Power Matters

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Power Capability vs. Wire Resistance

Reduced Twisted Pair Gigabit Ethernet PHY
Study Group
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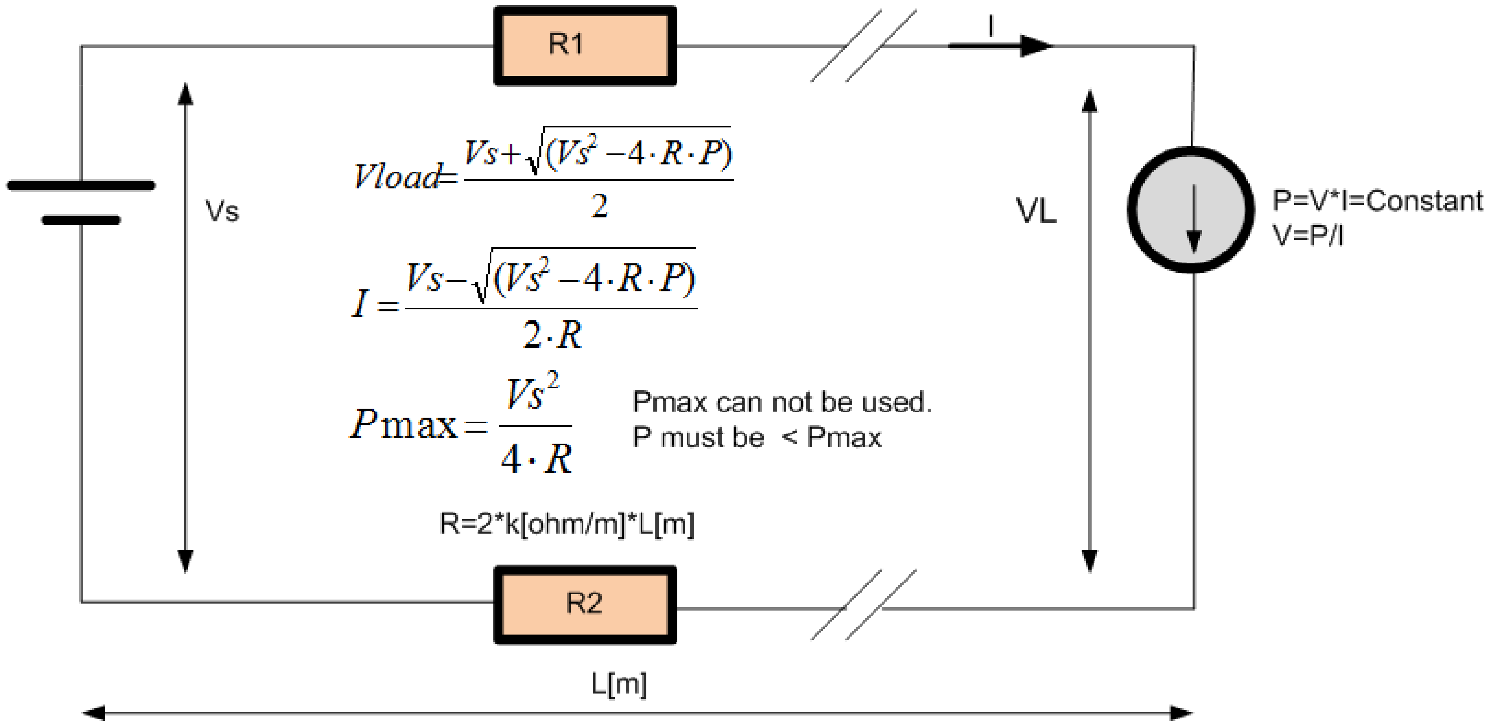
Objectives

- To review how pair wire resistance affects pair power capability for:
  - Different Source voltage
  - Different Loads
  - Different power channel resistance model
- How power capability may be increased

Background

- If power delivery is required together with cabling cost/weight reduction, using data pair wires for power delivery is a relevent approach.
- Since in the above case the power source is significantly far from the load, the source and load power system need to be analyzed with a remote power feeding model.
- Power source is current limited
- Cable length round trip =2*L with R resistance =R1+R2



$$Vload = \frac{Vs + \sqrt{(Vs^2 - 4 \cdot R \cdot P)}}{2}$$

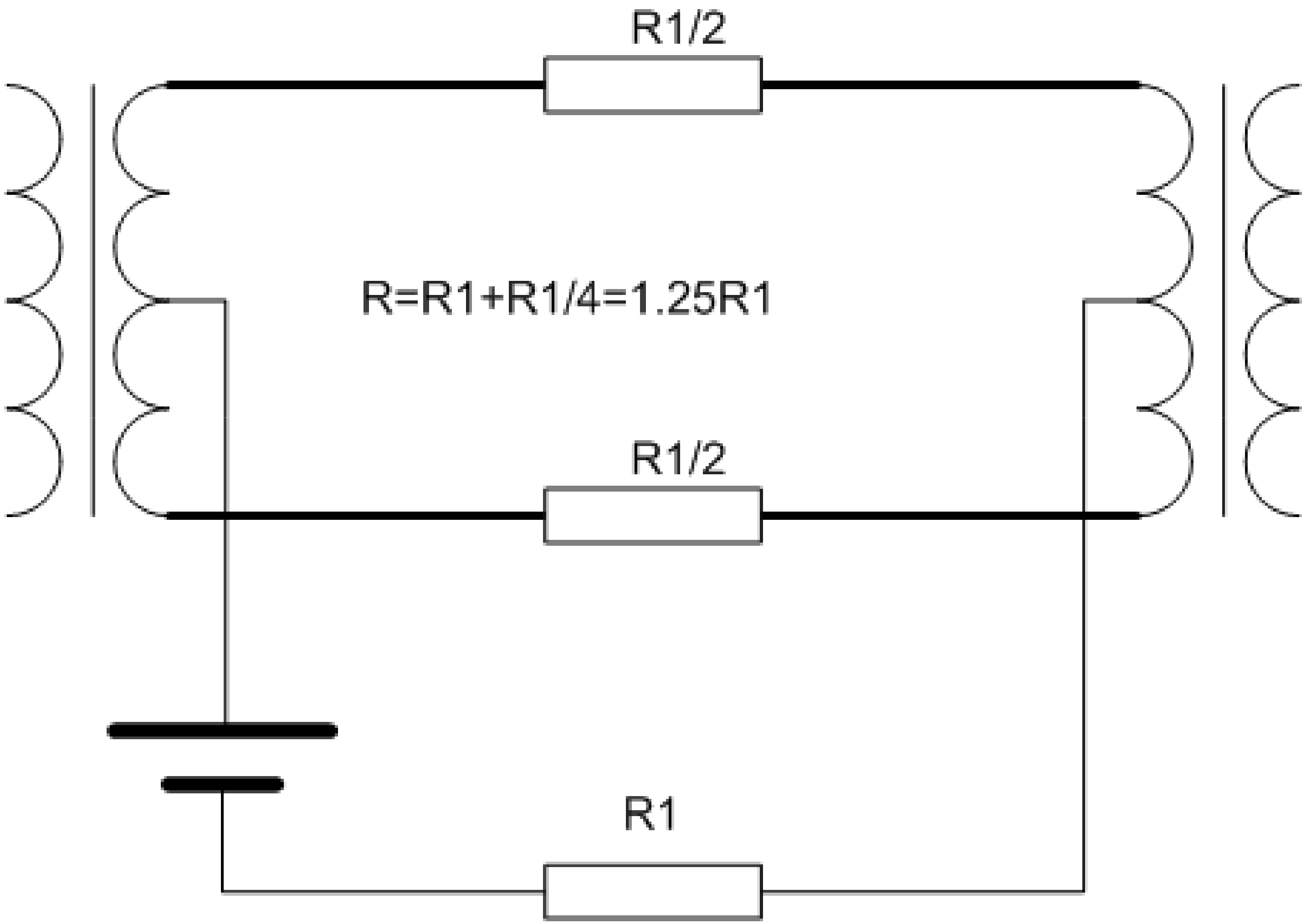
$$I = \frac{Vs - \sqrt{(Vs^2 - 4 \cdot R \cdot P)}}{2 \cdot R}$$

$$P\max = \frac{Vs^2}{4 \cdot R}$$

Terms used in this presentation

- Vs: Source Voltage
- VL: Load voltage
- R1, R2: Power bus wire resistance in both directions
- Pmax: is the maximum theoretical output power
- UVLO: Under Voltage Lock Out. Used to prevent shutting off the DC/DC converter due to voltage drop on the wires after DC/DC converter starts to consume power (Voff<Von).
- System Efficiency: The ratio between the power at the load to the power delivered by the source. Typically Efficiency=Eff>=0.8.
- Pactual: Is the practical output power which ensures operating point is at the stable operating region and allows design margins for UVLO function in DC/DC converters which is normally part of the load. Pactual=k*Pmax. K=~0.7.
  k may be reduced for achieving higher system efficieny.

One Pair Round Trip resistance Model

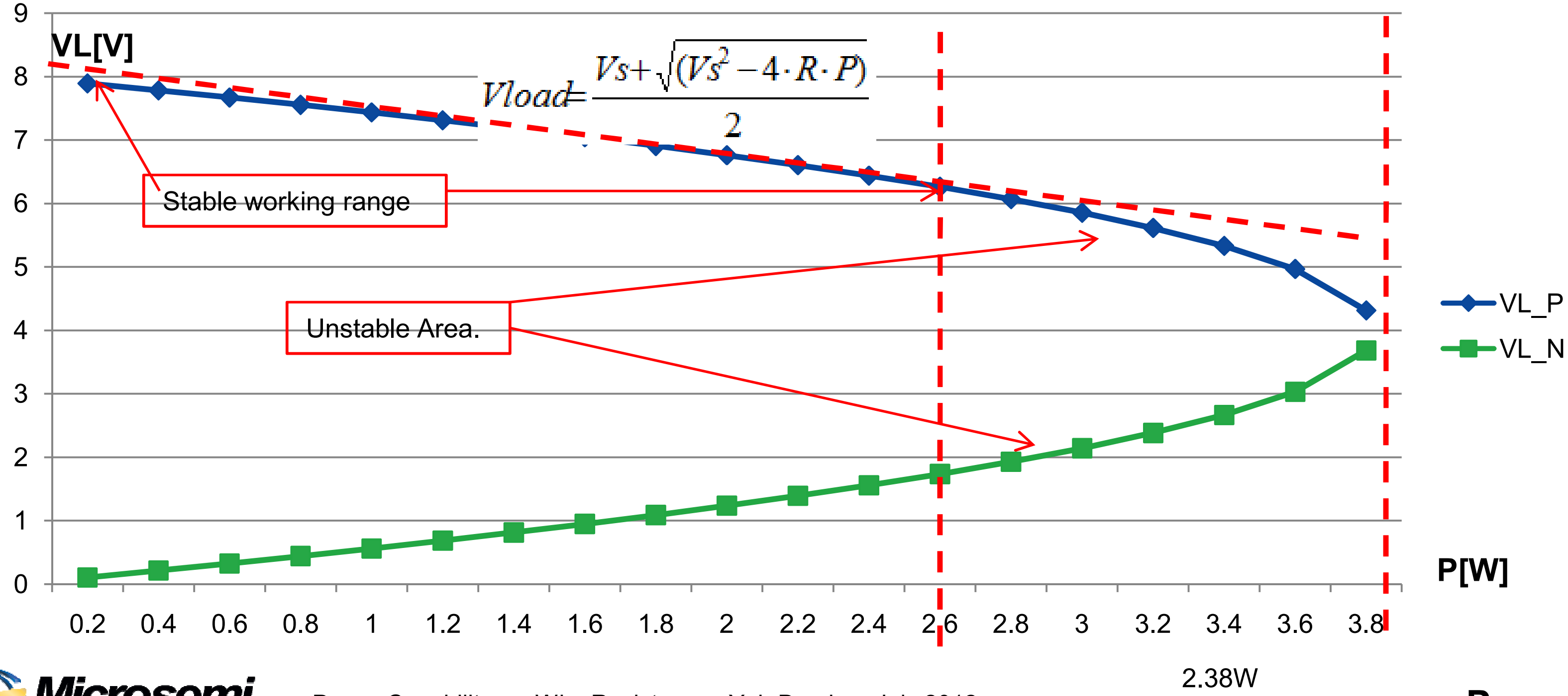


Load Voltage VL, vs. Load Power, P for one pair 25m AWG26, Vs=8V

- Complete Equation has two solutions (VL_P,VL_N) $$Vload = \frac{Vs \pm \sqrt{(Vs^2 - 4 \cdot R \cdot P)}}{2}$$
- Only positive (VL_P) range solution can be used due to stability considerations
- Plot of load voltage vs. load power for 8V source

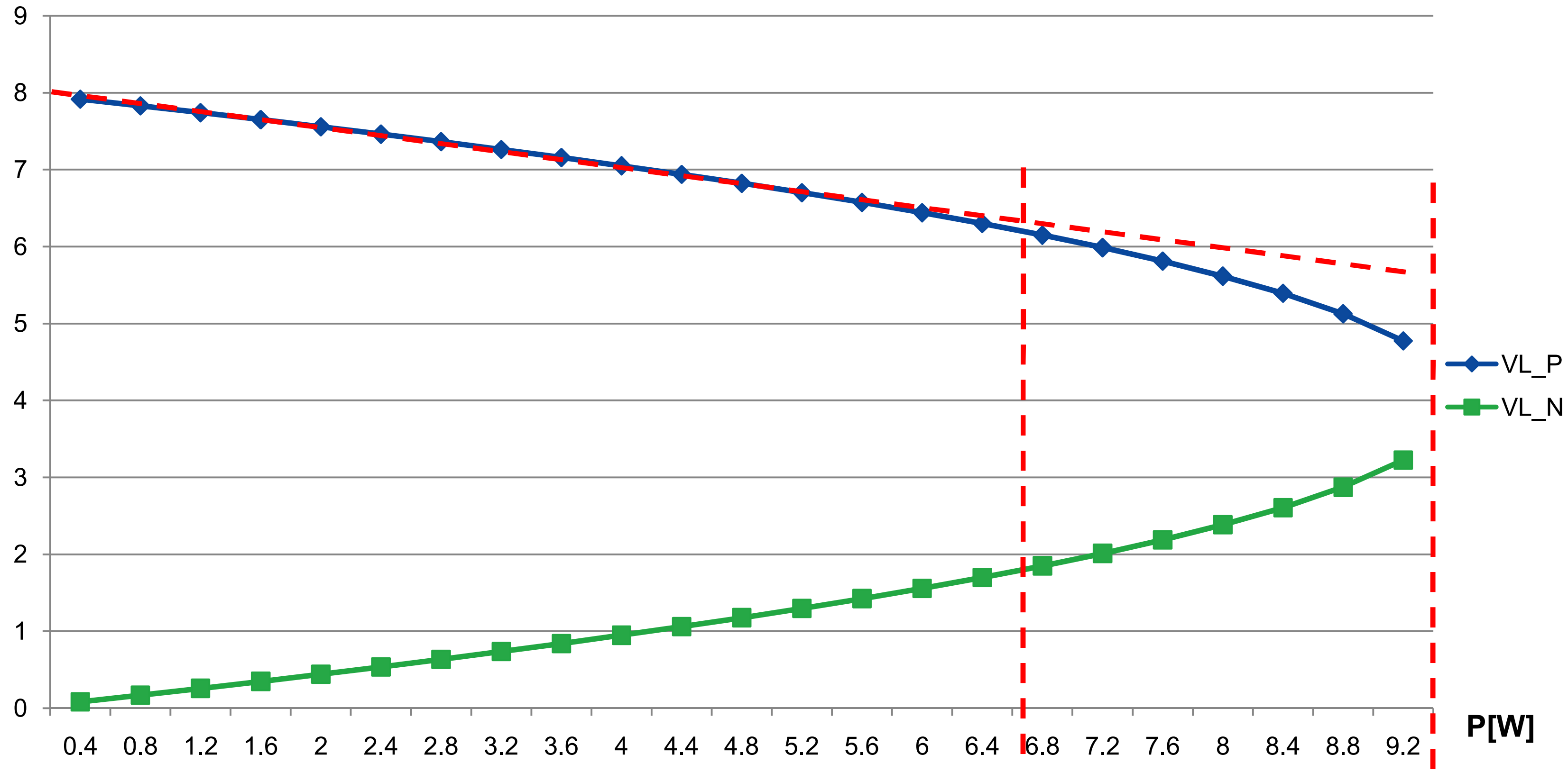
  and one 25m AWG26 pair of wires. Pmax=3.38W. Pactual=~2.67W (=~k*Pmax, k=0.7)

*Note: Pactual =~k*Pmax, k=0.7 is for stability and UVLO range margins. For keeping efficiency above 80%, lower factors than 0.7 should be used. With K=0.7, PD/PSE efficiency~=77%.*



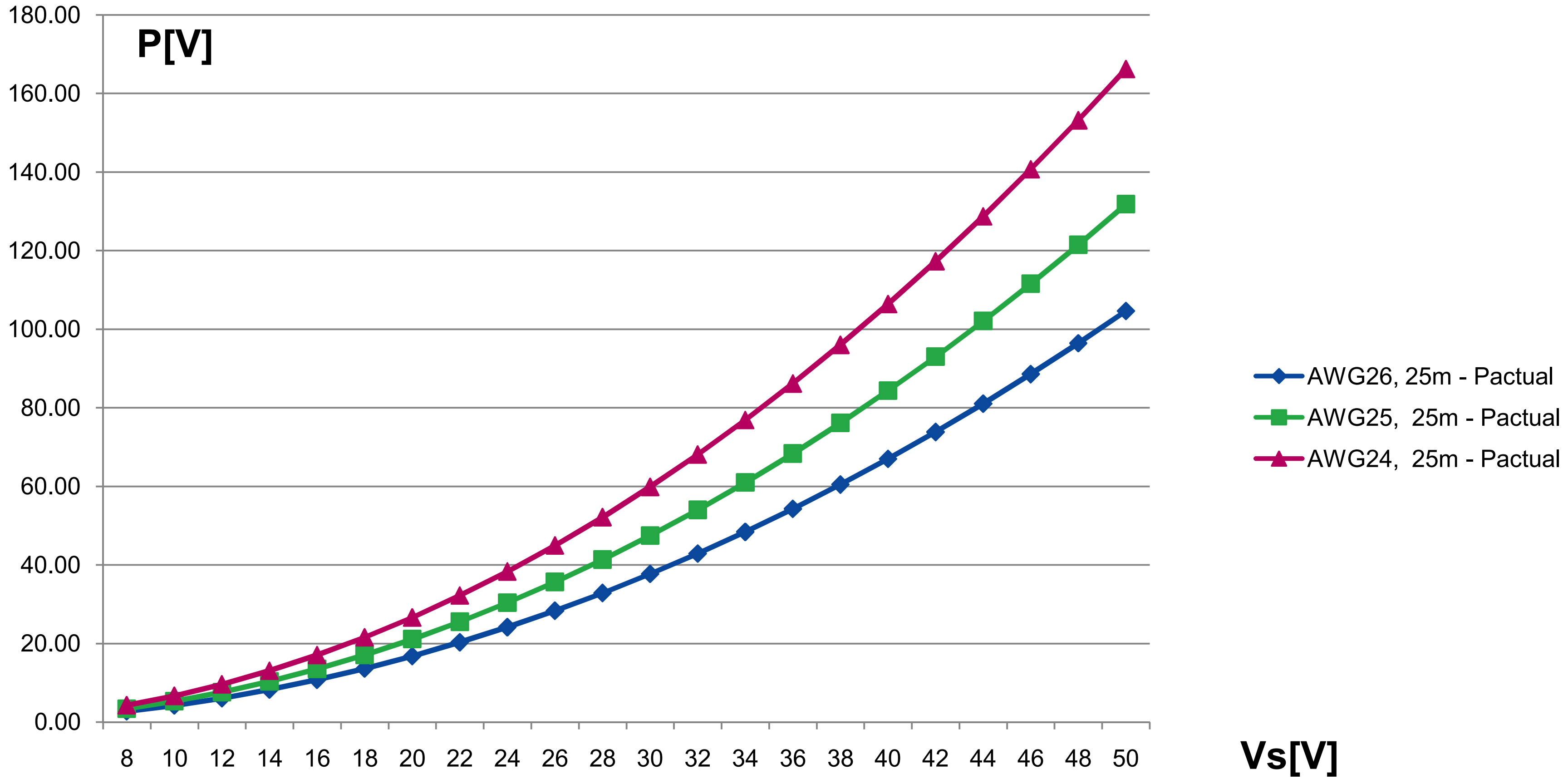
Load Voltage VL, vs. Load Power, P for one pair 10m AWG26, Vs=8V

- Pmax=9.55W. Pactual=~6.7W.
- Pactual=~0.7*Pmax
- *Note: Pactual =~k*Pmax, k=0.7 is for stability and UVLO range margins. For keeping efficiency above*
- *80%, lower factors than 0.7 should be used. With K=0.7, PD/PSE efficiency~=77%.*

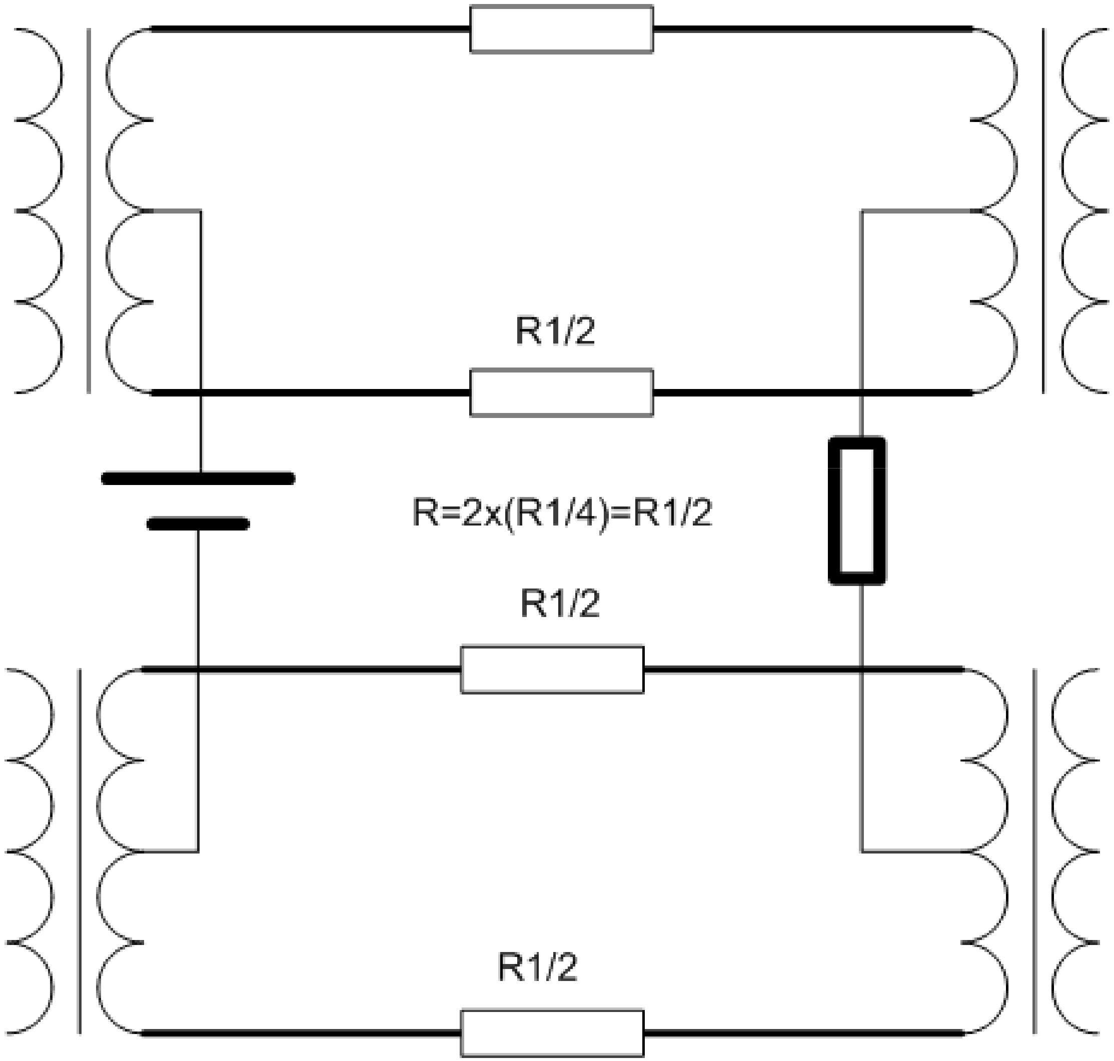


Practical load power as function of Vs, for 25m one-pair, AWG 26,25,24 wire

- At 8V for AWG26 we get Pactual=2.68W (Pmax=3.8W)
- At 8V for AWG24 we get Pactual=4.26W (Pmax=6W)
- *Note: Pactual =~k*Pmax, k=0.7 is for stability and UVLO range margins. For keeping efficiency above 80%, lower factors than 0.7 should be used. With K=0.7, PD/PSE efficiency~=77%.*

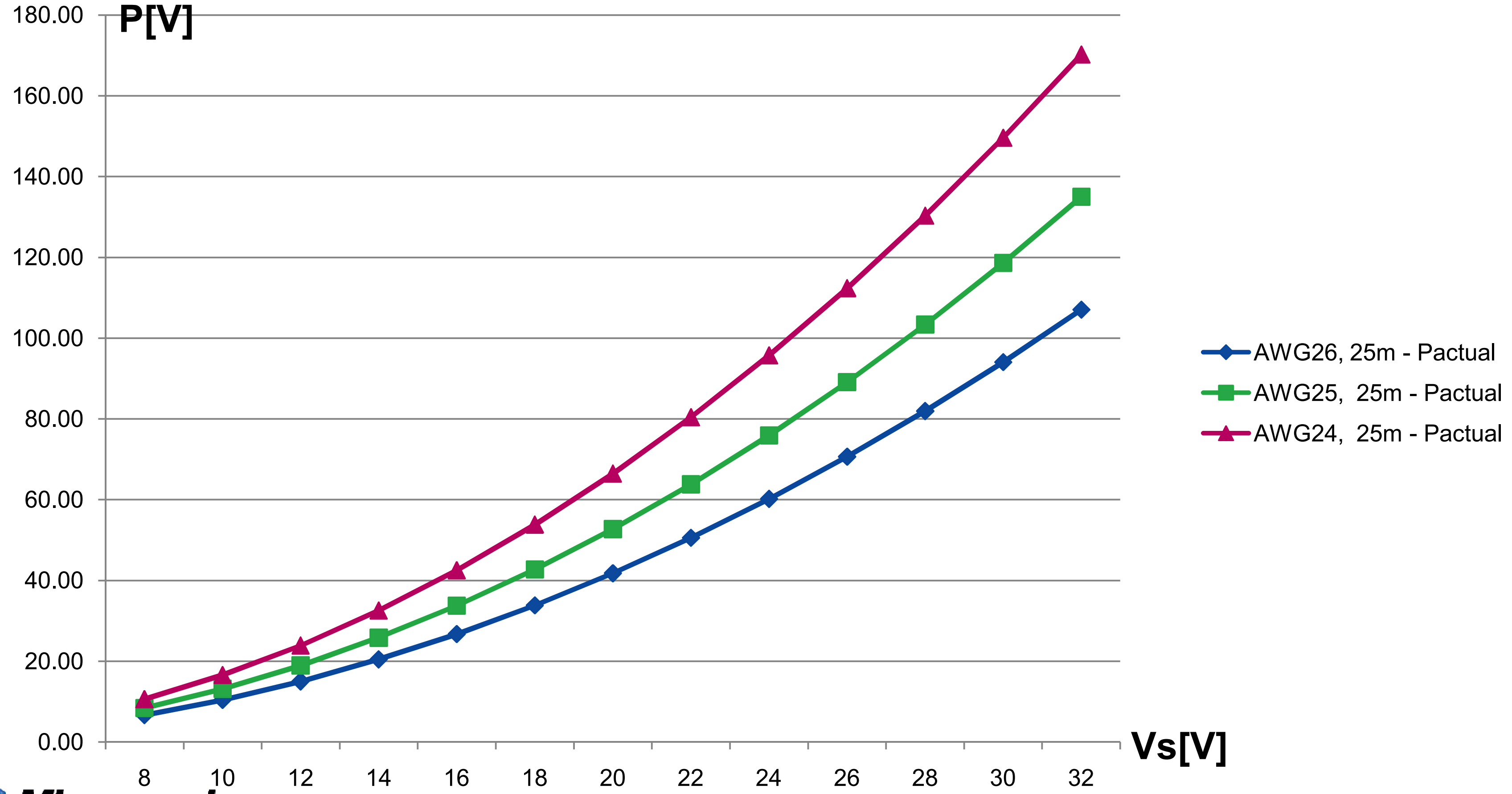


Two Pair Round Trip resistance Model



Practical load power as function of Vs, for 25m two-pairs, AWG 26,25,24 wire

- Two pairs alows 6.7, 8.4 and 10.6W for AWG26,25 and 24 respectively
- *Note: Pactual =~k*Pmax, k=0.7 is for stability and UVLO range margins. For keeping efficiency above*
- *80%, lower factors than 0.7 should be used. With K=0.7, PD/PSE efficiency~=77%.*



Summary -1. One pair. Maximum Practical power [W]

	25m			25m		
	One-Pair			Two-Pair		
	AWG 26	AWG 25	AWG 24	AWG 26	AWG 25	AWG 24
Vs						
8	2.68	3.37	4.26	6.69	8.44	10.64
12	6.02	7.59	9.57	15.06	18.98	23.94
24	24.09	30.37	38.30	60.22	75.93	95.75
27	30.49	38.44	48.47	76.22	96.10	
30	37.64	47.46	59.84	94.10		
38	60.39	76.14	96.02			
42	73.77	93.02				
48	96.36					
50						

- Resistance Model: **R=1.25R1.**
- R1=Wire resistance for a given distance [m]
- Maximum Practical Power=~k*Vs^2/(4*R). K=0.7 (Eff=%0.77). For efficiency>=0.8 reduce k.

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Summary -2. Two pair. Maximum Practical power[W]

	50m			50m		
	One-Pair			Two-Pair		
	AWG 26	AWG 25	AWG 24	AWG 26	AWG 25	AWG 24
Vs						
8	1.34	1.69	4.26	3.35	4.22	5.32
12	3.01	3.80	9.57	7.53	9.49	11.97
24	12.04	15.19	38.30	30.11	37.97	47.87
27	15.24	19.22	48.47	38.11	48.05	60.59
30	18.82	23.73	59.84	47.05	59.32	74.80
34	24.17	30.48	76.87	60.43	76.20	96.08
38	30.20	38.07	96.02	75.49	95.18	
42	36.89	46.51		92.22		
48	48.18	60.75				
50	52.28	65.91				

- Resistance Model: **R=0.5*R1**.
- R1=Wire resistance for a given distance [m]
- Maximum Practical Power=~k*Vs^2/(4*R). K=0.7 (Eff=%0.77). For efficiency>=0.8 reduce k.

Conclusions

- Attention should be given to:
  - AWG26 limits usable power at low source voltage e.g. 8V, 12V etc.
  - Using lower AWG rate (lower resistance e.g. 24..22)?
  - Using two pairs instead of one pair?
  - Using higer source voltage than 12V voltage source?

- Group to discuss
  - What is the minimum load required to support?
  - How to support it per the above alternatives or others

Discussion

Practical load vs. Vs, for one-pair model resistance at 25m AWG 26,25,24 wire

1 PAIR MODEL

AWG26, 25m				AWG25, 25m				AWG24, 25m			
Vs	R	Pmax	AWG26, 25m - Pactual	Vs	R	Pmax	AWG25, 25m - Pactual	Vs	R	Pmax	AWG24, 25m - Pactual
8	4.184	3.82	2.68	8	3.319	4.82	3.37	8	2.632	6.08	4.26
10	4.184	5.97	4.18	10	3.319	7.53	5.27	10	2.632	9.50	6.65
12	4.184	8.60	6.02	12	3.319	10.85	7.59	12	2.632	13.68	9.57
14	4.184	11.71	8.20	14	3.319	14.76	10.34	14	2.632	18.62	13.03
16	4.184	15.29	10.71	16	3.319	19.28	13.50	16	2.632	24.32	17.02
18	4.184	19.36	13.55	18	3.319	24.41	17.08	18	2.632	30.78	21.54
20	4.184	23.90	16.73	20	3.319	30.13	21.09	20	2.632	38.00	26.60
22	4.184	28.92	20.24	22	3.319	36.46	25.52	22	2.632	45.97	32.18
24	4.184	34.41	24.09	24	3.319	43.39	30.37	24	2.632	54.71	38.30
26	4.184	40.39	28.27	26	3.319	50.92	35.65	26	2.632	64.21	44.95
28	4.184	46.84	32.79	28	3.319	59.06	41.34	28	2.632	74.47	52.13
30	4.184	53.77	37.64	30	3.319	67.80	47.46	30	2.632	85.49	59.84
32	4.184	61.18	42.83	32	3.319	77.14	54.00	32	2.632	97.27	68.09
34	4.184	69.07	48.35	34	3.319	87.08	60.96	34	2.632	109.81	76.87
36	4.184	77.43	54.20	36	3.319	97.63	68.34	36	2.632	123.11	86.17
38	4.184	86.27	60.39	38	3.319	108.78	76.14	38	2.632	137.16	96.02
40	4.184	95.59	66.92	40	3.319	120.53	84.37	40	2.632	151.98	106.39
42	4.184	105.39	73.77	42	3.319	132.88	93.02	42	2.632	167.56	117.29
44	4.184	115.67	80.97	44	3.319	145.84	102.09	44	2.632	183.90	128.73
46	4.184	126.42	88.50	46	3.319	159.40	111.58	46	2.632	201.00	140.70
48	4.184	137.65	96.36	48	3.319	173.56	121.49	48	2.632	218.86	153.20
50	4.184	149.37	104.56	50	3.319	188.32	131.83	50	2.632	237.47	166.23

Practical load vs. Vs, for one-pair model resistance at 25m AWG 26,25,24 wire

TWO PAIR MODEL

AWG26, 25m				AWG25, 25m				AWG24, 25m			
Vs	R	Pmax	AWG26, 25m - Pactual	Vs	R	Pmax	AWG25, 25m - Pactual	Vs	R	Pmax	AWG24, 25m - Pactual
8	1.674	9.56	6.69	8	1.328	12.05	8.44	8	1.053	15.20	10.64
10	1.674	14.94	10.46	10	1.328	18.83	13.18	10	1.053	23.75	16.62
12	1.674	21.51	15.06	12	1.328	27.12	18.98	12	1.053	34.20	23.94
14	1.674	29.28	20.49	14	1.328	36.91	25.84	14	1.053	46.54	32.58
16	1.674	38.24	26.77	16	1.328	48.21	33.75	16	1.053	60.79	42.56
18	1.674	48.39	33.88	18	1.328	61.02	42.71	18	1.053	76.94	53.86
20	1.674	59.75	41.82	20	1.328	75.33	52.73	20	1.053	94.99	66.49
22	1.674	72.29	50.60	22	1.328	91.15	63.80	22	1.053	114.94	80.46
24	1.674	86.03	60.22	24	1.328	108.47	75.93	24	1.053	136.78	95.75
26	1.674	100.97	70.68	26	1.328	127.31	89.11	26	1.053	160.53	112.37
28	1.674	117.10	81.97	28	1.328	147.65	103.35	28	1.053	186.18	130.33
30	1.674	134.43	94.10	30	1.328	169.49	118.64	30	1.053	213.73	149.61
32	1.674	152.95	107.06	32	1.328	192.84	134.99	32	1.053	243.17	170.22

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Resistance vs. AWG for 5-30m, 1 pair length

				L=Cable length	5	10	15	20	25	30
AWG	Diameter (inch)	Diameter (mm)	Area [mm^2]	Copper Resistance [mOhm/m]	Copper Resistance for 10m round trip	Copper Resistance for 20m round trip	Copper Resistance for 30m round trip	Copper Resistance for 40m round trip	Copper Resistance for 50m round trip	Copper Resistance for 60m round trip
20	0.032	0.812	0.518	33.31	0.3331	0.6662	0.49965	0.6662	0.83275	0.9993
21	0.0285	0.723	0.41	42	0.42	0.84	0.63	0.84	1.05	1.26
22	0.0253	0.644	0.326	52.96	0.5296	1.0592	0.7944	1.0592	1.324	1.5888
23	0.0226	0.573	0.258	66.79	0.6679	1.3358	1.00185	1.3358	1.66975	2.0037
24	0.0201	0.511	0.205	84.22	0.8422	1.6844	1.2633	1.6844	2.1055	2.5266
25	0.0179	0.455	0.162	106.2	1.062	2.124	1.593	2.124	2.655	3.186
26	0.0159	0.405	0.129	133.9	1.339	2.678	2.0085	2.678	3.3475	4.017
27	0.0142	0.361	0.102	168.9	1.689	3.378	2.5335	3.378	4.2225	5.067
28	0.0126	0.321	0.081	212.9	2.129	4.258	3.1935	4.258	5.3225	6.387
29	0.0113	0.286	0.0642	268.5	2.685	5.37	4.0275	5.37	6.7125	8.055
30	0.01	0.255	0.0509	338.6	3.386	6.772	5.079	6.772	8.465	10.158
31	0.00893	0.227	0.0404	426.9	4.269	8.538	6.4035	8.538	10.6725	12.807
32	0.00795	0.202	0.032	538.3	5.383	10.766	8.0745	10.766	13.4575	16.149
33	0.00708	0.18	0.0254	678.8	6.788	13.576	10.182	13.576	16.97	20.364
34	0.0063	0.16	0.0201	856	8.56	17.12	12.84	17.12	21.4	25.68
35	0.00561	0.143	0.016	1079	10.79	21.58	16.185	21.58	26.975	32.37
36	0.005	0.127	0.0127	1361	13.61	27.22	20.415	27.22	34.025	40.83
37	0.00445	0.113	0.01	1716	17.16	34.32	25.74	34.32	42.9	51.48
38	0.00397	0.101	0.00797	2164	21.64	43.28	32.46	43.28	54.1	64.92
39	0.00353	0.0897	0.00632	2729	27.29	54.58	40.935	54.58	68.225	81.87
40	0.00314	0.0799	0.00501	3441	34.41	68.82	51.615	68.82	86.025	103.23