APPLICATION NOTE

ANP139 | Enclosure Shielding and EMC: A Comprehensive Guide to Electromagnetic Compatibility

Dr. Heinz Zenkner

1. INTRODUCTION

Electromagnetic compatibility (EMC) is essential for modern electronic devices, as it ensures interference-free operation and minimizes emissions. Enclosure shielding is a key element in this respect, as not only the device's own emissions are shielded from the outside world, but also external electromagnetic interference is attenuated. The following application note provides a detailed overview of the most important aspects of enclosure shielding in relation to EMC, and cover RF emissions, ESD protection, filter and shielding attenuation, enclosure openings, cable shield connections, as well as the effects of ground potential and eddy currents. Measures for improving shielding attenuation are discussed and evaluated by measurement.

2. BASIC PRINCIPLES OF EMC AND THE ROLE OF ENCLOSURE SHIELDING

Electronic devices emit electromagnetic waves that can interfere with neighboring systems. This particularly applies in areas such as medical, automotive and military technology, where malfunctions can have serious consequences. An optimally shielded enclosure reduces such electromagnetic emissions and protects the internal components from external sources of interference. Enclosure shielding also prevents electrostatic discharge (ESD), which can damage the electronics through sudden voltage flashovers. A high level of the shielding attenuation of the enclosure also improves the shielding effectiveness of the shielded peripheral cables connected. Furthermore, higher shielding attenuation of the enclosure makes the ground system more stable. This optimizes the limitation of transient overvoltages at the device's peripheral filters and increases filter attenuation in general, particularly at high frequencies, typically above 300 MHz. Shielding attenuation describes the ability of the enclosure to reduce electromagnetic fields. This attenuation is determined by the enclosure material, its thickness and design. High shielding attenuation ensures that less electromagnetic radiation escapes to the outside and that the internal components are better protected against external fields. It also increases the device's immunity to external electromagnetic interference and reduces the likelihood of the internal circuits being affected by external fields or malfunctions occurring. Filtering and limiting transient overvoltages are additional measures used for the targeted attenuation or reduction of specific interference levels in frequency ranges on connecting cables that leave the shielded space. In combination with enclosure shielding, this reduces overall emissions and increases the interference immunity of the system.

2.1 Enclosure openings and their effects on shielding attenuation

Enclosure openings – such as ventilation slots, plug connection points or operating access openings – represent potential weak points in electromagnetic shielding. Because electromagnetic waves can escape or enter through these openings, the overall attenuation of a enclosure can be significantly impaired. The degree of this impairment depends on various factors, including the wavelength of the interference radiation, the size and shape of the openings, as well as the conductivity of the enclosure material. These aspects are explained in greater detail below.

2.2 Dependence of leakage on wavelength and opening size

An opening in the enclosure allows electromagnetic radiation to pass through, especially if its size is comparable to or greater than the wavelength λ of the incident radiation. The relationship between the size of the opening d and the wavelength λ is described by the formula:

$$d \geq \frac{\lambda}{2} \qquad (1)$$

Openings with dimensions d (m) smaller than half the wavelength $\lambda/2$ (m) of the incident wave block significantly more radiation, as they are relatively small compared with the wavelength and the fields are therefore effectively attenuated. However, for openings that are larger than half the wavelength, attenuation decreases rapidly and the opening becomes a significant leakage point. At high frequencies (short wavelengths), even small openings are therefore problematic, whereas larger openings are tolerable at lower frequencies (longer wavelengths). In the worst-case scenario, attenuation is 0 dB for an opening with the dimension $d = \lambda/2$.

2.3 Influence of conductivity and eddy currents in the material

The conductivity σ of the enclosure material plays an important role in shielding attenuation. A highly conductive material such as copper or aluminum can effectively reflect and absorb electromagnetic waves, which improves the shielding effectiveness of the enclosure. The shielding attenuation S of a material against electromagnetic fields is determined, among other things, by the conductivity of the material and the penetration depth δ, which is specific to the material and frequency:

$$\delta = \sqrt{\frac{2}{\omega \cdot \mu \cdot \sigma}} \qquad (2)$$

where:

- δ is the penetration depth of the alternating current in the conductive material, (m)
- $\omega = 2 \cdot \pi \cdot f$ is the angular frequency $\left(\frac{1}{s}\right)$
- μ is the magnetic permeability of the material, $\left(\frac{V \cdot s}{A \cdot m}\right)$
- σ is the electrical conductivity of the material, $\left(\frac{1}{\Omega \cdot m}\right)$

The lower the penetration depth δ, the less electromagnetic radiation penetrates the material and the better the shielding effect. A high conductance value of the material σ therefore reduces the penetration depth of the charge carriers and increases the reflection of electromagnetic waves at the material surface, which improves attenuation.

2.4 Eddy currents and their effect on the shielding effect

When electromagnetic waves encounter the conductive material of the enclosure, eddy currents are induced in the surface. These eddy currents generate magnetic fields that counteract the incident fields and thus provide an additional attenuation effect. The effect of the eddy currents is frequency-dependent: At higher frequencies (shorter wavelengths), stronger eddy currents are induced, resulting in greater attenuation. The total attenuation S_{eddy} from eddy currents can be calculated using material parameters such as conductivity and permeability. The following applies to the induced eddy currents:

$$S_{eddy} = \alpha \cdot \frac{f \cdot d}{\sigma} \qquad (3)$$

where:

- α is a proportionality factor (dimensionless)
- f is the frequency of the incident wave, $\left(\frac{1}{s}\right)$
- d is the thickness of the material (m)
- σ is the electrical conductivity of the material, $\left(\frac{1}{\Omega \cdot m}\right)$

The higher the frequency and material conductivity, the more effective the attenuation from the induced eddy currents.

2.5 Basic measures for reducing emissions from enclosure openings

Conductive gaskets and grid inserts can be used to reduce leakage through openings. These measures enable the necessary airflow and signal transmission without significantly impairing shielding attenuation:

- Conductive gaskets (e.g., made of metallized fabric) close small gaps and ensure continuous electrical contact between the enclosure parts. This minimizes field coupling at the transitions and reduces radiation.
- Grille inserts are often used for ventilation slots. Such grilles typically have a mesh size that is significantly smaller than half the wavelength of the interfering radiation and therefore provide an electromagnetic barrier to electromagnetic waves.

Careful design and selection of materials and consideration of the frequencies and wavelengths of the interfering radiation can significantly improve the leakage and therefore the overall shielding attenuation of the enclosure.

2.6 The relationship between enclosure shielding attenuation and cable shielding attenuation

Enclosure shielding attenuation and cable shielding attenuation work together to minimize electromagnetic interference. The cable shield must be connected with low impedance to the enclosure ground at both ends to achieve effective shielding attenuation against both electric and magnetic fields. Poor enclosure shielding influences the effectiveness of the cable shield because:

- eddy currents in the enclosure shielding material cannot be fully compensated
- electromagnetic fields can penetrate the enclosure
- the enclosure, as the ground reference, potentially causes interference

and the cable shield connection therefore does not have an interference-free ground reference.

As a result, insufficient shielding attenuation of the enclosure can significantly impair the effective cable shielding attenuation, as interference fields are radiated along the cable.

The total attenuation S_{TOTAL} can be estimated using the principle of superposition:

$$S_{TOTAL} = -10 \cdot \log_{10}\left(10^{-S_{ENCLOSURE}/10} + 10^{-S_{CABLE}/10}\right) \qquad (4)$$

This formula shows that total attenuation decreases significantly if enclosure attenuation is poor, as cable shielding attenuation cannot take full effect. An enclosure with high shielding attenuation generally has a stable ground potential. A stable ground potential between the enclosure and cable shield is essential for continuous shielding effectiveness. If the enclosure and the cable shield are at different voltages, common-mode interference may occur, which manifests as unwanted interference currents along the cable. This interference reduces cable shield attenuation and increases the coupling of interference signals. A clean, low-impedance ground contact at the transition point between the enclosure and cable shield is essential to ensure consistent shielding effectiveness.

2.7 Cable shield connections and their role in overall shielding

Cable shield connections are another critical aspect of enclosure shielding. Because cables pass through the enclosure, they can act as antennas for electromagnetic interference. A robust, low-impedance connection between the cable shield and the enclosure is necessary to effectively dissipate interference signals. This measure reduces the coupling of interference via the cable into and out of the enclosure and represents an important contribution to enclosure shielding, which means that the quality of the connector and its contact with the enclosure play a crucial role here. In addition, filters are often provided at interfaces to attenuate high-frequency interference components and/or improve signal integrity. These filters require a reference ground that must be free from interference. Interference voltages often arise due to insufficient connections between individual enclosure components or due to eddy currents in shielding materials that are too thin. Eddy currents are induced currents that occur when electromagnetic fields encounter conductive materials. They lead to circulating currents, which in turn generate magnetic fields which can impair the shielding attenuation of both the enclosure and the cable shield. If these eddy currents spread uncontrollably across the enclosure, they can cause interference along the cable if it is not correctly connected.

High-quality material selection and a good ground connection are required to mitigate the effects of eddy currents and ensure end-to-end shielding. Preventing uncontrolled eddy currents can provide an additional attenuation effect, thereby increasing shielding attenuation in the overall system.

3. EXPERIMENTAL INVESTIGATION OF ENCLOSURE SHIELDING AND CORRECTIVE MEASURES

The following section uses simple laboratory experiments to clearly demonstrate the parameters and relationships already explained. The use of mechanical corrective measures for reducing interference emissions is shown, which do not require any modifications to the electronics. The effectiveness of these measures is verified experimentally using field probes and antennas.

3.1 Evaluation of enclosure weaknesses and the relationship with cable shielding attenuation

System preparations, test setup

The test steps show which measures are necessary to design a enclosure with a peripheral cable connected via D-Sub connector for it to be electromagnetically compatible (EMC-compliant). In addition, the shielding quality of various cables, particularly RS-232 cables, is examined and evaluated. The test setup for evaluating enclosure shielding attenuation and cable shielding attenuation is shown in Figure 1.

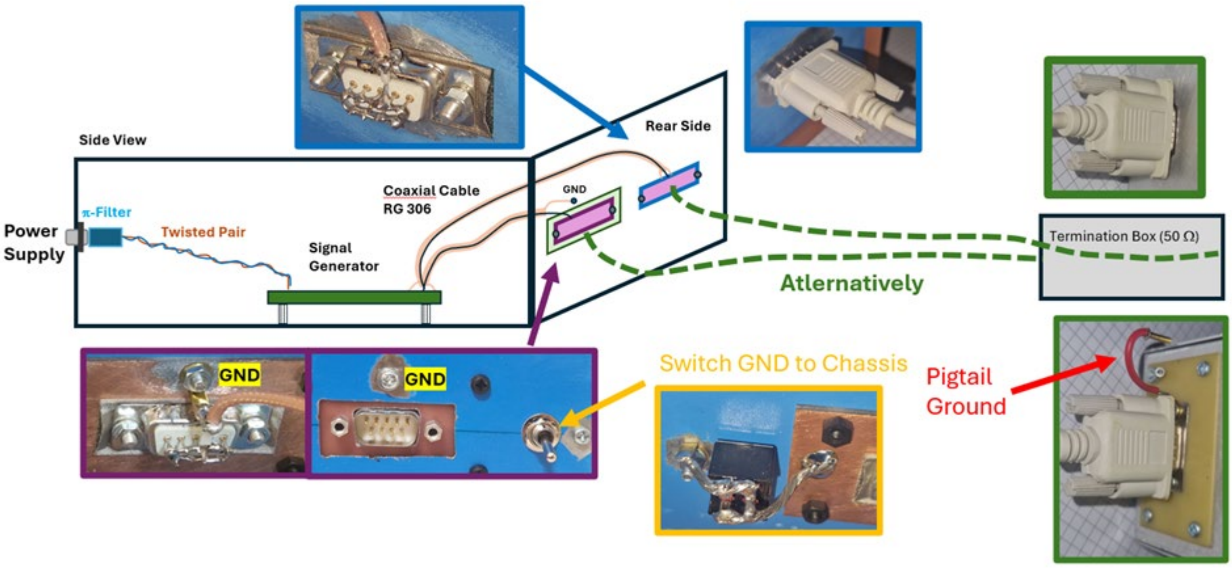


Figure 1: Schematic representation of the test setup for evaluating enclosure shielding attenuation together with cable shielding attenuation.

The enclosure contains a signal generator that generates a comb spectrum in the frequency range between 10 MHz and approx. 500 MHz. The signal is applied via a 50 Ω impedance to all 9 pins of both D-Sub connectors (WR-DSUB, no. 61800925023). The D-Sub connector on the left of the enclosure is mounted with its ground isolated and can be connected to the enclosure ground with low impedance by means of a toggle switch. The connector on the right has an 'ideal' connection to the enclosure. To ensure all-round contact, a conductive gasket (WE-LTS, no. 34150209) was used between the connector and the enclosure. The shielded 9-pin cable is terminated at a termination box, shown on the right in the image, which in turn contains one connector with 'ideal' contact with the enclosure and one isolated connector.

The isolated connector can be grounded to the enclosure via an approx. 30 mm long wire (pigtail).

To demonstrate shielding attenuation effects and influences, the base enclosure containing the signal generator needs to have high shielding attenuation. The individual painted enclosure components must be connected to each other to ensure high shielding attenuation of the enclosure. This measure is shown in Figure 2.

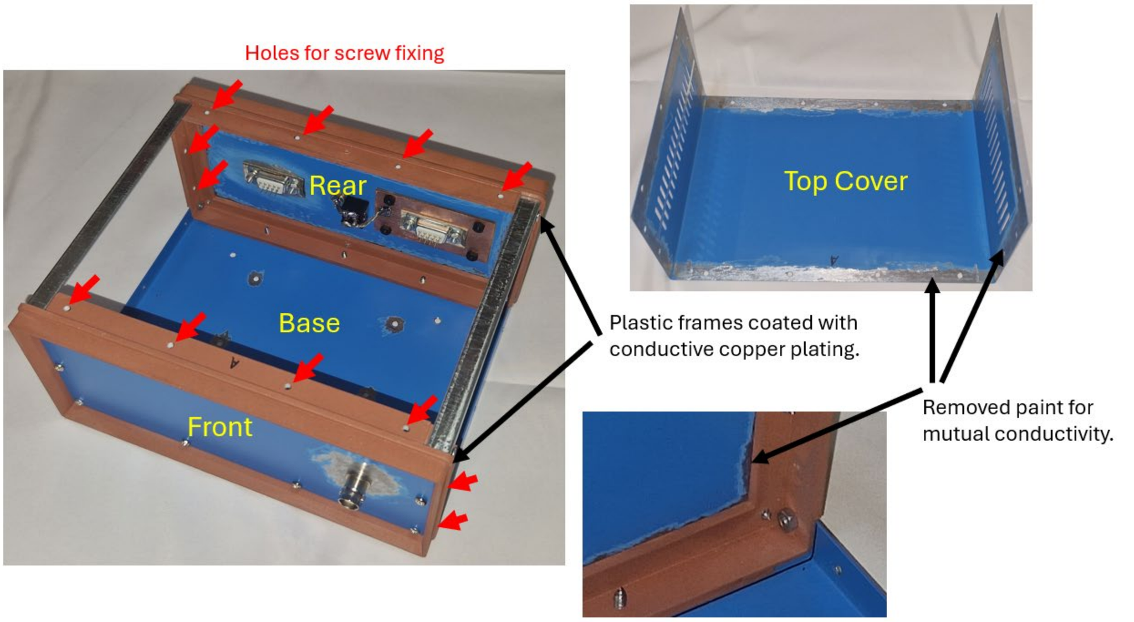


Figure 2: Increasing the shielding attenuation of the enclosure by connecting the individual components that were isolated in the original enclosure.

The plastic frames were coated with conductive copper plating, the surfaces at the edges of the sheet metal parts were ground, and additional screw holes were provided to reduce the gap lengths by connecting the enclosure base to the cover every 50 mm.

Measurements of shielding attenuation

The measurement setup is shown in Figure 3.

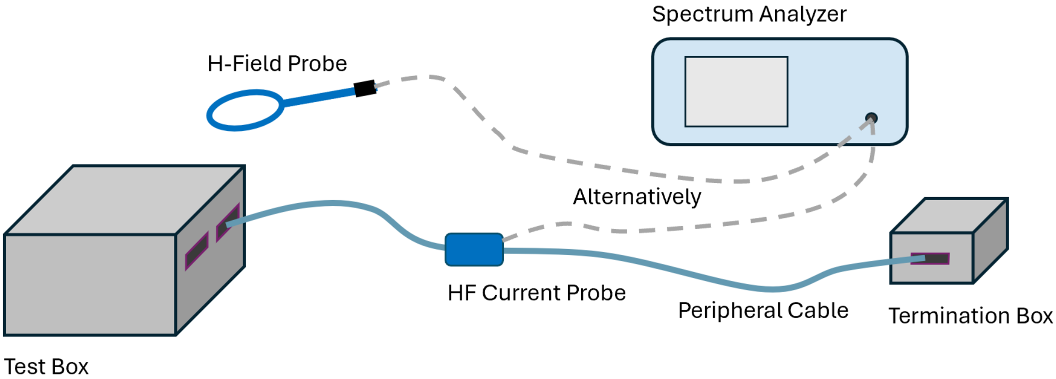


Figure 3: Setup for measuring the shielding attenuation of the enclosure and cable.

Two measurement methods were used to evaluate the measures and effects, such as the shielding attenuation of the enclosure and cables:

- Measurement using an H-field probe and a spectrum analyzer.
- Measurement using a current clamp on the peripheral cable and a spectrum analyzer.

A shielded single-core cable was used to demonstrate the influences on the shielding attenuation of the system. For comparison, measurements were performed under various conditions, the results of which are shown in the following figures.

The measurement results show that the highest shielding attenuation is achieved when the cable shield is connected at both ends in an RF-compliant manner. If the enclosure is closed with all-round contact, cable shielding attenuation is increased by approx. 4 – 7 dB (Figure 4). If the ground of the connector on the test box is isolated from the enclosure, the interference level increases by up to 40 dB (Figure 5).

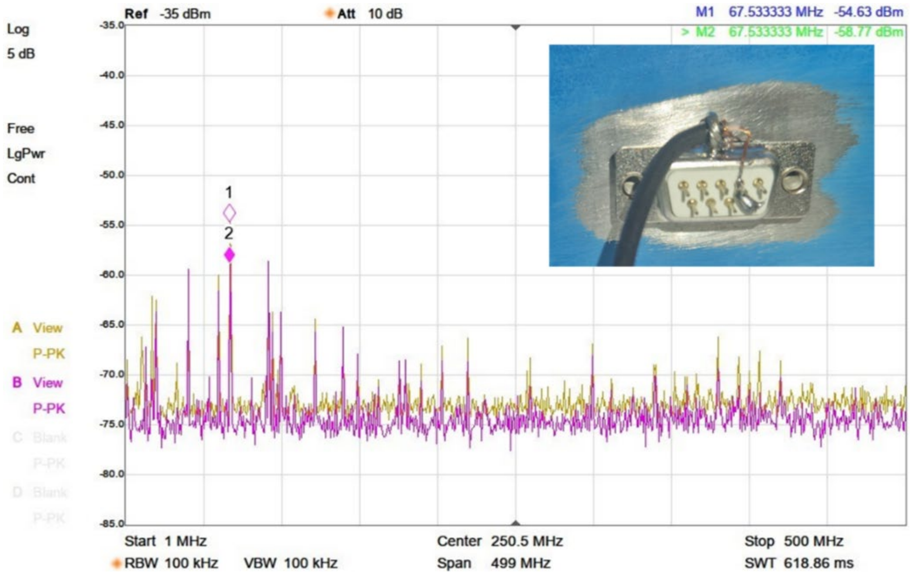


Figure 4: Emission of the shielded single-core cable. Connectors (D-Sub) of both enclosures contacted directly to the enclosure, yellow curve: enclosure open, purple curve: enclosure closed.

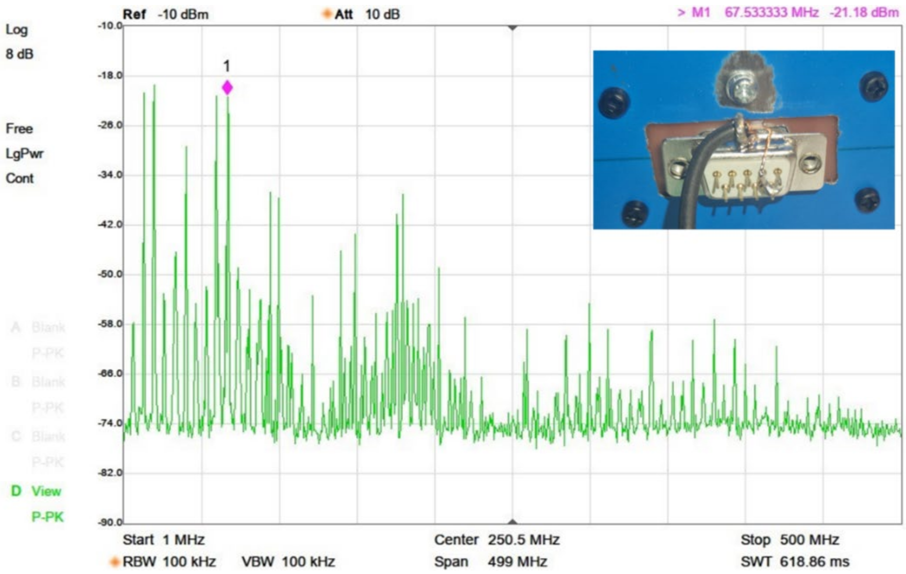


Figure 5: Emission of the shielded single-core cable. Shield of the D-Sub connector on the test box not contacted to the enclosure. enclosure closed.

If the connector is isolated, which is equivalent to an unconnected cable shield, it is irrelevant for the interference emitted via the cable whether the enclosure is open or closed (Figure 6).

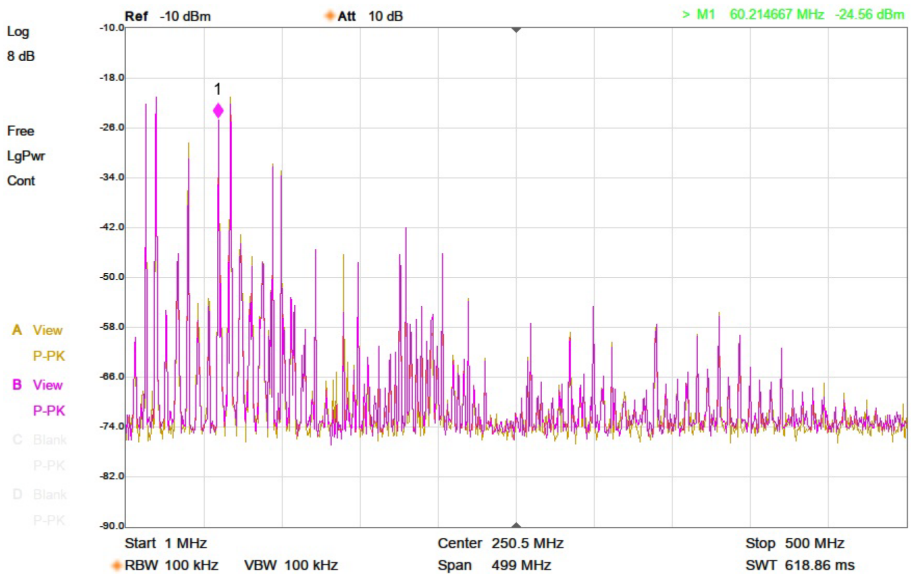


Figure 6: Emission of the shielded single-core cable. Shield of the D-Sub connector on the test box not connected to the enclosure. yellow: enclosure closed, pink: enclosure open.

This shows that the full set of measures is necessary to ensure electromagnetic compatibility. It is pointless to connect a perfectly shielded cable to an enclosure with low shielding attenuation, just as it is pointless to combine an inadequately shielded cable with an enclosure that has high shielding attenuation.

To achieve high shielding attenuation for an enclosure and effectively shield it against electromagnetic interference, a combination of different measures is required. Materials such as steel or aluminum offer high shielding attenuation. Thicker walls increase attenuation. All enclosure edges, openings and connections should overlap seamlessly and effectively to avoid leakage points through which electromagnetic waves could escape or enter, and to ensure electrical continuity for eddy currents induced by electromagnetic fields. Conductive gaskets, such as those coated with conductive fabric or WE-LT Conductive Shielding Gasket, should be used at the transitions between sheet metal parts to seal gaps and increase shielding attenuation. Coatings – such as conductive paints, electroplating or plating on plastic parts of the enclosure – can significantly improve shielding.

High shielding attenuation of a peripheral cable, which is necessary for effective shielding against electromagnetic interference, can be achieved by combining various measures. A fine-mesh copper or aluminum shield braid provides high shielding attenuation thanks to its good coverage and conductivity. Additional shielding made of aluminum or copper foil can shield electromagnetic interference in the higher frequency range more efficiently and improves overall shielding. However, the foil must be made of electrically conductive material. A low-impedance transition from the cable shield via the connector to the enclosure is important for achieving any meaningful shielding attenuation. Connectors should be carefully connected to the shield and ensure a seamless connection to avoid leakage points for electromagnetic radiation. A cable shield connected to ground at only one end only attenuates electric fields, but not the magnetic field component.

Various commercially available cables are compared below. The figures below provide an almost self-explanatory overview.

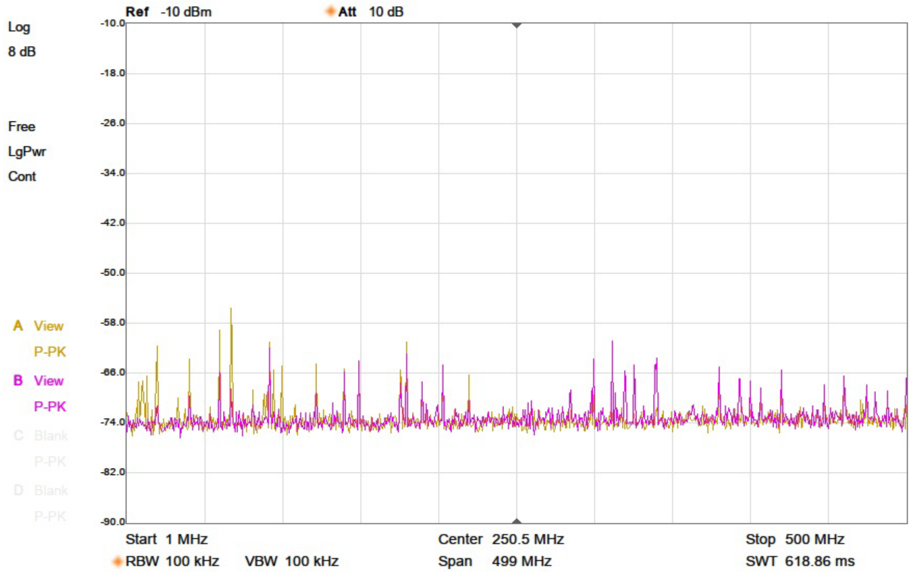


Figure 7: Shielding attenuation, yellow: single-core shielded cable, pink: double-shielded signal cable.

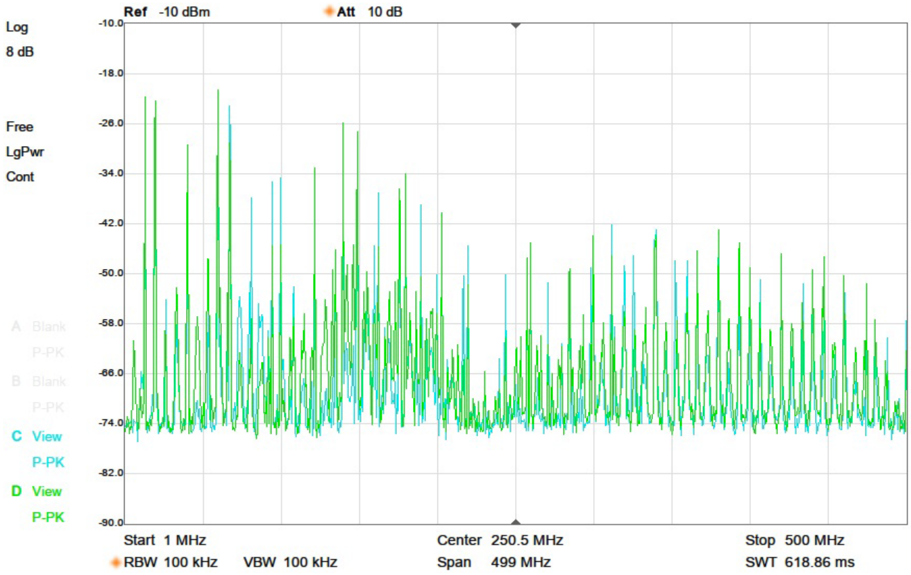


Figure 8: Shielding attenuation, blue: well-known manufacturer available in electrical markets, green: Asian online trade.

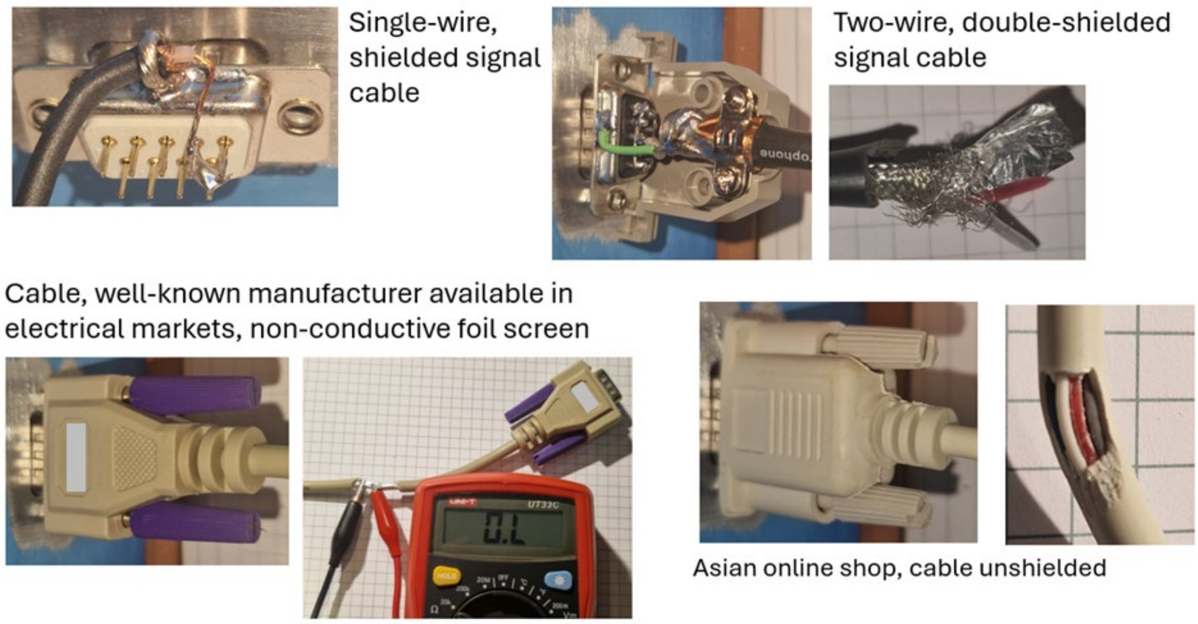


Figure 9: Cables used for the measurements in Figure 7 and Figure 8.

It should not go unmentioned that the corresponding cable interfaces can, of course, be equipped with filters. However, these filters require an interference-free reference ground to achieve the necessary attenuation. The following measurements clearly demonstrate this fact. In Figure 10, the unshielded cable was connected to a connector whose ground is attached to the enclosure in an RF-compliant manner. To demonstrate the need for a low-impedance reference ground, a WE 230016003 snap-on filter was connected between the interface and the cable. In the snap-on filter, a capacitor (C_X = 1 nF) is connected from each pin to ground; the filter circuit is shown in Figure 10. The filter attenuates the interference amplitudes by up to 25 dB.

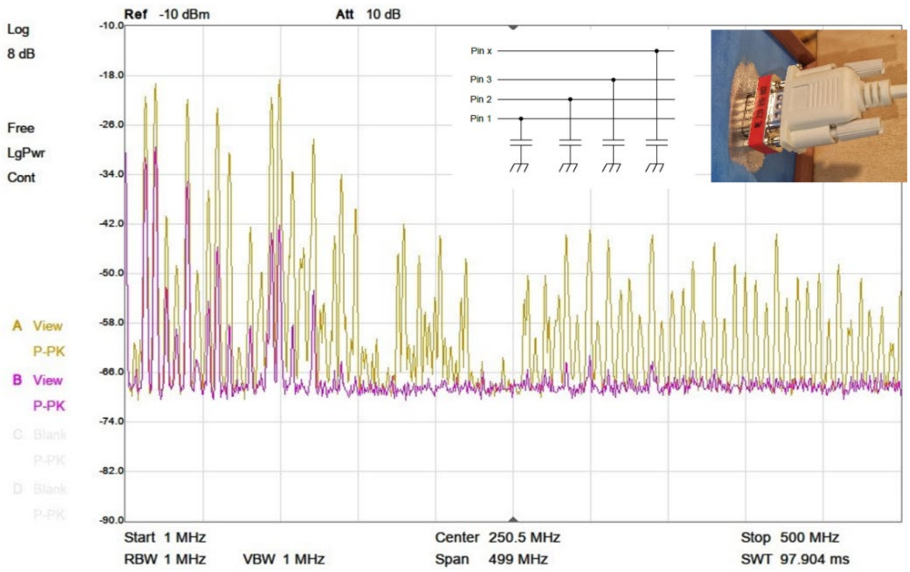


Figure 10: Emission of the shielded single-core cable. Connectors (D-Sub) of both enclosures contacted directly to the enclosure, yellow curve: enclosure open, purple curve: enclosure closed.

If, however, the filter is used on a connector whose ground is not connected to the enclosure, the result obtained is shown in Figure 11.

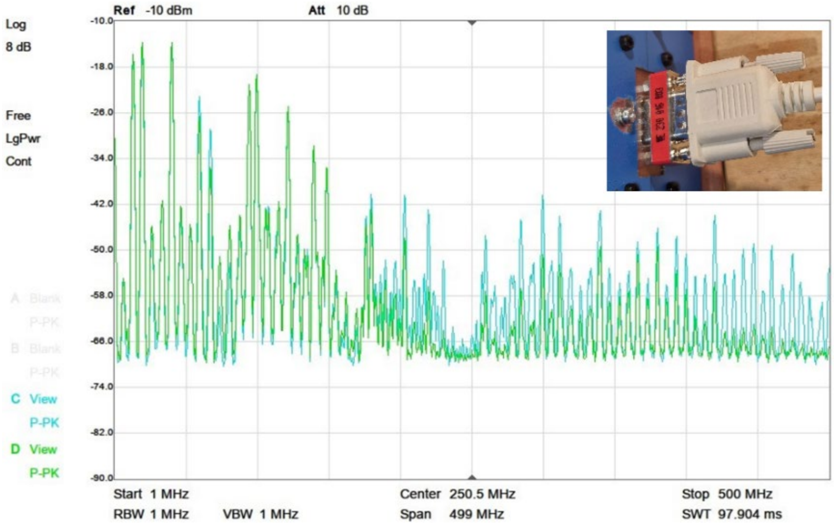
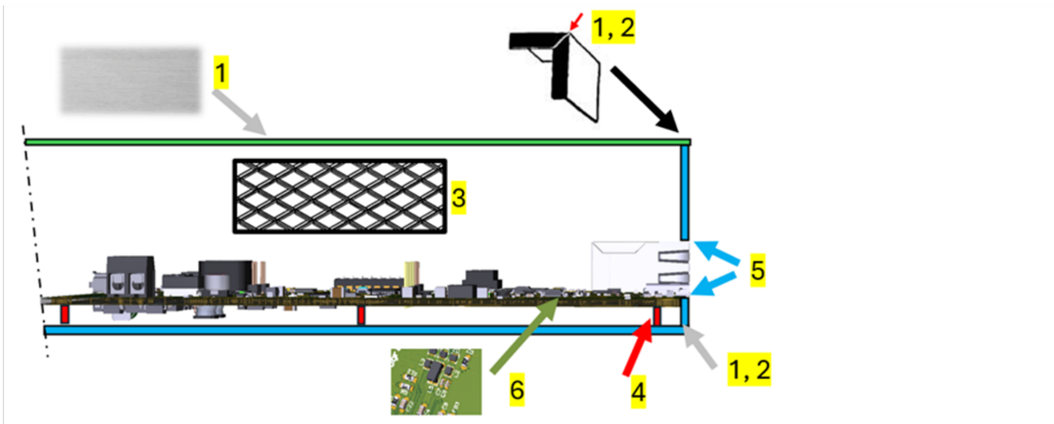


Figure 11: Emission of the shielded single-core cable. Shield of the D-Sub connector on the test box not connected to the enclosure; enclosure closed.

It is clear to see that the snap-on filter has almost no effect. The attenuation in the higher frequency range is due to random resonance phenomena and capacitive effects, which may vary depending on the cable.

Another point worthy of mention: It makes sense to equip cable interfaces with filters that provide additional protection against transient overvoltage. For this purpose, multilayer varistors or TVS diodes can be used with, or instead of, the capacitors, together with an SMD varistor or inductor connected in series. Further information is available in numerous application notes on the WE website.

To conclude Figure 12, shows a summary of the points necessary for an EMC-compliant enclosure and system design.



1. Metal surface: Must conduct well at all contact points, without oxidation.

2. Housing parts, cover: Seamless, good conductivity, all-round contact.

3. Ventilation grille: metal, small openings, surface as small as possible, seamlessly connected to housing.

4. Metal bolts: Highly conductive connection of the electronics ground to the housing.

5. All-round contact between the ground of the connector and the housing.

6. Filter of the interface, primary reference ground is the ground of the connector.

4th + 5th + 6th: Direct, low-impedance, galvanic connection with each other.

Figure 12: Summary of the points necessary for an EMC-compliant enclosure and system design.

3.2 Attenuation of an emission source on the PCB using absorber foil (EMI patch)

EMI absorber foil, also known as an EMI patch, is used to attenuate local high-frequency electromagnetic emission sources or to protect sensitive circuits against electromagnetic interference that could lead to malfunctions. These patches generally consist of two layers: an electrically conductive layer, such as metal foil, and a second layer made of RF-absorbing material, such as ferrite. EMI patches offer a flexible and effective solution for managing electromagnetic interference, particularly in situations where quick remedies or modifications are required without major redesigns. In the following cases, the use of absorber foil is a quick and elegant solution:

- Shielding sensitive components: If certain components in a circuit are particularly sensitive to ambient electromagnetic interference and require local protection. Examples include shielding interfaces, wires on assemblies, traces and filters.
- Resolving EMC problems in existing designs: If an electronic device has already been developed and EMC problems are discovered during testing, EMI patches can be applied to mitigate these problems without having to redesign the entire system.
- Improving enclosure shielding: If the existing shielding of an electronic enclosure, such as a metal enclosure, is insufficient, EMI patches can be applied to cover seams, joints or other weak points where electromagnetic energy could enter or escape.
- On-site repairs and retrofits: In situations where devices are already in use and EMC problems are discovered, EMI patches can be used as a quick fix to improve shielding without requiring extensive disassembly or modification.
- Temporary shielding during prototyping: During the development and prototyping phase, EMI patches can be used temporarily to test the effectiveness of the shielding before a final design is finalized.

The functional principle of the EMI patch is that a trace or electronic component (IC) carrying AC currents generates a stray magnetic field, as shown in Figure 13 for an IC.

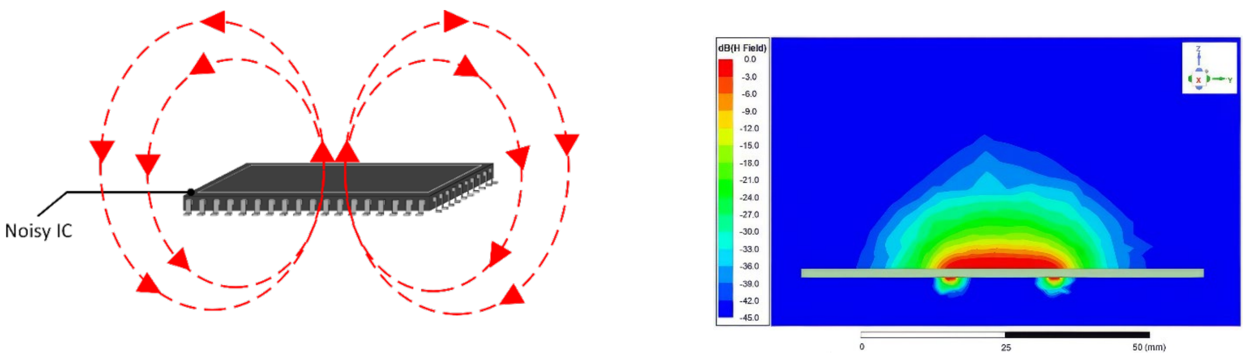


Figure 13: IC with surrounding stray magnetic field (schematic on the left, on a PCB on the right).

The magnetic field surrounding the chip can easily couple into neighboring circuits or other ICs, as well as into interface areas, filters and ground connections, and may then be radiated from the device as common-mode interference. This mechanism can work both ways, i.e., external interference can also enter the circuit and cause malfunctions.

The propagation of the field can be reduced by mechanical shielding that forms an electromagnetic barrier. One option is a hybrid absorber foil, as shown in Figure 14.

The hybrid absorber foil combines absorber material with an aluminum layer (Figure 14) and is easy to apply thanks to an adhesive layer. This combination enables higher attenuation of stray fields compared with pure ferrite foil thanks to multiple reflections. If the foil is used on its own with a magnetic permeability in the range of $\mu_r = 100$, it effectively attenuates electromagnetic interference. The metal layer also contributes to attenuation by generating eddy currents that counteract stray magnetic fields that could otherwise penetrate the ferrite foil. A large proportion of these fields is reflected by the foil back into the absorber material, where they are attenuated. If the metal layer is connected to GND, it acts as shielding against electric fields. The foil is available in both insulated and non-insulated variants, with the non-insulated variant enabling the GND connection mentioned above. The function of the shielding mechanism is shown in Figure 15.

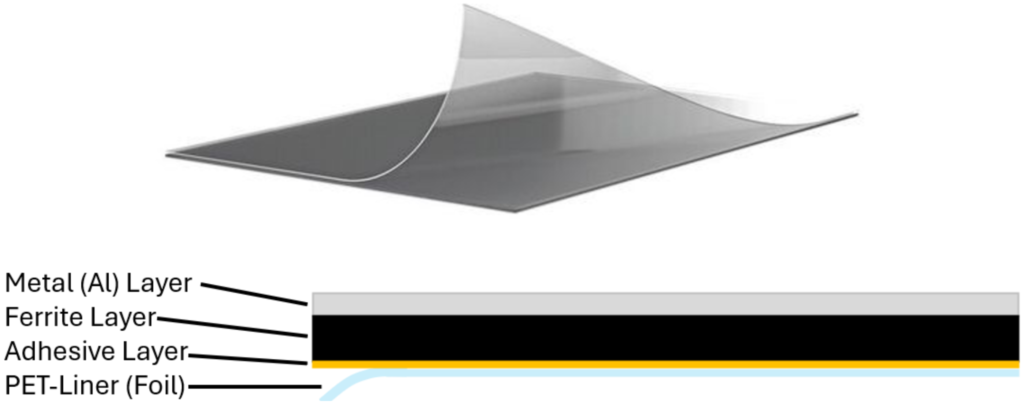


Figure 14: Hybrid absorber foil (EMI patch: WE-EMIP 371100, WE-EMIP 371000).

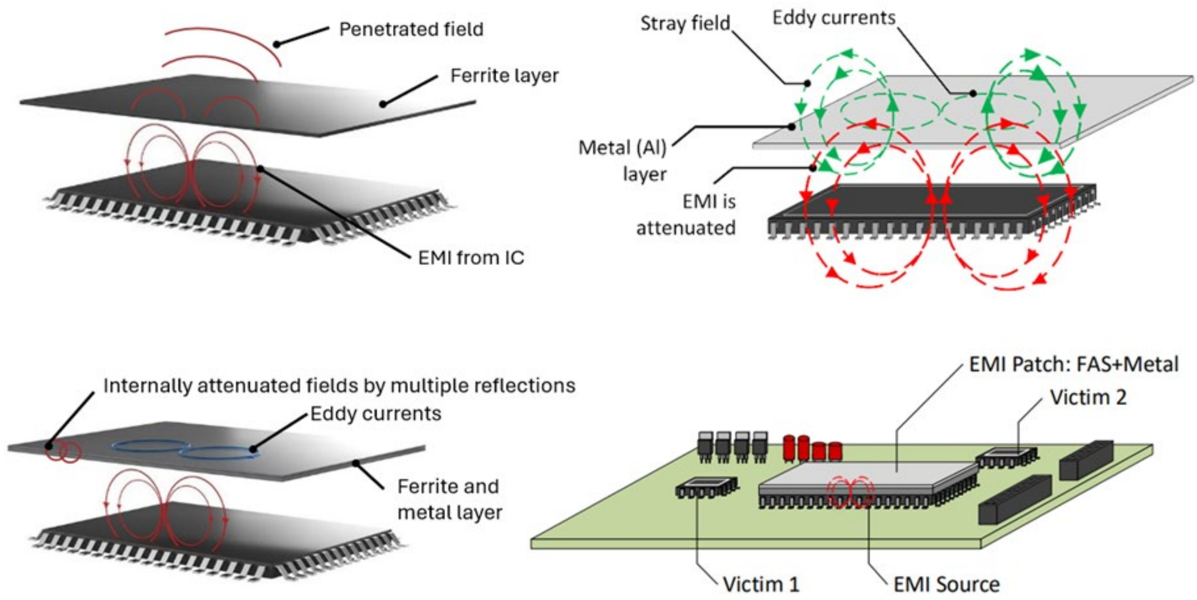


Figure 15: Representation of the function of an EMI patch.

3.3 Setup for evaluating the effectiveness of an EMI patch

Experiments were carried out to evaluate the effectiveness of an EMI patch. For this purpose, a broadband signal was fed into a test PCB which, to demonstrate the effectiveness of the patches, features a T-filter and various coupled and open trace structures. The measurement setup is shown in Figure 16.

A comb generator produces a spectrum of discrete amplitudes in the frequency range between 20 and 1500 MHz. A downstream amplifier increases the signal level by 30 dB up to 1000 MHz, making the level high enough to obtain unambiguous results during testing. The amplified comb spectrum is shown in Figure 17.
When the absorber layer is used on its own (left), it attenuates the electromagnetic interference, but some penetrates the absorber layer. If a metal foil is used on its own (right), eddy currents are created which generate a stray field.

The enclosure is a sheet steel cabinet purchased “online”, which consists of a bottom tray and a U-shaped cover, both painted all around with blue synthetic resin paint. The front and rear sides are set into white plastic frames, so that all components are electrically isolated from each another and RF-capable shielding cannot be expected.

Using a spectrum analyzer, a pin probe and an H-field probe, the RF levels on the PCB and the cabinet can be measured. The experimental PCB setup is shown in Figure 18.

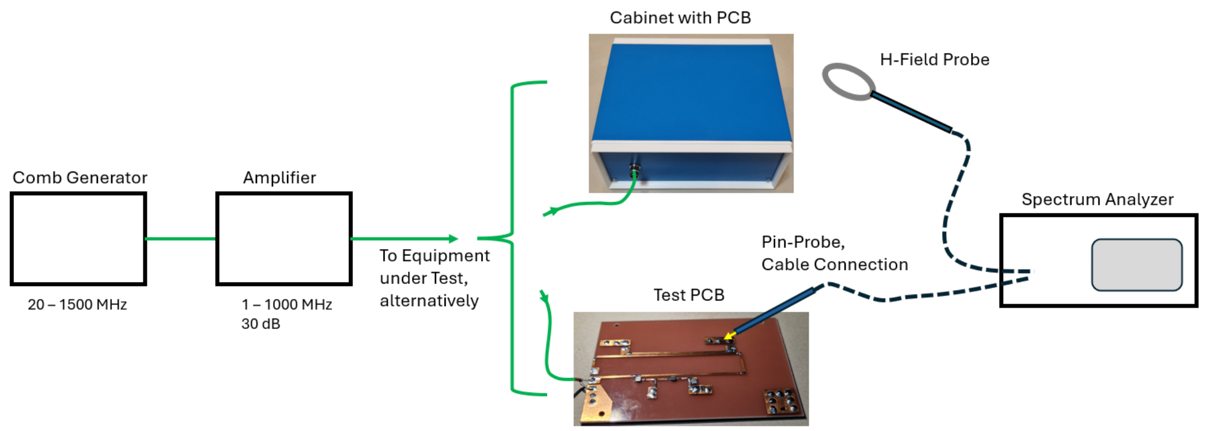


Figure 16: Measurement setup with comb generator, amplifier and spectrum analyzer.

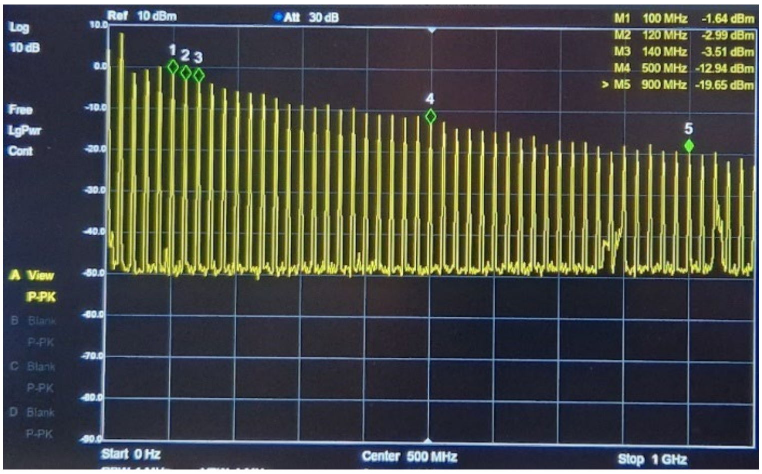


Figure 17: Spectrum of the signal source (comb generator and amplifier).

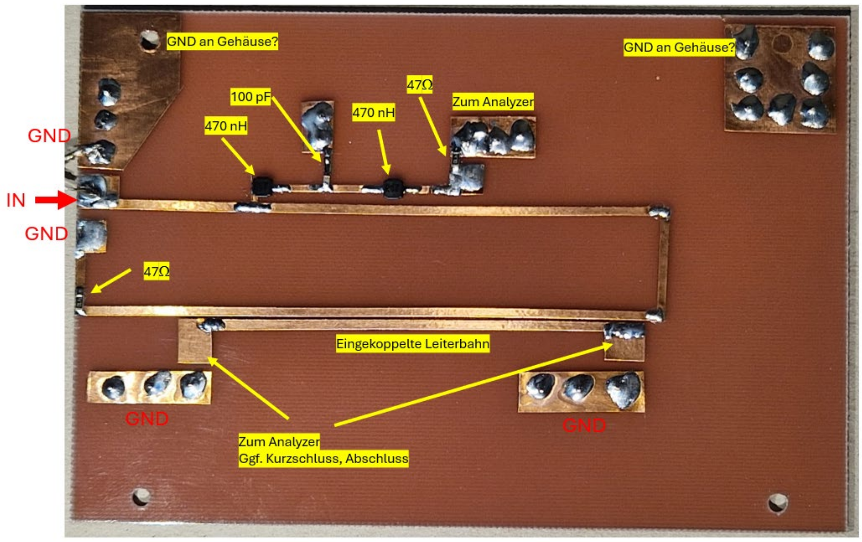


Figure 18: Test PCB, T-filter: L1, L2: 470 nH, WE-LQS, no. 74404041004 7, C1: 100 pF, WCAP-CSGP, no. 885012007082.

A T low-pass filter with a cutoff frequency of approx. 36 MHz is set up in the upper section of the assembly. The middle section contains a conductor loop terminated with a 47 Ω resistor, and in the lower section a trace open at both ends is arranged at a distance of 0.4 mm from the conductor loop. The circuit diagram of the test PCB is shown in Figure 19 for clarification.

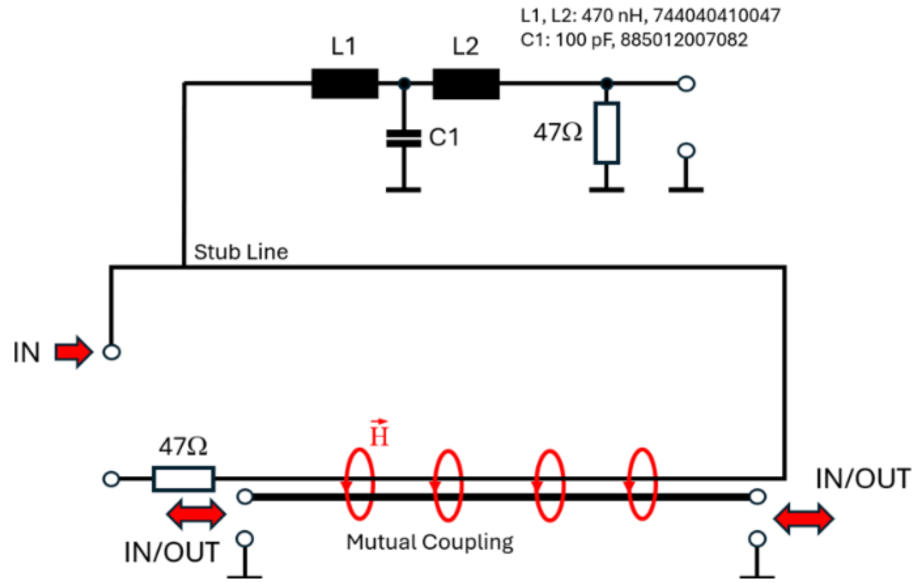


Figure 19: Circuit diagram and functional diagram of the test PCB according to Figure 18.

The insertion loss in the frequency range between 20 MHz and 100 MHz is shown in Figure 20; the attenuation up to 1 GHz is shown in Figure 21. The insertion loss was measured with a network analyzer in a 50 Ω system.

In the filter range, starting at approx. 400 MHz, there is a sharp decrease in filter attenuation; the difference between the attenuation at approx. 100 MHz and 1 GHz is over 18 dB. Part of the attenuation losses is attributable to parasitic effects of the components. However, another portion arises from direct "overshoot" between the input and output, which is facilitated by the high impedance of the T-filter as well as the close proximity of the trace loops on the input and output sides.

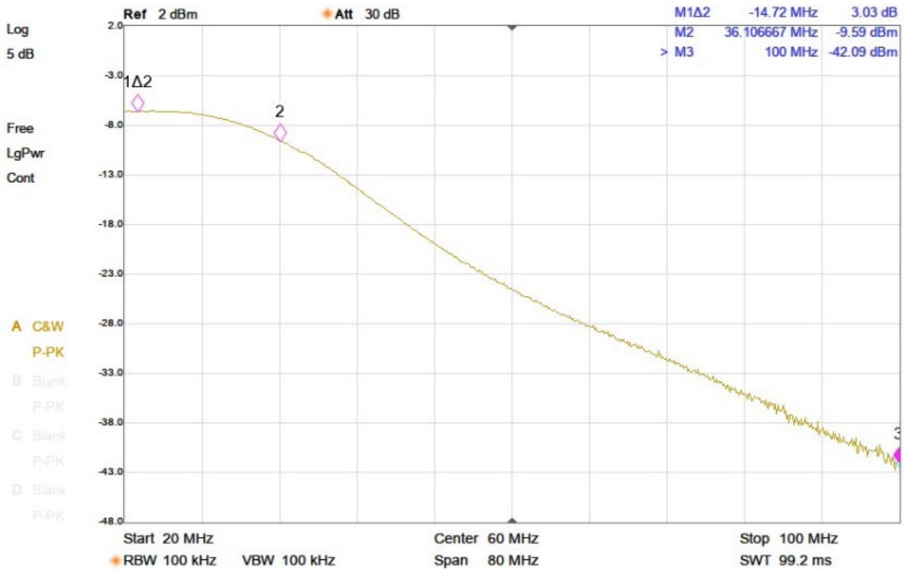


Figure 20: Insertion loss of the T-filter according to Figure 19 up to 100 MHz.

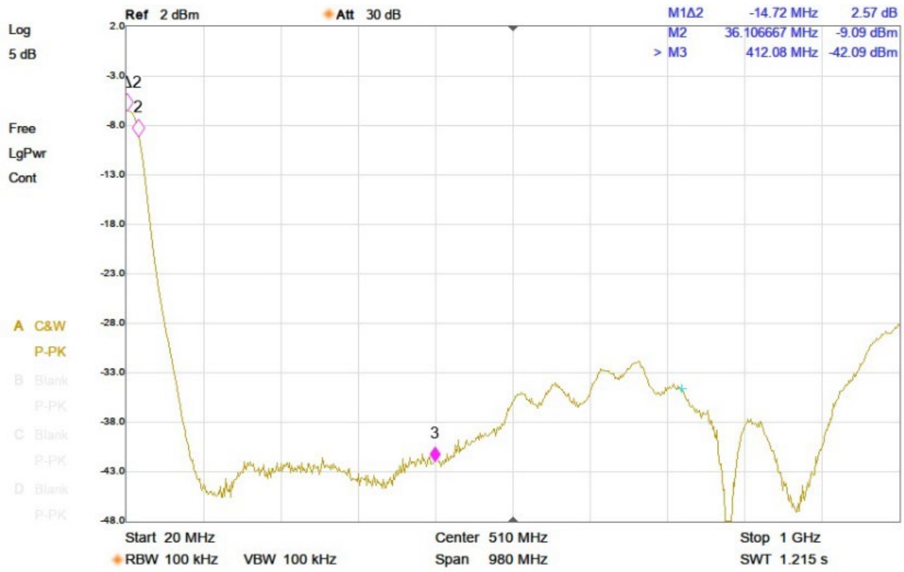


Figure 21: Insertion loss of the T -filter according to Figure 19 up to 1000 MHz.

3.4 Measuring the effectiveness of the EMI patches

The first measure, shown in Figure 22, is the use of an insulated EMI patch. The insertion loss of the T-filter was increased by applying three patches. The measurements on the PCB were carried out directly using a pin probe, as shown in Figure 22.

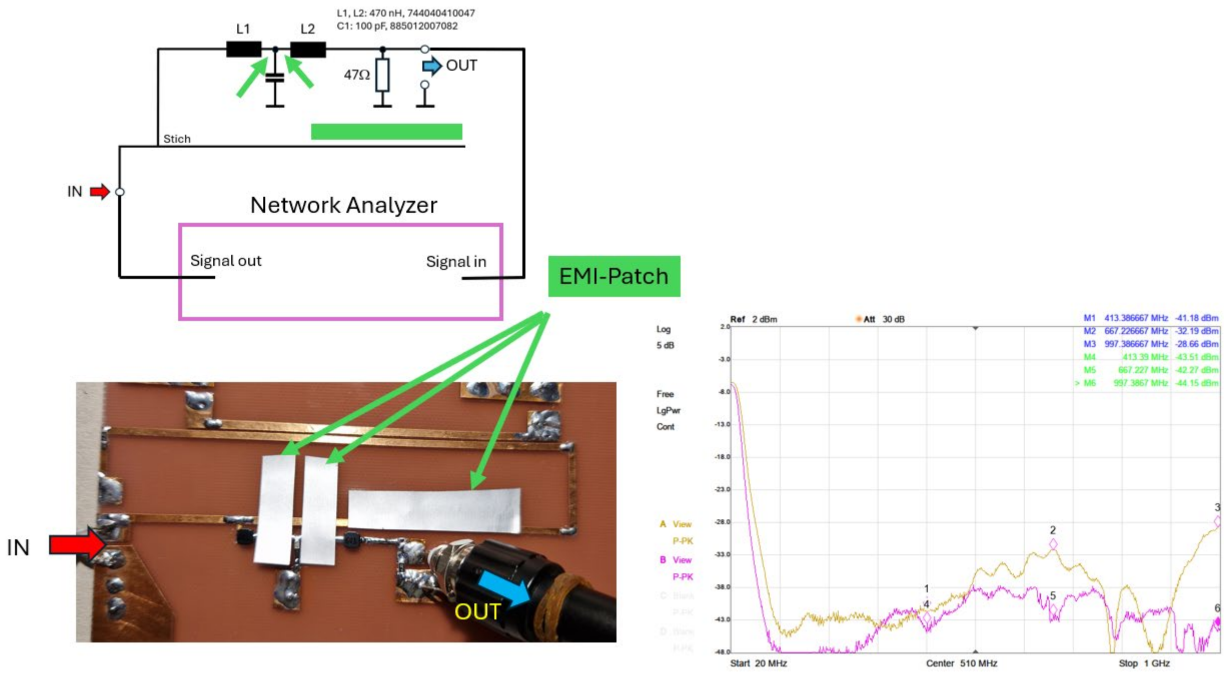


Figure 22: Improvement of the insertion loss of the π-filter using the WE-EMIP 371100 EMI patch.

The insertion loss of the filter is improved by applying the EMI patches through the following two effects:

- Reduction of reflections caused by mismatching. Every low-pass filter has high impedance in the blocking range, which blocks the signal to be attenuated but also produces reflections.
- Reduction of crosstalk caused by capacitive and inductive coupling between traces. High-impedance sections – e.g., the input and output of the T-filter, caused by the high impedance of the inductors at high frequencies – tend to exhibit capacitive coupling. Low-impedance current paths – e.g., the current loop in Figure 22 – generate magnetic fields that induce currents in neighboring conductors.

The frequency range above 800 MHz in Figure 22, between markers 5 and 6, is improved mainly by the attenuation provided by the two pads between the inductors. The range below this, up to marker 5, is improved by the attenuation provided by the long pad, which reduces inductive coupling.

The effect of inductive coupling can be illustrated by a further test according to Figure 23. The signal flows through the current loop terminated with a 50 Ω load and, due to the current di/dt, generates a magnetic field that couples into the neighboring trace. This trace is terminated with a 50 Ω load at one end; at the other end, the coupled signal is routed to the spectrum analyzer.

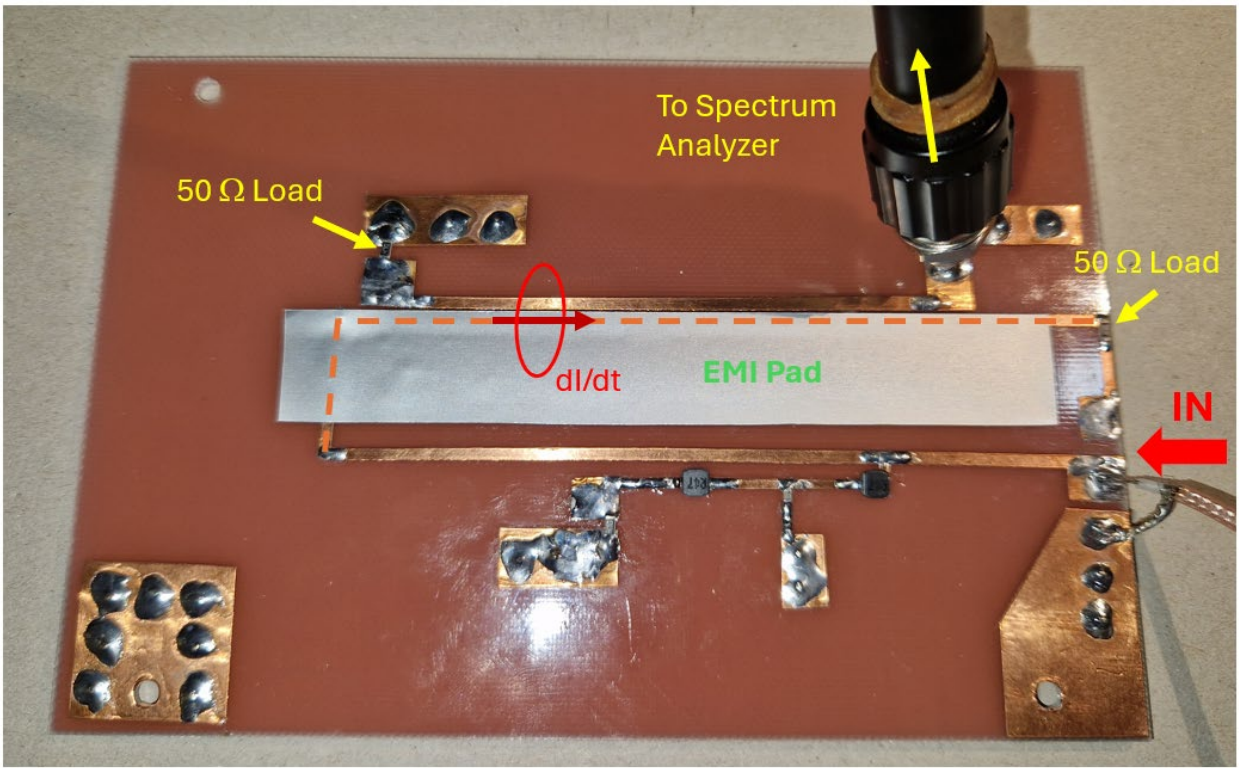


Figure 23: Setup for testing the magnetic coupling of two neighboring traces and the attenuation of the coupling using the WE-EMIP 371100 EMI patch.

The result of the measurements with and without the EMI patch is shown in Figure 24. In the range around 300 MHz, the EMI patch attenuates the coupled signal by up to 15 dB.

In the range above this, effectiveness decreases, but the inductive coupling without the EMI patch is also lower. From approx. 850 MHz (marker M2), the EMI patch shows good effectiveness at higher frequencies up to 1 GHz. The EMI patch does not need to be bonded to both traces for this purpose; it is sufficient to bond the material to the signal-carrying conductor loop, thereby largely preserving the signal integrity of the coupled trace.

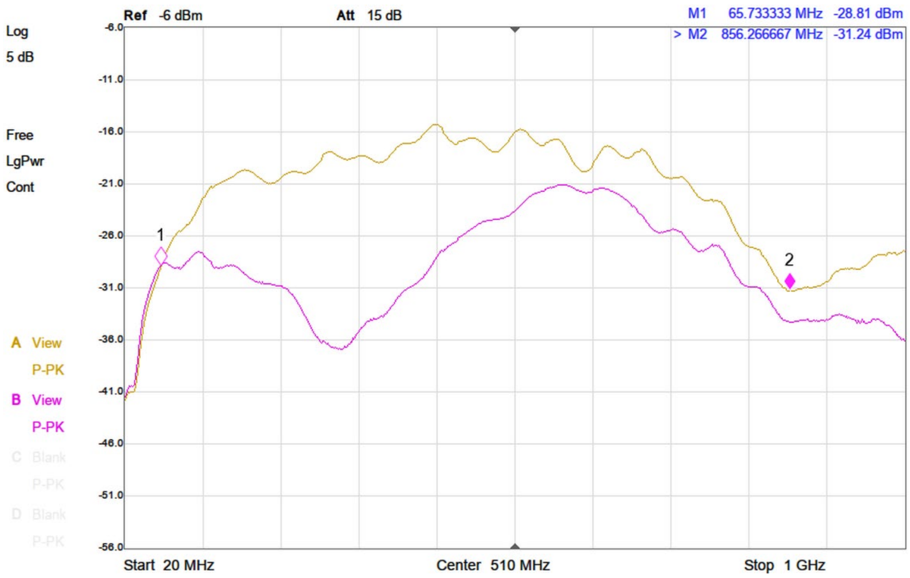


Figure 24: Spectrum of the coupled level, yellow: without an EMI patch, purple: With an EMI patch according to Figure 23.

The reduction of interference emissions considered so far has focused on coupling between traces and the components in the electronic assembly. The following section considers how such measures have an effect if the assembly is installed in a enclosure. Figure 25 shows the assembly installed in the cabinet; the ground plane of the assembly was not grounded to the enclosure.

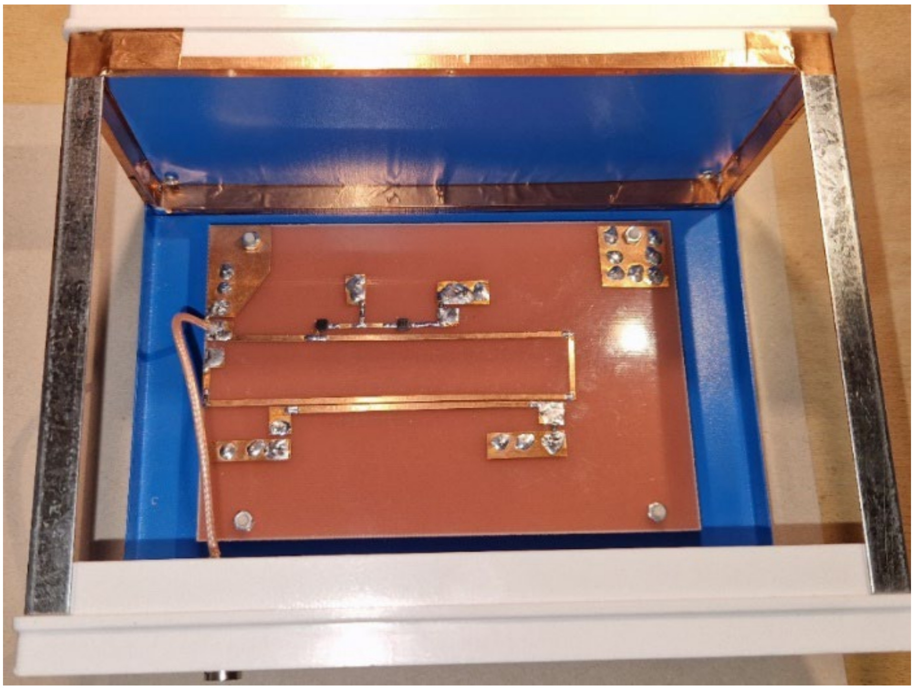


Figure 25: Assembly installed in the cabinet, signal input into the conductor loop via coaxial cable.

In order to demonstrate the effectiveness of the following measures using an EMI patch, the fully painted sheet metal parts and the front and rear sides of the cabinet, insulated with plastic frames, were made EMC-compatible. The plastic frames were covered with copper conductive tape, and the blue paint layer was removed from the contact surfaces of the cabinet parts.

Figure 26 shows the emission from the open device, measured with an H-field probe at the upper edge of the enclosure. The setup corresponds to Figure 16.

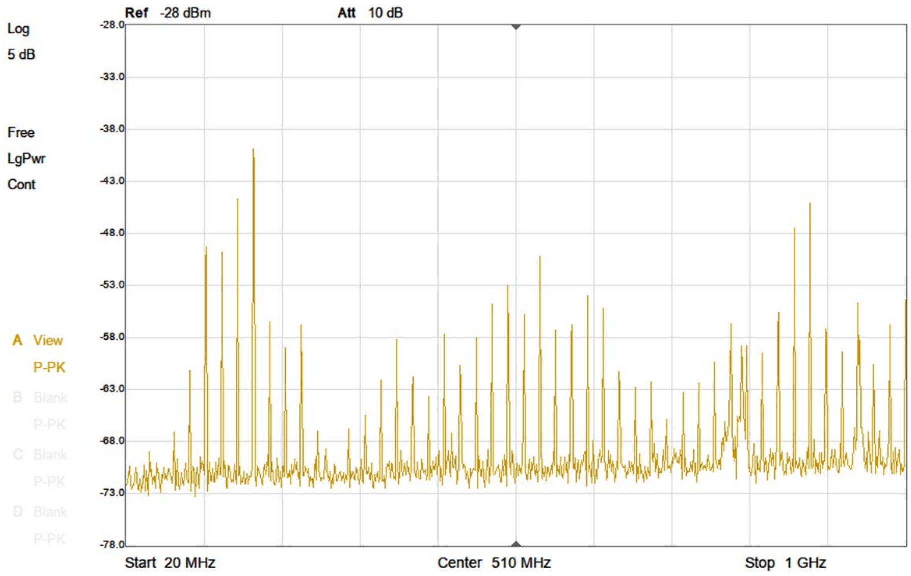


Figure 26: Emission spectrum of the conductor loop, assembly mounted in the device, measurement with H-field probe on the open device, upper edge of the enclosure.

Even if the enclosure itself is RF-proof, the problem often arises that ventilation slots are required, through which high-frequency radiation may be emitted. This situation is shown in Figure 27.

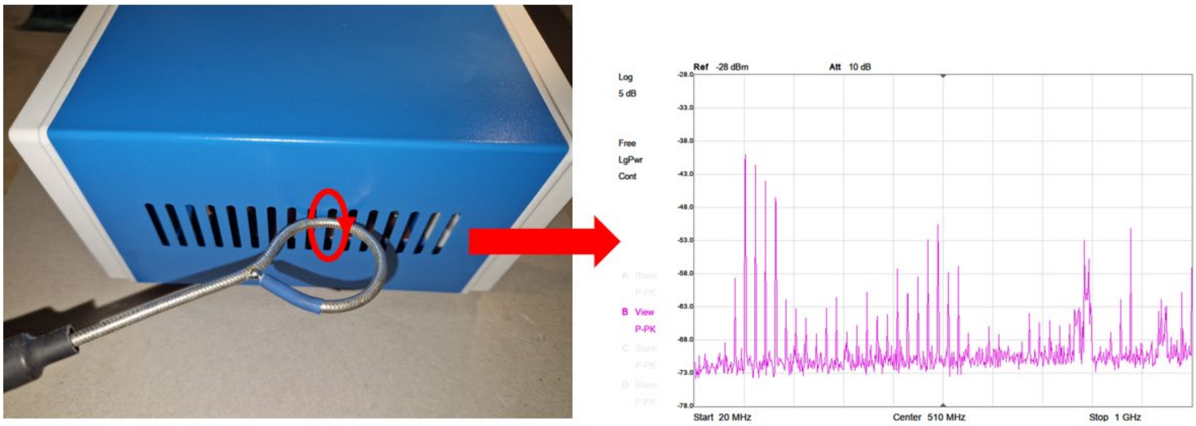


Figure 27: High-frequency emission via enclosure slots, measured with an H-field probe.

The group of slots was divided in half with an approx. 4 mm wide strip of WE-EMIP 371000 EMI patch to reduce emission while not excessively impairing air flow. The measure and the associated emission result are shown in Figure 28.

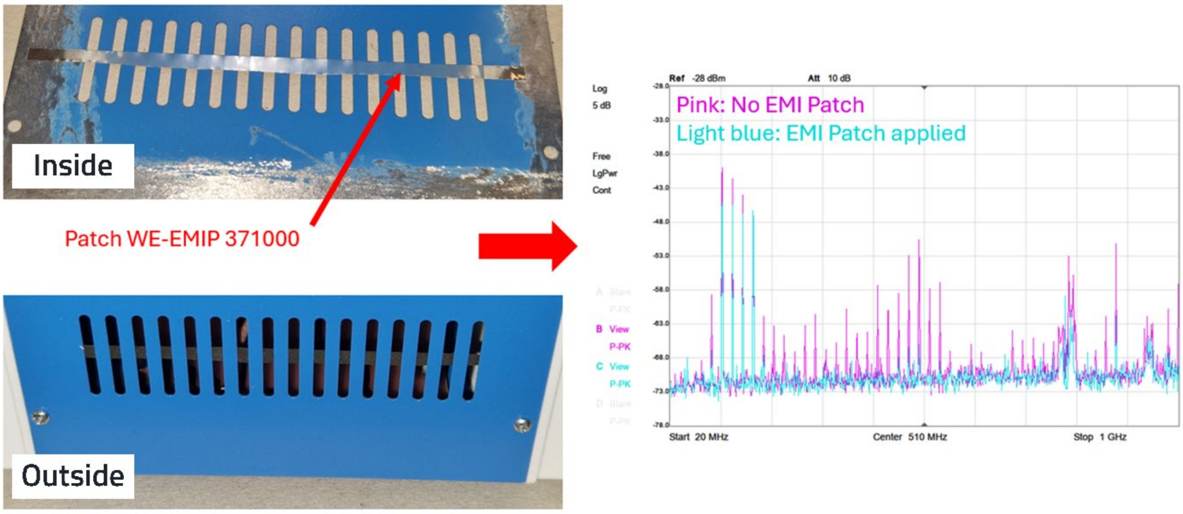


Figure 28: Effect of the EMI patch on reducing RF emission via enclosure slots.

It can be seen that the reduction in RF emission in the range up to approx. 200 MHz is approx. 3 – 5 dB, since emissions also occur via the lower edge of the enclosure. However, at higher frequencies the reduction in emission due to halving the slot lengths is significant, reaching up to 15 dB. As the EMI patch is self-adhesive, this measure can be implemented both for short-term testing in the EMC lab and in production. The EMI patch must make galvanic contact with each of the webs to achieve high attenuation of radiation emitted via the slots.

The comb spectrum of the amplitudes between 200 and 300 MHz is caused by resonance of the PCB and can be greatly reduced by contacting the ground plane to the enclosure. However, this causes a broadband increase in the level of those frequency portions that are lower without ground contact, as currents flow via the ground contact due to the potential differences generated on the PCB (Figure 29).

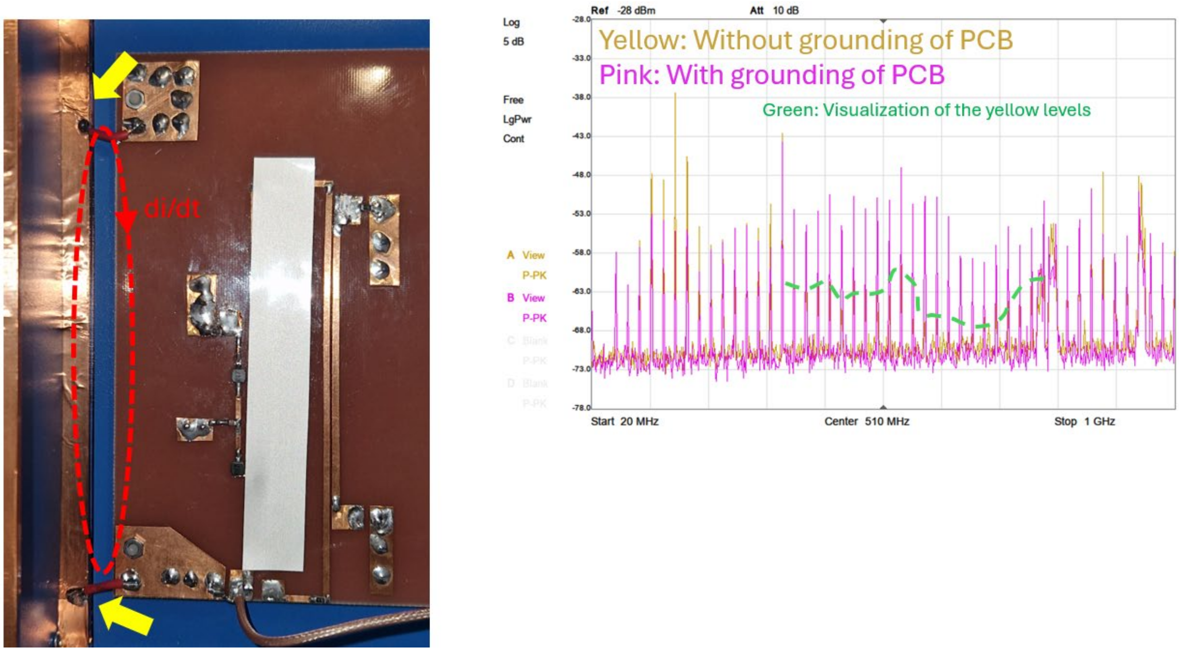


Figure 29: Reduction of the resonance between 200 and 300 MHz and broadband increase in the level from the ground connection.

3.5 Effect of EMI pads in field strength measurement with an antenna

The effectiveness of the measures has so far been measured in the near field using an H-field probe. The actual effectiveness was then verified by means of a field strength measurement (precompliance setup) at a distance of 3 m. The setup is shown schematically in Figure 30.

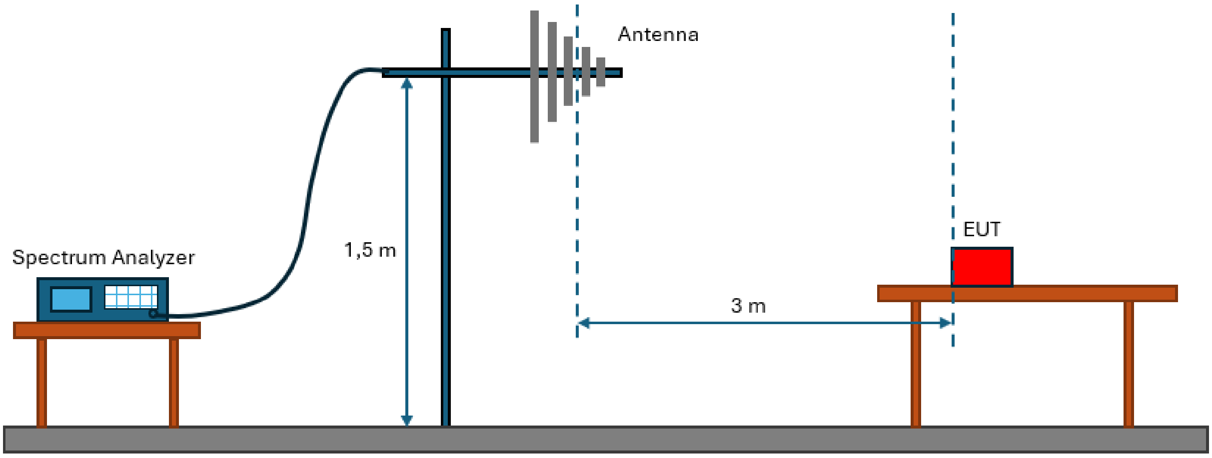


Figure 30: System arrangement for field strength measurement (precompliance set-up).

The measure was tested with and without an EMI patch on the trace terminated with a 50 Ω load. The result is shown in Figure 31; a high emission level at 360 MHz serves as a comparison.

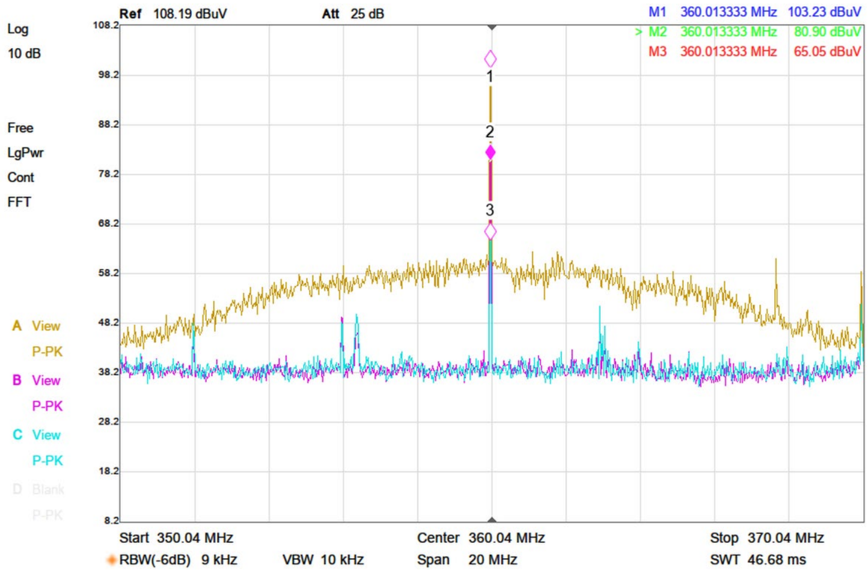


Figure 31: Comparison of interference levels with open enclosure (beige), closed enclosure (purple) and closed enclosure with an EMI patch (blue).

The high level with the open enclosure of approx. 103 dBµV/m is reduced to approx. 81 dBµV/m by closing the enclosure. Applying the EMI patch reduces the level by a further 16 dB to 65 dBµV/m. This measure is therefore highly effective in reducing the field strength. A prerequisite for use in the electronic circuit is that the signal integrity allows an EMI patch to be applied.

EMI patches offer an effective and flexible solution for attenuating electromagnetic interference in electronic circuits and devices. Their effectiveness is demonstrated through the absorption and reflection of electromagnetic interference, particularly at high frequencies. The experiments confirm their effectiveness by significantly reducing both interference reflections and inductive crosstalk. The patches are a quick solution suitable for both prototypes and existing devices to optimize EMC performance.

A. Appendix

A.1 References

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CONTACT INFORMATION

appnotes@we-online.com
Tel. +49 7942 945 - 0

Würth Elektronik eiSos GmbH & Co. KG
Max-Eyth-Str. 1 74638 Waldenburg Germany
www.we-online.com

REVISION HISTORY

Document Version	Release Date	Changes
ANP139a	2026/08/26	Initial release of the application note

Note: *The current version of the document and the release date are indicated in the footer of each page of this document.*