APLIKACIJSKI PRISPEVKI - APPLICATION ARTICLES

EMI Suppression

Part I: Definitions and Basics

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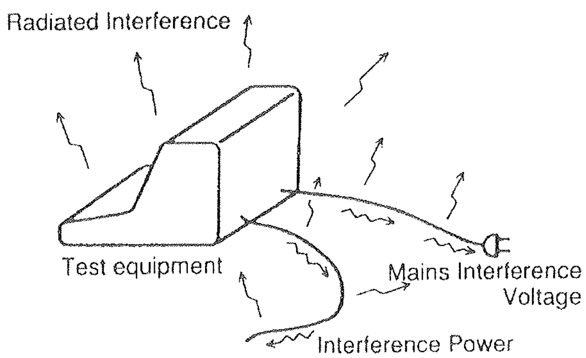
This is the first article in a series of articles which will be devoted to EMI occurance and its suppression using Murata EMI suppression components.

To start with, EMI basics, definition of terms and overview of suppression techniques will be given. Other articles will deal with EMI suppression in digital equipment, AC and DC power lines as well as with proper selection and guidance to usage of Murata EMI filters.

1.0 INTRODUCTION

The need for an "EMI free" electromagnetic environment has never been more important. Electronic and digital systems are increasing in the industrial, commercial and consumer markets, making what may be called electromagnetic compatibility a necessity. That is, various systems must be able to function in close proximity without either radiating noise or being affected by it.

In different countries in the world there are different rules and regulations already put into practice to control EMI emission. Equipment that does not meet these regulations cannot be sold or used in that country. Only to mention a few: FCC part 15 in USA, VDE 0871 in Germany, CSA C108.8 in Canada, EN 55022 in Europe, VCCI in Japan and CISPR Pub.22 in CISPR member countries. Basically, all these regulations define the noise measurement items, frequency, noise detection mode, as well as noise levels allowed. Typical noise measurement items are, figure 1:



- Radiated Interference (dB μ V/m)
- Mains Interference Voltage (dB μ V)
- Interference Power (dBpW)

Figure 1: Noise measurement items

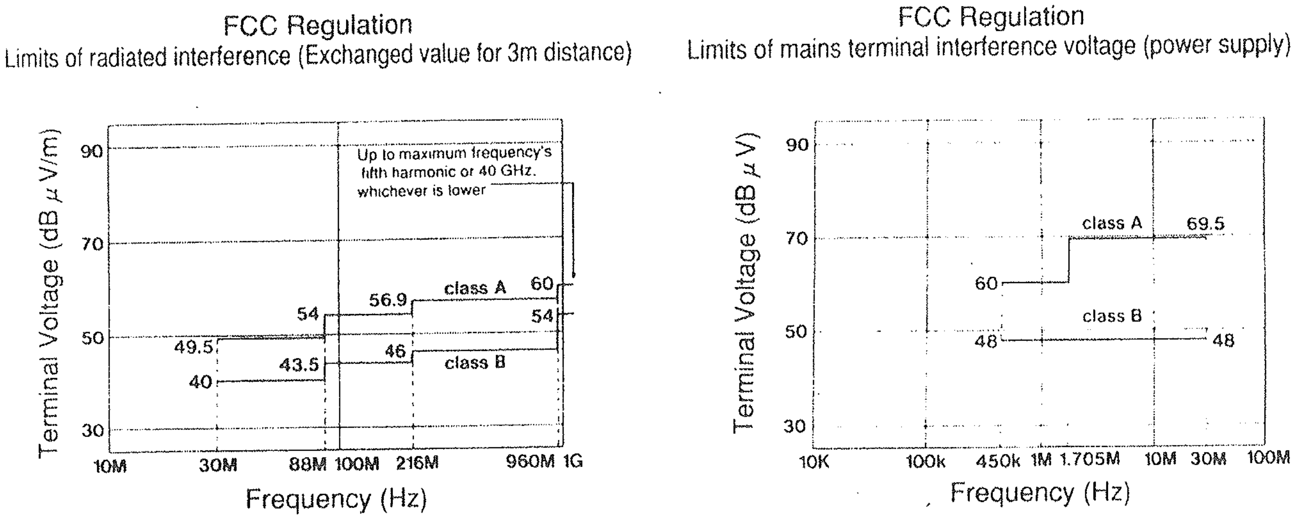


Figure 2: Noise limits of FCC part 15 regulation

- **Radiated interference:** the noise emitted from electronic equipment or connecting cables into the air and is measured using an antenna
- **Mains interference voltage:** the noise that propagates through electronic equipment's power supply cable and other connecting cables; this type of noise is measured using artificial mains network or high-impedance probe
- **Interference power:** the noise that propagates through or emitted from electronic equipment's power supply cable and other connecting cables and it is measured using an absorbing clamp.

However, each regulation stated has different measuring items and methods. As well, the limit noise levels vary depending on the frequency and the noise detection method.

As an example, in figure 2, limits of FCC Part 15 regulation are shown.

2.0 EMI SUPPRESSION PROCEDURES

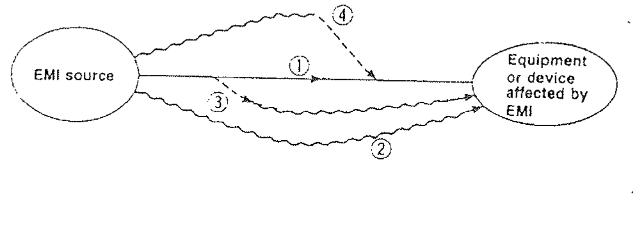
In order to effectively suppress the noise, a good knowledge about the noise sources and its propagation is needed.

EMI sources may be artificial, such as the presence of EMI generating components and circuitry or may be natural, such as the presence of lightning, dust storms and solar activity.

However, there are four basic modes for noise propagation, figure 3:

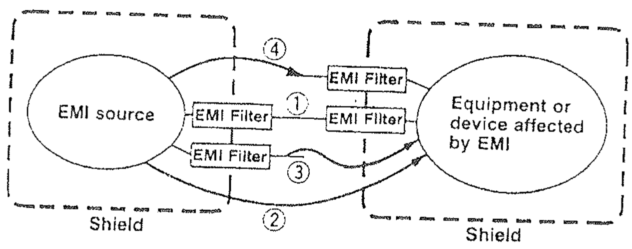
- Conductor propagation
- Space conduction
- Conductor propagation - space conduction
- Space conduction - conductor propagation

For effective noise suppression, therefore, it is necessary to know the noise-occurring state and to take countermeasures there. After grasping these transmitting routes of noise, shield should be made to prevent space conduction, and EMI suppression filter should be used to suppress conductor propagation, figure 4.



1. Conduction mode
2. Radiation mode (Radiation)
3. Conduction mode ———— Radiation mode (Antenna effect)
4. Radiation mode ———— Conduction mode (Receiver effect)

Figure 3: EMI propagation modes



	(source)	(received point)
1. Conduction mode	EMI Filter	EMI Filter
2. Radiation mode	Shield	Shield
3. Conduction mode — Radiant mode	EMI Filter	Shield
4. Radiation mode — Conducted mode	Shield	EMI Filter

Figure 4: Basic steps for EMI suppression

2.1 Identification of Source and Propagation Mode

As a first step for noise suppression, it is necessary to survey for the noise source and transmission route. Items to be tested are as follows:

1. **Identification of source and propagation mode**
   - from frequency distribution of EMI
   - from period of EMI
   - searching for most noisy point
2. **Identify EMI propagation mode**
   - radiation from equipment
   - radiation from I/O cables
   - radiation from internal wires
   - state of shielding conditions

The degree of identification of the noise source and the transmission route will determine the importance and method of noise suppression.

Generally, it is necessary to pay attention to the many cases of noise generation from the board.

2.2 Identification of Frequency Ingredients of the Desired Signal and EMI Frequencies Imposed on the Desired Signal

Upon clarification of the noise source and transmission route, it is necessary to select EMI suppression filters having the suitable frequency characteristics. The following are the examples of items to be researched regarding noise frequencies and effective signal frequencies for selecting the proper EMI suppression filter.

1) **Identify frequency ingredients of the desired signal**
   - from waveform
   - from design data
   - survey of operation when waveform is distorted

2) Identify EMI frequencies imposed on the desired signal
   - measuring EMI spectrum of system under test
   - search of EMI distribution in each EMI conducting route

2.3 Improvement of Grounding

In order to make the best use of EMI suppression filters or shields, and also, to reduce the noise radiated from the ground, the ground condition must be good.

When there is potential difference between the standard case ground and signal ground (SG), or between each SG even in the same board, the ground condition should be improved.

In such cases, improving techniques are as follows:
- try to use ground plane
- try to use multi-layer PCB
- try to change ground pattern
- try to use multi-point ground
- try to decrease voltage between one SG and another SG point

2.4 Countermeasures by Shielding

Directly radiating noise (space conduction) from the case or board can be effectively controlled by shielding. Note that if a shield covering a cable is broken, that shield will become a noise antenna. In case of shield structure with metal case, the case can be a stable ground, and noise can, thus, be easily suppressed.

Countermeasures by shielding may be the following:
- use metalic chasis
- use shielded cables
- put additional shield over the individual circuit on the PCB
- use shielded connectors

3.0 EMI SUPPRESSION BY FILTERING

3.1 Introduction and definitions

To achieve the maximum performance of an EMI filter, several areas must be considered. These include the selection of the correct filter based upon circuit impedance, functional bandwidth, noise freguencies/levels and of equal or more importance is the grounding of the filter and the circuit.

The effect of an EMI filter is generally expressed in terms of insertion loss which conforms to MIL-STD-220. The filter effect is expressed as a logarithm of the ratio of output voltage without a filter compared to output voltage with a filter in the circuit. In MIL-STD-220, the source and load impedance of the measuring circuit are specified as 50Ω, figure 5.

Filters can roughly be categorized as noise limiting type and noise separation type.

Noise limiting type filters, figure 6, are resistive and ferrite products which when installed in series with the signal line reduce the noise by, in the case of ferrites, turning the high frequency noise into heat. The advantage of the ferrite is that unlike a coil it does not set up reflections. These components are particularly useful when there is poor or no ground available, or capacitance cannot be tolerated by the circuit. The drawback to this type of filter is the limited insertion loss available, typically 5 to 15 dB.

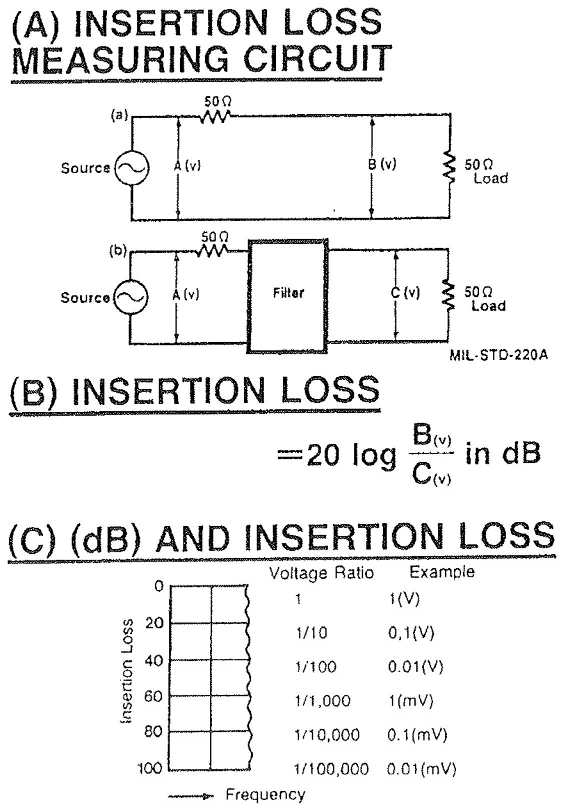


Figure 5: The definition of the insertion loss of a filter

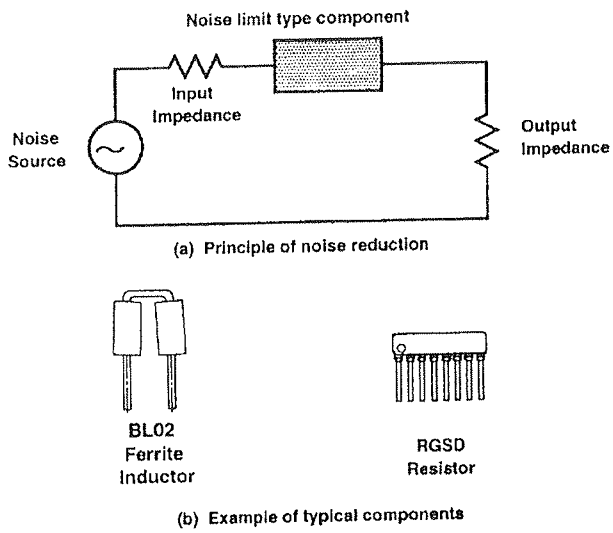


Figure 6: Noise limiting type filters

Noise separation type filters, figure 7, typically incorporate a capacitive element which strips the unwanted noise and channels it to ground. Frequently, a coil or a ferrite is also used to build a number of different circuit configurations. These filters can be selected to provide very steep attenuation curves and large insertion loss values up to 100dB or more. The trade-off here is cost, particularly as more sections are added to the filter, as well as size and weight.

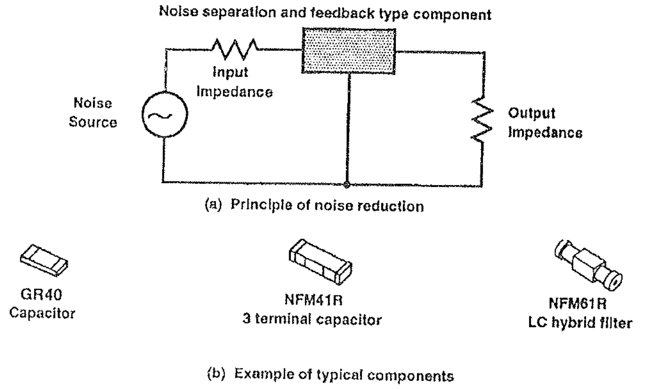


Figure 7: Noise separation type filters

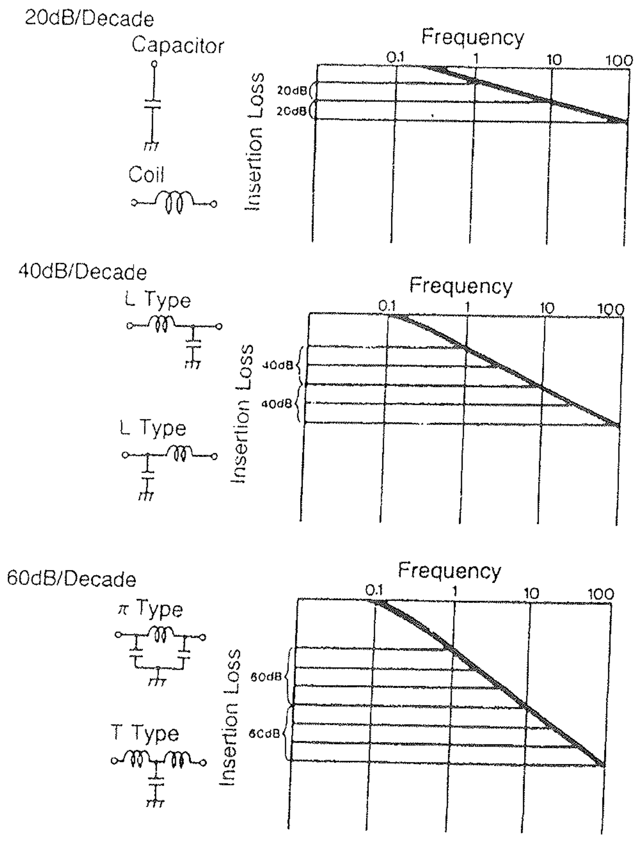


Figure 8: Typical low pass EMI filter circuits and their insertion loss characteristics

EMI filters are used to suppress or attenuate unwanted frequencies and the most commonly used type of EMI filter is the low pass filter. A single element EMI filter (a capacitor or inductor) typically provides an insertion loss slope of 20 dB per decade.

A dual element EMI filter (capacitor plus inductor in an "LC" or "CL" circuit) will typically provide 40 dB per decade.

A triple element EMI filter (such as a "Pi" or "T" circuit) will typically provide 60 dB/decade with a quadruple circuit providing an 80 dB per decade characteristics, figure 8.

3.2 Noise separation filters

The most popular and simple low pass filter is a capacitor. Its ideal characteristics is depicted in figure 9, while its impedance is governed by the expression:

$$Z_C = \frac{1}{2\pi f_C}$$

where C is capacitance, Z_C is capacitor impedance at the frequency f_C.

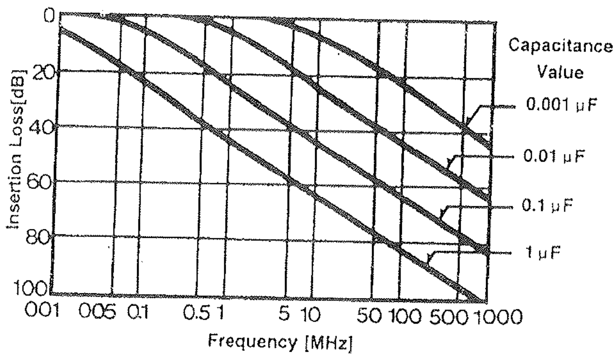


Figure 9: Theoretical insertion loss of an ideal capacitor

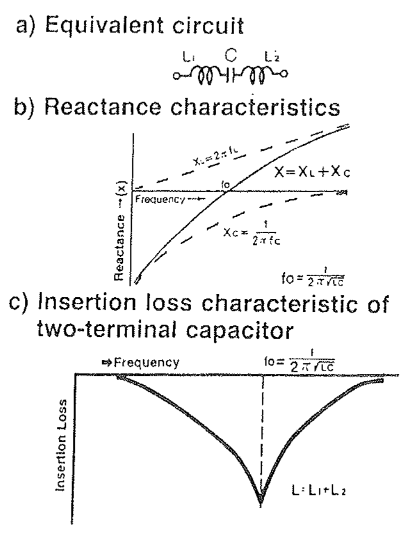


Figure 10: Real capacitor performance

When the capacitor, if ideal, is connected to the ground, the higher the frequency, the greater the insertion loss.

However, in an ordinary two-terminal capacitor, inductance is present in series with the capacitor, due to the inherent inductance of the lead wires. This series inductance results in a sharp resonant effect with the insertion loss diminishing rapidly, figure 10.

Capacitor Type	Series Inductance
Lead type Monolithic Ceramic Capacitor (0.01μF)	5 nH
Lead type Monolithic Ceramic Capacitor (1μF)	6 nH
Disk/Lead type Ceramic Capacitor (0.0022μF)	4.5 nH
Polyethylene Telephthalate Film Capacitor (0.03μF)	9 nH
Mica Capacitor (0.01μF)	52 nH
Polystyrene Film Capacitor (0.001μF)	12 nH
Polystyrene Film Capacitor (0.1μF)	100 nH
Tantalum Electrolytic Capacitor with Solid Electrolyte (16μF)	5 nH
Aluminum Electrolytic Capacitor (For RF use) (470μF)	13 nH
Aluminum Electrolytic Capacitor (470μF)	130 nH

Figure 11: Residual inductance of some typical capacitors

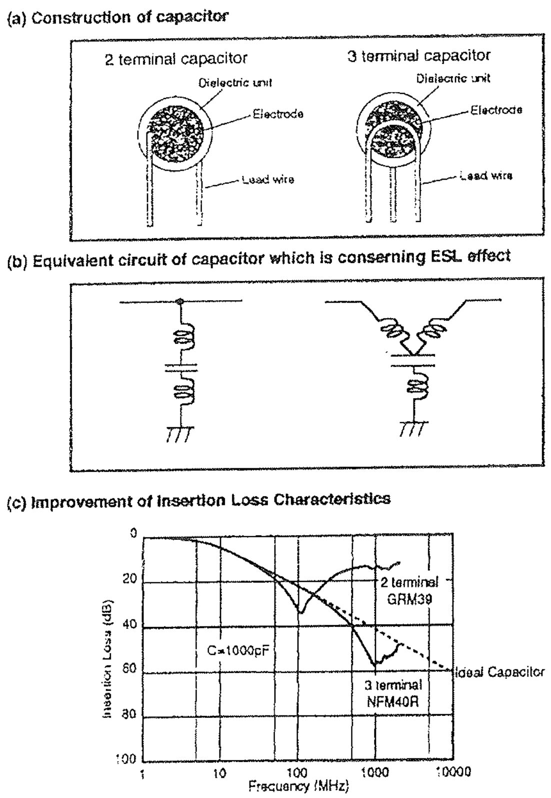


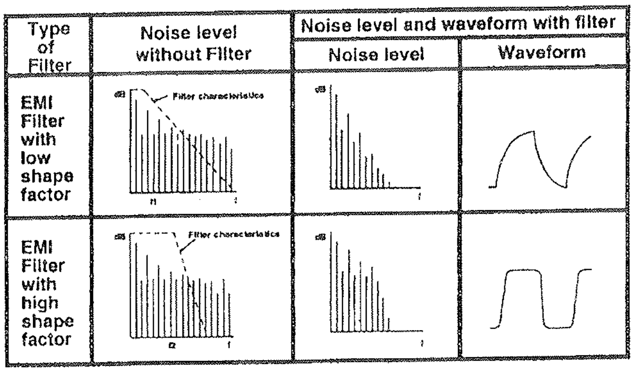
Figure 12: Improvement of insertion loss characteristics by using three-terminal capacitor

The residual inductance of capacitors is dependent on the electrode construction, and by the length of lead wires. In general, inductance distribution ranges between 5nH and 150nH, figure 11.

However, to improve insertion loss, it is mandatory to select a capacitor with inherently low residual inductance, or to use a three-terminal capacitor construction, figure 12.

Two leads at the line side of the capacitor provide line input and output respectively, thus reducing residual inductance. This in turn is converted positively in a filter element extending its suppression capabilities to higher frequencies. With this three-terminal construction, these capacitors are used for digital equipment and car audio equipment with EMI problems ranging from several tens of MHz to several hundred MHz.

In case the line to be filtered is a high speed digital line or video line, a more sophisticated type of filter must be used. To insure the integrity of the digital signal, a filter must be selected which will pass the sixth harmonic of the fundamental frequency. This will insure the signal will work but strips off the high frequency noise found in the corners of the square wave, figure 13. The filter must then very quickly start attenuating. The sharper the transition band to stop band attenuation, the better.



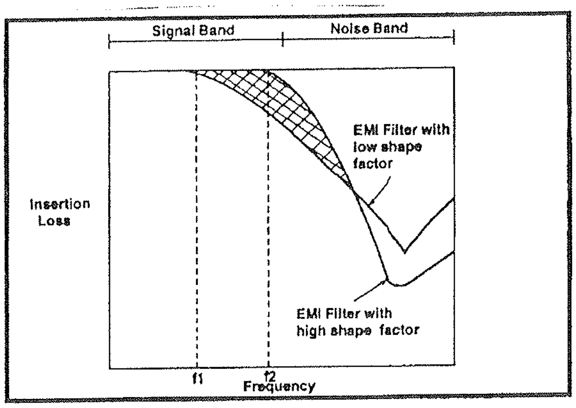


Figure 13: Low vs. high shape EMI filter factor and its effects

3.3 AC and DC Power Line Filtering

AC lines in many cases readily become paths for noise, which in turn effects other equipment (conducted interference). These lines also act as antennas, picking up noise radiated from other equipment (radiated interference). In order to prevent both of these undesirable effects, AC line filters are attached to the lines. These components effectively prevent noise from entering or radiating from AC lines.

There are two types of noise generated in power supplies, figure 14:

- normal mode noise is generated between lines and
- common mode noise is generated between both lines and ground

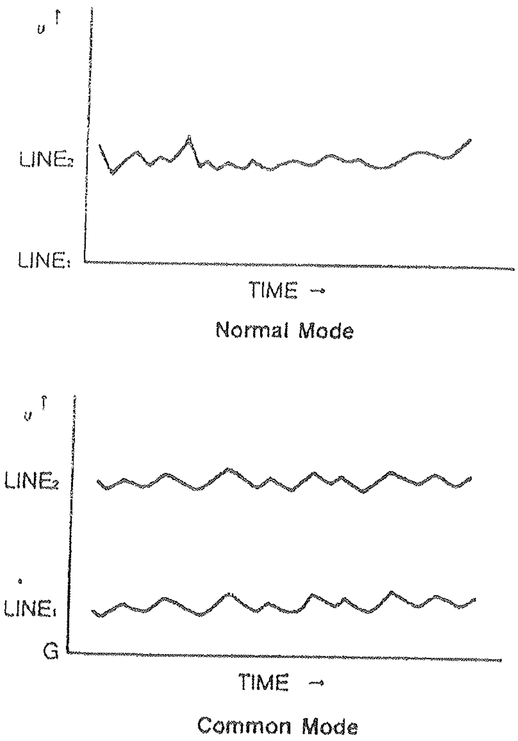


Figure 14: Noise mode of power supply

Therefore, circuit networks must be used which can suppress the noise of both modes, as shown in figure 15.

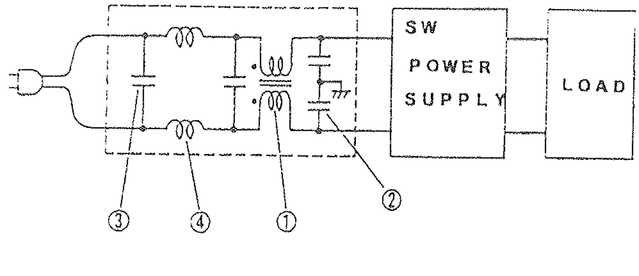


Figure 15: Basic filtering for AC line

The role of each element is described below:

NO.	ITEM	FUNCTION
1	COMMON MODE CHOKE COIL	SUPPRESSION OF COMMON MODE NOISE
2	LINE-BY-PASS CAPACITOR	SUPPRESSION OF COMMON MODE NOISE
3	ACROSS THE LINE CAPACITOR	SUPPRESSION OF DIFFERENTIAL MODE NOISE
4	DIFFERENTIAL MODE CHOKE COIL	SUPPRESSION OF BOTH MODE NOISE

In selecting the capacitance required for the line to line capacitors and the inductance of the common mode chokes, it is necessary to determine the lowest desired frequency to be filtered (cutoff frequency).

The value of the capacitance used in the line bypass (line to ground) application is limited by the maximum leakage current allowed by safety standards.

In order to meet regulations governing conducted noise, it is necessary only to be concerned with frequencies up to 30MHz. However, it becomes necessary to eliminate up to 300 MHz to prevent radiating and receiving higher frequency noise at the AC power lines. To improve high frequency attenuation characteristics, DC filters are installed on the secondary side (DC) of the power supply or by utilizing feed thru capacitors or 3-terminal capacitors as the bypass capacitors in the power line filter, figure 16.

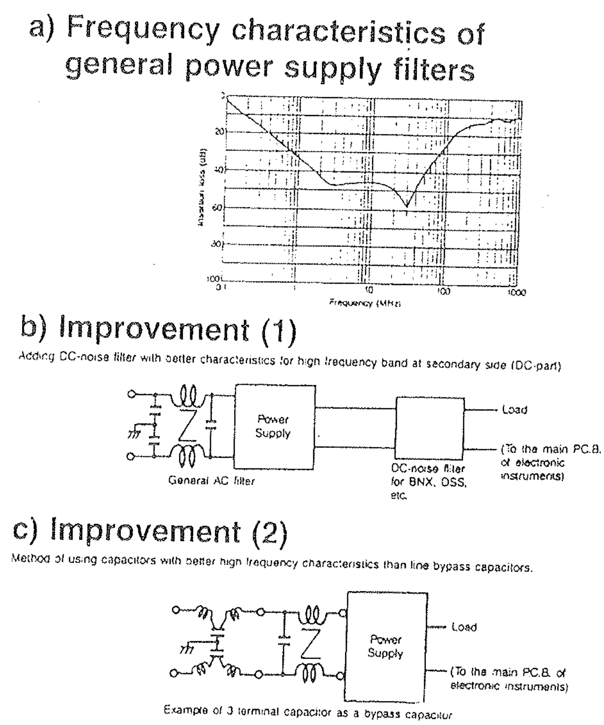


Figure 16: Improvement of noise characteristics in high frequency bands of power supplies

As an example of the type (1) improvement, Murata's block type EMI filters from BNX series completely eliminate noise from DC power circuits within extremely wide frequency range, figure 17. They are used in switching power supplies, engine control units, digital equipment, computer terminals and are installed on the DC side of the power supply.

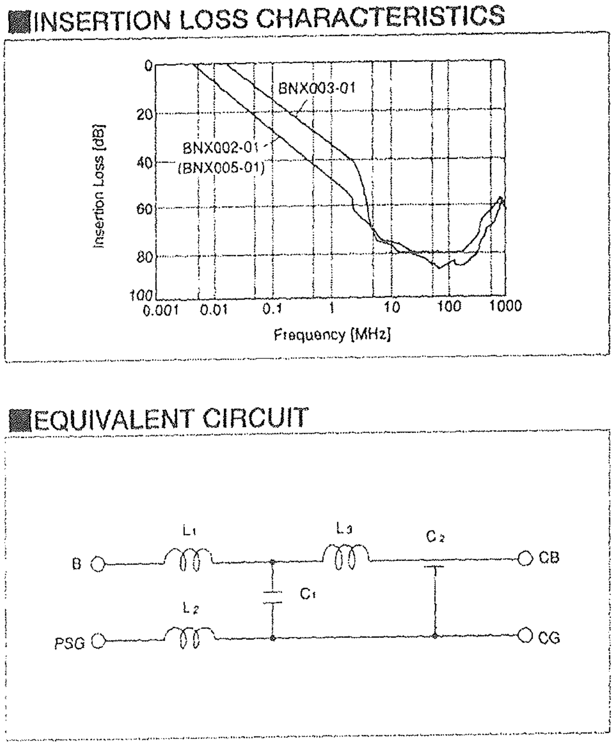


Figure 17: Insertion loss characteristics and equivalent circuit of Murata's BNX filters

COMMENT:

Murata entered the suppression filter field at an early stage in response to serious problems stemming from electromagnetic interference between electronic equipment. These pioneering efforts in the filter field resulted in the development and world-wide marketing of the EMI Suppression Filter (EMIFIL®).

In 1979 Murata successfully developed an on-board type EMIFIL® , thereby realizing a solution to PC board noise suppression.

In 1985, the EMIFIL® class on-board filter was further developed to produce a chip-based EMI suppression filter, thus substantially improving noise suppression in compact electronic equipment.

Based on more than thirty years of ceramic dielectric and ferrite technology experience, Murata's full range of high performance EMIFIL® serve to overcome and control all types of electronic equipment noise problems. Further, Murata's various noise suppression circuits, designed for the diversified needs of the electronic industry, offer great advantages in the pursuit of noise-free equipment.

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/2/ EMI Countermeasures, Application Guidance, Murata No.TE04ET

/3/ Measuring Expertise for EMI Regulation Compliance and Countermeasures, Murata No.TE06ET

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