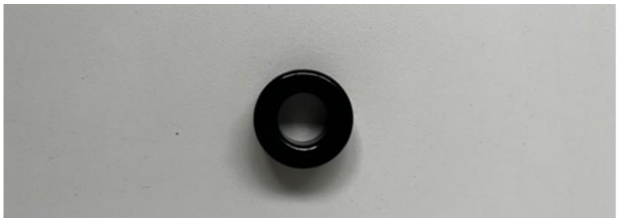
Magnetics, Inc. 0077894A7

Datasheet

Magnetics, Inc. 0077894A7 is a powder core material (Figure 1) that has low loss and high saturation fields. Known for the marketing name Kool Mu, it was formed by taking the known magnetic material, Sendust, and altering the manufacturing process to lower core losses. Possessing these specific properties makes it ideal for power factor correction circuits as well as pulse and flyback transformers. In-line noise filters and inductors are also common uses due to the near-zero magnetostriction. Kool Mu exhibits a potential saturation induction of 1 T.



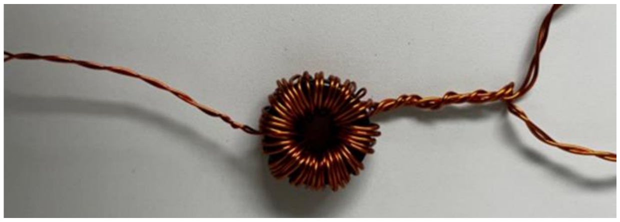


Figure 1. Kool Mu powder core (left) and wound Kool Mu powder core (right).

Date: March 2024

Revision 0

Acknowledgement

This technical effort was performed in support of the National Energy Technology Laboratory's (NETL) ongoing research in the U.S. Department of Energy's (DOE) Office of Electricity's (OE) Transformer Resilience and Advanced Components (TRAC) program. Testing was performed by the University of Pittsburgh.

NATIONAL ENERGY TECHNOLOGY LABORATORY

Dimensions and Magnetic Characteristics of Core

The focus of this datasheet is to measure the core loss and relative permeability at excitation frequency and saturation magnetization ranges appropriate for power electronics applications. The dimensions of the Kool Mu core characterized are presented in Table 1. Additional characteristics of the core are presented in Table 2.

Table 1. Core dimensions.

Dimensions			
Description	**Symbol**	**Sample Dimension (mm)[1]**	**Actual Dimension Used (mm)[1]**
Core Inner Diameter	ID	14.34	14.73
Core Outer Diameter	OD	27.31	26.92
Core Height	H	11.54	11.18

[1]Sample Dimension refers to the dimensions that include coating. These dimensions do not pertain to the effective area used, as this effective area was stated in the provided core manufacturer datasheet. A correction factor accounts for this where plausible, taking the ratio of Sample Dimension-to-Actual Dimension, multiplying the cross-sectional area with this term (see AMPED standard AMP-STD-0C for this calculation, and for other calculations).

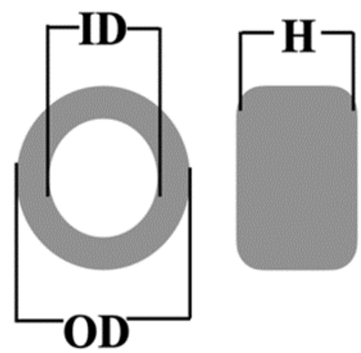


Table 2. Additional properties of Kool Mu core characterized in this work.

Magnetic Characteristics			
Description	**Symbol**	**Finished Dimension**	**Unit**
Effective Area	A_e	65.40	mm^2
Mean Magnetic Path Length	L_m	63.50	mm
Core Mass	C_M	0.0249693	kg
Density	D	5800	kg/m^3
Lamination Thickness	L_M	0	µm
Chemistry	FeSiAl Material	**Grade**	
Anneal		**Impregnation**	Unimpregnated
Core Supplier	MAGNETICS	**Part Number**	0077894A7
Wire Supplier	Remington Industries	**Wire Gauge**	18 AWG, two parallel strands (Primary) 20 AWG (Secondary)

Background

A core loss testing system was used at the University of Pittsburgh to characterize the core material. This system was used to measure relative permeability of Kool Mu at excitation frequencies up to 75 kHz, saturation magnetization up to 1 T, and temperatures up to 150 °C.

Measurement Setup

The relationship of magnetic flux density B vs. magnetic field strength H (BH curve), core losses, and permeability of the core tested are measured using the square waveform core loss testing system (CLTS) illustrated in Figure 2. The number of primary and secondary turns N_P and N_S were chosen from estimates of the probe and core saturation points by the relation defined in IEEE-393 and IEC 62044-3 where:

$$N_P = H_e l_e / i \quad (1)$$

$$N_s = \frac{V_{rms}}{k f A_e B_e} \quad (2)$$

For this datasheet N_P = 19 turns and N_S = 10 turns. In Equation 1, i is 90% of the current the current probe is rated for, H_e is the estimated value the setup can provide for field strength (assumed from i = 160 A), and l_e is the mean path length of the core. In Equation 2, the factor k is dependent on the waveform in question, f is frequency of each test, A_e is core effective area, B_e is the saturation flux density, and V_{rms} is 90% of the maximum voltage the probe is rated for at the given setting it takes the measurement.

Note: The primary winding is comprised of two parallel strands of 18-gauge wire.

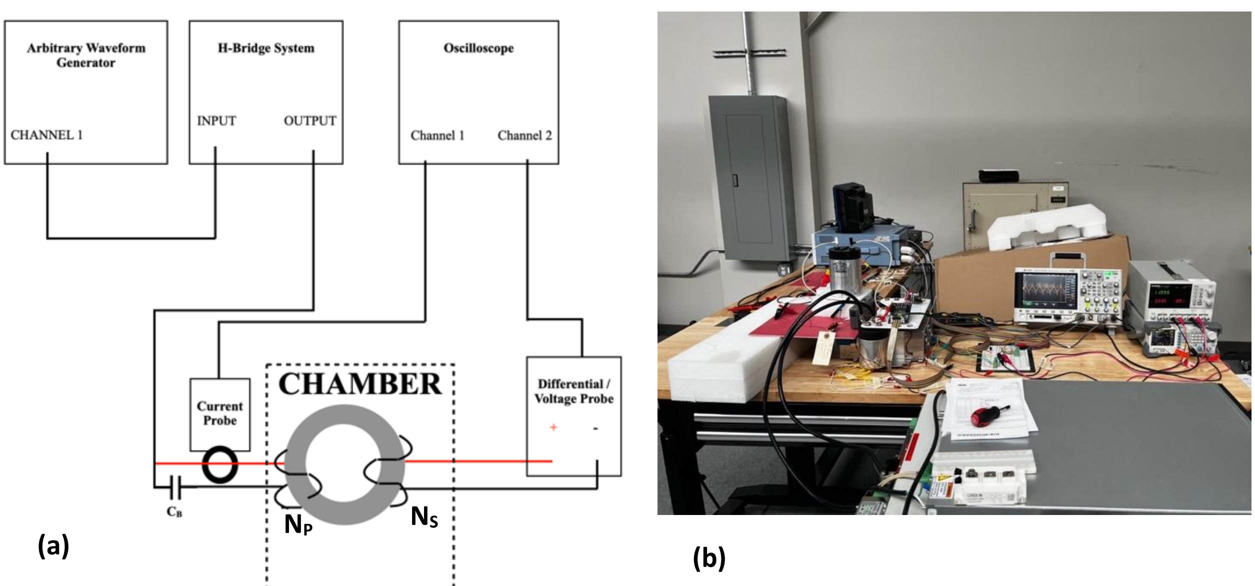


Figure 2. Square wave core loss testing system (CLTS) conceptual setup (a) and actual setup (b).

For measurements conducted at ambient temperatures, the core is exposed to the surroundings as indicated in Figure 3 (left panel). However, for measurements at controlled, elevated temperature it is necessary to place the wrapped core in a furnace as indicated in Figure 3 (right panel).

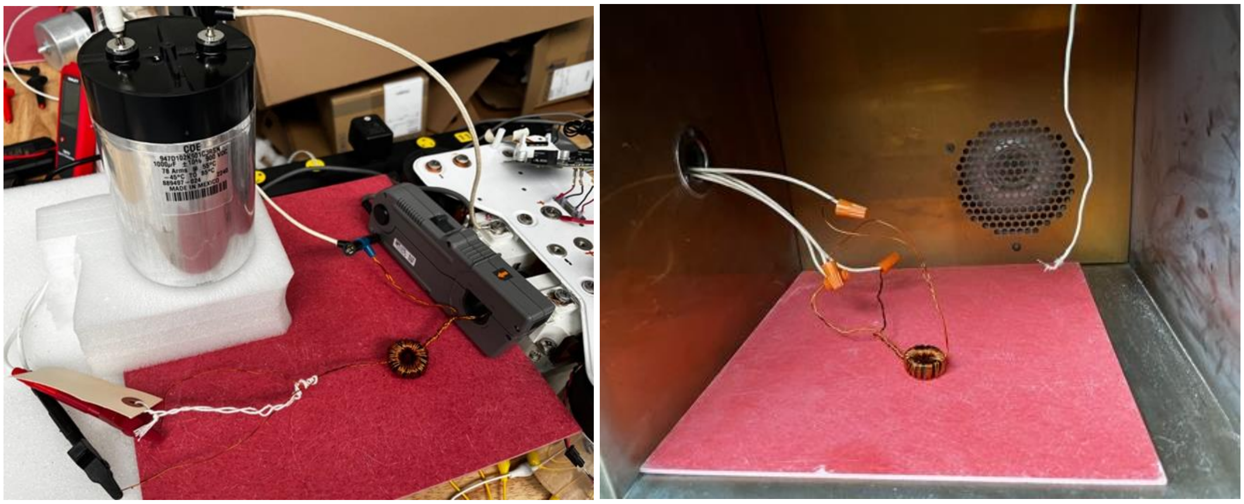


Figure 3. Situation of the core under testing at ambient conditions (left panel) and in a controlled, elevated temperature environment (right panel).

Core Loss Testing – Low Signal with H-Bridge Setup – Elevated Temperature – Manual Procedure

Per AMPED Standard AMP-STD-001, IEEE-393, and IEC 62044-1, IEC 62044-2, and IEC 62044-3, below is the procedure for manual operation of equipment for the low signal setup, to be applied as follows. For a more detailed and general procedure to apply the test, refer to the referenced standard described here.

1. Turn on the measurement equipment and allow sufficient time for stabilization (e.g., 20 minutes).
2. Using a DC power supply, in one channel, set the levels to 5 V_{DC} and maximum current of 0.500 Amps for breadboard inputs and the driver modules for the H-Bridge. For the other channel, set the voltage 24 V_{DC} and maximum current reading 3.2 Amps for the fans of the H-Bridge.
3. Set the arbitrary waveform generator, channel 2, to the following settings.
   a. Begin with a low signal, choosing square waveform.
      - Frequency. Set frequency as initial starting point at 10 Hz. Increase incrementally based on the desired frequencies necessary to perform measurements.
      - Amplitude. Begin with an amplitude value, in terms of peak-to-peak, (V_{PP}), at 5. Increase where deemed appropriate to make sure a fully functioning signal is observed in an acceptable tolerance.

- DC Offset, V_{DC}. Set to 1.
- Duty Cycle. 50%.

4. Set the oscilloscope to the following settings:
    a. Specify probe attenuation.
        - Current measurements were performed with a Yokogawa 701930. Current probe has an attenuation ratio of 0.01 V/A (100:1).
        - Voltage probe from Rigol, the RP1100D was used for voltage measurements, and set to an attenuation ratio of 1000:1.
    b. 60 Hz, 10-200 kHz data was captured with High Resolution settings under Waveform-Acquire Menu.
    c. 400 Hz-1 kHz data was captured with Normal Resolution settings under Waveform-Acquire Menu.
5. Connect from a DC power supply along the line where the capacitor connectors meet.
6. Turn on the low voltage DC power supply to first apply power to the fans and drivers.
7. Turn output of arbitrary waveform generator on.
8. Apply a DC signal into the H-Bridge from another DC power supply, presumably one that can output higher levels.
9. H-Bridge system verification check. Prior to connection of the core under testing, confirm the desired output at three locations on the oscilloscope: 1) the signal at one MOSFET driver; 2) the signal at the other MOSFET driver; and 3) output signal at the capacitor.
10. After verification of H-Bridge measurements, turn output of following equipment off in this order:
    a. DC power supply off.
    b. Arbitrary waveform generator off.
    c. Fan power off.
11. Connect the output leads of the core under testing to the positive (+) and negative (-) terminals of the H-Bridge test system.
12. Turn output of arbitrary waveform generator on.
13. Turn fan power on.
14. Tune DC power supply to a low level of voltage and current.
    a. Vary by quickly turning on and off power supply until desired level is reached.
    b. Examine the waveform on the oscilloscope until desired/predicted current or voltage level is reached.
    c. Examine the waveform on the oscilloscope read from the current probe on the input side and the differential probe on the output side.
15. At each temperature change, let the core soak for at least 5 minutes before taking any measurements.
16. Level the output voltage at the offset and adjust with flat head screwdriver, if possible. Note if probe does not have that capability.

   a. For data presented, voltage probe with asset number PRO0009 does not have the capability.
17. Once desired level is reached, capture the waveform.
   a. Be sure to capture 4-5 periods of the excitation signal being applied.
   b. Look for point of saturation for the core.
      - This can be visually examined when the waveform's maximum value no longer increases. Current waveform will show sharp pointed distortion. The voltage waveform will show more curvature at maximum and minimum points.
18. Auto zero and degauss the current probe before step 9. Also degauss where average current waveform value climbs above an acceptable tolerance of +/- 10 mA.
19. Setup included correction components for DC biasing part of the setup. See the test setup section for a diagram.
   a. The setup includes a biasing capacitor of 1000 uF.
20. Repeat steps 1–6 for other excitation waveforms for examined interest.
21. Record relevant data for data presentation.
22. Repeat step 11 to turn off all equipment upon completion of testing.

Anhysteretic BH Curves

Figure 4 illustrates the low-frequency BH curve measured at an excitation frequency of 10 kHz. Using this BH loop, the anhysteretic BH curve is fitted. Anhysteretic BH curves are computed as a function of flux density B according to Equation 3.

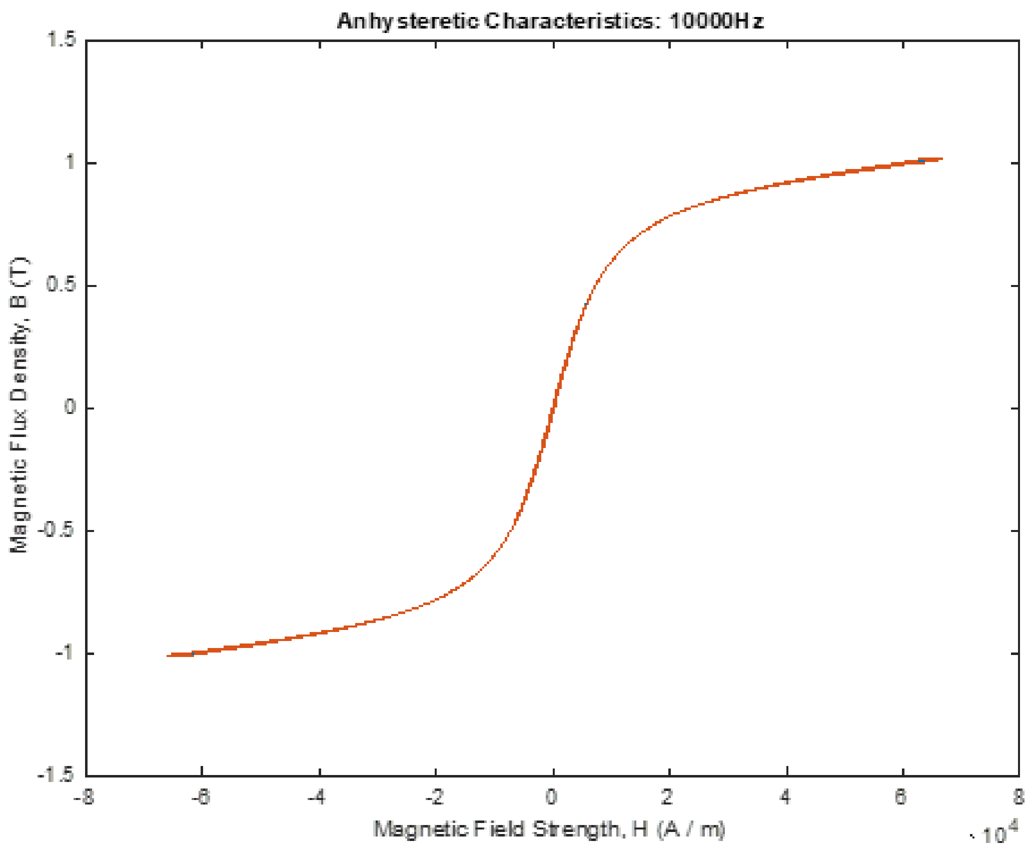


Figure 4. Low-frequency BH loop at 10 kHz excitation frequency.

$$
\begin{aligned}
B &= \mu_B(B)H \\
\mu_B(B) &= \mu_B \frac{r(B)}{r(B) - 1} \\
r(B) &= \frac{\mu_r}{\mu_r - 1} + \sum_{k=1}^{K} \alpha_k |B| + \delta_k \ln(\varepsilon_k + \zeta_k e^{-\beta_k |B|}) \\
\delta_k &= \frac{\alpha_k}{\beta_k}, \quad \zeta_k = \frac{1}{1+e^{-\beta_k \gamma_k}}, \quad \varepsilon_k = \frac{e^{-\beta_k \gamma_k}}{1+e^{-\beta_k \gamma_k}}
\end{aligned}
\tag{3}
$$

The anhysteretic plot is computed by fitting to the BH curve given in Figure 4. Coefficients given in Table 3 are fit to this equation in which relative permeability is expressed as a function of flux density B. For more information concerning the characteristic model equation, see Reference 2.

Table 3. Coefficients used in calculating the anhysteretic BH curve.

μr	α (1/T)	β (1/T)	γ (T)
10	93.2358	128.1669	0.01
	0.00448336	128.8356	0.010002
	0.00162345	120.9322	0.01
	0.00107539	123.7333	0.01

Core Losses

Based on measured data of core losses at various frequencies and considering the changes in the core's configuration, the Steinmetz estimation is provided. The Steinmetz equation is given as Equation 4. The Steinmetz coefficients k_h, α, and β, presented in Table 4, are obtained from empirical data. In Table 4, p_w is core loss per unit weight and has units of W/kg, f_b is base frequency, and B_b is base flux density. In computation, f_b is 1 Hz and B_b is 1 Tesla. More information is given in Reference 3.

$$P_w = k_h \left(\frac{f}{f_b}\right)^{\alpha} \left(\frac{B_{pk}}{B_b}\right)^{\beta} \tag{4}$$

Table 4: Empirical Steinmetz coefficients for core loss from Kool Mu cores studied at various temperatures. Excitation was achieved via square waveform with 50% duty.

Temperature	k_h (W/kg)	α	ß
Ambient	0.052435	1.10	1.5084
50 °C	0.061154	1.098	1.6358
100 °C	0.18739	1.12	1.8804
150 °C	0.091978	1.08	1.6662

Experimentally observed core loss values are compared to those predicted from Equation 4 at ambient temperature (Figure 5) and at 50 °C (Figure 6), 100 °C (Figure 7), and 150 °C (Figure 8).

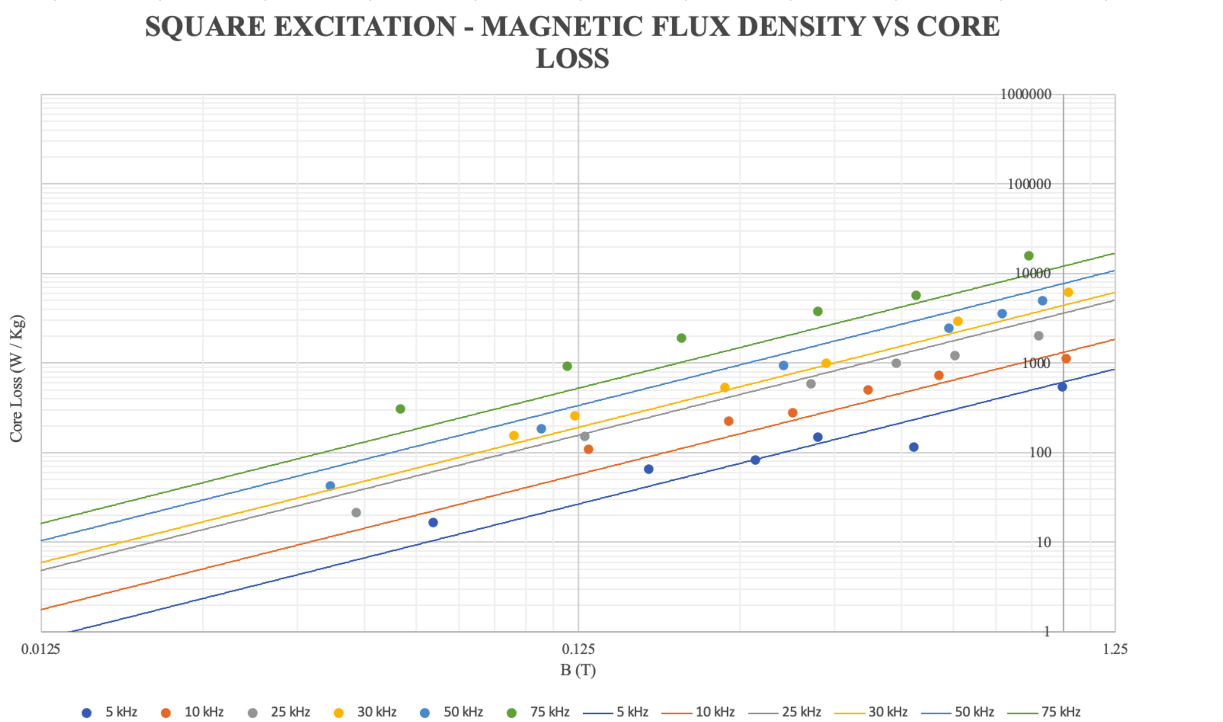


Figure 5: Core loss measured at ambient conditions vs. Steinmetz equation estimate: square 50% duty.

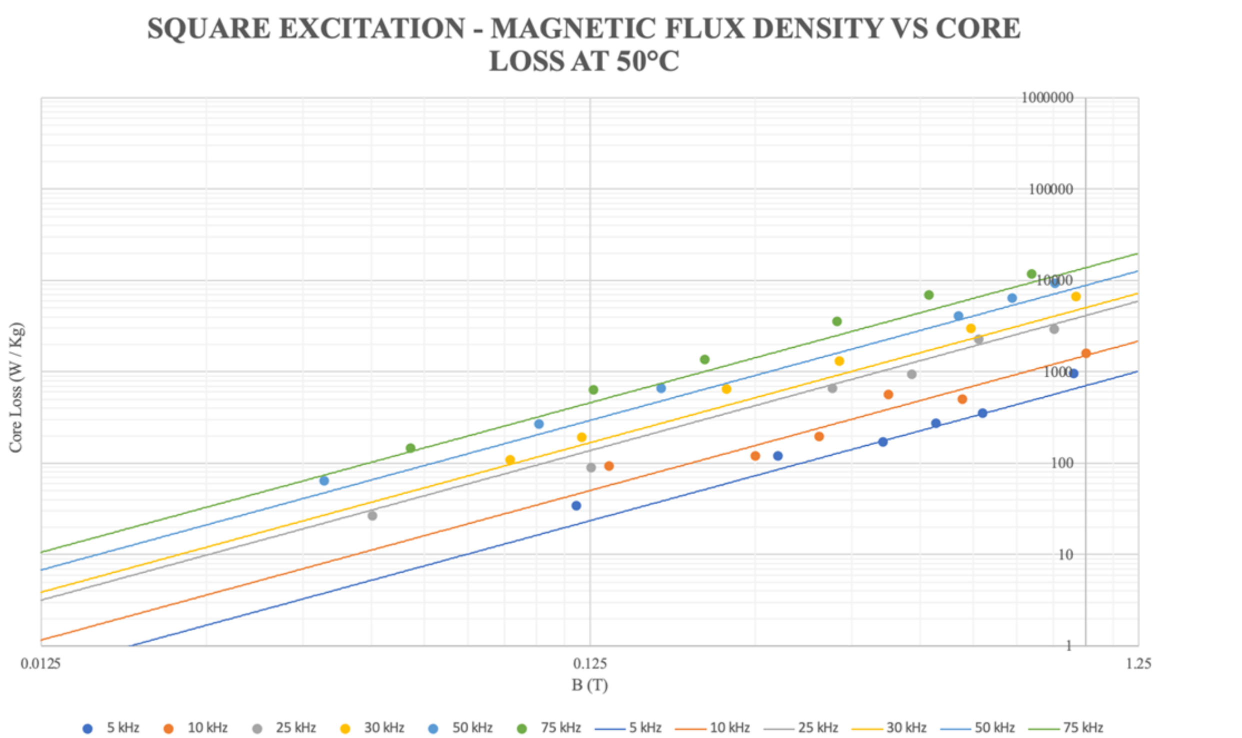


Figure 6. Core loss measured at 50 °C vs. Steinmetz equation estimate: square 50% duty.

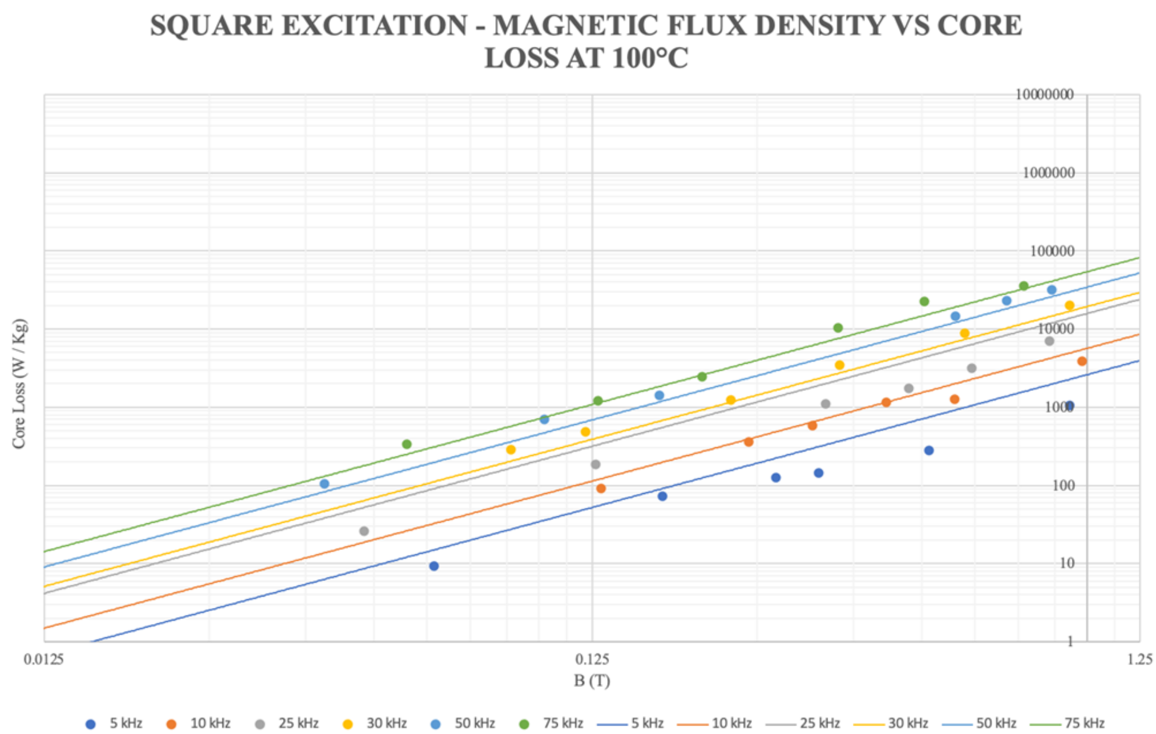


Figure 7. Core loss measured at 100 °C vs. Steinmetz equation estimate: square 50% duty.

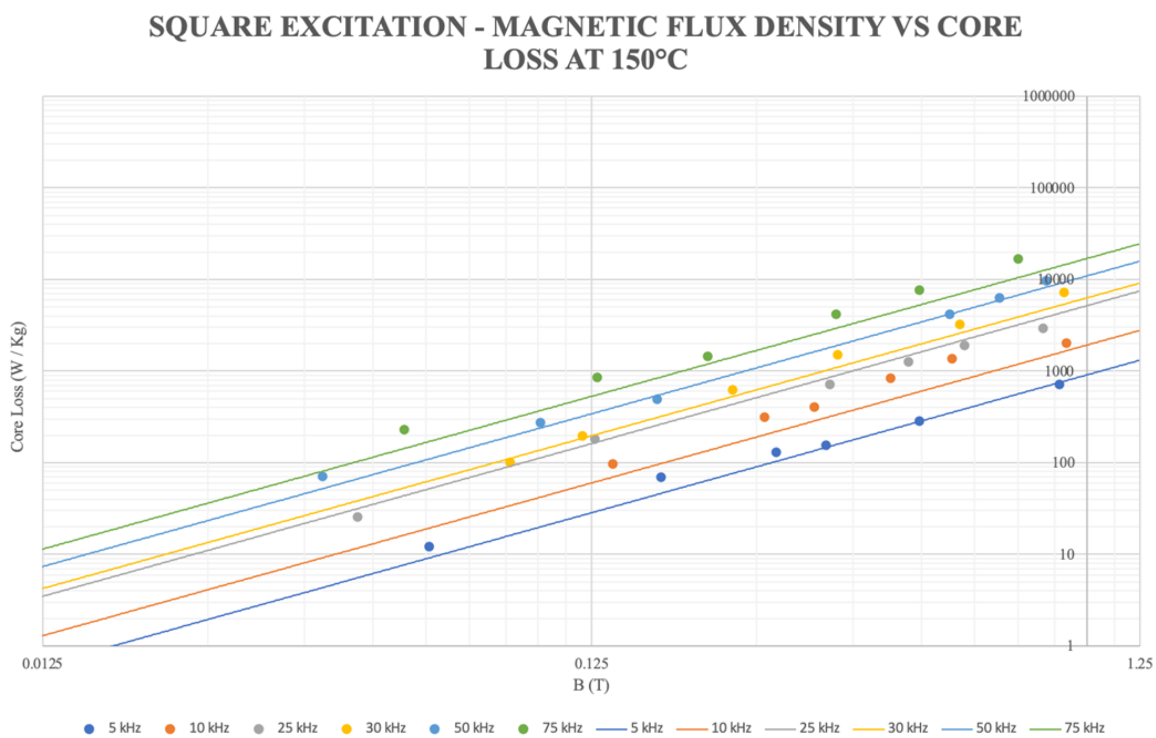


Figure 8. Core loss measured at 150 °C vs. Steinmetz equation estimate: square 50% duty.

Core Permeability

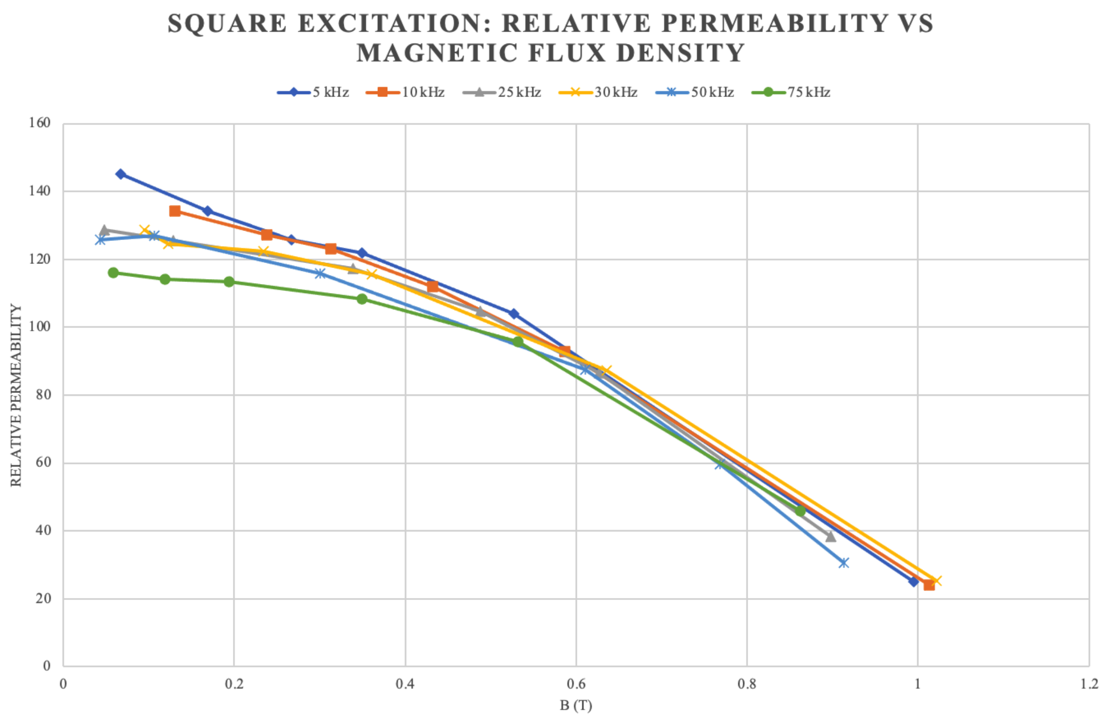


Figure 9. Relative permeability measured at ambient conditions vs. Steinmetz estimate: square 50% duty.

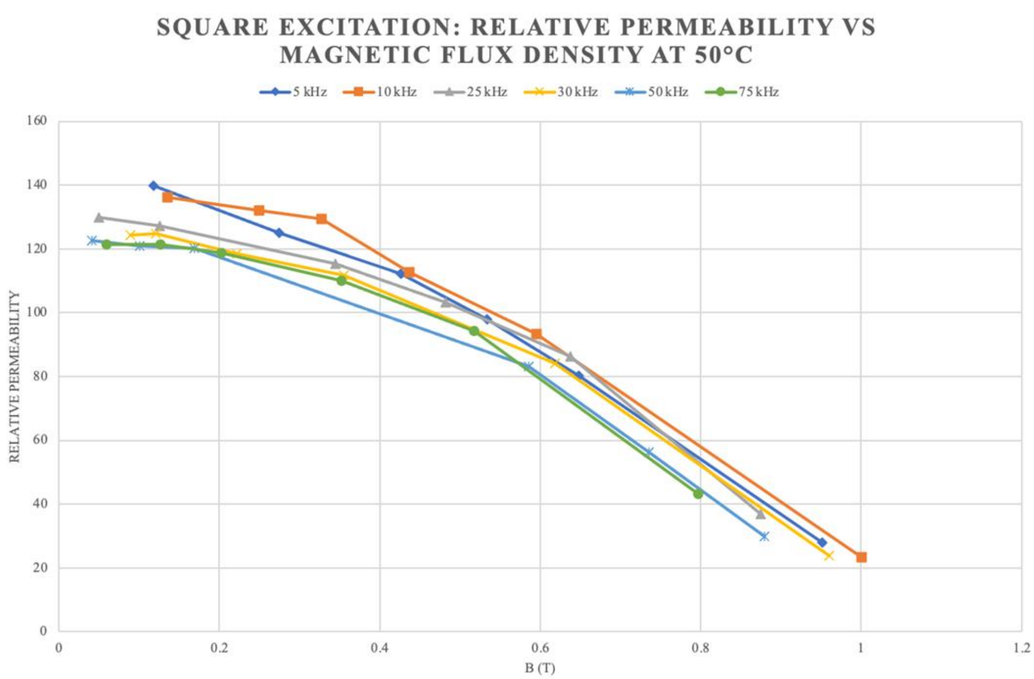


Figure 10. Relative permeability measured at 50 °C vs. Steinmetz equation estimate: square 50% duty.

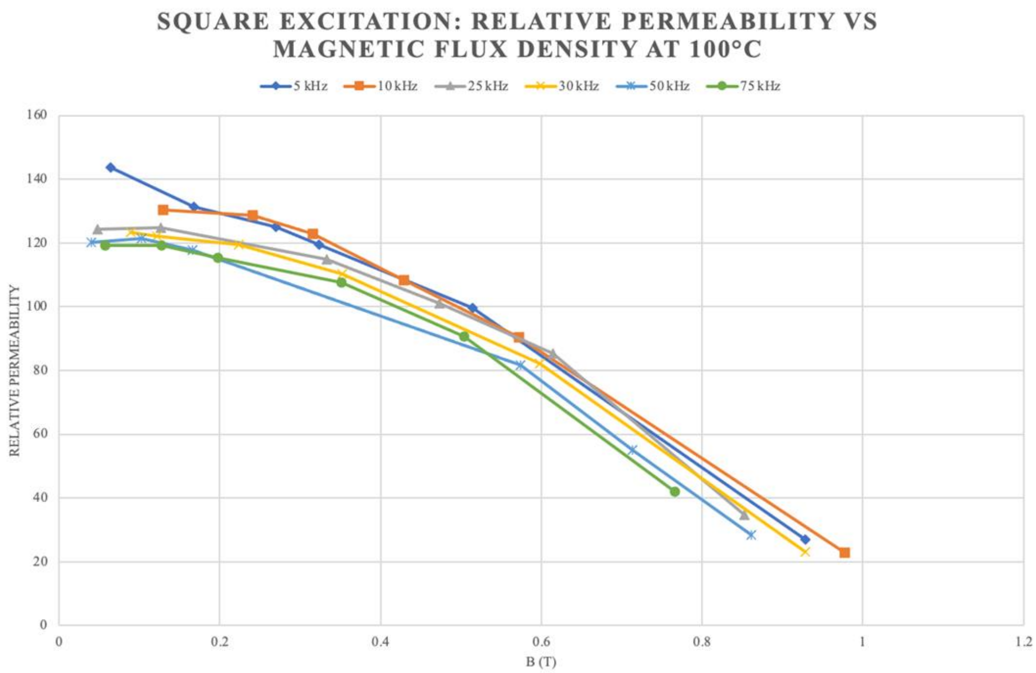


Figure 11. Relative permeability measured at 100 °C vs. Steinmetz equation estimate: square 50% duty.

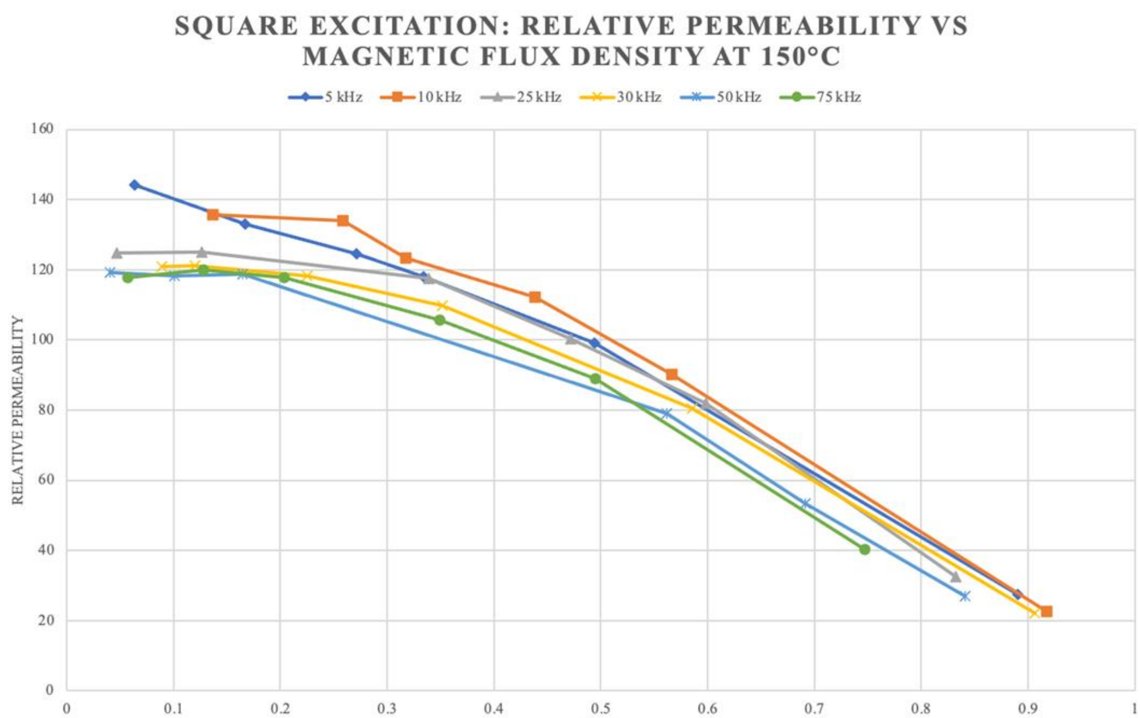


Figure 12. Relative permeability measured at 150 °C vs. Steinmetz equation estimate: square 50% duty.

Summary

Given the increasing demand for low-loss core materials in the high-voltage/high-frequency power electronics industries, knowledge of the core loss and relative permeability characteristics at increasingly demanding saturation magnetization up to 1 T and excitation frequency to 75 kHz is critical. Core material manufacturers typically provide core loss data for a very narrow range of applied voltage, frequency, and temperature conditions. This datasheet provides core loss and relative permeability information at temperatures up to 150 °C for voltage and frequency ranges of interest to high voltage and power electronics industries for a candidate powder core.

Reference

1. https://www.mag-inc.com/Media/Magnetics/Datasheets/0077894A7.pdf
2. G. M. Shane and S. D. Sudhoff, “Refinements in Anhysteretic Characterization and Permeability Modeling,” in *IEEE Transactions on Magnetics*, vol. 46, no. 11, pp. 3834-3843, Nov. 2010.
3. S. D. Sudhoff Page 191 Equation 6.3-2: *Power Magnetic Devices: A Multi-Objective Design Approach*, First ed.