10 Mb/s Single Twisted Pair Ethernet

Preliminary Cable Properties

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Overview

- Cable Properties
- Cable Measurements
- Insertion Loss
- Return Loss
- Signal Frequency
- Signal Encoding

Cable Properties – DC Parameters

- Fieldbus type A cable is specified in IEC 61158-2.
- The following table gives information about the DC resistance of commonly used fieldbus type A cables at 20 deg C (68 deg F) for different wire diameters:

Wire diameter	Loop resistance for 1000 m
AWG18	43.6 ohms
AWG16	28.5 ohms
AWG14	17.9 ohms

- At higher temperatures the resistance is higher.
- Especially when transmitting higher power to the field, the thicker wire diameters will be required to reduce the power losses over long run trunk cables.

Cable Properties – Characteristic Impedance

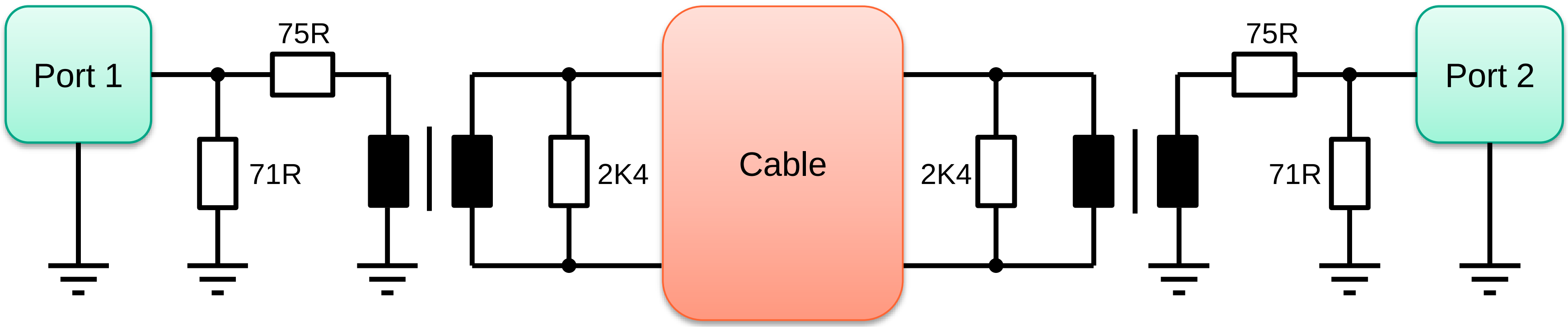
- Fieldbus cables type A are specified for a characteristic impedance of 80 ohms to 120 ohms at 39 kHz.
- Measurements show, that practically all cables have a characteristic impedance below 100 ohms in the relevant frequency range (100 kHz to 10 MHz). This has also been acknowledged by different cable vendors.
- The AWG18 cables tend to be in the range between 90 to 100 ohms, while the AWG14/AWG16 cables tend to be in the range of 80 to 90 ohms.

Cable Properties – IL & RL

- Insertion loss of the measured fieldbus installation cables is between about 1.8 dB and 2.3 dB at 4 MHz per 100 m, depending mainly on the wire diameter.
- A frequency of 4 MHz has been chosen, because the fundamental frequency of the communication signal used in the proof of concept setup (see other presentation) is 3.75 MHz.
- Insertion loss for stranded or flexible fieldbus cables can be significantly higher.
- Depending on the characteristic impedance a significant amount of return loss is coming from the mismatch between the 100 ohms reference impedance and the cable impedance.

Cable Measurements – Measurement Setup

- Different cables have been measured with a network analyzer.
- Due to the fact that the impedance of the NWA ports is 50 ohms, while the characteristic impedance of the cable is in the range of 100 ohms, a resistive impedance matching network has been used and the NWA has been calibrated accordingly.



- The transformers are needed to be able to couple the test signals symmetrically to the cable.
- The shield of the cable was open at both ends during the measurement.

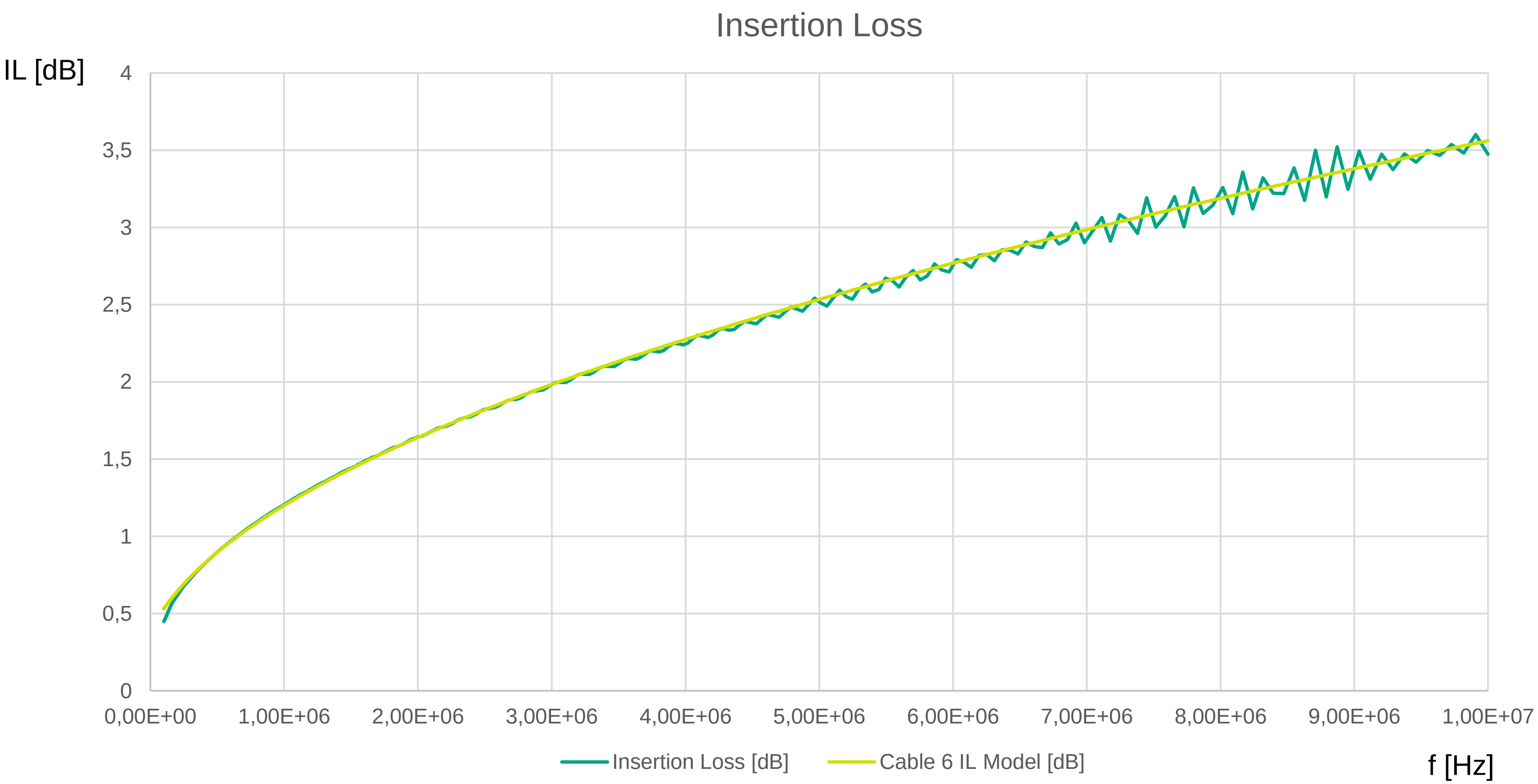
Cable Measurement – Cables

- Measured IEC61158-2 fieldbus type A cables:

Cable	Diameter	Length
Cable 1	AWG14/7	99 m
Cable 2	AWG18/32	98 m
Cable 3	AWG16/7	97 m
Cable 4	AWG16/7	97 m
Cable 5	AWG16/7	94 m
Cable 6	AWG18/1	1032 m
Cable 7	AWG18/1	120 m

Cable Measurements – IL Example

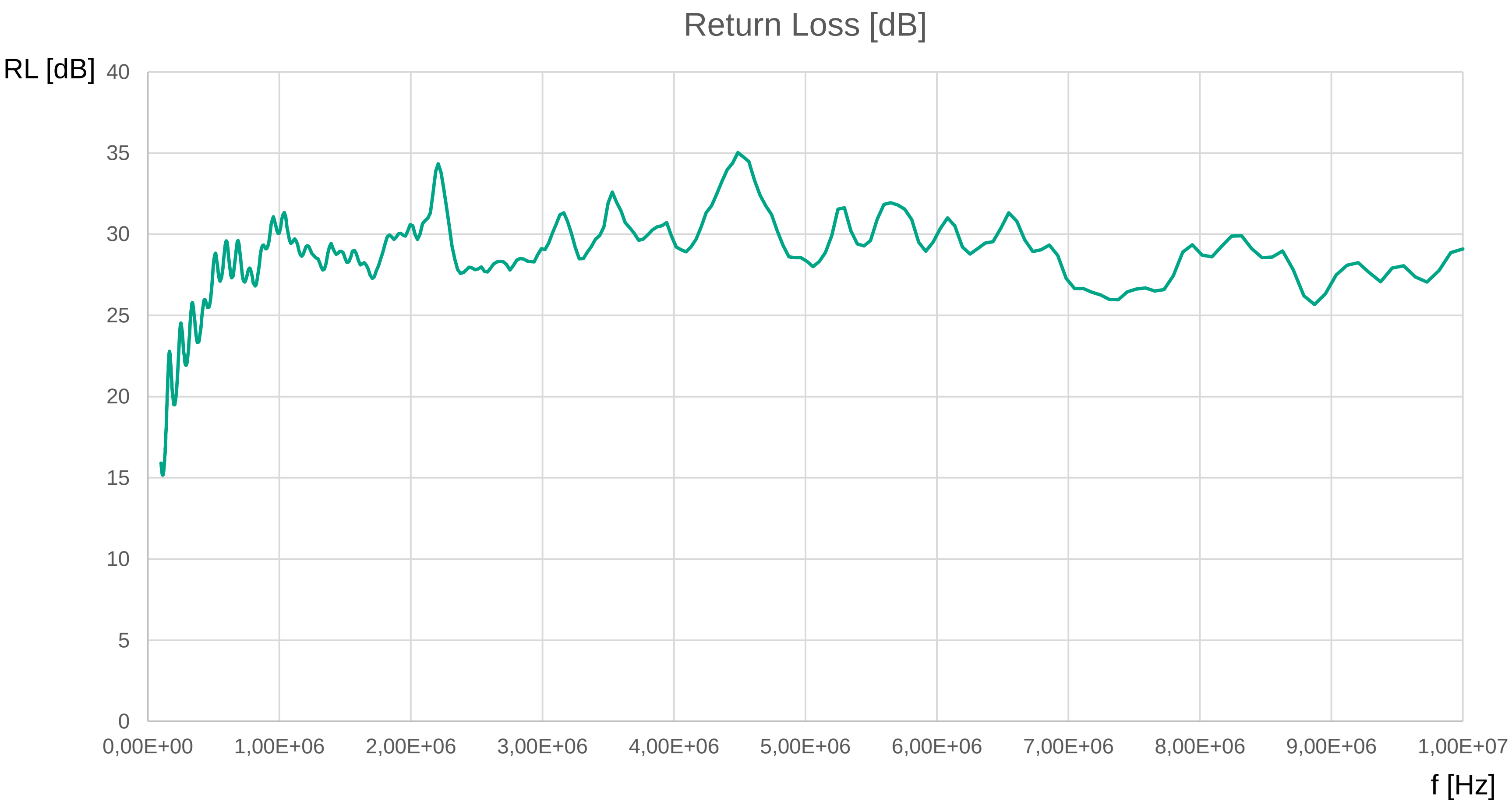
- Cable 6 insertion loss measurement (1032 m, AWG18/1, normalized to 100 m):



IL [dB] = -20 * log (|S21|)

Cable Measurements – RL Example

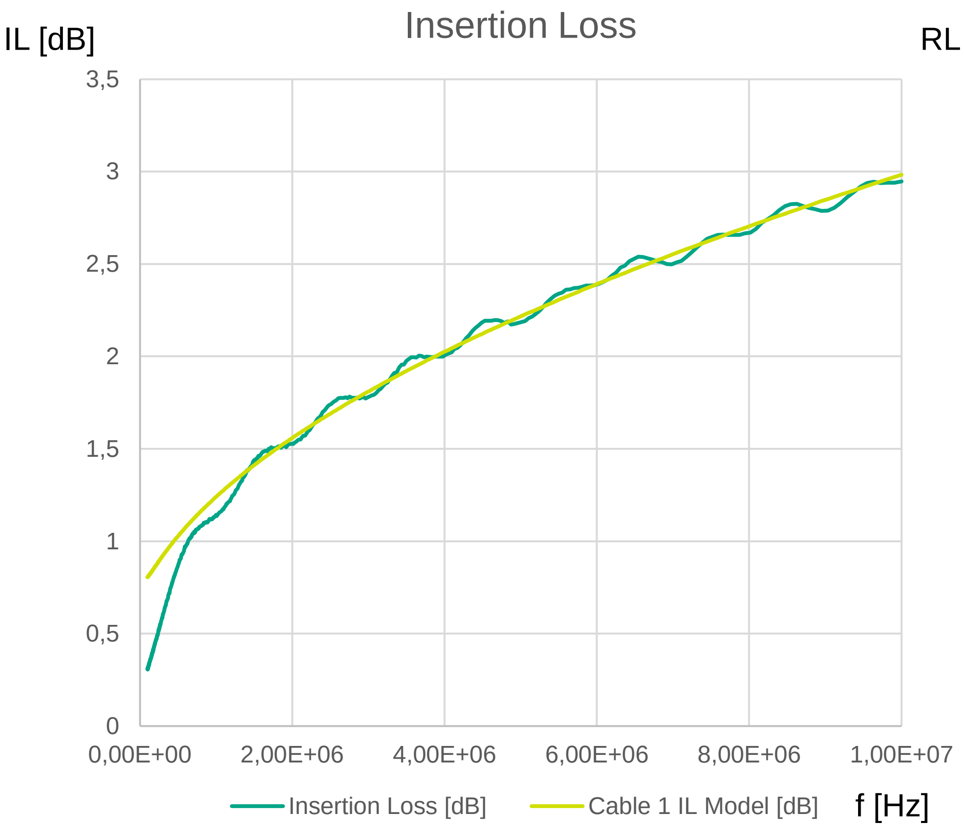
- Cable 6 return loss measurement (1032 m, AWG18/1):

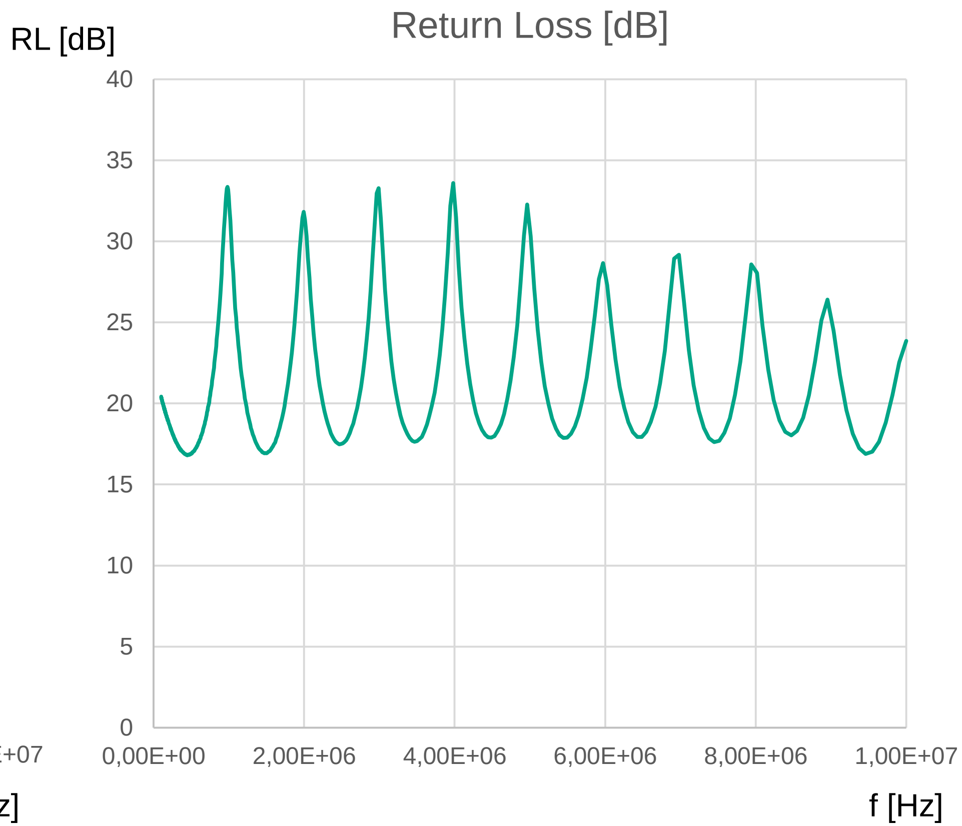


RL [dB] = -20 * log (|(Z – Z0) / (Z + Z0)|) = -20 * log (|S11|)

Cable Measurements – Reflections

- Cable 1 measurements (99 m, AWG14/7, insertion loss normalized to 100 m):

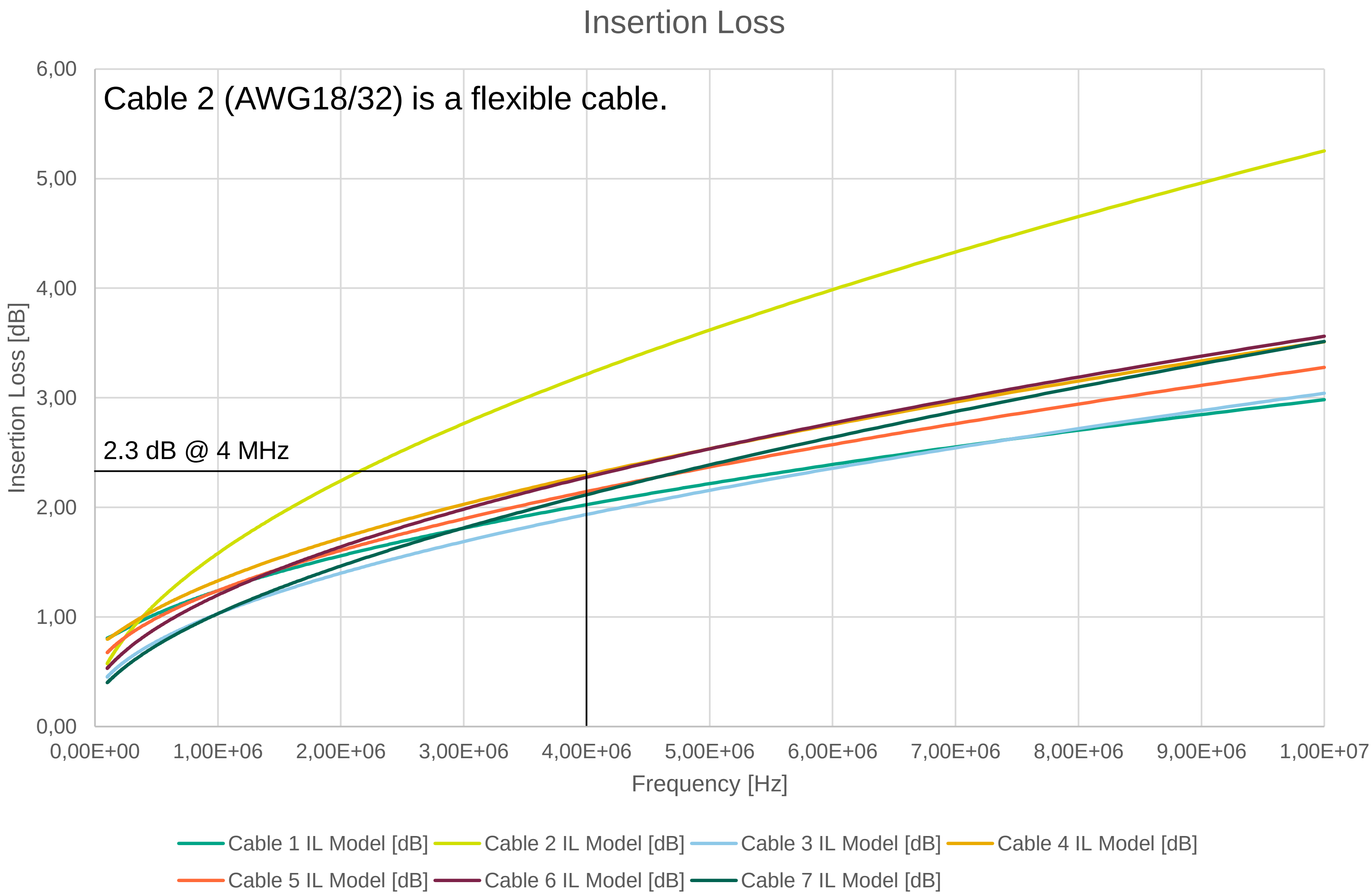




- The oscillations are coming from reflections at the cable end due to impedance mismatch with the termination network.

Cable Measurements – Cable Models

- Insertion loss for different cables (normalized to 100 m cable length):



Insertion Loss – Measurements

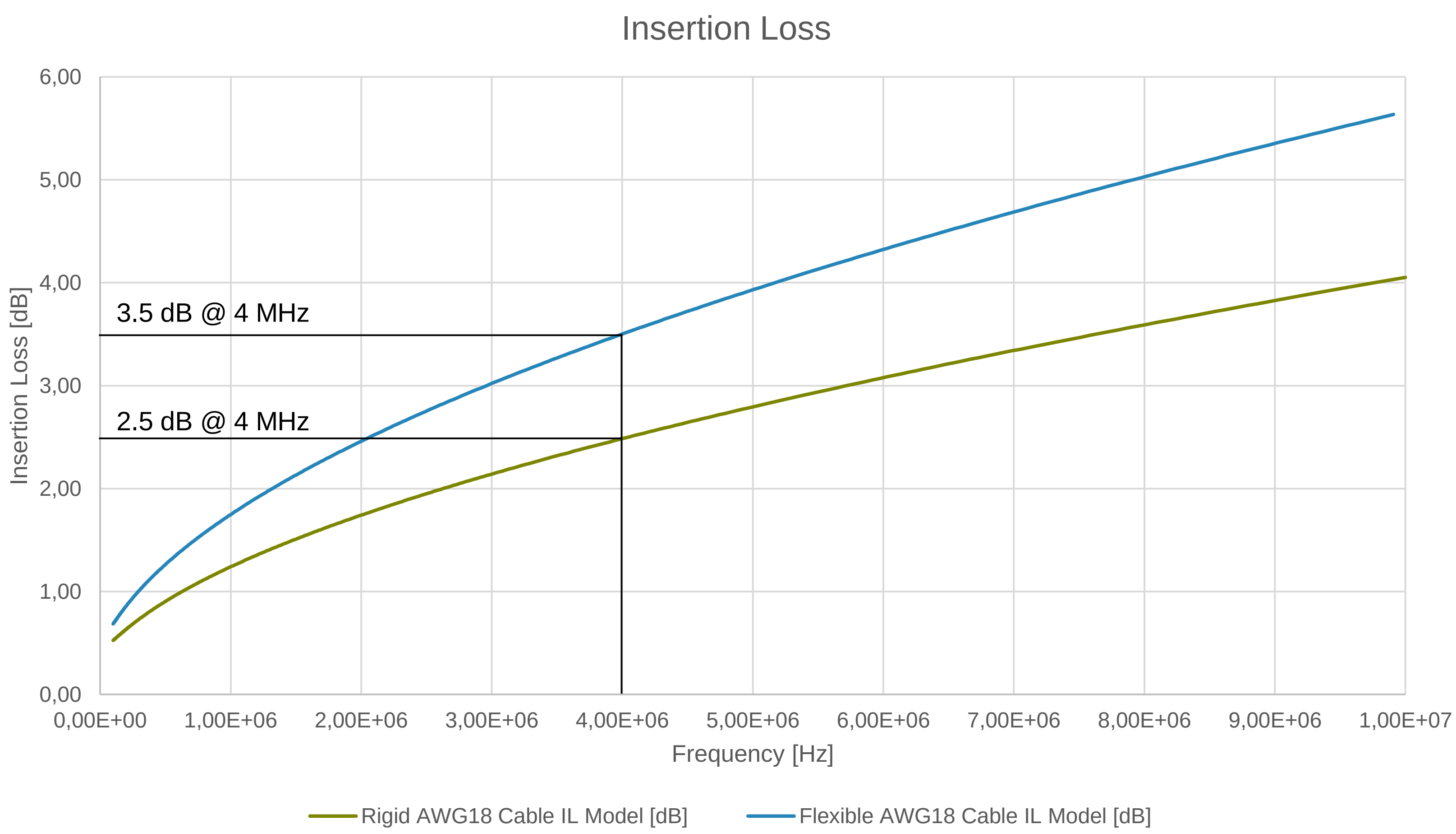
- Depending on the characteristic impedance and the cable length, there are significant reflections influencing the measurement, which need to be averaged, when calculating a cable model.
- Only typical cables have been measured, there is no worst-case estimation.
- Based on the measurements the following preliminary cable insertion loss models provide a little headroom to the measured values:

Cable type	Insertion loss per 100 m
AWG18 (rigid)	IL [dB] = 1.15 * SQRT(f/MHz) + 0.04 * f/MHz + 0.05 / SQRT(f/MHz)
AWG18 (flexible)	IL [dB] = 1.65 * SQRT(f/MHz) + 0.04 * f/MHz + 0.05 / SQRT(f/MHz)

- Main effect for the insertion loss in the frequency range up to 10 MHz is the skin effect (first term in the equation).
- Due to the proximity effect, AWG18/7 cables (which have 7 smaller diameter wires stranded together) will have a little higher insertion loss compared to rigid cables (AWG18/1). Flexible cables (e.g. AWG18/32, which have 32 small diameter wires stranded together) have a significant higher insertion loss.
- AWG14 or AWG16 cables have a similar or lower insertion loss depending on the structure compared to an AWG18 cable.
- **Because the insertion loss model is critical to the overall system performance, it is important to get more independent measurements.**

Insertion Loss – Cable Models

- Insertion loss for installation and patch cables (normalized to 100 m cable length):



Return Loss

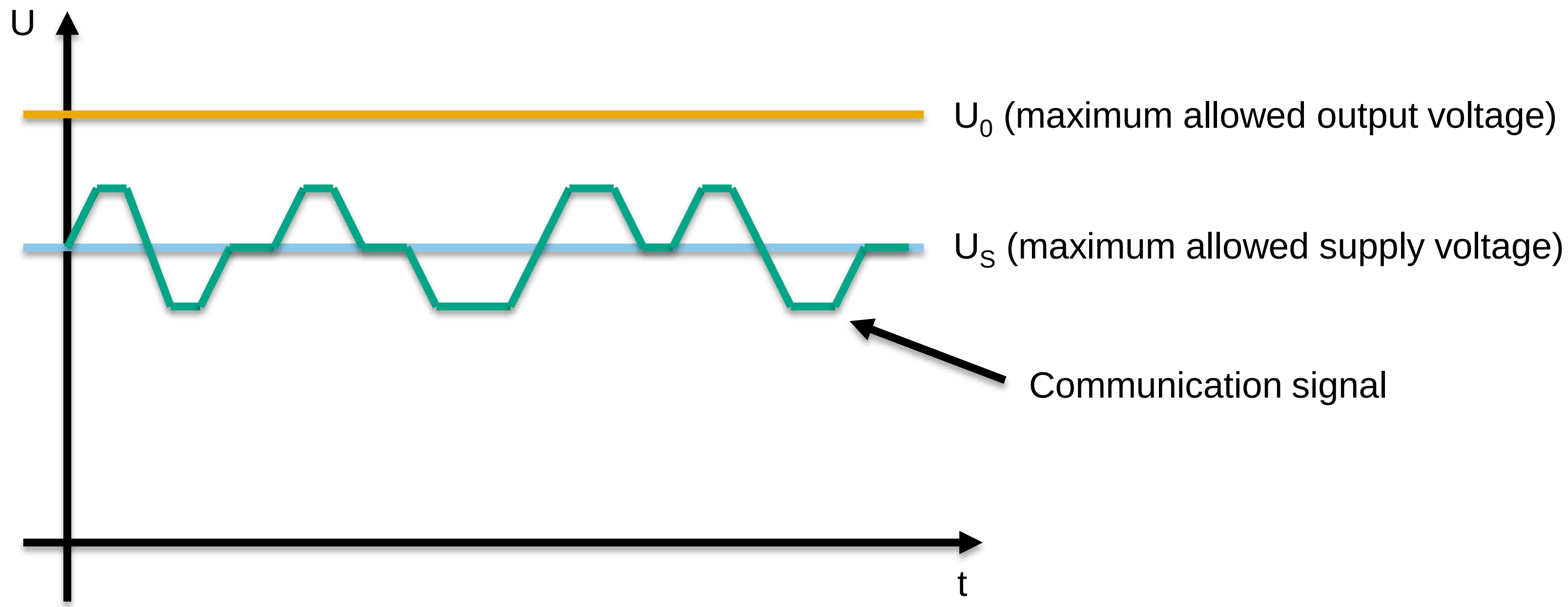
- RL [dB] = -20 * log (|(Z – Z0) / (Z + Z0)|)
- A high tolerance in characteristic impedance leads to a high return loss.
- Taking a termination of 100 ohms into account, for 80 ohms characteristic cable impedance the return loss is about 19 dB, for 90 ohms characteristic cable impedance the return loss is still about 25.5 dB.
- Comparing the return loss with the insertion loss of up to 25 dB for a 1000 m AWG18/1 cable at a frequency of 4 MHz the return loss can be in the same region or even higher than the insertion loss.
- Return Loss is the most critical parameter for a 2-wire full duplex communication.
- Return Loss can only be reduced by high cable quality (low tolerances in characteristic impedance) and good installation practice (not too much untwisting of the cable and as few connectors as possible).
- Nevertheless in practical installations the trunk cable may consist of different cable sections. In this case reflections will also occur at positions, where the cable type and therefore the characteristic impedance changes.
- Depending on the position where these reflections occur, they may be critical for the echo cancellation circuit as they could be treated as quite high uncorrelated noise.
- One possibility to filter out these reflections could be that the echo canceller has additional filter elements, which could be placed at the “positions” where the reflections occur.

Signal Frequency

- The long reach of the cable limits the possible signal frequency range to quite low values.
- Doubling the cable length also doubles the insertion loss in decibel.
- At 4 MHz signal frequency, even for rigid installation cables the insertion loss is already in the region of 25 dB (not taking into account several junction boxes).
- 25 dB insertion loss leads to a receive signal amplitude of about 5.6 % of the original transmit signal amplitude (e. g. 1 V signal amplitude at the beginning of the cable will lead to 56 mV signal amplitude at the end of the cable).
- The cable is often used at elevated temperatures up to 70 deg C (158 deg F), increasing the DC resistance and therefore also the insertion loss (or reducing the possible cable length).
- Fieldbus type A cables are typically insulated using polyolefins (PE/PP). These insulation materials are nonpolar and show over temperature only a small change in dielectric behavior at relatively low frequencies.
- Therefore the main effect on the signal attenuation is assumed to result from an increase of the cable resistance.
- The temperature coefficient of copper is about $4.1 * 10^{-3}$ 1/K. This leads to a resistance increase of about 20.5 % at an ambient temperature of 70 deg C (158 deg F) compared to 20 deg C (68 deg F).
- At higher temperature the insertion loss will therefore more likely be in the range of 27 dB @ 4 MHz per 1000 m.
- **Additional measurements will be necessary for confirmation.**

Signal Encoding

- Taking a Manchester coding as e.g. used for 10Base-T Ethernet would lead to a high signal frequency and thus to a high signal damping.
- One possibility, to also meet the signal level restrictions coming from intrinsic safety, could be to use a pulse amplitude modulation (e.g. PAM-3), which can be coded in a way to provide a DC free and nearly baseline wander free signal (e.g. by using a 4B3T line coding).
- Having a limited total signal voltage range due to intrinsic safety voltage limiting requirements, this would allow the highest possible signal amplitude to be transmitted at a relatively moderate signal frequency.



Thank You