DENKA®: SCIENTIFIC WHITEPAPER

Passive High-Frequency Filtering of Conducted Emissions (150 kHz – 30 MHz) for Power Quality, Asset Protection and Energy Performance.

v3.0.0 Latest update: 23rd September, 2026.

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1. Executive Summary

Denka® Platinum Plates are **passive, clip-on high-frequency (HF) filter elements** made from a Ni-Zn ferrite–ceramic composite. They attenuate conducted electrical noise produced by variable frequency drives (VFDs), active front-end rectifiers, solar inverters and switch-mode power supplies. They are designed for the CISPR 11 conducted-emission band of 150 kHz to 30 MHz [1]. Like the ferrite components used throughout electromagnetic-compatibility (EMC) engineering, the plates present a frequency-dependent, loss-dominated impedance. This converts HF noise energy into a very small amount of heat, while the 50/60 Hz power flow passes essentially unaffected [2, 3].

HF noise draws little power directly, but it does costly damage indirectly. Published research shows that HF distortion from power electronics raises losses and temperatures in the equipment it reaches. Hotter conductors have higher resistance, which raises losses further, and heat speeds up insulation ageing and failures [4, 5, 6]. By filtering this noise at its source circuits, Denka® plates act on the root cause of this loss-and-degradation chain.

■ WHAT THE RESEARCH SHOWS: THE HIDDEN COST OF HF DISTORTION

- **Motors:** converter-generated HF harmonics increase total motor losses by **8.7% to 19%** and raise winding temperature by about 8 °C [4, 7]. Under load, iron losses rise by 29% [8].
- **Transformers:** HF harmonics from inverters increase transformer eddy losses by **up to 33%** and accelerate insulation ageing by **22%** [5].
- **Cables:** supraharmonic currents add **1.6–2.4%** to fundamental-frequency cable losses, more than 10% of all harmonic-related losses [9, 10].
- **Heat feedback:** each 1 °C rise in a 37 kW motor added about 41 W of losses [4]. Insulation life roughly halves for every 10 °C of extra temperature [6].
- **Reliability:** bearings account for about **51%** of motor failures [11]. HF current passage has been identified as a prevalent cause of premature bearing failure in drive-fed motors [12, 13].

Percentages refer to the losses of the affected equipment, as reported in each study (see Section 2.3).

■ KEY BENEFITS AT A GLANCE

- **Lower losses and temperatures:** reduces the HF-driven share of losses and heating in cables, motors and transformers, which research quantifies at up to 8.7–19% of motor losses and 33% of transformer eddy losses [4, 5, 7].
- **HF noise filtering:** independently tested at KU Leuven / EnergyVille. Attenuation was confirmed across 1–30 MHz, increasing with frequency and reaching 13–15% (≈1.2–1.4 dB) per plate at 25–30 MHz (Section 7).
- **Asset protection:** reduces the HF stress on cables, motors, transformers, capacitors and insulation. The literature links this stress to extra heating, faster insulation ageing and cable-termination failures [10, 14].
- **Motor bearing protection** (when installed on motor cables at the drive output): targets the HF common-mode currents that cause VFD bearing erosion (EDM pitting and fluting) [13, 15, 16].
- **Cleaner electrical environment:** less conducted interference with PLCs, instrumentation, metering, communication and protective devices such as RCDs [14].
- **Simple and passive:** no power consumption, no moving parts, no galvanic connection to conductors and no rewiring. The plates clip onto existing conductors and are installed by qualified personnel.

■ HOW MUCH CAN DENKA® SAVE?

Field record: across more than 100 facilities worldwide, Denka® installations have typically delivered **8% to 15%** reductions in specific energy consumption (kWh per ton of product). A few sites reached about 20% (Denka® installation data).

Documented examples: Cleopatra Cement, Egypt (measured by SGS, ≈7% on raw-mill drives) and GSF Industrial, Egypt (11.5% plant level, payback under 1.5 years). See Section 8.

Important: savings are site-specific. They depend on the plant's HF noise level, the share of drive-fed load, cable lengths and operating profile. Each project should therefore begin with the diagnostic in Section 6 and be verified using IPMVP measurement-and-verification practice [17, 18].

Scope. Denka® plates are an HF filter. They complement, and do not replace, low-order harmonic filters (below ≈2.5 kHz) and capacitor-based power-factor correction. Those phenomena are governed by IEEE 519 and addressed with dedicated equipment [19].

2. The Problem: High-Frequency Conducted Emissions in Modern Plants

Modern industrial plants rely on fast-switching power electronics. VFDs typically switch at carrier frequencies of 2–16 kHz, and switch-mode supplies at 20 kHz to several hundred kHz. The steep voltage edges (high dv/dt) of these converters produce emission spectra reaching well into the MHz range [20, 21, 22]. Distortion at 2–150 kHz ('supraharmonics') and conducted RF noise at 150 kHz–30 MHz are now recognised as a growing power-quality concern [21, 22].

2.1 Propagation

Conducted emissions travel from the converter back toward the supply and into neighbouring equipment on the same network. This is why CISPR 11 limits and measures them at the equipment's mains port [1, 23]. A large share of this HF current circulates locally between nearby devices and their filter capacitors [22]. Filtering close to the noise source therefore protects the surrounding installation.

2.2 Documented effects on plant and equipment

- **Additional conductor losses:** HF current components flow in a thin outer layer of the conductor (skin effect) and see a much higher AC resistance than 50/60 Hz current. Supraharmonic-related losses have been estimated at roughly 10–20% of the losses attributed to ordinary harmonics [10, 23].
- **Additional core losses:** HF flux adds eddy-current and hysteresis losses in transformer and motor cores [10, 24].
- **Insulation stress and ageing:** superimposed supraharmonics have been shown to increase partial-discharge activity (by about 10% in cited tests) and to contribute to MV cable-termination failures [10, 14].
- **Motor bearing currents:** in drive-fed motors, HF common-mode current flows through the motor's stray capacitances and discharges through the bearings. The result is EDM pitting, fluting and premature bearing failure [13, 15, 20, 25].
- **Interference and nuisance events:** unwanted RCD tripping, disturbed power-line communication and metering, LED flicker, audible noise in capacitors and coils, and ageing of electronic components [10, 14].

2.3 Quantified impact in published research

Independent studies have measured how much HF distortion from power electronics adds to the losses and ageing of plant equipment:

Equipment / effect	Quantified finding	Conditions studied	Source
Induction motor – total losses	+8.7% total losses at rated load; +20% at no load	5.5 kW motor, PWM harmonics above 3 kHz vs sinusoidal supply	[7]
Induction motor – total losses & temperature	+9% to +19% losses; +8.3 °C average temperature; ≈41 W extra loss per 1 °C	37 kW premium-efficiency motor, several commercial converters	[4]
Induction motor – iron losses	+29% iron losses under load (+86% at no load); up to +13 °C	PWM (3.5–9 kHz switching) vs sinusoidal supply	[8]
Distribution transformer	Eddy losses up to +33%; insulation ageing 22% faster	Field measurements, 0–9 kHz harmonics from grid-connected inverters	[5]
MV cable feeder	Supraharmonic losses 1.6–2.4% of fundamental losses; >10% of harmonic losses	24-hour and 1-week measurements, 2–9 kHz	[9]
LV/MV networks	Supraharmonic losses ≈10–20% of harmonic losses; partial discharge ≈+10%	Review of measurements and studies	[10]
General harmonic distortion	Motors +6% losses at 10% voltage THD; transformers +10–15%; capacitor losses ×1.4	Engineering reference data	[26]
Insulation life	Life roughly halves for each 10 °C temperature rise	Arrhenius thermal-ageing principle	[6]
Motor reliability	Bearings ≈51% of motor failures; HF current passage a prevalent cause of premature failure in VFD motors	Industry survey; failure analysis of 20 VFD pump motors	[11, 12]

The loss chain. HF current adds skin-effect and core losses. The extra heat raises conductor resistance (about 0.39% per °C for copper), which raises losses again. One study measured about 41 W of extra loss per 1 °C of temperature rise in a 37 kW motor [4].

Sustained higher temperature and HF voltage stress accelerate insulation ageing and bearing damage, leading to failures, downtime and replacement costs [5, 6, 12].

Most loss quantifications to date cover the supraharmonic range (2–9 kHz) and drive-generated PWM harmonics. The same mechanisms, skin effect and core loss, grow stronger with frequency [23, 24].

3. How Denka® Works: A Passive High-Frequency Filter

3.1 Complex permeability: absorbing HF noise, passing power

A ferrite material is described by its complex permeability [2, 27]:

$$\mu(\omega) = \mu'(\omega) - j\cdot\mu''(\omega)$$

- **At 50/60 Hz,** the real part μ' dominates and the added series reactance ωL is negligible. Line-frequency power therefore passes essentially unaffected.
- **At high frequency (150 kHz–30 MHz),** the loss component μ'' rises and the material behaves as a resistance. It dissipates HF noise energy as a very small amount of heat instead of letting it propagate [3].

The time-averaged power absorbed per unit of material volume for sinusoidal excitation is:

$$P_{absorbed} = \pi \cdot f \cdot \mu_0 \cdot \mu''(f) \cdot |H_{peak}|^2 \cdot V_{plate}$$

Here $\mu_0 = 4\pi \times 10^{-7}$ H/m and H is the magnetic field produced by the noise current. Around a conductor carrying current I, the field is $H = I / (2\pi r)$, which is strongest close to the conductor. For this reason the plates are fitted directly against the phase conductors. Consistent with this filtering behaviour, the plate's self-heating stays at or below 0.4 °C [23].

3.2 Skin effect: why HF current is costly to carry

The skin depth δ of a conductor shrinks with frequency [23]:

$$\delta(f) = \sqrt{(\rho / (\pi \cdot f \cdot \mu_r \cdot \mu_0))}$$

Frequency	Skin depth in copper (δ)	Implication
50 Hz	9.2 mm	Near-uniform current distribution in typical cables
150 kHz	0.17 mm	HF current confined to a thin outer layer
2 MHz	0.046 mm	Effective area collapses; R_AC ≫ R_DC for this component
30 MHz	0.012 mm	Very high AC resistance for HF components

Each frequency component distributes independently. Total conductor loss is therefore the sum of the fundamental loss and the individual HF loss terms:

$$P_{total} = I_{50}^2 \cdot R_{50} + \Sigma \left(I_{k,HF}^2 \cdot R_{k,AC} \right)$$

Filtering the HF currents I_k,HF reduces the second term, which lowers the HF-related heating of cables and connections.

3.3 Core losses in motors and transformers

Iron losses are classically split into hysteresis, eddy-current and excess components [24]. The classical eddy-current term per unit volume is:

$$P_{eddy} = K_e \cdot B_{max}^2 \cdot f^2 \cdot t^2$$

HF flux superimposed on the fundamental adds to these losses, and to local heating in laminations and windings [10]. Filtering HF content at the source reduces this added component.

3.4 From filtering to energy performance

Section 2.3 shows that HF distortion adds losses in motors, transformers and cables and drives a heat–resistance–ageing chain. Filtering HF noise at its source circuits reduces this added stress. How much energy is recovered at a given plant depends on its noise spectrum, the share of drive-fed load, cable lengths and equipment design. Savings are therefore confirmed per site with recognised measurement-and-verification practice [17, 18]. Low-order harmonic distortion (THD up to the 50th harmonic) and displacement power factor lie outside the plates' design band. They are measured as part of the baseline for context [19, 28].

4. Product Specification

Property	Value
Function	Passive high-frequency conducted-noise filter
Versions	Commercial (Blue) and Industrial (Red)
Dimensions & weight	50 mm × 25 mm × 3.5 mm | approx. 21 g
Material	Ni-Zn ferrite / sintered ceramic composite (grade DT400L)
Design band	150 kHz to 30 MHz (CISPR 11 conducted-emission band)
Measured attenuation	13–15% (≈1.2–1.4 dB) per plate at 25–30 MHz; increases with frequency (KU Leuven, 2022)
Self-heating	≤ 0.4 °C under high-frequency noise absorption
Electrical	High-resistivity ceramic; no galvanic connection to conductors
Temperature rating	None
Maintenance	None: no consumables or moving parts; chemically stable ceramic
Environmental	Non-radioactive, asbestos-free, halogen-free, RoHS compliant (per manufacturer declaration)

5. Application & Installation

- **Distribution level:** on the phase-conductor outputs of the circuit breakers feeding non-linear loads (VFDs, rectifiers, SMPS panels, PV inverters). This limits HF noise propagating into the distribution network and neighbouring equipment [22].
- **Motor level (bearing protection):** on the motor cables at the drive output, where the common-mode currents behind bearing damage circulate. This follows the established practice of fitting common-mode ferrite or nanocrystalline cores there [15, 16, 25].
- **Installation:** clip-on, with no rewiring or modification to existing equipment. Installation must be carried out by qualified personnel in line with local electrical-safety rules for work in switchgear (e.g. NFPA 70E or equivalent). It can be scheduled during routine maintenance windows.

6. Pre-Installation Diagnostic & M&V Protocol

Each project follows a five-step protocol based on IPMVP Option B/C and ASHRAE Guideline 14 [17, 18]:

- **Step 1 – HF noise spectrum survey:** clamp an RF current probe around the phase conductors, connect it to a portable spectrum analyzer (e.g. Rigol DSA815 / Tektronix RSA306B), and sweep 2 kHz – 30 MHz using the probe's transfer

impedance. This is an in-situ diagnostic. It is not a CISPR 11 compliance test, which requires the CISPR 16 set-up [1, 21].

- **Step 2 – Thermal baseline:** calibrated infrared thermography of breaker output terminals, cables and motor terminal boxes.
- **Step 3 – Power-quality baseline:** log THD_I, THD_V and true power factor with a Class A analyzer (e.g. Fluke 435-II, harmonics up to the 50th). This documents the low-order power-quality context [19, 29].
- **Step 4 – Energy baseline:** log active energy (kWh) and production (tons) over a period covering the plant's full operating cycle. Build a baseline model that adjusts for production and other independent variables such as feed characteristics and product mix [17, 18].
- **Step 5 – Post-installation verification:** repeat Steps 1–4 after installation. Where practical, add an ON/OFF/ON (A-B-A) comparison under matched production to confirm that the savings come from the plates.

7. Independent Laboratory Testing (KU Leuven / EnergyVille)

In November 2022, the HF attenuation of Denka® plates was characterised at the KU Leuven & EnergyVille research centre (Genk, Belgium) by Ir. Hassan Pervaiz, Ir. Sergio Perez and Prof. Wilmar Martinez of the Power Electronics group [30].

- **Instrumentation:** Agilent 4294A precision impedance analyzer, Tektronix MDO3054 oscilloscope, Agilent 33500B waveform generator.
- **Method:** stepped frequency sweep from 1 MHz to 30 MHz in 1 MHz steps on two-wire test cables, with and without plates.
- **Result – broadband attenuation:** attenuation of the HF voltage was confirmed across the entire 1–30 MHz range compared with the bare cable.
- **Result – frequency dependency:** attenuation increased with frequency, consistent with ferrite loss behaviour (Section 3.1).
- **Result – peak performance:** Commercial (Blue) and Industrial (Red) plates achieved 13–15% attenuation of HF voltage (≈1.2–1.4 dB) in the 25–30 MHz band.

Scope of the test: this was a laboratory characterisation of HF attenuation on test cables, without 50/60 Hz load current. It did not measure energy consumption. Energy performance is established through the field measurements in Section 8.

8. Industrial Field Results

Denka® plates are installed in more than 100 facilities worldwide. Measured reductions in specific energy consumption have typically been 8–15%, with a few sites around 20% (Denka® installation data). Representative documented cases:

Facility & location	Metric	Measured outcome
Cleopatra Cement Factory, Egypt (measured by SGS)	Specific energy consumption of raw-mill induction drives (kWh/t)	≈7% reduction (SGS-reported 7.0%; mean 46.88 → 43.76 kWh/t). Power-draw variance improved by 59%, indicating steadier motor loading.
GSF Industrial Facility, Egypt	Specific consumption (kW/t) and plant power factor	11.5% reduction (78.69 → 69.61 kW/t). True power factor 0.94 → 0.96. Reported payback under 1.5 years.
Saj Ceramics, Kenya (BEST Energy)	Current THD on solar and pump circuits	Glaze Prep Mill 8 THD 24.52% → 9.76%; gasifier pumps THD 64.89% → 54.11%. Reported as site observations (see note).

Note: results are before/after measurements under site operating conditions. The Saj Ceramics THD values concern low-order harmonics (up to the 50th, ≤2.5 kHz), which are outside the plates' HF design band. They are reported as observations, not as a design claim.

9. Conclusion & Value Proposition

- **Proven HF filtering:** independently tested attenuation of conducted noise across 1–30 MHz, increasing with frequency [30].
- **Research-backed loss reduction:** targets a documented source of added losses (8.7–19% of motor losses, up to 33% of transformer eddy losses) and accelerated ageing [4, 5, 7].
- **Field-proven results:** 100+ facilities worldwide, typically 8–15% lower specific energy consumption, confirmed per site through the Section 6 protocol.
- **Asset protection:** less exposure of cables, motors, transformers and insulation to HF stress, a documented contributor to heating, ageing and failures [10, 14].
- **Bearing protection option:** motor-side installation targets the HF common-mode currents that damage drive-fed motor bearings [13, 15].
- **EMC good practice:** a cleaner HF environment for control, metering, communication and protection equipment [14].
- **Passive and low-maintenance:** no energy use, no moving parts, clip-on retrofit without rewiring.

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