# Screening effectiveness and transfer impedance of surge protection components in the installed condition


White Paper

HUBER+SUHNER

# Introduction

While the world's militaries increasingly rely upon seamless wireless communication networks for multi-domain battlefield readiness, protecting these mission critical networks from disruption and catastrophic failure becomes paramount.

Conversely, the ability to utilize Electronic Warfare (EW) tactics to incapacitate and/or destroy enemy offensive engagements and Command, Control, Communications, Cyber, Combat Systems, Intelligence, Surveillance and Reconnaissance (C5ISR) activities is critical to military preparedness in the 21st century. The ever-increasing reliance on wireless communication in developed nations – the control of electronic grids and infrastructure, the flow and security of data, and the increasing autonomy of Defense systems – provides a daunting indication of the damage a critical network disruption or failure could wreak on a vulnerable grid.

While there are various types of „soft" EW tactics designed to temporarily disrupt C5ISR networks, missile guidance systems, navigation systems and jamming equipment (anti-jamming), more focus needs to be placed on the protection of mission critical circuitry from destructive (hard) EW measures.

Today, Fast Electromagnetic Pulses (EMP) and High Power Microwave (HPM, narrow- and wide-band electromagnetic sources) are the most critically dangerous electromagnetic attack mechanisms employed by militaries worldwide. The integration of HPM, also known as Directed Energy Weapons (DEWs), have been effective as drone and missile countermeasures. High-power microwave emitting devices are designed to enter enemy targets through an antenna or sensor aperture to disrupt, incapacitate, or destroy sensitive circuitry and eliminate the threat.

Fast EMP produced by nuclear bursts can be just as disabling and are classified by a number of terms, including: NEMP, HEMP, Exo-NEMP (Exoatmospheric NEMP), Endo (low altitude) NEMP, SREMP (Source Region EMP) and SGEMP (System Generated EMP). The definitions of these pulses are outlined in many national defense standards as well as International Electrotechnical Commission Standards (IEC) for the protection of civil facilities against spectral threats. The NEMP frequency spectrum can reach up to several hundred MHz. At this frequency band, the resultant energy can easily enter a myriad of widely used communications equipment typically via antennas, as well as wired connections and shelters that are not carefully shielded.

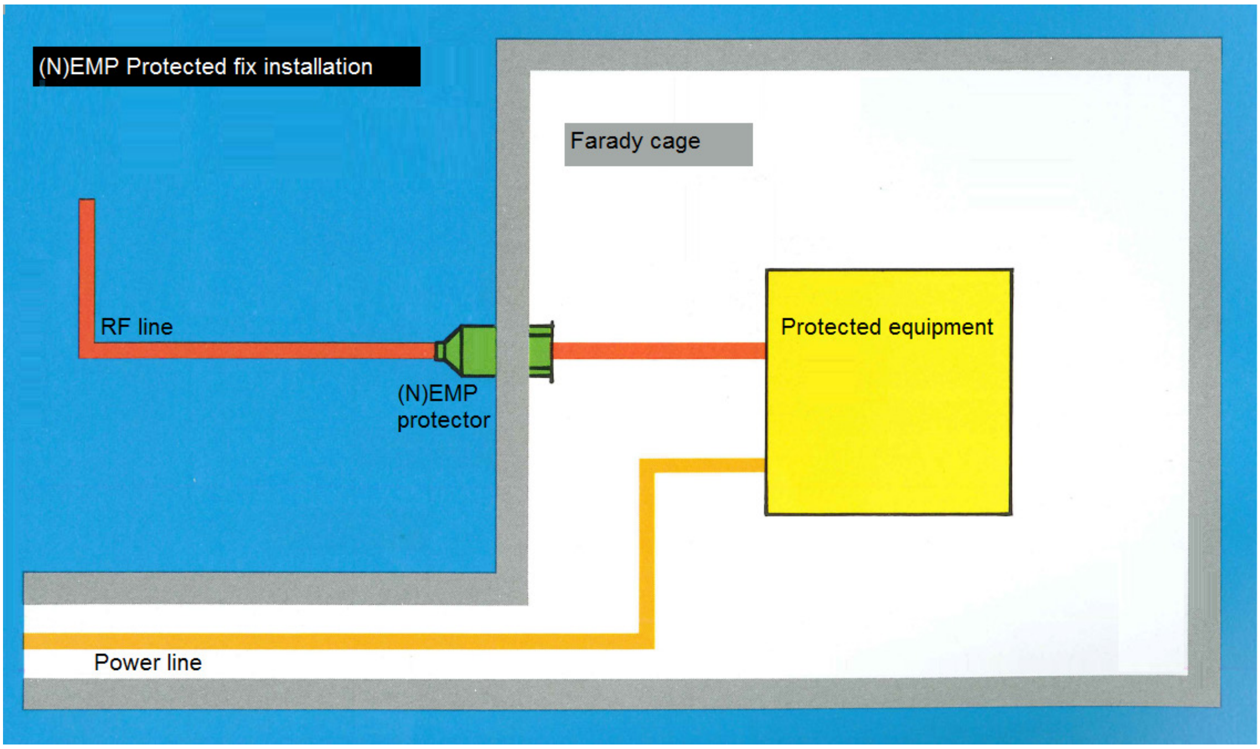
Generally, the protection against EMP must follow the rules set forth by MIL-STD-188-125. This standard establishes the minimum basic requirements and goals for grounding, bonding and shielding of ground-based communications equipment installations, subsystems and facilities including buildings and structures with their infrastructures.

The protective measures include stringent shielding (metallic enclosure or Faraday cages) and EMP protective devices for all conductive ports of entry (PoE). The screening effectiveness and contact resistance of the EMP protective devices are important in order to integrate these components into the metallic enclosure or a Faraday cage, without degrading the shielding effectiveness of the facility shield or falling short of the minimum requirements.

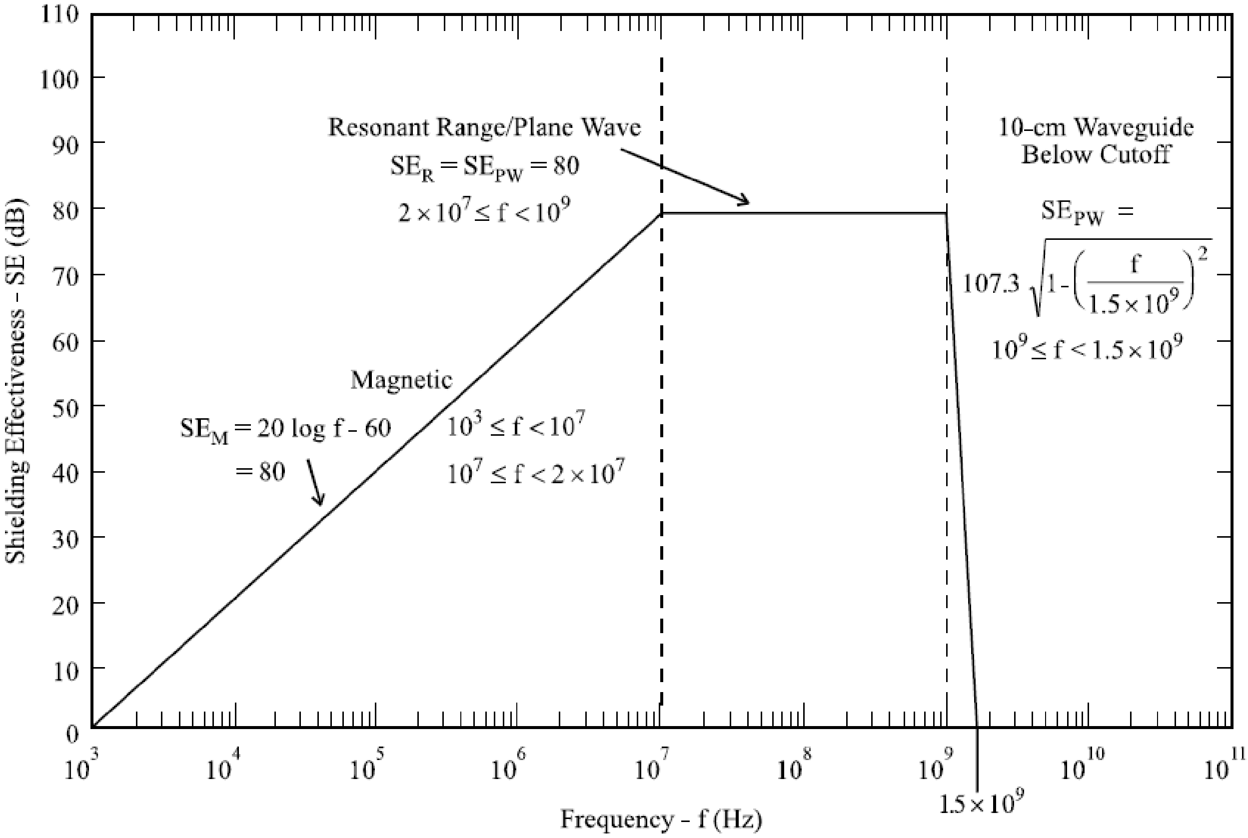
This white paper examines and quantifies the effects, depending on the selection of design, material and the chosen installation method of (N)EMP protectors, on the shielding attenuation and on the transfer impedance in EMP qualified systems.

# 1 Protection of electrical equipment against electromagnetic fields

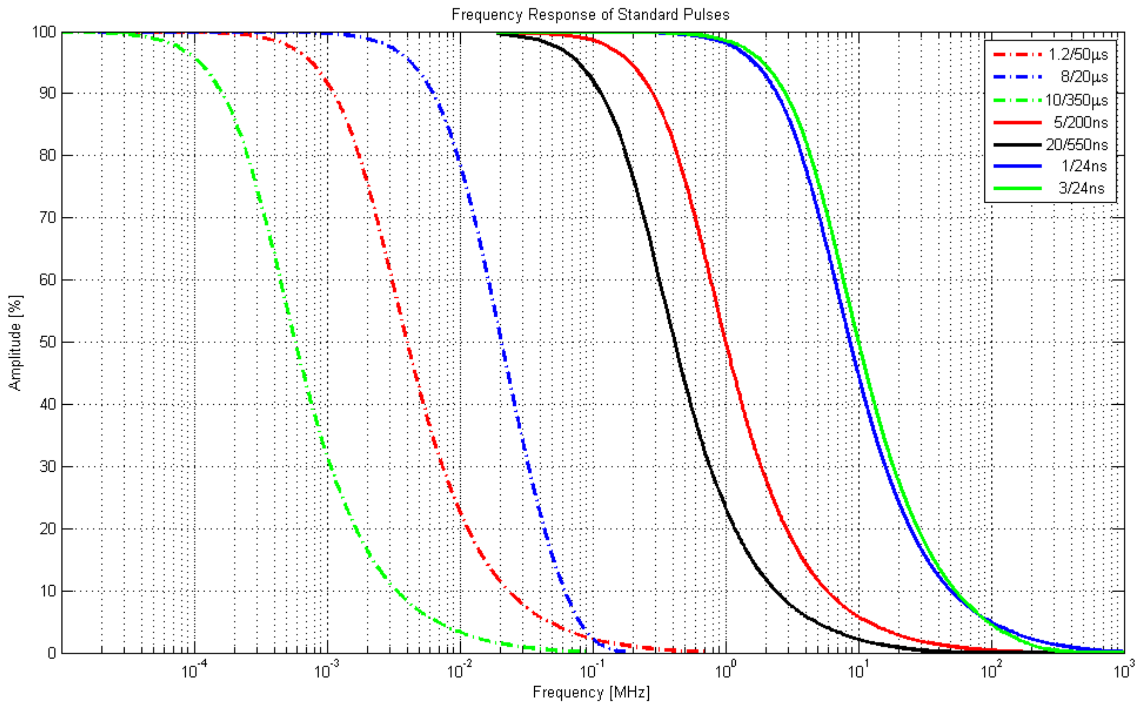
Equipment which must be protected from the negative effects of electromagnetic fields such as (N)EMP must be integrated within specially shielded rooms or housings (Faraday cage). These can be bunkers, fixed installation containers, vehicles or equipment chassis.



According to MIL-SDT-188-125 part 1 and part 2, the screening efficiency of these rooms must achieve a minimum level of 80 dB for frequencies ≥ 10 MHz. This stringent requirement can be met by implementing specific structural measures.



The following graph shows the frequency response and the relative amplitude of various standardized pulses.




The picture shows that, at frequencies > 1000 MHz, there is no need to worry about destructive coupling from Lightning or NEMP pulses into the Faraday cage.

**1.2/50 µs:** Frequency spectrum of the indirect lightning pulse (voltage) acc. to IEC 61000-4-5 and VG 96903-76

**8/20 µs:** Frequency spectrum of the indirect lightning pulse (current) acc. to IEC 61000-4-5 and VG 96903-76

**10/350 µs:** Frequency spectrum the direct lightning pulse (current) acc. to IEC 62305

**5/200 ns:** Exo-NEMP frequency spectrum acc.:
- MIL-STD-188-125-1 and MIL-STD-188-125-2
- VG 96903-80

**20/500 ns:** Exo-NEMP Earl time waveform (E1) frequency spectrum acc. MIL-STD-188-125-1

**1/24 ns:** Exo-NEMP frequency spectrum acc. to:
- VG 96903-78 resp. VG 96903-80 threat level „normal“

**3/24 ns:** Exo-NEMP frequency spectrum acc. to:
- VG 96903-78 resp. VG 96903-80 threat level „high“

Any point of entry into an EMI protected room can have a negative impact on the screening effectiveness. If successful, it becomes difficult to meet the requirements given in MIL-STD-188-125. It is therefore of utmost importance that the installation of cable entries and (N)EMP protection components is carried out in a highly calculated manner in line with the latest EMI / EMC installation rules. In particular, the exclusive use of products that offer a screening efficiency >> 80 dB when installed is recommended.

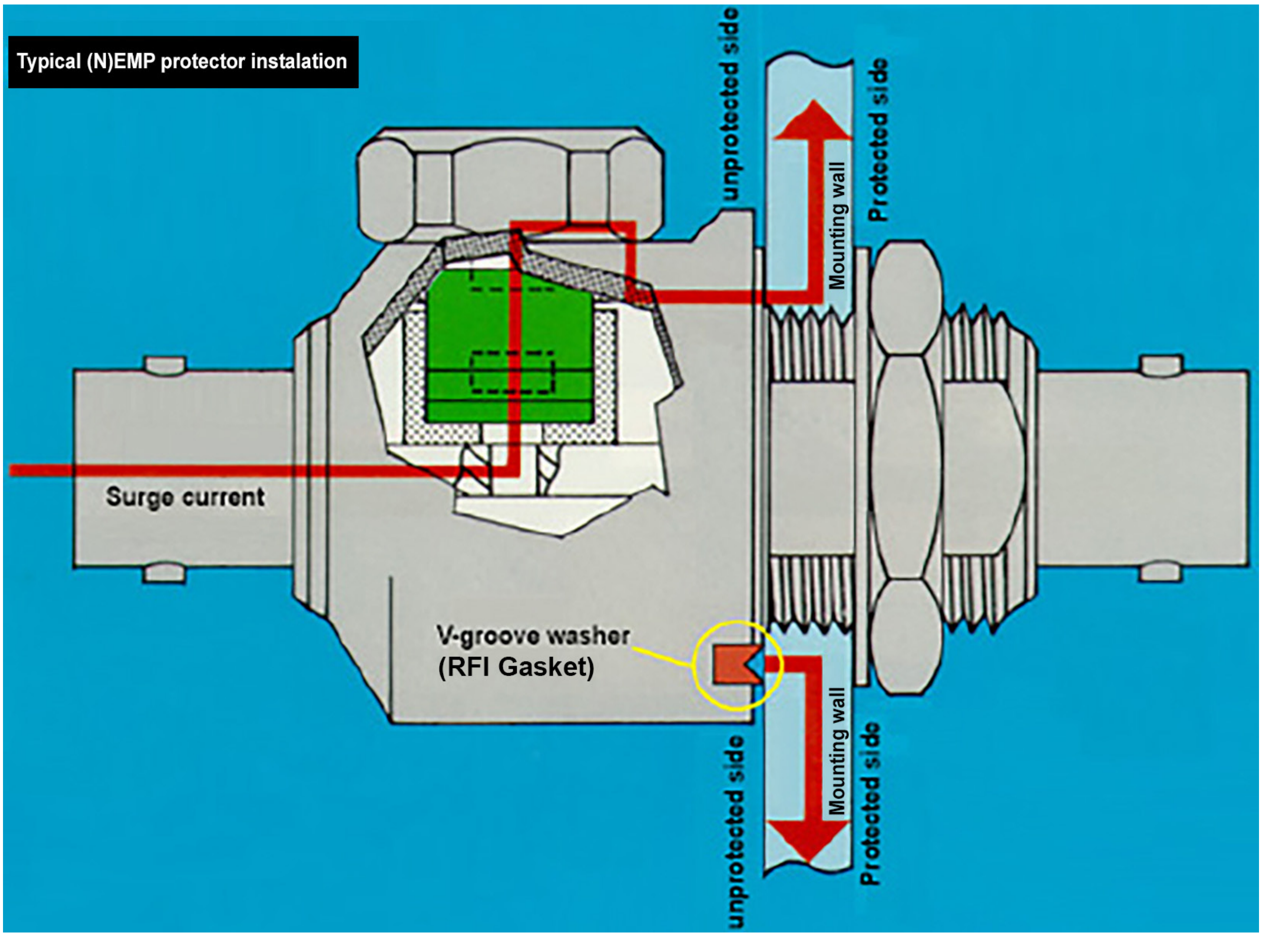
One must also consider the fact that each additional entry into the Faraday cage will impair the protective shield and that, consequently, each additional cable entry will downgrade the Faraday systems screening efficiency.

When looking at a typical coaxial (N)EMP protector the transition from the protector housing to the wall of the faraday cage is essential. To reach a high screening effectiveness between the unprotected and the protected area of an installation this transition must be realised with low-inductance and low-resistance. In addition it must be ensured that these values will stay stable over the full lifetime of the system.

The described contact resistance is known as “transfer impedance“.

Typical (N)EMP protector

Typical installation of a (N)EMP protector:



# 2 Transfer impedance versus screening efficiency

The transfer impedance ($Z_T$) can be converted from the measured screening efficiency ($a_s$) as follows:

| Screening Attenuation [dB] | Transfer Impedance [mΩ] in a 50Ω system |
|---|---|
| 0 | 25000 |
| 5 | 14100 |
| 10 | 7910 |
| 15 | 4450 |
| 20 | 2500 |
| 25 | 1441 |
| 30 | 791 |
| 35 | 445 |
| 40 | 250 |
| 45 | 141 |
| 50 | 79.1 |
| 55 | 44.5 |
| 60 | 25 |
| 65 | 14.1 |
| 70 | 7.91 |
| 75 | 4.45 |
| 80 | 2.5 |
| 85 | 1.41 |
| 90 | 0.791 |
| 95 | 0.445 |
| 100 | 0.25 |
| 105 | 0.141 |
| 110 | 0.0791 |
| 115 | 0.0445 |
| 120 | 0.025 |
| 125 | 0.0141 |
| 130 | 0.00791 |
| 135 | 0.00445 |
| 140 | 0.00025 |

$$|Z_T| = \frac{|Z_0|}{2} \times 10^{-\frac{a_s}{20}}$$

$$a_s = 20 \times \log_{10} \left|\frac{2\,Z_T}{Z_0}\right|$$

$a_s$ = screening efficiency $[dB]$

$Z_0$ = 50 Ω

$Z_T$ = transfer impedance $[m\Omega]$

**Note:** Transfer impedances for multiple inlets into a Faraday cage can be added. The sum of the transfer impedances can then be converted into the resulting screening efficiency of the Faraday cage.

**Example:** What is the resulting screening efficiency of 10 inlets into a Faraday cage of which each performs 100 dB screening efficiency?

| | | |
|---|---|---|
| 1) 100 dB is equal to a transfer impedance of | $Z_T$ | = 0.25 mΩ |
| 2) 10 inlets with each 0.25 mΩ => | $Z_T$ (total) | = 2.5 mΩ |
| 3) $Z_T$ (total) = 2.5 mΩ => | resulting screening efficiency 80 dB | |

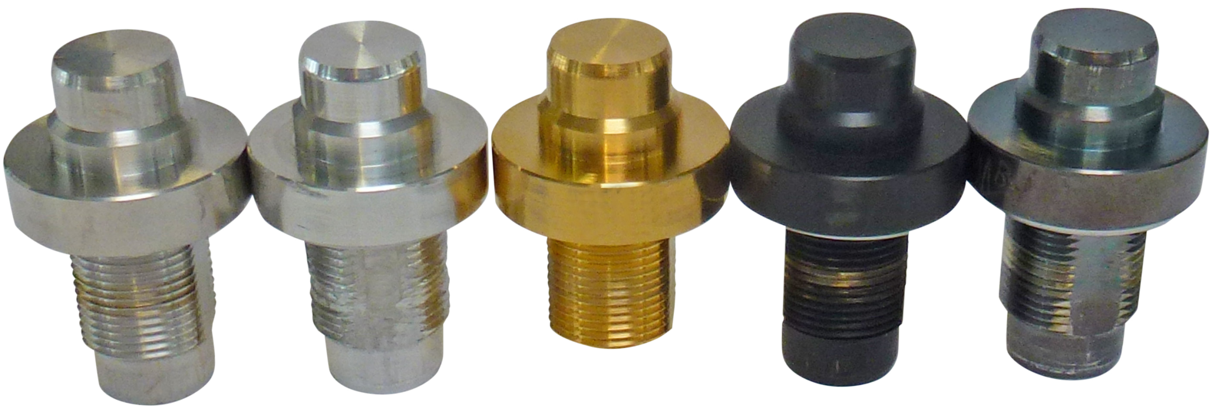
# 3 Test setup

To identify the best possible method to install (N)EMP protectors or other coaxial feed through components, HUBER+SUHNER has carried out a series of transfer impedance measurements acc. to IEC 62153-4-10[1]. The transfer impedance must be as low as possible and as stable as possible. The test series was performed with a combination of different test specimens. These test specimens simulate various installation approaches, various sample materials with different plating and various installation wall materials.

The following table and photos show the various test specimens:

| **Housing test specimen** | | **Mounting flange** | **Wall material of the Faraday cage** |
|---|---|---|---|
| **Material** | **Plating** | 1-hole flange without V-groove washer<br>1-hole flange with V-groove washer<br>4-hole flange without V-groove washer | Stainless steel<br>Copper<br>Aluminium |
| Brass | SUCOPLATE[2] | | |
| Brass | Black Silver | | |
| Brass | Gold | | |
| Brass | Black Chrome | | |
| Aluminium | Not plated | | |

Housing test specimen and plating variations:

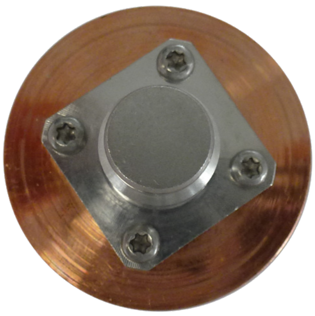


| Brass | Aluminium | Brass | Brass | Brass |
|---|---|---|---|---|
| SUCOPLATE | Not plated | Gold plated | Black Chrome | Black Silver |

1 IEC 62153-4-10 "Metallic communication cable test methods – Part 4-10: Electromagnetic compatibility (EMC) – Shielded screening attenuation test method for measuring the screening effectiveness of feed-throughs and electromagnetic gaskets double coaxial method"
2 SUCOPLATE® (CuZnSn)

Different mounting options:

1-hole flange



4-hole flange

V-groove washer
(RFI-gasket)

Different wall materials:

Stainless steel wall

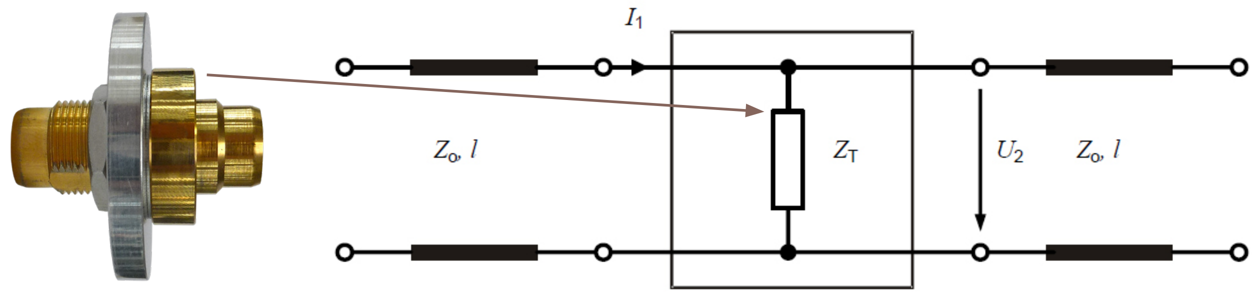
Copper wall

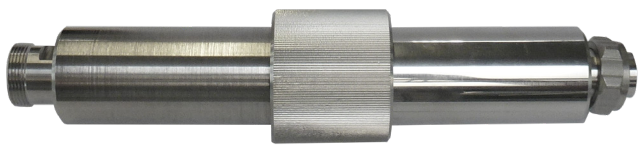
Aluminum wall

# 4 Transfer impedance acc. to IEC 62153-4-10

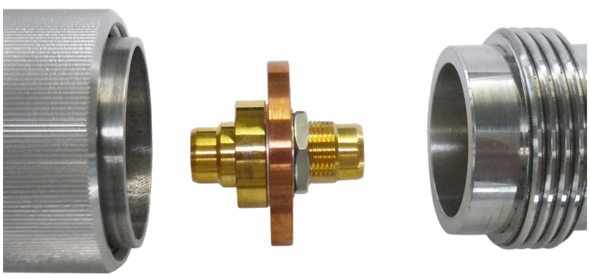
To verify the screening effectiveness or screening attenuation the test specimens were installed in a test tube (see below). At one end of the tube the RF signal is fed into the DUT and at the other end the voltage drop over the DUT is measured. The outcome of this is the screening efficiency of the test specimen.

Test setup to determine the screening effectiveness / transfer impedance (IEC 62153-4-10):



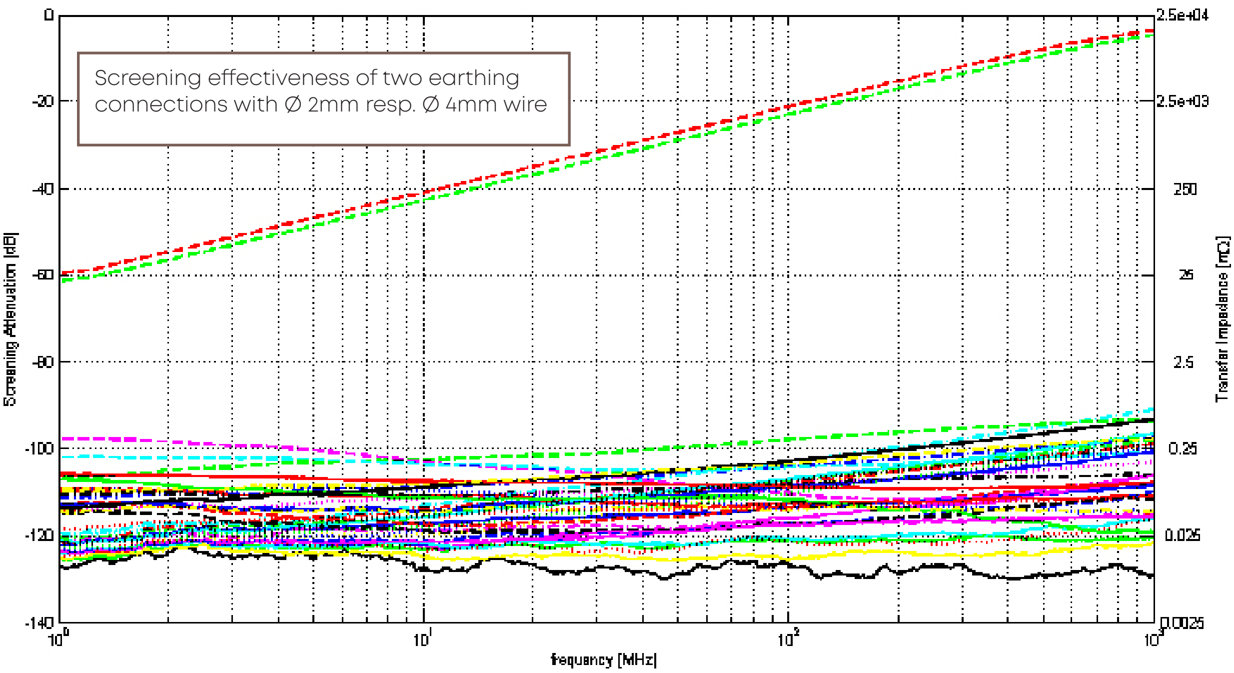
Closed test tube



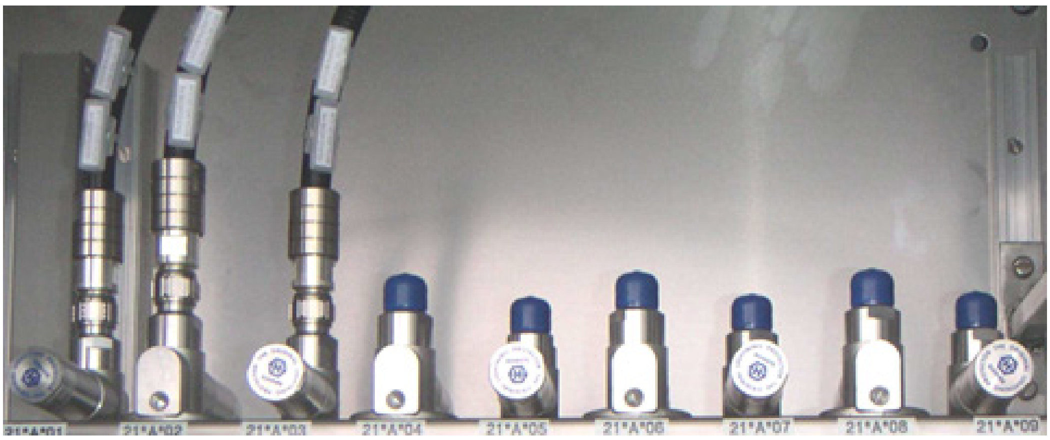
Open test tube with DUT
Test specimen: Brass gold plated
Wall: Copper

# 5 Test results

The analysis of the different material combinations shows a wide variation of the measured screening attenuation (effectiveness). All combinations meet the minimal screening effectiveness > 80 dB which is given in MIL-SDT-188-125 Part 1 and Part 2.

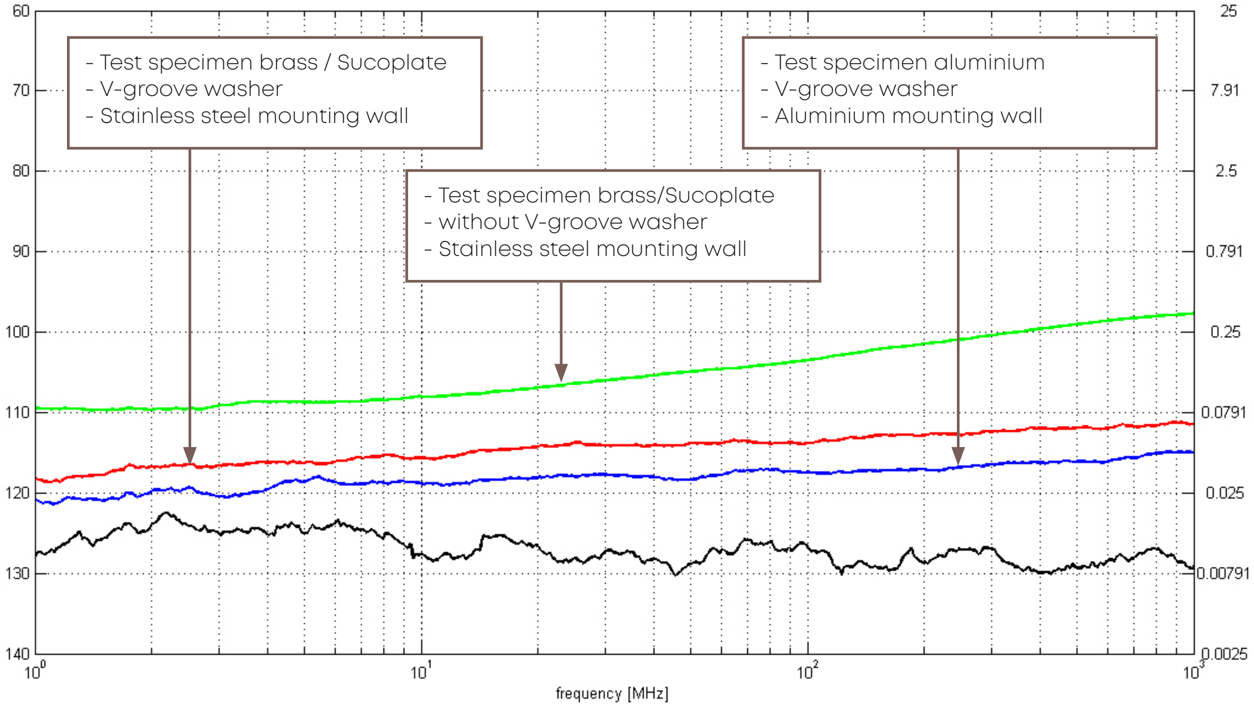



However, if we take into account that it is often necessary to route a large number of cable entries into a Faraday cage (nine in the picture below) it becomes evident that one should select the optimum material combination.



The screening effectiveness of an installation is calculated by adding the transfer impedances of all existing cable entries. The sum of these transfer impedances can then be converted into the resulting system screening effectiveness.

### 5.1 Comparison of the screening efficiency of installations with and without V-groove washer




**The advantages of the installation with the V-groove washer**
The V-groove washer made from soft copper offers the advantages of guaranteeing optimum contact resistance. It meets IP65 and when installed correctly, it provides long-term stability. It is fundamental to insert an unused V-groove washer whenever the bulkhead connection has to be opened. It is fundamental here to insert an unused V-groove washer whenever the bulkhead connection had to be opened. A further positive feature of the V-groove washer is that it can compensate for minor unevenness (scratches) in the mounting wall.

The mounting principle of the 1-hole flange with additional soft copper V-groove washer supports good screening effectiveness under (N)EMP interference. Such an installation is stable in the long term and guarantees IP65. However, to guarantee good screening effectiveness it is mandatory to install the components with the specified torque values. All tests were executed with an N7 wall surface finish.

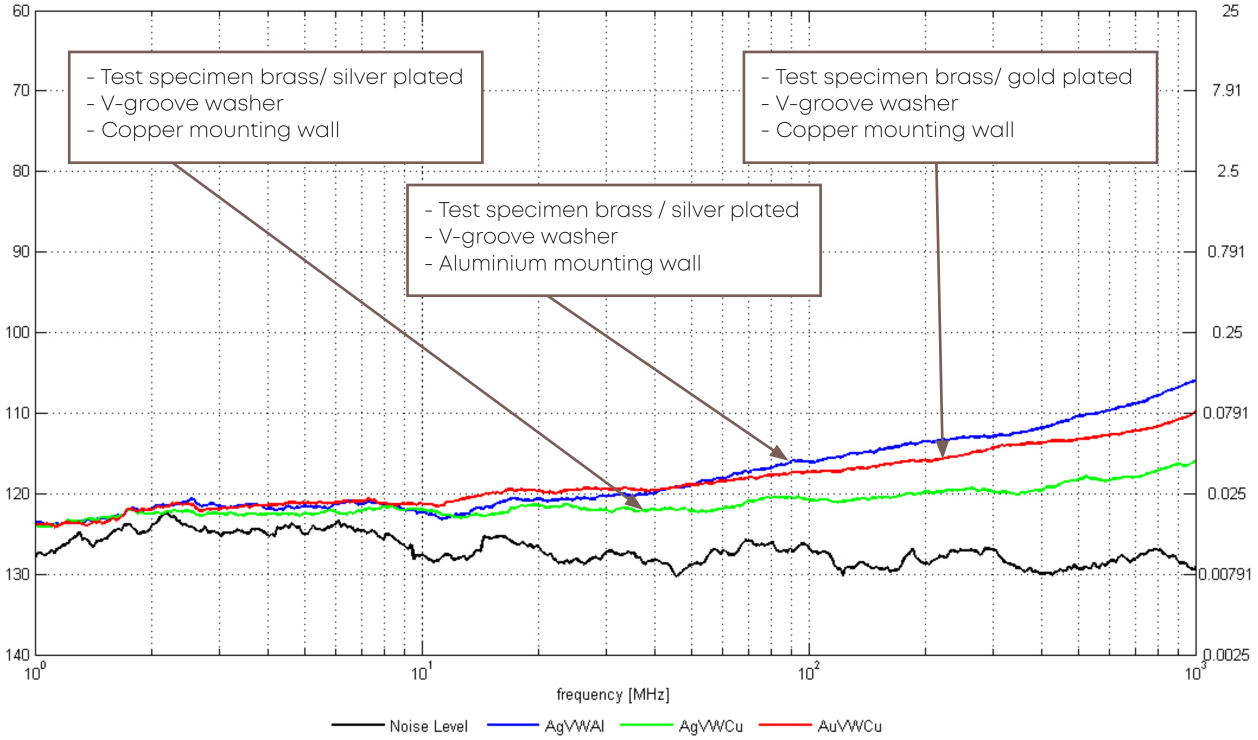
**The disadvantages of the installation without V-groove washer**

If a 1-hole flange is butt jointed onto a mounting wall without a V-groove washer, the screening effectiveness is reduced by up to 20 dB in the (N)EMP environment. In this case the material combination is an additional factor to consider. An installation without a V-groove washer is not considered to offer long-term stability. Water or humidity can penetrate and create corrosion in the contact area between the mounting wall and the feed through housing.

**The disadvantages of installing a 4-hole flange without a V-groove washer**

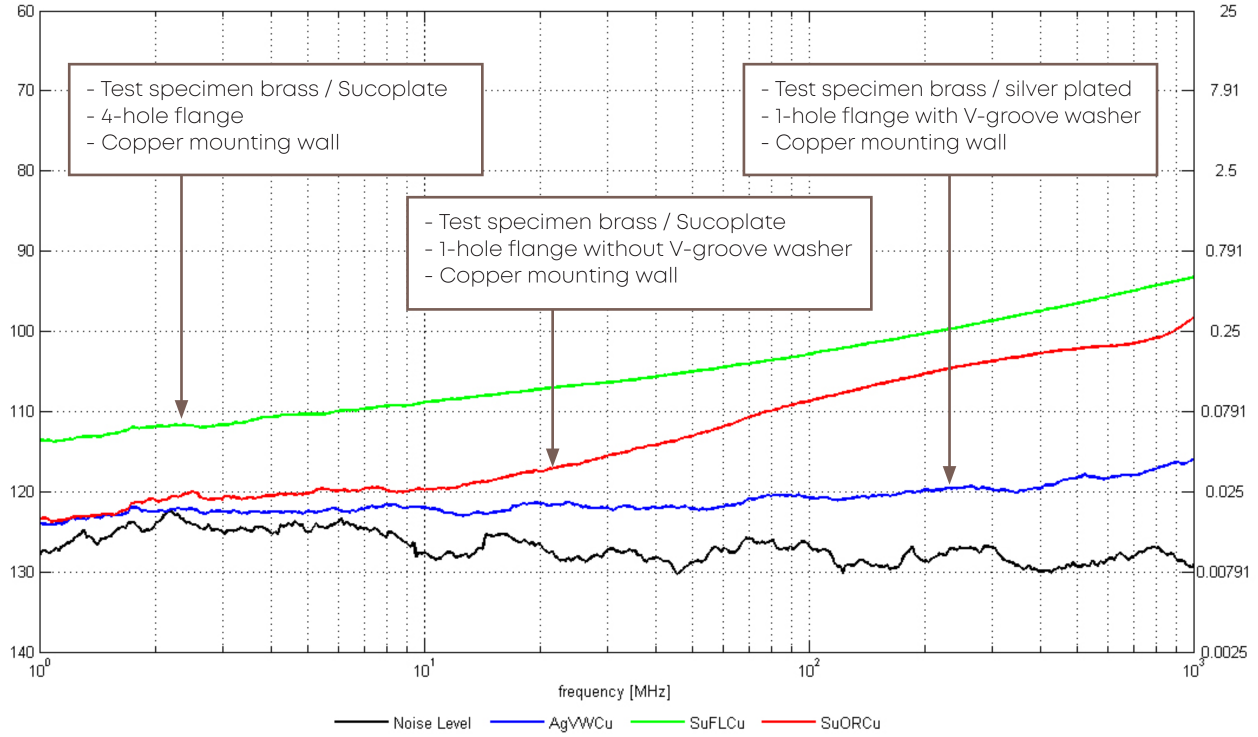
The installation using a 4-hole flange without a V-groove washer shows the worst results of all tested combinations (see also chapter 5.3). The contact pressure with only four screws from flange to mounting wall is not sufficient to keep the transfer impedance to a low enough level. Additionally, one must take into account here that the screening effectiveness of this installation principle will degrade over time.

### 5.2 Comparison of the screening efficiency of different test specimens installed on various wall materials



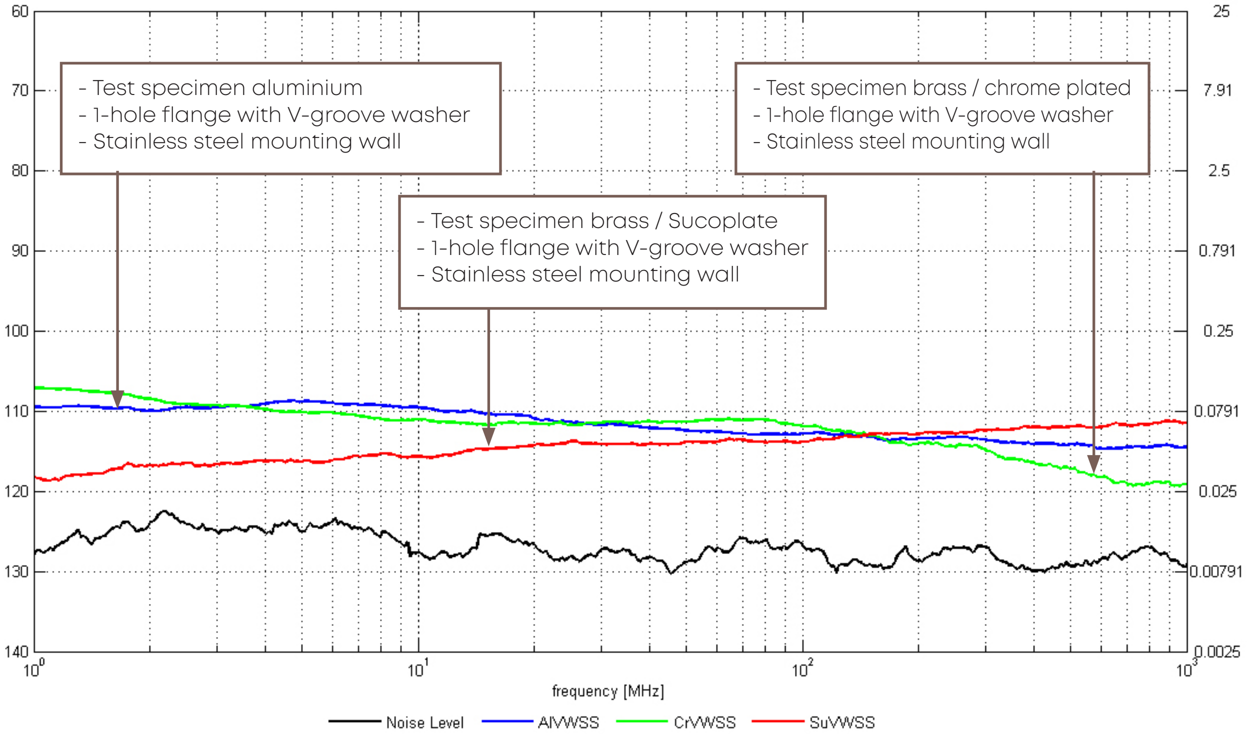

The three material combinations shown in the above graph exhibit the best performance in the entire series of measurements. The combination of an aluminium test specimen on an aluminium wall, which gives the same good results, is not shown in this chart.

**5.3 Comparison of the screening efficiency of test specimens with different flange mounting options**




The direct comparison between the 4-hole flange installation (without V-groove washer) and the 1-hole flange installation (with and without V-groove washer) clearly indicates how poorly the 4-hole flange performs. It is not possible to achieve sufficient contact pressure with four screws. The result could potentially be improved by adding a soft copper washer and the necessary milled slot into the flange.

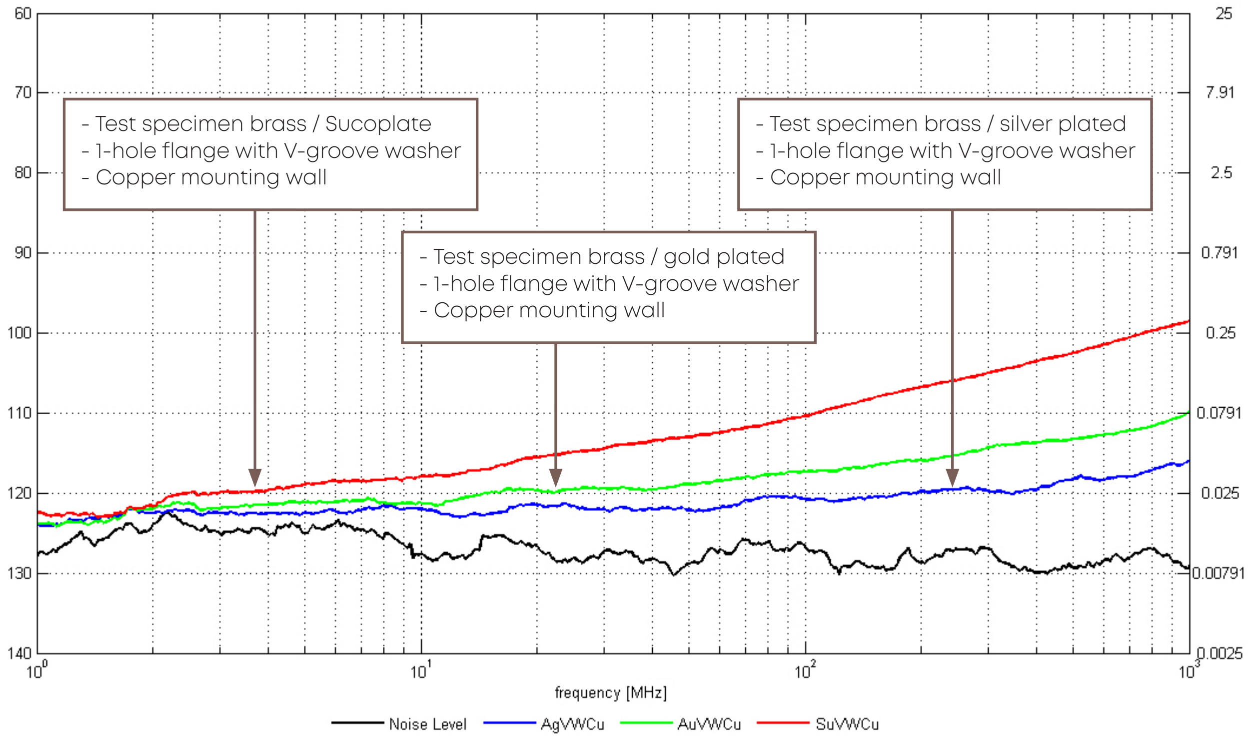
### 5.4 The three best performing test specimens installed on a stainless steel wall




The least qualified combinations of those tested on a stainless steel wall are:

- brass / gold plated specimen (worst combination)
- brass / silver plated (second worst combination)

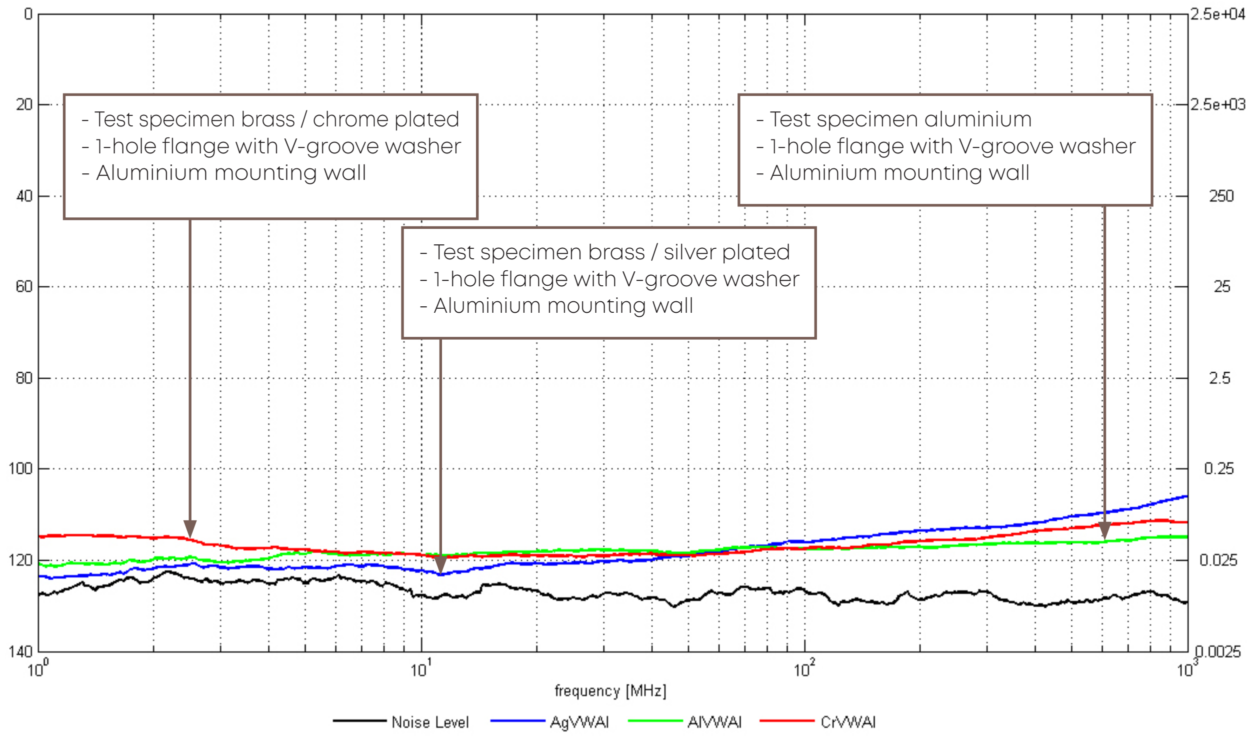
### 5.5 The three best performing test specimens installed on a copper wall




The least qualified of the tested combinations on a copper wall are:

- aluminium (worst combination)
- brass / chrome plated (second worst combination)

### 5.6 The three best performing test specimens installed on an aluminium wall




The least qualified of the tested combinations on an aluminium wall are:

- brass / gold plated (worst combination)
- brass / SUCOPLATE (second worst combination)

# 6 Summary

### 6.1 Qualitative summary

Ranking of the tested combinations:

| | | | Wall material | | |
|---|---|---|---|---|---|
| **Base material** | **Plating** | **Contact area** | **Copper** | **Stainless steel** | **Aluminium** |
| Brass | SUCOPLATE | 1-hole flange **with** V-groove washer | ● ● | ● ● ● | ● ● |
| Brass | Black Silver | | ● ● ● | ● | ● ● |
| Brass | Gold | | ● ● ● | ● | ● ● |
| Brass | Black Chrome | | ● ● | ● ● ● | ● ● ● |
| Aluminium | Not plated | | • | ● ● | ● ● ● |
| All materials and platings | | 1-hole flange **without** V-groove washer | • | • | • |
| All materials and platings | | 4-hole flange **without** V-groove washer | • | • | • |

● ● ● excellent material combination

● ● recommendable combination

● only recommendable under certrain conditions

• this combination is not recommended for security-relevant systems

### 6.2 Quantitative summary

Screening effectiveness: V-groove washer included in all combinations

| | **Base Material** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Brass with plating** | | | | | | | | **Aluminium** | |
| | Black silver | | Black chrome | | SUCOPLATE | | Gold | | Unplated | |
| **Mounting wall material** | 1 - 99 MHz | 100 - 1000 MHz | 1 - 99 MHz | 100 - 1000 MHz | 1 - 99 MHz | 100 - 1000 MHz | 1 - 99 MHz | 100 - 1000 MHz | 1 - 99 MHz | 100 - 1000 MHz |
| Copper | **> 120 dB** | **> 115 dB** | > 105 dB | > 100 dB | > 110 dB | > 98 dB | **> 120 dB** | **> 110 dB** | > 100 dB | > 90 dB |
| Stainless steel | > 100 dB | > 95 dB | > 105 dB | > 110 dB | **> 113 dB** | **> 110 dB** | > 95 dB | > 90 dB | > 105 dB | > 110 dB |
| Aluminium | > 115 dB | > 105 dB | **> 113 dB** | **> 110 dB** | > 105 dB | > 98 dB | > 105 dB | > 95 dB | **> 115 dB** | **> 115 dB** |

- We recommend the installation with V-groove washer because:

  – The V-groove washer guarantees high, long-term screening effectiveness, while at the same time protects the transition between the bulkhead and the mounting wall from corrosion.
  – The soft copper V-groove washer guarantees water tightness when mounted on wall material with an N7 surface finish.

- As single feed-through component into a Faraday cage, all the tested combinations comply with 80 dB screening effectiveness as specified in MIL-STD-188-125 part 1 and part 2.
- In combination with further feed-through components and doors or other inlets into a Faraday cage it is highly recommended to select optimum material combinations.
- Taking all tested wall materials into consideration, SUCOPLATE shows the most stable screening effectiveness results.
- Installations with 4-hole flange feed-through components are not recommended.

This paper is only an extract of a comprehensive internal test document. For questions which go deeper than the information gathered here please contact the HUBER+SUHNER AG product management team for (N)EMP products in Switzerland.

**References**


- **IEC 62153-4-10** Metallic cable test methods – Part 4-10: Electromagnetic compatibility (EMC) – Shielded screening attenuation test method for measuring the screening effectiveness of feed-throughs and electromagnetic gasket double coaxial method
- **IEC 61000-4-5** Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test
- **IEC 62305-1** Protection against lightning – Part 1: General principles
- **MIL-STD-188-125-1** High- altitude electromagnetic pulse (HEMP) protection for ground based C41 facilities performing critical, time-urgent missions Part 1 fixed facilities
- **MIL-STD-188-125-2** High- altitude electromagnetic pulse (HEMP) protection for ground based C41 facilities performing critical, time-urgent missions Part 2 transportable systems
- **VG 96903-78** Nuclear electromagnetic pulse (NEMP) and lightning protection – Test methods, test equipment and limiting values – Part 78: Direct injection of NEMP disturbing quantities via cables and cable harnesses of multi-application equipment (Test method LF 78)
- **VG 96903-80** Nuclear electromagnetic pulse (NEMP) and lightning protection – Test methods, test equipment and limiting values – Part 80: Testing of antenna terminals against NEMP and lightning interference (Test method LF 80)
- Measurement of the Shielding or Screening Effectiveness of Feed-throughs and Electromagnetic Gaskets up to 4 GHz and above by
  - Lauri Halme, Rauno Kytönen, Viktor Nässi, Mika Nupponen Helsinki University of Technology, Communications Laboratory Otakaari 5A, Espoo, Finland
  - Michael Wollitzer, Thomas Schmid, Eberhard Rodig Rosenberger Hochfrequenztechnik GmbH & Co KG Tittmoning, Germany
  - Bernhard Mund Bedea BERKENHOFF & DREBES GmbH Asslar, Germany

- **Lightning Protection Catalogue - HUBER+SUHNER AG**
- **Electro-chemical potential differences - HUBER+SUHNER AG**
- **NEMP Schutz von Bauten und Anlagen; Ausschuss EMP Arbeitsgruppe Schutzbauten**
- **General Mounting and Grounding Instruction for HUBER+SUHNER EMP Protectors**
- **Online Tools: EMP Protector Tool Box - HUBER+SUHNER AG**

# About the company

HUBER+SUHNER is a global company with headquarters in Switzerland which develops and manufactures components and system solutions for electrical and optical connectivity. With cables, connectors and systems – developed from the three core technologies of radio frequency, fiber optics and low frequency – the company serves customers in the communication, transportation and industrial sectors. The products deliver high performance, quality, reliability and long life – even under harsh environment conditions. Our global production network, combined with group companies and agencies in over 80 countries, puts HUBER+SUHNER close to its customers.

HUBER+SUHNER is well-known for its coaxial (N)EMP and lightning protection components.
The basic development of today's product portfolio was done in co-operation with the Swiss Federal Institute of Technology (ETHZ) and the Swiss Civil Defence. Large numbers of our (N)EMP protectors are implemented worldwide in defence and civil communication applications. Many of our products are listed under NATO stock numbers (NSN).

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