Power Supply Chokes

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A choke is a large inductance (coil) intended to pass DC but block (or "choke") AC. Chokes come in all sizes and shapes optimized for different frequencies, but I will focus on the iron-core variety that look like transformers: a spool of enamel-coated wire wound on an "E" + "I" shaped laminated iron core. (Also, the field coil of an electrodynamic speaker, if it is in series with the power supply, is a choke.) They are generally found with inductance values from about 1 Henry to 100 Henry. (The unit of inductance is the Henry, named after Joseph Henry, a 19th century American scientist who worked with electromagnets, and is the father of the doorbell.) These chokes are used as filters in high-voltage power supplies found in tube radios, particularly those designed prior to WW2.

**Figure 1 Power Supply Chokes.**

The seed for this article was planted when club member, Don Asquin, purchased a digital inductance meter. I had built an inductance meter several years ago, and was interested in how accurate it was. I have precision standards for 10mH and below, but nothing for larger inductances. We compared the two meters with chokes that we had on hand; although the meters were fairly close, there were enough differences that I decided to investigate further.

It turns out that an iron-core choke is a surprisingly complicated thing. These chokes have an inductance that depends on the DC current that flows thru it, on the AC current that flows thru it, and on frequency. So, you cannot expect consistency between measurements without excruciating attention to detail.

The permeability of iron (which is a measure of its ability to be magnetized) is known to increase with the presence of an AC field. See, for example, "Radiotron Designers Handbook (Fourth Edition)" by Langford-Smith, 1952, page 244, for a graph of the permeability of silicon steel. It shows up to a 5X increase in permeability when AC current is increased. I measured a 10H Hammond choke manually (by observing the resonant frequency with a 0.68uF series capacitor) at various levels of AC current and recorded the graph below. The low-current inductance is quite close to the published 10H value, but the inductance increases quickly, and by up to a factor of three, even at fairly moderate current levels. The three "X" marks are the same inductor measured with (left to right):

- my meter
- Don's digital meter
- the meter described in the last part of this article.

Note that the AC current through the inductor explains most of the discrepancy in the measured inductances.

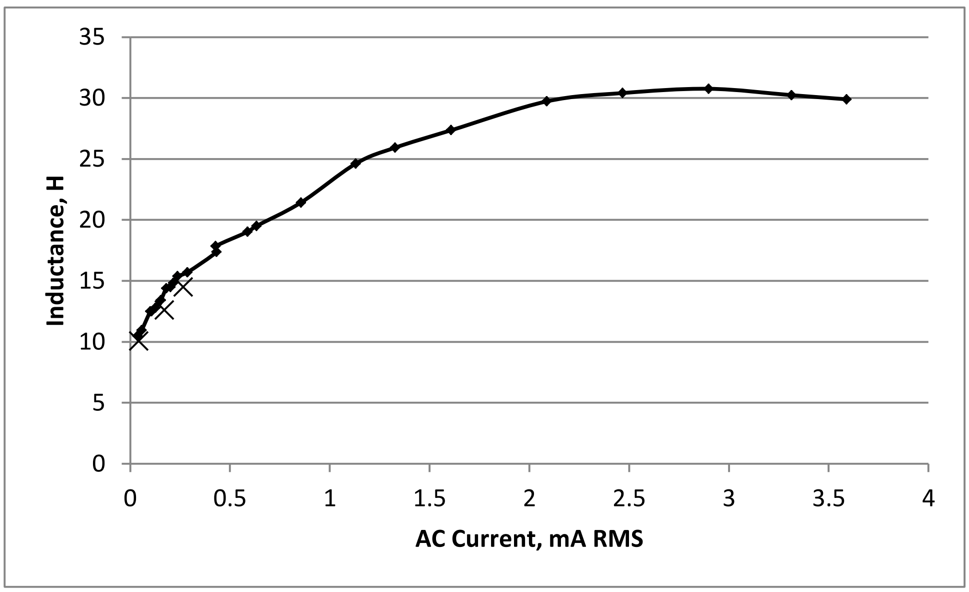


Figure 2 Inductance vs. AC Current for a 10H choke.

The inductance of a choke decreases with DC current. (I agree that it is counterintuitive that DC and AC current have the opposite effect.) This is a fairly well-known phenomenon, which is used to advantage in the "Swinging choke" used in a choke-input power supply filter. In a choke-input power supply, the first element in the power supply filter network is a series choke (so the rectifier tube "sees" an inductance). (The schematics are from "Applied Electronics", MIT Department of Electronics, 1943)

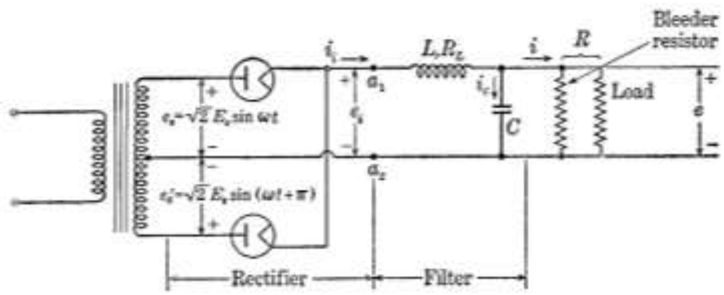


Figure 3 Choke-Input Power Supply.

This choke causes the rectifier current to remain somewhat constant over much of the AC cycle. The rectifier tube therefore conducts over much of the AC cycle. Contrast this with a capacitor input filter network, in which the first element is a shunt capacitor.

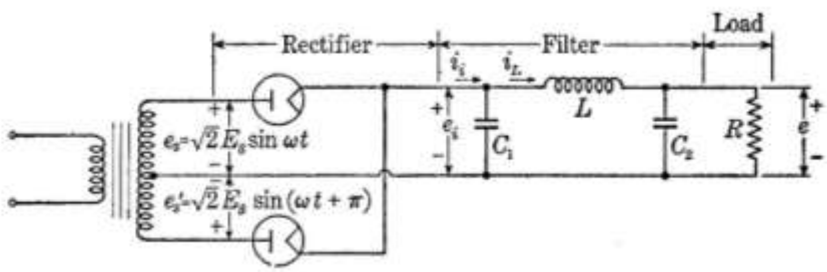


Figure 4 Capacitor-Input Power Supply.

This network results in a constant voltage at the rectifier tube. In this case, the rectifier tube will conduct only at the peak of the AC voltage, and when it conducts it must pass a very high current for a short time. A choke-input configuration has advantages: it offers better voltage regulation and efficiency over a range of power supply output currents, and a given rectifier tube can support more DC output current. The minimum choke inductance requirement is determined by the minimum current that is to be regulated (higher current needs less inductance), so it is advantageous for the choke inductance to be maximized at low current. On the other hand, too much inductance costs more, and will cause a given core dimension to saturate at high current (more current or more inductance will require a larger core to avoid saturation), so it is advantageous to minimize inductance at high current. In some cases, a small air gap can be added to the magnetic structure to reduce the maximum field at high current. An iron-core choke's maximum inductance at low DC current is a good thing, and a power supply choke will be optimized for this tendency.

The measured inductance of the same 10H Hammond choke versus DC current is shown below. It does not take much current for the inductance to drop measurably.

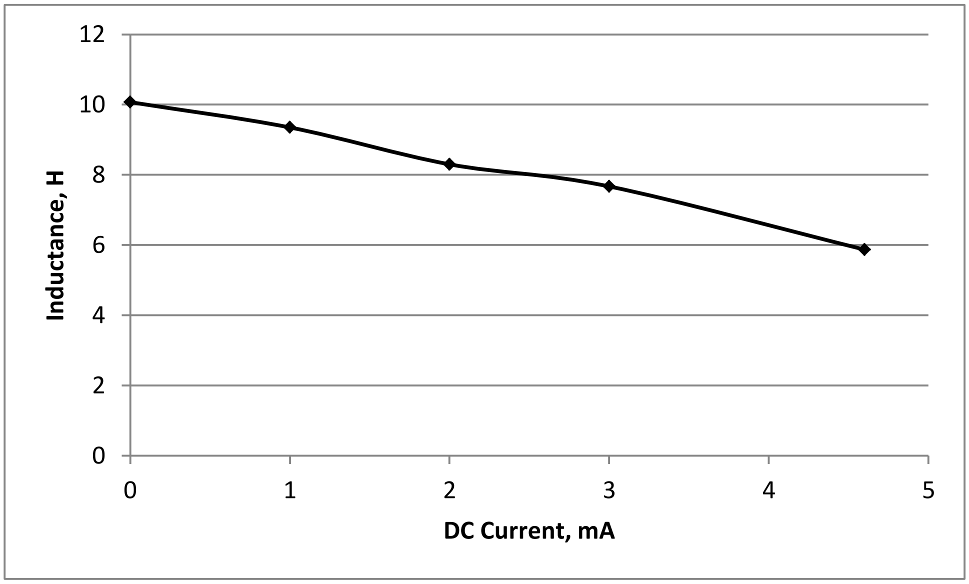


Figure 5 Inductance vs. DC current for a 10H Choke.

Inductor loss will determine the minimum frequency at which the inductor can be used. An inductor has several loss mechanisms (radiation, core loss (including eddy current loss), metal (copper) loss, dielectric loss) but at low frequency, metal loss will dominate. At a sufficiently low frequency, an inductor will start to look more like a resistor. All inductors have a resonant frequency; at this frequency their inductance is infinite, above this frequency they no longer behave like an inductor. Inductors must be measured between these frequencies. This implies that a good inductance meter will need to have a range of excitation frequencies to suit the value being measured.

Choke Meter

My usual inductance meter is rather complicated because it covers a range of 1uH to 30H. It measures the phase shift through an L-R network when excited with a sine wave, the frequency of which can be set over a 10000:1 range. So, it has a sine-wave generator, limiters, phase comparators and regulators. It seemed to me that there should be an easier way to measure the chokes that tube radio enthusiasts are likely to use. So, I devised a *much* simpler inductance meter based on the AC voltage across an inductor in an R-L circuit (a voltage divider formed between the resistor and inductor) excited at 60Hz. It is quick to use; you can read the inductance directly off of your digital voltmeter. As long as the voltage being measured is less than about one-fifth of the source (open circuit) voltage, the measured AC voltage is proportional (within 2%) to the inductance. When the output voltage is one-half of the source voltage, the error is about 15% (the meter will read low).

In principal, you could run this directly from the 120V AC line, but that would result in a terrible shock hazard so I recommend using a transformer. A common 24-25.2V transformer (any current) looks ideal; enough voltage but minimal shock hazard. And it results in simple resistor values. Figure 6 shows the circuit. Do not be fooled by the round resistor values; with a transformer output voltage of 26.526V, the nice even resistor values are perfect. On the "X 0.1" scale, that uses the 1K (1 watt) resistor, the AC voltmeter (use your digital volt meter, or any meter with a high input resistance) reads 0.1H/volt (accurate up to about 0.5H or 5V). So, connecting a 0.2H choke results in a 2V reading. Note that the series resistance of some inductors could add error on this scale. The “X 1” scale, that uses the 10K resistor, gives a 1H/volt sensitivity (up to about 5H). The “X 10” scale with the 100K resistor gives 10H/volt (2% accurate up to about 50H, though 15% accurate to over 100H)

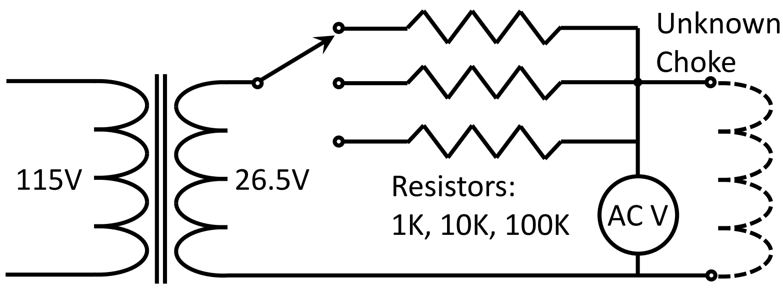


Figure 6 Simple Choke Measurement Apparatus.

You can use a lower voltage transformer, but you will end up with less inductance range. In any case, raid your transformer stock and find a transformer with a rating somewhere between 12 and 50 V. Measure its open-circuit voltage. The resistors can be selected, so that the meter is direct-reading. To achieve a 10X scale (so 1 volt on the meter means 10H), you need a resistor of 3770 ohms per volt (the open-circuit voltage at the output of the transformer). To achieve a 1X scale (so 1 volt on the meter means 1H), you need a resistor of 377 ohms per volt (the voltage at the output of the transformer). You can try a 0.1X scale (so 1 volt on the meter means 0.1H); you need 37.7 ohms per volt, so 1K for the 27V transformer. This will be good to about 0.5H, but beware that inductors of this size will start to have low “Q” at 60Hz, and this will degrade accuracy. Inductors with poor “Q” will tend to read high.

The magic 377 number will be familiar to people who have worked out the math for capacitors and inductors in North America: it is 2 X Pi X 60Hz. If you have 50Hz mains, then use 314 (pi) instead.

Thanks to Lea Barker and Don Asquin for advice in the preparation of this article.