Optional “Engineered” Power for 10BASE-T1S Multi-drop Ethernet

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January, 2018

Purpose of This Presentation

- G. Zimmerman and P. Jones' Presentation
  - No base line for optional multi-drop power distribution objective
- Initiate the discussion on multi-drop power

Objectives Change Goals

- Two link segments (15m & 1000m)
- One mixing segment (25m)
- Two PHYs
  - One supporting
    - half-duplex over 15m link segment
    - optional full-duplex over 15m link segment
    - optional half-duplex multidrop over 25m mixing segment
  - One supporting
    - full-duplex over 1000m link segment
- Optional power distribution –
  - over 15m link segment
  - over 1000m link segment
- Optional Multidrop power distribution (*No current BASELINE)
  - over 25m mixing segment

Content

- Engineered multidrop power
  - Multi-drop power modeling
  - Multi-drop power verification method
  - Multi-drop power verification examples using power verification method

- Initial thoughts on multi-drop power and 10BASE-T1S

“Engineered” Multi-drop Power System

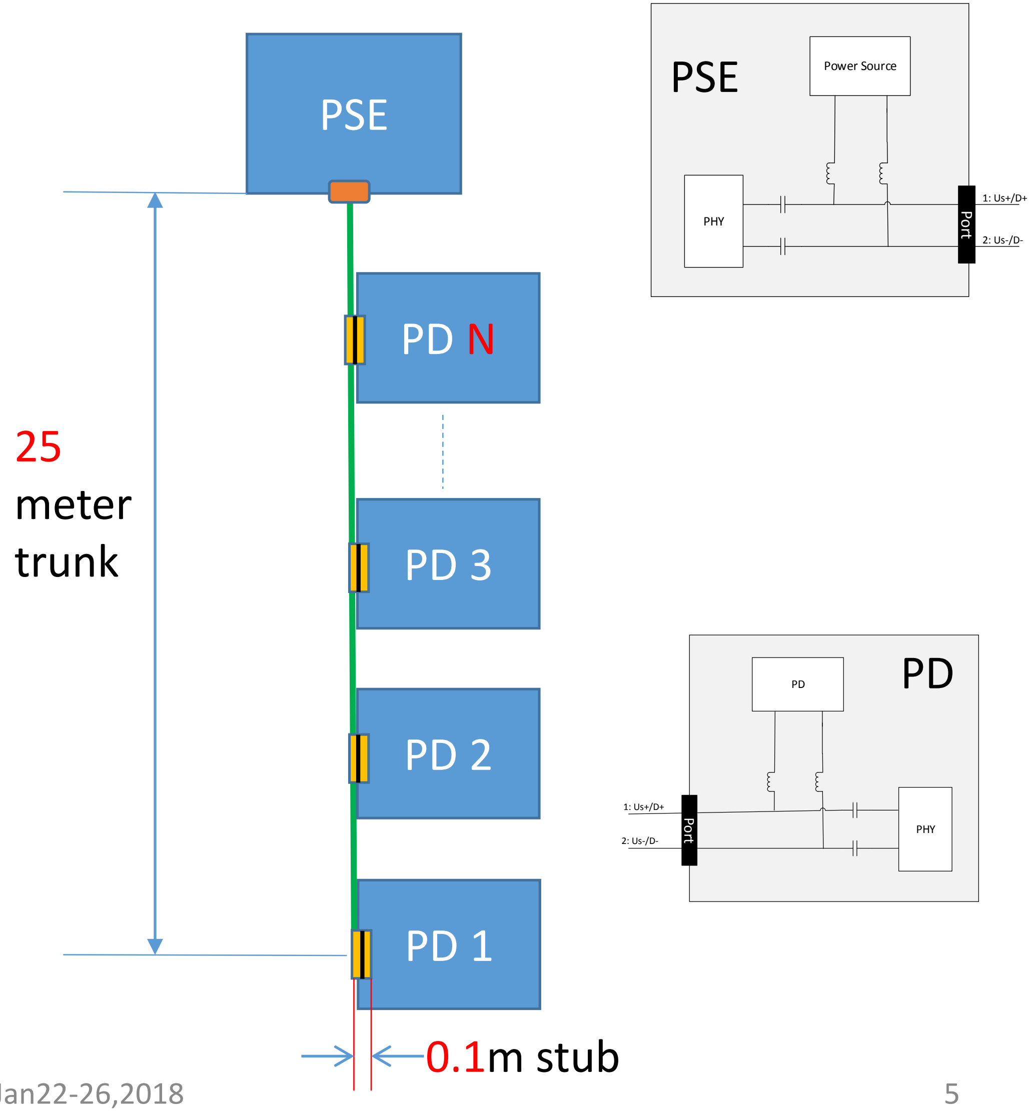
- “engineered” power system
  - Known PDs and PDs’ power requirements
  - Known cable length and type and PD position
- Power up directly
  - No power detection
  - No power classification
  - PSE should endure the in-rush current during power up
  - PD should limit the in-rush current during power up
- Power failure
  - PSE has overload protection
  - PD has low voltage monitoring

Multi-drop Power Topology

- PSE on one end
- PDs distributed along the trunk
- PDs are directly connected to stubs from the trunk

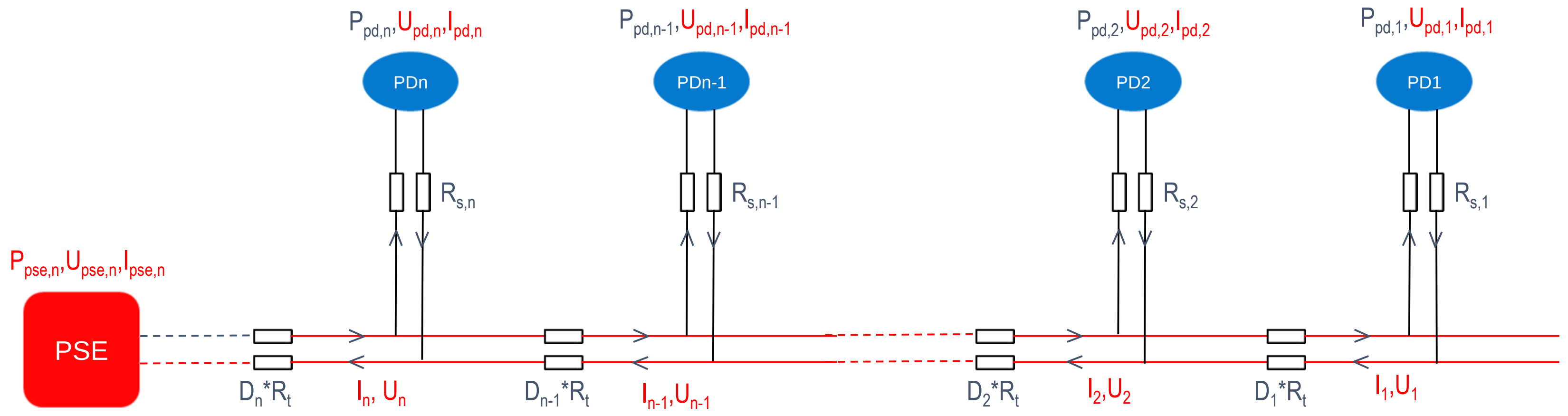
- Trunk length: 25m
- Stub length: 0.1m
- Number of PDs: TBD,7/15/31

- Assumption: Connection between Trunk and Stub is prebuilt and the trunk cable is continuous



Multi-drop Power Modeling

- Physical Topology
  - n, number of PDs
  - $D_1,\ldots,D_n$(m), Distance between PDs
  - R_t(ohms/m), Trunk Cable Type
  - $R_{s,1},\ldots, R_{s,n}$(ohms), Stub cable and connector
- PD's power, voltage and current
  - $P_{pd,1}, \ldots, P_{pd,n}; U_{pd,1}, \ldots, U_{pd,n}; I_{pd,1}, \ldots, I_{pd,n}$
- PSE's power, voltage and current
  - $P_{pse,n}, U_{pse,n}, I_{pse,n}$
- Junction point voltage and current
  - $U_1, \ldots, U_n; I_1, \ldots, I_n$



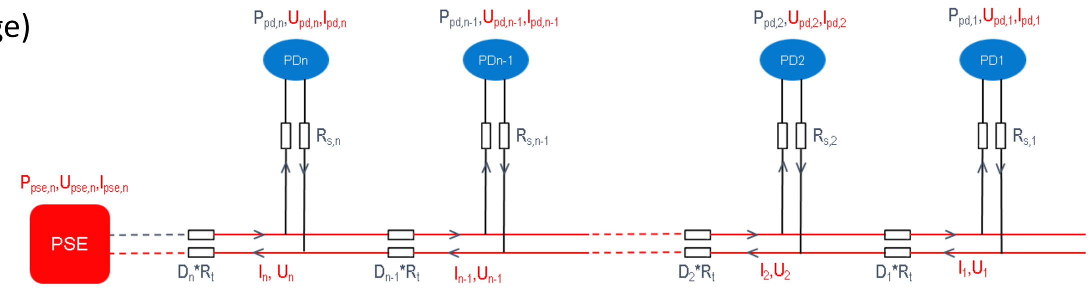
Multi-drop Power Verification Method

Determine whether a PSE can supply a given multi-drop power system

- Determine PDs' power requirements and multidrop physical topology
  - PD's power information: $P_{pd,1}$, …, $P_{pd,n}$ (PD's power consumption), $U_{pd,min}$ (PD's minimal input voltage)
  - Physical topology information: N (number of PDs), D_1,…,D_n (distance between PDs), R_t (trunk cable type), $R_{s,1}$,…,$R_{s,n}$(stub cable and connector)

- Determine PSE's capability and cable's current rating
  - $P_{pse,min}$ (PSE's minimum output power), $U_{pse,min}$ (PSE's minimum output voltage)
  - $I_{cable,max}$ (Cable's maximum current)

- Calculate demanded PSE's capability for a given multidrop power system
  - $P_{pse,n}$, $U_{pse,n}$, $I_{pse,n}$ (n=N) and corresponding power efficiency (e)
  - Calculation method in next slide



- Determine the verification results by comparing demanded PSE capability to real PSE's capability
  - PSE power limitation: If $P_{pse,N} > P_{pse,min}$, then PSE can not power N PDs because the power capability is not enough
  - Voltage drop limitation: Else if $U_{pse,N} > U_{pse,Min}$, then PSE can not power N PDs because the voltage is dropped too much along the trunk cable
  - Cable current limitation: Else if $I_{pse,N} > I_{cable,max}$, then the demanded current surpasses the current rating of the trunk cable
  - Success: Else, PSE can power N PDs successfully

Method to Calculate Demanded PSE Capability

- Known PDs' power and PDs' input voltage
  - For example, $P_{pd,1} = P_{pd,2} = \dots = P_{pd,n} = 1.0W$
  - For example, $U_{pd,1} = U_{pd,2} = \dots = U_{pd,n} = 11.0V$
- Calculate demanded PSE capability using iterative equations here for a given topology ($D_1,\dots,D_n$, R_t, $R_{s,1},\dots,R_{s,n}$)
  - $P_{pse,n}$, $U_{pse,n}$ and $I_{pse,n}$

$U_{pse,n} = U_n + I_n * 2 * D_n * R_t$
$I_{pse,n} = I_n$

$P_{pse,n} = U_{pse} * I_{pse}$
$e = (P_{pd,1} + \dots + P_{pd,n}) / P_{pse,n}$

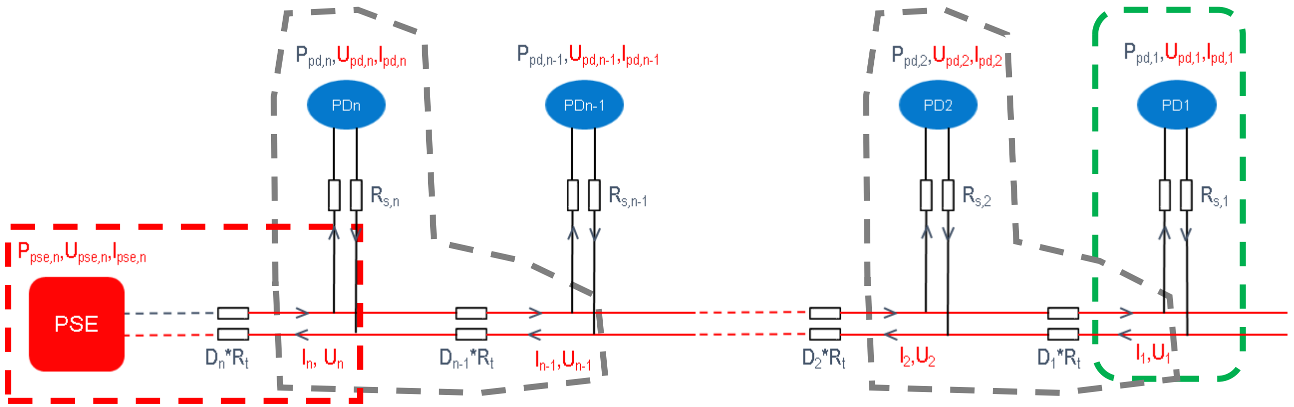
$U_n = U_{n-1} + I_{n-1} * 2 * D_{n-1} * R_t$

$I_n = I_{n-1} + I_{pd,n}$

$I_{pd,n} = (U_n - Sqrt(U_n * U_n - 8 * R_{s,n} * P_{pd,n}) / 4 * R_{s,n}$

$U_{pd,n} = U_n - I_{pd,n} * 2 * R_{s,n}$

$I_{pd,1} = P_{pd,1} / U_{pd,1}$,
$U_{pd,1} = 11.0$
$I_1 = I_{pd,1}$
$U_1 = U_{pd,1} + I_{pd,1} * 2 * R_{s,1}$



$U_{pd,n} * I_{pd,n} = P_{pd,n}$ **and** $U_{pd,n} = U_n - I_{pd,n} * 2 * R_{s,n}$
$\Rightarrow (U_n - I_{pd,n} * 2 * R_{s,n}) * I_{pd,n} = P_{pd,n}$
$\Rightarrow (2 * R_{s,n}) * I_{pd,n}^2 - U_n * I_{pd,n} + P_{pd,n} = 0$

Quadratic equation of one unknown
- $ax^2+bx+c=0$ ($a \neq 0$)
- $x = (-b \pm Sqrt(b^2-4ac))/2a$

$I_{pd,n} = (U_n - Sqrt(U_n * U_n - 8 * R_{s,n} * P_{pd,n}) / (4 * R_{s,n})$

Configurations for Case Study

Assumptions

- All PDs get the same power (e.g. 1.0W)
- All stubs' max loop resistance: 0.2ohm

Constraints

- PSE minimum output power: 72W = 24V*3A
- PSE minimal output voltage 21.6V = 24.0V*90%
- PD minimal input voltage: 11.0V

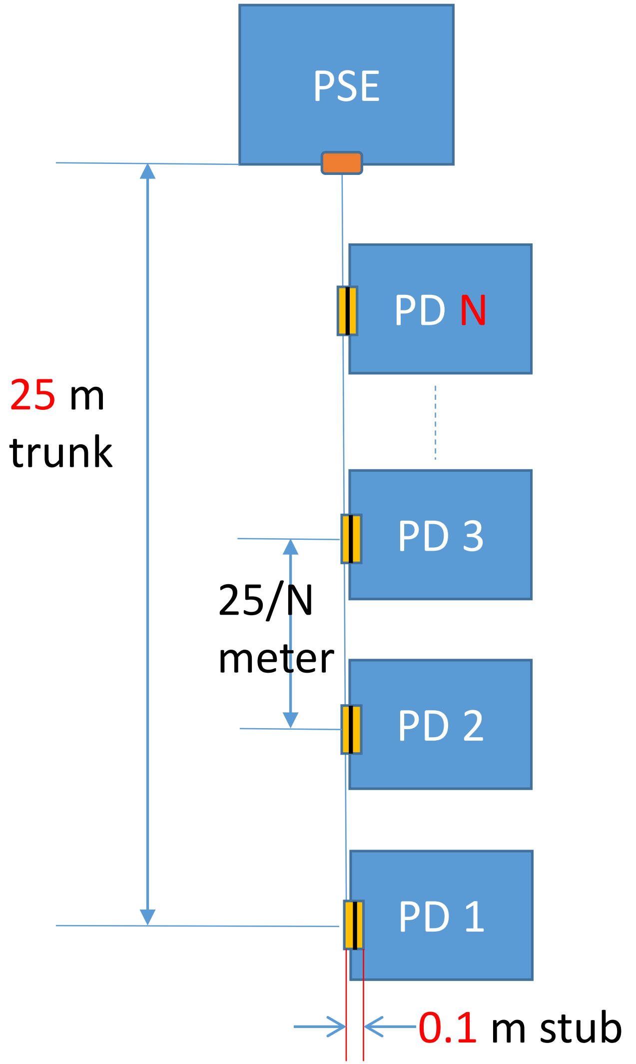
Variables

- Cable Types
  - Ethernet cable (AWG24,AWG22)
  - Fieldbus cable (AWG18)
- PD power level, cover typical sensors
  - 1W, 2.5W, 5W
- Number of PDs
  - 7, 15,31, industrial/lift use cases (24VDC)

Cable Type, R_t, (ohms/m per wire)	PD power, P_{pd} (W)	Number of PDs, N
0.0938 (AWG24)	1	31
	2.5	15
	5.0	7
0.0590 (AWG22)	1	31
	2.5	15
	5.0	7
0.0233 (AWG18)	1	31
	2.5	15
	5.0	7

Case1: Normal Topology

- Trunk cable length: 25 m
- Stub length: 0.1 m
- PDs are located uniformly along the trunk
  - Length of the trunk cable between neighbor PDs is same



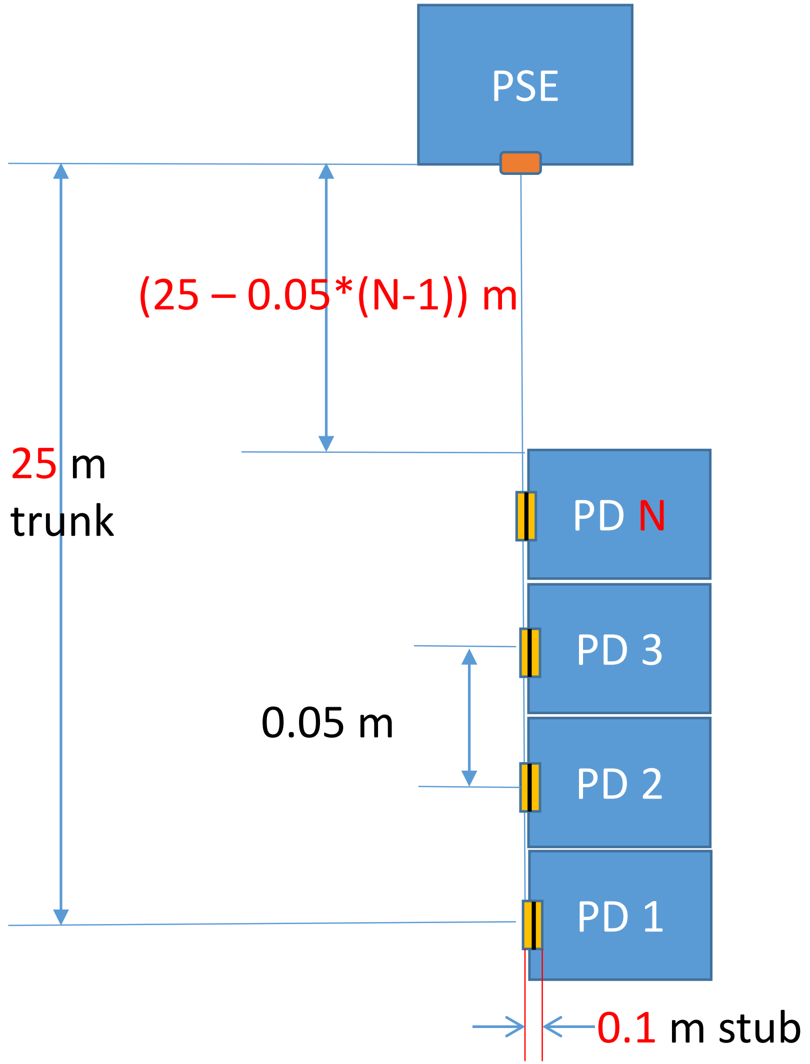
Data for Normal Topology

Trunk Length, L (m)	Trunk loop DCR, $R_{loop,max,trunk}$ (ohms)	Cable current limit, $I_{cable,max}$ (A)	Cable Type, R_t, (ohms/m per conductor)	PD power, $P_{pd,n}$ (W)	PD voltage, $V_{pd,n}$ (V)	Number of PDs, N	PSE output power (W)	PSE output voltage (V)	PSE Output current (A)	Power Efficiency (%)	Trunk loss (W)	Trunk loss Percentage (%)	Verification results
25	4.69	1 *2	0.0938 (AWG24)	1	18	18 *3	19.62	20.43	0.96	91.74	1.61	8.2	Limited by cable current
				2.5	18	7 *3	19.24	20.57	0.94	90.95	1.72	8.92	Limited by cable current
				5.0	18	3 *3	16.66	20.61	0.81	90.06	1.61	9.68	Limited by cable current
	2.95	2 *2	0.0590 (AWG22)	1	18	31(37*1)	33.92	20.57	1.65	91.41	2.90	8.54	Success
				2.5	18	15 (15*1)	41.95	21.21	1.98	89.39	4.40	10.48	Success
				5.0	18	7 (7*1)	39.36	21.24	1.85	88.92	4.26	10.83	Success
	1.16	4 *2	0.0233 (AWG18)	1	18	31(66*1)	32.20	19.04	1.69	96.27	1.18	3.67	Success
				2.5	18	15(26*1)	39.36	19.31	2.04	95.27	1.81	4.59	Success
				5.0	18	7(13*1)	36.85	19.33	1.91	94.97	1.75	4.75	Success

*1 Maximum number of PDs that PSE can power (for AWG22, limited by cable current; for AWG18, limited by PSE power)
*2 Values here are only for calculation, need discussions on what value should be used for variant use cases
*3 Fail to power the configured number of PDs because of the limit of the cable current

Case 2: Worse Case Topology

- Trunk cable length: 25 m
- Stub length: 0.1 m
- All PDs are on the far end of the trunk cable
  - Length of the cable between 2 PDs is 0.05 m



Data for Worse Case Topology

Trunk Length, L (m)	Trunk loop DCR, $R_{loop,max,trunk}$ (ohms)	Cable current limit, $I_{cable,max}$ (A)	Cable Type, R_t, (ohms/m per conductor)	PD power, $P_{pd,n}$ (W)	PD voltage, $U_{pd,n}$ (V)	Number of PDs, N	PSE output power (W)	PSE output voltage (V)	PSE Output current (A)	Power Efficiency (%)	Trunk loss (W)	Trunk loss Percentage (%)	Verification results
25	4.69	1	0.0938 (AWG24)	1	18	18*	22.58	22.61	0.998	79.72	4.57	20.23	Limited by cable current
				2.5	18	7*	21.92	22.56	0.972	79.84	4.39	20.03	Limited by cable current
				5.0	18	3*	18.29	21.95	0.833	82.00	3.24	17.75	Limited by cable current
	2.95	2	0.0590 (AWG22)	1	15	30*	41.28	20.72	1.99	72.68	11.25	27.26	Limited by cable current
				2.5	15	12*	41.65	20.89	1.99	72.02	11.59	27.82	Limited by cable current
				5.0	15	6*	41.83	20.93	1.99	71.71	11.73	19.08	Limited by cable current
	1.16	4	0.0233 (AWG18)	1	18	31	34.33	19.96	1.72	90.31	3.31	9.64	Success
				2.5	18	15	42.51	20.42	2.08	88.21	4.95	11.65	Success
				5.0	18	7	39.47	20.3	1.94	88.67	4.37	11.06	Success

* Fail to power the configured number of PDs because of the limit of the cable current

Observations

- For the given 72W PSE@24V and 25m multi-drop power system with 31 PDs@1W or 15 PDs@2.5W or 7 PDs@5W
  - For AWG18 cable, system can work in worst case topology with big margin
  - For AWG22 cable, system can work in normal case topology with no margin, but can not work in worse case topology because of the limit of the cable current
  - For AWG24 cable, system can not work in normal case topology because of the limit of the cable current

- Trunk cable's voltage drop is not a limit due to the short length (25m)
- Larger conductor gets better power efficiency
- The more PDs close to PSE, the better power efficiency
- Stub's power loss can be ignored due to very short length (0.1m)

Current Progress on Power Objectives

- Define new P2P PoDL types for 10BASE-T1L
  - Already had baseline including power class and power parameters
  - C. Diminico's presentation on power class
  - S. Graber's presentation on power parameters

Class	Vpse, min V	Ipi, max (A)	Rloop (60C) ohm	Ppd (1000m) W
new 1	20	.102	59	1.4
new 2	20	.155	39	2.2
new 3	50	.255	59	8.9
new 4	50	.388	39	13.6

Summary

- An easy path for implementing a powered 10BASE-T1L structure would be to adopt the parameters which are required for PHY interoperability in the PoDL standard:
  - MDI Return Loss (tbd)
  - Maximum noise/ripple voltage (e.g. 100 mV_{pp})
  - Maximum in-band noise/ripple voltage (e.g. 10 mV_{pp})
  - Provide adopted corner frequencies for noise/ripple voltage measurement (e.g. f_1 = 3.18 kHz, f_2 = 100 kHz)
  - PSE output voltage slew rate (e.g. 2 V/ms)
  - PD input voltage slew rate (e.g. 2 V/ms)
  - PD input current slew rate (e.g. 100 mA/ms)
  - Adopt maximum loop resistance (e.g. 40 to 45 % maximum voltage drop across the cable)
  - Add new PoDL types (e.g. one for the 10BASE-T1L PHY and one universal type for 10/100BASE-T1(L))
- For point-to-point systems, which benefit from the PoDL features this allows an easy path to support the 10 MBit/s PHYs.
- For engineered systems including daisy-chain and multi-drop topologies, a good approach could be to take all relevant parameters from Clause 104, but do not implement the probing or classification sequences from PoDL (and just power up the devices, as it is known, what is there).
- For plug-and play point-to-point systems PoDL seems to be a good choice also for 10 MBit/s speeds.

- Define new P2P PoDL types for 10BASE-T1S
  - No baseline, but similar to 10BASE-T1L

- Define multidrop PoDL for 10BASE-T1S
  - No baseline, and significantly different from P2P PoDL

Mixed PoDL Systems?

- Multidrop PoDL is different from P2P PoDL
  - One PSE power multiple PDs over a mixing (multidrop) link segment
- Would multidrop PoDL devices mix with P2P PoDL devices?

	ID	Description
Normal cases	Case 1	A multidrop PD plugged onto a stub of a multidrop network (mutidrop PSE)
	Case 2	A p2p PD plugged onto a p2p segment (p2p PSE)
Abnormal cases	Case 3	A p2p PD plugged onto a stub of a multidrop network (multidrop PSE)
	Case 4	A multidrop PD plugged onto a p2p segment (p2p PSE)

Preserve Data Communication Integrity

- The power parameters that impact data communication for p2p PoDL is conceptually applicable to multidrop PoDL

- PSE parameters
  - PSE ripple
  - PSE voltage transient

- PD parameters
  - PD ripple
  - PD voltage transient
  - PD current transient
  - PD input capacitor

PSE parameters might be same to p2p PSE's, however PD's parameters should consider sum of each PD parameter as a factor to communication

Additional Thoughts on Multidrop Power

- Preserve power operation
  - PD voltage rating (maxim voltage to withstand, minimum voltage to operate)?
    - Need to consider voltage type (48V,24V,12V)?
  - PD power up inrush current?
    - PSE needs to consider all PDs' inrush current?
- Power class is "engineered"?
- Consider general fault tolerance requirement?
  - The wire pair of the MDI shall, under all operating conditions, withstand without damage the application of short circuits of any wire to the other wire of the same pair or ground potential or positive voltages of up to 50 V dc with the source current limited to 150 mA, as per Table 96–6, for an indefinite period of time. Normal operation shall resume after the short circuit(s) is(are) removed
- DC resistance of mixing segment (trunk and stub)?
- …

Summary

Conclusions

- Presented multidrop power modeling
- Presented a general multi-drop power verification method
- Examined multi-drop power examples using power verification method
- Discussed initial thoughts on multi-drop power and 10BASE-T1S

Need further Contributions

- Multidrop power specification approach
- Use cases (industrial automation, automotive, …) that should be considered for multidrop power
- Power parameters to preserve 10BASE-T1S PHY communication integrity including point-to-point and multidrop

Thank You!