Initial Permeability, Losses & Inductance Factor

Three properties can be measured, using only an inductance meter to measure an equivalent series inductance and resistance. From these values, and a knowledge of the inductor sample, three parameters may be derived. These are:

Inductance Factor, A_L, given by

$$A_{L[nH/t^2]} = \frac{L_{[nH]}}{n^2}$$

where L is the inductance in nH, and

n is the number of turns,

Initial Permeability (the real part only), μ_i, given by

$$\mu_i = \frac{L}{L_o}$$

where L is the measured inductance, and

L_o is the air core inductance.

Losses, described by $\tan\delta/\mu_i$, given by

$$\frac{\tan\delta}{\mu_i} = \frac{L_o R_s}{\omega L^2}$$

where μ_i is the initial permeability,

$\tan\delta/\mu_i$, is the lossy component of the total reactance,

ω is $2\pi f$, and

other terms as defined above.

Equipment: Precision LCR meter.

Test Conditions: Flux Density < 10 Gauss

Frequency: as specified.

The core is stabilized at room temperature (22° C) and wound with the correct number of turns. Since most LCR meters have a resistor, usually 100 Ω, in series between the oscillator and the unknown to be measured, the number of turns should be chosen such that the reactance of the core is at least 10 Ω. This condition ensures that a minimum of 10% of the test signal is applied to the core.

With the frequency set and voltage adjusted for test conditions, the LCR meter will measure R_s and L_s. Caution: When measuring very small value reactances, be sure to test the accuracy of the measurement instrument.

Changes in Inductance versus Temperature & Curie Temperature

These two tests may be performed using an inductance meter and a temperature controlled oven. The inductance meter will measure R_s and L_s.

Equipment: Precision LCR meter
Temperature Controlled Chamber for DUT

Test Conditions: Flux Density <10 Gauss
Temperature as specified

Frequency: 10 to 100 kHz.

The cores to be tested are placed in the temperature chamber and subjected to two stabilizing temperature cycles, with approximately two hours at each temperature.

The first inductance measurement, L_1 is made at the lowest temperature, θ_1, after a thirty minute soak at that temperature. This procedure is repeated up to the highest specified temperature, θ_2. A measurement made in the 20°C to 25°C range is considered the reference inductance, L_{ref}, at the reference temperature, θ_{ref}.

After measuring the highest temperature, a final measurement should be made again at the reference temperature. Both measurements of the reference inductance should be the same within the bridge accuracy. If these two readings are significantly dissimilar, more temperature stabilizing cycles may be needed to eliminate irreversible inductance changes in the samples. From the inductance reading at various temperatures, the temperature coefficient of inductance may be calculated from

$$T.C. = \frac{L_{\theta 2} - L_{ref}}{L_{ref}(\theta_2 - \theta_{ref})} = \frac{L_{\theta 2} - L_{\theta 1}}{L_{ref}(\theta_2 - \theta_1)}$$

where all terms are as defined above.

For Curie Temperature measurement, temperature is slowly increased while inductance is monitored. The temperature at which core inductance decreases to 10% of the room temperature value is the Curie Temperature.

Flux Density, Residual Flux Density, Coercive Force, & Amplitude Permeability

There are four intrinsic material parameters that can be determined from the B-H loop measurement. The core under test is used as a transformer and the relationship between winding current (H) and secondary winding integrated voltage (B) is measured. This relationship is displayed using the "X versus Y" display mode on an oscilloscope. Magnetic terms are readily expressed in electrical terms to calibrate the display in units of Oersteds (Oe) versus Gauss (G). Once this calibration is achieved, salient points on the B-H curve may be easily obtained.

Equipment: Function Generator
Amplifier
RC Network
Dual Channel Oscilloscope

The test circuit is as shown at the right. Resistor R_1 is kept small in comparison with the inductive reactance of the wound sample. Cores must be properly installed and wound with primary and secondary winding. Field strength, H, is set by varying the current which is read as voltage across resistor R_1.

$$H_{[Oe]} = \frac{0.4\pi nI}{l_{e[cm]}} = \frac{0.4\pi n_p V_p}{l_{e[cm]} R_1}$$

Flux density of the cores is determined by integrating the secondary voltage using the RC circuit.

$$B_{[G]} = \frac{R_2 C V_p 10^8}{n_s A_{e[cm^2]}}$$

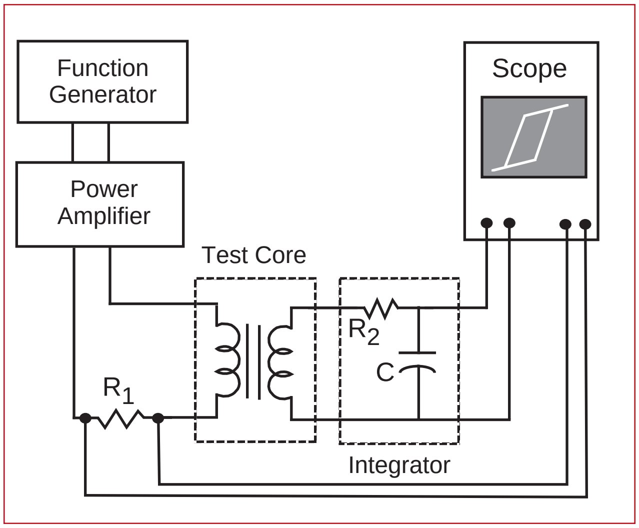
where R_2 is the integrating resistance, and C is the integrating capacitor.

From the displayed hysteresis loop saturation flux density, B_S, values for coercive force, H_c, and residual flux density, B_r, may be determined once the oscilloscope is calibrated.

Finally, amplitude permeability, μ_a, is given by

$$\mu_a = \frac{\hat{B}}{H}$$

where $\hat{B}$ represents peak flux density between 10 Gauss and saturation, an H is the corresponding field strength.



Test set up for measuring parameters of the B-H Loop.

Pulse Characteristics

An open collector drive circuit is used to drive a pulse through a transformer with the secondary open circuited. The effect of the transformer on the pulse is observed by monitoring waveforms.

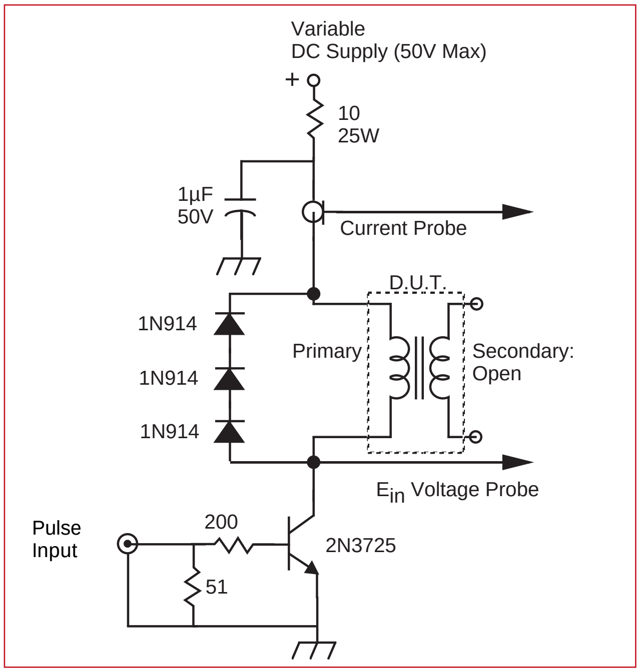
Equipment: Pulse Generator
DC Power Supply
Pulse Drive Circuit–appropriate for application
Dual Channel Oscilloscope
Current Probe

Test Conditions: Pulse Amplitude, Pulse Width, and Pulse Repetition Rate as specified.
Temperature; 23°C ± 3°C.

The test toroid to be measured is wound with a sufficient number of turns to produce at least 100 µH of inductance. The core is excited by applying square voltage pulses. The test circuit is shown below.

Pulse inductance, L_P, pulse Inductance Factor, A_{LP}, and the voltage time product, E-T, are measured in accordance with section 16.7 of IEC367-1.

Pulse inductance is specified as greater than 90% of sine wave initial inductance.



Test set up for measuring pulse characteristics.

Power Loss

Power loss is readily measured using a Volt-Amp-Watt (VAW) meter.

Equipment: Signal Generator
Power Amplifier
Clark Hess 256 VAW Meter
Temperature Chamber

The equipment is connected as shown below.

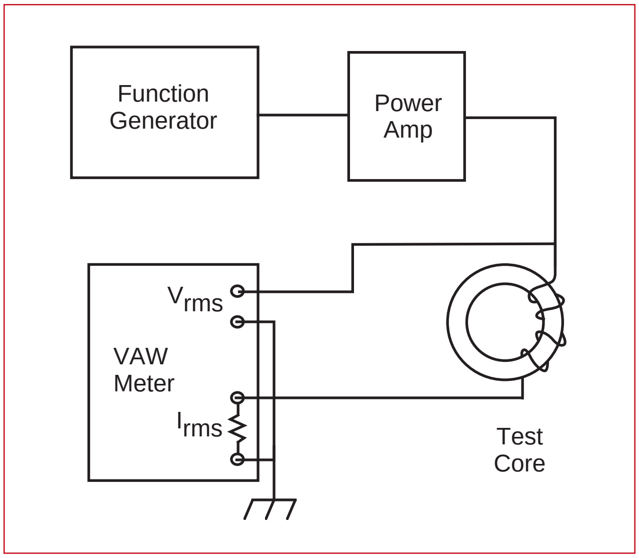
Frequency is set and voltage is adjusted to the desired flux density level, given by the relation

$$E_{[Vrms]} = 4.44 f n B_{[G]} A_{e[cm^2]} 10^{-8}$$

Power losses are indicated by the VAW meter in watts. Measurements are made as rapidly as possible to avoid temperature rise in the samples.

Material power loss density is determined by dividing the measured power loss by the effective volume of the ferrite core.

A VAW meter may also be used to measure magnetizing current, I_m. This value can be used to calculate the winding loss ($I_m^2 R_{ac}$), a part of the total measured power loss.



Test set up for measuring power loss.

Measurement of Impedance Of Ferrite Components

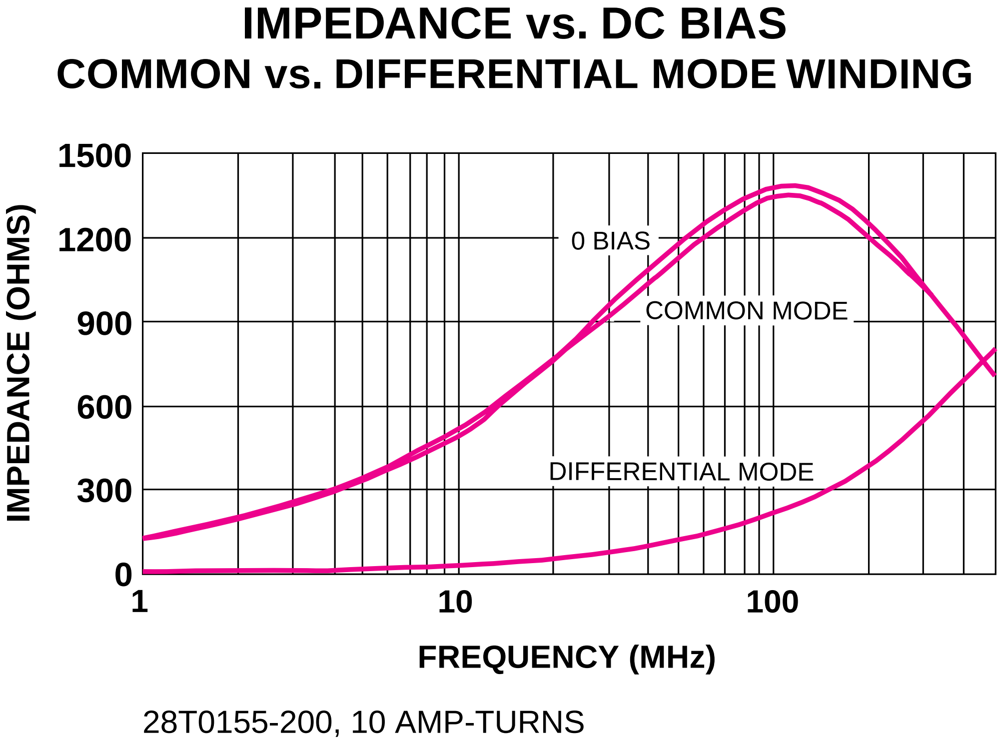
The most common property referenced for soft magnetic materials is permeability. Permeability is a complex property comprised of real (reactive) and imaginary (resistive) components. At the lower end of the RF scale, impedance can be calculated from inductance as $Z = 2\pi fL = X_L$ and is dominated by the reactive component of permeability.

As frequency increases, impedance is driven by the resistive component and can be calculated as $Z = \sqrt{R^2 + (j\omega L)^2}$, where R represents the resistive component and $j\omega L$ represents the reactive component. At higher frequencies permeability will approach zero and impedance will reach a maximum value comprised of a purely resistive component. Impedance, like permeability, varies with temperature, frequency, signal current, DC bias, and the presence of any extraneous fields.

The useful impedance obtained from a ferrite component depends on its application, number of turns, and winding method. See below for an illustration of the effect of differential versus common mode winding techniques on the net impedance of a core.

Impedance measurements are made on an RF impedance analyzer. Measurements for this catalog were made on a Hewlett-Packard 4195A Network/Spectrum Analyzer with a 41951A Impedance Test Kit. All impedance curves represent gross measurements with number of turns and DC Bias current applied as shown (unless noted otherwise). In all cases the length of the conductive path between the part under test and the test fixture is kept to a minimum and in a fixed position to minimize parasitic capacitance.

All impedance measurements with DC Bias utilize the internal circuitry of the impedance analyzer. Measurements are also possible with an external source of DC current using an RF choke and a blocking capacitor to isolate the bias circuit from the RF circuit.



These curves show the effect of ten amp-turns of DC bias on the same core wound two different ways. In the differential mode, wherein there is a single winding carrying direct current, the core is pushed far into saturation (ten amp-turns on a T0155-200 corresponds to 13.7 Oersteds). In the common mode, wherein the direct current returns through a coil of the opposite winding direction and an equal number of turns, the only deviation from zero-bias arises from leakage inductance, which is inherently low in toroids.