Expert contribution on

Wire diameter vs. current carrying capacity

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1. Wire basics

In all electrical installations we know one rule which everywhere is followed and till now was never questioned:

The higher the current, the larger the wire diameter or the cross section has to be. Some examples from power distribution networks in Switzerland:

Wire cross section	AWG	Maximum current carrying capacity
1mm^2	17	6A
1.5mm^2	15	16A
2.5mm^2	13	20A
4mm^2	11	25A
6mm^2	9	35A
10mm^2	7	40A
16mm^2	5	63A

2. What was first defined

IEEE defined two link segments in 802.3cg for 10Base-T1L:

- **A 1000m link:**

146.7.1.1.1 Insertion loss for PHYs in the 2.4 Vpp operation mode

For PHYs in the 2.4 Vpp operation mode, the insertion loss of each 10BASE-T1L link segment shall meet the values determined using Equation (146–10).

$$\text{Insertion loss}(f) \le 10\left(1.23 \times \sqrt{f} + 0.01 \times f + \frac{0.2}{\sqrt{f}}\right) + 10 \times 0.02 \times \sqrt{f} \quad (\text{dB}) \qquad (146\text{–}10)$$

- **A 590m link:**

146.7.1.1.2 Insertion loss supported for PHYs in 1.0 Vpp operation mode

For PHYs in the 1.0 Vpp operation mode, the insertion loss of each 10BASE-T1L link segment shall meet the values determined using Equation (146–11).

$$\text{Insertion loss}(f) \le 5.9\left(1.23 \times \sqrt{f} + 0.01 \times f + \frac{0.2}{\sqrt{f}}\right) + 10 \times 0.02 \times \sqrt{f} \quad (\text{dB}) \qquad (146\text{–}11)$$

It is important to understand, both link segments have the same wire diameter, therefore they have the same current carrying capacity.

3. How the confusion started

Cabling committees took the 590m link segment of AWG18 wires and made from it a 400m link segment of AWG23 wires.

So far that is not bad as both have the same attenuation, respectively the 400m link segment is always slightly below the 590m AWG18 link segment.

However, with the reduction of the wire diameter also the current carrying capacity was reduced.

Here as example ANSI/TIA-568.5, published on 25th February 2022. Both channels can be also found in ISO/IEC 11801-1 AMD1.
SP1-1000: AWG18
SP1-400: AWG23

ANSI/TIA-568.5

6.3.7 Channel insertion loss

SP1-1000 single pair channel insertion loss limits are derived from equation (3).

$$InsertionLoss_{SP1-channel1} = 10 \cdot (InsertionLoss_{conn}) + (InsertionLoss_{SP1-1000_{cable_{1000m}}})\ dB \quad (3)$$

SP1-400 single pair channel insertion loss limits are derived from equation (4).

$$InsertionLoss_{SP1-channel400} = 5 \cdot (InsertionLoss_{conn}) + (InsertionLoss_{SP1-400_{cab\ 400m}})\ dB \quad (4)$$

Clause 6.6.6 defines cable insertion loss.

$InsertionLoss_{conn}$ is the insertion loss of connecting hardware.

$$InsertionLoss_{conn} = 0.02\sqrt{f} \quad (5)$$

Channel insertion loss shall meet or be less than the values determined using the equations shown in table 7 for all specified frequencies.

Table 7 - Channel insertion loss

	Frequency (MHz)	Insertion loss (dB)
SP1-1000	$0.1 \le f \le 20$	$10 \cdot (1.23\sqrt{f} + 0.01f + \frac{0.2}{\sqrt{f}}) + 10 \cdot 0.02\sqrt{f}$
SP1-400	$0.1 \le f \le 20$	$4 \cdot (1.82\sqrt{f} + 0.0091f + \frac{0.25}{\sqrt{f}}) + 5 \cdot 0.02\sqrt{f}$

3. How the confusion started

For completeness, here the channel list according ISO/IEC 11801-1 AMD1:

T1-A-1000: AWG18

All other channels: AWG23

6.6.3.2 Insertion loss/attenuation

The insertion loss requirements are applicable to all single pair cabling Classes.

The insertion loss (*IL*) of a single pair channel shall meet the requirements in Table 48. The insertion loss values for a single pair channel at key frequencies are given in Table 49 for information only.

Table 48 – Insertion loss for a single pair channel

Class	Frequency MHz	Maximum insertion loss [a] dB
T1-A-1000 [b]	$0,1 \leq f \leq 20$	$10 \cdot \left(1,23 \cdot \sqrt{f} + 0,01 \cdot f + \frac{0,2}{\sqrt{f}}\right) + 10 \cdot 0,02 \cdot \sqrt{f}$
T1-A-400 [c]	$0,1 \leq f \leq 20$	$4,05 \cdot \left(1,82 \cdot \sqrt{f} + 0,0091 \cdot f + \frac{0,25}{\sqrt{f}}\right) + 5 \cdot 0,02 \cdot \sqrt{f}$
T1-A-250 [c]	$0,1 \leq f \leq 20$	$2,55 \cdot \left(1,82 \cdot \sqrt{f} + 0,0091 \cdot f + \frac{0,25}{\sqrt{f}}\right) + 4 \cdot 0,02 \cdot \sqrt{f}$
T1-A-100 [c]	$0,1 \leq f \leq 20$	$1,05 \cdot \left(1,82 \cdot \sqrt{f} + 0,0091 \cdot f + \frac{0,25}{\sqrt{f}}\right) + 4 \cdot 0,02 \cdot \sqrt{f}$
T1-B [c]	$0,1 \leq f \leq 600$	$1,05 \cdot \left(1,8 \cdot \sqrt{f} + 0,005 \cdot f + \frac{0,25}{\sqrt{f}}\right) + 4 \cdot 0,02 \cdot \sqrt{f}$
T1-C [c]	$0,1 \leq f \leq 1\,250$	$1,05 \cdot \left(1,8 \cdot \sqrt{f} + 0,005 \cdot f + \frac{0,25}{\sqrt{f}}\right) + 4 \cdot 0,02 \cdot \sqrt{f}$

[a] Insertion loss (*IL*) at frequencies that correspond to calculated values of less than 3,0 dB shall revert to a maximum requirement of 3,0 dB.

[b] Cord cable used in the channel is expected to have no de-rating based on construction.

[c] 10 m of 50% de-rated (based on construction) cord cable is assumed in the equation.

4. Today's status

Related standardisation bodies took over the same specification, here as example SC46C, which is defining the cable for these channels. Also here, we have 2 different wire diameters:
A-1000: AWG18
A-400: AWG23

6.3.3.1 Attenuation at 20 °C operating temperature

The maximum attenuation, α, in the frequency range from 0,1 MHz to 20 MHz shall not exceed the values obtained from Equation (2) using the coefficients indicated in Table 3.

$$\alpha = a\sqrt{f} + bf + c/\sqrt{f} \qquad (2)$$

where

α is the attenuation expressed in dB/100 m
a, b, c are constants indicated in Table 3
f is the frequency expressed in MHz

Table 3 – Attenuation equation constants

Cable type	Constants		
	a	b	c
A-1000	1,23	0,01	0,2
A-400	1,82	0,0091	0,25

4. Today's status

TIA SPEC(https://spec.tiaonline.org/):

- **wireless is not practical as these devices must be powered by batteries or a separate power cable. Wired connectivity run simultaneous data and power.**
- **footprint for 4-pair has high cost for micro-IoT devices and is not fitting into smaller equipment. SPE with its smaller footprint... Standardization of OT and IoT is critical to widespread adoption.**

SPE IPN(https://www.single-pair-ethernet.com/en):

- **SPE is the basis that makes IIoT and Industry 4.0 possible.**
- **SPE allows connection of field devices, sensor/actuator technology.**
- **Ethernet communicates space- and cost-efficiently, cloud to the field level.**
- **Why does classic Ethernet reach its limit in industrial applications? IIoT and Industry 4.0 require a slim, lightweight and powerful infrastructure.**
- **What are the advantages of SPE in industrial applications? The industry has discovered the advantages of slim cabling with SPE.**
- **Will existing Ethernet infrastructures be replaced by SPE? SPE is used where gains can be realised through significant space and weight savings.**

4. Today’s status

SPE IPN(https://www.single-pair-ethernet.com/en):

- **What are the advantages of SPE? Higher efficiency: Cost-efficient due to higher packing density and higher flexibility due to weight savings.**

SPE SA(https://singlepairethernet.com/en/):

- **sensor to the cloud, cost-effective and space-saving components.**
- **Advantages: Reduction of space and weight, more compact cable trays, Integration of up to four devices, tighter bending radii possible for cabling**

Wiring requirements

Different applications have different cabling requirements. The relevant
Refer to the following table for cabling requirements:

	Automotive industry	Building automation	Process automation	Factory Automation
Application focus	**Car wiring harness**	**Control cabinet wiring Field wiring (e.g. KNX)**	**Field wiring sensors**	**Ind. Control cabinet wiring Field wiring Sensors**
Transmission rate Transmission link	10 MBit/s – 1 GBit/s 15-40 m	10 MBit/s – 1 GBit/s < 1000 m	10 MBit/s < 1000 m	10 MBit/s – 1 GBit/s ≤ 100 m
Conductor cross section	AWG 26-22	AWG 26-22	AWG 22-18	AWG 26-22

4. Today’s status (replaced by slide 8+9)

A look on all the homepages handling with SPE (TIA SPEC, SPE IPN and SPE SA) use the following keywords:

- **Thin cables**
- **Flexible cables**
- **Lower fire load**
- **Easier and faster installation**

If you ask anybody about SPE, they will tell you at least 2 of the points above, this are the market expectations.

The dilemma is obvious, we cannot deliver 1GBit/s or more over 1000m with 50W included. Somehow we have to bring the expectations into an area which is possible.

5. This slide to add

Title: Considering dependency of wire diameter and current carrying capacity

As wire diameter is a key parameter for current carrying capacity, smaller diameters will not allow the same amount of current per conductor. Therefore, the powering classes must be split into 2 groups:

- **Maximum current carrying capacity (today 2 A) for AWG18 wires to provide the maximum power to the PD. This includes a future proof current increasement from todays 1.6 A to 2.0 A per conductor.**
- **Reduced current carrying capacity for AWG23 wires to provide reduced power of maximum 20 W to the PD. All devices, sensors and actors which require more power must be wired with AWG18 wires only.**
- **Keyed connectors shall be used to avoid a wrong insertion of small wire diameters into a PSE capable to deliver the maximum power.**

Discussion