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Index

Conducted Immunity Basics

TEKBOX
DIGITAL SOLUTIONS

1   Relevant standards

IEC / EN 61000-4-6   basic
ISO11452-4   automotive
MIL-STD-461G   defense
RTCA DO-160C   avionics

IEC / EN 61000-4-6 specify stress levels in terms of open circuit voltage in a 150 Ohm system.
All other standards specify stress levels in terms of injected current.

2   Transducers for conducted immunity testing

- CDN -   Coupling / De-Coupling Network
- BCI clamp -   Bulk Current Injection clamp
- EM clamp -   Electromagnetic clamp

While many standards specify conducted immunity tests to be carried out with BCI probes, IEC / EN 61000-4-6 specifies immunity testing for any of the above listed transducers. However, it gives clear priority to CDNs and specifies criteria for the selection of the transducer. CDNs are used in the frequency range from 150 kHz to 80 MHz or from 150 kHz to 230 MHz. The preference for CDNs comes from their property to establish a well-defined RF impedance of 150 Ohm.

CDNs have the advantage of offering both coupling and decoupling in a single device. Furthermore, among all three transducers, it requires least RF power to achieve the desired stress level. The disadvantage lies in its specific design, which requires different models depending on whether testing DC supply lines, AC supply lines, balanced data lines, unbalanced data lines, etc. Manufacturers may offer up to fifty or more CDN models.

BCI clamps can be used to inject RF into any type of cable, supply lines, data lines, etc. Due to its non-invasive design, they are very easy to apply. Main disadvantage is lack of decoupling between EUT and supply / AE. BCI probes are typically available with a bandwidth of 150 kHz to 100 MHz or 250 MHz for immunity testing according EN 61000-4-6 or 1 MHz to 400 MHz for automotive immunity testing.

EM clamps are used where it is not possible to use a CDN. They offer both coupling and decoupling. They have a relatively low insertion loss, thus requiring only moderate power RF amplifiers. They can be used in the frequency range up to 1 GHz.

Typical RF power amplifier output power to obtain a test level of 10V:

- CDN   7 W
- BCI clamp   176 W
- EM clamp   28 W

3   IEC / EN 61000-4-6 - why 150 Ohm common mode impedance?

IEC / EN 61000-4-6 specifies conducted immunity tests, which emulate electromagnetic disturbance due to electromagnetic fields coming from RF transmitters. In other words, the test simulates susceptibility of equipment to radiated disturbance.
The electromagnetic field may act on the whole length of any cable connected to installed equipment. The cables connected to the equipment behave as passive receiving antennas. With respect to electromagnetic susceptibility, the connected cables are assumed to be in resonant mode ($\lambda/4$, $\lambda/2$ open or folded dipoles, etc.) having a common mode impedance of 150 Ω.
Consequently, the test set up substitutes resonating cables (= antennas with 150 Ohm common mode impedance) by coupling / decoupling devices with 150 Ω common mode impedance.

4 CDN basics

Similar as LISNs being the central components for conducted emission testing, CDNs are essential for conducted immunity test set-ups. CDNs are used to couple RF into cables.
Whereas the CISPR standards specify conducted emission measurements, IEC 61000-4-6 is the main standard for conducted immunity testing.

The preferred coupling and decoupling devices are CDNs, for reasons of test reproducibility and decoupling of the power supply / AE. Furthermore, CDNs require significantly lower RF power, to achieve the same test levels, compared to EM clamps or BCI clamps. The main coupling and decoupling device parameter, the common mode impedance seen at the EUT port, is specified in the table below:

	Frequency band		
Parameter	150 kHz – 24 MHz	24 MHz – 80 MHz	80 MHz – 230 MHz
I Common mode impedance I	150 Ω ± 20 Ω	150 Ω + 60 Ω / - 45 Ω	150 Ω ± 60 Ω

Usage of CDNs:

Line type	Examples	CDN - type
Power supply (AC and DC) and earth connection	AC mains DC in industrial installations Earth connection	CDN - Mx
Screened cables	Coaxial cables cables used for LAN and USB connections cables for audio systems	CDN - Sx
Unscreened balanced lines	ISDN lines telephone lines	CDN - Tx
Unscreened unbalanced lines	Any line not belonging to other groups	CDN – Afx or CDN - Mx

Coupling Decoupling network according to IEC 61000-4-6, example M1, M2, M3:
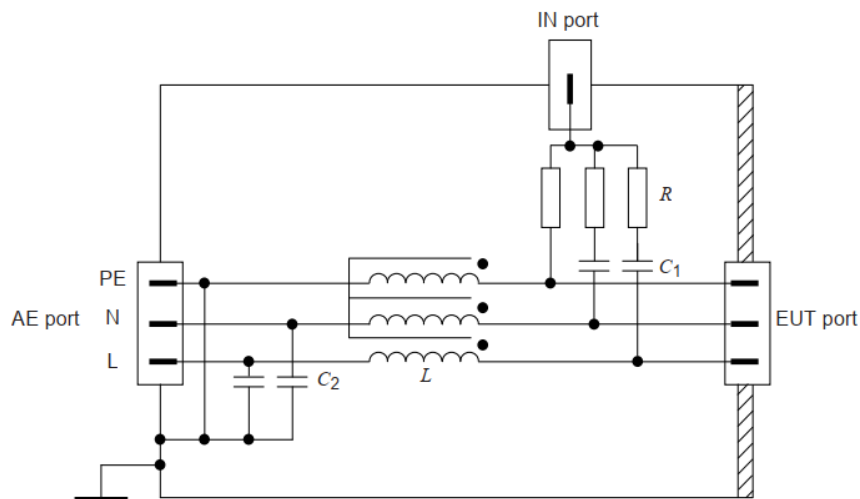
IEC 2627/13

CDN-M3, C_1 (typical) = 10 nF, C_2 (typical) = 47 nF, R = 300 Ω, $L \geq 280$ μH at 150 kHz
CDN-M2, C_1 (typical) = 10 nF, C_2 (typical) = 47 nF, R = 200 Ω, $L \geq 280$ μH at 150 kHz
CDN-M1, C_1 (typical) = 22 nF, C_2 (typical) = 47 nF, R = 100 Ω, $L \geq 280$ μH at 150 kHz

Figure D.2 – Example of simplified diagram for the circuit of CDN-M1/-M2/-M3 used with unscreened supply (mains) lines (see 6.2.2.2)

The performance of the CDN shall not be degraded by saturation of the magnetic material due to current drawn by the EUT. Wherever possible, the network construction should ensure that the magnetizing effect of the forward current is cancelled by that due to the return current.

If in actual installations the supply wires are individually routed, separate CDN-M1 CDNs shall be used. All input ports shall be treated separately. If the EUT is provided with functional earth terminals (e.g. for RF purposes or high leakage currents), they shall be connected to the reference ground plane:

– through the CDN-M1 when the characteristics or specification of the EUT permits. In this case, the (power) supply shall be provided through an appropriate CDN-Mx type network;

– when the characteristics or specification of the EUT do not permit the presence of a CDN-M1 network in series with the earth terminal for RF or other reasons, the earth terminal shall be directly connected to the reference ground plane. In this case the CDN-M3 network shall be replaced by a CDN-M2 network to prevent an RF short-circuit by the protective earth conductor. When the equipment was already supplied via CDN-M1 or CDN-M2 networks, these shall remain in operation; for a 3-phase supply, a similar adjustment needs to be done regarding the use of an appropriate CDN-Mx type network.

Warning: The capacitors used within the CDNs bridge live parts. As a result, high leakage currents may occur and safety connections from the CDN to the reference ground plane are mandatory.

5   Immunity test set up

The picture below shows a basic conducted immunity test set up.

The impedance of the coupling / decoupling device at the EUT port of CDNs results from the source impedance at the RF port in series with 100 Ohm internal impedance. The source impedance needs to be 50 Ohm in order to achieve 150 Ohm at the EUT port. The output impedance of RF wideband power amplifiers is typically not very close to 50 Ohm across the entire frequency range. Adding a 6 dB attenuator to the RF power amplifier output results in an impedance much closer to the required 50 Ohm.
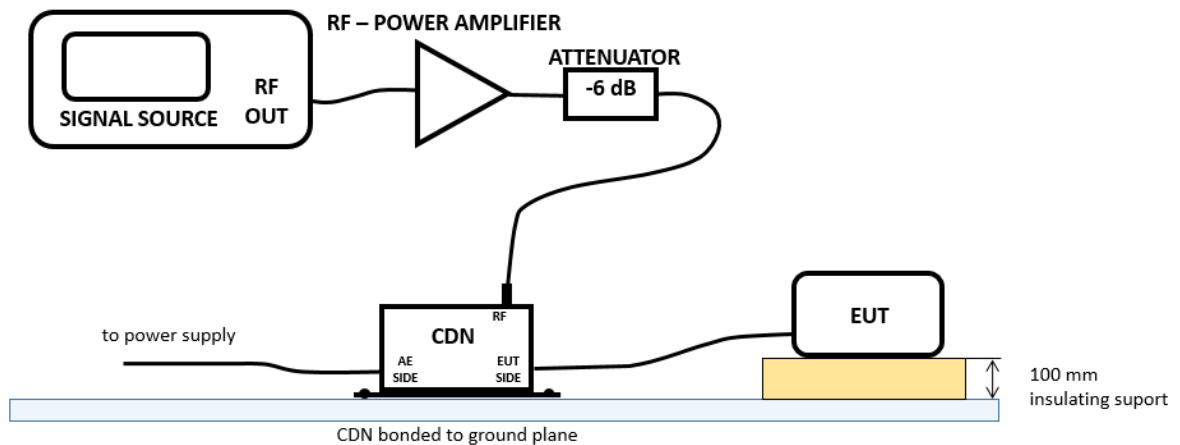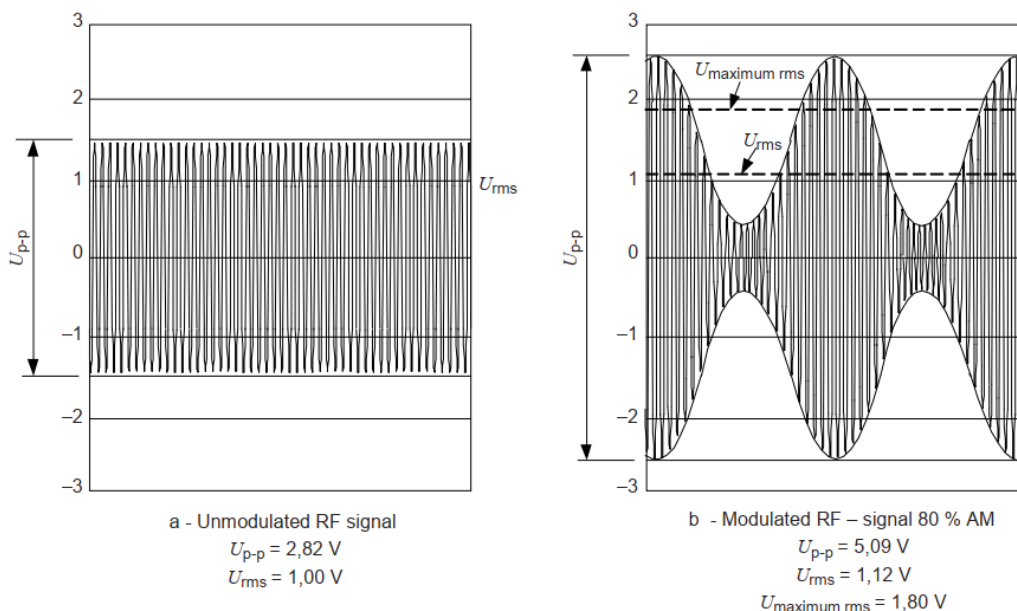

Following test levels are specified:

Level	Voltage level (e.m.f.)	
	U_0 [V]	U_0 [dBμV]
1	1	120
2	3	129.5
3	10	140
X*	Special	
* "X" can be any level, above, below or in between the others. The level has to be specified in the dedicated equipment specification		

The test levels are open circuit voltages set at the EUT port of the coupling devices. For testing of the equipment, this signal is 80 % amplitude modulated with a 1 kHz sine wave to simulate actual threats. The effective amplitude modulation is shown below:

a - Unmodulated RF signal
U_{p-p} = 2,82 V
U_{rms} = 1,00 V

b - Modulated RF – signal 80 % AM
U_{p-p} = 5,09 V
U_{rms} = 1,12 V
$U_{maximum\ rms}$ = 1,80 V

Consequently, the level of the modulated signal must be 5.1 dB higher than the test levels specified by the standard. The insertion loss of a typical CDN is approximately 10 dB from RF input to the output of a 150 Ohm to 50 Ohm adapter at the EUT port. Adding a 6dB attenuator to improve matching of the RF power amplifiers would require following amplifier output power:

Level	unmodulated rms voltage	modulated rms voltage	unmodulated RF power	modulated RF power	Including 6 dB attenuator
1	1 V	1.8 V	6 mW / 7.6 dBm	19 mW / 12.7 dBm	74 mW / 18.7 dBm
2	3 V	5.4 V	50 mW / 17 dBm	204 mW / 23.1 dBm	0.8 W / 29.1 dBm
3	10 V	18 V	0.55 W / 27.4 dBm	1.8 W / 32.5 dBm	7.1 W / 38.5 dBm

Note that specified stress level voltages are open circuit voltages at the EUT port. The voltages measured during calibration must be multiplied by 3 to allow for the 50 Ohm to 150 Ohm conversion and again by 2 to reach the open circuit voltage. Hence, the measured voltage during calibration is 1/6 th the voltage of the desired stress level. In logarithmic figures, the measured voltage is 15.5 dB lower than the open circuit voltage.

The standard test frequency range is 150 kHz – 80 MHz, with certain device classes being tested from 150 kHz – 230 MHz.

6   CDN characterization and calibration

Frequency range:
Although the requirements in the standard are specified for the frequency range 150 kHz up to 80 MHz, the applicable frequency range depends on the normal installation and operation conditions of the equipment to be tested. In general, the stop frequency will be 80 MHz. In some cases, where small-sized equipment is considered (dimension < λ/4), dedicated product standards may prescribe that the stop frequency is extended up to a maximum of 230 MHz. When using this test method up to higher frequencies, results are influenced by the size of equipment, the type(s) of interconnecting cables used, and the availability of special CDNs, etc. Further guidance for proper application should be supplied in the dedicated product standards.
On the other hand, NAMUR NE 21 extends the applicable frequency down to 10 kHz.

Set up:

• The test generator (RF out) shall be connected via the 6 dB-attenuator to the RF input port of the CDN.
• The EUT port of the CDN shall be connected in common mode via a 150 Ω to 50 Ω adapter to a measuring equipment having a 50 Ω input impedance.
• The AE-port shall be loaded in common mode with a 150 Ω to 50 Ω adapter, terminated with 50 Ω.

The assembly is outlined below.

With direct injection to screened cable (CDN-S types), the 150 Ω load at the AE-port is not required as the screen will be connected to the ground reference plane at the AE-port side.

With the CDN M-types, CDN AF-types and CDN T-types the 150 Ω connector is according to standard prescribed, yet the calibration values for these CDN types are virtually independent of the load. This is because these types have capacitors against ground at the AE-port side, which generate a RF-short circuit, comparable to those of the S-types.

Thus with the CDN M-types, CDN AF-types and CDN T-types the load of 150 Ω at the auxiliary equipment connector can be dispensed with.

In order to calibrate a CDN you require:

• specific calibration adapters
• ground plane exceeding the length of the CDN 20 cm on each side
• 150 Ω to 50 Ω adapters
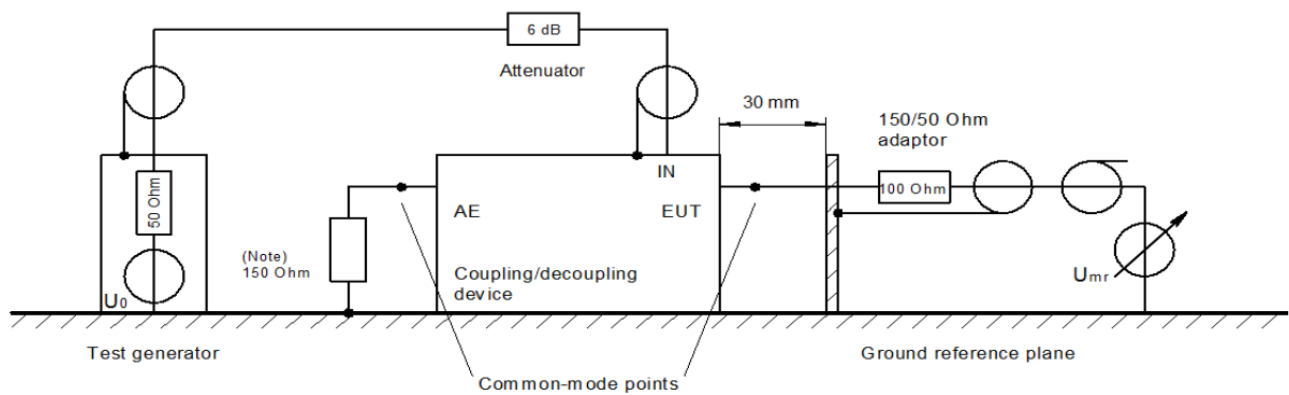

CDN common mode impedance
measurement set-up:
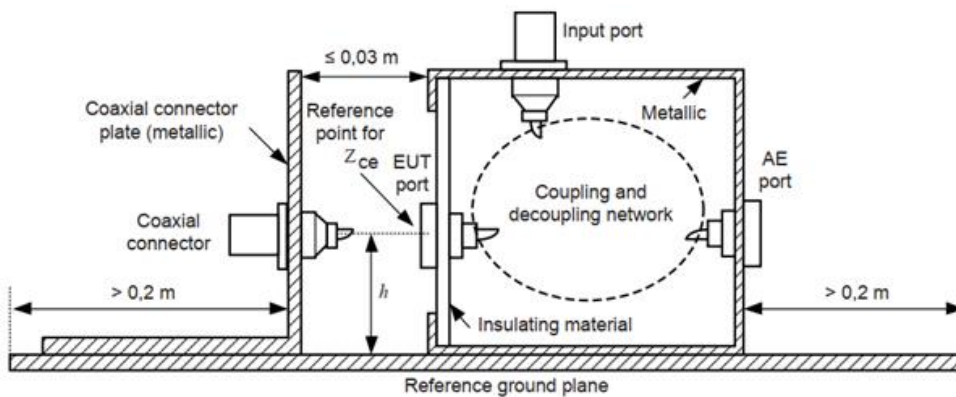
IEC 2597/13

– Reference ground plane: shall exceed the projection of the coupling and decoupling devices and other components by at least 200 mm.

– The coaxial connector shall be connected horizontally to the EUT port.

– The height h of the EUT port depends on the individual CDN, which may vary from 30 mm to 100 mm; particular large current CDNs have an EUT port located higher above the reference ground plane.

– Connector plate (with the coaxial connector): 100 mm × 100 mm for h = 30 mm and 150 mm × 150 mm for other values of h.

– Both connector plates shall be made out of copper, brass or aluminium and shall have a good RF contact.

The input port is terminated with 50 Ω. The impedance requirement shall be met with the AE port open or shorted to ground.

CDN common mode impedance values:
150 kHz – 24 MHz: 150 Ω ±20 Ω
24 MHz – 80 MHz: 150 Ω +60 Ω /-45 Ω
80 MHz – 230 MHz: 150 Ω ±60 Ω
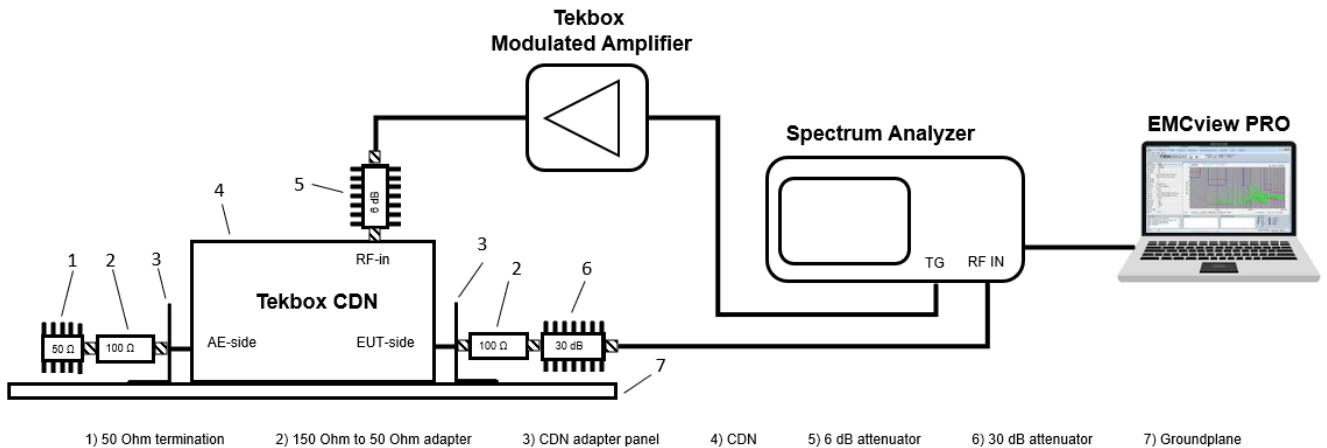
Voltage division factor
Measurement set-up:
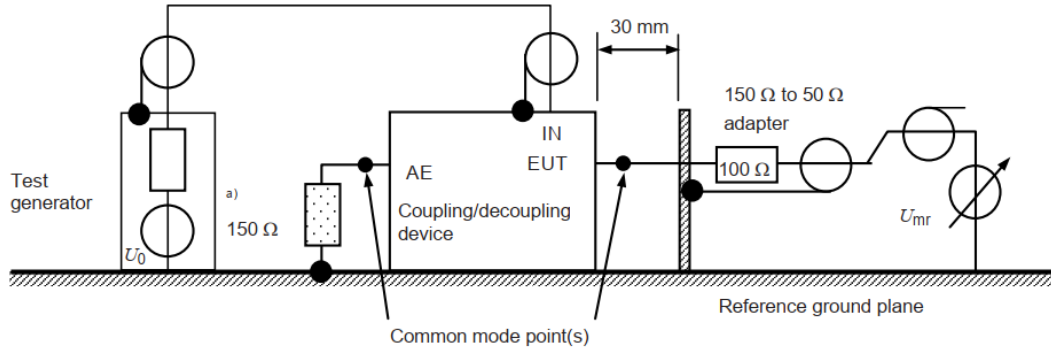
Voltage division factor RF-port to EUT-port:
150 kHz – 80 MHz: 9.5 dB ± 1dB
80 MHz – 230 MHz: 9.5 dB +3 dB / - 2 dB

7 Conducted immunity pre-compliance testing using CDN

EN 61000-4-6 calibration set up using EMCview PRO

1) 50 Ohm termination   2) 150 Ohm to 50 Ohm adapter   3) CDN adapter panel   4) CDN   5) 6 dB attenuator   6) 30 dB attenuator   7) Groundplane

- Test Level 1:   1V RMS, 1 kHz / 80% AM modulated
- Test Level 2:   3V RMS, 1 kHz / 80% AM modulated
- Test Level 3:   10V RMS, 1 kHz / 80% AM modulated
- Test Level X: special (unspecified)

The specified test levels are open circuit voltages at the EUT port of the CDN.

The voltages measured during calibration must be multiplied by 3 to allow for the 50 Ohm to 150 Ohm conversion and again by 2 to reach the open circuit voltage.

Hence, the measured voltage at the output of the 150 Ohm to 50 Ohm adapter is 1/6 th the voltage of the desired stress level. In logarithmic figures, the measured voltage is 15.5 dB lower than the open circuit voltage.

Example: Test level 2

U_0= 3V RMS open circuit voltage at the EUT port of the CDN = 3V/6 = 0.5V RMS at the output of the 100 Ohm to 50 Ohm adapter.

The required power at the output of the modulated amplifier is:

U_0/6 [dBm] + CDN insertion loss + 6 dB (Attenuator) + 5.1 dB (80% AM RMS)

Assuming 10 dB insertion loss for the CDN, the required RF power is:

7 dBm + 10 dB + 6 dB + 5.1 dB = 28.1 dBm = 0.65 Watt

During calibration, EMCview Pro will make a stepped sweep, for each frequency adjusting the tracking generator level in order to achieve 7 dBm + 5.1 dB -30 dB = -17.9 dBm at the spectrum analyzer input. The tracking generator level table will then be used to set levels during the actual immunity test.

The typical insertion loss of a CDN with attached 150 Ohm to 50 Ohm adapter is 10 dB.

Adding the 6 dB attenuator and 5.1 dB for the AM RMS conversion results in a quasi-insertion loss of 10 dB + 6 dB + 5.1 dB = 21.1 dB.

For open circuit voltages of 1V, 3V and 10V, the corresponding power at the output of the 150 Ohm to 50 Ohm adapter is -2.6 dBm, 7 dBm, 17.4 dBm RMS CW. Add 5.1 dB to cover the RMS power of 80% AM modulation.

Consequently, the required power at the input of the 6 dB attenuator for class 1/2/3 is 18.5 dBm / 28.1 dBm / 38.5 dBm.

The table below reflects the insertion loss versus frequency of a real CDN in order to set the required input power for the TBMDA5.

Frequency [MHz]	TBMDA5 output power to achieve stress level 1 [dBm]	Corresponding TBMDA5 input power [dBm]	TBMDA5 output power to achieve stress level 2 [dBm]	Corresponding TBMDA5 input power [dBm]
0.15	17.3	-22 dBm	27.3	-12 dBm
0.5	16.6	-23 dBm	26.6	-13 dBm
1	16.9	-22 dBm	26.9	-12 dBm
10	17.8	-22 dBm	27.8	-12 dBm
100	18.7	-19 dBm	28.7	-9 dBm
230	20	-19 dBm	30	-9 dBm

Table 4 - measured input power settings for the TBMDA5 in order to achieve stress level 1 and 2

The maximum output power of the TBMDA5 is approximately 3 dB short with respect to power level 3. As a compromise, the 6 dB attenuator could be replaced by a 3 dB attenuator.

EMCview PRO has the capability to automatically adjust the tracking generator level in order to achieve the desired stress level voltage. The output is a calibration table, which is loaded and applied during the immunity test.
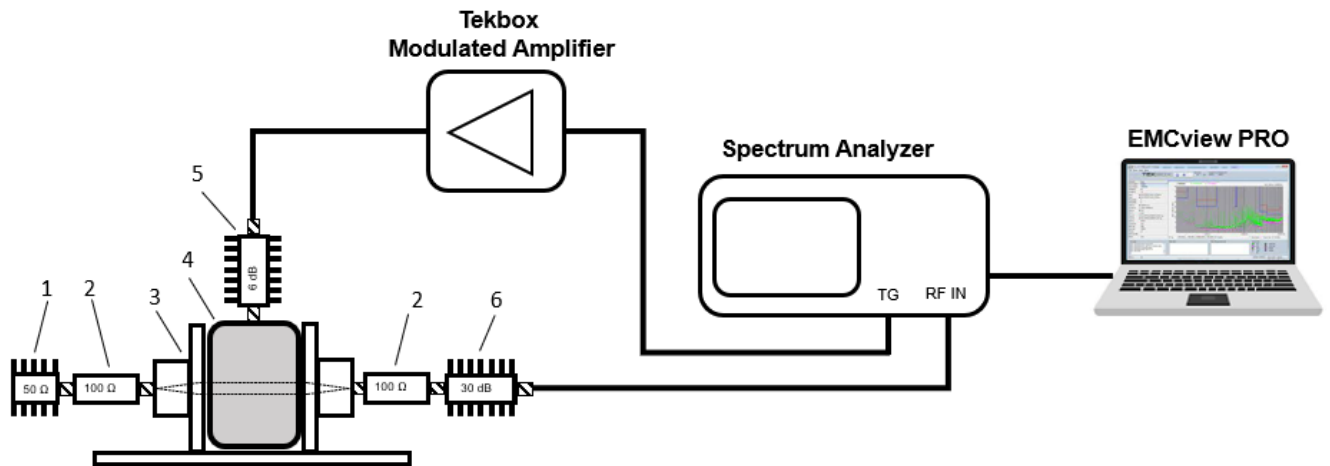
EN 61000-4-6 immunity test set up using EMCview PRO
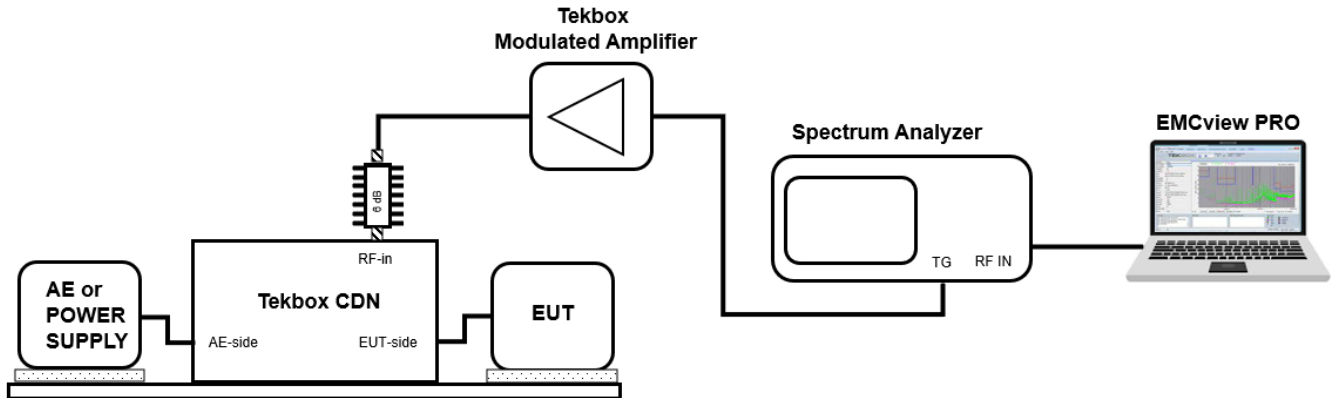
8 Conducted immunity pre-compliance testing using BCI clamps

EN 61000-4-6 specifies stress levels in terms of voltage and calibrates the immunity set up using a 300 Ohm loop. Other standards specify stress levels in terms of injected current.

EN 61000-4-6 300 Ohm loop BCI calibration set up using EMCview PRO

1) 50 Ohm termination   2) 150 Ohm to 50 Ohm adapter   3) BCI probe calibration fixture   4) BCI probe   5) 6 dB attenuator   6) 30 dB attenuator

- ▪ Test Level 1:   1V RMS, 1 kHz / 80% AM modulated
- ▪ Test Level 2:   3V RMS, 1 kHz / 80% AM modulated
- ▪ Test Level 3:   10V RMS, 1 kHz / 80% AM modulated
- ▪ Test Level X: special (unspecified)

The specified test levels are open circuit voltages at the output of the calibration fixture.

The voltages measured during calibration must be multiplied by 3 to allow for the 50 Ohm to 150 Ohm conversion and again by 2 to reach the open circuit voltage.

Hence, the measured voltage at the output of the 150 Ohm to 50 Ohm adapter is 1/6th the voltage of the desired stress level. In logarithmic figures, the measured voltage is 15.5 dB lower than the open circuit voltage.

<u>Example:</u> Test level 2 U_0= 3V RMS open circuit voltage at the output of the calibration fixture = 3V/6 = 0.5V RMS at the output of the 100 Ohm to 50 Ohm adapter.

The required power at the output of the modulated amplifier is:

U_0/6 [dBm] + BCI probe insertion loss + 6 dB (Attenuator) + 5.1 dB (80% AM RMS)

Assuming 16 dB insertion loss for the BCI probe in a 300 Ohm loop, the required RF power is:

7 dBm + 16 dB + 6 dB + 5.1 dB = 34.1 dBm = 2.6 Watt

During calibration, EMCview Pro will make a stepped sweep, for each frequency adjusting the tracking generator level in order to achieve 7 dBm -30 dB = -23 dBm at the spectrum analyzer input. The tracking generator level table will then be used to set levels during the actual immunity test.

EN 61000-4-6 immunity test set up using a BCI probe and EMCview PRO
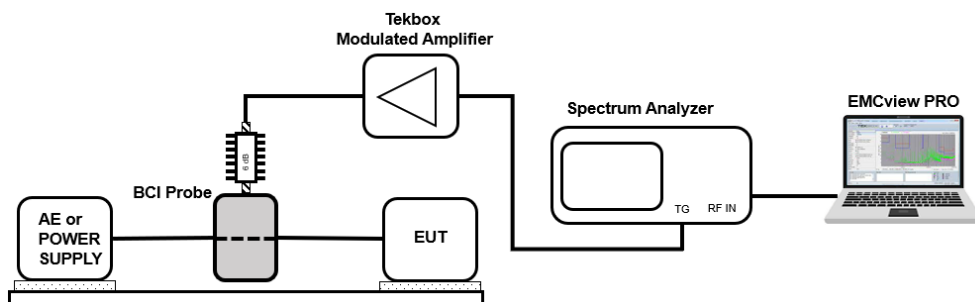

ISO 11452-4 / MIL-STD-461 / DO 160A calibration set up using EMCview PRO

The automotive immunity standard ISO 11452-4 as well as immunity standards for defense and avionic products specify stress levels in terms of induced disturbance current.

Traditional calibration and test methods use current monitoring probes in order to create a control loop, thereby maintaining the required disturbance current. Levelling loops can be fooled by cable resonances. High impedance resonances cause the RF amplifiers output power to raise, in order to achieve the specified disturbance current. Similarly, low impedance resonances may significantly reduce the RF amplifiers output power. This situation is unrealistic of most real-life electromagnetic environments and could create a severe over-test or under-test situation.

In order to get around the over-test / under-test problems associated with the closed loop test method, the standards offer the substitution method (open loop), where the disturbance current is set by measuring current induced into a 100 Ohm loop. Forward and reflected power is measured using a directional coupler while setting the RF power to achieve the required disturbance current levels into the 50 Ohm load. During actual immunity test, the forward power level is set according to the value recorded during calibration.

Substitution calibration method set up for pre-compliance purpose:
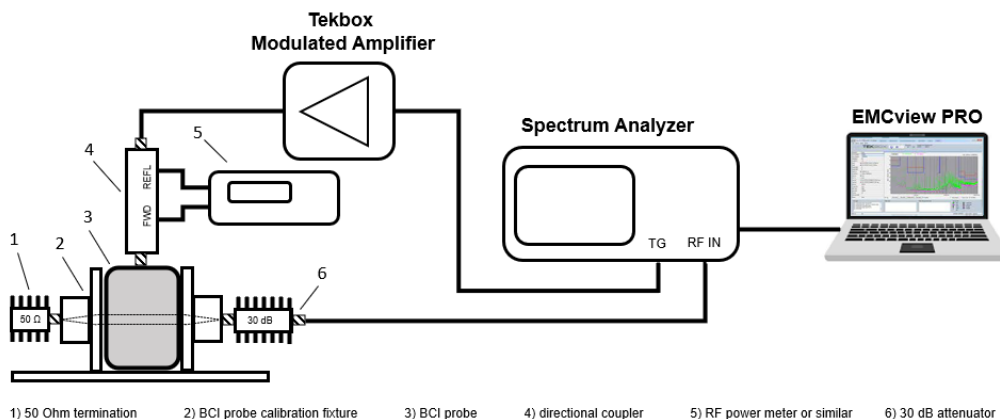
1) 50 Ohm termination   2) BCI probe calibration fixture   3) BCI probe   4) directional coupler   5) RF power meter or similar   6) 30 dB attenuator

Example: Test level I – 60 mA

A power of 22.6 dBm is required to achieve a current of 60 mA in a 50 Ohm load.

Assume 8dB insertion loss for a typical BCI probe in a 100 Ohm loop.

Assume 1 dB insertion loss for the directional coupler

The required power at the output of the modulated amplifier is:

Test level [dBm] + BCI probe insertion loss + 6 dB (Attenuator) + 5.1 dB (80% AM RMS)

22.6 dBm + 8 dB + 1 dB + 5.1 dB = 36,7 dBm = 4.7 W

Example: Test level IV – 200 mA

A power of 33 dBm is required to achieve a current of 200 mA in a 50 Ohm load.

Assume 8dB insertion loss for a typical BCI probe in a 100 Ohm loop.

Assume 1 dB insertion loss for the directional coupler

The required power at the output of the modulated amplifier is:

Test level [dBm] + BCI probe insertion loss + 6 dB (Attenuator) + 5.1 dB (80% AM RMS)

33 dBm + 8 dB + 1 dB + 5.1 dB = 47.1 dBm = 51.3 W

ISO 11452-4 / MIL-STD-461 / DO 160A immunity test set up using EMCview PRO

Refer to the standards for detailed drawings of the corresponding test set ups.

9   PC Software for immunity testing

Tekbox provides two software versions for EMC pre-compliance measurements

EMCview provides a feature to control the tracking generator output frequency and level and carry out sweeps with constant tracking generator level.
EMCview PRO provides a more sophisticated feature, which is able to carry out calibration sweeps for CDN and BCI based set ups. The resulting calibration file is used to set the tracking generator level during the immunity test sweep.

Tekbox EMCview currently supports Rigol, Siglent, Owon, R&S FPC and FPH series spectrum analyzers.
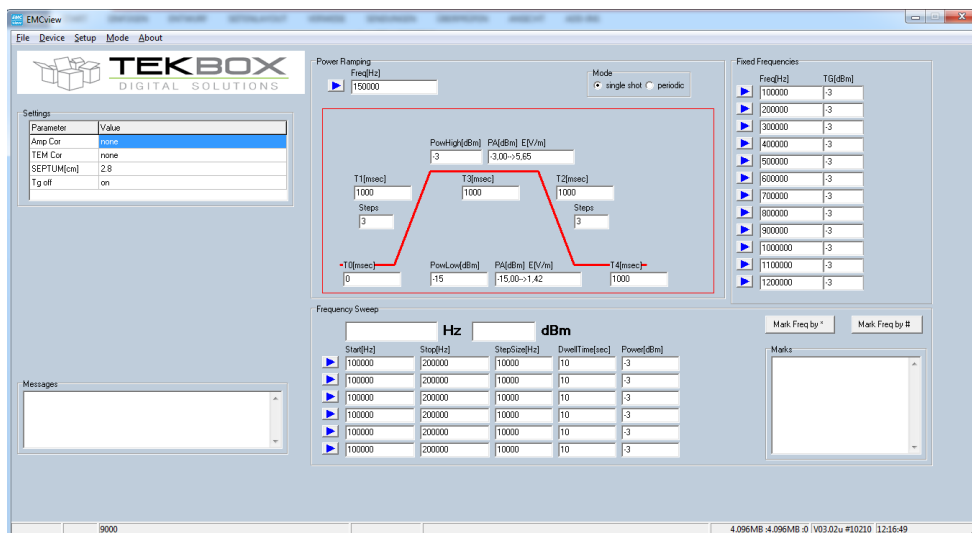

Figure 11 – screenshot of the tracking generator control feature of EMCview / EMCview Pro
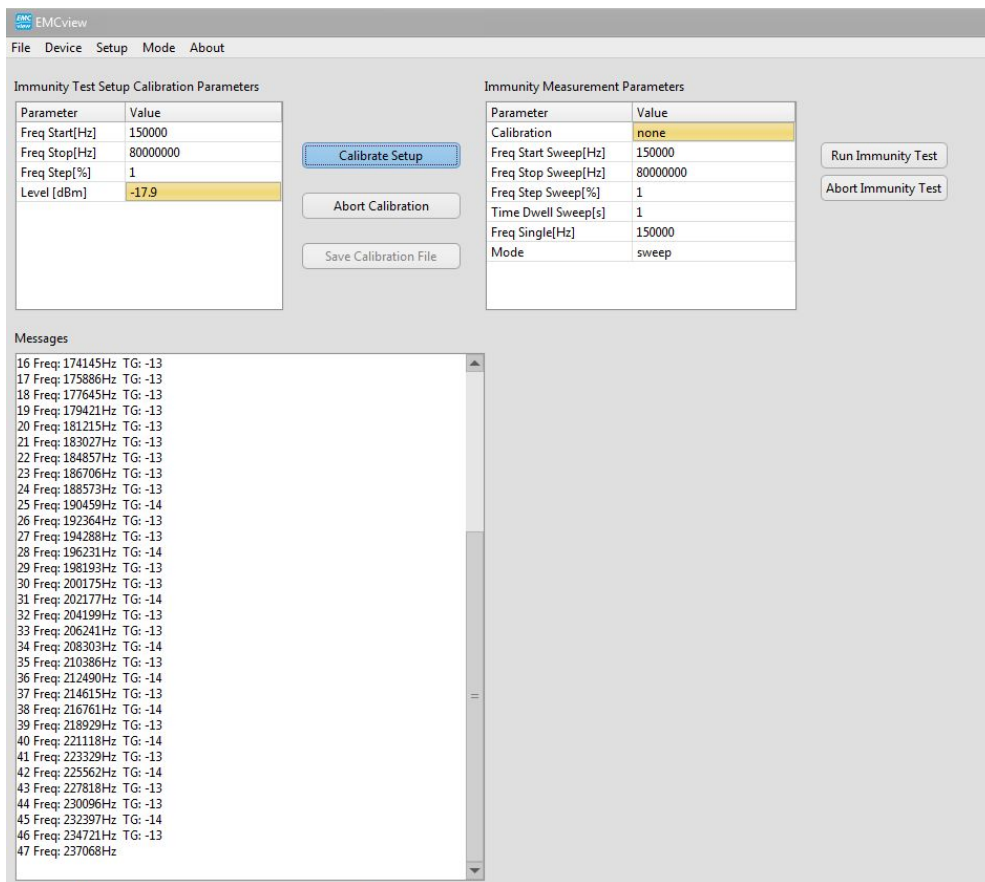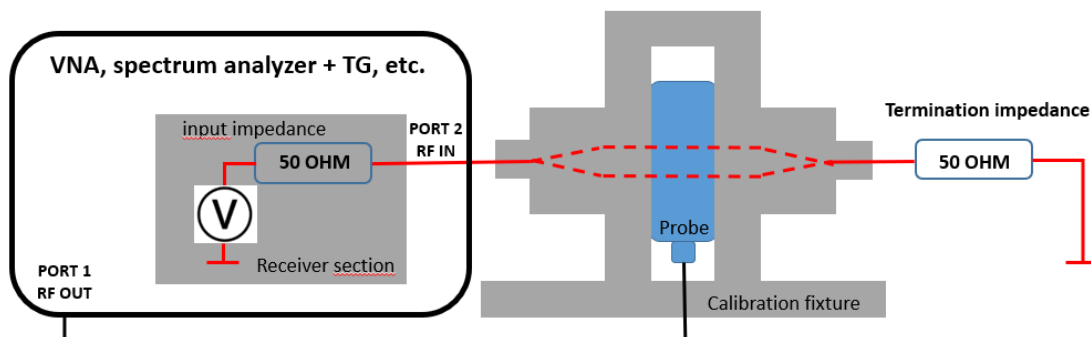
Figure 12 – screenshot of the immunity test feature of EMCview Pro

## 10 100 / 300 Ohm loop impedance with respect to BCI-clamps

Data sheets specify insertion loss of BCI clamps with respect to loop impedance. What does it mean?

The insertion loss of a BCI-probe may be characterized measuring S21 with a VNA as shown below:

Adding the source impedance of the VNA with the termination impedance of 50 Ohm results in 100 Ohm loop impedance.

Conducted Immunity Basics

Depending on standard, the BCI-probe may also be characterized in a 300 Ohm loop:
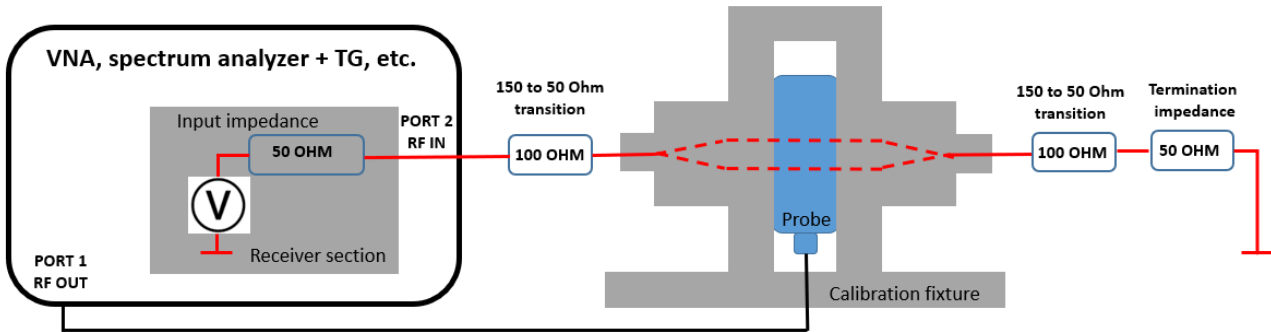
11 History

Version	Date	Author	Changes
V 1.0	27.9.2022	Mayerhofer	Creation of the document

Visit https://arbenelux.com/brands/tekbox-precompliant-emc-test-equipment/ or contact us for more details

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