10 Mb/s Single Twisted Pair Ethernet
Conducted Immunity

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EMC Generator Noise Amplitude

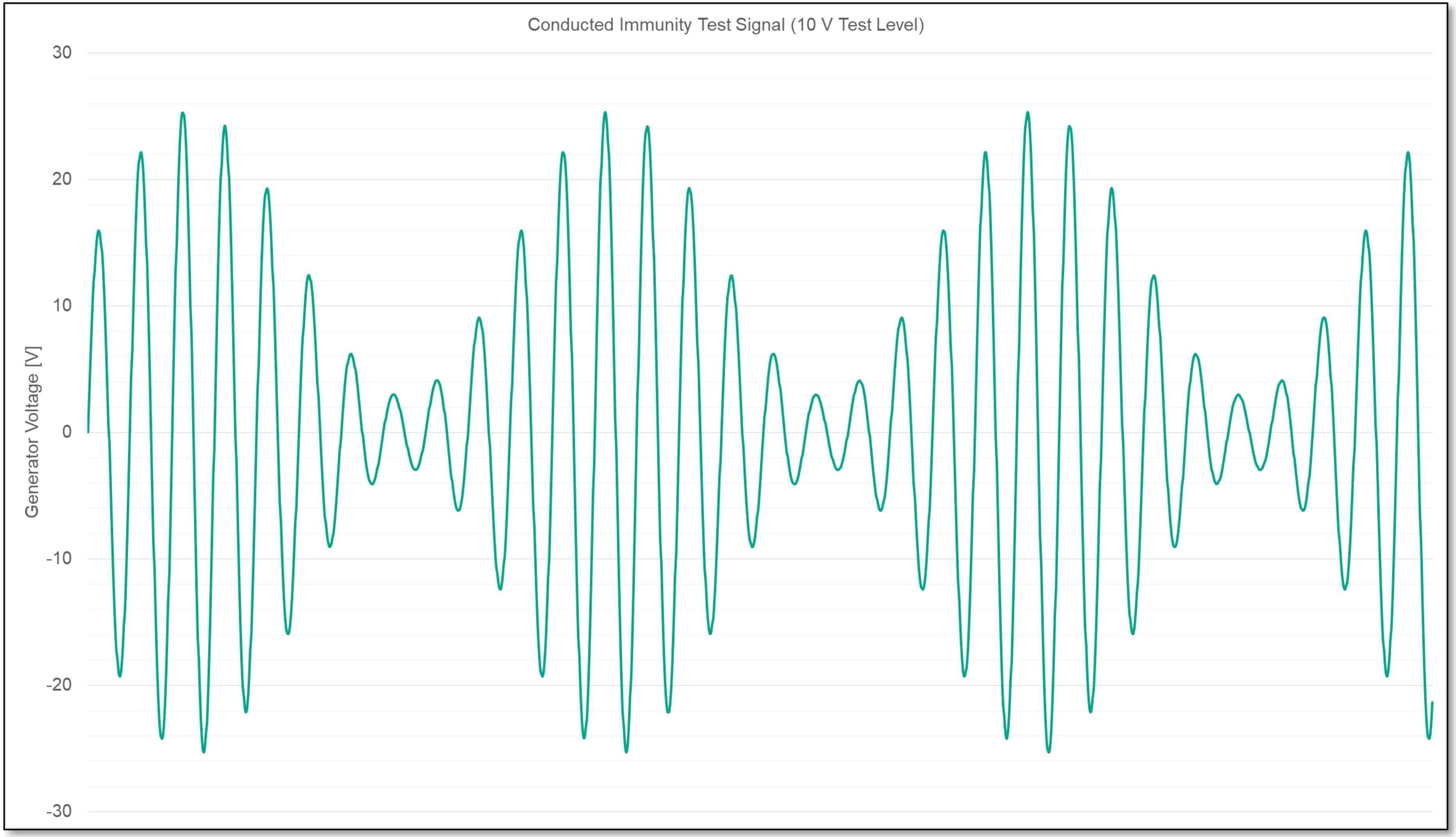
- Conducted immunity testing is done with a severity level of **3 V** for E_1/E_2 and a severity level of **10 V** for E_3.
- The frequency range for conducted immunity testing is **150 kHz to 80 MHz for IEC 61326** and **10 kHz to 80 MHz for NE 21**.
- **Preferably**, if available and suitable, **CDNs should be used for immunity testing**, otherwise an EM test clamp may be used.
- The test signal is a sine wave, which is AM modulated with 1 kHz, 80 %.
- The described test levels lead to the following peak-to-peak open circuit output levels at the generator:

$$U_{Gen} = 3\ V_{rms} \times 2 \times \sqrt{2} \times 1.8 = 15.3\ V_{pp}\ for\ E_1\ or\ E_2$$

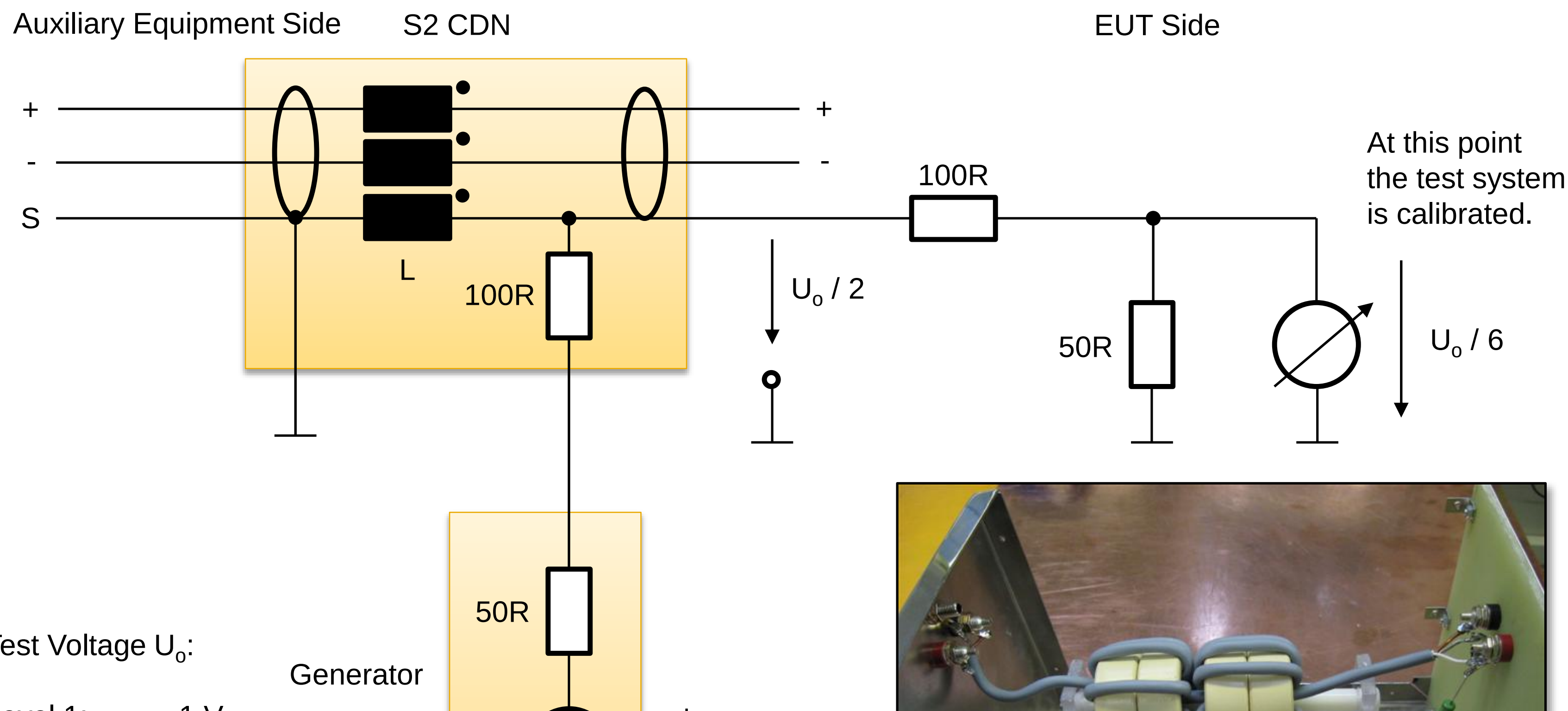
$$U_{Gen} = 10\ V_{rms} \times 2 \times \sqrt{2} \times 1.8 = 50.9\ V_{pp}\ for\ E_3$$

- In practice, not the full energy is transmitted from the generator output to the load, as there is a series resistance of 50 Ω plus some few dB loss (when using the EM test clamp) or a series resistance of 150 Ω (when using CDNs) between the internal generator source and the EUT.
- Before the measurement the system is calibrated, so that **half of the generator voltage** is present at the EUT under the assumption of a **coupling impedance between the EUT and earth of 150 Ω**.
- In this case of impedance matching the maximum energy is transferred and there is only half of the open circuit generator voltage present at the shield, thus reducing the needed noise attenuation factor by 6 dB.

EMC Generator Noise Amplitude

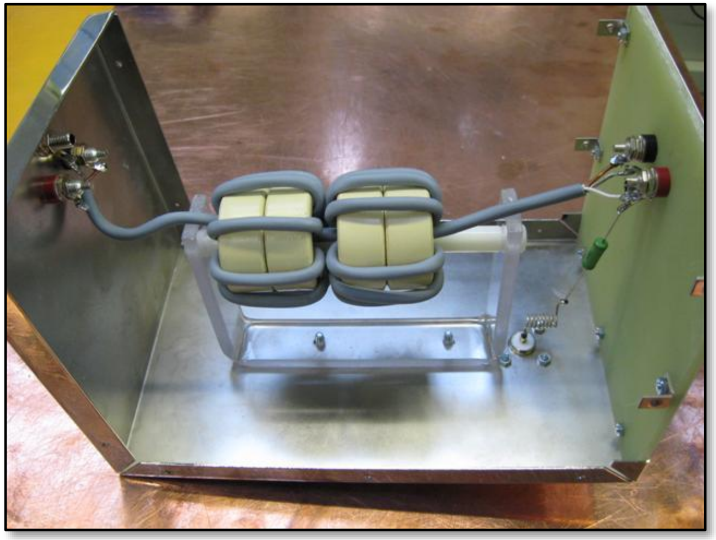


Coupling-Decoupling-Network Calibration



Test Voltage U_o:

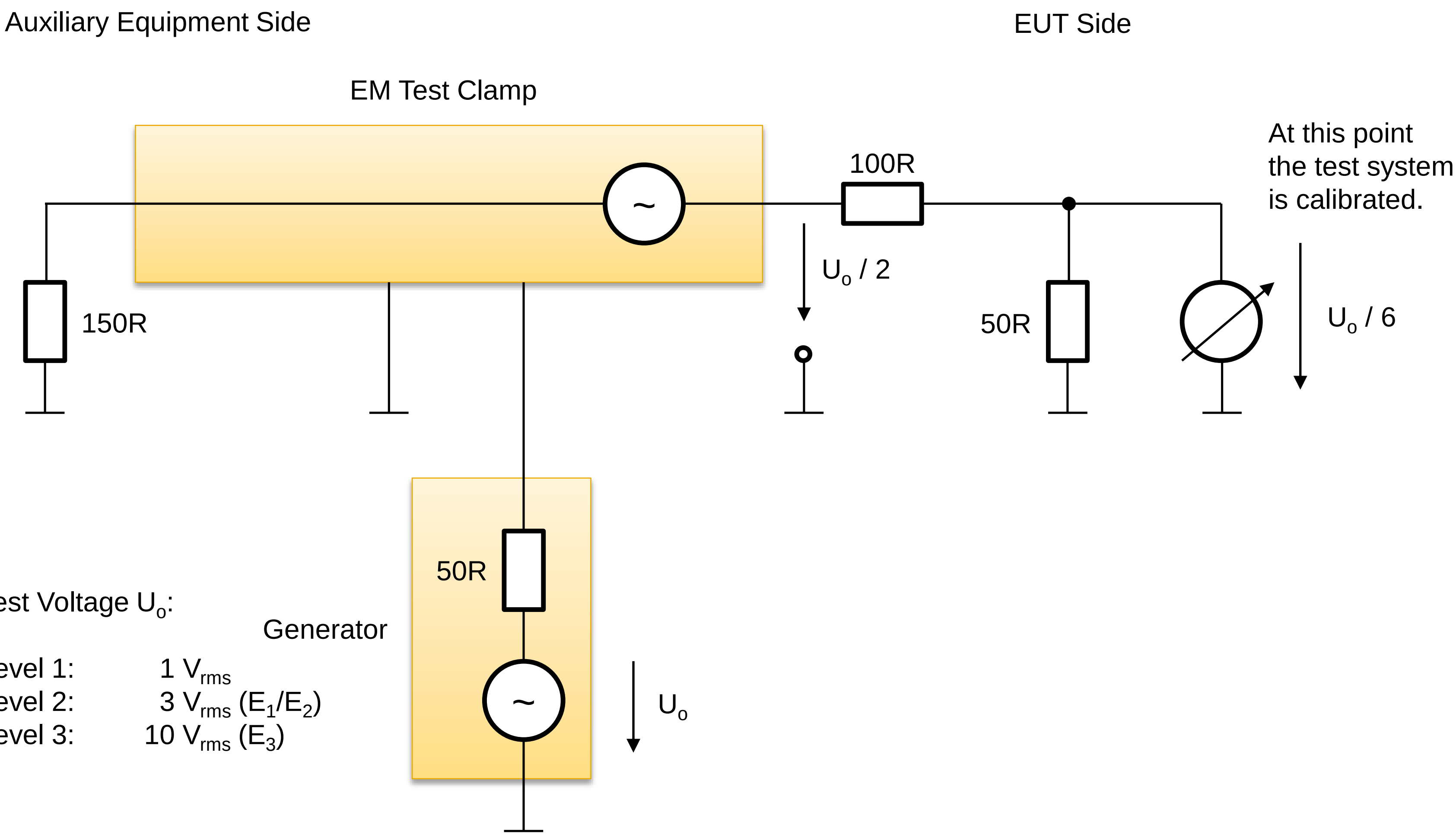
Level 1: 1 V_{rms}
Level 2: 3 V_{rms} (E_1/E_2)
Level 3: 10 V_{rms} (E_3)



During the calibration the AM modulation is disabled.

EMC Test Setup using CDNs

EM Test Clamp Calibration



Test Voltage U_o:

Level 1: 1 V_{rms}
Level 2: 3 V_{rms} (E_1/E_2)
Level 3: 10 V_{rms} (E_3)

During the calibration there is no AM modulation.

Shielded Cables

- The noise immunity of the 10BASE-T1L evaluation board is about **30 mV$_{pp}$** assuming a worst-case link segment (25.4 dB IL @ 3.75 MHz) and alien noise coming from an additional (attenuated) transmitter connected to the link segment (http://www.ieee802.org/3/cg/public/Sept2017/Graber_3cg_14_0917.pdf, pages 12 and 13) and about **40 mV$_{pp}$** using a typical 1000 m AWG18/1 cable (22.7 dB IL @ 3.75 MHz) and a sine wave interferer (http://www.ieee802.org/3/cg/public/May2017/Graber_3cg_07_0517.pdf, page 27) stepping fast between different frequencies.

- Adding some (small) margin, and counting for a maximum noise tolerance of **25 mV$_{pp}$** for narrow band sine wave noise, which is changing fast enough, so that the digital filters cannot follow, the following noise attenuation factors are needed (**assuming 150 Ω coupling impedance between the EUT and earth**):

$$Noise\ Attenuation\ Factor = 20 \times log_{10}\left(\frac{15.3\ V_{pp}}{25\ mV_{pp}}\right) - 6\ dB = 50\ dB\ for\ E_1\ or\ E_2$$

$$Noise\ Attenuation\ Factor = 20 \times log_{10}\left(\frac{50.9\ V_{pp}}{25\ mV_{pp}}\right) - 6\ dB = 60\ dB\ for\ E_3$$

- These minimum noise attenuation factors can be used as flat values between 0.1 and 20 MHz:

Frequency (MHz)	(dB)		
	E_1	E_2	E_3
0.1 to 20	≥ 50	≥ 50	≥ 60

Shielded Cables

- What is **still missing** is the **correlation value** between the **noise coupling factor** shown on the previous page and the needed **coupling attenuation factor** of the cable.
- As this correlation value is currently unknown, it is initially suggested to use a **worst-case correlation value of 1.0** (there is no additional attenuation) and also to assume that **the impedance of the EUT to earth is about 150 Ω** (which is a standard assumption performing conducted immunity testing and allows for a reduction of 6 dB as mentioned on the previous slide).
- In this case the identical values for the coupling attenuation factor of the cable as for the noise attenuation factor are required (if a higher coupling impedance between the EUT and earth needs to be assumed, then up to 6 dB higher values than shown below would be required):

Frequency (MHz)	(dB)		
	E_1	E_2	E_3
0.1 to 20	≥ 50	≥ 50	≥ 60

- This leads to the same minimum required coupling attenuation values for E_2 and E_3 as in the current 802.3cg D2.2 standards draft and for a 10 dB increase in the required coupling attenuation for E_1.
- Reason for this is, that E_1 and E_2 use the same immunity test level of 3 V, so that also identical coupling attenuation values are required.

Unshielded Cables

- While the CDN can only be used for shielded applications (as a Type-T CDN for unshielded symmetric lines has an internal capacitance which is too high and blocks the communication signal), the EM test clamp can be used for both shielded and unshielded cables.
- Thinking about unshielded cables and that in such a case the TCL value is providing the differential to common mode, respective the common mode to differential mode conversion factor and assuming, that the field of the EM test clamp is (primarily) coupled as a common mode signal into the unshielded cable, then also the TCL values within the interesting frequency range (which, depending on the input filters of the PHY is between 0.1 kHz and about 10 MHz) need to be in the same range as the coupling attenuation of a shielded cable.
- For 10BASE-T1S a Mode Conversion of 40 dB is feasible and 43 dB have been suggested to be safe (see http://www.ieee802.org/3/cg/public/Jan2018/beruto_3cg_02_0118_revB.PDF).
- The used BCI severity level (Class IV) was 200 mA_{pp}, resulting in a common mode voltage of 20 V_{pp} driving the 200 mA_{pp} into 100 Ω.
- The resulting 200 mV_{pp} differential signal assuming a MC of 40 dB are acceptable compared to a receive signal in the range of about 500 mV_{pp} at the sampling point after transmitting over a worst-case mixing-segment.

Unshielded Cables

- For a 10BASE-T1L signal the attenuation at Nyquist frequency is about 26 dB, thus for a 2.4 V_{pp} PAM-3 signal the expected amplitude after 1000 m is about 120 mV_{pp} for 3 levels, thus about 60 mV per level.

- As for 10BASE-T1S, the suggested noise tolerance of 25 mV_{pp} is also using up about 40 % of the receive signal amplitude.

- For 10BASE-T1L it is only intended to use unshielded cables for E_1 and E_2 environments.

- Therefore for conducted immunity testing the peak-to-peak voltage at the point, where the cable is in the EM test clamp is calibrated to be about 7.65 V_{pp} (15.3 V_{pp} / 2) instead of 20 V_{pp}.

- Compared to a mode conversion of 40 dB as for 10BASE-T1S, for 10BASE-T1L a noise attenuation of:

$$Noise\ Attenuation\ Factor = 20 \times log_{10}\left(\frac{7.65\ V_{pp}}{25\ mV_{pp}}\right) = 50\ dB$$

  is required in the relevant frequency range between 0.1 and 10 MHz.

- Above 10 MHz a decrease in the noise attenuation factor could be allowed, as the input filter of the PHY IC will limit incoming noise above 10 MHz.

Unshielded Cables

- Assuming also for unshielded cables a **correlation factor of 1.0** between the required **noise attenuation factor** and the **TCL value** as a **worst-case approach**, then the required TCL value will be identical to the noise attenuation factor (also under the **assumption of 150 Ω coupling impedance to earth**).
- Taking a minimum TCL value of 50 dB @ 10 MHz into account, the resulting TCL values are:

	Frequency (MHz)	E_1	E_2
TCL	$0.1 \le f \le 10$	≥ 50 dB	≥ 50 dB
	$10 \le f \le 20$	$\geq 50 - 20 \log_{10}(f / 10)$ dB	$\geq 50 - 20 \log_{10}(f / 10)$ dB

- The suggested TCL value has a flat limit line below 10 MHz. For the TCL definitions in the current 802.3cg D2.2 draft the TCL values get quite high (up to 86 dB for 2.4 V and E_2), which makes it difficult to measure, while for the PHY itself it gets more critical in the higher frequency range, as the signal in the lower frequency range is significantly stronger.
- In the frequency range above 10 MHz, there is a decrease in the required mode conversion value by 20 dB per decade, which reflects the behavior of a first order low pass filter within the PHY input circuitry.
- At 10 MHz the required TCL value for E_1 is 12 dB higher and for E_2 it is 2 dB higher than defined in draft D2.2. The difference is again related to using the same test levels for E_1 and E_2.

Common Mode Noise

- Independent from the differential mode noise discussed on the previous slides, especially when using unshielded cables, high common mode levels can add additional requirements to the PHY analog frontend, as the common mode noise can lead to a situation, where the operational amplifiers in the analog frontend may be overdriven by the common mode input signal.

- Using the PHY IC with unshielded cables therefore can lead to a need for a large common mode choke or even a transformer isolation of the PHY IC, which also blocks the common mode noise from reaching the PHY IC analog frontend.

- For unshielded cables, even for E_1 and E_2, the common mode voltage may be up to 7.65 V_{pp}, assuming a 150 Ω coupling impedance between the EUT and earth (and even up to 6 dB higher in case a higher coupling impedance to earth needs to be assumed).

- Depending on the intended process geometry of the PHY IC high common mode input voltage requirements therefore may add a significant burden on the PHY IC implementation, which also needs to be discussed, independently from the TCL definitions, especially when using unshielded cables.

Open Items

- The values currently given in the 802.3cg draft for E_2 and E_3 are not far away from the suggested values in this presentation (for E_1 there is an offset of 10 dB).

- The values provided in this presentation rely on a coupling model between the EUT and earth having an impedance of 150 Ω as it is typically assumed for EMC testing; this assumption reduces the required attenuation factors by 6 dB. If a higher coupling impedance value needs to be assumed, then worst-case up to 6 dB higher coupling attenuation and TCL values are required.

- Currently a worst-case correlation factor of 1.0 between the needed noise attenuation factor and the coupling attenuation factor of the cable is assumed.

- For the correlation factor and the assumed coupling impedance value between the EUT and earth input from cable manufacturers and EMC engineers is required, to validate, if these assumptions are correct.

- Related to the quite high common mode noise requirements using unshielded cables, especially when taking low power and small size process geometries into account, there is also input from PHY IC vendors needed.

Thank You