VITESSE

SimpliPHY Gigabit Ethernet PHY Series

SimpliPHY'd™ 10/100/1000BASE-T Magnetics and EMI Control

Application Note

1 Scope of This Document

Many factors govern the proper selection of magnetics to achieve the best system performance from copper Gigabit Ethernet PHYs. This Application Note offers guidance on selecting the best magnetics configurations for use with Vitesse's SimpliPHY™ Series transceivers to achieve targeted EMI objectives at the lowest system cost. The resulting simplifications of the magnetics used with Vitesse's SimpliPHY™ products lead to the concept of SimpliPHY'd Magnetics.

2 Role of Magnetics in Gigabit Ethernet Systems

While not explicitly required by IEEE 802.3-2002, magnetics are the most commonly used method of meeting the requirements of the 10/100/1000BASE-T PMA electrical interface. However, there is no one standard configuration that meets all objectives for all designs at the lowest cost. Magnetics offer a straightforward solution to many functions of this interface, including electrical isolation, signal balancing, common-mode rejection, impedance matching, and EMI reduction. Following is a brief description of each of these areas.

2.1 Electrical Isolation

For safety, the IEEE specification requires a 10/100/1000BASE-T port to be able to withstand 1500 Vrms at 50 Hz to 60 Hz for 1 minute between ports or from each port to the chassis ground. Transformers can easily and inexpensively meet this isolation requirement and are commonly used for this purpose.

2.2 Signal Balancing/Common-Mode Rejection

Each 10/100/1000BASE-T network cable consists of four sets of twisted pairs connected in a balanced configuration. While there are various circuit topologies that can provide the necessary balanced operation without magnetics, transformers simply and easily provide the balanced connection to each pair of a cable and also provide very effective rejection of common-mode signals.

The common-mode rejection of a transformer functions in both of the signal directions of a port. This common-mode rejection attenuates common-mode signals coming both from the cable to the PHY and also from the PHY (and its surrounding system) to the cable. Reducing common-mode signals picked up by the cable from its environment improves the signal-to-noise ratio of the system and allows the PHY's DSP to more easily recover the data signal and achieve the desired bit error rate. Attenuating common-mode signals going onto the cable helps to reduce EMI. This is discussed further in Section 2.4.

2.3 Impedance Matching

Each twisted pair in a CAT5 cable is designed to have a characteristic impedance of 100 Ohms. In some situations this might not be compatible with other electrical parameters of the transmitting and receiving circuitry. Should an impedance transformation be required, transformers with winding ratios other than 1:1 can accomplish an impedance transformation according to the formula,

$$Z_2' = Z_2 * (N_1/N_2)^2$$

Where,

Z_2 is the impedance connected to transformer winding 2,

Z_2' is the Z_2 impedance as seen from transformer winding 1,

N_1 is the number of wire turns on transformer winding 1, and

N_2 is the number of wire turns on transformer winding 2.

2.4 EMI Reduction

All high-speed digital devices create and use radio frequency (RF) energy. If this energy is allowed to escape into the device's environment it can become a source of Electromagnetic Interference (EMI). 10/100/1000BASE-T PHYs are high-speed digital devices and they are often used in systems containing other high-speed devices. It is necessary to carefully design such systems to minimize the amount of RF energy reaching the ports, since this energy can be easily radiated from the CAT5 cables.

Designers use multiple techniques to control RF emissions. While there is no one technique or component that can guarantee a successful low-EMI design, generally the measures involved fall into one of three categories: **minimization, containment**, and **filtering**.

Minimization involves addressing the sources of RF energy that are causing the EMI. If the source energy is minimized there will be less need for additional reduction measures. It is not the purpose of this Application Note to cover all aspects of EMI reduction, but it is important to list some of the major techniques used to minimize the energy emitted from EMI sources. These techniques include:

- Use the slowest practical rise and fall times on digital signals, especially clocks. These edges can often be slowed sufficiently simply by inserting a series resistor of a few tens of Ohms close to the signal source.
- Keep high-speed digital lines, especially clocks, as short as possible. Route them over unbroken ground or power planes. This will help to avoid turning these signal lines into efficient antennae.
- Avoid routing high-speed lines near lines going off-board. Capacitive and inductive coupling between traces can couple RF energy onto the off-board lines and into any cables connected to them.
- When high-speed lines on a circuit board must cross over off-board lines, ensure that they do so at right angles. Where the lines must run parallel to one another, maximize the spacing between them, and minimize the length of the parallel section. This will help to reduce the coupling between the lines.
- Consider using differential interfaces for especially problematic lines. Since signals in differential lines are equal and opposite to one another, their fields tend to cancel each other at distances much larger than the spacing between the differential pair members. There is also the option to use low voltage signaling in these cases, further reducing emissions.

Containment measures serve to prevent RF energy from escaping into the environment. The two basic techniques of containment are shielding and filtering. Shielding makes use of the fact that no electromagnetic field can pass through a perfect electrical conductor. If a source of RF energy can be completely enclosed within an unbroken conducting container, then none of that energy will exist outside of the container. If there are holes, seams, connectors, etc. passing through the container, or if the container is made of a poorly conducting material, then energy can escape and create EMI.

Various containment methods are used in system design. The primary method is to enclose the circuitry within a conductive housing or chassis. This can be made of either metal or plastic that has been treated to have a conductive surface. Individual pieces of the chassis must be in good conductive contact with one another. Conductive gasket material, multi-fingered leaf springs, and closely spaced screws are some of the techniques often used to ensure good conduction between chassis sections. Any holes through the chassis must be shielded to prevent EMI. This shielding can be made of metal screen or perforated metal if airflow must be allowed.

It is not practical to fully shield all holes in a chassis. This is especially true of those made for connectors. In these cases, filtering is often the only EMI preventative method available.

Filtering involves passing signals that must exit a chassis through frequency-selective circuits that attenuate the RF energy sufficiently well to meet EMI requirements. There is often a tradeoff between providing adequate attenuation of the EMI energy and maintaining the integrity of the desired signal. This is where the distinction between common-mode and differential signals becomes advantageous.

In 10/100/1000BASE-T systems, differential signals are used to convey the data in each port. Fortunately, most of the EMI energy present on these same ports is in the form of a common-mode signal. Magnetic devices such as transformers and common-mode chokes do an excellent job of strongly attenuating common-mode signals while passing differential signals nearly unchanged.

3 Magnetic Component Configurations for Vitesse PHYs

Magnetics assemblies for 10/100/1000BASE-T systems are available from a variety of vendors in four basic circuit topologies. For the purposes of this paper they will be arbitrarily assigned a type designation.

These are:

1. Transformer only (Type I)
2. Transformer with PHY-side common-mode choke (Type II)
3. Transformer with media-side common-mode choke (Type III)

and,

4. Transformer with media-side common-mode choke and autotransformer (Type IV).

Why are there so many choices? Perhaps an explanation of the functions of the Type IV configuration will help to answer this question.

A diagram of this configuration is shown in Figure 1. This is sometimes referred to as a “12-core” design due to the fact that three separate magnetic cores are used in each of the four sub-channels of a single 1000BASE-T port. Unlike Vitesse PHYs, the first 10/100/1000BASE-T PHYs on the market used a line driver that could only sink current. Because of this, a transformer center tap connection to a power source, Vdd, was necessary. When it was determined that additional common-mode filtering was needed for EMI reduction, a common-mode inductor was added to the cable side of the transformer. Since current flows through all three connections on the PHY side of the transformer, a simple two winding common-mode choke could not be used there. However, placing the choke on the cable side of the transformer caused another problem. It forced the addition of an autotransformer to provide a connection point for the Bob Smith Termination. This network provides a matching impedance to the common-mode characteristic impedance of a CAT5 twisted cable pair. This helps to prevent the cable from acting as a resonant antenna causing potential EMI problems at certain frequencies.

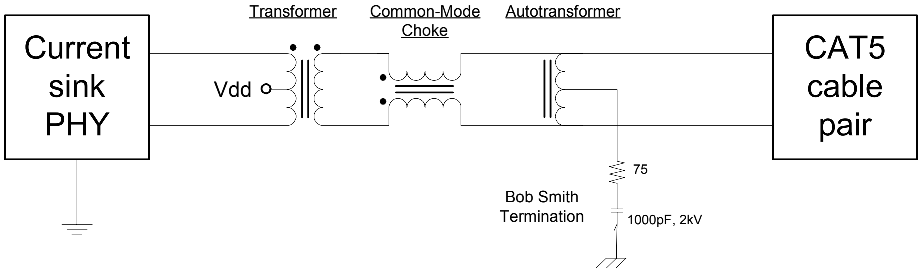

Figure 1: Type IV Configuration

As a cost-reduction measure, designers will sometimes place the common-mode choke on the cable side of the transformer and eliminate the autotransformer. This Type III configuration is depicted in Figure 2. Although this configuration will still pass data in conformance to the 802.3 specification, unfortunately it interferes with the operation of the Bob Smith Termination. The common-mode choke’s inductance is now in series with the Bob Smith Termination’s common-mode resistance, causing a mismatch with the common-mode transmission line impedance of the cable. Systems using this configuration run the risk of increased EMI due to standing waves on the CAT5 cable. Vitesse does not recommend the use of Type III magnetics with its SimpliPHY^{TM} transceivers.

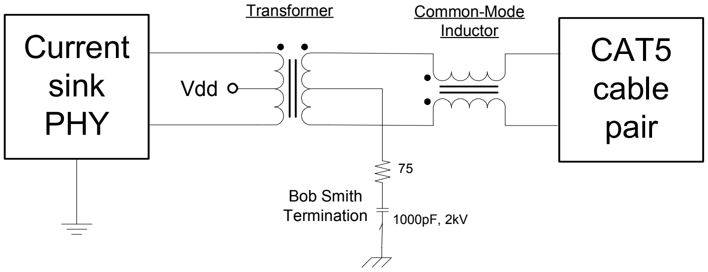

Figure 2: Type III Configuration (not recommended)

Vitesse PHYs do not use a current sink cable driver. Instead, they use a fully differential active driver that can both source and sink current. Because of this, there is no need to connect the center tap of the transformer to a power source. This enables the use of a simpler magnetic topology since, if a common-mode choke is needed for EMI reduction, it can be placed on the PHY side of the transformer. This in turn makes it possible to connect the Bob Smith Termination directly to the transformer's cable side center tap, eliminating the need for an autotransformer. This configuration is shown in Figure 3.

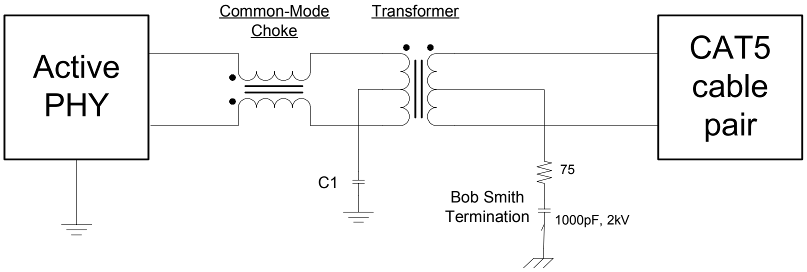

Figure 3: Type II SimpliPHY'd Configuration*

This simplified configuration is sometimes called an "8-core" design since two cores are used for each of the four sub-channels of a single 1000BASE-T port. Capacitor C1 improves EMI filtering by providing a low impedance shunt for any common-mode signals present after the common-mode choke.

For applications with less stringent EMI requirements, the common-mode choke can be eliminated. This configuration is shown in Figure 4.

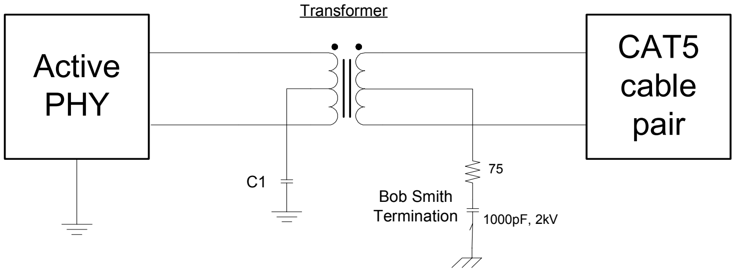

Figure 4: Type I SimpliPHY'd Configuration

Together, the Type I and Type II configurations are termed SimpliPHY'd Magnetics when used with Vitesse's SimpliPHY^{TM} transceivers. The Type I configuration offers the lowest cost solution, but it does require careful attention to design details in order to minimize EMI. In this case it is especially important to ensure that no high speed signals are routed close to the lines between the PHY and the transformer since there will be no common-mode choke to attenuate the resulting coupled signals.

---

* The common-mode choke can be part of the integrated magnetics module, or it can be a discrete device such as the Murata DLP31DN900ML4L. See section 6 for more information.

4 EMI Test Results

Tests with Vitesse SimpliPHY^{TM} transceivers have confirmed that the SimpliPHY'd Magnetics configurations, shown in Figure 4 and Figure 3 respectively, can successfully meet the EMI requirements of EN55022 in actual multi-port systems. They have also shown that the skill of the magnetics manufacturer is as important as the topology of the magnetics design. This can be seen in Figure 5 and Figure 6 where, in a well-shielded 24-port switch, Type IV designs from different manufacturers show significantly different EMI results in spite of their identical data sheet specifications and schematics.

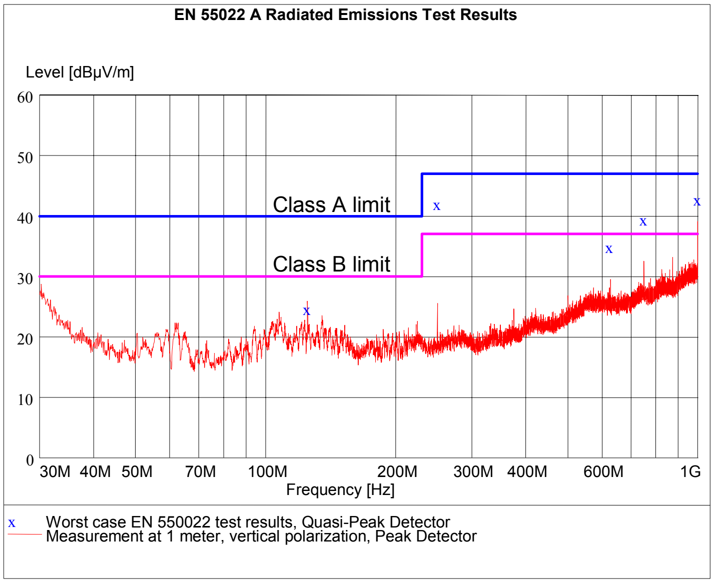

Figure 5: Manufacturer A Type IV magnetics in 24-port switch

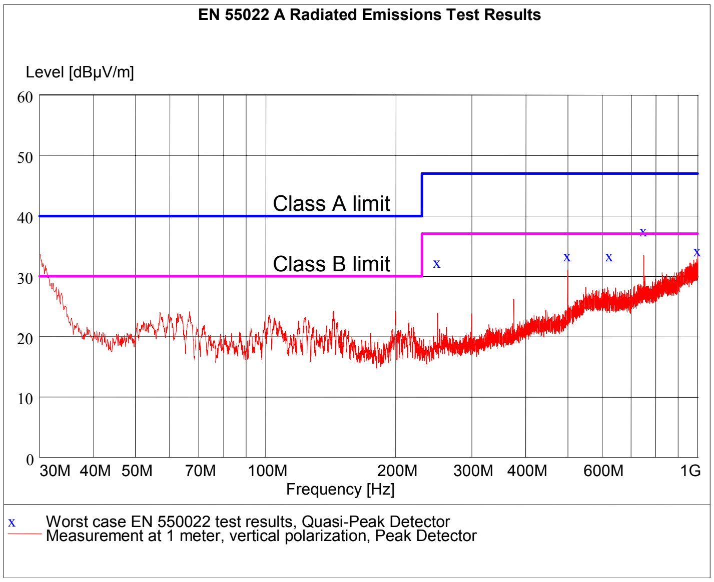

Figure 6: Manufacturer B Type IV magnetics in 24-port switch

To test the EMI performance of SimpliPHY'd Magnetics, a 12-port 1000BASE-T switch was tested using both Type I and Type II magnetics integrated with RJ45 connectors. The results of the Type I tests are shown in Figure 7.

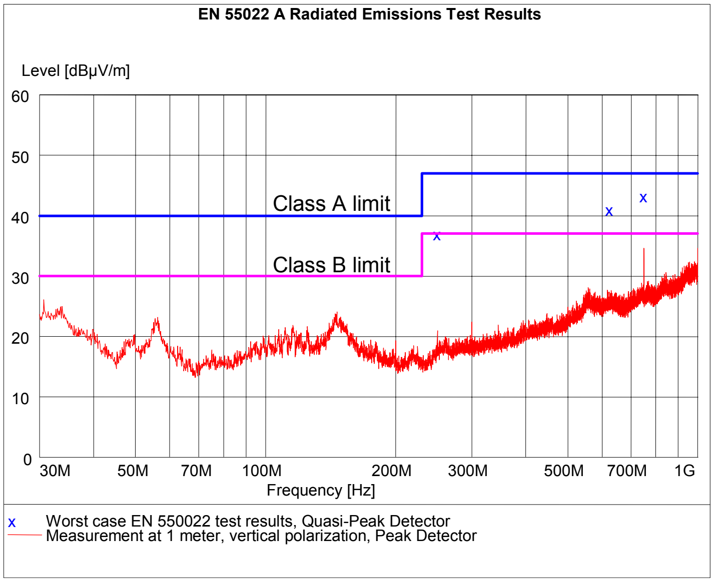

Figure 7: Type I magnetics in 12-port switch

The results of the Type II tests are shown in Figure 8.

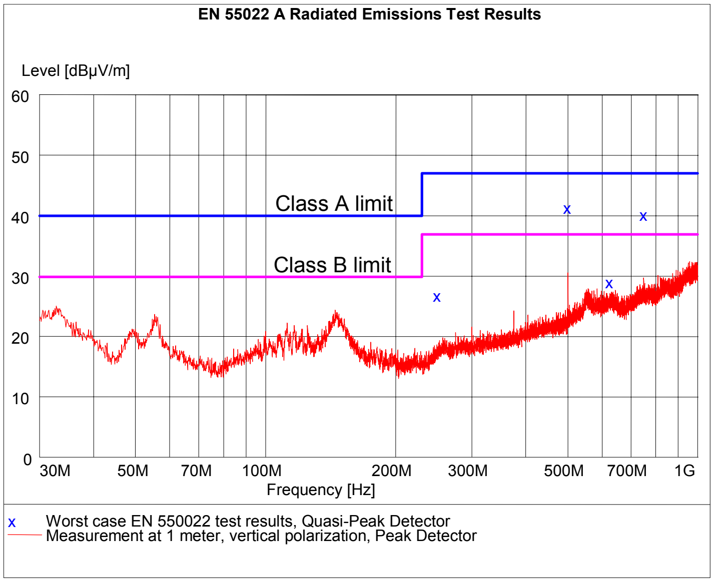

Figure 8: Type II magnetics in 12-port switch

Note that in both cases the system is able to pass the Class A requirements as signified by the uppermost limit line shown on each plot. The Type II design in Figure 8 even comes within 6dB of meeting the Class B requirements.

5 Magnetics Selection Guidelines

The optimal magnetics topology for a given system is determined by the application. There is generally a tradeoff between the amount of EMI suppression required and the cost of the magnetics. Designs requiring the least suppression can take full advantage of the lowest cost magnetics.

Two factors determine the amount of EMI suppression required in a given design. The first is the amount of EMI allowed by the relevant standards. In most parts of the world the levels are set by the EN55022 standards. In the US, the FCC has adopted these same emissions levels. In these standards two classes of products are defined, each with its own emissions limits. Class A products are those marketed for industrial and institutional markets. Class B products are those that are marketed for use in homes. The Class B limits are set 10dB lower than the Class A limits in an effort to reduce the possibility of interference with other equipment normally found in homes. Since Class A limits are less stringent, there is the potential to use lower cost magnetics in systems designed for the non-home markets.

The second factor determining the amount of EMI suppression needed in a given system is the amount of EMI energy generated in the equipment. This might be obvious, but it is important to state nonetheless. As mentioned above in section 2.4 on EMI Reduction, multiple factors determine the amount of EMI energy present at the connection ports of a piece of equipment. Many of these factors can be improved at no additional system cost. To truly minimize the cost of a piece of equipment, it is important to review each of these factors and ensure that minimal RF energy is present at each CAT5 port before addressing the selection of magnetics.

Note that Vitesse SimpliPHY™ transceivers are designed to minimize the amount of RF energy present in their cable driver outputs. The fully balanced architecture and careful design of the output devices keeps this unwanted energy to a minimum.

In 10/100/1000BASE-T systems, a key factor determining the amount of EMI energy generated is the number of ports present in a system. A single port will produce less EMI energy than a system having dozens of ports. The higher port count systems will require more EMI suppression on each port in order to meet a given system limit.

Table 1 gives recommended magnetics configurations as a function of the number of 1000BASE-T ports in a system and the desired EMI limit classification level. These recommendations are extrapolated from the results of numerous radiated EMI tests made on multiple systems. Keep in mind that these are only recommendations. For reasons given elsewhere in this paper, results in any given system can vary widely. Also as mentioned previously, seemingly equivalent magnetics from different vendors can vary significantly in their EMI suppression performance. A key point to note is that it will be very difficult to build systems with 48 or more ports that will meet the Class B EMI requirements. This will most likely require very careful design and collaboration with the selected magnetics vendor.

Number of Ports per Chassis	**EMI Limits**	
	Class A	**Class B**
1	Type I	Type I
4	Type I	Type II
5	Type I	Type II
8	Type I	Type IV
12	Type I	Type IV
24	Type II	Type IV
48	Type II/IV	----

Table 1: Recommended magnetics configurations for Vitesse SimpliPHY™ transceivers

6 SimpliPHY'd Magnetics and EMI control for SFP applications

EMI performance requirements are typically even stricter in SFP applications than in Gigabit Ethernet Switch applications. Major manufacturers' product requirements specify that Copper Gigabit Ethernet SFP modules meet FCC Part 15 Class B with 6dB of margin. Using Vitesse's VSC8221 SFP PHY with SimpliPHY'd Magnetics is an optimal EMI solution for Copper Gigabit Ethernet SFPs.

6.1 Magnetic Component Configurations for SFP PHYs

- Existing SFP vendors currently use Type IV magnetics in a custom form factor in order to meet the stringent EMI requirements. Due to the space constraints of the SFP and the custom nature of these modules, they are much more expensive that traditional Type IV magnetics.

- EMI tests conducted on SFP reference designs using the VSC8221 show that it is possible to meet the stringent SFP EMI requirements using an of the shelf Type I magnetic module along with a 0402 size surface mount common mode choke inserted between the PHY and Magnetic module. This configuration provides the EMI benefits of a Type II configuration while enabling the use of cheaper off the shelf magnetics.

6.2 EMI Test results

Some SFP manufacturers have problems meeting the FCC Class B with 6dB of margin requirement using custom form factor magnetics. VSC8221 based SFPs can meet FCC Class B with 6dB of margin using off the shelf components.

Results of some OATS (open area test site) EMI tests conducted on different SFP modules are shown below. These plots show the FCC – 6dB margin and the emissions at some of the peak frequencies.

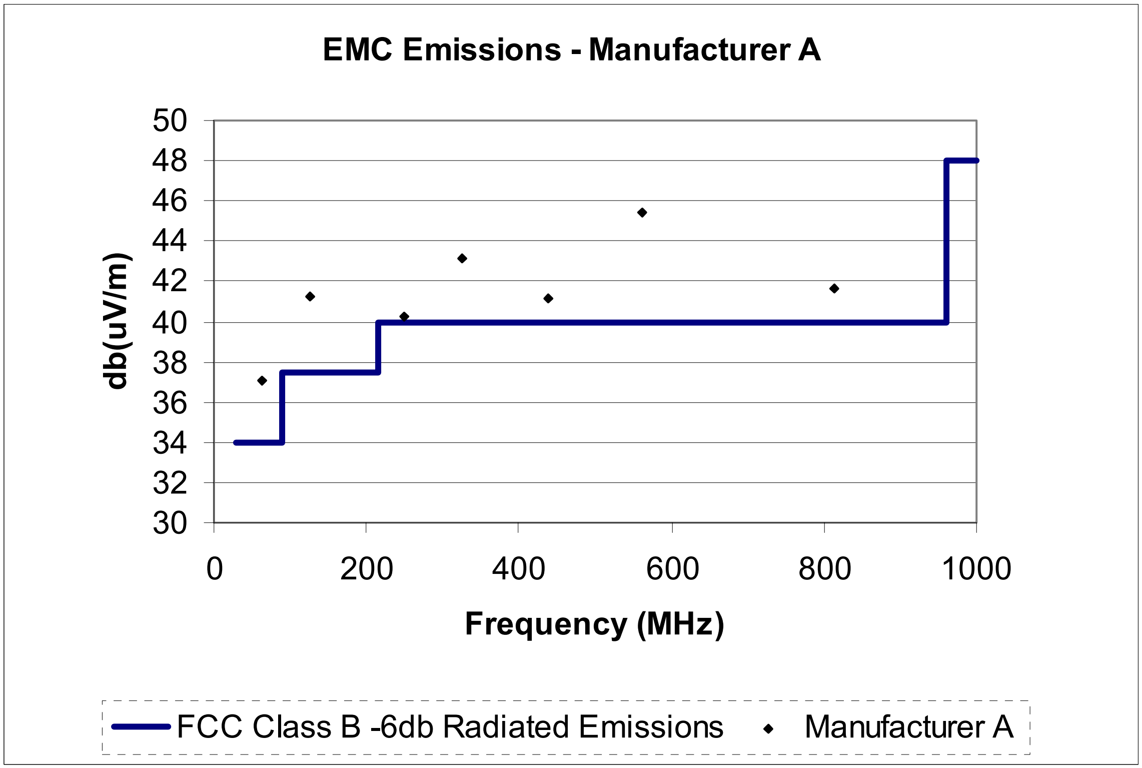

Figure 9: SFP Manufacturer A using custom magnetics – (Failing EMI)

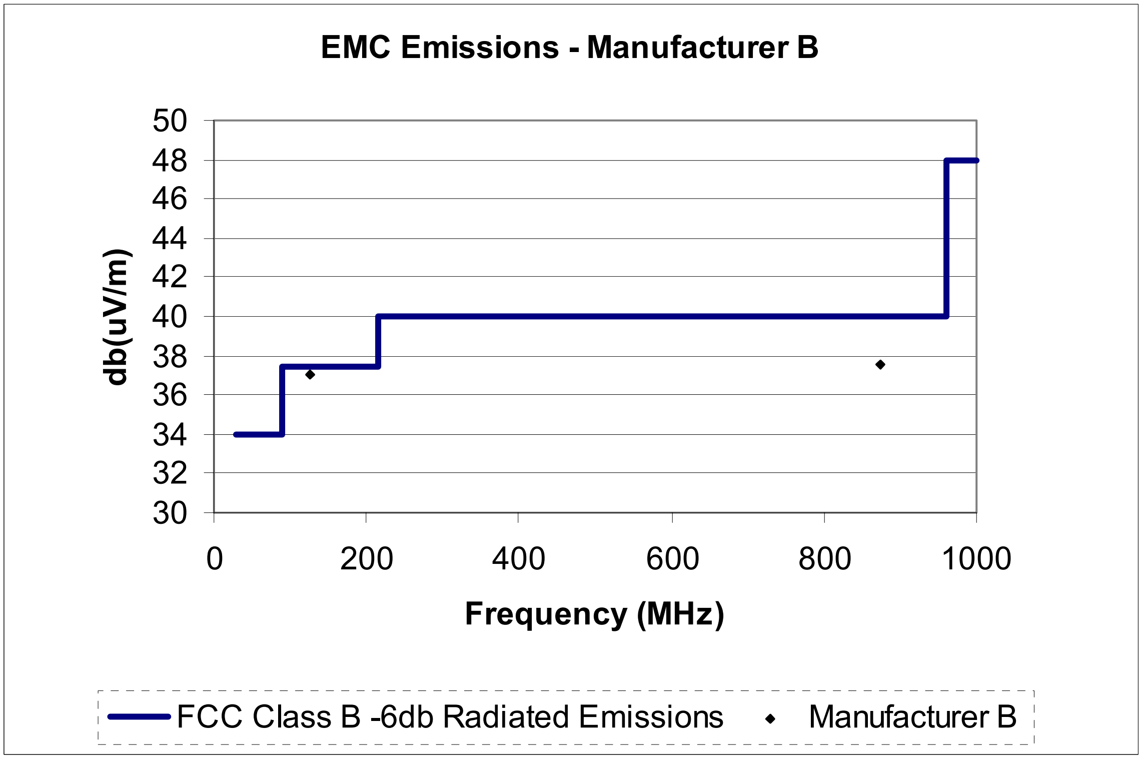

Figure 10: SFP Manufacturer B using custom magnetics – (Passing EMI)

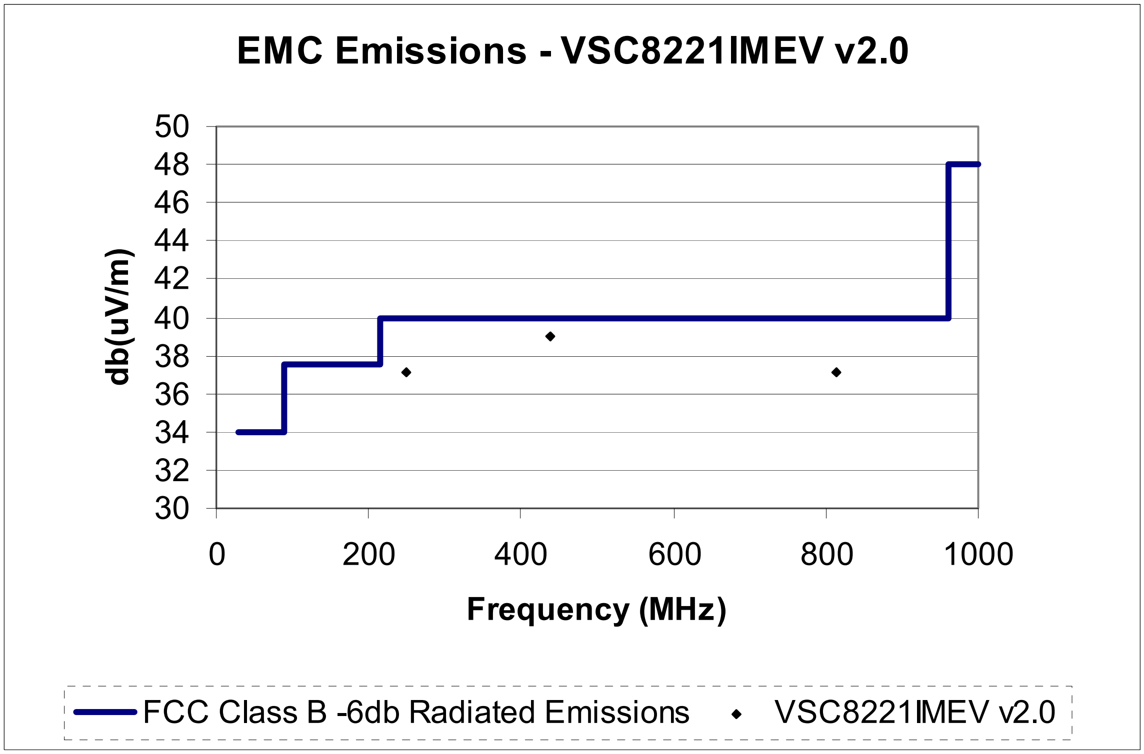

Figure 11: VSC8221 PHY based SFP using off the shelf magnetics – (Passing EMI)