A Practical Approach to EMI Suppression Using Ferrite Chips

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Ferrite chips can be classified for standard signal, high-speed signal, power line and ultra-high frequency applications.

Introduction

With the increasing emphasis placed on emissions and immunity by the FCC and other international regulatory agencies, design engineers are encouraged to prioritize EMC at the forefront of their designs. For this reason, there have been intense studies in the field of electromagnetics which have provided breakthroughs in EMI filter technology, particularly ferrite chips. This continuous effort for improvement has affected ferrite chips in areas such as size, performance, and popularity.

However, even with this trend of improvements, there still exists a sense of uncertainty on how to solve EMI problems using ferrite chips. This is why it is necessary to understand the nature of EMI and the specific characteristics of ferrite chips. This article will address the basic principles of EMI and ferrite chips. It will explain the characteristics of ferrite chips at low and high frequencies and how they are beneficial in reducing EMI. It will also discuss how a large variety of ferrite chips has been narrowed down to four application-specific categories to simplify the selection process.

EMI Concepts

Three elements are required for an EMI problem to exist. There must be a noise source, noise receiver and a coupling path for the noise generated to reach the receiver. Although these elements may not be easily identifiable, if any one is eliminated, the threat of EMI is obsolete.

In order to eliminate one of these elements, the designer must know the noise location and understand the medium in which EMI is transmitted. Noise can be transmitted via a conductor, or radiated through the air. Figure 1 illustrates the four modes of noise coupling:

- Conducted mode (1)
- Radiation coupling to equipment (2)
- Secondary radiation coupling to equipment (also called cable reradiation) (3)
- Radiation coupling to cables (antenna effect) (4)

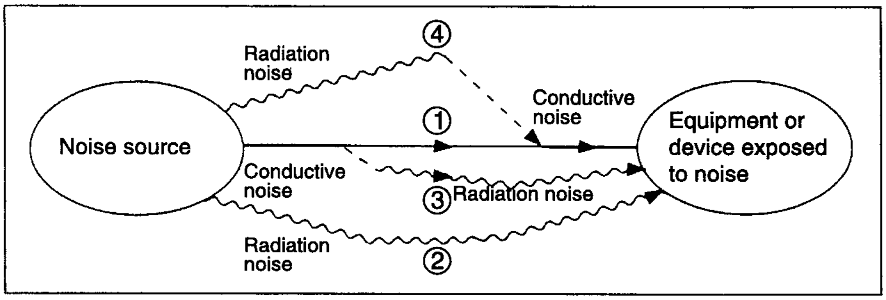

Figure 1. *EMI Propagation Modes.*

The basic rule of thumb is that there are two methods for achieving EMC, shielding and EMI filtering. EMI filtering is effective in reducing conducted noise as well as preventing emissions from radiating. Furthermore, EMI filters are available in compact surface-mount packages and are cost-effective. Shielding is effective in preventing radiated noise; however it cannot prevent the possibility of radiation between circuits under the same shield and it is quite expensive. For these reasons, ferrite chips have become one of the more widely used methods for suppressing EMI.

Ferrite Chip Characteristics

Ferrite chips have a unique feature that results in a complex impedance (Z) that has both a real (R) and imaginary part (jX).

$$Z = R + jX \text{ or } (Z^2 = R^2 + X^2)$$

The imaginary component yields an inductive reactance, while the real component provides pure resistance. The value of this feature is that the relationship of these components varies with frequency. As shown in Figure 2, the inductive component is dominant at low frequencies and the resistive component becomes dominant at high frequencies. This is further illustrated with the impedance curve in Figure 3. At frequencies below 5 MHz, the ferrite chip provides a small inductive impedance of approximately 150 ohms, while at frequencies above 100 MHz, the impedance increases to well over 1000 ohms and is basically resistive.

For this reason, ferrite chips can be

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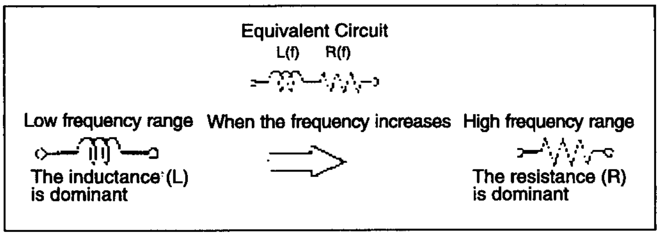

***Figure 2**. Ferrite Chip Equivalent Circuit.*

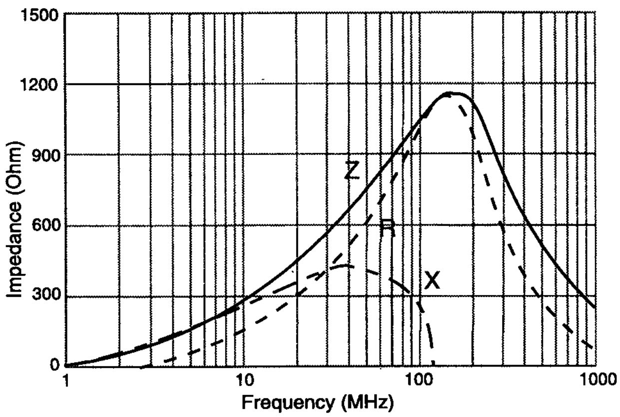

***Figure 3**. Impedance Provided by a Ferrite Chip.*

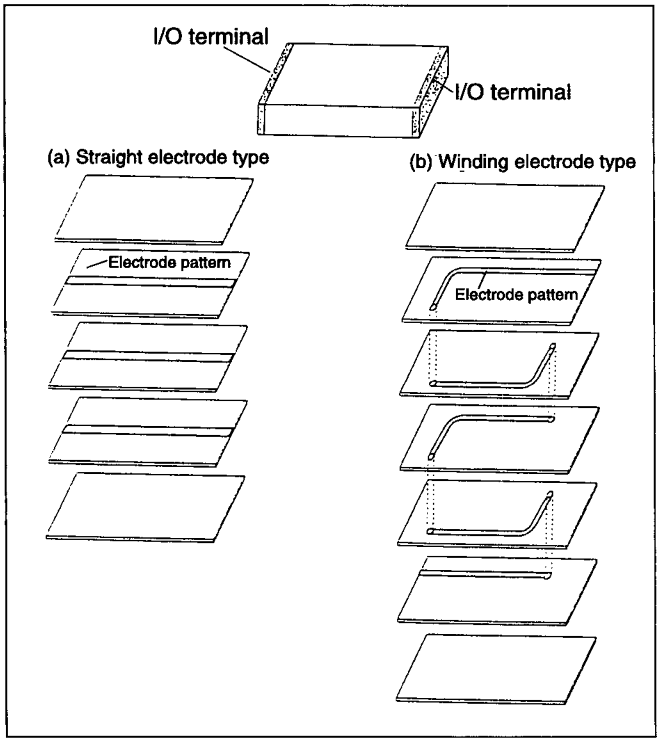

***Figure 5**. Monolithic Structure of Ferrite Chip.*

thought of as frequency-dependent resistors. Since noise is a high frequency phenomenon, when these ferrite chips are inserted in series with the signal line, the resistive component dissipates unwanted high frequency noise in minute amounts of heat.

Ideally, the impedance of a ferrite chip will continue to increase as the frequency increases. However, a closer look at the impedance curve in Figure 3 reveals that the impedance increases until the frequency reaches a certain level, and then it decreases. This is due to the inherent stray capacitance that exists between the external electrodes (I/O terminals) and between the windings of the internal electrode. Figure 4 illustrates the typical effect of stray capacitance on the performance of a ferrite chip. As the

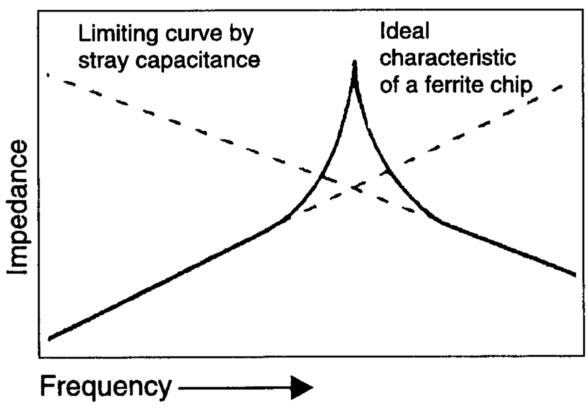

***Figure 4**. Resonant Frequency (XC = XL).*

frequency increases, the inductive characteristics of ferrite chips tend to become more capacitive. This is why it is necessary to understand the frequency at which the noise problem occurs when selecting a ferrite chip.

To ensure this inevitable event takes place at the highest possible frequency, ferrite chips are a monolithic construction that minimize the stray capacitance, hence increasing the effective frequency range. Figure 5 illustrates the structure of a surface-mount ferrite chip in which an electrode pattern is printed on ferrite sheets to form a series element component.

Based on the internal electrode structure and the composition of the ferrite material, ferrite chips can be designed to meet a wide array of desired performances. Most recent trends require ferrite chips to have small case size, variation in impedance levels, high rated current, low DCR, high frequency characteristics and sharp roll-off characteristics.

Types of ferrite chips

Over the years, there have been many advancements in surface-mount technology and in ferrite materials which have significantly increased the variety of ferrite chips. With so many variables to consider, including size, impedance level, and performance, the selection process can be extremely difficult. In a successful attempt to ease this process, a method was devised to narrow the variety of ferrite chips according to application. Currently, ferrite chips can be classified into one of four application-specific categories:

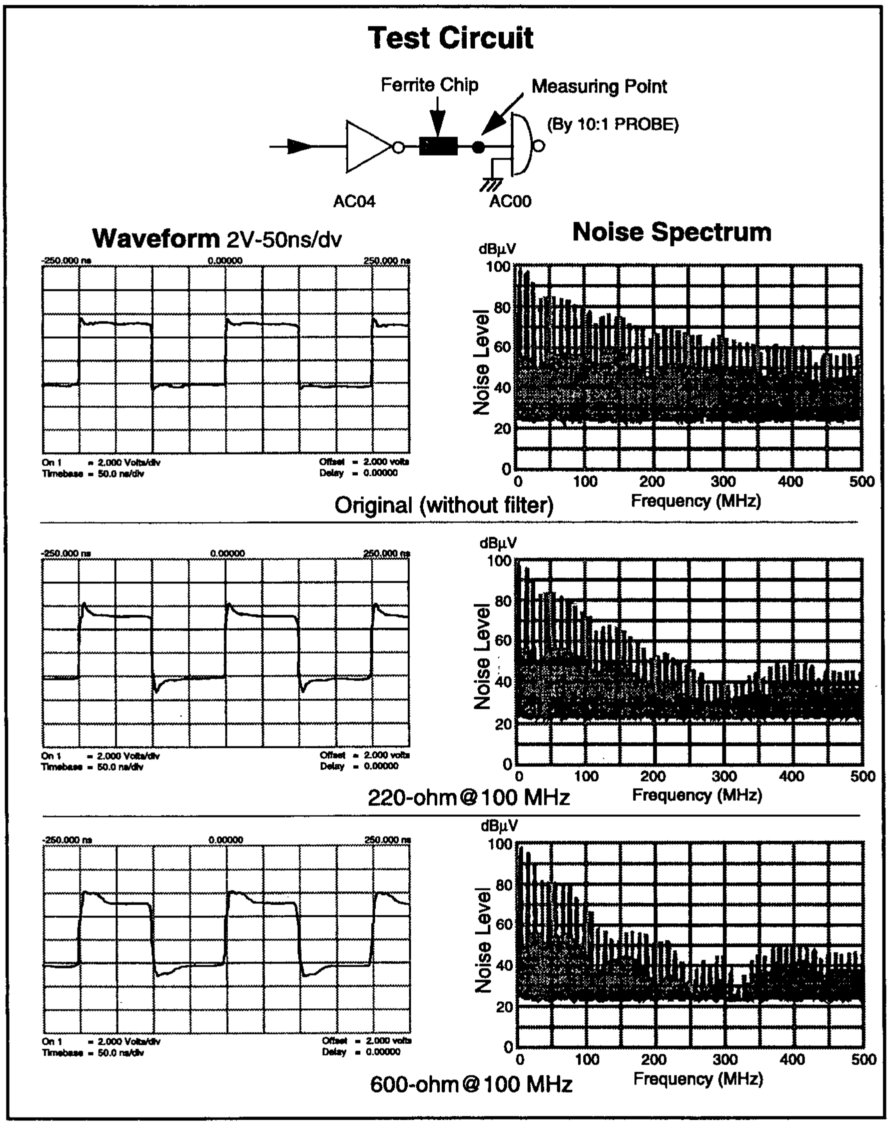

Figure 6. *Effects of Ferrite Chip Installation in a Circuit.*

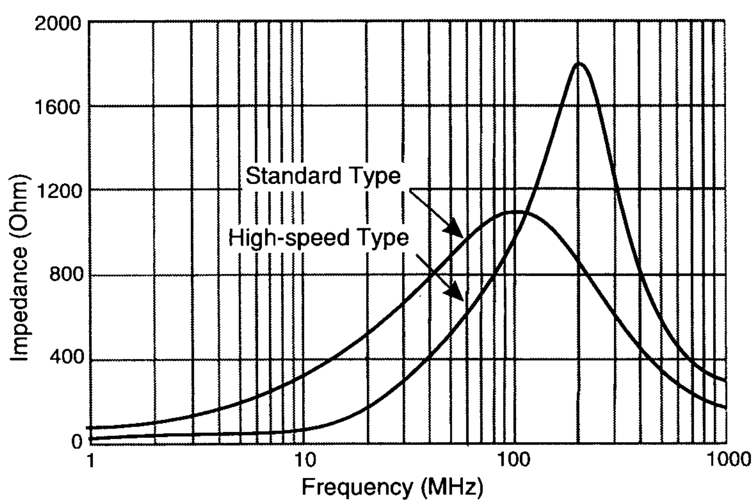

Figure 7. *Standard Ferrite Chip vs. High-speed Ferrite Chip.*

- Standard signals
- High-speed signals
- Power lines
- Ultra-high frequencies

Standard signals are defined as lower-frequency, lower-current signals which require effective impedance over a broad frequency range. To achieve a broadband frequency response, the ferrite material typically has a high permeability that increases the performance of the filter, particularly at low frequencies. Figure 6 shows the effects of using standard signal ferrite chips by inserting them in a test circuit. First, the 220-ohm ferrite chip is installed and a reduction of approximately 10 dBµV can be observed in the noise spectrum. Next, the 600-ohm ferrite is inserted and an even greater reduction, nearly 20 dBµV, is displayed. The results are shown in the waveform as the severity of the spike decreases when the filters are added. This type of filter is ideal for I/0 ports, IC power lines, and signal lines.

High-speed signals operate at a higher frequency than standard signals. Therefore a filter is needed that will not affect the lower frequencies or desired signal, but will provide significant impedance at high frequencies. Figure 7 is an illustration of the impedance characteristics of a ferrite chip designed for standard signals versus one designed for high-speed signals. As can be seen, the high-speed signal filter has minimal impedance in the low frequency range, but experiences a sharp increase in impedance as the frequency increases. The minimal impedance in the low frequency range prevents interference with the desired signal.

A further explanation of the performance of high-speed ferrite chips is shown in Figure 8. In this demonstration, a test circuit is assembled and the noise spectrum is measured without a filter, with a high-speed ferrite, and then with standard ferrite. By observing the noise spectrums, it can be

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concluded that both filters provide excellent impedance characteristics. However, due to the broad frequency range of the standard signal ferrite, the desired signal is affected and the result is waveform cornering. Notice that if the appropriate filter is not selected, the attempts to suppress EMI emissions can be more harmful than beneficial, in that circuit operations are affected. The high-speed ferrite chip is designed for applications with high-speed circuits such as computers and peripheral equipment.

Power lines are very similar to standard signal lines in that they require attenuation over a broad frequency range. Therefore the characteristics are similar. However, the power line ferrite chip is designed for high current applications. This is achieved by modifying the design of the inner electrode for a low DC resistance, hence increasing the rated current.

Figure 9 provides a good example of the performance of the power line ferrite chip. By inserting the 30-ohm and the 60-ohm ferrite chips, noise reduction of 10 dBµV and 14 dBµV respectively are displayed in the noise spectrum. Currently there are ferrite chips designed for power lines rated for 6 A in an 1806 size and 3 A in 0805. Obviously, with the high current capability of this ferrite chip, the applications are typically DC power lines.

Ultra-high frequency applications have EMI problems well beyond 1 GHz. These applications require a filter that will provide significant impedance at particularly high frequencies. It can be viewed as shifting the window of the effective frequency range of the standard signal ferrite to extend to the GHz range. Figure 10 provides an illustration of the performance of the ultra-high frequency ferrite chip. These are extremely useful in the telecommunication industry where the transmitting and receiving frequencies are quickly approaching the GHz range.

Figure 11 provides a summary of the selection process for surface-mount ferrite chips.

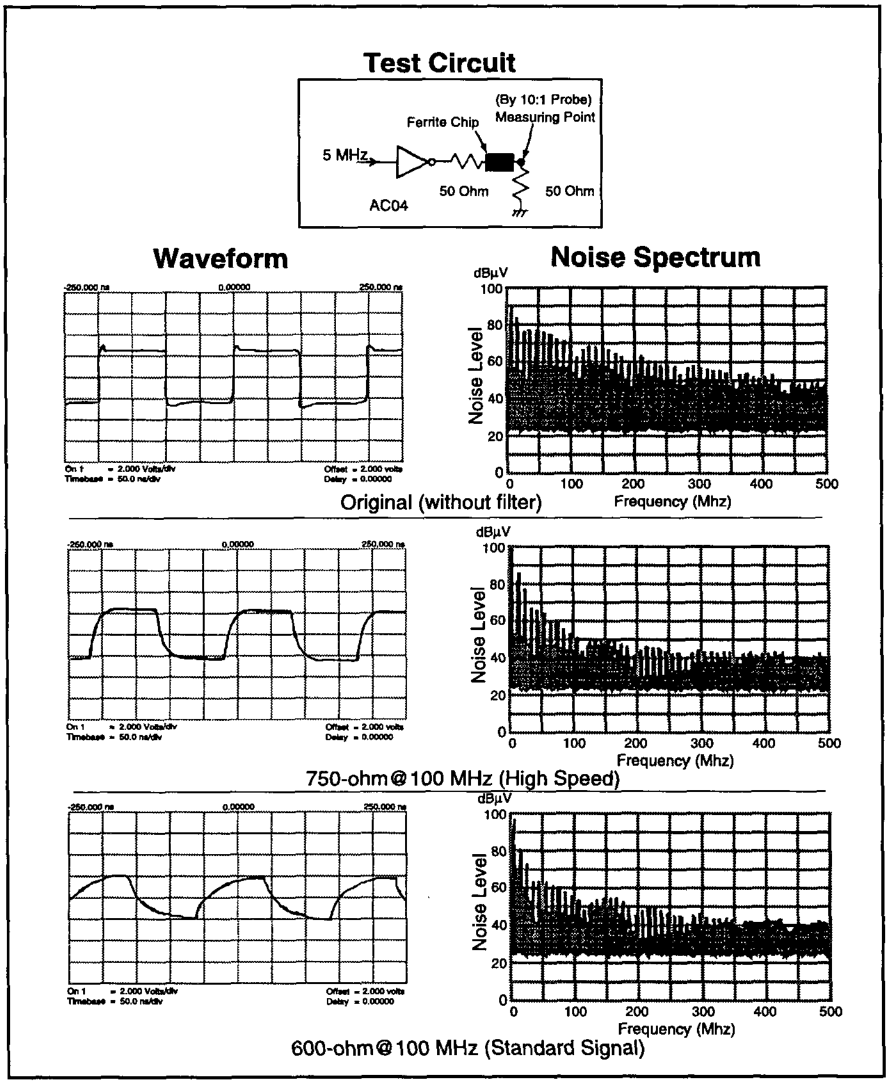

Figure 8. *High-speed Signal Ferrite Chips.*

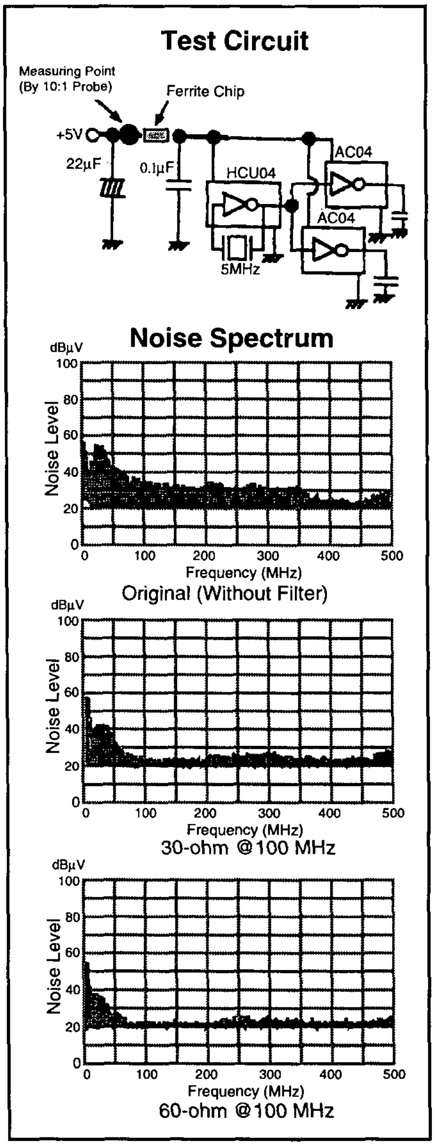

Figure 9. *Power Line Ferrite Chip.*

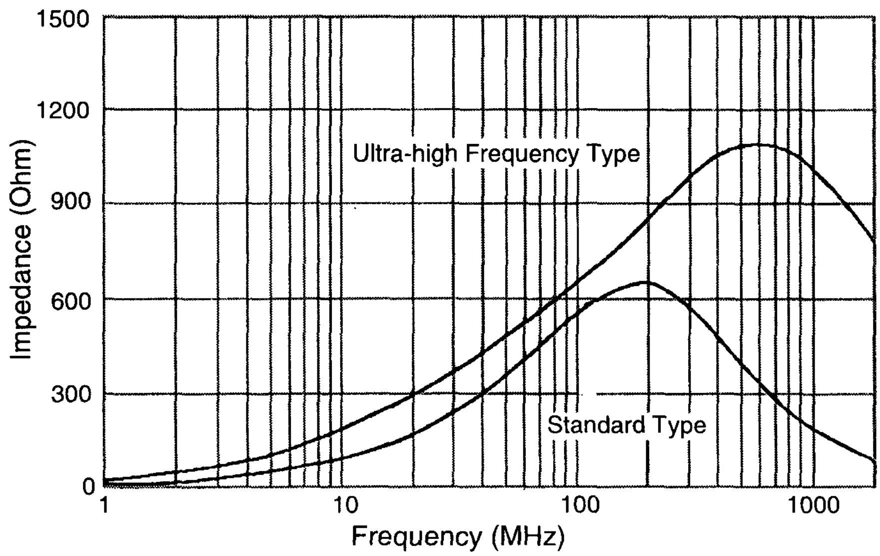

Figure 10. *Ultra-high Frequency Ferrite Chip.*

Summary

In recent years there has been heavy emphasis placed on the harmful effects of EMI emissions and this trend is expected to continue as operating frequencies increase. Therefore, it is imperative for design engineers to be knowledgeable on the principles of EMI and the various resources available to control it. One of the more popular methods for achieving EMC is filtering using ferrite chips. These ferrite chips have physical and constructional properties that make them ideal filters. They also are very simple to install because there is no need for a ground design. Another nice feature of ferrite chips is that they are classified in four application-specific categories. This makes it easy to narrow down an otherwise broad variety of filters to suit a particular application.

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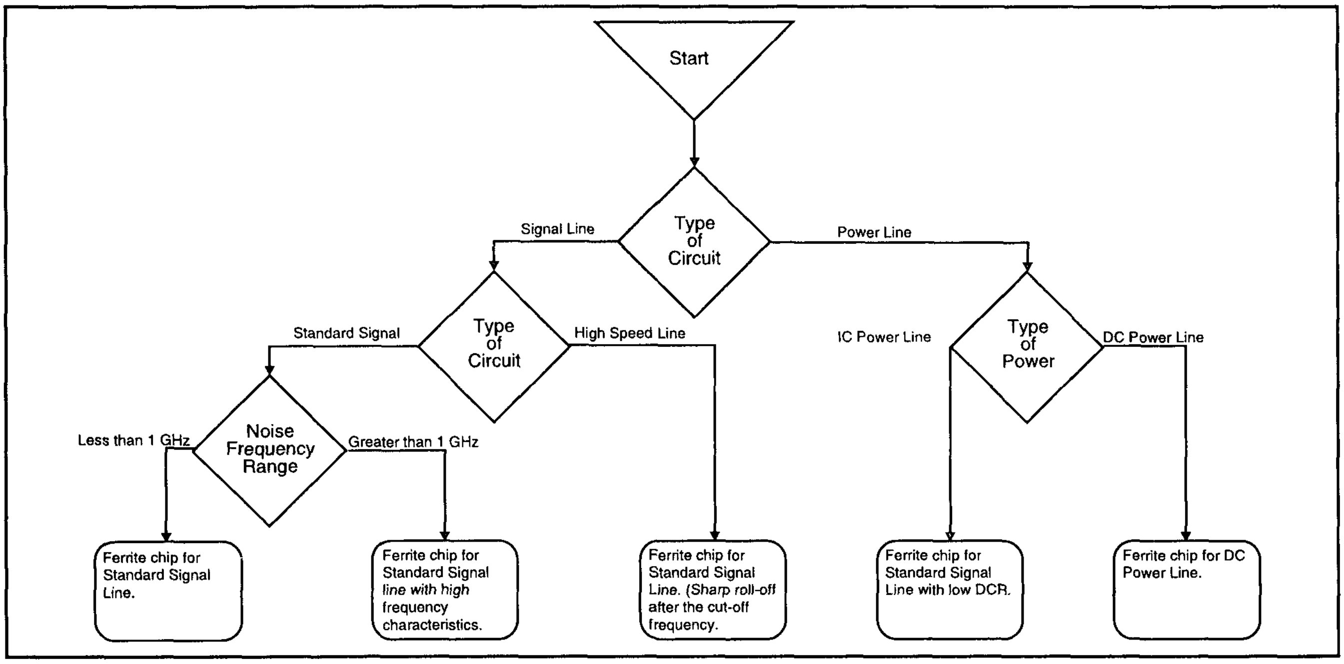

Figure 11. *Surface-mount Ferrite Chip Selection Chart.*