Introduction

There has been a move to replace the fieldbus in automotive and industrial applications to a two wire Ethernet based system, increasing the data throughput in addition to simplifying device management by using a single physical layer protocol.

In response, the IEEE association released amendments detailing Single Pair Ethernet (SPE) along with a protocol to inject power over this system, reducing the cost of running power lines. The new specification covering a method to inject power over SPE is known as Power over Data Lines (PoDL).

Due to the relative infancy of SPE and more so it's limited deployment into everyday applications at present, Silvertel does not currently produce any modules designed to operate to the PoDL specification. However, for a proprietary implementation, Silvertel PoE modules are suitable, and this application note covers the use of Silvertel's existing PoE modules to provide power to a system using SPE.

PoE for SPE

PoE and PoDL are not interoperable; they have a different supply voltage range and power class levels and detection methodology. However, in a closed system, where all elements are controlled, it is possible to supply power over SPE to devices using Silvertel's existing range of PoE modules.

The primary consideration when incorporating a PoE system over SPE is to ensure that the data transmission is not being compromised. In standard PoE applications, noise introduced as a result of the addition of power onto the data carrying conductors is common across each of the signal pairs, allowing the injection and extraction of this power to be simply performed using the centre taps of signal transformers with little impact to the data integrity.

When it comes to SPE, with only two conductors present, the power has to be injected across the same two conductors being used for the data signals. This means that to integrate and extract the power from the data signals, filtering needs to be applied to separate the high frequency data signals from the DC power.

Silvertel has a range of different PoE modules for different power outputs and size requirements suitable for the majority of applications, this note will use the example of the Ag6120 in combination with the Ag9700, Ag53000 or Ag5400 families of PD modules, allowing applications of up to 30W.

Cabling

In PoE applications, in order to maintain the supply voltage reaching powered devices, the maximum loop resistance for PoE applications of Type 2 or greater (>20W) is 12.5Ω, this equates to transmitting power up to 100 meters over Cat5 cable using AWG 26 cabling.

With SPE, current is no longer flowing through four conductors, however the typical gauge of cable that is used will remain unchanged, as a result devices should be capable of being powered with cable lengths of up to 50m with no issue. If longer cabling lengths are required, either a higher gauge cable or higher supply voltage should be used to reduce increased transmission losses.

For comparison, the maximum loop length specified for PoDL is 6.5Ω for all applications, except for those in the 12V unregulated power classes, where it is lowered to 6Ω. This results in application distances of up to 25m with AWG 26 cabling, with the distance increasing with larger gauges.

SPE Filter

The filter used to integrate and extract the power from the cable (MDI) will consist of two DC blocking capacitors and two inductors. These create a high pass filter for the data path. The corner frequency of this filter is dictated by the value of the 50Ω termination resistors and the data signal droop requirement, detailed lower in this application note.

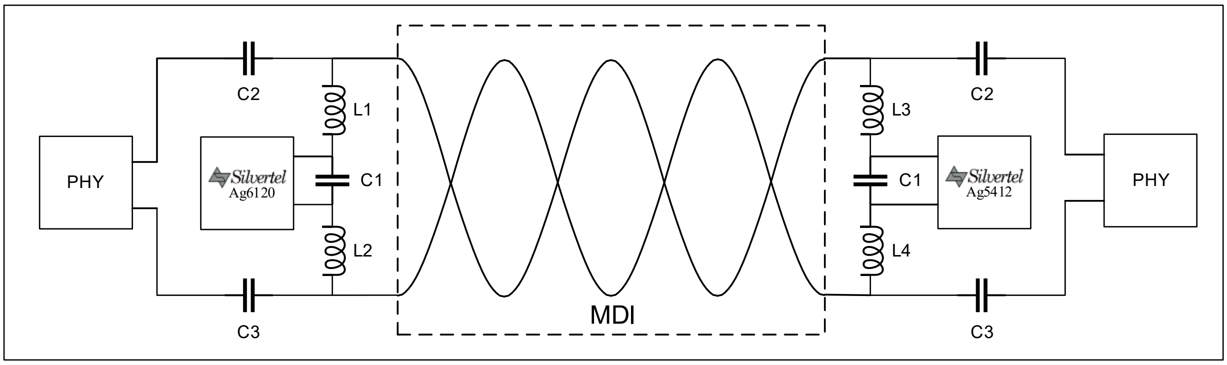


Figure 1

Inductor Selection

The Inductor has two functions, it creates a high pass filter with the termination resistor, and reduces the droop seen in the data signal.

Ideally the inductors used in the filters should be matched i.e. L1 should match L2. This can best be achieved by using a coupled inductor, however this comes with added inter-winding capacitance. This can be reduced by choosing a coupled inductor with sectional windings. The use of two separate inductors of the same value can be a more cost and space effective option at the expense of worsened EMC performance resulting from any mismatch between the inductors.

With the incorporation of a DC blocking capacitor, the DC component of the data signal will exhibit a droop, this droop is inversely proportional to the inductance value of the filter, and as a result can be reduced by selecting a larger inductance.

Both the 100Base-T1 and 1000Base-T1 standards use Pulse Amplitude modulation 3 (PAM3) as the standard encoding system. This system implements a state transition protocol that prevents more than five consecutive non-zero symbols from being transmitted. In addition to this the specification for 1000Base-T1 stipulate that the droop should be no more than 27% over 500ns, while for 100Base-T1 this should be no more than 45% over the same time period of 500ns. If these droop requirements are met the signal voltage level should not drop enough for incorrect data to be received.

For this demonstration the stricter droop requirement of 27% over 500ns will be used.

$$L \geq \frac{-R \times t_{droop}}{Ln(1 - \Delta Droop)}$$

Equation 1

Using Equation 1, with a termination resistance of 50Ω a t_{droop} of 500ns and a ∆Droop of 0.27, the inductor of the filter should be at least 79.4µH.

When selecting the inductors, care should be taken with regards to the return loss that will be imposed on the data signal, large value inductances will have a favourable loss characteristic at low frequencies but may have a detrimental impact at high frequencies. Additionally, the inductors' current rating and DC resistance should be considered, as overrating these can lead to choosing inductors that use a heavier gauge wire which will have higher parasitic capacitances, lowering the self-resonant frequency and as a result, worsening the return loss at higher frequencies.

One method of achieving the required filter inductance while maintaining the return loss requirement across a broad frequency range is to implement a cascade inductor network of increasing inductor value, widening bandwidth of the return loss. The filter inductors with the highest self-resonant frequency should be the closest filter components to the MDI.

This inductor network will need decoupling to dampen any resonant interaction.

To achieve operation with 10Base-T1L, 100Base-T1 and 1000Base-T1, the chosen network will contain a cascade network of 68µH, 10µH, 1.5µH inductors and a ferrite bead, giving a total inductance of 79.5µH.

Capacitor Value

The filters capacitor affects the damping ratio of the network, this can be critically dampened or, for a broader bandpass response, over-dampened. The capacitance value can be calculated by Equation 2.

$$C \geq \frac{4L\tau^2}{R^2}$$

Equation 2

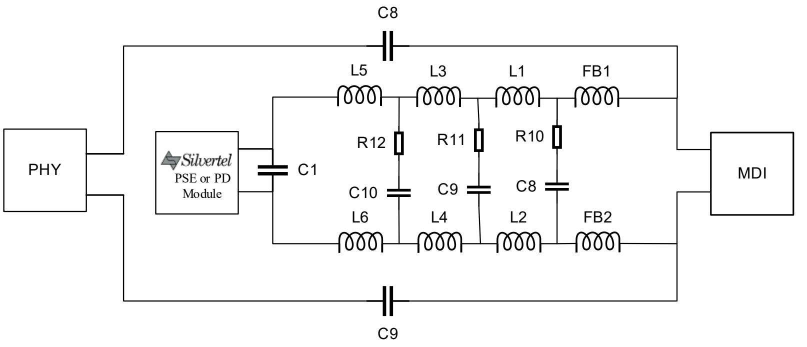
Using the values above, the value of the capacitor should be at least 127nF for a critically dampened network, i.e. τ= 1.

It is important to note that these capacitors will be biased by the supply voltage for the PoE power delivery, up to 57V÷2, resulting in a derating of their effective capacitance. An appropriate capacitor should be chosen that maintains its capacitance while biased. For best performance NP0 ceramics should be used for their stability with bias voltage and temperature.

Choosing a capacitor value of 150nF 50V NP0 capacitor will provide a stable overdamped network that will not vary with temperature or voltage. A cheaper alternative would be to use a 220nF 100V X7R in a 1210 package, this should provide suitable dampening.

Filter Design

The final filter design for integrating PoE over an SPE connection as shown in Figure 2, this filter should allow for data rates of up to 1Gbps.



Device	Value
L1, L2	1.5μH
L3, L4	10μH
L5, L6	68μH
FB1, FB2	1KOhm @100MHz
C3	10nF
C6, C7	150nF
C8, C9, C10	8.2pF
R10, R11, R12	2.4KΩ

Figure 2

Limitations

10BASE-T1L has a transmission frequency ranging from 0.1 to 20 MHz and 100BASE-T1 has a transmission frequency ranging from 0.3 to 66 MHz. When using an inductance of 79.5μH, the corner frequency of the filter, as per Equation 3, will be 100KHz. While this will allow for full operation across the frequency range of the SPE standards, it is below the switching frequency of the DCDC convertor in our modules, this cannot be changed without reducing the inductance such that the droop requirement is not met. Our testing has shown that the data transmission is not impacted.

$$F_{c2} = \frac{R}{2\pi L}$$

Equation 3

Conclusion

The purpose of this application note is to demonstrate how Silvertel's existing PoE product range, together with the filter requirements defined within, can offer a proprietary end-to-end solution for integrating power in an SPE application, reducing the cabling costs and eliminating the need for running power to hard-to-reach locations.

Silvertel also offer bespoke and custom solutions based on volume and work with a global blue-chip customer base.

For further information and assistance on your SPE implementation using Silvertel modules, contact Applications Support on apps.support@silvertel.com

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Silver Part No.	Description	Value	Location:	Qty:	Package:	Rating:	Tol:	Supplier Pt NO:	PSE	PD
	PoE PD Module	PoE Module	U1	*See Table	Custom	-	-	Silver Telecom Part	Ag6120	Ag5300
	Bridge Rectifier	CD-HD201, MBS4	BR1	*See Table	SMT	-	-	Bourns	0	1
	Protection Diode	SMAJ58A	D1	1	SMA	-	-	Vishay, ST Micro, Diodes Inc	-	-
	Zener Diode	BZX384C30V	D2	*See Table	0805	-	-	Vishay	BZT52C30	0R
	SM LED	RED LED	LED1	1	SMT	-	-	Wurth - 150 141 RS7 310 0	-	-
	Inductor	7447649015	L1. L2	2	SMT			Wurth	-	-
	Inductor	SDR0403-100ML	L3, L4	2	SMT			Bourns	-	-
	Inductor	SDR0805-680KL	L5, L6	2	SMT			Bourns	-	-
	Ferrite Chip	≥1000Ω@100MHz	FB1, FB2	2	0805	≥ 1A	25%	TDK MPZ2012S102A, Wurth 742792096	-	-
	Capacitor Electolytic	220μF/470μF	C1	*See Table	Through Hole pitch:5mm	-	20%	Wurth	860020775019	860040475008
	Ceramic multi-layer	10uF	C2	1	1206	100V	20%	Samsung, NIC, TDK, Murata, Kemet & AVX	-	-
	Ceramic multi-layer	10nF	C3	1	1206	100V	20%	Samsung, NIC, TDK, Murata, Kemet & AVX	-	-
	Ceramic multi-layer	1000pF 2KV	C4, C5	*See Table	1206	2KV	20%	Samsung, NIC, TDK, Murata, Kemet & AVX	0	2
	Ceramic multi-layer	150nF/220nF	C6, C7	2	1210	100V	NP0	C1210X154J5GACTU, QMK325B7224KN-T	-	-
	Ceramic multi-layer	8.2pF	C8-C10	3	0603	100V	NP0	Samsung, NIC, TDK, Murata, Kemet & AVX	-	-
	Resistor - 0805	249R	R1	*See Table	0805	125mW	1%	Royal Ohm, Eurohm & Yageo	0	1
	Resistor - 0805	68K	R2	*See Table	0805	125mW	1%	Royal Ohm, Eurohm & Yageo	0	1
	Resistor - 1206	0R	R3	*See Table	0805	125mW	1%	Royal Ohm, Eurohm & Yageo	0	1
	Resistor - 0805	2.4K	R5	1	0805	125mW	1%	Royal Ohm, Eurohm & Yageo	-	-
	Resistor - 1206	0R	R6-9	*See Table	1206	125mW	1%	Royal Ohm, Eurohm & Yageo	4	0
	Resistor - 0603	2.4K	R10-R12	3	0603	100mW	1%	Royal Ohm, Eurohm & Yageo	-	-
	SPE Connector	9452812800	J1, J2	2	Through Hole	-	-	Harting	-	-
	DC Power Connector	DC-001	J3	1	Through Hole	-	-	Toby DC-001-B-2.5MM-R	-	-
	Link	3 Way	LK1	*See Table	Through Hole	-	-	Toby LHCS-03S-R-060-034, Wurth 61300311121	0	1
	Module Socket	4 Way	U1a	*See Table	Through Hole	-	-	Toby SLW-104-01-G-S	0	1
	Module Socket	7 Way	U1b	1	Through Hole	-	-	Toby SLW-107-01-G-S	-	-
	PCB	Rev.2 -65.0mm x 61.0mm			-	-	-	Silver Telecom Part	-	-
	Jumper Links	Links	-	*See Table	-	-	-		0	1
	Feet	Sticky Feet	-	4	-	-	-	Affix RF-022, SJ-5003		