Heating Effects for Remote Power Delivery Over Bundled Cables

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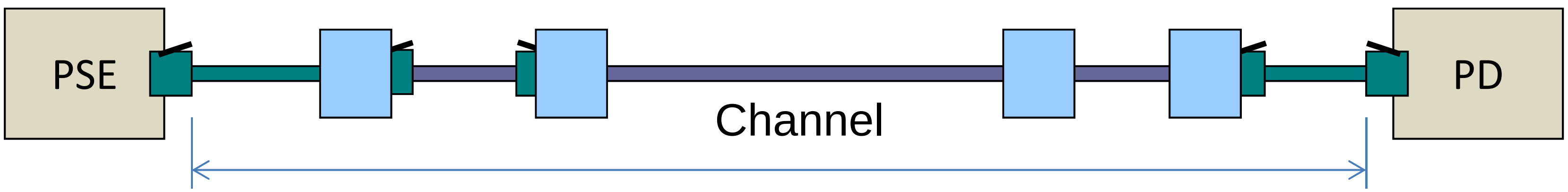
12 February, 2014

Agenda

- Power over Ethernet Standards
- Power delivered versus I^2R losses
- Heating Study over Bundled Cables
  - Test setup
  - Test results & discussion
  - Temperature rise versus bundle size & cable type
  - Important design considerations
- Summary

Power over Ethernet Standards

- Remote power Delivery from the Power Sourcing Equipment (PSE) to the Powered Device (PD)
  - Power over Ethernet (PoE) Standards
    - IEEE 802.3af-2003 (PoE 12.95 Watts to PD over 2 pairs)
    - IEEE 802.3at-2009 (PoE+ 25.5 Watts to PD over 2 pairs)
      - Minimum Category 5e required
      - Source current of 600 mA
      - Maximum 10°C temperature rise when powering over 4 pairs
      - PoE technology can deliver 51 Watts to PD when powering over 4 pairs (2 x 2 pairs)



IEEE 802.3at Type 1 (IEEE 802.3af)

	Variable	Min	Max	Unit
	V_{PSE}	**44**	**57**	**Volts**
Min Cat 3	R_{Ch}	20	20	Ohms
	P_{Class_PD}	13.0	13.0	Watts
	I_{Cable}	**0.350**	**0.350**	**Amps**
	V_{PD}	37	50	Volts
2 Pairs	P_{Port_PD}	**12.95**	**17.5**	**Watts**

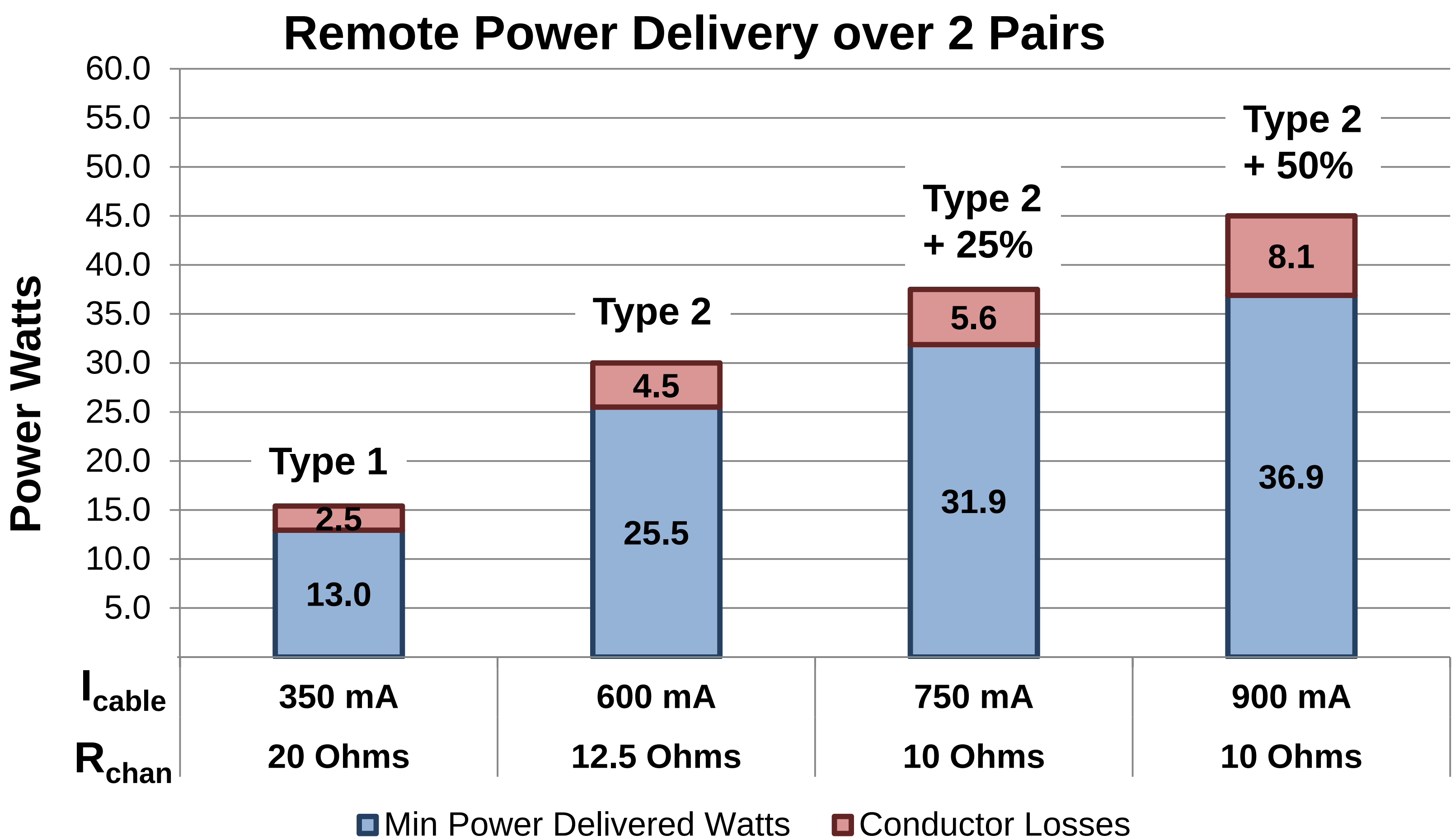
IEEE 802.3at Type 2

	Variable	Min	Max	Unit
	V_{PSE}	**50**	**57**	**Volts**
Min Cat 5e	R_{Ch}	12.5	12.5	Ohms
	P_{Class_PD}	25.5	25.5	Watts
	I_{Cable}	**0.600**	**0.600**	**Amps**
	V_{PD}	42.5	49.5	Volts
	P_{Port_PD}	**25.5**	**29.7**	**Watts**

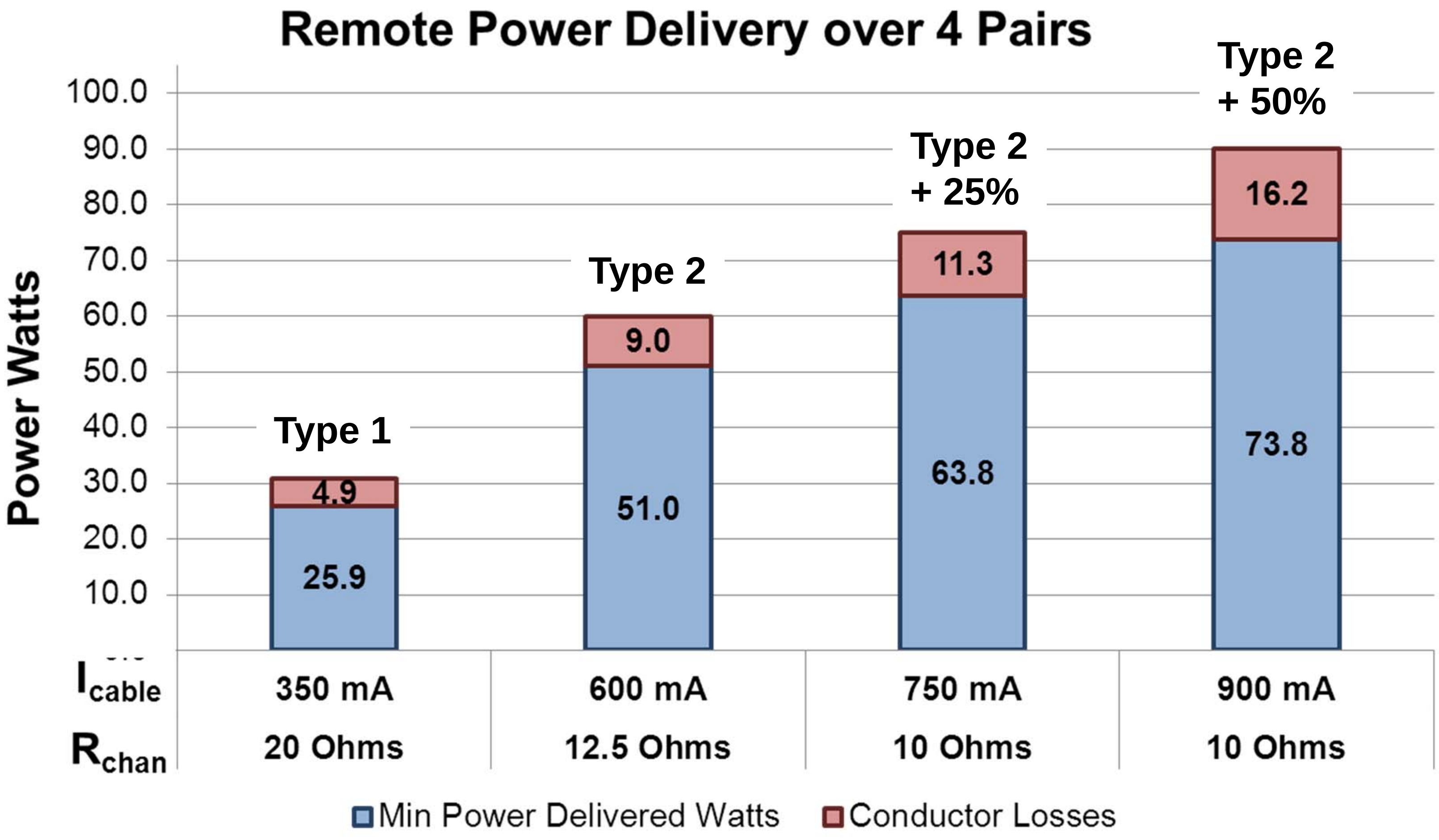
Resistive Heating

- Heat is generated within the cable bundle due to the current flowing in the conductors of the pairs that are energized
- The amount of resistive heating that is generated is proportional to the I^2R losses of the conductors that are carrying the current
- If the resistance of each conductor is R, then the resistance of a pair (two conductors in parallel) is R/2
- Since the current travels along one pair and returns along another pair, the pair resistance when powering over two pairs is
  (R/2 + R/2) = R, the same as a single conductor
- The PoE+ standard assumes a maximum dc pair loop resistance (R_{Chan}) of 12.5 Ohms for a 100 m category 5e channel
  - This includes an allowance for temperature variations, connectors & cords

Power Delivered vs I^2R Losses



Power Delivered vs I^2R Losses



Remote powering over bundled cables

How much power can safely be delivered from the PSE to the PD?

The key factor is the temperature rise in the center of a cable bundle

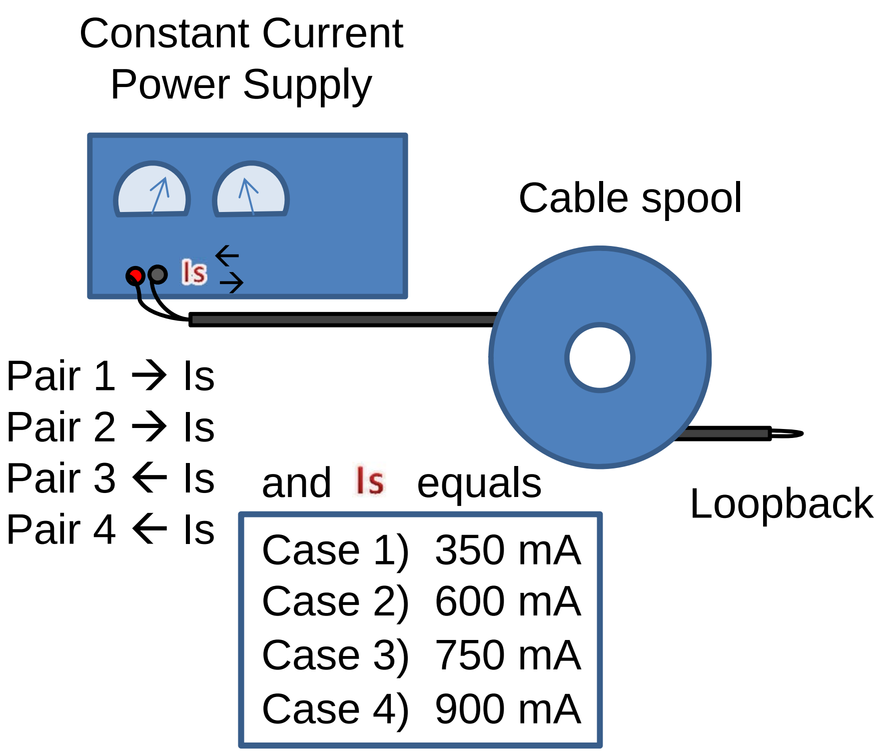
We performed a controlled experiment to evaluate the heat generated in a cable bundle when delivering direct current (dc) power to the powered device

Cable Types Tested

Cable Label	Category	Maximum Conductor dc Resistance @ 20°C (68°F)	Description
C6A-R7.4	6A	7.4 Ohms/100 m (328 ft)	23 AWG solid copper, 4 pairs, H-Spline, CMR
C6-R6.6	6	6.6 Ohms/100 m (328 ft)	23 AWG solid copper, 4 pairs, X-Spline, CMR
C6-R7.7	6	7.7 Ohms/100 m (328 ft)	23 AWG solid copper, 4 bonded pairs, X-Spline, CMP
C6-R8.2	6	8.2 Ohms/100 m (328 ft)	23 AWG solid copper, 4 pairs, tape separator, CMP
C5e-R8.9	5e	8.9 Ohms/100 m (328 ft)	24 AWG solid copper, 4 pairs, CMR

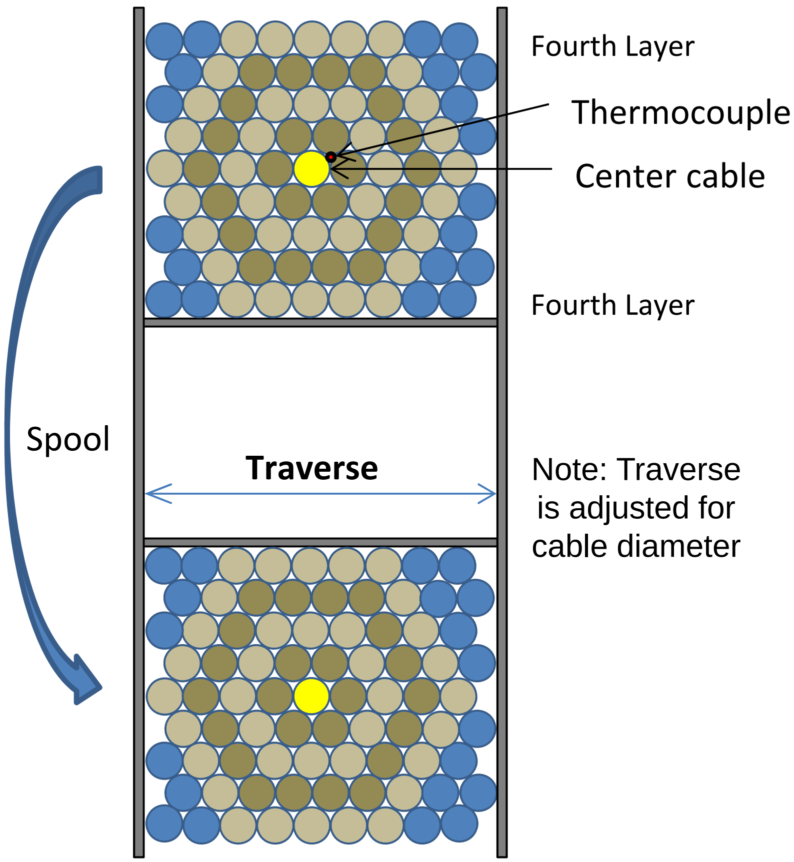
Cable label, Category, dc resistance and description of the cables tested

Test setup for PoE heating experiment



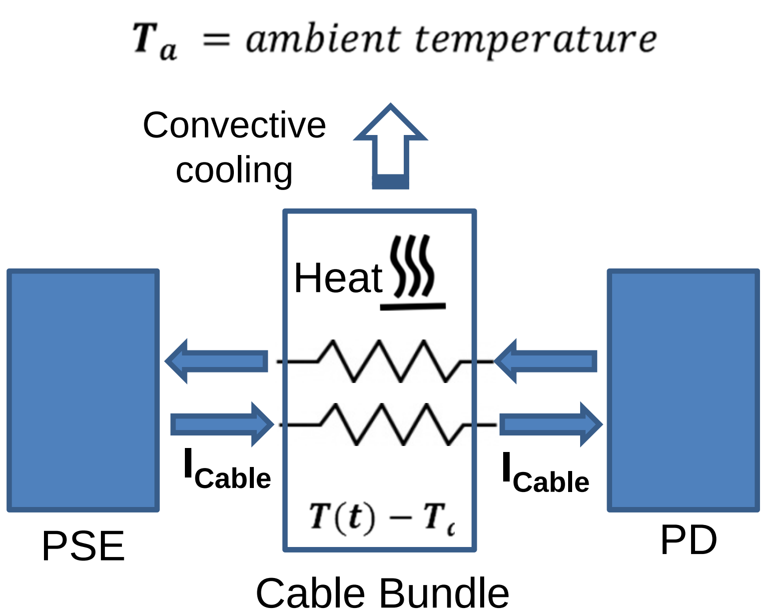
- The same test setup was used for testing all cable types
- The controlled experiment was performed by energizing two pairs as well as four pairs with different levels of applied current

Cable spooling configuration



- Cables highlighted in light and dark gray correspond to a 60 around one cable bundle
- The additional cables shown in blue color generate more heat than a 61 cable bundle
- Also, the side and bottom flanges reduce the heat dissipation to ambient air
- Our results show that the 81 cable configuration on a spool is equivalent to a 100 cable bundle suspended in air

Thermal Time Constant



Eqn. (1) $$\Delta T(t) = \Delta T_f\left(1 - e^{-t/\tau}\right)$$

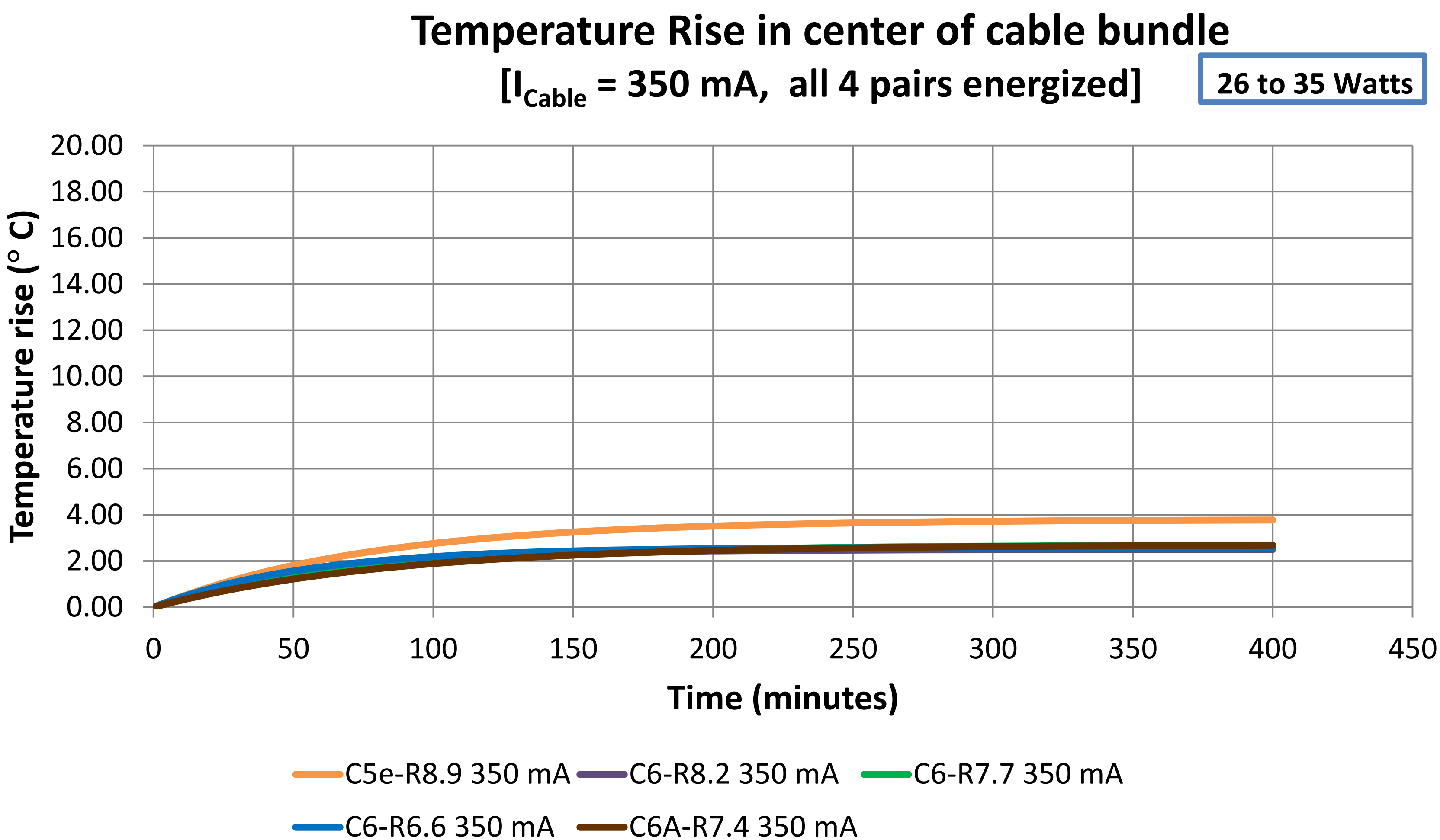
where, $\Delta T(t) = T(t) - T_a$
and τ *is thermal time constant*

- Diagram at left illustrates the heat transfer mechanism for a system consisting of a cable bundle that carries current (I_{cable}) from the power source to the powered device
- Heat is generated within the cable bundle due to resistive heating of the conductors and is dissipated to the environment through convective cooling
- The temperature in the center of the cable bundle rises at an exponentially slow rate until equilibrium is reached

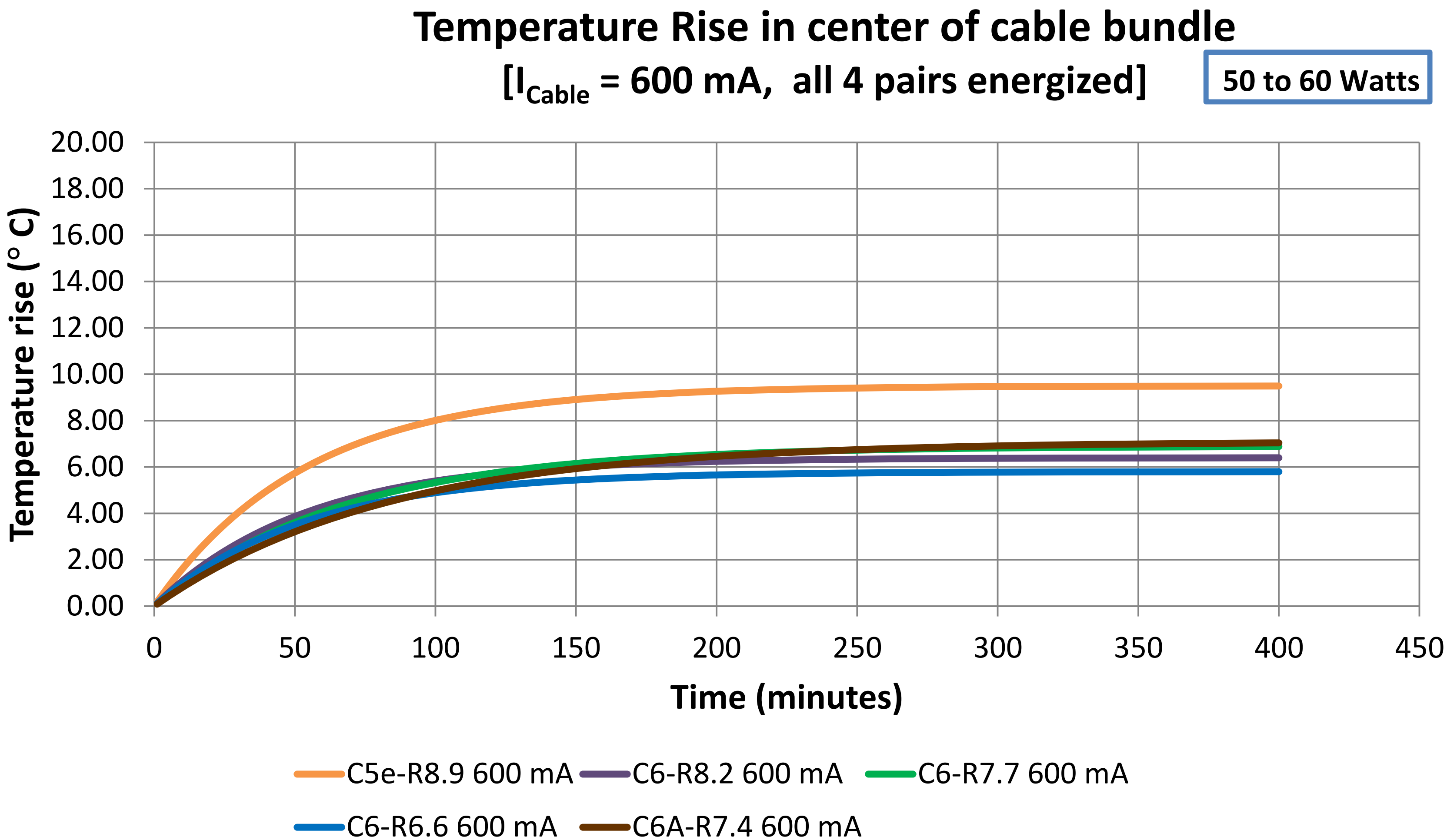
Temperature Measurements

- The temperature in the center of the cable bundle and the ambient temperature of the room were measured using thermocouples
- The temperature rise is determined from equation (1) by adjusting the thermal time constant to provide the best fit to the measured data
- For all the cable types, it takes between four and six hours ($t \geq 4\frac{1}{2}$ thermal time constants) to reach an equilibrium temperature.

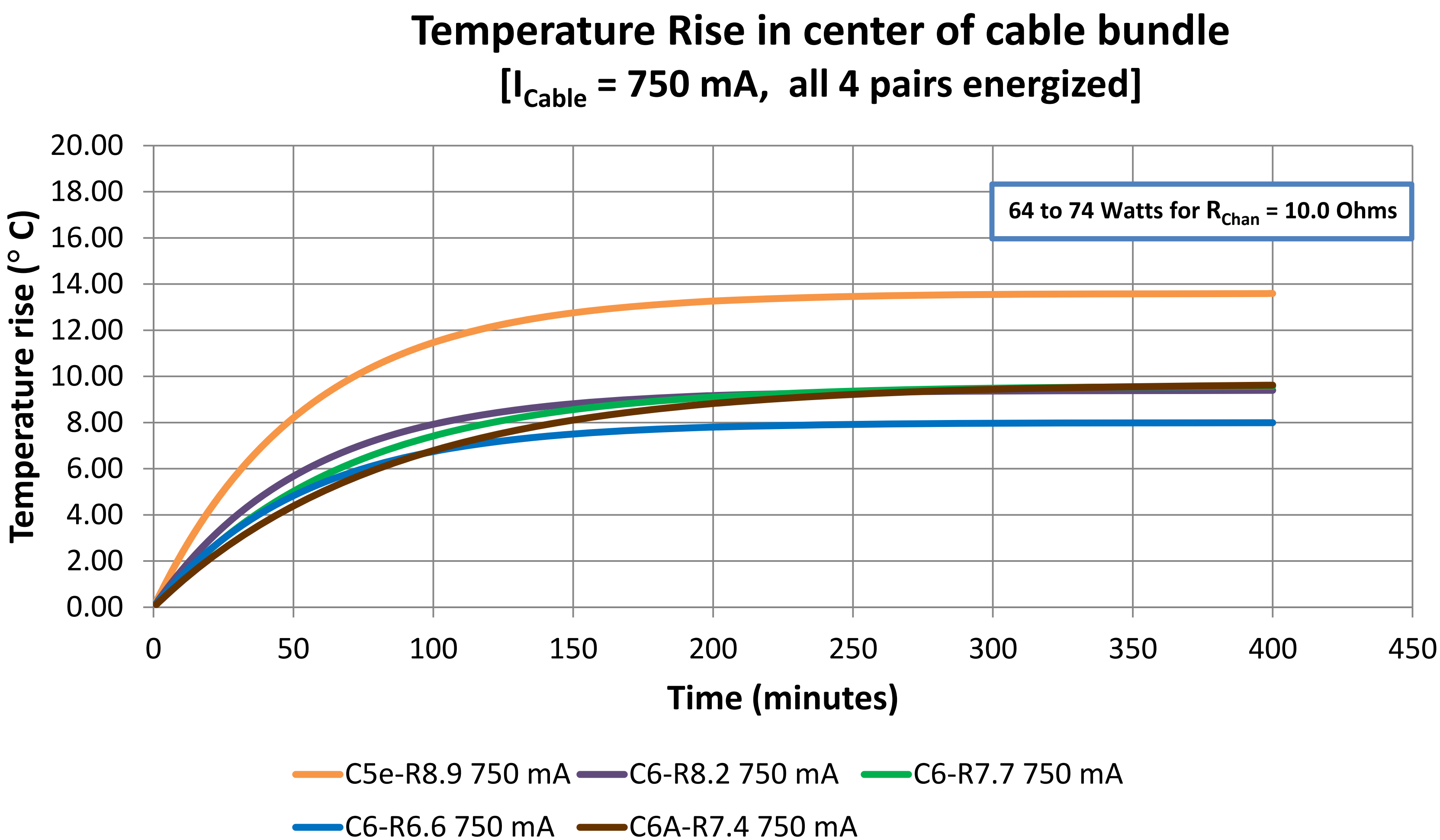
Test Results I_{Cable} = 350 mA



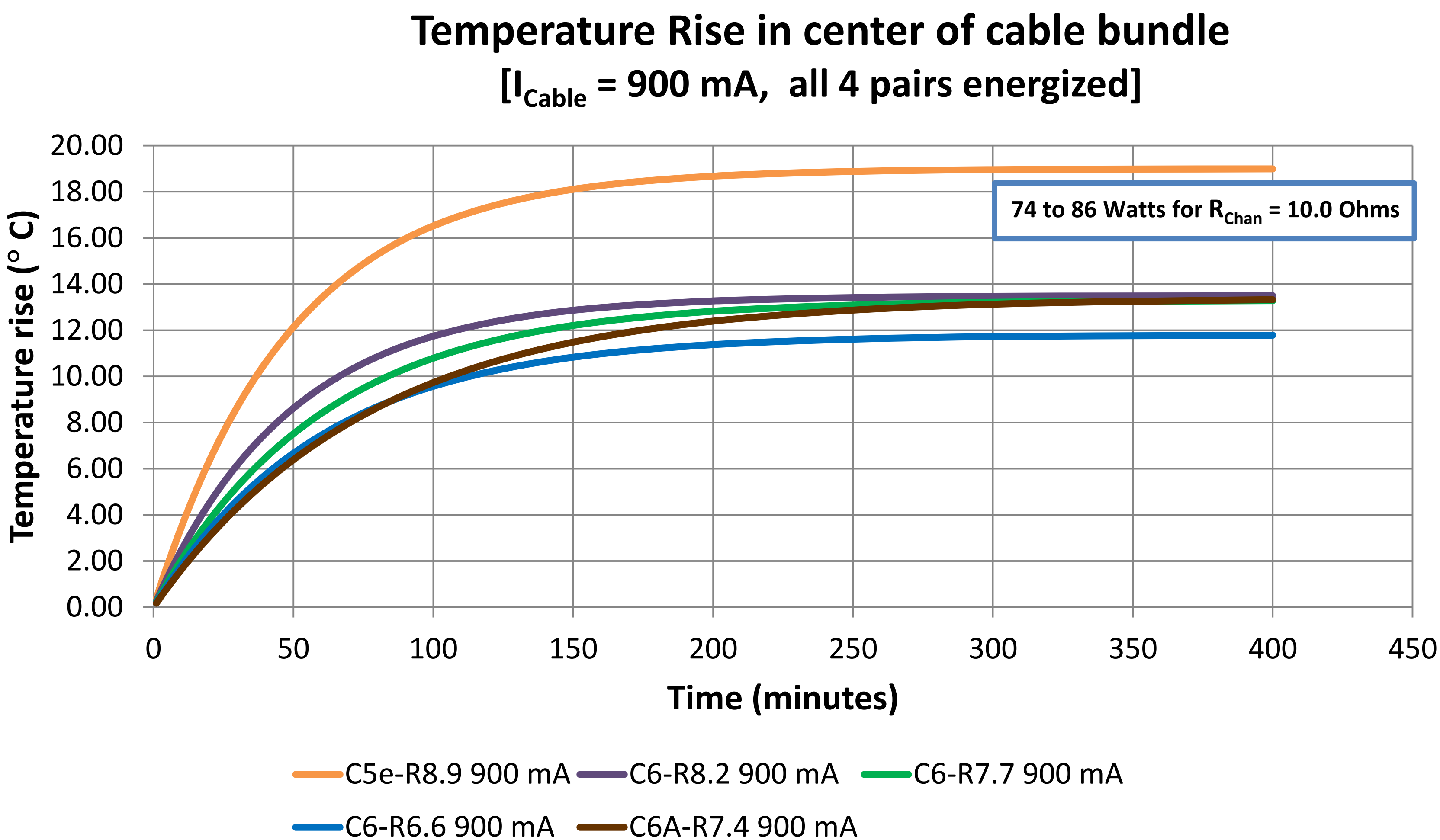
Test Results I_{Cable} = 600 mA



Test Results I_{Cable} = 750 mA



Test Results I_{Cable} = 900 mA



Discussion

Temperature rise at equilibrium

- Type 2 operation with 600 mA source current

  C5e-R8.9 → ΔT_f approaches 10°C

  C6-R8.2, C6-R7.7 and C6A-R7.4 → ΔT_f is 7°C

  C6-R6.6 → ΔT_f is 6°C

- Type 2 + 25% operation with 750 mA source current

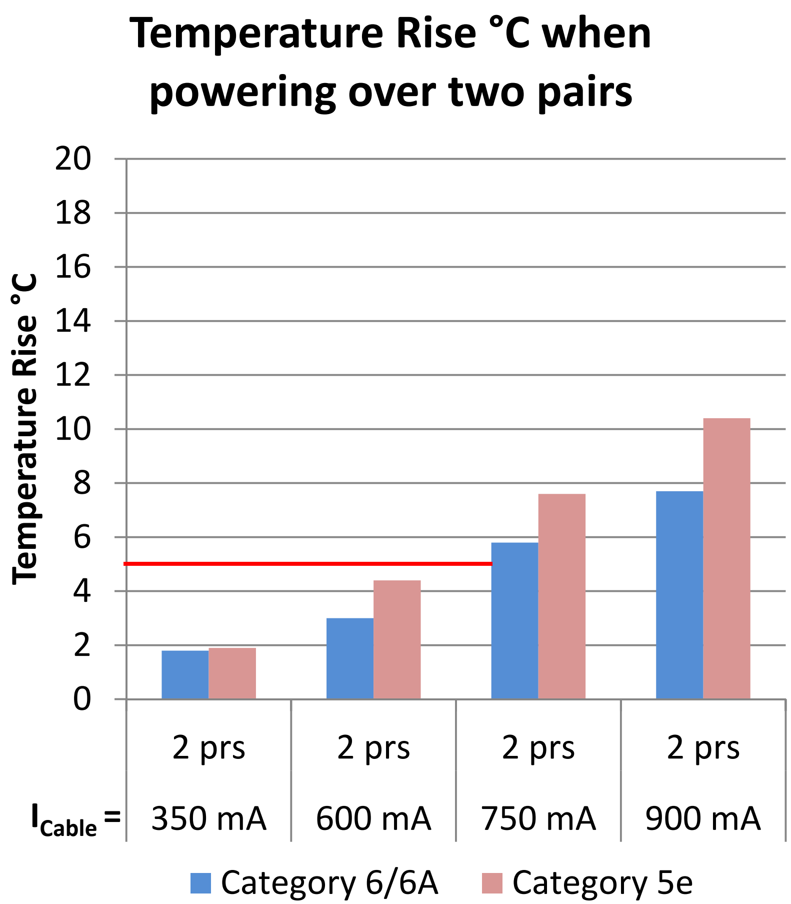
  C5e-R8.9 → ΔT_f approaches 14°C

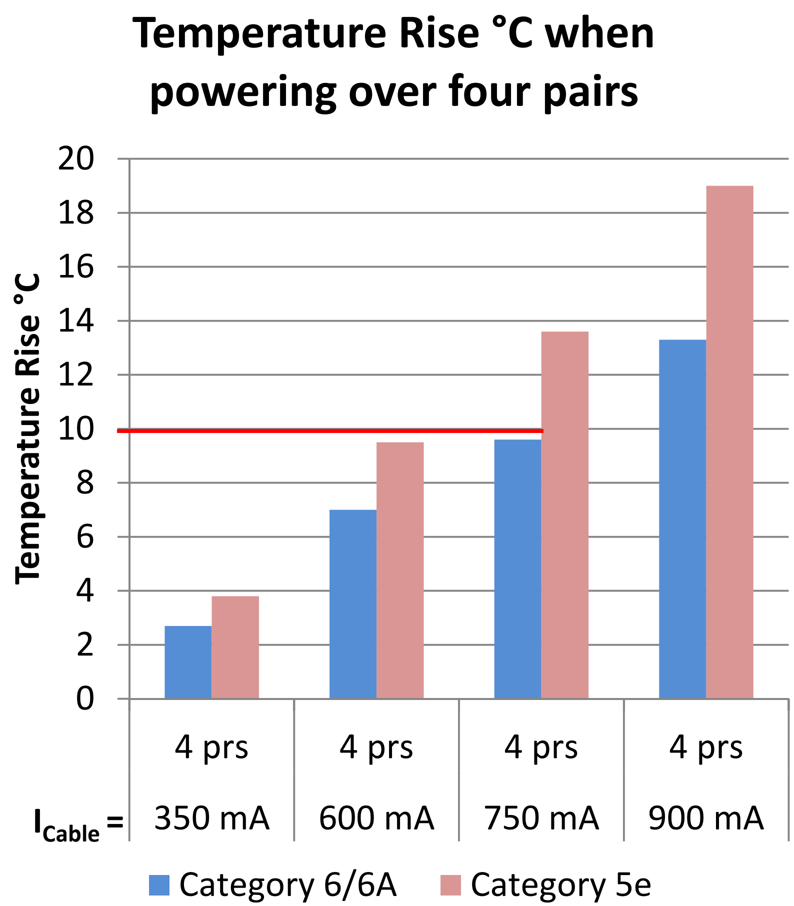
  C6-R8.2, C6-R7.7 and C6A-R7.4 → ΔT_f is ≤ 10 °C

  C6-R6.6 → ΔT_f is ≤ 8 °C

- Category 6 /6A cables can deliver up to 25 percent more power than category 5e cables while remaining within the maximum temperature rise of 10 °C specified by IEEE 802.3at Standard
- Category 6 (C6-R6.6) low-loss cables can deliver up to 35 percent more power that category 5e cables under the same constraints

Powering over 2 pairs vs. 4 pairs

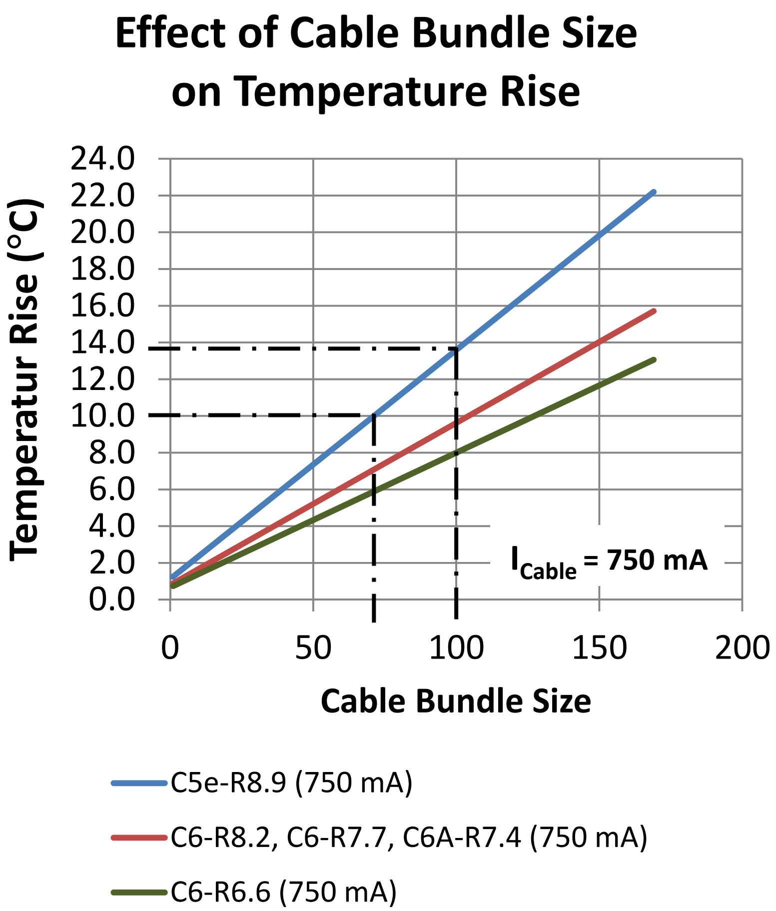




Temperature rise vs. bundle size

- What is the temperature rise for different size cable bundles?
  - TIA TSB-184 “Guidelines for Supporting Power Delivery over Balanced Twisted-Pair Cabling” provides an example of the temperature rise of different size cable bundles for a source current of 720 mA
  - The same relationship was applied to the temperature rise data that we measured at 750 mA for different cable types
  - The temperature rise as a function of bundle size for different cable types is shown in the following slide

Temperature Rise vs. Bundle Size



- Temperature rise
  - 13.6 °C for a bundle size equivalent to 100 category 5e cables
  - 10 °C if the cable bundle size is reduced to 70 cables
  - 7 °C for 50 cables, or roughly half the temperature rise that was measured for a bundle size of 100 cables
- Counter argument
  - If a cable tray is filled with cables delivering maximum power with all pairs energized, the temperature rise can be significantly higher
  - for a projected bundle size of 150 category 5e cables the temperature rise can be as high as 20 °C

Important design considerations

- In practice, not all cables are carrying maximum power, and not all cable pairs are energized at the same time

For any installation with remote powering requirements, it is important to consider

1) the number of powered devices
2) the maximum and average power delivered to each device
3) the density and bundling configuration of cables and
4) the power-handling capability of the installed cables

Summary

- How much power can be delivered to a powered device through the telecommunications cable?
  - the answer is not black and white
  - it depends on the cable type and the cable configuration
- The maximum temperature rise specified in the IEEE 802.3at standard is 10 °C when powering the device using all 4 pairs for Type 2 operation
- Based on this constraint, the maximum power delivery for a worst case bundled configuration of 100 cables is:
  - 50 to 60 W over category 5e cables (C5e-R8.9),
  - up to 74 W over category 6/6A cables (C6-R8.2, C6-R7.7 and C6A-R7.4)
  - up to 80 W for low loss category 6 (C6-R6.6) cables