Application Note

Standard to Single Pair Ethernet Migration Guide

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Abstract

In robotics, vast amounts of data from cameras, sensors, and motors must be collected and processed efficiently. Ethernet provides an interface for real-time communication between sensors, motor controllers, and robot controllers. The growing demand for more efficient and maneuverable robots requires the optimization of component size and weight. An increasingly common option for this optimization involves switching the communication interface in a robot from Standard Ethernet to Single Pair Ethernet (SPE). The smaller and lighter cables used with SPE allow for more flexible and compact robot designs. Reducing weight also contributes to lower power consumption for robot movement. This methodology applies to many fields outside of robotics that are also looking to maximize system performance. This application note serves as a guide for key considerations when switching a design from Standard Ethernet to SPE.

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1 Introduction

Migration from Standard to SPE can be dissected into the categories of system implementation, PHY-level differences, and real-time signaling protocol selection. This application note discusses these considerations and provides comparisons between both types of Ethernet applications.

Texas Instruments offers a variety of Ethernet PHY transceivers for both Standard Ethernet and SPE applications. To serve as an example for rollover considerations, this document discusses the DP83826A Standard Ethernet PHY and the DP83TC813-Q1 SPE PHY. The DP83826A PHY is low latency, low power and supports 10BASE-Te and 100BASE-TX Ethernet protocols. The DP83TC813-Q1 is an IEEE802.3bw and Open Alliance compliant 100BASE-T1 PHY.

2 Standard Versus Single Pair Implementation

Both Standard and Single Pair Ethernet PHYs are connected to a processor through the Media Independent Interface and to a link partner PHY through the Media Dependent Interface (MDI). The key difference between the devices is the implementation of the MDI connection. Standard Ethernet uses up to four differential pairs of wires to transmit data. For 10Mbps (10BASE-TX) and 100Mbps (100BASE-TX) Ethernet, only two pairs are used. An example of this is shown in Figure 2-1. For 1Gbps (1000BASE-T) Standard Ethernet, all four pairs are used. A transformer is placed between the PHY and connector to provide DC isolation from the connector, protection against EMC events, and for impedance matching purposes.

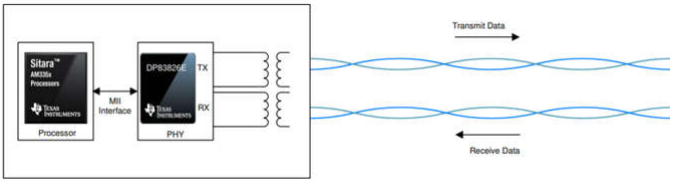


Figure 2-1. Standard Ethernet PHY Implementation

Single Pair Ethernet uses only one pair of wires for the MDI and does not require a transformer. This implementation is shown in Figure 2-2.

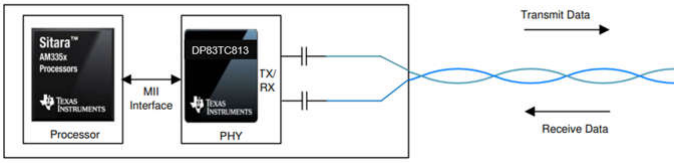


Figure 2-2. Single Pair Ethernet PHY Implementation

The Single Pair Ethernet PHY implementation also uses additional components on the MDI. A common-mode choke (CMC) filters common mode noise to prevent PHY receiver disruption and to reduce radiated emissions. Two capacitors are used for DC isolation, which contributes to a reduced size compared to a Standard Ethernet implementation with a transformer. A comparison of the complete PHY connections between Standard and Single Pair Ethernet is shown in Figure 2-3.

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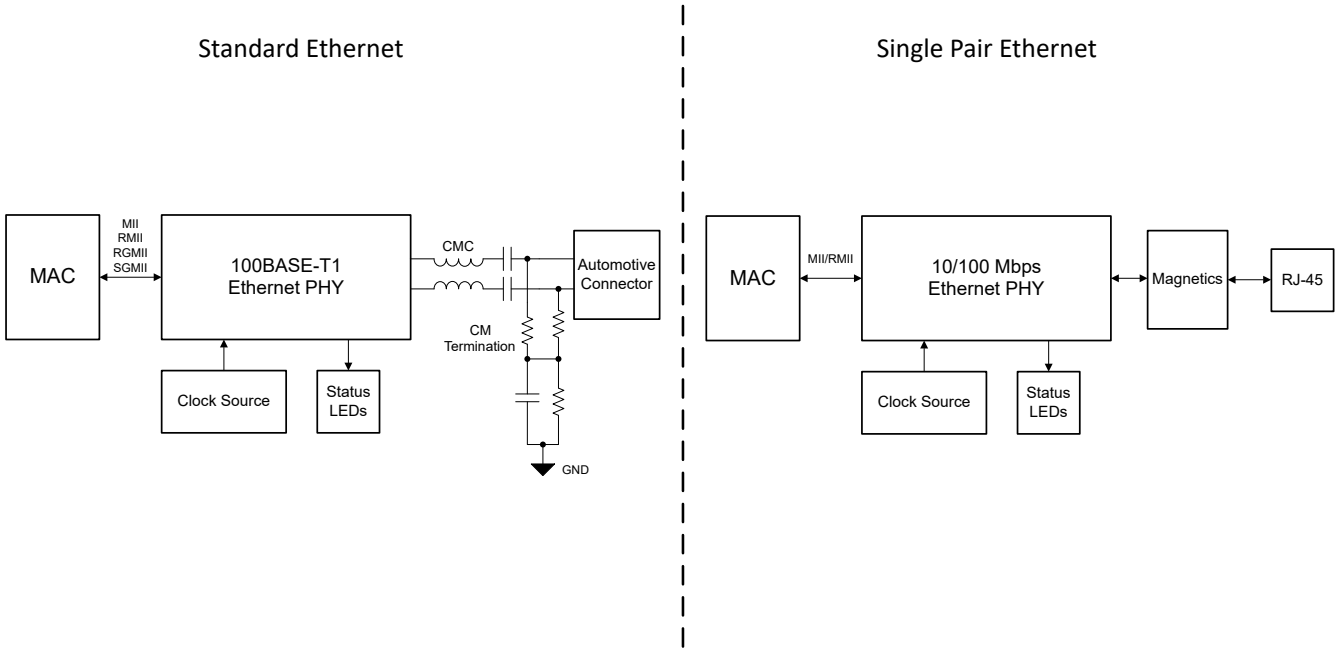


Figure 2-3. Standard vs SPE PHY Implementation

The full overview of Standard Ethernet and SPE, including topologies, cable and connector types, and sample applications is shown in Figure 2-4 according to the IEEE802.3 standard.

IEEE802.3 | Key Types of Ethernet PHYs

*TI expected performance

	Standard ENET			Single Twisted Pair ENET			
Cable type	2+ twisted pairs / 4+ wires			1 twisted pair / 2 wires			
Description	10BASE-T	100BASE-TX 100BASE-FX	1000BASE-T 1000BASE-X	10BASE-T1S	10BASE-T1L	100BASE-T1	1000BASE-T1
Hero Parts	DP83822 (FX), DP83826A (TX)		DP83867/9	DP83TD5x5-Q1	DP83TD510	DP83TC813/5-Q1	DP83TG720/1-Q1
Maximum Bandwidth (Mb/s)	10M	100M	1000M	10M		100M	1000M
Standard Cable Reach (m/link)	100m / *150m			25m / *100m	1km / *2km	15m / *40m	40m
Node count support				8 / *32			
Point-to-point, Line, Ring, Star, Extended Star	✓						
Multidrop				✓			
Data Transfer	Full-duplex or Half-Duplex			Half-Duplex	Full-duplex		
Industrial Protocols	EtherCAT		*EtherCAT G				
	Profinet						
Sending Power over Ethernet	Power over Ethernet (PoE)			Multidrop Power over Ethernet (MPoE)	Power over Data Line (PoDL)		
IEEE 1588			*1588v2 Timestamp			*802.1AS Timestamp & sync	
Cable / Connectors	Cat 7, Cat 6, Cat 5e, RJ-45, SMF, SFP			Rosenberger	Type A/ Type B Automotive Cables, Leoni Dacar547/647	Rosenberger, BM04B-GHS-TBT, MATEnet	
Application Requirements	Real-time, deterministic, lowest latency			Multidrop	1km reach	Small space, lightweight	
Applications	Industrial automation | Energy infrastructure Robotics | Building Automation | Data Center			Automotive HVAC Robotics	Building & process automation	Automotive Robotics Industrial Automation	

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Figure 2-4. IEEE Ethernet Standards

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3 Key PHY Differences

When migrating from a Standard Ethernet design to a Single Pair Ethernet design, there are several PHY-level differences to consider. Primarily, factors such as size and power consumption should be reviewed. In addition, Standard and SPE PHYs often have differing operating temperature ranges. The following table defines these parameters and how they vary between a Standard and Single Pair Ethernet PHY.

Table 3-1. PHY-Level Differences

Parameter	Standard Ethernet DP83826A	Single Pair Ethernet DP83TC813-Q1
Data rate	10/100 Mbps	100 Mbps
IC Size	5x5mm	5x4mm
Power Consumption	< 160mW	< 230mW
Operating Temperature	DP82826AE: -40°C to +105°C DP82826AI: -40°C to +85°C	-40°C to +125°C
EMC	ESD Direct Contact: ± 9kV Class A	ESD Direct Contact: ± 8kV
Latency (TX + RX)	210ns	724ns

In addition to IC size, it is important to consider the board space required for the implementation of a PHY. For this comparison, the PCB layouts of the DP83826A EVM and DP83TC813-Q1 EVM are compared in the following figures, respectively. Although this is an example of the board space used for a sample application, it shows the general trend that SPE requires less board space than Standard Ethernet.

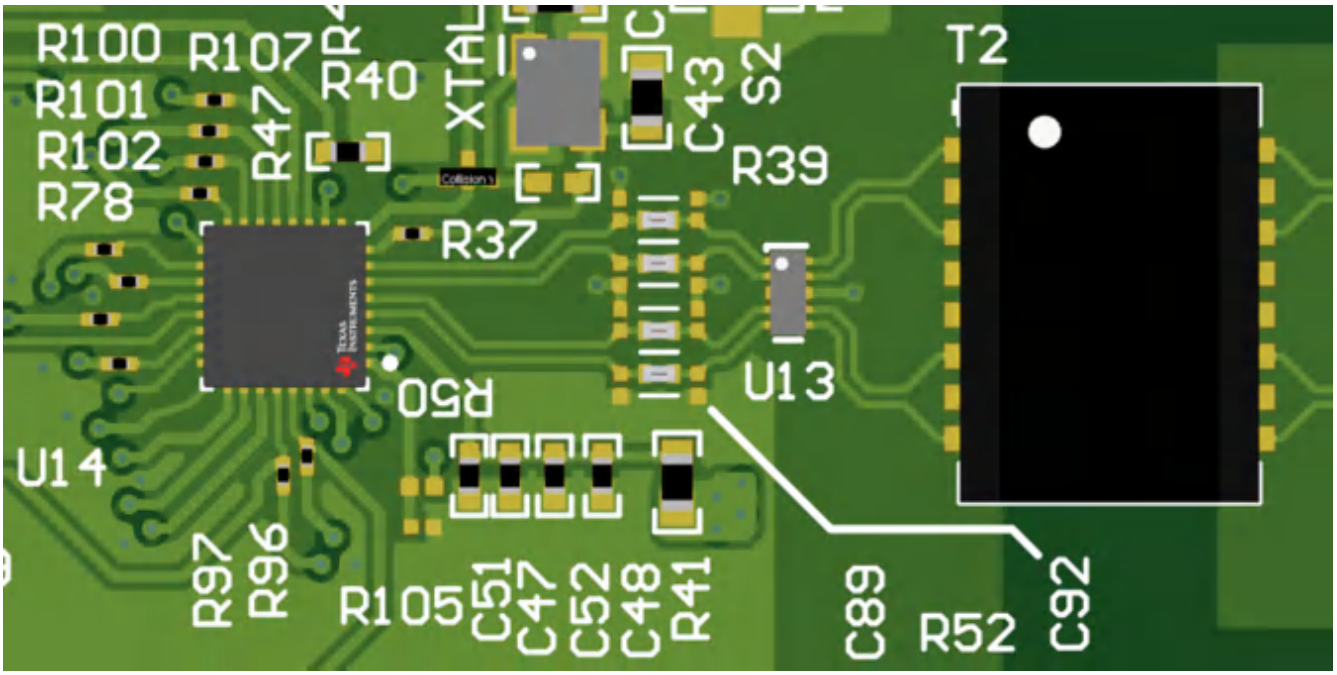


Figure 3-1. DP83826A EVM Layout

Board space: Approximately 40mm × approximately 25mm

PHY Body size: 5mm × 5mm

Transformer (T2): 12.7mm × 9.09mm

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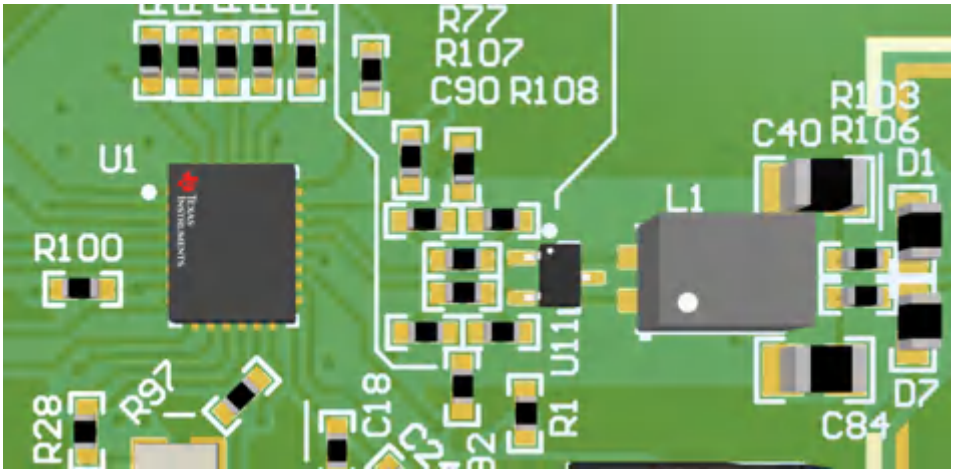


Figure 3-2. DP83826A EVM Layout

Board space: Approximately 30mm × approximately 15mm

PHY Body size: 5mm × 4mm

CMC (L1): 4.5mm × 3.2mm

Finally, the form factor differences between Standard Ethernet and SPE must be examined. The different cables, connectors, and other external components contribute to the overall size and weight of the system implementation. These considerations are outlined in Table 3-2. One key advantage of SPE that is demonstrated in this table is the smaller cabling size and weight generally required.

Table 3-2. Form Factor Differences

Component	Standard Ethernet	Single Pair Ethernet
Cabling	Number of wires: 4 or 8 Total diameter: 5 – 6.5mm Total weight: 30-50kg/km	Number of wires: 2 Total diameter: 2.5 – 4.0mm Total weight: 15-50kg/km
Connectors	RJ45 connector: 30g, 2cm³	M8 Connector: 20g, ~8mm diameter M12 connector: 30g, ~12mm diameter
Magnetics	Ethernet connections require separate isolation transformer (approximately 1cm²)	No external magnetics required

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4 EtherCAT and TSN

Regular Ethernet communication is often not sufficiently fast and predictable for many applications, such as the real-time control of a robot. Industrial protocols offer a solution that allows for ultra-low latency and precise data transfer. One of the most widely used protocols is Ethernet for Control Automation Technology (EtherCAT). EfherCAT was developed by Beckhoff Automation specifically for industrial applications and uses the same Physical/Data Link layers as Ethernet. In Ethernet systems, data is routed through many different nodes in a Controller/Peripheral configuration and data is sent or received based on packet requests. In EtherCAT systems, the controller is the only node allowed to send data frames. It sends data for the entire node network with a data packet passing through every node. This topology is shown in Figure 4-1.

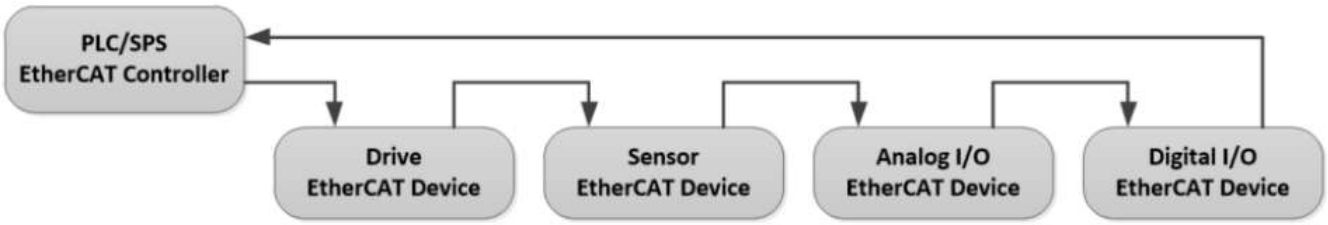


Figure 4-1. EtherCAT Topology

The key features of EtherCAT are:

- Distributed clocks: A precise time-synchronization method across the EtherCAT devices and the controller
- Fast link-drop detection with loopback: When an Ethernet PHY detects a link down, the PHY notifies the EtherCAT MAC. Within 10 µs, EtherCAT MAC loops back the EtherCAT frames
- Ring topology: EtherCAT devices are connected in a circular configuration forming a closed loop. Each device is connected to two other devices, creating a continuous pathway for data transmission
- Cable redundancy: Two port cable redundancy compensates for any failure of a communication peripheral in an EtherCAT system

However, EtherCAT is not supported for SPE applications. Therefore, other options for real-time signaling must be considered when migrating to a Single Pair system. Time-Sensitive Networking (TSN) is becoming an increasingly popular route for this. TSN is a set of IEEE standards that allows for deterministic and time-synchronized data to be sent over regular Ethernet infrastructure. With the necessary protocols and services enabled on-top of TSN to enable TSN components, this set of standards can match the capabilities of EtherCAT. More information about implementing TSN can be found in the *Designing a Deterministic scalable Ethernet backbone for Robotics*.

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5 Key Rollover Considerations

If moving from a DP83826A design to one using the DP83TC813-Q1, there are several further items to consider in addition to the general migration recommendations outlined earlier in this document. These are discussed in Table 5-1.

More detailed information about the implementation and configuration of both devices can be found in their respective schematic review checklists: DP83TC813 Schematic Review Checklist and DP83826A Schematic Checklist

Table 5-1. DP83826A to DP83TC813 Rollover

	DP83826A	DP83TC813
Pinout/Footprint	32-pin QFN	28-pin VQFN
Cable	2- or 4-pair CAT5/6 cable	Single twisted-pair cable
MDI	Magnetics	CMC, DC blocking resistors, MDI coupling capacitors, and ESD Shunt resistor
MAC Interface	MII and RMII	MII, RMII, RGMII, and SGMII
Configuration	• Can be configured via MDIO register writes or bootstrapping • Does not require an initialization script	• Can be configured via MDIO register writes or bootstrapping • Requires an initialization script for TC10 compliance

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6 Summary

This application note discusses important considerations when moving from a Standard Ethernet to a Single Pair Ethernet design. It reviews system and form factor differences, PHY features, and real-time signaling. A high-level comparison between the DP83826A Standard Ethernet PHY and the DP83TC813-Q1 SPE PHY is also examined.

7 References

1. Texas Instruments, *DP83TC813x-Q1 TC-10 Compliant Small Form Factor 100BASE-T1 Automotive Ethernet PHY*, datasheet.
2. Texas Instruments, *DP83826Ax Deterministic, Low-Latency, Low-Power, 10/100 Mbps, Industrial Ethernet PHY*, datasheet.
3. Texas Instruments, *Advancing Humanoid Robotics with Single Pair Ethernet Application Brief* , application brief.

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