APPLICATION NOTE

EIE/AN91001
Workbench EMC evaluation method

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Philips
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1.0 INTRODUCTION

In many mass manufactured electrical and electronic products, printed wiring boards (PWBs) are used in a non-shielded application because it would be too expensive to do otherwise, e.g., hand-held cassette players, telephones, televisions, etc. As such, the product related EMC requirements directly apply to the (main) PWB containing semiconductors. To meet economic constraints, EMC solutions need to be taken, as far as possible, within the semiconductors, such that the needs for external measures diminish. In order to select between the various applications suggested by different vendors, an EMC qualification is required, too.

Generally, the designer will face problems with CAD tools for PWB and semiconductor lay-out. The main problem is that all routers known are random routers which can do their functional job quite well on a bi- or multi-layer PWB, or with single or double metal processes. It will therefore be such that if the PWB or semiconductor is routed several times, using the same input, the results can be totally different. EMC results are commonly bad, mainly because the router is not told which lines need priority and which need to be close together.

An additional problem to face is that both product and semiconductor developments need to go faster, by using all available tools. By adding as few as possible external (passive) components and considering geometrical constraints given by the automatic assembly tools, we hope that it complies with the often stringent **mandatory** EMC requirements.

The above given problems ask for an EMC evaluation method, by which the designer can, at any stage of the design, determine the degree of satisfying the EMC requirements. This EMC evaluation technique must be easy to use, easy to handle, and not too expensive to assure usage of this method. The concept is based on the technical information now available in draft IEC 801-6. This concept will be explained in chapter 2.

2.0 TEST METHOD

2.1 EMC regulations and standards

With respect to EMC standards, we can concentrate ourselves best to the generic emission and immunity requirements given in European Standards EN 50081-1 and EN 50082-1 which become legally enforceable from 1992 onwards, especially to the European Market. In these standards, reference is made to either IEC documents or CENELEC standards in which certain disturbance or emission phenomena are depicted. For most product groups, the IEC CISPR 11/22 documents or CENELEC European Norm 55011/22, class B apply for RF-emission, whereas for immunity phenomena IEC 801-2 through -6 or CENELEC 55024-x apply.

In our particular case, considering IC-development and IC-application, the most important document is draft IEC 801-6 as it can be applied both to immunity **and emission**. The validity is given by the fact that the EM-radiation properties of cables and wires connected to the Device or Equipment Under Test (DUT ot EUT) are substituted by simple passive networks. As passive networks have reciprocity both emission and immunity can be evaluated in the same set-up.

2.2 Basic concept

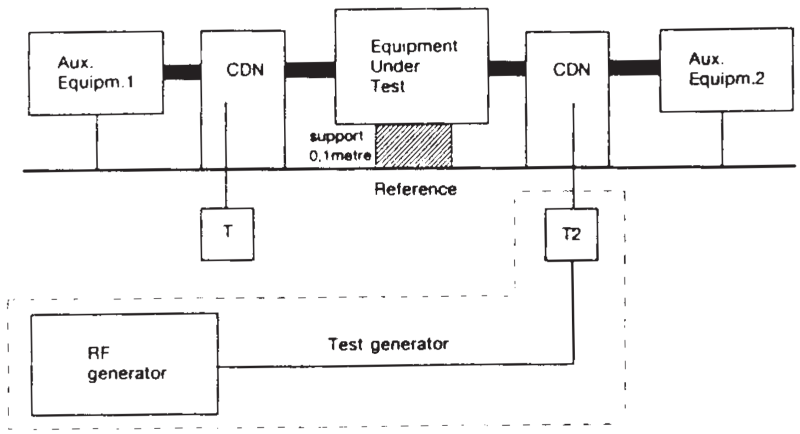
With the method, according to draft IEC 801-6, immunity to **conducted** RF-disturbances is tested. The set-up simulates the EM radiation effects by coupling the induced disturbing signals through Coupling/Decoupling Networks (CDNs) via the cables and wires to the PWB under test in a defined way, Figure 1. This method is applicable in the frequency range 150kHz up to 230 (1000) MHz. The set-up with CDNs simulates “passive” cables which are, from the radiation point of view, at resonant length. The dimension of the PWB(s) between these cables and wires is assumed to be short compared to wavelengths involved.

According to the existing radiation measurement procedures, either the cable contributions are eliminated by adding ferrites on them to serve reproducibility (EN 55020) or the cables shall be adjusted in length and geometry with each frequency to obtain maximum radiation (EN 55011/22). With the conducted “interaction” method, which simulates radiated RF-field phenomena, both problems are solved.

NOTE 1: This method also reproduces the electric and magnetic near-fields to the PWB, associated with the source of disturbance (E and H in Figure 2).

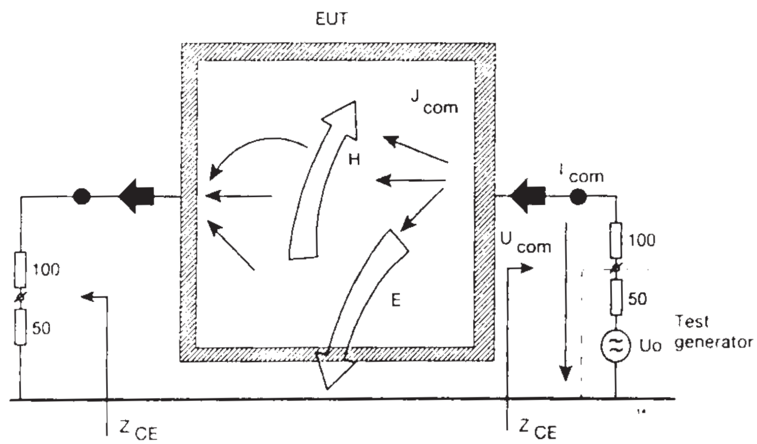
NOTE 2: The method of publication 801-6 does not provide the injection (or measurement) of the current from an ideal current or voltage source. It rather provides the coupling of the disturbance signal from a real source, having a “radiation” resistance of 150Ω, i.e., short-circuit current as well as open voltage are limited.

CDNs are mainly defined by the common-mode impedance represented at the EUT-port side, which needs to be about 150Ω to reference (±20Ω, freq. ≤ 30MHz, +60/–45Ω, freq. > 30MHz). Every CDN fulfilling the impedance requirements given in draft IEC 801-6 can be used. Typical application examples are given in Figure 3 for shielded and Figure 4 for unshielded cables. In Figure 5, a simplified drawing for mechanical construction is given. By using new NiZn ferrite ($\mu_r \geq 1000$), the entire frequency range can be covered by using one toroid on which we have 17 windings, $L_{(150kHz)} \geq 280\mu H$, and one bead-on-cable only.



T = 50Ω termination
T2 = Power attenuator
CDN = Coupling and decoupling network system

Figure 1. Schematic set-up for immunity test to RF conducted disturbances



Z_{ce}: Common-mode EUT-point impedance of the coupling and decoupling network system, Z_{ce} = 150Ω.
Note: The 100Ω resistors are given by the coupling and decoupling networks.
The left input is terminated by a (passive) 50Ω load and the right input is loaded by the test generator.

U_o: Test generator output voltage.

U_{com}: Common-mode voltage between EUT and reference plane.

I_{com}: Common-mode current through the EUT.

J_{com}: Common mode current density in the EUT.

E, H: electric and magnetic fields.

Figure 2. Equivalent circuit of Figure 1 to explain the electromagnetic near-fields approximated by common-mode currents and voltages induced by a RF-source according to the immunity method to conducted disturbances.

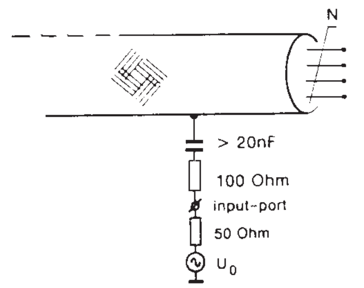


Figure 3. Coupling to shielded cables

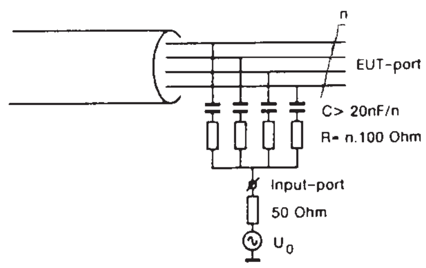
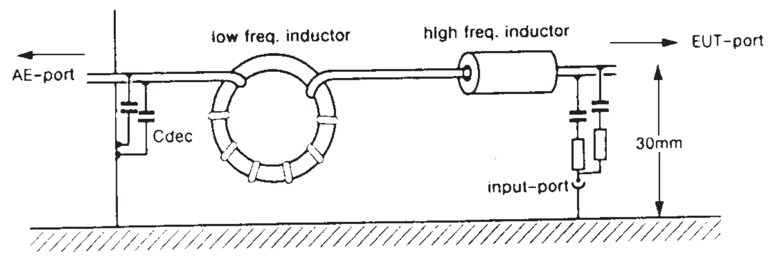


Figure 4. Coupling to un-shielded (multi-wire) cables



Typ. C_{dec} = 47nF, $L_{150kHz)} \geq 280\mu H$

Note: Low frequency inductor: 17 windings on a toroid, material 4A15 RCC36/23/15
High frequency inductor: tube, material 4A11, D10/d6.5/L40

Figure 5. Mechanical drawing for the Coupling/Decoupling Network (CDN)

2.3 Test set-up for individual PWB units

According to draft IEC 801-6, the PWB is placed on an insulating support, 0.1 meter above an earth reference plane. If the PWB will be used in a cabinet were a metal part is more near to the PWB than 0.1 meter, e.g., an adjacent PWB or a metal floor plate, then that shorter distance must be used. The earth reference plane shall exceed the projected geometry of the PWB and the used CDNs on all sides by at least 0.2m.

On all cables, measures to obtain high common-mode impedances at the frequencies of interest or CDNs must be inserted. The number of CDNs should be limited (between 3 and 5) by restricting oneself to the representative functions and main (disturbing) current distributions occurring to the application in practice. The CDNs need to be placed directly on the earth reference plane, making proper contact to it, at a maximum distance of 0.3 meter from the PWB. The cables between the CDNs and the PWB shall be as short as possible. Their height over the earth reference plane must be kept between 30 and 50 mm (as long as possible).

All auxiliary equipment, AE, required for the defined operation of the PWB, according to the specifications of the product, must be connected through high common-mode impedances or through CDNs to the PWN, e.g., communication, modem, printer, sensor, etc. This shall also be done for all auxiliary equipment necessary for ensuring proper data transfer and assessment of the functions.

> **WARNING 1:** *As measures to obtain high common-mode impedances* ***and*** *CDNs are transparent for functional signals, part of the disturbance signal may enter the auxiliary equipment in this way. As such, filtering measures will be inevitable.*

2.4 Workbench Faraday cage

The present proposal, suitable for small application boards and semiconductor evaluation, is a table-top size Faraday cage where all the connections to DC-supply and other auxiliary equipment are made through filters mounted on the wall of the Faraday cage. The wires and cables from these filters to the PWB need to be wrapped on a ferrite toroid, Philips NiZn material 4A15, to create a high common-mode impedance towards the walls of the Faraday cage (= earth reference plane), similar to the construction given in Figure 5. Then by means of resistors defined impedances, 150Ω (100Ω in series with an external 50Ω coaxial load), are applied to simulate the radiation or reception performance of the cables or wires which might be connected to this application board in practical (product) application.

> **NOTE 3:** When a workbench Faraday cage is used, the earth reference plane is extended all around the PWB under test. As a result of the dimensions of the workbench Faraday cage, distance between PWB and CDN will remain ≤ 0.3 meter.

To keep this method simple, the maximum number of common-mode measurement points is set to 3. All other wires and cables must be provided with a RF-blocking (high common-mode impedance) device towards the feed-through panel on the wall of the Faraday cage.

The common-mode measurement points on the PWB selected for evaluation are:

– at the DC-power supply connector,

– at the input port connector, and

– at the output port connector.

Dependent on the implementation of the application board, containing one or several ICs, the emission or immunity performance can be measured (Figures 8 and 9). In those set-ups, the coaxial 50Ω loads outside the Faraday cage shall be exchanged in turn with either the selective voltmeter (spectrum analyzer) or the disturbance source.

For worst-case testing the three connector positions, which are selected as common-mode points, are distributed all alongside the PWB (Figure 6a). This arrangement is chosen because one cannot predict the geometrical layout the customer is going to use in his product.

> **NOTE 4:** Only if an application is required (to fulfill the requirements) such that all connectors are placed on one side only (Figure 6b), it must be tested as such. As a result, this condition then, shall be clearly stated in the application report.

The determination of the common-mode points of the selected ports is based on the cables or wire-geometrics likely to occur in product application. Furthermore, dependent on the product application, the appropriate CDN shall be selected.

– When shielded cables are used, the shielding is referred to as common-mode point of that port (towards the wall of the Faraday cage), no matter how many wires are within that shielding.

– When unshielded cables are used, the common-mode impedance shall be established by placing a number of resistors to each individual wire such that the total common-mode resistance equals 100Ω (+ 50Ω external) towards the reference, being the wall of the Faraday cage. In series with those resistors capacitors (C_{total} ≥ 20nF) must be applied such that the impedance requirements are still met.

In product applications where an IC is fed by a signal source properly defined, i.e., signal and ground return are adjacent tracks, separation ≪ 1mm, **and** the tracks are short, length ≤ 0.1 meter, a coaxial CDN-type can be applied. The same applies for the output configuration. Commonly, supply traces are not kept adjacent properly from IC to supply and therefore an unbalanced two-wire CDN should be used. If an IC is properly decoupled, supply and ground will be RF-short-circuited and a coaxial CDN can be applied.

WARNING 2: *With analog circuits, outputs often cannot handle high capacitive loading which is represented by CDNs and its cables. As only the demodulated component at 1kHz is of interest, an RC-filter needs to be used in between output and CDN (see Figure 7).*

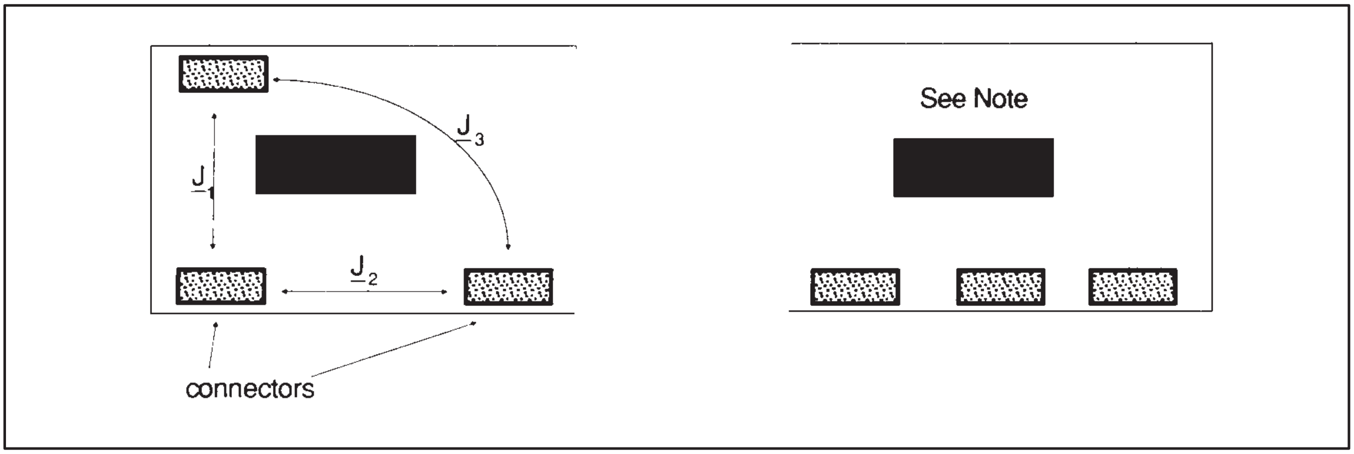


Figure 6. Typical arrangements of inputs, outputs and supply alongside the IC

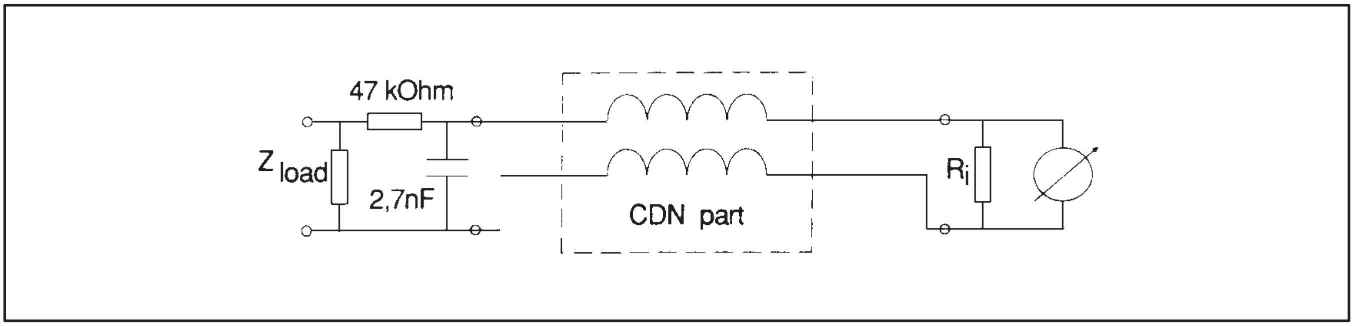


Figure 7. Filter/impedance matching network necessary to lower capacitive loading at IC outputs

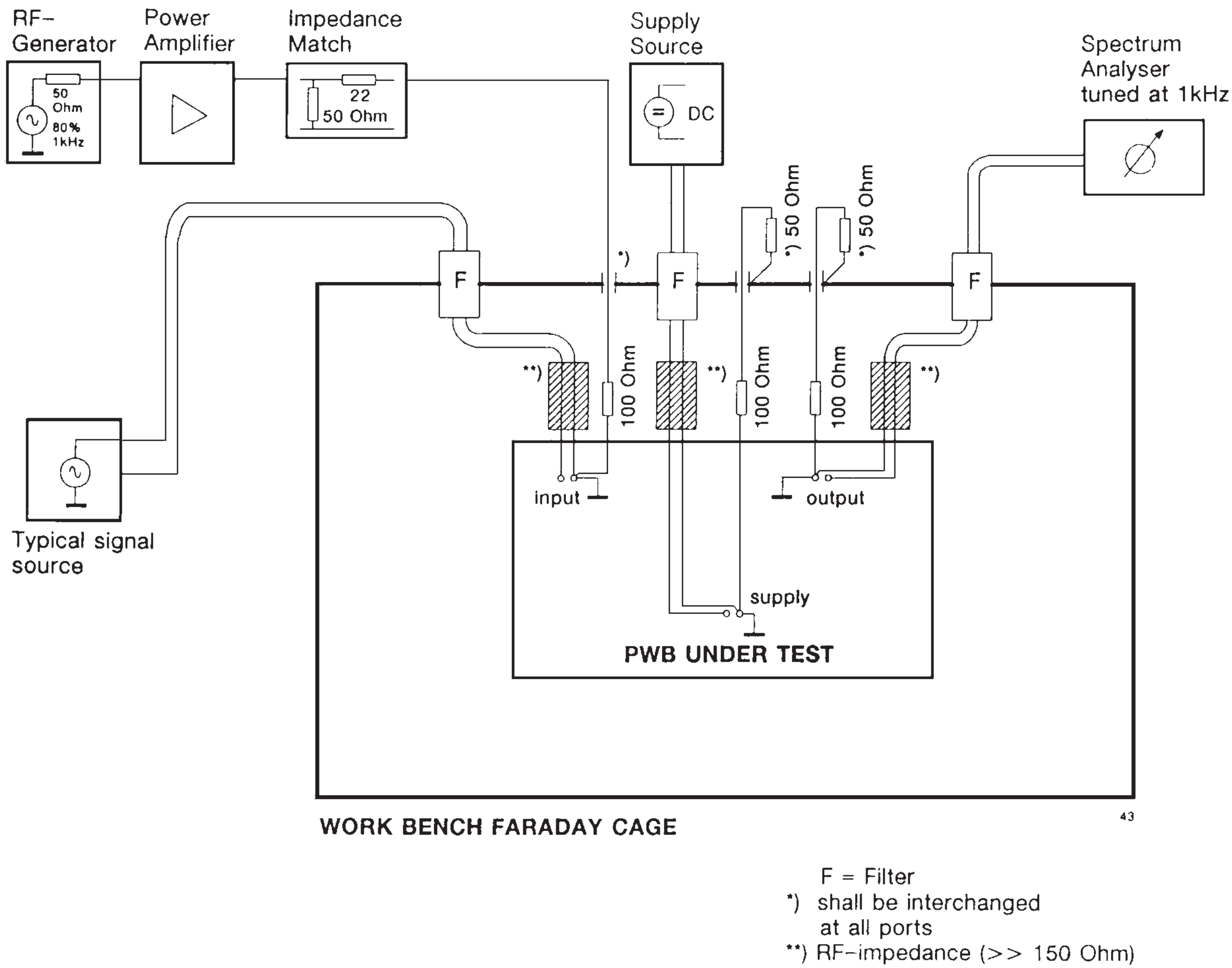


Figure 8. Simplified set-up for immunity testing of the PWB using the workbench Faraday cage

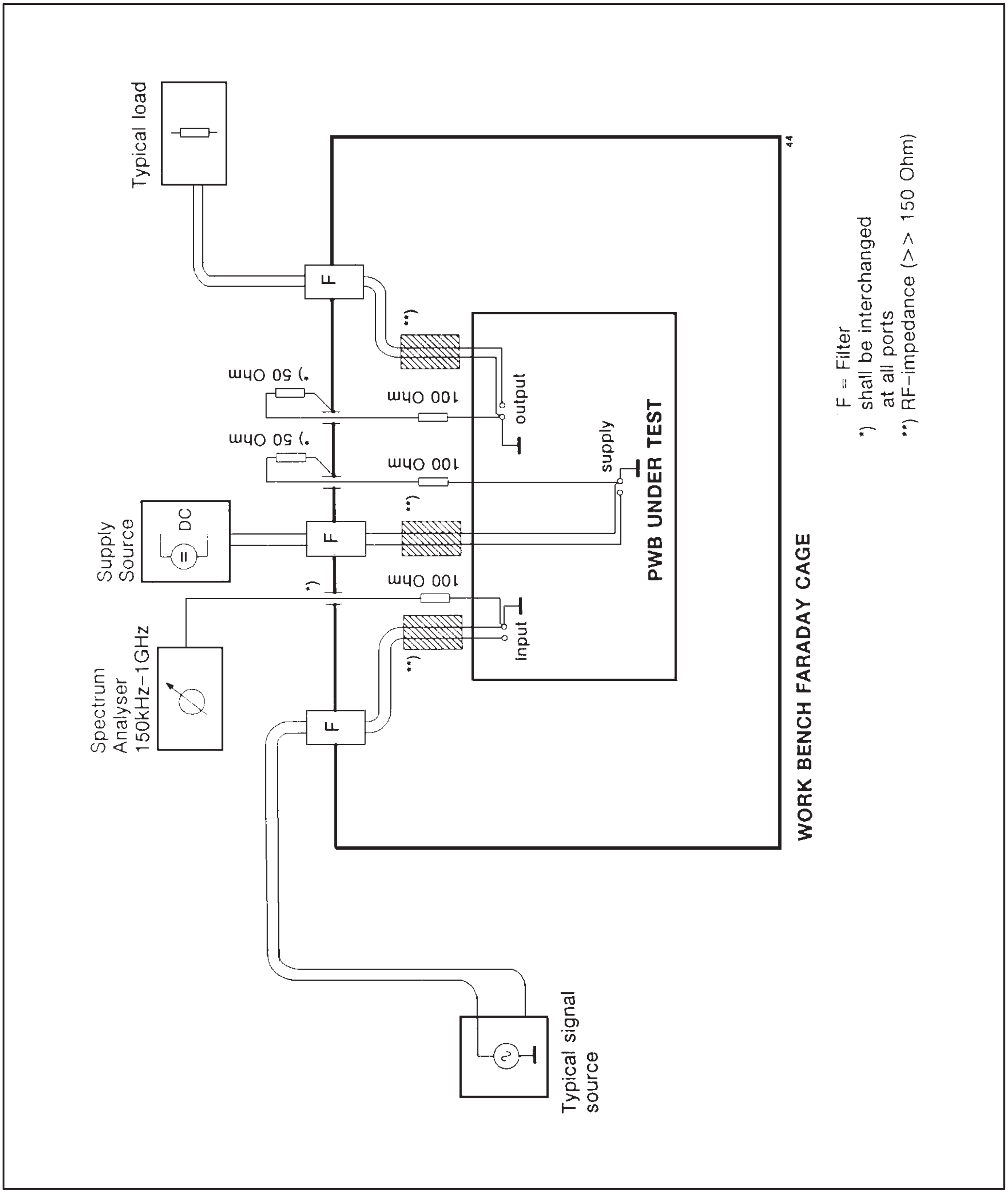


Figure 9. Simplified set-up for emission testing of the PWB using the workbench Faraday cage

2.5 Test equipment verification

The verification of the disturbance signal used with immunity testing shall be done as follows:

1. The RF generator is set at 10MHz **un-modulated**. The output level shall be adjusted such that an RMS voltage of, e.g., 3 Volts appears at the port which will be connected to the coaxial feed-throughs (with the 100Ω series resistor behind) of the Faraday cage. This voltage is measured across the output of the 50Ω impedance matching network using a high input impedance RF-voltmeter.

2. Amplitude modulation must be turned on, using a 1kHz sinewave (987.5Hz / 1005Hz — see chapter 3) and the modulation depth must be set to 80%. By means of an oscilloscope, this AM-signal shall be observed. Neither clipping nor modulation inversion may occur on the signal wave shape.

   In this case, the peak-to-peak level will be 15.3 Volt.
   3 Volt RMS = 4.24 Volt peak = 8.48 Volt peak-to-peak un-modulated.
   3 Volt 80% modulated then becomes 15.27 $Volt_{P-P}$.

3. When this verification is accomplished, this signal is provided to the coaxial feed-through connected to the common-mode point under test.

With respect to emission measurements and the verification of the receiver used, further reference is made to IEC CISPR publication 16.

If the emission limit is given in Quasi-Peak or Average limits, the emission performance shall be measured in Peak-mode first (because it is fastest to apply).

1. If the PWB satisfies the Average requirements, using the Peak-mode, no further measurements have to be carried out.

2. When the PWB **does not** satisfy the Average requirements but complies with the Quasi-Peak requirements, additional measurements in Average mode need to be carried out.

3. When the PWB **does not** fulfill either of the requirements, both measurements: Quasi-Peak and Average have to be carried out. Normally, there will be insufficient margin and PWB modifications will be necessary.

NOTE 5: If the RF-signal is a continuous sinusoidal wave, then the indications from either Peak, Quasi-Peak and Average-mode detectors will be equal.

2.6 Requirements

With conducted immunity measurements, the limit applicable to the product, e.g., draft IEC 801-6, can be used directly for verifying the IC application.

When radiated immunity requirements are given, a transformation from electric fieldstrength requirements to induced voltages and currents has to be considered. For indication the following relation can be considered:

1 $Volt_{emf}$ (150Ω in series) shall be taken for 1 Volt/meter (travelling wave, far field condition, generated by a tuned dipole antenna, distance ≥ 3 meters) in case the cables and EUT are exposed to the EM-field, i.e., transformation ratio = 0dB.

0.3 $Volt_{emf}$ (150Ω in series) shall be taken for 1 Volt/meter (travelling wave, far field condition, generated by parallel plate or strip-line set-ups) in case only the EUT is exposed to the EM-field and cables are excluded, i.e., transformation ratio = –10dB.

NOTE 6: The transformation ratio will depend on product size, the way cables are routed and frequency.

When carrying out conducted emission measurements in the frequency range, frequency ≥ 30MHz, where the radiation limits are given in µVolt/meter, measured at 10 meter distance, the following approximation can be applied:

E_{limit} = 30 dBµV/m (= 30µV/m) at 10 meter distance from the object.

$E = (7/d).\sqrt{(P_t)}, \quad P_t = U^2/150\Omega$

$E = (7/10).\sqrt{(U^2/150)} \quad = U/17.5$

E(dBµV/m) = U(dBµV) – 25dB.

In some emission standards, e.g., automotive and information technology equipment, conducted emission requirements are given over a large frequency range. Those requirements shall be adhered without any transformation.

In portable applications such as radio or television where an on-top antenna is used, functional requirements will be much more sever than the legal requirements. Those functional limits need to be measured on the product, without any annoying disturbances, and thereafter the relation given in chapter 2.6 can be applied to the found limit.

3.0 EXAMPLES

All applications, e.g., a single op-amp, a transmission/speech circuit for telephone, μP or video processor are tested on immunity with impedances (symmetrical and asymmetrical loading) at inputs and outputs applied according to the application instructions (which shall be stated in the application report!!).

When these (input, output) impedances are passive, they can be either outside or inside the workbench Faraday cage. When these are active, they should be outside. When coaxial feed-throughs are used, care must be taken by additional measures (low-pass-filters; see Figure 7) that the RF-energy which will be superimposed on either input or output lines does not adversely affect the performance of the auxiliary equipment **and** that by measures the source or load impedance remains properly defined (even at RF).

The signal wires going from the application board to the feed-through connectors or filters shall be provided with an RF-blocking impedance, represented by 14–17 turns on a 4C65 (frequency ≥ 1MHz) or better 4A15 ferrite toroid.

By means of three 100Ω resistors (PR 37 or PR 52, or equivalent power metal film resistors), the common of the input, output and supply is then coupled to the three coaxial feed-through connectors as indicated in paragraph 2.3. Externally, these connections are either coupled to the RF-disturbance generator, the selective voltmeter or terminated by a 50Ω coaxial resistor.

NOTE 7: The layout of the PWB shall be made such that either the typical performance of the circuit is tested (non-optimized mono- or bi-layer) or on, e.g., multi-layer with every precaution taken to have optimal EMC performance of the IC in this application.

NOTE 8: If the latter application cannot satisfy the EMC requirements, then no designer/customer will be capable of making a proper product with it at reasonable costs.

3.1 Audio applications

3.1.1 Immunity

The audio circuit shall be set at nominal (gain) conditions. When necessary or obtainable, a 1kHz generator can be used to make the required setting. The baseband 1kHz output signal across the normal load shall be measured. This level will be taken as a reference for the immunity performance testing.

The disturbance signal (RF, 80% modulated by 1kHz) shall be applied to one of the common-ports of the PWB under test in turn, while the other ports are terminated to reference by 50Ω. A demodulated signal level (1kHz only) of 40dB less than the nominal signal level across that load is acceptable for proper operation. This level can be measured either by a low frequency spectrum analyzer or a sensitive AC-Voltmeter with a 1kHz band-pass in front (as described in EN 55020). A typical pass-band bandwidth of 500Hz is sufficient for these kins of measurements.

Example: The nominal level o the a,b-lines of a telephone system is 100mV (across 600Ω). The signal level across the earpiece can be measured and may be 30mV (example only!!, determined by dynamic sensitivity of the earpiece). The level of the demodulated signal across that same earpiece, with the disturbance signal applied to the PWB shall be less than 0.3mV.

3.1.2 Emission

In most cases the emission from linear applications is nil unless it contains some oscillator. In the latter case, the disturbance generator shall be replaced by a spectrum analyzer covering the frequency range of interest, commonly 9kHz to 1GHz. As the emission will be continuous (at the fundamental and its harmonics), the detector chosen in the spectrum analyzer will not influence the readings. Where possible, the bandwidth requirements as stated in IEC CISPR publication 16 shall be adhered.

3.2 Video applications

3.2.1 Immunity

With video applications it will be such that most applications are based on an interlaced video frame sequence of 25 or 30Hz. In both situations the spectrum around 1kHz is fully crowded by harmonics of the frame frequency. It is therefore, that the modulation frequency, nominal 1kHz should be shifted a little up/down such that it becomes an inter-harmonic of the frame frequency.

Examples: 25Hz → 987.5Hz
30Hz → 1005Hz

To obtain nominal settings of the video application, a color bar signal is applied to the circuit to be fully operational.

The demodulated signal at the outputs, e.g., CVBS, RGB, or sync. can be measured by using a spectrum analyzer with a resolution bandwidth of ≤ 6Hz. This selectivity is required to obtain a signal-to-noise ratio sufficient to discriminate the demodulated signal from the wanted signal. Here the demodulated signal to nominal signal $level_{(peak\text{-}to\text{-}peak)}$ ratio has to be about –55 to –60dB to be just not perceptible on the screen. This limit level can be found by superimposing a 1kHz signal to the normal signal while observing the picture. The 1kHz generator level is increased up to a level where it becomes just perceptible on the screen. This level referred to the functional signal is then taken as limit for the signal-to-interference ratio (S/I).

> **NOTE 9:** Special care shall be taken to assure that the demodulation of the spectrum analyzer is much less than the limit level to be measured. Additional low-pass filters (see Figure 7) may be required! Furthermore, it may be necessary to use a comb-filter to lower the level of the frame harmonics.

Example: The video signal level of the G-signal from the processor board to the video output stage is $3600mV_{P\text{-}P}$. Then the demodulated signal shall be less than $3.6mV_{(peak)}$.

> **NOTE 10:** Disturbing signals may also effect synchronization and as such appear as vertical zig-zag lines on the screen. This effect can only be measured by using a jitter or phase modulation meter between sync-out of the pattern generator and the output signal coming form the PWB.

3.2.2 Emission

As indicated above, emission from the PWB is measured by replacing the disturbance generator by a spectrum analyzer or selective voltmeter. In analog applications, emission will be caused by the video signal itself and some oscillator signals used for demodulation, mixing, etc. According to the emission standard EN 55013, the test page pattern of teletext shall be used as video information. Where possible, the bandwidth and detector requirements as stated in IEC CISPR publication 16 shall be adhered.

3.3 Digital applications

3.3.1 Immunity

With digital applications, the main problem will be the fact that it needs wide address and data buses for operation. As these wide buses are inconvenient for this method, these shall be limited by simplifying the circuit or by introducing parallel-to-serial and serial-to-parallel decoders. Preferable, these decoders must be used on the PWB under test such that only one serial line will be fed through the wall of the cage. To isolate the decoders from the IC under test, series resistors, e.g., 1kΩ, shall be used in-between the decoders and the IC. The common-mode points on the PWB needs to be chosen close to the IC to be tested instead of the **serial decoder** input and output ports indicated in chapter 2.4.

By means of a tap, the signals at the output of the IC shall be monitored by means of an oscilloscope or a logic analyzer with an analog input and adjustable threshold levels. As criteria, the output signal of the IC may not exceed the specified high/low levels other than during functional transitions.

When testing the inputs, the worst case DC-levels shall be superimposed to the input signal (if it does not already contain a DC-component from a previous stage). When the disturbance signal is applied to the common-mode points chosen, the signal levels at the outputs shall be observed.

With more complex circuits it can be such that analog **and** digital inputs and outputs are available. By closing the loop; data → digital out → digital in → analog out → analog in → compare with initial data and turn on/off a flag, which drives a LED, a powerful test program is carried out.

3.3.2 Emission

For proper operation, the normal program or coding shall be applied to the IC such that the emission measured is representative for a typical application. In case of a microprocessor, the outputs can be driven such that a digital ramp function (bit 0 = frequency F0, bit 1 = F0/2, etc.) is generated over its 4, 8, or 16 bits wide data bus. All buses will have typical length, e.g., 0.1 meter. The end of the bus shall be terminated as indicated in the application report, e.g., by 50pF//3.3kΩ. The common-mode points for the IC under test shall be taken (similar as with immunity) to measure the emission performance of the IC in its application.

4.0 THE WORKBENCH CAGE PARAMETERS

The size of the workbench Faraday cage is chosen in such a way that it can contain most typical application and evaluation boards:

Length : 500mm
Width : 350mm
Height : 150mm

The Workbench Faraday cage is made from carbon-free iron 1.5mm thick. A conductive gasket is used between the box and the cover to make proper contact. The inside of the box is covered with an anti-static insulating material.

The connections through the wall can be made by:

Coax	:	5 x BNC
Single line	:	4 x π-filter, (2 x 1.35nF + 8μH, 2 Amp., 50 Volt max.),
		6 x Feed-through capacitors, (62nF, 16 Amp., 500 Volt max.).

The shielding effectiveness in $H_{x,y,z}$ directions is better than 60dB in the frequency range 1 to 1000MHz, measured with two 60mm electrically shielded loops according to Mil. Std. 220. An example of the shielding effectiveness of the workbench Faraday cage is given in Figure 10.

The characteristics of the π-filters (Low-Pass-Filter at 1MHz) and the feed-through capacitors are given in Figure 11. The choice for these filters is made such that by additional external measures the filtering performance can be enhanced at low frequencies. For most applications, the given performance will be sufficient. These π-filters can also be used at the outputs of digital circuits when using a 100Ω resistor in series. In this case, the pass-band is limited to about 500kHz, which is still sufficient to allow, for instance, I^2C communication.

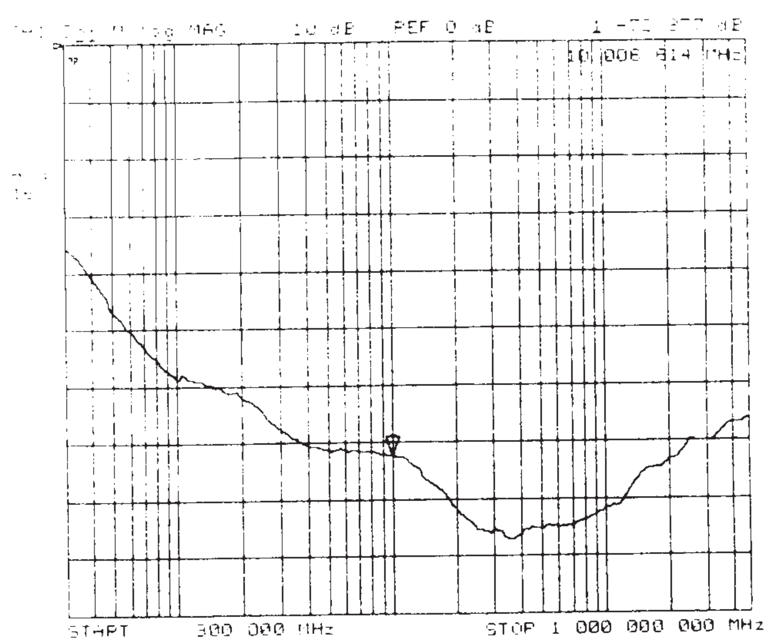


Figure 10. Shielding effectiveness of the workbench Faraday cage

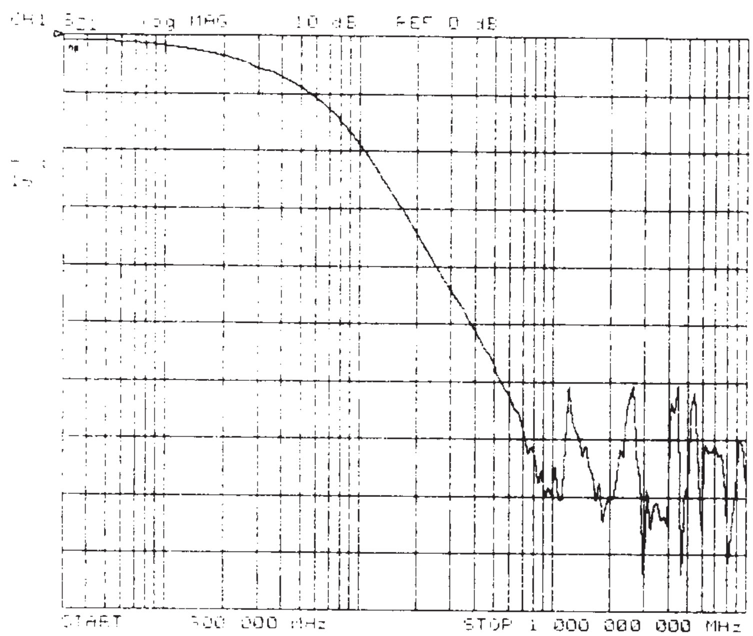


Figure 11. Performance of the π-feed-through filter used with the workbench Faraday cage

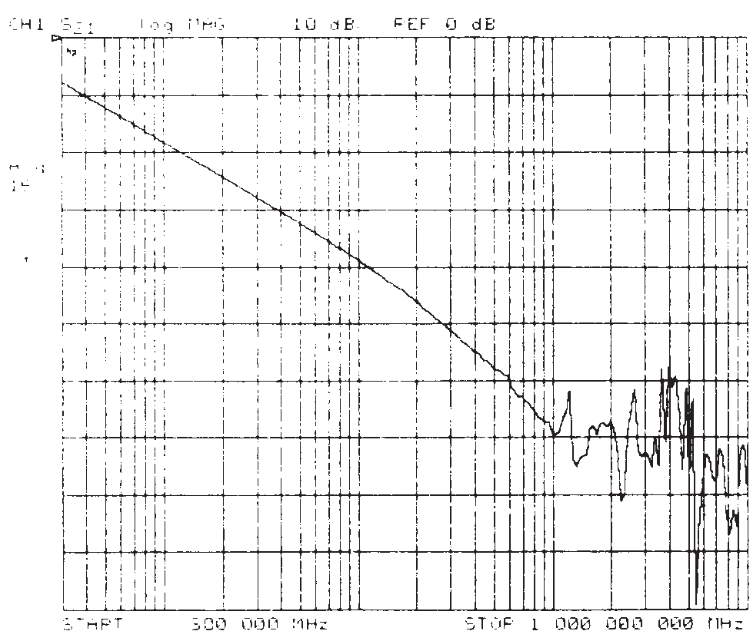


Figure 12. Filter performance of the feed-through capacitor used with the workbench Faraday cage

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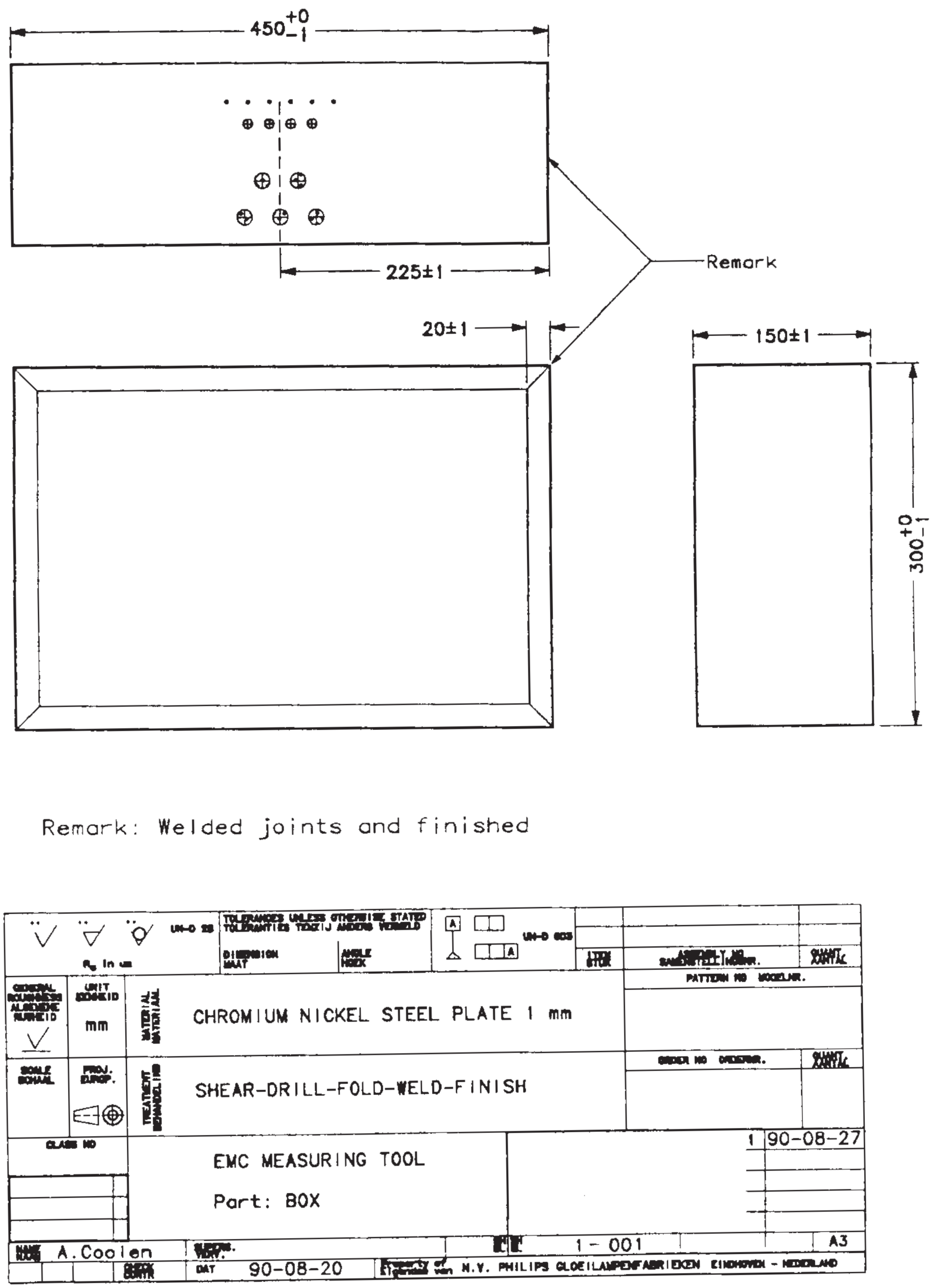

Figure 13. Drawing of the workbench Faraday cage

Workbench EMC evaluation method

EIE/AN91001

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