

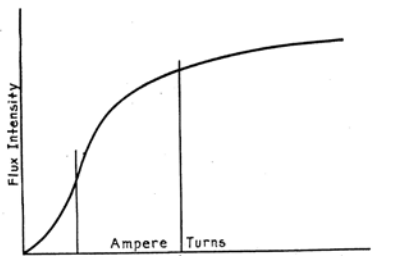
Old power supply chokes typically don't come with a rating plate stating their inductance and DC current rating. Manufacturers like Rola were an exception, with labelling such as 14H at 60mA measured at 10V 100Hz, with 560Ω DC resistance for the choke type 14/60.



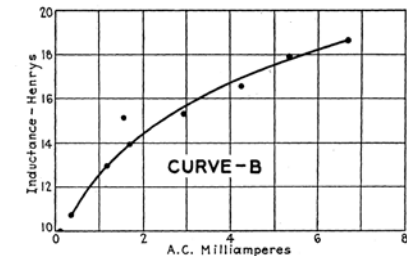
ROLA 14/60 choke

Within a valve amplifier, the high voltage (HT) DC supply with "choke input" filter applies a very large 100Hz AC voltage across the choke which is much greater than 10V, and contains substantial higher harmonic levels (one end of the choke cycles from 0V to the peak of the AC supply, and the other end of the choke is pinned to the HT DC voltage). Whereas a smoothing choke application, where the choke is connected between two capacitors, experiences a much lower AC voltage (likely to be less than 10V at 100Hz, with relatively low harmonic levels).

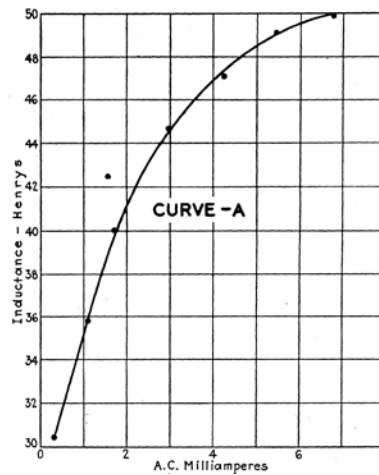
The inductance of an iron-cored choke can vary significantly with applied AC voltage (ie. ac current), and with the level of DC current passing through the choke. Results below, from [1], show those characteristics. So it is important to compare choke ratings only when similar operating conditions are being applied, and to be aware that the choke inductance value by itself is only half the story for power supply use.



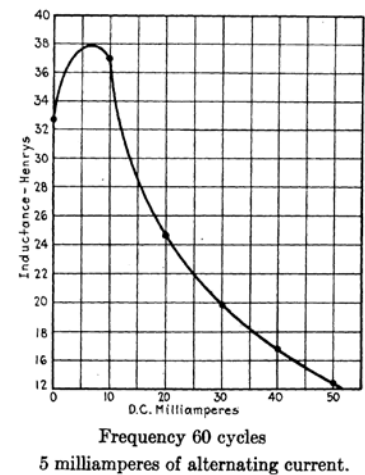
Typical Magnetization Curve of Transformer Iron.



Frequency 60 cycles. Curve A—with no direct current. Curve B—with 50 milliampers of direct current flowing.



Choke inductance measurements [1] showing variation with AC & DC current.

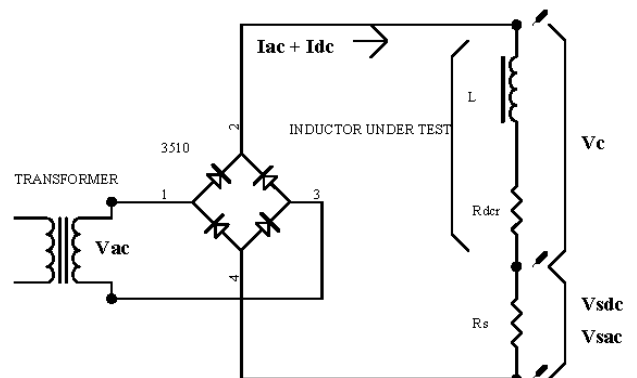


Frequency 60 cycles 5 milliampers of alternating current.

Simple measurement scheme

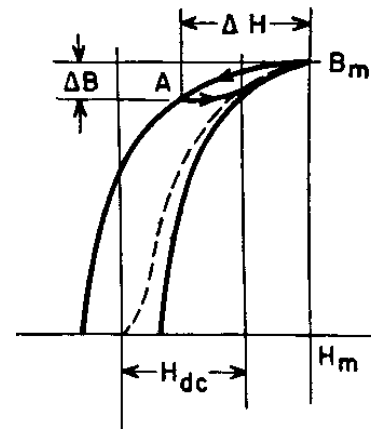
Choke inductance can be measured using a relatively simple method that passes DC plus AC current through the choke. The test circuit uses the choke to load the rectified output of a transformer power supply. A low value sense resistor R_s is typically used to make I_{dc} and I_{ac} current measurements. The choke is shown as an inductance L and a DC resistance R_{dcr} . The total DC resistance of the loading circuit is $R_{dcr} + R_s$.

By using different AC supply voltage levels, V_{ac} (rms), the level of DC current can be varied. The AC waveform applied to the choke is a rectified sine wave with a DC level of $0.9 \cdot V_{ac}$, and so a DC current of about $I_{dc} = 0.9 \cdot V_{ac} / (R_{dcr} + R_s)$ flows through the choke.



The AC voltage across the choke has a level of $V_c = 1.27 \cdot V_{ac} / (n^2 - 1)$, where $n=2,4,6..$ (ie. the even harmonics of the mains frequency) [2]. The harmonic levels drop off rapidly, so simply using just the $n=2$ (ie. 100Hz) harmonic frequency indicates that the applied AC voltage on the choke is approximately $V_c = 0.42 \cdot V_{ac}$. The AC current can be approximated by $I_{ac} = V_{ac} / (1500 \cdot L)$, where L is in Henry - this approximation assumes $f=100\text{Hz}$, the choke reactance ($2 \cdot \pi \cdot f \cdot L$) is much larger than R_{dcr} , and only 2nd harmonic current is significant. If we assume $R_{dcr} \gg R_s$, then the previous equations can be rejigged to show that DC current is larger than the AC current by the ratio of about $I_{dc} / I_{ac} = 1350 \cdot L / R_{dcr}$, which is 38 times for the Rola choke example.

With $R_{dcr} \gg R_s$, this test measures the small signal (incremental) inductance of the choke, where a relatively large DC current is passing in comparison to the AC current, and is similar to a smoothing choke



application. With respect to what the choke core experiences for this application, the graph on the right shows the choke core magnetised with the DC magnetising force H_{dc} , and a smaller AC magnetisation level ΔH is superimposed which causes a cyclical magnetisation loop to be followed between A and B_m .

This measurement scheme does not inherently measure inductance at just a specific frequency and excitation voltage, due to measurement waveform distortion including mains frequency harmonics and non-harmonic distortion from the mains voltage/transformer/diode rectifier. The influence of shunt capacitance is also neglected, as it is likely to be $\gg 100x$ the inductive impedance. However, in practise the scheme gives very good inductance measurement precision when compared with impedance measurement techniques (see later). For the purpose of power supply choke design, the test frequency and waveform are typical of that application, where choke inductance can vary so much with operating conditions.

The above measurement is made at twice the mains frequency, and a separate measurement is needed to determine the general self-resonant frequency (SRF) of the choke. The self-capacitance in the choke winding causes the rising choke impedance with frequency to level off at the SRF and then impedance falls for ripple frequencies higher than SRF (see later plot). Vintage power chokes of 10-14H, and DC current ratings of 60-125mA are likely to have a self-resonant frequency of about 3-5kHz. Modern fluorescent ballast type chokes typically have significantly higher SRF of at least 10kHz.

When the mains supply is turned off, or the supply disconnected in some manner, and twice during each mains cycle, the DC current in the test circuit commutates through the diode bridge, which acts as a free-wheeling diode (similar in action to the protection/suppression diode typically placed across a DC relay coil).

Test Method

Use a true-rms meter to measure V_{sac} across sense resistor R_s (to derive $I_{ac} = V_{sac} / R_s$), and to measure V_c across the choke. Choke impedance Z is then $Z = V_c / I_{ac}$. For most types of choke, the choke inductance can be approximated by the impedance, such that choke inductance $L = Z / (2 \cdot \pi \cdot f)$, as $|Z| = \sqrt{((2 \cdot \pi \cdot f \cdot L)^2 + R_{dcr}^2)}$ and $(2 \cdot \pi \cdot f \cdot L)^2 \gg R_{dcr}^2$. A calculation spreadsheet is available [4], and accounts for the effect of R_{dcr} on the choke inductance calculation. Measure the DC Voltage V_{sdc} across sense resistor R_s . DC current through the choke is then $I_{dc} = V_{sdc} / R_s$.

Using a small value for R_s (ie. 10 Ω) will require a meter with at least 1-10mV resolution, such as a cheap Aneng AN8009. Some DVM's like a Fluke 115 handheld won't do (although it has a 600mV AC-DC range, this can over-range due to the DC level exceeding 600mV even though the AC level being measured is low, and so 6VAC range is only available). Raising R_s value to say 100 Ω will help with poorer resolution meters, and shouldn't really affect accuracy or be significant compared to R_{dcr} for many chokes. Check your meter performance specification as part of preparing to take measurements. Choke input filter parts are designed for higher applied AC voltage – this requires a larger R_s (eg. 470 Ω with higher power rating $>20\text{W}$) to apply say 50Vrms and pass over 100mA_{dc}, otherwise the measured inductance will be lower than rated.

A tapped transformer can be used to change the V_{ac} level, to apply different DC current levels, and allow inductance droop to be plotted. My first test setup used 12V, 20V, 32V and 52VAC secondaries, and two multi-tapped 0-24VAC transformers would be quite practical, but I now use the heater supply of a vintage valve tester with 0.6 to 117V in 19 steps. The supply needs sufficient current rating to suit the DC current being applied to the choke (eg. a 1A secondary rating would suit many chokes used in valve amps). Any diode bridge with 6A or more rating should be fine.

If needed, the value of the sense resistor R_s can be increased in order to lower the DC current level relative

to the applied inductor AC voltage level, as $I_{dc}/V_{ac} \sim 0.9 / (R_{dcr} + R_s)$, allowing inductance to be measured under power supply conditions applicable to a choke-input filter. If needed, the rectified waveform could be RC filtered before the choke is connected, so as to attenuate higher ripple frequencies.

Note that there is a lower limit to V_{ac} that is needed to generate a level of I_{dc} , due to inherent R_{dcr} .

An example choke measurement jig is presented in [7] and provides assessment of an example measurement.

Choke Performance

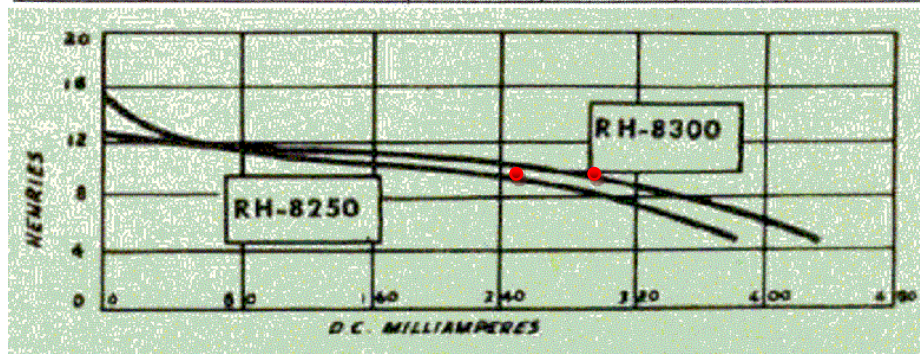
The example 14H Rola choke was measured using the described test method. The nominal transformer voltage V_{ac} used for four measurement points is given in the following table. R_{dcr} was measured at 535Ω , and SRF at 6kHz ($C \approx 50pF$).

V_{ac}	12 V	20 V	32 V	52 V
I_{dc}	17 mA	30 mA	50 mA	82 mA
I_{ac}	0.6 mA	0.9 mA	1.4 mA	2.7 mA
V_c	5.85 V	9.17 V	14.1 V	23.1 V
L	15.5 H	16.2 H	16.1 H	13.6 H

The test results agree well with the 14H at 60mA DC part rating, noting that V_c is greater than the spec level of 10Vrms for $I_{dc}=50mA$, and hence measured L would be a bit lower at the V_c spec level. As V_c increases when larger V_{ac} is applied, the measured inductance can increase even though I_{dc} has increased.

The measured drop in inductance with DC current, along with the DC resistance of the choke, can provide a good estimate of the manufacturer's DC current rating for the part. The following product curves of inductance are from Chicago Transformer chokes at 10V 60 Hz excitation [3]. The power loss at rated max DC current is about 5.5W for each choke (note that these are large chokes). The much smaller example Rola choke has a max power loss of only 2W at rated 60mA DC. Hubelhank presented a consistent test result using a similar measurement technique, circa 1956 [5].

Catalog No.	Inductance Henries	Max. D-C Current, Ma.	D-C Resistance in Ohms	Insulation Test Volts RMS	Case Size	Wt. Lbs.
RH-8250	8	250	90	2500	22	10½
RH-8300	8	300	60	3500	22	12½



Uncommon iron-cored chokes for valve amp power supplies

The typical fluoro ballast choke is compact, double insulated, uniformly gapped by two rows of C laminations butting to a square lamination central core, and appears fine to sit at 600VDC or more and be used for a choke-input filter. A 240VAC 18/20W choke is very common, measures about 1.5-2H, and would be suitable for up to 300mA DC (power dissipation up to 5W). A 240VAC 9/13W choke measures 3H at 100mAdc and 2.7H at 200mAdc, with $R_{dcr}=140\Omega$ and SRF=5kHz, and would be fine for up to about 200mAdc (power dissipation about 5W).

An ATCO EC18/20 240VAC 50Hz choke gave measurement levels of $R_{dcr}=54\Omega$, $SRF=10\text{kHz}$ (150pF shunt):

Vac	12 V	20 V	32 V	52 V
Idc	147 mA	260 mA	420 mA	517 mA
L	1.88 H	1.69 H	1.45 H	1.26 H



Some Wurlitzer organs included a large number of note inductors (iron-cored with variable gap setting), of which a few provide up to 4H inductance and are suitable for up to 30mA DC (eg. suitable for screen and preamp filtering).

A Wurlitzer 500407 inductor from a 4100B organ (set with minimum gap) gave measurement levels of $R_{dcr}=266\Omega$:

Vac	12 V	20 V	32 V
Idc	30 mA	50 mA	90 mA
L	4.1 H	2.3 H	0.9 H



Ripple trap assessment

The test circuit can be used to measure the changing AC current harmonics passing through a choke with a parallel capacitor (and series dampening resistance), sometimes referred to as a ripple trap (a technique used in power supplies to enhance the attenuation of the dominant $2f$ ripple component – see [6]). Displaying the ripple current (voltage across sense resistor) on a spectrum analyser shows the increasing attenuation of the $2f$ harmonic as the parallel capacitance value is increased towards LC resonance, but also shows a corresponding increase in the magnitude of higher ripple frequencies being passed through. The filter capacitor following the choke bypasses the ripple currents, with the net result of a lower rms ripple voltage across that capacitor. Given the likelihood of choke inductance being higher than its rated value when DC current is below the rated level, and given the increase in higher order harmonics with increasing capacitance, it is recommended that a lower capacitor value is used than what would be expected to tune the rated inductance at $2f$ – perhaps at least 20% lower. The dampening resistance R_c in series with the capacitor is typically twice the choke R_L , although the Q can be calculated as $\sqrt{LC} / (R_c + R_L)$.

Output Transformer Primary Inductance

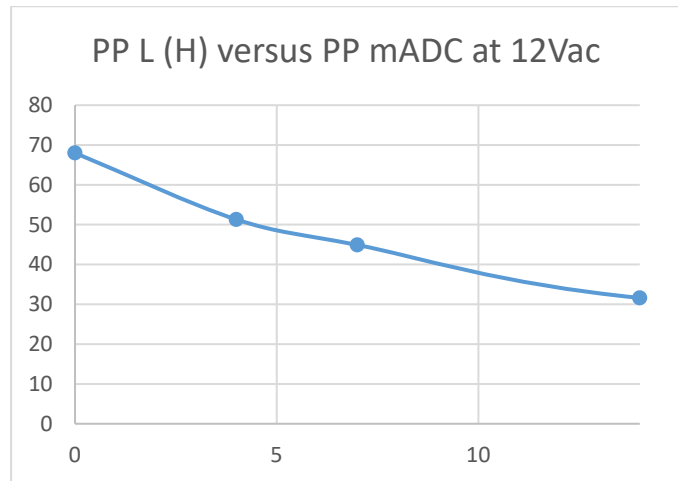
OT primary inductance influences the low frequency roll off of an amplifier, and forms an RL high pass filter with the output stage valve's internal resistance R_a . The choke test circuit can be used to measure primary winding inductance at a given DC current level for an SE output transformer, and to indicate the change in inductance at zero, idle and twice idle current. In a PP amp, apart from the OT design itself, a DC imbalance from valve mismatch and/or bias mismatch can significantly lower primary inductance L.

Plate-Plate winding inductance of a PP output transformer can be measured with an unbalanced DC current level. When testing the P-P inductance of an output transformer, the test circuit applies DC current in both half-primary windings, but as the DC current is not being cancelled by the CT feed location, then the DC current level equates to an imbalance level twice as large. It is likely that the test circuit R_s will need to be made fairly large in order to suppress I_{dc} down to a level typical of an unbalanced output stage.

The plot on the right includes a 68H P-P inductance value from a simple transformer fed test circuit (ie. no DC bias), as well as 3 test values taken in the choke test circuit when using high values of R_s (up to 6k8 Ω).

The transformer is a Red Line AF5/20 with 5k Ω PP, and 15W hi-fi ratings. If idle bias current was 50mA nominal, then the 4mA test value would be equivalent to an 8mA imbalance between valves (eg. 46mA + 54mA). In that situation, the primary inductance would be down about 25%, compared to a balanced output stage.

Similarly, a common-mode choke can be measured for differential inductance with an unbalanced DC current level.



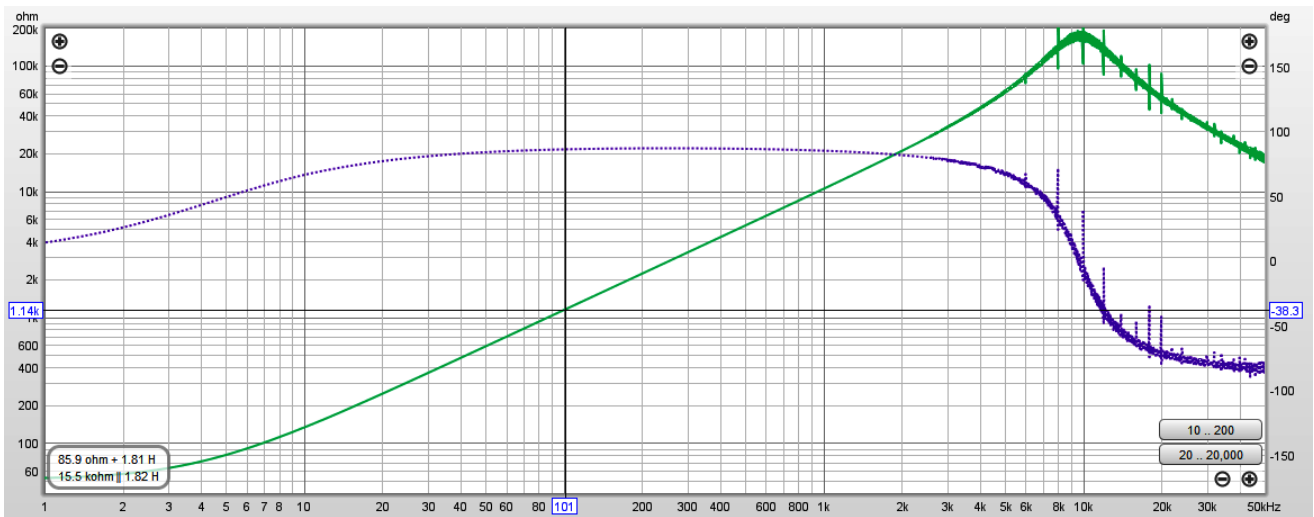
Impedance measurement

Modern soundcard interfaces and software like Room EQ Wizard ([REW](#)) allow passive parts like chokes to be measured for impedance across a wide frequency range (eg. 2Hz to 96kHz). The software allows an automated easy scan to be made to identify SRF and the AC signal inductance (with no DC current), which can be cross-checked against the measured inductance with DC current as described earlier in this article.

The excitation voltage applied to a choke depends on the soundcard output – for example the EMU 0404 USB interface I use has a headphone output with up to 2Vrms into low impedance parts when using a 100 Ω sense resistor. When the [interface test setup](#) is accurately calibrated using 1% tolerance resistors or better, the inductance results are similarly accurate.

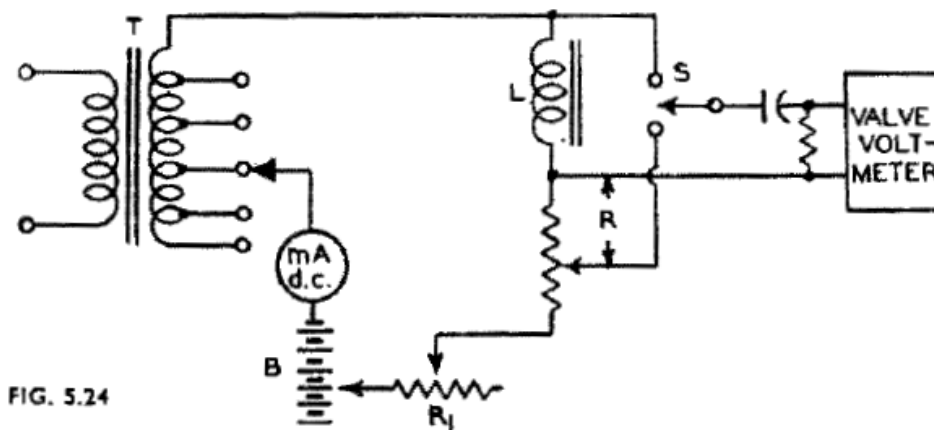
The impedance plot below is of the ATCO EC18/20 240VAC 50Hz choke identified in the earlier section on uncommon iron-cored chokes. The frequency span is from 1Hz to 50kHz and the green impedance magnitude (ohm) trace clearly shows the SRF at 10kHz, and the impedance reducing towards the DC resistance of 54 Ω as frequency falls through 1Hz. The purple impedance phase (deg) trace shows the expected nearly +90 deg phase shift in the frequency band from about 30Hz to 2kHz, with phase falling to a capacitive -90 deg on the higher side of the SRF. Below about 30Hz, the phase starts to fall towards 0 deg as the part acts more like a pure resistance and can't support being inductive. The inductance at 100Hz is shown as 1.81H, which is comparable to the 1.88H measurement result shown earlier for 12Vac excitation with 150mADC bias. Above 100Hz, the inductance slowly falls as core permeability falls with frequency, with inductance 1.67H at 1kHz.

Although REW can calculate an [equivalent lumped model of an inductor part](#), the model is too simple to represent typical laminated steel core chokes, and often the measurement frequency span has to be constrained otherwise the model defaults to a capacitor part. Hence it is better to record the choke inductance at a specific test frequency like 100Hz, and at the test excitation voltage level, to allow valid comparison with other measurement instruments and methods.



Classic measurement methods

Radiotron Designer's Handbook 4th Edition (p.250) describes one classic measurement method shown in the diagram below. Two separate supplies are connected in series, requiring the AC transformer secondary to carry the test DC current, and the battery and DC ammeter to carry the test AC current. Switch S is toggled and 'R' is adjusted to show the same AC voltage across the choke as across 'R', and then the value of 'R' is measured and equated to the choke impedance ($2\pi fL$). Note that the measurement is made at the mains frequency, rather than twice the mains frequency as applied to a power supply filter choke. This method is not easy to set up due to the requirement for a battery, and care is required to avoid any significant capacitive coupling paths.



Vintage laboratory style measurements were made with a bridge technique, with the Hay's bridge as shown below (from [Terman, 1935](#)) being the most appropriate (as a normal bridge using a reference inductance arm would be unwieldy with an air-cored reference of sufficient inductance). The DC path is only through the lower arms of the bridge (as capacitors block DC through the upper arms and through the oscillator). A filter reactor and headphones allow the bridge balance point to be identified. The method is not simple due to complexity of parts and a need to keep stray capacitance negligible to balance the bridge.

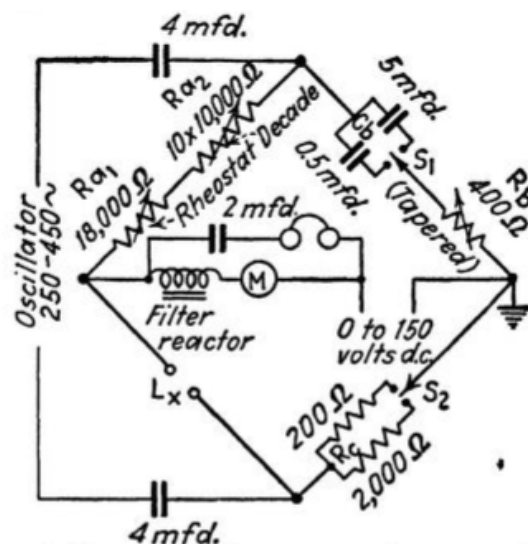


FIG. 39.—Hay bridge arranged to measure incremental inductance.

References

- [1] [‘The Measurement of Choke Coil Inductance’](#), C.A.Wright & F.T.Bowditch, 1927.
- [2] [Fourier Analysis](#), Lucas Illing, 2008.
- [3] Chicago, [Transformers and filter reactors, CTC-58](#).
- [4] <https://www.dalmura.com.au/projects/OT%20calcs.xls>
- [5] [‘Use those "junk-box" chokes’](#) by S.H. Hubelhank, 1956. Reprinted in [Sound Practices](#), Fall 1994.
- [6] ["Smoothing Circuits: \(2\) Inductance-capacitance"](#), ‘Cathode Ray’, WW Nov, 1949.
- [7] [Choke measurement jig](#)

Additional on-line test measurement resources that I have come across:

https://www.angelfire.com/electronic/funwithtubes/Filter_Choke_Analyzer.html

<https://www.qsl.net/i0jx/supply.html>