Development of Improved EMC Power Line Filter in New Type

Dong Il Kim[1] · Eun-Mi Kim[1] · Young-Sup Ahn[2] · Mi-Hwa Jeon[1]

Abstract

Most of malfunctions in electronic equipment or systems controlled by processors is occurred by the differential- and common-mode noises, and the electrical fast transient (EFT). The International Electrotechnical Commission (IEC) has prepared the dummy signal to test the immunity level of the equipment. For the countermeasure against the differential- and common-mode noises, and the EFT, we designed, fabricated, and tested a new electromagnetic compatibility (EMC) filter, which is composed of feed-through capacitors and ferrite beads with high permeability. As a result, the filter showed excellent differential- and common-mode noises filtering, and immunity improving characteristics over the frequency band from 30 MHz to 1.5 GHz and 1.8 GHz, respectively.

Key words : EMC Filter, Ferrite Beads, Feed-through Capacitors.

Ⅰ. Introduction

Recently, according to the rapid spread of electronic and controlling equipment the control of electromagnetic wave environment becomes an important issue. Thus the countermeasure against the electromagnetic interference (EMI) and the electromagnetic susceptibility (EMS) are to be severely required. Since the regulations and rules concerned to EMI/EMS get more strict internationally, we are now confronted with the crisis of a trade barrier[1]. The recommendations and regulations for electromagnetic wave environment had been established and enforced in 1970 by the Comite International Special des Perturbations Radioelectrique (CISPR), the Federal Communication Commission (FCC), the Voluntary Control Council for Interference (VCCI), the German Verband Deutscher Elektrotechniker (VDE), the CE mark, and so on [2],[3].

Nowadays many extensive studies on noise filtering and countermeasure against the EFT are carried out. Especially the EFT becomes a big problem in EMC countermeasure for control processors or electric equipment[4]. However, it is very difficult to carriy out countermeasures against EFT because it has high voltage and broadband characteristics. In the past, thus, countermeasures against EFT have not been studied enough[5].

In this paper, we suggest an improved countermeasure method by inserting the newly designed EMC filter circuits with ferrite beads and feed-through capacitors in AC power line. The proposed EMC filter has good filtering characteristics as much as 15 dB to 25 dB compared with conventional one in the frequency band from 10 MHz to 1.5 GHz. Furthermore, the developed filter reduces the EFT effect in the order of 15~25 dB compared with conventional one in the frequency band from DC to 1.8 GHz, and satisfies the IEC 61000-4-4.

Ⅱ. Design of EMC Filter

The conventional filters are available against the EFT in the level 2 as IEC 61000-4-4, but they can not do the role at the high level above the level 3 since the characteristics against the EFT are not enough. Furthermore, for extra safety of the electronic or controlling systems from the EFT, the EMC countermeasure must be worked for the communication equipment and for the control and factory automation systems up to level 4 for the conducted transient.

Conventionally, a filter using capacitors and ferrite beads, or an isolation transformer has been used for countermeasure against the EFT. However, the filter using usual capacitors and ferrite beads does not make the countermeasure over broad frequency band, while an isolation transformer can do it but has the weak points of heavy weight, large volume, and high price.

To solve the above problems, we designed a new EMC filter using feed-through capacitors and Ni-Zn ferrite beads with high permeability. Fig. 1 shows a proposed EMC filter, where the feed-through capacitors were used since they have resonance frequency above 1 GHz and good characteristics even in the high frequency band.

Fig. 2 shows the simplified equivalent circuit for the EMC filter and power transmission line. Fig. 3(a) shows the equivalent circuit between the hot(H) and the ground(G),

Manuscript received November 10, 2008 ; revised December 11, 2008. (ID No. 20081110-037J)
[1]Dept. of Radio Sciences & Engineering, Korea Maritime Univ., Pusan, Korea.
[2]Dept. of Electronics & Comm. Engineering, Korea Maritime Univ., Mokpo, Korea.

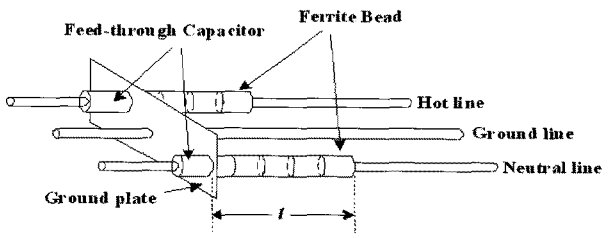


Fig. 1. Construction of EMC filter.

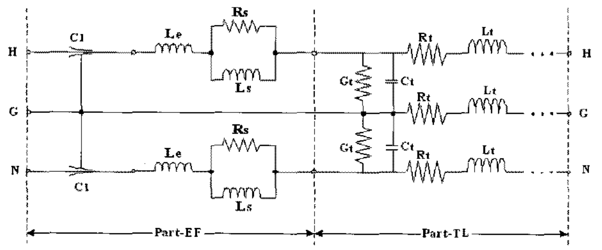
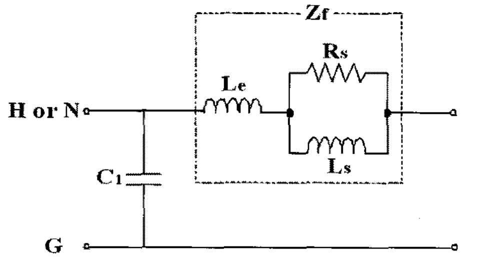
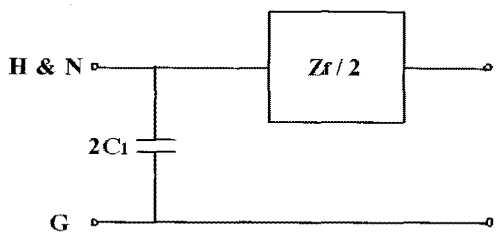


Fig. 2. Equivalent circuits of the EMC filter(Part-EF) and transmission line(Part- TL).



(a) For differential-mode(DM)



(b) For common-mode(CM)

Fig. 3. Equivalent circuits of the filter part.

or the Neutral(N) and G of the EMC filter part for differential mode(DM) noise. The ABCD-matrix for the differential mode can be obtained by eq. (1).

$$\begin{bmatrix} A_{DM} & B_{DM} \\ C_{DM} & D_{DM} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_{C_1} & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_f \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & Z_f \\ Y_{C_1} & Y_{C_1} Z_f + 1 \end{bmatrix} \tag{1}$$

where,

$$Y_{C_1} = j2\pi f C_1,$$
$$Z_f = j\omega L_e + \left(\frac{1}{R_s} + \frac{1}{j\omega L_s} \right)^{-1} \tag{2}$$

On the other hand, the equivalent circuit for the common-mode(CM) noise is as shown in Fig. 3 (b), and the ABCD-matrix for the CM noise is expressed as eq. (3).

$$\begin{bmatrix} A_{CM} & B_{CM} \\ C_{CM} & D_{CM} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 2Y_{C_1} & 1 \end{bmatrix} \begin{bmatrix} 1 & Z_f/2 \\ 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & Z_f \\ 2Y_{C_1} & Y_{C_1} Z_f + 1 \end{bmatrix} \tag{3}$$

The relative permeability μ_r can be expressed by eq. (4)[6].

$$\mu_r = 1 + \frac{\mu_i}{1 + jf/f_m} \tag{4}$$

where μ_i is the initial permeability, f_m is the relaxation frequency, and f is the frequency. We used the ferrite beads with μ_i=2,000 and f_m=3.12 MHz.

In addition, the other parameters are given by eq. (5).

$$C_1 = 2{,}000 \ \text{[pF]}$$
$$L_e = 2 \times 10^{-8} \mu''_r \mu_0 \ln(b/a) \times l \ \text{[H/m]}$$
$$R_s = 2\pi f_m \mu'_r \mu_0 l K \ [\Omega/\text{m}]$$
$$L_s = \mu''_r \mu_0 l K \ \text{[H/m]} \tag{5}$$

where a and b are the inner and outer radii, l is the length of the ferrite bead, and K is the constant value of 0.003, which is determined by the dimension of the ferrite bead.

From the eqs. (1) and (3), the transmission coefficient T in dB as the filter characteristics obtained by eq. (6).

$$T(dB) = 20 \log \left| \frac{2}{A_i + B_i + C_i + D_i} \right| + \alpha_p$$
$$i = \text{DM or CM} \tag{6}$$

where α_p is the loss in dB for the power line only.

Ⅲ. Experimental Result

3-1 Filter Characteristics

Fig. 4 and 5 show the designed and fabricated EMC filter, and the experimental set-up using the network analyzer (Hewlett Packard : Model 8753D), respectively.

The measurements of the differential- and the common-mode noise transmissions for the fabricated EMC filter were carried out as shown in Figs. 6 and 7, respectively.

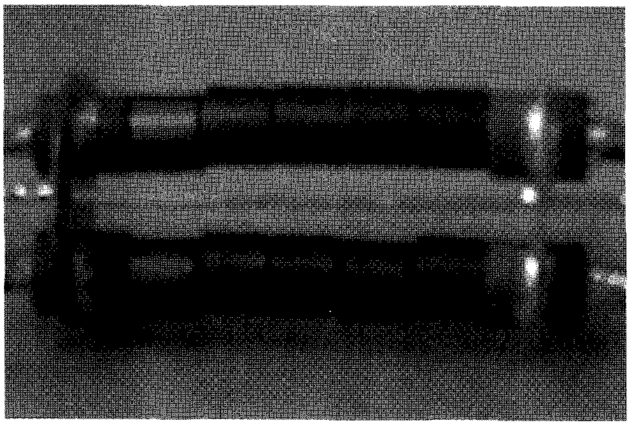


Fig. 4. The photograph of the fabricated EMC filter.

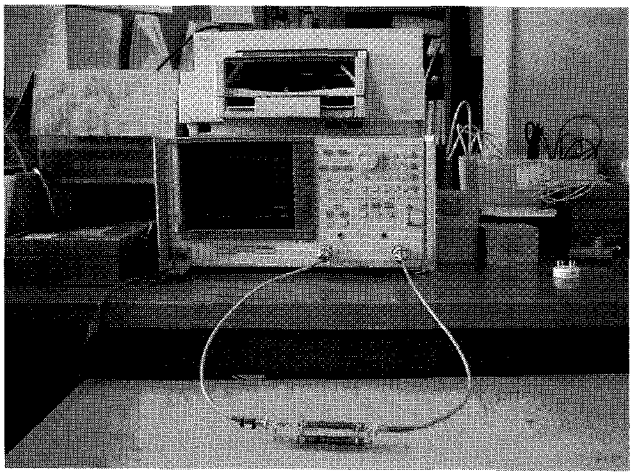


Fig. 5. Set-up to analyze the frequency characteristics of EMC filter(for CM and DM modes).

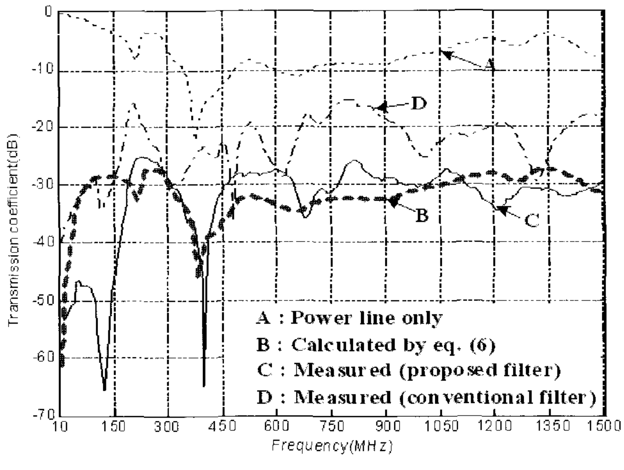


Fig. 6. Filtering characteristics for differential-mode(DM).

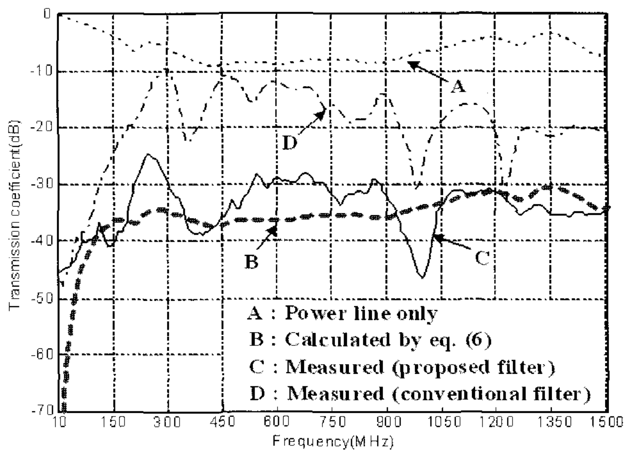


Fig. 7. Filtering characteristics for common-mode(CM).

From the experimental results, it was clearly shown that the theoretical transmission coefficients (B in Figs. 6 and 7) proposed by the simplified model agree well with the measured ones (C in Figs. 6 and 7) as a tendency. On the other hand, the measured attenuation characteristics of the proposed filters were improved as much as 15 to 25 dB in the frequency band of 10 MHz~1.5 GHz as shown in Figs. 6 and 7.

3-2 Characteristics for EFT

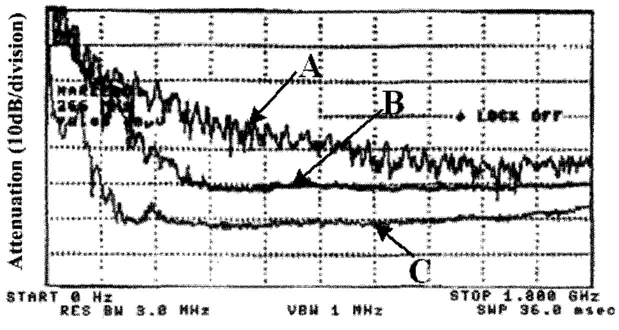
The EFT test pulse waveform in the IEC 61000-4-4[8] is given by eq. (7).

$$V(t) = AV_p(1-e^{-t/t_1})e^{-t/t_2} \tag{7}$$

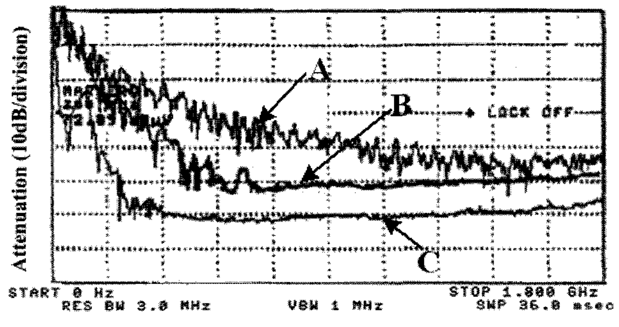
In addition, the test parameters specified in IEC 61000-4-4 for EFT/Burst test are described in the reference of [8]. When A is a constant and V_p is the maximum peak value of the open circuit voltage, t_1 is 3.5 ns, and t_2 is 55.6 ns.

We composed an immunity measurement system for the IEC 61000-4-4 by the EMC analyzer(Hewlett Packard : Model 8591EM) and the burst-generator(EMV-Systeme Schöder GmbH : Model SFT4000) and measured the EFT reduction characteristics[10],[11]. Fig. 8(a) to (c) show the experimental results at the level-2 to 4, and A, B, and C in the figure depict the spectrum level of the transmitted power for the EFT input with each level. As shown in Figs. 8(a) to (c), the proposed filter can reduce the EFT effect as much as 8 to 25 dB compared with the conventional one.

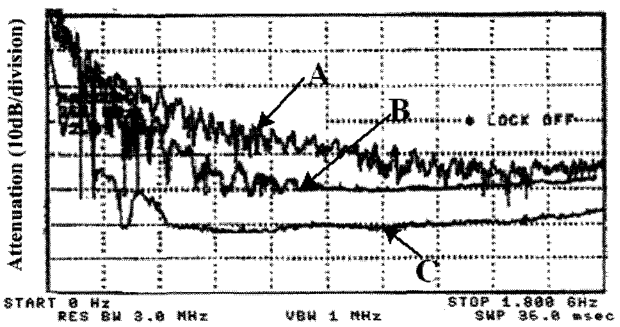
In addition, after the power line with the conventional and the proposed filters were connected to a personal computer, the dynamic characteristics for the conventional and the proposed filters were tested by applying the EFT level 2 to 4, respectively. As the results, it was shown that the proposed filter was safe for the EFT in each level, while the PC was failed when the conventional one was used.



(a) At level 2 of IEC 61000-4-4



(b) At level 3 of IEC 61000-4-4



(c) At level 4 of IEC 61000-4-4

Fig. 8. The measured results of immunity test(A: Without filter, B: With conventional filter, C: With proposed filter).

Ⅳ. Conclusion

An EMC filter for power line with excellent performance was proposed and designed, which is composed of ferrite beads and the feed-through capacitors. It was confirmed by experiments that the filter has high attenuation characteristics for differential- and common-mode noises over broad frequency band from 10 MHz to 1.5 GHz.

Furthermore, the proposed filter has very good characteristics to reduce the EFT effect as much as 8 to 25 dB compared with the conventional one. Therefore, it is expected that the newly developed EMC filter is to be effectively used for industrial, military, and medical equipment to reduce malfunctions and to be suitable for IEC 61000-4-4.

This work was supported by Gwangju-Jeonnam Regional Office of Small and Medium Business Association in Korea.

References

[1] F. D. Martzloff, T. F. Leedy, "Electrical fast transients, application and limitation", *IEEE Trans Industry*, vol. IA-26, pp. 151-159, Jan.-Feb. 1990.

[2] C63-Electromagnetic Compatibility, New York: The Institute of Electrical and Electronics Engineers, 1989.

[3] IEEE Standard Collection-Electromagnetic Compatibility, New York: The Institute of Electrical and Electronics Engineers, 1992.

[4] M. Lutz, J. P. Lecury, "Electrical fast transient IEC 801-4. susceptibility of electronic equipment and systems at higher frequencies and voltages", in *Proc IEEE International Symp. EMC*, pp. 189-194, 1992.

[5] Henry W. Ott, *Noise Reductionin Electronic Systems*, John Wiley & Sons, pp. 137-157, 1988.

[6] Yoshiyuki Naito, "Formulation of frequency dispersion of ferrite permeability", *IECE of Japen*, vol. J59-C, no. 5, pp. 297-304, May 1976.

[7] V. Prased Kodal, *Engineering Electromagnetic Compatibility*, IEEE press, pp. 171-176, 1996.

[8] IEEE Guide on Surge Testing for Equipment Connected to Low-Voltage AC Power Circuit, IEEE C 62.45-1987, New York: The Institute of Electrical and Electronics Engineers, 1987.

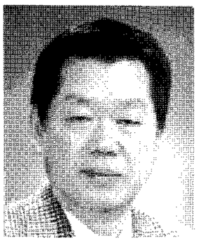
[9] F. D. Martzloff, T. M. Gruzs, "Quality site surveys: factsiction and fallacies", *IEEE Trans Industry Applications*, vol. 24, pp. 1005-18, Nov.-Dec. 1988.

[10] Richard Lee Ozenbaugh, *EMI Filter*, Marcel Dekker, INC. pp. 56-100, 1996.

[11] Shunji Satoh, Toshiki Shimasaki, Komatsu, Hideki Yaega-shi, and Shigeki Kirino, "EMI reduction technologies for transmission equipment", *NEC Technics*, vol. 5, no. 6, pp. 36-41, 1998.

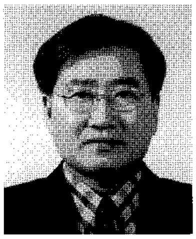
[12] R. Perez, *Handbook of Electromagnetic Compatibility*, New York, Academic Press, 1995.

Dong Il Kim



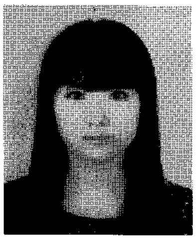
was born in Daejeon, Korea. He received the B.E. and M.E. degrees in nautical science and electronic communications from the Korea Maritime University, in 1975 and 1977, respectively. He received the Ph.D. degree in electronics from the Tokyo Institute of Technology in 1984. Currently, he is professor of the Dept. of radio sciences & engineering at the Korea Maritime University. He was in charge of the president of the Korean Institute of Electromagnetic Engineering and Science (KIEES) and the IEEE Korea Chapter Chairman from 2002 to 2003. His research interests include the design of microwave circuits and CATV transmission circuits, development of EM absorber, and EMI/EMC countermeasures. He received the Academy-Industry Cooperation (A-I-C) Award from Korea A-I-C. Foundation in 1990, Treatise Awards from the Korean Institute of Electromagnetic Engineering and Science (KIEES) and the Korea Institute of Navigation in 1993 and 1998, and the Korea President's Award from the Promotion of Science and Technology in 1995, respectively. He is a member of IEEE, the Institute of Electronics, Information and Communications of Japan, the IEEC of Korea, the KICS, and the KIEES.

Young-Sup Ahn



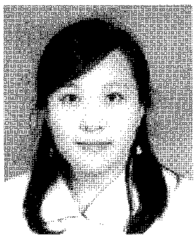
was born in Muan, Korea in 1955. He received B.E. M.E. and Ph.D. degrees from the Dept. of Nautical Science (Korea Maritime University, Pusan, Korea) in 1979, 1988 and 1994, respectively. He is currently a Professor in the Division of Maritime Transportation System, Mokpo National Maritime University. His research interests include the development of an EM absorber, RCS analysis, and the design of navigation aids.

Eun-Mi Kim



was born in Pusan, Korea in 1984. She received B.E. degree from the Korea Maritime University in 2007. She is currently pursuing an M.S. degree under the supervision of Prof. D. I. Kim at the Korea Maritime University. Her research interests include the design of M/W circuits, and EMI/EMC analysis and countermeasures.

Mi-Hwa Jeon



was born in Daejeon, Korea in 1984. She received B.E. degree from the Korea Maritime University in 2007. She is currently pursuing an M.S. degree under the supervision of Prof. D. I. Kim at the Korea Maritime University. Her research interests include the design of M/W circuits, and EMI/EMC analysis and countermeasures.