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

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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 distribution proposal

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

- Multi-drop power modeling
- Multi-drop power verification method
- Multi-drop power verification examples using power verification method
- Multi-drop power class specification method and example
- Power parameters to operate with 10BASE-T1S including point-to-point and multidrop

“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

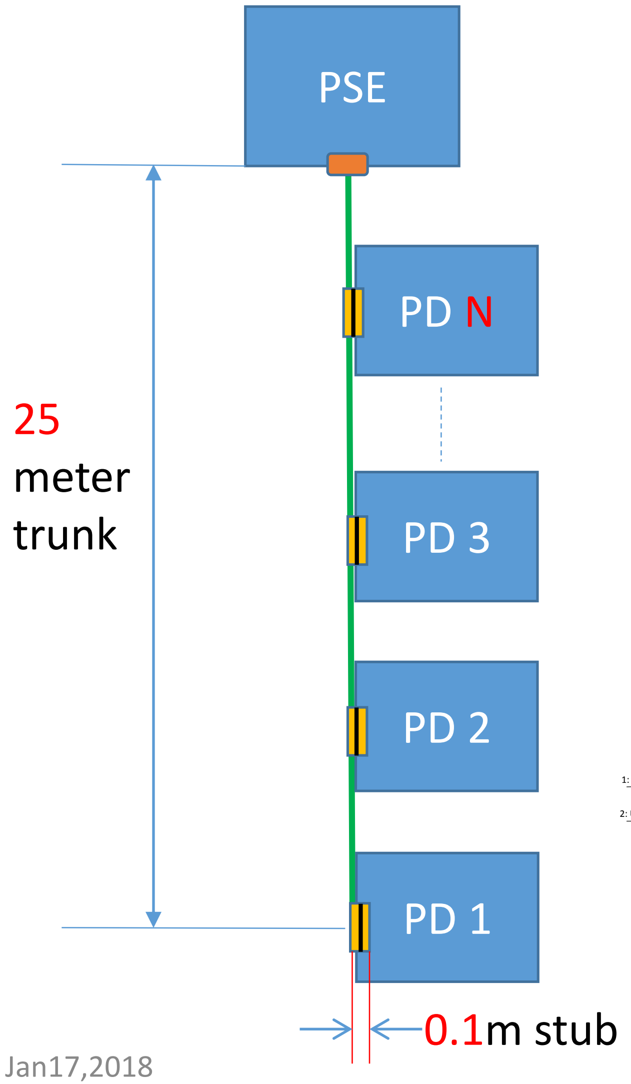
- Power failure
  - PSE has overload protection
  - PD has low voltage monitoring

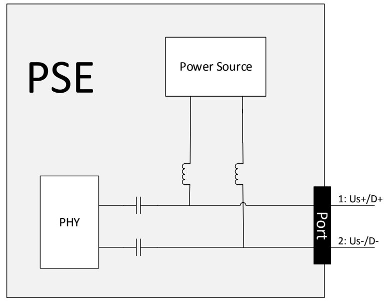
Multi-drop Power Topology

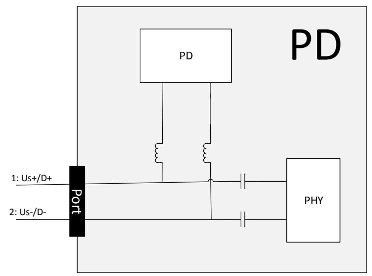
- PSE on one end
- PDs distributed along the trunk

- 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

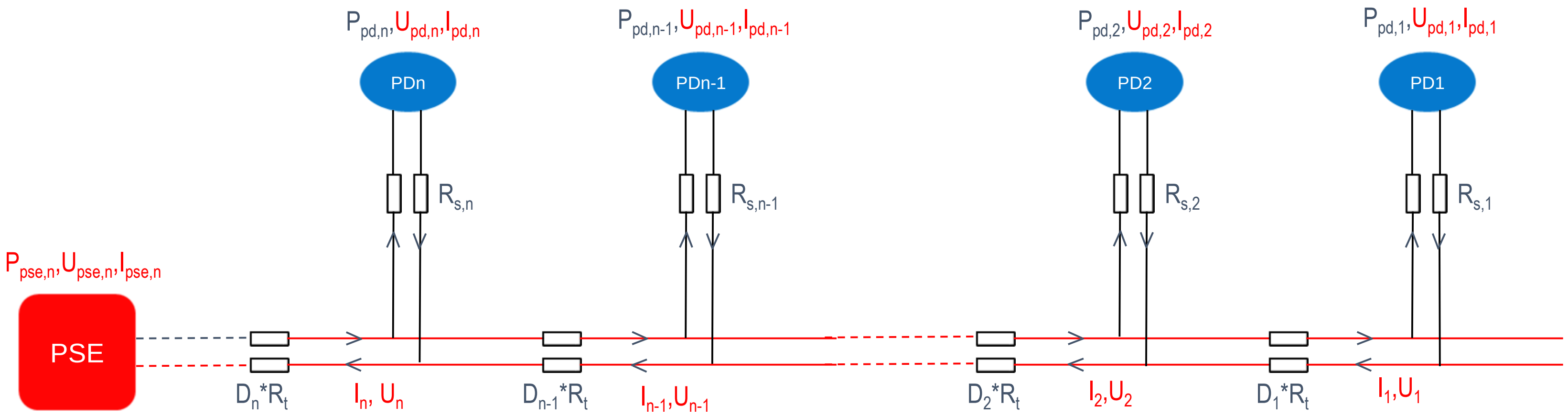






Multi-drop Power Modeling

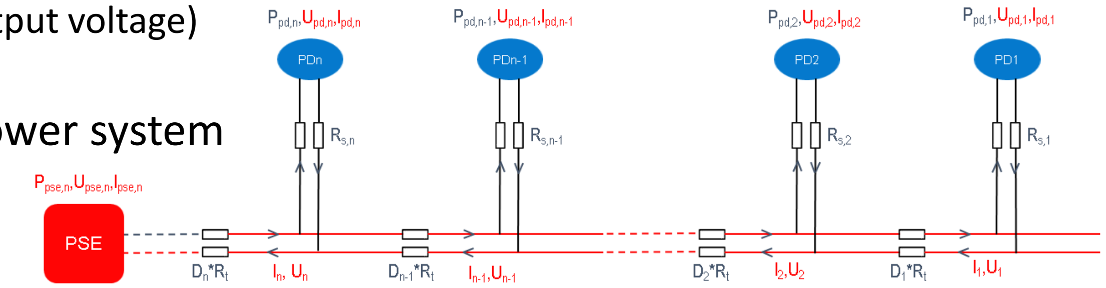
- Physical Topology
  - n, number of PDs
  - $D_1,\ldots,D_n$(m), Distance between PDs
  - R_t(ohms/m), Trunk Cable Type
  - $R_{s,1},\ldots, R_{s,n}$(ohms), Stub cable and connector
- PD's power, voltage and current
  - $P_{pd,1}, \ldots , P_{pd,n}; U_{pd,1}, \ldots , U_{pd,n}; I_{pd,1}, \ldots , I_{pd,n}$
- 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
  - $P_{pse,max}$ (PSE’s maximum output power), $U_{pse,min}$ (PSE’s minimum output voltage)
- 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
  - Power Limitation: If $P_{pse,N} > P_{pse,Max}$, 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
  - Success: Else, PSE can power N PDs

Method to Calculate Demanded PSE Capability

- Known PDs' power and PDs' minimal input voltage
  - For example, $P_{pd,1} = P_{pd,2} = \ldots = P_{pd,n} = 1.0W$
  - For example, $U_{pd,1,min} = \ldots = U_{pd,n,min} = 11.0V$

- Calculate demanded PSE capability using iterative equations here for a given topology ($D_1,\ldots,D_n$, R_t, $R_{s,1},\ldots,R_{s,n}$)
  - $P_{pse,n}$, $U_{pse,n}$ and $I_{pse,n}$

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

$I_{pse,n} = I_n$

$P_{pse,n} = U_{pse} * I_{pse}$

$e = (P_{pd,1} + \ldots + P_{pd,n}) / P_{pse,n}$

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

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

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

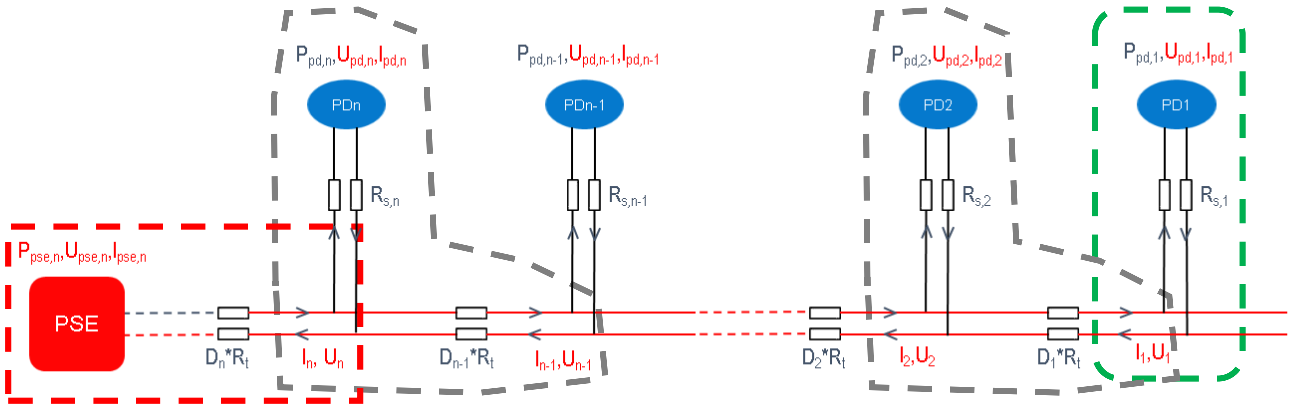
$U_{pd,n} = U_n - I_{pd,n} * 2 * R_{s,n}$

$I_{pd,1} = P_{pd,1} / U_{pd,1},$

$U_{pd,1} = 11.0$

$I_1 = I_{pd,1}$

$U_1 = U_{pd,1} + I_{pd,1} * 2 * R_{s,1}$



$U_{pd,n} * I_{pd,n} = P_{pd,n}$ 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 maximum output power: 72W = 24V*3A
- PSE minimal output voltage 21.6V = 24.0V*90%
- PD minimal input voltage: 11.0V

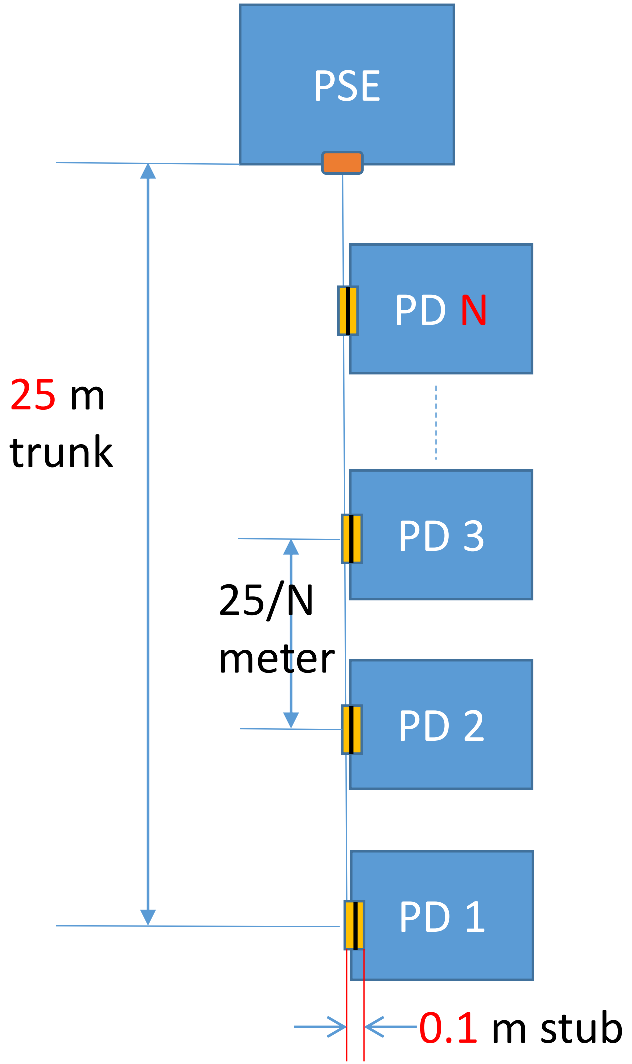
Variables

- 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



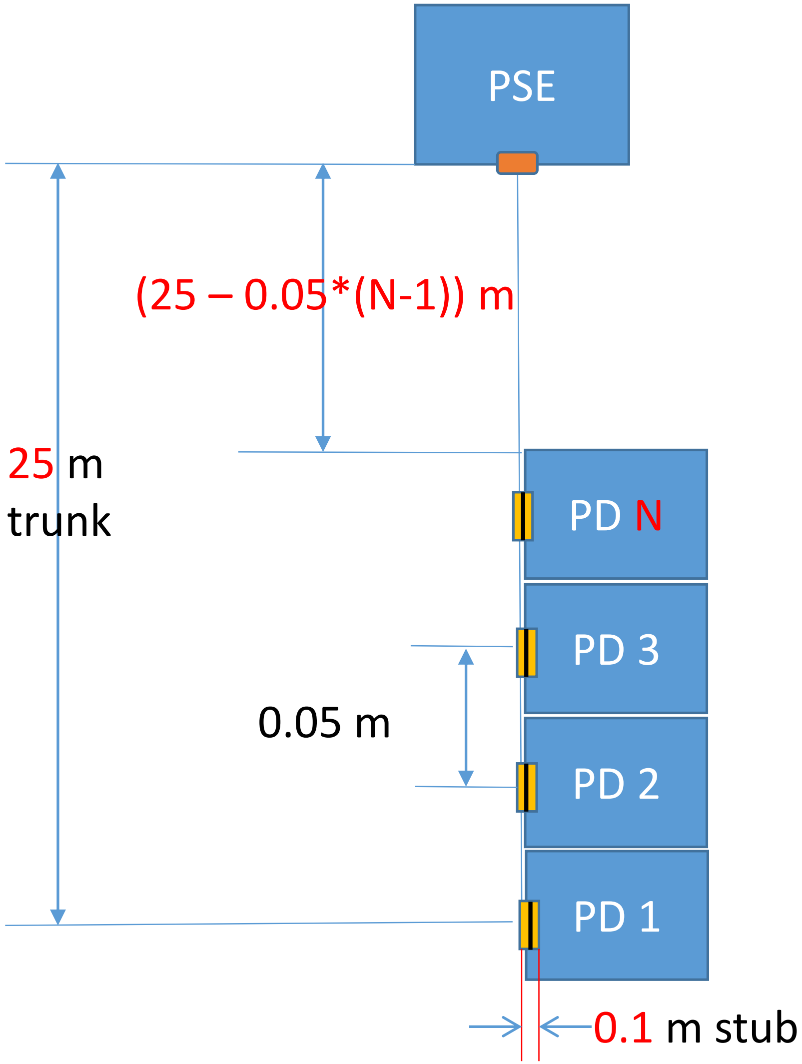
Data for Normal Topology

Trunk Length, L (m)	Trunk loop DCR, $R_{loop,max,trunk}$ (ohms)	Cable Type, R_t, (ohms/m per conductor)	PD power, $P_{pd,n}$ (W)	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	0.0938 (AWG24)	1	31(55*)	41.67	17.27	2.41	72.28	11.53	27.67	Success
			2.5	15(21*)	53.31	18.72	2.85	65.59	18.29	34.30	Success
			5.0	7(10*)	50.43	18.76	2.69	59.79	20.17	39.99	Success
	2.95	0.0590 (AWG22)	1	31(67*)	38.18	15.06	2.53	79.60	7.77	20.34	Success
			2.5	15(26*)	48.26	16.03	3.01	74.01	12.48	25.86	Success
			5.0	7(13*)	45.51	16.06	2.83	69.45	13.77	30.27	Success
	1.16	0.0233 (AWG18)	1	31(78*)	34.08	12.66	2.69	90.17	3.33	9.75	Success
			2.5	15(31*)	42.20	13.08	3.23	86.93	5.44	12.89	Success
			5.0	7(15*)	39.62	13.10	3.02	84.45	6.01	15.18	Success

* Maximum number of PDs that the PSE can power at corresponding configuration

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 Type, R_t, (ohms/m per conductor)	PD power, $P_{pd,n}$ (W)	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	0.0938 (AWG24)	1	30*	58.02	21.52	2.69	51.58	28.07	48.37	Voltage drop limitation
			2.5	12*	58.03	21.37	2.71	51.57	28.03	48.31	Voltage drop limitation
			5.0	6*	58.08	21.34	2.72	51.49	28.03	48.25	Voltage drop limitation
	2.95	0.0590 (AWG22)	1	31	53.17	19.01	2.80	58.22	22.19	41.73	Success
			2.5	15	70.91	20.89	3.39	52.78	33.40	47.10	Success
			5.0	7	64.59	20.34	3.18	54.07	29.50	45.68	Success
	1.16	0.0233 (AWG18)	1	31	39.85	14.18	2.81	77.74	8.84	22.19	Success
			2.5	15	50.81	14.93	3.40	73.34	13.26	26.10	Success
			5.0	7	46.82	14.73	3.18	74.66	11.70	24.99	Success

* Can not power expected number of PDs due to voltage drop limitation

Observations

- For a 25m trunk multi-drop power system
  - In any case A 72W PSE (24V, 3A) can power 31 PDs @1W each or 15 PDs @2.5W each or 7 PDs @ 5.0W each for a cable with less than 2.95 ohms trunk loop DC resistance (AWG22, AWG18)
    - There is big margin (around 20-30W or 3-8V) to the power or voltage drop limit
  - At most cases, A 72W PSE (24V, 3A) can power 31 PDs@1W each or 15 PDs @2.5W each or 7 PDs @5.0W each for a cable with 4.79 ohms trunk loop DC resistance (AWG24)
    - Voltage drop limitation occurs for the worse case topology
  - Larger conductor gets better power efficiency, and the more PDs close to PSE, the better power efficiency
  - Stub's power loss can be ignored due to very short length

Multi-drop Power Class Specification

- Parameters specified for power class
  - 10BASE-T1L Point-to-point, Diminico's presentation
    - $V_{pse,min}$, $I_{pi,max}$, R_{loop}, P_{pd}
  - 10BASE-T1S Point-to-Point, use 100BASE-T1 PoDL power classes?
  - 10BASE-T1S Multidrop?
    - PSE: $V_{pse,min}$, $I_{pse,max}$
    - DCR: $R_{loop,max,trunk}$, $R_{loop,max,stub}$
    - PD: $P_{pd,total,min} = N_{pd,max} * P_{pd,avg,min}$
    - Specify total minimal power delivered to all PDs and trunk and stub DC loop resistance?

Point-to-point power class

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

Multi-drop power class?

Class	$V_{PSE,min}$ (V)	$I_{pse,max}$ (A)	$R_{loop,max,trunk}$ (ohm)	$R_{loop,max,stub}$ (ohm)	$P_{pd,total,min}$ (W)
1					
2					
3					

Multi-drop Power Class Examples

Class	$V_{PSE,min}$ (V)	$I_{pse,max}$ (A)	$R_{loop,max,trunk}$ (ohm)	$R_{loop,max,stub}$ (ohm)	$P_{pd,total,min}$ (W)
1	21.6	2.50	4.69	0.2	37.5
2	21.6	2.25	2.95	0.2	37.5
3	21.6	2.0	1.16	0.2	37.5

Note: this table is inferred from case 1 normal topology. The data for worse case topology might be considered to specify the power classes so all cases can be covered

Multi-drop Power Parameters for Interoperation with 10BASE-T1S PHY

- Need contributions, Not addressed in this presentation

- Steffen Graber's presentation "10BASE-T1L PoDL Ideas" propose a method for 10BASE-T1L which could be a reference

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.

Summary

Conclusions

- Presented multidrop power modeling
- Presented a general multi-drop power verification method
- Examined multi-drop power examples using power verification method
- Proposed multi-drop power class specification method and examples

Need further Contributions from Task Force

- Experts' inputs on the power specification method
- Thoughts on multi-drop power classes that should be specified considering different use cases (industrial automation, automotive, …)
- Power parameters should be worked out for interoperation with 10BASE-T1S PHY including point-to-point and multidrop

Thank You!