High Speed Differential Interfaces and the Need for Common Mode Filtering and Protection

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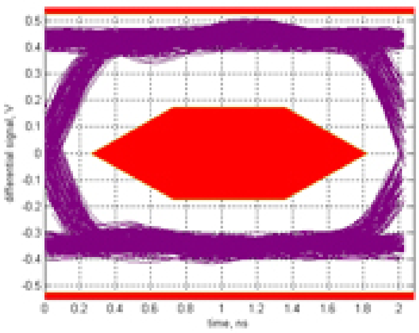
In the operating environment seen by electronics today there are numerous sources of electromagnetic interference (EMI) and radio frequency interference (RFI). This is due in large part to the increased use of RF technology. These types of interference result in the need for common mode filtering in applications utilizing differential interfaces. Although the desire in utilizing differential signaling is to minimize the effects of EMI/RFI, the effects are not eliminated entirely. The differential signal can become corrupted by external noise such that it is not discernable at the receiver. Also, with the noise having coupled into the electronics inside a device, other circuitry where differential signaling is not incorporated may be affected and cause addition problems.

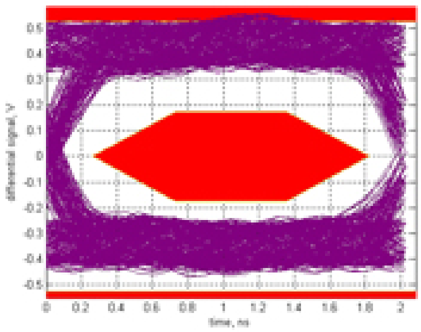


[1]

Hi-speed USB 2.0 is one of the most popular types of differential data interfaces. Thus, the objective of this article is to demonstrate the necessity and benefit of utilizing a common mode filter to reject the EMI/RFI noise in a high speed USB 2.0 application. In addition, protecting the interface from electrostatic discharge (ESD) events will be discussed. Common causes of interference include ESD, lightning, switching power supplies (such as DC/DC converters), and wireless devices such as mobile phones, wireless routers, video game consoles, and netbooks. The most common sources come from devices operating between 800 MHz and 3 GHz, however, with expanding technology these limits are being pushed down to 700 MHz and up to 6 GHz. All these sources provide for an environment rich in interference that can prove harmful not only to each other but also to the operation of other types of devices. The focus will be on USB 2.0 as it is employed in portable devices such as mobile phones and how EMI/RFI interference can cause signal integrity issues without proper filtering.

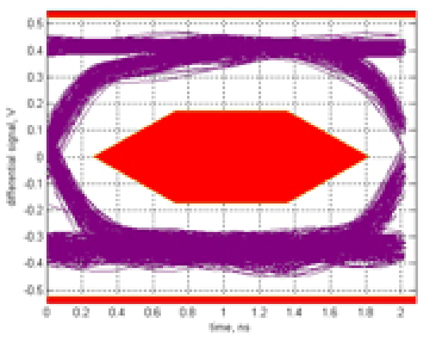
USB 2.0: Common Mode Filter Requirements

In a hi-speed USB 2.0 interface data is sent differentially over two wires at a speed of up to 480 Mbps. In order to understand the filtering requirements for such a signal, it is important to first understand the nature of the signal. The signal is a differential signal meaning that it is not referenced to ground, the two signals are referenced to each other. Data is transmitted over two lines with each line being exactly 180 degrees out of phase with the other. The two lines are commonly denoted as D+ and D- implying the phase nature of the signal. This means that an appropriate filter topology must be used to properly filter any unwanted content while not degrading the signal integrity of the desired differential signal.



[2]

In the case of USB 2.0, a single-ended filter topology is not sufficient; one must use a filter with a differential topology such as a common mode choke. This type of filter permits the passing of the desired differential data without affecting signal integrity while filtering out common mode signals that result from EMI and RFI. The inductive properties of the common mode filter create a wide pass band up to 3 or 4 GHz for differential signals while simultaneously causing a narrow pass band of less than 100 MHz for common mode signals.



[3]

Next, the necessary passband needed to permit the signal to pass with good integrity needs to be understood. For a 480 Mbps signal, the maximum fundamental frequency that can be generated is from an alternating pattern of 1s and 0s (1-0-1-0-1-0…) which results in 240 MHz. Since the signal itself is a form of a square wave, the necessary bandwidth needed to pass the signal can be found from the Fourier series approximation to be roughly three times the fundamental frequency.

This would result in a minimum necessary bandwidth of 720 MHz for the differential signal.

Finally, the amount of attenuation necessary to sufficiently remove the effects of undesired common mode signals must to be determined. This is dependent upon the application, but in general the more attenuation the better.

USB 2.0: Signal Integrity Requirements

To understand the bandwidth requirements of the signal, a measure of the signal integrity needs to be defined. It is common practice to measure an eye diagram of the signal to determine the quality of the received signal. The eye diagram shows a collection of transitions of the signal between states and gives an indication of how well the receiver can interpret the data being transmitted. High speed data transmission schemes have a specific mask or template in the eye diagram that a signal must meet to be compliant. A typical high speed USB 2.0 eye diagram including the mask template is shown in Figure 1.

The signal shown in Figure 1 would be received with ease by a USB 2.0 transceiver since, as shown, the signal is without any eye diagram mask violations. Now consider a scenario where a common mode noise signal is introduced. For this example, a small amount of common mode noise with a frequency of 900 MHz and a peak amplitude of 75 mV is introduced. This frequency is chosen to emulate noise caused by the operation of a typical mobile phone. When the common mode noise signal is introduced, as Figure 2 illustrates, the eye diagram becomes quite degraded.

In Figure 2, the whole upper bound of the mask is being violated and signal transitions are becoming degraded and moving closer to violating the mask also. It would be virtually impossible for the receiver to interpret the data being transmitted in this case. There is too much noise present on the signal for the receiver to effectively differentiate between states under these conditions. This is with only a small amount of noise present with an amplitude of only five percent of the USB 2.0 signal amplitude.

USB 2.0: Protecting the Interface

Not only is it important to filter EMI/RFI noise, but it is important to protect sensitive internal circuits from ESD events that can be harmful and even destructive. Under these conditions, a common mode filter with integrated low capacitance ESD protection such as the NUC2401 from ON Semiconductor is necessary. This filter provides the necessary bandwidth for the high speed USB 2.0 signal, proper common mode attenuation, and ESD protection for sensitive internal circuits. The integrated ESD protection has very low capacitance.

The resultant eye diagram in Figure 3 has no mask violations in either the upper or lower bounds or within the central region of the mask. This is with over five times the amplitude of noise introduced than in Figure 2. Even with such a high noise level, the resultant eye diagram at the output of the filter is discernable at the receiver and has maintained excellent signal integrity.

Summary

In an environment rich in interference from numerous sources, filtering is incredibly important. A differential interface should help minimize some common mode noise effects; however, there are still issues with signal integrity as has been shown here. In addition, without proper filtering at the entry point to a device, such as the USB port, the noise can disrupt other internal circuitry. The ideal solution to remove this noise and absorb any ESD event at the entry point is to use a common mode filter with integrated ESD protection. Utilizing a common mode filter such as the NUC2401 enables the USB 2.0 interface to be much more robust in terms of immunity to EMI/RFI noise while also providing ESD protection. Even a small amount of EMI/RFI noise introduced to the high speed USB 2.0 signal can disrupt the signal and cause it to be indiscernible to the USB receiver.

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