# Development of Improved EMC Filter for EFT in Power Supply

Dae-Hwan Bae[1] · Dong Il Kim[2] · Jae Man Song[3]

## Abstract

Since the most of malfunctions in the industrial equipment controlled by processors is consist of the electrical fast transient (EFT)[1],[2], the International Electrotechnical Commission (IEC) prepared the dummy signal to test the immunity level of the equipments. To work out a countermeasure for the malfunction, We designed a new electromagnetic compatibility (EMC) filter for high power supply, which is consisted of a feed-through capacitor and ferrite materials with high permeability. The ferrite material is surrounded with a power cable or is inserted on the cable's second layer in order to increase common-mode inductance. We have obtained a excellent insertion loss characteristics over the frequency band from 150 kHz to 30 MHz. The developed new EMC filter satisfy IEC 61000-4-4 and is suitable for industrial, militaly, and medical equipments with reduced malfuntions.

## Ⅰ. INTRODUCTION

According to the rapid development of information and electronic equipment, electromagnetic wave environment becomes worse and the EMI/EMC countermeasures are severely required. Since the regulation and rules concerned EMI/EMC get more strict in developed countries, we are now confronted with the crisis of a trade barrier[1]. The recomandations and regulations for electromagnetic wave environment had been established and enforce from 1970 by Comite International Special des Perturbations Radioelectrique (CISPR), Federal Communication Commission (FCC), Voluntary Control Council for Interference (VCCI), Verband Deutscher Elektrotecniker (VDE), CE mark, and so on [3],[4].

Recently, extensive studies are carried out concerned with the EMC countermeasure. However, it is very difficult to work out countermeasure for EFT because it has high voltage and broad frequency band characteristics. Thus, In the past several years there has been a few research results on the countermeasure[5].

In this paper, we proposed a perfect countermeasure method by adopting the EMC filter in AC power line. The proposed EMC filter is to satisfy the IEC 61000-4-4 in time domain and reduce the EFT of 4 kV to 200 V in the frequency band from 150 kHz to 30 MHz.

## Ⅱ. ANALYSIS OF EFT/BURST

The designed EMC filter for high power supply must pass the distinction resisting, electric power, and waterproofing examinations by the electricity safety regulations.

It is most important to analyze EFT[2]. There are emission noise through a space and conductive noise though a conductor in EMC. However, it is very difficult to work out countermeasure for conductive noise because of high power and high speed in the case of the power supply circuit or the equipment under test (EUT)[3].

EFT is a kind of electromagnetic interferences, which is characterized by a burst of repetitive (nonperiodic or periodic) and is consist of relatively short duration pulses or transients. Typical EFT waveform is shown in Fig. 1(a) and (b). Each burst may have several kilovolts intensity with pulse rise time of about 5 ns. The duration of each transient pulse, the instantaneous intensity for which is at least 50% of the peak value, is typically 50 ns[6].

The EFT-type disturbances are generated when inductive -capacitive circuits are interrupted. When inductive loads such as relay coils, timers, motors, and connectors are connected to or disconnected to the line, a spark occurs between the mechanical contacts. The resultant switching frequency itself changes during the switching process.

The EFT is a pulse train interference of an equipment, and makes a circuit malfunction even when the intensity of a single pulse is not strong enough to disturb the equipment performance.

The EFT usually reaches at a receptor as a conducted electromagnetic interference through either power line, signal line, or control cable. The common-mode type is frequently used when the EFT reaches at a receptor via power lines[2].

An approximate analytical expression for the EFT pulse wave

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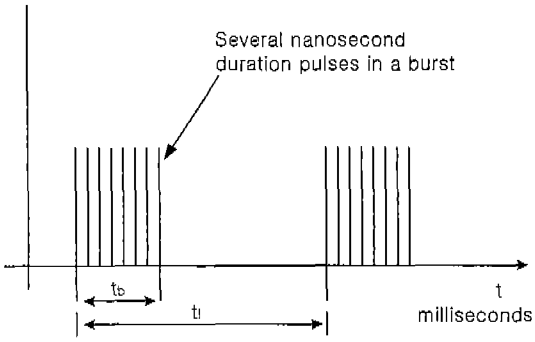
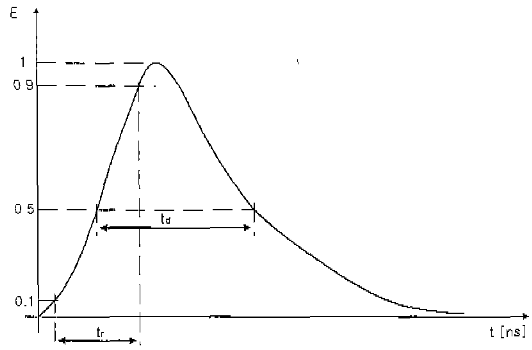
form[7] is given by

$$V(t) = A\ V_p(1 - e^{-t/t_1})\, e^{-t/t_2} \quad (1)$$

where $A$ is a constant, $V_p$ is the maximum peak value of the open circuit voltage, $t_1$ = 3.5 ns, and $t_2$ = 55.6 ns. By using the parameters listed in Table 1, the output of the test generator is guaranteed.




(a) Burst of pulses




(b) Individual pulse in a pulse train

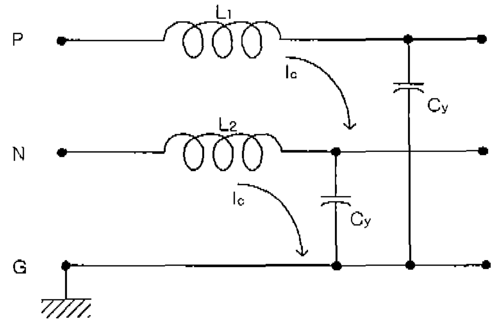
Fig. 1. WaveformS of electrical fast trans-ients ( $t_b$ ; burst duration, $t_i$ ; burst interval, $t_p$ ; pulse interval, $t_r$ ; pulse rise time, $t_d$ ; pulse duration).

Table 1. Test parameters specified in IEC 61000-4-4 for EFT/Burst test

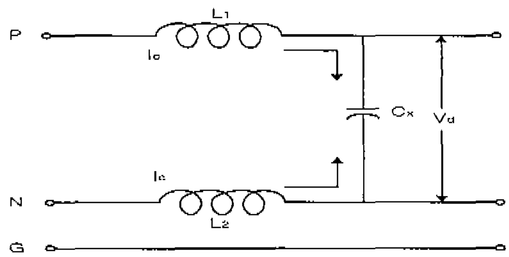
| $t_b = 15\,ms$, $t_i = 300\,ms$, $t_r = 5\,ns$, $t_d = 50\,ns$ | | | |
|---|---|---|---|
| Level | Test voltage on power line [kV] | Test voltage on signal/data/ control line [kV] | $t_p$[$\mu$s] |
| 1 | 0.5 | 0.25 | 200 |
| 2 | 1 | 0.5 | 200 |
| 3 | 2 | 1 | (400/200) |
| 4 | 4 | 2 | 400 |
| Tolerance for $t_b$ and $t_i$ is 20%.<br>Tolerance for $t_r$ and $t_d$ is 30%.<br>Tolerance for test voltage is +10%.<br>Tolerance for $t_p$ is +20%. | | | |

## Ⅲ. COMMON-MODE FILTER

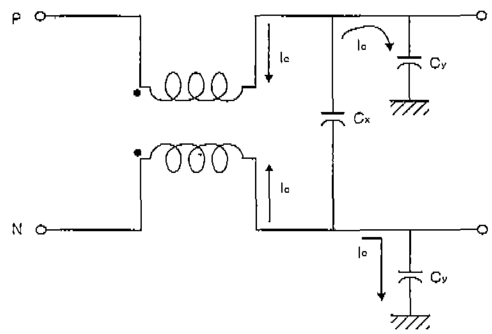
Generally, a common-mode filter is designed so as to possess high source impedance and low load impedance by using an LC filter with capacitance on the load side and inductor on the source side as shown in Fig. 2. To increase the attenuation and realize a steep skirt response, several LC stages may be cascaded. The capacitors $C_y$ in Fig. 2 bypass the common-mode current to ground. The capacitors $C_x$ in Fig. 2 bypass the phase -to-neutral current and prevent them while reaching at the load. If a low source impedance is desirable, a T-section low-pass filter configuration may be used. In the case of high source impedance, a large phase-to-ground capacitor is effective to filter




(a) Phase-to ground




(b) Phase-to-phase




(c) L-section with balun inductor

Fig. 2. Common-mode filter.

common-mode interferences. However, large capacitances result in high leakage current flow in the ground wire and create a potential shock hazard. For this reason, the electrical safety agencies impose a limitation of the maximum value of the phase-to-ground capacitor, while the permissible maximum leakage current depends on the line voltages.

When $Z_g = Z_L = R_0$, the insertion loss is given by eq.(2)[11]

$$IL(dB) = 10 \log_{10} [1 + F^2 \frac{(1-6)^2}{d^{2/3}} - 2F^4 \frac{1-d}{d^{1/3}} + F^6] \quad (2)$$

where $d = L/2C\,R_0^{\,2}$ is damping factor. $F$ is defined by

$$F = f/f_0 \quad (3)$$

where,

$$f_0 = \frac{1}{\pi\sqrt{2LC}} = \frac{R_0}{\pi L} = \frac{1}{2\pi\, r_0 c}$$

when $d = 1$, and

$$f_0 = \frac{1}{\pi (4\, R_0 L\, C^2)^{1/3}}$$

when $d \neq 1$.

## Ⅳ. DESIGN, FABRICATION AND EXPERIMENTAL RESULTS

In measurement of the EFT, the typical filter inserted to the equipment cabinet satisfied the level 2 of IEC 61000-4-4, but it did not satisfied the level 3.

For extra safety of the electric systems and human body, the countermeasure against EFT up to level 3 must be worked out in the communication equipments, and the control and factory automation systems. Therefore, the immunity by the countermeasure for the EFT has to be maintained in the electric systems by an LC filter or an isolation transformer. However, the conventional EMI filter using LC circuits does not make the countermeasure in the broad frequency band. On the other hand, an isolation transformer has some weak points such as heavy weight, large volume, and high price.

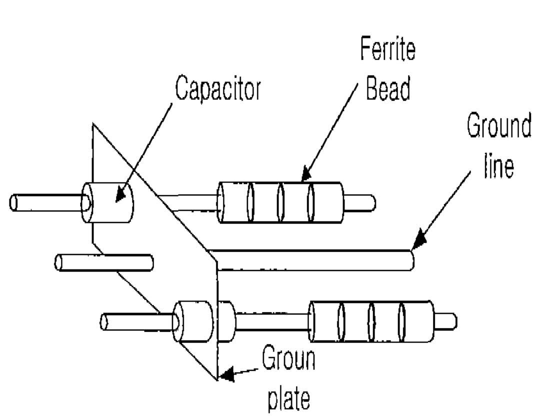



Fig. 3. Construction of EMC filter in the high-power supply.

Fig. 4. The photograph of the fabricated EMC filter.

To solve these problems, we designed a new EMC filter by using Ni-Zn ferrite beads with high initial permeability, mica capacitors of 0.1 $\mu$F, and feed-through capacitors of 2,000 pF in ceramic type. As the result of simulation, we obtained the attenuation characteristics of 10~20 dB in the frequency 150 kHz to 30 MHz. This filter has a resonance frequency above 1 GHz. Fig. 3 and 4 show the construction of the designed EMC filter and the photograph of the fabricated filter, respectively.

### 4-1 Filter Characteristic

The measurements[8] for common-mode characteristics of the EMI filters were carried out in the frequency domain by Hewlett Packard model 8753D network analyzer shown in Fig. 5. The attenuation[8] is improved as much as 20 dB to 40 dB in the frequency band from 150 kHz to 30 MHz as shown in Figs. 6 and 7.

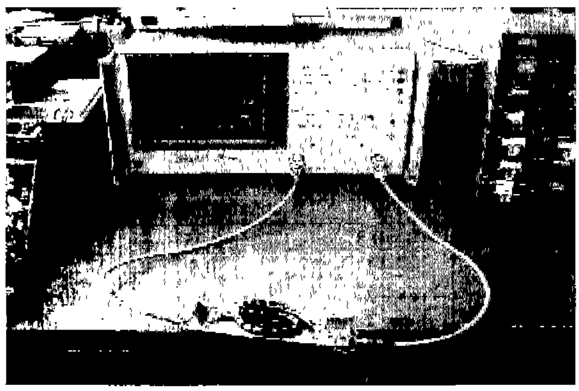


Fig. 5. Setup to analyze the frequency charateristics of EMC filter.

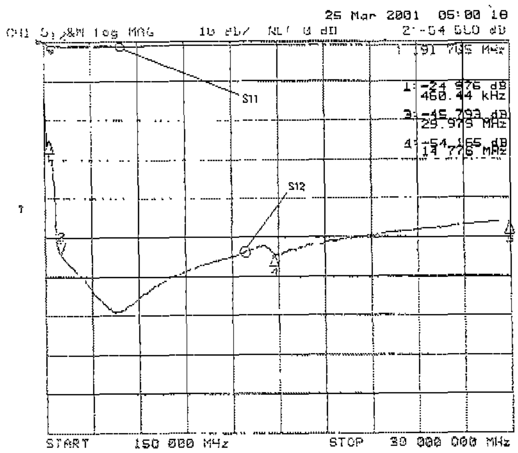



Fig. 6. Measured results for Common-Mode Characteristics of the EMC filter (conventional type).

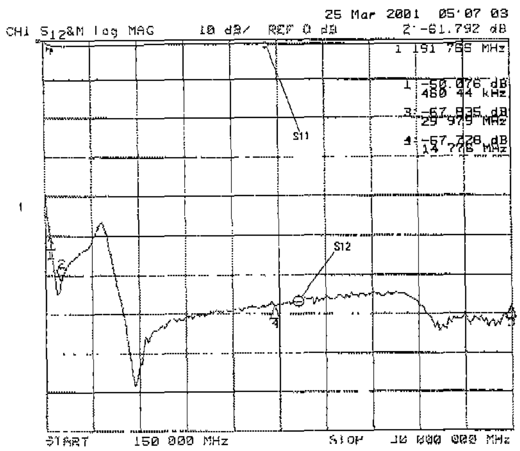



Fig. 7. Measured results for Common-Mode Characteristics of the EMC filter (newly proposed type).

#### 4-2 Immunity Characteristic

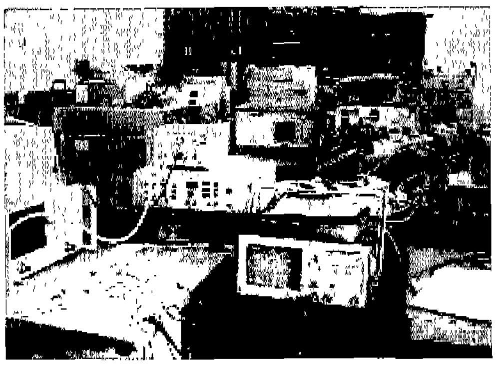


Fig. 8. Setup to analyze the EMC filter for IEC 61000-4-4 (time domain).

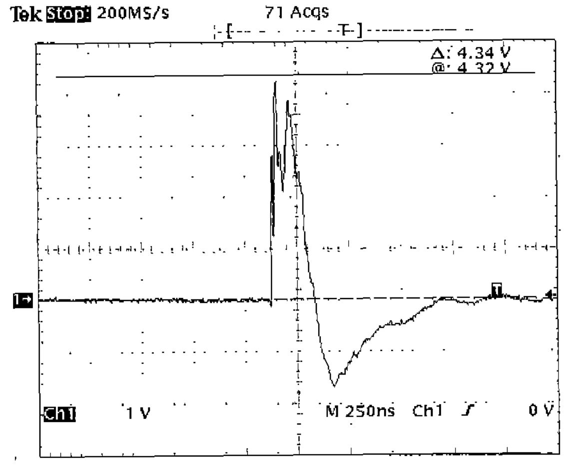



Fig. 9. Measured results for immunity test at Level 4 of IEC 61000-4-4(conventional type).

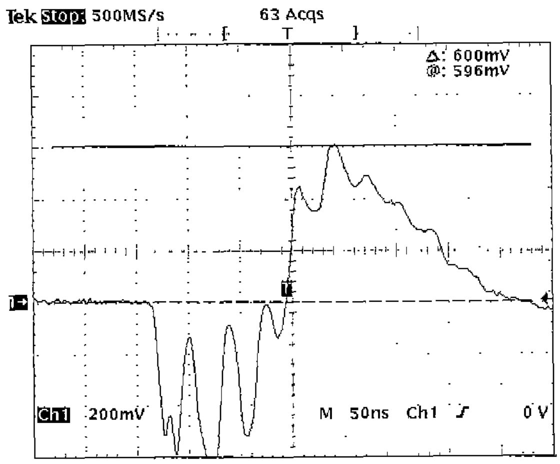



Fig. 10. Measured results for immunity test at Level 4 of IEC 61000-4-4 (newly proposed type).

Fig. 8 shows an immunity measurement system for IEC 61000-4-4. The system is composed of oscilloscope (TDS340A), burst-generator (SFT4000), and line impedance stabilization network (LISN) in time domain[9],[10]. The test range was level 4. As a result, the attenuation was reduced to 200 V from the initial stage of 4 kV as shown in Figs. 9 and 10.

## V. CONCLUSIONS

The purpose of this research was to develop EMC filter for a high power supply which is consisted by ferrite beads and the feed-through capacitors. The developed EMC filter in this research showed the excellent attenuation characteristics in the frequency band over 150 kV to 30 MHz. Furthermore, the filter reduced the EFT of 4 kV to 200 V at level 4 of IEC 61000-4-4.

The designed EMC filter in this research is suitable for IEC 61000-4-2, 3, 5, and 6, and could be applied to military, industrial, and medical instruments.

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