Industrial Ethernet: Designing for success in harsh industrial environments

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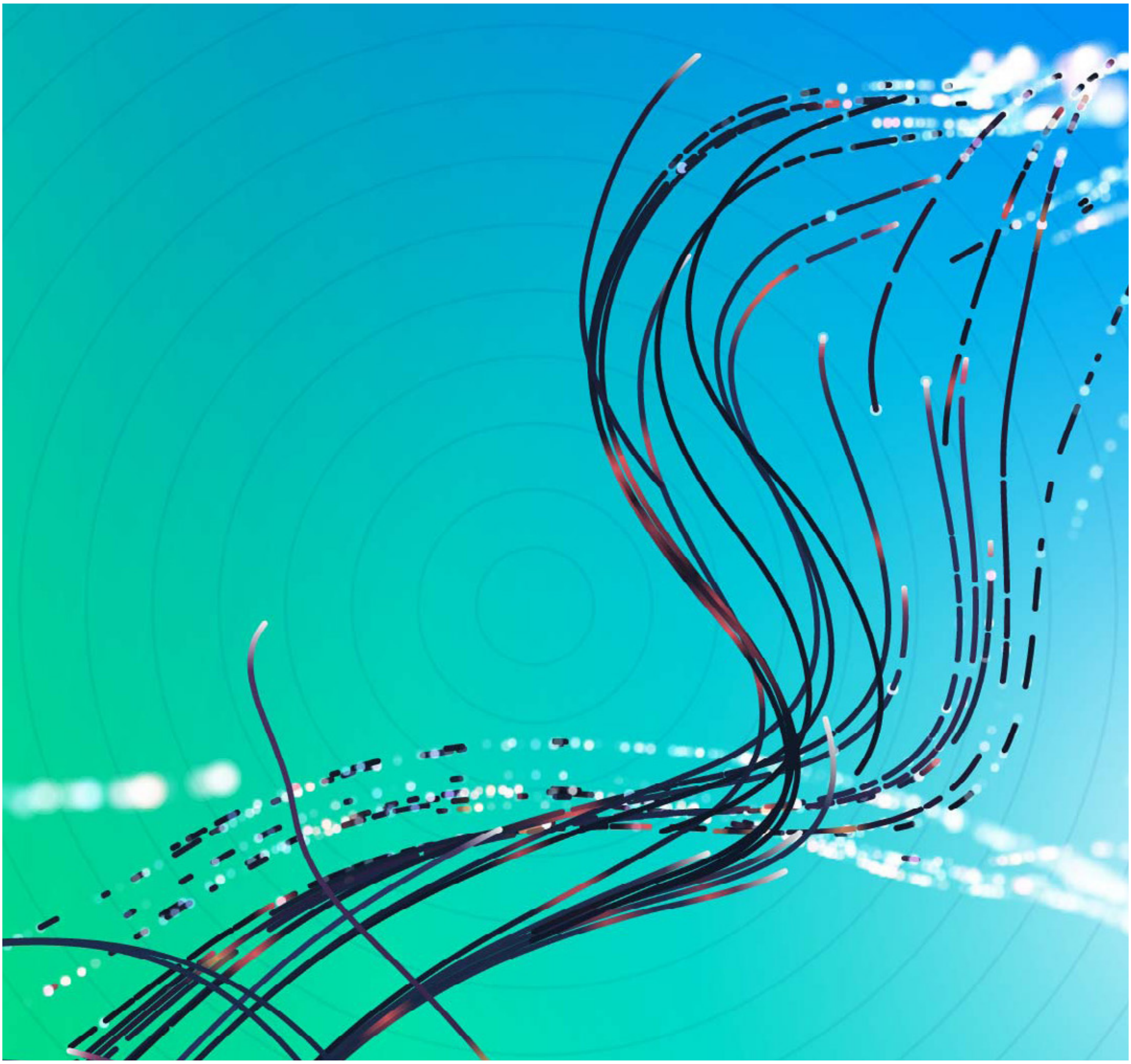

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Introduction

Ethernet is rapidly gaining adoption as the dominant networking method for an increasing number of applications outside of the IT domain. Industrial applications such as process control, automation, and industrial robots are increasingly popular use cases. However, the operating environment is significantly different from an IT environment. Industrial facilities are typically full of motor-driven automation and process control equipment. With potentially long cable runs, the risk of interference from high current spikes and transients is significant. In this article, we investigate how Industry 4.0 is leading the deployment of industrial Ethernet connectivity. We'll also discuss how the differences in the operating environment between IT and operational technology (OT) mandate a more robust and reliable physical layer.

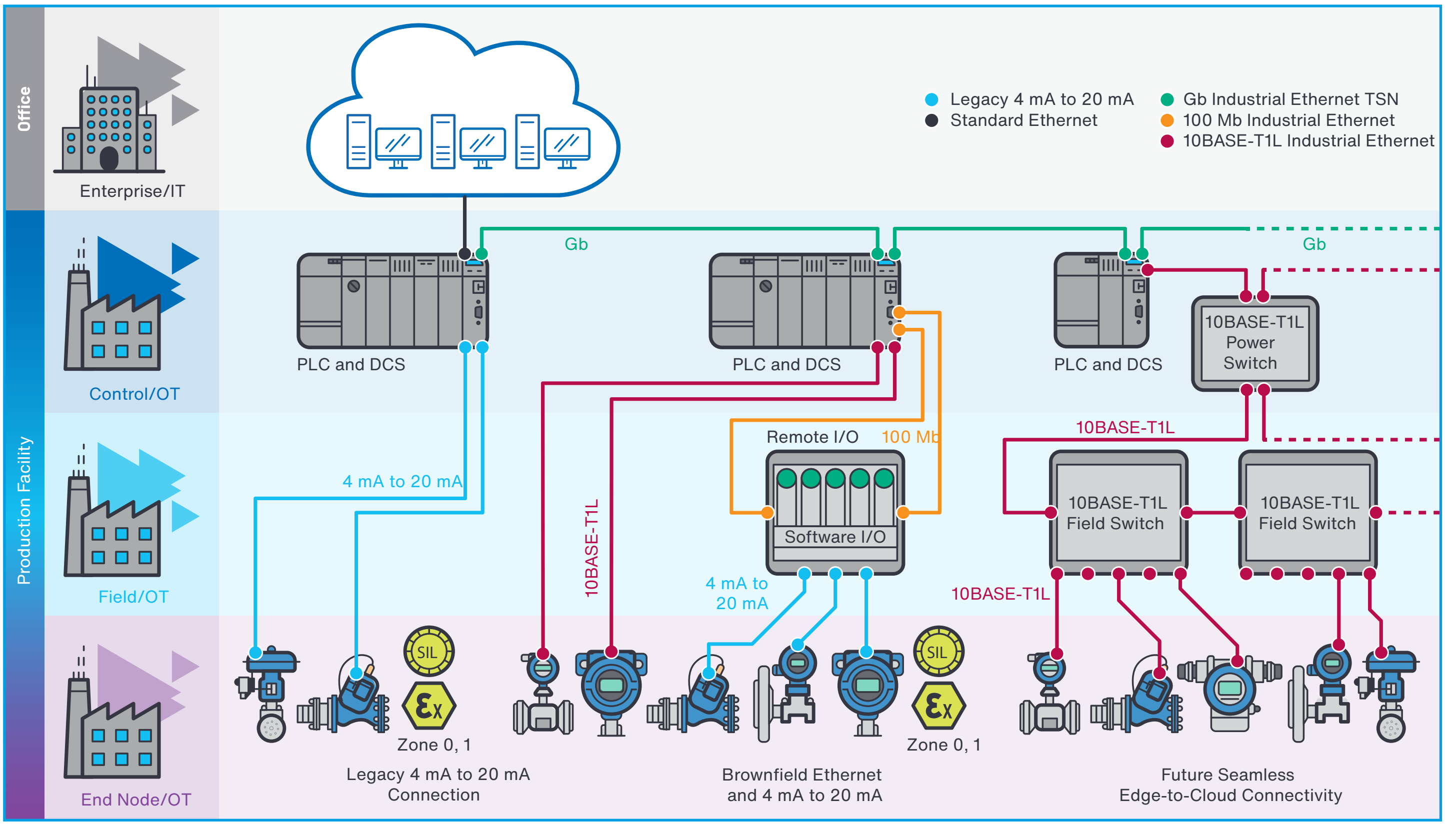

Figure 1 - An example of industrial edge-to-cloud deployment.

As industrial initiatives such as Industry 4.0 and the broader Industrial Internet of Things (IIoT) gather momentum, the need to manage the interoperability across a disparate automation landscape is increasingly essential. To achieve a single, seamless, and converged network, any new network topology must support the legacy infrastructure existing in most factories and production facilities (see figure 1). There is also a growing need for deterministic behaviour across the whole industrial system, not just for isolated individual items of plant. Ethernet provides a flexible, scalable, and well-supported networking protocol upon which to establish an industrial variant. As a result, several industrial Ethernet protocols now exist that use modified media access control (MAC) layers to incorporate support for:

- legacy networking protocols
- low latency
- deterministic features

Industry support for further developing the Ethernet protocol for industrial applications has led to the creation of the time-sensitive networking IEEE 802.1 Ethernet extension. However, unlike the conventional use of Ethernet within offices and data centres, the industrial domain presents several challenges, particularly concerning the physical layer (PHY).

Industrial Ethernet and PHY level challenges

The PHY is responsible for converting information from the data link layer into electrical signals to send and receive across the physical network cabling. The PHY of the Ethernet IEEE 802.3 standard stipulates signalling speeds, network topologies, and electric signal specifications. In this context, the signals transmitted and received across the network will encounter high levels of electrical noise generated by a variety of switch-gear, production equipment, and electric motors. High voltage and high current surges produce radiated and conducted electromagnetic interference in the form of spikes and transients. In large production facilities, with long cable runs (perhaps up to 100 metres), and equipment producing electromagnetic emissions, such unwanted interference is likely to become induced on the network cables. All equipment connected to the network needs a high degree of electromagnetic immunity (EMI) designed in. Another electrical disturbance comes from electrostatic discharges (ESD). ESD can occur during installation or maintenance of equipment but is also prevalent in production environments with fast-moving materials such as conveyor belts and other production lines. The likelihood of these electrical conditions occurring with an office or data-centre environment is low. However, when designing industrial systems, there is a need for extra precautions to mitigate the effects of EMC/ESD.

Summary of Industrial Ethernet PHY Requirements for Robust Industrial Ethernet Applications

Table 1. Consumer vs. Industrial Ethernet PHY Requirements

PHY Key Features	Consumer Ethernet PHY	Industrial Ethernet PHY	Benefit
Ambient Temperature Operation	0°C to 70°C	−40°C to +105°C	Robust operation in harsh industrial applications
Gb PHY Latency (RGMII)	>400 ns	<300 ns	Reduced network cycle time
Gb PHY Power	>500 mW	<350 mW	IP66/IP67 product without fans or heat sinks
EMC/ESD Robustness	Not required	Surge, EFT, ESD, radiated immunity, conducted immunity, radiated emissions, conducted emissions	Reduced product development and certification time and cost, robust product
Package Size	48-lead, 7 mm× 7 mm	40-lead, 6 mm× 6 mm	Smaller form factor products
Product Lifetime	Short	20 to 25 years	Long product availability

Figure 2 - Comparison of consumer v. industrial PHY requirements.

Equipment designed for industrial applications must comply with several internationally recognised EMC and ESD standards, and meet the practical needs of the environment in which it's installed (see figure 2). The standards referred to include the following EN and IEC standards: 61000-4-5 (surges), 61000-4-4 (electrical fast transients), 61000-4-2 (ESD), and 61000-4-6 (conducted immunity). Also, not only should the equipment be protected from EMI/ESD, but it must also not produce any interference emissions from itself. This requirement is covered by standard EN/IEC 55032 for radiated and conducted emissions compatibility (EMC).

For the equipment manufacturer, certification against the standards listed above is a time-consuming and costly process. Selecting components that already comply with the EMC/ESD standards can save considerable amounts of time and speed getting the new product to market.

Another aspect of PHY design and operation is thermal management. As network speeds increase, especially with Gigabit data rates becoming the norm, the amount of supporting circuitry increases too. Factory floor space is always at a premium, with the minimum amount of space available for control cabinets. These cabinets are themselves under pressure to squeeze more and more functions into a limited area, increasing the need for low power consumption, high energy efficiency applications. Equipment mounted closer to the machinery also requires thermal design considerations. Encapsulating or sealing inside a water-resistant enclosure places several design constraints in the way heat can be dissipated while maintaining intrinsic protection against fluids and dust. Again, components that have energy efficient and low power characteristics simplifies both the mechanical and the electronics design tasks considerably. Most PHYs used in consumer and office equipment have an operating temperature range of 0 ° C to + 70 ° C. Within a space-constrained design, the ambient temperature may well exceed this. The specification for an industrial Ethernet PHY should, therefore, meet the industrial temperature range of -40 °C to + 105 °C.

Two other essential selection criteria of a PHY used in industrial Ethernet applications are latency and data rate scalability. Latency has two considerations:

1. To be as low as possible to maintain low levels of network cycle time (the time to read and collect information from all attached network devices).
2. To offer a latency time that is predictable for time-sensitive, real-time applications.

Since most industrial Ethernet deployments use a line and ring topology, each connected device requires two ports - data in & data out. These add to both pass-through latency and power consumption.

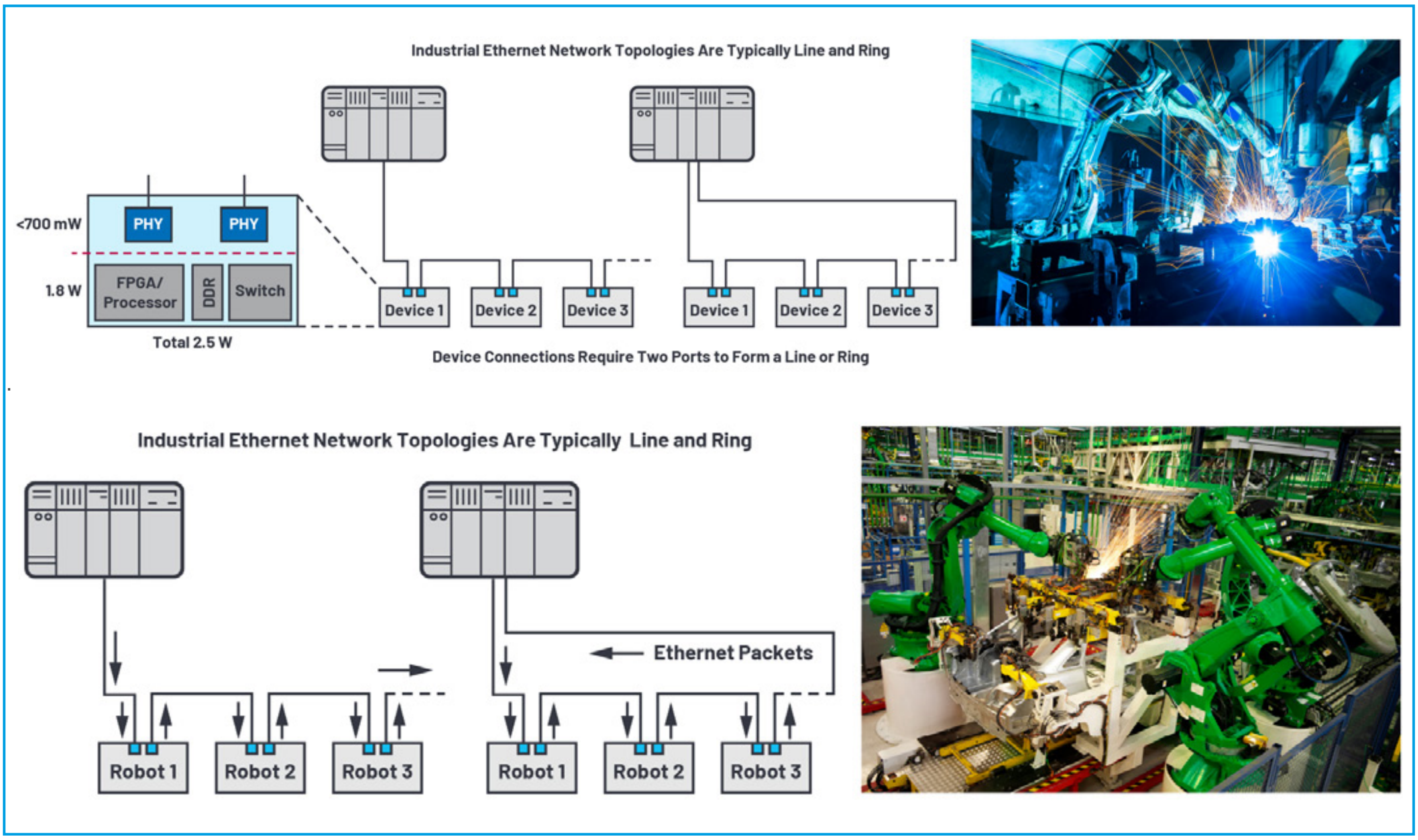

Figure 3 - The importance of low-latency in an industrial Ethernet network.

Data rate scalability future proofs the PHY against new data standards. Industrial automation equipment typically requires an in-service life of 15 - 25 years. During that time, devices using new standards such as the low power, low data rate PHY standard IEEE 802.3cg/10BASE-T1L, will see deployment. High bandwidth advancements will add to the list of requirements for the PHY.

The architecture of a PHY designed for industrial Ethernet applications

An example of a robust Ethernet PHY specifically designed for operating in the harsh industrial environment, and with extended temperature operation up to + 105 °C is the **Analog Devices ADIN1300**.

This low power energy efficient 10/100/1000 Gigabit single-port PHY consumes less than 350 mW when operating in 1000BASE-T mode, and conforms to all the industrial EMC/ESD standards previously discussed in this article. Latency in 1000BASE-T operations is 68 ns in transmit and 226 ns during receive. The ADIN1300 meets all the requirements of the EtherCAT industrial Ethernet protocol. Figure 4 illustrates the functional block diagram of a simple application.

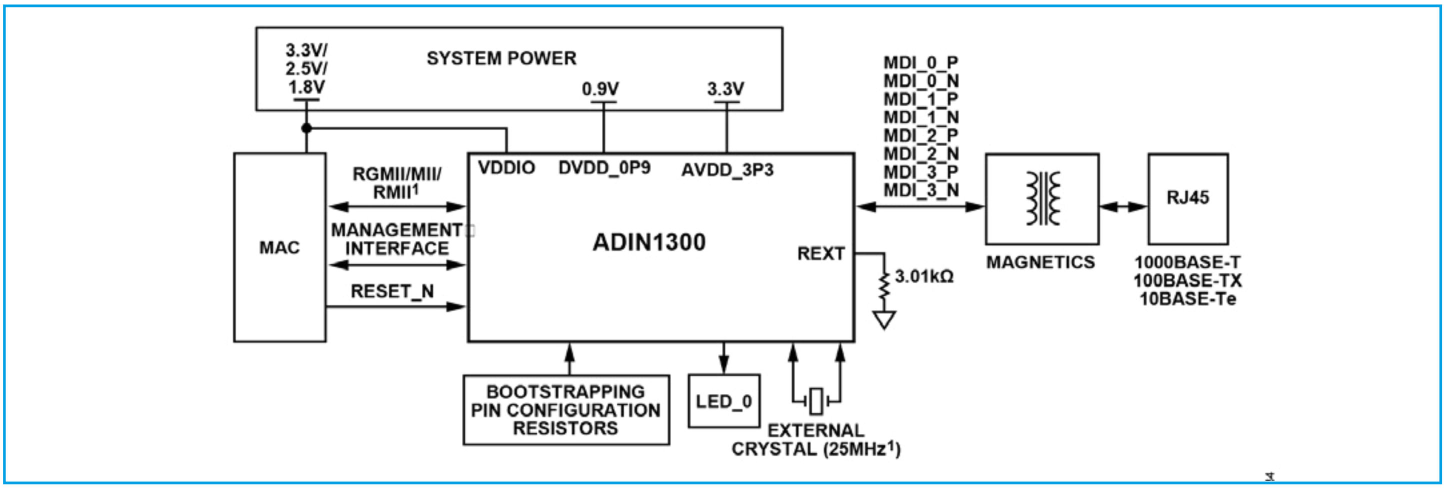

Figure 4 - A simplified application block diagram of the ADIN1300.

When designing a PHY circuit, the selection of the magnetics needs careful attention. Achieving galvanic isolation between the host application and the network protects both sides against faults and transients - an essential part of any Ethernet design. IEEE 802.3 standards – referring to IEC 60950 – require a minimum isolation voltage of either 1500 Vrms or 2250 VDC for 60 seconds. A specially designed transformer such as the **Würth Elektronik Super-Tiny Signal Transformer WE-STST 74930000** is ideal for use with the ADIN1300 PHY. This compact discrete device measures 4.7 mm x 3.22 mm x 2.9 mm (L x W x H), allowing a high level of design flexibility and making good use of available space on the PCB, In addition, the automated production of this transformer minimises the deviation/variability between parts when compared to hand-wound ring cores. Figures 5 & 6 show example circuit implementations and PCB layout for the ADIN1300 and WE-STST 74930000.

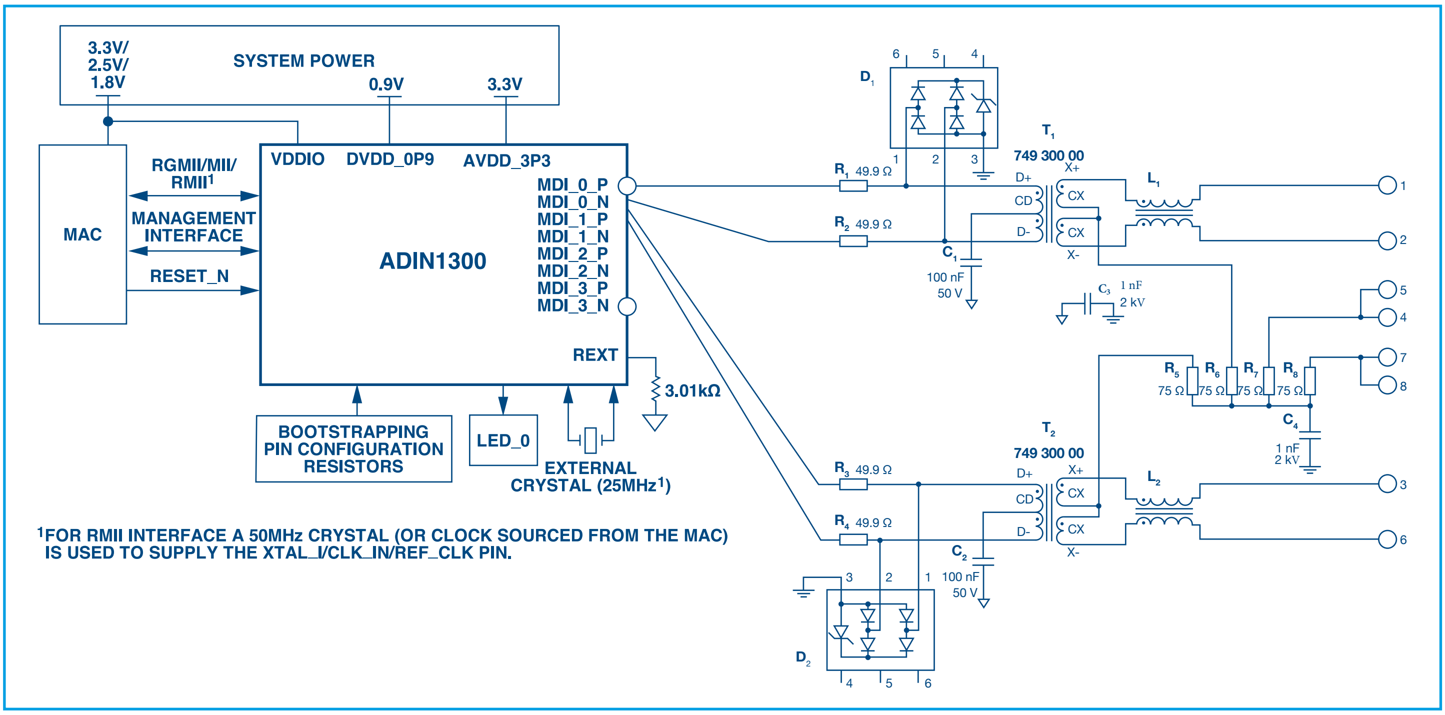

Figure 5 - Simplified Typical Application Block Diagram.

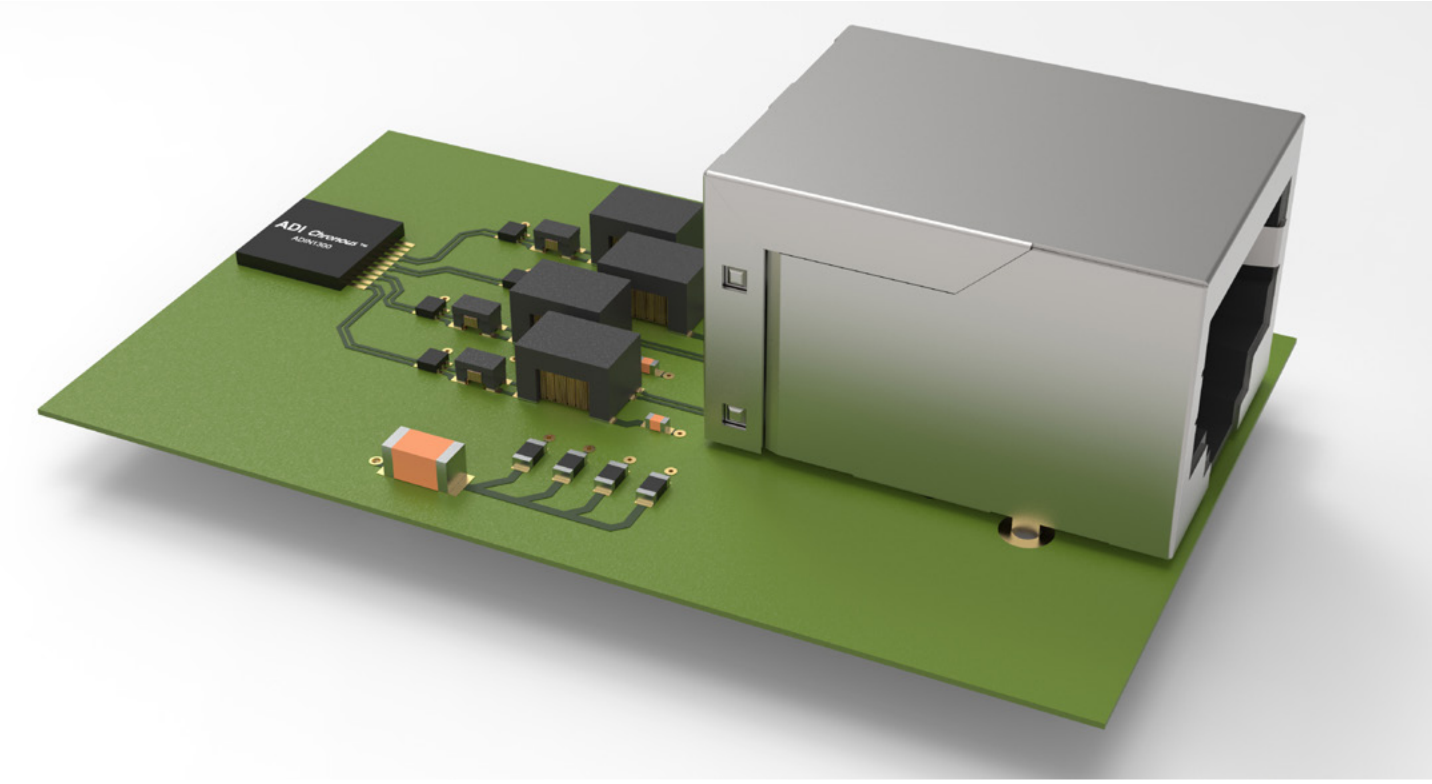

Figure 6 - Example pcb layout.

Conclusion

When designing an industrial Ethernet application, the selection of the PHY requires careful attention. The PHY must be capable of working reliably in environments subject to extreme electrical noise and adhere to ESD and EMC specifications. Also, as with many space-constrained designs, the need to operate at extended temperatures is paramount, as is the need for low-power credentials. The ADIN1300 and the Würth Elektronik STST-74930000 complement each other perfectly in such applications.