Measuring Ferrite Chokes

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A ferrite choke is a parallel resonant circuit, formed by inductance and resistance coupled from the core and stray capacitance that results from interaction of the conductor that forms the choke with the permittivity of the core, and, if the choke is wound, the capacitance between turns.

These chokes are very difficult to measure for two fundamental reasons.

1) The stray capacitance that forms the parallel resonance is quite small (typically 0.4 – 5 pF), which is often less than the stray capacitance of the test equipment used to measure it.
2) Most instrumentation measures RF impedances by measuring the reflection coefficient in a 50-Ω circuit.

Reflection-based measurements have increasingly poor accuracy when the unknown impedance is more than about 3x the impedance of the analyzer, because the value of the unknown is computed by differencing analyzer data, and even very small errors in the raw data cause very large errors in the computed result. While the software used with reflection-based systems use calibration and computation methods to remove systemic errors like fixture capacitance from the measurement, these methods have generally poor accuracy when the impedance being measured is in the range of typical ferrite chokes.

A simple method that works

The key to accurate measurement of high impedance ferrite chokes is to set up the choke as the series element of voltage divider (see Figure 1), using a well-calibrated voltmeter to read the voltage across a well-calibrated resistor that acts as the voltage divider's load resistor.

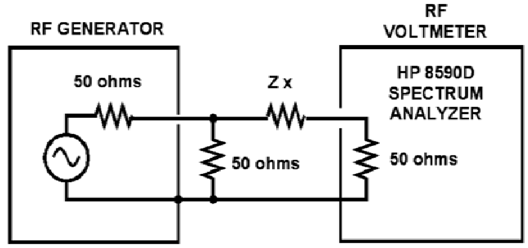

Figure 1 – Choke measurement setup

The fundamental assumption of this measurement method is that the unknown impedance is much, much higher than the impedance of both the generator and the load resistor. The voltage divider is driven by an RF generator, which must be terminated by its calibration impedance (because the generator is calibrated only when working into its calibration impedance, and the test circuit is a high impedance). An RF spectrum analyzer with its own internal termination resistor can serve as both the voltmeter and the load. Alternatively, a simple RF voltmeter or scope can be used, with the calibrated load impedance being provided by a termination resistor of known value in the frequency range of the measurement.

Making measurements

With the unknown in place, obtain values for the voltage across the load resistor as the generator in increments of about 5% over the range of interest, and record the data in a spreadsheet. Use the same frequencies for all chokes so that data can be plotted and compared. Using the spreadsheet, solve the voltage divider equation backwards to find the unknown impedance. Plot the data as a graph of impedance (on the vertical axis) vs frequency (on the horizontal axis). Scale both axes to display logarithmically.

Accuracy

This method yields the magnitude of the impedance, but no phase information. Accuracy is greatest for large values of unknown impedance (worst case 1% for 5,000 ohms, 10% for 500 ohms). Accuracy can be further improved by correct for variations in the loading of the generator by the test circuit. Measure the voltage at the generator output with the unknown connected and use that voltage as the input voltage. The voltmeter must be un-terminated for this measurement.

Obtaining R, L and C values

In a second spreadsheet (or another page in your measurement spreadsheet), create a new table that computes the magnitude of the impedance of a parallel resonant circuit for the same range of frequencies as your choke measurements. Set up the spreadsheet so that you enter values for R, L, and C at the top of the spreadsheet, with the calculations for each frequency based on the values of R, L, and C that you have entered. Also at the top of your spreadsheet, compute the resonant frequency and Q for values you have entered. Create a graph that plots this computed impedance over the same range of frequencies as the measurements, and with the same plotted scale as the measurements.

Now, 1) set R equal to the resonant peak of the measured impedance; 2) pick a point on the resonance curve below the resonant frequency that's about one-third of the impedance at resonance, and compute L for that value of inductive reactance; 3) pick a value for C to produce the same resonant frequency of the measurement. 4) if necessary, adjust the values of L and C until the computed curve most closely matches the measured curve. These R, L, and C values can be used in circuit models (NEC, SPICE) to predict the behavior of circuits using ferrite chokes.

Capacitance errors

This setup can be constructed so that its stray capacitance is small, but it won't be zero. A first approximation of the stray capacitance can be obtained by substituting for the unknown a non-inductive resistor whose resistance is in the same general range as the chokes being measured, then varying the frequency of the generator to find the -3dB point (where $X_C = R$). This test for the setup in the photograph yielded a stray capacitance value of 0.4 pF. **(***A surface-mount film resistor will have the least reactance, but may be impractical due to its small size. Low-wattage carbon composition resistors are acceptable if leads are kept as short as possible – Ed.*)

Accounting for stray capacitance

Since the measured curve includes stray capacitance, the actual capacitance of the choke will be slightly less than the computed value. If you have determined the value of stray for your test setup, subtract it from the computed value to get the actual capacitance. You can also plug this corrected value into the theoretical circuit to see how the choke will actually behave in a circuit (that is, without the stray capacitance of your test setup). You won't see the change in your measured data, only in the theoretical RLC equivalent.

Dual resonances

In NiZn materials (types #61, #43), there is only circuit resonance, but MnZn materials (#77, #78, #31) have both circuit resonance and dimensional resonance. The dimensional resonance of #77 and #78 is rather high Q and clearly defined, so R, L, and C values can often be computed for both resonances. This is not practical with chokes wound on #31, because the dimensional resonance occurs below 5 MHz, is very low Q, is poorly defined, and blends with the circuit resonance to broaden the impedance curve. The result is a dual-sloped resonance curve – that is, curve fitting will produce somewhat different values of R, L, and C when matching the low-frequency slope and high frequency slope. When using these values in a circuit model, use the values that most closely match the behavior of the choke in the frequency range of interest.