Abracon Ethernet Solutions

Understanding Ethernet Magnetics Features and Design Considerations

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Introduction

There are not many technologies that exist today that have the longevity of Ethernet. The communications technology dates back to the 1970s and was invented by Xerox. It wasn't until the 1980's the IEEE standards group ratified the specification and it began to be widely adopted by the industry. In fact, by the 1990's there was a very large installed base of equipment and more importantly the large cabling infrastructure. Fast-Ethernet (100Mbs) was ratified in the mid 1990's which only strengthened Ethernet adoption and cabling infrastructure.

As a result, formidable competitive technologies, like Token Ring, never came to fruition. Token Ring (IEEE802.5) had a few disadvantages, one of which was cost. Token Ring hardware cost was higher and adoption for an existing Ethernet network would require a full redesign of the cabling infrastructure. Another disadvantage was solely due to Token Ring network cabling topology. Since the network nodes were in a ring configuration, if one node failed or went offline unexpectedly, the whole subnetwork would go down. How does the network administrator determine which node is faulty when the whole network is down?

Today, Ethernet is still the most cost effective solution and twisted-pair copper cabling remains cheaper than fiber optics. Twisted-pair copper cabling, which is the physical medium for all Base-T standards, is still used today supporting data rates of 10Gpbs. Nodes are point-to-point such that they connect into a a central hub/switch independently (star configuration). Keep in mind, every standard supported by the IEEE committee is backward compatible to all previous standards. Meaning, the latest 10GBase-T hardware is compatible with the same fast-Ethernet cabling and hardware from the 1990s.

Designing an IEEE compliant interface is not a trivial task. This publication is intended to help the designer by highlighting important features of the circuitry between the PHY and cable which includes the magnetic isolation and filtering and the RJ45 connector.

Evolution of Auto-MDIX

Historically, endpoints (eg computers) and hub/switches contain different wire pair configurations. One can think of this link as a simple serial port where one end of the connection transmits (TX) to the other end receive (RX) port achieving a full duplex connection. Therefore, connecting an endpoint to a switch or hub, requires a simple straight through cable connection. On the other hand, connecting two devices of the same type, for example switch to switch, there exist a wire pair mismatch and a link will never be established. The solution for older networks was using a cross over cable that "swizzles" the RX and TX pair so that a full duplex link can be established between endpoints of the same type.

Switches and hubs historically had what was referred to as an MDI-X interface, while endpoints like computers had MDI interfaces. In order to automatically resolved wire-pair mismatches between these two different interfaces, a feature call Auto-MDIX was introduced. The feature was introduced around the ratification of the 1000Base-T spec and only as an optional feature.

Auto-MDIX is a feature enabled as part of the PHY interface inside the silicon chip.

The PHY chip will auto-swizzle the pairs until a link is established. The algorithm requires symmetry between the RX and TX channels of the interface, so it is important to ensure the magnetics circuitry (integrated or discrete) maintain symmetry. It should be noted only one end of the link is required to support Auto- MDIX, providing further backward compatibility with older hardware which have no concept of Auto-MDIX.

Components of the Ethernet Interface

The Ethernet physical interface is fairly simple and only contains 3 elements -the PHY, Isolation/filtering magnetics and the RJ45 connector. The complexity is contained within the PHY to support features such as Auto-MDIX, link negotiation and establishment.

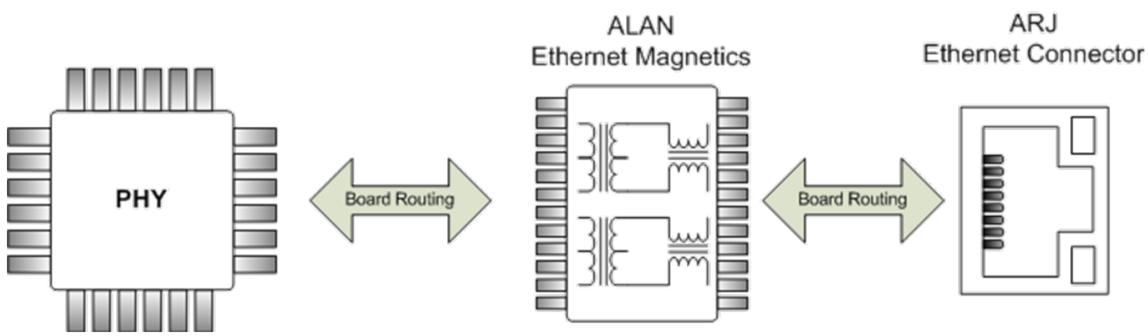

Figure 1: Basic Ethernet PHY interface

The isolation and filtering magnetics are also fairly complex, but designers can use integrated solutions that contain the isolation transformer and filtering within one monolithic package (See Abracon's ALAN Ethernet magnetics solutions). In this case, the PCB designer must then be able to design the interconnection between the PHY and magnetics keeping in mind board design rules for differential signaling and to provide proper isolation between the PHY chip and the RJ45 connector. (See Abracon's jack only RJ45 solutions).

Magnetics Integration

Abracon also has integrated magnetics inside the RJ45 connector. By integrating magnetics, it provides a solution for high density designs where PCB real estate is a premium. Furthermore, integrating the magnetics greatly simplifies the board design/routing. Care must still be taken when designing the PCB traces between the PHY and integrated magnetics connector.

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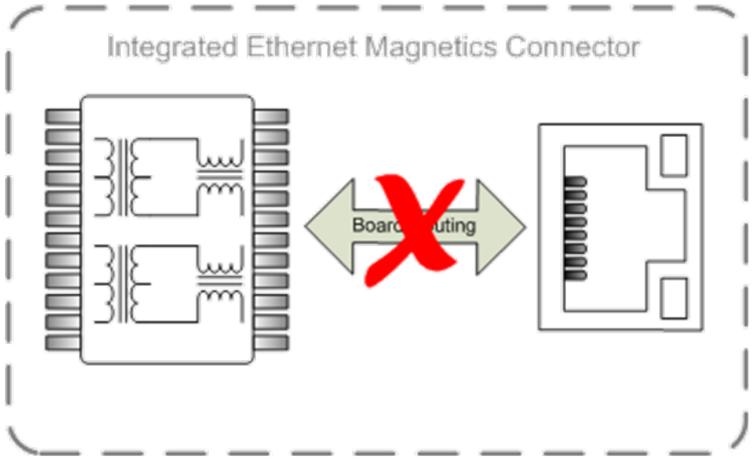

Figure 2: Integrated Ethernet Magnetics Connector

Selecting the Correct Magnetics

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Voltage mode vs Current mode PHYs

There are two different types of PHYs which differ in the way the signaling is constructed and transmitted. This difference is referred to voltage-mode and current-mode drivers used by the phy device; specifically, how the common mode voltage is supplied to each data pair.

Voltage mode PHYs are more common today due to its power advantages over current mode drivers. PHYs implementing voltage mode drivers on their MDI pins, provide the common mode voltage to the isolation transformer. This bias voltage allows proper construction of the differential PAM signaling on the wire pair. Each wire-pair is connected independently and isolated form one another. Therefore, its best to select magnetics that allow access to each transformer's center taps. The center taps don't need to be accessible if they are internally connected to ground through capacitors. Grounding the center taps through capacitors is the correct termination for voltage-mode configurations.

Current mode PHYs only drive the differential PAM signaling. The common mode voltage used to bias the signals is provided by a power supply on the board. Typically, the transformers center taps are connected together and pulled up to at 2.5v or 3.3v power well.

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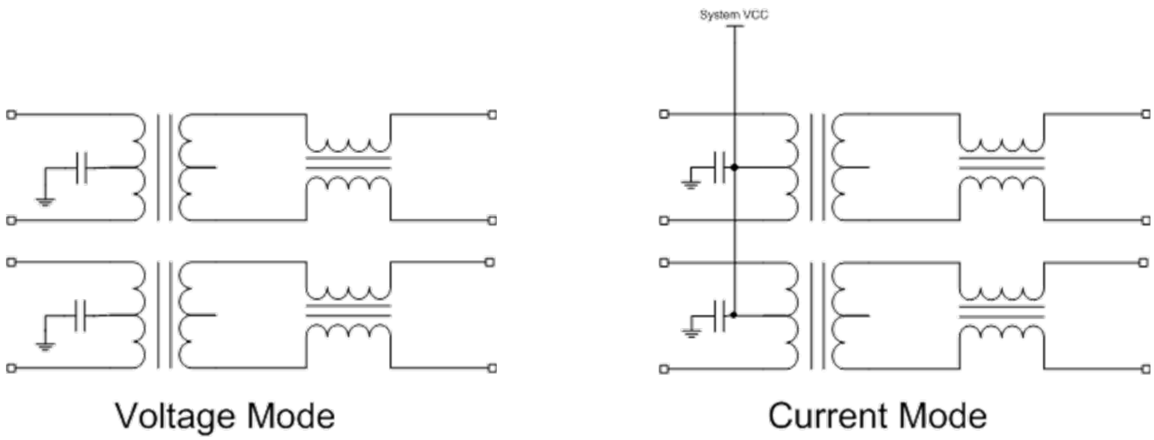

Figure 3: Voltage Mode vs Current Mode

When designing the suitable matching network, a Vector Network Analyzer (VNA) can probe the test circuit on the board and determine the impedance at the antenna input. (See Figure 6.) Measuring the S-parameter and VSWR bandwidth analyzes the on-board chip antenna performance. Tuning can further improve antenna performance. Abracon's "Antenna Impedance Matching – Simplified" white paper offers additional information.

Power Over Ethernet (PoE)

The explosion of IoT and other "remote" power requirements of the industry have driven the IEEE consortium to develop a technology which enables remote endpoints to be powered through the Ethernet cable. Power Over Ethernet was introduced to the industry under the 802.3at specification and has since continued to improve the power handling capability of the Ethernet cable under the 802.3at and 802.3bt specifications.

The PoE end-to-end solution consists of a device that supplies the power, also known ad the PSE (Power Supply Equipment) and the endpoint which consumes the power, known as the PD (Powered Device). A typical PSE is a switch or Hub while the PD could be a variety of equipment, like security camera, wireless access points, etc.

For 10/100 Base-T designs, power is injected onto the cable via unused data pairs since these interfaces only use 4 out of the 8 pins in the RJ45 connector. Another possibility is to inject the power on the isolation transformers line-side center tap, sometimes referred to as "phantom power" since power is transmitted on the same conductors used for data. The illustration below shows a conceptual implementation of a PSE end-point using the isolation transformers center tap.

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Isolation between the system and cable has always been a requirement, hence the use of the isolation transformers on each data pair. PoE power injection onto the cable requires additional isolation designed into the PoE power supply. The designs can vary and may use full wave bridge rectifiers, ESD circuitry, optical isolation, etc. However, every design must provide an inductive isolation transformer to carry the output power to the cable.

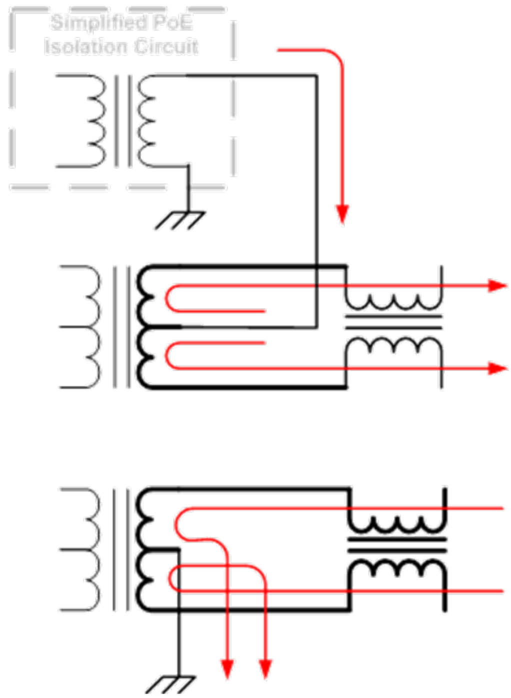

Figure 4: Simplified PoE Isolation Circuit

The table below lists the available power provided by the PSE and consumed by the PD. It should be noted, power at the PD is a function of the cabling length and material used for the conductors. Copper cabling provides the best performance, while aluminum (cheaper) will cause a higher DC resistance across the cable, hence less power at the PD. If the cabling of the end application is unknown, design to the worst-case scenario.

Specification	802.3af (PoE)	802.3at (PoE+)	802.3bt (4PPoE)	802.3bt (PoE++)
PSE POWER	15.40W	30W	60W	100W
POWER AT PD	12.95W	25.50W	51W	71W
MAX CURRENT	350ma	600ma	600ma	960ma

Table 1

Mechanical Requirements

Mechanical restrictions become very important when designing systems with small, compact footprints. The component length, width and height become critical when deciding the correct component. In fact, many applications require low profile options. Low profile applications typically require sub 12mm height and have no additional seating offset.

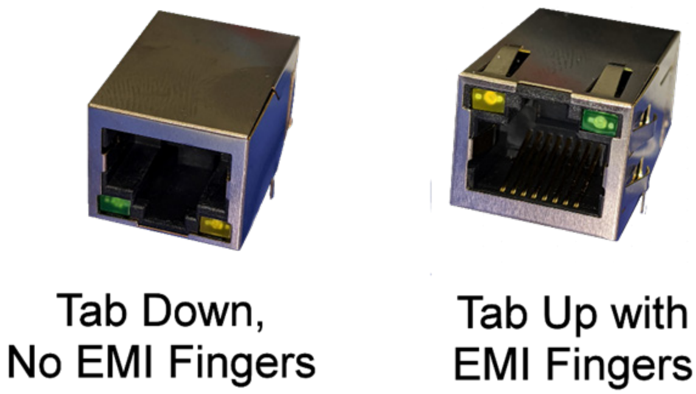

Figure 5

Tab Orientation & EMI Fingers

Reducing height is ultimately constrained by the mechanical dimensions of the RJ45 plug, The standard RJ45 plug body is 6.6mm with an additional 2.7mm for the tab.

Refer to the illustration above to help understand the differences between tab orientation and EMI fingers. Both examples are right-angle solutions and will extend beyond the edge of the PCB. Vertical solutions can be considered when top entry is required, and the PCB is perpendicular to the RJ45 connector.

Gold Flashing

One last characteristic of the RJ45 is its gold plating on the contacts which mate with the cable contacts. Typical gold flashing on these contacts are a standard 6µ inches. Designing systems which operate above the 1GBase-T data rate will benefit from a more robust electrical connection to cable and thicker gold plating will achieve this enhancement. Abracon provides designers with the option of increasing gold plating up to 50µ inches.

Design Considerations

When designing a system its best to have the following decisions resolved before starting the design of the Ethernet interface. These details and their category include:

Q: Board/System Design: What data rate is required?
This is an important decision which ultimately is answered by the requirements of the end application. The answer affects the interface considerably by defining the required data rate, number of data pairs to be routed, etc.

Q: Board Design: density of design, single port, multiport?
Single port designs are easier to route than multiport. This is especially true if the multiple ports are ganged RJ45 connectors. Large multi-port designs may have routing challenges due to the large number of connections and the proximity of the magnetics to the integrated PHY chip. It may be advantageous to use discrete ALAN magnetics as opposed to a fully integrated solution.

Q: Board Design: Is external shielding required?
Ethernet interfaces usually require shielding to help overall performance within the system. Noise and EMI can be reduced significantly using the jacks that are shielded.

Q: Board/System Design: PoE required? What power level?
Implementation of PoE will affect the board design considerably, particularly the layout of power and ground planes and electrical isolation between the system and cable/connector side. For multiport PoE designs, thermal dissipation issues should be carefully considered.

Q: Visual Performance: Are LEDs required? Color? Bi/tri color?
There are many different possibilities wen determining the best LED configuration. Colors representing link, activity and link speed are usually mandated by system architects or business units to maintain consistently across product lines. RJ45 connectors without magnetics do not include LEDs but instead provide light pipes. When designing using light pipes, the board designer needs to implement the correct LEDs on the board in a location which interface to the light pipes.

Q: System Design: EMI fingers
Is the RJ45 being inserted through a cutout of a metallic panel that is grounded to the chassis? If so, EMI fingers provide a gap filler between the RJ45 shield and the system panel assuring good connection to ground.

Q: Ergonomics: Tab up or down?
The tab configuration really has to do with the best ergonomic solution. The RJ45 cable connector includes a tab which provides a locking mechanism assuring the cable has proper connection to the RJ45 contacts. The tab can be depressed using the thumb or index finger, however many system architects believe the tab is meant to be pressed by the thumb.

Summary

The designer can alleviate many headaches by considering these parameters prior to starting the design. Hopefully this publication will aid the reader in understanding the basic, high-level considerations when selecting the best Ethernet solution. This document can also be used as a guideline for determining an accurate cross to Abracon solutions as many of the parameters mentioned here are searchable parameters on the Abracon website. Check back periodically to the Abracon web site for more in-depth articles and how Abracon can help customers design their next Ethernet project.

As Ethernet continues to thrive into it's 5th decade, new technologies will be developed to further enhance data throughput, latency reduction, power efficiently, etc. Just in the last decade, there has been adoption of Energy Efficient (Green) Ethernet for power sensitive applications or high-density datacenter designs where every watt is scrutinized and measured against the cost of cooling. Accurate timestamping has also been adopted (IEEE-1588) by datacenters, especially those of financial institutions who depend on accurate, time-sensitive transactions. The list continues...

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