ENT-AN0098

Application Note

Magnetics Guide

June 2018

Microsemi

a Microchip company

Contents

1 Revision History

The revision history describes the changes that were implemented in the document. The changes are listed by revision, starting with the most current publication.

1.1 Revision 2.2

Revision 2.2 was published in June 2018. The following is a summary of the changes:

- The obsolete EMC/EMI section was removed.
- Details on 12-core and 8-core magnetics were updated. For more information, see 12-Core Magnetics and 8-Core Magnetics.
- A section on PoE was added. For more information, see Power-over-Ethernet and Magnetics.

1.2 Revision 2.1

Revision 2.1 was published in April 2016. The following is a summary of the changes:

- Return loss data was updated.
- Magnetic suggestions were added.

1.3 Revision 2.0

Revision 2.0 was published in June 2012. The following is a summary of the changes:

- Text regarding CMC on the PHY side was updated.
- EMC test data was simplified.

1.4 Revision 1.2

Revision 1.2 was published in October 2007. In revision 1.2, the 12-port (2 × 6) Power-over-Ethernet (PoE) magnetic modules were added.

1.5 Revision 1.1

Revision 1.1 of this document was published in July 2006. The following is a summary of the changes:

- The EMC test results for the VSC8601/8641 family were added.
- The 8-core, 3-wire CMC on PHY side was added.

1.6 Revision 1.0

Revision 1.0 was published in April 2006. It was the first publication of this document.

2 Using Magnetics

This application note provides a designer with basic knowledge of magnetic modules as well as some test data. Proper understanding of the magnetic module features to be used with Microsemi PHY and integrated switch/PHY devices is very important to ensure the best electromagnetic compatibility (EMC) and IEEE conformance of the finished product.

For background information, reference IEEE 802.3-2012 CSMA/CD Access Method and Physical Layer Specification and FCC–Part 15: Radio Frequency Devices.

2.1 The Role of Magnetics in Ethernet Systems

While not explicitly required by IEEE 802.3, 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 EMC improvement. The following sections briefly describe each of these areas.

2.1.1 Electrical Isolation

For human safety, the IEEE specification requires a 10/100/1000BASE-T port to be able to withstand 1,500 VAC 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.

2.1.2 Signal Balancing/Common-Mode Rejection

Each 10/100/1000BASE-T network cable consists of four sets of twisted pairs connected in a balanced configuration. Transformers simply and easily provide the balanced connection to each pair of a cable and can also provide a very effective rejection of common-mode signals.

The common-mode rejection of a transformer functions in both 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. This common-mode attenuation is beneficial for the following reasons:

- Reduction of the common-mode signals picked up by the cable from its environment improves the signal-to-noise ratio of the system. This allows the PHY DSP to more easily recover the data signal and achieve the desired bit error rate. This is also known as electromagnetic immunity.
- The noise from the board circuits can couple to the sensitive signal traces going from the PHY to the magnetics, coupling equally to both signals of a differential pair and creating common-mode noise. This noise will be attenuated by the magnetics and improves the EMC performance. Because 10/100 /1000BASE-T uses unshielded twisted pair cables, the cables radiate any common-mode noise that is coupled through the magnetics and onto the cables.

3 Magnetic Types

Several different magnetic types are available, all conforming to IEEE requirements. Only those containing a common-mode choke (CMC) are described in this document.

The common elements of all magnetic types are the transformer and the Bob Smith termination. The key concepts of the common elements described in the following sections.

3.1 Transformer Concepts

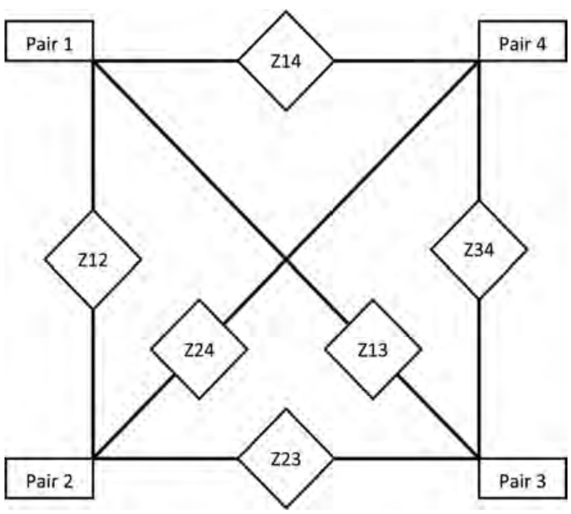
The purpose of the transformer with a 1:1 ratio is to create galvanic isolation between the cable and the system. The PHY-side center tap of the transformer should connect through a capacitor to ground.

The key performance metric affecting the transformer is winding tolerance. Winding tolerances affect amplitude step-up/step-down from the primary to secondary side of the transformer, and should remain within ± 2% for adequate margin in amplitude template tests.

3.2 Bob Smith Concepts

Robert (Bob) W. Smith's patented idea proposes a way to reduce the common-mode currents on a multi-pair system (for example, CAT5 network cable). It is based on the fact that the pair-to-pair relationships of a CAT5 cable form transmission lines in themselves. Due to the approximate symmetry in the construction of the CAT5 cable, each pair has the same relation with any other pair. This is shown in the following illustration.

Figure 1 • Intrinsic Characteristic Impedance Between Each Pair of the Four Pairs



Providing those pair-to-pair transmission lines with termination matching their characteristic impedance in order to absorb the reflected wave and prevent the standing wave from occurring significantly lowers parasitic interference radiation.

The high-voltage capacitor between the common point of all the four resistors and the chassis ground is not a part of Bob Smith termination, but helps in filtering the noise residue managing to leak out through the transformer.

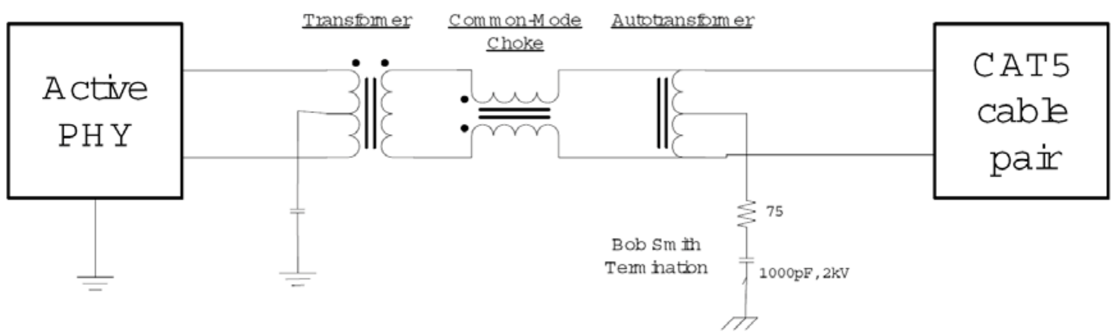
3.3 Common-mode Choke and the Auto-transformer

Magnetics can be split into two groups based on their common-mode rejection elements, the CMC, and auto-transformer. 12-core magnetics consist of transformer, a common-mode choke, and an auto-transformer. 8-core magnetics consist of a transformer and a CMC. Their advantages and disadvantages are described in the following sections.

3.4 12-Core Magnetics

A 12-core magnetic module consists of a transformer, CMC, and an auto-transformer (that is, three separate magnetic cores) for each of the four twisted pairs in the cable. This is shown in the following illustration.

Figure 2 • 12-Core Magnetic (One Pair Shown)



The purpose of the CMC is to attenuate common-mode noise in the twisted pair. This includes noise coming from the system itself—where the CMC decreases the electromagnetic emission (that is, doing the signal filtering for the entire customer's system)—and noise coming from the outside (where the CMC improves the electromagnetic immunity).

The auto-transformer presents high impedance to the differential signal in the twisted pair, as though not existing for it, but very low impedance to the common-mode currents flowing to the Bob Smith termination.

3.5 8-Core Magnetics

The 8-core magnetic only has a transformer and a CMC. The CMC construction and purpose is the same as 12-core magnetics, but the CMC can be located on either the cable side or the PHY side of the transformer.

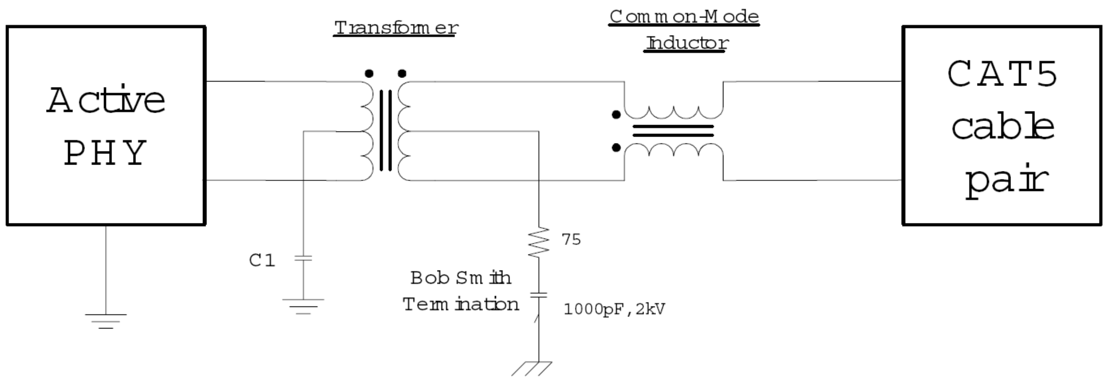
Based on PMA compliance testing results when transformers have CMC on the PHY side, it is recommended that future designs avoid this magnetic configuration. The template test for PMA compliance has reduced margin in the PHY-side CMC location compared to the cable-side CMC.

For older designs where PHY-side CMC magnetics have been used successfully and passed applicable system-level standard tests, the PHY-side CMC magnetic may continue to be used.

To minimize stray current flows between pairs on a cable, the magnetic should route out the transformer center-taps on individual pins so each can be individually AC-coupled. Ganged connections of multiple center-taps, whether connected directly or by chokes, are not recommended. Board designs that require lower pin counts should consider integrated magnetic modules with individually decoupled center taps routed into a single ground pin.

The following illustration shows an 8-core magnetic channel with the CMC on the cable side of the transformer, as well as recommended center tap routing.

Figure 3 • 8-Core Magnetic with CMC on Cable Side (One Pair Shown)



3.6 8-Core Versus 12-Core Magnetics

Generally speaking, the appropriate magnetic selection should be made based on system-level considerations (such as board EMI/EMC) that are specific to a particular design.

8-core magnetics are cheaper but riskier, and so are cautiously recommended to skilled designers. 12-core magnetics make the design process much easier without demanding extensive experience in the layout art, especially if the Ethernet module is a part of a system with a big digital section that generates a lot of noise.

3.7 Other Factors

Although the schematic representation of different magnetic modules looks alike, there might be significant difference in their electrical and EMC performance. Quality of construction affects the coupling between signal paths on each side of the transformer and CMC cores, and so can affect the overall performance of a magnetic module. When selecting a specific vendor's part, the manufacturing quality should be considered based on historical performance measured on real systems.

3.8 Integrated Versus Discrete Magnetics

To minimize the component count and the product size, some manufacturers deliver magnetic modules in which the magnetic block is built into the RJ45-type connector block. As with any compromise, this has both advantages and disadvantages.

The advantages include a lower component count (which translates into a lower production/assembly cost), potentially better EMC shielding of the sensitive cable-side signals by the metal shield, and smaller footprint than separate magnetics and a connector. The disadvantages are that it is harder to rework if a magnetic/connector is failing during production test (which can result in a higher production cost) and, due to the space limitations, the magnetics cores are smaller and closer to each other, which degrades crosstalk and EMC characteristics and increases nonlinear distortion and losses.

The electromagnetic emission performance can be especially better or worse, depending on the product they are used in. The integrated magnetic/connector modules have a metal shield placed around the whole part that effectively screens the part from any noise that is present inside the system box. However, due to the small size of the magnetic part of the module, there is a greater risk that the noise is coupled between the cable side and the PHY side of the magnetics, thereby limiting the common-mode choke effectiveness. The size of the magnetic cores used in the magnetic/connector combinations are typically smaller than those used in discrete magnetics, and so the performance is lower.

Using separate magnetics and connectors has the advantage of lower coupling between the different parts inside the magnetics, and this results in better common-mode filtering. The disadvantage is that, once the signals have been filtered by the magnetics, they are routed to the connector on the PCB and careless routing of the medium-dependent interface (MDI) traces adjacent to noise sources on the PCB can couple and consequently create EMC problems.

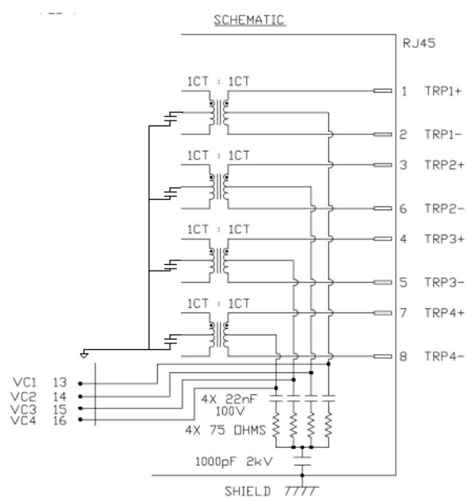
The designer needs to balance these advantages and disadvantages against each other when deciding what to use in their board design.

3.9 Power-over-Ethernet and Magnetics

The IEEE Power over Ethernet (PoE) task force defined optional power entities that provide a 10BASE-T, 100BASE-TX, or 1000BASE-T device with power over its existing MDI interface. In PoE systems, the PHY's MDI carries a large DC voltage reference for each half of the differential pair.

The following illustration shows a typical example of the power connection to the MDI.

Figure 4 • Power Connection to the MDI



In the circuit shown, a common-mode DC voltage exists on individual twisted pairs connected to the VC pins. The Bob Smith termination resistors must be isolated from the power system's DC voltage reference using DC-blocking capacitors. Ceramic capacitors in the 10 nF range are sufficiently small values so as to not perturb the pair-to-pair impedance matching of the Bob Smith circuit.

Note: No PoE magnetics commercially-available today include an auto-transformer (12-core). PoE magnetics offerings are limited to one choke for common-mode rejection.

4 Test Data

This section provides relevant test data.

4.1 EMC Test Data

The following table summarizes the different magnetics and magnetic/connector combinations that have been tested with the SparX customer evaluation boards (EVBs). Experiments have been conducted with and without a closed metal chassis and, as no noisy circuits exist on the SparX-G8 (VSC7388) and SparX-G5 (VSC7385) EVBs, the EMC results did not differ significantly.

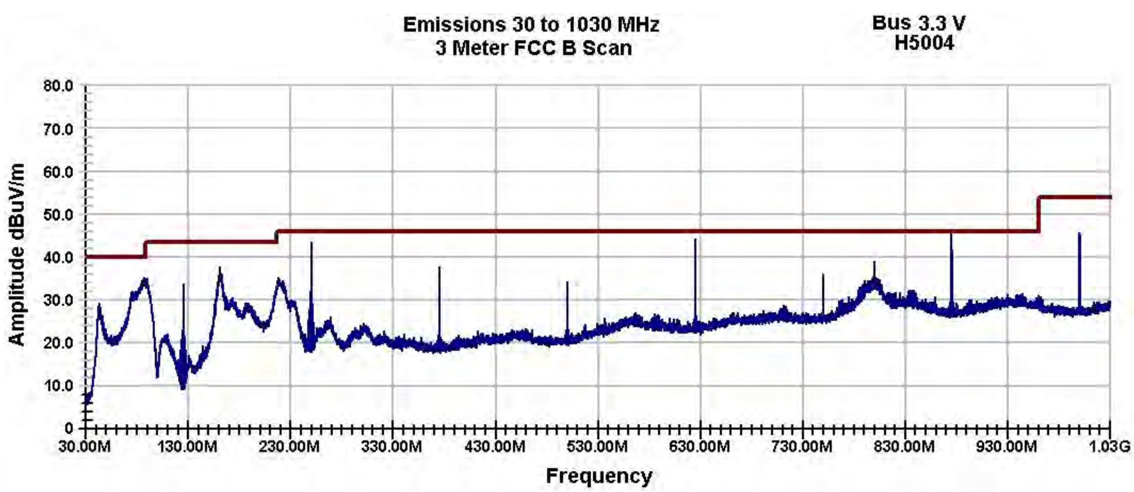
All data provided is without chassis.

Table 1 • EMC Test Data

Vendor	Part Number	Configuration	Test Setup	*EMC Class* (FCC, Part 15)	Margin
Pulse	H5008	Single, 12-core	SparX-G8 Managed EVB	B	9.2 dB
Pulse	H5009	Single, 8-core	SparX-G8 Managed EVB	B	1.3 dB
Pulse	H5007	Single, 12-core	VSC8641/VSC8601 EMC Board	B	2.1 dB
Pulse	H5004	Single, 8-core	VSC8641/VSC8601 EMC Board	B	1.0 dB
Pulse	LF9207A	Single, 12-core	SparX-G8 Managed EVB	B	2.0 dB

The following illustration shows EMC emissions for the VSC8601/8641 PHY Family.

Figure 5 • EMC Emissions: VSC8601/8641 PHY Family



4.2 IEEE Return Loss Data

Return loss is specified and maintained for all impedances from 85 Ω to 115 Ω. Measurement data presented at a nominal 100 Ω load is inadequate for assessing specification compliance.

The IEEE 802.3 standard, paragraph 40.8.3.1, states the following:

> The differential impedance at the MDI for each channel shall be such that any reflection due to differential signals incident upon the MDI from a balanced cabling having an impedance of 100 Ω ± 15% is attenuated, relative to the incident signal, at least 16 dB over the frequency range of 1.0 MHz to 40 MHz and at least 10-20log(f/80) dB over the frequency range 40 MHz to 100 MHz (f in MHz). This return loss shall be maintained at all times when the PHY is transmitting.

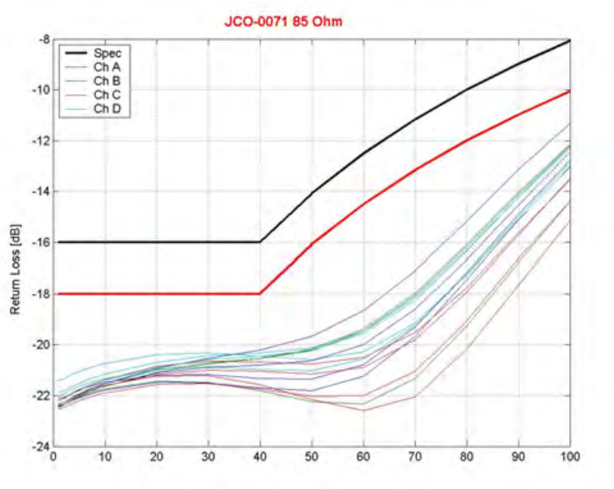
This standard is summarized in the following table.

Table 2 • IEEE Minimum Return Loss for Reference Impedance of 100 Ω

Return Loss (dB)	Frequency (MHz)
16	1–40
10–20 *$\log_{10}$ (f / 80) where f is the frequency in MHz	40–100

The specification is plotted in black in the following representative return loss plot, along with measurement data from a Microsemi PHY.

Figure 6 • Return Loss Specification: Recommended and Measured



There are two key points to emphasize about the return loss plot:

- For a real system with output impedance contributions from both PHY outputs and a magnetic transformer to satisfy the IEEE specification, magnetics with a return loss margin of at least 2 dB (versus the IEEE 802.3 specification at the MDI) are recommended. The red curve in the plot reflects a 2 dB back-off from the IEEE 802.3 limit.
- The measured return loss is flat to within 3 dB up to 40 MHz–50 MHz. That flatness is a key aspect in maintaining signal integrity.

5 Suggested Magnetics

This section lists the suggested characteristics for selecting a magnetics product compatible with Microsemi 1000BASE-T Ethernet PHYs. Use the magnetic vendor's datasheet or lot-sample test data to check for the following characteristics.

- Return loss as specified in IEEE Return Loss Data
- Turns ratio tolerance: (1:1) ± 2%
- Common-mode choke on the line side for all applications that permit line-side CMC
- Center-tap isolation between each pair (A, B, C, D) of the magnetic
- Line-side center-taps that can be individually terminated with Bob Smith termination

Contact your Microsemi representative for more information about specific magnetics that have proven successful with Microsemi Ethernet PHYs.

Microsemi Headquarters
One Enterprise, Aliso Viejo,
CA 92656 USA
Within the USA: +1 (800) 713-4113
Outside the USA: +1 (949) 380-6100
Sales: +1 (949) 380-6136
Fax: +1 (949) 215-4996
Email: sales.support@microsemi.com
www.microsemi.com

VPPD-01740