Application Report

Extend Network Reach with IEEE 802.3cg 10BASE-T1L Ethernet PHYs

ABSTRACT

The IEEE 802.3cg 10BASE-T1L specification unlocks the potential for exciting new opportunities for Ethernet communications in long-distance applications. By supporting 10-Mbps full-duplex communications up to a distance of 1,000 meters through a single pair of twisted wires, the standard makes the *impossible* possible in terms of utilizing Ethernet for two-wire long-distance communications. Single-pair Ethernet PHYs such as the DP83TD510E help designers more easily implement this standard while also extending cable reach beyond the standards specifications. The DP83TD510E surpasses the 1-km at 1.0 Vpp and 2.4 Vpp requirement of the standard and is capable of transmitting signals up to 2,000 meters.

This additional cable length helps designers extend the reach of industrial communications without increasing system weight or cabling costs. The extended supported length also improves the longevity of shorter cables, allowing for more cable degradation without sacrificing transmission quality. External components, layout and cable types play an important in achieving the long cable reach. This application note discusses the features of the DP83TD510E and key specifications of external components to achieve the maximum cable reach as well as cable specifications to consider for these long reach applications.

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Trademarks

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1 Introduction

The 10Base-T1L standard allows connected devices in building and factory automation, monitoring stations, and sensing applications to reach new lengths through single-pair Ethernet. Designing a robust system to handle the challenges of communicating over 1,000 meters requires careful consideration of the capabilities of an Ethernet PHY and the specifications of the cable. The DP83TD510E Single-Pair Ethernet (SPE) PHY is a 10Base-T1L, IEEE 802.3cg compliant Ethernet transceiver. The DP83TD510E's 1.0 Vpp and 2.4 Vpp operating modes offer design flexibility in maximizing cable reach for building, factory and process automation, including intrinsic safety applications. The following sections discuss each of these features or tools.

Cable length considerations:

- Establishing link through Auto-negotiation and forced modes
- Establishing link in 1.0 Vpp and 2.4 Vpp output operating modes
- Adjusting external MDI terminations to optimize cable impedance
- Understanding medium requirements for cable selection

Each section provides background into the functionality of the PHY and guidance on how to design for each mode of operation.

2 Terminology

10Base-T1L	10Mbps full-duplex communication over single balanced pair of conductors standard
PHY	Physical layer transceiver
Vpp	Peak-to-peak voltage
PAM3	3-level Pulse Amplitude Modulation
MAC	Media Access Controller
MDC	Management Data Clock
MDIO	Management Data I/O
LSM	Low speed mode
DME	Differential Manchester Encoding
PMA	Physical medium attachment

3 Establishing a Link

3.1 Auto-Negotiation

The 802.3cg standard requires 10Base-T1L PHYs to support auto-negotiation in *low-speed-mode* (LSM). In LSM, the PHY sends differential Manchester encoded (DME) pages at 625 Kb/s to advertise its capabilities to its link partner.

In normal operation, the DP83TD510E utilizes 3-level Pulse Amplitude Modulation (PAM3) signal transmitted over a single differential pair at 7.5MBd. The 10Base-T1L standard is unique in that it specifies that a PHY may support an increase transmit and receive capability, boosting the PAM3 amplitude from 1.0 Vpp to 2.4 Vpp. The greater transmit capability helps the PHY overcome attenuation over long cable lengths to extend the maximum reach of the PHY.

The DP83TD510E supports hardware and software configurations to advertise 1.0 Vpp or 2.4 Vpp and 1.0 Vpp capability during auto-negotiation. It also has the capability to adapt the transmit voltage to 2.4 Vpp or 1.0 Vpp as determined during auto-negotiation. DP83TD510E by default advertises 1.0 Vpp only. If both 1.0 Vpp and 2.4 Vpp are advertised and the Link Partner also supports 2.4 Vpp, the DP83TD510E will be configured to 2.4

Vpp. The DP83TD510E offers LED based indication to indicate PHY is operating in 2.4 Vpp or 1.0 Vpp operating mode.

This strap defines the voltage level requested by PHY during Auto Negotiation. It is reflected in register 0x020E[12]. While using Force mode for link-up, the strap controls the output voltage and reflects in register 0x18F6[12].

Table 3-1. Transmit Output Operating Voltage Bootstrap

Pin Name	Strap Name	Pin #	Default	Setting	
LED_2	Strap7	28	0	0	1.0 Vpp
				1	2.4 Vpp

Table 3-2. PMA_CTRL (address = 0x18F6) [reset = 0x0000]

Bit	Field	Type	Reset	Description
12	CFG_INCR_TX_LVL	R/W	0x0	1 = Enable 2.4 Vpp operating mode
				0 = Enable 1.0 Vpp operating mode

3.2 Forcing Host-Client Configuration

Ethernet PHYs operate as either host or client when a network link is established. The host device uses a local clock to set the transmitter timing over the Ethernet port. The client device relies on the recovered clock from its received signal to set its transmitter timing operation. The DP83TD510 will resolve the Host-Client relationship through auto-negotiation when enabled.

The Host-Client configuration, as well as output voltage mode, can be set manually if auto-negotiation is disabled. The maximum cable reach of the PHY may be extended by forcing both the Host-Client relationship and output voltage operating mode. Specific cable characteristics may limit the reach of 10BASE-T1L's low-speed auto-negotiation protocol by attenuating or distorting the DME over the channel. For example, a cable with high insertion loss around 625 kHz distorts the auto-negotiation pulses and the link partner may fail to complete the auto-negotiation process by not interpreting the received signal properly. Forcing the PHY into the desired mode of operation bypasses auto-negotiation and allows extended cable reach. The following configurations are offered by the DP83TD510E to enable "Force Mode". Please note, while using force mode, auto-negotiation shall be prevented by disabling MR_AN_ENABLE on both the DUT and link partner. Please see Table 3-3. One of the PHYs (DUT or link partner) shall be configured for host and the other for client.

3.2.1 AN_CONTROL (address = 0x7200) [reset = 0x1000]

Table 3-3. AN_CONTROL (address = 0x7200) [reset = 0x1000]

Bit	Field	Type	Reset	Description
12	MR_AN_ENABLE	R/W	0x1	1 = enable Auto-Negotiation process
				0 = disable Auto-Negotiation process

3.2.2 PMA_PMD_CTRL (address = 0x1834) [reset = 0x4000]

Table 3-4. PMA_PMD_CTRL (address = 0x1834) [reset = 0x4000]

Bit	Field	Type	Reset	Description
14	CFG_M-S_Value	R/W	0x1	1 = Configure PHY as HOST
				0 = Configure PHY as CLIENT

3.3 1.0 Vpp vs. 2.4 Vpp Operating Mode

According to the IEEE 802.3cg specification, the PMA transmitter output voltage must fall within a +5% to -15% range of the selected operating mode, 2.4 Vpp or 1.0 Vpp. The table below shows the 10Base-T1L output differential voltage limits of each operating mode.

Table 3-5. PMA_PMD_CTRL (address = 0x1834) [reset = 0x4000]

Operating Mode	Min	Typ	Max	Units
1.0V p2p	0.85	1.0	1.05	V

Table 3-5. PMA_PMD_CTRL (address = 0x1834) [reset = 0x4000] (continued)

Operating Mode	Min	Typ	Max	Units
2.4V p2p	2.04	2.4	2.52	V

The operating mode of the DP83TD510 can be configured through auto-negotiation, with 2.4 Vpp taking priority if both modes are advertised. If auto-negotiation is disabled, the PHY will operate at 1.0 Vpp and can be configured to 2.4 Vpp operating mode through register settings.

4 10Base-T1L Cable Parameters

The DP83TD510 is designed to reach up to 2,000 meters over a single balanced pair of conductors that meet the characteristics described below. The cable may be shielded or unshielded:

4.1 Characteristic Impedance

The DP83TD510 has external termination on the MDI pins suitable for intrinsic safety applications. A key advantage of this design allows the DP83TD510 to be used with cables with varying characteristic impedances. The 10Base-T1L standard uses 100 ohm reference impedance in its link segment characteristics specifications. However, if a customer wants to introduce the DP83TD510 into an existing application with different characteristic impedance, the external termination of the DP83TD510 can be adjusted to accommodate the application.

The schematic shown in Figure 4-1 highlights the external MDI termination resistor in the DP83TD510 design that can be tuned for cable impedance. Figure 4-1 shows a design for 100 ohm characteristic impedance with R1 and R2 values of 49.9 ohms on TD_P and TD_N pins.

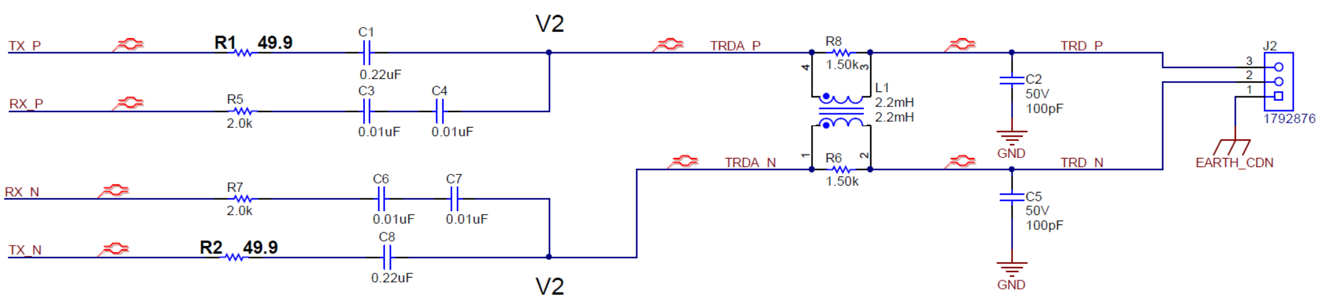

Figure 4-1. 100 ohm Characteristic Impedance Cable Design

Figure 4-2 shows a design for 125 ohm characteristic impedance cable with R3 and R4 values of 62.5 ohms on TD_P and TD_N pins.

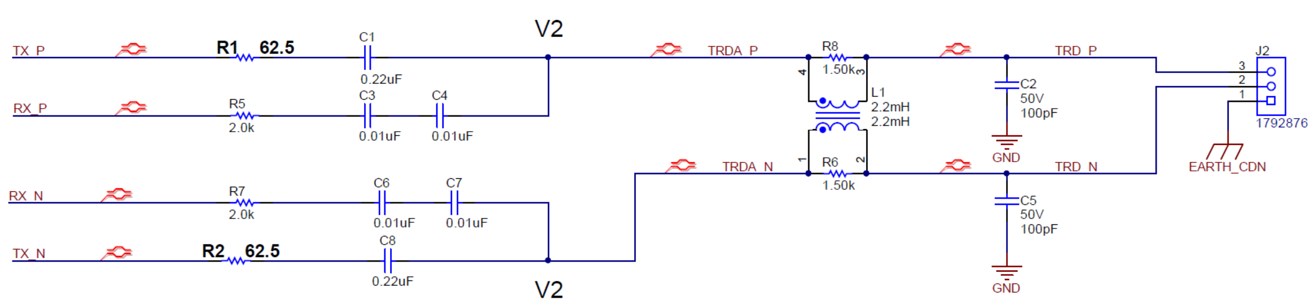

Figure 4-2. 125 ohm Characteristic Impedance Cable Design

4.2 Insertion Loss

Insertion loss in 2.4Vpp operating mode is modeled by:

$$2.4Vpp\ Insertion\ loss\ (f) \leq 10\left(1.23 * \sqrt{f} + 0.01 * f + \frac{0.2}{\sqrt{f}}\right) + 10 * 0.02 * \sqrt{f} \quad (dB)$$

Where f is the frequency in MHz between 0.1<=f<=20 (1)

Insertion loss in 1.0Vpp operating mode is modeled by:

$$1.0Vpp\ Insertion\ loss\ (f) \leq 5.9\left(1.23 * \sqrt{f} + 0.01 * f + \frac{0.2}{\sqrt{f}}\right) + 10 * 0.02 * \sqrt{f} \quad (dB)$$

Where f is the frequency in MHz between 0.1<=f<=20 (2)

4.3 Return Loss

The 10Base-T1L link should adhere to the following return loss specification to limit the noise from mismatches to the 100 Ω reference impedance:

$$\geq 9 + 8 * f\ where\ 0.1 \leq f < 0.5\ MHz\ (dB)$$
$$\geq 13\ where\ 0.5 \leq f \leq 20\ MHz\ (dB)$$ (3)

4.4 Maximum Delay Link

The 10Base-T1L link propagation delay should be less than 8,834 ns between frequencies 0.1 MHz to 20MHz.

4.5 Electromagnetic Classifications

The following cable specifications are dependent on their electromagnetic noise environment, which can be classified as E_1, E_2, or E_3 based on Table 4-1.

Table 4-1. Cable Specifications

Electromagnetic	E_1	E_2	E_3
Conducted RF	3 V at 150kHz to 80MHz	3 V at 150kHz to 80MHz	10 V at 150kHz to 80MHz

4.6 Differential to Common Mode Conversion

Differential to common mode conversion applies to **unshielded** cables in E_1 and E_2 environments as shown in Table 4-2.

Table 4-2. Differential to Common Mode Conversion

	Frequency (MHz)	E_1	E_2
TCL	$0.1 \leq f \leq 10$	$\geq 50\ dB$	$\geq 50\ dB$
TCL	$0.1 \leq f \leq 20$	$\geq 50 - 20\log_{10}\left(\frac{f}{10}\right)\ dB$	$\geq 50 - 20\log_{10}\left(\frac{f}{10}\right)\ dB$

4.7 Coupling Attenuation

Coupling attenuation applies to **shielded** cables in E_1, E_2, and E_3 environments as shown in Table 4-3.

Table 4-3. Coupling Attenuation

Frequency (MHz)	(dB)		
	E_1	E_2	E_3
0.1 to 20	≥ 50	≥ 50	≥ 60

4.8 DP83TD510 Cable Reach Performance

The channel characteristics described above have a clear effect on the PHYs ability to establish a link. Two Fieldbus cables, the Siemens 6XV1830-5EH10 and Belden 3076F, show how insertion loss can affect the maximum cable reach of the DP83TD510. Both cable samples are shielded, single twisted pair Fieldbus cables applicable for process and factory automation.

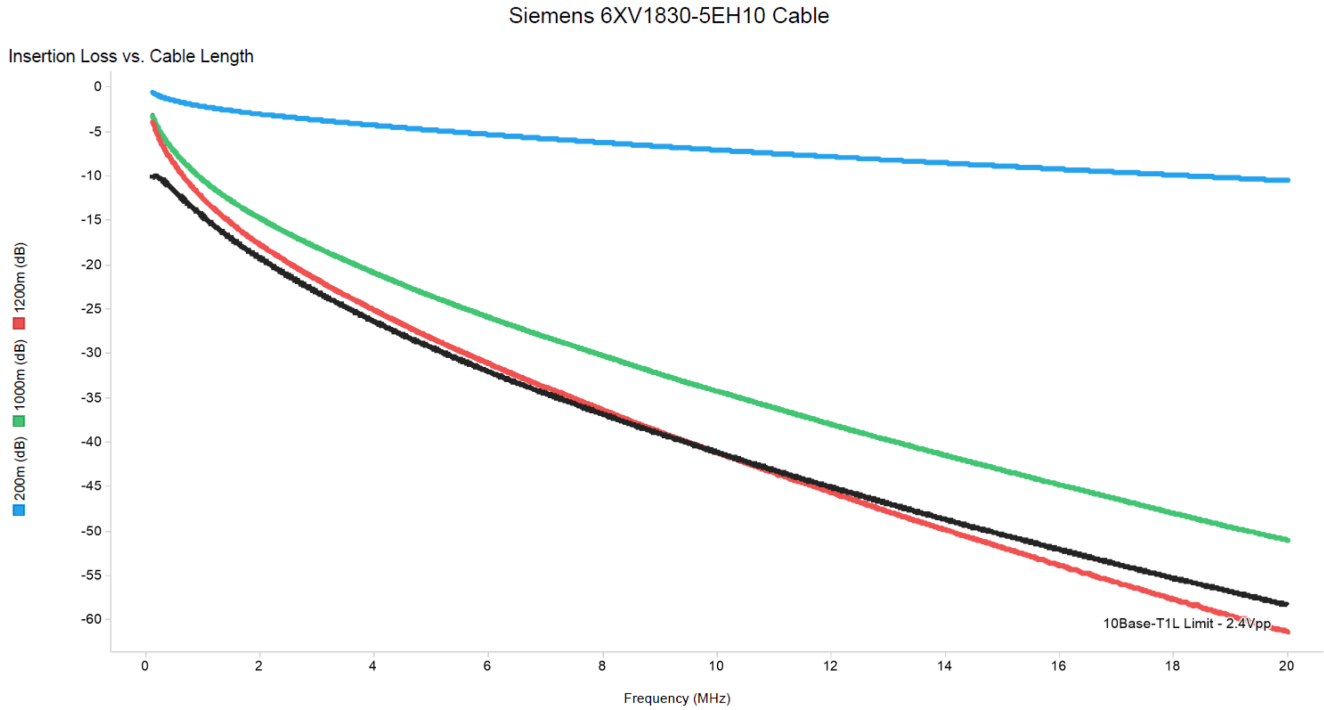

Figure 4-3. Siemens 6XV1830-5EH10 Cable

The insertion loss profile of Siemens cable shows that it complies with the 10Base-T1L insertion loss profile over 1,000 meters, with violations occurring near 1,200 meters. Table 4-4 demonstrates the DP83TD510 can establish a link through auto-negotiation with this cable up to 1,200 meters.

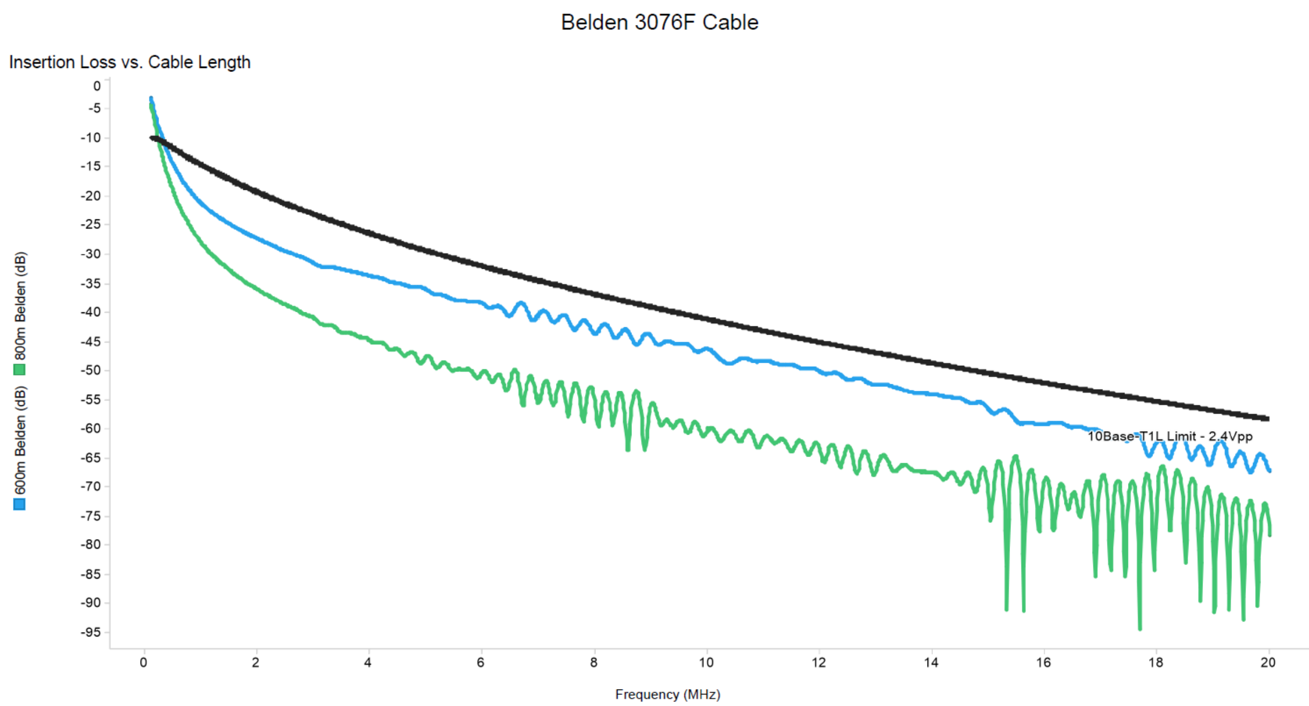

Figure 4-4. Belden 3076F

The Belden cable does not meet the 10Base-T1L insertion loss profile specification. Note the LSM auto-negotiation signaling at 625kbps suffers from this profile and the DP83TD510 can auto-negotiate up to 260 meters, shown in Table 4-4.

Table 4-4. DP83TD510 Cable Reach at Room Temperature

Cable	Auto-Negotiation Cable Reach (m)	Auto-Negotiation w/additional DSP ANEG Config Cable Reach (m)	Forced Mode Cable Reach (m)
Siemens 6XV1830-5EH10	1700	2000	2000
Belden 3076F	400	600	600

When the limitations of insertion loss at the LSM auto-negotiation rate are removed, the DP83TD510 can achieve greater cable reach. When utilizing the auto-negotiation feature, a DSP ANEG script can be run to achieve the same cable lengths seen in forced mode. The script is described below. This script writes to registers only in MMD 0x1F. If using the USB-2-MDIO tool configure the registers, verify that the *Extended Register* drop-down is set to *Yes*.

```
begin
001F 8000 // hard reset
08A6 04A8 // belden enable & IDX force enable
08A1 0D14 // FAGC disabled
08A4 0180 // FAGC init
08A5 0824 // DEQ offset = 2
08F0 0088 // IDX lim = 8, scaling factor for 7
08A2 7A66 // ADC BO aneg
08A3 0552 // ADC BO aneg
001F 4000 // soft reset
end
```

5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (October 2020) to Revision A (April 2021) **Page**

- Updated 1,700 meters to 2,000 meters throughout the document.. 1
- Updated ...*building automation and intrinsic safety applications* to… *factory and process automation, including intrinsic safety applications*...2
- Updated by combining two tables into one with updated parameters... 5