IEEE802.3at Task Force

Current Carrying Capacity
Analysis of TR42.7 update to IEEE802.3at

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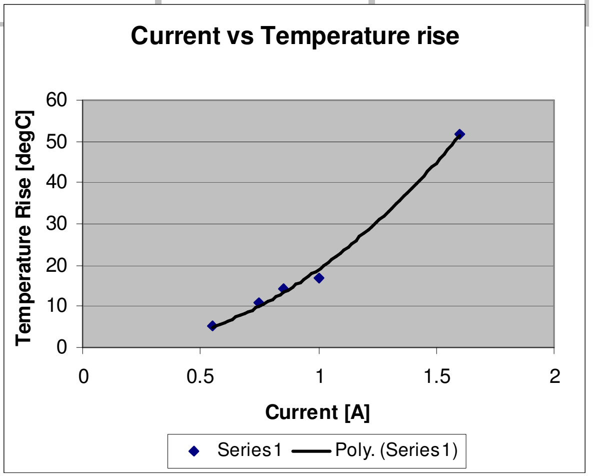
Objectives

- Analyzing TR42.7 Test Results
- Deriving PD max power as function of Ambient temperature
- Deriving Derating Curves
- Review of TR42.7 test results vs other standards and lab tests
- Summary and Open questions

TR42.7 results

			b ~~m~~	0	0	0
			m ~~b~~	20	15	12
Current Level	**WC 5e**	**WC 6**	**WC 6A**	**FIT 5e**	**FIT 6**	**FIT 6A**
350				2.45	1.8375	1.47
500		4.0		5	3.75	3
550	5.4	4.7	4.0	6.05	4.5375	3.63
750	10.8	7.4	7.4	11.25	8.4375	6.75
800				12.8	9.6	7.68
850	14.1	11.3	5.6	14.45	10.8375	8.67
1000	16.8	15.0	11.7	20	15	12
1300				33.8	25.35	20.28
1600	51.8	38.0	31.1	51.2	38.4	30.72

- **m** and **b** are the constants of the fitting function dt=**m**I^2+**b**

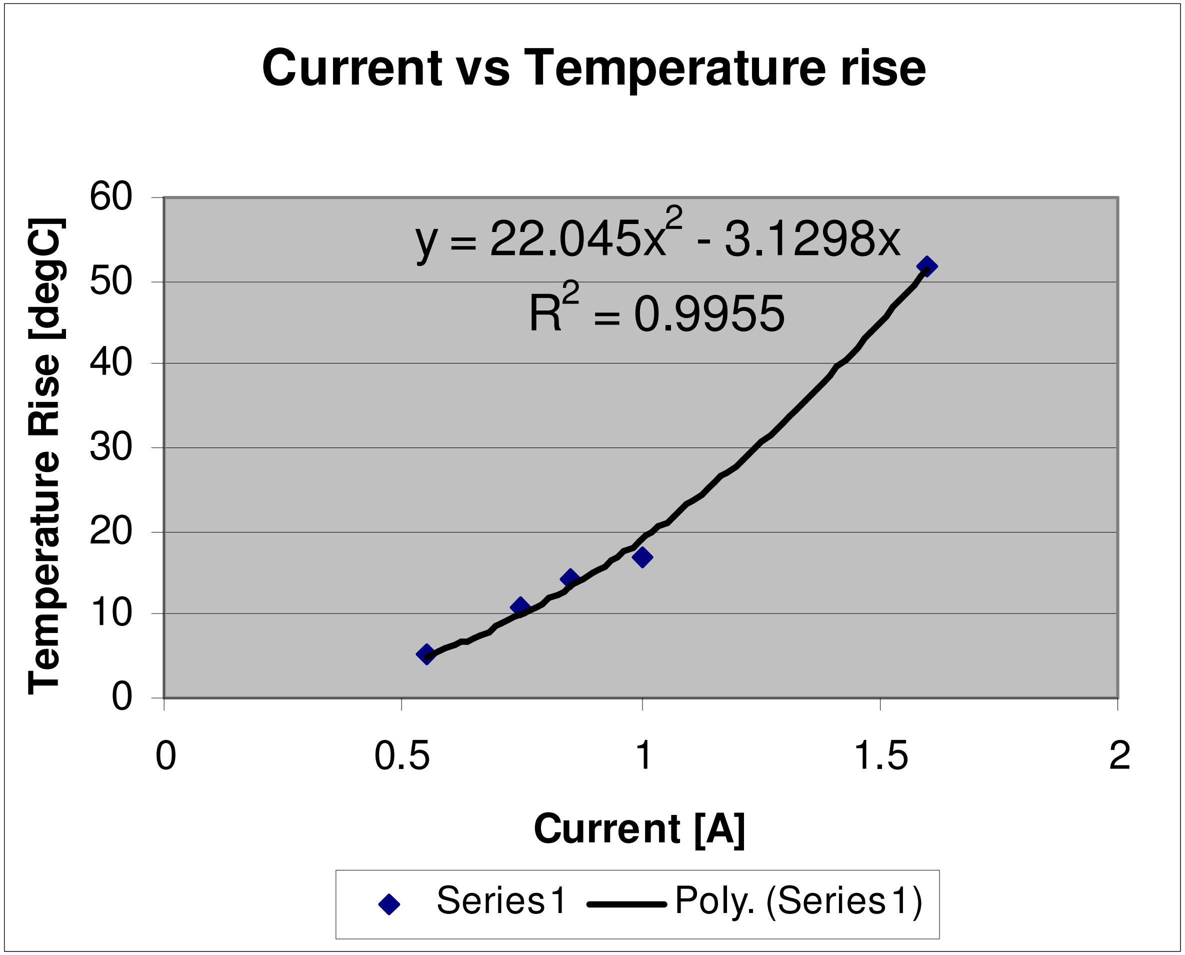


TR42.7 results – cont.

- 720mA at Ta=45degC while all wires in the cable are conducting i.e. 4 pairs-8 wires are carrying current of 360mA per wire.
- Bundle consists of 100 cables
- Current decreased to zero at 60degC as function of I^2.
- Max power at 100 cables is limited to ~5000W.
- 30W/2P and 60W/4P.

Focusing on CAT5E worst case results

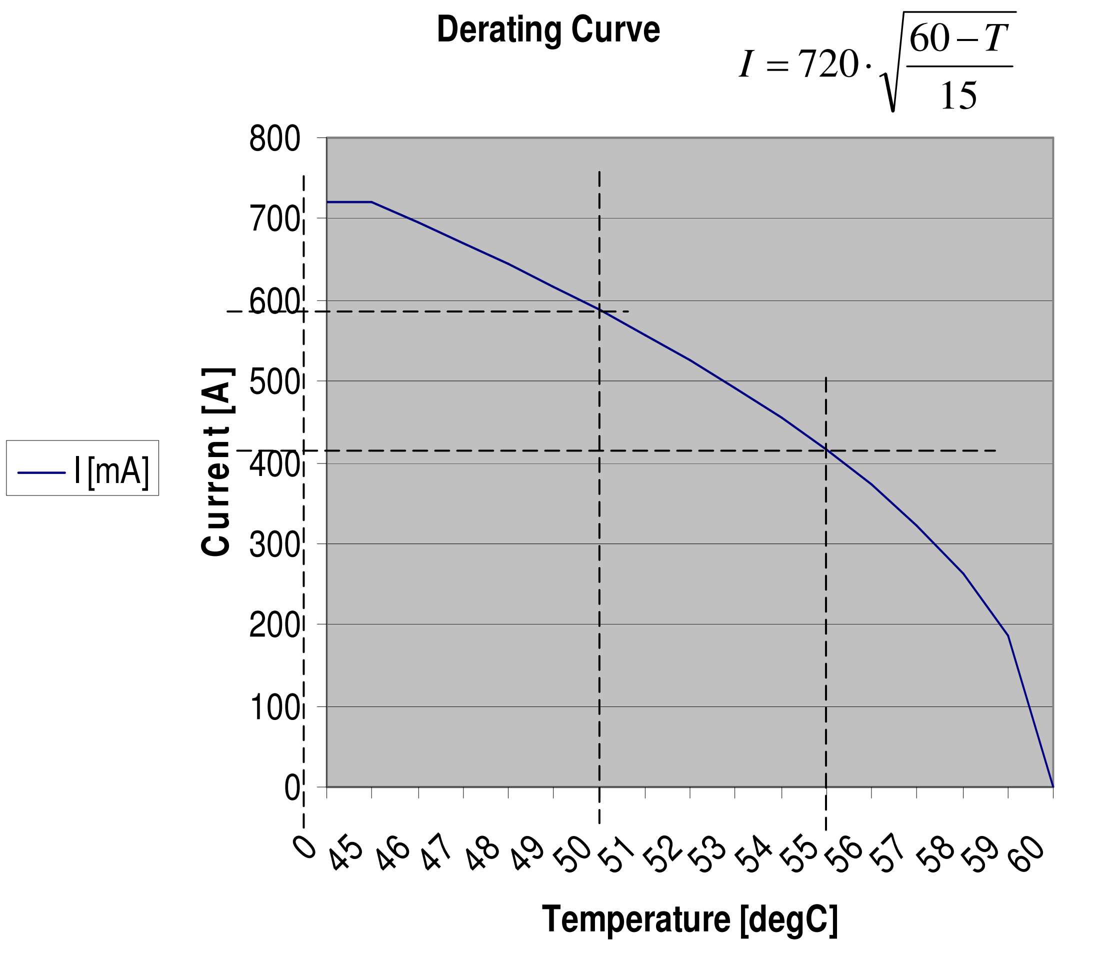
I	Tr
0.55	5.4
0.75	10.8
0.85	14.1
1	16.8
1.6	51.8



Actual fitting function should be mX^2+bX+C to account for resistance changes over temperature. ***See Annex A for Tr vs Current equation derivation***

Derating Curve (Current vs. Ambient Temperature)

T [degC]	I [mA]	Ppd[W]
0	720	29.5
45	**720**	**29.5**
46	696	28.7
47	670	27.9
48	644	27.0
49	617	26.1
50	**588**	**25.1**
51	558	24.0
52	526	22.8
53	492	21.6
54	455	20.2
55	**416**	**18.6**
56	372	16.9
57	322	14.8
58	263	12.3
59	186	8.9
60	**0**	**0.0**



$$I = 720 \cdot \sqrt{\frac{60-T}{15}}$$

See annex C for derating curve equation

Data Summary

		y = 22.045x2 - 3.1298x				
I [mA]	Tr[degC]	Tr [degC]	Vpse	Ppse	Ppd	Vpd
	Test Results	Prediction				
0.35		1.61	50	17.5	15.97	45.63
0.4		2.28	50	20	18.00	45.00
0.45		3.06	50	22.5	19.97	44.38
0.5		3.95	50	25	21.88	43.75
0.55	**5.4**	**4.95**	**50**	**27.5**	**23.72**	**43.13**
0.6		6.06	50	30	25.50	42.50
0.65		7.28	50	32.5	27.22	41.88
0.7		8.61	50	35	28.88	41.25
0.75	**10.8**	**10.05**	**50**	**37.5**	**30.47**	**40.63**
0.8		11.60	50	40	32.00	40.00
0.85	**14.1**	**13.27**	**50**	**42.5**	**33.47**	**39.38**
0.9		15.04	50	45	34.88	38.75
0.95		16.92	50	47.5	36.22	38.13
1	**16.8**	**18.92**	**50**	**50**	**37.50**	**37.50**
1.05		21.02	50	52.5	38.72	36.88
1.1		23.23	50	55	39.88	36.25
1.15		25.56	50	57.5	40.97	35.63
1.2		27.99	50	60	42.00	35.00
1.25		30.53	50	62.5	42.97	34.38
1.3		33.19	50	65	43.88	33.75
1.35		35.95	50	67.5	44.72	33.13
1.4		38.83	50	70	45.50	32.50
1.45		41.81	50	72.5	46.22	31.88
1.5		44.91	50	75	46.88	31.25
1.55		48.11	50	77.5	47.47	30.63
1.6	**51.8**	**51.43**	**50**	**80**	**48.00**	**30.00**

TR42.7 results vs others standards and tests

Source	Temperature Rise [degC]	Current /Wire [mA]
TR42.7[1]	6	275[5]
NASA[2]	5	275[5]
Others[3,4]	5-7	275[5]

Notes:

1,2,3,4: See REFERENCE slide for data source.

5: 275mA/wire as comparison point was selected due to its presence in all sources

Good correlation between inputs, therefore technically we do have good and reliable base line.

Summary and open questions

- TR42.7 gave us its recommendations: 360mA/wire @ Ta=45degC in all pairs.
- Recommendations are with good agreement with other data sources
- Open Questions
  - Should the IEEE802.3at take design margin?
    - TR42.7 recommendations are max limits of cabling infrastructure
    - IEEE should not exceed this level..
    - Existing equipment designed for 40-50degC ambient so cabling temperature may be at higher temperature.
      - Should TR42.7 work includes sufficient margin to account for actual higher cabling ambient temperatures?

What next ? Questions , Discussion

Annex A - Temperature rise vs Current

- Showing how Tr is a polynomial function of the current I, of the form mX^2+bX+C which takes the copper resistance as function of temperature as a variable too.
- Tr=Temperature rise in the center cable
- n=Number of cables in a bundle
- Theta_n= Thermal resistance of n cables bundle
- P=Power dissipated per cable
- R=Cable resistance
- K=Copper coefficient [1/degC]
- Rref = Cable resistance at Reference temperature Tref

$$(1)\ \ Tr = n \cdot P \cdot \Theta_n$$

$$(2)\ \ Tr = n \cdot \Theta_n \cdot I^2 \cdot R$$

$$(3)\ \ R = R_{REF} + K \cdot R_{REF} \cdot (T - T_{REF}) =$$

$$(4)\ \ R = R_{REF} + K \cdot R_{REF} \cdot Tr$$

$$(5 = 2 + 4)\ \ Tr = n \cdot \Theta_n \cdot I^2 \cdot \left(R_{REF} + K \cdot R_{REF} \cdot Tr\right)$$

$$(6)\ \ Tr = n \cdot \Theta_n \cdot I^2 \cdot R_{REF} + K \cdot R_{REF} \cdot Tr \cdot n \cdot \Theta_n \cdot I^2$$

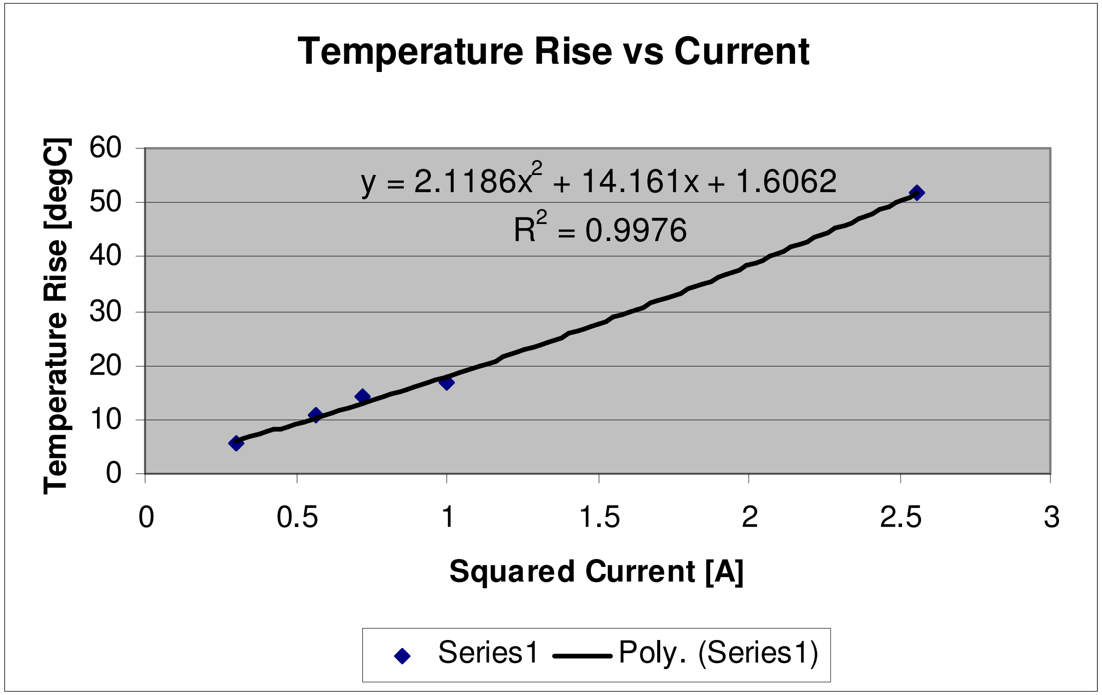
$$(7)\ \ Tr \cdot (1 - K \cdot R_{REF} \cdot Tr \cdot n \cdot \Theta_n \cdot I^2) = n \cdot \Theta_n \cdot I^2 \cdot R_{REF}$$

$$(8)\ \ Tr = \frac{n \cdot \Theta_n \cdot I^2 \cdot R_{REF}}{1 - K \cdot R_{REF} \cdot Tr \cdot n \cdot \Theta_n \cdot I^2} = mX^2 + bX + C \therefore$$

Annex A1 – Sanity check for Annex A using TR42.7 measurements

- Performing Curve fit for the TR42.7 data by expressing Tr as a function of I^2.
- If Curve fit is of the form Y=mX^2+b then plotting it as Tr =f(I^2) would give linear curve otherwise it will be of the form Y=mX^2+bX+C.

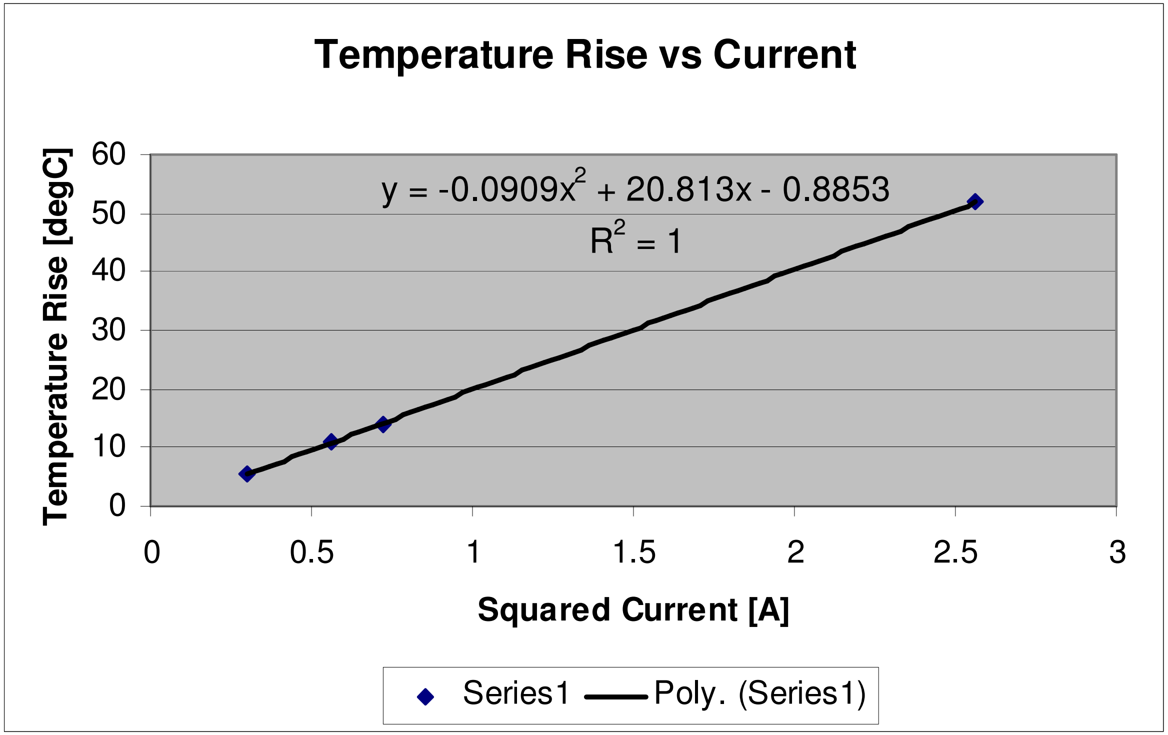
I	I^2	Tr
0.55	0.3025	5.4
0.75	0.5625	10.8
0.85	0.7225	14.1
1	1	16.8
1.6	2.56	51.8



Annex A1 – Sanity check for Annex A cont.

- Even if we will decide that measurement point #4 is an error and we should take it out then the results will be:

I^2	Tr
0.3	5.4
0.56	10.8
0.72	14.1
2.56	51.8



- We still have small effect of X^2 however it is very close to linear equation as expected

Annex B = PD input voltage as function of the current

- Ppd=Power at PD input
- Ppse=Power at PSE output
- Ipse=Ipd=Current at PSE output
- Rcable=Cable resistance
- Assuming PD input impedance is negative i.e. Ppd=Vpd*Ipd=Constant due to DC/DC converter operation

- Ppd=Ppse - Cable Loss
- Ppd=Vpse*Ipse-Ipse^2*Rcable
- Vpd=Ppd/Ipd=Ppd/Ipse
- **Example: For Vpse=50V, Ipse=720mA, Rcable=12.5 ohm, Ppd=29.5W, Vpd=41V**
- General case: $$Vpd_{1,2} = \frac{Vpse \pm \sqrt{Vpse^2 - 4 \cdot Rcable \cdot Ppd}}{2}$$
- UVLO deletes 2nd solution (the negative part)

Annex C – Derating Curve Equation

$$(1)\ Tr = P \cdot \Theta = I^2 \cdot R \cdot \Theta$$

$$(2)\ T = Tr + Ta$$

$$(3)\ Tr = T - Ta = I^2 \cdot R \cdot \Theta$$

$$(4)\ (5)\ 60 - 45 = 0.72^2 \cdot R \cdot \Theta = 15$$

$$(7)\ R \cdot \Theta \cong \frac{15}{0.72^2}$$

$$(8)\ T - Ta = I^2 \cdot \frac{15}{0.72^2}$$

$$(9)\ I^2 = \frac{T - Ta}{\frac{15}{0.72^2}} =$$

$$(10) I = 0.72 \cdot \sqrt{\frac{T - Ta}{15}}\ \therefore$$

$$45 \le t \le 60$$

1. Practical assumptions:
2. Assuming thermal resistance is constant.
3. Assuming Cable resistance change vs Temperature is small
4. For more accurate equation see Annex A as example for equation derivation.

References

- (1) TR42.7 Update to IEEE 802.3at - Current Carrying Capacity of Cabling, http://www.ieee802.org/3/at/public/jan07/0107_TR42_1.pdf
- (2) 802.3 PoEPlus Maximum Power, http://www.ieee802.org/3/poep_study/public/jul05/koonce_2_0705.pdf
- (3) DC Current vs. Temp Rise, http://www.ieee802.org/3/at/public/may06/dupuis_1_0506.pdf
- (4) UTP Cable limits, http://www.ieee802.org/3/at/public/nov06/darshan_1_1106.pdf