

Pre-compliance EMI measurements & Electrical safety testing

EMI Measurements - Agenda

- Introduction – EMC
 - Compliance vs. pre-compliance measurements
- List of basic standards
- Measurement of radiated interference
 - Measurement setup
 - Equipment – EMI receiver, antennas, accessories
 - Measurement procedure
- Conducted interference
 - Arrangement of the measurement setup
 - Coupling devices, LISNs
 - Measurement procedure
- Our offer, examples of measurement setups

Introduction

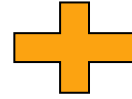
- During the development of a new product, it is necessary to ensure compliance with the requirements of various standards, including, among many others, those in the field of EMC
- The ultimate goal is to successfully verify the product's compliance with the requirements (either by one of the notified bodies or independently) and issue the declaration of conformity
- EMC-related device design is not simple and it can be an iterative process
 - Repeated modifications to the product based on measurement results
- Without the ability to perform its own measurements during development, the manufacturer is fully reliant on testing conducted in commercial laboratories
 - These measurements are quite expensive
 - Low time flexibility - measurement must be booked in advance
 - It is necessary to transport the DUT with all accessories and personnel to the test lab

Introduction

- Compliance tests
 - Measurements performed by a certified laboratory - a notified body
 - Laboratory equipment and procedures must fully comply with the requirements of the relevant standards
 - Tests are typically conducted at the end of product development to assess the product's compliance with the requirements of the standards; otherwise, they are unnecessarily expensive
- Pre-compliance tests
 - The equipment and procedures can be simplified to some extent; the goal of these tests is merely to approximate the “official” results as closely as possible
 - Testing is done by the manufacturer
 - Measurements can be performed at various stages of development - this can ultimately make the entire process much simpler, faster and cheaper
 - A one-time investment in measuring equipment; the other difficulties mentioned above regarding repeated testing in commercial laboratories are eliminated

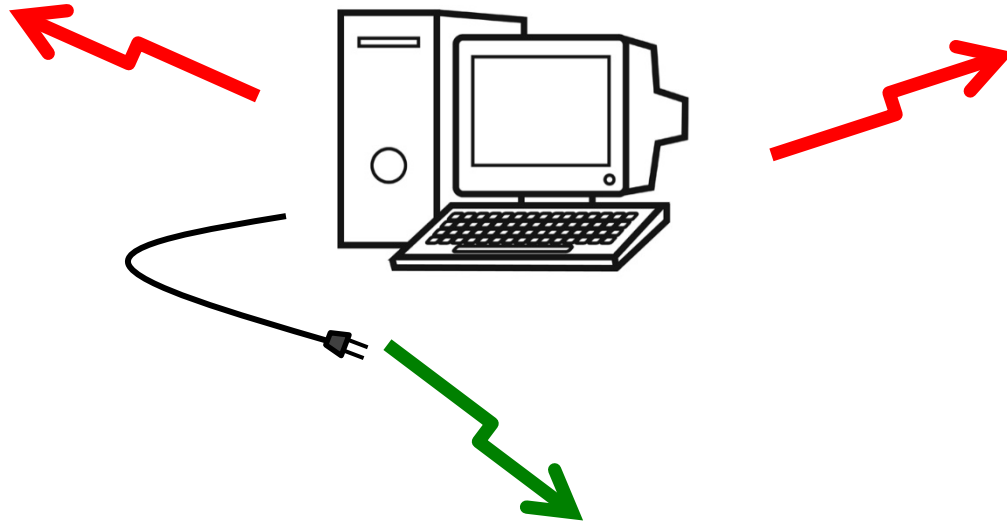
EMC (Electromagnetic Compatibility)

EMI
(Electromagnetic Interference)



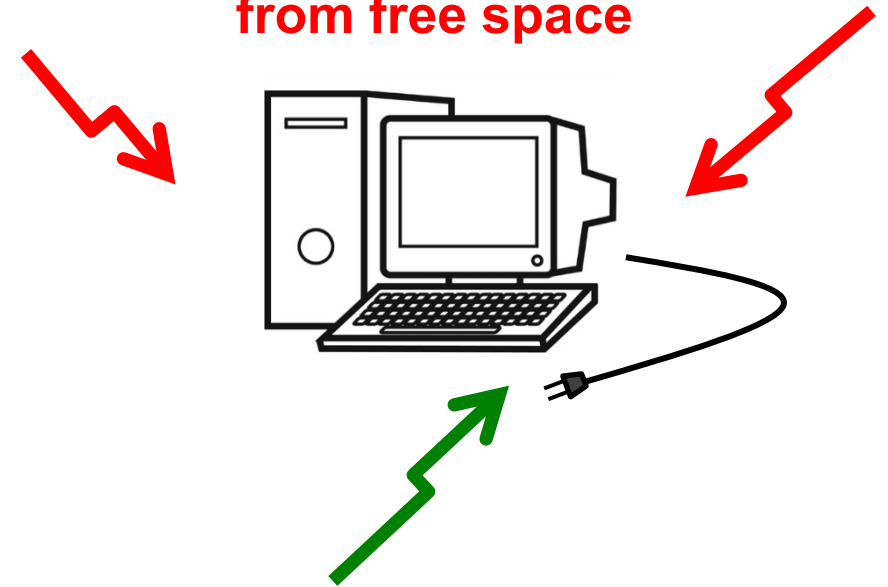
EMS
(Electromagnetic Susceptibility)

radiated interference



conducted interference

interference received
from free space



and from cabling

EMC - Product Testing

- Recommended procedure for new product development (from an EMC perspective):
 - 1) Identify the standards applicable to the product type
 - Product testing procedure, limit values, ...
 - 2) Product testing during development (pre-compliance measurements)
 - Selection of suitable components (comparison of components from different manufacturers)
 - Testing of individual assemblies/modules
 - Testing of finished prototypes
 - Gradual modification of the device based on measurement results
 - Upon successful completion of this phase, there should be a high probability of a smooth process during certification testing
 - In some cases, thorough pre-compliance measurements can even replace certification testing

EMC - Product Testing

3) Certification/compliance testing

- Conducted at a selected commercial laboratory
- Ideally, the product will pass the tests on the first attempt
- The “official” results can then be used to “calibrate” and verify your own pre-compliance measurement setup (by comparing the results obtained from your own measurements with those from an accredited laboratory)

- Testing is also important after a new product is launched on the market:
 - Repeated measurements on selected samples during mass production
 - Verifying repeatability in terms of EMI (differences in cable placement, etc.)
 - New measurements following hw and sw modifications (potential impact on emissions)
 - Changes in component suppliers, device firmware updates, etc.

EMI – Basic Overview of Standards

- Basic Standards
 - Describe EMC issues in general (equipment, methods);
do not define specific requirements for the devices under test
 - EN 55016-1-1 ED.4 – measuring instruments for EMC measurements
 - EN 55016-1-2 ED.2 – coupling devices; conducted interference
 - EN 55016-1-3 ED.2 – auxiliary equipment; disturbance power (absorption clamps)
 - EN 55016-1-4 ED.4 – antennas and test sites; radiated emissions
 - EN 55016-2-1 ED.3 – methods for measuring conducted emissions
 - EN 55016-2-2 ED.2 – methods for measuring disturbance power (absorption clamps)
 - EN 55016-2-3 ED.4 – methods for measuring radiated emissions

EMI – Basic Overview of Standards

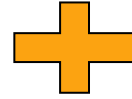
- Generic standards
 - Define general requirements for tested devices not covered by other specific product standards; product standards are based on them to a certain extent
- **EN 61000-6-3 ED.3**
 - generic standard for measuring emissions in residential, commercial or light industrial environments
- **EN 61000-6-4 ED.3**
 - generic standard for measuring emissions in industrial environments

EMI – Basic Overview of Standards

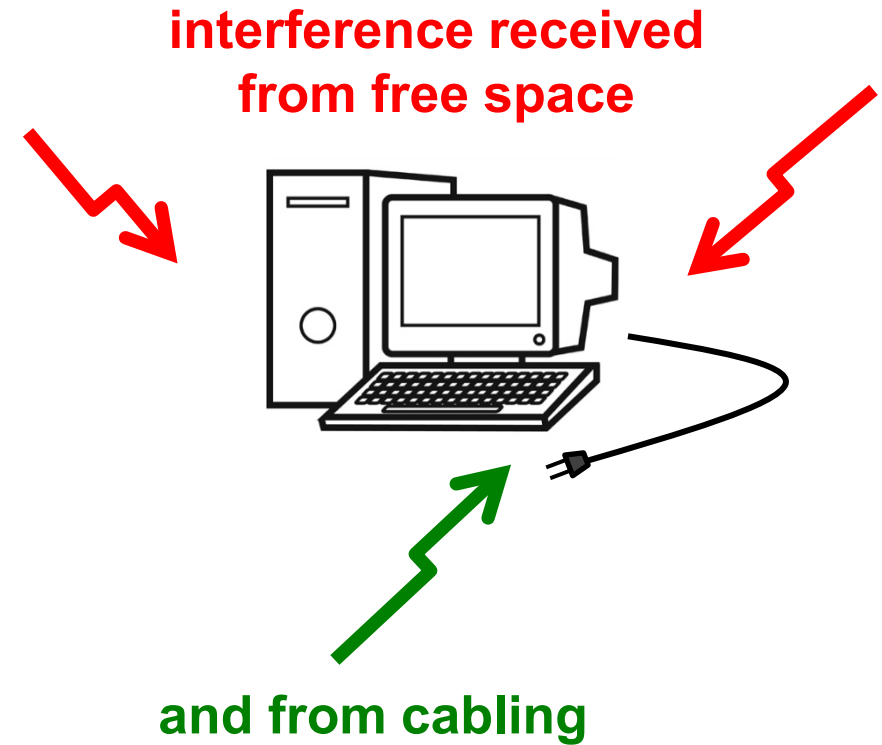
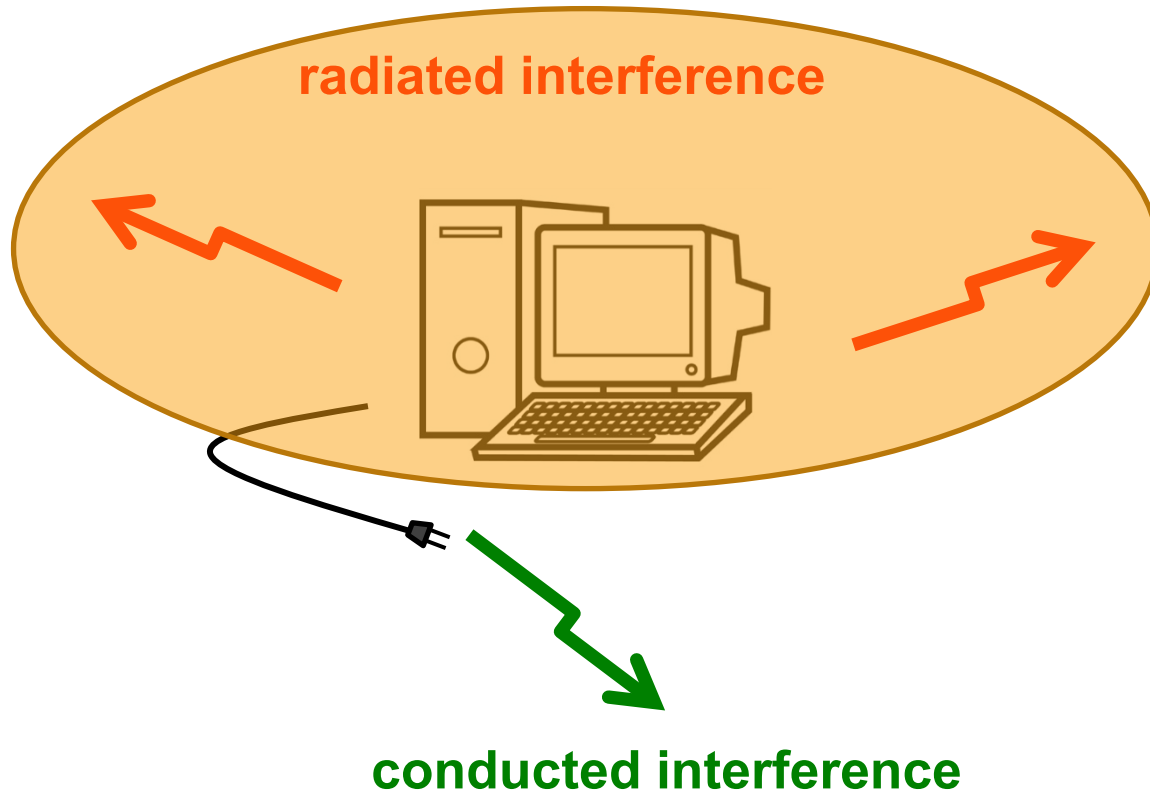
- Product-specific standards
 - Define requirements for equipment falling within a specific product category
 - **EN 55011 ED.4**
 - industrial, scientific, and medical equipment; limits and methods for measuring radiated emissions
 - **EN 55014-1 ED.5**
 - requirements for electromagnetic disturbance emissions for household appliances, power tools, and similar devices
 - **EN 55015 ED.5**
 - limits and methods of measurement of electromagnetic disturbances caused by electric lighting fixtures and similar equipment
 - **EN 55032 ED.2**
 - emission requirements for multimedia equipment

EMC

EMI
(Electromagnetic Interference)



EMS
(Electromagnetic Susceptibility)

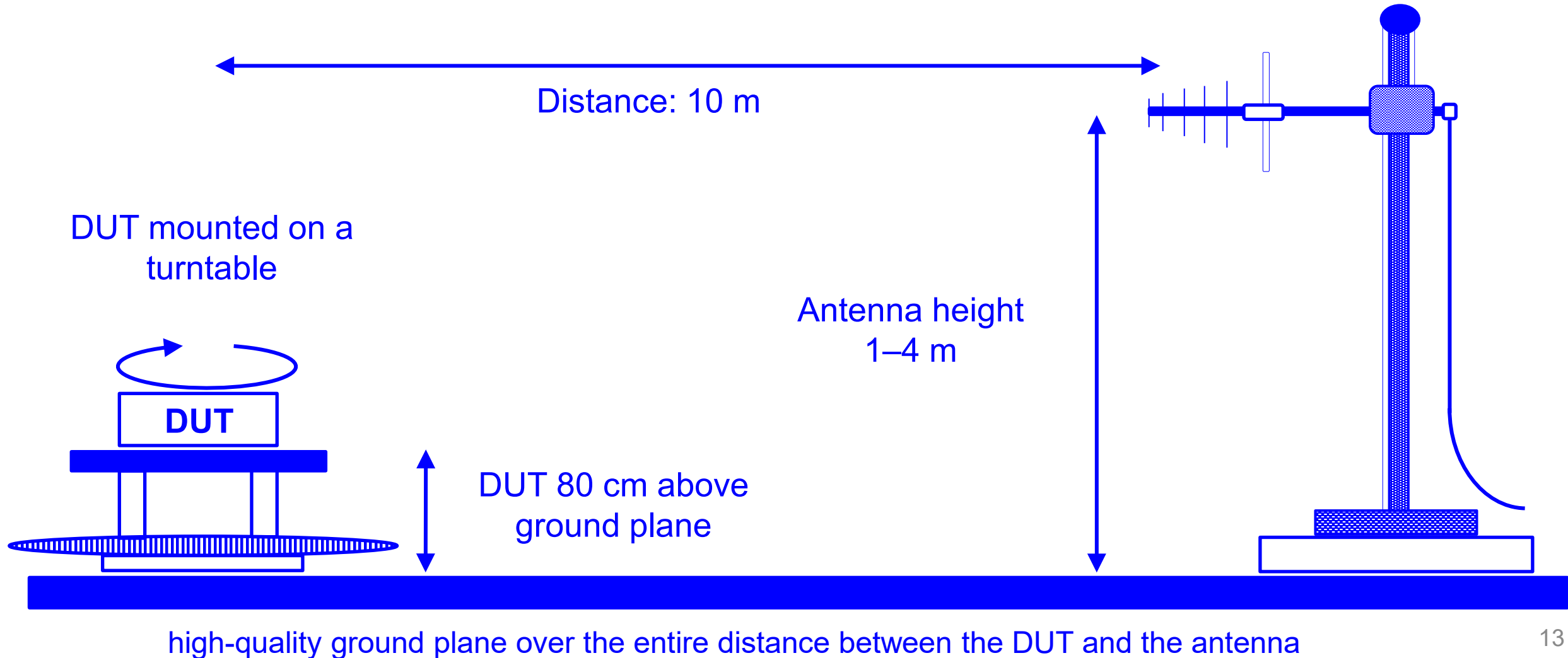


EMI - measurement of radiated interference

- The measured physical quantity is always the electric or magnetic field intensity in a certain distances from the tested device (in far field)
- Exact testing requirements for the device under test (DUT/EUT) must always be determined from the specific standard
 - frequency bands, limits, measuring equipment, and test site layout
- The typical standard measurement distance is 10 m; alternatively, measurements can be taken at distances of 3 m and 30 m (with appropriate correction of the limits)
- Measurements are performed either at an outdoor test site (OATS), in a semi-anechoic chamber (SAC), or in a fully anechoic chamber (FAC)
 - Measurements in OATS and SAC are performed in the same manner (takes into account reflection from the conductive floor plane); different requirements for measurements in FAR

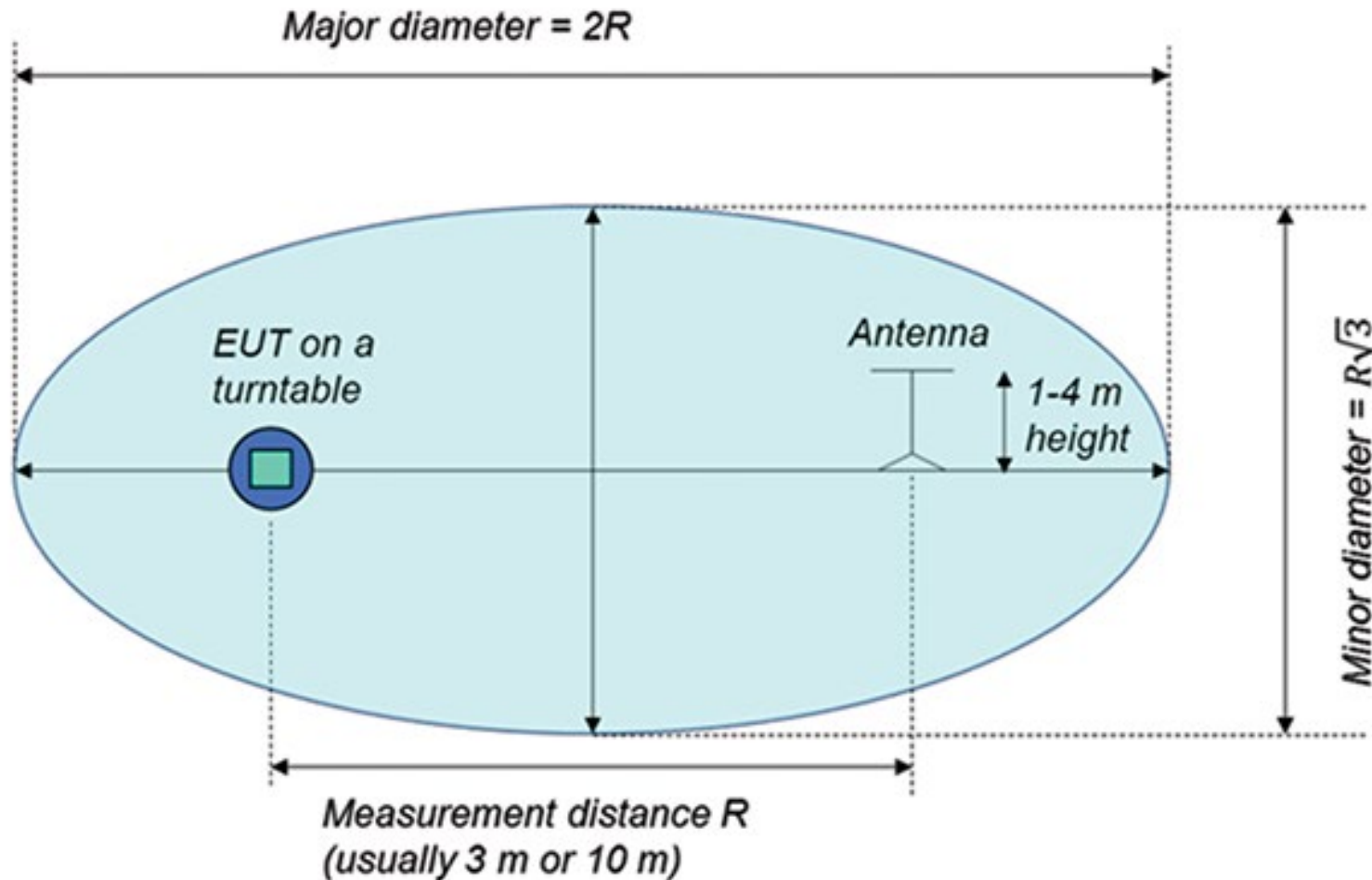
EMI - measurement of radiated interference

- Frequency band typically ranging from 30 MHz to 1 GHz
- Typical measurement setup in OATS or SAC:



EMI - measurement of radiated interference

- Floor plan of the test site layout (ellipse without metal objects):



EMI - measurement of radiated interference

- Outdoor Test Site (OATS)



EMI - measurement of radiated interference

- Semi-Anechoic Chamber (SAC) - Example of a facility built by H TEST in Brno:



EMI - measurement of radiated interference

- Semi-Anechoic Chamber (SAC) - Example of a facility built by H TEST in Ostrava:



EMI—measurement of radiated interference

- Chamber with only the corner covered with absorbers (cheaper option):



Equipment for compliance measurements

- Equipment required for certification measurements (ideal case):
 - 1) Test site meeting all standard requirements
 - OATS, **SAC**, FAC
 - Antenna mast with the ability to adjust the antenna height and polarization
 - Turntable for the DUT
 - 2) Measuring receiver that meets all the requirements of the EN 55016-1-1 standard
 - Requirements for measurement accuracy of harmonic and wideband signals
 - Special intermediate-frequency (RBW) EMC filters and detectors (QPK, PK, AVG)
 - Very high dynamic range and overload factor
 - 3) Set of magnetic and electrical antennas (depending on the frequency band)
 - Preamplifiers and other equipment, if necessary

Equipment for pre-compliance measurements

- Typical equipment used for pre-compliance measurements:

- 1) Open area test site - the closer it is to the requirements of the standards, the better

- Conductive ground plane - the specified limits account for the superposition of the direct signal and the signal reflected from the ground
 - Ability to adjust the antenna height (for example, at least two discrete positions)
 - The “CISPR ellipse” - area around the DUT and the measurement antenna free of conductive objects
 - the length of the major axis is $2 \cdot X$; the minor axis is $\sqrt{3} \cdot X$ (where X is the measurement distance)
 - Ideally, as far away as possible from other sources of radio signals in the tested bands

- 2) Spectrum/Signal analyzer or pre-compliance test receiver

- Less stringent requirements, significantly lower price; typically without preselection filters, ...
 - Often in the form of an optional application for modern signal analyzers
 - Well-suited for narrowband signals, problematic for impulse interference

Equipment for pre-compliance measurements

3) Small broadband antenna (or antennas)

- Often electrically small antennas, which are less suitable for use at low frequencies
- Using typical antenna factor data supplied by the antenna manufacturer

4) Near-field probes

- Indispensable for locating sources of interference around or inside the devices under test

5) Other equipment

- Reference sources (CNE – comparison noise emitter; ERS – emission reference source)
 - comb generators used to verify the test site
- “golden devices”
 - a product similar to the device under test, whose emissions have previously been measured in a reliable manner (e.g., by a certified testing laboratory)
 - used as a reference for ongoing verification of the integrity of the test setup
 - should be kept, if possible, in a completely unaltered state

Equipment and accessories

- Examples of reference sources:



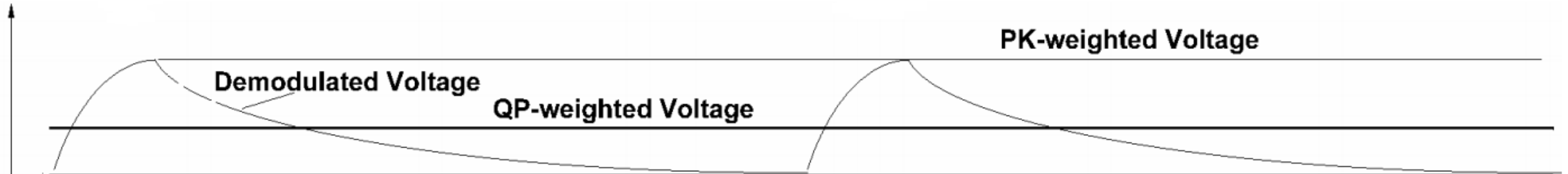
Equipment and accessories

- Signal analyzer acting as an EMI receiver:



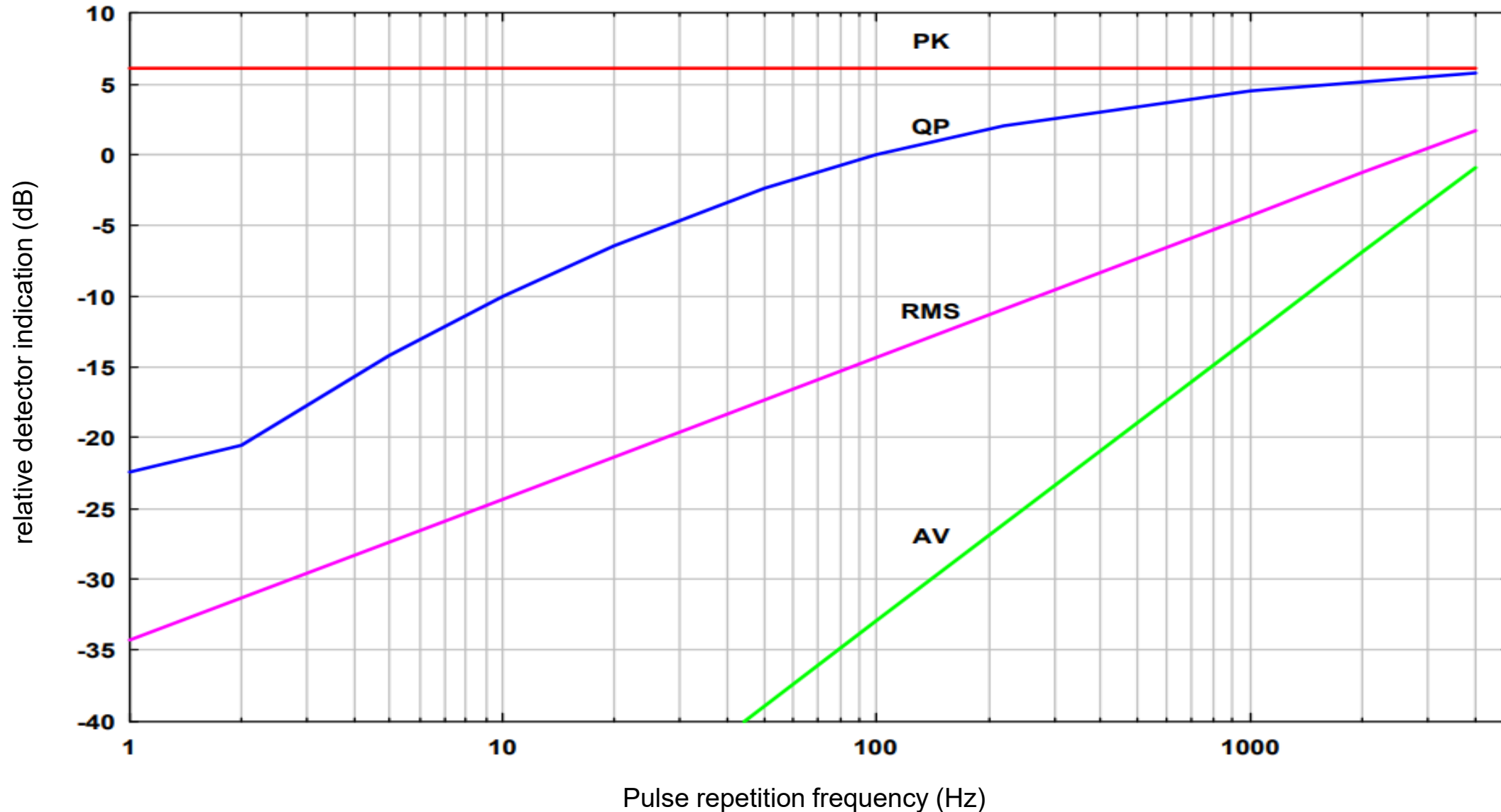
EMI analyzer – basic requirements

- Frequency range as needed; at least typically from 9 kHz to 1 GHz
- Special EMI intermediate-frequency filters: 200 Hz, 9 kHz, 120 kHz, 1 MHz
 - Bandwidth defined for a 6 dB roll-off; specified selectivity curve
- EMI detectors: quasi-peak (QP), average (AV), peak (PK), RMS
 - For pulse signals, the readings of all detectors except PK depends on the PRF (weighted detectors) - defined charge and discharge time constants of the detector circuit in combination with the time constant of the indicator; the following applies: $PK > QP > RMS > AV$
 - For an unmodulated CW signal, $PK = QP = RMS = AV$



EMI analyzer – basic requirements

- Relative EMI detector readings as a function of pulse repetition frequency:



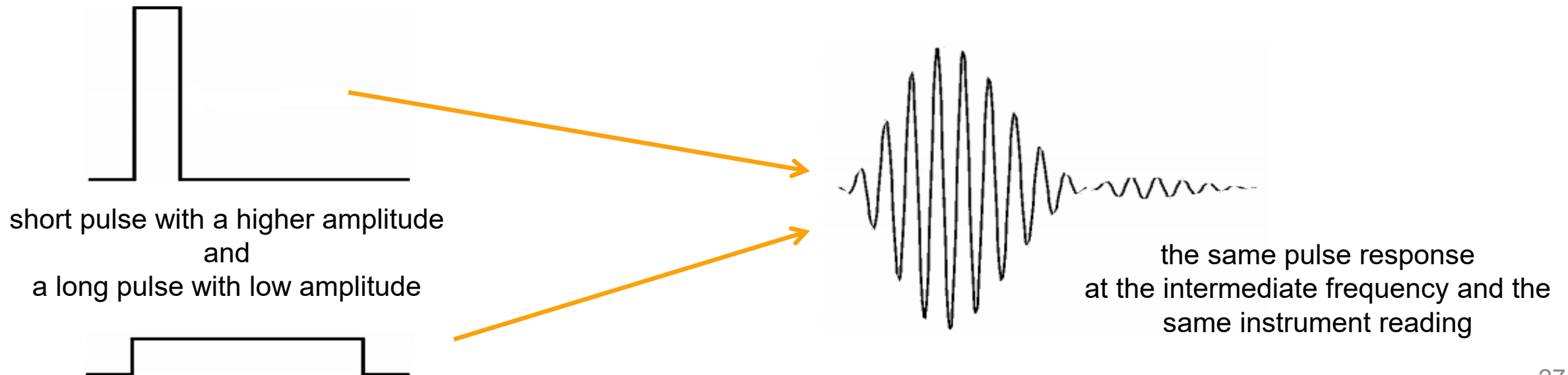
EMI analyzer

- Requirements for a measuring receiver with a QP detector according to the standard EN 55016-1-1 (for individual EMC bands - A, B, C, D, E):

band	A	B	C	D
frequency range	{9 - 150} kHz	{0,15 - 30} MHz	{30 - 300} MHz	{300 - 1000} MHz
B_{-6dB}	200 Hz	9 kHz	120 kHz	120 kHz
τ_{charge}	45 ms	1 ms	1 ms	1 ms
$\tau_{discharge}$	500 ms	160 ms	550 ms	550 ms
$\tau_{indicator}$	160 ms	160 ms	100 ms	100 ms

EMI analyzer

- The EN 55016-1-1 standard has relatively strict requirements on EMI compliance receivers regarding dynamic range and overload capability
 - The instrument should be capable of correct indication for both unmodulated CW signals and various broadband pulses
 - In case of pulses, the instrument response depends on their pulse area (amplitude * duration); the same indication occurs for the same pulse area
 - Short pulses with high amplitude are more demanding on the input circuits than long “low” pulses



EMI analyzer

- Short pulses with high amplitude represent the only signal for which the presence of preselection filters at the input has a significant effect on the measurement
 - Bandpass filters limit the energy of the wideband input signal and thus prevent overload of the receiver's input circuits (mixer, etc.)
 - For CW signals and longer lower pulses, the advantage of the preselector is not apparent
- **For typical pre-compliance measurements, a SA with EMI mode is usually sufficient**
 - Offering the same functions as a conventional test receiver
 - Modern SAs with EMI mode offer all the functions present in compliance measurement receivers
 - Simple definition of correction curves for external devices (antennas, etc.)
 - Prescan and subsequent detailed measurements at problematic frequencies

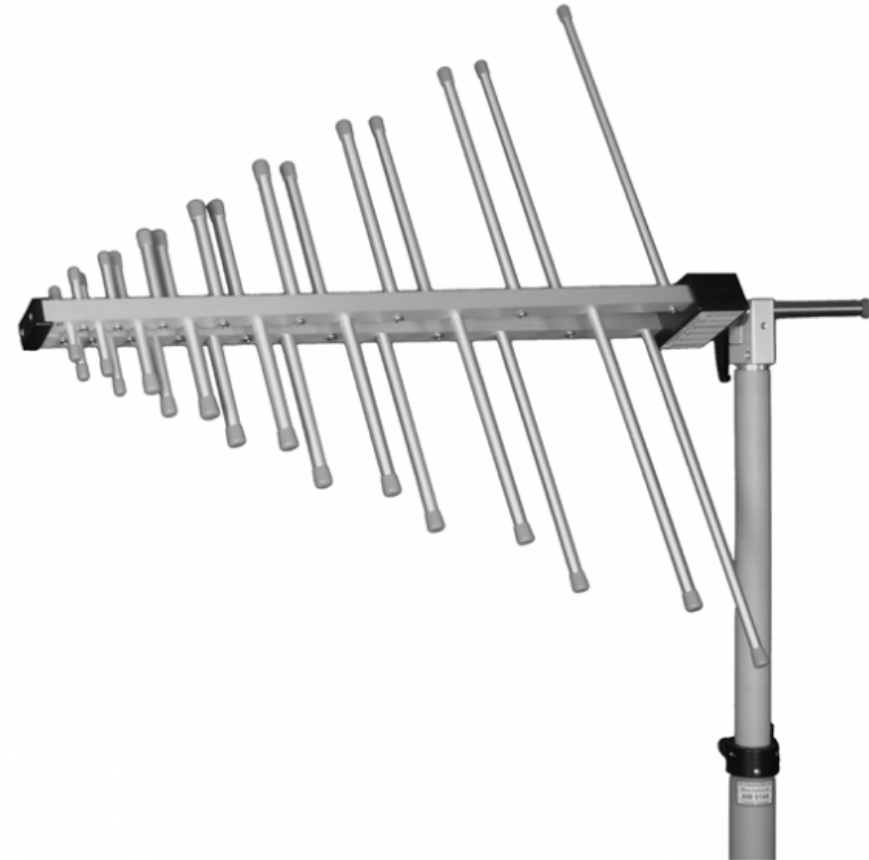
EMI equipment - antennas

- Frequency range from approximately 9 kHz to 30 MHz - **active magnetic loop** or **electric rod (monopole)** antennas
 - Measurement of the electric or magnetic component in the near field



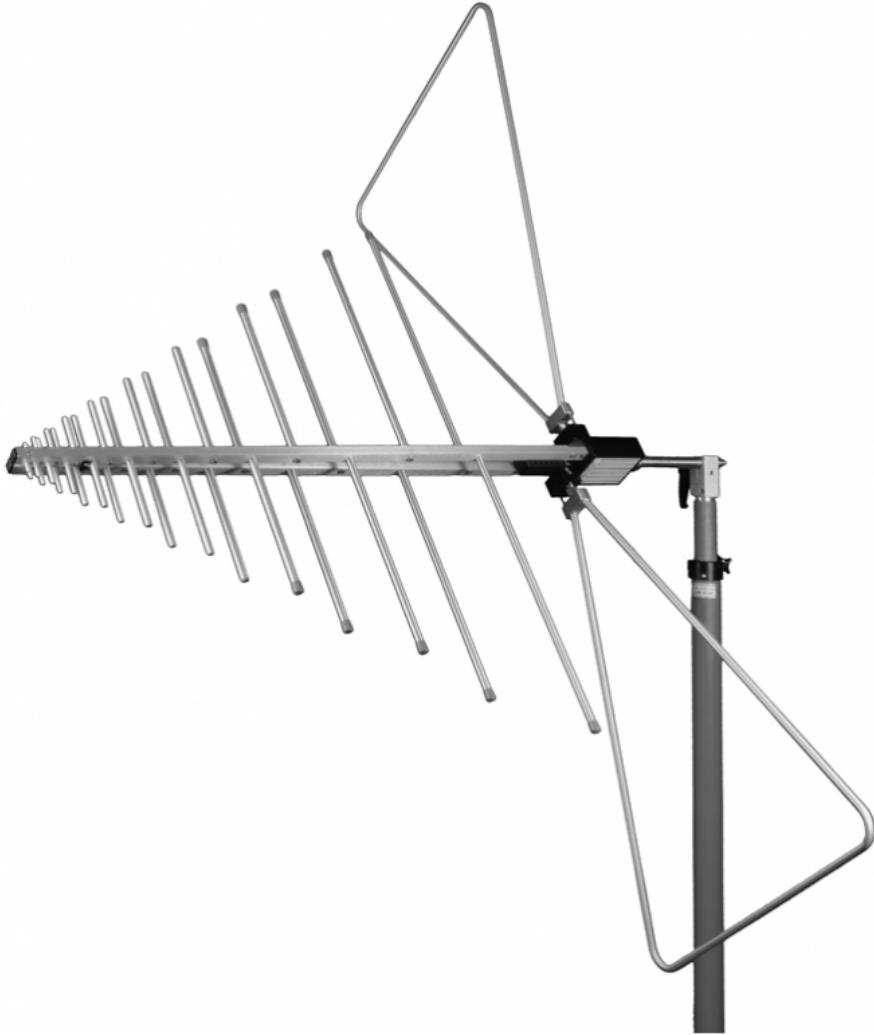
EMI equipment - antennas

- In the 30 MHz to 1 GHz band – **biconical** (~30 to 300 MHz) and **log-periodic antennas** (~200 MHz to 2 GHz)



EMI equipment - antennas

- Alternatively, in the 30 MHz to 1 GHz (up to 2 GHz) band, a single hybrid broadband antenna (BiLog) can be used:



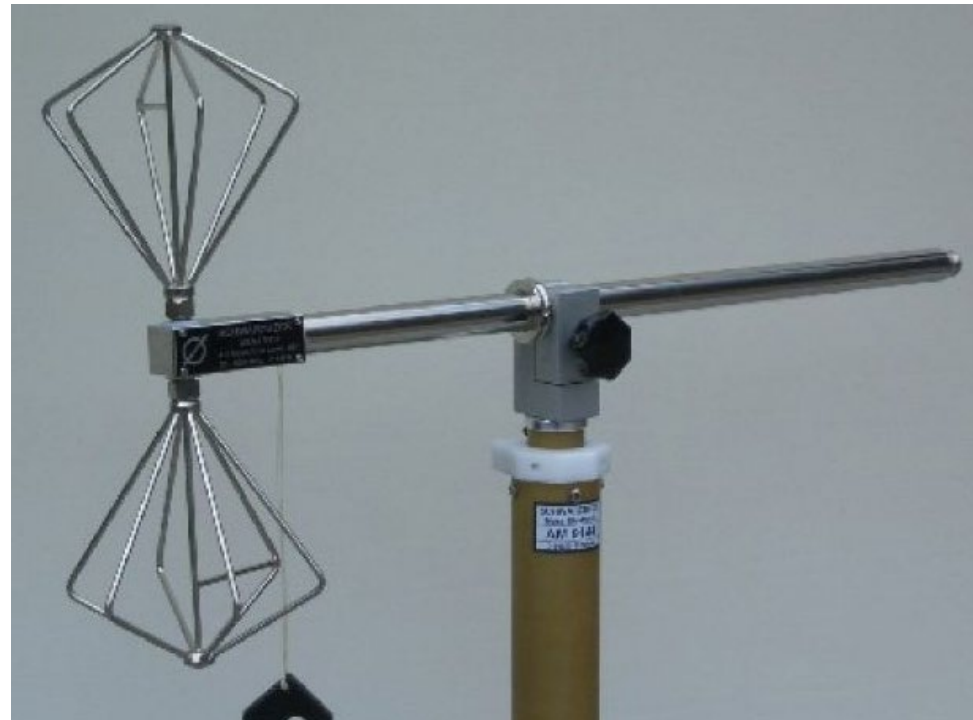
EMI equipment - antennas

- At frequencies higher than 1 GHz:
 - conventional horn antennas (frequency range up to one octave)
 - broadband “double-ridged horn” antennas (frequency range up to over one decade)



EMI equipment - antennas

- For very basic pre-compliance, smaller and less expensive antennas can be used
 - Can theoretically cover the entire band from 30 MHz to 1 GHz, however below ~ 100 MHz, these electrically small antennas are not sensitive enough; this limits their usefulness



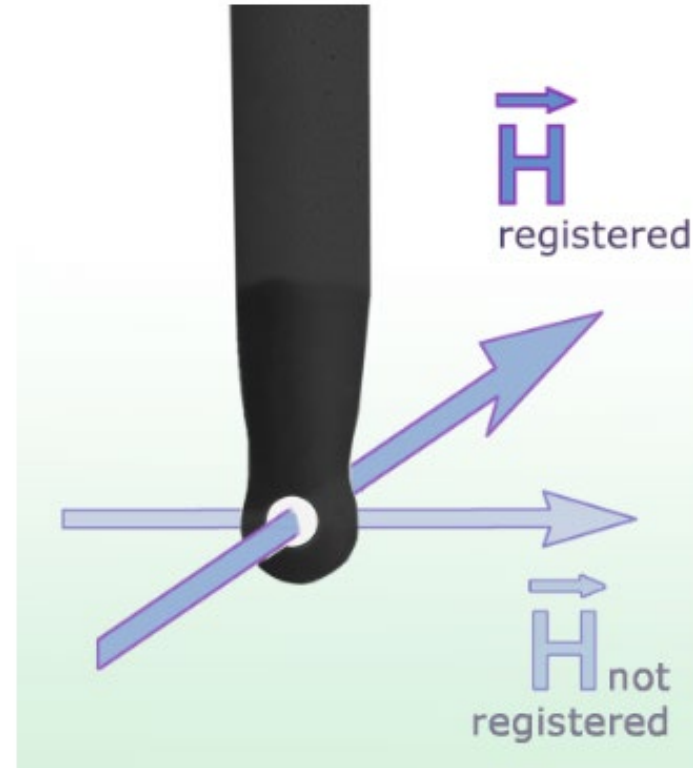
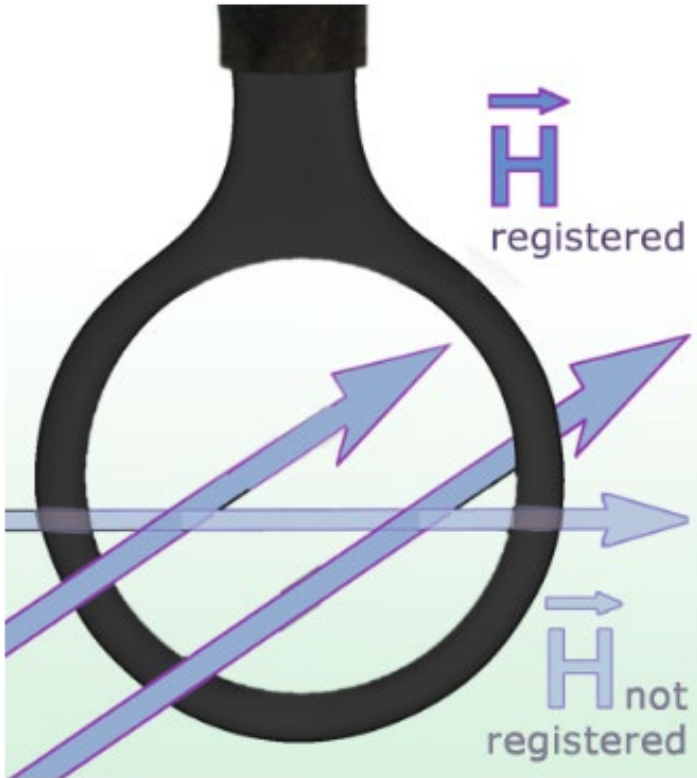
EMI equipment - near-field probes

- Near-field probes can be used to precisely locate the sources of interference
 - electric or magnetic field probes; various types and sizes
 - larger probes can also be used at greater distances (in centimeters) from the interference source
 - smaller probes are used to locate the source of interference as precisely as possible at very short distances (often by direct contact to the PCB)



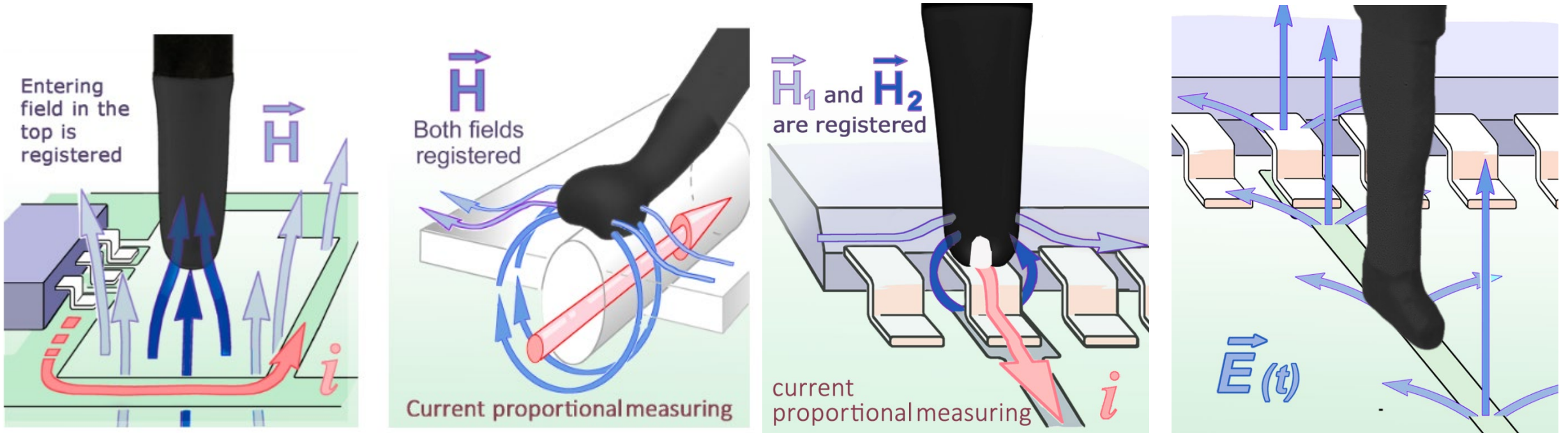
EMI equipment - Near-Field Probes

- Example of a large and small magnetic field loop probe:



EMI equipment - near-field probes

- Various probe variants:



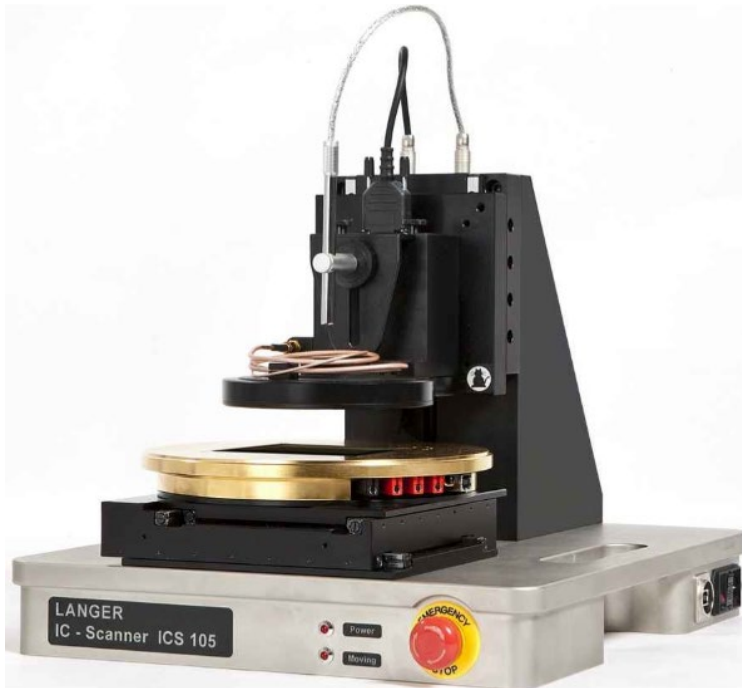
EMI equipment - Near-Field Probes

- Langer EMV offers a wide variety of probe models:
 - standard passive probes:
 - “LF” from 100 kHz to 50 MHz
 - “RF” from 30 MHz to 3 GHz – most commonly used
 - “XF” from 30 MHz to 6 GHz
 - “SX” from 1 GHz to 20 GHz
 - “HR” up to 40 GHz
 - “MFA” active probes from 1 MHz to 6 GHz
 - “microprobes” with a resolution of 60 to 300 μm usable in the 500 kHz to 6 GHz band



Positioners for near-field probes

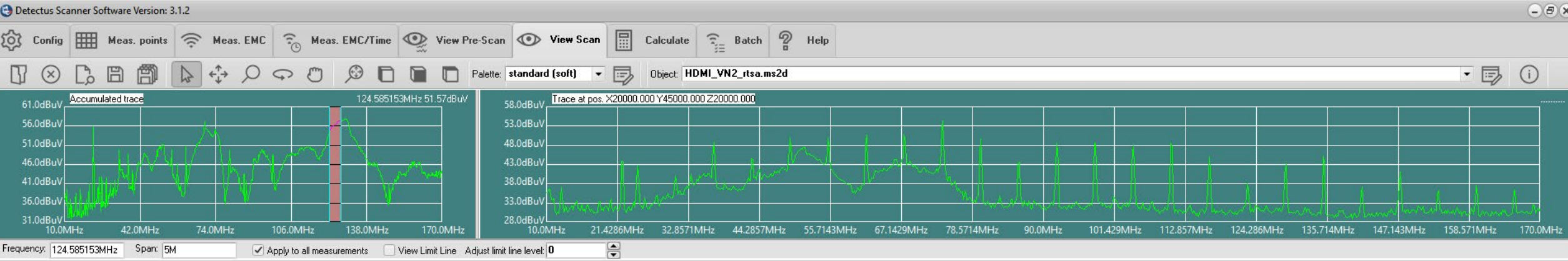
- When measuring spurious emissions, particularly on PCBs and integrated circuits, positioners can be used to enable precise and repeatable scanning of a defined area
- Can use standard near-field probes and position them automatically along 2, 3, or 4 axes
- A major advantage is the high repeatability of measurements and the ability to accurately compare measurement results, for example, after various design changes



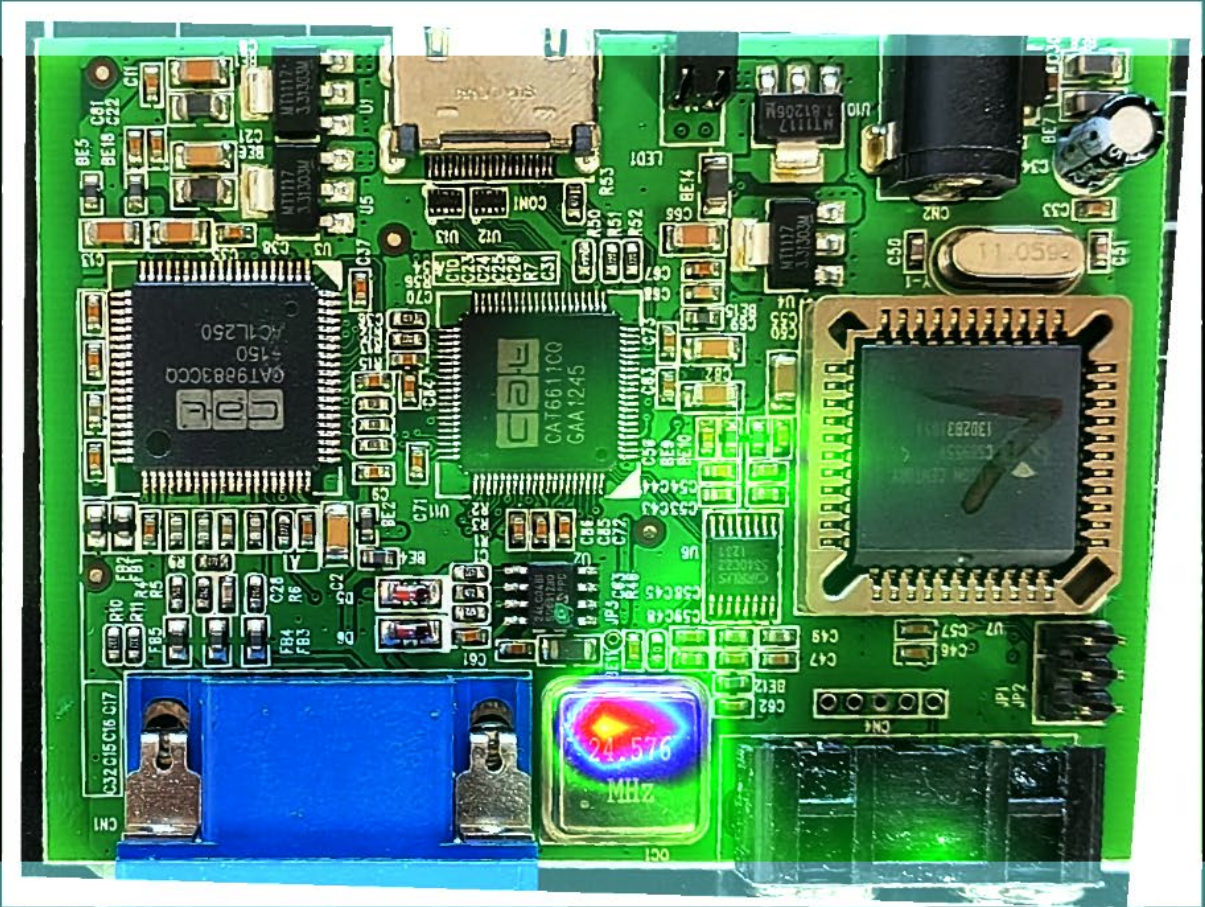
Positioners for Near-Field Probes

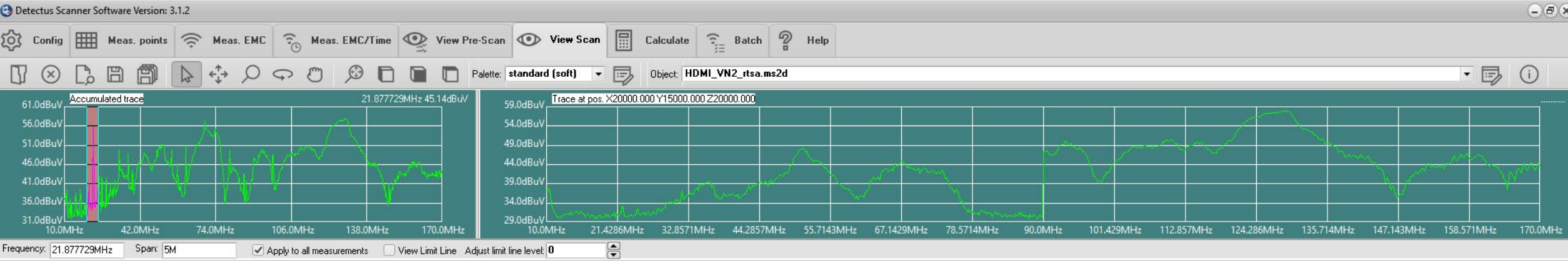
- Example of the measurement results (heat map on a single selected frequency)



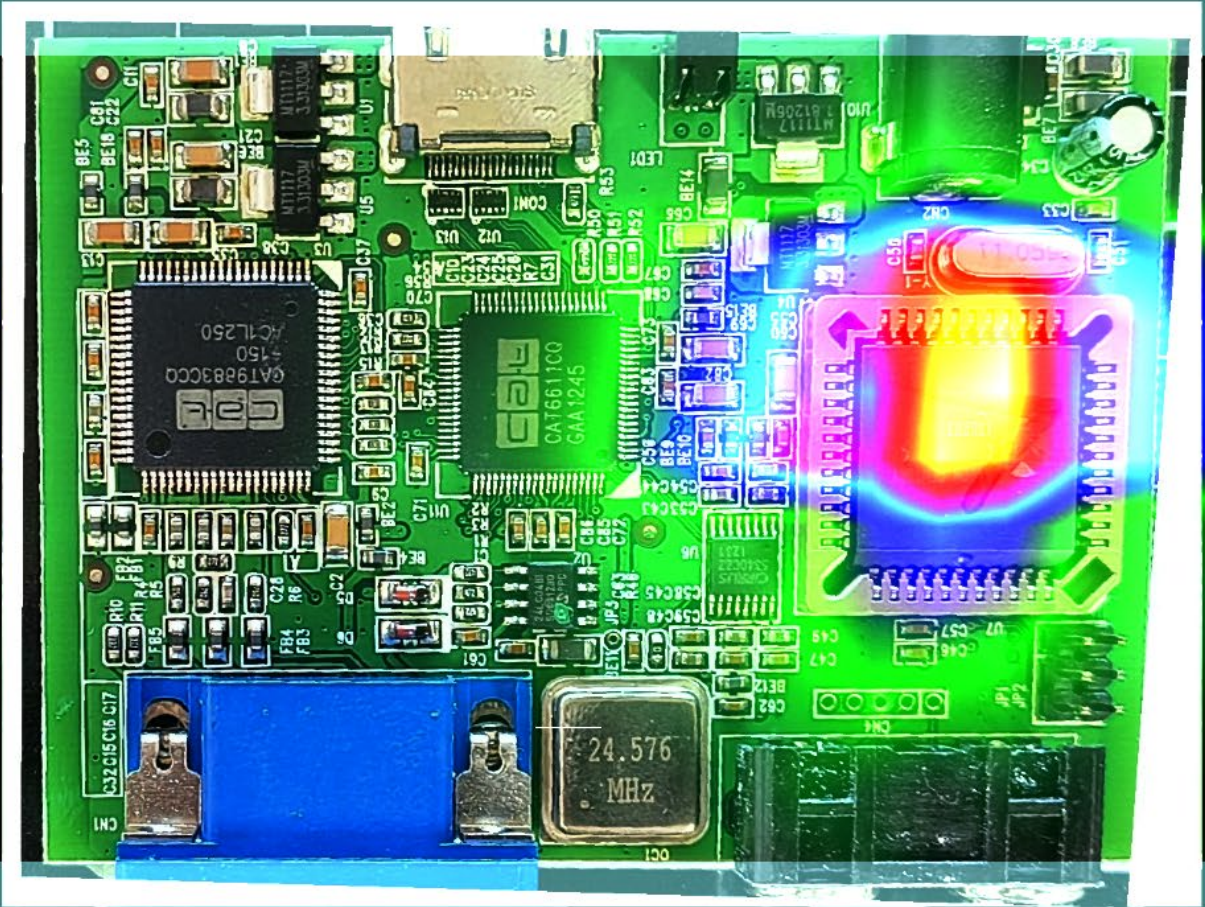


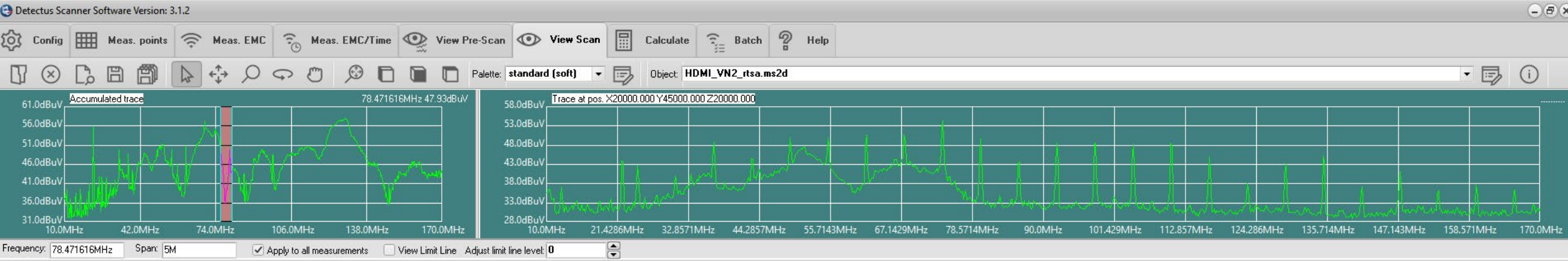
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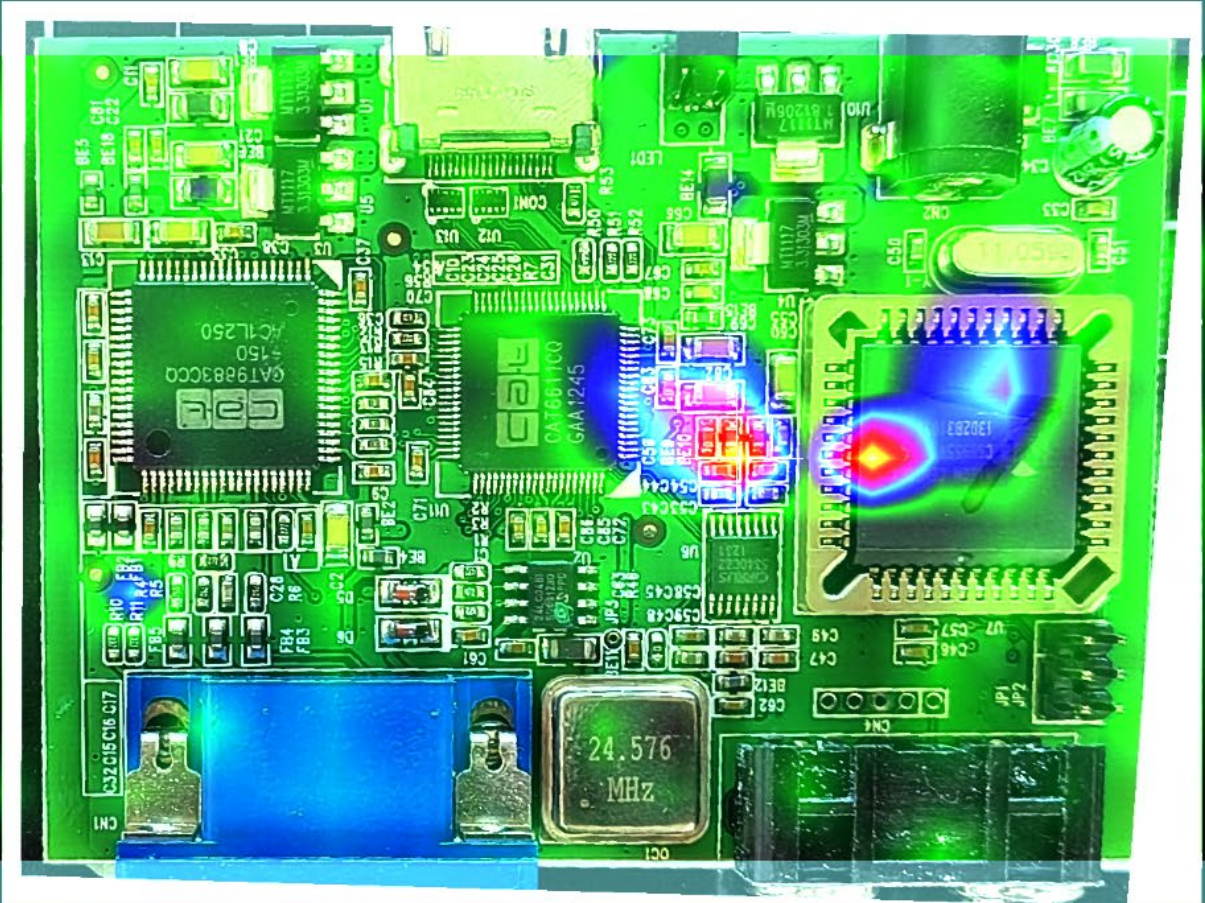


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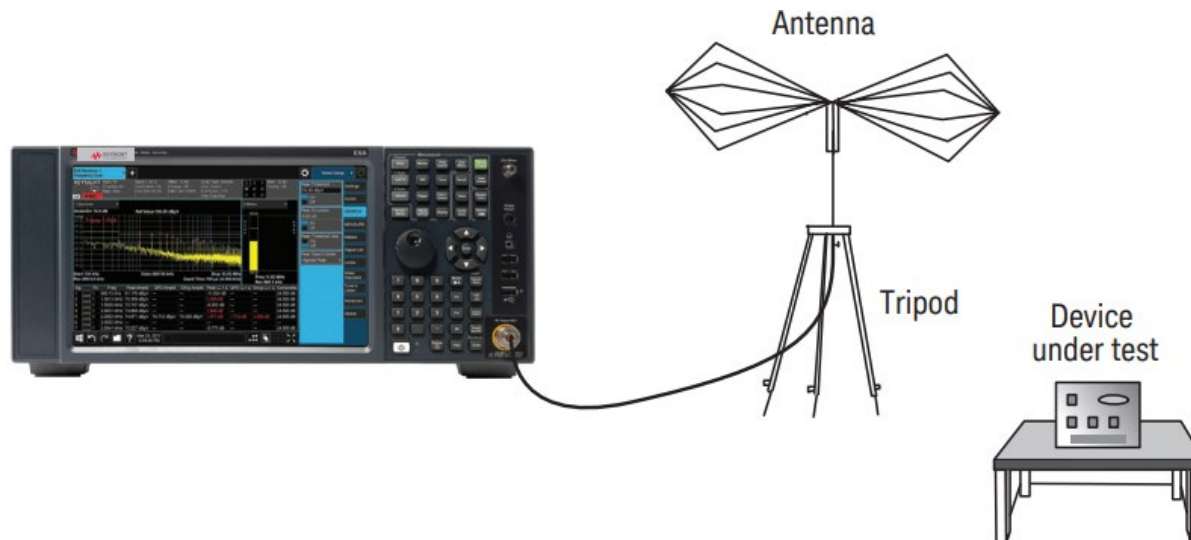
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Recommended Measurement Procedure

1) Measurement preparation - setting up the measurement site

- Measurement receiver, antenna cable, antenna stand, (preamplifier), antenna, DUT; proper arrangement of all components
 - Pre-compliance measurements are typically done outdoors (preferably) or inside larger rooms
 - The floor should be covered by conductive surface (between the antenna and DUT)
 - The standard measurement distance is usually 10 m
 - During pre-compliance tests, the measurement distance may be reduced to as little as 3 m (to increase the signal-to-noise ratio of the measured signals relative to ambient signals)



Recommended Measurement Procedure

2) Measurement preparation – configuring the measuring receiver

- The procedure for this step will vary depending on the instrument used
 - For instruments with a special mode for EMI measurements, configuration can be significantly simplified
- Setting the frequency range, IF filters for individual bands, frequency step, measurement time and detectors for individual measurement phases
- Setting the input attenuation (often 0 dB) and the internal preamplifier
- Selecting the limit curve according to the applicable standard
 - Limits are always defined for measurements at a specific distance; when changing the measurement distance, the limit curve must be shifted by $-20 \cdot \log(d_{\text{new}} / d_{\text{original}})$
 - Most instruments allow the whole curve to be shifted even without direct editing
 - On some instruments, it is also possible to select a specific “guard band” below the limit curve, which serves as a margin for measurement uncertainties
- Selection of the appropriate frequency responses of the antenna factor for the antenna in use and other correction curves (cable, amplifier, adapters, etc.)

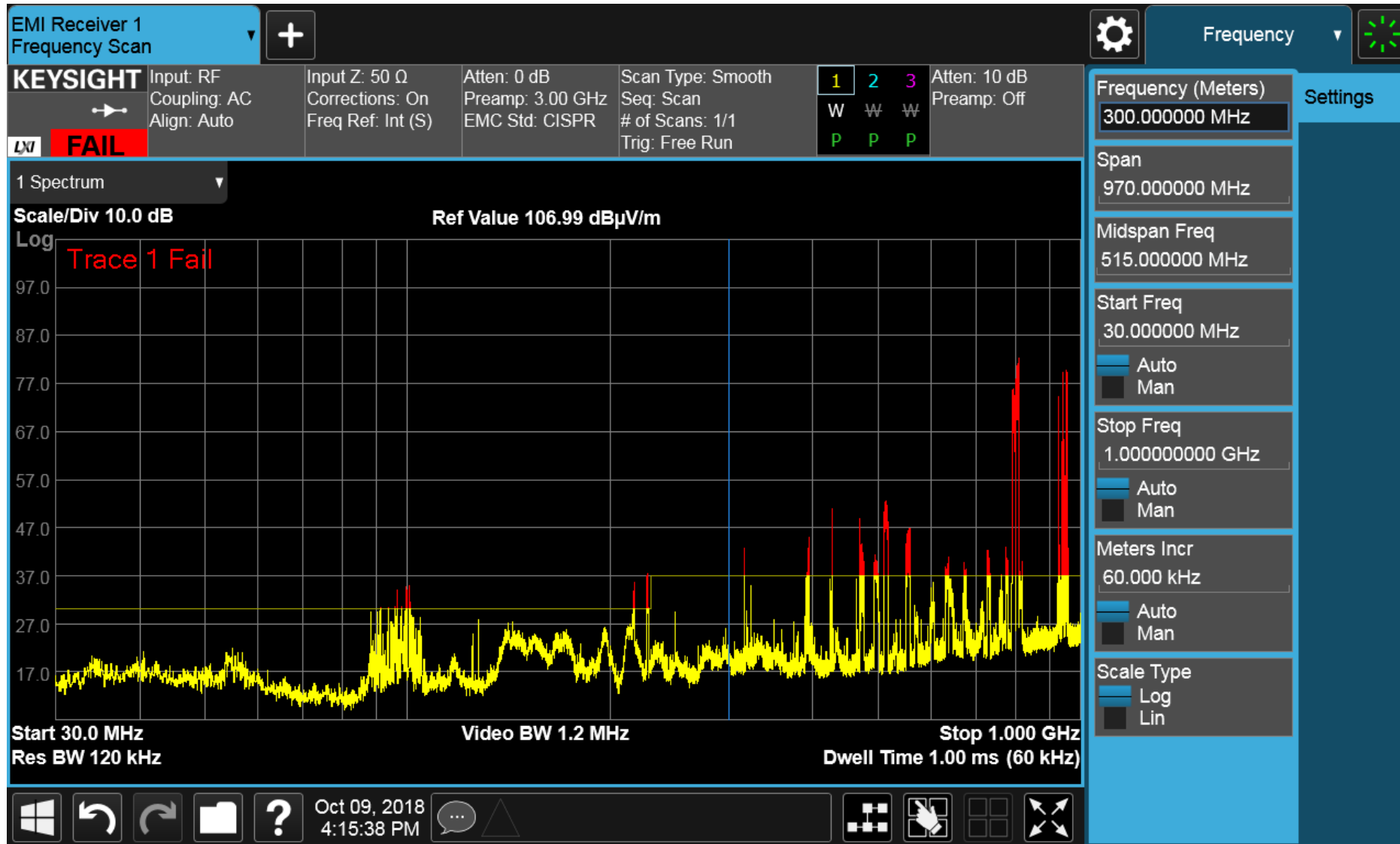
Recommended measurement procedure

3) Measurement - Identifying ambient interference signals

- The surrounding “ambient” radio spectrum in heavily congested
 - it may be hard to distinguish signals emitted by the DUT when measuring outside a chamber
- Before measuring the DUT itself, it is necessary to perform an initial quick scan (or several) with the PK detector while the DUT is turned off
 - “max hold” function and multiple sweeps can be used to capture the entire interference spectrum
- On most instruments with an EMI mode, it is possible to save a table of spectral peaks exceeding the limit and use it during subsequent measurements with the DUT to distinguish new signals
- The potential reduction in measurement distance (e.g., from 10 m to 3 m) may be used to increase the signal-to-noise ratio between signals originating from the DUT and those from the surrounding environment

Recommended Measurement Procedure

- Example of a measurement of ambient interference signals:



Recommended Measurement Procedure

4) Measurement with the DUT

- The built-in EMI application typically offers three basic functions:
 - “SCAN” – a quick measurement across the selected frequency band using Peak detector
 - “SEARCH” – search for signals exceeding the selected limit line
 - “MEASURE” – final measurement of signals present in the signal list using the EMI detectors (Quasi-peak and/or EMI Average)
- Measurement procedure:
 - a) “SCAN” + “SEARCH” with the DUT turned off
 - Identification of signals from the surrounding environment; saving the table for future use
 - b) “SCAN” + “SEARCH” with the DUT powered on and oriented in the first position
 - All signals exceeding the threshold found in this step are again added to the signal table (interference signals from the surrounding environment + any new ones from the DUT)

Recommended Measurement Procedure

- c) Use the duplicate marking function and delete the marked signals
 - This function automatically detects and marks signals that appear multiple times in the signal table (i.e., signals from the surrounding environment)
 - Ideally, this would eliminate all signals not originating from the DUT
- d) Check the list of remaining signals with levels exceeding the threshold and, if necessary, exclude those that were not automatically marked in the previous step
 - Possible methods for identifying the origin of signals:
 - Turning the DUT off and on again (if practical)
 - Rotating the DUT or placing a conductive surface in front of the DUT
 - If there is no significant change in the signal level, it likely originates from another source and can be removed from the list
 - Use of the “tune and listen” function - allows for easy identification of AM and FM radio station signals
 - The two-antenna method - using a second identical antenna oriented in the same direction and placed at a larger distance
 - If the signal level at a given frequency doesn’t change much when switching the antennas, the signal is likely from the external environment and can be excluded

Recommended Measurement Procedure

- e) Detailed final measurement of signals likely originating from the DUT
- This measurement is performed using detectors specified in the standard (QP, AV)
 - The EMI detectors require a longer measurement time to obtain accurate data (even several seconds) - the entire measurement takes longer, and it is desirable to perform it at as few frequencies as possible
 - For pulse signals, QP and AV detectors indicate a lower level than the PK detector
 - An over-limit result from the initial scan with a PK detector can be fine with the QP or AV detectors
 - The final output is a table of signals filled with the results for all relevant detectors

Sig		Trc	Freq	Peak Amptd	Neg Amptd	EAvg Amptd	Peak LL1 Δ	Neg LL1 Δ	EAvg LL1 Δ	Comp
1		1	166.56 MHz	47.254 dBμV/m	-17.459 dBμV/m	34.233 dBμV/m	4.254 dB	-60.459 dB	-8.767 dB	9.52
2	✓	1	168.25 MHz	58.436 dBμV/m	33.822 dBμV/m	51.041 dBμV/m	15.436 dB	-9.178 dB	8.041 dB	9.61
3		1	174.74 MHz	50.262 dBμV/m	32.155 dBμV/m	46.153 dBμV/m	7.262 dB	-10.845 dB	3.153 dB	9.79
4	✓	1	184.27 MHz	56.806 dBμV/m	30.041 dBμV/m	49.467 dBμV/m	13.806 dB	-12.959 dB	6.467 dB	10.0
5		1	200.24 MHz	46.149 dBμV/m	-11.364 dBμV/m	35.694 dBμV/m	3.149 dB	-54.364 dB	-7.306 dB	10.5
6		1	205.69 MHz	44.328 dBμV/m	-14.445 dBμV/m	32.736 dBμV/m	1.328 dB	-57.445 dB	-10.264 dB	10.7
7		1	216.01 MHz	45.770 dBμV/m	-15.055 dBμV/m	34.775 dBμV/m	2.770 dB	-58.055 dB	-8.225 dB	11.2

Recommended Measurement Procedure

- f) Clear the signal table, reload the saved signals from the external environment, change the orientation of the DUT, and repeat steps b) through e)
 - Another set of problematic frequencies
 - This step should be repeated for different DUT positions and, if applicable, for horizontal and vertical polarization of the measuring antenna
- g) If all sets of results obtained with the same antenna orientation contain a signal with an almost identical level, it may be an overlooked signal from an external source unrelated to the DUT

Troubleshooting

- Identification of interference sources at problematic frequencies using near-field probes
- Searching for problematic areas on printed circuit boards:
 - The source of the radiation can be roughly identified in advance based on the frequency
 - E-field probes are effective in areas of transient voltage changes
 - Circuit sections with higher impedance; short traces near integrated circuits, ...
 - Unlike H-field probes, they are not very sensitive to orientation
 - H-field probes respond to time-varying currents
 - Areas with lower impedance, with higher currents
 - Relatively sensitive to the orientation of the loop - can be used to determine the direction of the current flow
 - At higher frequencies, lines with defined and generally lower impedance are used, and flowing currents are the dominant source of radiation
 - → Magnetic probes are generally more useful for troubleshooting EMI issues

Troubleshooting

- For enclosed devices, it makes sense to search, for example, in areas around enclosure joints, various bushings (shafts, etc.), or protruding cables
- Measurement results obtained using near-field probes cannot be extrapolated to far-field measurements
- When measuring with near-field probes, it is recommended to use the classic spectrum analyzer mode - rapid sweeping across a wide frequency range



Troubleshooting

- Eliminating sources of excessive radiation is an iterative process
 - Once problematic areas are identified, the equipment must be modified
 - Modifying printed circuit boards, replacing components, modifying or adding shielding
 - After the modifications are complete, new measurements must be performed
 - In the initial phase, repeated measurements using near-field probes may be sufficient
 - To get relevant results, the configuration must be as close as possible to the original measurement
 - The probe should be placed as close as possible to the PCB (direct touch if practical) and oriented the same way during the reference and repeat measurements (alternatively, you can rotate the probe and use the “max hold” function on the spectrum analyzer)
 - These results are always relative - difference in dB between the state before and after modification
 - If the location is the only source of interference at a specific frequency, the same relative change should also be observed during far-field measurements

Measurement Example

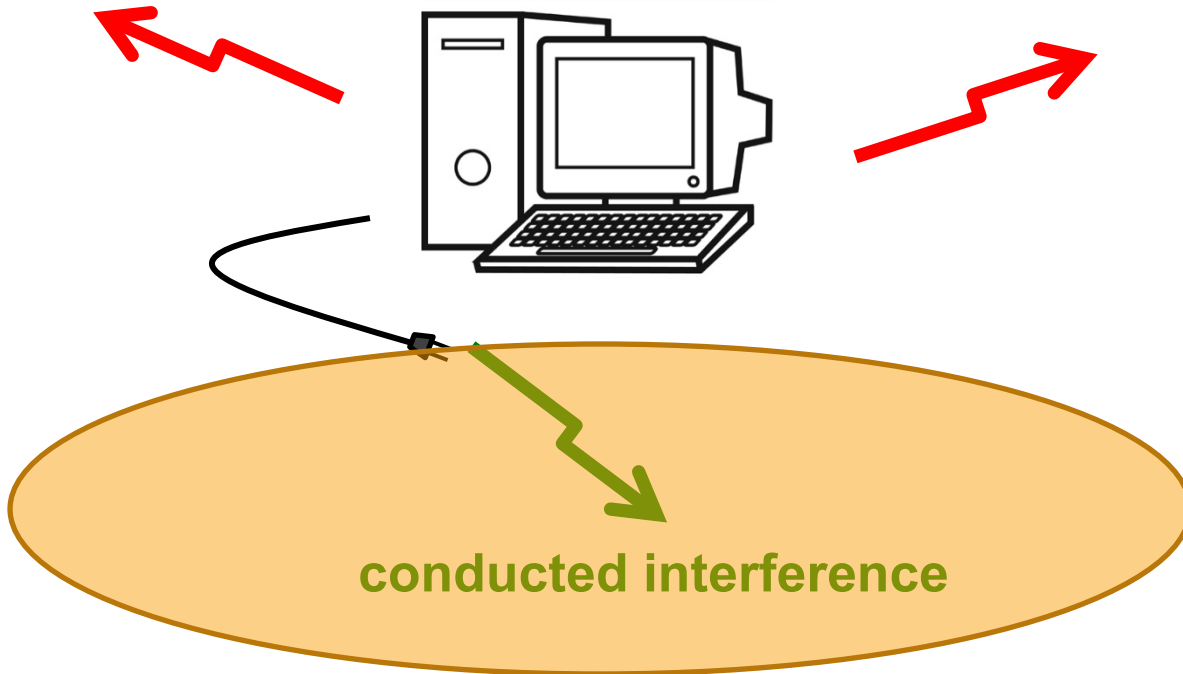
EMC

EMI
(Electromagnetic Interference)

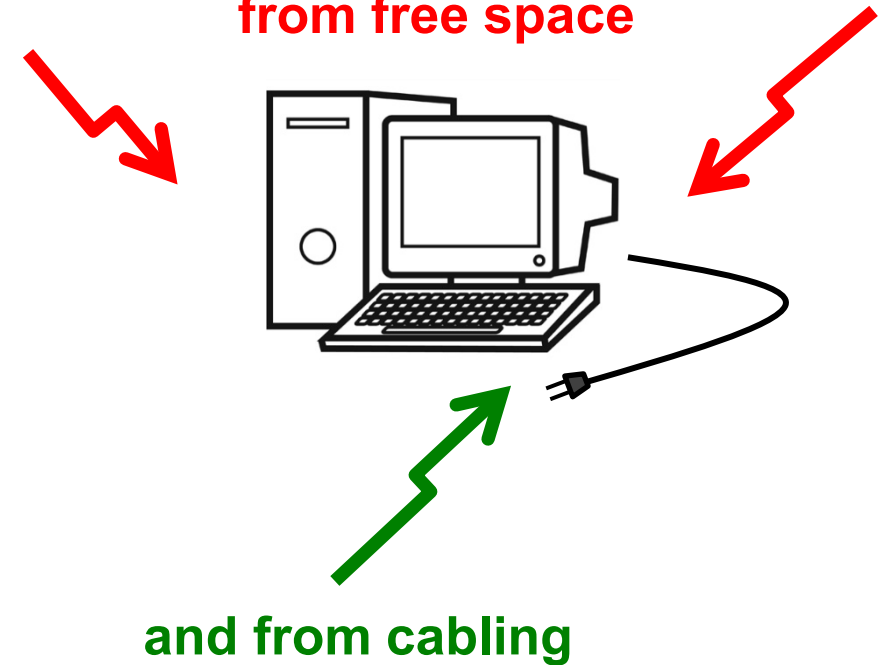


EMS
(Electromagnetic Susceptibility)

radiated interference
in free space



interference received
from free space



Conducted interference

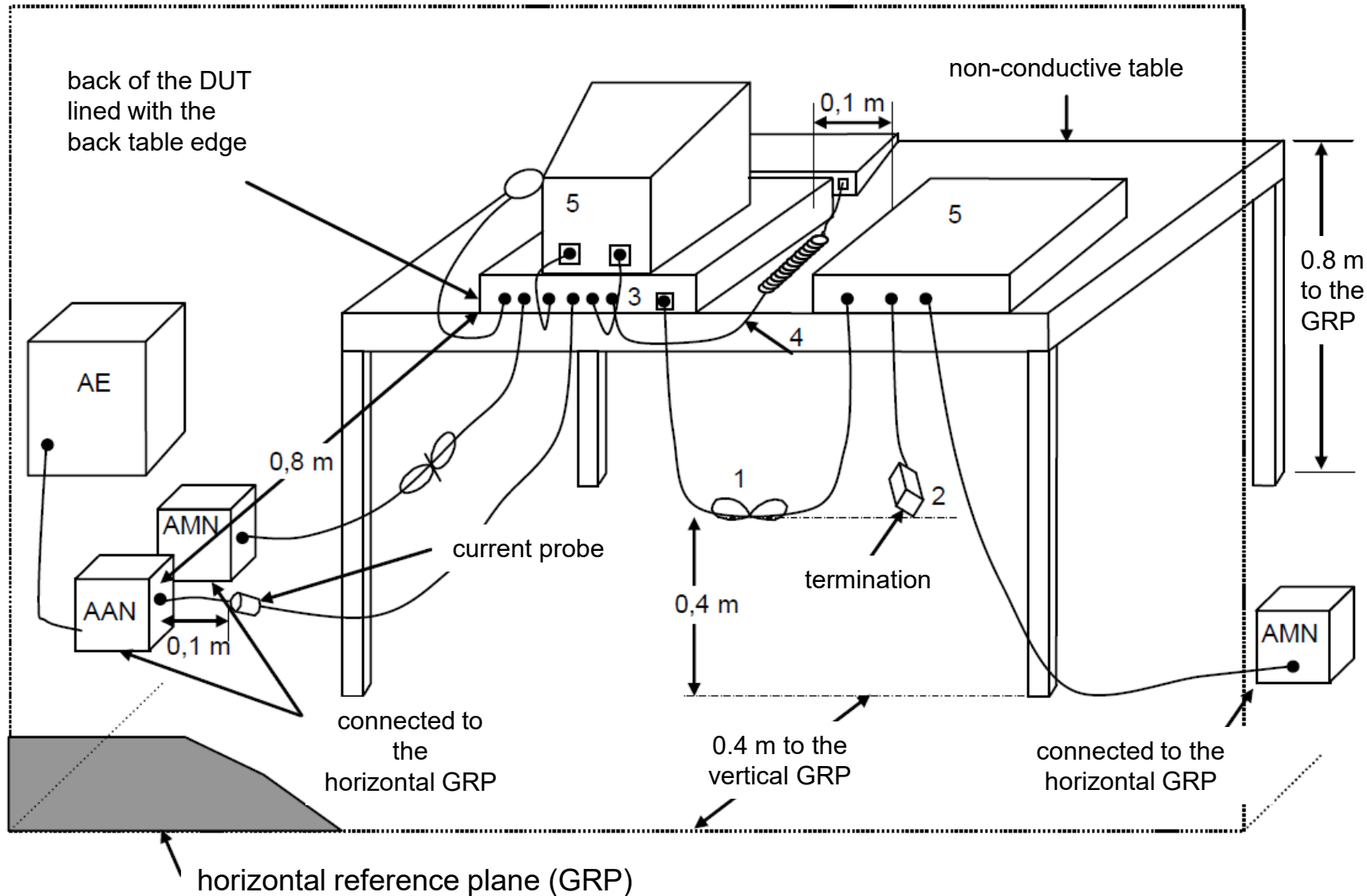
- In this case, we measure the voltage, current, or power of interference signals which are propagated from the DUT via the power supply line
- As with the radiated emissions, it is always necessary to determine the exact testing requirements for the DUT from the applicable standards
- Measurements are typically performed in the frequency range from 150 kHz to 30 MHz
 - Some standards require a wider frequency range (from 9 kHz and/or above 30 MHz)
- Measurements of conducted emissions are generally simpler and more repeatable (in most cases)
 - a pre-compliance test setup can meet the requirements of the standards very closely while still maintaining a reasonable price
- **During measurements, the DUT is connected to a live power supply**
 - which is potentially hazardous; extra caution is required during measurements; only trained personnel should have access to the measuring equipment

Conducted interference

- Equipment used:
 - 1) Test setup in accordance with standard requirements
 - Horizontal and vertical conductive reference planes (GRP – ground reference plane)
 - Non-conductive (wooden) table, 80 cm high
 - 2) measuring receiver in accordance with the EN 55016-1-1 standard
 - Same as for radiated interference
 - Special EMC filters and detectors (QPK, PK, AVG)
 - Sufficient dynamic range
 - 3) Coupling/decoupling devices
 - Used to couple the interference signals from the DUT to the measuring receiver
 - 4) Additional optional accessories
 - Isolation transformer, “transient limiter,” ...
 - Shielded room or tent

Test site layout

- Typical measurement setup:

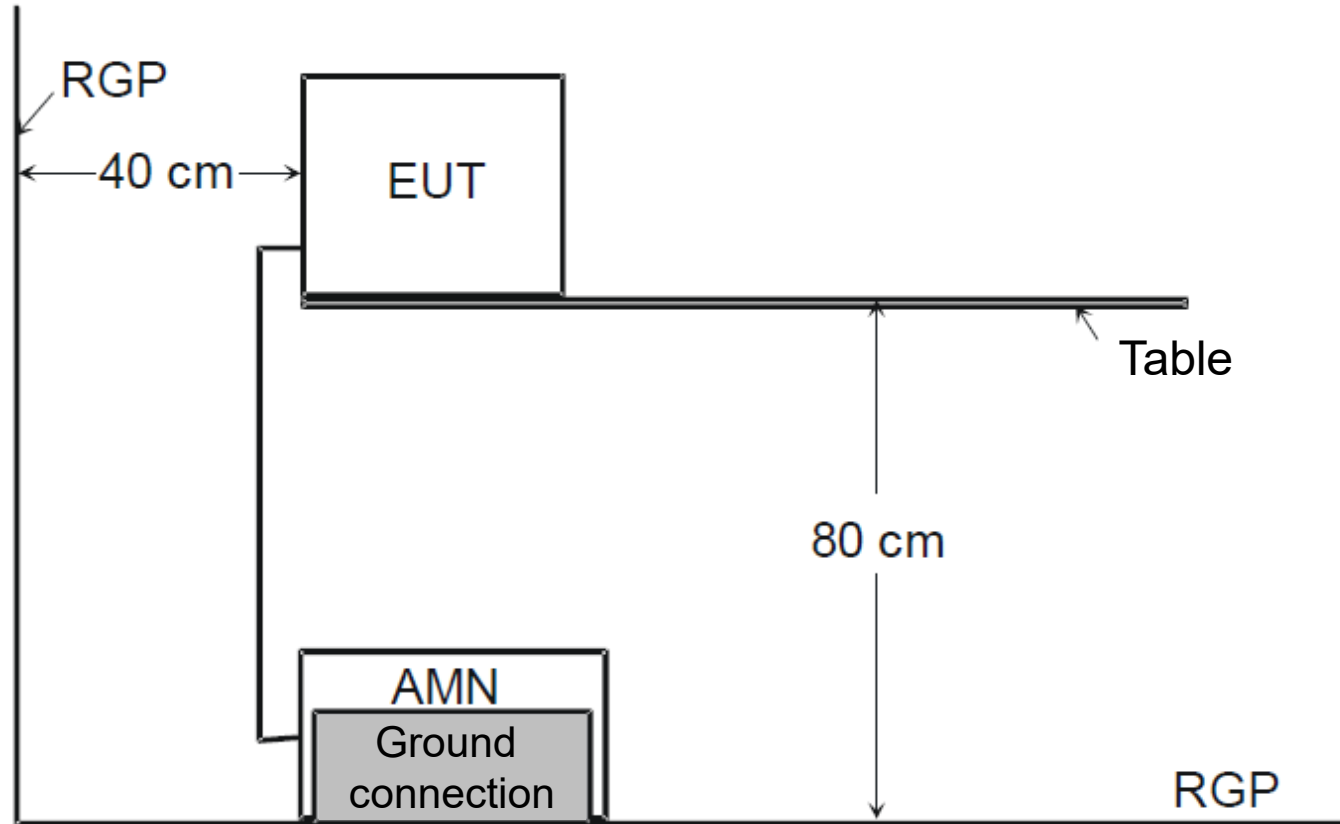


Interference transmitted via the power cord

- Explanation of abbreviations used:
 - AMN – artificial mains network
 - V-type artificial network; LISN
 - simulation of power supply network impedance; coupling of unbalanced voltages
 - used on AC and DC power lines
 - AAN – asymmetric artificial network
 - coupling of asymmetric (common-mode) voltages on symmetric (balanced) signal lines
 - AE – associated equipment
 - equipment required for the operation of the EUT
 - is not part of the system under test
 - RGP – reference ground plane
 - flat conductive surface serving as a common reference for measurements
 - creates defined parasitic capacitances in the vicinity of the EUT

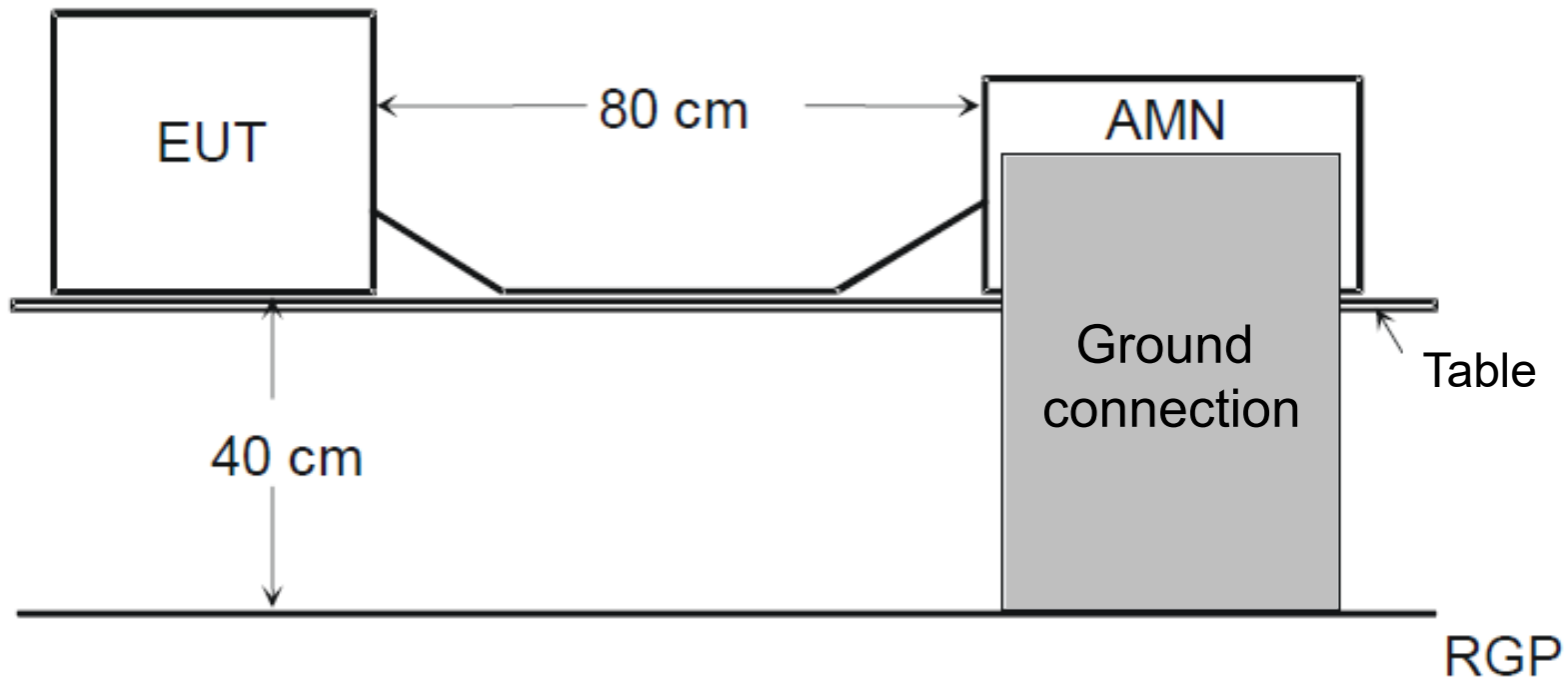
Test site layout

- Typical (optimal) test site layout for benchtop equipment (side view):



Test site layout

- Alternative test setup for benchtop equipment (side view):



Test setup

- If the DUT consists of multiple interconnected components (e.g., keyboard, mouse, etc.), everything should be arranged as it would be during normal use
- The rear of the DUT lined with the edge of the table, 0.4 m from the vertical RGP
- The AMN placed on a horizontal RGP 0.8 m from the DUT and 0.4 m from the vertical RGP
- The AMN must be electrically connected to the RGP via a low-inductance conductor with an impedance of less than $10\ \Omega$ at a frequency of 30 MHz
 - A direct connection between the AMN housing and the RGP (if the AMN is on the ground plane)
 - Otherwise, a flat conductive strip with a length-to-width ratio of less than 3 should be used
- The power supply cable to the DUT should be 1 m long
- Any interconnecting cables hanging over the edge of the table closer than 40 cm from the horizontal RGP must be folded so they keep this minimum distance

Coupling devices

- Non-invasive coupling devices:
(don't require interruption of the measured power or communication lines)
 - 1) Near-field probes
 - Approximate measurements near cables; inexpensive and easy to make “at home”
 - 2) Current probes
 - Current transformers that can be wrapped around a conductor or bundle of conductors
 - Can be calibrated, allowing for relatively accurate measurements
 - Some standards use these probes as supplementary coupling devices
 - 3) Voltage probes
 - Contact voltage probes with capacitive coupling for measuring disturbance voltage, for example, at power supply terminals (when a LISN can't be used)
 - 4) Absorption clamps
 - These are essentially a combination of a current probe and impedance stabilization in the form of a series of ferrite rings which progressively absorb RF energy
 - Most effective at higher frequencies (above 30 MHz)

Coupling devices

- Current probe:



Coupling devices

- Voltage probe:



Coupling devices

- Absorption clamps:



Artificial networks

- Artificial network (LISN – Line Impedance Stabilization Network / AMN – Artificial Mains Network)
 - Invasive coupling device - requires interruption of the measured line
 - Measurements are performed under precisely defined impedance conditions
 - Major advantage over non-invasive methods, which only measure voltage or current but do not provide repeatable well defined impedance for the DUT (when “looking” into the power grid)
 - Much more accurate and repeatable results

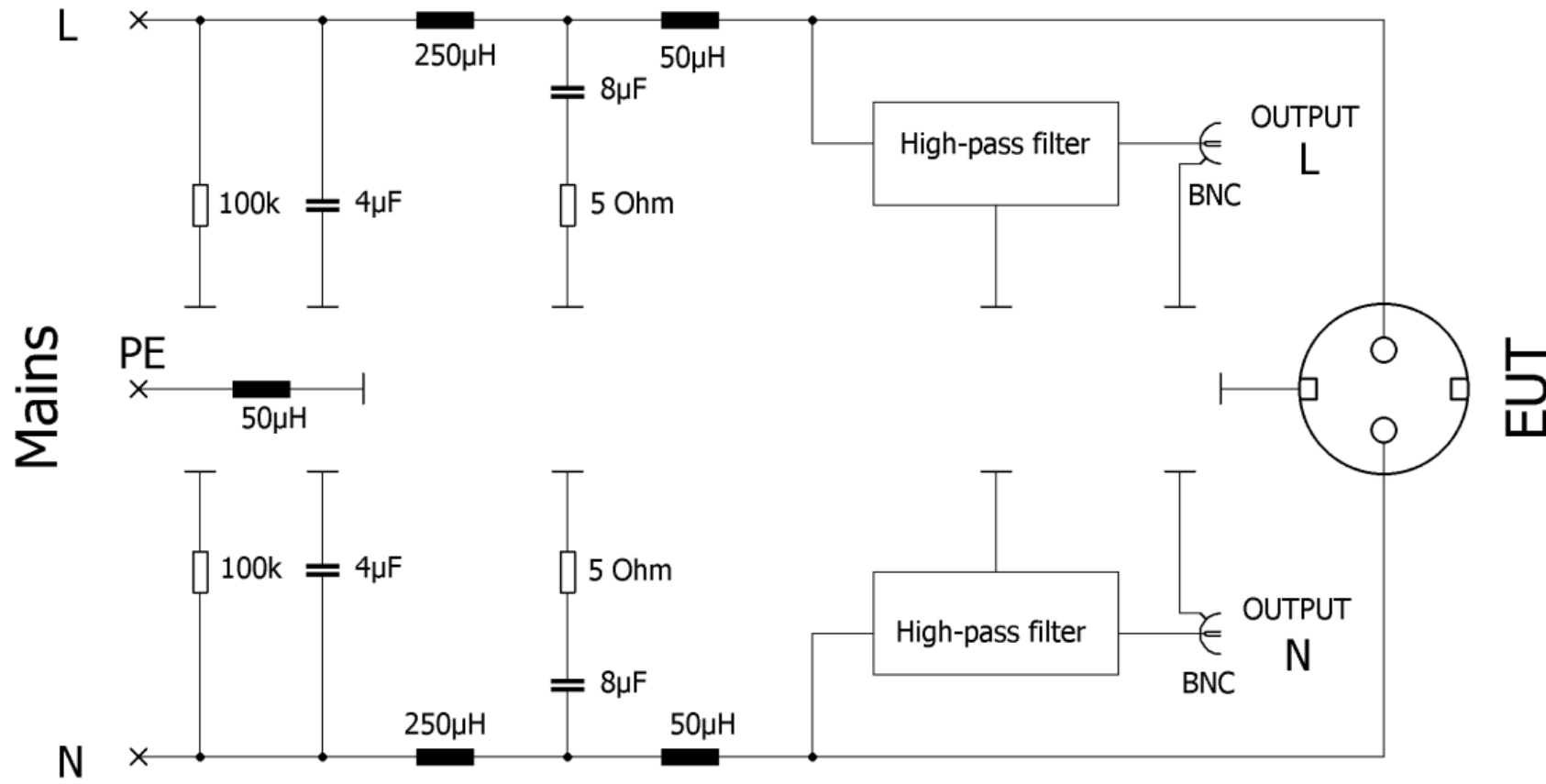


Artificial networks

- An artificial network performs three basic functions:
 - a) Acting as a low-pass filter between the actual power supply network and the DUT
 - It filters out high-frequency components of the signal from the power grid that could affect the measurement (by being mistaken for signals from the DUT)
 - Blocks interference generated in the DUT - protecting other devices
 - b) Routes the RF signals from the DUT to the measuring receiver (coaxial connector on the LISN)
 - c) From the DUT's perspective, it provides a defined frequency response of the output impedance
 - The DUT operates under clearly defined conditions—measurements are repeatable
- Artificial networks are the preferred coupling device probably in all major standards (in the 9 kHz to 30 MHz band)
- Various types - single-phase or multi-phase; rated for different currents, remote control, ...

Artificial networks

- Circuit diagram of a single-phase V-type $50\ \Omega \parallel (50\ \mu\text{H} + 5\ \Omega)$ AMN:



Artificial networks

- When performing measurements with artificial networks, it is always necessary to pay close attention to safety
 - By design, artificial networks exhibit high leakage currents in the order of hundreds of mA (large capacitances in parallel with the grid network input)
 - It is necessary to ensure sufficient (double) grounding during operation
 - To the PE conductor of the grid input and to the reference ground plane of the measurement setup
 - Additional grounding must always be connected first, before connecting the power supply, and disconnected only after the power supply has been disconnected
 - The grounding must be rated to carry short-circuit current
 - Artificial networks should be equipped with safety warnings
 - The power distribution system cannot be equipped with a standard residual current device (RCD)
 - If the residual current device cannot be disconnected, an isolation transformer or AC power supply must be used

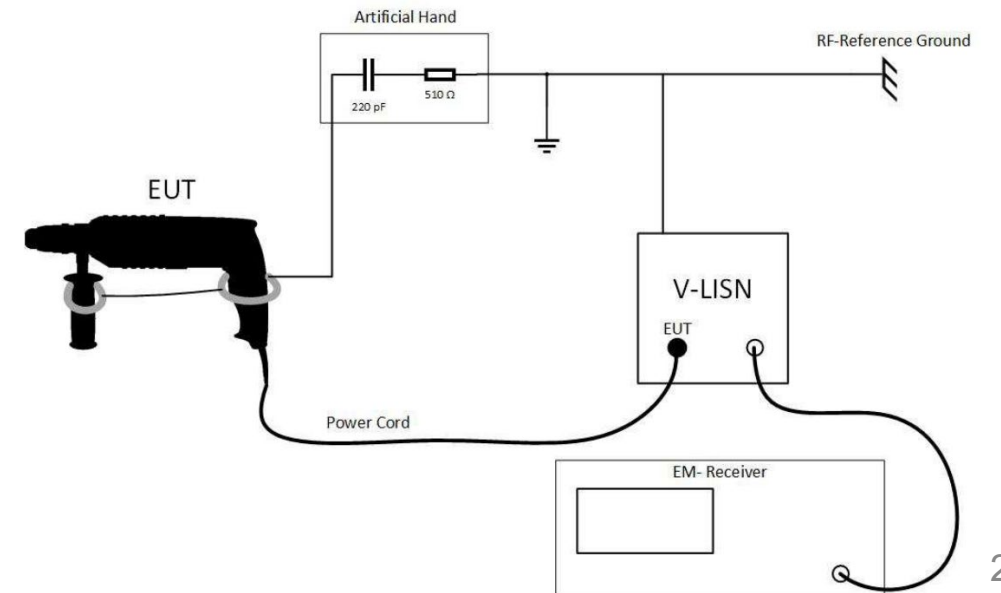
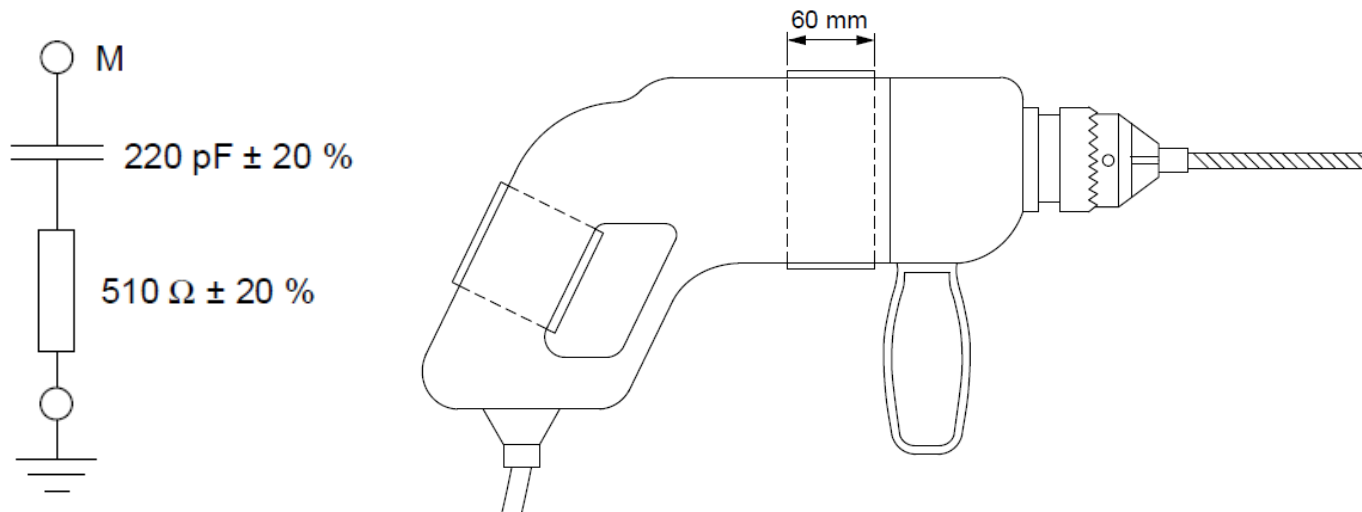
Artificial networks

- Example of safety warnings with recommended procedures:



Artificial networks – Artificial Hand

- Most of the AMNs are equipped with an “artificial hand” circuit and a terminal for connecting to the DUT
 - The artificial hand is designed to simulate a human operator’s touch when testing relevant devices (power tools, household appliances, keyboards, etc.)
 - Touch can have a significant effect on the level of interference radiated from the DUT via the power supply line, especially at higher frequencies (~5 MHz – 30 MHz)
 - The way how to use the artificial hand is specified by the relevant product standards
 - The artificial hand circuit consists of an RC circuit (inside the AMN) and a metal foil that is applied to the DUT in a defined manner



Conducted interference

- Transient limiter (pulse limiter)
 - Typically a diode voltage limiter combined with an attenuator
 - Can be used to protect the input of the EMI receiver from high-voltage pulses generated in the DUT (for example when it is switched on or off)
 - The use of a limiter is strongly recommended (relatively cheap device which can save a very expensive measuring receiver)



Conducted interference

- Shielded chambers or tents
 - Shielded enclosures can be used in cases where the measurement is affected by signals from the surrounding environment
 - A shielded room or smaller enclosure can be built relatively inexpensively; a shielded tent made of conductive fabric is highly portable and can be set up repeatedly only when measurements are needed



Recommended Measurement Procedure

1) Measurement preparation - setting up the measurement site

- Measuring receiver, LISN, pulse limiter, cables, reference ground planes, wooden table, DUT; proper arrangement of all components
 - Measurement site layout as previously mentioned; always necessary to check the relevant standards and adhere to the correct procedures and recommendations
 - Thorough secondary grounding of the LISN!
 - ideally directly to the horizontal RGP, if the LISN has a metal housing
 - otherwise, using the shortest possible low-inductance conductor - a metal strip
 - Connecting the LISN to the power grid, the DUT to the LISN, and turning on the measuring receiver

Recommended Measurement Procedure

2) Measurement preparation - configuring the measuring receiver

- Similar to the procedure for radiated emissions measurements
- Setting (selecting) the frequency range, IF filters for individual bands, frequency step, measurement time, and detectors for individual measurement phases
 - measurements are most commonly done in Band B (150 kHz – 30 MHz), or in Band A (9 kHz – 150 kHz) + B
- Setting the input attenuation and, if necessary, the internal preamplifier
- Selecting the limit curve according to the applicable standard
 - Voltage limits specified in dB μ V
- Selection of correction factors for LISN and other components of the measurement chain (cable, adapters, transient limiter, etc.)

Recommended Measurement Procedure

3) Measurement - identifying signals not originating from the DUT

- Initial measurement with the DUT turned off
 - Search for external signals that may somehow enter the measurement setup
 - Ambient signals not originating from the DUT are generally much less problematic in this case compared to measuring radiated emissions using an antenna
- Perform a quick scan of the entire measured PK band with the detector, ideally multiple times using the max hold function
 - Multiple measurements for individual phase conductors (N , L_1 , L_2 , L_3)
- Save the results for later use (if any signals were found)

Recommended Measurement Procedure

4) Measurements with the DUT (example procedure for Keysight instruments)

- Usually much simpler than measuring radiated interference
 - If no external signals were found during the measurement with the DUT switched off, there is no need to search for and delete duplicates in the signal table
- Measurement procedure:
 - a) “SCAN” + “SEARCH” with the DUT powered on and the first conductor selected
 - All detected signals exceeding the limit are added to the table
 - b) Detailed final measurement of signal levels originating from the DUT
 - Measurements using detectors specified in the relevant standard (QP, AV)
 - The output is again a table of signals containing data from all relevant detectors
 - c) Clear the signal table, switch the currently measured conductor to LISN, and repeat steps a) and b)



What we can offer

1) Keysight Technologies

- signal analyzers, EMI compliance receivers, RF accessories



2) Rigol

- affordable signal analyzers with EMI receiver functionality



3) UNI-T

- Affordable signal analyzers with EMI receiver functionality



4) GW Instek

- Affordable LISN





What We Offer

5) Langer EMV-Technik

- EMC testing equipment (EMI and EMS), consulting
- interference generators, near field probes, accessories, ...



6) ETS-Lindgren

- wide range of high-quality equipment for EMC testing (EMI and EMS)
- antennas, amplifiers, chambers, all accessories



7) Schwarzbeck Mess-Elektronik

- EMI receivers, antennas, artificial networks, various probes, wide range of accessories



8) Pendulum

- Detectus EMC scanners

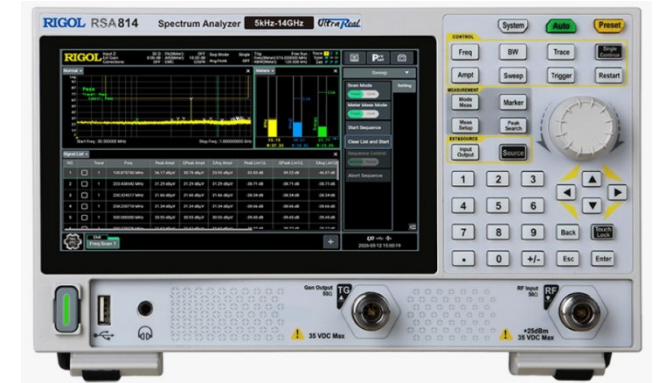


Pre-compliance test setup

- Example of a measurement setup:

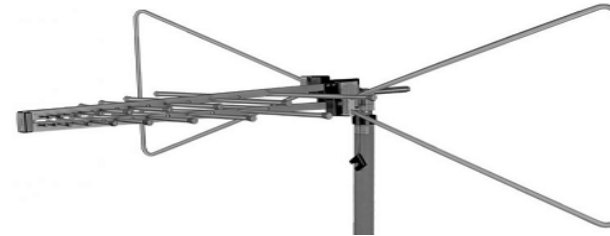
1) Signal analyzer **Rigol RSA3015N** or **Rigol RSA804**

- Frequency range 9 kHz to 1.5 GHz (or 4.5 GHz)
- Preamplifier
- Integrated application for EMI measurements



2) **Schwarzbeck VULB 9168** antenna

- Broadband “BiLog” antenna
- Frequency range from 25 to 2000 MHz
- Suitable tripod or mast capable of supporting this antenna



3) **Langer EMV-Technik** near-field probe set

- Probe sets for various applications
- Includes a coaxial connection cable



Pre-compliance test setup

4) GW Instek GLN-5040A artificial network

- Single-phase V-type artificial network ($50\ \Omega \parallel (50\ \mu\text{H} + 5\ \Omega)$)
- Built-in transient limiter and 10 dB attenuator
- Continuous current up to 16 A



Compliance test setup

- Example of a measurement setup:

- 1) Semi-anechoic chamber (SAC)

- Measurements free of the influence of external signals
- Various chamber sizes according to customer needs
- Turntable for automated DUT rotation

- 2) Keysight N9038B MXE and N9048B PXE EMI receivers

- frequency range 3 Hz to 44 GHz (various models)
- Full-featured EMI receiver compliant with standard 55016-1-1

- 3) Schwarzbeck VULB 9168 antenna

- Broadband “BiLog” antenna
- Frequency range from 25 to 2000 MHz
- Antenna mast capable of automated height and polarization adjustment



Certification test setup

4) Langer EMV-Technik near-field probe set

- Probe sets for various applications
- Including a connecting coaxial cable

5) Schwarzbeck NSLK 8126 artificial network

- Three-phase V-type artificial network ($50\ \Omega \parallel (50\ \mu\text{H} + 5\ \Omega)$)
- Continuous current up to 16 A per phase



EMC

EMI

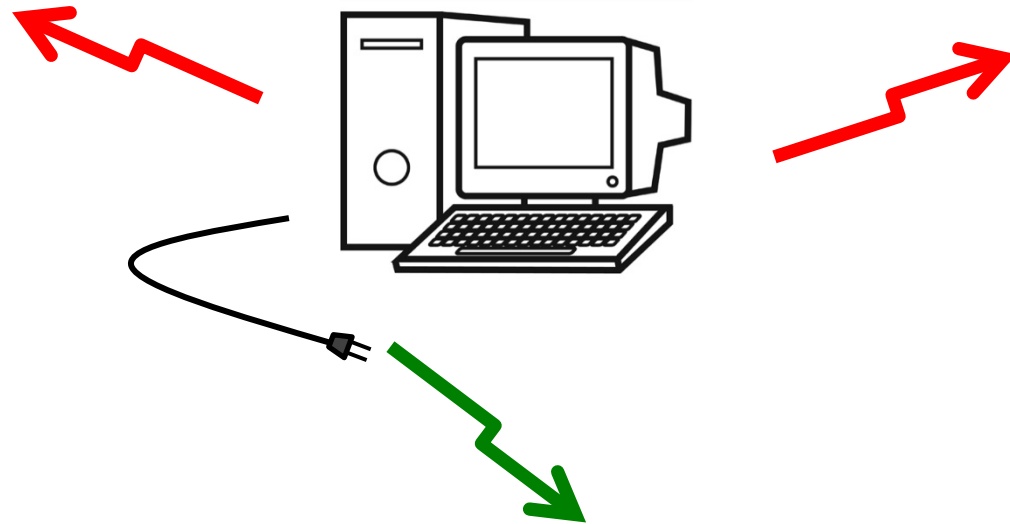
(Electromagnetic Interference)



EMS

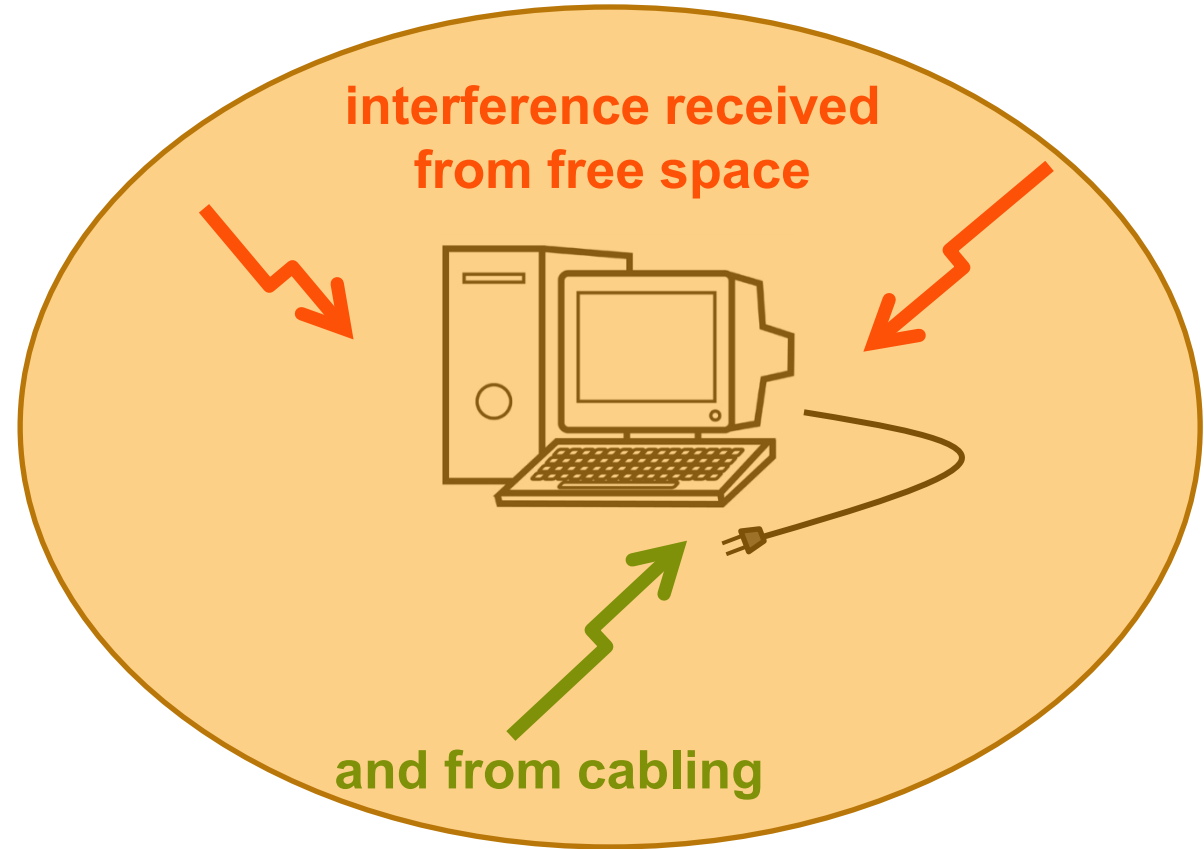
(Electromagnetic Susceptibility)

radiated interference
in free space



conducted interference

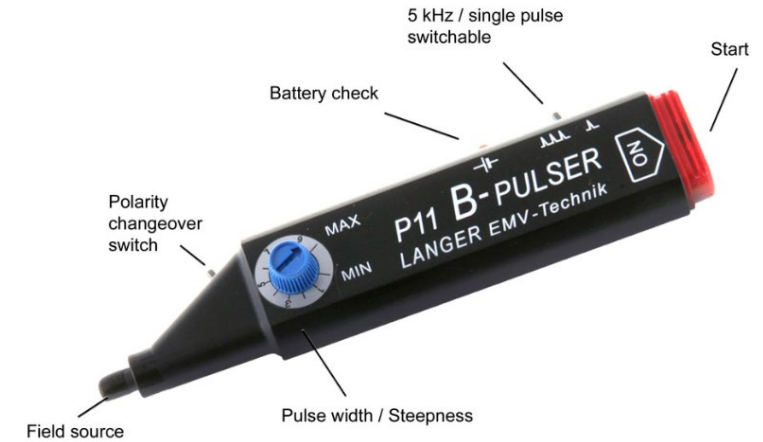
interference received
from free space



and from cabling

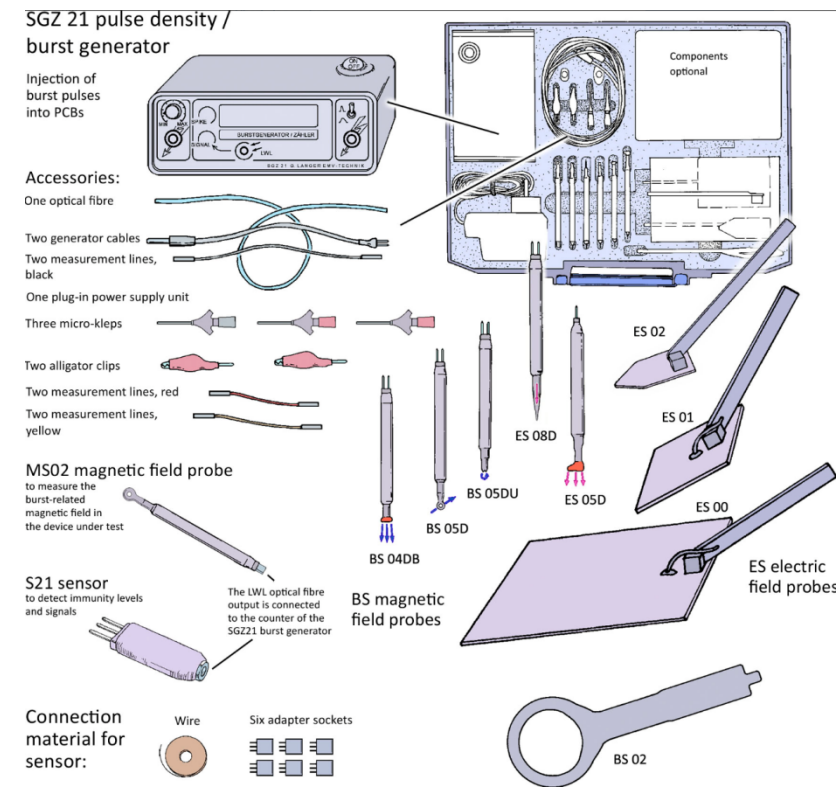
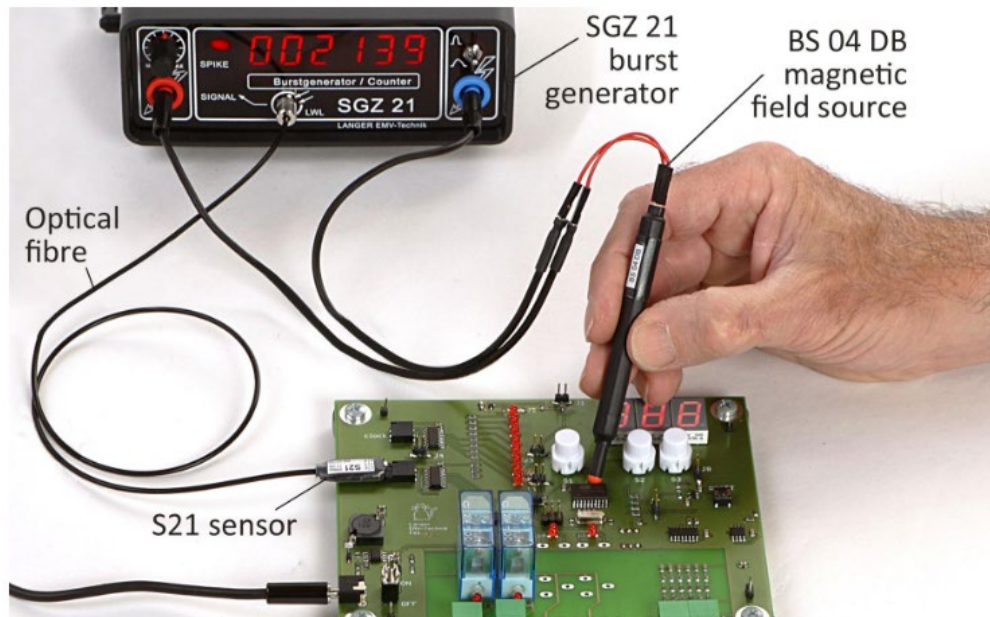
Basic pre-compliance immunity testing

- Langer EMV “Mini Burst” generators
 - Ideal for testing on PCBs for resistance against ESD and EFT (“burst”) electric and magnetic fields
 - Can be used to quickly identify “weak points” in the circuit design
 - Non-contact generators of both electric and magnetic field and one model with needle contact for direct connection



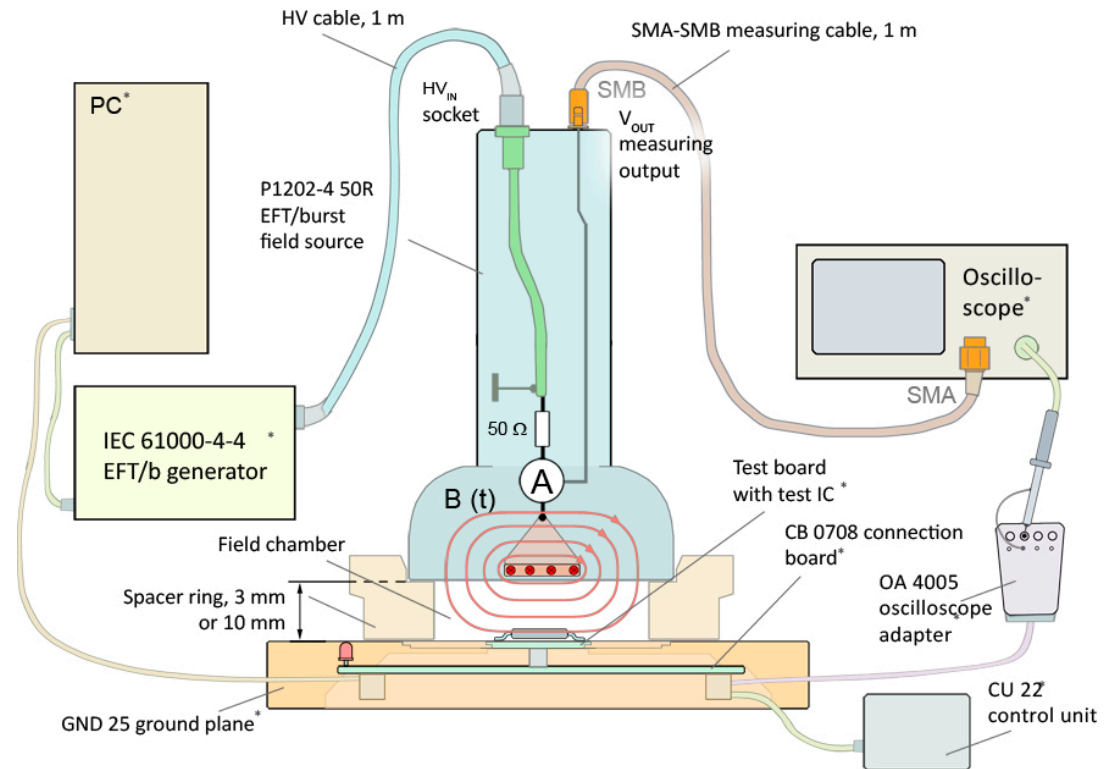
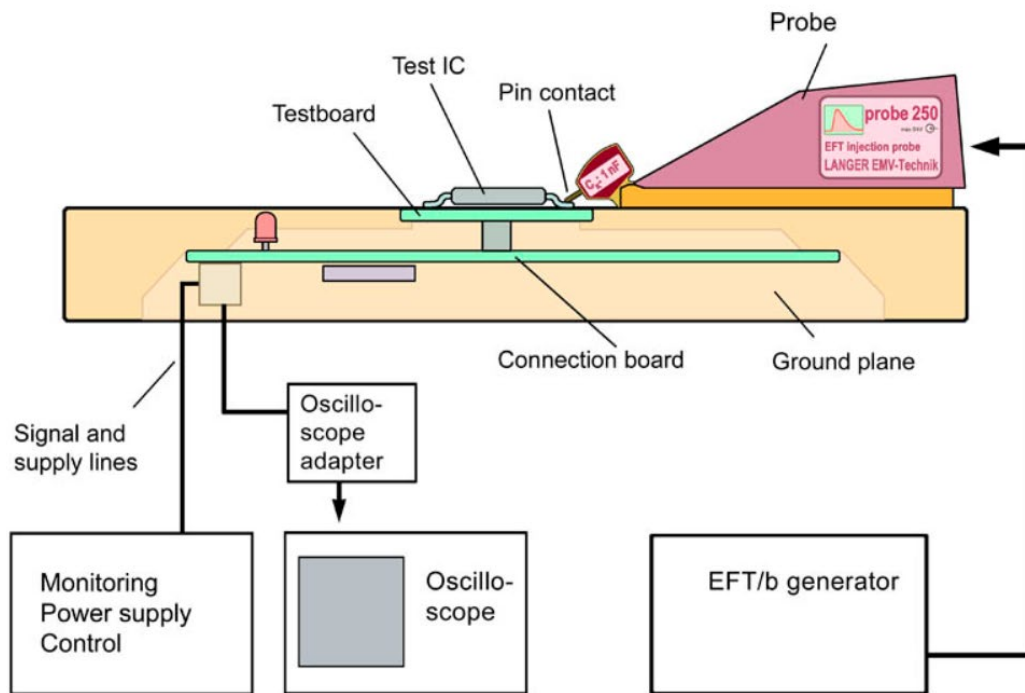
Basic pre-compliance immunity testing

- Langer EMV “Immunity Development System”
 - A kit designed for advanced pre-compliance testing of immunity to interference and for identifying problematic areas in designed circuits
 - Fast pulse generator
 - Set of electric and magnetic field probes (various variants)
 - Optically isolated probe for monitoring of a selected power or communication line on the test board during the test



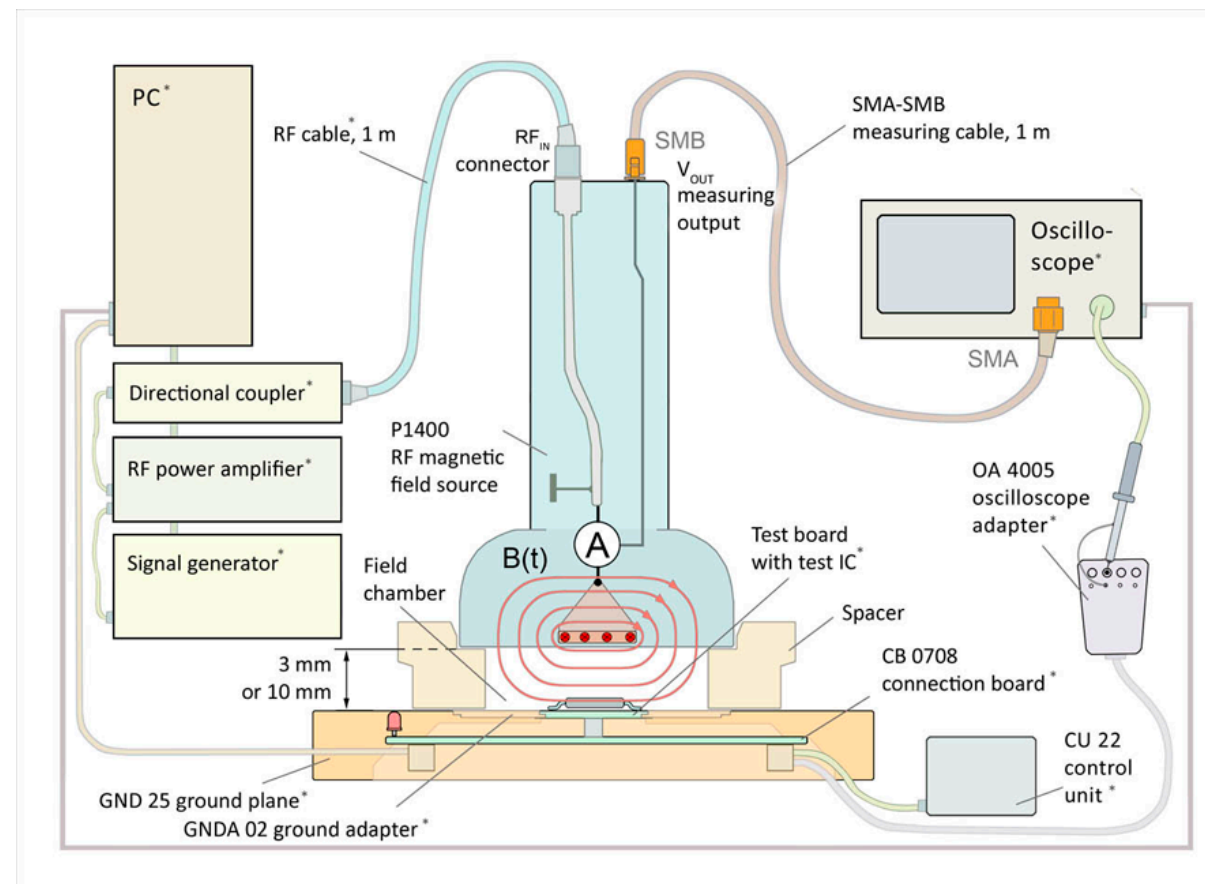
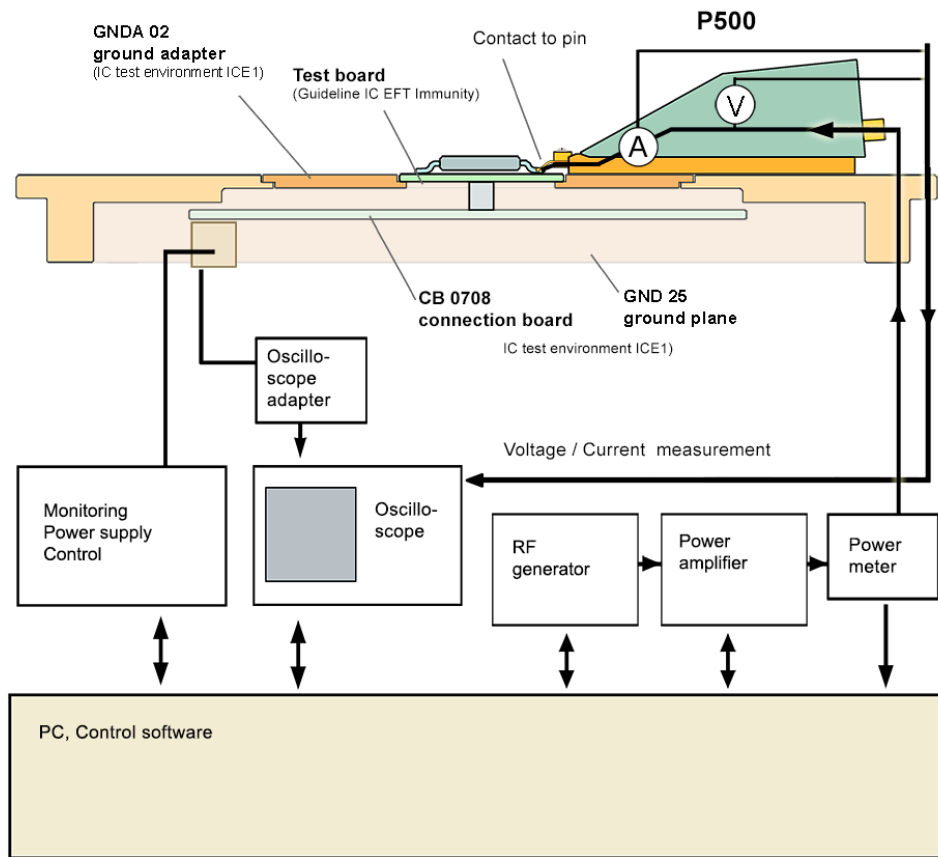
Basic pre-compliance immunity testing

- Langer EMV – test sets for testing the immunity of integrated circuits
 - “EFT” (electrical fast transients) and ESD generators - direct galvanic connection or coupling via an electric or magnetic field



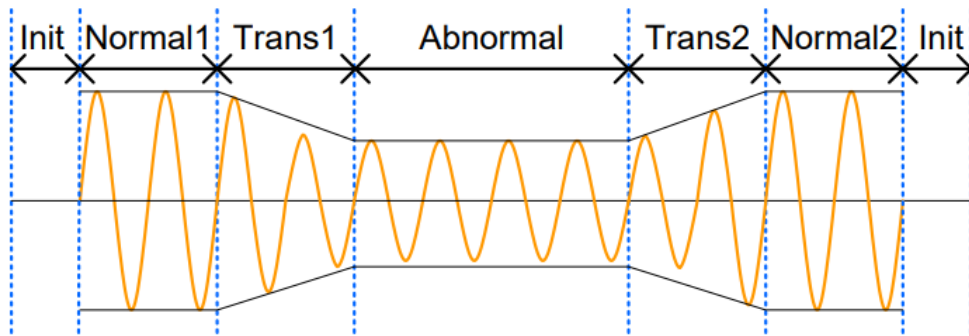
Basic pre-compliance immunity testing

- RF interference – injection of RF energy into the power supply of integrated circuits in accordance with IEC 62132-4



Power supply fault simulation

- Resistance to various power supply disturbances, which can be simulated using modern AC and DC power sources, is also related to the testing of electrical equipment's immunity
- modern AC power sources can simulate sudden or gradual changes in the output parameters:
 - AC voltage, DC offset, frequency
 - User can define the duration of individual steps (abnormal state, transitions)



- Simulation of harmonic distortion in the waveform (amplitude of specific harmonic frequencies)
- Ability to generate pre-defined non-harmonic waveforms (square wave, sawtooth, etc.) as well as fully user-defined waveforms

Power supply fault simulation

- Modern DC power supplies may include a function generator and essentially work as a combination of a generator and an low frequency amplifier
 - Optimized primarily for generating “clean” and precise DC voltage and current
 - Frequency limitation to tens or hundreds of Hz, primarily because of the output capacitance



Function	Short description
Sine	Sine wave generation with adjustable amplitude, offset and frequency
Triangle	Triangular wave signal generation with adjustable amplitude, offset, rise and fall times
Rectangular	Rectangular wave signal generation with adjustable amplitude, offset and duty cycle
Trapezoid	Trapezoidal wave signal generation with adjustable amplitude, offset, rise time, pulse time, fall time, idle time
DIN 40839	Simulated automobile engine start curve according to DIN 40839 / EN ISO 7637, split into 5 curve sequences, each with a start voltage, final voltage and time
Arbitrary	Generation of a process with up to 99 freely configurable curve points, each with a start and end value (AC/DC), start and end frequency, phase angle and duration
Ramp	Generation of a linear rise or fall ramp with start and end values and time before and after the ramp
XY table	XY generator, USB stick loadable current curve (table, CSV)
PV table (PS) PV EN50530 FC table (PS)	Functions to simulate a solar panel (PV function), also according to EN 50530, or fuel cell (FC function), both with table calculation based upon adjustable parameters
Battery test	Battery charge and discharge test with constant or pulsed current, along with Ah, Wh and time counters
MPP tracking	Simulation of the characteristic tracking behavior of solar inverters when seeking to find the maximum power point (MPP) when being connected to typical sources such as solar panels

Power supply fault simulation

- If higher bandwidth is required, DC-coupled low-frequency amplifiers are available; can serve as completely versatile power sources
 - Four-quadrant - source, load, bipolar; highly configurable
 - Voltage source (voltage amplification), current source (transconductance amplifier)
 - Various voltage and current ranges switchable as needed (high voltage + low current or vice versa)
 - User-defined compensation networks when used in current source mode
 - Output bandwidth typically in the range of tens to hundreds of kHz
 - Require an external function/arbitrary waveform generator to produce the desired waveform
 - Lack the capability for internal precise measurement of output voltage and current
 - Typical applications include testing various automotive or aviation devices, where relevant standards often require waveforms with rapid changes that standard DC power supplies “cannot keep up with”



1

2

3

4

5

6

7

8

DEFAULT DIP SWITCH

SETTINGS SHOWN

DIP SWITCH SETTINGS

1

OPERATION (CV / CC)

CV

CC

—

Controlled-voltage or controlled-current operation

2

COMPENSATION (CC1 / CC2)

CC1

CC2

—

Compensation network (for controlled-current operation)

3

LOW PASS FILTER

OFF

ON

—

Enable 50 kHz low-pass filter

4

GAIN (20 / 6)

20

6

—

Gain selection (20 / 6)

5

ELECTRONIC GAIN MATCHING

ON

OFF

—

Enable electronic gain matching (for parallel multi-amp operation)

6

MASTER / FOLLOWER

MASTER

FOLLOWER

—

Multi-amp configuration

7

VOLTAGE INPUT (LOW / HIGH)

LOW

HIGH

—

Low (line-level) input or high input (up to 180V)

8

DC / AC COUPLING

DC

AC

—

DC enable or DC block

RED = FACTORY DEFAULT

Measurement Example

Power supply fault simulation – our offer

- AC power supplies
 - GW Instek – single- or three-phase power supplies with various power ratings; affordable price
 - Chroma – various AC/DC power supplies, grid simulators, ...
 - Keysight – advanced three-phase AC/DC power supplies
- DC power supplies
 - Elektro-Automatik – a wide selection of affordable high-power DC power supplies and loads
 - Keysight – a large number of models across various categories; RP7900 (faster than comparable DC power supplies)
 - Chroma
 - GW Instek
- Amplifiers
 - AE Techtron – a very wide selection of amplifiers
 - Dr. HUBERT

Electrical Safety - Agenda

- Introduction
- Basic list of standards
- Safety measures, Appliance protection classes
- Basic Tests
 - Dielectric strength
 - Insulation resistance
 - Protective grounding tests
 - Leakage currents
- Electrical safety testers
- Our offer

Electrical Safety

- Ensuring product safety is one of the key objectives for all manufacturers
 - Electrical energy poses potentially a significant risk to people; therefore, electrical safety plays a major role in overall product safety
 - Almost all standards request the same basic set of tests
 - The specific test conditions and limit values vary among standards
- 1) Type tests
 - More stringent and comprehensive; conducted during the certification of a new product; used to identify design flaws
 - 2) Production line tests (Routine tests)
 - Conducted on all manufactured units of a given product; the goal is to detect major manufacturing defects

Electrical safety testing - Standards

- Basic overview of current product standards:
 - 1) Electrical appliances for household and similar purposes
 - Type tests: EN **60335-1** ED.4
 - Unit testing: EN **60335-1** ED.4 (Annex A) / EN **50106** ED.2
 - 2) Audio/video equipment, information and communication technology
 - Type testing: EN **62368-1** ED.2
 - Unit testing: EN **62911**
 - 3) Medical electrical equipment
 - Type testing: EN **60601-1** ED.2
 - Unit testing: EN **60601-1** ED.2
 - 4) Safety requirements for electrical measuring, control, and laboratory equipment
 - Type testing: EN **61010-1** Ed. 2
 - Unit testing: EN **61010-1** Ed. 2 (Annex F)

Electrical Safety

- Electrical safety can be generally ensured in three basic ways:

1) Through insulation

- Insulation generally prevents the user from coming into contact with live parts of the appliance
- Standards distinguish between various categories of insulation - basic insulation, supplementary insulation, double insulation (a combination of basic and supplementary), and reinforced insulation
 - Different requirements in terms of electrical strength
 - All appliances must be equipped with at least the basic insulation

2) By connecting accessible conductive parts of the appliance to the protective conductor

- Supplementary protection to insulation; conductive parts of the appliance's enclosure are connected to the protective earth conductor (PE)
- In the event of insulation breakdown, accessible conductive parts do not become live (they are grounded)

3) By powering the appliance with “safety extra-low voltage” (SELV)

- Protection is ensured by the low (safe) level of the supply voltage

Electrical Safety

- Protection classes for appliances:

- 1) Class 0 appliances

- Safety is ensured solely by the use of basic insulation (the appliance enclosure may be made of metal or insulating materials)
 - Any accessible conductive parts are not connected to the protective conductor in any way
 - Products from this category are banned in many countries (EU)

- 2) Class I appliances



- Electrical safety is ensured by combination of basic insulation and protective grounding of the exposed conductive parts of the device
 - The power supply must include a protective conductor; the connection is three-pole
 - This measure is particularly useful in combination with a residual current device (RCD)

Electrical Safety

3) Class II appliances



- Safety is ensured by using double (basic + supplementary) or reinforced insulation (both variants must provide the same level of protection)
 - In the case of double insulation, it is possible to test the basic and supplementary insulation separately
 - Reinforced insulation consists of a single layer of material (which doesn't need not be homogeneous)
- Protective grounding is not used; the power cord has two wires
- The appliance enclosure may be made of metal or insulating material (in which case the housing may constitute the entire supplementary or reinforced insulation)

4) Class III appliances



- Appliances powered by safe low voltage (maximum 50 V AC rms; 120 V DC) in which no higher voltages are generated
- If the safe low voltage is derived from the power supply network, a safety transformer or other converter with separate windings and insulation meeting the requirements for double or reinforced insulation must be used

Electrical Safety

- Basic tests (in terms of protection against electric shock):
 - 1) Dielectric strength (hipot; ACW, DCW)
 - Determines if insulation breakdown occurs at a specific test voltage
 - 2) Insulation resistance (IR)
 - Measures the actual resistance of the insulation at given DC test voltage
 - 3) Ground continuity (GC) test
 - Checks whether the protective grounding is correctly connected (measures and evaluates the resistance of the PE circuit)
 - 4) Protective grounding stress test (ground bond; GB)
 - Measures the resistance of the protective grounding circuit when subjected to a high current for an extended period of time
 - 5) Leakage current (LC)
 - Measures the currents flowing from the DUT into protective ground during normal operation



Dielectric strength

- Dielectric Withstand Test (hipot, ACW, DCW, ...)
- Very important test which is performed during both type and routine testing
 - Each manufactured unit is tested after final assembly
 - The conditions for routine tests are less stringent than those for type tests
- The insulation in the DUT is subjected to a voltage much higher than the normal operating voltage (U_{nominal}) during this test
 - Test voltage according to the applicable standard; for example $(1000 + 2 \cdot U_{\text{nominal}})$ V
 - Testing is typically performed between the primary AC circuit and the low-voltage secondary circuit, or between the primary AC input and the ground of the device
- The voltage is gradually increased over several seconds to the target value, which is then maintained for certain time (seconds for routine testing and ~ minute for type tests)
 - During the test, the DUT is monitored for dielectric breakdown (current rising above a set threshold, electrical discharge, etc.)

Dielectric strength

- AC or DC voltage may be used during this test
 - Depends on the standard requirements; the choice can be based on the nature of the nominal voltage present on the tested insulation during normal operation
- 1) When measuring with AC voltage, the capacitance of the filtering Y-capacitors and the capacitance of the dielectric affect the resulting current
 - + It is easy to verify that the tester is correctly connected to the DUT (certain current is always flowing); testers can be configured to report an error when the circuit is open
 - + Testing with both voltage polarities simultaneously
 - + No need for a longer voltage ramp-up at the start of the test or discharging the DUT at the end
 - Relatively high current ($\sim$ mA) may flow during the test; the tester must be configured to tolerate higher currents (potential risk to the operator)
 - The AC test is generally more “harsh” on insulation than a DC test

Dielectric Strength

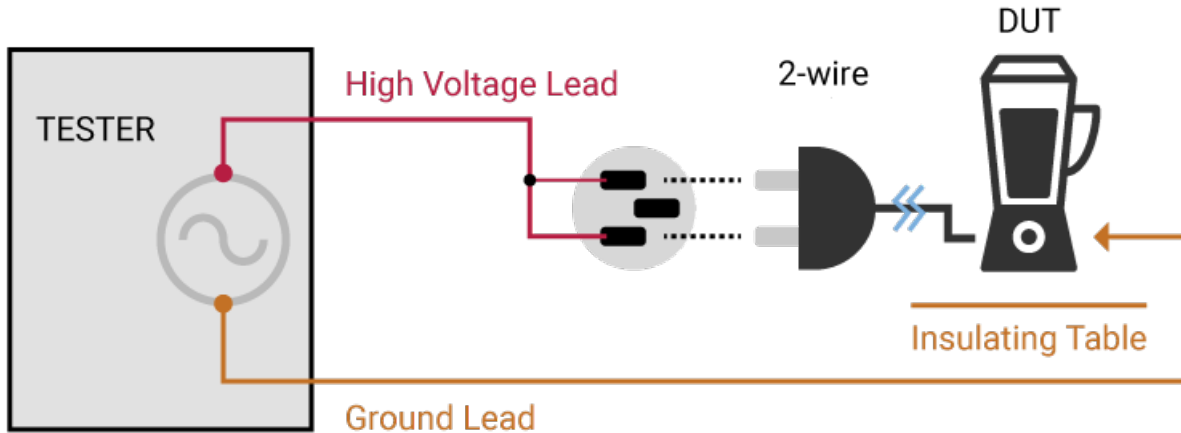
2) In a DC test, only the insulation resistance contributes to the current

- Higher test voltage needs to be selected; typically corresponding to the peak value of the specified AC voltage (i.e., AC rms voltage $\times \sqrt{2}$)
- The currents are typically an order of magnitude smaller ($\sim$ tens of μA)
 - $\rightarrow$ The tester can be set to a lower current threshold ($\sim 1 \text{ mA}$), which can be safer
- At the beginning of the test, the voltage must be increased slower (because faster voltage ramp will charge the capacitances with higher current – may trip the threshold)
 - Any dielectric breakdown can be detected early at this ramp-up stage; the test can be interrupted before complete breakdown (and destruction) of the dielectric
- At the end of the test, the DUT must be discharged (filtration capacitors, ...)
- Testing with DC voltage can be considered a more modern and safer method

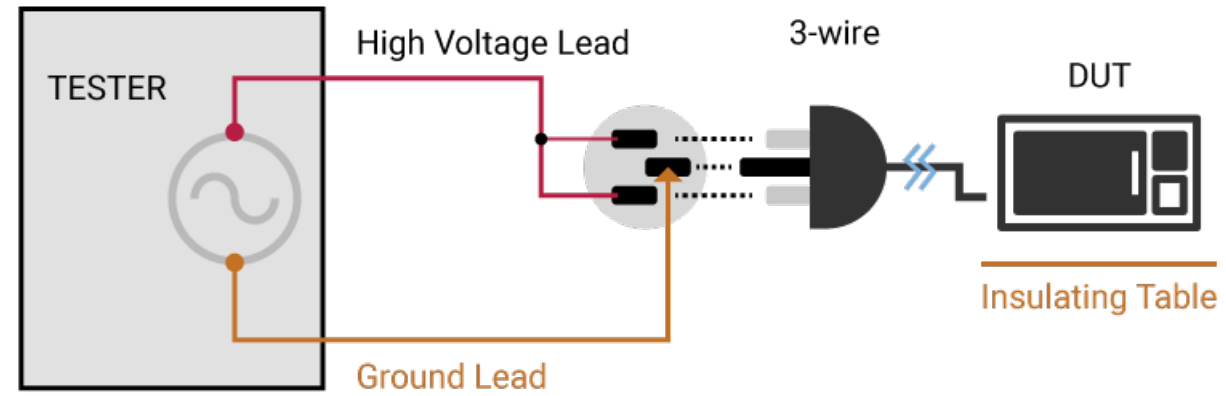
Dielectric Strength

- Examples of measuring circuit connections:

Two-wire connection

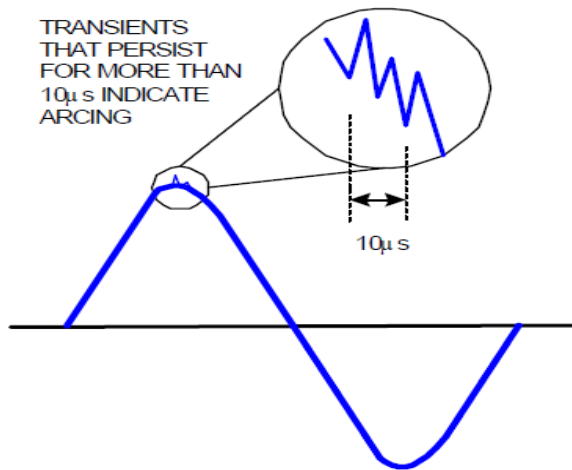


Three-wire connection

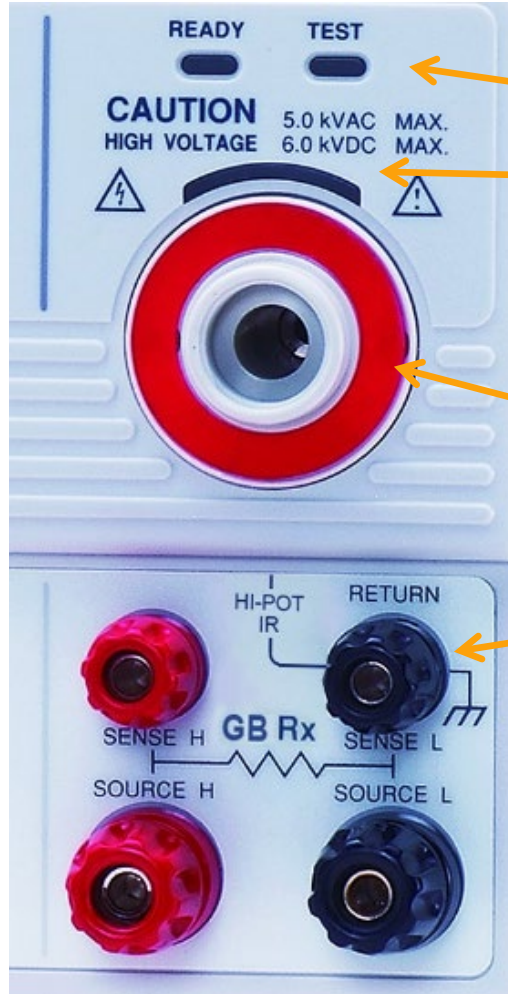


Dielectric Strength

- Modern testers typically include an arc detection feature
 - Arcing often indicates imminent dielectric failure
 - Arcing detection is performed continuously during the test
 - Tester can terminate the measurement before severely damaging the DUT
 - Arcing is accompanied by rapid changes in voltage and current
 - The tester can detect these high-frequency components in the signal



Dielectric Strength – DUT connection



LEDs clearly indicate the tester status (ready / test in progress) and the presence of hazardous voltages

The DUT is connected between these terminals; the terminal with high potential is clearly marked and equipped with a safety connector

Insulation resistance

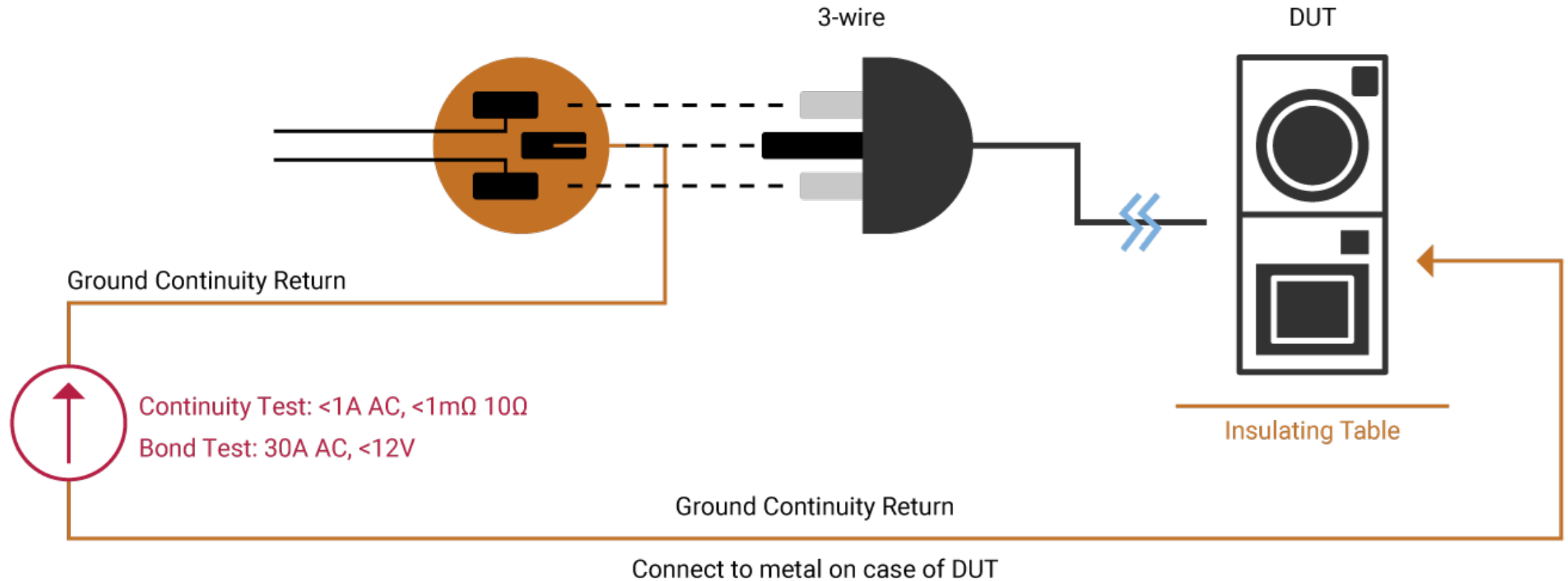
- The purpose of this measurement is to determine the resistance of the tested insulation
 - Usually only a type test
 - Typically performed using a relatively low DC voltage (for example 500 V)
 - A non-destructive test in most cases
 - Resistance measurement is performed after a defined period following the application of the test voltage (after the capacitances are charged and the dielectric relaxation subsides)
 - The test voltage is first increased to the nominal value over a certain period of time; then, after a specified delay, the measurement is taken, and the dielectric is discharged
 - The goal is to measure a steady-state current through the dielectric
 - The test result is positive if the resistance value exceeds a specified limit (typically, for example, 2 MΩ or 4 MΩ, depending on the category of the insulation being tested)

Protective Grounding Stress Test

- This test verifies the integrity of the protective grounding circuit under a high current load (for example, twice the expected maximum current)
 - It is very important from a safety perspective
 - Most often performed only during the type testing
- A high-current source (at low voltage) is connected between the main protective grounding terminal and the point on the equipment that should be grounded (enclosure)
 - Four-wire connection is used - two conductors supply current, two conductors for voltage measurement – “Kelvin” connection; eliminates the parasitic resistance of the test leads
 - The test current (~20 A – 32 A) is maintained for a certain period of time (typically one to two minutes)
 - Based on the known current and the measured voltage, the ground circuit resistance is calculated; this value must not exceed the limit specified by the standard (typically 0.1 Ω)
 - The open circuit voltage is low (for example 8 V), so this test is considered to be safe

Protective Grounding Stress Test

- Typical measurement setup:

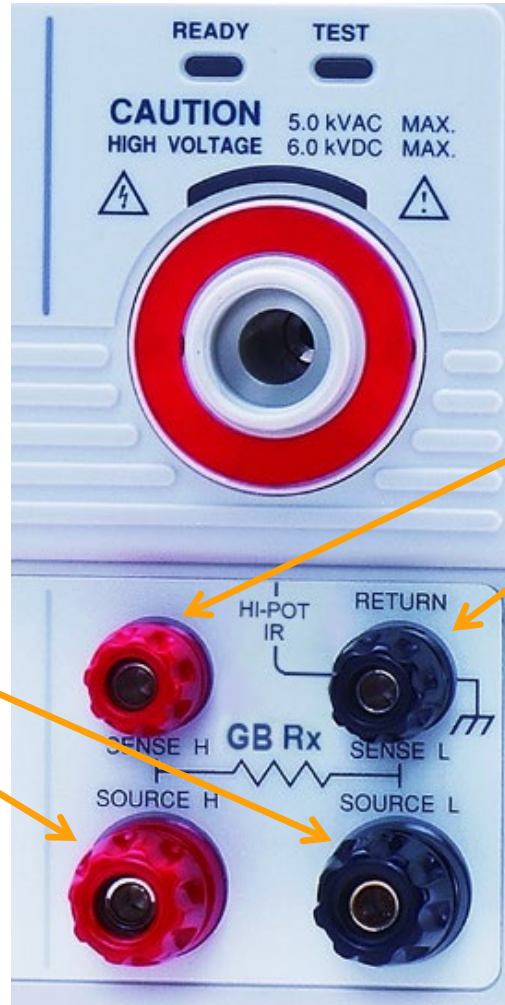


Protective ground - continuity

- This test also verifies the resistance of the protective grounding system, but under significantly milder conditions - DC current of approximately 1 A is typically used
- The goal is to verify the correct connection of the grounding circuit without placing unnecessary stress on the conductors (which could be damaged)
- This test is typically performed during routine testing, where the primary goal is to detect manufacturing defects (design errors are eliminated during type testing)

Protective Grounding Tests

- Connecting the DUT to the tester during grounding tests (continuity or GB):



“source” terminals supplying the test current;
H denotes the higher potential;
L denotes the lower potential

“Sense” terminals for measuring voltage on the circuit under test

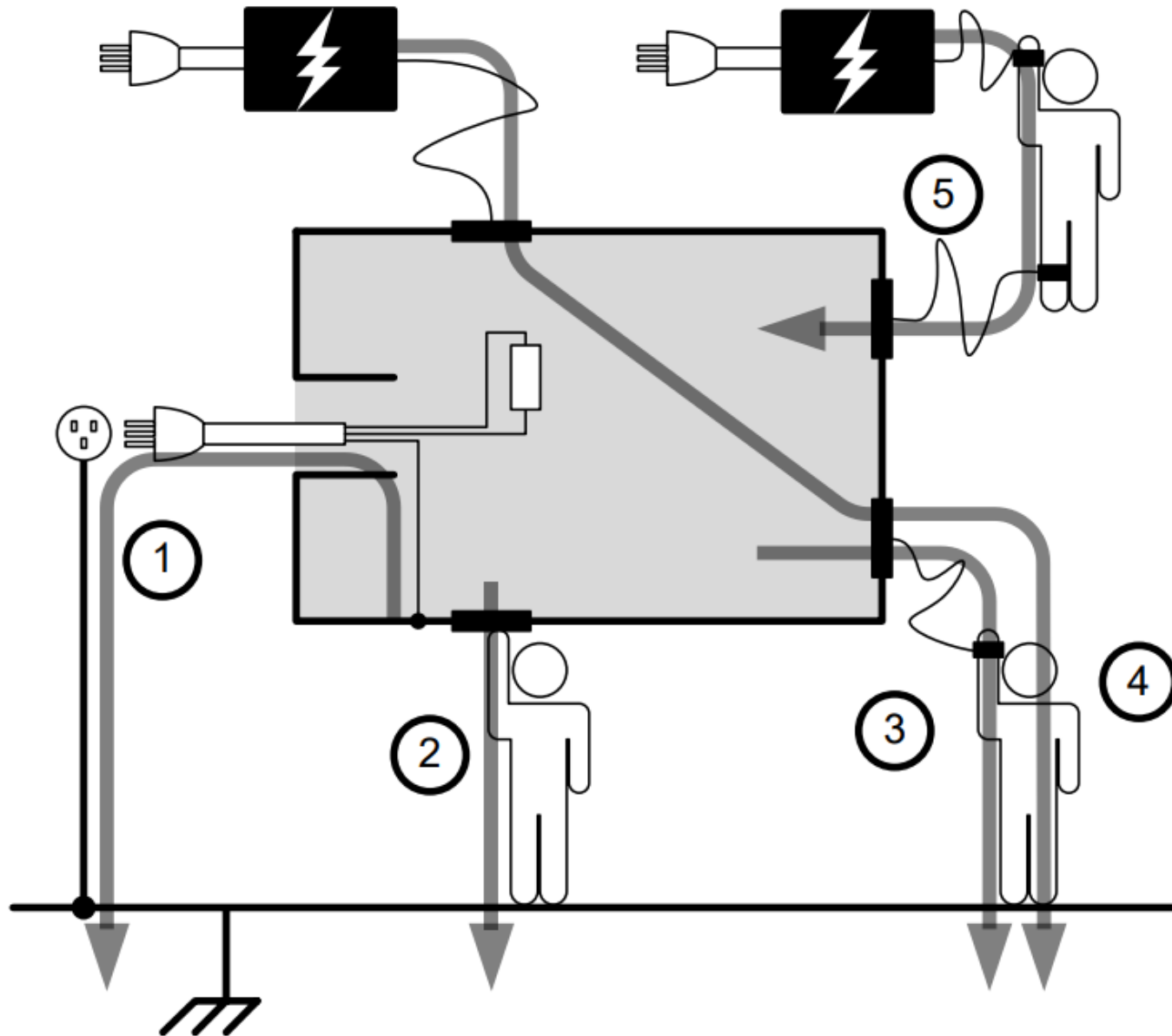
The type of test and the location of the measured resistance are clearly indicated between the terminals

Measurement example

Leakage currents

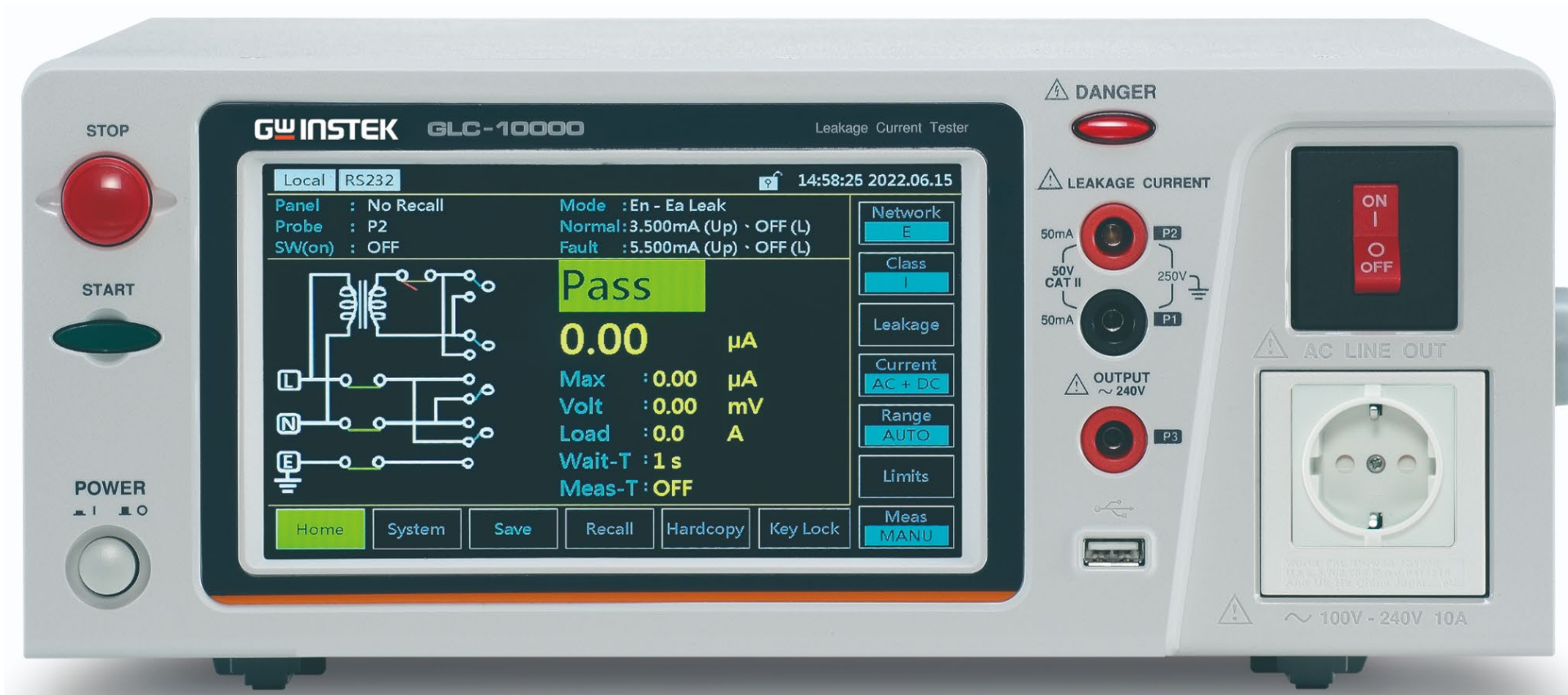
- Small, non-functional electrical currents that flow from live parts through insulation or stray capacitances to ground, enclosures, or human touch points during normal operation
 - Either directly through the PE conductor (“earth leakage current”) or through the user touching the enclosure (“touch current”)
- During this test, the device is connected to the power supply and turned on
- Measurements are taken under normal conditions and under conditions simulating a single fault
 - 1) Under normal conditions, all protective measures are intact
 - 2) Under a single-fault condition, one of the protective measures is defective; when measuring leakage currents, the following single-fault conditions are tested:
 - interruption of the protective earth (PE) conductor
 - interruption of one of the power supply conductors

Leakage currents



Leakage current through the patient—measurement

- Example of a leakage current tester:

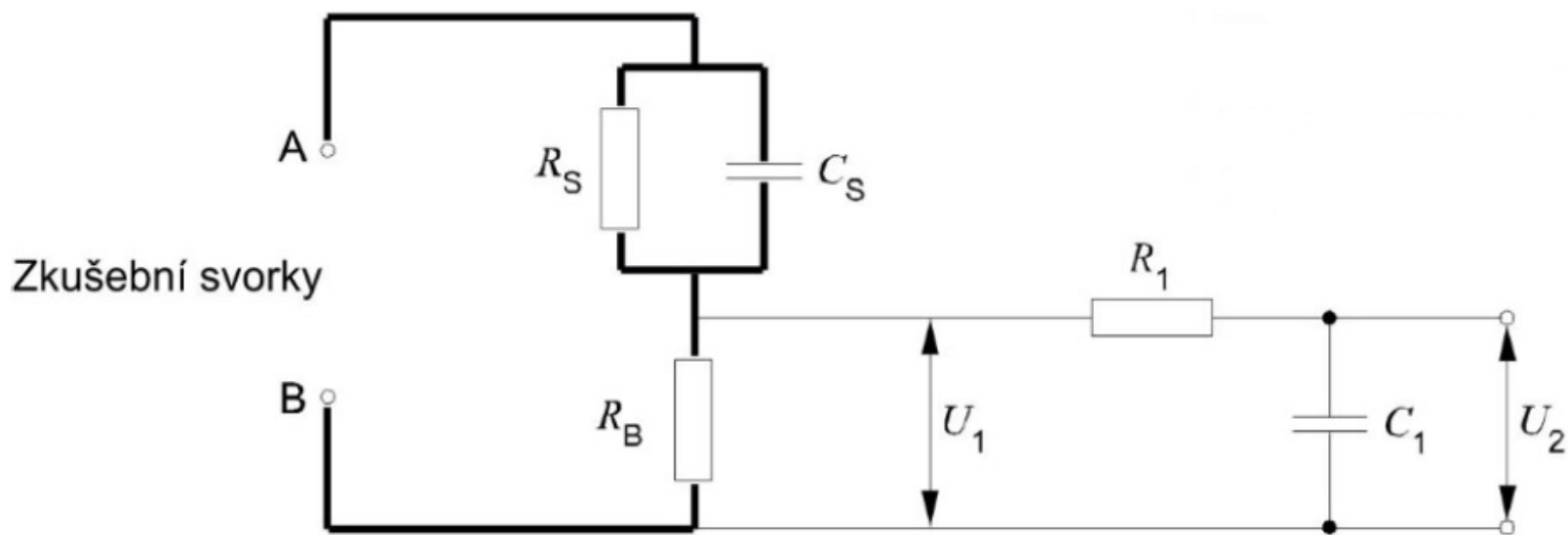


Leakage currents

- Relevant standards specify different limits for leakage currents depending on the type of device (protection class, portability, etc.)
- The most stringent requirements apply to medical devices, where even very small currents can potentially cause injury or death
- Different models simulating human body impedance are used during the tests to ensure measurement repeatability
 - These models consist of various R/C combinations, and the leakage current value can be calculated from the voltage measured at a specific point in the circuit
 - The typical impedance value at power-line frequency ranges from 1 k Ω to 2 k Ω for most circuits

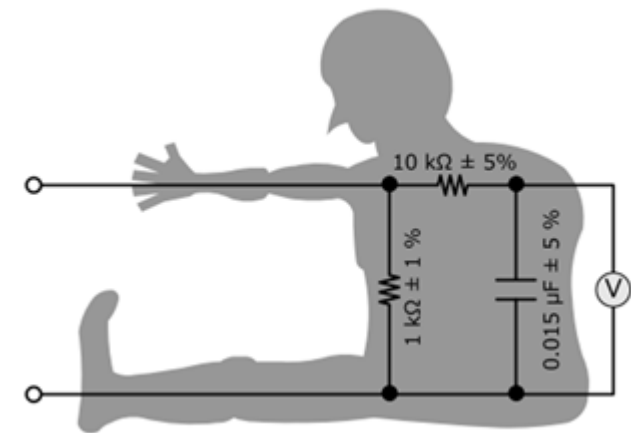
Leakage currents

- Example of the most common equivalent circuit used for leakage current measurements:



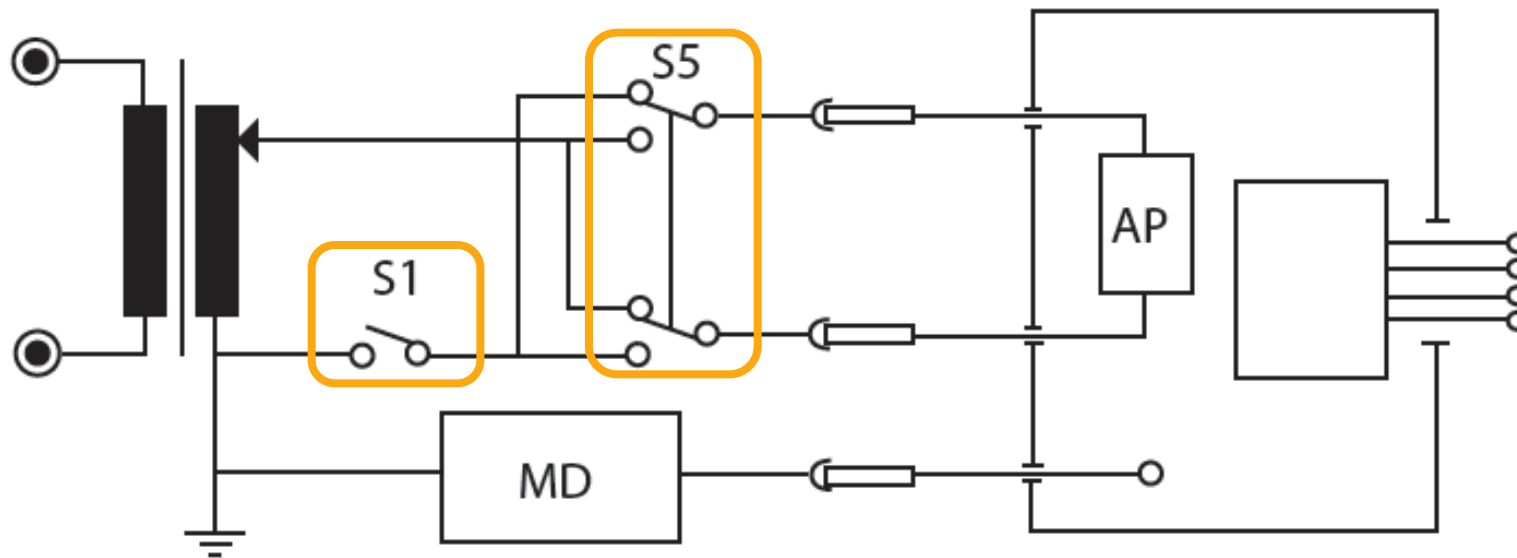
R_S 1 500 Ω
 R_B 500 Ω
 C_S 0,22 μF

R_1 10 000 Ω
 C_1 0,022 μF



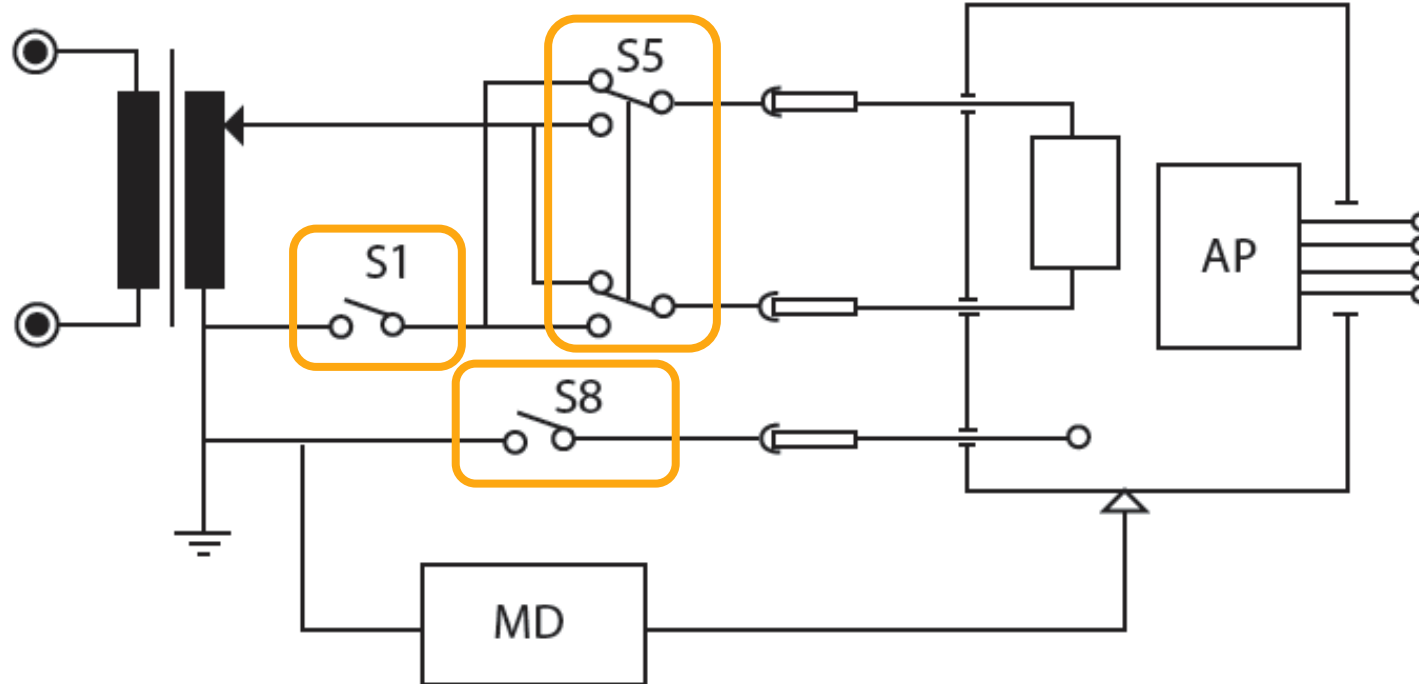
Measurement of the Earth leakage current

- This measurement is performed only on Class I devices
- Tester (MD) measures the current flowing through the PE conductor
- The measurement is performed under normal operating conditions and with the neutral conductor disconnected (S1) for both supply polarities (S5)



Measurement of the Touch leakage current

- The current that would flow through the human body when touching the DUT's enclosure
 - In case the enclosure is made of insulating material, the measurement is performed using a conductive foil measuring 10 x 20 cm, simulating a human palm
- Measurements are again taken under normal conditions and under conditions with a broken protective conductor (S8) (Class I only) or a broken neutral conductor (S1) for both polarities (S5)



Electrical Safety Testers

- Safety testers are offered by multiple manufacturers in a wide variety of models
- Single-purpose or combination devices
 - Most common is a combination of dielectric strength, insulation resistance, and grounding tests
- Testers differ more significantly in the parameters available for individual tests
 - For dielectric strength, testers are available in different power (current) classes:
 - Typical values are 500 VA, 200 VA, and 100 VA
 - Some standards define minimum required short circuit current, thereby allowing only testers of the highest category (500 VA) to be used for certification type tests
 - For the ground bond test, different models are able to produce different test currents
 - Lower-end models may be limited, for example, to a current of 25 A or 30 A, some standards require a higher current for certain devices

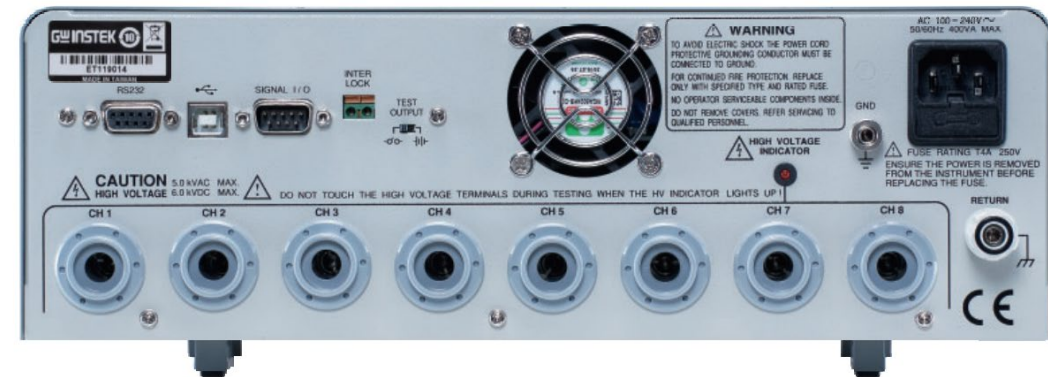
Electrical Safety Testers

- Combined tester for ACW, DCW, IR, and GB tests:



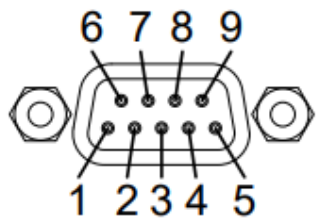
Electrical Safety Testers

- Some tester models may include an integrated multiplexer
 - Able to perform parallel electrical strength testing on multiple products simultaneously (or at multiple points on a single product)
 - Alternatively, there are multiplexers that can be connected as external accessories

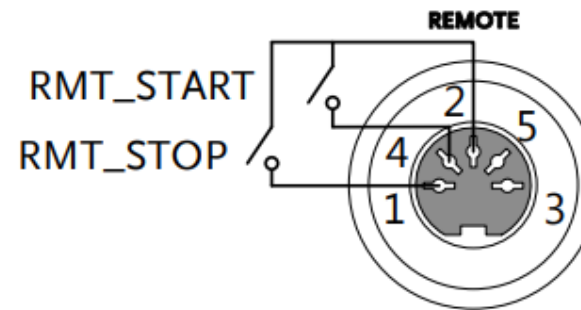


Electrical Safety Testers

- Testers are typically operated in the following ways:
 - 1) Manually via the front panel (configuration and test start)
 - 2) From an external computer/PLC via communication buses
 - Configuration, test control, and result upload; typically using SCPI-like text commands
 - 3) Via external electrical signals
 - Can be useful, for example, on production lines
 - Start/stop inputs; outputs indicating a test in progress and a pass/fail result



INTERLOCK1	1
INTERLOCK2	2
INPUT_COM	3
INPUT_START	4
INPUT_STOP	5
OUTPUT_TEST	6
OUTPUT_FAIL	7
OUTPUT_PASS	8
OUTPUT_COM	9



Electrical Safety Testers

- To ensure operator safety, testers typically include the following features:
 - Interlock – the device provides contacts that must be short-circuited before the test is allowed to start; can be used to connect external switches (safety doors, light etc.)
 - Terminals with hazardous potential are designed to prevent accidental contact; they are clearly marked, and the presence of voltage is indicated by a warning LED during the test
 - The test is controlled manually using two start/stop buttons
 - The stop button is typically large and red; pressing it immediately terminates the test



What We Offer

- Manufacturers of electrical safety testers that we represent:

1) GW Instek

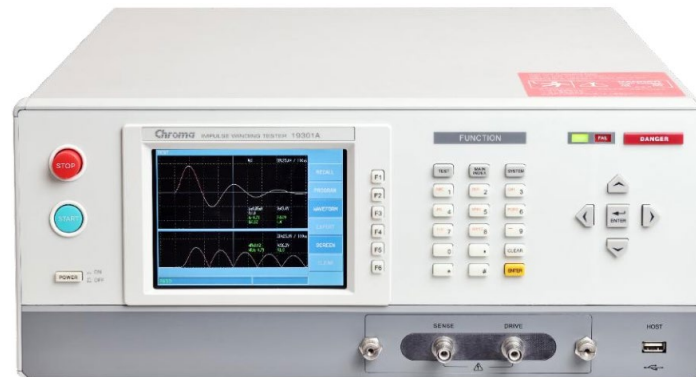
- Five series of combination testers (ACW, DCW, IR, GB)
 - 100 VA: **GPT-960x**
 - 200 VA: **GPT-980x** (older series), **GPT-1200x**
 - 500 VA: **GPT-990x** (older series), **GPT-1500x**
 - All series feature four models (x) – ACW only; ACW+DCW; ACW+DCW+IR; ACW+DCW+IR+GB
- Protective grounding and leakage current tester
- Eight-channel multiplexer for electrical strength tests on multiple devices in parallel (up to four multiplexers combined → up to 32 channels) – usable only with GPT-9800 and GPT-9900
- GPT-9500 – 150 VA testers (ACW, DCW, IR) with a built-in 8-channel multiplexer
- GPT-15012 – special high-voltage model: DCW 12 kV / IR 5 kV



What We Offer

2) Chroma

- Several types of combination testers, including “all-in-one” models (ACW, DCW, IR, GB, LC)
- Separate protective grounding tester
- Some tester models with an integrated multiplexer
- Chroma also offers various safety testers for specialized applications:
 - Partial discharge – detection of faults in insulation (voids)
 - Battery surge testers – testing lead-acid batteries and certain types of resistors
 - Winding testers – the tester generates a short pulse and monitors the response (coils, transformers)
 - Lithium battery insulation tester



Conclusion

If you have any questions or requests,
you can contact us at the following email address:

info@htest.hu

Thank you for your attention!