Understanding and Selecting Surface-Mount EMI Filters

GERRY HUBERS, FRANK TILLEY, SHINJI WAKAMATSU, and ROBIN WILSON
Murata Electronic North America, Inc.*

INTRODUCTION

Achieving EMC continues to be a critical issue for electronic systems. The well-known trends related to EMI are that operating frequencies will continue to rise, and electrical circuits and systems will become more dense and operate in closer proximity to each other. These trends affect the elements of EMI in such a manner as to guarantee that EMI issues will continue to gain importance for design engineers.

METHODS OF EMI SUPPRESSION

The elements required for EMI are an EMI generator, an EMI receiver, and a path through which the EMI generated can reach the EMI receiver. The reduction of any one of these elements results in a reduction of EMI. Methods to reduce EMI include proper PCB layout, shielding, and filtering.

A PCB layout which is designed with EMC in mind will greatly reduce EMI. However, PCB layout alone is usually not enough to achieve EMC on modern systems. Shielding is effective on radiated emissions, but does nothing for conducted noise. Shielding also allows the distinct possibility of EMI between circuits under the same shield. EMI filters reduce conducted noise, prevent radiated emissions before they have a chance to radiate, and are cost-effective.

EMI FILTER PERFORMANCE

The purpose of an EMI filter is to remove energy from unwanted fre-

Tradeoffs between filters include size, cost, and ease of use.

quencies. The performance of an EMI filter is expressed in terms of either impedance (Z) or insertion loss (IL), both as a function of frequency.

To determine the IL of a filter, a circuit with a defined source and load impedance is measured for load voltage before V(B) and after V(A) the filter is added (Figure 1). MIL-STD-220 specifies 50 ohms for source and load. IL is calculated by

$$\text{IL (dB)} = 20 \cdot \log_{10} \frac{V(A)}{V(B)}$$

TYPES OF EMI FILTERS

There are two basic types of EMI filters: the noise limiting type and the noise separating type. Noise limiting filters dissipate the energy of unwanted frequencies in the form of heat. Noise separating filters direct the energy of unwanted frequencies to ground. Figure 2 shows how the two types of filters are installed in a circuit. EMI filters are designed to reduce EMI noise in the kHz to GHz range, with most problems occurring between 30 MHz and 300 MHz.

Noise Limiting Filters

Noise limiting is accomplished by resistive or inductive type filters. A well-known example is the ferrite bead. Ferrite has a unique frequency dependent characteristic, in that the permeability has both a real and imaginary component. The imaginary component yields an inductive reactance, while the real component provides straight resistance. At higher frequencies, the resistive component becomes dominant. Because of this dominant resistive component, ferrite beads are known as frequency dependent resistors.

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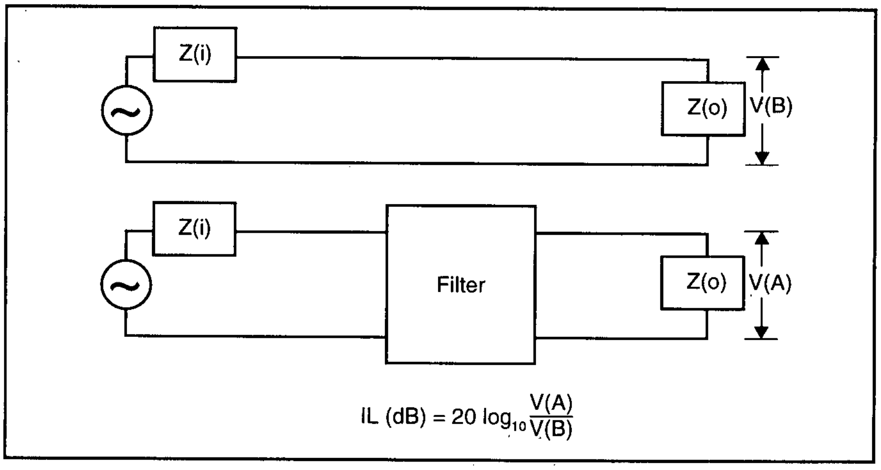

***Figure 1**. Circuit Before and After Insertion of Filter.*

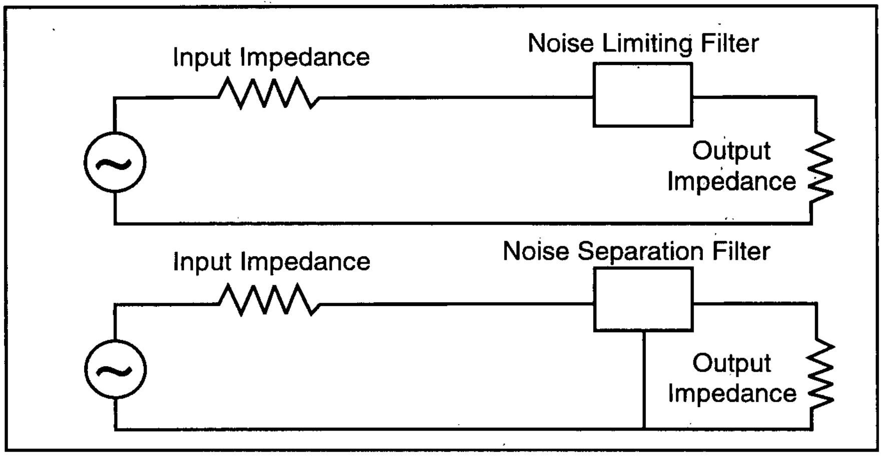

***Figure 2**. Insertion of Noise Separating and Noise Limiting Filters.*

Early ferrite bead designs consisted of cylindrically shaped ferrite material in which wires could be inserted. These leaded filters and the ferrite beads provided 50 to 100 ohms in the frequency range 30 MHz to 300 MHz. Due to advances in multilayer technology, current surface-mount ferrite beads can provide over 2000 ohms in the same frequency range or a significant impedance across a much broader range of frequencies.

Selecting Noise Limiting Filters

The variety of SMT ferrite beads has increased in recent years. Vital characteristics to consider are impedance at 100 MHz (an industry standard), bandwidth/cutoff frequency, and current carrying ability.

Applications for SMT ferrite beads can be classified as standard signal frequencies, high-speed signal frequencies, and high current power applications. Standard signal frequencies, defined as lower frequency and lower current signals, require an effective impedance across a broad range of frequencies. High-speed signals require a high frequency cutoff with a sharp increase in impedance beyond the cutoff frequency. Power applications require a low dc resistance and high-rated current.

With newly developed ferrite material and technology, SMT ferrite beads have frequency selection and curve shaping ability. SMT ferrite beads are available with up to a 6-A rated current in an EIA size 1806, 3-A rated current in EIA sizes 1206/0805, and 1-A rated current in an EIA size of 0603.

Noise Separating Filters

Noise separation is accomplished with capacitive element filters. Capacitive element filters include two-terminal capacitors and feed-through capacitors. Feed-through capacitors can also be broken down into the following categories: 3-terminal capacitors, pi filters, T filters, and hybrids. Ideally, a capacitor will provide 20 dB/decade of IL. However, a closer look at the parasitic elements of a capacitor distinguishes between the different capacitive elements mentioned.

An ordinary 2-terminal capacitor has a series inductance attributed to the inherent inductance of the lead wires/terminations. Typical 2-terminal capacitors have an equivalent series inductance (ESL) of approximately 5 nH. The LC combination dictates that at some frequency, the device will resonate. The resonant frequency can be calculated by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

At frequencies lower than the resonant point, the IL will continue to increase. Beyond the resonant point, the IL will decrease. If the inductance can be reduced, the resonant frequency will be increased, producing a higher resonant frequency. The higher resonant frequency yields more performance at higher frequencies.

The traditional bulkhead mounted feed-through capacitor can achieve near ideal performance since the current to ground is dissipated immediately into the ground plane. That means an infinite number of current paths are leaving the device in all 360 degrees. Each current path is adjacent to another current path of the same magnitude, so the magnetic flux generated by each current path is canceled with the magnetic flux generated on adjacent current paths. Since the total sum of magnetic flux is zero, the inductance is also zero.

The purpose of the SMT 3-terminal capacitor is to decrease the series inductance to ground. The internal construction of the SMT 3-terminal capacitor emulates that of the bulkhead-mounted feed-through capacitor. As a result, the ESL to ground is greatly reduced and the 3-terminal capacitor has superior high frequency IL. The ESL of the SMT 3-terminal capacitors is approximately 0.1 nH. The low inductance makes three-terminal capacitors ideal for EMI applications at frequencies from 100 kHz to beyond 2 GHz. Levels of insertion loss for surface-mount 3-terminal capacitors range between 20 dB and 80 dB.

Selecting Noise Separation Filters

As with noise limiting filters, selection criteria are beneficial in choosing the proper filter for specific applications. Vital characteristics to consider are cutoff frequency, slope of the IL curve as a function of frequency, and the resonant frequency. Applications for SMT 3-terminal capacitors can be classified as standard signal frequencies, high-speed signal frequencies and power applications.

Standard signal frequencies require an effective IL across a broad range of frequencies. High-speed signals require a high frequency cutoff with a sharp increase in IL beyond the cutoff frequency. Power applications require a low dc resistance and high-rated current. SMT 3-terminal capacitors are available

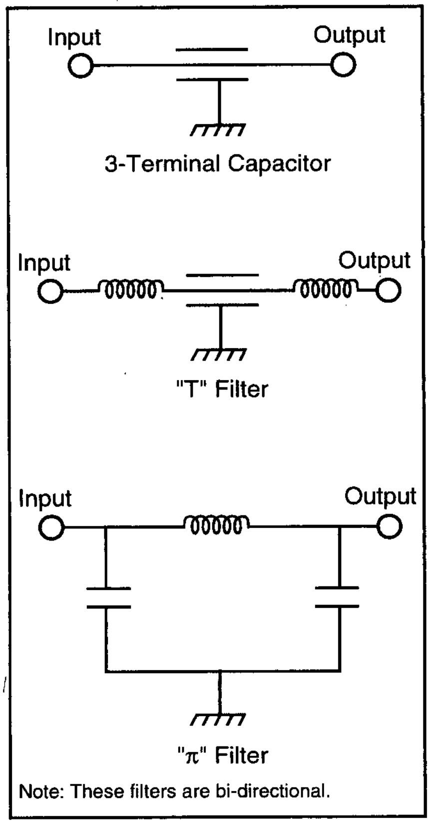

***Figure 3**. Equivalent Circuits for Noise Separating Filters.*

with up to a 6-A rated current in an EIA size 1206.

Standard 3-terminal capacitors are suitable for standard signal frequencies. High-speed signals can be accommodated with pi-type capacitors as they tend to increase IL quickly beyond the cutoff frequency. T-type filters work well in both standard signal frequencies and in power applications due to a broadband IL in the 10-dB to 50-dB range and high rated currents of 2 A to 6 A. Equivalent circuits can be seen in Figure 3.

COMMON-MODE CHOKE COILS

When operating frequencies get high enough to intermix with detectable noise frequencies, a common-mode choke coil can be useful in separating and attenuating EMI energy. An undistorted waveform is maintained for the operating frequency.

Standard EMI filters gradually increase their impedance beyond low frequency signals to attenuate the noise frequencies (Figure 4a). When the signal frequencies are close to the noise frequencies, a higher performance filter can increase the impedance rapidly beyond signal frequency to attenuate the noise frequencies (Figure 4b).

In cases where signal frequencies are intermixed with noise frequencies, a common-mode choke coil can reduce the noise frequencies without distorting the signal frequencies (Figure 4c).

Common-mode choke coils are available in both monolithic and wire-wound packages. In EIA standard sizes from 1206 to 2020, currently available common-mode choke coils can handle up to 2 A or up to 4000 ohms at 100 MHz.

SUMMARY

Selection criteria is beneficial in defining a particular filter for specific applications, as summarized in Figure 5. Tradeoffs between filters include size, cost, and ease of use. Ferrite beads are the smallest, least expensive, and easiest to use. Im-

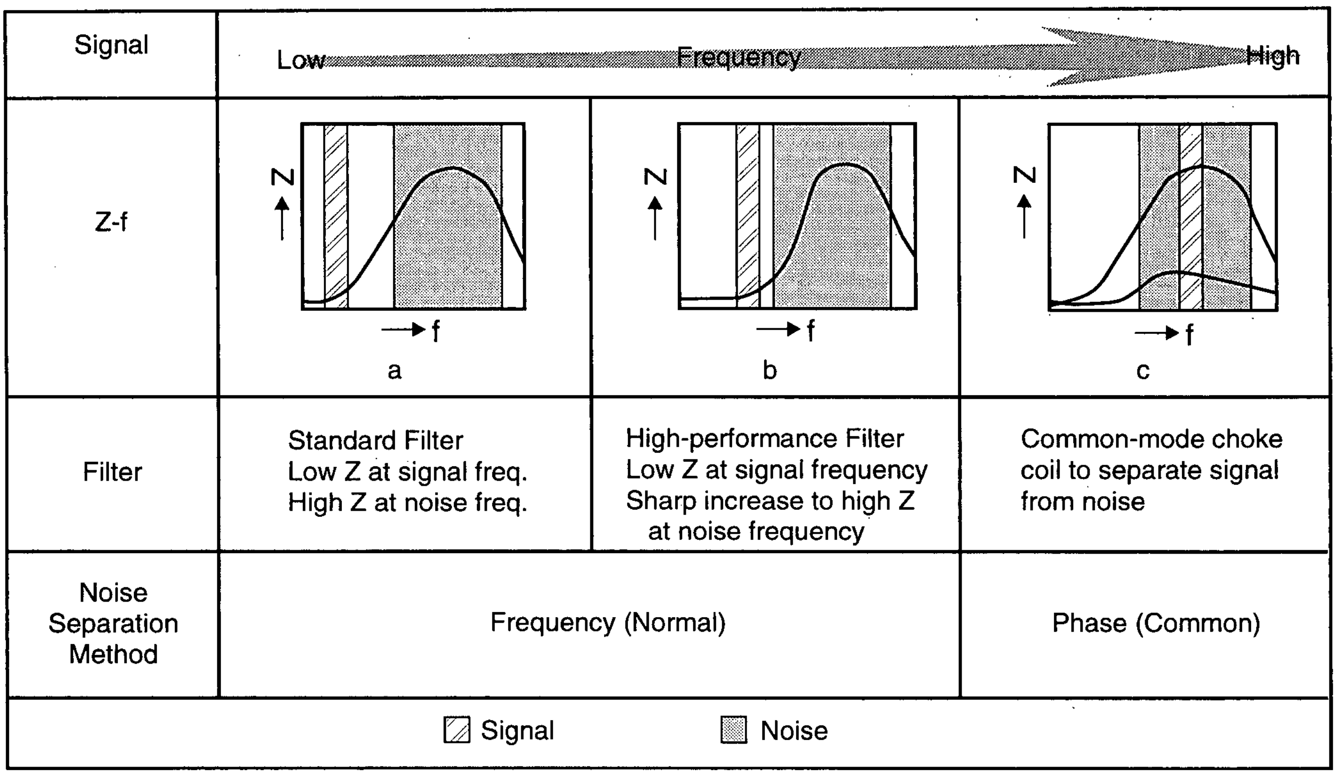

***Figure 4**. Use of Standard Filter, High Performance Filter and Common-mode Choke Coil.*

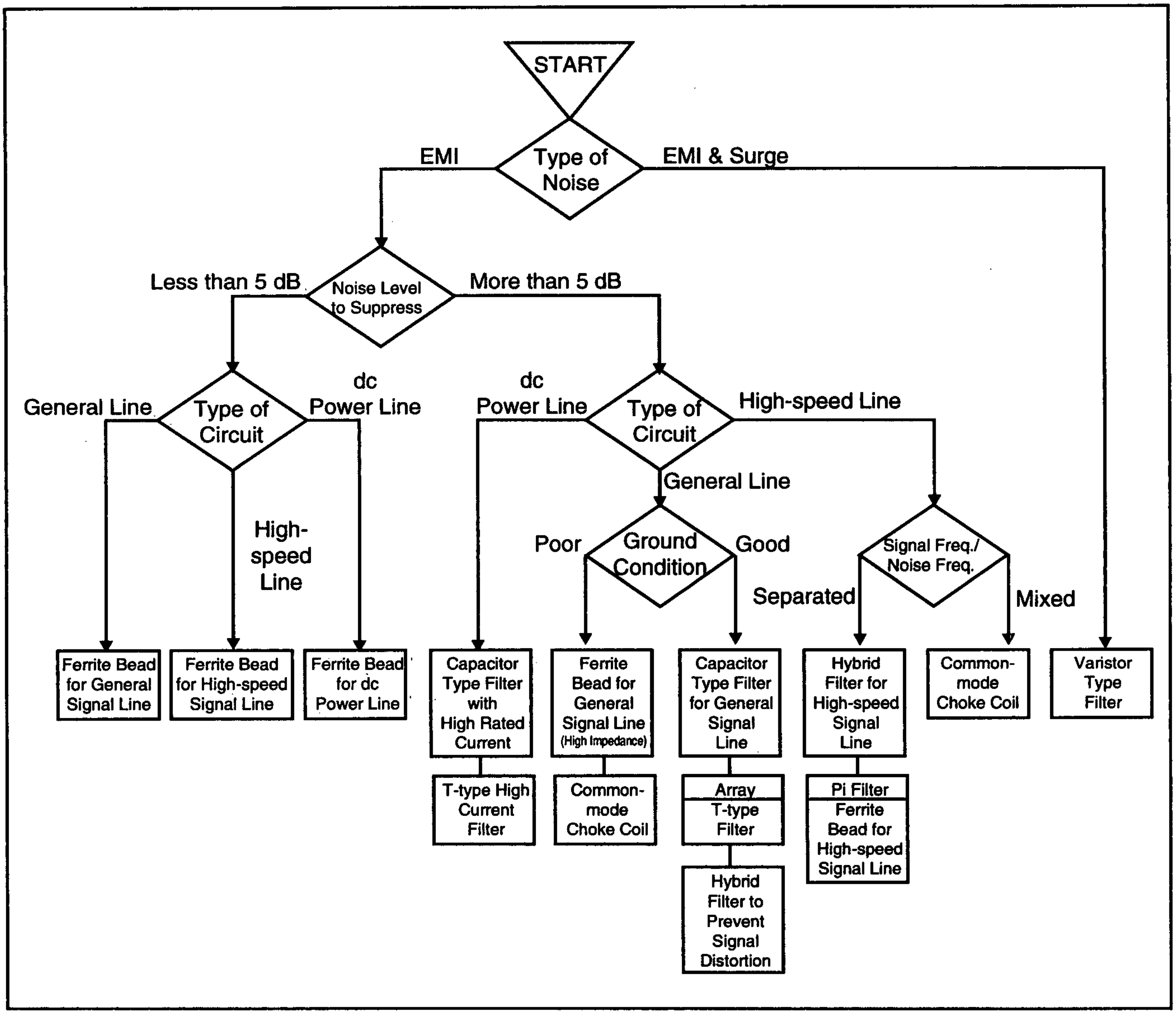

Figure 5. *EMI Filter Selection Guide.*

proved performance, higher self-resonant frequencies, and low equivalent series inductance can be achieved when stepping up to a multi-element 3-terminal capacitor. It should be noted that the industry trends are a reduction in size and cost. These reductions are the result of improved manufacturing processes, improved materials, and the economy of scale.

GERRY HUBERS, *CET P.E, has over 5 years experience as product engineer/manager with Murata Electronics in EMI filters and SMT chip inductors, including technical applications and marketing support. He is a member of the IEEE and has published several papers related to EMC. (770) 436-1300.*

FRANK TILLEY *is a product engineer for EMI filters and chip inductors at Murata Electronics. He received his bachelor's degree in electrical engineering from the University of Tennessee, Chattanooga. He is a member of the IEEE, as well as the EMC Society, and has published several papers related to EMC. (770) 436-1300.*

SHINJI WAKAMATSU *has been a product engineer for EMI filters and chip inductors at Murata Electronics North America for the last year. Prior to that, he worked with Murata Electronics' EMI filters/chip inductors group in Takefu, Japan, where he was involved in chip inductor development for three years, and product engineering for two years. He is the author of two EMC-related papers to be published this year. (770) 436-1300.*

ROBIN WILSON *has worked in the design engineering and marketing departments of Murata's Canadian facility, where military EMI filters were produced. In 1985, he assumed responsibility as product manager of the PCB EMI filter line, which comprises commercial EMI filters. He attended St. Lawrence College in Cornwall, Ontario, Canada and graduated with an Electronics Engineering Technologist Diploma in 1972. He is a current member of the IEEE, is involved in the P3 Inductor Committee of the EIA, and has published several papers related to EMC. (770) 436-1300.*