SUPPORT NOTE

SN032 | WE-FNCS: Flexible Nanocrystalline Sheets for Magnetic Shielding and Wireless Power Transfer Efficiency

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1. INTRODUCTION AND THEORETICAL BACKGROUND

The integration of magnetically coupled technologies into electronic circuits may lead to undesired effects caused by uncontrolled magnetic fields. These fields can result in functional disturbances as well as electromagnetic compatibility (EMC) issues. This support note discusses the underlying causes and possible mitigation methods.

A dedicated test setup was developed to reproduce real-world conditions in a controlled laboratory environment. Many of the effects observed can be reduced by using magnetically permeable materials. For this reason, the behavior and performance of such materials are examined in detail, with the primary focus placed on WE-FNCS (Flexible Nanocrystalline Sheets).

The first part of this support note briefly introduces the relevant theoretical principles and explains the key aspects of magnetic shielding. The second part investigates the application of shielding material in wireless power transfer systems. In this context, the material is used less for shielding and more for guiding and concentrating the magnetic flux, thereby improving overall system efficiency.

In addition, the effects of eddy currents generated by magnetic fields induced in conductive plates are analyzed.

1.1 Inductive Coupling

Inductive coupling works by driving the transmitter coil with an alternating current, thereby generating a time-varying magnetic field. This alternating magnetic flux induces an electrical voltage in a receiver coil in accordance with Faraday's law of induction. If a load is connected and the receiver coil is positioned such that a sufficient portion of the magnetic flux couples into it, current flows and electrical energy can be transferred efficiently to supply the load. This principle forms the basis of transformers as well as wireless power transfer systems, such as those used in electric toothbrushes. It is also utilized in RFID/NFC systems for applications including access control and electronic payment solutions.

The current caused by the induced magnetic field in the receiver coil can be rectified and regulated to supply electronic circuits or charge batteries. Figure 1 shows an example of two tightly coupled coils, of equal size, with diameters much larger than the distance between them.

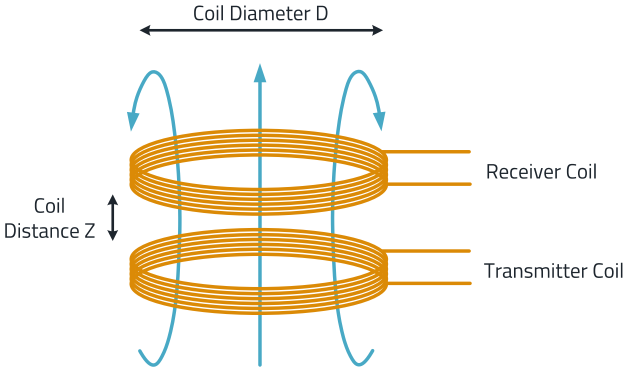

Figure 1: Tightly coupled coils with Z much smaller than D.

1.2 Eddy Currents

The transfer efficiency of an inductive system can be improved by increasing the coupling factor, allowing a larger proportion of the transmitter's magnetic flux to link with the receiver coil. If the distance between the transmitter and receiver coils is relatively large, the system is considered loosely coupled because only a small fraction of the generated magnetic flux reaches the secondary side.

Independent of the coupling factor, additional losses may occur when conductive materials are located near the alternating magnetic field. These losses are caused by eddy currents (Foucault currents), which are induced current loops generated within conductive materials. According to Faraday's law, the induced currents generate magnetic fields that oppose the change in magnetic flux.

As illustrated in Figure 2, eddy currents circulate in planes perpendicular to the magnetic field. Their magnitude depends on the magnetic-field strength, the enclosed loop area, the rate of change of magnetic flux, and the electrical resistivity of the material.

In addition, the geometry of the conductive structure – such as slots, holes or interruptions in the metal surface – significantly influences the magnitude and distribution of the eddy currents and therefore the resulting losses and shielding effects.

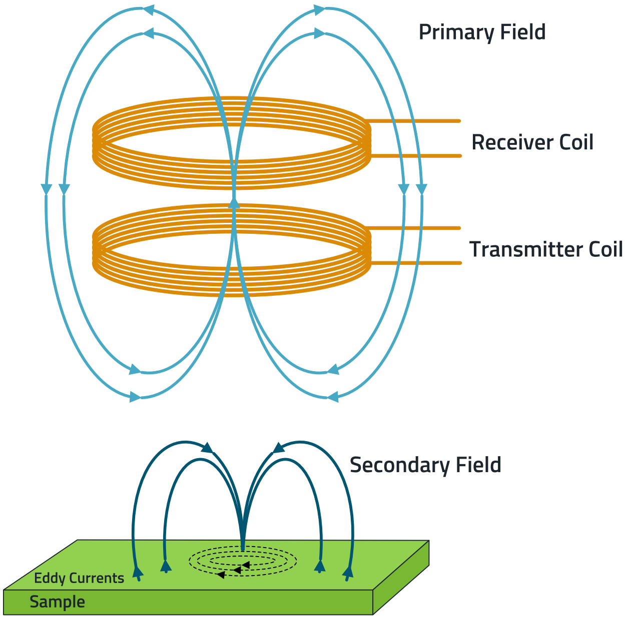

Figure 2: Diagram of eddy currents caused by placing a conductive surface close to the coil.

1.3 Magnetic Shielding

Magnetic shielding materials primarily provide a low-reluctance path that redirects magnetic flux. In alternating magnetic fields, however, additional losses occur due to hysteresis and eddy currents within the material, resulting in partial dissipation of magnetic energy.

Wireless power systems often generate considerable electromagnetic emissions because of their relatively loose coupling. As a result, such systems may be less suitable for applications with stringent EMI or EMF requirements. In these applications, the purpose of the magnetic shielding material is not only to reduce stray magnetic fields, but also to concentrate and guide the magnetic flux within the intended energy-transfer path while protecting surrounding circuits and nearby electronic devices.

Magnetic permeability describes a material's ability to guide magnetic flux. High-permeability materials, such as ferrites, provide a low-reluctance path that concentrates and redirects magnetic field lines, making them highly effective for magnetic shielding and magnetic flux control.

The permeability of magnetic materials is frequency-dependent and complex-valued. It consists of a reactive (μ') component, which describes the material's ability to store and guide magnetic energy, and a loss component (μ''), which represents magnetic losses and energy dissipation within the material.

Figure 3 shows the typical complex permeability behavior of WE-FNCS materials as a function of frequency. The real permeability component (μ') dominates at lower frequencies and enables efficient magnetic flux guidance and shielding effectiveness. With increasing frequency, μ' decreases while the loss component (μ'') becomes increasingly significant due to magnetic relaxation and eddy-current effects within the material structure.

This frequency-dependent behavior is particularly important for wireless power-transfer and EMC applications, since both shielding effectiveness and magnetic flux guidance strongly depend on the operating frequency range. High μ' values are beneficial for efficient magnetic-field control and inductive coupling, whereas increased μ'' contributes to electromagnetic energy dissipation and EMI suppression.

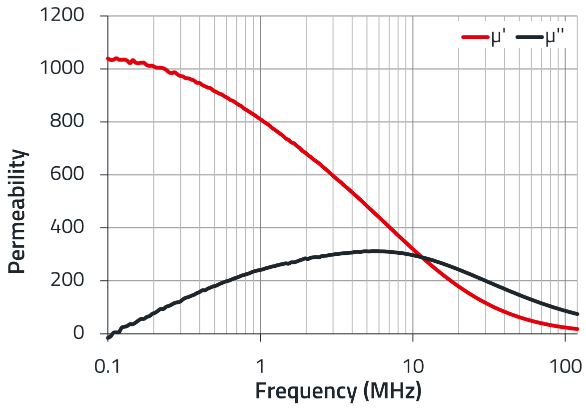

Figure 3: Typical frequency-dependent complex permeability behavior of WE-FNCS material showing the reactive permeability component (μ') and the magnetic loss component (μ'').

Figure 4 illustrates the magnetic-field distribution in a wireless power transfer system without magnetic shielding (left) and with magnetic shielding (right). Without magnetic shielding, a large portion of the magnetic flux spreads into the surrounding environment, resulting in increased stray-field emissions and reduced coupling efficiency between the transmitter and receiver coils. Nearby conductive or electronic structures may therefore be exposed to unwanted magnetic-field coupling and additional eddy-current losses. By introducing a magnetic shielding material, the magnetic flux is concentrated and redirected into the intended energy-transfer path between the coils, thereby reducing stray magnetic fields, improving coupling efficiency, and minimizing interaction with surrounding structures.

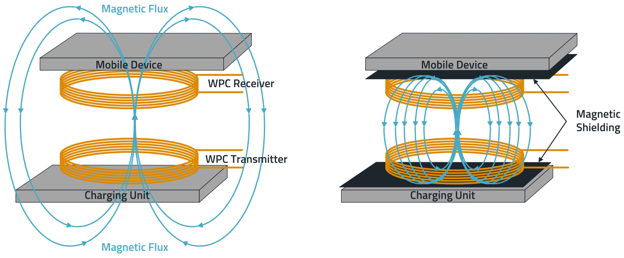

Figure 4: Wireless power communication without magnetic shielding (left) and with magnetic shielding (right).

Materials with a high μ'' component are commonly used for high-frequency EMI suppression because they absorb electromagnetic energy effectively. In contrast, materials with high μ' and low losses are preferred in applications where efficient magnetic flux guidance and high energy-transfer efficiency are required. Additional information regarding magnetic materials and shielding concepts can be found in the corresponding application note ANP016.

1.4 Shielding Materials for PCB Troubleshooting

Magnetic and electromagnetic shielding materials are not only used as permanent components within electronic systems but also as valuable tools during EMC debugging and PCB troubleshooting.

In complex electronic assemblies, unwanted coupling mechanisms caused by electric fields, magnetic fields, or high-frequency current paths are often difficult to identify directly. In such cases, temporary shielding can help localize the origin of interference and evaluate possible mitigation strategies.

Flexible shielding materials are particularly useful during development because they can easily be placed over sensitive circuit areas, cables, switching nodes, or magnetic components without requiring modifications to the PCB itself. Depending on the material properties, the shielding may either absorb high-frequency electromagnetic energy, redirect magnetic flux, or reduce capacitive coupling between adjacent structures.

In switching power supplies and wireless power systems, for example, shielding materials are frequently applied near inductors, transformers, or high-current switching loops in order to reduce radiated emissions and minimize unwanted coupling into neighboring circuits. Similarly, temporary shielding can be used to investigate whether EMC problems are caused by magnetic-field coupling, electric-field coupling, or common-mode current paths.

The effectiveness of the shielding strongly depends on the material characteristics, including permeability, conductivity, thickness, and frequency behavior. In addition, the placement and mechanical integration of the shielding material are critical, since incomplete coverage, unintended current loops, or excessive proximity to magnetic components may alter the electromagnetic behavior of the system itself.

As a result, shielding materials can serve not only as EMC countermeasures but also as practical diagnostic tools for identifying dominant coupling mechanisms and optimizing PCB layouts during the development process (Figure 5).

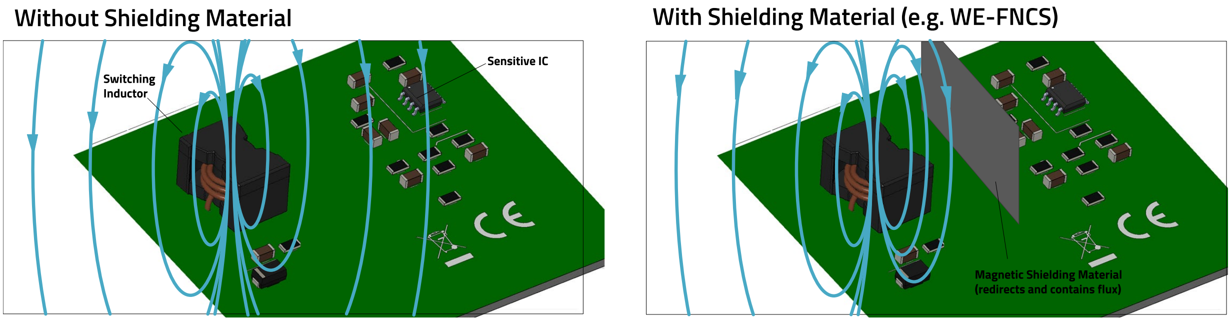

Figure 5: Example of using magnetic shielding material during PCB troubleshooting and EMC debugging.

The left side of Figure 5 illustrates a switching inductor without shielding material, where stray magnetic flux couples into adjacent sensitive circuitry and may cause interference or EMC problems. The right side shows the application of a magnetic shielding material (e.g., WE-FNCS), which redirects and concentrates the magnetic flux, thereby reducing unwanted coupling into neighboring circuits.

2. EXPERIMENTAL APPROACH

This section describes the laboratory measurements used to characterize WE-FNCS compared with other magnetic materials. The experimental approach is based on exposing the material samples to an alternating magnetic field generated between two inductively coupled coils.

The setup consists of two copper coils. One coil act as the transmitter (emitter), while the second coil serves as the receiver. The transmitter coil is connected to the 50 Ω output of a signal generator supplying a sinusoidal signal. The receiver coil is connected to an oscilloscope with a 50 Ω input termination in order to measure the induced voltage. Since the transmitter coil impedance is frequency dependent, the transmitter current should be monitored, or the receiver voltage should be normalized to the transmitter current. This allows the influence of the investigated material to be separated more clearly from frequency-dependent source and coil impedance effects. The complete measurement setup is shown in Figure 6.

Additional information regarding the coil parameters, excitation conditions, and other relevant measurement details is provided in Table 1 and Table 2 (Appendix A.1).

Using the setup described above, two types of measurements are performed. The first investigates the attenuation of magnetic coupling in order to evaluate the influence of the material on the magnetic field between the coils. The second examines eddy-current effects and their impact on inductive wireless power transfer efficiency.

2.1 Effect at Low & Medium Frequency

To evaluate the influence of magnetic material on an inductive link, the change in magnetic coupling between the transmitter and the receiver coil is measured. This is achieved by placing the material sample in the center between the two coils and observing its effect on the induced voltage and transferred power under defined operating conditions.

The inserted material modifies the magnetic flux distribution between the coils by either redirecting, concentrating, or partially attenuating the magnetic field. Depending on the material properties – particularly permeability and magnetic losses – the decrease in coupling between the coils will vary.

The corresponding measurement setup is shown in Figure 7. In this configuration, the magnetic shielding material is positioned directly between the emitter and receiver coils to evaluate its influence on the magnetic link.

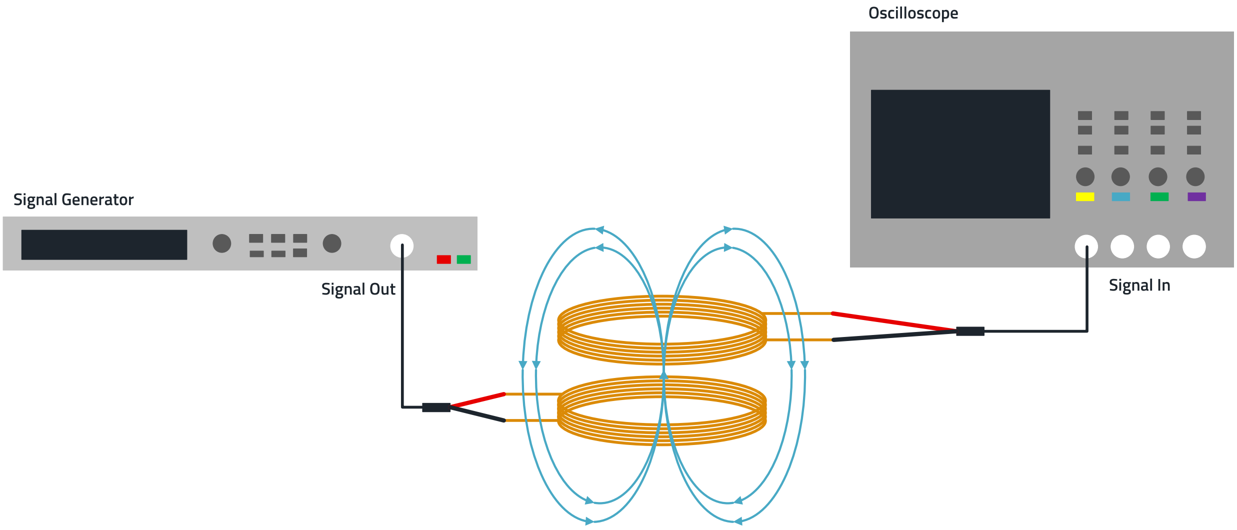

Figure 6: Setup for measuring magnetic coupling and induction between two coils.

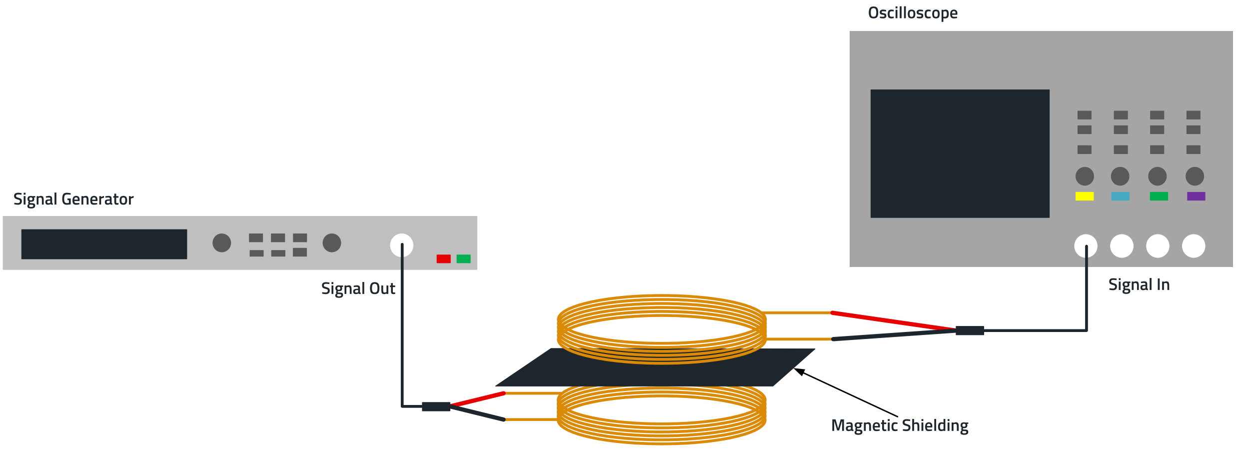

Figure 7: Measurement setup with magnetic shielding material placed between the transmitter and receiver coils for evaluating its effect on magnetic coupling.

2.2 Measurement Result Shielding Effect @200 kHz – 1 MHz Frequency Range

Figure 8 shows the measurement results obtained with the setup described in section 2.1. First, the reference measurement was performed without any magnetic material placed between the coils (black trace). Subsequently, different magnetic shielding materials were inserted between the transmitter and receiver coils and the induced voltage was measured.

The investigated materials include a 0.1 mm thick MuMETAL™ sheet (dashed black trace), as well as thin Flexible Absorber Sheet (WE-FAS) laminates (0.1 mm) from the 3441 and 324xxx material families (light grey traces). Finally, three WE-FNCS materials with identical thickness but different permeability values were evaluated:

- **353001**: Thickness of 0.09 mm and relative permeability 1000 (continuous red trace);
- **353011**: Thickness of 0.09 mm and relative permeability 2000 (dashed red trace);
- **353021**: Thickness of 0.09 mm and relative permeability 10000 (dotted red trace).

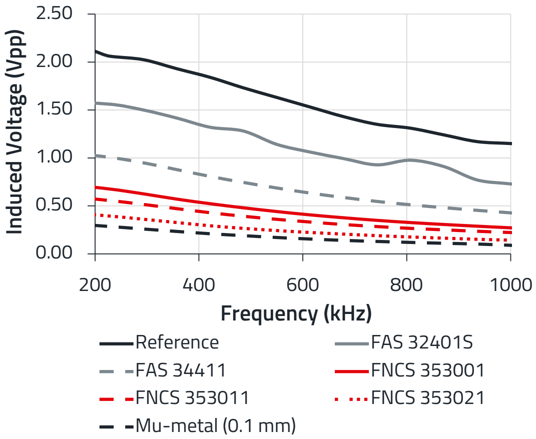

Figure 8: Induced voltage measured at low frequencies for different magnetic shielding materials.

As shown in Figure 8, the induced voltage of the reference setup decreases with increasing frequency. This behavior is mainly caused by parasitic effects within the measurement setup, including stray capacitances, frequency-dependent coil impedance, non-ideal coupling behavior, and increasing losses within the magnetic field path. As a result, the inductive link deviates progressively from ideal transformer behavior as the frequency increases. Therefore, the observed frequency-dependent voltage behavior should be interpreted with regard to the frequency-dependent impedance of the transmitter coil and the resulting transmitter current.

The measurements further demonstrate that, for materials with comparable thickness, the induced voltage decreases as the magnetic permeability increases.

This behavior is expected because higher-permeability materials provide a lower-reluctance path for the magnetic flux and therefore redirect a larger portion of the magnetic field away from the receiver coil.

Within the investigated frequency range, the WE-FNCS materials show significantly stronger attenuation compared to the WE-FAS absorber sheets. Among the tested materials, only the MuMETAL™ sheet provides slightly higher attenuation than the highest-permeability WE-FNCS variant.

An alternative representation of the measurement results is shown in Figure 9, where the reduction of the induced voltage relative to the reference measurement is plotted. The reduction was calculated as the difference between the induced voltage measured without shielding material (Vref) and the voltage measured with the material inserted between the coils (V_shield).

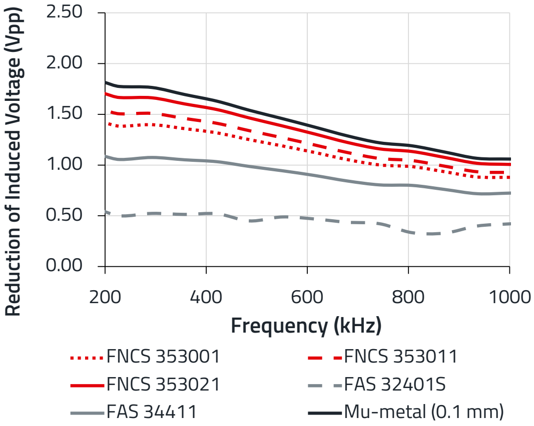

Figure 9: Calculated reduction of the induced voltage (Reduction = $V_{ref} - V_{shield}$) for different magnetic shielding materials vs frequency.

3. INDUCTIVE WIRELESS POWER TRANSFER APPLICATION

Wireless power transfer (WPT) systems based on inductive coupling are widely used in consumer and industrial electronics. Typical applications include electric toothbrushes, wearable devices, smartphones, medical equipment, and contactless charging systems. In these applications, electrical energy is transferred through a time-varying magnetic field generated between a transmitter and a receiver coil.

Most inductive wireless power systems operate in the frequency range between several tens of kilohertz and a few megahertz.

In practical systems, the operating frequency is commonly selected as a compromise between coil size, transfer efficiency, switching losses, electromagnetic emissions, and system cost. Increasing the operating frequency allows smaller magnetic components and coils, but also increases AC resistance, eddy-current losses, dielectric losses, and EMC challenges.

The efficiency of inductive power transfer depends strongly on the magnetic coupling between the coils. In practical application, conductive structures located near the magnetic field – such as metal housings, batteries, shielding plates, or mechanical support structures – may significantly reduce efficiency. Alternating magnetic fields induce eddy currents within these conductive structures, resulting in additional power dissipation and distortion of the magnetic flux distribution. Consequently, less magnetic flux couples into <the receiver coil and the transferred power decreases.

To reduce these effects, magnetic shielding materials are commonly placed behind or around the coils. In wireless charging systems, such materials are typically not used for classical shielding purposes, but rather for magnetic flux guidance. The objective is to redirect and concentrate the magnetic field into the intended coupling path while simultaneously reducing stray magnetic fields and minimizing eddy-current generation in nearby conductive structures.

High-permeability materials are particularly suitable for this purpose because they provide a low-reluctance path for the magnetic flux. As a result, they can improve coupling, reduce magnetic leakage fields, and increase immunity against nearby metallic objects.

3.1 Experimental Setup for Wireless Power Transfer

To investigate the influence of magnetic shielding materials on inductive wireless power transfer, a laboratory setup representing a practical charging application was developed. The setup emulates a typical wireless charging system, such as those used in low-power consumer electronics.

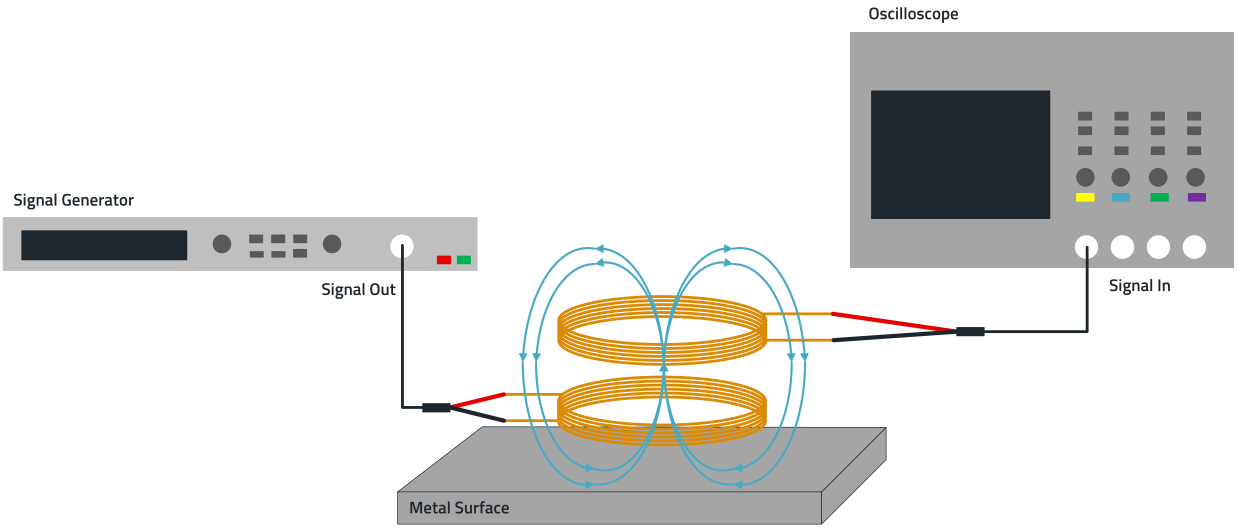

Figure 10: Wireless power transfer measurement setup with a conductive metal surface below the transmitter coil and without magnetic shielding material.

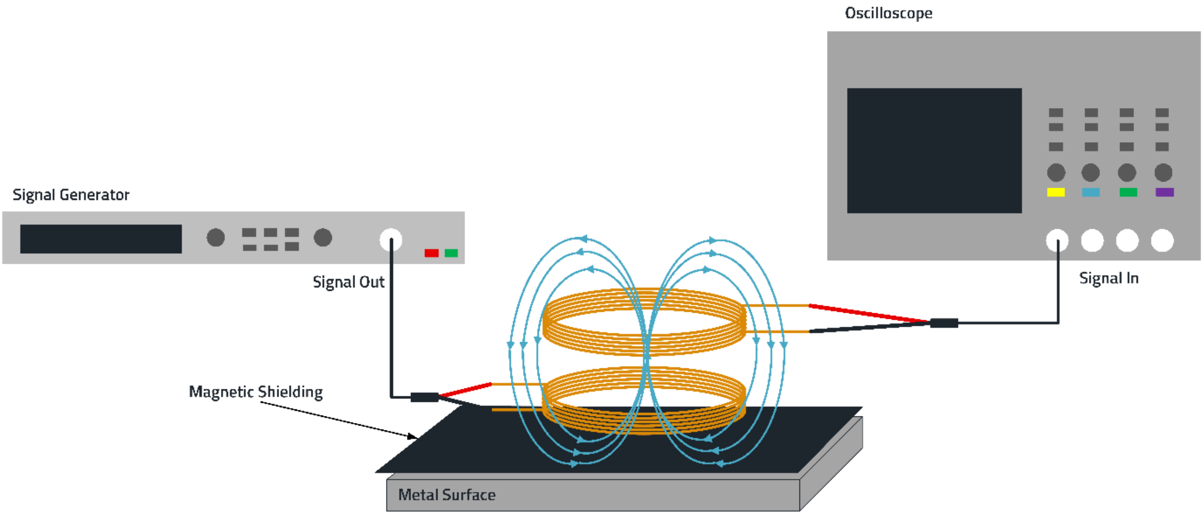

Figure 11: Wireless power transfer measurement setup with magnetic shielding material inserted between the transmitter coil and the conductive metal surface.

Figure 10 shows the reference setup consisting of two inductively coupled coils positioned above a conductive metal plate. The metal surface represents nearby conductive structures commonly found in practical products, such as metallic housings, batteries, mounting frames, or shielding elements. Due to the alternating magnetic field, eddy currents are induced within the metal surface, resulting in magnetic losses and distortion of the magnetic flux distribution.

In Figure 11, a magnetic shielding material is inserted between the transmitter coil and the conductive metal surface. The shielding material redirects the magnetic flux and reduces the eddy-current interaction with the metal plate. As a result, the magnetic coupling between the coils is improved and the transferred power increased.

The transmitter coil was driven by a sinusoidal excitation signal, while the induced voltage at the receiver coil was measured using a terminated oscilloscope input. The measurements were performed over a frequency range representative of typical inductive wireless power transfer systems.

3.2 Measurement Result: Inductive Wireless Power Transfer @200 kHz – 1 MHz Frequency Range

For the wireless power transfer measurements, two reference configurations were evaluated. The first reference measurement was performed without any conductive metal surface below the transmitter coil and therefore represents the maximum achievable magnetic coupling and transfer efficiency within the given setup (dashed black trace). The second reference measurement was performed with a conductive metal surface placed below the transmitter coil (solid black trace).

As expected, the presence of the metal surface significantly reduces the induced voltage. This behavior is caused primarily by eddy-current losses within the conductive plate as well as distortion and partial cancellation of the magnetic flux. The induced eddy currents generate counteracting magnetic fields according to Lenz's law, thereby reducing the effective magnetic coupling between the coils.

After the reference measurements, different magnetic shielding materials were laid on the metal surface between the transmitter coil and the metal surface itself in order to evaluate their capability to restore the magnetic coupling and improve power-transfer efficiency.

Figure 12 shows the measurement results for the three investigated WE-FNCS materials:

- **353001:** thickness 0.09 mm, relative permeability $\mu_r \approx 1000$;
- **353011:** thickness 0.09 mm, relative permeability $\mu_r \approx 2000$;
- **353021:** thickness 0.09 mm, relative permeability $\mu_r \approx 10000$.

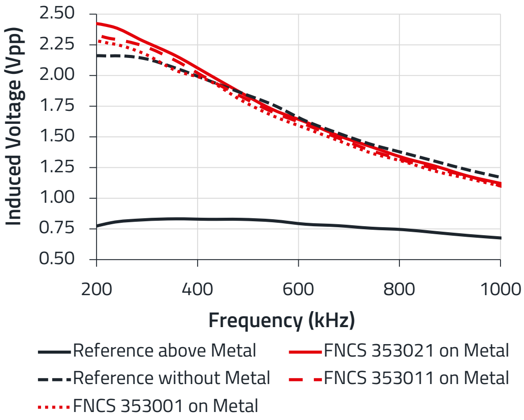

Figure 12: Induced voltage in the wireless power transfer setup for different WE-FNCS materials and reference configurations.

The results demonstrate that the magnetic shielding materials substantially improve the induced voltage compared to the unshielded metal reference. Furthermore, the improvement increases with material permeability. The highest-permeability material, WE-FNCS 353021, provides the strongest recovery of magnetic coupling and approaches the performance of the reference measurement without the metal plate.

This behavior confirms that high-permeability materials effectively redirect the magnetic flux away from the conductive metal surface and back into the intended coupling path between the transmitter and receiver coils.

Figure 13 compares WE-FNCS 353021 with a 0.1 mm Flexible Sintered Ferrite Sheet (WE-FSFS 374004) and a 0.1 mm MuMETAL™ sheet. The measurements show that all investigated materials improve transfer efficiency compared to the unshielded metal configuration. However, clear differences can be observed regarding their effectiveness over frequency.

The WE-FNCS material provides the highest induced voltage across most of the investigated frequency range, indicating particularly efficient magnetic flux guidance under these conditions. The MuMETAL™ sheet also improves the transfer efficiency significantly, although its performance decreases more strongly at higher frequencies. The WE-FSFS material exhibits intermediate behavior between the materials investigated.

The results demonstrate that the selection of magnetic shielding material strongly influences wireless power-transfer efficiency, particularly in systems operating near conductive structures where eddy-current effects dominate magnetic-field behavior.

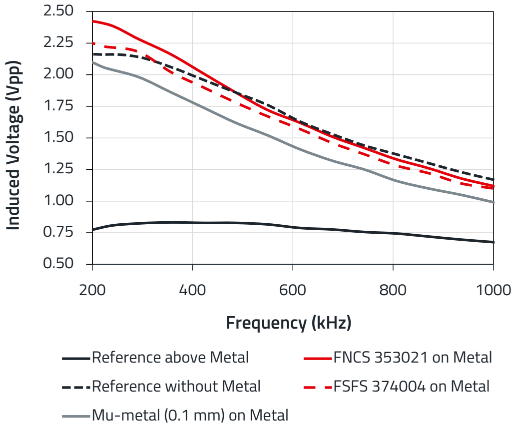

Figure 13: Comparison of induced voltage for WE-FNCS 353021, Flexible Sintered Ferrite Sheet (WE-FSFS 374004), and MuMETAL™ in the wireless power transfer setup.

4. CONCLUSION

The experimental investigations presented in this support note demonstrate the significant influence of magnetic shielding materials on magnetic-field distribution, inductive coupling behavior, and wireless power-transfer efficiency.

For the low-frequency coupling measurements, the investigated WE-FNCS materials show substantially stronger attenuation compared to the investigated WE-FAS material families (32401S and 34411). This behavior is primarily attributed to the significantly higher magnetic permeability of the nanocrystalline material, which provides more effective magnetic flux guidance and redistribution.

The measurements further demonstrate a clear correlation between permeability and shielding performance. Higher-permeability WE-FNCS variants redirect a larger portion of the magnetic flux away from the receiver coil, thereby reducing the induced voltage more effectively. In addition, the material thickness influences the achievable shielding performance, since thicker magnetic layers provide a larger effective magnetic path and increase flux-handling capability under the investigated conditions.

Among the tested materials, only the 0.1 mm MuMETAL™ sheet achieved slightly stronger attenuation in the low-frequency shielding measurements. However, WE-FNCS offers several practical advantages, including lower weight, improved mechanical flexibility, easier handling and integration, and potentially lower system cost depending on the application. These characteristics make WE-FNCS particularly attractive for compact electronic systems and industrial integration.

In the wireless power-transfer measurements, the investigated WE-FNCS materials consistently improved the induced voltage and therefore the effective magnetic coupling in the presence of nearby conductive metal structures. The measurements clearly demonstrate that conductive surfaces located near the transmitter coil strongly reduce transfer efficiency due to eddy-current generation and magnetic-field distortion. By introducing a high-permeability magnetic layer between the coil and the conductive structure, a significant portion of the magnetic flux can be redirected back into the intended coupling path.

Compared with the investigated Flexible Sintered Ferrite Sheet (WE-FSFS) and MuMETAL™ materials, WE-FNCS exhibited very strong performance across the investigated frequency range and provided the highest recovery of induced voltage under the given measurement conditions. The results confirm that high-permeability nanocrystalline materials are highly effective for improving inductive wireless power-transfer systems operating near conductive structures.

Overall, the measurements demonstrate that WE-FNCS combines efficient magnetic flux guidance, strong shielding effectiveness, and favorable mechanical properties. Consequently, the material represents a highly suitable solution for applications involving magnetic shielding, EMC optimization, inductive coupling control, and wireless power-transfer systems.

A APPENDIX

A.1 Tables

Parameter	Value
Receiver Coil Turns	24
Receiver Coil Diameter	5 cm
Transmitter Coil Turns	15
Transmitter Coil Diameter	5 cm
Distance Between Coils Z	2 mm
Self-Resonant Frequency	5 MHz
Sample Size	60 x 60 mm

Table 1: Coil parameters and the size of the sample.

	Type	Amplitude (V_{pp})	Current (mA)	Frequency
Injected Signal	Sinusoidal	4	100	From 200 kHz to 1 MHz

Table 2: Excitation condition corresponds to the characteristics of the injected signal.

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