# Generic Specification for Ferrite Cores

Edward Herbert

# Biography: Edward Herbert

Ed earned a Bachelor of Engineering degree in Electrical Engineering from Yale University, Class of 1963.

He worked as a design engineer, a project engineer, an engineering supervisor, then as engineering manager until 1985. Since then, Ed had been independent, promoting patented technology for license.

Within PSMA, Ed is Co-Chairman of the Magnetics Committee

Ed was a champion of the core loss studies at Dartmouth and is the champion of the present drilled cores study at SMA.

# Who uses magnetic core specifications, and why?

**For the vendors of magnetic components,** the specifications are their way of promoting their products to the designers.

**For the design engineer,** the specifications provides the information needed to select and apply magnetic components to their designs.

**Good specifications** that are trusted and provide accurate and useful information will encourage the use of a vendor's component. The component will be more likely to be designed into new products.

**Magnetic component specifications** are widely disparaged, and many vendors recognize the need for improvement

**Objective:** We are trying to start a conversation about how to make the specifications for magnetic cores more relevant to power converter designers, starting with core loss specs and graphs.

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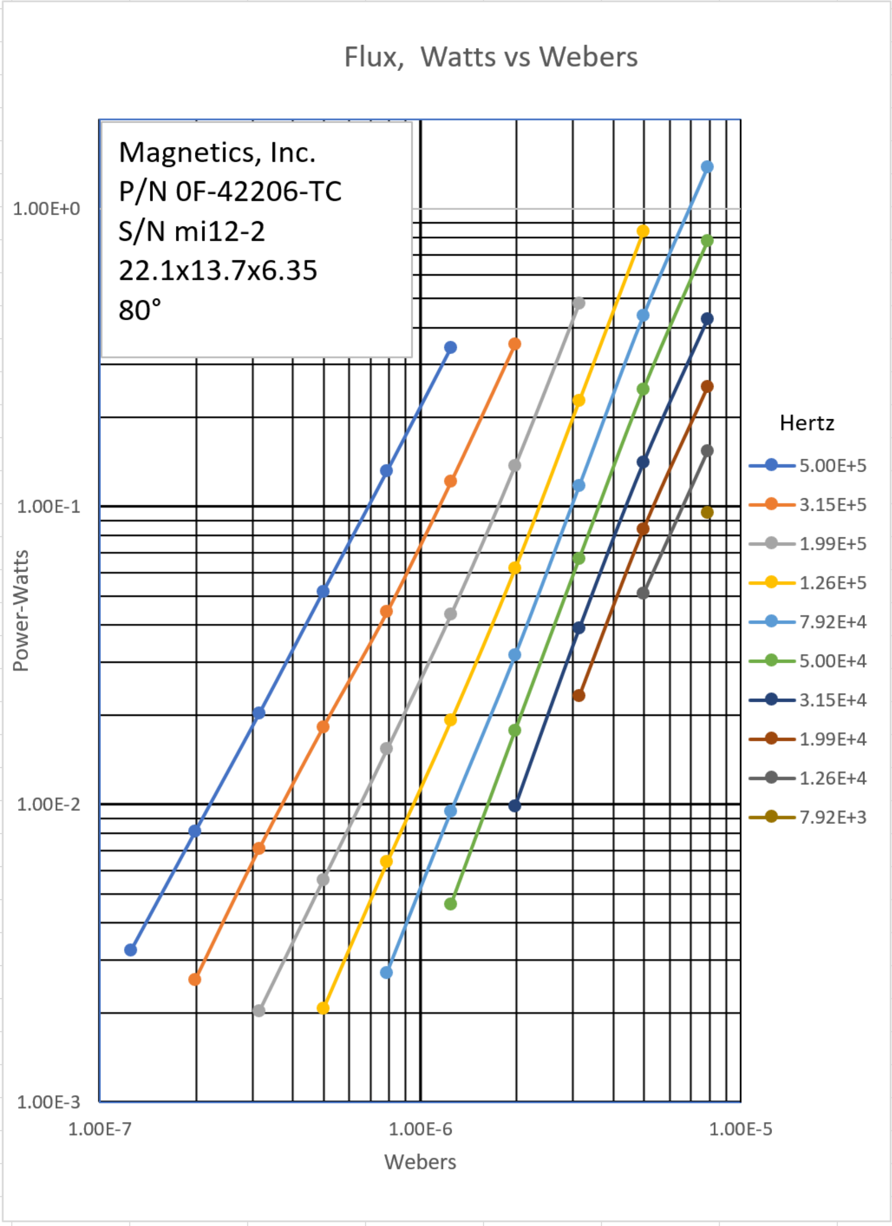
# Some housekeeping rules

**Use standard units.** SI units are preferred, but some smaller units, like mT, mm, cm, are acceptable.

**The manufacturer,** part number, serial number, size and temperature should be clearly stated on all graphs.

**Graphs should use real data.** The graph on the right shows the ac core loss in a toroid for various frequencies. The X-axis is flux, and the Y-axis is the loss in watts.

**The curves show the actual test points,** (the dots) and the curves do not extend beyond where there are real test data.



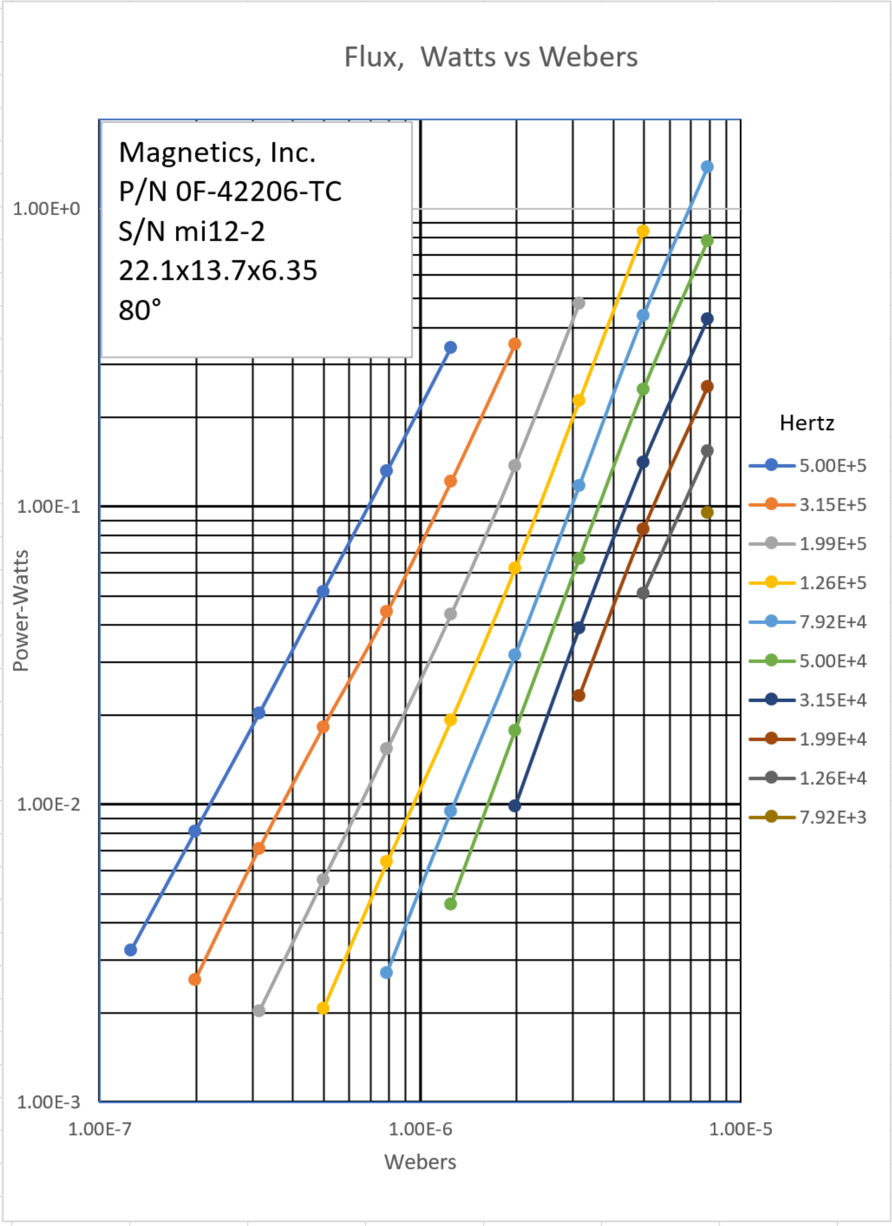
# Legacy data

**Some legacy graphs must be includeded because they are expected.** The graph on the right shows the losses accurately for the data given.

**However,** this graph is practically useless for finding the optimum operating frequency and applied excitation to minimize core loss.

**Core loss <u>decreases</u> with <u>increasing</u> frequency** for a given excitation voltage, to a point, then, as eddy currents become dominant, loss increases.

**Can you see that in this graph?**



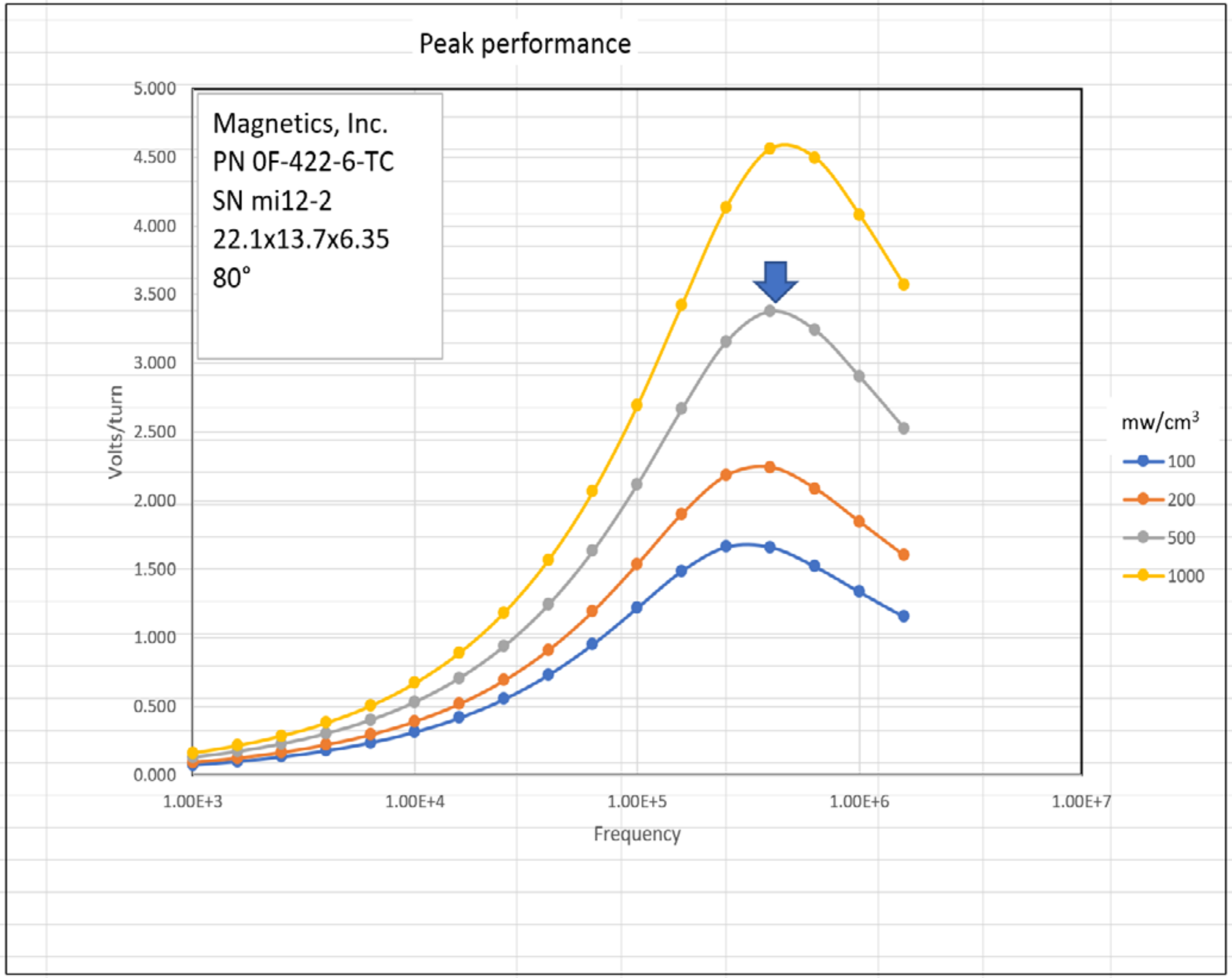
# Getting to the point

**The familiar B*f curve** most directly identifies the optimum operating point for a core.

**For a specific core, with square-wave excitation,** the familiar B*f curve can be scaled to show the volts per turn
for a specific power density vs frequency.

**The arrow** shows the **prime point**, the frequency where the loss is lowest for 500 mw/cm$^3$, and the voltage that the flux will sustain at that point, in volts/turn.

**GaN and SiC** make it more likely that magnetic components can be designed for their optimum operating point.

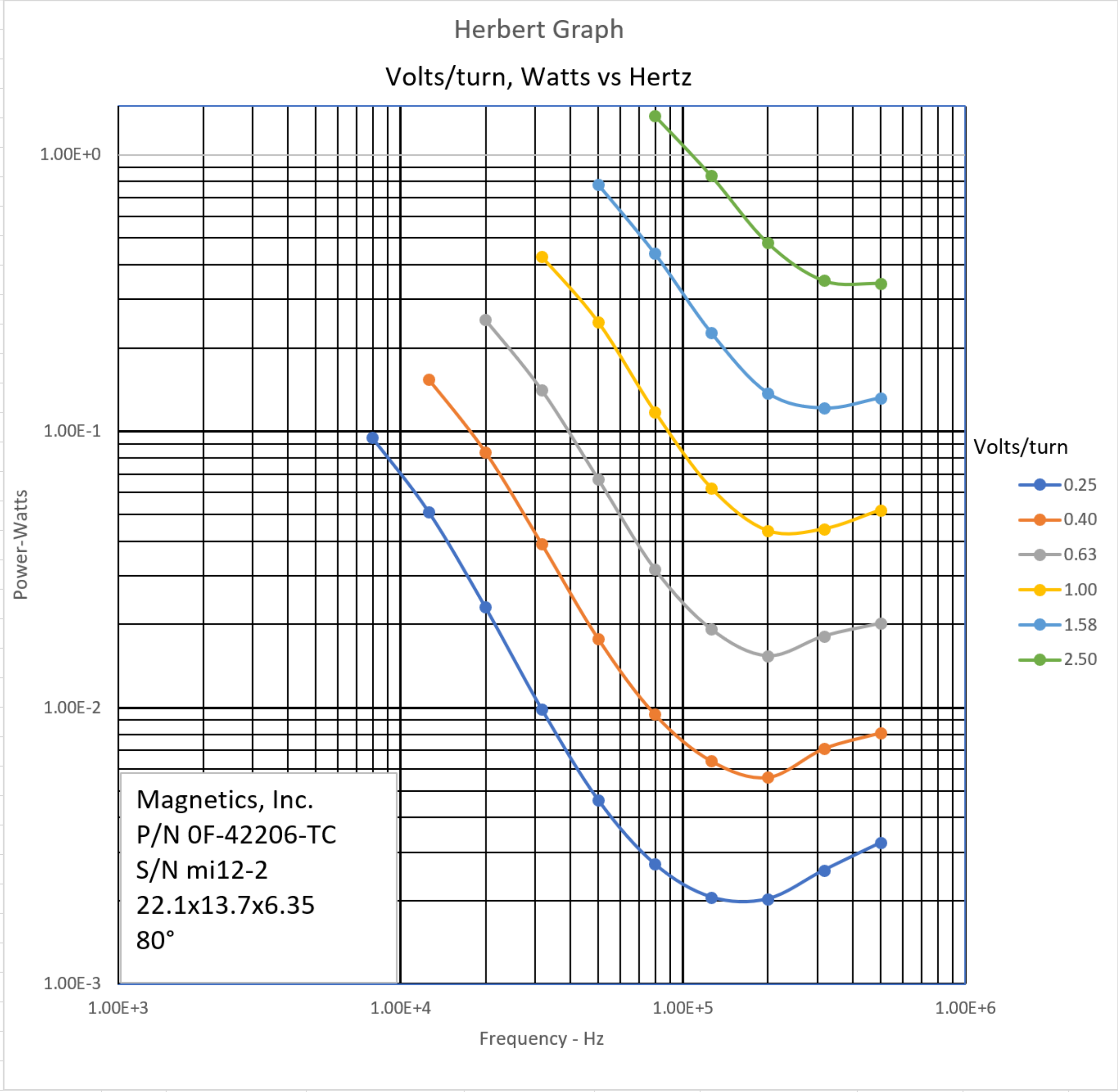


# A broader view

**The peak performance curve** most directly identifies the optimum operating point for a core, but it is not very good at showing the losses of the core at other operating points.

**For that, I recommend a graph** with curves of constant excitation voltage, with frequency as the X-axis and core loss as the Y-axis.

**To find the core loss** at any excitation voltage and frequency, draw a vertical line from the frequency to the excitation voltage of interest, then draw a horizontal line to the Y-axis. Read the loss in Watts.



# Core spec vs Material Spec

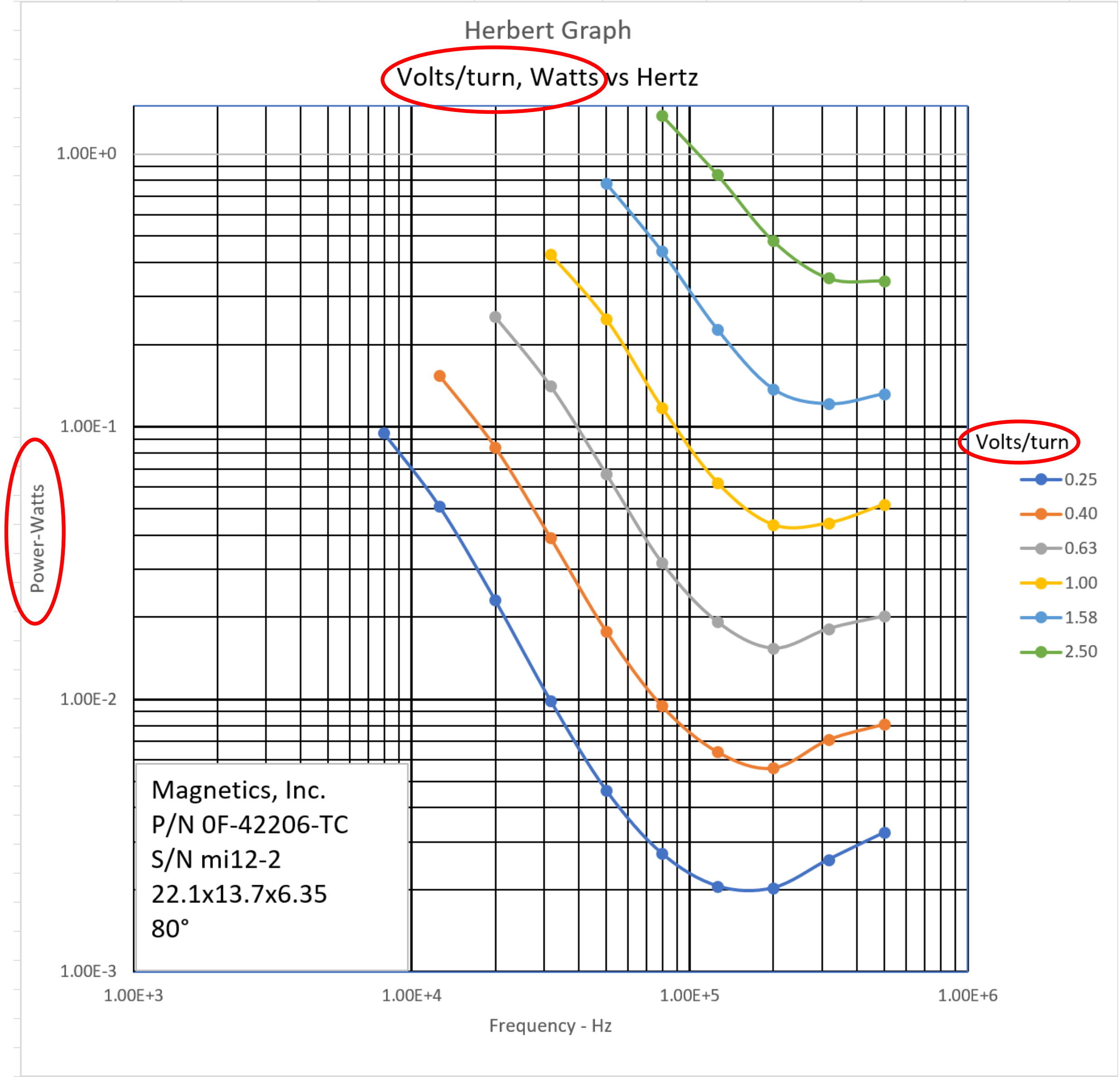
***Where is $\hat{B}$?   Where is $\frac{W}{m^3}$ ?***

**For specific cores,** there is no need to divide volt-seconds/turn by $\boldsymbol{A_e}$ to get $\hat{\boldsymbol{B}}$. There is no need to multiply the result by $\boldsymbol{V_e}$ to get Watts.

**For the hysteresis loop,** there is no need to divide ***n*I*** by $\boldsymbol{l_e}$ *to get* $\frac{n*I}{m}$ .

**For a specific core,** use the electrical units without the geometric units. The geometric units are constants for a specific core, and can be factored into the scale factors.

**For a material spec, or a spec for a family of cores,** $A_e$; $V_e$; $l_e$; $\hat{B}$ ; $\frac{W}{m^3}$ and $\frac{n*I}{m}$ are normalizing factors, and must be used.

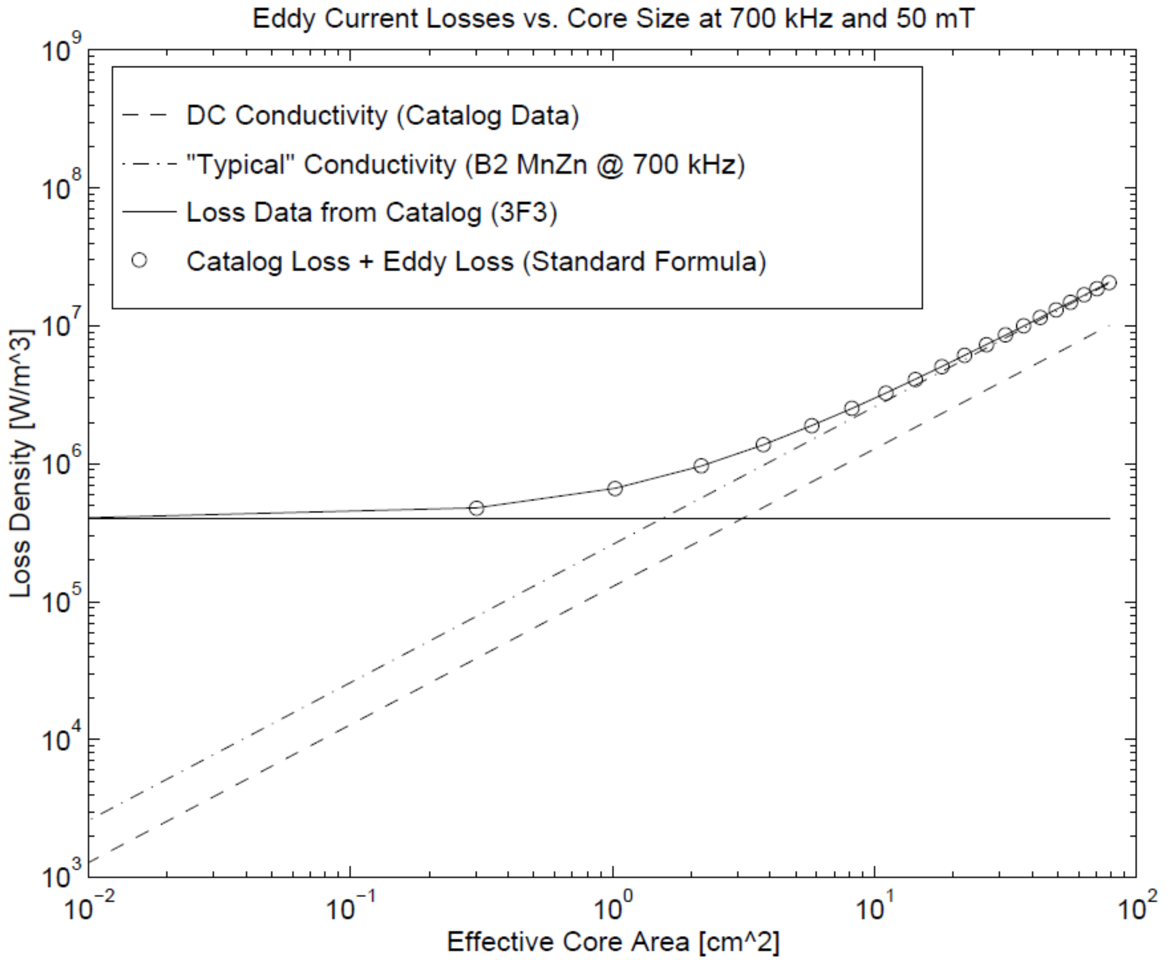


# Expect a specification for every core

**It is known, <u>but largely ignored</u>, that different sized cores have different losses.** This is not new. The graph on the right is copied from Glenn Skutt's thesis, presented in 1996.

**The optimum operating point** for a core is very dependent on its size.

**That does not mean that there must be a catalog sheet** for every core, but a data sheet for every core should be available "on line" or on a USB stick.

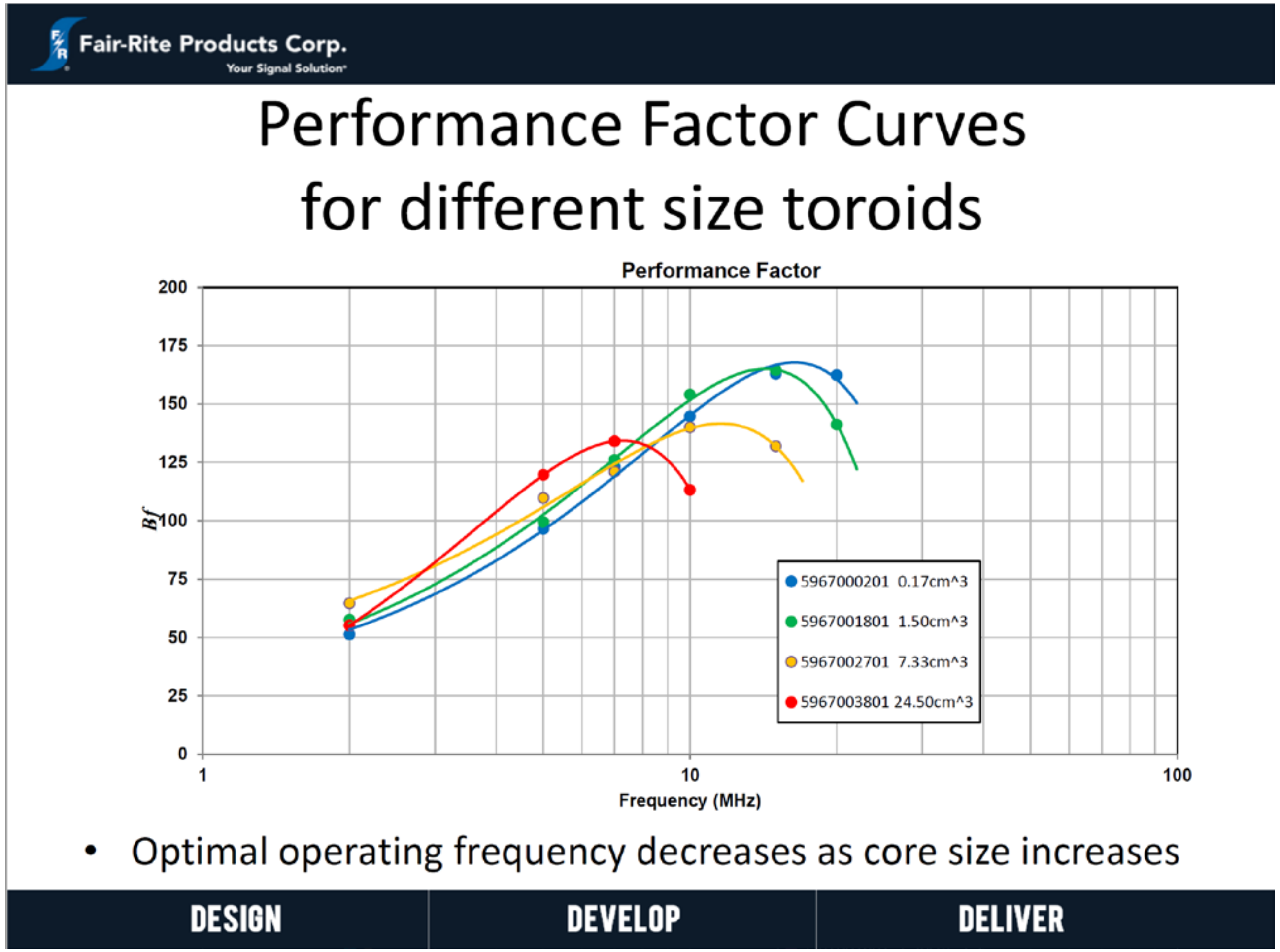


# Size affects the core properties

**SMA is doing research with PSMA sponsorship** with the objective of finding how flux propagates in ferrite.

**At the workshop last year,** John Lynch of Fair-Rite showed us the slide on the right that demonstrates that the performance factor curves are very different for different sized cores of the same material.

**The optimum operating point** for a core is dependent upon its size.



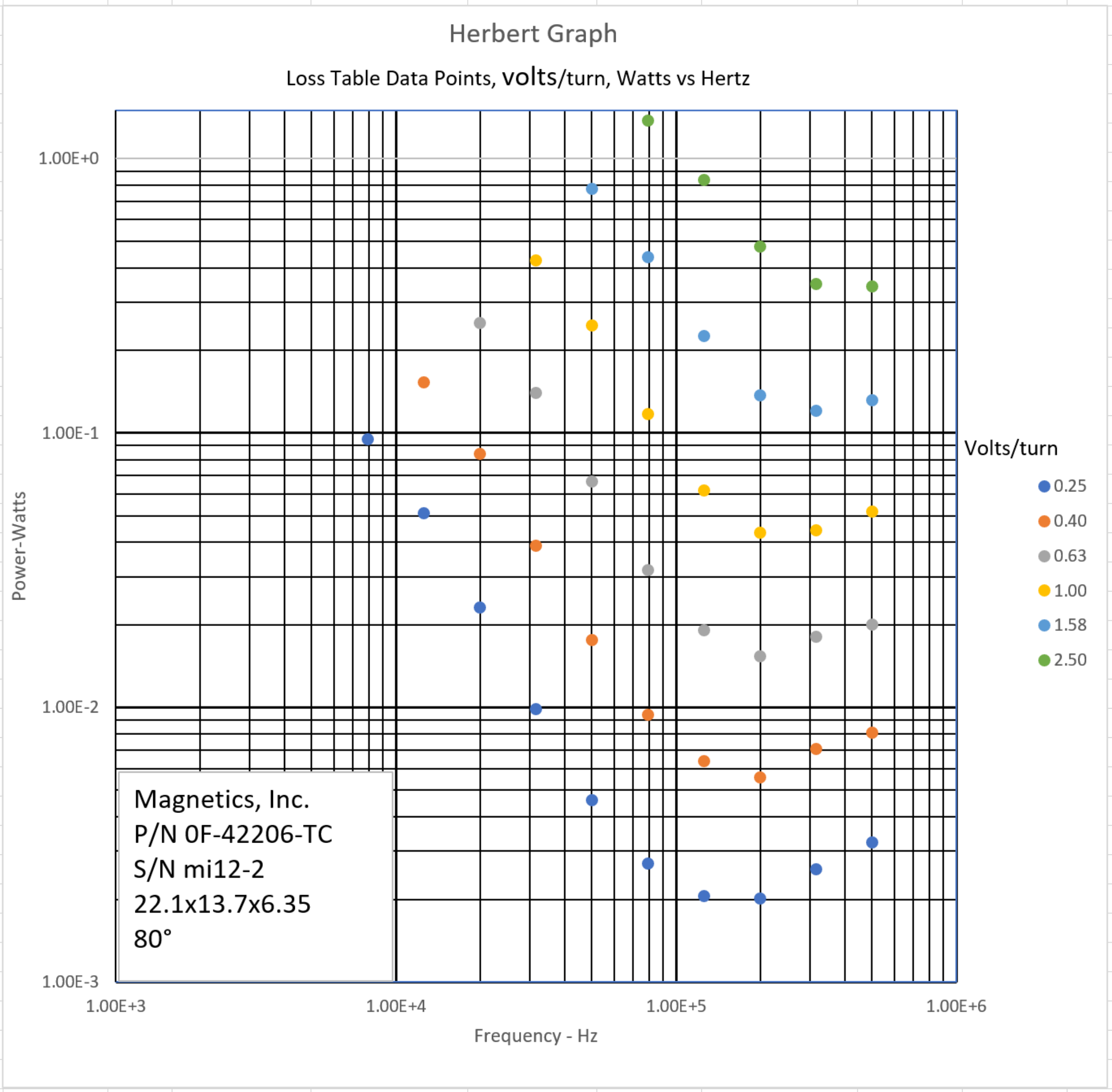
# Loss map, graph

**Each point** on the graph shown is the core loss at a unique combination of square-wave excitation voltage and frequency.

**The sequence increments** are arbitrary, but even log steps are suggested, to make an orderly pattern and have consistent data.

**The loss for each point** is determined by taking a very large number of samples per period of the excitation current and the sense winding voltage.

**The core loss** for each data point is a step-wise integration of the data.



# Loss map, table

**Each entry** in the table is the core loss at a unique combination of square-wave excitation voltage/turn (the columns) and the frequency (the rows).

**The graphs** are good for visualization, but if the data are used for calculations, the digital loss map is much better.

**These tables** probably do not belong in a catalog or data sheet, but it would be easy to provide a down-load site to make them available in digital format. They could be provided on a USB stick.

| | 0.25 | 0.40 | 0.63 | 1.00 | 1.58 | 2.50 |
|---|---|---|---|---|---|---|
| 5.00E+5 | 3.24E-3 | 8.10E-3 | 2.02E-2 | 5.18E-2 | 1.32E-1 | 3.43E-1 |
| 3.15E+5 | 2.58E-3 | 7.11E-3 | 1.82E-2 | 4.43E-2 | 1.21E-1 | 3.50E-1 |
| 1.99E+5 | 2.03E-3 | 5.59E-3 | 1.54E-2 | 4.36E-2 | 1.37E-1 | 4.80E-1 |
| 1.26E+5 | 2.06E-3 | 6.41E-3 | 1.92E-2 | 6.22E-2 | 2.27E-1 | 8.39E-1 |
| 7.92E+4 | 2.72E-3 | 9.46E-3 | 3.17E-2 | 1.18E-1 | 4.39E-1 | 1.38E+0 |
| 5.00E+4 | 4.63E-3 | 1.77E-2 | 6.70E-2 | 2.48E-1 | 7.79E-1 | |
| 3.15E+4 | 9.87E-3 | 3.91E-2 | 1.41E-1 | 4.27E-1 | | |
| 1.99E+4 | 2.32E-2 | 8.42E-2 | 2.53E-1 | | | |
| 1.26E+4 | 5.11E-2 | 1.54E-1 | | | | |
| 7.92E+3 | 9.51E-2 | | | | | |

**The missing entries** are points where the flux is too high.

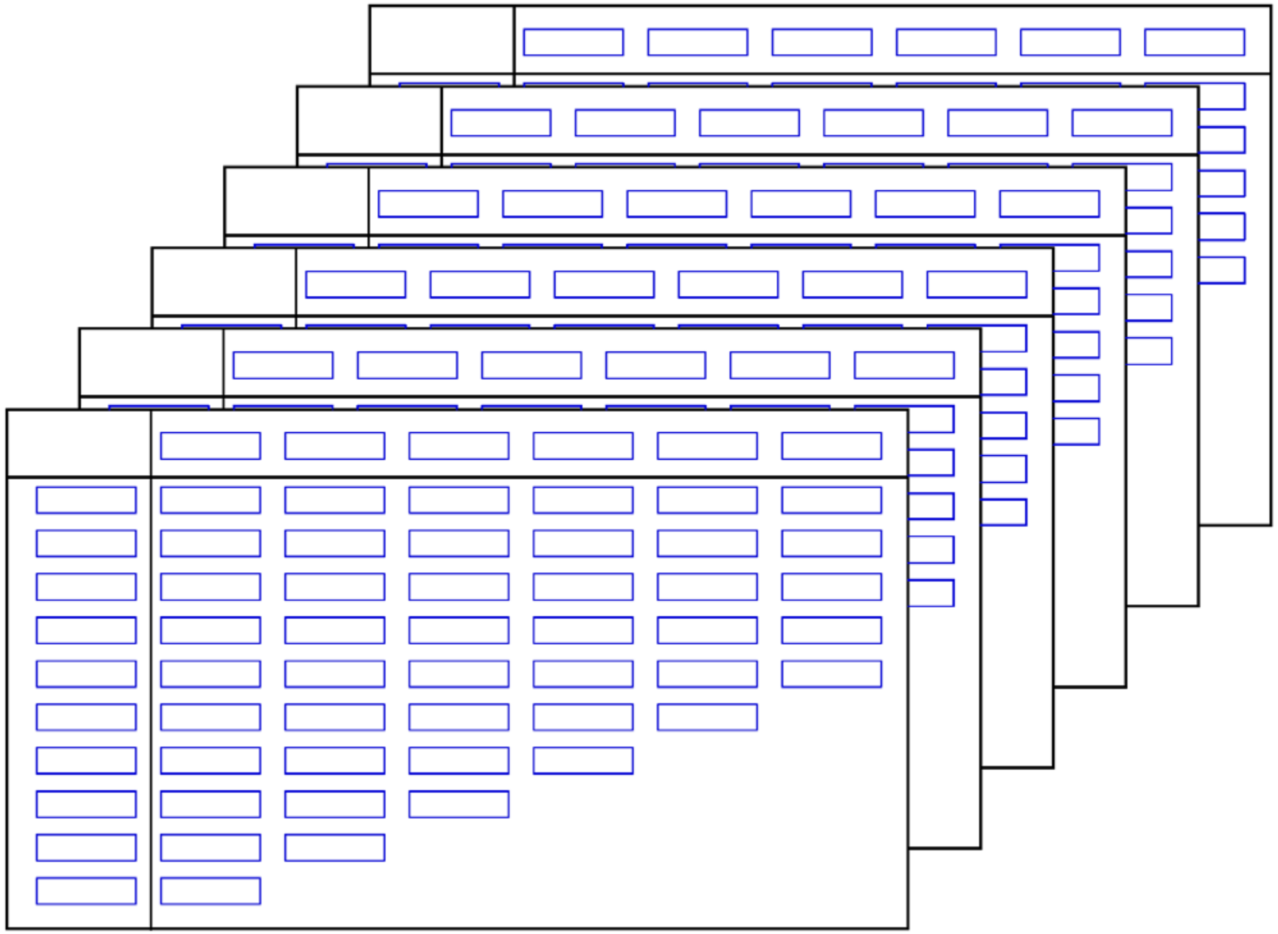
**The flux limit** is determined by the lowest voltage and the lowest frequency. Any higher voltage at that frequency would over-drive the flux.

# Loss map, with duty-ratio

**If there are other conditions** for which data needs to be taken, a new page is added for each.

**The example** shows that we may want to test for duty-ratio = 0.1; 0.3; 0.5; 0.7; 0.9 and 1.0, as an example.

That is six conditions, so it requires six digital tables.



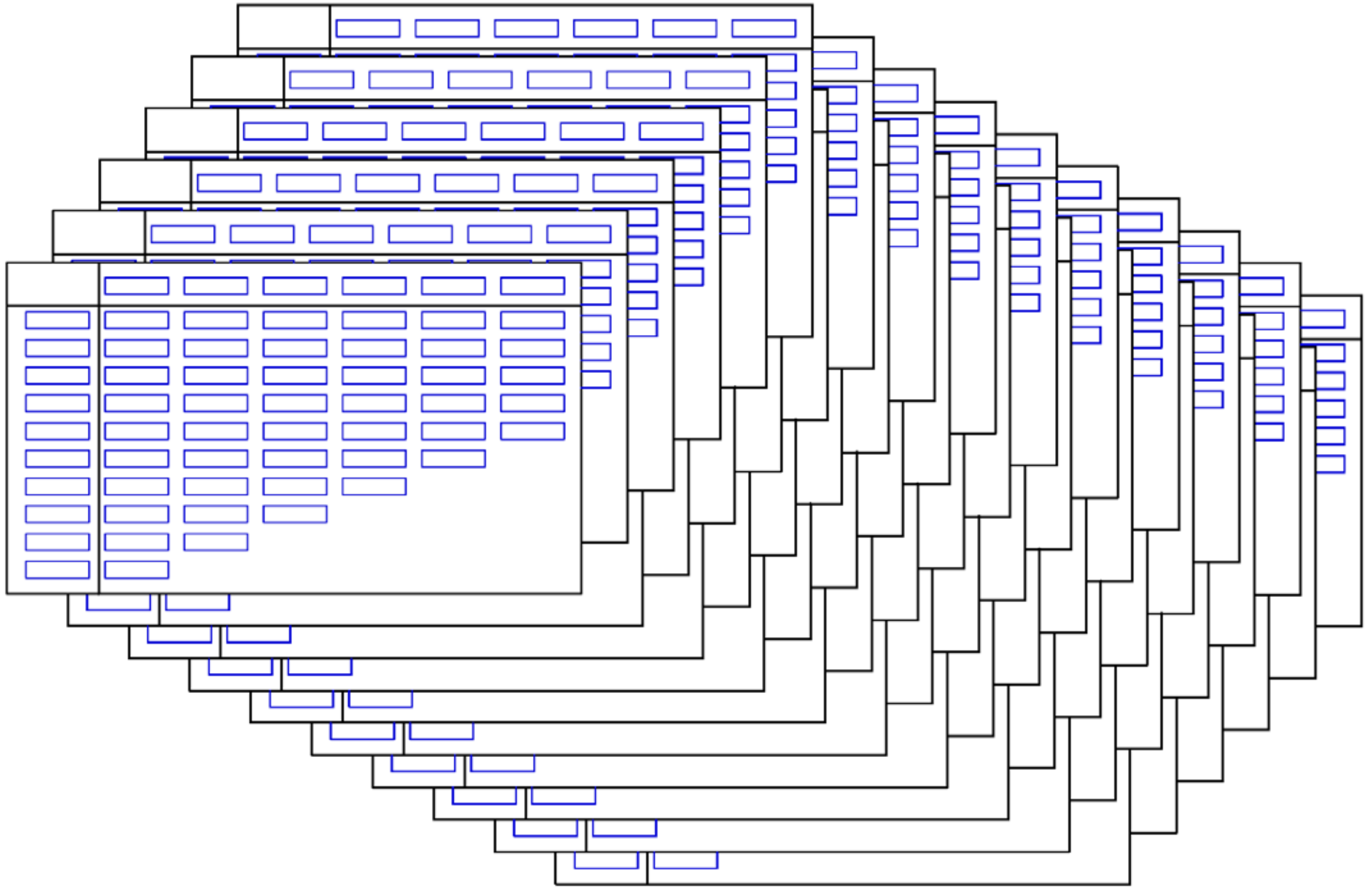
# Loss map, with temperature

**The data should be taken over the temperature range.** Ten temperatures is a reasonable number, as an example.

**The example** shows that we now have 60 tables.

**That is a lot of data,** but it can be taken very quickly with automated test equipment, and it does not take up much disc space by today's standards.

**Changing and stabilizing the temperature** will take much more time than taking the data.

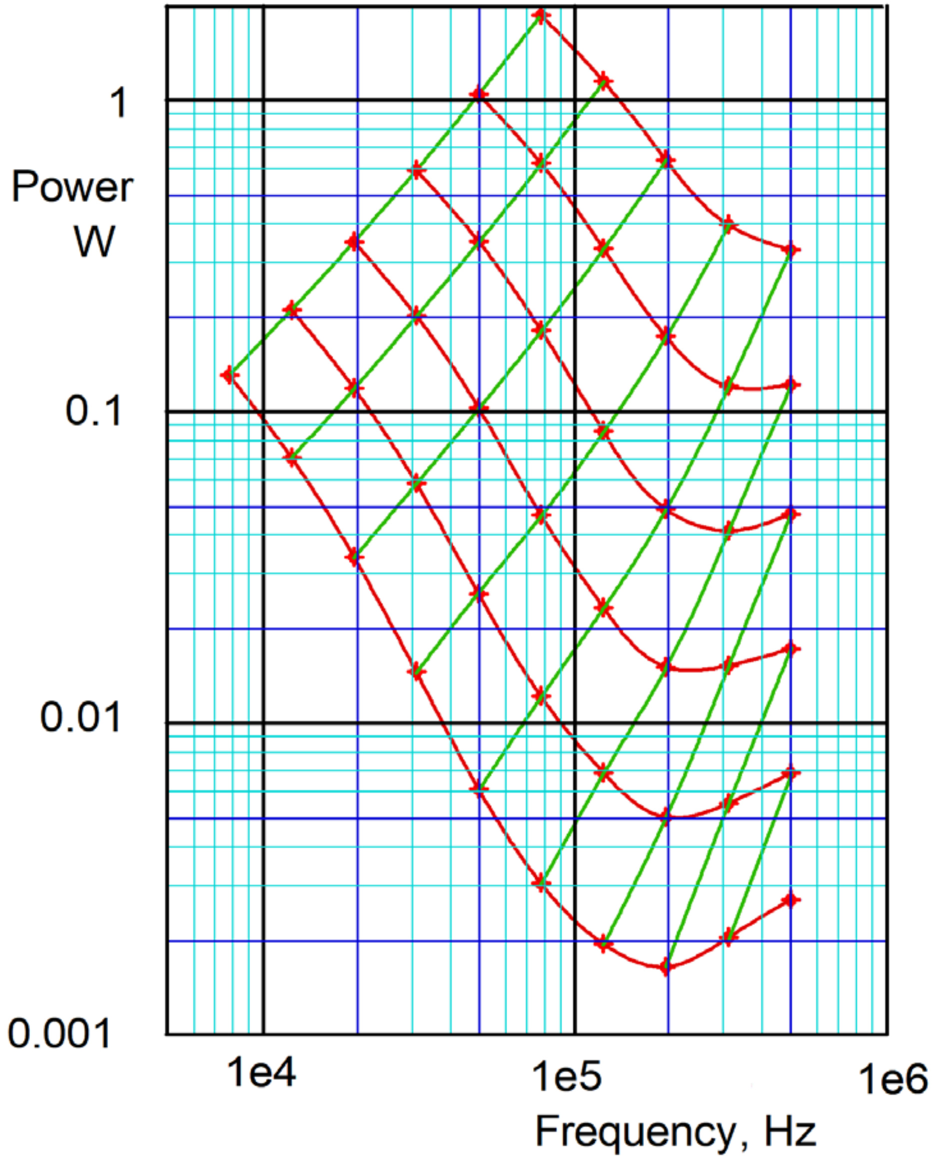


# Graphs

**The data in the loss map** can be used to make many of the graphs for a spec sheet.

**The example** shows that the data points can be connected to give a graph of the loss vs frequency in terms of flux (volt-seconds/turn), the **green lines,** resembling the usual $\hat{\boldsymbol{B}}$ curves, or they can be connected in terms of the excitation voltage, (volts/turn), the **red lines,** to make the Herbert curve.

**Calculating the traditional $\hat{\boldsymbol{B}}$ curves** requires knowing $A_e$ but otherwise uses the same data.



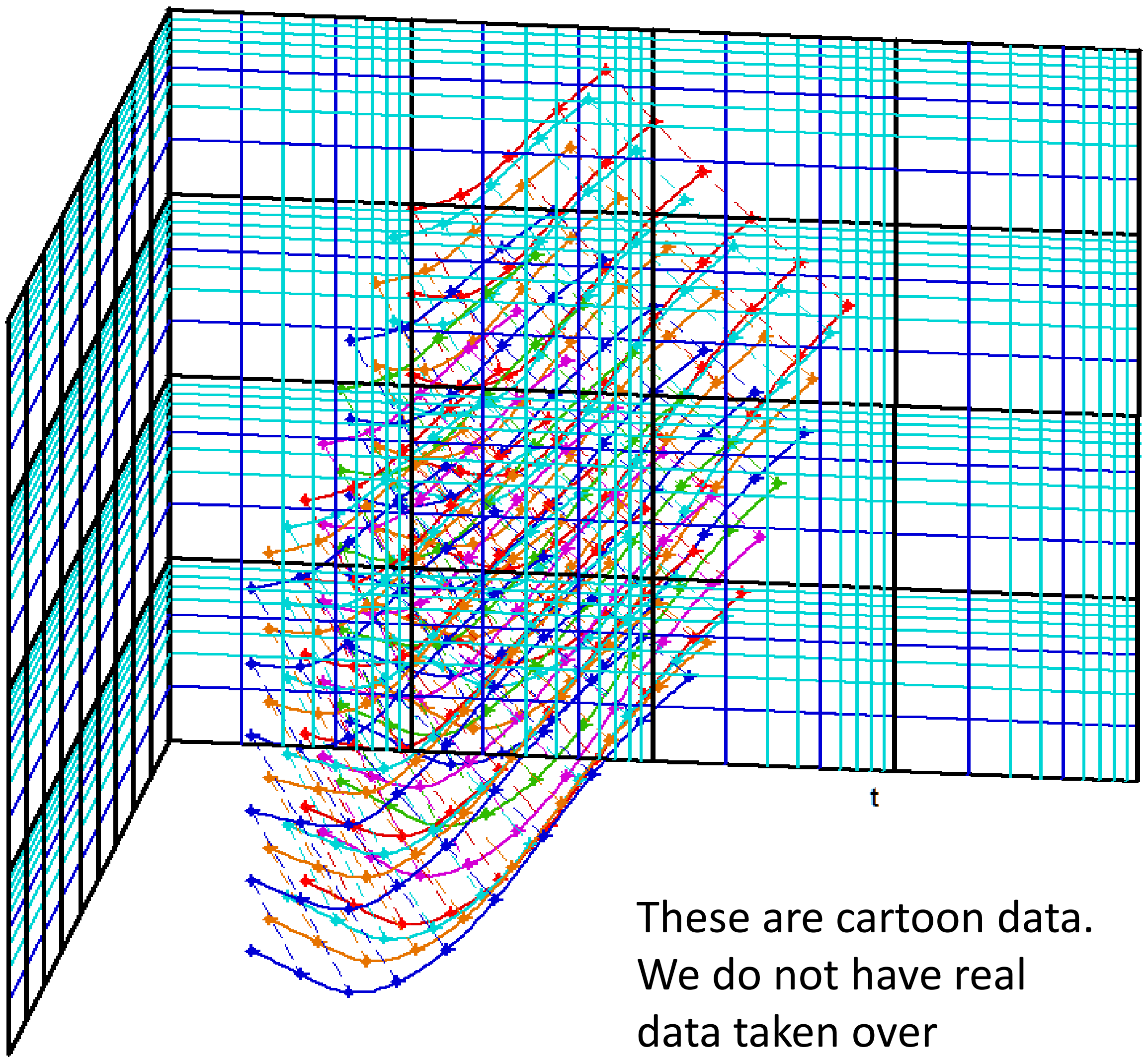
# Loss map, 3-D

**This drawing shows data** arranged as a 3-D array, (X, Y, Z).

**Basically,** similar data taken with different conditions are stacked so that the X- and Y-axes are common for all of the data sets, but the Z-axis is used for the varying condition, for example, temperature.

Originally, the X-axis is frequency, and it still is. The Y-axis is the core loss in watts, and it still is. The curves are varying excitation voltage, and they still are.

**The Z-axis** is now temperature.

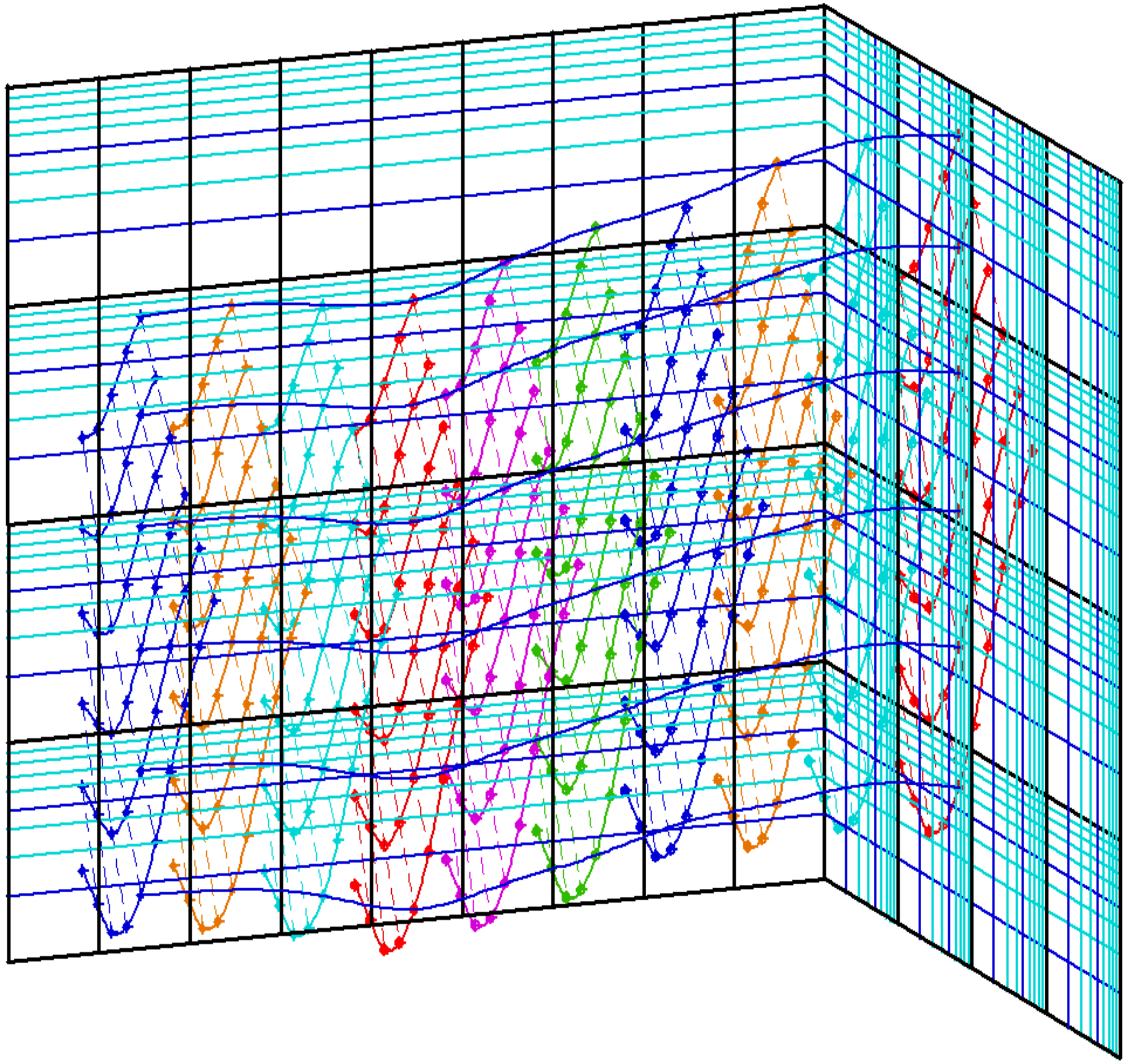



These are cartoon data. We do not have real data taken over temperature.

# Loss map, 3-D, rotated

**This drawing shows the 3-D data** rotated to show the Z-axis (temperature) more clearly

**Lines are drawn** connecting data points with the same conditions, in this example, frequency and excitation voltage.



These are cartoon data. We do not have real data taken over temperature.

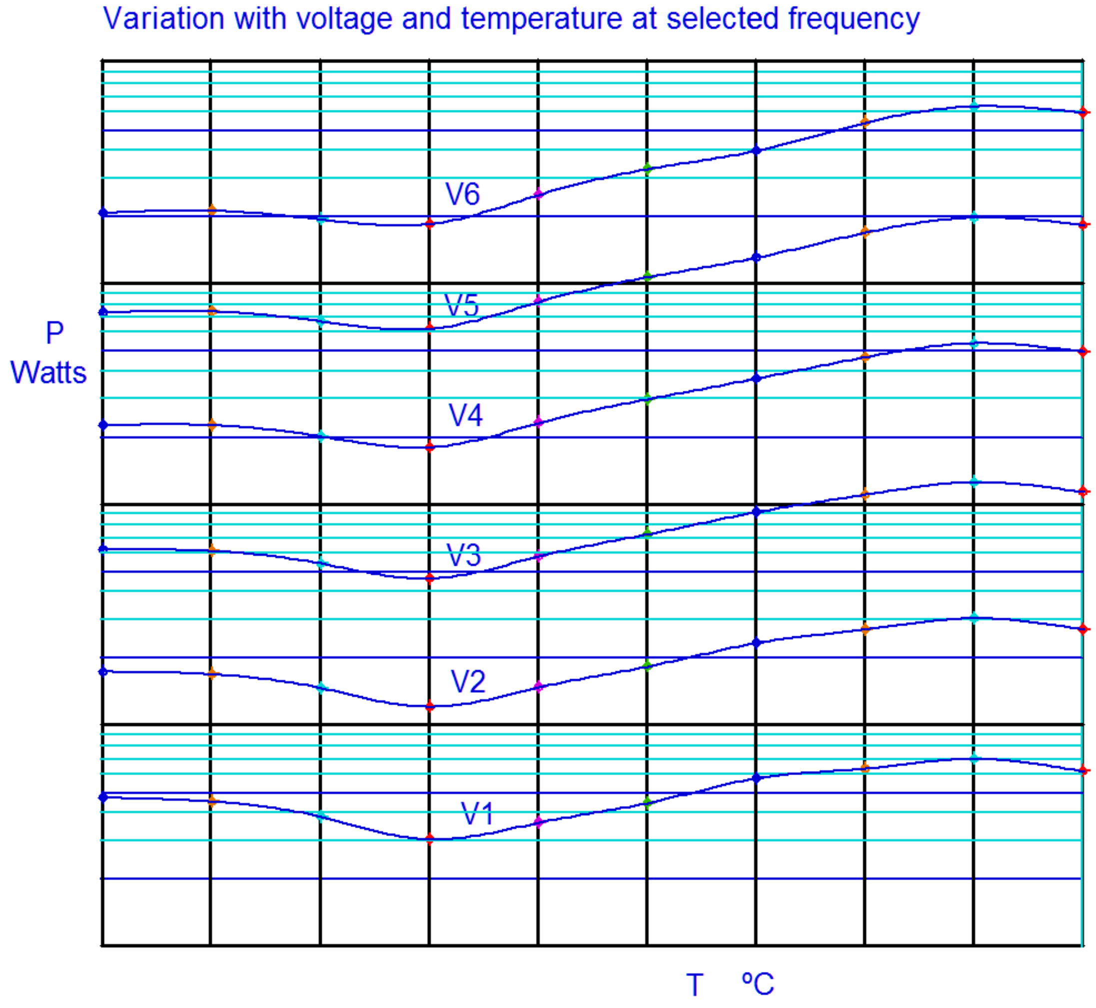
# Loss map, 3-D, rotated 90°

**When the 3-D data** is rotated 90°, the Z-axis becomes the horizontal axis.

**The Y-axis is still the core loss.** The graph now shows how the loss varies with temperature for the selected frequency and excitation conditions.

**This example** shows six excitation voltages all at a selected frequency.  The loss at any temperatue can be read directly on the Y-axis.

**If the digitized data** is available, a user can select and display the variation with temperature of any operating point.




These are cartoon data. We do not have real data taken over temperature.

# Which points to graph for varying temperature?

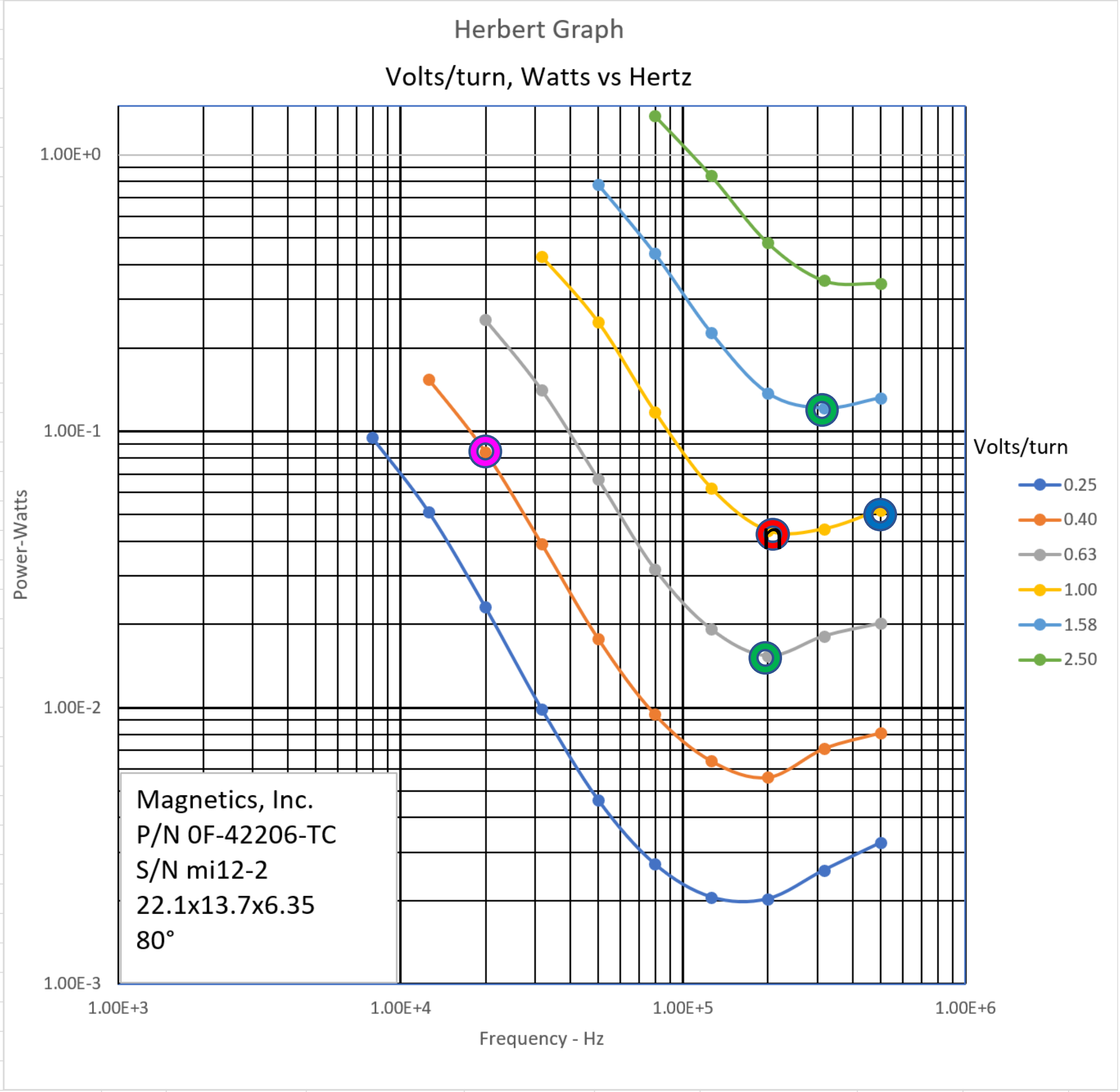
**The prime point,** of course, indicated by the red circle.

**Two more at loss nulls,** but with higher and lower loss, indicated by the green circles.

**One where hysteresis losses dominate,** the magenta circle.

**One where eddy current losses dominate,** the blue circle.

The hysteresis losses and the eddy current losses are likely to have different temperature characteristics.



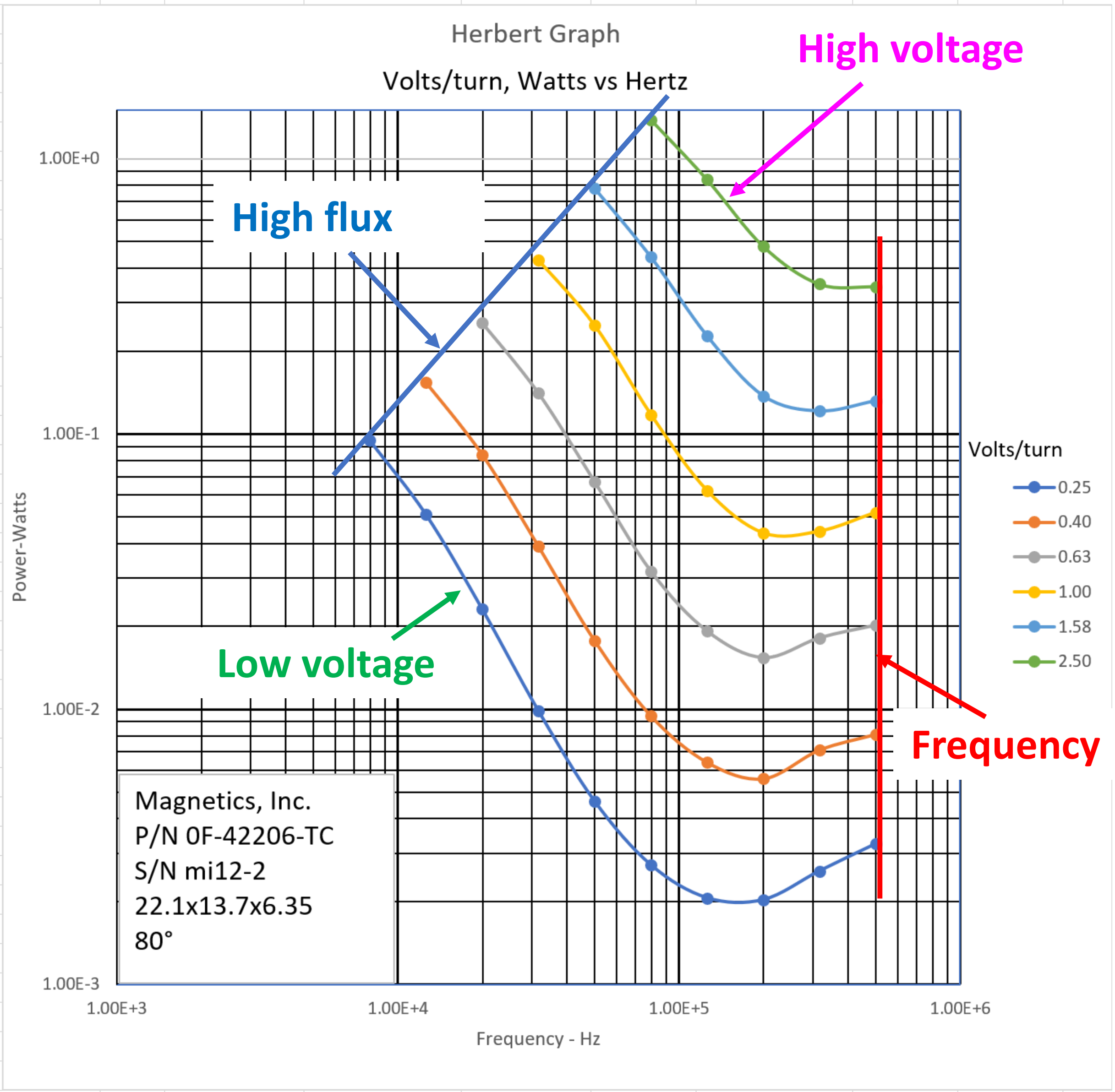
# What limits the graph?

**Frequency** may be limited by the capabilities of the test equipment.

**Voltage** may be limited by the excitation voltage source, particularly for low duty-ratio excitation, where $V_p = V_{avg}/d$.

**Flux capacity** may limit the extension of the curves in the upper left.

**Low excitation voltage** may be difficult to measure accurately, and there is little point to measuring mW core losses.



# Steinmetz-like equation

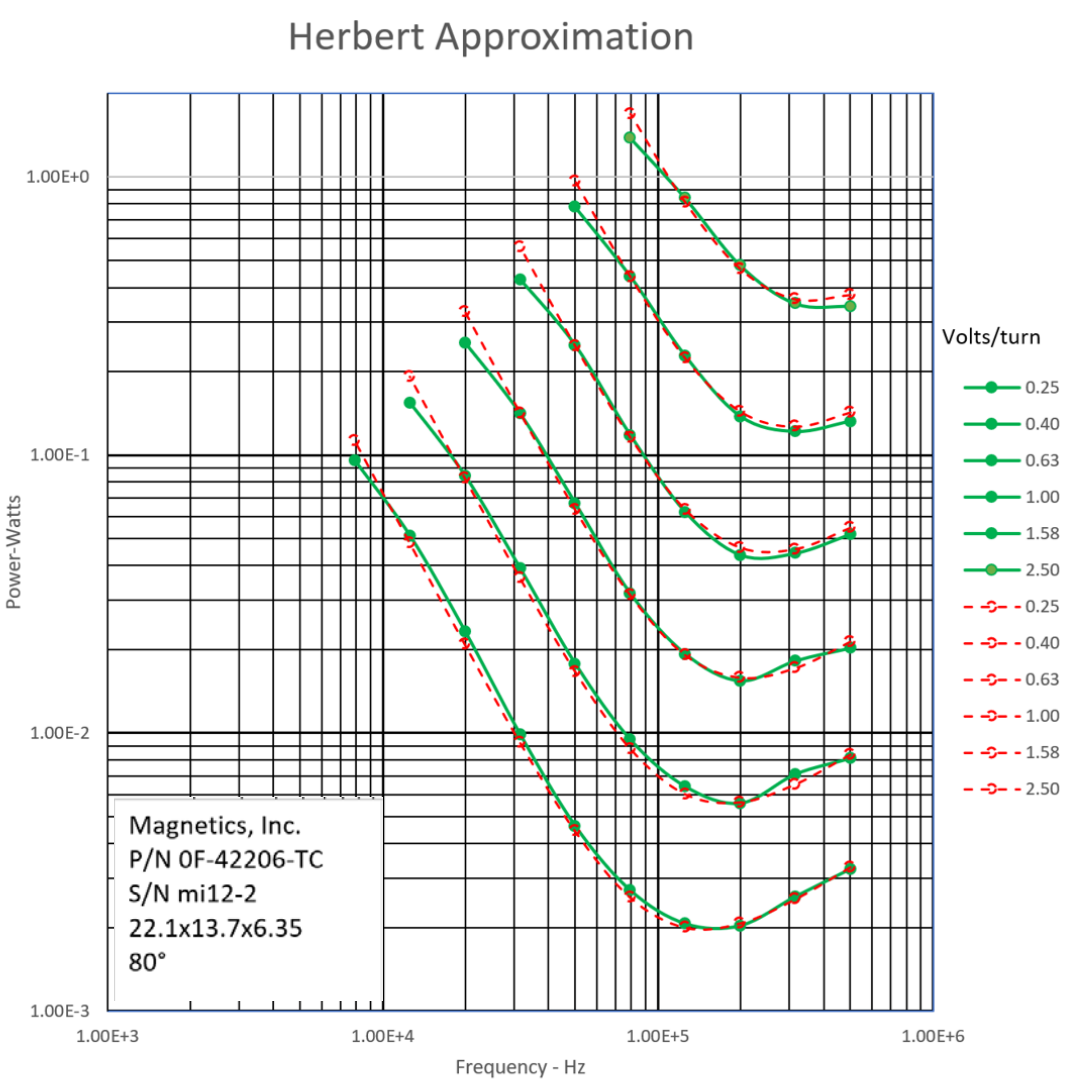
**Much effort has gone into finding an equation** that will approximate the losses over the entire range of interest for excitation and frequency.

**This equation seems to work fairly well.**

$$P_c = k * f^{\delta} * \left(1 + \left(\frac{v}{V_b}\right)^{\alpha} * \left(\frac{f_b}{f}\right)^{\beta}\right) * v^2$$

**The green lines and dots are data,** and **the red dashed lines are the approximation.**

| | | | |
|---|---|---|---|
| $k$ | 4.200E-07 | $\beta$ | 2.500E+00 |
| $\delta$ | 6.500E-01 | $V_b$ | 1.250E+00 |
| $\alpha$ | 1.000E+00 | $F_b$ | 9.615E+04 |



# Steinmetz-like equation

$$P_c = k * f^{\delta} * \left(1 + \left(\frac{v}{V_b}\right)^{\alpha} * \left(\frac{f_b}{f}\right)^{\beta}\right) * v^2$$

For the F-42206-TC core, the constants are:

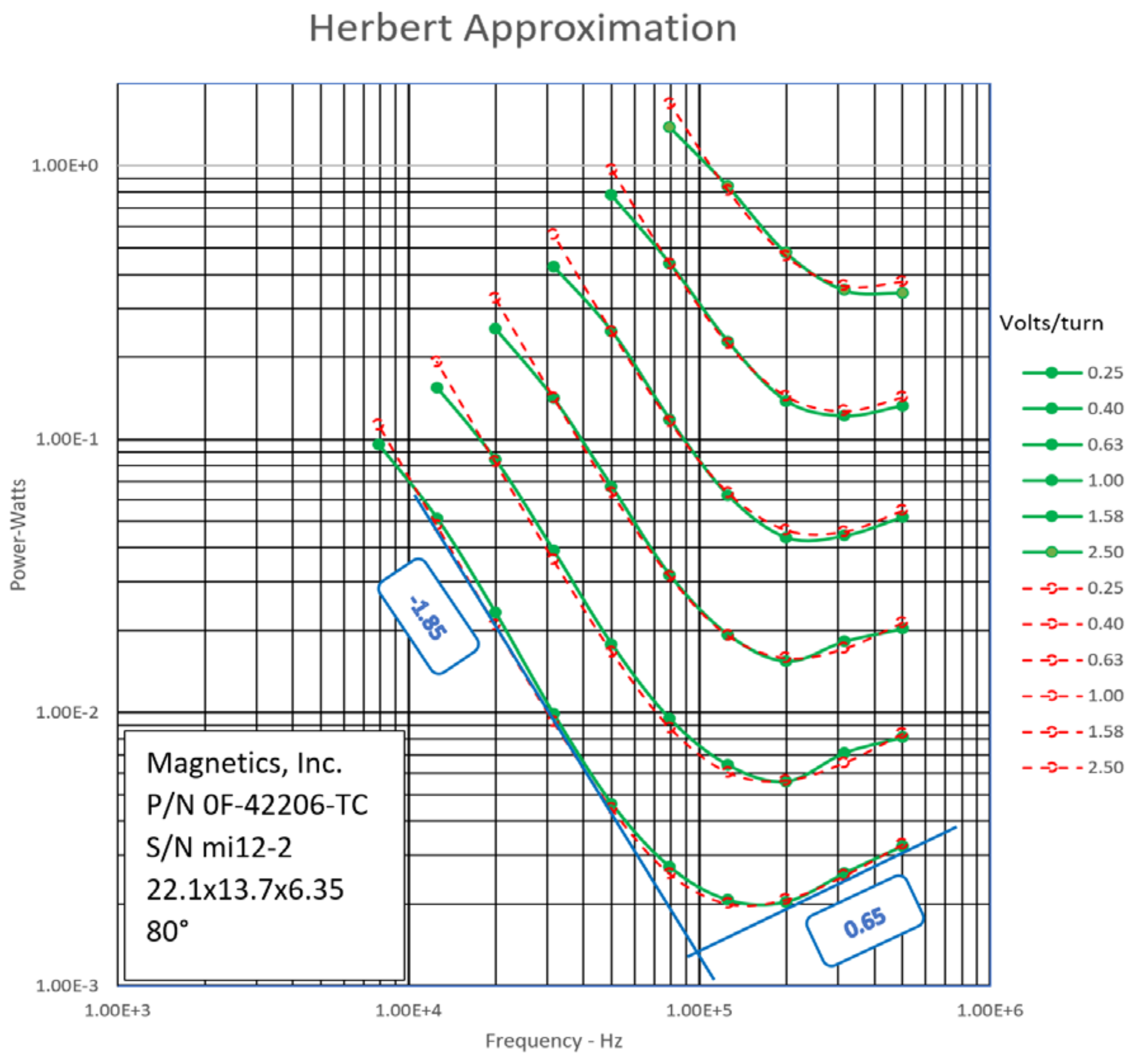
| | | | |
|---|---|---|---|
| $k$ | 4.200E-07 | $\beta$ | 2.500E+00 |
| $\delta$ | 6.500E-01 | $V_b$ | 1.250E+00 |
| $\alpha$ | 1.000E+00 | $F_b$ | 9.615E+04 |

**The constant $\delta$ = 0.65** is the slope of the asymptote of the curve on the right-hand end in the example above.

**The constant $\beta$ = 2.5** is derived from the slope of the asymptote of the curve on the left by subtracting it from $\delta$ = 0.65. That is, 0.65 –(–1.85) = 2.5

**The constant $V_b$** is a baseline voltage.

**The constant $f_b$** is 96 kHz, and is approximately at the intercept of the asymptotes.



# Steinmetz-like equation

$$P_c = k * f^{\delta} * \left(1 + \left(\frac{v}{V_b}\right)^{\alpha} * \left(\frac{f_b}{f}\right)^{\beta}\right) * v^2$$

For the F-46113-TC core, the constants are:

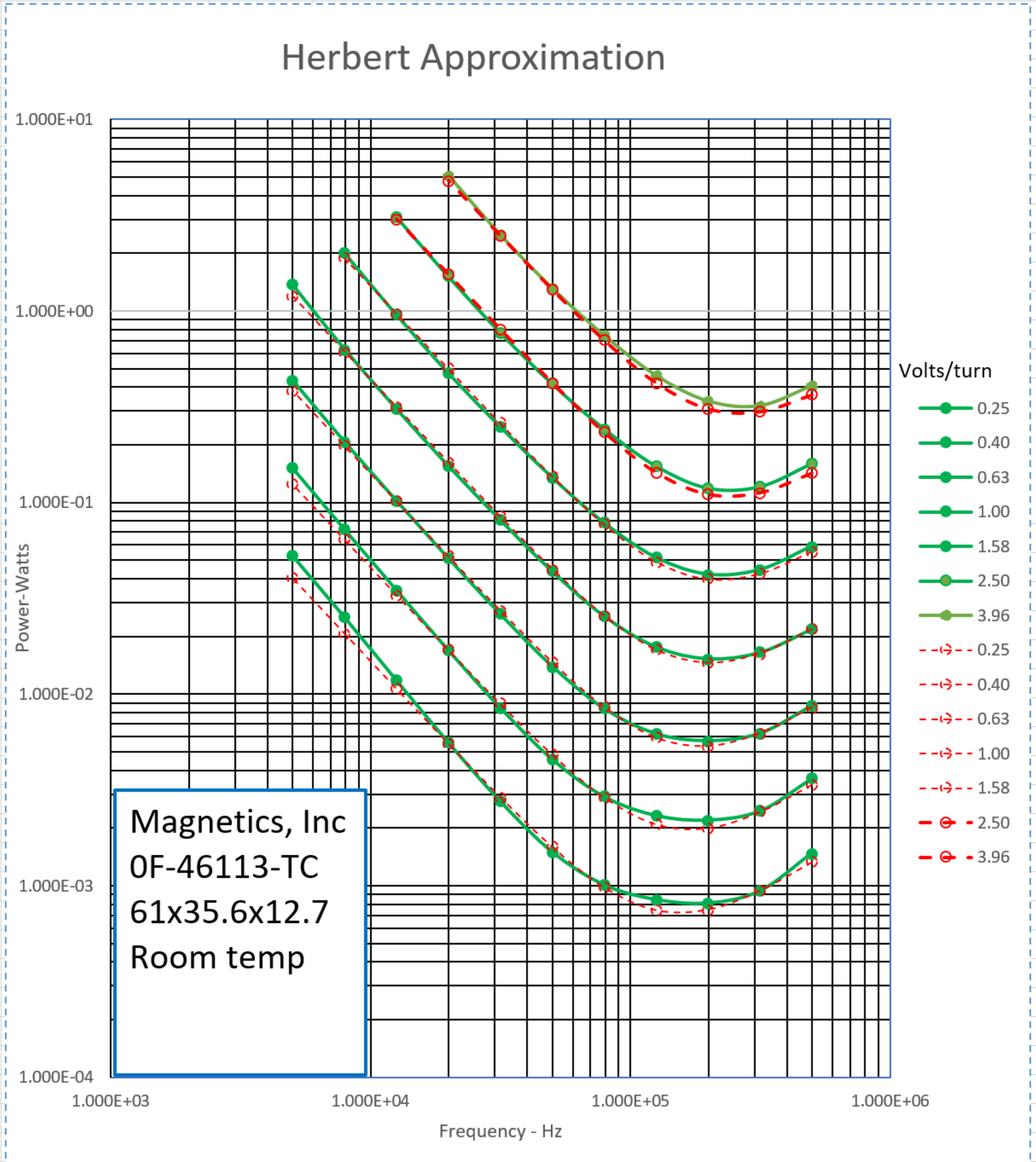
| | | | |
|---|---|---|---|
| $k$ | 9.500E-09 | $\beta$ | 2.350E+00 |
| $\delta$ | 9.000E-01 | $V_b$ | 2.000E+00 |
| $\alpha$ | 4.500E-01 | $F_b$ | 1.450E+05 |

***This is a curve-fitting equation only.***

**Any correlation to real phenomenon in the core is purely coincidental.**

**The number of examples** with a good fit is limited, but growing, giving some confidence that this is a useful equation for ferrite toroids.

**If the approximation proves to be reliable**, the equation and its constants should be on the spec sheet for the core.

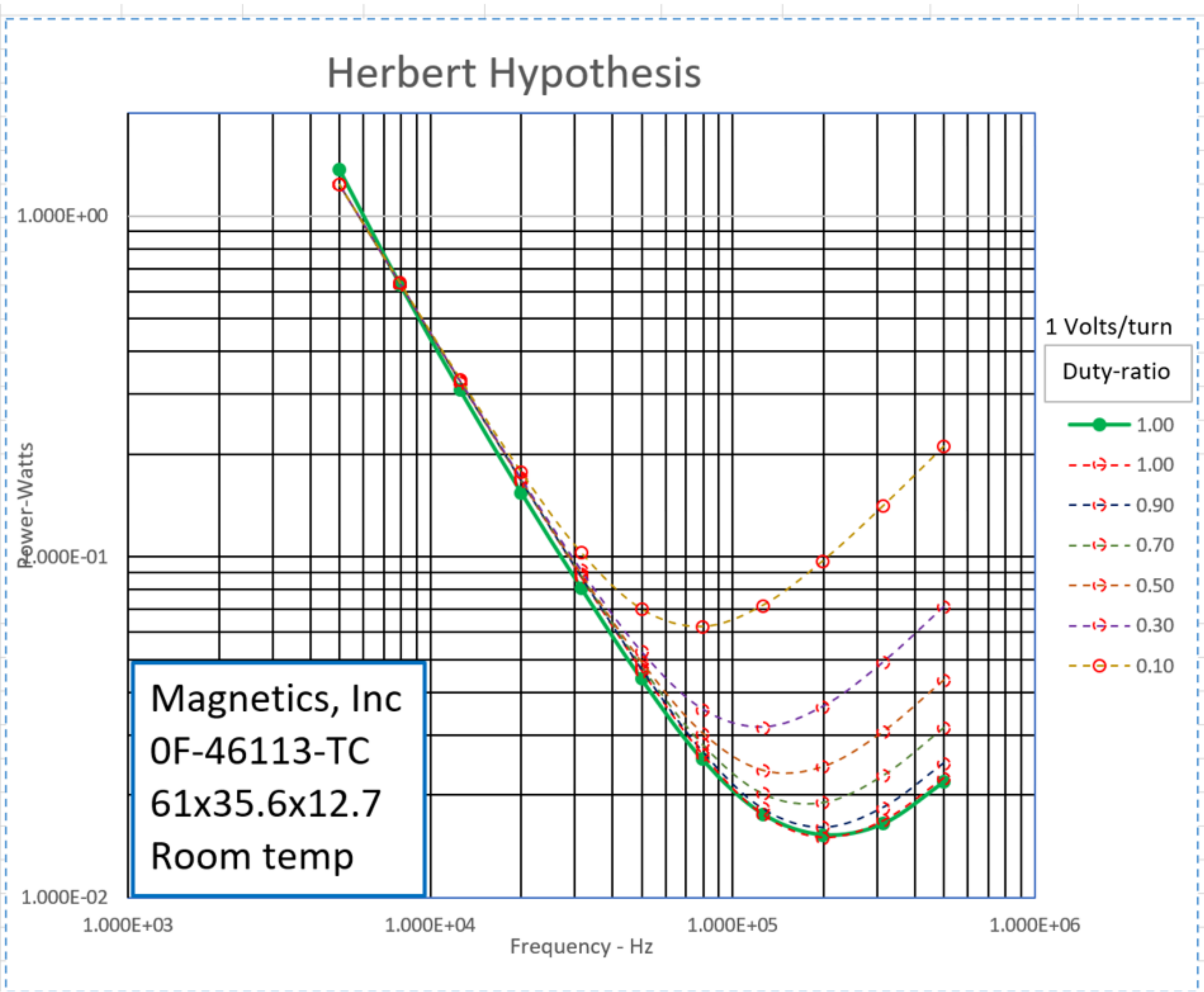


# Low duty-ratio data

**There is a need for accurate core loss data at low duty-ratios.** We do not know what low duty-ratio data will look like, so the graph at the right is hypothetical.

**Just like the other conditions,** a loss map can be made for various low duty ratio conditions, and the results can be plotted on a graph.

**In the hypothetical example**, the average excitation voltage is constant, with varying duty-ratio used for the different dashed red curves. These data should be useful to those designing buck and boost converters.



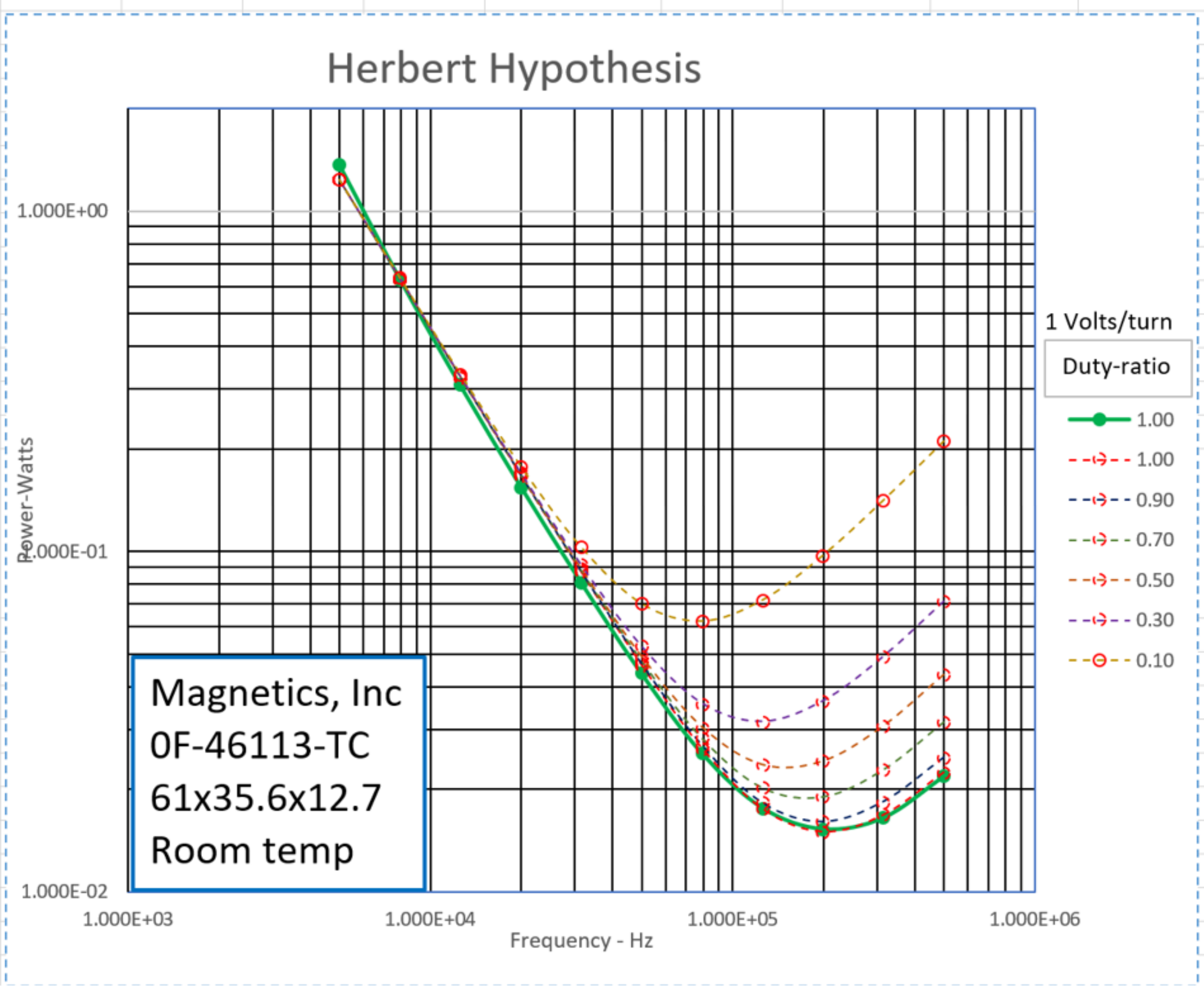

These are cartoon data. We do not have real data for low duty-ratio.

# Low duty-ratio data

**Low duty-ratio loss** defies analysis, but the loss graph does NOT attempt to explain anything, it is proposed as just a graph of measured data.

**Low duty-ratio losses** have been analyzed using the "apparent frequency" or the on-time pulse width (composite waveform hypothesis), with limited success.

**The PSMA-Dartmouth** core loss studies found that there is an "off-time phenomenon" that relates to loss of energy when there is no excitation. It seems to be an exponential decay during the off time, and it seems to have a fixed time constant.




These are cartoon data. We do not have real data for low duty-ratio.

# Accuracy required

**One excuse that is heard frequently** for the crude data in ferrite data sheets is that the core-to-core and lot-to-lot variations are significant, so accurate data is pointless.

**That might be true,** if the only use for the data is for one operating point.

**However,** if data are taken for comparison purposes, high accuracy is needed.

**For example,** if data are taken at two temperatures and you want to know the temperature coefficient of the core, small errors in the voltage will make the comparison meaningless.

**The accuracy of frequency** probably is high enough, inherently . Signal generators and oscilloscope time bases are very accurate.

**The accuracy of voltage** is much more of a problem. While programmable power supplies can supply very accurate voltage outputs, voltage drops through the test equipment and IR drops in the wiring and windings can add significant error.

# Voltage accuracy

**Voltage errors are magnified significantly.** Consider the Steinmetz equation, and the exponent of $\widehat{\boldsymbol{B}}$ . It is typically 2.3 to 2.7. Errors in voltage are magnified by the same exponent when calculating core loss.

**For example**, if the target excitation voltage is 10 V, but the actual voltage is 9.7 V, the error in the power is $\left(\frac{9.7}{10}\right)^{2.6} = 0.92$. The error in the calculated core loss is 8 % for a 3 % error in voltage.

**Two methods** of improving accuracy follow. ***Both should be used!***

1. When the data are taken for the first run, the average voltage magnitude from the sense winding is calculated to high accuracy. That average, *Vact,* is subtracted from the target voltage, *Vtgt*. If the difference is significant, the difference, *Verr,* is added to the test voltage and the data are taken again. Usually, one additional test run is sufficient, but this can be repeated if necessary until the desired accuracy is achieved. Less than 0.5 % voltage error is the goal.

2. For any remaining error (< 0.5 %), the calculated power can be interpolated by the approximation:

$$Pl \cong \left(\frac{Vtgt}{Vact}\right)^{2.5} * Pcalc$$

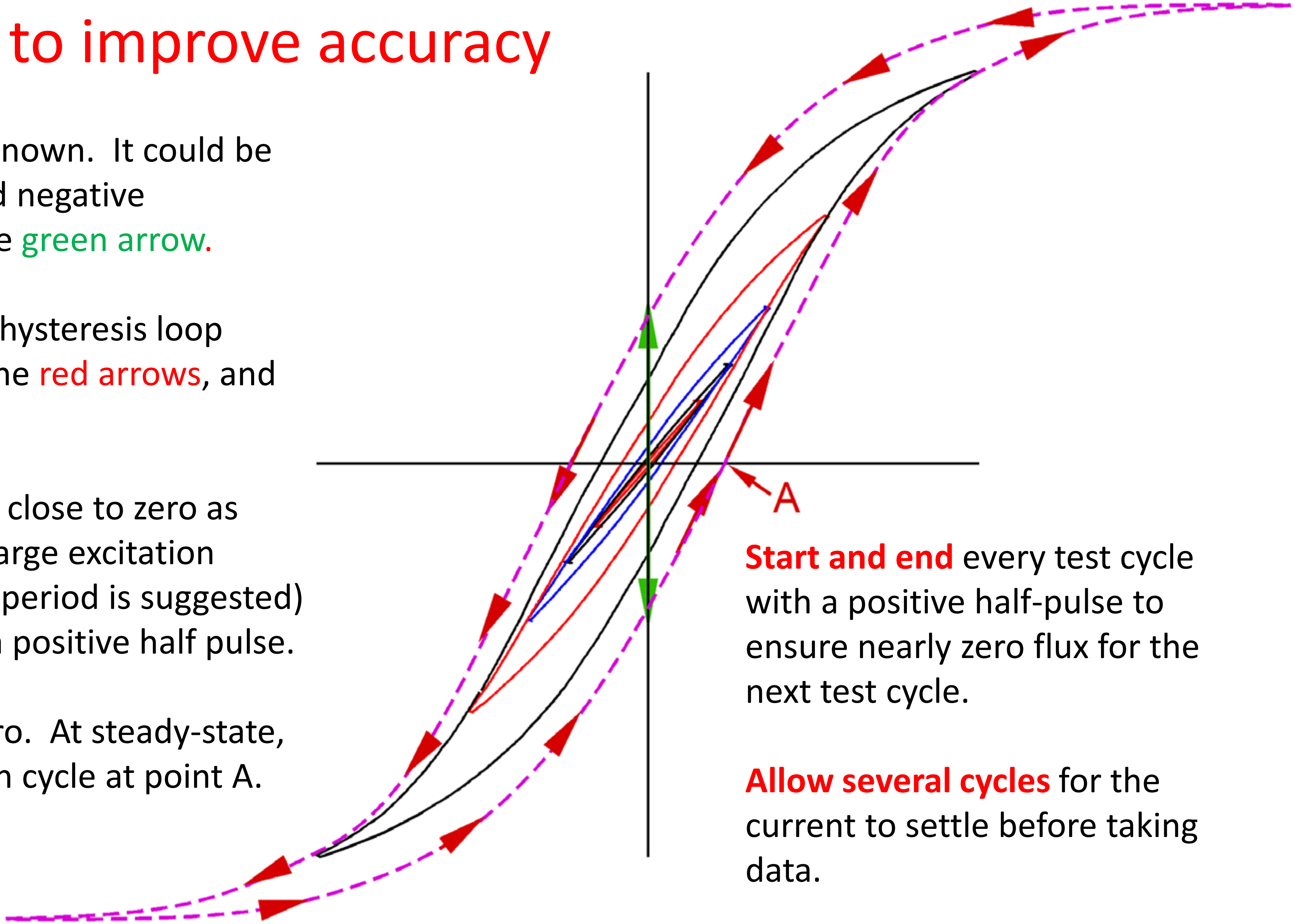
# Core conditioning to improve accuracy

**The initial flux** of a core is not known. It could be anywhere between positive and negative remanence, anywhere along the green arrow.

**At steads-state conditions,** the hysteresis loop should start at point A, follow the red arrows, and return to point A.

**To ensure** that the flux starts as close to zero as possible, cycle the core with a large excitation initially (a low voltage and long period is suggested) for several cycles, ending with a positive half pulse.

**The current** initially starts at zero. At steady-state, the current starts and ends each cycle at point A.




**Start and end** every test cycle with a positive half-pulse to ensure nearly zero flux for the next test cycle.

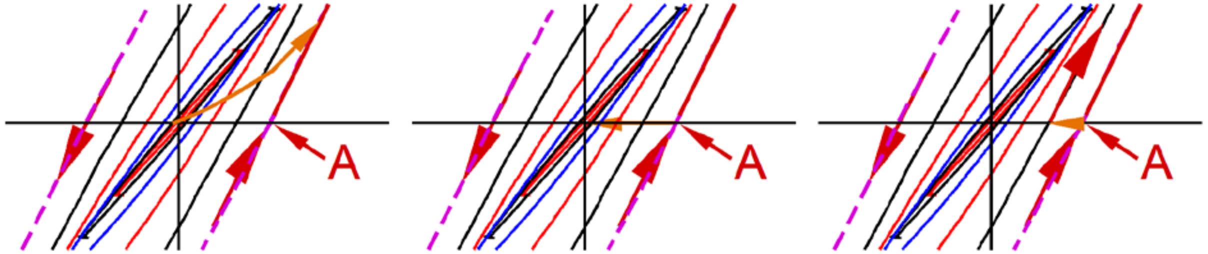
**Allow several cycles** for the current to settle before taking data.

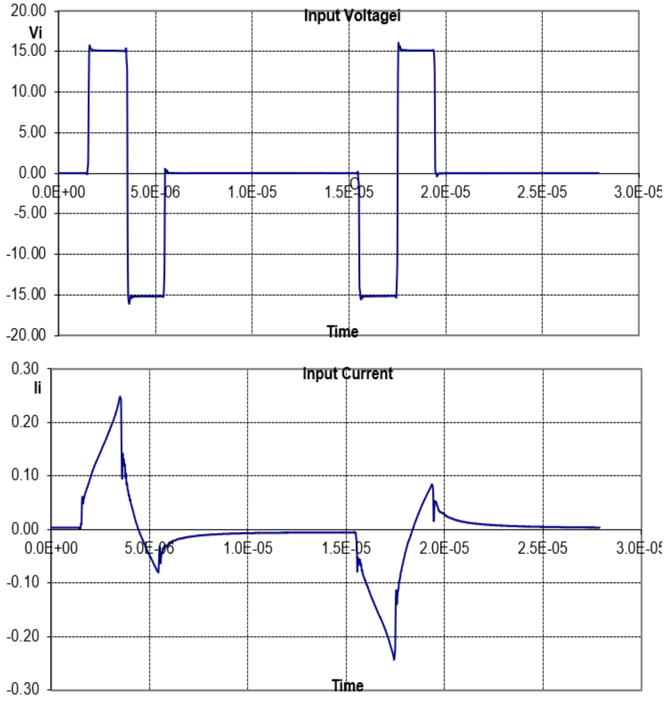
# Current conditioning

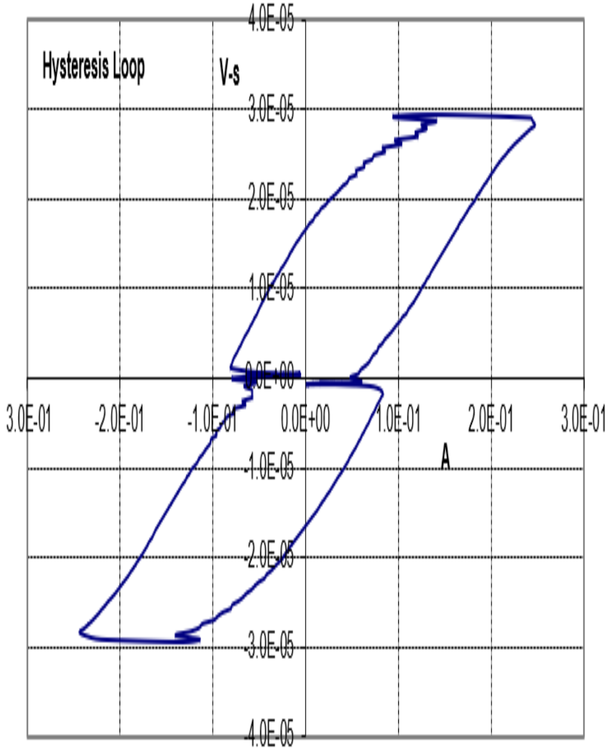
**We do not yet have data** on what the current does when excitation is first applied and between test runs.

**At the end of a test,** the current will return to zero. The switching circuit should NOT be open-circuited during this time, to prevent spiking, which would affect the flux conditioning for the next test step.

**The PSMA-Dartmouth** core loss studies may provide some insight. One of the experimental excitation waveforms used half power pulses. It looks as if the current settles down in about 10 us.



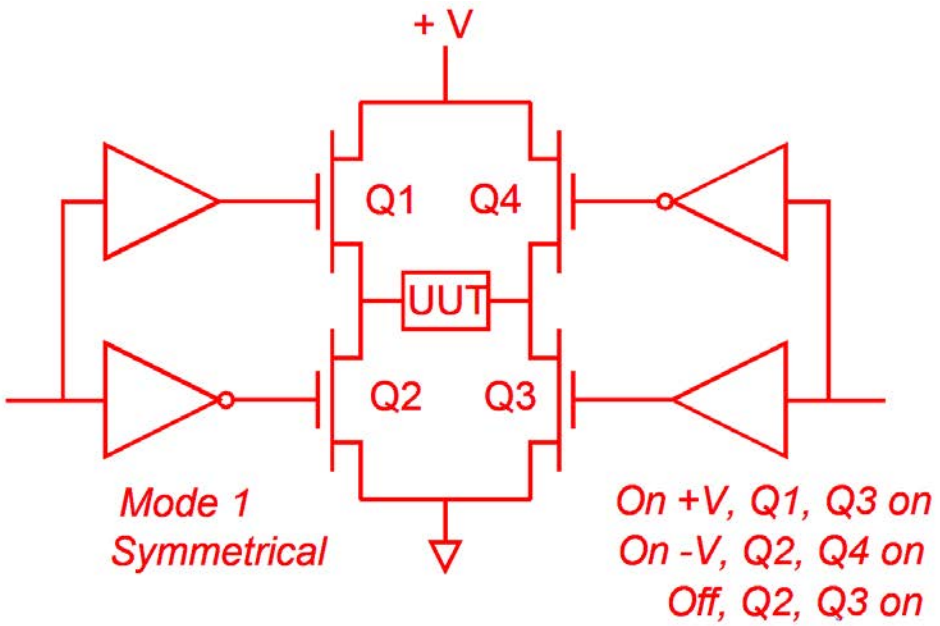
# H-bridge

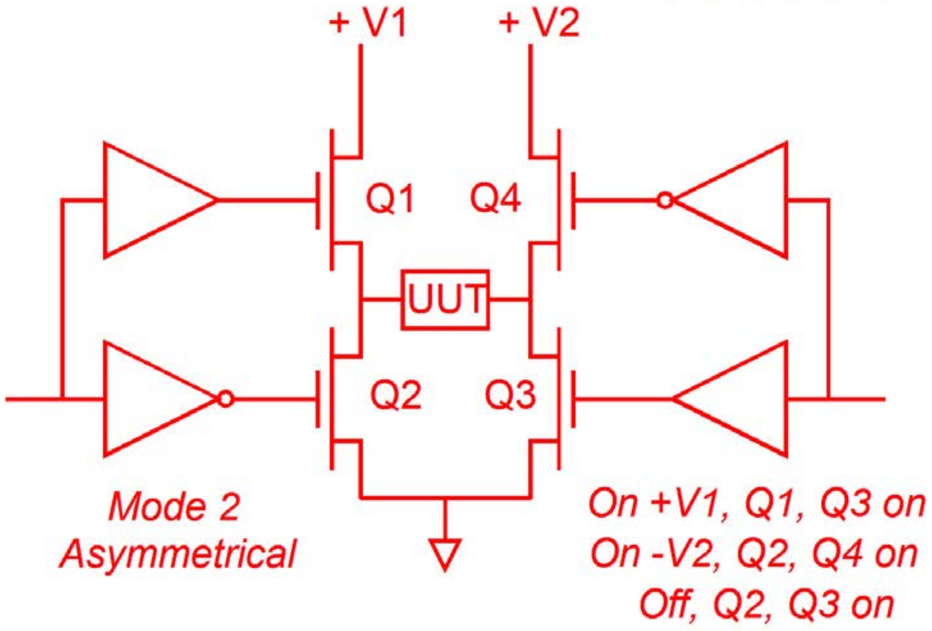
**The wavefroms for the unit under test (UUT)** can be generated with an H-bridge.  It has four modes of operation; two are shown here.

**Mode 1 is for symmetrical operation.** The voltage is the same magnitude for each half cycle.  The waveform can be low duty-ratio.

**Mode 2 is for asymmetrical operation.** The voltage can be different on the positive and hegative half cycles, but the volt-seconds must balance.

**The UUT is inductive,** so it must never be open circuited when it is conducting current.



# H-bridge

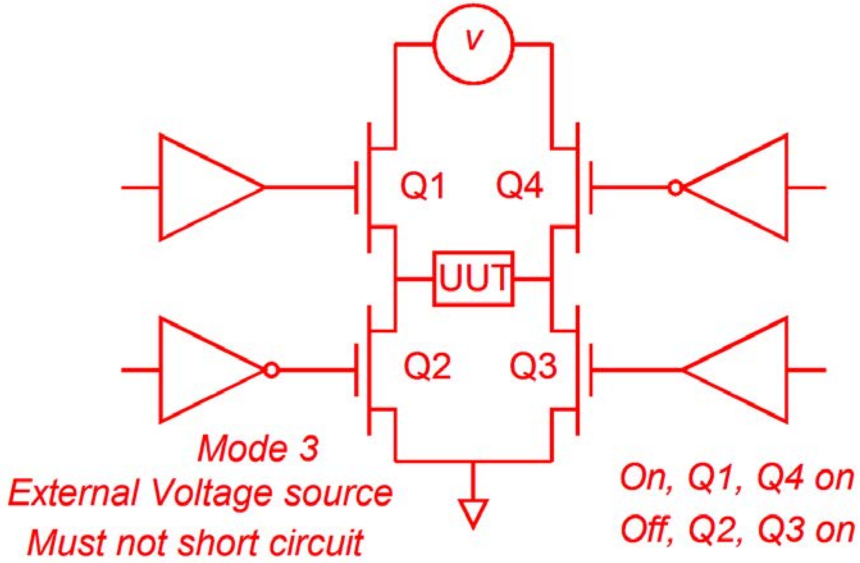
**Mode 3 is for excitation from an external voltage source,** such as a sine wave generator. The voltage source must not be short circuited.

**Mode 4 is for excitation from an external current source.** The current source must never be open circuited.

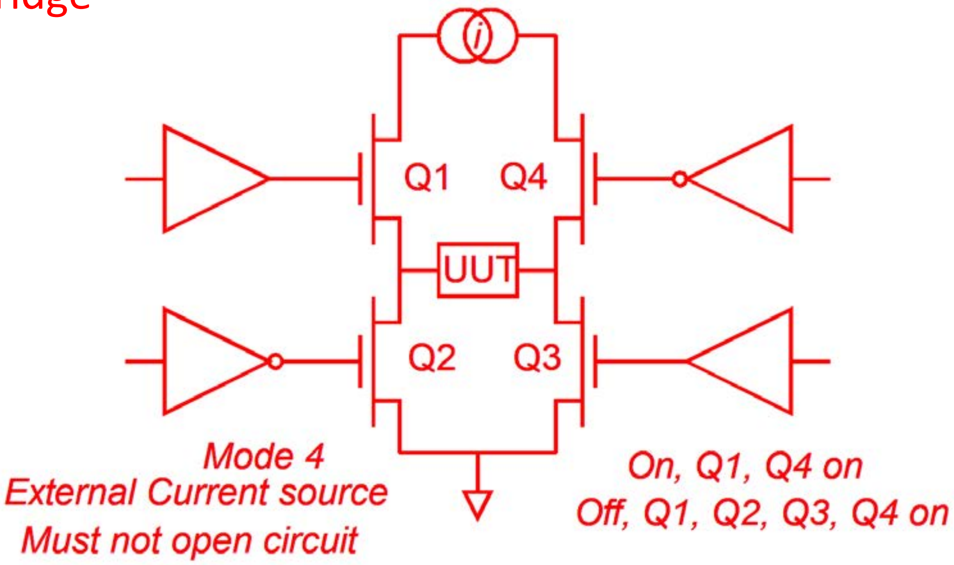
**The H-bridge can gate** the external sources to ensure that the test cycle starts and stops with positive half pulses.

**The UUT is inductive,** so it must never be open circuited when it is conducting current.

**The external source** must be isolated or biased such that its voltage does not go below ground.




H-bridge



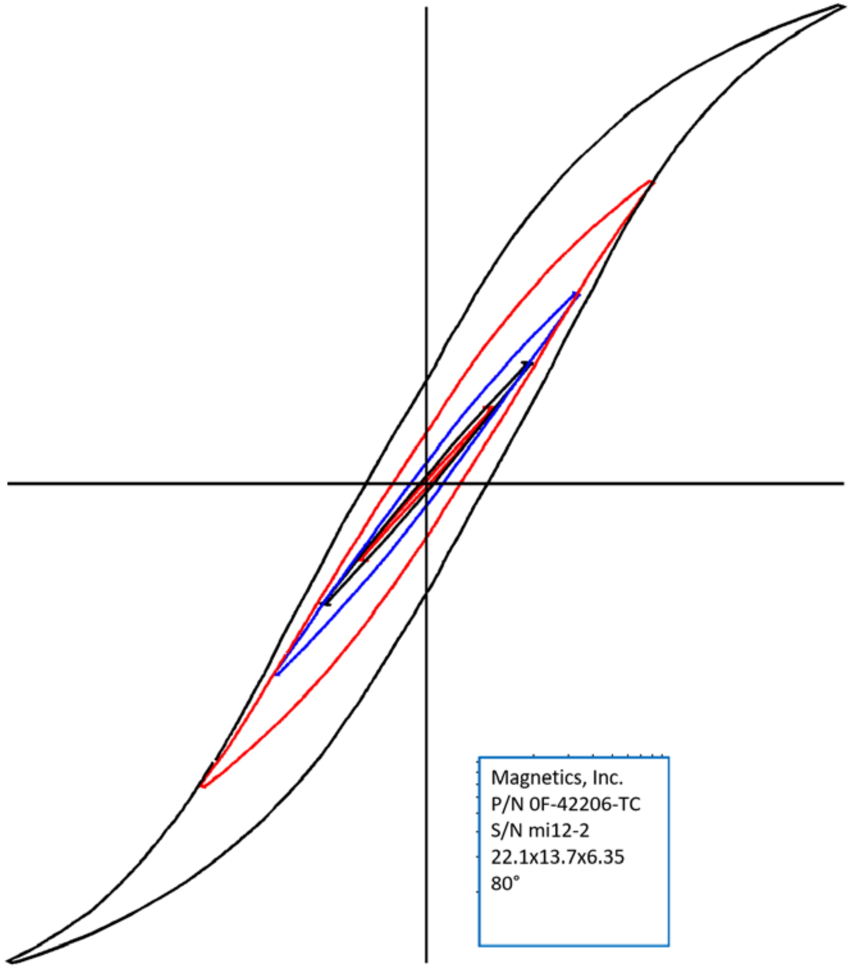
# Other core parameters

**If the primary data** are retained, each test point has the data necessary to show the hysteresis loop for that test point. In the loss map that is proposed, there are 51 hysteresis loops, and many more over temperatures.

**Many of the core parameters** are derived from measurements of the hysteresis loop. The problem will not be lack of data, but deciding which to use. Those with special requirements can calculate the parameters that they need at any loss point.

**Six hysteresis loops** are shown for varying frequency at one excitation voltage for one core.

**To take one example, *$\mu$*,** (the slope of the curve), it can be seen that it varies a lot. Deciding where to measure ***$\mu$*** will be a challenge. With the primary data available, a user with special requirements can find ***$\mu$*** at any point of interest.



# Primary data format

**The primary data** probably are generated with a digital oscilloscope or other digitizer. The file sizes can be huge.

**The format,** sample size and the number of data points varies significantly, enough so that it is unlikely that different users could use the raw data unless it is standardized. That is not likely to be possible with equipment from different vendors.

**Down-sampling** to a standard format is suggested. There are many algorithms for down-sampling, like boxcar averaging, that retain high data accuracy.

**The Dartmouth format** is suggested, partly because a large archive of data from the PSMA –Dartmouth core loss studies will be available to everyone. It seems to be a well-thought out format, with flexibility.

**The Dartmouth format** has exactly 1,000 samples for one cycle of test data. There are five columns of data, three of which are needed for core loss: Time, Primary current and Sense winding voltage. The other columns can be used for QC or special tests.

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | time | sync | out | V | I |
| 2 | second | Volt | Volt | Volt | Ampere |
| 3 | -2.00E-07 | 2.73E-01 | 4.36E+00 | 2.01E+00 | 1.38E-02 |
| 4 | -1.98E-07 | 2.54E-01 | 4.36E+00 | 2.16E+00 | 1.50E-02 |
| 5 | -1.96E-07 | 2.44E-01 | 4.36E+00 | 2.18E+00 | 1.48E-02 |
| 6 | -1.94E-07 | 2.25E-01 | 4.36E+00 | 2.18E+00 | 1.33E-02 |
| 7 | -1.92E-07 | 2.34E-01 | 4.36E+00 | 2.15E+00 | 1.12E-02 |
| 8 | -1.90E-07 | 2.34E-01 | 4.36E+00 | 1.87E+00 | 8.67E-03 |
| 9 | -1.88E-07 | 2.34E-01 | 4.36E+00 | 1.45E+00 | 5.63E-03 |
| 10 | -1.86E-07 | 2.34E-01 | 4.36E+00 | 1.11E+00 | 2.03E-03 |
| 11 | -1.84E-07 | 2.44E-01 | 4.36E+00 | 9.33E-01 | -1.25E-03 |
| 12 | -1.82E-07 | 2.64E-01 | 4.36E+00 | 8.73E-01 | -3.91E-03 |
| 13 | -1.80E-07 | 2.83E-01 | 4.36E+00 | 7.25E-01 | -5.70E-03 |
| 14 | -1.78E-07 | 2.93E-01 | 4.36E+00 | 5.61E-01 | -6.56E-03 |
| 15 | -1.76E-07 | 3.03E-01 | 4.36E+00 | 4.83E-01 | -7.03E-03 |
| 16 | -1.74E-07 | 3.03E-01 | 4.36E+00 | 4.98E-01 | -6.56E-03 |
| 17 | -1.72E-07 | 3.03E-01 | 4.36E+00 | 6.02E-01 | -5.39E-03 |
| 18 | -1.70E-07 | 3.03E-01 | 4.36E+00 | 7.82E-01 | -3.52E-03 |
| 19 | -1.68E-07 | 3.03E-01 | 4.36E+00 | 1.02E+00 | -1.41E-03 |
| 20 | -1.66E-07 | 2.83E-01 | 4.36E+00 | 1.27E+00 | 7.81E-04 |
| 21 | -1.64E-07 | 2.64E-01 | 4.36E+00 | 1.51E+00 | 2.81E-03 |
| 22 | -1.62E-07 | 2.44E-01 | 4.36E+00 | 1.70E+00 | 4.53E-03 |
| 23 | -1.60E-07 | 2.34E-01 | 4.36E+00 | 1.81E+00 | 5.63E-03 |
| 24 | -1.58E-07 | 2.34E-01 | 4.36E+00 | 1.85E+00 | 5.63E-03 |
| 25 | -1.56E-07 | 2.25E-01 | 4.36E+00 | 1.84E+00 | 5.31E-03 |
| 26 | -1.54E-07 | 2.15E-01 | 4.36E+00 | 1.81E+00 | 4.30E-03 |
| 27 | -1.52E-07 | 2.34E-01 | 4.36E+00 | 1.77E+00 | 3.67E-03 |
| 28 | -1.50E-07 | 2.44E-01 | 4.36E+00 | 1.71E+00 | 2.81E-03 |
| 29 | -1.48E-07 | 2.64E-01 | 4.36E+00 | 1.64E+00 | 1.80E-03 |
| 30 | -1.46E-07 | 2.83E-01 | 4.36E+00 | 1.54E+00 | 7.81E-04 |
| 31 | -1.44E-07 | 2.93E-01 | 4.36E+00 | 1.44E+00 | 0.00E+00 |
| 32 | -1.42E-07 | 2.93E-01 | 4.36E+00 | 1.34E+00 | -2.34E-04 |
| 33 | -1.40E-07 | 2.93E-01 | 4.36E+00 | 1.26E+00 | -7.03E-04 |
| 34 | -1.38E-07 | 2.93E-01 | 4.36E+00 | 1.20E+00 | -7.81E-04 |
| 35 | -1.36E-07 | 3.03E-01 | 4.36E+00 | 1.17E+00 | -6.25E-04 |
| 36 | -1.34E-07 | 2.83E-01 | 4.36E+00 | 1.16E+00 | -7.81E-05 |
| 37 | -1.32E-07 | 2.64E-01 | 4.36E+00 | 1.18E+00 | 6.25E-04 |

# Further possibilities to explore

**Bruce Carsten** has suggested that all cores should have a resonant sweep, looking for loss anomalies. A student whom he advises, Craig Baguley, has noted acoustic resonance in some cores, which affects the losses.

**Permittivity and resitsivity:** Part of the investigation of flux propagation at SMA is to investigate the permittivity and resistivity of samples of ferrite. Fair-Rite has machined some special shapes for this purpose. These parameters probably should be in the spec for a core. Since they will vary with frequency and temperature, graphs and/or tables will be needed.

**Current biasing:** We can consider testing losses with dc bias currents. This probably is more important when we study low permeability and gapped cores.

**Current driven excitation:** The core loss results at the prime point and regions close to it probably will look similar whether driven by voltage or by triangular current (di/dt), with small difference due to the variability of the inductance. Current driven excitation will be much better for exploring high excitation as the core saturates.

**SMA reported changes in the core** due to strain, with significant changes due to winding stress. If this can be quantified, it would be useful information for a spec.

# Further possibilities to explore

**PSMA sponsored** two special projects exploring aspects of core loss this year.  Both were planned and approved late in the year, so the conclusions of the studies are preliminary at this time.

**Next year,** we should consider starting special projects much earlier, with the objective of having results for the 2019 workshop.

**Please give thought** to worthwhile projects that we could undertake.  Following the workshop, we will ask all participants to complete a survey, and special project proposals and planning will be an important part of that.

**Please participate in the survey and make suggestions!**

Thank you.

Questions?