Outline of EMC Design Methods

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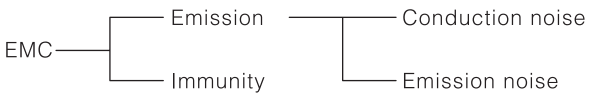
1 What is EMC Design?

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

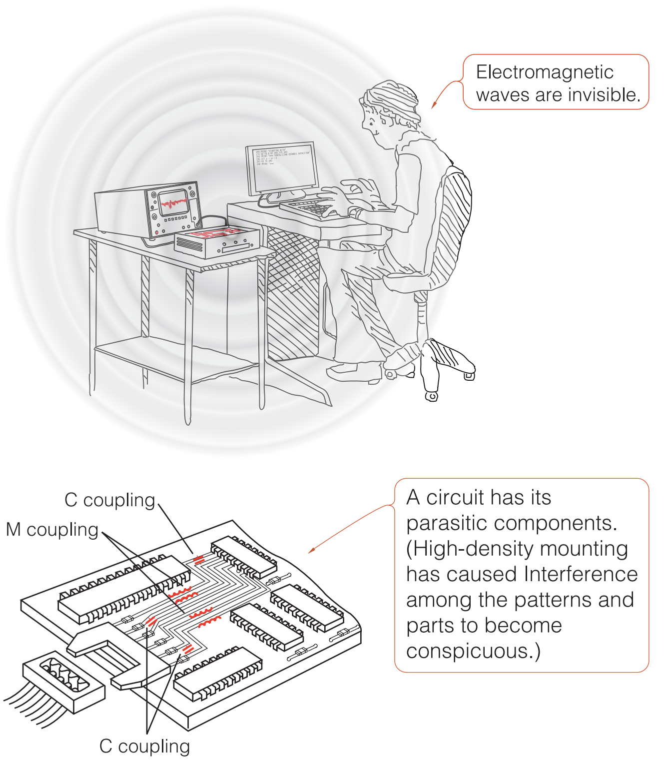
From the viewpoint of noise resistance, circuits that handle faint analog signals, such as sensors, are most in need of countermeasures for immunity. Generally, analog circuits are easily damaged by noise and digital ones are not. This means ironically that digital signals have high-frequency components 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



*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).

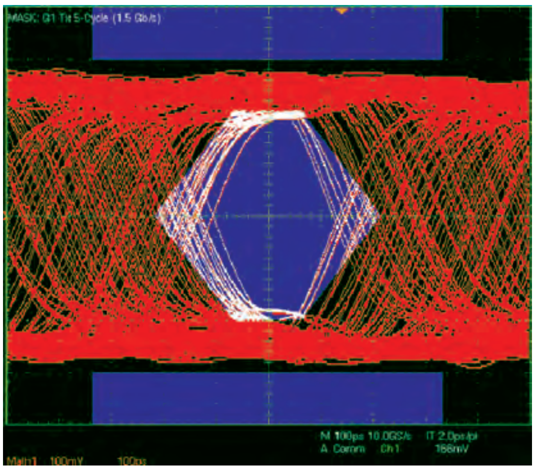
● Measure to be Taken at a Noise-generating Source

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).

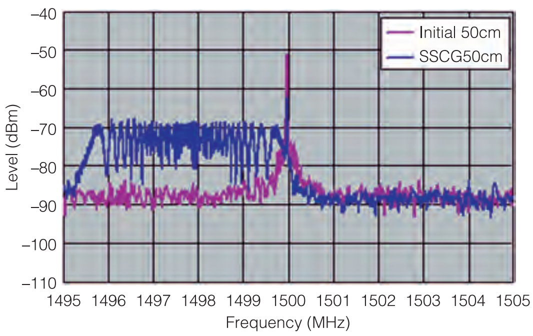
An entirely different method than those mentioned above that may be used for a noise-generating source is Spread Spectrum Clocking (SSC). This method handles a digital signal by introducing a degree of jitter that does not affect the operation of the circuit (Figure 3). Due to the jitter, the signal 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.



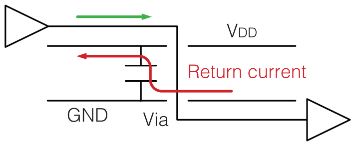
*2 Parasitic components include reactance, etc. that are not shown in the circuit diagram. ESL of a capacitor and coupling among patterns are also parasitic components (Figure 2).

● 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.

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

Figure 5 EBG Structure

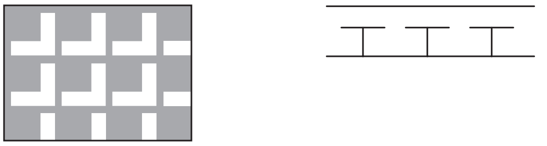


Figure 6 EBG Structure's Propagation Characteristic

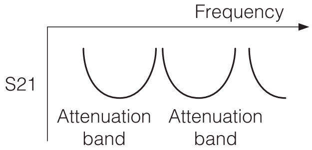
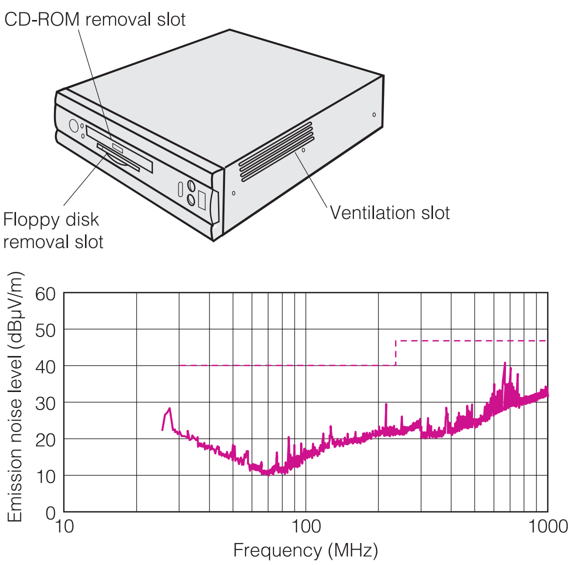


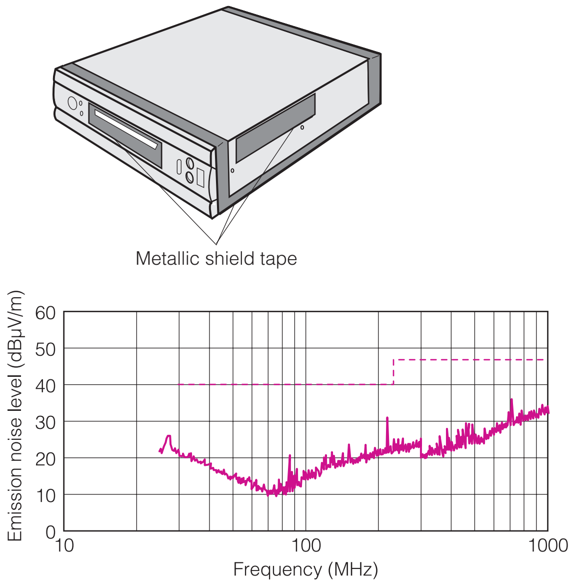
Figure 7 shows the result of an experiment conducted with a personal computer (see [11]). After the holes or openings were covered with metallic shield tape, the noise level around 550 to 750 MHz improved by about 10 dB.

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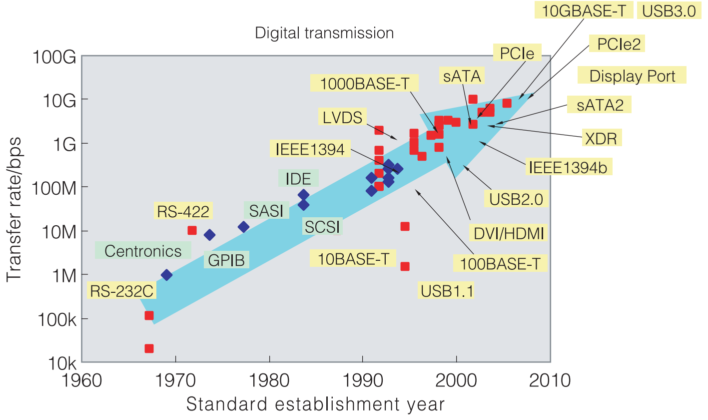
*3 Generally, because the return path of noise is far away in the common mode, the loop area tends to be larger. Therefore, the noise is regarded as a major cause of emission noise (see [3]).

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).

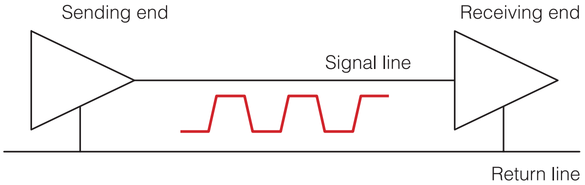
Figure 8 Accelerated Digital Transmission



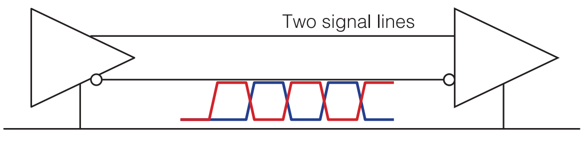
In normal data transmission, the sending and receiving ends are connected by one line, but because one line is needed also for the return path, two lines in total are needed, and high/low voltage is sent. In differential transmission, two lines are used and three lines in total are needed with one line 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



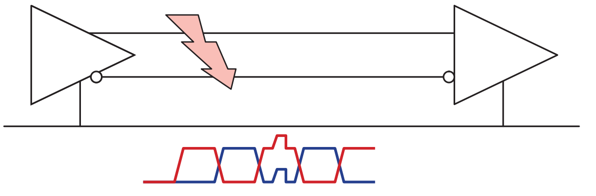
(b) Differential transmission



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)