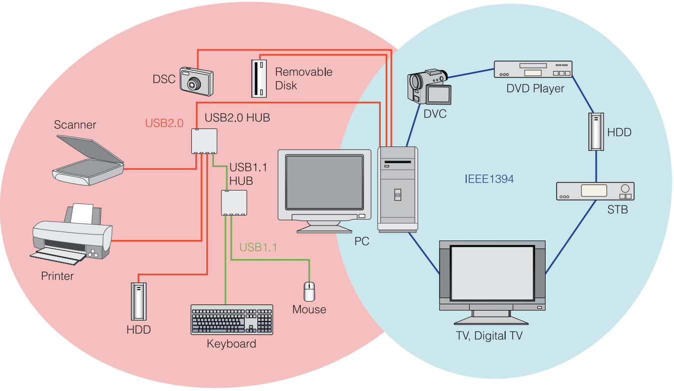
In addition to computers, other home information appliances have also become more advanced, and internet connections are now available for AV equipment, so interfaces that can handle digital information with low signal deterioration have become more important.

This will explain methods for EMC countermeasures on high-speed interface signals, which have become more common for computers and information appliances.

Common High-Speed Interfaces

USB: USB is used for connecting computers with peripheral devices (such as CD-ROMs, scanners, printers, and DSCs) (Figure 1). In 2000, the USB 2.0 standard was implemented, which made three transfer speeds available; LS (1.5 Mbps), FS (12 Mbps), and HS (480 Mbps), which allows for DSC image data to be transferred at high speeds (Photo 1).

Figure 1 USB and IEEE1394 Equipment Used



Digital audio devices use USB as the standard interface for transferring audio files from computers downloaded from the internet.

Recently, video contents can also be viewed by mobile devices in addition to audio files, making it necessary to have faster transfer speeds.

In 2008, “USB 3.0” was released, allowing for a transfer speed of 5 Gbps based on the demand mentioned above. There is a demand for distributing large-size video contents, so this new standard has potential to be more common on mobile phones and digital audio devices in addition to computers. Therefore, this interface merits close attention.

Photo 1 What is USB?

- USB, which stands for Universal Serial Bus, is an interface for connecting computers with peripheral devices.
- USB cables contain four lines; Data+ and Data– differential signal lines, and the power and GND lines.
- There are three transfer speeds available; USB 1.1, LS (Low Speed): 1.5 Mbps, FS (Full Speed): 12 Mbps, and with version 2.0, HS (High Speed): 480 Mbps was added.
- Connection requires a host computer.
- The number of ports can be expanded using HUBs, and a maximum of 127 devices can be connected.

USB Connector

Series A Series B

USB Receptacle

Series A Series B

Photo 2 What is IEEE?

- IEEE is an interface for connecting computers with peripheral devices and AV devices.
- IEEE contains six lines including two differential signal lines which are TPA and TPB, and the power / GND line (There is a 4-pin connector without the power / GND line).
- There are three transfer speeds; S100: 100 Mbps, S200: 200 Mbps, and S400: 400 Mbps
  However, 1394.b will support 800 Mbps or higher.
- Generally, a host is not necessary, and it can be used for connection between devices.
- A maximum of 63 devices can be used for one bus.

IEEE1394 Connectors

6-pin type 4-pin type

IEEE1394 Receptacles

6-pin type 4-pin type

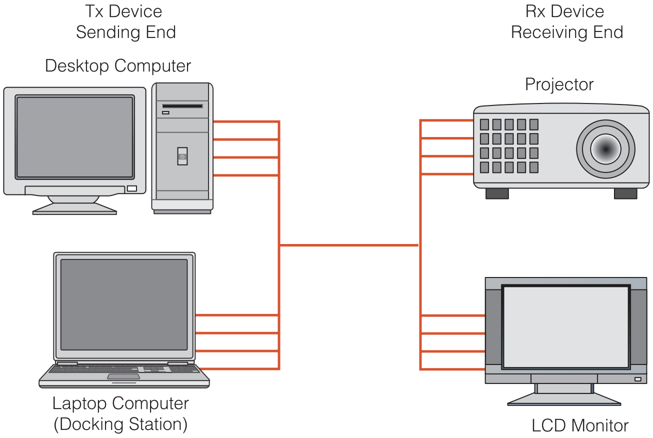
IEEE1394: IEEE1394 is an interface that was initiated by Apple Computer, which calls it Firewire, and was adopted by the IEEE and has become more common (Figure 1, Photo 2). This is a standard interface for video related devices such as flat panel TVs, DVD recorders, and DVCs with practical use speeds ranging from 100 to 800 Mbps.

The roadmap for the IEEE interface has been set to achieve speeds of up to 3.2 Gbps, so higher speed communication will be available in the future. With few exceptions, IEEE does not require the concept of a HOST. High-speed transferring and recording of MPEG signals between AV devices is possible using simple remote control operation. The directional movement for this interface is half duplex.

DVI / HDMI: DVI and HDMI interfaces are used for sending digitized image signals output from a computer to a monitor, which used to be done using analog RGB data. These interfaces allow for uncompressed digital video signals to be transferred at high speeds. The TMDS method is used and the maximum speed is 1.65 Gbps, with the transfer frequency generally reaching 850 MHz. With DVI, only video signals can be transferred (Figure 2).

Figure 2 DVI Interface (Panel Link) Usage Example

* DVI: Digital Visual Interface



With HDMI, in addition DVI video signals, audio signals can be sent simultaneously when connected to AV devices. HDMI also allows for copyright protection, and in the United States, digital TVs must be equipped with HDMI inputs. This interface has quickly become widespread (Figure 3). The directionality for this interface is one directional from the HOST to the TARGET.

S-ATA: S-ATA is an interface used for computer HDDs which has come to replace the IDE method. Serial ATA is used because of the demand for a high-speed interface to handle large amounts of data (Figure 4). The speed for S-ATA is 3 Gbps, and can be sorted into classes based on the usage purpose, such as for internal connections or external HDDs. There are different voltages used for transferring data. The directionality is half-duplex.

Figure 3 HDMI Interface Usage Example

* HDMI: High Definition Multimedia Interface

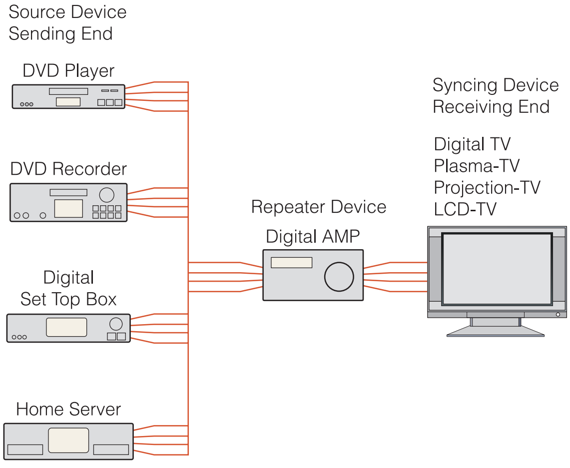
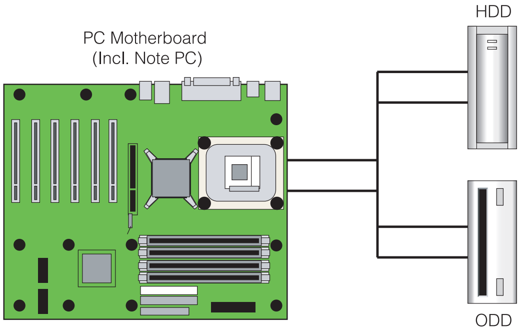


Figure 4 S-ATA (Serial ATA) Usage Example

* S-ATA: Serial AT Attachment



DisplayPort: Whereas HDMI is the standard digital interface for AV device connections, DisplayPort is an interface for connecting computers with monitors. DVI has been used as an interface for connecting computers and monitors, but it seems that this will be replaced by DisplayPort because it is smaller and capable of higher transfer speeds.

DisplayPort contains four “Lanes” of differential pair line. There are two link rate modes for each lane; 1.62 Gbps (Low bit rate) and 2.7 Gbps (High bit rate). In addition, with DisplayPort, the clock signal is embedded in the data signal, so there is no clock line as with HDMI / LVDS. Therefore, the maximum transfer rate is 10.8 Gbps (2.7 Gbps × 4), making is compatible with resolutions of QXGA (2048 × 1536) and higher.

The standard frequency during 2.7 Gbps transfer is 1.35 GHz, which places it in the GHz range. In the past, most noise problems with high-speed interfaces were related to the band below 1 GHz. However, with DisplayPort, the standard frequency noise spectrum exists in the GHz band, so it is necessary to verify interference problems related to wireless applications.

PCI-Express for internal computer bus connections, and Infiniband for connecting servers, which operate at over 3 Gbps, have also been released as advanced interfaces. It is expected that differential transfer methods will become more common as interfaces capable of transferring signals at higher speeds while minimizing the number of wires (Table 1).

Table 1 Common High-Speed Interface Types and Speeds

USB 1.1 / USB 2.0	12 Mbps / 480 Mbps
IEEE1394.a/b	400 Mbps / 800 Mbps
LVDS	1.12 Gbps: UXGA
Mini-LVDS	1.12 Gbps: UXGA
RSDS	160 Mbps
S-ATA I / II / III	1.5 Gbps / 3 Gbps / 6 Gbps
DVI	1.65 Gbps: UXGA
HDMI	3.4 Gbps: 1080 p / 16 bit gradation
DisplayPort	2.7 Gbps
PCI Express (I/II)	2.5 Gbps / 5 Gbps
USB 3.0	5 Gbps

2 | What is Differential Transmission?

Various methods for transferring high-speed signals have been proposed and have come to be used. In order to improve EMC, this section will explain the differential transfer method, which is commonly used for these interfaces.

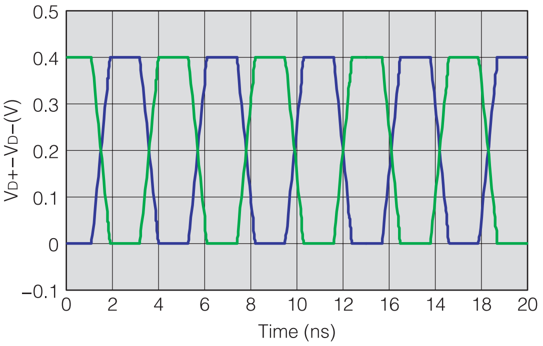
The differential transfer method uses two signals that have 180° opposite phases, which is different from single line data transfer. This transmission method is also referred to as balanced transmission, which has a smaller amount of unnecessary radiation than with the normal single-end transmission method, and also has the characteristic that it is more resistant to influence from other devices. However, in reality, common mode noise is generated due to differential signal unbalance, noise current leaks from other circuits on the substrate to the outside through the connector, and noise is radiated through the cable, which acts like an antenna.

In the above, it was explained that the unbalance of the differential signal causes common mode noise, and this section will explain more details about this unbalance. Figure 5 shows ideal differential transmission and the signal waveform with phase shifting between differential signals. The ideal common mode voltage, which is expressed as the total of the two signals, is linear. However, when the signal has poor symmetry among the channels, unbalanced components are generated. This is referred to as skew.

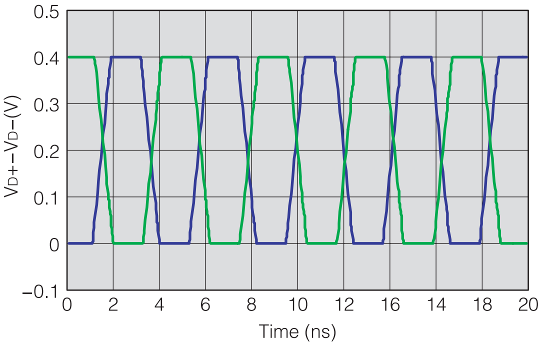
Figure 5 Differential Signal Unbalanced Components

Differential Signal Waveform

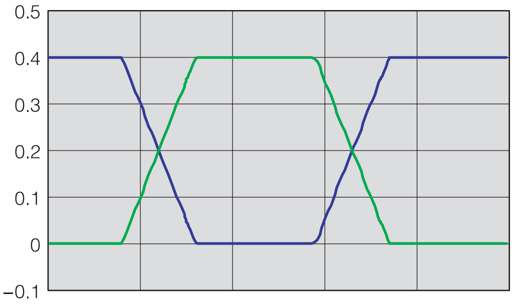
(a) Ideal differential signal



(b) Phase shifting (0.1 nsec.)

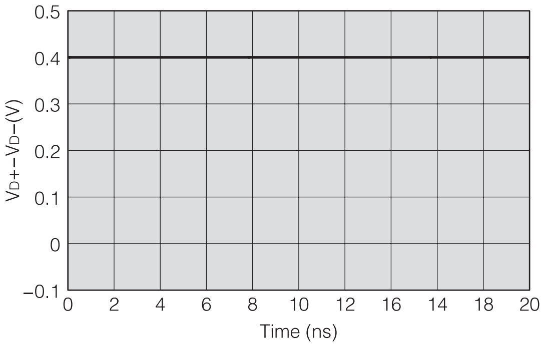


Blowup of (a)

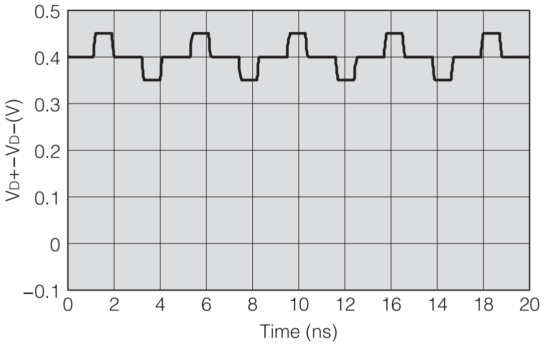


D+ + D– (Common Mode Voltage)

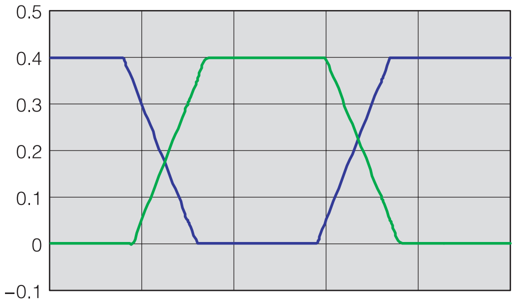
(a) Ideal differential signal



(b) Phase shifting (0.1 nsec.)



Blowup of (b)

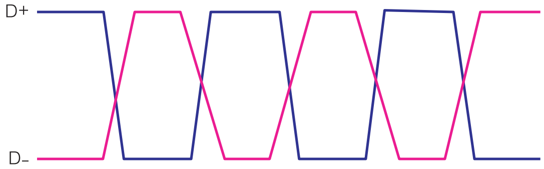


As shown in Figure 6, unbalanced components are also generated by other unbalances such as differences in the rise and fall times and differences in the pulse width and amplitude. Unnecessary common mode radiation increases if the amplitude of the unbalanced components is higher.

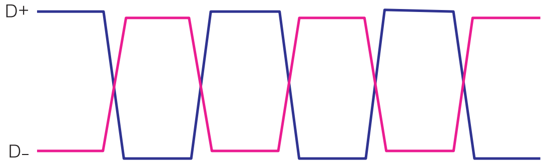
Common Mode Filters are components with 1:1 transformer characteristics consisting of coupled coils between two channels. The main purpose of these filters is to suppress common mode current, but they are also effective for correcting differential signal unbalance. When a signal is input to one channel, the same signal is induced to the other channel so that balance can be maintained between both lines.

Figure 6 Other Possible Causes of Unbalance

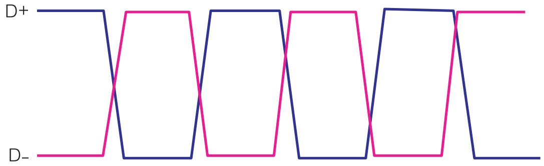
(a) Difference in rise and fall times



(b) Voltage potential difference



(c) Difference in pulse width



As shown in Figure 7, the input voltages for the two channels are expresses as V_1 and $–V_2$, and the output voltages are expressed as V_1out and $–V_2$out. The output voltage is the total of aV_1 and $–aV_2$ voltages that pass each channel, and the total of the $–bV_1$ and bV_2 voltages that are induced.

This is shown in the following equations.

$$V_{1}\text{out} = aV_1 + bV_2$$

$$V_{2}\text{out} = -aV_2 - bV_1$$

The coefficients a and b include the coupling coefficients between the channels, the common mode inductance, and the termination resistance.

This is shown in the following.

Coupling Coefficient: $K = 1$,

When Common Mode Impedance $Z_c >>$ Termination Resistance: Z_0,

$$a = b = 1/2,$$

$$V_{1}\text{out} = -V_{2}\text{out} = V_1/2 + V_2/2$$

Therefore, when V_1 and V_2 are different, the absolute values of the absolute voltages are equal.

Figure 8 shows the differential signal waveform for USB 2.0 HS (High Speed) mode. This shows that the unbalanced component of the common mode voltage was corrected by installing a Common Mode Filter. This shows the effectiveness of reducing unnecessary common mode radiation. Based on this result, it can be said that Common Mode Filters are effective components for the EMC countermeasures of differential signal lines.

The differential mode impedance of Common Mode Filters can be reduced in the high-frequency band through magnetic coupling of the channels. Therefore, there is no danger of influencing high-speed differential signal waveform quality. Common Mode Filters with high coupling are better because they have lower differential mode impedance. Details regarding the effectiveness of correcting skew will be explained in Chapter 4 using test results, which will help to show the how Common Mode Filters can be used to reduce EMI.

Figure 7 Advantages of Common Mode Filters

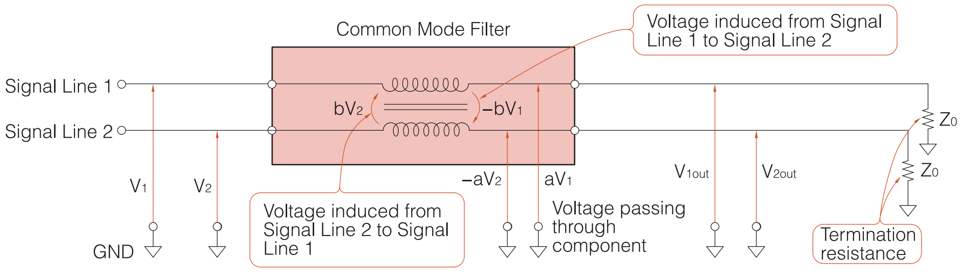


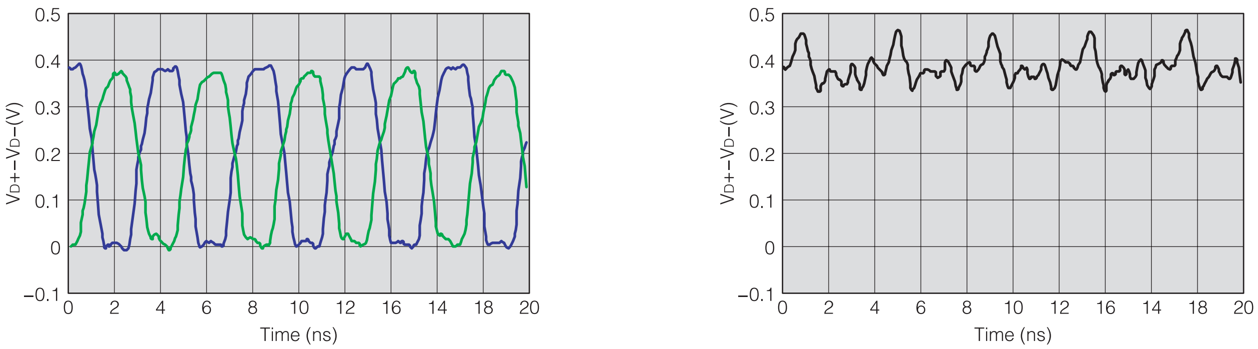
Figure 8　Differential Signal Unbalanced Components

Differential Signal Waveform

D+ + D– (Common Mode Voltage)

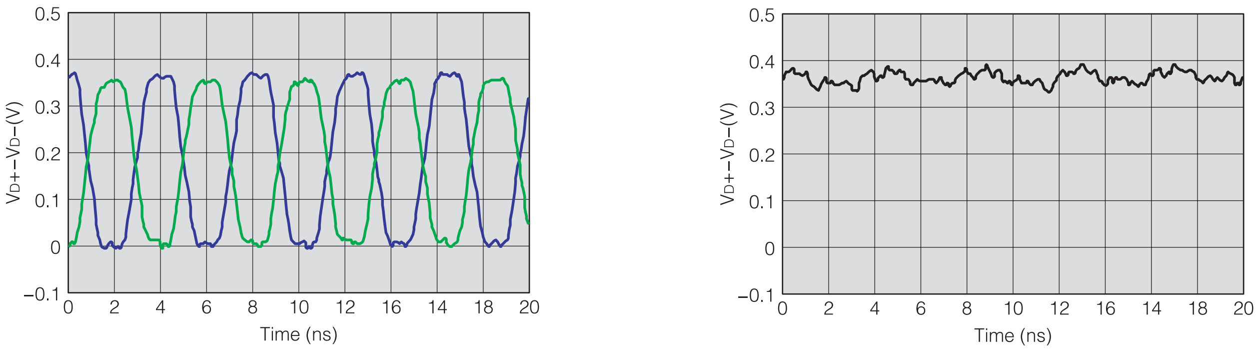
(a) USB 2.0 device differential signal

(a) USB 2.0 device differential signal



(b) Common Mode Filter Application Example (ACM2012-900-2P)

(b) Common Mode Filter Application Example (ACM2012-900-2P)



3 EMC Countermeasures for Gigabit Transfer Interfaces

DVI (Digital Visual Interface) and HDMI (High Definition Multimedia Interface) are designed using high-speed TMDS (Transition Minimized Differential Signaling) so that large amounts of information such as HDTV video signals can be sent without being compressed.

These interfaces are often used for multimedia devices such as Digital TVs, computers, DVD players, STBs, DVD recorders. Directionality is not bidirectional, and the circuit configuration is for sending information one-way from the sender to the receiver. The speed reaches up to 1.6 Gbps, and the basic frequency reaches 800 MHz or higher. This frequency is four to five greater than for USB and IEEE1394, so the details of the requirements for signal quality are regulated (Figure 9).

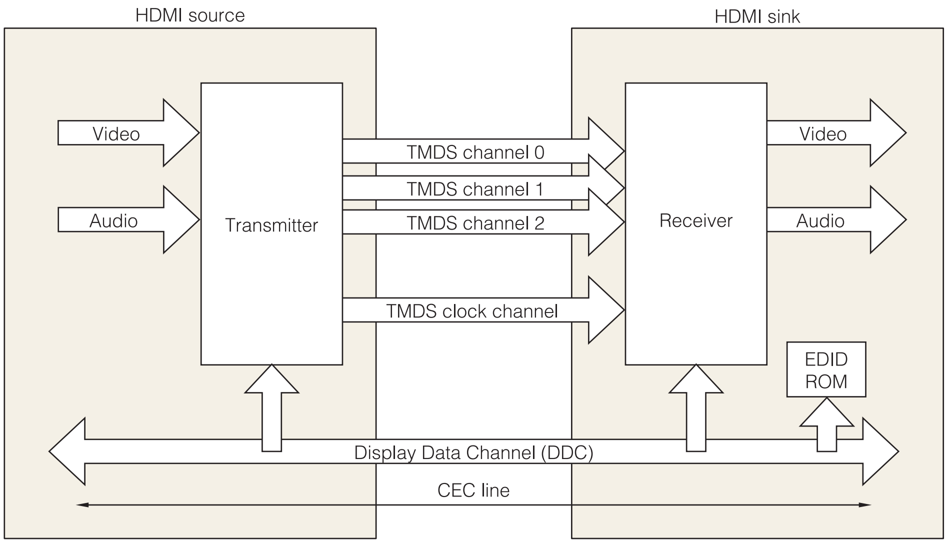
For this purpose, the following are used.

Eye-patterns

Transmission Line Characteristic Impedance (Cables and Wires on PCBs)

High-frequency (fifth to seventh order of 800 MHz) EMI can occur, so it is important to implement countermeasures for high-frequency EMI.

Figure 9　HDMI Interface Connection Diagram



This section will explain the characteristics of newly developed Common Mode Filters for DVI, HDMI, and DisplayPort, their influence on the signal, and their effectiveness for EMI suppression.

1) Common mode filters for HDMI and DVI with 6 GHz cutoff frequency and for DisplayPort with 8 GHz cutoff frequency

Common Mode Filters are used to suppress EMI by installing them to interfaces that handle Gigabit signals. As mentioned in the explanation for USB and IEEE1394, signal quality is strongly affected. Because of this, it is necessary to optimize the cutoff frequency for each interface based on the insertion loss of the differential mode. As a result, it is possible to transfer high-speed TMDS signals without causing strain. With digital signal transmission, transmission is at least five times (fifth order harmonics) that of the fundamental wave so that signal quality can be maintained during transmission.

When Common Mode Filters (ACM-H and TCM-H Series) are used for HDMI, 6 GHz cutoff frequency allows for fifth order harmonics of 2.225 Gbps (about 1.1 GHz) to pass through sufficiently at the 1080p Deep Color transfer rate, which means the HDMI signal quality can be maintained. The cutoff frequency of Common Mode Filters for DisplayPort (TCM-U Series) was extended up to 8 GHz so that there is no signal deterioration of 2.7 Gps signals (Figure 10 and Figure 11).

2) Eye-pattern

With HDMI, the Eye-pattern is regulated, so if the signal contains strain, it cannot pass the standard. Common Mode Filters for HDMI help to ensure the 6 GHz bandwidth so that products can easily pass the Eye-pattern test. Figure 12 shows the measurement conditions, and Figure 13 (a) shows the measurement results for DVI.

Similarly, the Eye-pattern is also regulated for DisplayPort. When a TCM1210U Series component for DisplayPort is used, the 2.7 Gbps signal does not deteriorate. Figure 13 (b) shows the eye diagram for the sending baseplate. Figure 13 (c) shows the eye diagram for a 10 m cable. The Common Mode Filter did not cause deterioration on the eye diagram with a 10 m cable, which indicates that TCM1210U can be used to reduce noise while maintaining signal quality.

Figure 10 Common Mode Filter for HDMI that Ensures the 6 GHz Band

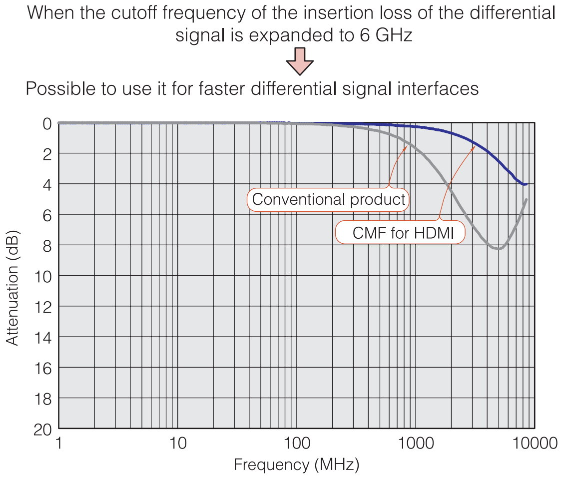


Figure 11 High-band, High-Quality Winding Type CMF

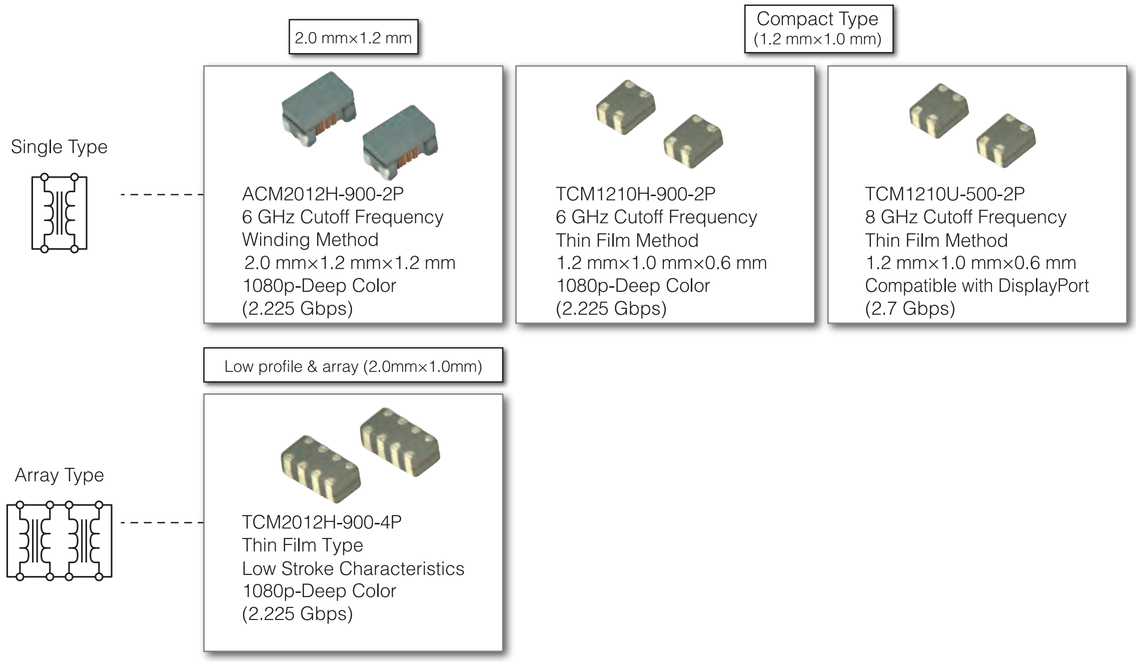


Figure 12　DVI (UXGA: 1.65 Gbps) Waveform Measurement Conditions

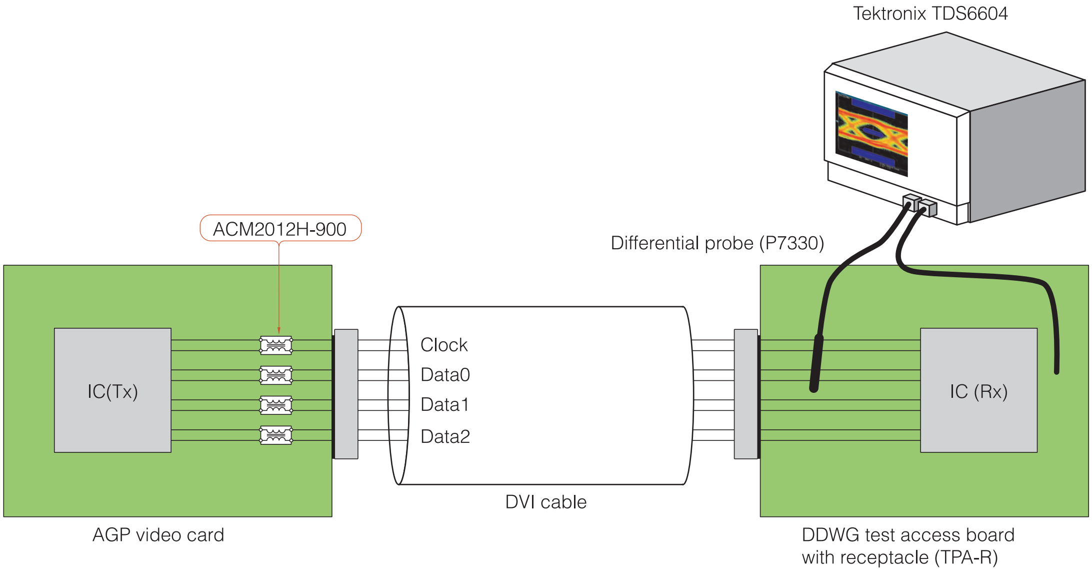
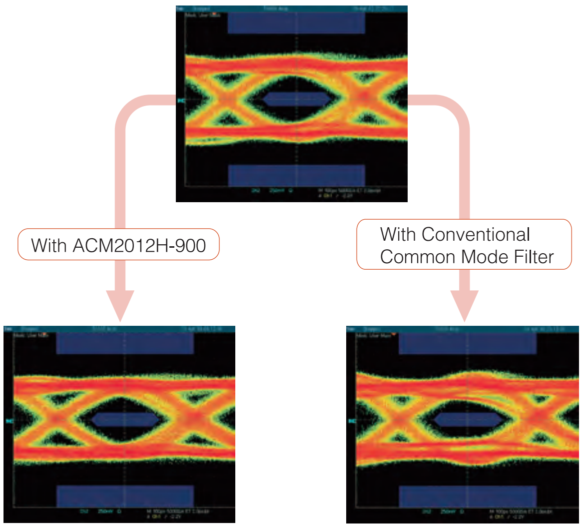
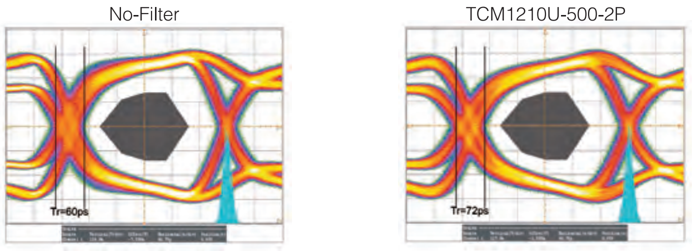


Figure 13

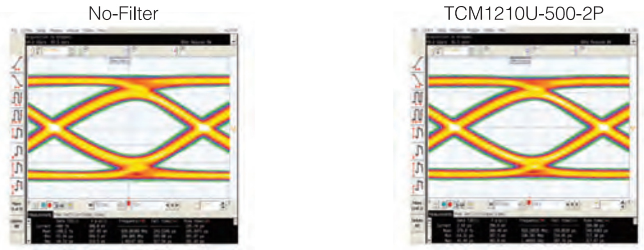
(a) HDMI waveform



(b) DisplayPort waveform at the sending baseplate
(2.7 Gbps during transmission)



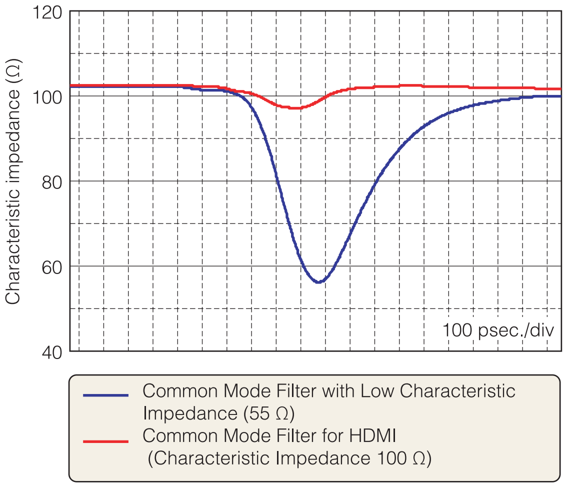
(c) DisplayPort waveform at receiving baseplate using 10m cable
(2.7 Gbps during transmission)



3) Characteristic Impedance

HDMI standards regulate TDR (Time Domain Reflectometry) characteristics. This regulates the characteristic impedance for the transmission line so that high-speed signals can be transmitted. The characteristic impedance for PCB patterns equipped with ICs, cables mainly used for transmission lines, and connectors for connections are set at 100 ±15 Ω. If a Common Mode Filter not recommended for TMDS (or for DVI and HDMI) is used on a TMDS line to suppress EMI, the product will not meet this regulation. For HDMI, the test conditions for regulating connectability will not be met (Compliance tests for HDMI are regulated so that connectability can be guaranteed. If this test is not passed, a product cannot be approved for as an HDMI device.). Common Mode Filters for HDMI are design so that the characteristic impedance between the lines is 100 Ω, which means they can be used safely (Figure 14).

Figure 14



4) EMI Measurement Examples

Figure 15 shows an efficiency example of EMI suppression for HDMI. Figure 16 shows a sample circuit using one of our Common Mode Filters.

Figure 15 Effectiveness of EMI Suppression for HDMI Devices Using an HDMI Filter

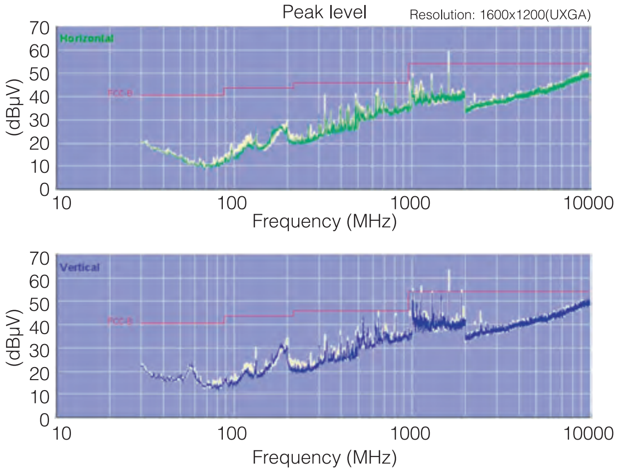
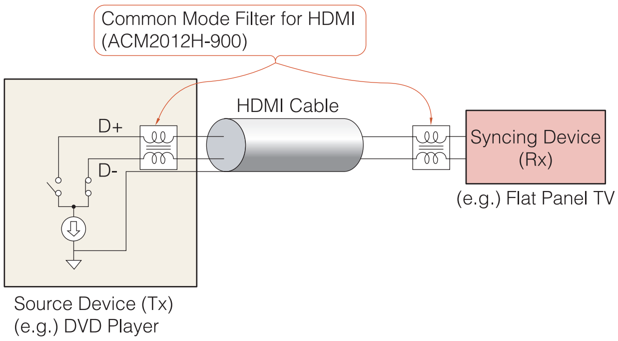


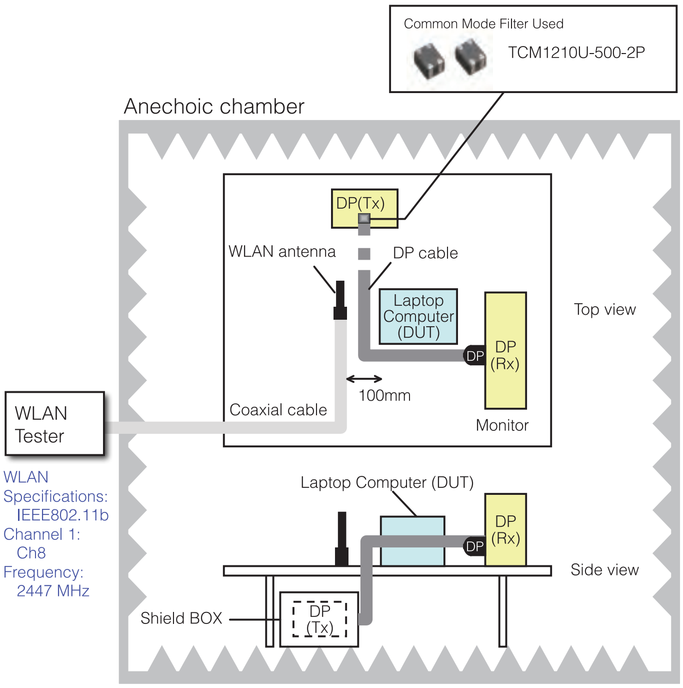
Figure 16 Similar Countermeasures Implemented to a Differential Line with a Total of 4 Pairs: Data Channel (3 Pairs) and Clock Signal (1 Pair)



As with other interfaces, it is necessary to consider noise radiation for DisplayPort. However, computers and monitors are set as the target, so it is also necessary to consider noise interference from wireless devices for computers that use wireless signals such as WLAN and Bluetooth. This noise can be effectively suppressed using Common Mode Filters. Figure 17 shows a measurement diagram for verifying the influence of wireless devices. Figure 18 shows the measurement results. A WLAN device was used for testing. Using IEEE802.11b at 2.4 GHz, it was confirmed that WLAN reception sensitivity differed when noise suppression components were used and when they were not used. By installing a filter, noise was reduced by about 2 to 3 dB.

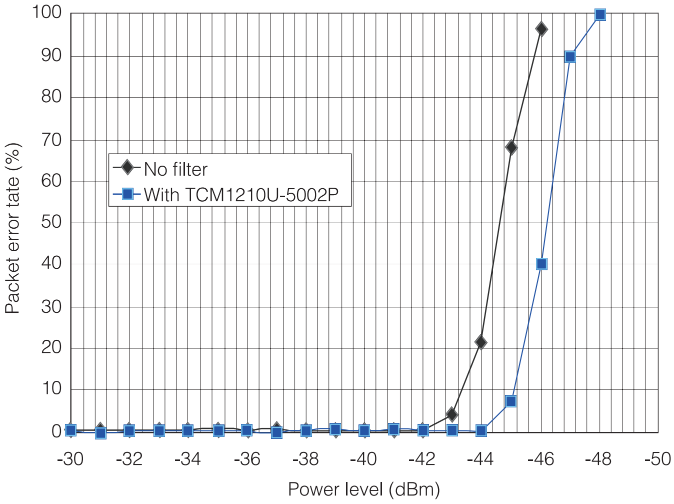
In the past, noise countermeasures have been implemented to meet FCC and CISPR noise standards. However, from now, it is expected that countermeasures will need to be implemented for electromagnetic noise, which affects the operation of wireless devices.

Figure 17 Verification of the Influence of DisplayPort on WLAN Devices (Measurement Conditions)



- Verified how much the DisplayPort cable affected the reception sensitivity of a laptop computer with built-in WLAN.
- A graphic board was used as the DisplayPort sending end. A Common Mode Filter was installed at the base of the DisplayPort connector.
- A W-QXGA LCD monitor was used at the receiving end.

Figure 18 Verification of the Influence of DisplayPort on WLAN Devices (Measurement Conditions)



- The expression “No filter” means a short circuit occurred without using a filter. A TCM1210U Common Mode Filter was used.
- The packet error rate of the vertical axis was calculated based on the error packet from the sent packets (1000 packets).
- The horizontal axis indicates the power of the WLAN tester. The filter improved sensitivity by about 2 dB.

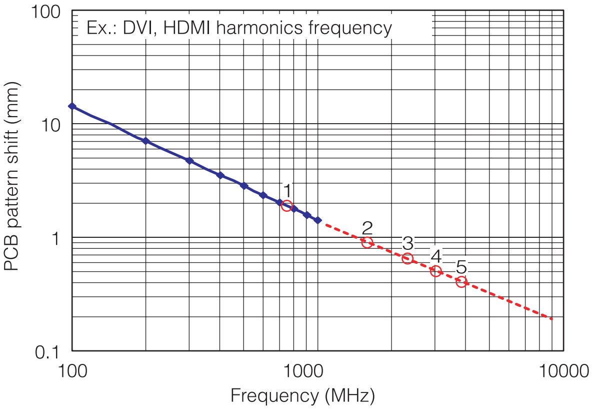
4 How Do Common Mode Filters Suppress Differential Signal Noise?

As mentioned previously, the differential transmission method is used for many devices. The following will explain how Common Mode Filters can be used to suppress differential signal EMI showing basic test results.

A signal generator was used instead of an actual IC in order to simplify the tests, and an accurate signal was used where skew was given to the differential signal, a Common Mode Filter was installed on the differential line, and then efficiency was verified.

IC output itself may already contain skew, and skew may occur during differential signal transmission due to rise and fall characteristic variation. In addition, when the differential signal from the IC is transmitted by the PCB pattern and cables, the difference in the distance to the receiver terminal may be viewed as skew.

Figure 19 Frequency Characteristics Example



Condition: Calculation was made using a ε4.5 transmission line on a glass epoxy board.
The signal transmission speed was 141,323 km/sec. for the ε4.5 glass epoxy board.

Figure 19 is a graph that shows the amount of difference with the PCB pattern can cause skew at the frequency of the differential transmission method that is normally used. The necessary transmission time for skew to occur at 1% at each frequency was calculated. For example, when a signal was transmitted using DVI and HDMI at 800 MHz, the difference in the pattern length was about 2 mm, and skew of about 1% occurred. Therefore, a stricter pattern design is needed for high-order harmonic components.

Figure 20 shows the devices and circuit diagram that were used for testing. A pattern that can receive the differential signal from the signal generator on the baseplate was prepared and then the component was installed. A shielded cable about 1 m long and with a characteristic impedance of 100 Ω was installed, and it was terminated at 100 Ω. The waveform and EMI was observed by changing the skew from 0 to 3% with a basic frequency set at 100 MHz and amplitude set at 400 mV.

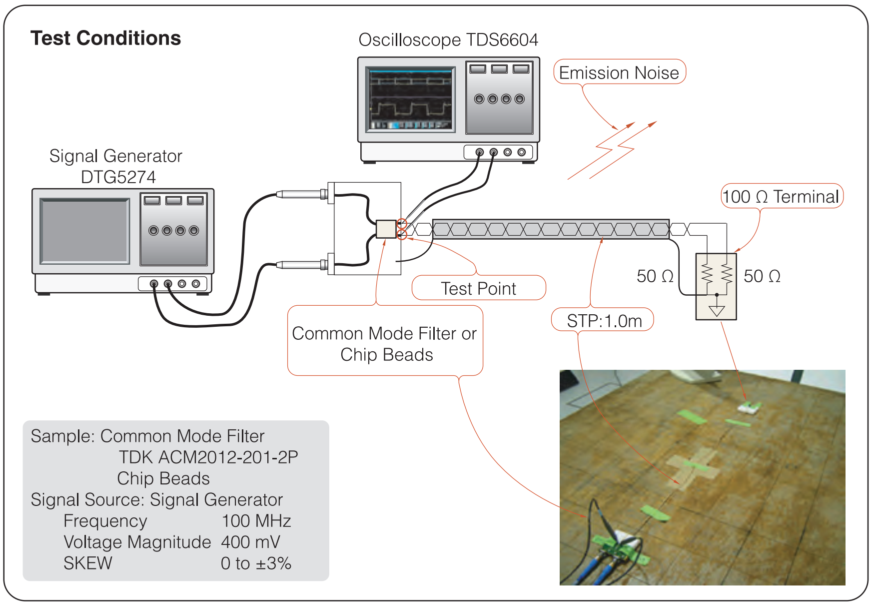
Figure 21-1 shows the waveform when skew was 0%. The throughput was the waveform when no noise components were used. ACM2012-201-2P is a Common Mode Filter often used for USB and IEEE1392 for EMI countermeasures. Measurements were also made when chip beads were used, which are commonly used for EMI countermeasures on signals other than differential signals.

The first waveform in Figure 21-1 is based on the measurement of the differential signal using a single-end probe. The second waveform is the measurement of the common mode voltage with the differential signal added. If a voltage occurs here, noise is radiated as EMI.

The third waveform in Figure 21-1 shows the difference of differential signals, and this waveform is transferred as the input of the receiver terminal IC. The second common mode voltage needs to be given attention.

Figure 21-2 shows when approximately 1% skew is given to the differential signal from the signal generator. A small amount of common mode voltage was observed. However, the voltage amount was according to the order: EMI Components > Chip Beads > Common Mode Filter. The voltage was almost nonexistent when a ACM2012 Common Mode Filter was used.

Figure 20 Diagram of Test Equipment and Circuit



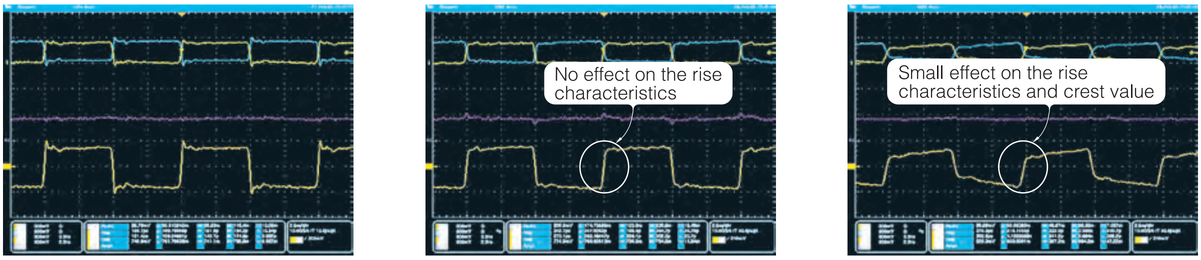
Sample: Common Mode Filter
TDK ACM2012-201-2P
Chip Beads
Signal Source: Signal Generator
Frequency 100 MHz
Voltage Magnitude 400 mV
SKEW 0 to ±3%

This shows the effectiveness of Common Mode Filters for correcting skew.

Figure 21-3 and Figure 21-4 show the waveforms when the skew amount sent from the signal generator was increased to 2% and 3%. The amount of common mode voltage gradually increased when no EMI components were used and when chip beads were used. However, when a Common Mode Filter was used, skew was corrected and the voltage was almost nonexistent. Also, when chip beads were used, the differential signal and the voltage magnitude of the signal at the receiver terminal were affected, so it was found that crest value was small.

Figure 21-1　Waveform Data when Skew was Impressed

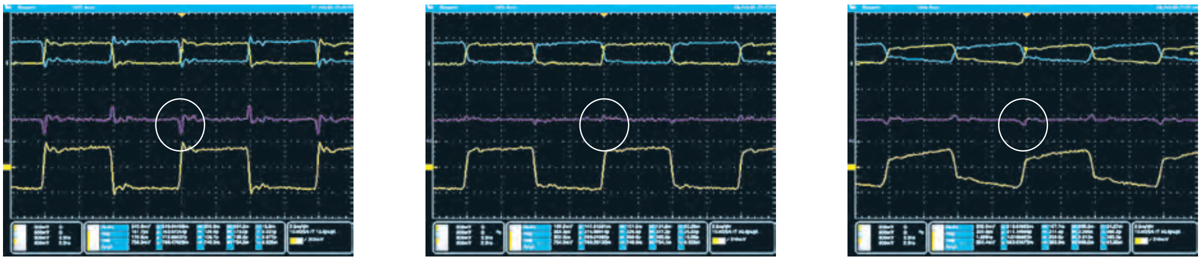
SKEW: 0%



No EMI Components　　With Common Mode Filter　　With Chip Beads

Figure 21-2

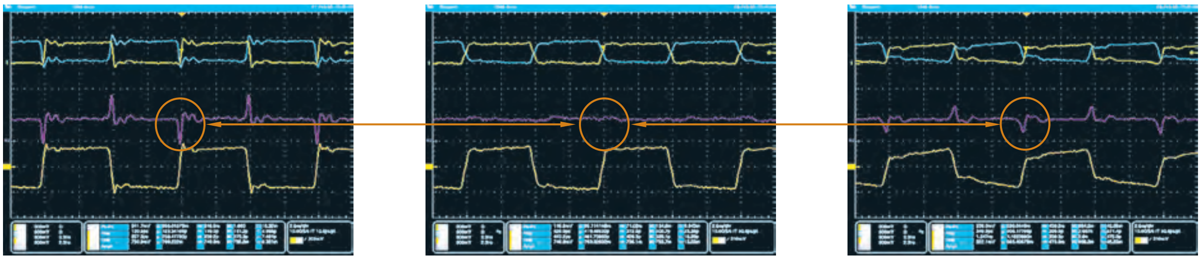
SKEW: 1.0%



No EMI Components　　With Common Mode Filter　　With Chip Beads

Figure 21-3

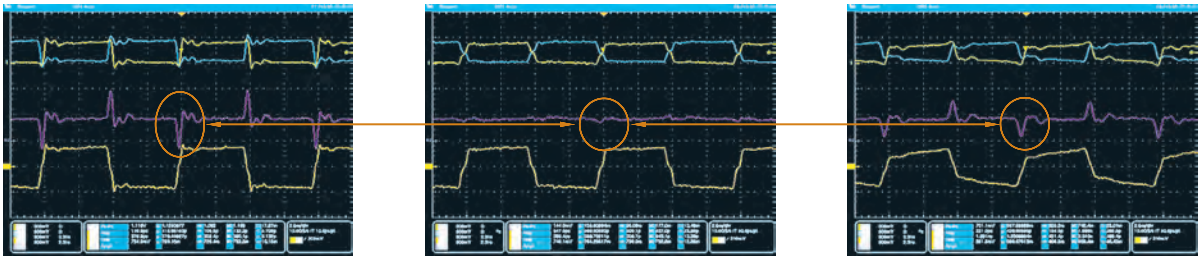
SKEW: 2.0%



No EMI Components　　With Common Mode Filter　　With Chip Beads

Figure 21-4

SKEW: 3.0%



No EMI Components　　With Common Mode Filter　　With Chip Beads

Figure 22 shows a graph with the common mode voltage changes plotted. When a Common Mode Filter is used, the common mode voltage was almost nonexistent even when the skew was large.

Figure 22 Common Mode Voltage due to Skew

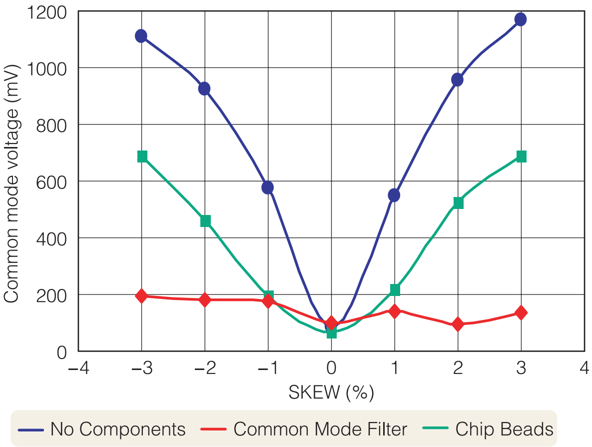


Figure 23 shows the measurement data for EMI radiation characteristics when a 3-m anechoic chamber was used. It was found that Common Mode Filters are very effective at suppressing EMI.

Figure 24 shows a graph plotting the EMI radiation characteristics based on odd-order harmonics including the fundamental wave.

When chip beads were used, the amplitude of the fundamental wave was affected, so EMI occurrence was smaller than when a Common Mode Filter was used at 0%. When a Common Mode Filter was used, it was transmitted without deterioration of the waveform. Therefore, it was lower than when no EMI components were used, but slightly higher radiation characteristics were found than when chip beads were used. Regarding the radiation characteristics from the third to ninth order, the Common Mode Filter was able to reduce EMI radiation up to the harmonics regardless of the amount of skew.

In this way, it was found that Common Mode Filters are able to suppress EMI by effectively correcting skew.

This effectiveness can also be expected when used with actual ICs. Therefore, Common Mode Filters are essential for EMI countermeasures on differential signals, which will continue to become faster.

Figure 25 and Figure 26 show examples of Common Mode Filters.

Figure 23 Effectiveness of Suppressing EMI

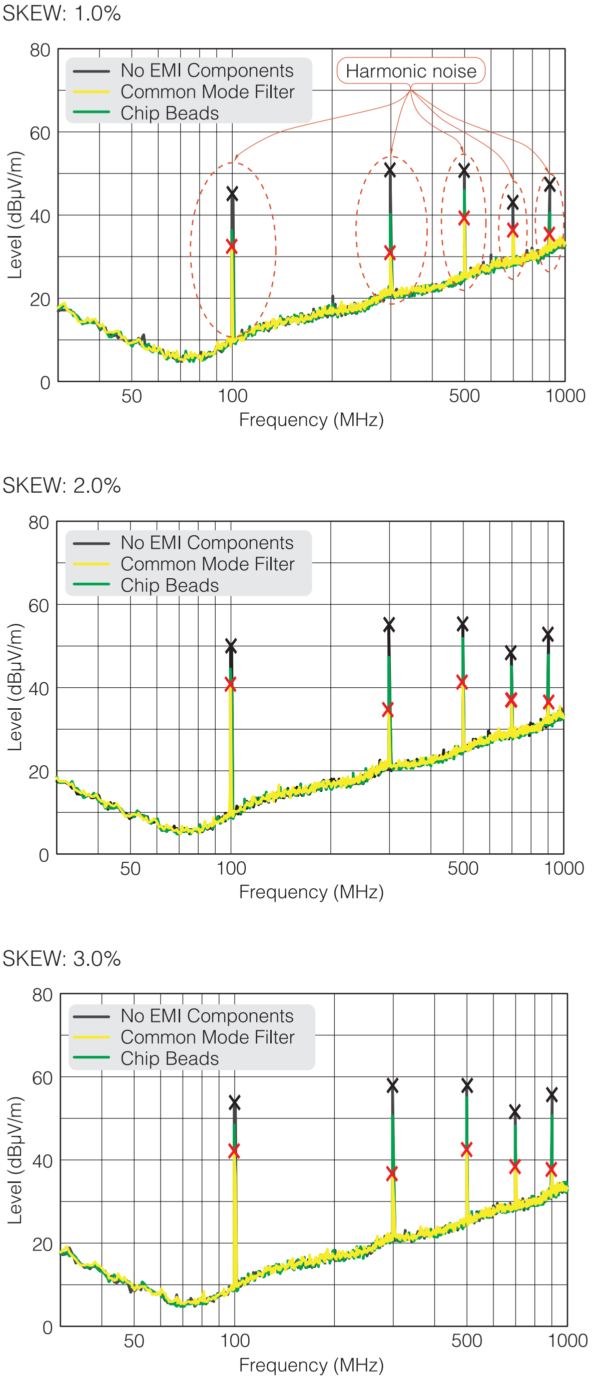
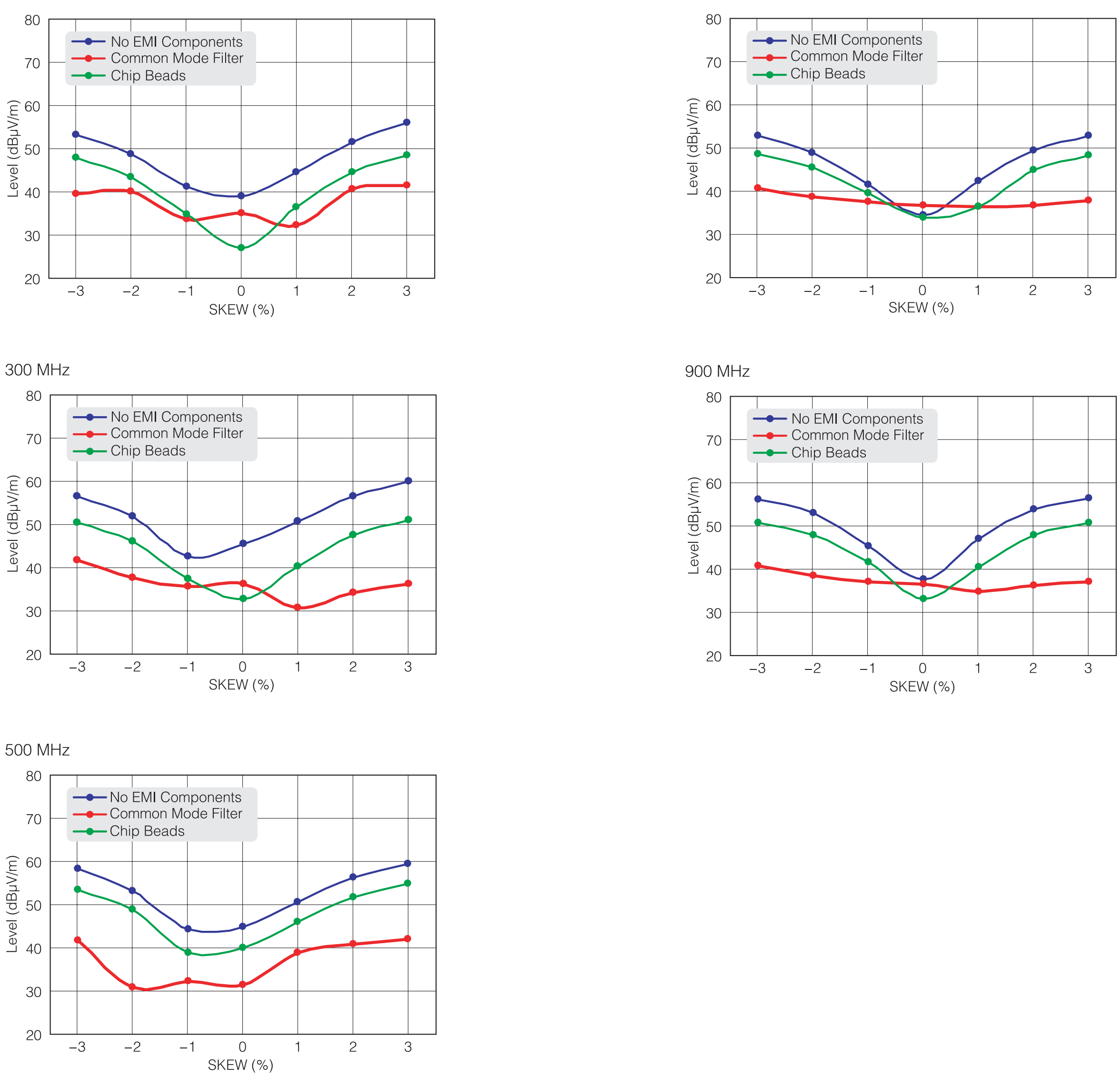


Figure 24 Effectiveness of Suppressing EMI at the Harmonics Spectrum


100 MHz

700 MHz

300 MHz

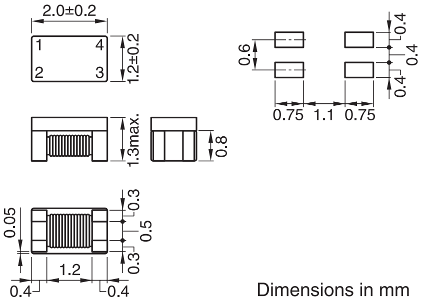
900 MHz

500 MHz

Figure 25 Common Mode Filter Example (1)

ACM2012 Type

Shape / Dimensions and Recommended Land Pattern



Dimensions in mm

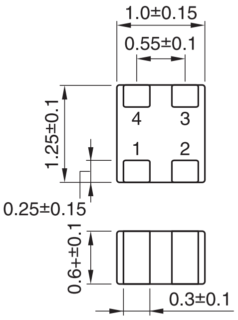
Electrical Characteristics

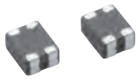
Part No.	Impedance (Ω) typical [100 MHz]	DC resistance (Ω) max. [For 1 line]	Rated current Idc (A) max.	Rated voltage Edc (V) max.	Insulation resistance (MΩ) min.
ACM2012-900-2P	90	0.19	0.4	50	10
ACM2012-121-2P	120	0.22	0.37	50	10
ACM2012-201-2P	200	0.25	0.35	50	10
ACM2012-361-2P	360	0.5	0.22	50	10
ACM2012-102-2P	1000	1.1	0.1	50	10

Figure 26 Common Mode Filter Example (2)

TCM1210 Type

Shape / Dimensions

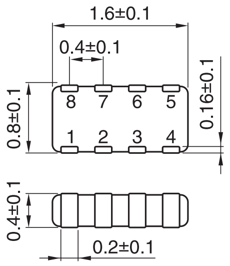


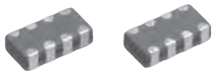


Dimensions in mm

TCM1608 Type

Shape / Dimensions





Dimensions in mm

Electrical Characteristics

Part No.	Impedance (Ω) typical [100 MHz]	DC resistance (Ω) max.	Rated current Idc (A) max.	Rated voltage Edc (V) max.	Insulation resistance (MΩ) min.
TCM1210-650-2P	65	1.5	0.1	10	10
TCM1210-900-2P	90	1.75	0.1	10	10
TCM1210-201-2P	200	2.7	0.1	10	10
TCM1210-301-2P	300	3.5	0.05	10	10
TCM1608-350-4P	35	0.85	0.1	10	10
TCM1608-650-4P	65	1.3	0.1	10	10
TCM1608-900-4P	90	1.5	0.1	10	10
TCM1608-201-4P	200	3.0	0.05	10	10

· Operating temperature range: -25 to +85°C

TDK EMC Technology **Practice Section**

EMC Countermeasures of Low Voltage Differential Signaling Circuits

TDK Corporation　Magnetics Business Group
Toshio Tomonari

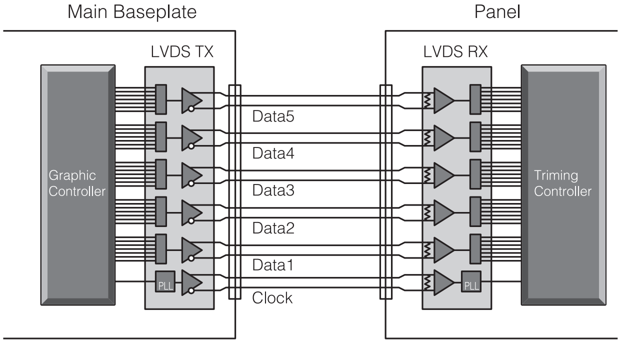
1 Introduction

Low Voltage Differential Signaling (LVDS) is the most common differential transmission system, and it is used for many devices that require high-speed transmission because of its general-purpose properties. As mention is another chapter, USB 2.0 and DVI, HDMI, and DisplayPort are external interfaces that are used to connect devices. However, LVDS is used as an internal interface for many devices for connecting baseplates. This can be used for various purposes and is therefore used by many devices. This section will discuss issues related to EMC which can occur with LVDS, along will solutions using displays as examples such as TVs and monitors.

Figure 1 shows some of the LVDS configurations for connecting the main baseplate and panel of a display. Generally, the LVDS circuit consists of clock and data lines, and are configured according to the following.

LINK = Clock × 1 + Data × 5

Figure 1　LVDS Configuration Example



Display LVDS transmission using Clock × 1, Data × 6 for one link

The transmission rate for one data line is the clock frequency multiplied by seven.

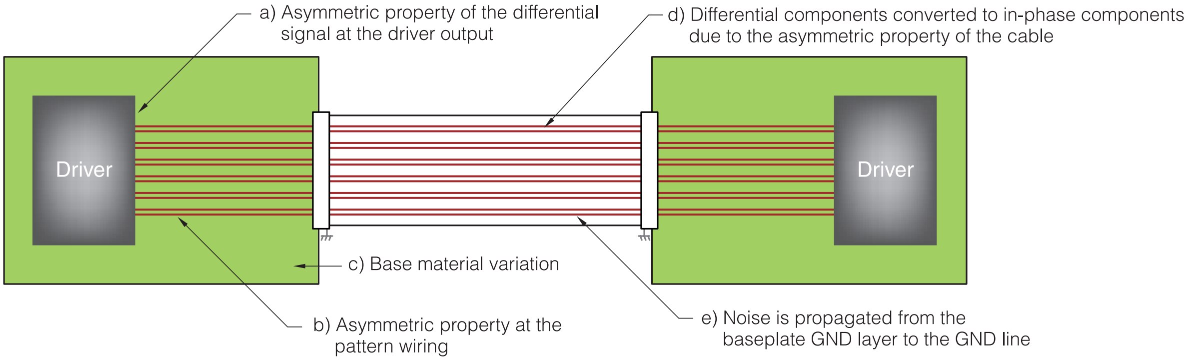
For example, when the clock frequency is 74 MHz, Data Line 1 is 518 Mbps, and the basic frequency is 259 MHz.

Recently, TVs have come to have higher definition displays, so the transmission capacity of one LINK is not sufficient, so in some cases the number of LINKs has increased to two. In such cases, the configuration is Clock × 1 + Data × 10, nearly doubling the number of lines.

2 EMC Issues Related to LVDS

With LVDS, termination ends at 100 Ω between differential lines, and impedance matching is executed for the differential signal. However, in-phase components are nearly open, so in-phase components are reflected at the terminal end. The reflected in-phase components are propagated through the cables that connect the baseplates, which can cause unnecessary radiation. Basic noise countermeasures involve removing in-phase components, which is especially important for LVDS because in-phase components have a major effect on it. Therefore, in order to implement noise countermeasures for LVDS, it is important to understand the location and cause of in-phase components. The possible locations of in-phase components are the baseplates and cables that consist of physical layers (Figure 2). The following are the factors related to the occurrence of in-phase components with baseplates and cables.

Figure 2　Factors that Contribute to In-Phase Induced Radiation Noise



a) Asymmetric property of the differential signal at the driver output

d) Differential components converted to in-phase components due to the asymmetric property of the cable

c) Base material variation

b) Asymmetric property at the pattern wiring

e) Noise is propagated from the baseplate GND layer to the GND line

Baseplates

- a) S+ / S– phase shifting at the output of the LVDS driver
- b) Variations of the baseplate material (electric permittivity)
- c) Wire unbalance

Cables

Cable specifications are not regulated for LVDS as is the case with HDMI, DVI, so various types of cables are used such as FPCs, twin axial cables, and twist pair cables. The waveform quality differs according to the cable because the transmission characteristics are different according to the type.

However, it is believed that factors causing noise radiation are the same (The processing method for connections between the harness and plug connection / GND also effects noise radiation, so it is an important factor to consider for noise countermeasures, but it differs according to the type of cable and the cable manufacturer, so it is not considered here as a general factor.).

The following are the factors related to cable noise radiation.

- d) Unbalance between the differential pair + and – lines, and weak electromagnetic couple of the + line and – line can cause differential signals to be converted to in-phase components.
- e) GND noise on the baseplate is propagated through the sealed coating of the cable, and the cable acts as an antenna, becoming a noise source.

If a cable is the main cause of noise radiation, the effectiveness of noise countermeasures implemented to the baseplate is limited, so it is important to select cables carefully.

3 Effective Usage of Common Mode Filters

Common Mode Filters, which are components used for EMC countermeasures, are effective for suppressing baseplate in-phase noise radiation causes a), b), and c) (Figure 3).

Figure 3 Points to Consider when Selecting Common Mode Filters

Conditions		Filter Parameters
• Differential signal should not be attenuated	→	Differential characteristic impedance
• High common mode rejection ratio	→	Common mode impedance

TDK has a wide lineup of Common Mode Filters for meeting various needs. It is important to select components carefully in order to improve the EMC of high-speed differential interfaces. Common Mode Filters must have the following two characteristics.

1. Not attenuate differential signals
2. Have a high common mode rejection ratio

Characteristic 1 means that the filter does not affect the signal so that signal quality can be ensured, even when loss is proportionally large to the cable length and type for the size of the panel.

As for characteristic 2, a higher common rejection ration is needed in order to suppress noise over the 10 MHz band, which is assumed for low resolution because the LVDS clock signal changes according to the resolution.

Common Mode Filter parameters related to the above two characteristics are according to the following.

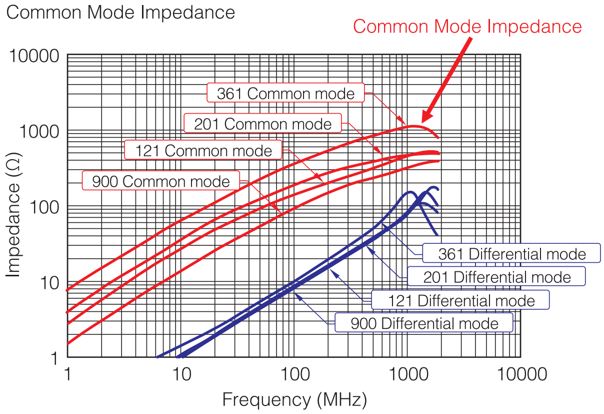
1 → Differential characteristic impedance (LVDS characteristic impedance is 100 Ω)

2 → Common mode impedance

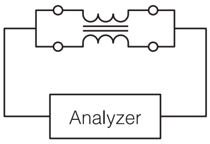
The common mode impedance can be referenced in one of our catalogs (Figure 4).

Figure 4 Common Mode Filter Frequency Characteristics

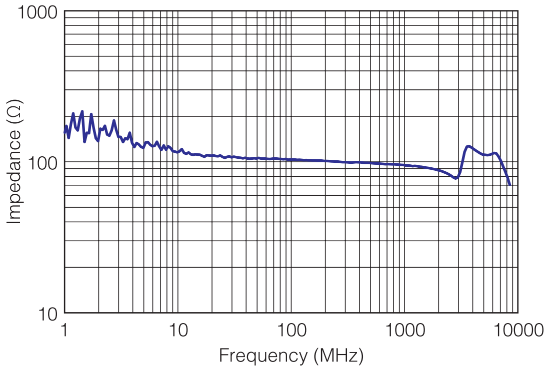
Common Mode Impedance



Measurement Circuit



Differential Characteristic Impedance

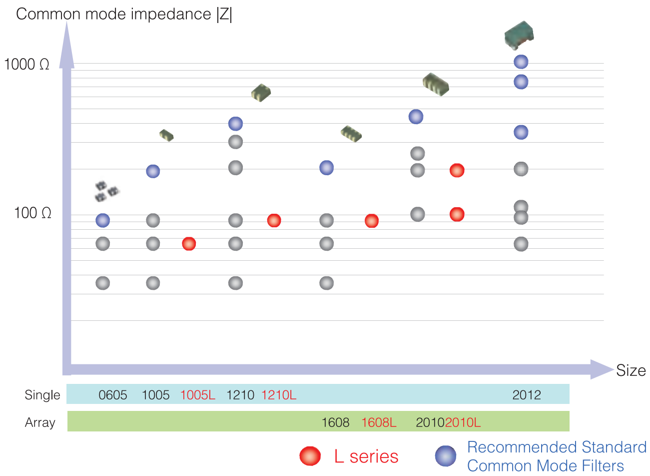


Examples of frequency characteristics for the differential characteristic impedance of Common Mode Filters with network analyzers
Impedance was around 100 Ω over a wide band, and the impedance was matched.
TDR (Time Domain Reflectometry) is a common method for evaluating the characteristic impedance using the time axis.

The differential characteristic impedance can not be referenced in one of our catalogs, so please inquire about this to TDK directly. However, all TDK Common Mode Filters have been developed taking into consideration the differential characteristic impedance, so signal quality is good when the recommended component is used.

Figure 5 shows a lineup of TDK Common Mode Filters for LVDS. The 2012 size filter is compatible with an impedance of 1000 Ω at 100 MHz. The maximum impedance for 1210 size filter is 400 Ω. The TCM-L Series shown in the figure was specially developed for LVDS, and its characteristics will be explained later.

Figure 5 TDK's Lineup of Common Mode Filters According to Size



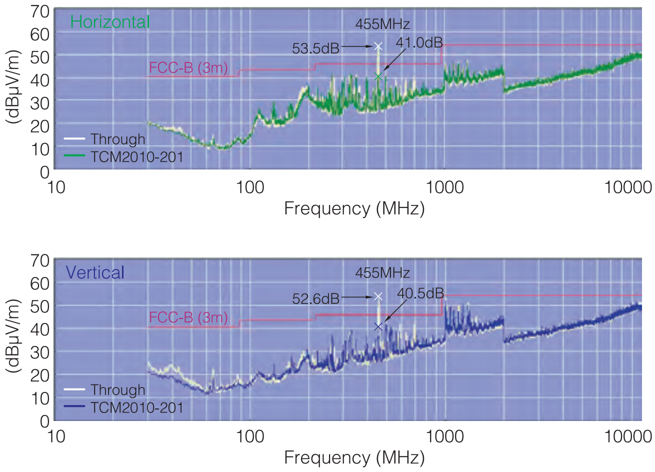
The higher the common mode impedance, the more effective it is at removing in-phase components.
It is recommended to use the filter with the highest impedance for each size.
The L Series was specially developed for LVDS. These components are effective for long cables, as is explained later.

In addition to the electrical characteristics mentioned above, size is also an important factor. LVDS lines consist of 5 to 11 differential lines including clock lines, which require more filters according to the number of lines. Therefore, filters need to be small. TDK's lineup includes the smallest single component filters in the industry (0605 size), and array components including 1608 size filters, which allow us to meet various demands.

Up to here, features of Common Mode Filters and TDK-LVDS Common Mode Filters have been explained. From now, their efficiency will be explained using evaluation results from actual sets.

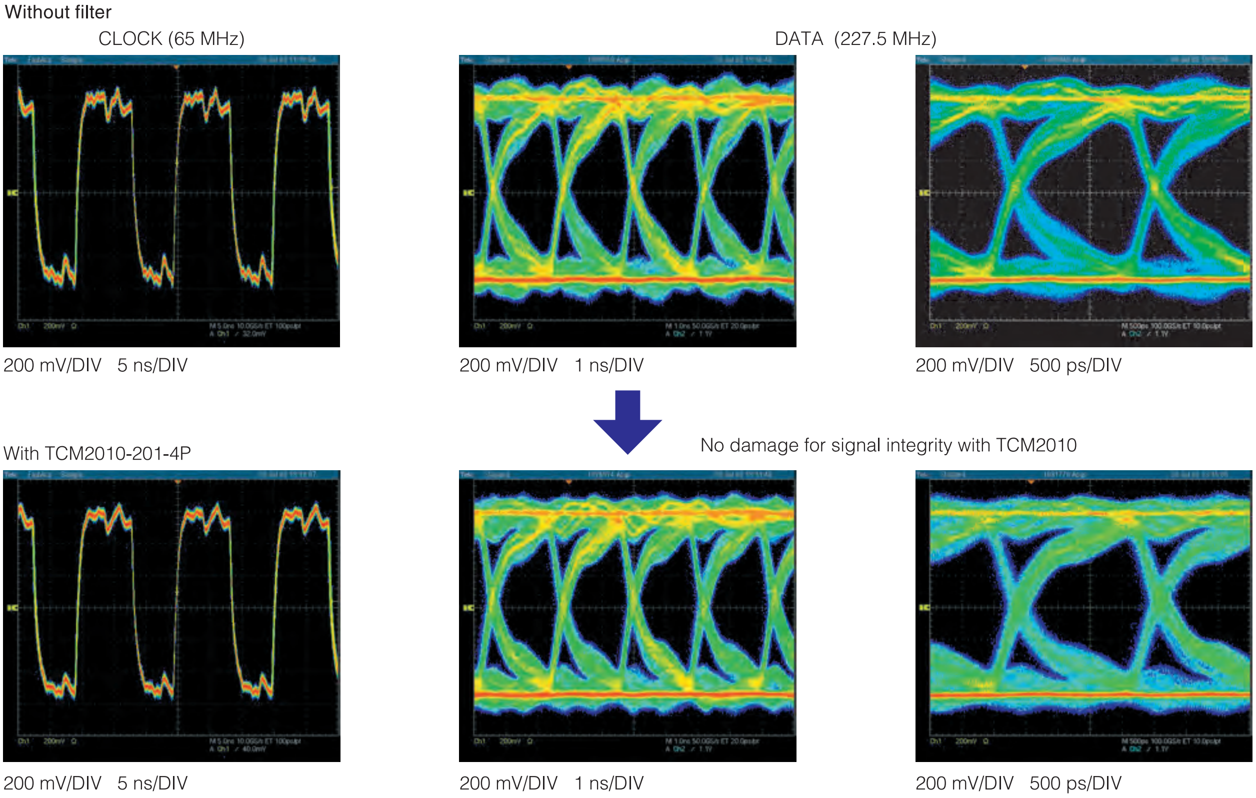
Figure 6 shows the waveform measurement results for a computer. The clock frequency was 65 MHz and the Data rate was 455 Mbps. It was found that the waveform quality was not affected by the Common Mode Filter. Figure 7 shows the results of the noise radiation measurement for the computer. The filter was shown to be effective at the peak frequency of the noise, which was 455 MHz.

Figure 7 Effectiveness Examples of Common Mode Filters for Suppressing Radiation Noise (Using Filters with a Common Mode Impedance of 200 Ω)



Radiation noise evaluation results for Common Mode Filters for laptop computer LVDS cables between the main baseplate and display.
It was shown that using a filter could reduce noise by up to 12 dB [455 MHz].
A filter with a common mode impedance of 200 Ω was used.

Figure 6



No damage for signal integrity with TCM2010

4 Common Mode Filters for LVDS Features and Effectiveness of the TCM-L Series

Common Mode Filters are effective for suppressing LVDS radiation noise, but in recent years, panels have become larger and LVDS cables have become longer, creating new problems.

The following two problems exist.

1. Because of the longer cables, impedance mismatching occurs causing waveform quality to deteriorate.
2. Because of the longer cables, the radiation noise level increases.

In such cases, the Common Mode Filters mentioned in the previous section 3 may have only limited effectiveness. To resolve this problem, the TCM-L Series was developed. These Common Mode Filters are effective for the two problems mentioned above according to the following.

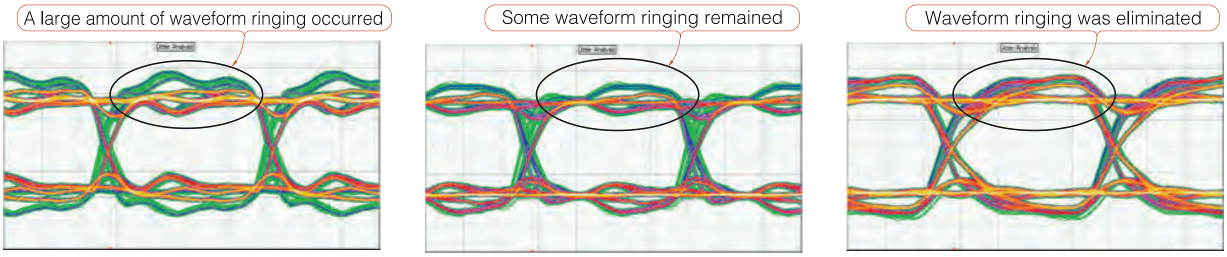
1 → They remove reflected components so that waveform quality can be improved.

2 → They reduce the radiation noise level.
(By improving differential characteristics → In-phase components are removed.)

Figure 8 shows the measurement results for the LVDS waveform using TCM-L Series filters. When no filter was used, the Eye Diagram showed superimposed high-frequency components on the waveform due to reflection. In this situation, the waveform quality did not change even when TCM2010-201-4P was used. However, when TCM2010L-201-4P was used, the reflected components of the high-frequency wave could be removed, and the eye became wider. As a result, the waveform quality improved.

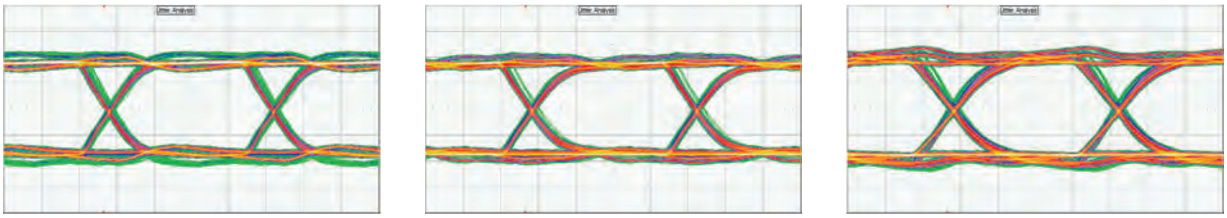
Figure 8 Examples of Waveform Shapes when TCM-L Series Filters are Used

LVDS Signal Waveform CLOCK frequency = 75 MHz (Sending end)



No Common Mode Filter With TCM2010-201-4P With TCM2010L-201-4P

LVDS Signal Waveform CLOCK frequency = 75 MHz (Receiving end)



No Common Mode Filter With TCM2010-201-4P With TCM2010L-201-4P

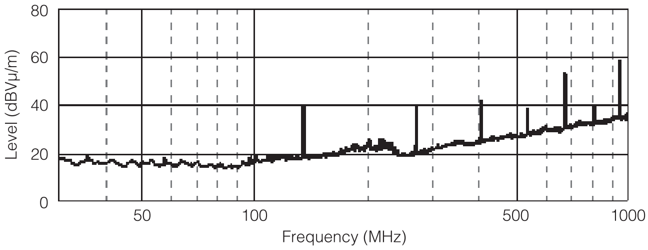
The impedance did not matched at the connector and cable for the LVDS line, so the LVDS signal waveform was greatly deformed.
At that time, a general Common Mode Filters allowed the deformed waveform to pass, but the TCM-L Series filter was able to reshape the deformed signal.
Waveform strain due to impedance mismatching can be reduced, which makes it more effective at reducing noise.

Next, Figure 9 shows the radiation noise measurement results. The CLOCK frequency was set to 135 MHz in order to create strict EMC conditions. The cable was a twin axial cable, which is often used for LVDS. When no filter was used (Figure 9a), a strong peak was found in the harmonics of the LVDS signal.

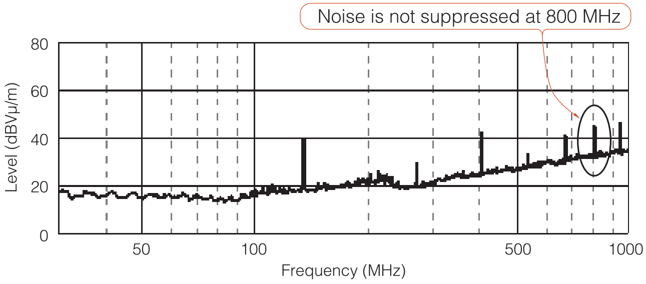
When TCM2010-201-4P was used (Figure 9b), this was removed, but the peak was still obvious at 500 MHz and higher. Therefore, TCM2010L-201-4P was used, and as a result, the peak no longer exists at 810 MHz (Figure 9c).

Figure 9 Examples of Radiation Noise Suppression Using TCM-L Series Filters

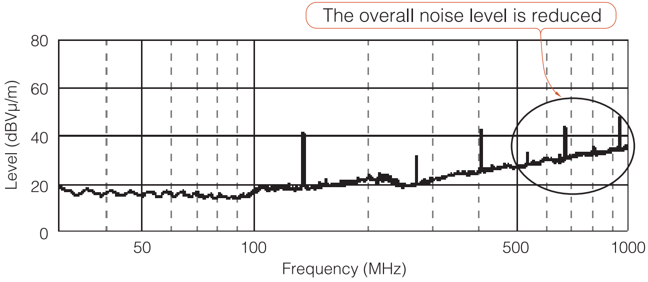
a) No Common Mode Filter



b) With TCM2010-201-4P


Noise is not suppressed at 800 MHz

c) With TCM2010L-201-4P


The overall noise level is reduced

TCM-L Series filters can remove noise that was not removed using a standard Common Mode Filter.
The harmonic components at 135 MHz remained, which is assumed to be clock noise superimposed on the GND line.
A clamp filter is effective for removing this noise.

This series of filters is effective for frequencies where normal Common Mode Filters are not effective, which indicates that they are effective for radiation noise related to cables.

5 TDK Thin-Type Clamp Filters

Figure 9 shows the noise measurement results. It was found that the harmonics components remained at 135 MHz, which is assumed to be clock noise superimposed on the GND line. Clamp filters are effective for suppressing in-phase components such GND system noise for the whole cable. TDK has developed thin-type clamp filters. Figure 10 shows a clamp filter for flat cables.

Figure 10 TDK's Thin-Type Clamp Filter

TDK's thin-type clamp filters, which have the same thickness as the ferrite core
These filters are good for devices with limited space such as thin LCD-TVs, PDP-TVs, DSCs, and DVCs.

6 Conclusion

The features and effectiveness of Common Mode Filters for LVDS was explained here. It can be said that Common Mode Filters are effective for reducing in-phase noise generated by baseplates.

The TCM-L Series can also be used to effectively resolve radiation noise problems related to cables. Therefore, these components can be used as noise countermeasures. In the future, display resolutions will continue to increase, so it is expected that new interfaces (DisplayPort and V-by-One) will become replacements. However, because LVDS is an established and low-cost technology, it will continue to play a major role as an interface between baseplates.

Therefore, LVDS noise countermeasures will continue to be important. It is also believed that the need for the components introduced here will increase as wireless devices become equipped on TVs. TDK has been making efforts to provide solutions to the latest problems related to EMC. Please do not hesitate to consult with TDK.

USB2.0 Technical Manual

TDK Corporation Magnetics Business Group
Mitsuharu Mizutani

1 Introduction

USB2.0 was released in April of 2000 and it has become the standard interface for connecting computers with peripheral devices.

This standard was established by a collaboration of Compaq, HP, Intel, Lucent, Microsoft, NEC, and Philips.

Until 2000, USB1.1 was available with data transfer speeds of 1.5 Mbps (Low speed) and 12 Mbps (Full speed). With USB 2.0 came the addition of 480 Mbps (High speed).

Comparison of Impedance Data Transmission Speeds for Each Interface (Mbps)

IEEE1394	USB1.1	USB2.0
100	1.5	1.5 (Low speed)
200	12	12 (Full speed)
400		480 (High speed)

* In 2009, USB3.0 was released which adds a 5 Gbps SuperSpeed transfer mode.

USB2.0 consists of four lines; two differential signal lines, the Vcc line and GND line. The repetitive pulse frequency at 480 Mbps is 240 MHz, so components for improving EMC such as chip beads affect the signal waveform, which means they are not appropriate. Common Mode Filters are best because they have less of an effect on the signal. TDK has conducted operation verification tests in collaboration with Intel and NEC, and have selected the optimal products for improving EMC.

2 USB2.0 Waveform Response Standards

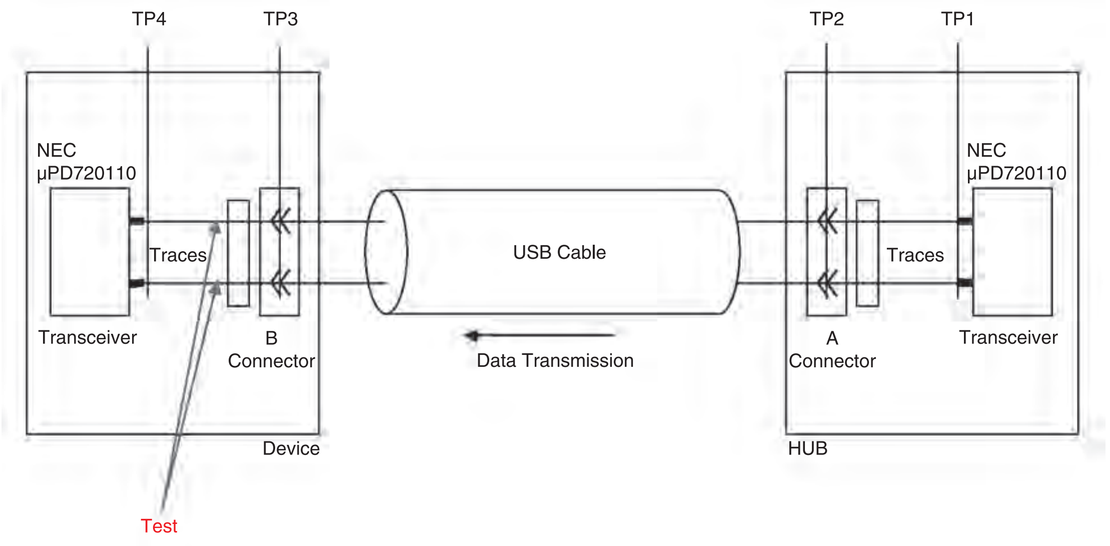
Strict standards are set for high-speed transmissions of 480 Mbps in order to prevent operation problems. The Eye-pattern and SYNC Field waveform response standards are especially important.

2-1. Eye-pattern

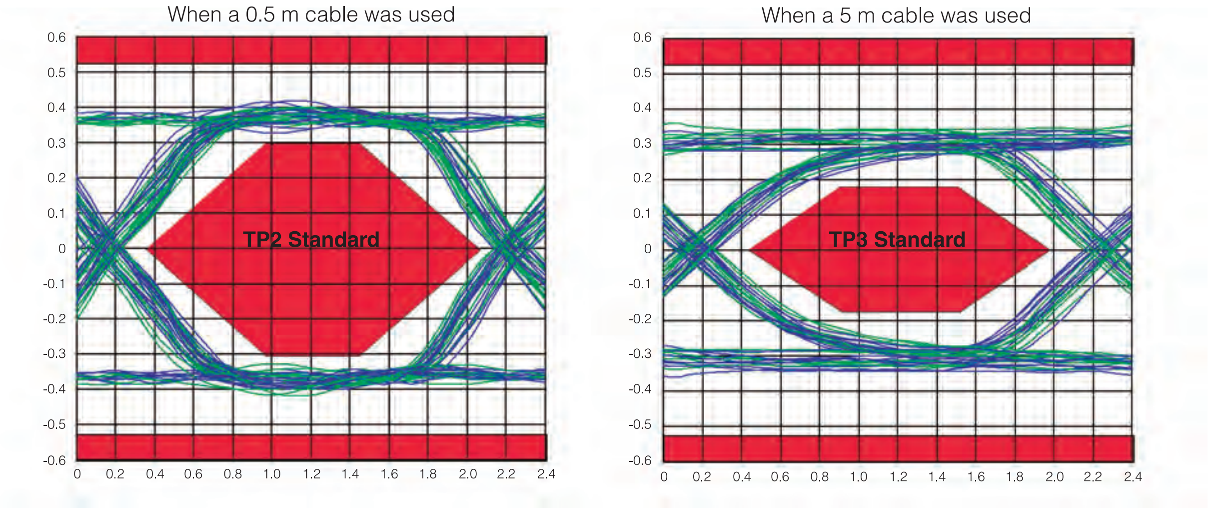
Eye-patterns is used to verify that the differential signal is transmitted with the proper waveform.

Standards differ according to the Test Points (TP_1 to TP_4) between devices. In reality, waveforms also differ according to the length of cables. Measured data using a short cable (0.5 m) and a long cable (5 m) will be used as examples.

The following figure shows the connections. Data sent from the HUB and the waveform were observed at the Device Test Point.



Observed Waveform If the waveform does not enter the red area, it is considered to have met the standard. The stricter TP2 standard was met for the 0.5 m cable.


When a 0.5 m cable was used

When a 5 m cable was used

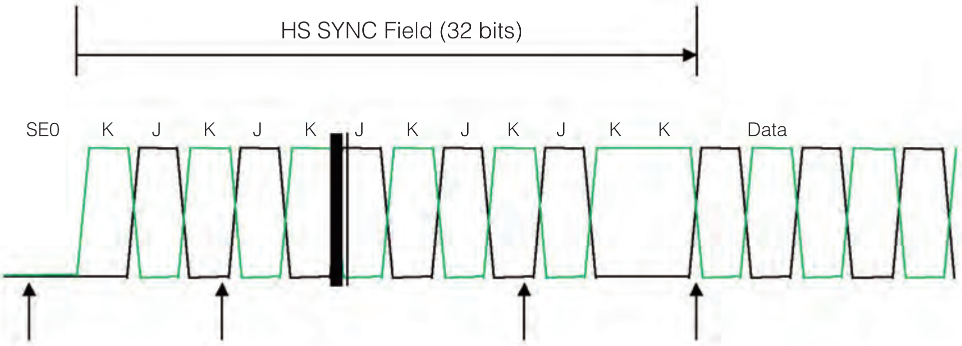
2-2. SYNC Field Waveform Response

For USB2.0, data is transferred with a 400 mVp-p differential signal.

After data is transferred, a 32-bit signal is transferred as an interval signal before the next data begins being transferred. This 32-bit interval signal is referred to as the SYNC Field.

When Common Mode Filters are used for improving EMC, the beginning of the SYNC Field signal is given to the minus side because of coupling between the Common Mode Filter lines. This is the most important point to consider when selecting a Common Mode Filter. For safe operation, the desired voltage is 150 mV or higher starting from the first bit of the SYNC Field signal.

Explanation of SYNC Field



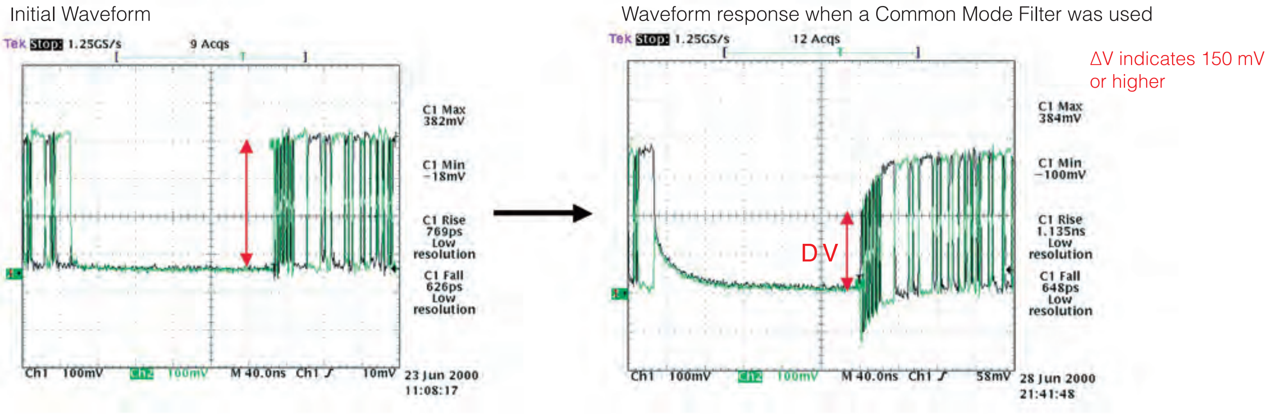
Receiver squelched differential envelope below 100 mV

Differential envelope exceeds 150 mV reception enabled within four symbol times

Clock recovery circuit must lock in time to detect end of SYNC

End of SYNC detected, receiver begins data recovery

SYNC Field Waveform Response


Initial Waveform

Waveform response when a Common Mode Filter was used

ΔV indicates 150 mV or higher

3 Selecting Optimal Components for Improving EMC

For 480 Mbps high-speed transmission, it is important to select components that can effectively remove noise components without affecting the signal waveform.

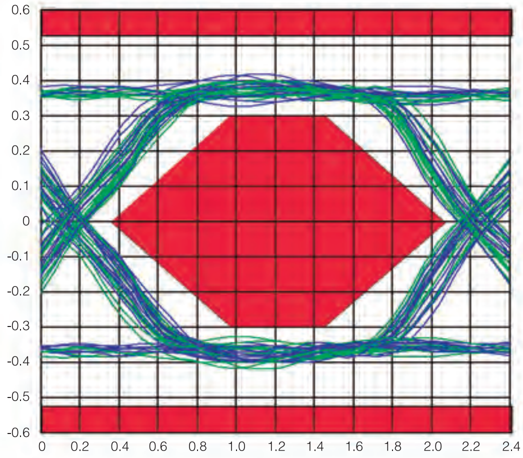
It is also important to verify that no errors occur by conducting operation tests using USB2.0.

When checking waveforms and conducting operation tests, it is necessary to consider actual usage conditions, so it is necessary to use the same components for improving EMC for both the HOST that sends the signal and the DEVICE that receives the signal.

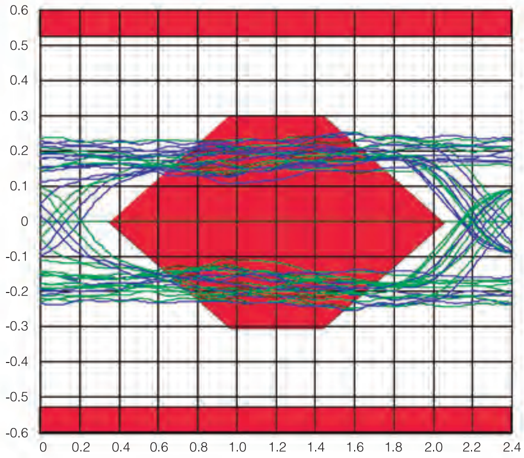
All data here is based on when the same components for improving EMC are used for both ends.

3-1. Comparison of Eye-patterns Using Various Components for Improving EMC (0.5 m Cable)

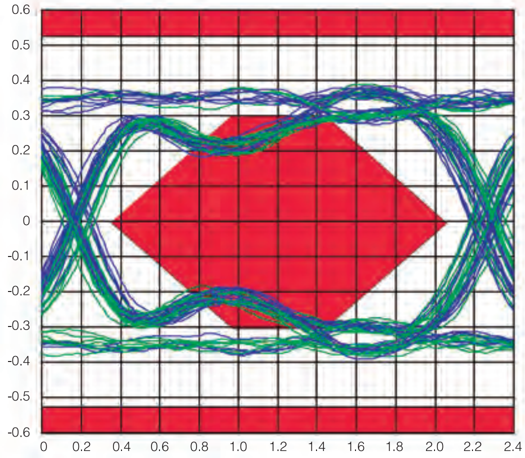
1. Initial value



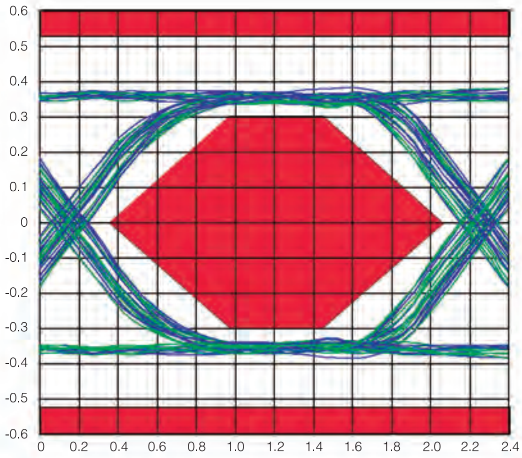
2. With MMZ1608Y121B (Chip Beads)
Impedance is 120 Ω at 100 MHz



3. With ZJYS51R5-2P (Common Mode Filter)
Common Mode Impedance is 600 Ω at 100 MHz



4. With ACM2012-900-2P (Common Mode Filter)
Common Mode Impedance is 90 Ω at 100 MHz

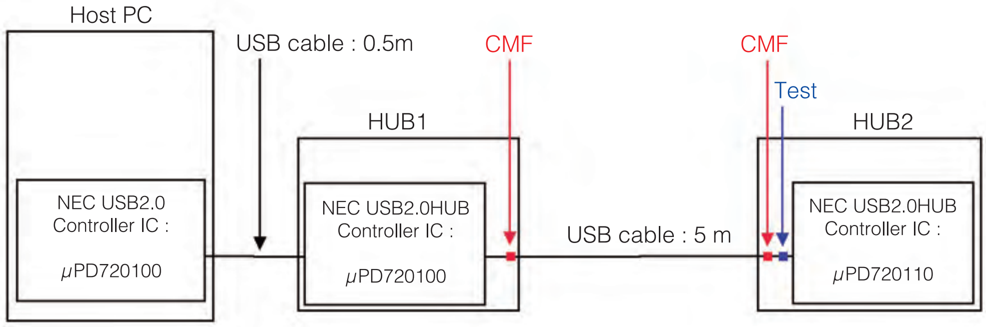


As shown by the above, Eye-pattern 2 shows that the differential signal at 240 MHz has attenuation due to the impedance of the chip beads. Eye-pattern 3 shows that the differential signal is strained because the characteristic impedance of the Common Mode Filter is very different from the USB2.0 standard of 90 Ω. Both waveforms are in the red area, meaning they are NG.

Eye-pattern 4 shows the proper characteristic impedance, and it was evaluated as OK.

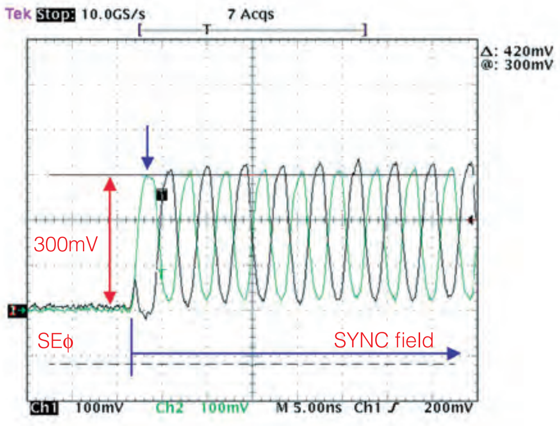
3-2. Comparison of SYNC Field Waveform Responses Using Various Components for Improving EMC (5 m Cable)

Connection for Evaluation

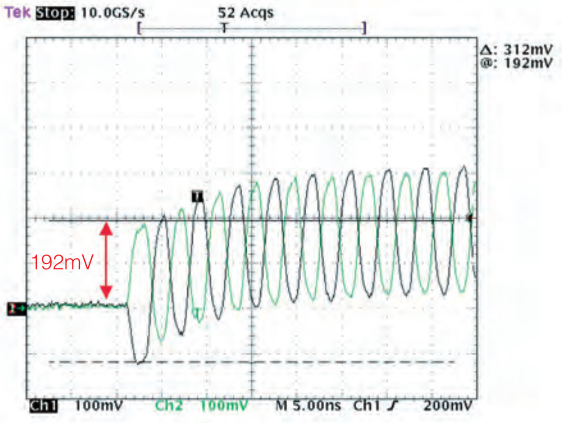


Evaluation Results

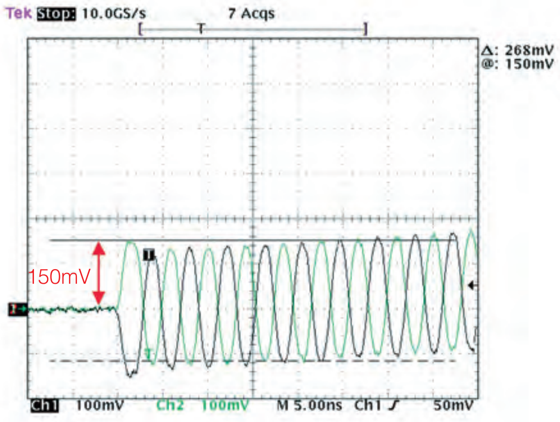
1. Initial value



2. With ACM2012-900-2P (Common Mode Filter)
   Impedance is 90 Ω at 100 MHz



3. With ACM3225-102-2P (Common Mode Filter)
   Common Mode Impedance is 1000 Ω at 100 MHz



As shown in the above data, the waveform 3 shows that SYNC Field voltage was low and therefor was evaluated as NG. The waveform in 2 shows the SYNC Field voltage was high from the beginning because the common mode impedance was kept low, so it was evaluated as OK.

4 Recommended Components for Improving EMC

Because USB2.0 is capable of high-speed 480 Mbps bandwidth, components that cause unstable operation can not be used even if they are effective at removing noise.

Based on this, the recommended components were selected by evaluating Eye-patterns and SYNC Field waveform responses.

The following components are recommended.

2-Line Common Mode Filter:

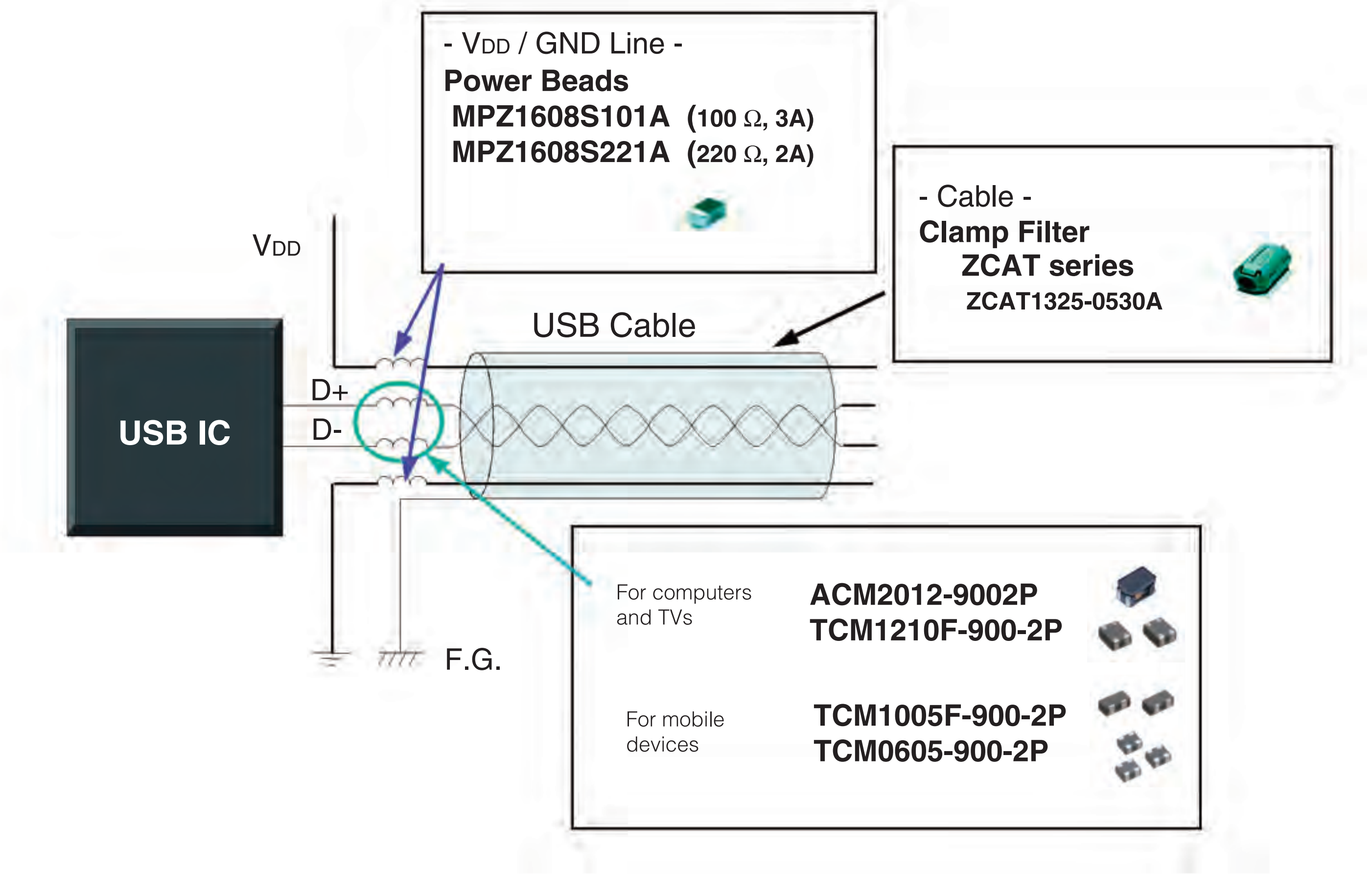
For Computers and TVs ACM2012-900-2P, TCM1210F-900-2P
For Mobile Devices TCM1005F-900-2P, TCM0605-900-2P

When a 2-Line Common Mode Filter is used, it is also recommended to use chip beads for the Vcc line and GND line.

Chip Beads for DC Lines:
MPZ1608S101A, MPZ1608S221A

If the FCC or VCCI standards cannot be met after implementing final radiation noise prevention measures, a split type ferrite core can be used for USB cables, which are easy to implement and are very effective.

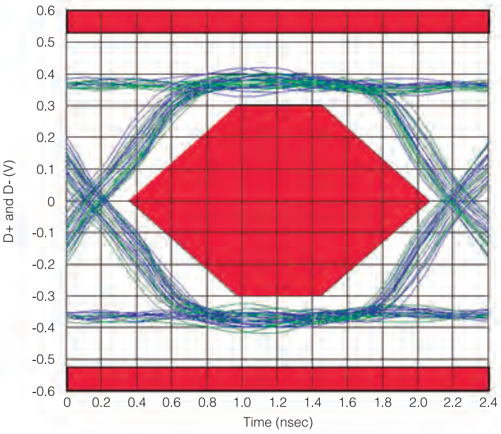
List of Recommended Components



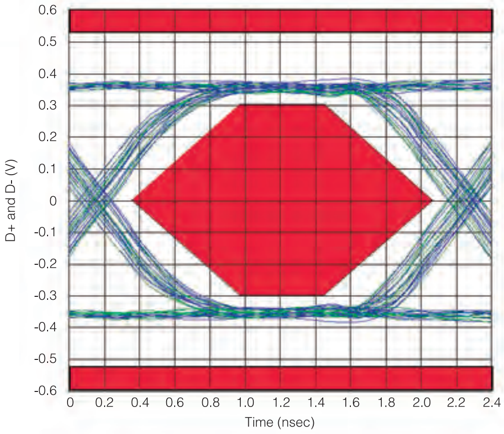
Eye-pattern Data for Recommended Common Mode Filters

Cable Length: 0.5 m

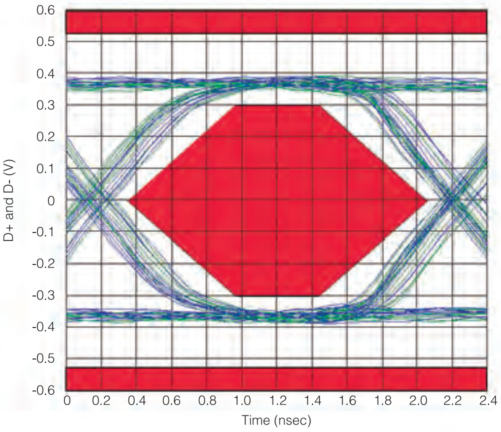
1. Initial value (No Common Mode Filter)



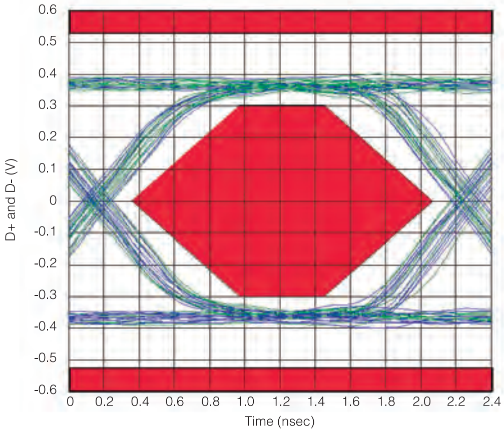
2. ACM2012-900-2P



3. ACM3225-800-2P



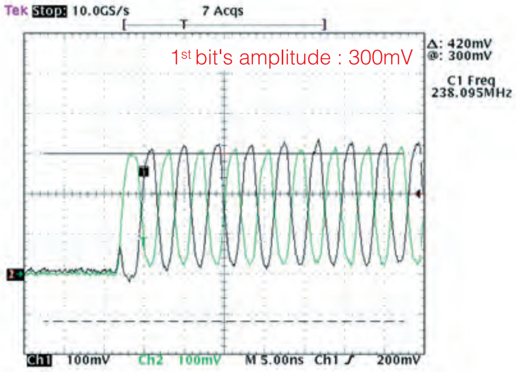
4. ACM3225-161-2P



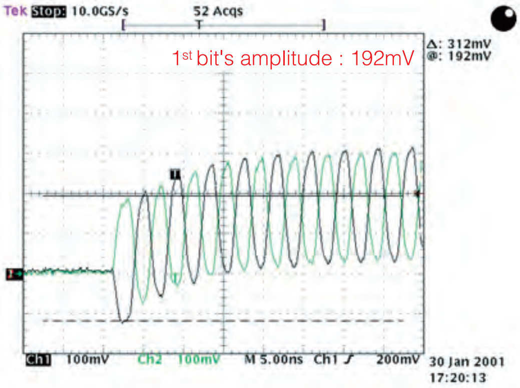
Eye-pattern Data for Recommended Common Mode Filters

Cable Length: 0.5 m

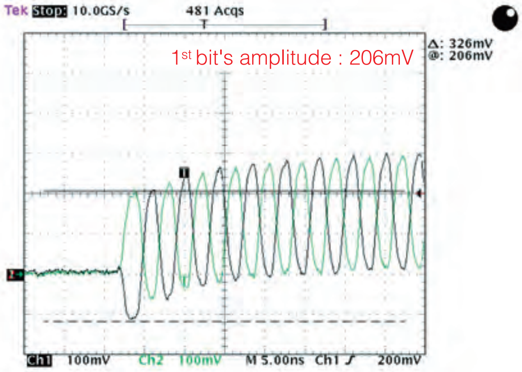
1. Initial value (No Common Mode Filter)


1st bit's amplitude : 300mV

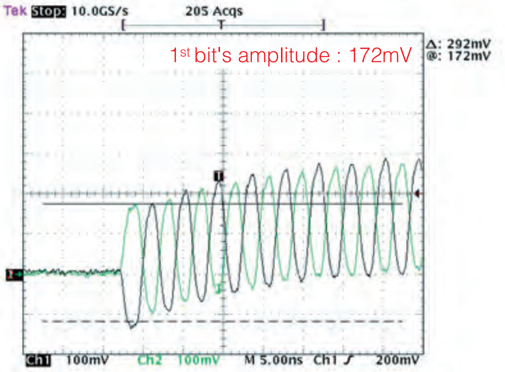
2. ACM2012-900-2P


1st bit's amplitude : 192mV

3. ACM3225-800-2P


1st bit's amplitude : 206mV

4. ACM3225-161-2P


1st bit's amplitude : 172mV

5 Effectiveness Examples of Common Mode Filters for EMC Countermeasures

This section will explain the effectiveness of the recommended Common Mode Filters for EMC countermeasures.

5-1. Differential Signal Waveform Shaping Effectiveness

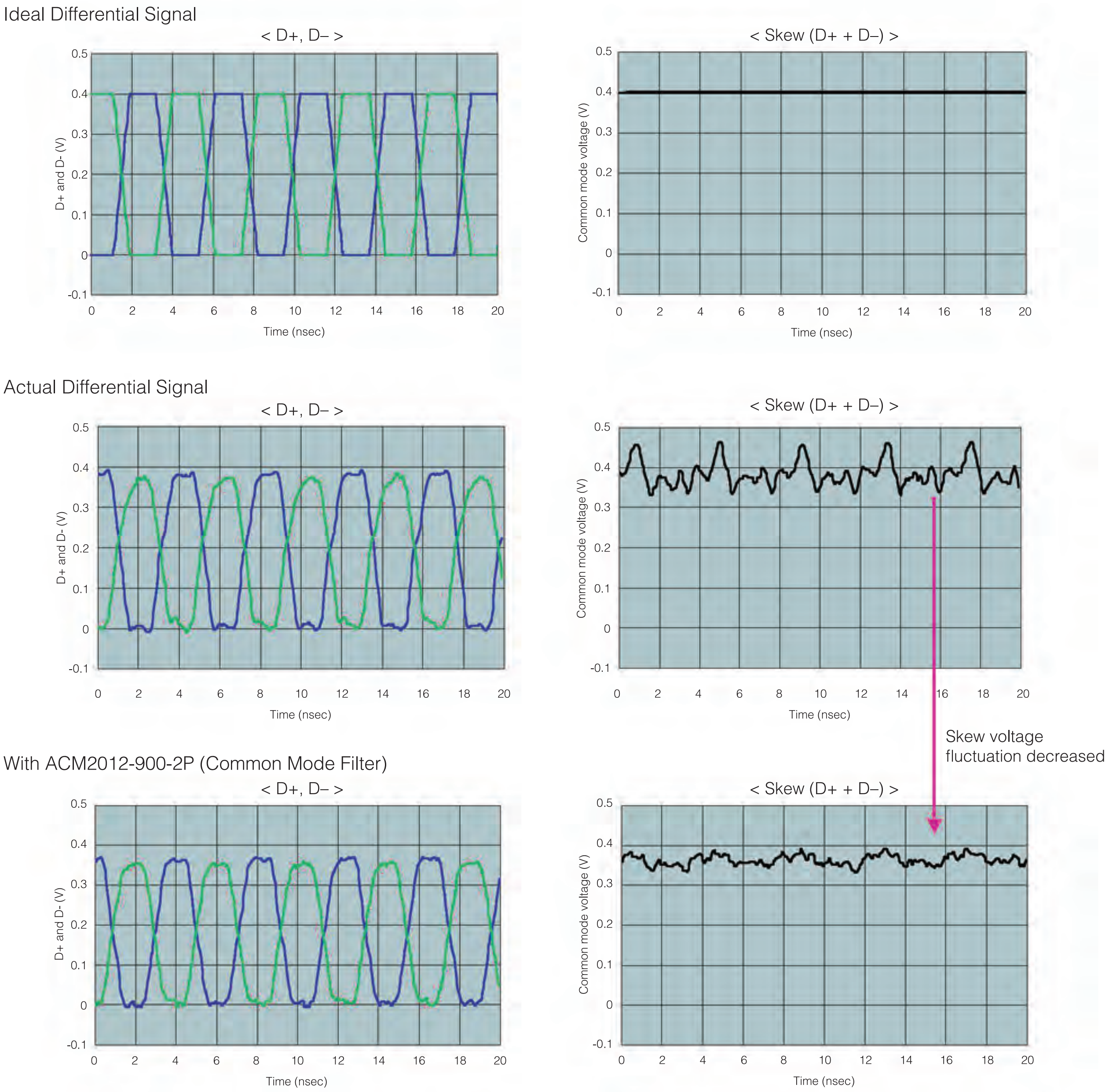
An ideal differential signal has no waveform strain and has no phase lag, and skew is a fixed voltage.

Skew is the total of the + signal (D+) and – signal (D–) ((D+) + (D–)).

In reality, differential signals contain some strain, and skew is not a fixed voltage.

This is the cause of radiation noise.

By using a Common Mode Filter, it is possible to make the waveform as close as possible to ideal via waveform shaping. Skew voltage fluctuation is also reduced, which helps to reduce radiation noise.



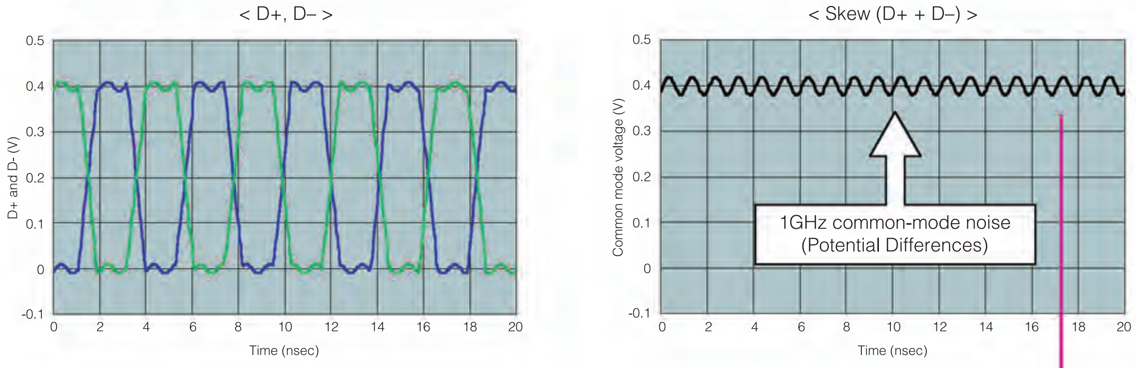
5-2. Effectiveness of Reducing Common Mode Noise Superimposed on the Differential Signal

When common mode noise is superimposed on the differential signal, skew also worsens and radiation noise is generated.

Common Mode Filters can effectively reduce common mode noise without negatively impacting the differential signal.

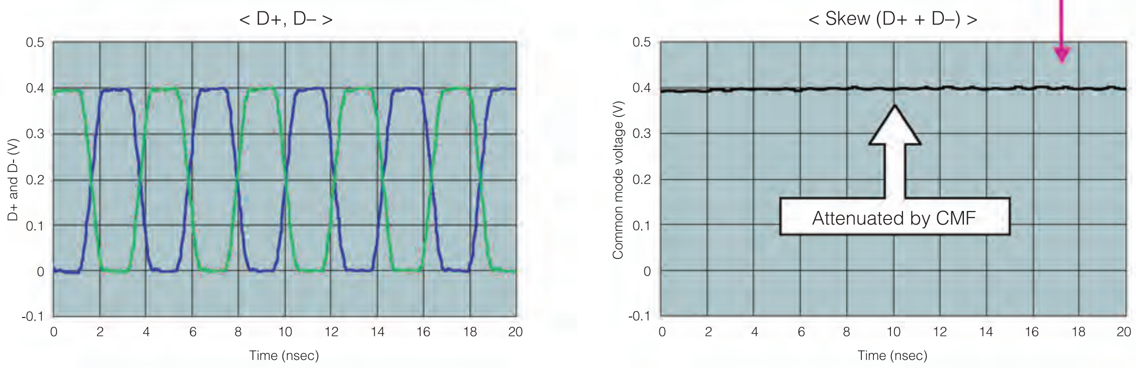
This effectiveness was calculated based on simulations. The effectiveness of Common Mode Filters was calculated when common mode noise of 1 GHz was superimposed on a differential signal.

Ideal differential signal when 1 GHz common mode noise was superimposed



Common mode noise contained in the skew decreased

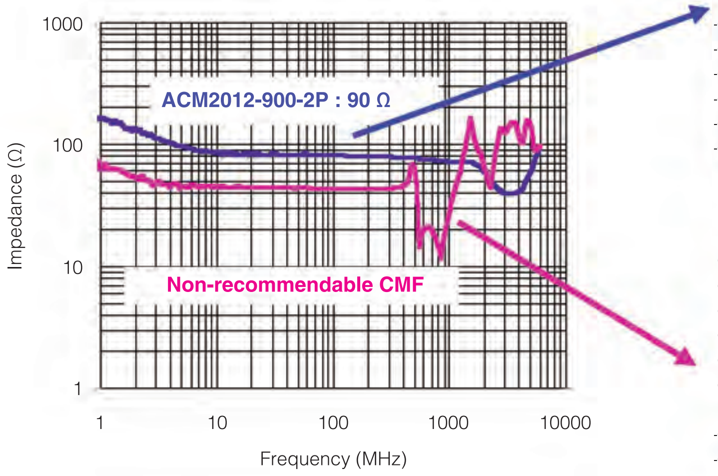
With ACM2012-900-2P (Common Mode Filter)

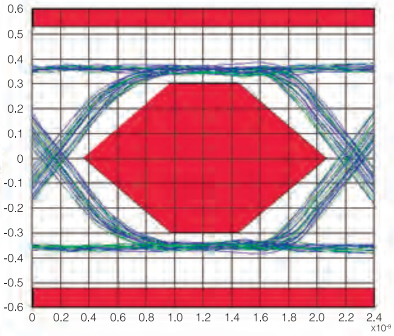


6 Common Mode Filter Characteristic Impedance and its Influence on the Eye-pattern

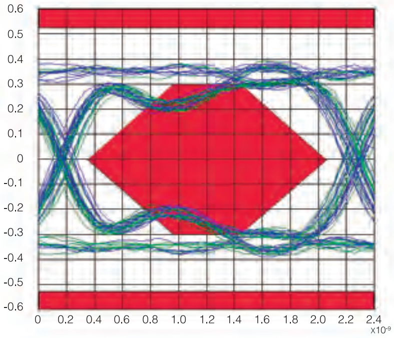
The characteristic impedance is regulated to 90±20 Ω for USB2.0 signal lines.

If a Common Mode Filter is used with a characteristic impedance that is far beyond the standard, the Eye-pattern will deteriorate.



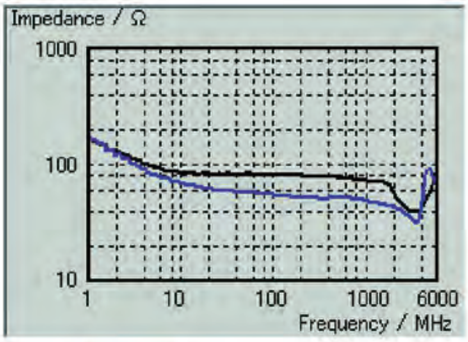


When a proper Common Mode Filter was used



When an improper Common Mode Filter was used

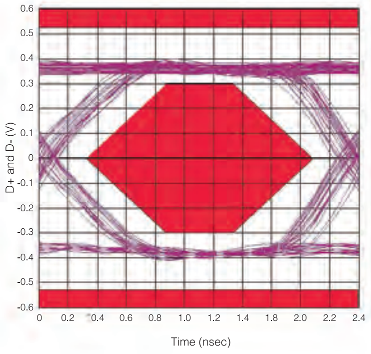
Comparison of characteristic impedance when ACM2012-900-2P with 90 Ω was used and when a Common Mode Filter with 60 Ω was used



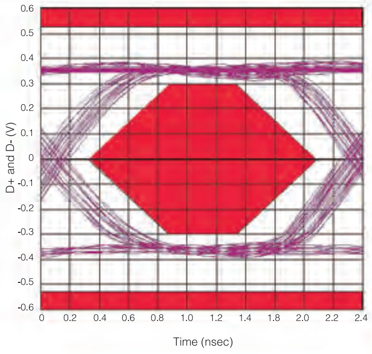
Characteristic Impedance Comparison Data

ACM2012-900-2P and Low Impedance Common Mode Filter

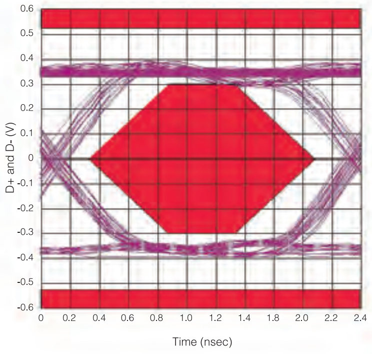
Eye-pattern deteriorated



No Common Mode Filter



With ACM2012-900-2P

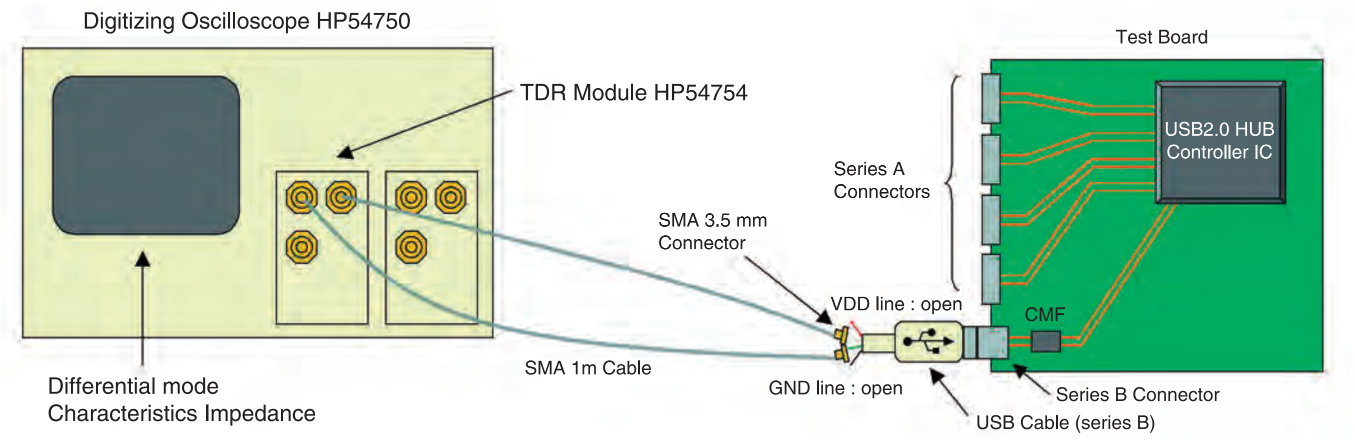


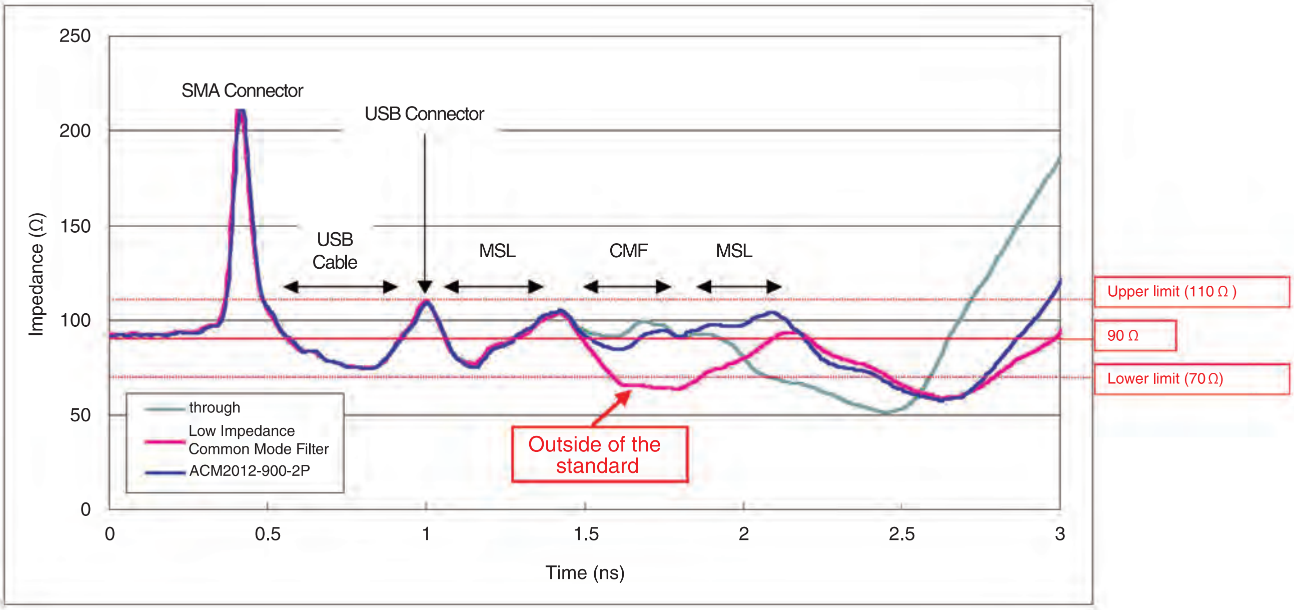
When a Common Mode Filter with a characteristic impedance of 60 Ω was used

7 Difference with TDR According to the Difference of Characteristic Impedance (TDR: Time Domain Reflectometry)

TDR is regulated as the characteristic impedance for USB 2.0 transmission system.

The following will explain the difference with TDR when an ACM2012-900-2P filter was used on an IC evaluation board, and when a Common Mode Filter with a low characteristic impedance was used.





Measurement Results:

The TDR standard cannot be met when a Common Mode Filter with a low characteristic impedance is used.

Mobile Phones and EMC Design

TDK Corporation Magnetics Business Group
Masashi Orihara

1 Noise Countermeasures for Mobile Phones

Mobile phone functions have been expanding to point where the original telephone function seems just and extra feature. They have developed into mobile tools. Expanded features such as cameras and high-resolution screens mean that higher frequency signals are used, which creates harmonics causing higher levels of noise in the communication frequency band.

Several radio sending and receiving methods are frequencies used for mobile phones. Mobile phones are devices for sending and receiving radio waves, so noise from the phone itself can become interfering waves that can deteriorate performance. Devices themselves are compact, so the noise source and the antenna for sending and receiving are very close, within 10 cm. As a result, even a small level of noise causes the input power to the antenna to become large.

This problem is directly related to reception sensitivity, so it is not a serious problem in locations where there is a strong radio wave. However, it can be impossible to receive a signal in locations where the radio wave is weak.

To resolve this issue, noise suppression components can be added to signal lines on the baseplate where the harmonics flow, which cause noise. Figure 1 shows examples of countermeasure components.

Different signal transmission interfaces are used according to mobile phone performance and cost, so it is necessary to select components according to this. Generally, Common Mode Filters are used for high-speed differential transmission lines, which have balanced transmission, whereas chip beads and three-terminal filters are used for single-ended lines, which have unbalanced transmission. Recently, reception functions for FM radios, TVs, wireless LANs, and GPS (Global Positioning System) have been added to mobiles phones. Therefore, it has become necessary to implement noise countermeasures over a wide frequency band. TDK's MZA1608 chip bead array, which contains multiple lines integrated into one chip, and MEA1608 three-filter array, which contains four lines and is 1608 size (1.6 × 0.8 mm), have been developed as countermeasure components to be equally effective for multiple signal lines. In addition, the TCM1608 Series of Common Mode Filters, which are 1608 size and contain two pairs of filters, have also been developed.

It has become common to use a combination of these components as countermeasures for low to high frequencies and for common mode and differential mode.

Figure 1 Block Diagram of Mobiles Phones and Explanation of Countermeasure Components

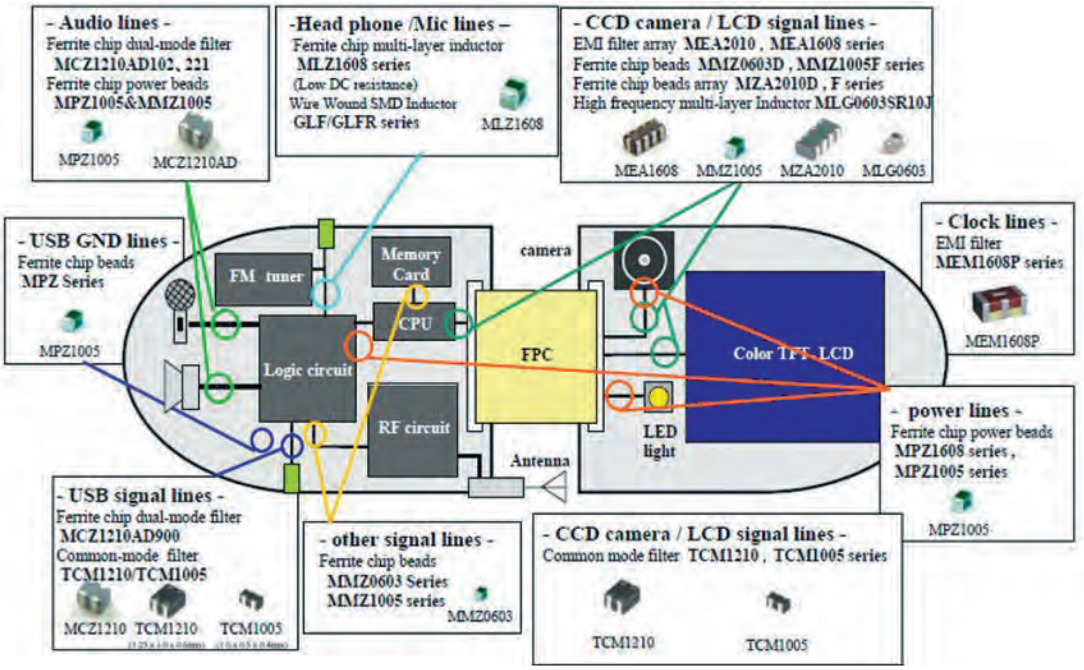
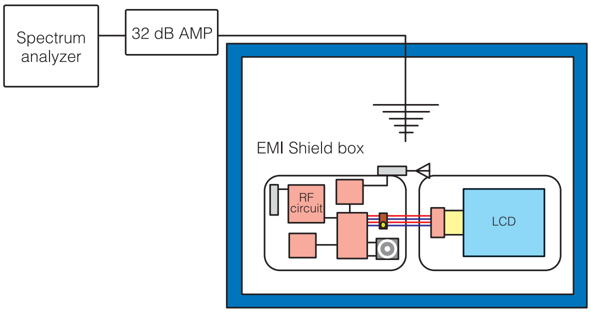


Figure 2 Measurement Connection

Noise from the terminal was measured when a video was played at full-screen display



2 Countermeasures

Many portions in mobiles phones use digital signals including the data from display units such as LCDs and camera modules. Therefore, high-order harmonics at these locations are radiated as noise from lines on the baseplate or from cables that connect baseplates. It is necessary to remove unnecessary harmonics that are originally supposed to be the data signal by reflecting them using inductor components that are inserted on the signal line by using heat transformation due to resistance components, and by using bypass to the GND via capacitor components between the GND.

Three-terminal filters with inductors and capacitors, chip beads with magnetic materials, and Common Mode Filters with magnetic coupling can be used. Chip beads and Common Mode Filters can be used in combination with chip capacitors.

3 Examples of Noise Countermeasures

Digital Signal Line

Figure 3 shows the noise mainly from the FPC (Flexible Printed Circuits) received by the 1seg antenna of an actual mobile phone. It was found that the noise level greatly increased in the 470 to 770 MHz range, which is used for digital TV. Therefore, a three-terminal filter was used on the signal line (image signals to the LCD) before it reached the FPC.

As shown in Figure 3, it was confirmed that noise could be greatly reduced by using the MEA1608PE three-terminal filter array.

This shows that the main cause of the noise was the FPC.

Figure 3 Emission Noise from a Mobile Phone

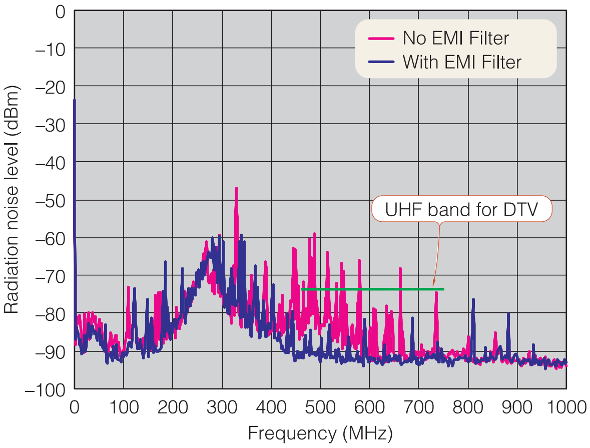
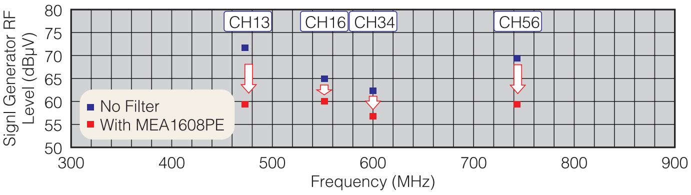


Figure 4 shows the evaluation results for improving reception sensitivity for 1seg broadcast using a filter. It was found that the noise that interrupted the broadcast wave could be reduced, and the original reception sensitivity could be restored.

Figure 4 Improved 1seg Reception Sensitivity when a Filter is Used

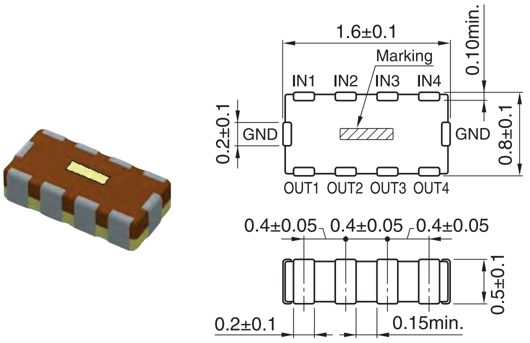


Channel	Channel Frequency	Sensitivity Improvement
13	473 MHz	13 dBµV
16	551 MHz	5 dBµV
34	599 MHz	6 dBµV
56	743 MHz	10 dBµV

Figure 5 shows the size and characteristics of the MEA1608PE220 component that was used for the test. By comparing this with MEA1608LC (Figure 6), which is a conventional product for mobile phones, it is possible to acquire a large amount of attenuation at 500 MHz maximum, which is the low frequency for the digital TV broadcast frequency band. This was realized using the same 1608 size as the conventional product by reviewing the filter circuit and the design for the built-in multilayer coil and capacitor.

Figure 5 MEA1608PE220 Three-Terminal Filter Array

Appearance, Size, and Frequency Characteristics



Dimensions in mm

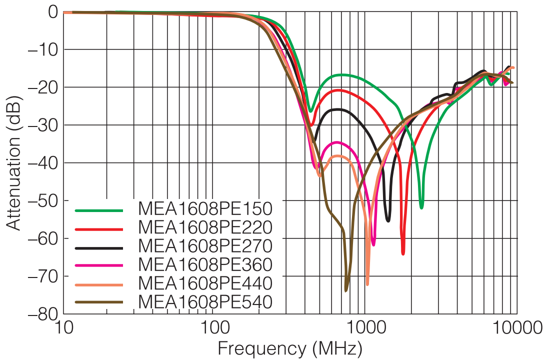
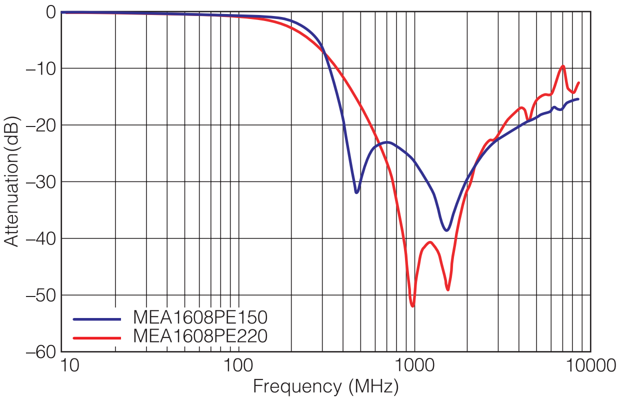


Figure 6 Comparison of Frequency Characteristics for MEA1608LC and MEA1608PE



Compared to the conventional MEA1608LC (Figure 9), the MEA1608PH Series (Figure 7), which has a high-frequency cutoff (–3 dB), can be used for higher signal frequencies. TDK's product lineup contains filters according to the frequency where noise needs to be reduced. However, it is also necessary to consider the influence on the signal waveform. It is also important to consider the capacitance in addition to the bandpass characteristics of the filter.

Figure 7 Filter for Higher Passband Frequencies for Handling High-Speed Signals

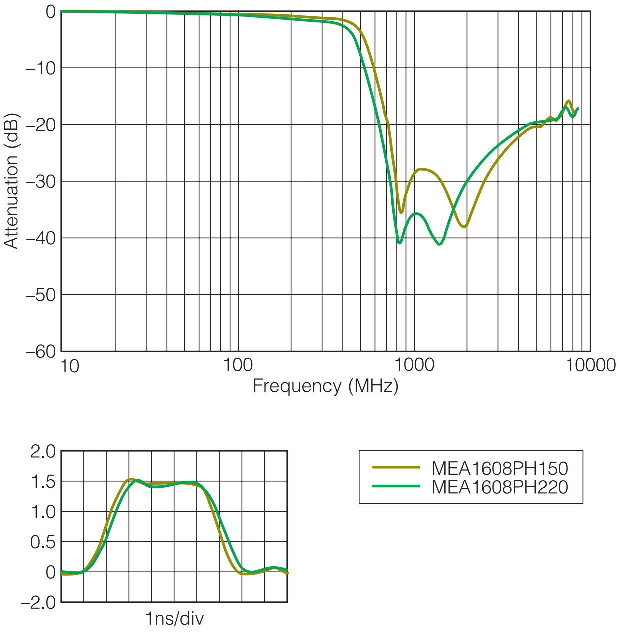


Figure 8 shows a comparison of the signal waveform and attenuation after passing the filter. Compared to the capacitance of 22 pF (MEA1608LC220), 4 pF (MEA1608LC040) had a shorter signal rise time and improved response characteristics.

It is necessary to select components with a lower capacitor capacitance when high-speed signal rise is needed.

Figure 8 Changes to the Signal Waveform by the EMI Filter

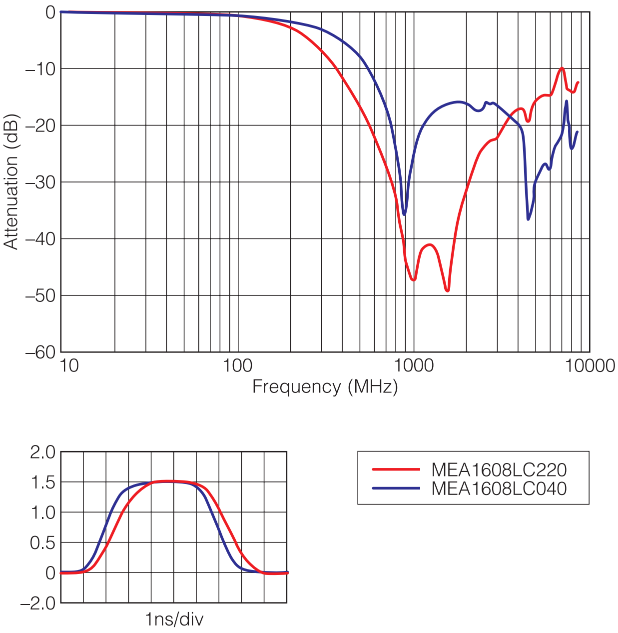
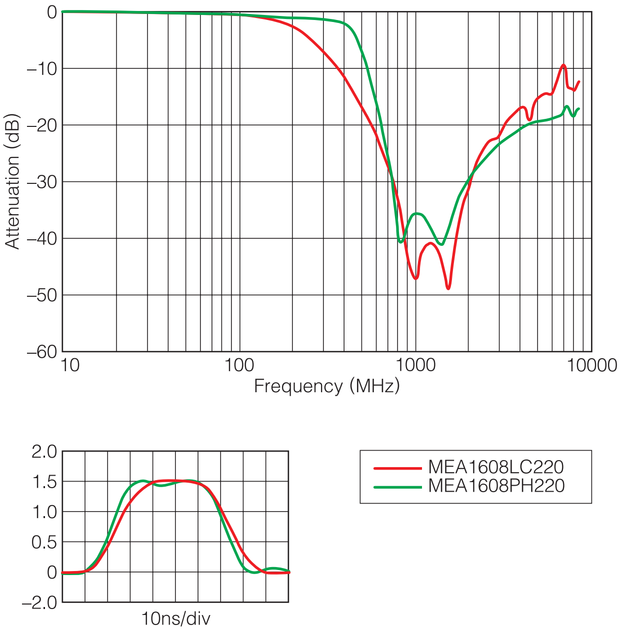


Figure 9 Comparison of Frequency Characteristics for MEA1608LC and MEA1608PH

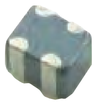


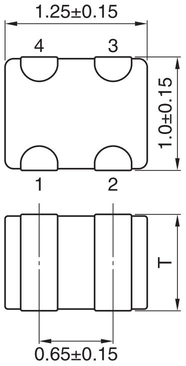
Audio Signal Lines

Burst noise can occur on audio systems due to the transmission waves of mobile phones. As a countermeasure, chip beads and common mode chip beads can be used on the audio line of microphones and speakers. Figure 10 shows examples of characteristics and internal circuits for the MCZ1210 Series of common mode chip beads.

Figure 10 MCZ1210 Common Mode Chip Beads

Appearance, Size, and Frequency Characteristics

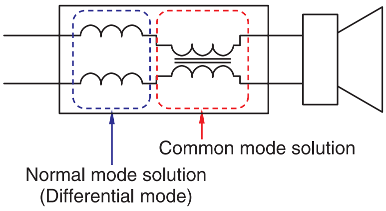




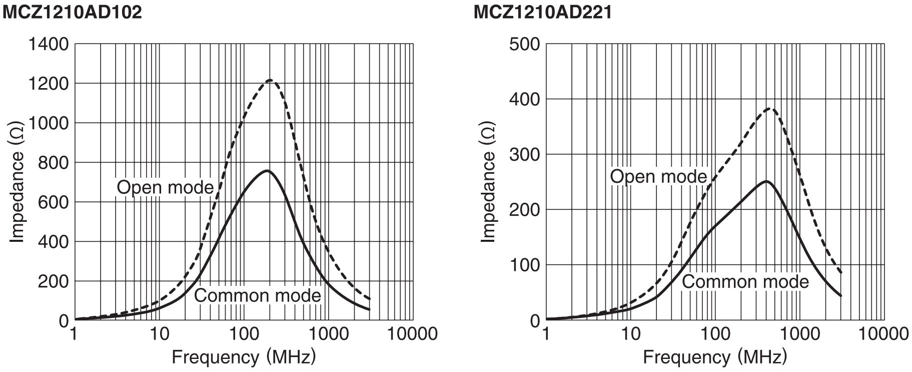
Dimensions in mm

T	Weight
0.5±0.10mm	3 mg
0.85±0.15mm	4 mg

MCZ1210AD102
for Audio signal line



Impedance Frequency Characteristics



Mobile Phone
EMC Design for Differential Interference

TDK Shonai Corporation
Satoru Saito

1 Background

Mobile phones have become multifunction devices with many different functions contained in a small body including digital cameras, 1seg TVs, music players, and electric money (as known as e-money). Some mobile phones are equipped with full keyboards and they can be used like computers. In addition, displays have become larger and have higher resolution requiring faster signal transmission. As a result, differential transmission has begun to be used in addition to single-ended transmission. Therefore, conventional noise countermeasures for single-ended transmission are no longer enough. This section will explain examples of noise countermeasures for mobile phone differential transmission lines.

2 Mobile Phone Differential Transmission Lines and their Countermeasures

Basic System Configuration and Signal Flow

Differential signals are used for the following three systems, as shown in Figure 1.

1. From the CPU to the LCD line
2. From the CPU to the camera line
3. From the CPU to the USB2.0 line

These lines are connected using an FPC or thin coaxial cable. However, because they are long, they can act as antennas and radiate noise, which becomes a factor that negatively affects peripheral circuits, especially the RF circuit. Generally, the differential transmission method has less noise, but in reality, self-poisoning occurs when there is skew between signals or noise from other circuits enters the signal line.

Noise Countermeasures

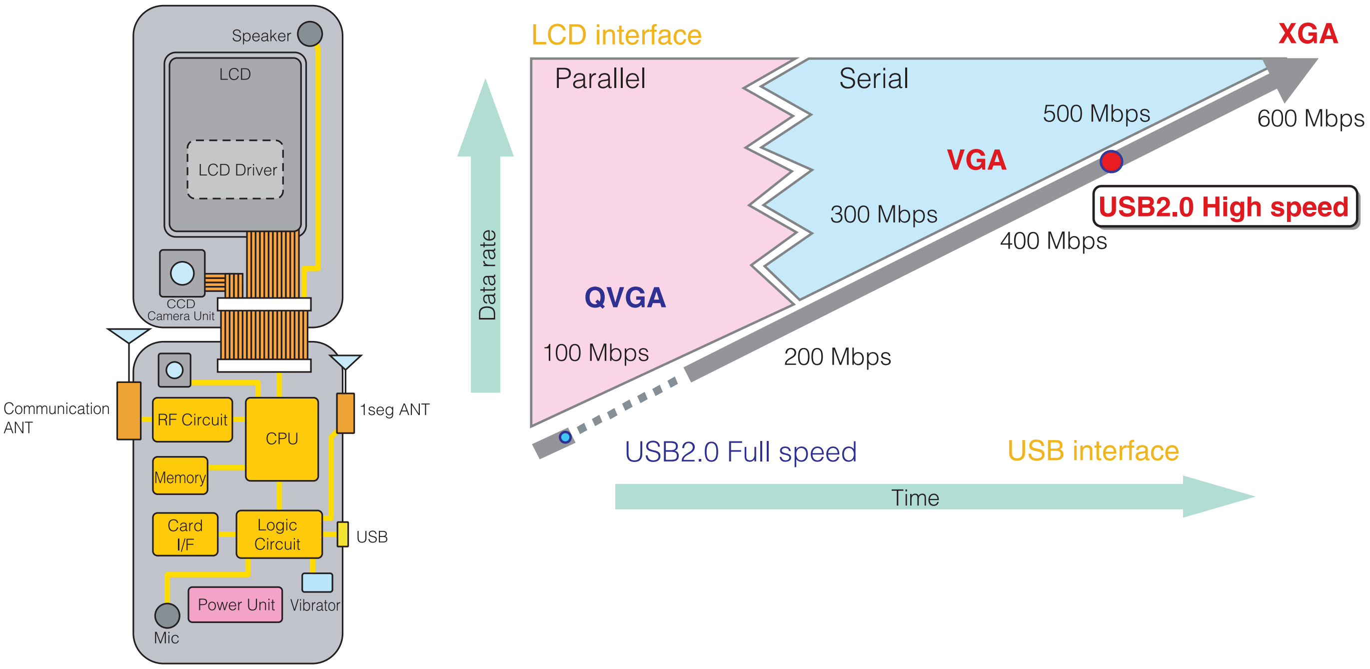
In order to prevent self-poisoning, it is necessary to suppress unnecessary noise from cables that can act as antennas.

1. Cable (transmission line) impedance matching → Reflection noise
2. Pattern design to prevent skew → Common mode noise due to skew
3. Component and cable layouts that prevent noise

There are usually restrictions for implementing item 3 because of the device design. Therefore, items 1 and 2 are important.

When items 1 and 2 are not sufficient for reducing noise, it is necessary to use filters that are compatible with differential signals.

Figure 1 Signal Waveform Quality



Method for Suppressing Differential Signal Noise

As is important with suppression of all signal line noise, it should be possible to acquire the maximum noise suppression while minimizing the effect on the signal. From this viewpoint, Common Mode Filters are the only components that can reduce common mode noise without affecting the signal.

The following are examples of this suppression method.

Examples of Countermeasures for LCD Differential Interface

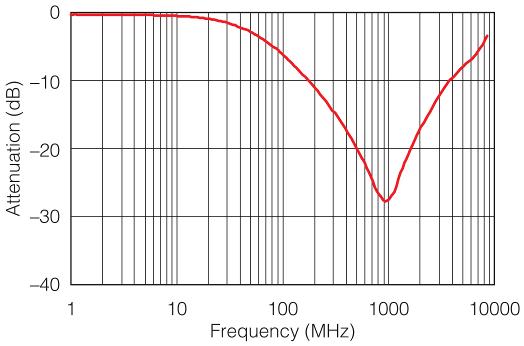
CPU → LCD Controller

The following are examples of countermeasures using actual devices.

First, the Common Mode Filters that were used had the following characteristics.

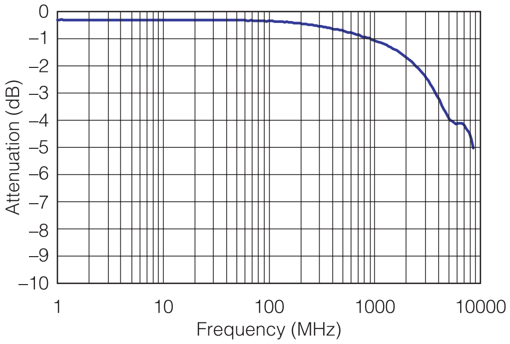
1. Common Mode Attenuation (Scc21) Figure 2
   This is an index for measuring the removal of common mode noise from differential signals.
   The greater the amount of attenuation, the greater the common mode noise is attenuated.

Figure 2　Scc21



2. Differential Attenuation (Sdd21) Figure 3
   This is an index for measuring the influence (weakness) on the differential signal.
   The smaller the attenuation, the smaller the effect on the signal waveform. Generally, this is referred to as the cutoff frequency.

Figure 3　Sdd21



Next, Figure 4 shows the signal waveform when a Common Mode Filter is installed.

When a filter is used, signals can be transmitted on the clock and data lines without affecting the waveform.

Figure 4　Signal Waveform Quality

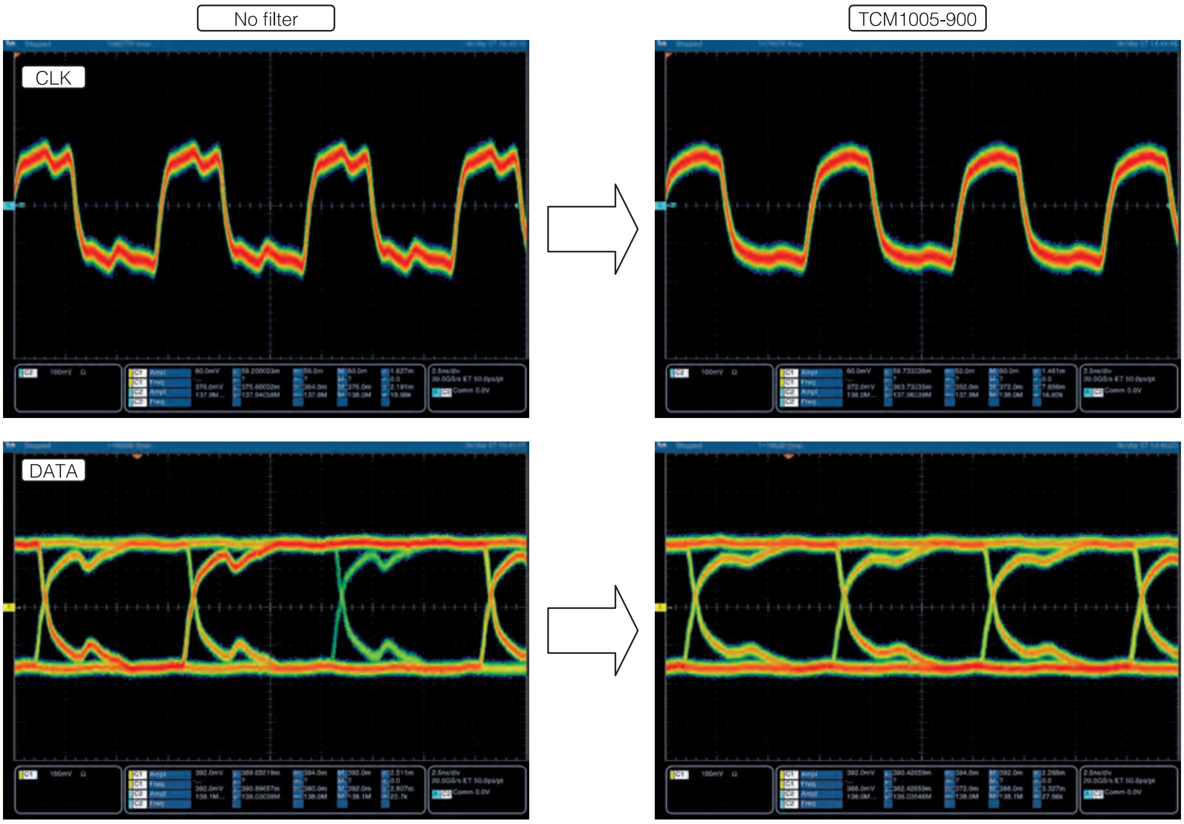
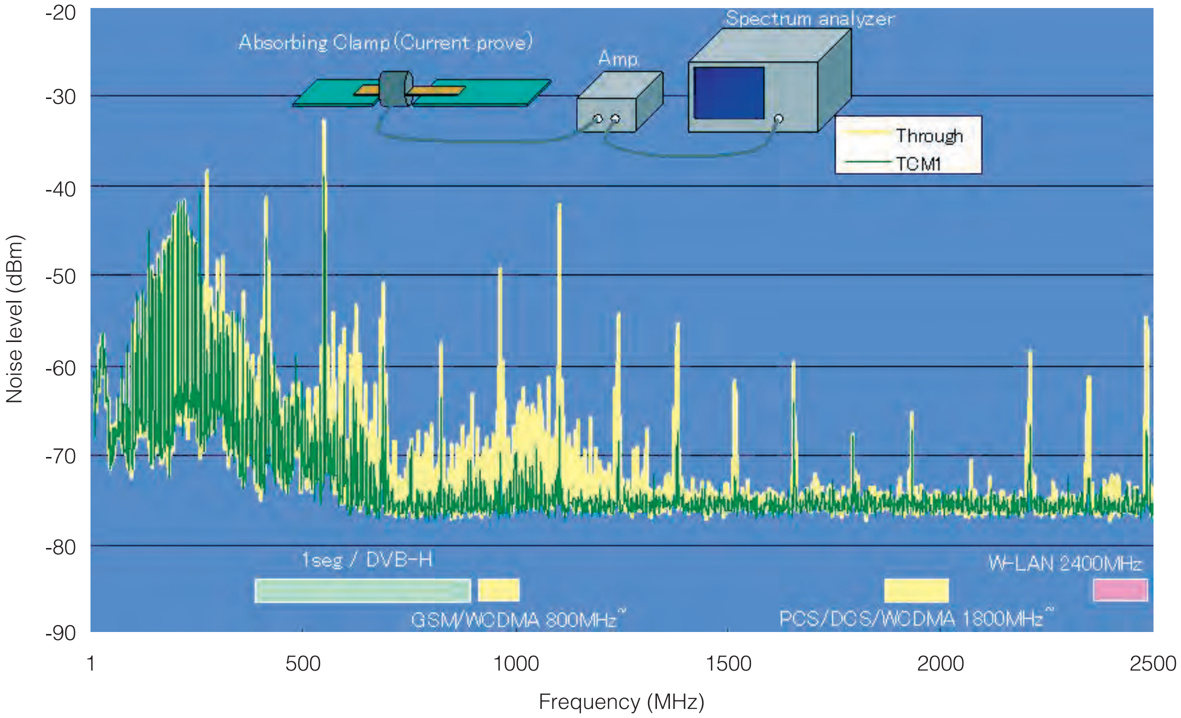


Figure 5 shows the effectiveness of the noise countermeasure. This data shows how much noise is generated from the LCD differential interface of a mobile phone.

Figure 5 Signal Waveform Quality

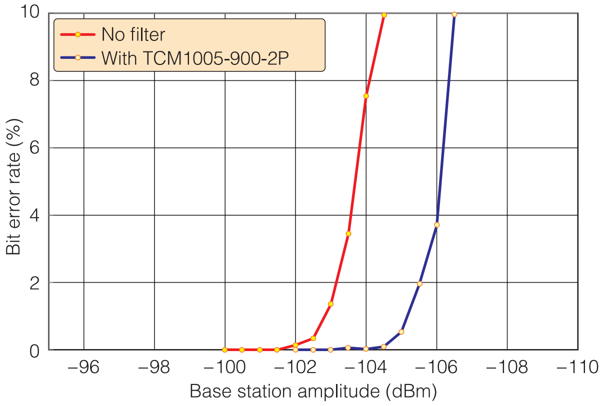


It was found that the harmonic noise of the differential signal occurred in the 1seg band and communication frequency band of the mobile phone. Noise was greatly attenuated when a Common Mode Filter was installed.

The following shows the effectiveness for improving reception sensitivity of mobile phones by reducing the noise of the differential interface.

In Figure 4, noise at the GSM band was suppressed when a Common Mode Filter was used, and the amount of noise passing the communication antenna decreased. It was also found that reception sensitivity was improved by several dB.

Figure 6 Mobile Phone Reception Sensitivity (GSM900 Band)



3 Conclusion

In the future, LCD resolutions will continue to increase and built-in cameras will have more pixels, so it is expected that differential interfaces will become even more widely used. Therefore, it will be more important to optimize the designs for signals, GNDs, and shielding.

If more countermeasures are needed even when these are optimized, please consider using Common Mode Filters, which are effective for differential signals.

Examples of Countermeasures for Static Electricity

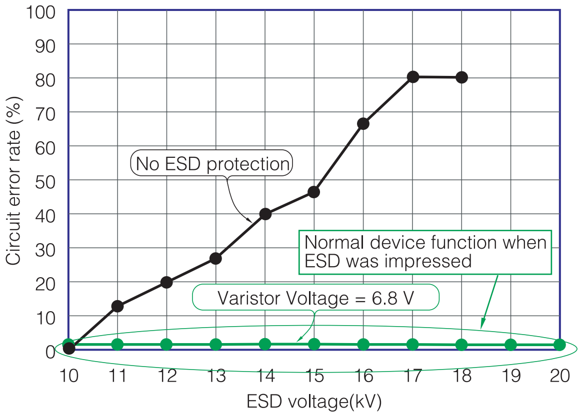
TDK Corporation Sensors and Actuators Business Group
Takeshi Yanata

1 Examples of Countermeasures for Keypad Line Static Electricity

This will explain examples of countermeasures for static electricity on mobile phone keypad lines.

A mobile phone was set to camera mode, and ESD was impressed to the keypad. Next, the number of device malfunctions was counted and the malfunction percentage was calculated. Figure 1 shows the malfunction percentage of the device when a chip varistor was used for the keypad line and for when no ESD protective device was used. When no ESD protection was used, the malfunction percentage increased according to the increase in the ESD charge voltage.
A malfunction phenomenon occurred where the LCD turned OFF. When a chip varistor was used, no malfunction occurred even when the ESD charge voltage was increased. This shows that chip varistors can be used to effectively reduce ESD from keypad lines.

Figure 1 Test Results



2 Examples of Countermeasures for Headphone Line Static Electricity

This will explain countermeasures for static electricity on digital AV player headphone lines.

ESD was impressed to headphones while audio was being played. Next, the number of device malfunctions was counted and the malfunction percentage was calculated. Figure 2 shows the malfunction percentage of the device for when a varistor with a voltage of 8 V was used for the headphone line and for when a varistor with a voltage of 6.8 V was used. When the varistor with a voltage of 8V was used, the malfunction percentage of the device increased according to the increase in the ESD charge voltage. On the other hand, when a varistor with a voltage of 6.8 V was used, no malfunctions occurred at ESD charge voltages of 10 kV or less. Next, the cause of this result will be explained using an ESD clamp waveform when a single chip varistor was used as shown in Figure 3. Figure 3 shows that the ESD clamp voltage of the 6.8 V type varistor was lower than the 8 V type varistor. It is believed that the reason why the 6.8 V type varistors could reduce the malfunction percentage was because of the reduction of the influence on the later steps of the IC / circuit. As mentioned previously, the key when selecting a countermeasure is considering the tendency where items with a low varistor voltage have better efficiency as ESD clamps. This is a good example for showing the effectiveness of items with a low varistor voltage for circuits that need to be protected.

Figure 2 Test Results

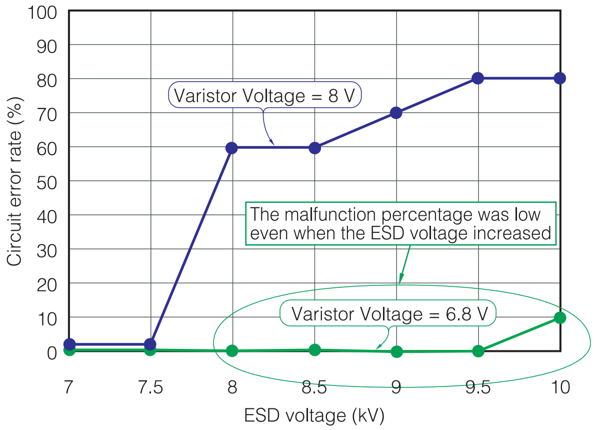
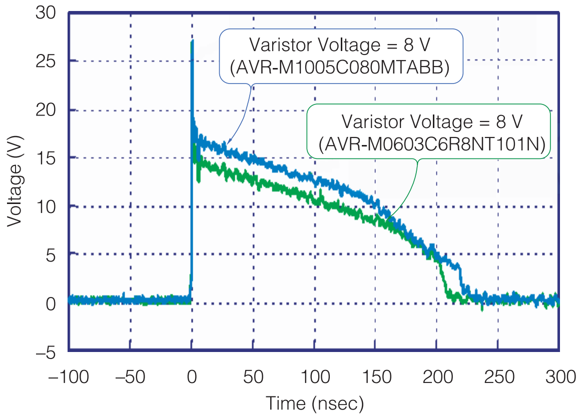


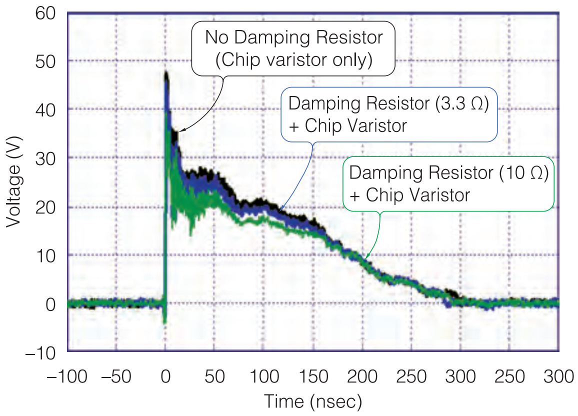
Figure 3 Measurement Results



3 Examples of Countermeasures Using Damping Resistors

Another countermeasure for protecting circuits from ESD is using damping resistors. Figure 4 shows the ESD clamp waveform according to the damping resistance. A series of damping resistors was used on a line, and it showed better ESD clamp characteristics than when only a chip varistor was used. Damping resistors may affect normal circuit operation. However, damping resistors are effective as ESD countermeasures.

Figure 4 Measured Waveform (ESD Voltage = 2 kV)



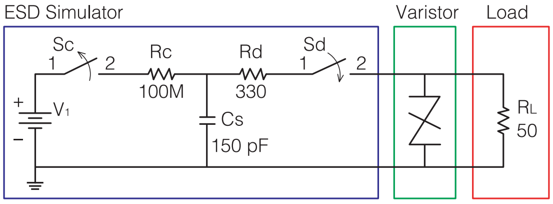
ESD Simulation

TDK Corporation Sensors and Actuators Business Group
Takeshi Yanata

■ Simulation for Static Electricity Countermeasures

This will explain the method for efficiently removing static electricity using simulations. As with static electricity tests, the simulations used a simulation circuit consisting of a load circuit, static electricity generator, and countermeasure component as shown in Figure 1.

Figure 1



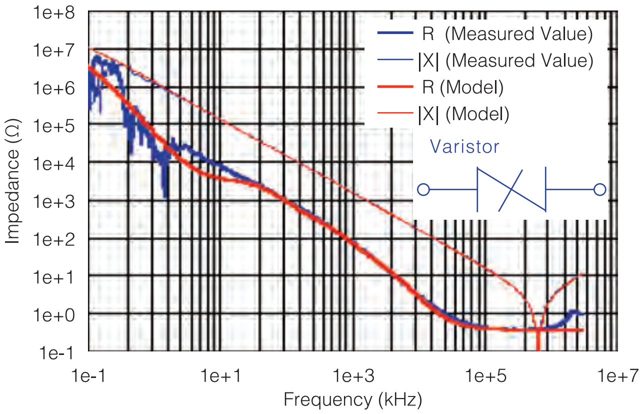
1 Simulation Model

● **Load Circuit :** The circuit for the test target device was used. Here, a resistance of 50 Ω (R_L) was set the same as the measured waveform.

● **Static Electricity Generator** : This consisted of a DC power supply (V_1), charge switch (Sc), charge resistor (Rc), energy storage capacitor (Cs), discharge resistor (Rd), and discharge switch (Sd). Here, a human body model was used, so Cs was set to 150 pF, and Rd was set to 330 Ω. The V_1 output voltage was set to 2 kV. The set IC of the Cs was set to the same voltage as the V_1 output voltage so that the calculation could begin with the Cs at full charge. The charge resistance was 100 MΩ (standard 50 to 100 MΩ). The switch was set to low resistance (1 mΩ) during contact, and was set to high resistance (10 GΩ) while open.

● **Countermeasure Components :** These are acquired from each vender. Static electricity tests include wide frequency components, so a wide range of accurate electrical component models are needed. Figure 2 shows examples of the characteristics for the electrical component models. TDK provides very accurate electrical component models such as for chip varistors.

Figure 2

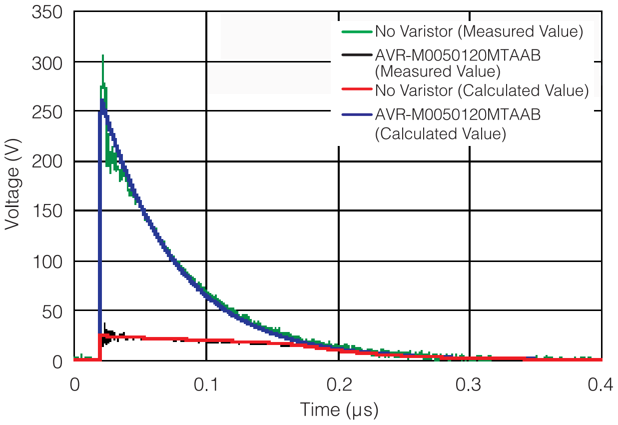


2 Simulation Results from the Static Electricity Tests

Figure 3 shows the results of the simulations.

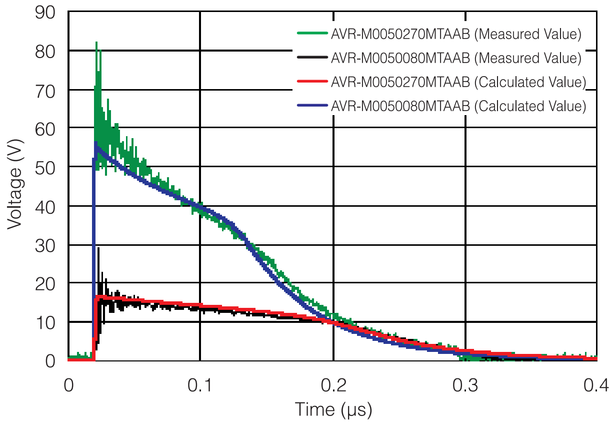
When no countermeasure component was used (blue line), the peak voltage was about 260 V, and when a chip varistor (AVR–M1005C120MTAAB) was used (red line), the peak voltage was reduced to about 25 V. Actual measurement results were almost the same.

Figure 3



Next, Figure 4 shows the simulation results when two varistors with different varistor voltages were used. When AVR–M1005C270MTABB was used, the peak voltage was about 60 V, and when AVRM1005C080MTAAB was used, the peak voltage was about 15 V. It was verified that the requirements were met by using AVR–M1005C080MTAAB when the allowable voltage was 30 V or less.

Figure 4



3 Conclusion

Usually, there are many samples available for tests, and there are other factors such as waveform quality, so there are many tests that need to be executed. When the countermeasure components are not sufficient, the target device may be damaged during testing. Actual measurements are required for final verification, but simulations make it possible to eliminate unnecessary tests. As a result, static electricity countermeasures can be determined more efficiently.

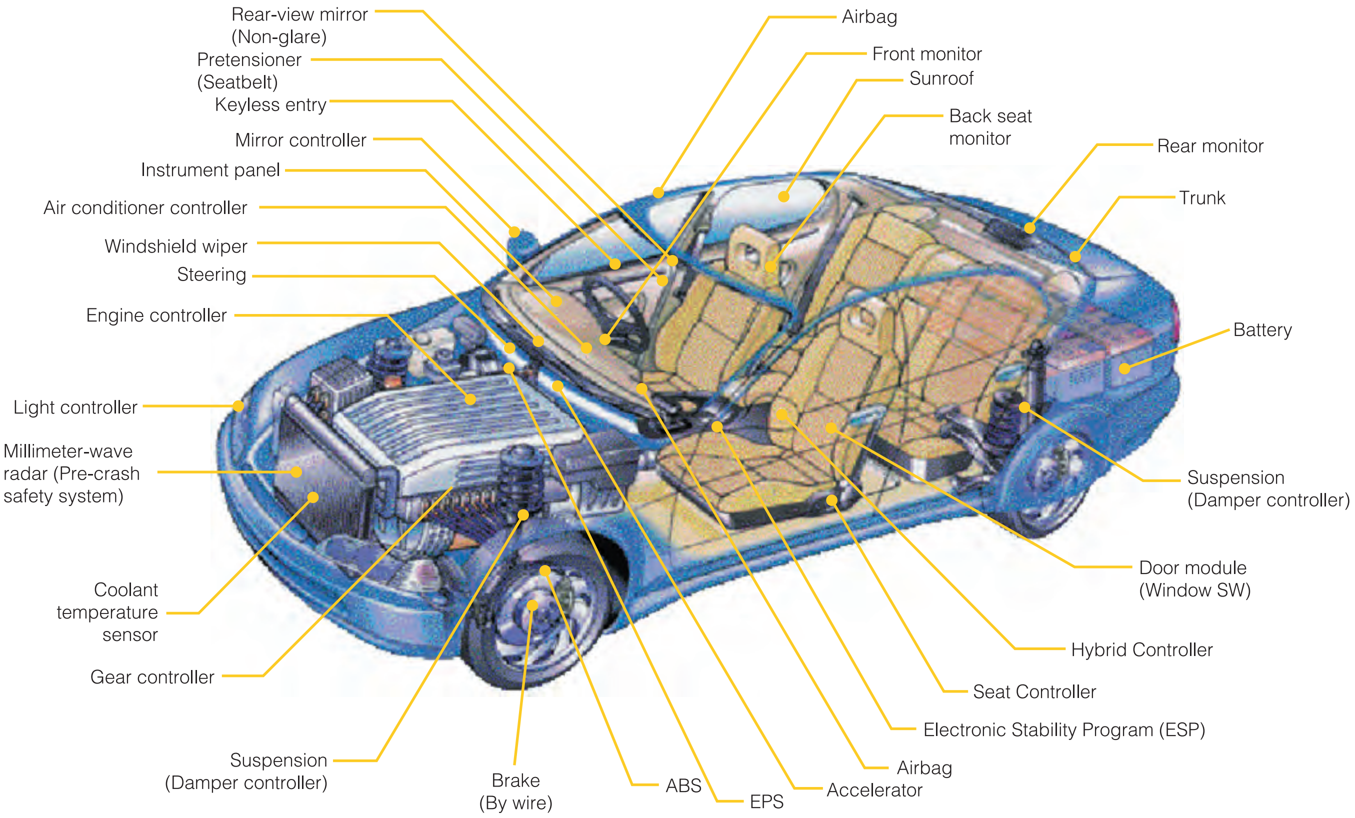
EMC Countermeasures for In-Vehicle Communication Networks

TDK Corporation Magnetics Business Group
Toshio Tomonari

1 Introduction

In recent years, Electronic Control Units (ECUs) have become more commonly used according to the higher functionality of vehicles. Because of this, standard interfaces for connections between devices are needed, and optimal interfaces are used according to each usage for connections between devices. Common vehicle communication network interfaces are CAN and LIN, and the next-generation interface FlexRay that can allow for drive-by-wire systems. These interfaces have different data rates, but the internal connections are the same. Various noise sources exist inside of vehicles, so it is necessary to design circuits by taking EMC into consideration so that devices are not affected by external noise and do not themselves emit noise. This will explain EMC countermeasures for CAN, FlexRay, and LIN in-vehicle communication networks.

Figure 1 Examples of Vehicle Communication Networks (CAN / LIN / MOST / FlexRay)



2 Why do Cars Need Communication Networks?

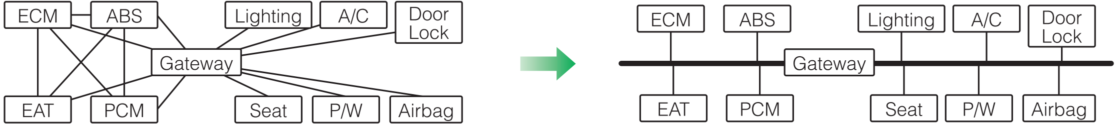
Buzz words in the current automobile industry are ‘fuel efficient’ and ‘low emissions.’ The global oil crisis of 2008 is still fresh in people’s minds. Since then, US automobile manufacturers have been finally moved to develop low-emission vehicles. The US government also began to take positive steps toward counteracting global warming. The whole world is now moving in that direction. Under this situation, developed countries are establishing stricter standards for vehicle emissions (EURO5 in Europe, ZEV regulations in California USA, and Japan’s 2010 Emission Regulations).

While emission regulations have become stricter, advanced collision avoidance controller functions such parking assists, backup cameras, millimeter-wave radars have become important elements. Figure 1 shows how electronic control units are used for current vehicles. This shows that ECUs are for everything including familiar functions such as door operation and basic vehicle functions such as suspension, driving, turning, and stopping functions.

In the future, vehicle functions will continue to become even more advanced. However, advanced functions will require even more ECUs, which in turn will require more harnesses. As a result, fuel consumption and emissions may increase. Emission regulations and advanced vehicle functions are in conflict with each other. One solution to this problem is vehicle communication networks. Figure 2 shows the merits of vehicle communication networks. Efforts for developing network devices can help reduce the number of harnesses needed for one-to-one connections. In addition, vehicle communication networks can be sorted into three different types according to the purpose (Figure 3).

The CAN and LIN interfaces are used for the body system because they do not require high-speed communication. However, the high-speed and safe FlexRay interface is used for the powertrain system which handles core functions such as driving, turning and stopping. The MOST and IDB1394 interfaces are mainly used for multimedia systems that need to send image and audio data because they are capable of transferring data over 100 Mbps.

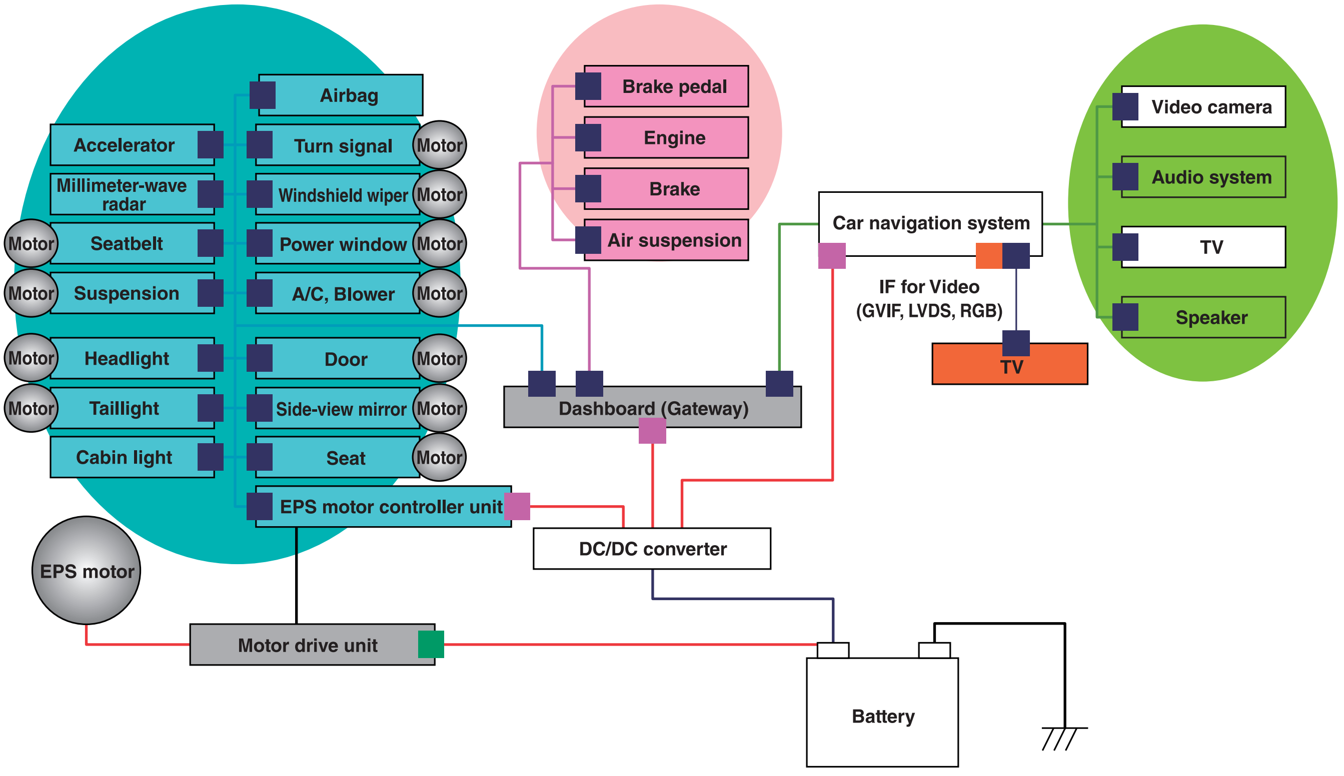
Figure 2 Merits of Vehicle Communication Networks



Wiring for Conventional Electrical Component Control

For the CAN Vehicle Communication Networks

Figure 3 Vehicle Communication Network Configuration



Vehicle Communication Network for the Body System (CAN, LIN)

Vehicle Communication Network for the Powertrain System (FlexRay)

Vehicle Communication Network for the Multimedia System (MOST) (IEEE1394)

3 Vehicle Noise Standards and Issues Related to EMC

CISPR25 is the international EMC standard for vehicle noise emission, and ISO11451/11452 the international EMC standard for immunity (Figure 4).

Figure 4 Vehicle EMC Standards

Evaluation of Actual Vehicle

Emission Standards	CISPR12, CISPR25 EN55012, 25
Immunity Standards	ISO11451-2 (Radiated Immunity)
	ISO11451-3 8 (Radiated Immunity) *Vehicle wireless devices
	ISO11451-4 (BCI Method)
	ISO10605 (ESD)

Component Evaluation

Emission Standards	CISPR25 EN55025
Immunity Standards	ISO11452-2 (Radiated Immunity)
	ISO11452-3 (TEM Cell Method)
	ISO11452-4 (BCI Method)
	ISO11452-5 (Stripline)
	ISO11452-7 (DPI)
	ISO10605 (ESD)

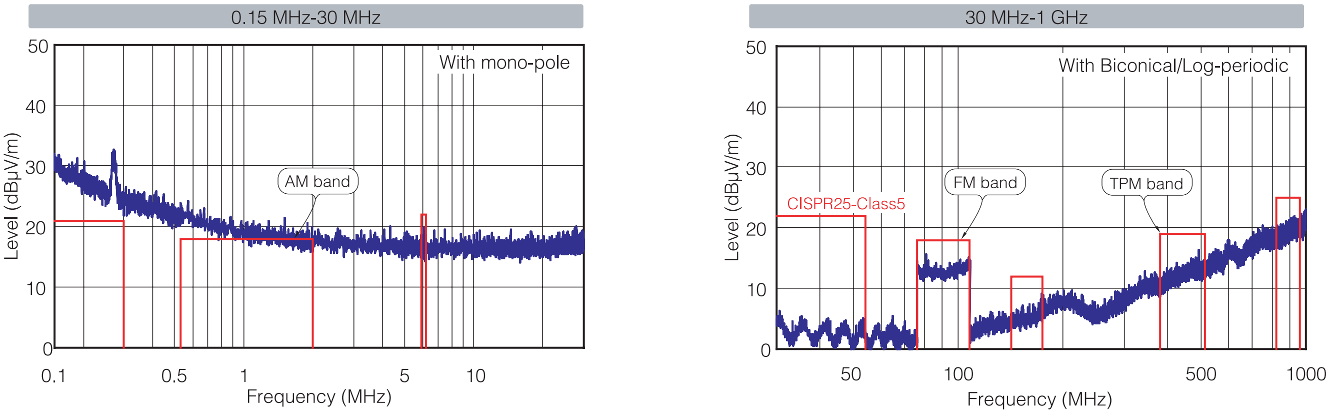
Errors due to noise related to devices equipped in vehicles can directly affect the life of the user. It is also necessary to prevent interference with wireless systems such as AM and FM radio and TPM (Tire Pressure Monitoring) sensors. Therefore, the standards for these regulations are much stricter than with standards for devices such as TVs and computers.

Figure 5 shows examples of this. Figure 5 (a) shows the measurement results for dark current noise in a 3 m anechoic chamber. It was found that it was over the standard in the band range from 150 kHz to 1 MHz even when no electronic device was operating. This was due to the performance of the antenna amplifier. Clearly, it is difficult for the dark current noise level to be within the standard. When this standard is applied without the margin in the 1 MHz or higher band where it does not depend on the performance of the amplifier, the radiation noise level from the ECU was almost not permitted.

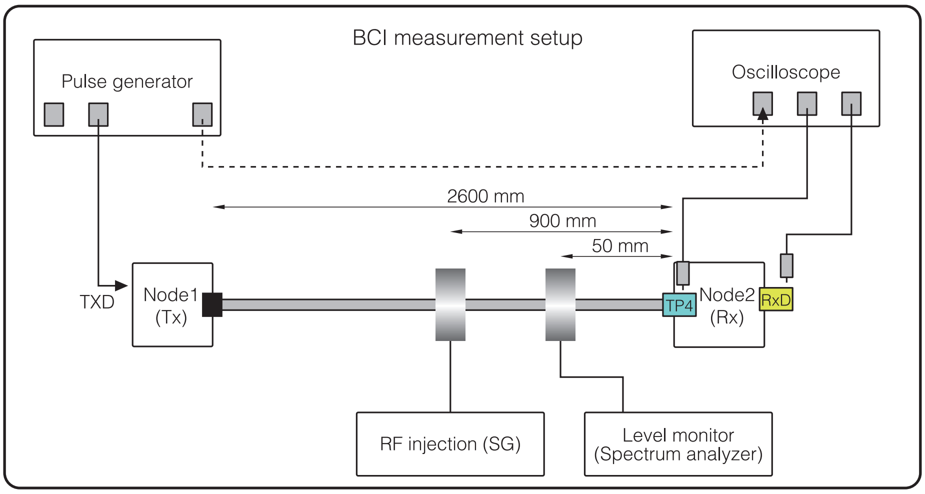
Figure 5 (b) shows an example of an immunity measurement result. When noise is applied to the UTP cable that connects the vehicle communication network interface

Figure 5 Strict EMC Standards for Vehicle Devices

(a) Radiation noise



(b) Immunity

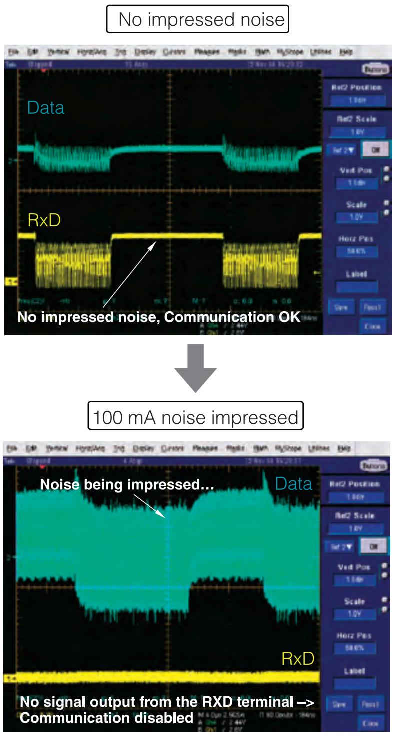


Immunity Test Conditions and Results

The BCI (Bulk Current Injection) Method was used for testing.

A large current occurred on the data line when noise was impressed.

Because differential transmission used, there was no effect up to a certain current level, but when the impressed current was over 100 mA, a communication error occurred.



No impressed noise

No impressed noise, Communication OK

100 mA noise impressed

Noise being impressed...

No signal output from the RXD terminal –> Communication disabled driver using the BCI method, communication was disabled. When components for improving EMC were removed, noise resistance became worse, which caused communication to be disabled. This demonstrates the importance of EMC design for immunity.

With the exception of LIN and CAN, vehicle communication networks use differential transmission because it has low amplitude, low noise radiation, and is resistant to outside noise. Physical layers are used in consideration of EMC. However, there are various noise locations, noise types, and various frequencies inside of vehicles including noise related to the ferromagnetic field due to high currents, noise related to the motor system, and burst noise from the sparkplug. Therefore, ECUs may be affected even when differential transmission is used.

In addition, from the viewpoint of radiation noise, differential transmission should have low EMI, but in reality, the noise emission level for the whole system is not zero because the two lines (plus and minus lines) are not perfectly symmetrical. Therefore, measures need to be taken to improve noise immunity and emission.

4 Effectiveness of Common Mode Filters

As explained in other chapters, Common Mode Filters are effective at improving EMC for differential transmission (for more details about Common Mode Filters, refer to “Common Mode Filters that Eradicate the Causes of Emission Noise Without Affecting Signals” and “Improving EMC for High-Speed Differential Interfaces”).

The following two benefits can be acquired by using Common Mode Filters.
1. Suppression of radiation noise
2. Improved immunity

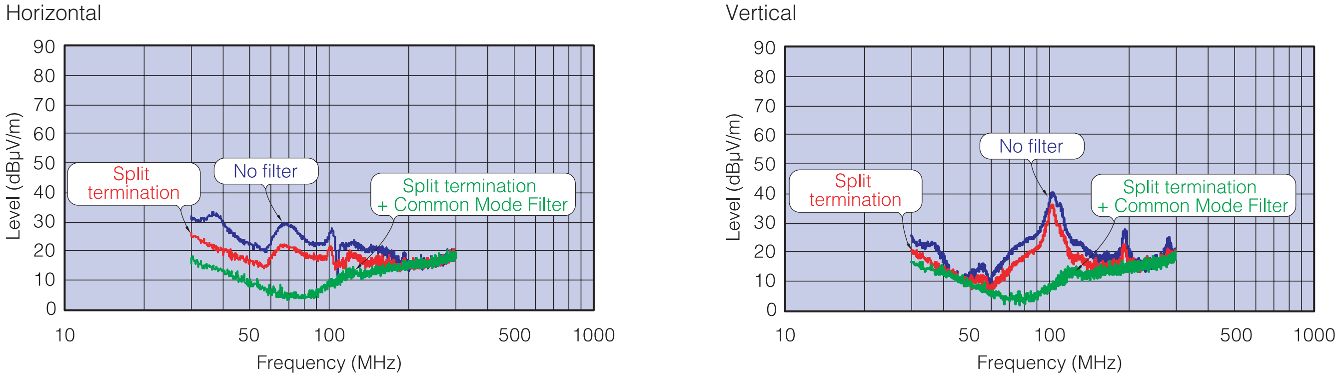
This shows that Common Mode Filters can be used to resolve problems related to EMC for vehicle communication networks.

Figure 6 shows the results for Common Mode Filter effectiveness, which were verified using and actual CAN-IC. A general ACT45B-510-2P Common Mode Filter for CAN was used, which will be explained later.

The next section will explain recommended TDK Common Mode Filters for CAN and FlexRay, and countermeasures and filter for improving EMC for LIN.

Figure 6 Effectiveness of Common Mode Filters for the CANBUS Line (Radiation Noise)

(a) Radiation Noise Measured Data

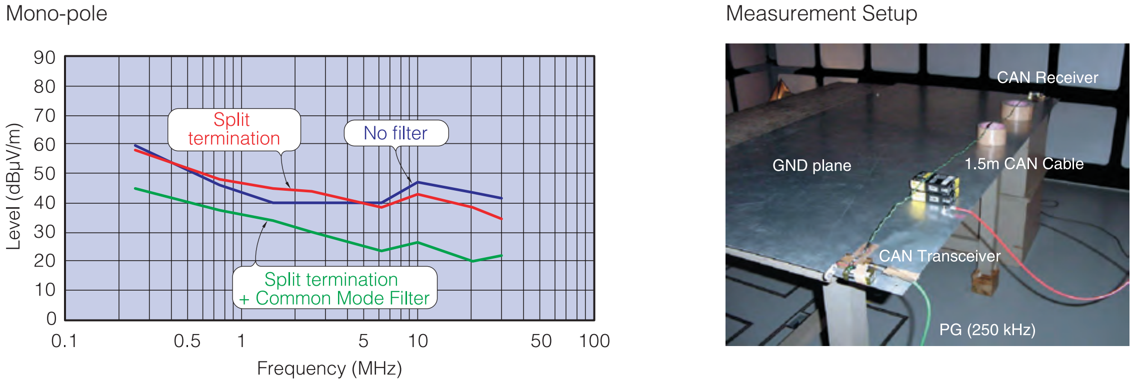


Horizontal

Vertical

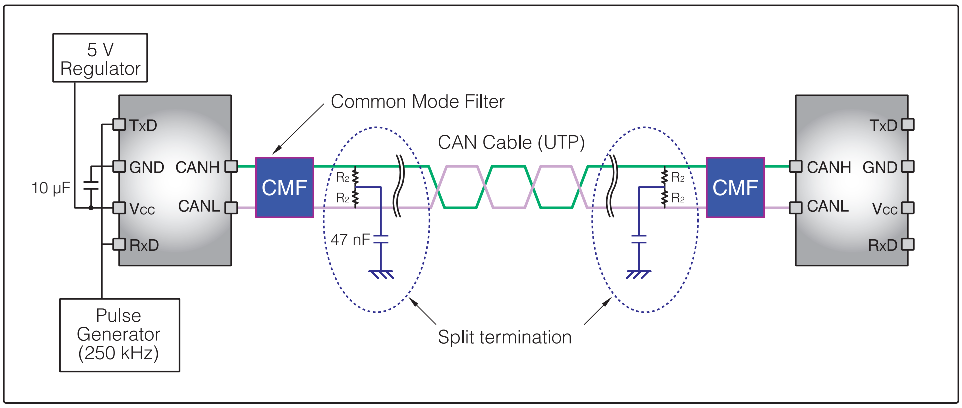
Mono-pole

Measurement Setup



* Split termination is explained below.

(b) Measured circuit

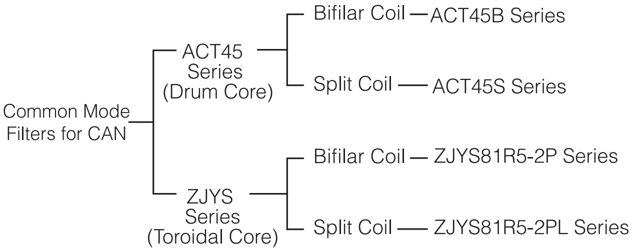


Split termination is for making common mode components flow to the GND by connecting the midpoints of two resistors with the GND so that the common mode components can be reduced.
For CAN and FlexRay, it is applied to the end terminal resistor of the main bus.
When the branch node ends with a resistance of less than 10 kΩ, split termination can apply to this resistance for suppressing common mode noise. However, the effectiveness is limited due to the high resistance.

5 CANBUS Filter

CAN has been around since it was adopted by Daimler AG back in 1992. It was not a standard from the beginning. After each manufacturer developed their own interfaces for vehicle communication networks, CAN was selected as a standard around the year 2000 for development efficiency, cost reduction, and connectivity based on standardization. Since CAN has been used for over ten years, TDK's Common Mode Filters have long been used for CANBUS through several transitions. TDK's Common Mode Filters for CANBUS are sorted into two series based on the configuration (Figure 7).

Figure 7 TDK's Common Mode Filter Lineup for CANBUS



One is the toroidal core type ZJYS Series and the other is the drum core type ACT Series.
These have the following characteristics.

(1) Split coil type with impedance in the differential mode (Dual mode filter)
(2) Bifilar coil type with no impedance in the differential mode (Common Mode Filter)

Type (2) Common Mode Filters are normally used because they do not affect signals. Type (1) has impedance in order to suppress differential mode noise components, so they are used according to the type of noise.

The operating temperature range for the ZJYS Series is –40 to +125 °C, and the operating temperature range for the ACT45B Series is –40 to +150 °C*. These are both designed to meet all requirements as components of vehicle devices.

* The ACT45B Series is designed so that reliability is guaranteed up to 150 °C for high-temperature environments such as the engine room.

6 Filters for FlexRay

The next generation vehicle communication network "FlexRay" has the same EMC problems as CAN. Circuit design is an important way to improve immunity and suppress radiation noise with FlexRay. The transmission rate is faster than with CAN (maximum transmission rate is 10 Mbps depending on the specifications). Therefore, it is necessary to consider signal quality when selecting a filter. In addition, a high common mode impedance is needed for improving immunity. Based on the above, the FlexRay specifications [*1] and application notes[*2] released by the FlexRay Consortium mention the electrical specification for Common Mode Filters. The following are the published filter specification.

DCR: 2 Ω or less
(Operating Temperature Range: –40 to +125 °C)
L value: 100 μH
Leakage inductance: < 1 μH

Reference standards are according to the following.

[*1] FlexRay_Electrical_Physical_Layer_Specification_V2.1_Rev.B
[*2] FlexRay_Electrical_Physical_Layer_Application_Notes_V2.1_Rev.B

TDK provides two types of Common Mode Filters for FlexRay; a drum core type and a toroidal core type (Figure 8).

Both products use solderless connection technology.

Figure 8 Common Mode Filters for FlexRay

ACT45R-101-2P	Product Name	ZJYS90V-101-2PTL
Solderless Joint	Features	Solderless Joint
100 µH	Inductance	100 µH
–40 to +150 °C	Operating Temperature Range	–40 to +125 °C
<2 Ω [150 °C]	DCR	<2 Ω [125 °C]

7 Noise Countermeasures for LIN

LIN bus uses single-ended transmission instead of differential transmission. Therefore, ferrite beads, capacitors, and three-terminal filters are effective countermeasures for noise. The LIN transmission rate is slower than CAN and FlexRay at under 100 kbps. It is also necessary to use beads and capacitors with a relatively large invariable. Figure 9 shows examples of countermeasures based on an immunity test.

When no countermeasure components were used during the immunity test, communication errors occurred according to the impressed noise. The influence of the impressed noise could be removed by using a three-terminal filter (TDK Part No.: ACF321825-331, C:300 pF).

Recommended Components for LIN

Three-terminal filter: ACF Series

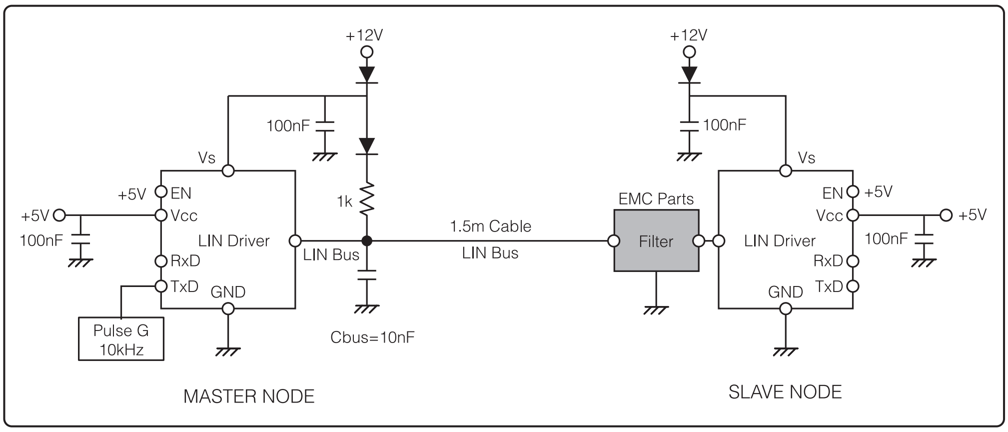
Inductor:	NLV Series	NLV25T-XXXX-EFD
		NLV32T-XXXX-EFD
	NLCV Series	NLCV25T-XXXX-EFD
		NLCV32T-XXXX-EFD

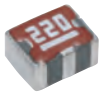
Figure 9 Method for Improving EMC for LIN

(a) Example Circuit for EMC Countermeasures

LIN (Local Interconnect Network)

LIN bus uses single-ended transmission, so an LC filter is best





ACF3218 series

Test Conditions:

: Filter was installed on the slave node side

: Diameter: 1 mm, Harness: 1.5 m

: The harness was also connected to the GND and a 12 V battery harness

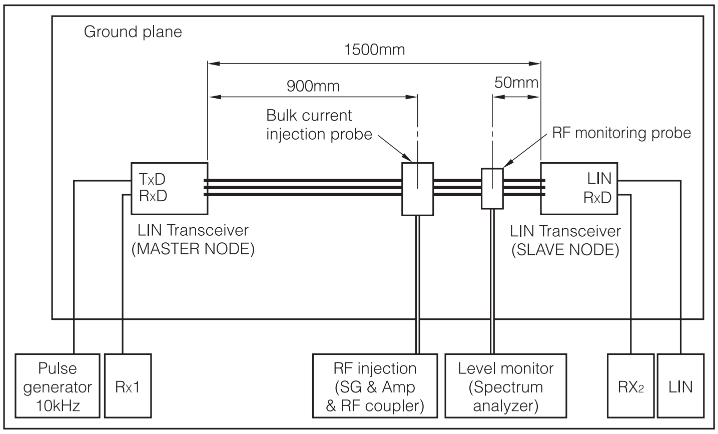
: 20 kbps (= 10 kHz) was impressed to the TxD terminal of the master node

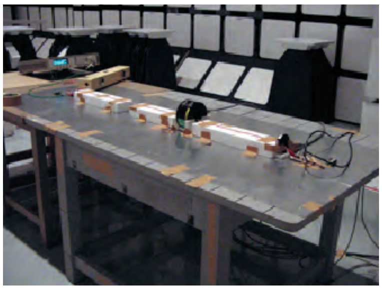
: Cbus = 10 nF

(b) Evaluation Circuit

LIN Harness BCI (Bulk Current Injection) Test

Measured in an Anechoic Chamber: A probe was used to impress a high-frequency current to the cables.

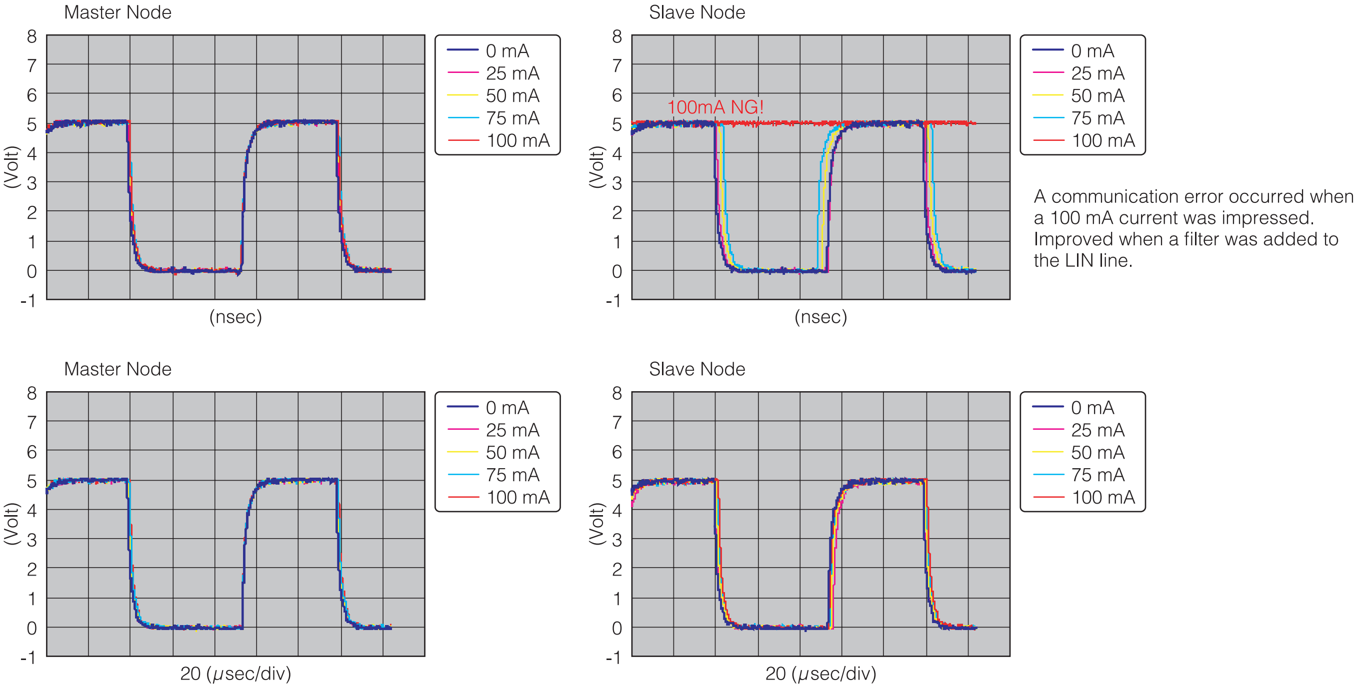




(c) Test Results

Output waveform measured from the receiving end Rx when BCI (0 to 100 mA) was impressed

No EMC filter



A communication error occurred when a 100 mA current was impressed. Improved when a filter was added to the LIN line.

8 Conclusion

As explained in the above, technology for improving the EMC of vehicle devices is important so that devices can operate correctly. In the future, the number of wireless devices will continue to increase as functions become more advanced, which will mean that technology for improving EMC will become even more important. The components explained in this material have an auxiliary role of improving EMC, but they are very effective. TDK will continue to develop products based on evaluation data related to vehicle communication networks so that various requirements can be met. There are other noise countermeasure examples that could not be explained here, so please ask for more information.

Noise Countermeasures for AC Power Lines

TDK Corporation Magnetics Business Group
Suguru Masaki

As was explained in “EMC Filter for Power Sources to Prevent Noise Intrusion and Emission at the AC Power Supply Part”, noises emitted from equipment will be transmitted via the AC power supply line, intrude into other connected equipment, and can cause malfunctions or a deterioration in their performance, consequently it is very important to reduce noise emission from AC lines. In this article, we will introduce the noise assessment method based on IEC’s noise regulation standard CISPR (Comité international spécial des perturbations radioeléctriques), and will explanation about methods for noise reduction, and show experimental data.

1 Assessment Methods for Noise Transmitted via AC Power Supply Lines

Measurement Method Specified by EU Standards

EN (European Norm), the noise regulation standard of Europe, is specified based on CISPR.

In IEC’s noise regulation standard CISPR (Comité international spécial des perturbations radioélectriques), the measurement method and limit values for conductive noise emitted from power cords of electronic equipment are specified. The measurement method specified in the standard is shown in Figure 1.

Place the equipment under test on an 80 cm high wooden desk. Connect the power cord to the noise measuring instrument called LISN (Photo 1) placed 80 cm away from the equipment under test. The LISN is to be placed on the surface of a large conductor, in other words, on an earth. The radio interference measuring instrument will detect and display the levels of noise output from LISN.

Figure 1 Measurement Method of AC Power Supply Line’s Conductive Noise Specified by CISPR

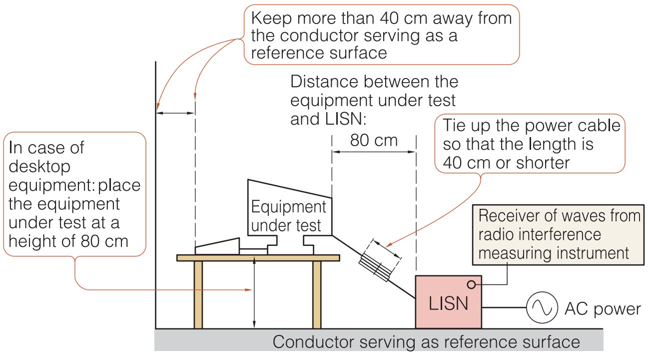
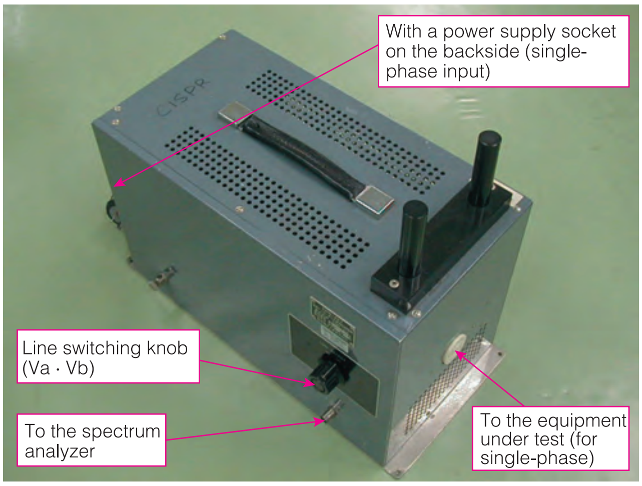


Photo 1 Appearance of LISN (KNW-407, Type V, Kyoritsu Corp.)



Principles of LISN

The LISN (Line Impedance Stabilizing Network) is a sort of jig that enables the quantitative assessment of the level of noises emitted from the power cords of electronic equipment.

The internal circuit of LISN is shown in Figure 2. It is a simple filter circuit consisting of resistance, inductor and capacitor. Voltages of interfering waves can be measured under the same conditions, even if the impedance on the side of the power supplier varies. Within the frequency band to be measured (0.15 to 30 MHz), the impedance seen from the side of the equipment under test will also be stabilized at 50 Ω. The two major purposes of LISN are as follows:

(1) To stabilize the impedance between the voltage line conductor and the grounding wire and the impedance between the neutral line conductor and the grounding wire at 50 Ω.

(2) To block conductive noises transmitted from the power source

Figure 2 Example of LISN’s Internal Circuit

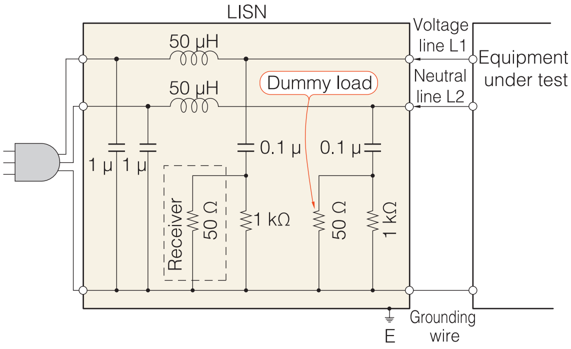
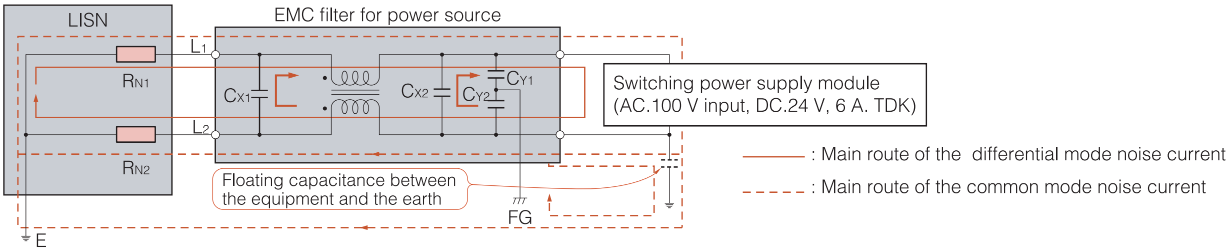
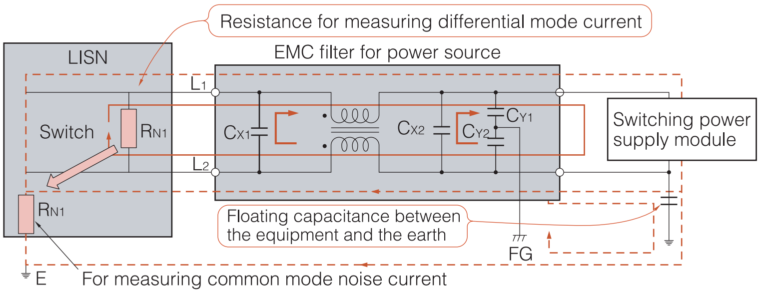


Figure 3 Conductive Noise Measurement Methods Using Standard Type LISN (Type V) and LISN for Separating Transmission Modes (Type Δ), and the Noise Flow

(a) Standard noise measurement circuit (type V)



(b) Circuit for measuring the transmission modes separately (type Δ)



As is shown in Figure 3 (a), in order to measure noise the level of conductive noise is obtained by measuring voltage drops on both ends of the LISN resistances set. The drop in the voltage indicates the noise voltage between the power supply line and the ground (called line-ground voltage), whose value is the sum of common mode noise and differential mode noise. The level of the conductive noise is generally called noise terminal voltage (dBμV)

Measuring Method of Actual Noise Levels

If the frequency components of the noise are not understood, first connect the LISN spectrum analyzer, and check the noise spectrum. The values to be displayed by the spectrum analyzer are peak values. Set a short sweep time and establish the frequency exceeding the regulated value.

Once you have narrowed down the noise frequency to be dealt with, set the measurement frequency of the radio interference measuring instrument to the same frequency. Display the values while switching between quasi-peak detection mode and average detection mode, and consider countermeasures by comparing them with the standard value.

Measuring Common Mode and Differential Mode Separately

Conductive noise transmission modes can be classified into two modes, the common mode and the differential mode. We have learned that it is effective to apply a common mode filter for common mode noises. Noise emitted to AC power sources can also be classified into common mode and differential mode, the countermeasures also vary according to each mode.

Although it is not possible to separate the two modes when using a standard LISN, it is possible if you use the type shown in Figure 3 (b). Its structure enables switching the resistance for measurement between the common mode and the differential mode. LISN of the type shown in Figure 3 (a) are called type V, the standard LISN specified by CISPR and FCC (Federal Communications Commission). This is the general type of LISN.

LISN of the type shown in Figure 3 (b) are called type Δ. This type used to be applied when measuring conductive noise in TV bands, but since CISPR and FCC specified type V as the standard LISN, it has almost completely ceased to be used. However, this is the only LISN capable of measuring both the common mode and differential mode separately, and is also a useful tool for noise assessment.

Example of Measuring a Power Source Terminal Separating the Transmission Modes

Examples of measuring the power source terminal voltage of a switching power supply module using LISNs of type V and type Δ are shown in Figure 4 and Figure 5.

As is shown in Figure 5, measurement can be carried out by separating the common mode noise and the differential mode noise, when using type Δ LISN. It can be identified from Figure 5 that the main component of the conductive noise is in common mode, indicating that in the first place countermeasures against common mode noise will be needed.

Figure 4 Conductive Noise Spectrum of Switching Power Supply Module Measured Using Type V LISN

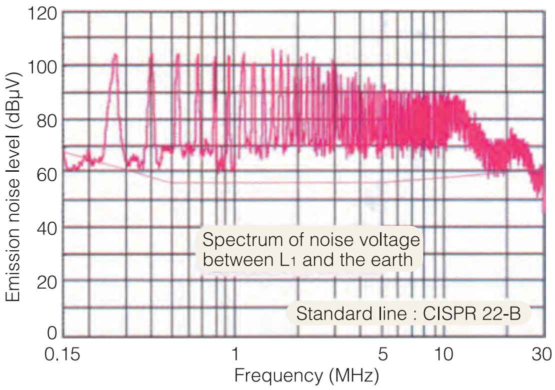
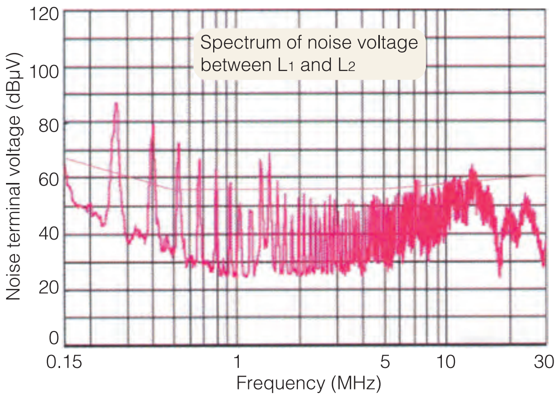
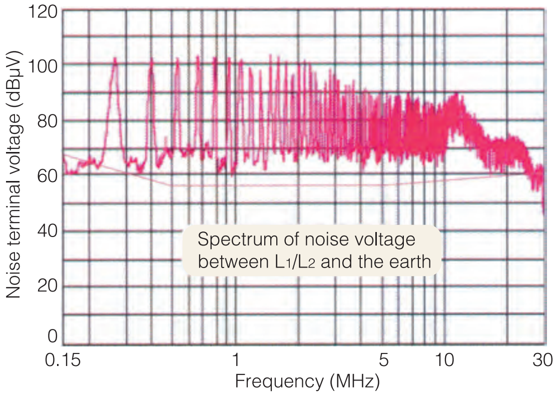


Figure 5 Conductive Noise Spectrum of Switching Power Supply Module Measured Using Type Δ LISN

(a) Measurement of differential mode



(b) Measurement of common mode



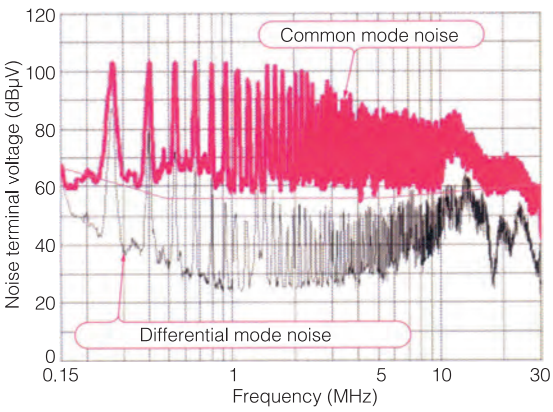
2 Countermeasure Examples against the Noise Terminal Voltage of a Switching Power Supply Module

Countermeasures and Noise Reduction Effects

(1) Countermeasures against common mode noise

As is shown in Figure 6, common mode noises were high reaching around 100 dBμV and before countermeasures were taken they exceeded the standard limit value by more than 40 dBμV.

Figure 6 Conductive Noise Spectrum of Switching Power Supply Module without Noise Countermeasures



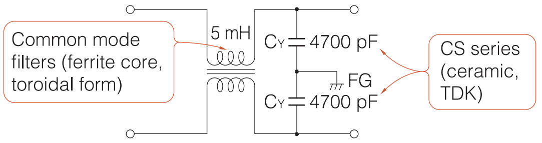
Therefore, we inserted common mode filters in the AC lines as is shown in Figure 7, and inserted 4700 pF capacitors to the lines leading to the frame ground (FG). These capacitors are called Y capacitors. As a result, common mode noise was reduced enough to fall below the regulation value, as is shown in Figure 7 (b).

(2) Countermeasure against differential mode noise

As is shown in Figure 7 (b), differential noise at bandwidth 150 kHz to 2 MHz exceeded the standard regulation value. Therefore, we inserted capacitors of 0.47 μF between the AC lines, as is shown in Figure 8 (a). These capacitors are called X capacitors. As a result, the noise level fell below the standard regulation value, as is shown in Figure 8 (b).

Figure 7 Common Mode Noise Countermeasures and Their Effects

(a) Add two common mode filters and Y capacitors



(b) Vector of noise terminal voltage

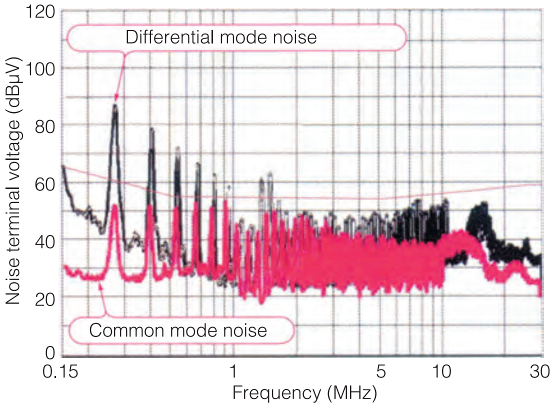
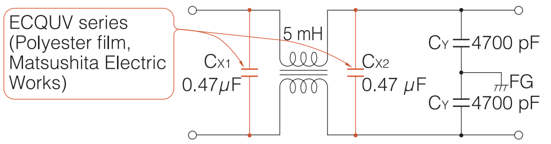
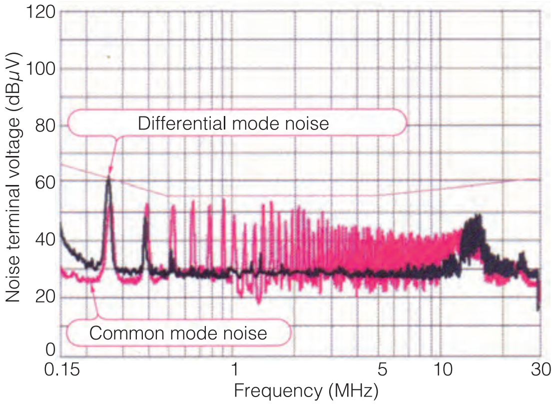


Figure 8 Differential Mode Noise Countermeasures and Their Effects

a) Add two common mode filters and Y capacitors



(b) Spectrum of noise terminal voltage

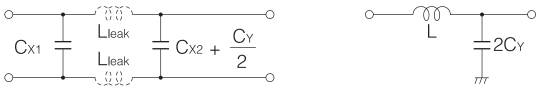


■ Key Points in Choosing Countermeasure Components

(1) Common mode filter

Equivalent circuits are shown in Figure 9. The common mode filter has a leak inductance of several to several dozen μH. Although the core reaches saturation easier when this component is high, it also helps to reduce differential mode noise. A two-mode filter is a part that positively utilizes this component. Countermeasures against saturation and against differential mode noise are in a trade-off relationship.

Figure 9 Equivalent Circuits of Common Mode Filters


(a) Equivalent circuit for differential mode signals

(b) Equivalent circuit for common mode signals

▶ Y capacitor

Y capacitors connected between the AC lines and the FG work to let out the common mode noise current to the FG. These are also called “common mode capacitors”.
Leakage current according to the frequency and voltage of the AC power source will flow into the Y capacitor. The leakage current increases when the capacitance of Y capacitors become larger and there is a risk of electric shock; restrictions are placed on the capacity by safety standards such as UL (Underwriters Laboratories Incorporated), in order to prevent the leakage current amount from exceeding a certain value.

Normally, two Y capacitors will be used as in Figure 7 and Figure 8. As the AC lines will be connected by capacitances, it will also prove effective against differential mode noise. The effect will be especially high at high frequencies around 8 to 10 MHz.

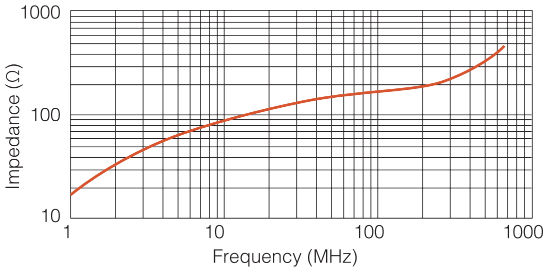
▶ X capacitor

X capacitors to be connected between the AC lines are effective only against differential mode noise. They are also called differential mode capacitors, and those with comparatively large capacities around 1 μF are used. As X capacitors are connected between the lines and are not connected between the line and the earth, even if they break there will be no danger such as the risk of electric shock. Frequency bands where X capacitors prove effective are lower than those of Y capacitors, being around 150 kHz to 1 MHz

3 Clamp Filters should be Used to Block the Intrusion of a Sharp Noise Pulse

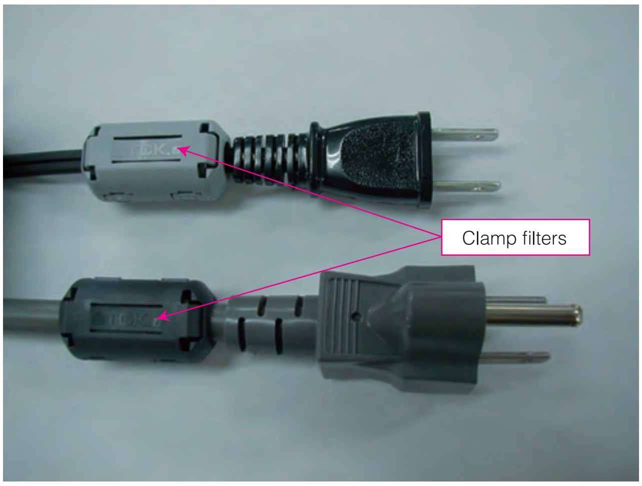
As is shown in Figure 10, a clamp filter is a part capable of maintaining impedance up to the high frequencies. Just by attaching it to the cable, it is very effective as a countermeasure against pulse noise with high frequency components and noises of external origin such as static electricity.

Figure 10 High Impedance Characteristic is Maintained up to High Frequency Band when Using a Clamp Filter



AC power cords with clamp filters (ZCAT2035-0930A) attached are shown in Photo 2.

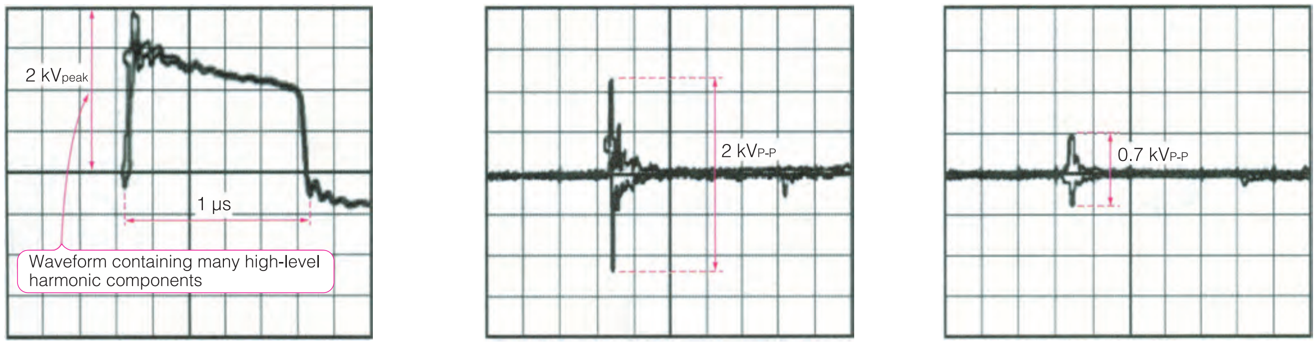
Photo 2 Clamp Filters Attached to AC Power Cords



The reduction effect of pulse noise before and after attaching the clamp filter is shown in Figure 11. We applied a pulse voltage with peak voltage of 2 kV and a pulse width of 1 μs to the primary side of the switching power supply module, and observed the voltage waveform appearing on the secondary side. When a clamp filter is applied, the peak value of the waveform of the noise leaking out to the primary side will be reduced from 2.0 kVp-p to 0.7 kVp-p.

When using a general EMC filter on a power line, no effect could be expected against high frequency components above 30 MHz. Even if you use an EMC filter on a power line compatible with high-voltage pulses, if the pulse noise shows a sharp rise, it is possible that pulse noises with high peak values would be output to the secondary side. In that respect, it will be possible to obtain a stable reduction effect even at the high frequency band, if you use a clamp filter.

Figure 11 Reduction Effect of High-Speed Pulse Noises by a Clamp Filter



(a) Input Vin

(b) Output before applying clamp filter Vout

(c) Application of clamp filter ZCAT3030 (wound twice)

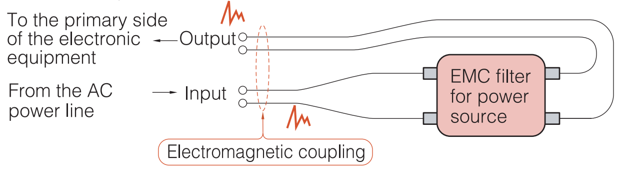
4 To Increase the Performance of an EMC Filter for Power Line

Do not Arrange Input Wires and Output Wires close together

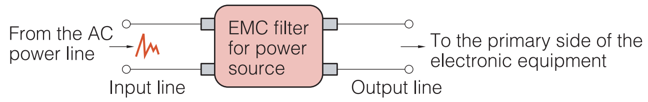
Please try to keep input wires and output wires away from each other, as shown in Figure 12. If the input/output wires come in contact with each other such as when they are bound together, the noise inhibiting effect will be reduced, since the eliminated noise will be taken up again by floating capacitance and electromagnetic coupling.

Figure 12 Keeping the Distance between the Input / Output Wires of an EMC Filter for Power Line

(a) Bad example



(b) Good example



Keep the Impedance between the EMC Filter and the Earth as low as possible

Keep the impedance between the ground of the EMC filter for the power line and the earth as low as possible.

When the case is made of metal, it is possible to reduce high-frequency noises just by connecting the case and the equipment's FG. When the chassis of the equipment is painted, it will be necessary to realize a low-impedance connection status, by such means as scraping the paint off, as shown in Figure 13. When the case is made of plastic, a lead wire as thick and short as possible should be used for connecting. Transitions of decay characteristics for connecting the case of an EMC filter for power line, RSAN-2010 type (single-phase AC. 250 V, 10 A, TDK-Lambda) with the earth, and for connecting it with the earth using a wire rod as long as 10 cm, are shown in Figure 14.

Figure 13 Connect Earth Terminal of the EMC Filter for Power Line after Scraping Off the Paint from the Chassis

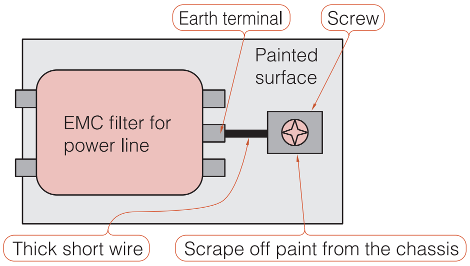
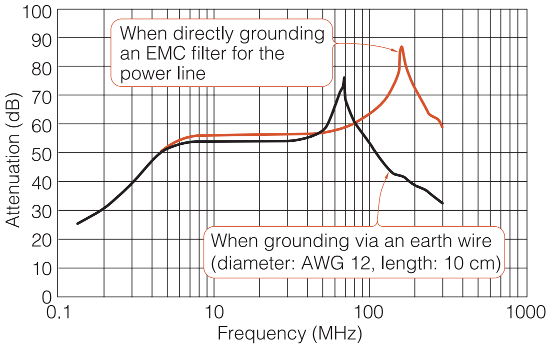


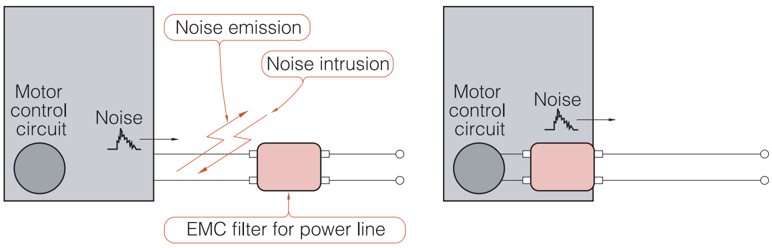
Figure 14 How to Ground an EMC Filter for Power Line, and the Attenuation Change in Conductive Noise



Separation of Input/Output by Shielding

As is shown in Figure 15, the EMC filter for the power line should be set as close as possible to the noise source, or at the input/output point of the electronic equipment. If it is placed outside the equipment and wired from there, it may become the cause of noise radiation, or reversely, of malfunction due to noise intrusion into the power supply line.

Figure 15 The EMC Filter for the Power Line should be Placed Close to the Noise Source


(a) Bad example

(b) Good example

References

(1) Toshio Kinoshita; Basics and Practice of EMC, Nikkan Kogyo Shimbun, LTD., 1997)

(2) Tim Williams; EMC for Product Designers, Newnes, 1992

(3) Clayton R. Paul; Introduction to EMC, pp.482 to 483, Feb. 1996, mimatsu-data-system

(4) Yoshio Masuno; Additional Volume of Electronics November, pp. 89 to 90, 1998, Ohmsha, Ltd.

TDK EMC Technology **Practice Section**

Circuit Simulation and Technical Support Tools

TDK Corporation Application Center
Tetsuya Umemura, Katsushi Ebata

1 Utilization of Computer Simulation

In recent years, computer simulation has been actively introduced in the areas of circuit design and equipment design; simulation saves considerable time and money compared to actually producing experimental circuits and equipment and repeating tests. The increased power and performance of both hardware and software, enabling much faster complex computation is also a factor promoting its popularization.

2 Accuracy Improvement of Computer Simulation

Although the use of computer simulation seems to have been spreading as mentioned above, there are those engineers who question its validity on the grounds that "the actual results do not match the simulation results". Although it may be true that "God is the only one" who can really know, it can also be said that computer simulation in recent years has made considerable advances as a tool for understanding the outline of phenomena.

There are two prominent factors that affect the reliability of computer simulation; one is the computational principle, the so-called "computational engine", and the other is the "modeling technique".

A "computational engine" is a system for enabling computational calculation created by the innovative efforts of each simulator manufacturer, based on principles derived from past experiences. The results and computation time varies according to each computational engine, even when performing a simulation of the same circuit.

"Modeling techniques" tend to depend largely on the user of the simulator. If the model to be simulated is not close to reality, the result will mirror this, even if the computational engine is excellent. However, a high level of expert knowledge and experience are required in order to master modeling techniques.

Let's take an example of a ceramic capacitor. A comparative example of impedance characteristics between the actual measurement data of a ceramic capacitor (0.1 μF) and the model data computed based on the "equivalent circuit model" is shown in Figure 1. Whereas results of all models match that of the actual measurement regarding |Z| characteristic, it is clear that model 1's result regarding ESR (Equivalent Series Resistance) characteristic do not match the actual measurement data. Although capacitors are modeled as ⊣ ⊢ in circuit simulators, components such as resistance components and inductance components are included in the actual capacitor, and without the use of a model that reflects those components more accurately, the result may be that "the results of simulation and actual measurement do not match". However, caution is needed when setting up a simulation, for if too many complex models are used in order to pursue computational accuracy, computing time will be considerably extended.

Figure 1 Comparative Examples of Actual Measurement and Models regarding Ceramic Capacitor (0.1 μF)

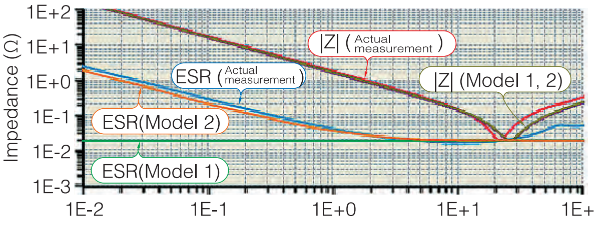


Table 1 TDK Technical Support Tools

Classification	Name	Outline
Windows® application	Component characteristic analysis software "SEAT"	Sophisticated applications such as display of component characteristics, pulse response simulation, and display of DC bias/temperature characteristics
Web application	Components characteristic viewer "CCV"	Display and compare data such as a component's frequency characteristics and DC bias/temperature characteristics on the browser
General purpose electronic component models	S-parameter Data Library	Collective data of actual measured S-parameters
	Equivalent Circuit Model Library	Collective data of equivalent circuit models in PDF format
	SPICE Netlist Library	Collective data of equivalent circuit models in netlist format
Dedicated electronic component models for simulators	Component Library for Agilent ADS	Equivalent circuit models, circuit schematic symbols and footprint data of the components
	Component Library for Ansoft Designer® & NEXXIM®	
	Component Library for Zuken CR-5000 Lightning	
	Component Library for Cadence Allegro® PCB SI	Equivalent circuit models of the components
	Component Library for Cadence Allegro® PCB PI option	

3 TDK Technical Support Tools

In order to respond to various modeling needs TDK Technical Support Tools provide many electronic component models and the software for utilizing them. The contents of TDK Technical Support Tools at this writing are shown in Table 1. They are based on general purpose electronic component models (S-parameters and equivalent circuits), and the component characteristic analysis software “SEAT” and the components characteristic viewer "CCV" are software developed to display characteristics and perform simple circuit simulations using information on general purpose electronic component models. General purpose electronic component models were processed into dedicated models for simulators, so that they could be easily used by each simulator, ensure ease of arrangements from the component palette attached to the simulator, or ensure their footprint information can be obtained in combination with the CAD function. All tools/models can be used for free.

Website of technical support tools
http://www.tdk.co.jp/etst/index.htm

4 Component Characteristic Analysis Software “SEAT”

Screen shot of the component characteristic analysis software “SEAT” is shown in Figure 2.
Main functions of “SEAT” are as below:

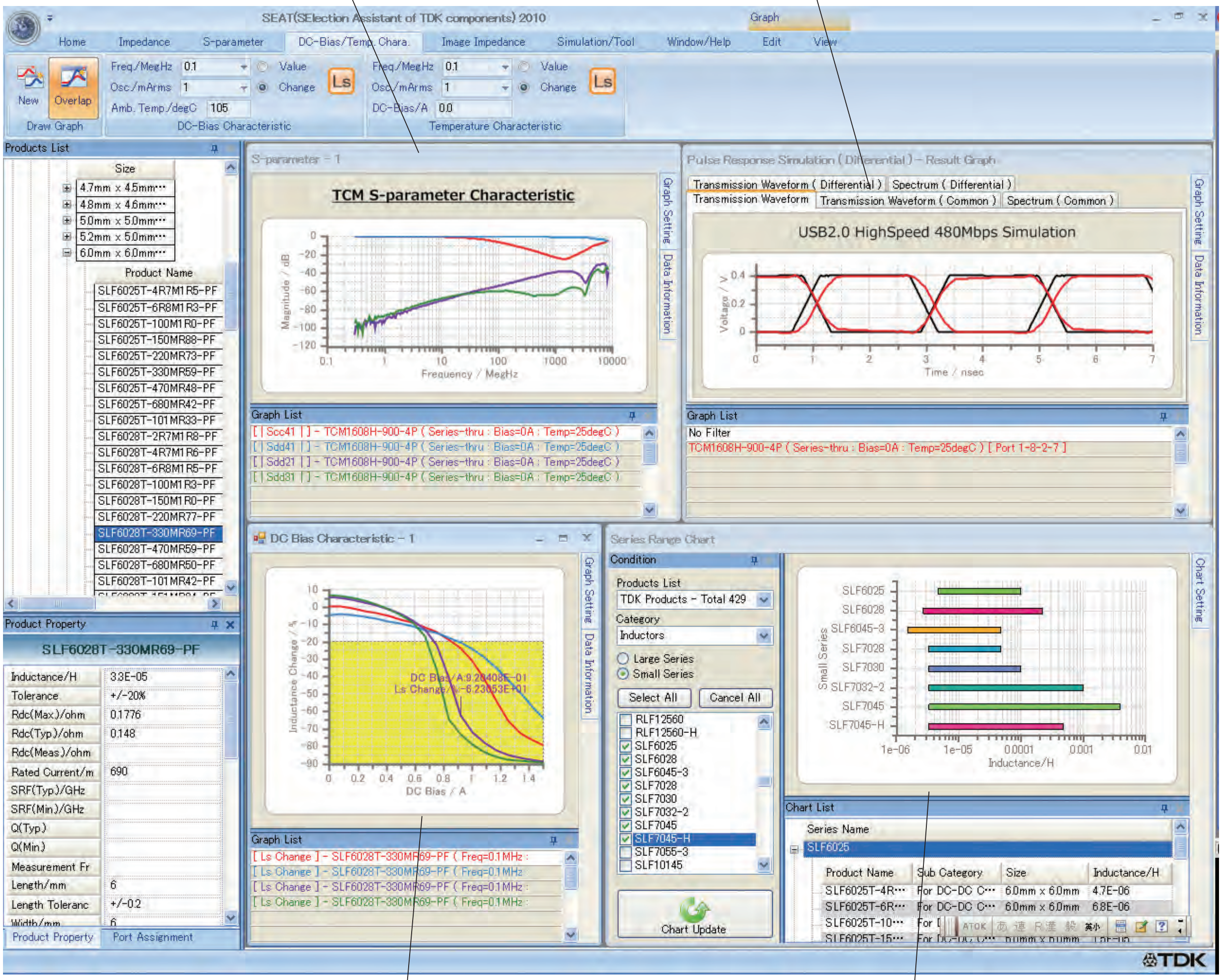
- Several thousand components such as coils, capacitors, beads, 3-terminal filters, common mode filters, varistors, NTC thermistors and baluns are included.
- Display of characteristics such as impedance and S-parameters
- Pulse response simulation
- TDR simulation
- DC bias/temperature characteristics simulation
- User-defined filter (tool for combining multiple components)
- User-defined component
- Characteristic impedance computation tool (tool for computing characteristic impedance from physical dimensions of the transmission line)

When using “SEAT”, it is not only possible to display frequency characteristics, but also to check the component’s effect through pulse response simulation, or to estimate the degree of characteristic change that will happen upon application of DC bias, or under any given temperature conditions.

Figure 2 Screen Shot of the Component Characteristic Analysis Software “SEAT”

Display of the component’s frequency characteristics, etc

Pulse response simulation



Freq./MegHz 0.1
Osc./mArms 1
Amb. Temp./degC 105
Freq./MegHz 0.1
Osc./mArms 1
DC-Bias/A 0.0

4.7mm x 4.5mm···
4.8mm x 4.6mm···
5.0mm x 5.0mm···
5.2mm x 5.0mm···
6.0mm x 6.0mm···

SLF6025T-4R7M1R5-PF
SLF6025T-6R8M1R3-PF
SLF6025T-100M1R0-PF
SLF6025T-150MR88-PF
SLF6025T-220MR73-PF
SLF6025T-330MR59-PF
SLF6025T-470MR48-PF
SLF6025T-680MR42-PF
SLF6025T-101MR33-PF
SLF6028T-2R7M1R8-PF
SLF6028T-4R7M1R6-PF
SLF6028T-6R8M1R5-PF
SLF6028T-100M1R3-PF
SLF6028T-150M1R0-PF
SLF6028T-220MR77-PF
SLF6028T-330MR69-PF
SLF6028T-470MR59-PF
SLF6028T-680MR50-PF
SLF6028T-101MR42-PF

SLF6028T-330MR69-PF

Inductance/H	3.3E-05
Tolerance	+/-20%
Rdc(Max)/ohm	0.1776
Rdc(Typ)/ohm	0.148
Rdc(Meas)/ohm	
Rated Current/m	690
SRF(Typ)/GHz	
SRF(Min)/GHz	
Q(Typ)	
Q(Min)	
Measurement Fr	
Length/mm	6
Length Toleranc	+/-0.2
Width/mm	6

[ ] Scc41 [ ] - TCM1608H-900-4P (Series-thru : Bias=0A : Temp=25degC)
[ ] Sdd41 [ ] - TCM1608H-900-4P (Series-thru : Bias=0A : Temp=25degC)
[ ] Sdd21 [ ] - TCM1608H-900-4P (Series-thru : Bias=0A : Temp=25degC)
[ ] Sdd31 [ ] - TCM1608H-900-4P (Series-thru : Bias=0A : Temp=25degC)

No Filter
TCM1608H-900-4P (Series-thru : Bias=0A : Temp=25degC) [Port 1-8-2-7]

DC Bias/A:9.28408E-01
Ls Change/%:-6.23053E+01

[Ls Change] - SLF6028T-330MR69-PF (Freq=0.1MHz :
[Ls Change] - SLF6028T-330MR69-PF (Freq=0.1MHz :
[Ls Change] - SLF6028T-330MR69-PF (Freq=0.1MHz :
[Ls Change] - SLF6028T-330MR69-PF (Freq=0.1MHz :

Products List: TDK Products - Total 429
Category: Inductors
○ Large Series
● Small Series
Select All | Cancel All

☐ RLF12560
☐ RLF12560-H
☑ SLF6025
☑ SLF6028
☑ SLF6045-3
☑ SLF7028
☑ SLF7030
☑ SLF7032-2
☑ SLF7045
☑ SLF7045-H
☐ SLF7055-3
☐ SLF10145

Series Name: SLF6025

Product Name	Sub Category	Size	Inductance/H
SLF6025T-4R···	For DC-DC C···	6.0mm x 6.0mm	4.7E-06
SLF6025T-6R···	For DC-DC C···	6.0mm x 6.0mm	6.8E-06
SLF6025T-10···	For [		

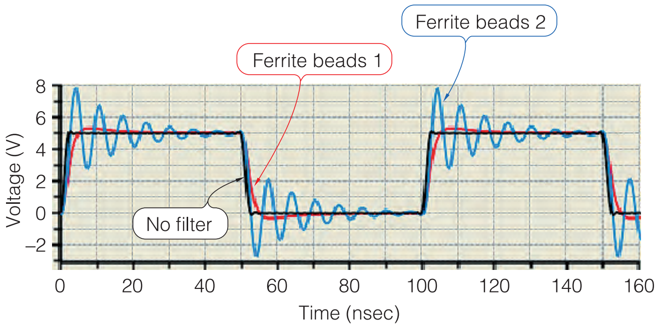
Extensive component search function

Display of DC bias/temperature characteristics

Ferrite beads are a typical noise countermeasure component and Figure 3 gives the computation results of pulse response simulation showing their influence on transmission waveform. Voltage waveforms on the side of the receiver are displayed, the result without a filter are in black line, and the results when two different ferrite beads were inserted right after the driver are shown in red and blue lines. Since ringing waveforms such as those displayed in blue line may appear and cause adverse effects depending on circuit conditions, it is possible to save time and reduce costs, by using tools such as “SEAT” to narrow down the target in advance.

SEAT website
http://www.tdk.co.jp/eseat/index.htm

Figure 3 Effect Example of Ferrite Beads in Pulse Response Simulation (Single End)



5 Components Characteristic Viewer “CCV”

Screen shot of the components characteristic viewer “CCV” is shown in Figure 4. Although “CCV” is not equipped with the simulation function included in “SEAT”, it is characterized by the fact that frequency characteristics and DC bias/temperature characteristics can be displayed on the browser.

It is also very easy to operate, and you will be able to display the component characteristics by selecting the component and using the wizard (three steps). In concrete terms, take the following steps as shown in Figure 5:

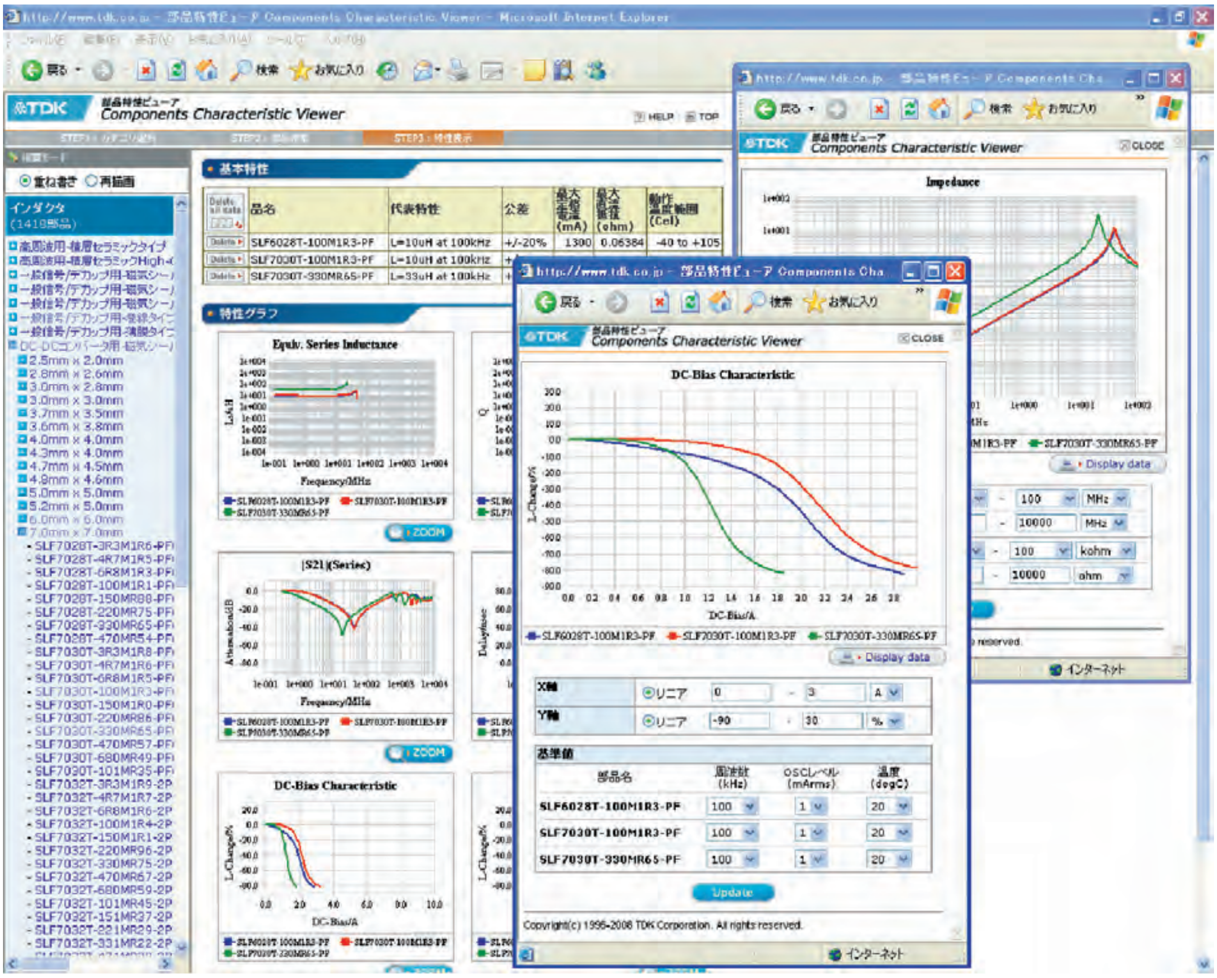
Step 1: Select the component category
Step 2: Narrow down the target product (no need to enter, if narrowing down is not necessary)
Step 3: Select a component from the component list on the left side of the screen

When the above steps are taken, the component characteristics will be displayed on the right side of the screen. Graphs will be overlaid when selecting another component, making it easy to perform comparative evaluation.

As “CCV” is an easy-to-operate web application without any need of installation, we strongly recommend its use for selecting components.

CCV website
http://www.tdk.co.jp/ccv/index.asp

Figure 4 Screen Shot of Components Characteristic Viewer “CCV”



基本特性

	品名	代表特性	公差	最大直流電流 (mA)	最大直流抵抗 (ohm)	動作温度範囲 (Cel)
Delete	SLF6028T-100M1R3-PF	L=10uH at 100kHz	+/-20%	1300	0.06384	-40 to +105
Delete	SLF7030T-100M1R3-PF	L=10uH at 100kHz	+			
Delete	SLF7030T-330MR65-PF	L=33uH at 100kHz	+			

X軸	● リニア	0	3	A
Y軸	● リニア	-90	30	%

基準値

部品名	周波数 (kHz)	OSCレベル (mArms)	温度 (degC)
SLF6028T-100M1R3-PF	100	1	20
SLF7030T-100M1R3-PF	100	1	20
SLF7030T-330MR65-PF	100	1	20

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Figure 5: Three Steps of CCV

Step 1: Selecting the category

カテゴリを選択して、「NEXT」ボタンをクリックしてください。

○ フェライトビーズ	(ACC, HFxxACB, MMZ, MMZ-C, MPZ, ZBFS シリーズ)
○ フェライトビーズアレイ	(MZA シリーズ)
○ コモンタイプフェライトビーズアレイ	(MCZ シリーズ)
● インダクタ	(CPL, GLCR, GLF, GLFR, GLQ, LTF, MLF, MLF-J, MLG, MLK, MLP, MLZ, NL, NLC, NLCV, NLCV-PFR, NLFC, NLFV, NLHV, NLV, RLF, SLF, SPM, TFC, TPL, VLCF, VLF, VLM, VLP, VLS シリーズ)
○ 積層セラミックコンデンサ（C<=0.1uF）	(C(一般用, 中耐圧, 高耐圧, X8R), CKG シリーズ)
○ 積層セラミックコンデンサ（C>0.1uF）	(C(一般用, 中耐圧, X8R), CKG シリーズ)
○ 低ESL貫通コンデンサ	(CKD シリーズ)
○ 3端子フィルタ	(ACF, ACH, ACH32C, MEM シリーズ)
○ 3端子フィルタアレイ	(MEA シリーズ)
○ コモンモードフィルタ	(ACM, ACT, TCM, ZBYS, ZCYS, ZJYS シリーズ)
○ コモンモードフィルタアレイ	(TCM, ZJYS シリーズ)
○ バリスタ	(AVRL, AVR-M シリーズ)

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Step 2: Narrowing down

このステップでは部品の絞り込みをします。
基本特性もしくは周波数特性に値を入力して、「NEXT」ボタンをクリックしてください。
何も入力されていない場合は、現在のカテゴリに含まれるすべての部品が表示されます。

品名 :
形状 : すべて
シリーズ名 : すべて
最大定格電流(mA) : -
最大直流抵抗(ohm) : -

最小 <= お選びください <= 最大 at 周波数 MHz

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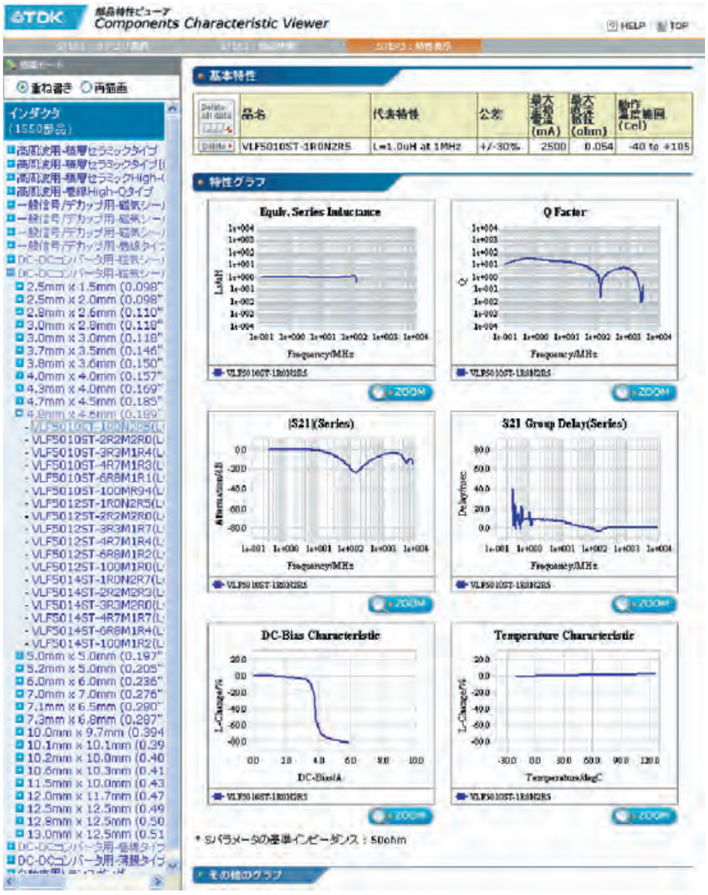
Step 3: Display of product characteristics



Delete all data	品名	代表特性	公差	最大定格電流(mA)	最大直流抵抗(ohm)	動作温度範囲(Cel)
Delete	VLF5010ST-1R0N2R5	L=1.0uH at 1MHz	+/-30%	2500	0.054	-40 to +105

* Sパラメータの基準インピーダンス：50ohm

6 Electronic Component Models for Circuit Simulation "TVCL"

When designing electronic circuits using circuit simulation, simulation models for various factors making up the circuit (semiconductors, passive components, connectors, substrate traces, etc.) are necessary. TDK provides circuit simulation models of various electronic components (TDK Virtual Component Library). The contents are introduced below:

Characteristics of TDK's Electronic Component Models for Circuit Simulator

- Various products included

Numerous general purpose passive electronic components of TDK are included, such as capacitors, inductors, ferrite beads, common mode filters, 3-terminal filters, pulse transformers, varistors, baluns, etc.

- Compatibility with circuit simulators

In order to be compatible with circuit simulators, we have prepared eight libraries such as those shown in the lower half of Table 1. Among these, the general purpose component models were created in a general purpose format, so that they can be used by various circuit simulators. Also, dedicated electronic component models for simulators are created exclusively for a specific circuit simulator, with data such as circuit schematic symbols and footprints included, in addition to equivalent circuit model data.

- We provide the latest models via the Internet

All models are provided via the Internet.

The URLs are as follows:

Japanese site http://www.tdk.co.jp/tvcl/
English site http://www.tdk.co.jp/etvcl/

Contents of Each Library

TDK's electronic component models for circuit simulators consist of nine libraries, making it possible to select the optimum library according to factors such as the circuit simulator to be used and the purpose. The contents of each library are introduced below:

- S-Parameter Data Library

This is collective data based on actual measured S-Parameters. It is written in the widely common Touchstone format, and can be read directly by many simulators. (See Figure 6)

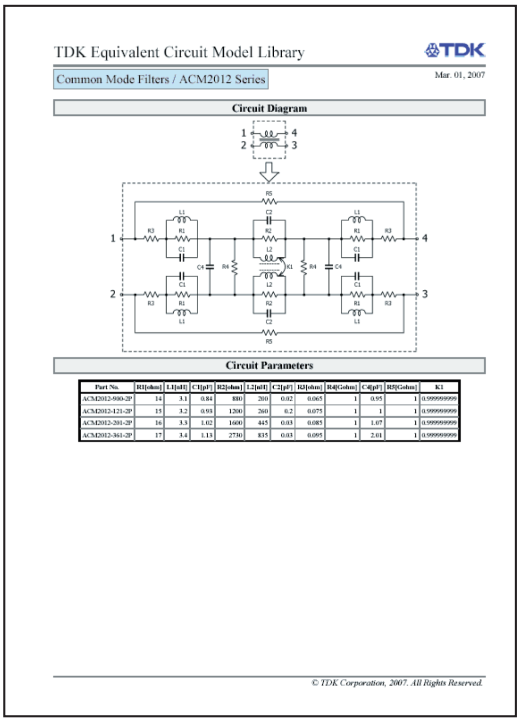
Figure 6　An Example of S-Parameter Data Library

```
! Port assignments
! 1 ---@@@--- 2
!
! Measurement condition
!  Operating Temperature = 25 Cel
!  DC Bias Current = 0 A
!
! TDK Corporation
!
# MHz S MA R 50
0.0000  0.0010  -0.0000 0.9991  -0.0000  ···
0.3000  0.0602  -84.612 0.9947  -3.4358  ···
0.3141  0.0628  -85.264 1.0005  -3.5931  ···
0.3289  0.0677  -85.119 0.9990  -4.1515  ···
    ·
＜中略＞
    ·
8500.0  0.3809  -120.98 0.8349  -35.585  ···
```

- Equivalent Circuit Model Library

Equivalent circuit model is a circuit for duplicating the frequency characteristics of an actual component by the circuit simulator. Data of equivalent circuit models are written in PDF format in the Equivalent Circuit Model Library (See Figure 7).

Figure 7　An Example of Equivalent Circuit Model Library



TDK Equivalent Circuit Model Library

Common Mode Filters / ACM2012 Series

Mar. 01, 2007

Circuit Diagram

Circuit Parameters

Part No.	R1[ohm]	L1[nH]	C1[pF]	R2[ohm]	L2[nH]	C2[pF]	R3[ohm]	R4[Gohm]	C4[pF]	R5[Gohm]	K1
ACM2012-900-2P	14	3.1	0.84	880	200	0.02	0.065	1	0.95	1	0.999999999
ACM2012-121-2P	15	3.2	0.93	1200	260	0.2	0.075	1	1	1	0.999999999
ACM2012-201-2P	16	3.3	1.02	1600	445	0.03	0.085	1	1.07	1	0.999999999
ACM2012-361-2P	17	3.4	1.13	2730	835	0.03	0.095	1	2.01	1	0.999999999

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- SPICE Netlist Library

Data of equivalent circuit models are written in the SPICE netlist format. Since a general purpose SPICE format is used, this library can be read directly by many simulators. (See Figure 8)

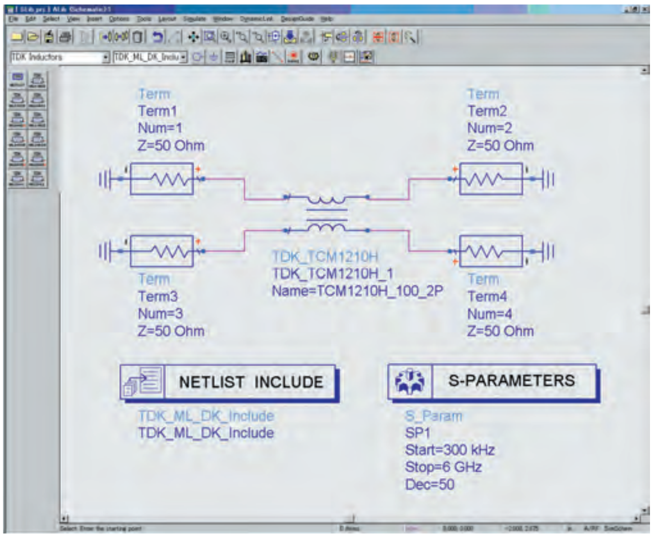
Figure 8　An Example of SPICE Netlist Library

```
*--------------------------------------------------
* SPICE Netlist Generated by TDK Corporation
* TDK P/N: ACM2012-900-2P (Common Mode Filter)
* Property: Zc(at 100MHz) = 90 [ohm]
* Model Generated on Dec. 04, 2006
*--------------------------------------------------
* External Node Assignments:
*
*  1 ---@@@--- 4
*       ===
*  2 ---@@@--- 3
*
*--------------------------------------------------
.SUBCKT ACM2012_900_2P 1 2 3 4
C11 11 12 0.84p
C12 21 22 0.84p
C13 31 32 0.84p
C14 41 42 0.84p
C21 12 42 0.02p
C22 22 32 0.02p
C41 12 22 0.95p
C42 32 42 0.95p
    ·
＜中略＞
    ·
R42 32 42 1G
R51 1 4 1G
R52 2 3 1G
.ENDS ACM2012_900_2P
*--------------------------------------------------
```

- Component Library for Agilent ADS

This library is to be used with ADS of Agilent Technologies. Data of circuit schematic symbols and footprints are included, in addition to the equivalent circuit model data. It is also compatible with the Discrete Optimize function of ADS, making it possible to automatically select the optimum component. (See Figure 9)

Figure 9　An Example of Electronic Component Model for Agilent ADS



Term
Term1
Num=1
Z=50 Ohm

Term
Term2
Num=2
Z=50 Ohm

TDK_TCM1210H
TDK_TCM1210H_1
Name=TCM1210H_100_2P

Term
Term3
Num=3
Z=50 Ohm

Term
Term4
Num=4
Z=50 Ohm

TDK_ML_DK_Include
TDK_ML_DK_Include

S_Param
SP1
Start=300 kHz
Stop=6 GHz
Dec=50

- Component Library for Ansoft Designer® & NEXXIM®

This library is to be used with Ansoft Designer and NEXXIM of Ansoft Corporation. Data of circuit schematic symbols and footprints are included, in addition to the equivalent circuit model data. (See Figure 10)

- Component Library for Zuken CR-5000 Lightning

This library is to be used with Zuken Inc.’s CR-5000 Lightning. Data of circuit schematic symbols and footprints are included, in addition to the equivalent circuit models of common mode filter. (See Figure 11)

- Component Library for Cadence Allegro® PCB SI

This library is to be used with Cadence Allegro PCB SI of Cadence Design Systems, Inc. Equivalent circuit models of common mode filter and ferrite beads are included.

Figure 10 An Example of Electronic Component Model for Ansoft Designer® & NEXXIM®

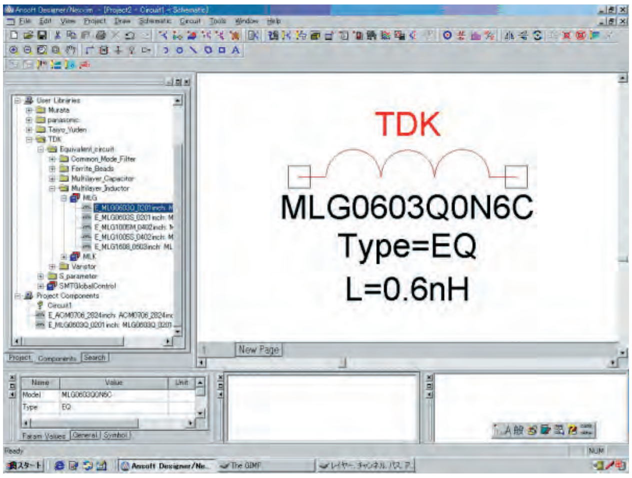
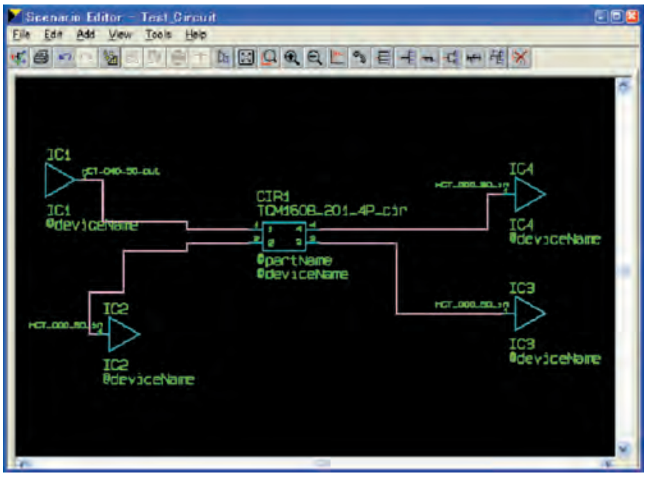


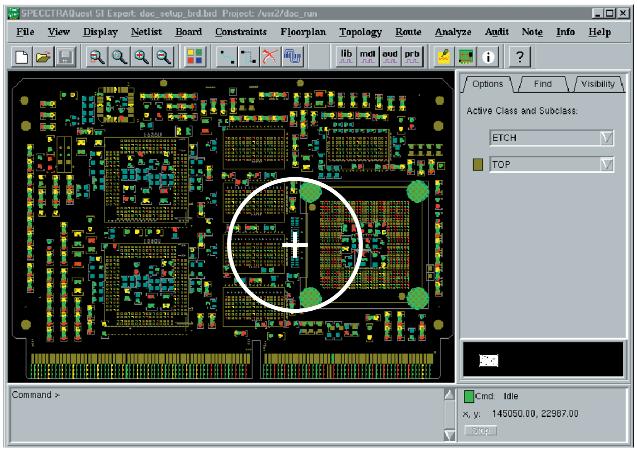
Figure 11 An Example of Electronic Component Model for Zuken CR-5000 Lightning



- Component Library for Cadence Allegro® PCB SI option

This library is to be used with Cadence Allegro PCB SI option of Cadence Design Systems, Inc. Equivalent circuit models of laminated ceramic capacitors are included. (See Figure 12)

Figure 12 An Example of Cadence Allegro® PCB PI Option

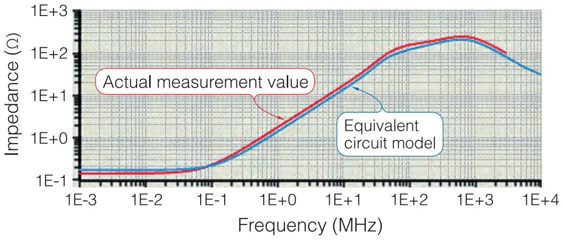


Comparison of Equivalent Circuit Models and Actual Measurement Values

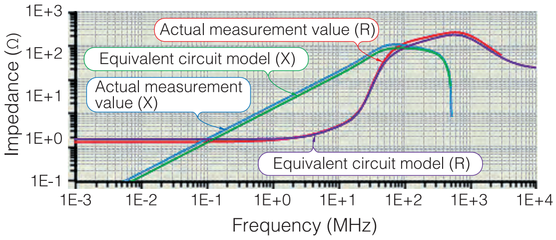
As the characteristics of the materials making up the electronic components and the internal structure of the components themselves are taken into consideration in TDK's equivalent circuit models, it is possible to duplicate the characteristics of the actual components in detail. The comparative results of impedance characteristics regarding ferrite beads (MMZ1005D121C) between the equivalent circuit model and the actual measurement value are shown in Figure 13. It can be seen that for a wide range of frequencies the equivalent circuit model duplicates the behavior of the actual component very well. In order to have reliable circuit simulation results, it is essential to use such highly accurate simulation models.

Figure 13 Comparison of Equivalent Circuit Models and Actual Measurement Values (MMZ1005D121C)

(a) Impedance components (|Z|)



(b) Resistance component, reactance component



7 Conclusion

We have here introduced technical support tools provided by TDK. We hope you will utilize them for purposes such as electronic circuit design and EMC countermeasures.

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Allegro® is the registered trademark of Cadence Design Systems, Inc.

Other company names and product names described are registered trademarks or trademarks of each company.

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