White Paper

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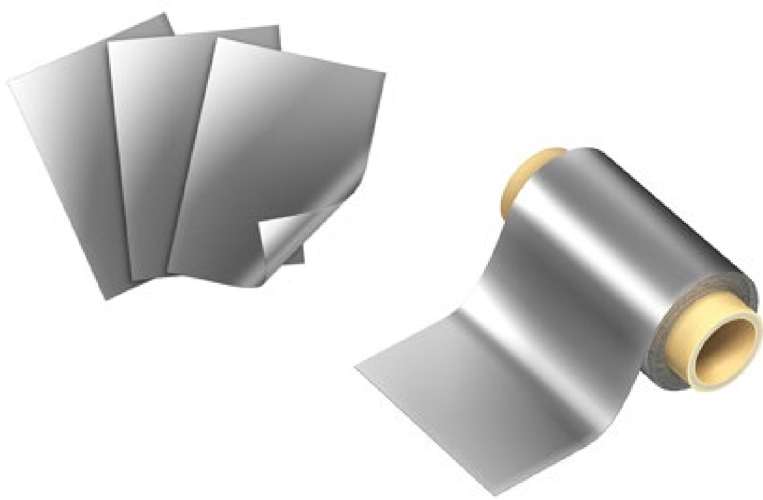
Magnetic Shields for NFC Applications

Introduction

TDK Flexields (a registered trademark in Japan) are thin, flexible magnetic sheets and depending on the material's properties, are used to: 1) suppress unwanted electromagnetic interference (EMI) signals, 2) improve NFC antenna performance, 3) contain the magnetic flux (ϕ) and shape the magnetic field (H) in wireless power applications, 4) provide a means of magnetic coupling in inductive wireless power systems, and 5) provide a magnetic field "bypass" to route it away from other components or metal. The parameters of greater importance of these magnetic sheets differ depending on the application. This paper will focus solely on the requirements for NFC applications and is intended to provide a clearer understanding of the magnetic material parameters' impact on performance, how Flexield works, and what is going on in terms of the Physics.



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Background

Unlike for EMI noise suppression applications where TDK's Flexield magnetic sheets [shields] are used as stand-alone solutions, magnetic shields targeting Near-Field Communication (NFC) applications are combined with a thin metal coil structure [pattern] to create relatively high quality factor (Q) antennas. Therefore, the total antenna performance is dependent on both the antenna structure AND the magnetic material used as the shield. Additionally, similar to magnetic inductive wireless power applications, NFC also looks to optimize the magnetic coupling factor (K) to improve performance and efficiency, which is heavily dependent on the shielding material and its properties. Finally, since coil currents are low in NFC, neither thermals and/or magnetic shield saturation are a concern, meaning the magnetic flux density (Bs) value is of lower importance and the shield thicknesses can be much thinner. The reduction of thickness though, can come with a trade-off in performance in terms of range. This factor is further complicated in an application where metal is present.

Why Magnetic Shields?

The primary functions of magnetic shields in NFC applications are to: 1) protect against performance reducing features such as metal objects directly behind the antenna, 2) shape/direct the magnetic H field, 3) influence the quality factor (Q) of the inductive antenna, 4) increase the coupling factor (K) between the two antennas, 5) help set the inductance value (Ls) for resonant tuning, 6) complete the magnetic field path, and 7) improve security by encapsulating the magnetic field and its respective information. Metal objects, in particular, can absorb or disturb the magnetic flux lines of the generated H field, e.g. Eddy currents, which reduce the effective range and can shift the inductance value and self-resonance frequency and thus reduce performance due to tuning issues between the two antennas.

Where directionality is required, for example on a wall mounted controlled access badge reader, the desired signal needs to be projected outwards away from the wall. By adding a magnetic shield, the spatial H field can be projected outwards from the shield and in the desired direction thus preventing the magnetic flux (ϕ) from going into the wall and subsequent metal objects. If and when the magnetic flux gets into metal areas, a certain amount of the flux is absorbed or altered and Eddy currents are created. This means that some of the magnetic field energy will be converted into heat and also the magnetic field path is impacted. The net result is that the inductance value will decrease and the resonant frequency will drift away from the required 13.56 MHz. The effect of this drifting will mean the system will be detuned, have less sensitivity and the range will be decreased. The self-resonant frequency is given by:

$$SRF = \frac{1}{2\pi\sqrt{LC}}$$

Where:

L = loop antenna inductance

C = capacitance of tuning capacitors

From Equation 1, both the antenna's inductance and the circuit capacitance are critical in determining the self-resonance frequency.

An example of a loop antenna solution is shown in Figure 1 and consists of an air coil attached to a magnetic shield in a specific configuration in order to make it an effective antenna.

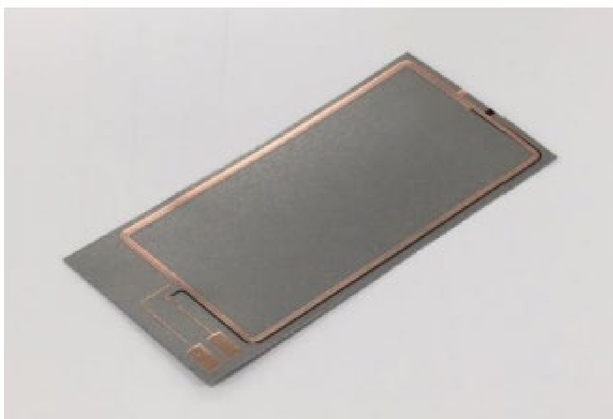

Figure 1 – NFC copper plated passive loop antenna on IFL04 Flexield

Choosing magnetic shields, for short-range, low power communication applications, requires attention to key parameters and understanding what is important. Permeability (μ') and the material loss (μ") value both need to be considered. Additionally, the physical size, in the X/Y/Z directions, may be restricted and this may limit the antenna's performance. Therefore, it is paramount that one starts with the best shield material possible, especially as the maximum shield thickness is reduced and/or the communication range needs to be increased.

Magnetic shields consist of various materials with common ones being metal powder, ferrite, and polymer materials with the performance of each material being unique. "Similar" materials, on paper at least, from different suppliers can behave vastly different. It is advised to always get the behavior curves over frequency since magnetic shield material parameters can only be given as just that, stand-alone material values. Each NFC antenna configuration and pattern will be unique and therefore, it will be up to the designer to either simulate one's antenna design with various available materials or perform actual testing.

For NFC applications, where optimizing wanted signals and frequencies is key, the following complex permeability (μ) equation can be used to help understand the shield material:

$$\mu = \mu' - j\mu'' \qquad \text{Eq. 2}$$

Where:

μ’ – is the material’s permeability (hence related to energy storage)

μ” – is related to the material’s inner losses

Over frequency, both of these parameters will change, and how much, depends on the material. The μ’ and μ” curves for TDK’s IFL05K material are shown in Figure 2.

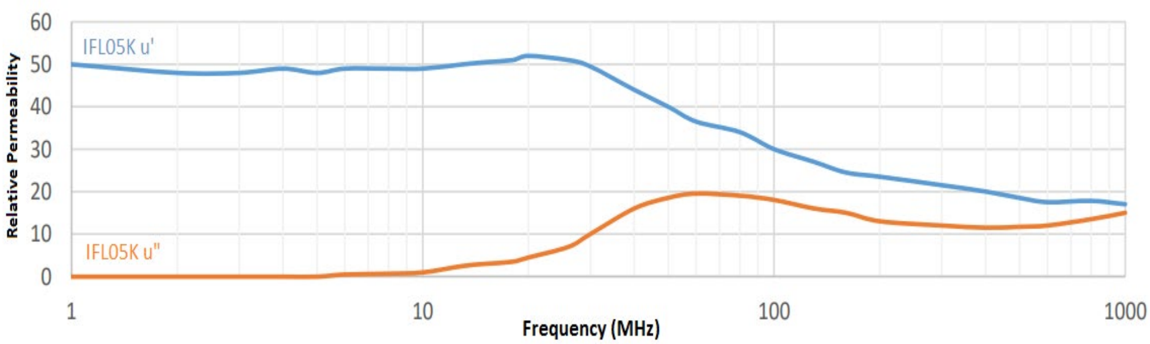

Figure 2 – μ’, μ” frequency behavior curves for IFL05K material

Permeability defines the ability of a material to support the formation of a magnetic field within itself and contain magnetic flux. μ”, at lower values, creates a lesser resistive path for any magnetic flux passing through the material and allows the wanted signal to pass through less impeded. Each unique material’s composition, density and inner grain size and shape will impact both μ’ and μ”.

Magnetic Shield Characterization

The first key parameter used to quantify a material is the quality factor. Q is a figure of merit that describes the material’s potential to store energy relative to the loss within the material, and is thus related to both μ’ and μ”, and given by:

$$Q = \mu'/\mu'' \qquad \text{Eq. 3}$$

For NFC applications, performance is dependent on the Q value, but many times more emphasis is put upon increasing μ’, and hence, increasing K. This means that two different materials with the same Q value, but not the same µ' (or K) value, will behave differently and equates to differing communication ranges. Magnetic shield manufacturers continue to strive to increase the µ' and lower the µ" values of their respective materials.

Since both µ' and µ" change over frequency, as shown in Figure 2, this implies the Q value also changes over frequency. A high Q material at one frequency may be very low Q at another frequency.

Coupling factor (K), is a dimensionless value that ranges between 0 and 1, and is given by:

$$K = \frac{M}{\sqrt{L_{TX} \times L_{RX}}} \qquad \text{Eq. 4}$$

Where:

M = mutual inductance between two antennas

L_{TX} = inductance of the reader/writer antenna

L_{RX} = inductance of the target device antenna

Permeability greatly influences magnetic coupling through mutual inductance. Mutual inductance can be explained as the impact two individual inductors (antennas) have on one another's inductance value as they are brought into close proximity. As the two antennas get closer together, there is an additional magnetic influence that increases the inductance value on each side

The last key figure of merit is given as:

$$\mu' \times t \qquad \text{Eq. 5}$$

Where,

µ' – permeability

t – thickness of the magnetic shield

The higher this figure of merit value, the better the performance. However, at some point, continuing to increase the thickness of a particular material no longer offers any real benefit and may just add thickness, weight and cost. It is also important to note that if a higher µ' material is used, then the thickness can remain the same to achieve better performance or, if required by physical limitations, the thickness can be reduced and have the same performance. This provides the designer with options if thickness is a driving factor.

Material Selection Considerations and Test Results

To further showcase the highlighted parameters, permeability and material thickness of Equation 5, impact on communication distance, three different materials, each at three different thicknesses, were put through actual testing. The three TDK Flexield materials used were IFL04, IFL05K and IFQ06. Some of the key material parameters, along with communication range results, are provide in Table 1. The μ' values ranged from 45 for IFL04 to 55 for IFQ06 and μ" values from a low of 1.1 for IFL04 to a high of 2.0 for IFQ06 with all measurements performed at 13.56 MHz. As mentioned previously, both the μ' and μ" values do change over frequency.

The data contained in Table 1 was obtained using a ViVOPay 5000M NFC Read/Writer and a 50 x 50 mm passive loop antenna in a card device. For a passive receiver tag or card, the receiver device needs to be powered first and then read by an active R/W device to retrieve the information. The loop antenna used for the testing, is shown in Figure 3.

Magnetic sheet material				Communication distance					
				w/o metal			w/ metal		
Magnetic sheet material	μ' 13.56 MHz	μ" 13.56 MHz	Q 13.56 MHz	magnetic sheet (t=50um)	magnetic sheet (t=100um)	magnetic sheet (t=200um)	magnetic sheet (t=50um)	magnetic sheet (t=100um)	magnetic sheet (t=200um)
IFL04	45	1.1	40.91	32.0 mm	41.1 mm	44.5 mm	13.0 mm	18.0 mm	24.3 mm
IFL05K	50	1.5	33.33	33.1 mm	42.1 mm	46.7 mm	13.0 mm	20.0 mm	27.2 mm
IFQ06	55	2	27.50	33.8 mm	43.5 mm	49.3 mm	13.8 mm	21.3 mm	30.2 mm

Table 1 – communication distance vs. material vs. thickness

One can see that there are actually two coil patterns for the tested antenna. The larger loop coil, around the perimeter is used for the communications and data transfer and the smaller loop coil pattern is used for energy harvesting and transfers power to the smart chip (integrated circuit) to allow the transferring of data.

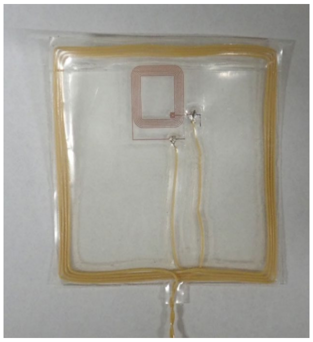

Figure 3 – antenna loop coil used in communication range testing

In Table 1, one can clearly see that the higher µ' material, IFQ06, provides the best range for all thicknesses, and with and without metal present right behind the shielding material. It is also shown that the IFQ06 material at 100 um thickness, is close in performance to 200 um IFL04 material. For the no metal case, IFQ06/100 um yields a range of 43.5 mm and the IFL04/200 um is at 44.5 mm. When putting a metal plate behind the shields, the IFQ06/100 um reduces 21.3 mm and the IFL04/200 um drops to 24.3 mm.

So why not just always use the highest µ' material? Simple answer is price. There is typically a price premium associated with leading edge materials. If price is a driving factor and "good enough" range is the target, then one can look at lower µ', lower cost materials. Additionally, if the shield thickness is not an issue, then the designer can use a thicker, lower µ' material per the figure of merit in Equation 5.

Material Selection Process

The following are some of the key steps when trying to determine the right magnetic shield material for NFC and other low power communication systems. The listed order is a recommendation only but is useful to ensure all design/product aspects are considered and addressed.

Identify the operating frequency – if for HF RFID or NFC, then this will be 13.56 MHz, though some of these same materials can be use for 6.78 MHz resonant wireless power applications.

Identify the needed range – the designer needs to know early on what they are up against. This requirement will drive many of the design considerations, e.g., material and thickness.

Identify the maximum shield area (X/Y) – not only is the K value impacted by the overlap area of the two antenna shields, but also the Q is directly proportional to the loop antenna diameter or the smallest dimension. Having the shield and loop pattern as large as possible will help extend the range.

Identify the maximum thickness – as was shown in this paper, the thickness has an impact on performance. This can be more of a challenge if the antenna size is limited or if the required range is extended.

Identify if any metal will be directly behind the shield – also as was shown in this paper, metal directly behind the shield has a major impact on the range. If metal exists, the designer may not have a choice but to increase the shield thickness or if not available, negotiate with the mechanical or industrial designers to gain more thickness for the shield.

Cost factors – the shield material, size and thickness will all impact the cost. It is best to get a general idea of the complete antenna assembly or shield-only cost prior to making the final shield selection.

Identify the power level – if low power, there is usually no concern about magnetic saturation and the material's Bs value. Also with lower power, less magnetic flux can escape out the back of the shield so this may allow for a thinner shield.

Identify sensitive components – if no sensitive components or no metal is present, the designer may choose to not have a magnetic shield. For many entry type security badges, there is no magnetic layer used.

Obtain the material data curves – this information, along with the frequency, will help determine which material is the right material for each application.

Obtain the test results – compare results versus requirements and make any adjustments needed in terms of material and thickness or even the antenna pattern itself.

Lay-out factors – can the antenna be moved to another area and allow a larger antenna or remove any metal directly behind the shield? Would this move allow for a thicker shield?

Other factors – will the shield be shared with another technology requiring a magnetic shield? This is true for cell phones that combine NFC and wireless charging coils on the same magnetic shield. Being at vastly different frequencies from the magnetic inductive technology (ex: Qi or Wireless Power Consortium at roughly 128 KHz) or one of the existing standard magnetic resonance technologies (AirFuel at 6.78 MHz) it will be difficult to choose a material that optimizes both functions. There would then be a needed trade-off between the two and a compromise in performance of one or the other or even both.

Regulatory testing – as with many RF and communication products, regulatory standards must be met and agency testing must be performed. If initial testing shows borderline compliance, the shield thickness may need to be increased.