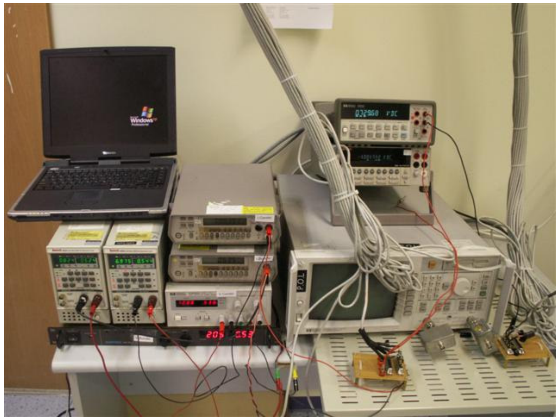
IEEE802.3at Task Force



UTP Cables Temperature Tests

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Many thanks and acknowledgements to the Project team:

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www.powerdsine.com

Introduction

- Test setups are based on "Draft 1 October 15, 2005 Test Procedure”.
  http://www.ieee802.org/3/at/public/nov05/di_minico_1_1105.pdf

- Tested Cables: UTP PVC graded 60℃.
  - Testing Insertion loss and Temperature Rise of UTP cables at different temperatures and DC currents.

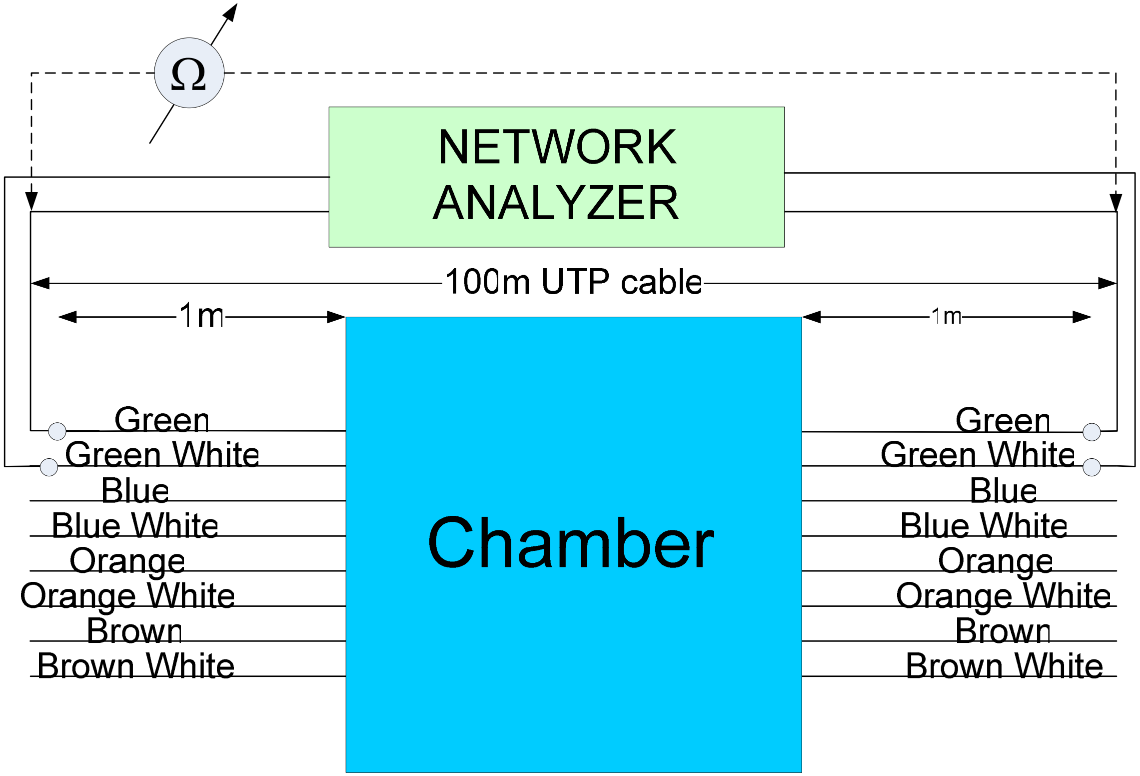
- Target: To suggest values for the maximum current per wire.

Table of Contents

- Type of tests
- Heat Chamber tests
- Temperature rise vs. Current tests
- Summary
- Conclusions
- Recommendations

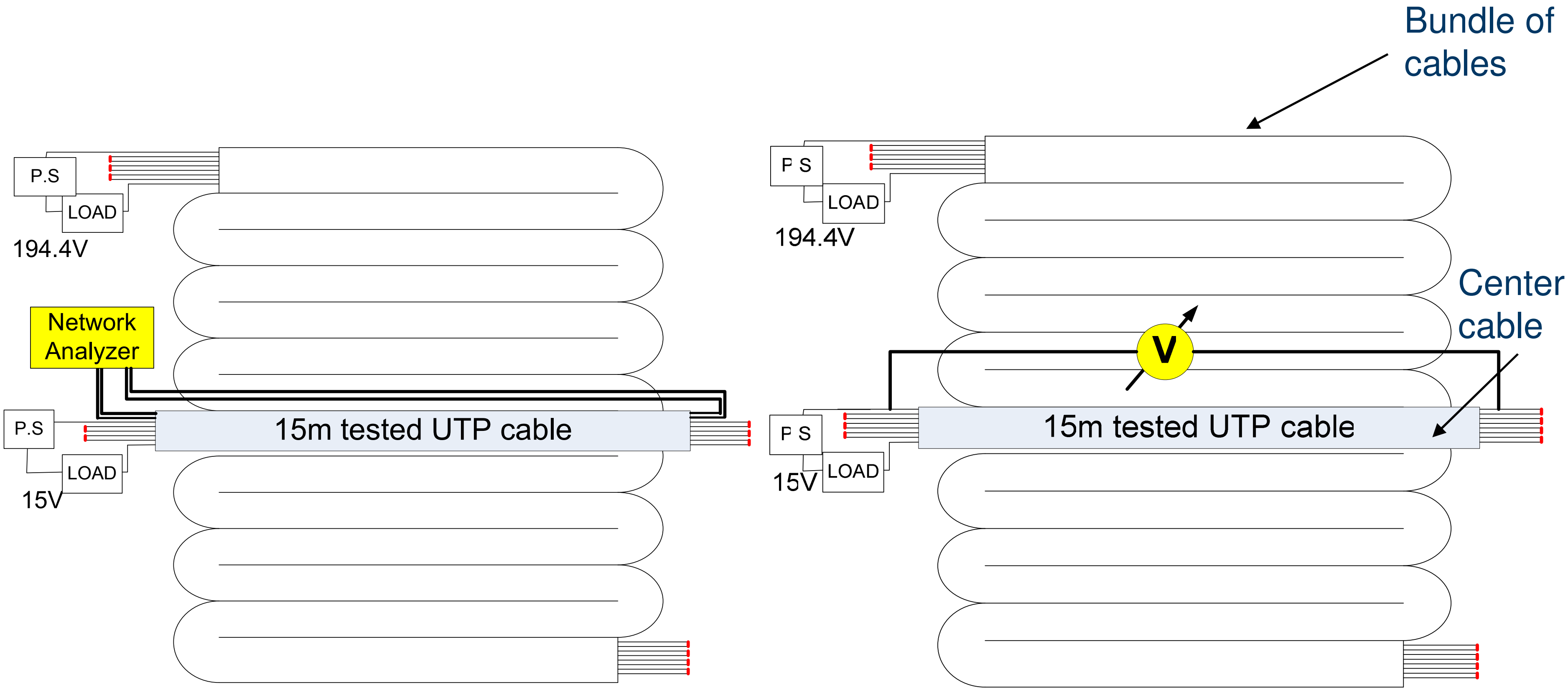
Types of tests – Heat chamber

- Changing the environmental temperature in a range of 20℃-60℃
- Measuring the resistance and insertion loss of the cable.
- Testing 2 pairs out of 4 (Blue and Green pairs)



Types of Tests - Current

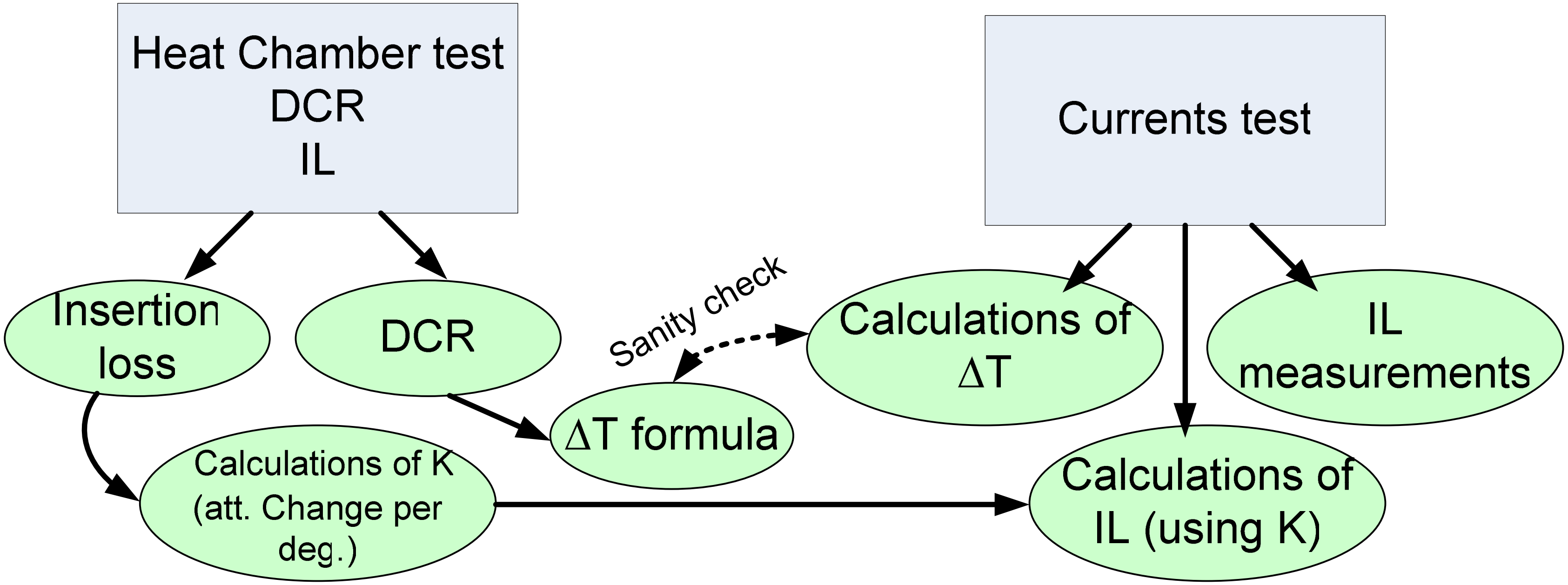
- Changing the current over a bundle of cables in an air conditioned room.
- measuring the resistance and insertion loss of the cable.



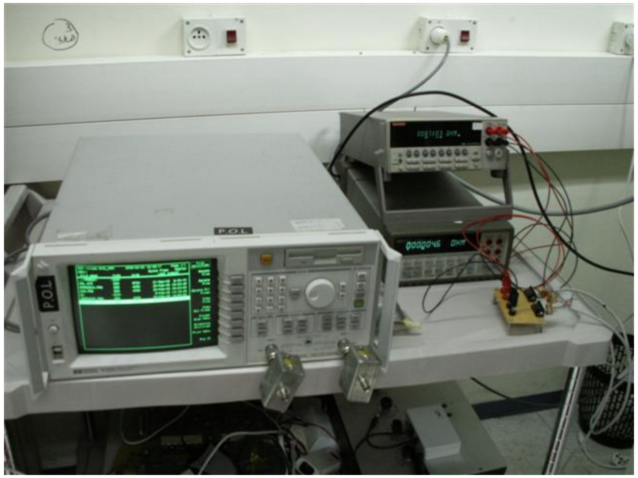
Terms and Abbreviations

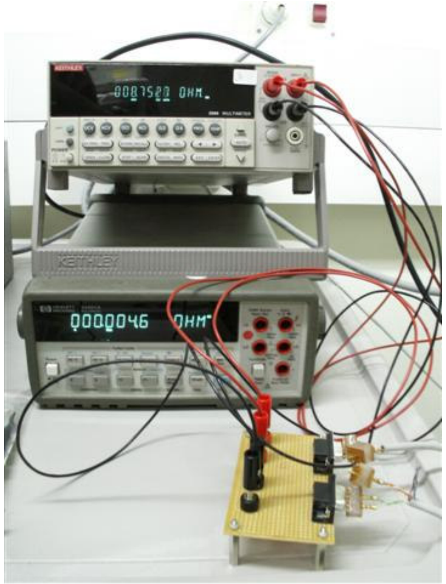
- Tref – Reference temperature = 20℃ all along the test.
- ΔT – Temperature difference from reference temperature.
- K - The attenuation increase (in percentage) related to temperature difference (ΔT), [%/C].
- αT – Insertion loss (IL), or attenuation (Att.) at the measuring temperature.
- αTref– Insertion loss (IL), or attenuation (Att.) at reference temperature (20℃).
- Tcoef – Temperature coefficient, the resistance change due to temperature change. Copper const. is 0.00393 [1/C°]

What do we get from these tests?

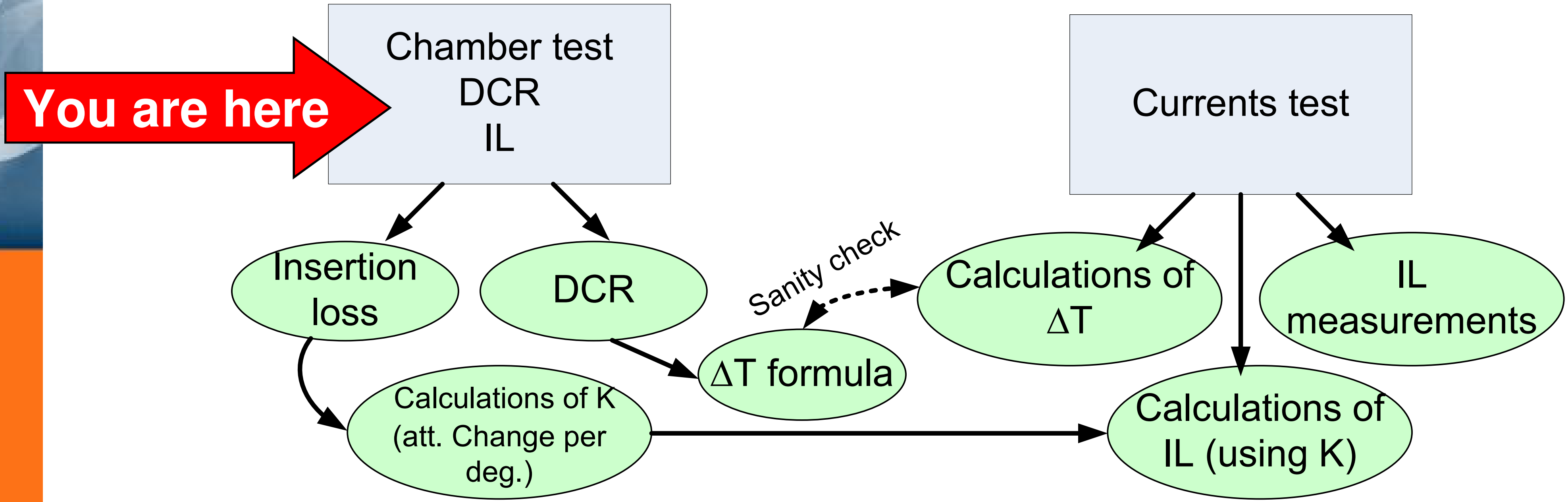


Heat Chamber Test





Heat Chamber Ttest



Heat Chamber Test

- Test target
  - To measure DCR and IL in different temperatures and produce K factor for each temperature.
    - *K factor is the attenuation increase (in percentage) related to temperature difference (ΔT), [%/c]*

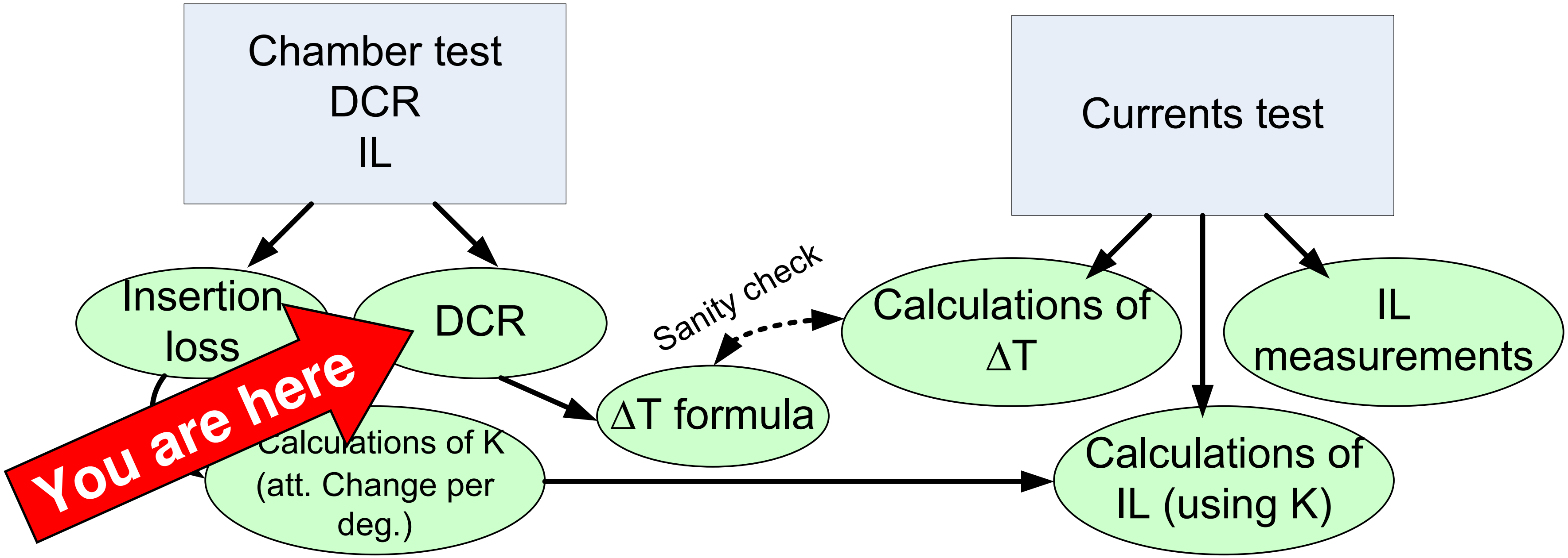
$$\Delta T = \frac{R - Ref}{Ref \cdot Tcoef} \quad [°C]$$

- Test setup
  - 100m UTP cable rolled on a cylinder.
  - 2 meters of cable outside the chamber.

- Test environment:
  - Const. temp. of 20℃ to 60℃, 5℃ steps.
  - Const. 60% relative humidity.

- Test equipment
  - 4 wire DVM.
  - Network analyzer.

Heat Chamber Test - DCR

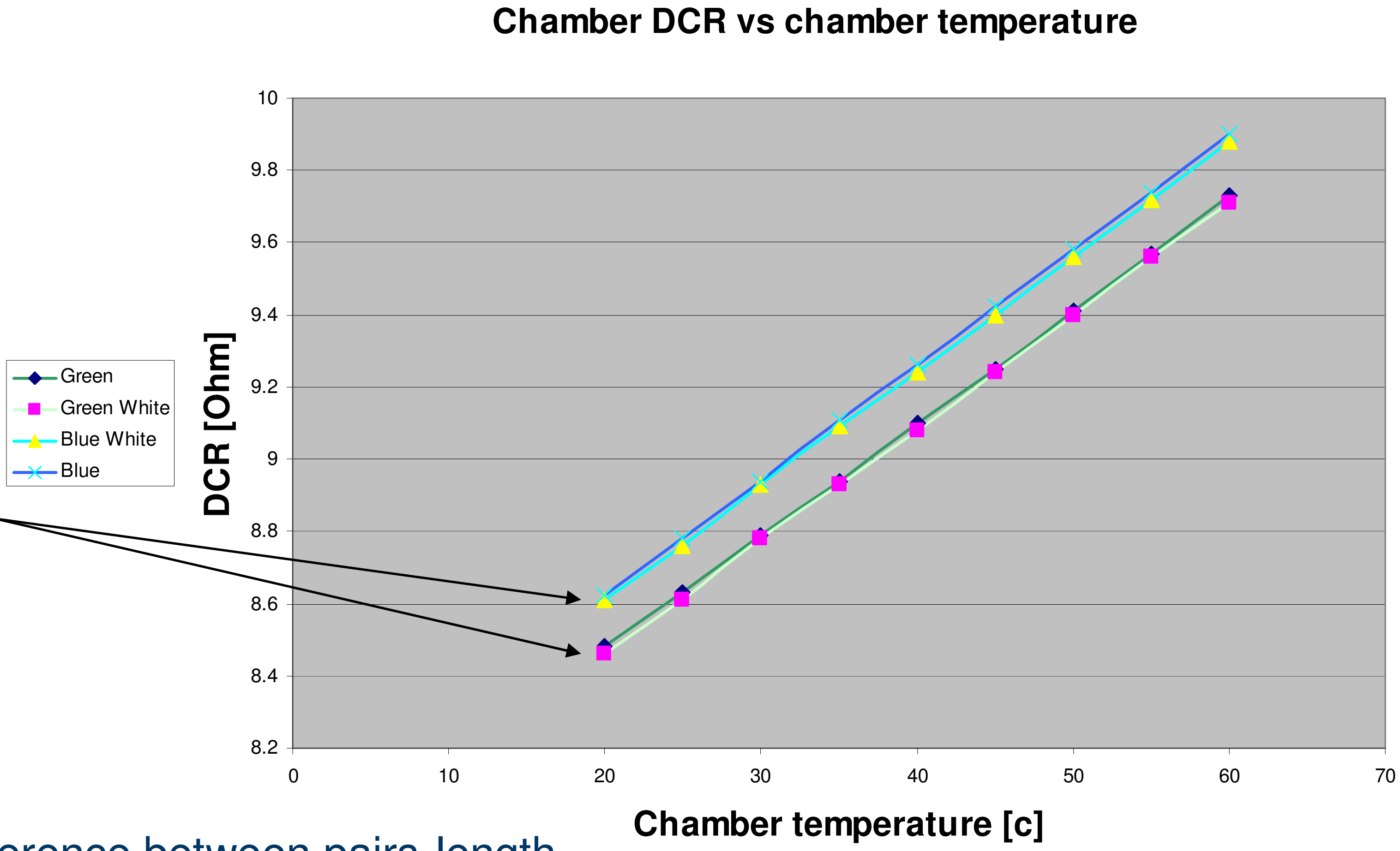


Heat Chamber Test – DCR Results

Change of the resistance due to temperature rise for 4 single wires

- Linear rise in DCR as temperature rise.

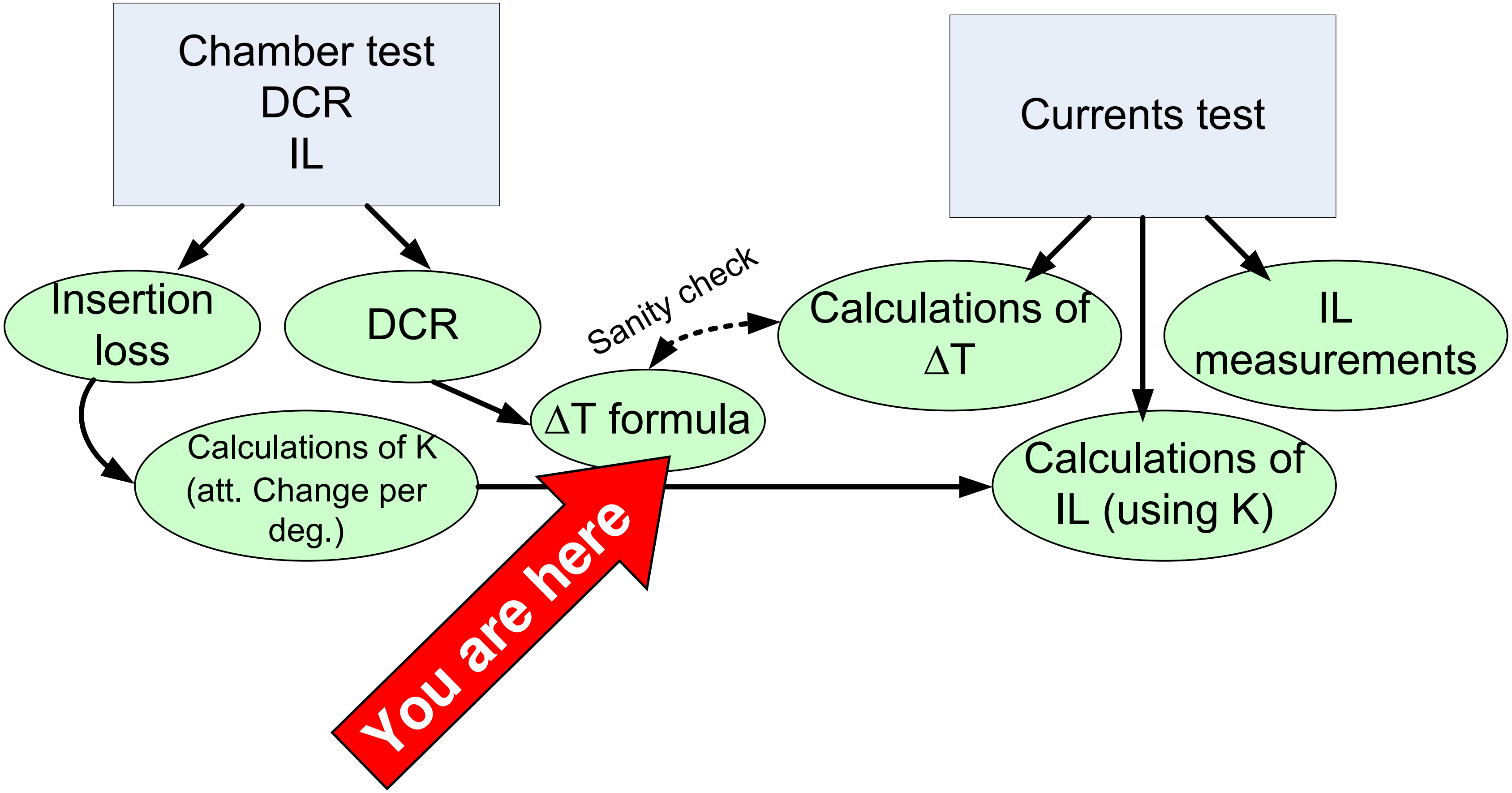
- 0.15Ω diff. out of 8.6Ω is 1.74m length diff. out of 100m



There is a difference between pairs length.

Cat5e std. allows ~7% between pairs length according to skew in propagation delay.

Heat Chamber Test – Calculations of ΔT



Heat Chamber Results – Calculated ΔT

Resistance in tested temp

Resistance in ref. temp. (20℃)

$$\Delta T = \frac{R - Ref}{Ref \cdot Tcoef} \quad [°C]$$

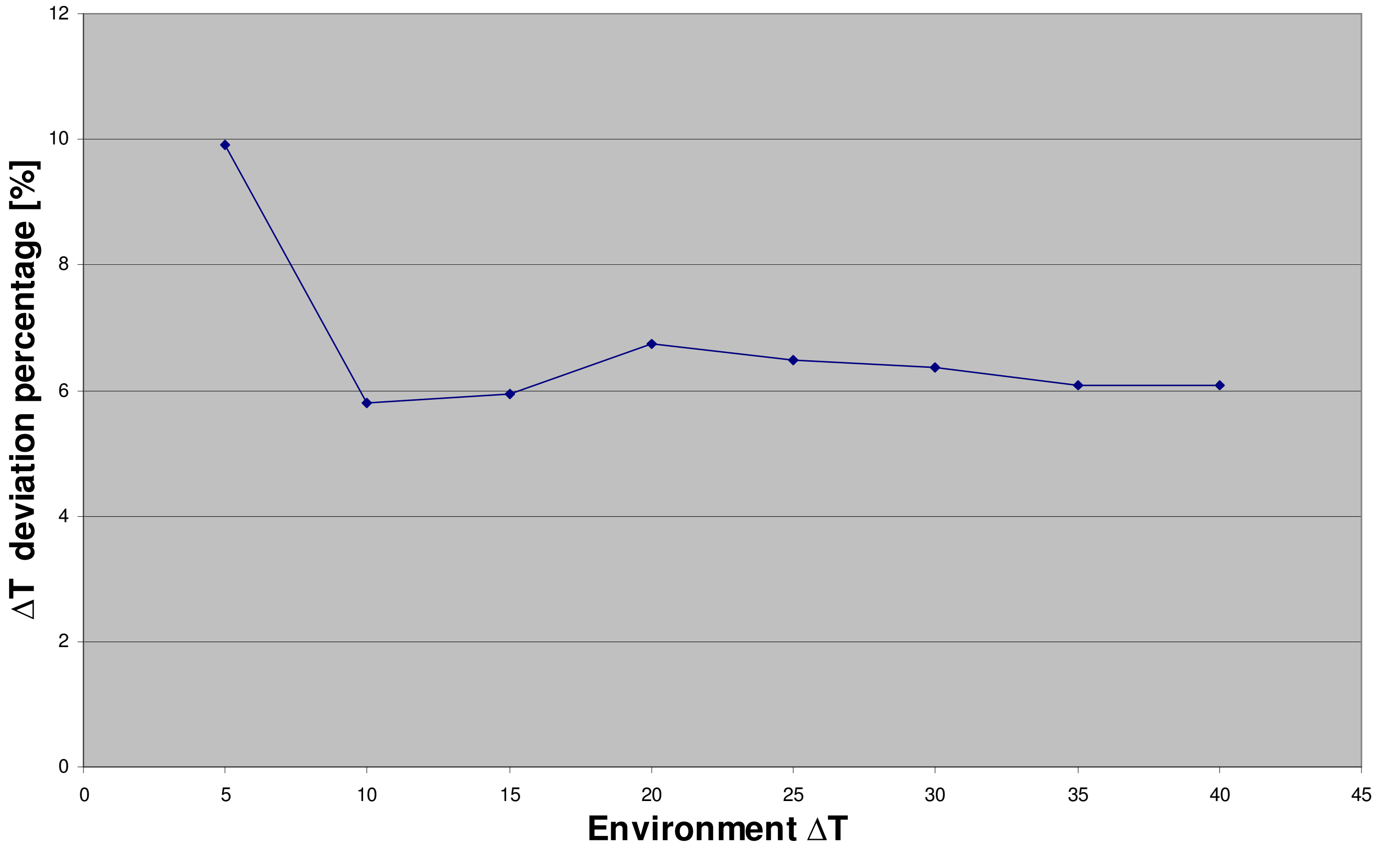
0.00393 copper const. [1/℃]

Calculated ΔT is the temp. difference as yielded from the resistance difference.

Heat Chamber Results –ΔT

Sanity check in order to validate chamber results reliability.

Comparison between calculated ΔT and chamber setup ΔT (Tref=20℃)



6% deviation in 60℃

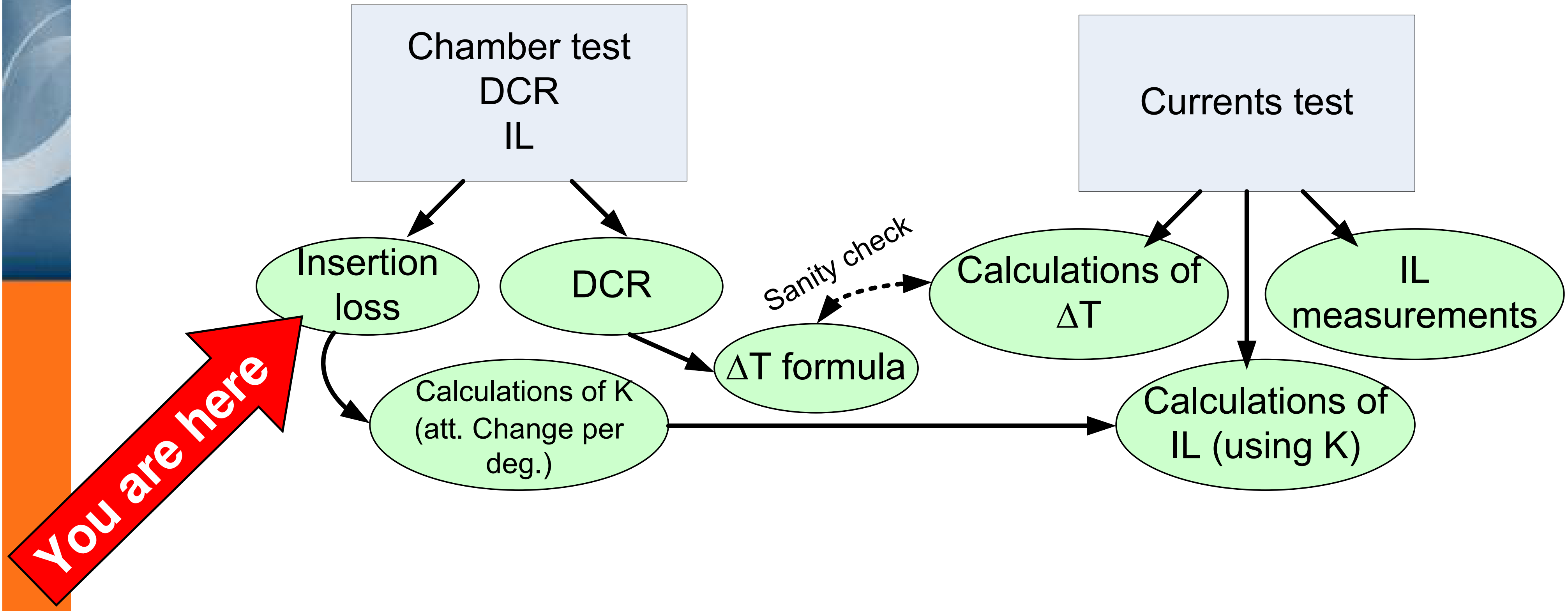
(37.5℃ instead of 40℃)

10% to 6% deviation between calc. ΔT and chamber setup ΔT

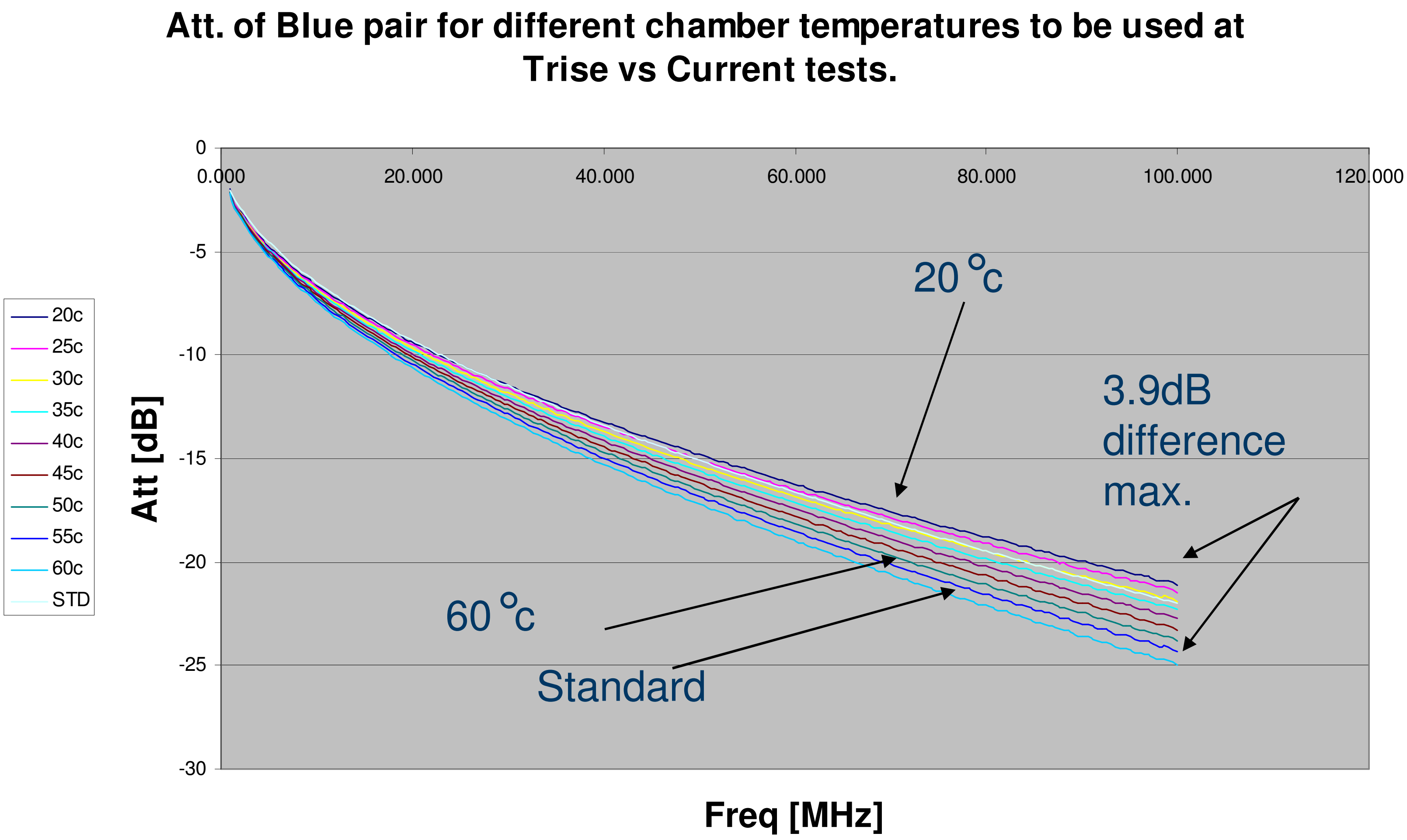
Error Analysis

- Measurement accuracy (chamber, DVM)
  - DMM accuracy is 0.01Ω which reflects 0.03℃
  - Chamber accuracy is +/-0.5℃ (total 1℃)
    - Total maximum measurement deviation is 1.03℃
- 1.5℃ error is still unexplained
  - Some of the heat may be dissipated by test setup leads
- Continue the work while assuming error is within acceptable range to draw some useful conclusions.

Chamber Test - Insertion Loss

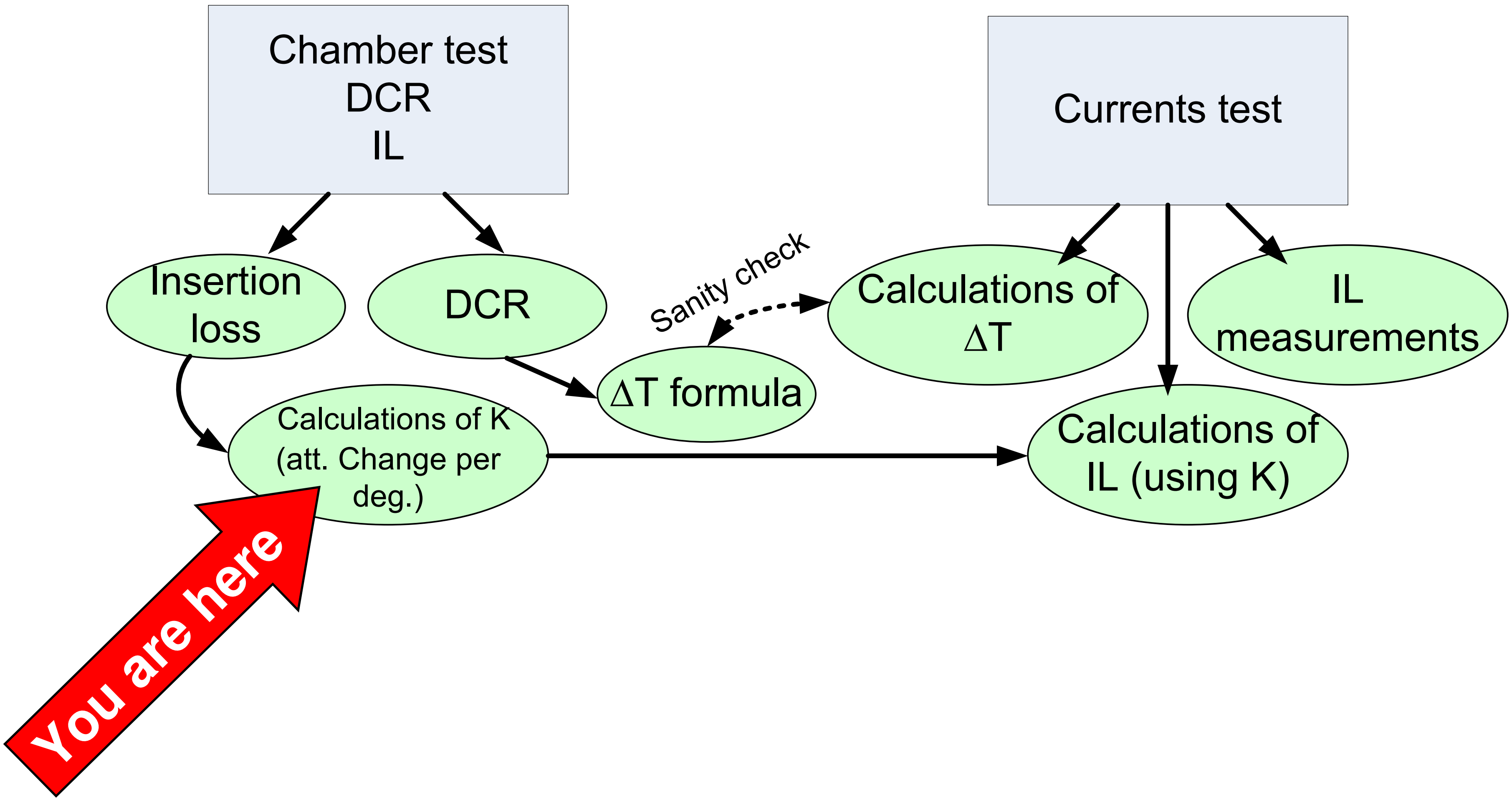


Chamber Test – IL Results

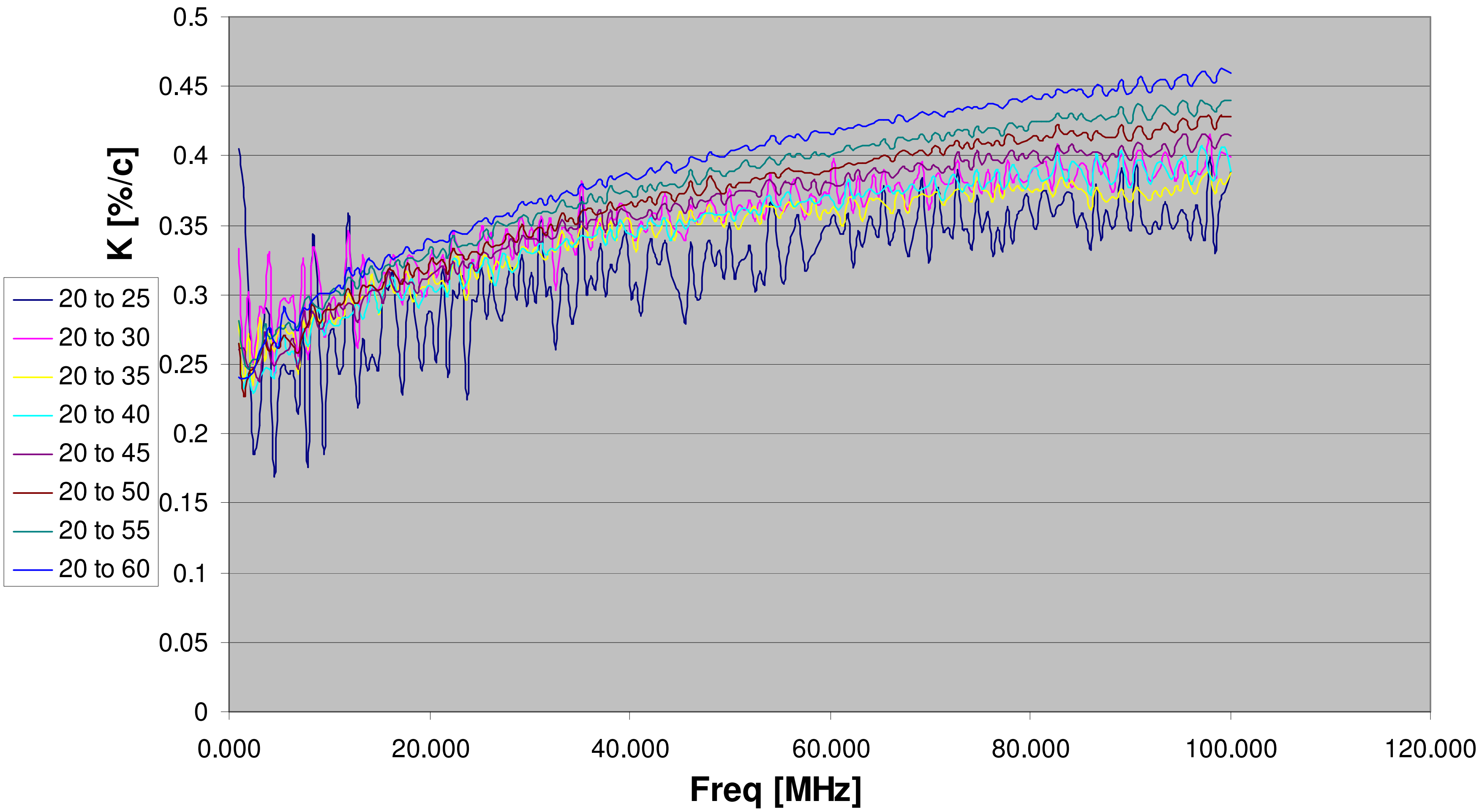


IL complies the cat5e standard for tested temperatures

K constant calculations



K constant (used for calculating Att.)

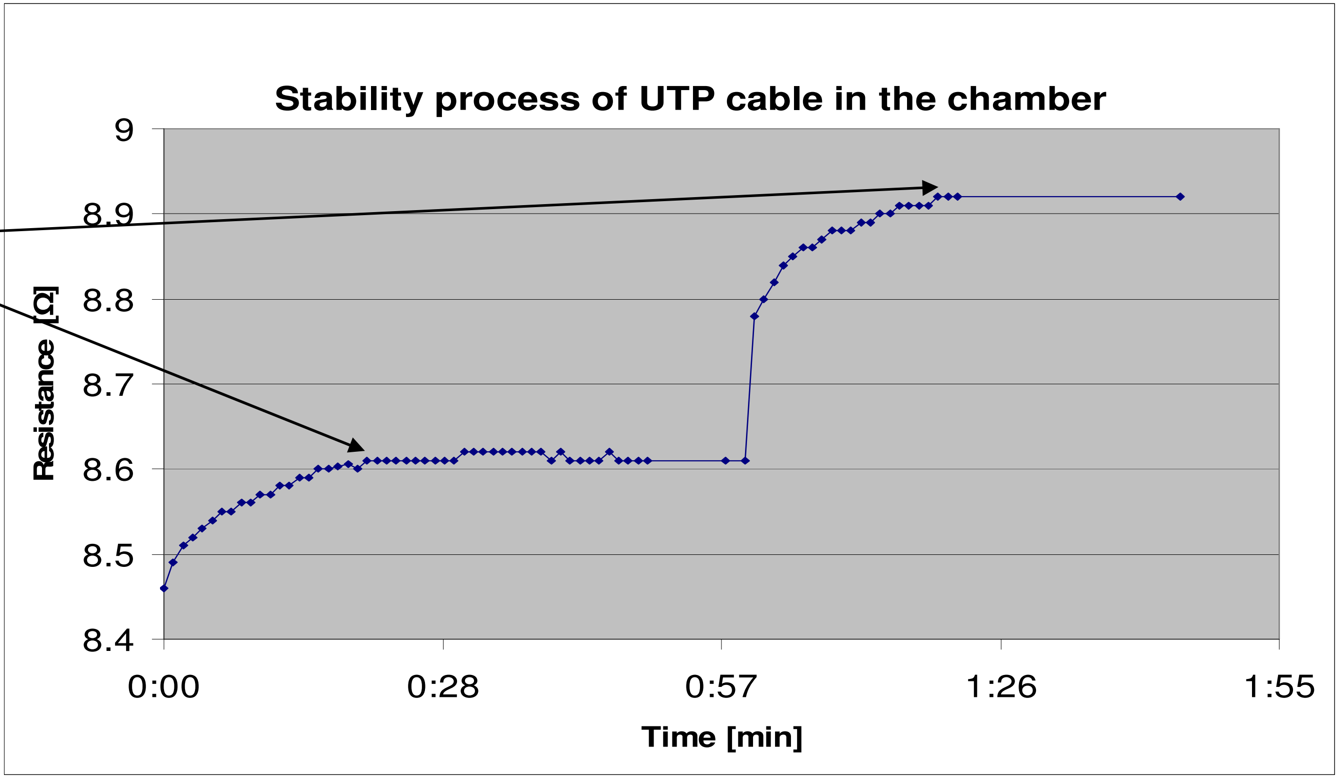


$$k = \frac{(\alpha T - \alpha Tref)}{\alpha Tref \cdot \Delta T} \cdot 100 \qquad [\% / ^\circ C]$$

Heat Chamber Test – Chamber stabilization

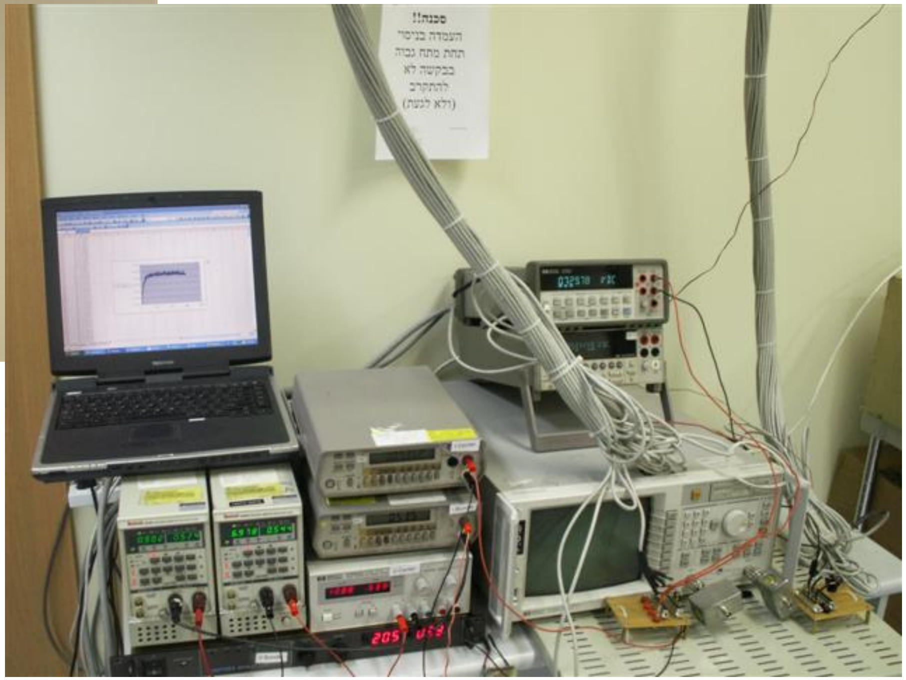
Resistance change as a function of time for single wire in the 100m cable. The graph describes 2 steps of 5℃ each in the heat chamber.

After ~20 minutes the chamber temp. is stable.

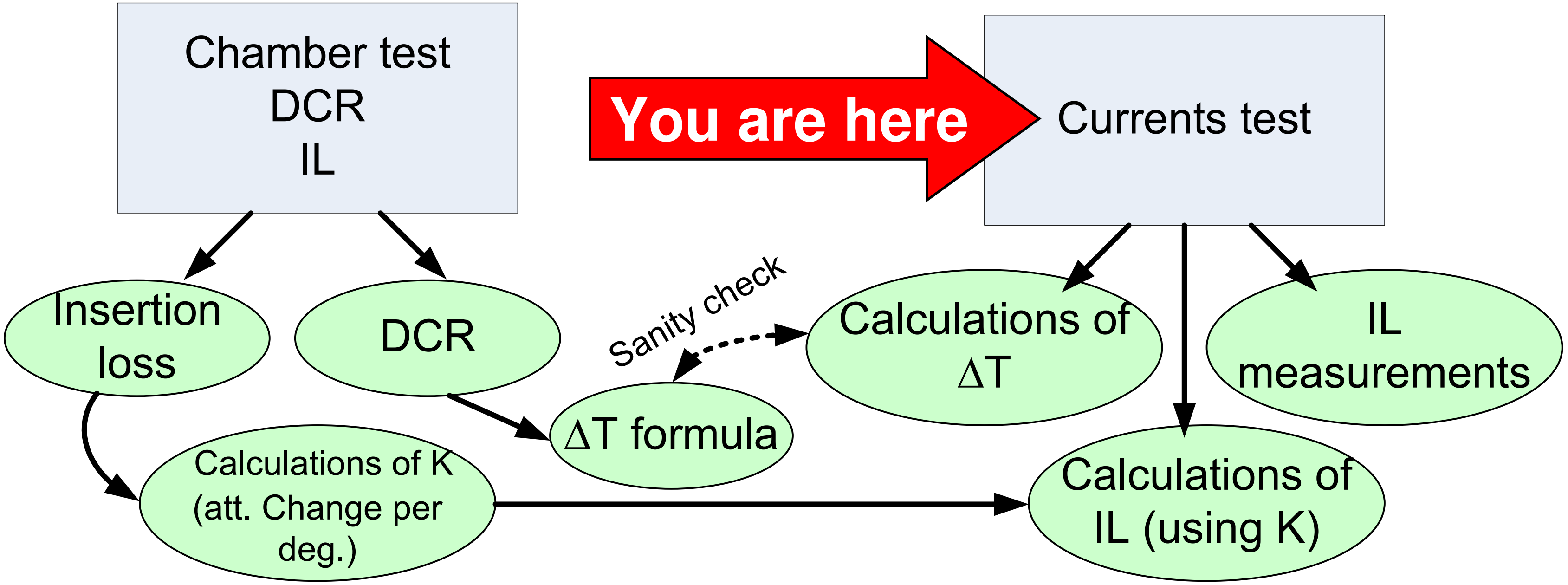


As a result of this test, 60 minutes of stabilization time have been used, instead of 4 hours recommended in the test setup draft.

Current Tests in Air Conditioned room



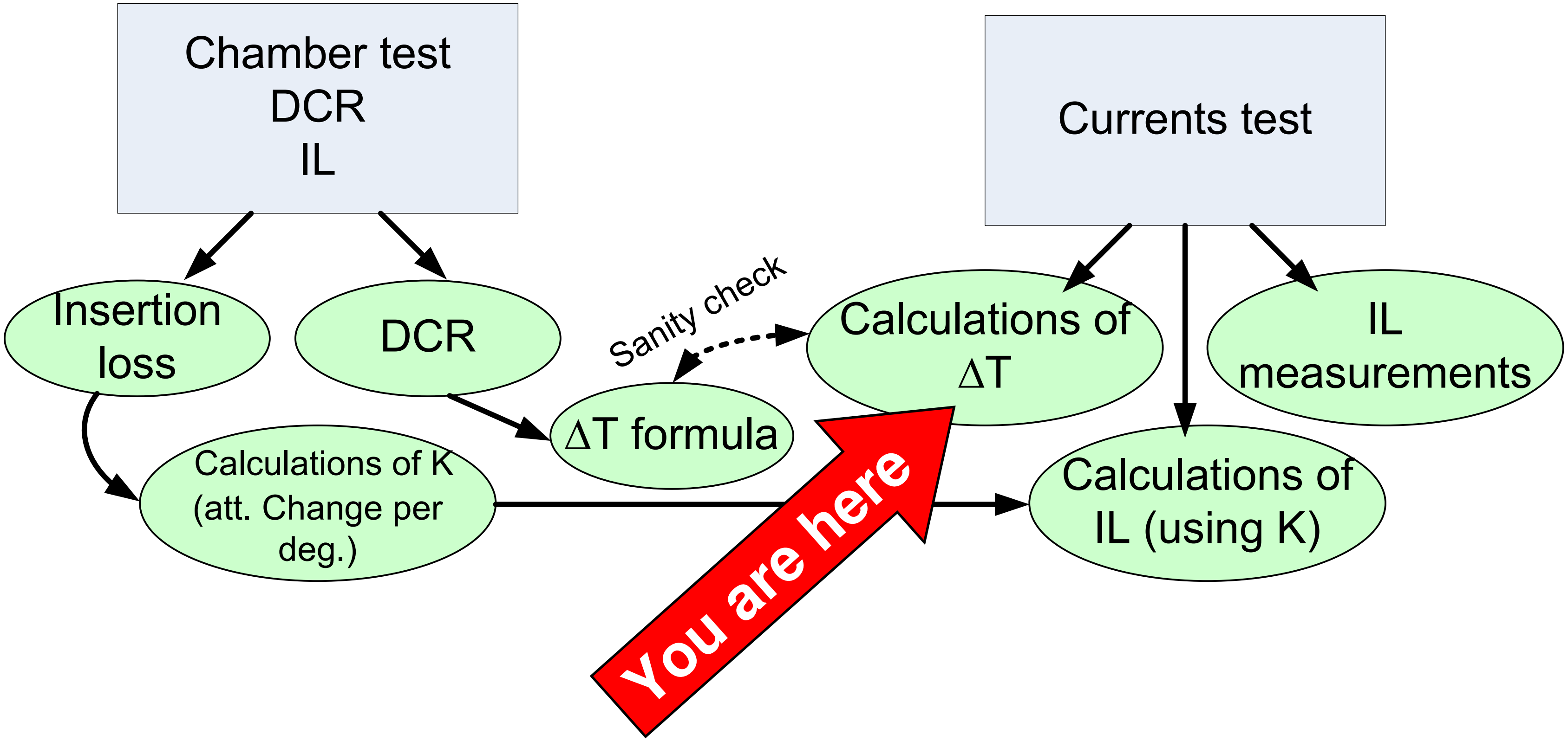
Current Tests



Current Tests

- Test target
  - To test the temperature rise and IL change caused by current flow through the cables.
- Test setup
  - 15.6m bundle of 37 cables.
  - 0.6m of the center cable are not bundled (setup limitations).
  - Currents of 0 to 500mA in all wires including 36 cables and center cable.
  - Center cable temperature rise is to be analyzed.
  - Center cable is from the same manufacturing series as the tested cable in the heat chamber.
- Test environment
  - Air conditioned room in 20℃.
- Test equipment
  - 4 wire DVM
  - Network analyzer
  - 2 * power supply
  - 2 * Electronic load
  - 2 * DVM (to measure constant current)

Current Tests - ΔT Calculations

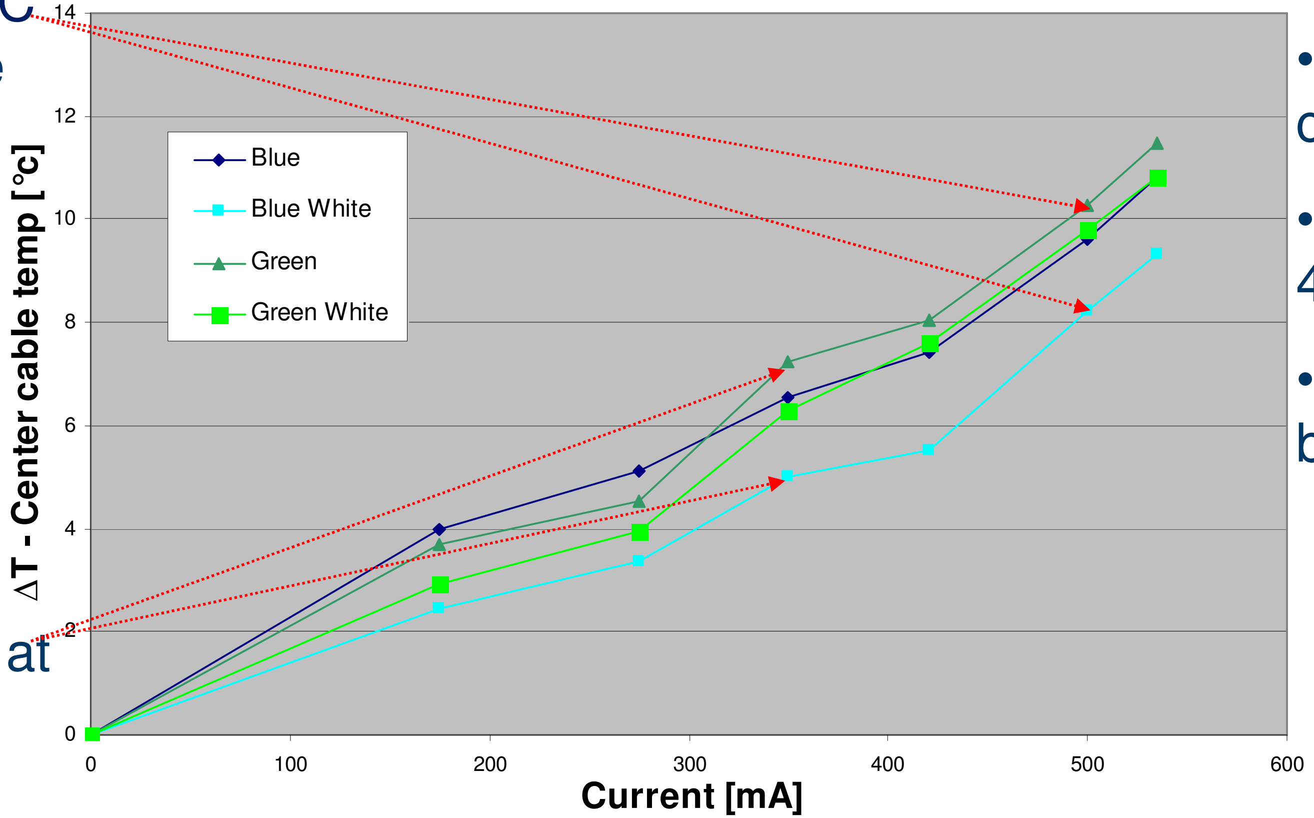


Current Tests - Heating Results

Center cable temperature rise due to current flow over all wires.

8.2°C to 10.3°C at 500mA/wire

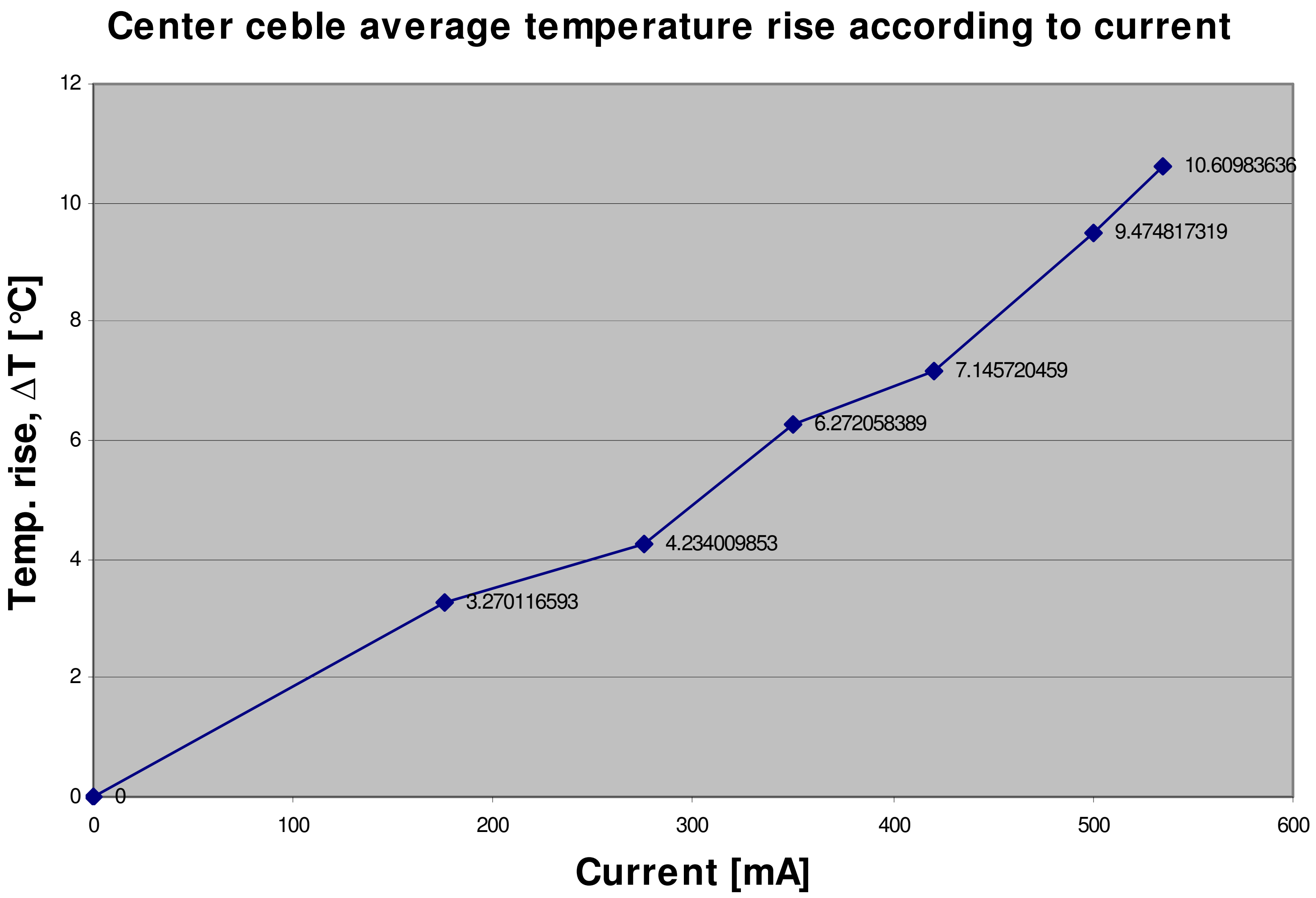
5°C to 7.25°C at 350mA/wire



- All wires conducting
- Each cable 4 pairs
- 37 cables in bundle

- Curve fit will show that Temperature Rise is function of I^2.
- Measurement error is highest at lowest temperature (explains curve shape errors)

Current Tests – Average Heating Results

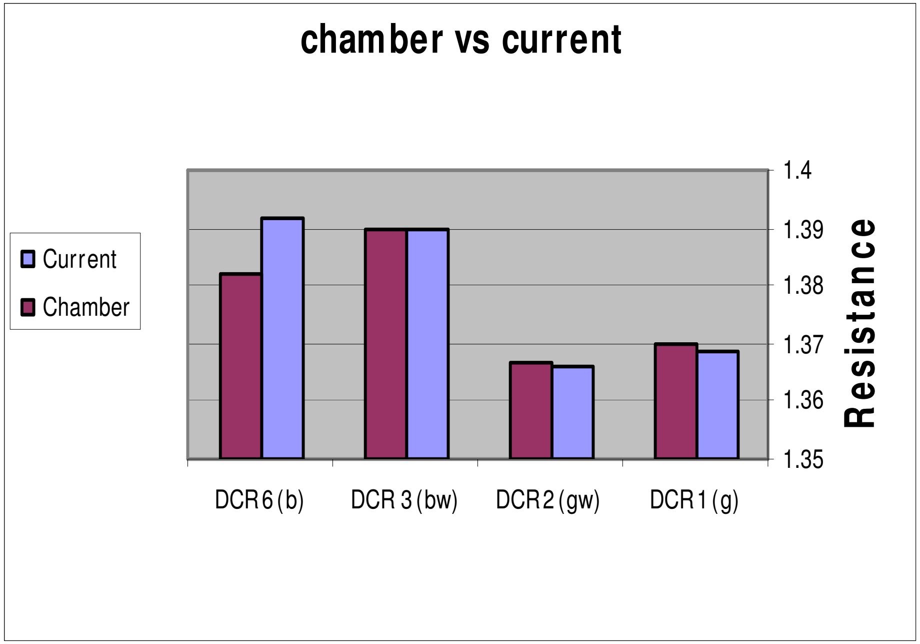


Sanity Check

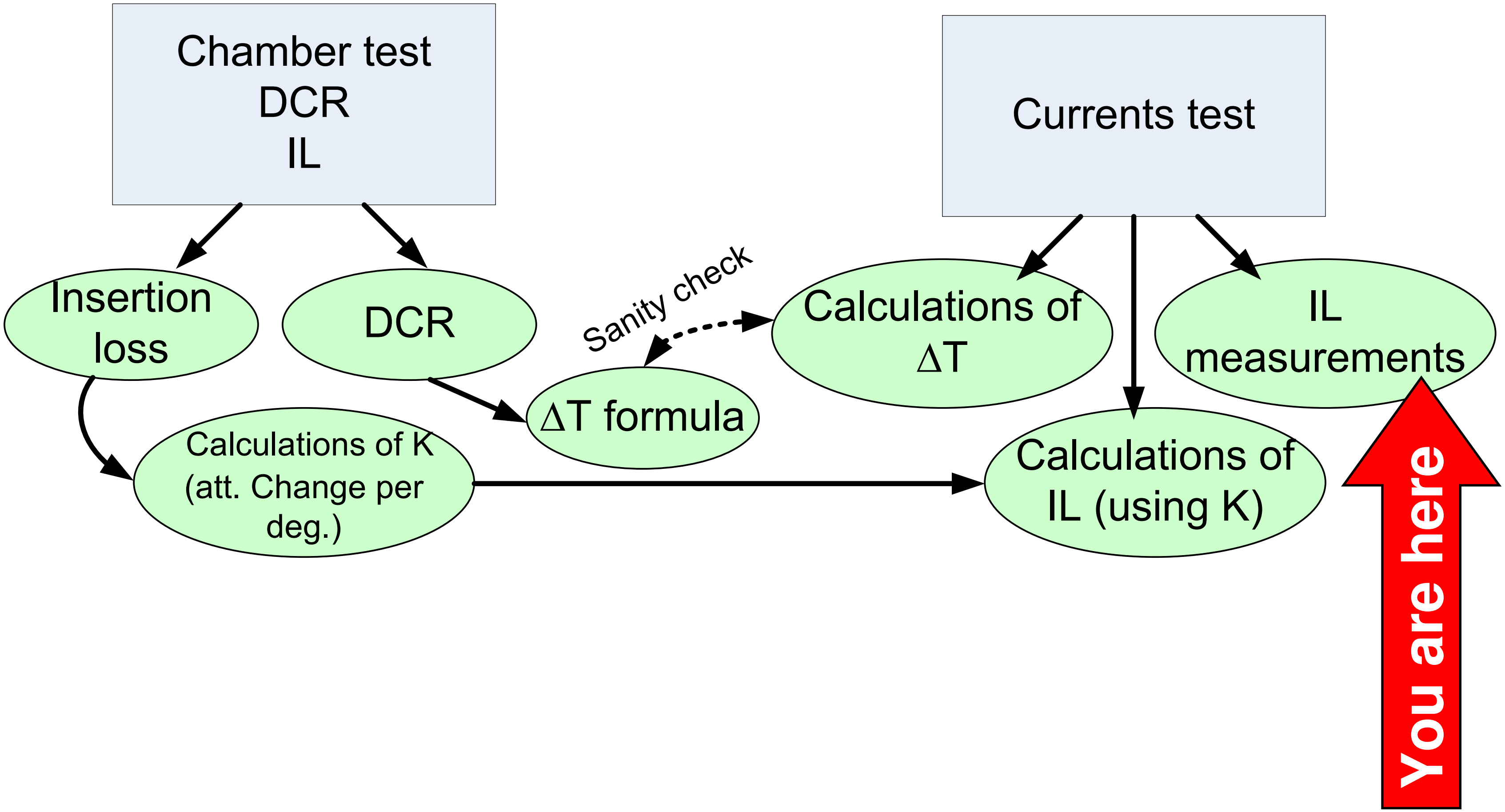
- **Target** - to check if the center cable resistance complies with the calculated temperature.

- **Steps**:
  - Cable resistance at 500mA was taken.
  - Calculated ΔT caused by current flow.
  - Chamber was set to ΔT+Tref.
  - The resistance is measured at this temp.
  - Compared chamber measured resistance to current tests measured resistance.

- **Result:**
  - average error = **0.12%**
  - Maximum error = **0.68%**
  - Minimum error = **0.05%**

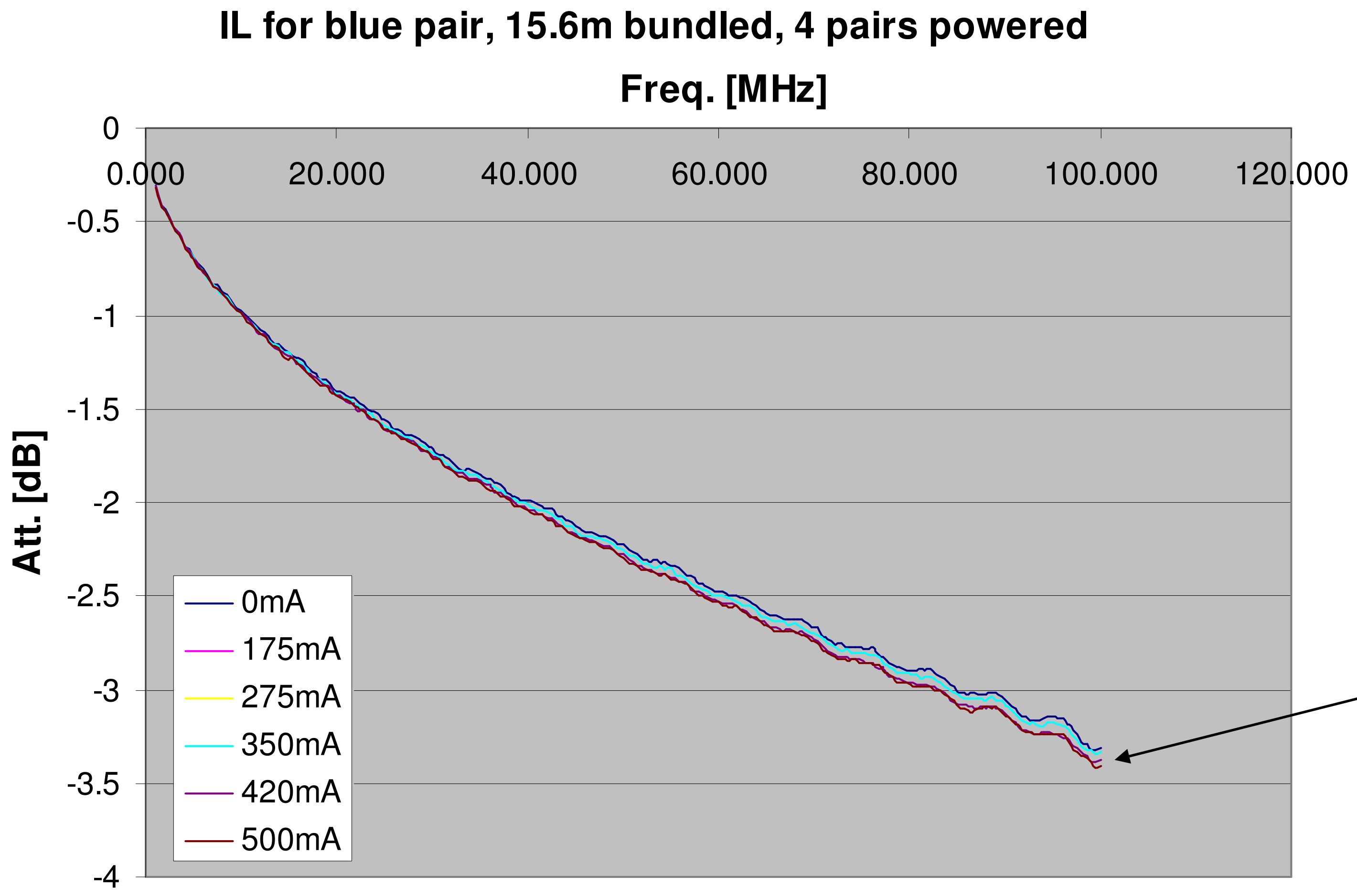


Current Tests – IL Measurements



Current Tests - IL Results

IL (related to freq.) results of one pair at different currents



- Room temp.
- 15.6m cable
- 37 cables in a bundle

0.11dB att. at 15.6m between 0mA to 500mA, which equivalent to 0.75dB att. at 100m

Sanity Check

Step 1: Current Test

Data: Att. for 15.6m @ 500mA is 0.11dB higher than Att. @ 0mA.

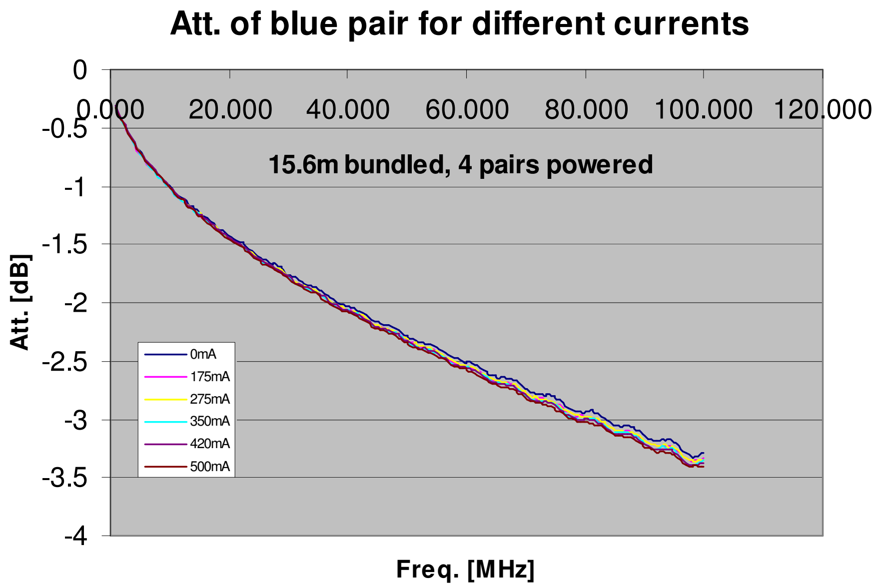
This reflects 0.75dB @ 100m.

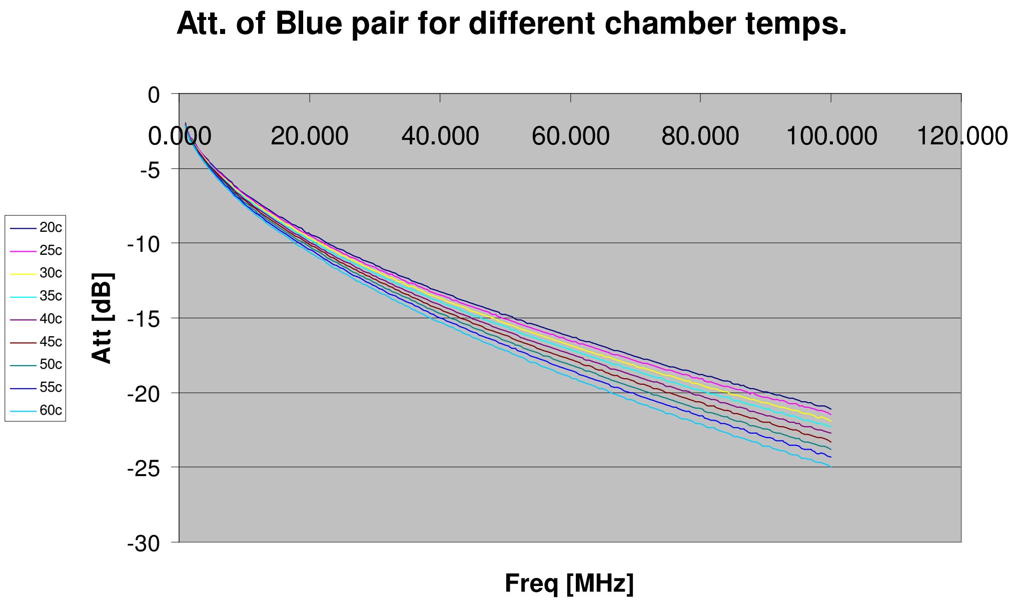
According to equation (Trise vs Attenuation in slide 20) attenuation increase of 0.75dB indicates temperature rise of 10℃

Step 2: Heating Chamber Test

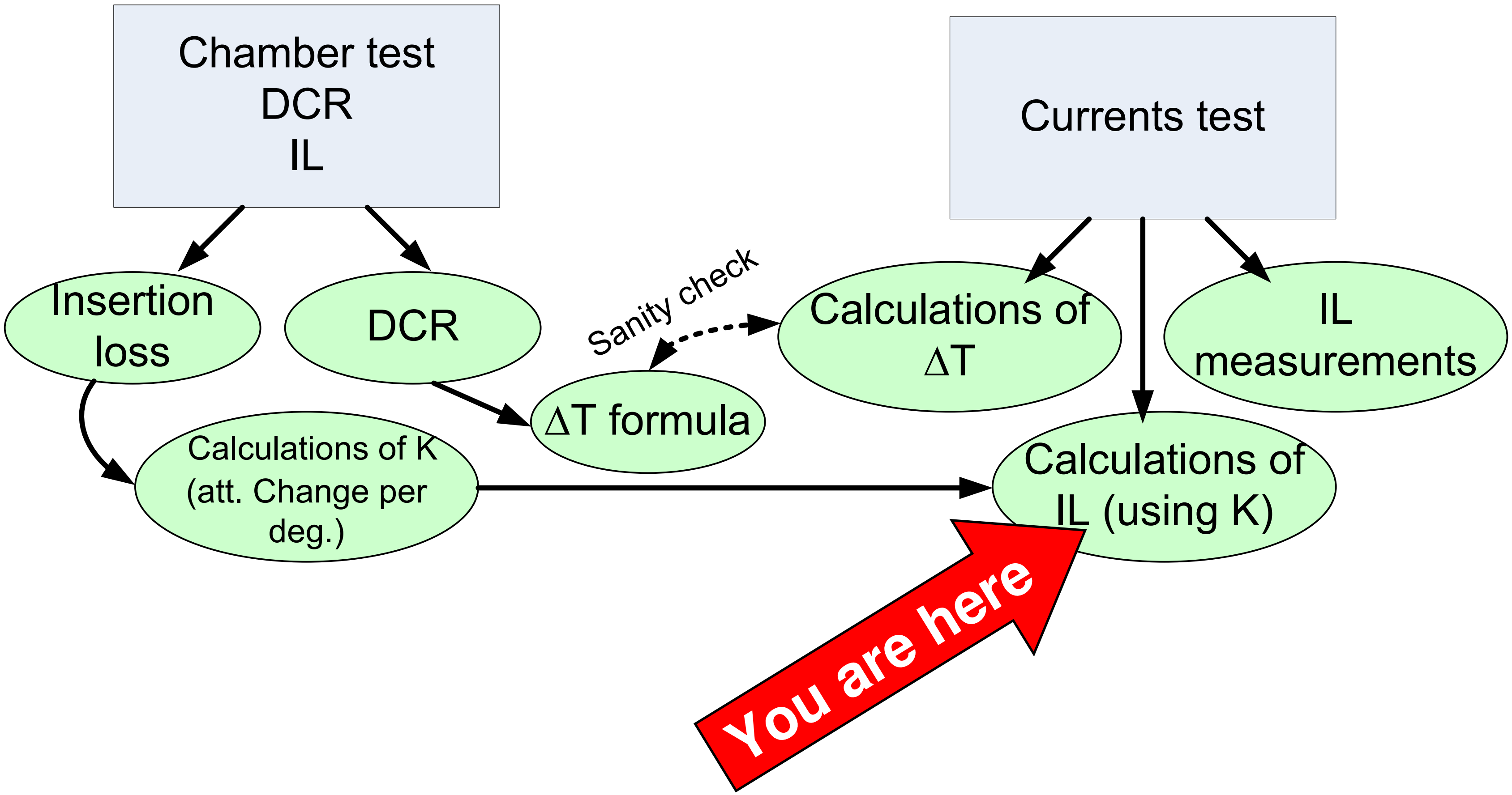
Chamber temperature was increased by 10℃ (From 20℃)

Measured attenuation was increased by 0.8dB which is close to 0.75dB above

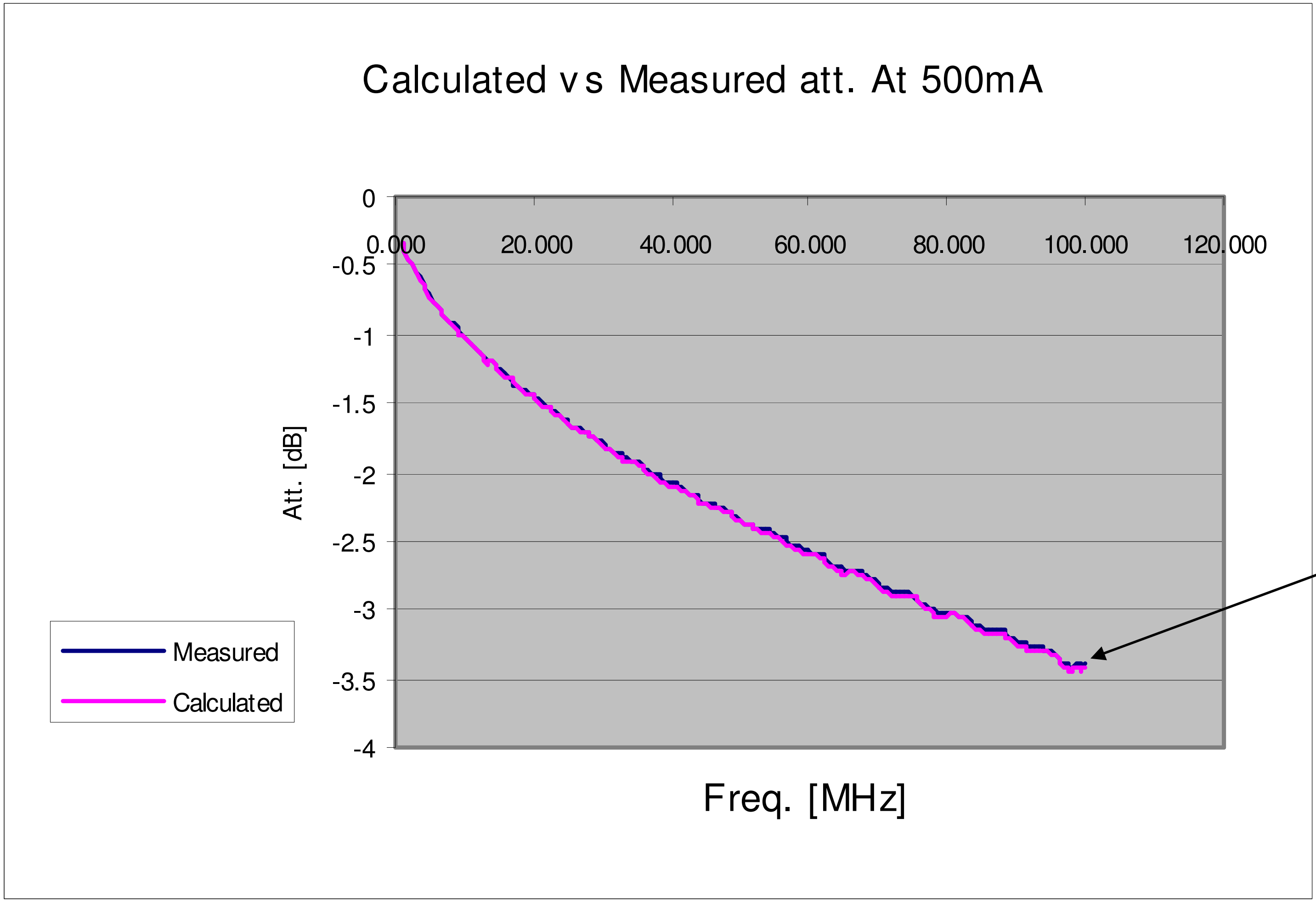




Current Tests – IL Calculations



Measured IL Compared to Calculated IL



Max 1.1% error

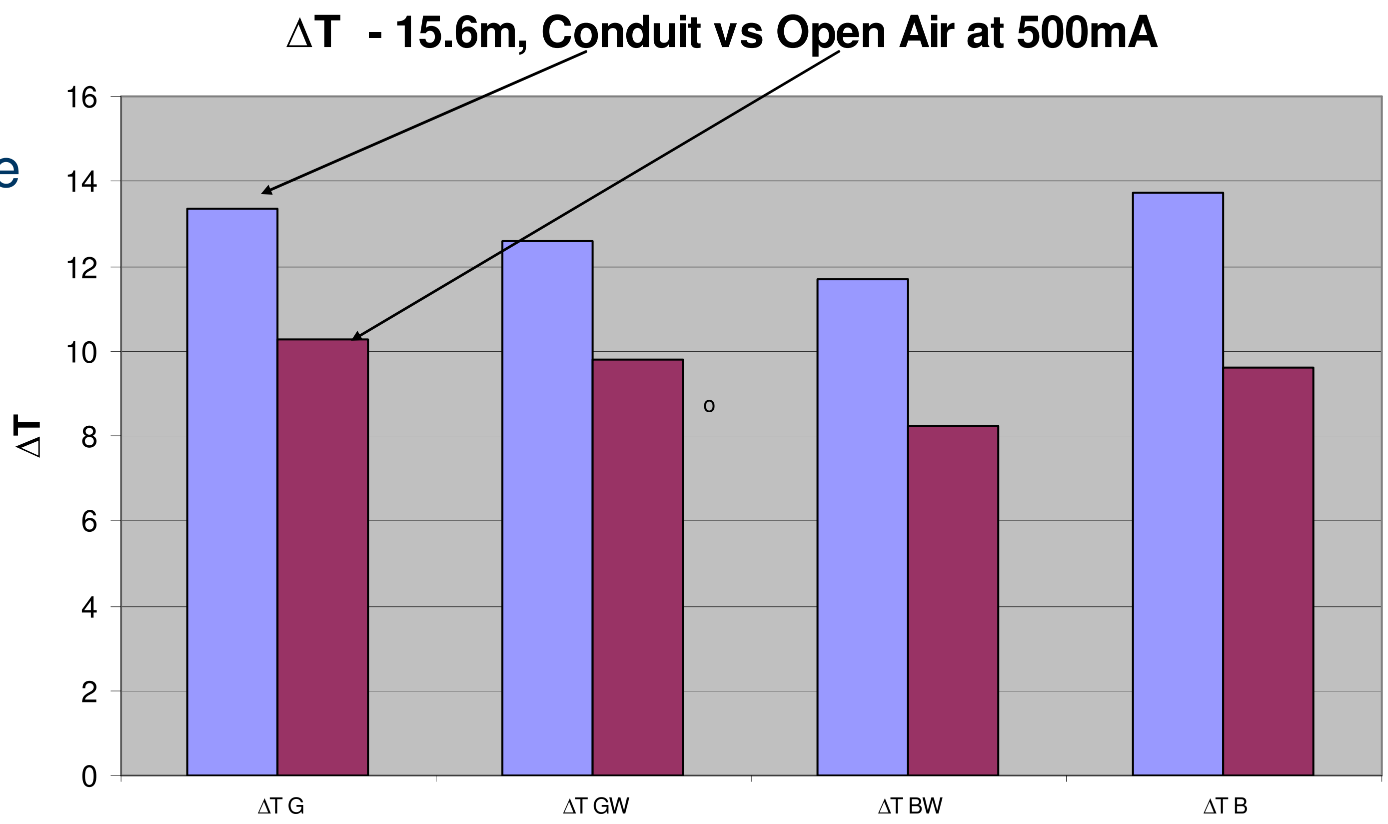
$$\alpha T = \alpha Tref + \left[\Delta T \cdot \alpha Tref \cdot \left(\frac{k}{100}\right)\right]$$

K@ΔT=10℃ was taken

Conduit Test 500mA Comparison

ΔT comparison for 4 wires out of 8 conducting wires, between setups of a bundled cables in open air and in a conduit. Test was taken at 500mA current flow, 15.6m cable.

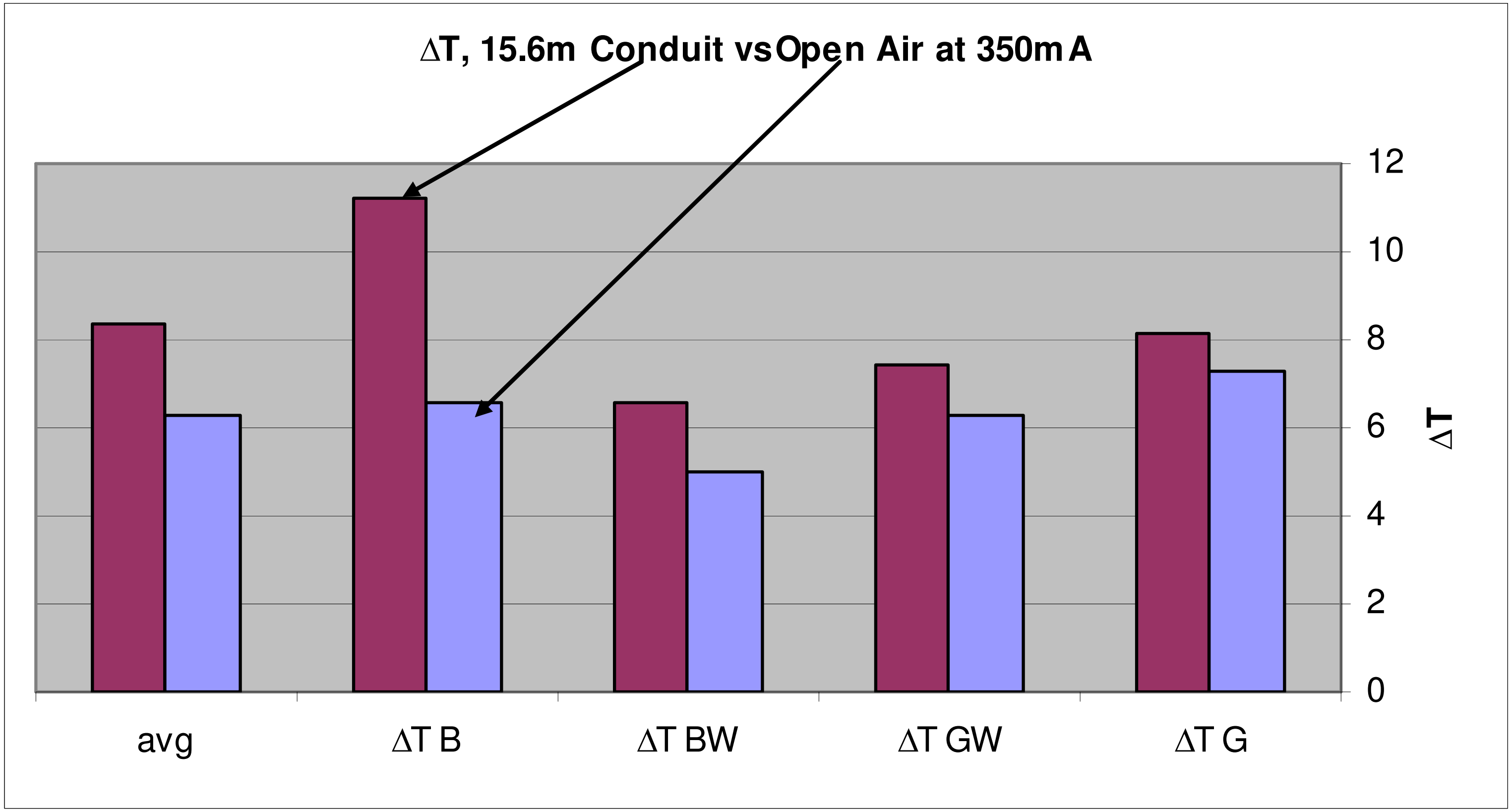
“Conduit” temperature is ~3.9℃ higher than “open air”



Green Green White Blue White Blue

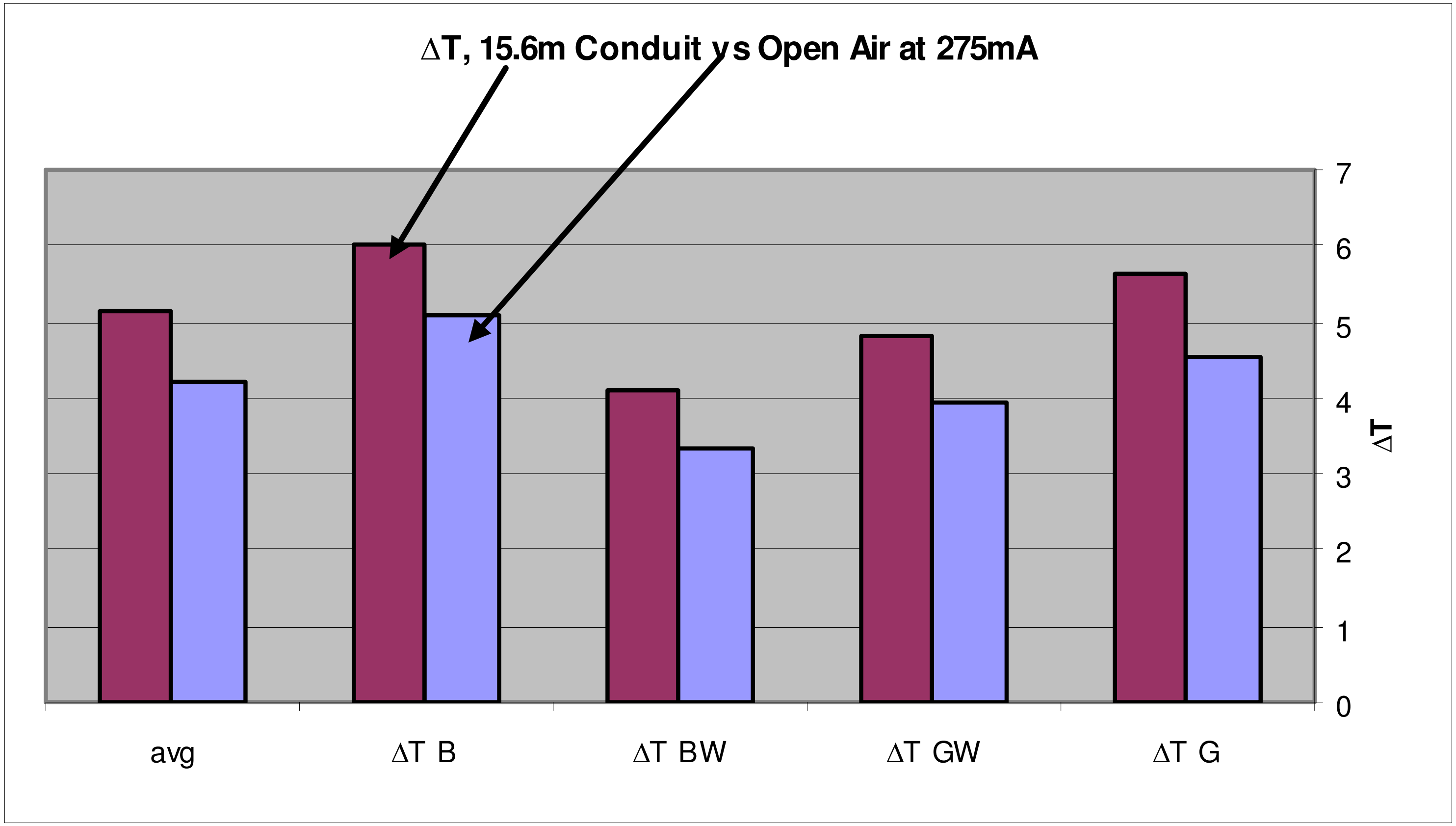
Conduit Test 350mA Comparison

ΔT comparison for 4 wires out of 8 conducting wires, between bundle in open air and bundle cable in a conduit setups. Test was taken at 350mA current flow, 15.6m cable.



Conduit Test 275mA Comparison

ΔT comparison for 4 wires out of 8 conducting wires, between bundle in open air and bundle cable in a conduit setups. Test was taken at 275mA current flow, 15.6m cable.



Worst Case is at 60℃ and not at 20℃ copper temp.

- Until now, reference temperature of 20℃ was investigated. However it does not represent the temperature rise when the cable is in environment of 60℃.

- In order to simulate the temperature rise at 60℃ due to current flow <u>we need to adjust the temperature</u> rise at 20℃ by the (Rcable(@60℃)/Rcable(@20℃))^0.5 ratio.

Rationale

$$\Delta T = \Delta P \cdot \Theta$$

$$\Delta T = I^2 R \cdot \Theta$$

$$\Delta T = I(Tref = 20)^2 R(Tref = 20) \cdot \Theta$$

$$\Delta T = I(Tref = 60)^2 R(Tref = 60) \cdot \Theta$$

$$I(Tref = 20)^2 R(Tref = 20) \cdot \Theta = I(Tref = 60)^2 R(Tref = 60) \cdot \Theta$$

$$I(Tref = 60) = I(Tref = 20) \cdot \sqrt{\frac{R(Tref = 20)}{R(Tref = 60)}}$$

$$\sqrt{\frac{R(20)}{R(60)}} = 0.934$$

For any dT and for any Current (assuming thermal resistance is constant),

$$I(Tref = 60) = I(Tref = 20) \cdot 0.934$$

Tests Restrictions

- The edges of the tested cable are not in the same environment as the rest of the cable. This is due to setup limitations.
- Chamber stabilization – The test procedure[1] requires 4 hours. 20 minutes found sufficient, 1 hour stabilization time is used.
- Setup in Air conditioned room – It is difficult to stabilize a room temperature, and there is an error of ~+/-1 ℃ .
- 15m, 37 cables bundle – The test procedure[1] requires 100m bundle, however, since cable attenuation is linear with cable length, shorter bundle simplifies the setup (15m bundle is used) and lower voltages can be used for the experiment.
- IL test under current – It is difficult to test a wire under current, therefore it was taken out of current while tested.
- No homogeneity between wires – Different results for different wires in the same cable. More tests required in order to get worst case result.

Summary of Test Results

- Measured ΔT for various currents and environments
- Reference temperature=20°C. At 60°C, Trise will be higher by >7%
- All results are average value and not max value.
- 37 cables in a bundle is not the worst case installation. Hence higher temperature rise is expected.
- Measurement accuracy is higher as temperature difference gets higher

Test configuration	Current per wire					
	175mA	275mA	350mA	420mA	500mA	535mA
All 4 pairs conducting in *free air*	3.17°C	4.2°C	6.3°C	7.14°C	10.3°C	11.5°C
All 4 pairs conducting in *Conduit*	3.27°C	5.2°C	8.35°C	9.27°C	13.7°C	NOT TESTED

Data Analysis

- For the tested UTP cable:
  - IR meets the CAT5 standard and its data sheet up to 500mA.
  - Temperature rise for 4P, 37 cables bundled in a conduit, all wires conducting: **13.7°C**
  - According to TIA work: Max recommended temperature rise: **10°C**
  - Hence max current per wire according to TIA recommendations at **Ref temperature=20°C**:

$$\Delta T = \Delta P \cdot \Theta = I^2 R \cdot \Theta$$

$$13.7 = (0.5 \cdot 8)^2 \cdot R(33.7 \deg C) \cdot \Theta = 16 \cdot R(33.7 \deg C) \cdot \Theta$$

$$R \cdot \Theta = \frac{13.7}{16} = 0.85625$$

$$10 = (I \cdot 8)^2 \cdot R \cdot \Theta = 64 \cdot I^2 \cdot 0.85625 = 54.8 \cdot I^2$$

$$I(Trise\_\max = 10 \deg C, Tref = 20 \deg C) = \sqrt{\frac{10}{54.8}} = 0.427A$$

  - Adjusting to **60°C environment: 0.427Ax0.934 =0.398A max.**
  - Taking 6db margin for IEEE specification i.e. Trise max=5degC
    - Accounting for worst case installations $I(Trise\_\max = 5 \deg C) = \sqrt{\frac{5}{54.8}} = 0.3A \max$
    - Adjusting to **60°C environment: 0.3Ax0.934 =0.28A max per wire.**

Recommendations

	Trise	Ta	Tcopper	Current per wire	Comments
	℃	℃	℃	mA	
Based on Test Results	10	50	60	398	
Taking 6dB margin to handle worst case installations, measurement errors etc.					
Based on Test Results	5	55	60	280	
Other Reference Data from previous presentations					
NASA Spec.	5			275	

Note: Ignoring cable life time as function of temperature

References

- 1. http://www.ieee802.org/3/at/public/nov05/di_minico_1_1105.pdf
- 2. http://www.ieee802.org/3/poep_study/public/jul05/koonce_2_0705.pdf