RF Plate Choke

By Charles T. Rauch, Jr. W8JI

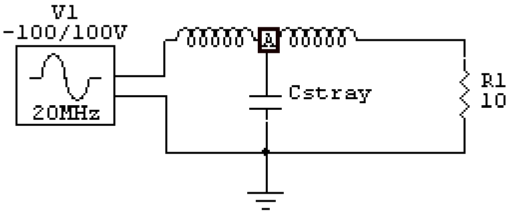
Let's go through the design and testing of a RF choke, and see why and how they work. This will probably be the first place you will find much of the information on how to design and test a choke.

While I own impedance test sets that can measure and plot choke characteristics, I want to show others how to get by with minimal test gear.

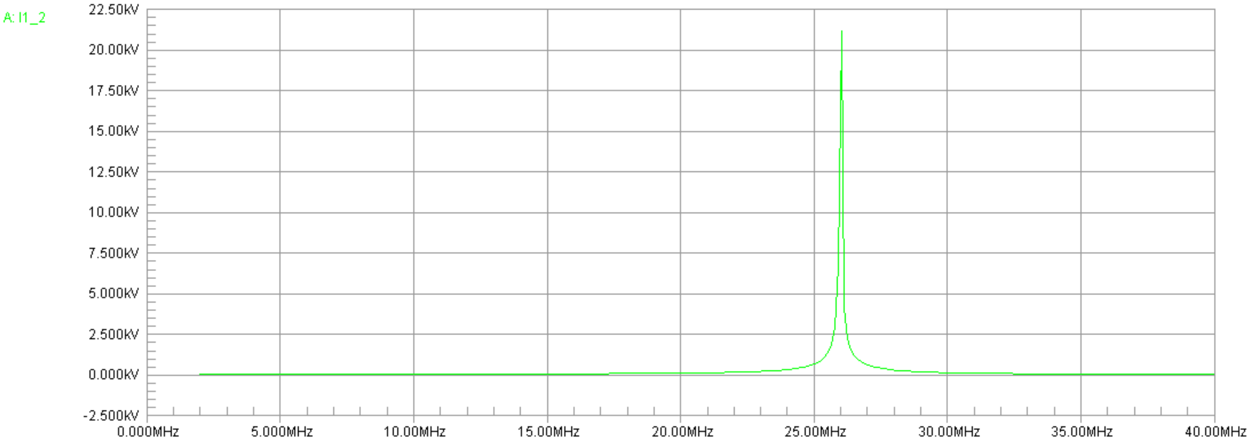
Impedance Limits

The plate choke needs a certain amount of impedance on the lowest operating frequency. The exactly amount of reactance varies with the operating impedance of the output device, the Q of the choke, and how much compensating capacitance is in the tank tuning capacitor (in a shunt-fed pi-network). By the time we cover 160 meters in a fairly high operating impedance tank, we will have unwanted ***series resonances*** up above 10 MHz.

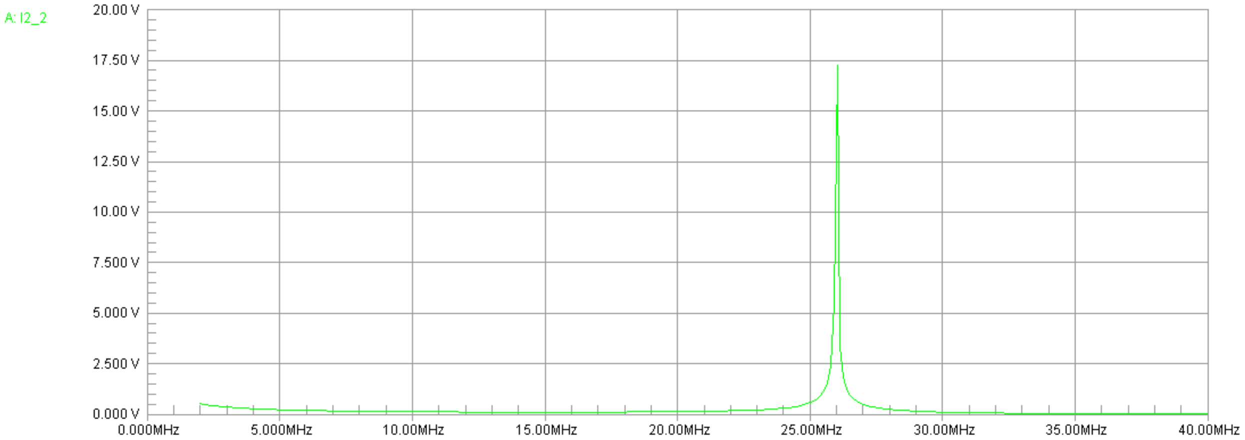
Series resonances are formed when the choke looks like back-to-back L networks. Electrically, at the lowest frequency series-resonant point, the choke looks like this:



The sweep waveform below shows the voltage at point A.



This is with 200 volts peak-to-peak excitation, NOT the full voltage of the amplifier. The waveform below shows RF current through the choke. DC current is not shown, and would be superimposed on the RF current. 10 volts=1 ampere:



Ever wonder why an amplifier can arc and bang when operated near self-resonance of the plate choke? The text above should explain it to you! Voltage at the center of the choke can be so high the choke arcs for several inches. The choke becomes a good Tesla coil, with peak RF voltage near the coil's middle for the first-order resonance.

Mounting the Choke

At upper frequency limits, a typical choke can have peak voltages several times the operating dc voltage at some points along the windings. Stray capacitances also tend to concentrate RF currents into small areas of the winding. Because stray capacitance aggravates voltage and current stresses, and because stray capacitance shifts series-resonances lower in frequency, a clear location for the choke is most desirable. If possible, a choke should be 1/2 its winding length, or four times the winding diameter, away from things that add capacitance. This includes large dielectrics, which increase stray capacitances from increased dielectric factor loading of electric fields.

How to Move the Series Resonance

Choke designs require a certain minimum inductance, to ensure reasonable impedance near lower frequency limits. If the choke is physically large, and if reactance is fairly large at the lowest frequency, and if a wide frequency range is covered, unwanted series-resonances can fall within desired upper operating ranges. This can result in very high currents and voltages from normal fundamental RF excitation, although it is sometimes blamed on a "parasitic" by less knowledgeable designers or technicians. The solution is to move undesired series-resonances outside desired frequency ranges.

Many publications, including the ARRL Handbook, and many personal opinions, claim choke winding gap designs are "magic". At one time, the ARRL Handbook reported there was no rational, logical, reasoning behind removing sections of solenoid choke windings. This is not true, and really only shows those who make such statements do not understand why a choke has series resonances, or how to move the resonances. If we understand why a choke misbehaves on some frequencies, we will easily understand how to "correct" problems in the RF choke by using gapped windings.

There actually is a method to designing choke winding gaps. Since the series-resonance problem is rooted in the choke behaving like two (or multiples of two) back-to-back L-networks, the solution is very obvious.

When moving unwanted series-resonances, the system's necessary minimum inductance often rules out significant inductance reductions. Turns must be added or removed where they have the largest effect on series resonances, with minimal reduction of lower frequency inductance. To do this, the designer must find the highest voltage area of the winding ***at the problematic frequency***, and reduce capacitance ***at that physical point in the winding***.

The capacitance involved in the series resonance is generally on the order of a few picofarads, or less. The designer generally does not want to locate the choke center near metal (or even dielectrics other than air) because metallic masses, or even dielectrics other than air, will move series resonances lower in frequency.

Generally, the designer wants to do everything possible to move series resonances upwards in frequency, keeping as many high-order resonances as possible above the highest operating frequency.

The most expedient way to move series resonances is to change the winding pitch at the very center of the choke for lowest resonance, or in the electric field's "hottest" winding areas, in the case of higher-order resonances. A typical solenoid choke of constant pitch has capacitance controlling the lowest resonance located in the very middle of the winding length. This is area where inductances, forming the two phantom back-to-back L-networks, are evenly distributed in both directions. At this inductive center-point, just one or two picofarads of capacitance can move the series resonance as much as 50% in frequency! The exact amount of movement depends on winding pitch, form diameter, and the overall inductance of the choke.

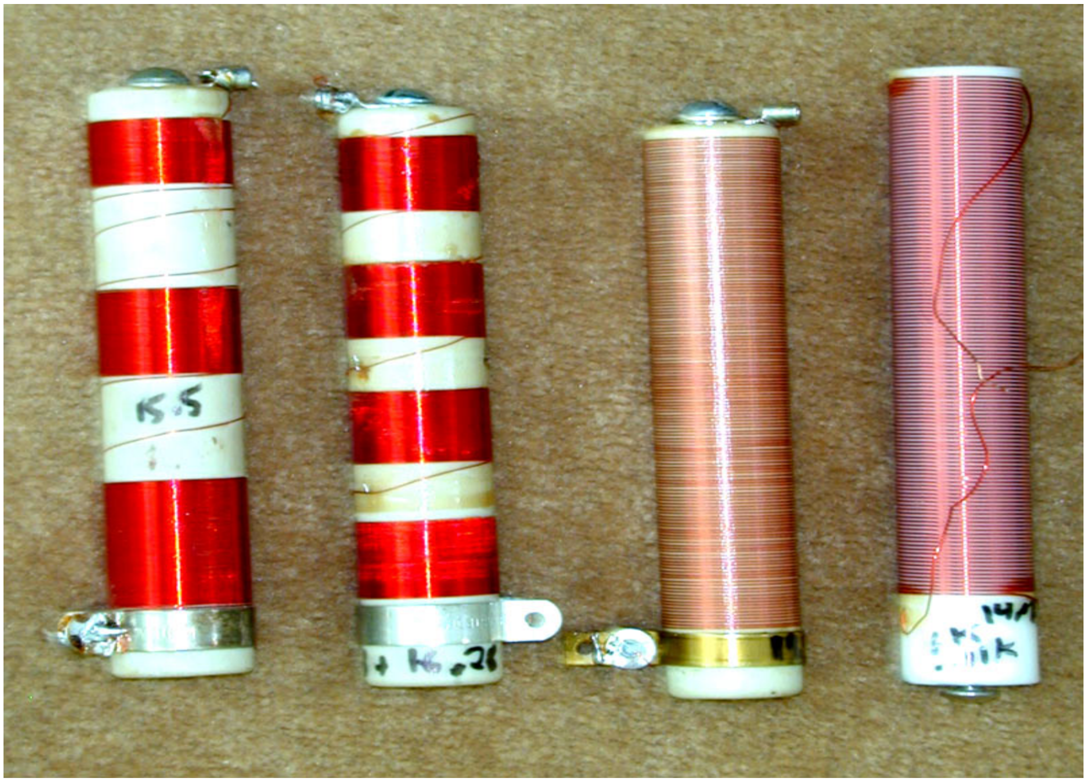
The gaps in the Ameritron chokes (or any gapped choke I design) are not placed by accident. The winding gaps are placed by design.

The most effective way to move a resonance is to remove wire from the area where voltage is at maximum.

1. A full winding choke is tested through all desired frequency ranges
2. If a series resonance appears inside a band, the highest voltage area is located
3. Wire is removed from the highest voltage area to shift unwanted resonance up
4. The choke is retested

The 1990's Ameritron choke design appears on the far left. Starting with a continuous winding core, the fully wound choke had resonances at 10 MHz and 20 MHz. Looking at voltage hot spots, sections of windings were removed. The lower gap near the choke middle moved the 10 MHz resonance up to 12.5 MHz or so. This shifted the upper resonance from 20 MHz to near the 24.8 MHz band. The upper gap moved the resulting second-order series-resonance from 25 MHz up to 27 MHz. Without the upper gap, the second overtone resonance is too close to 24.8 MHz. The gaps park unwanted series-resonances between 30 and 20 meters, and at the lower end of 11 meters. This results in the highest possible inductance for 160 meters, while keeping harmful resonances away from normal operating frequencies.

On early solenoid chokes, before we had WARC bands, resonances were more easily parked in clear spots. There was no need to move higher order resonances out of an "overtone" or harmonic relationship with the lowest frequency series resonance. The double gaps reflect a change in choke design from the Heathkit and Ameritron chokes I designed before WARC bands existed. Variety of winding styles from left to right:



3-unequal section tight wound. 245 µH nominal with resonances at 11.7 and 16.3 MHz.

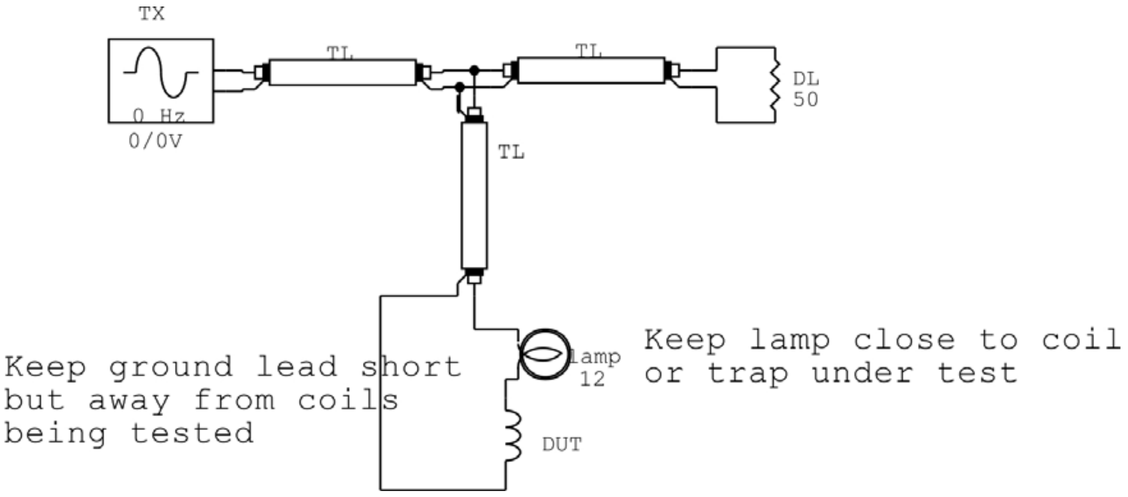
4-equal section tight wound. 229 µH nominal with resonances at 13 and 16.8 MHz.

Single section space-wound. 117 µH nominal with resonances at 19.5 and 27.3 MHz.

Single section space-wound iron core. 906 µH nominal with resonances at 13.5 and 24.1 MHz. The iron core choke has low Q, and runs much hotter for a given RF current. Series resonances are also very wide, the lower resonance rendering this choke unusable between 13 and 14.5 MHz.

From the above data, we can reasonably conclude an evenly-spaced winding produces the poorest multiple-band high-voltage choke. The choke can have a great deal more inductance by using a tight winding pitch, with harmful resonances moved by intentionally inserting large gaps at appropriate places.

Testing the Choke



Keep ground lead short
but away from coils
being tested

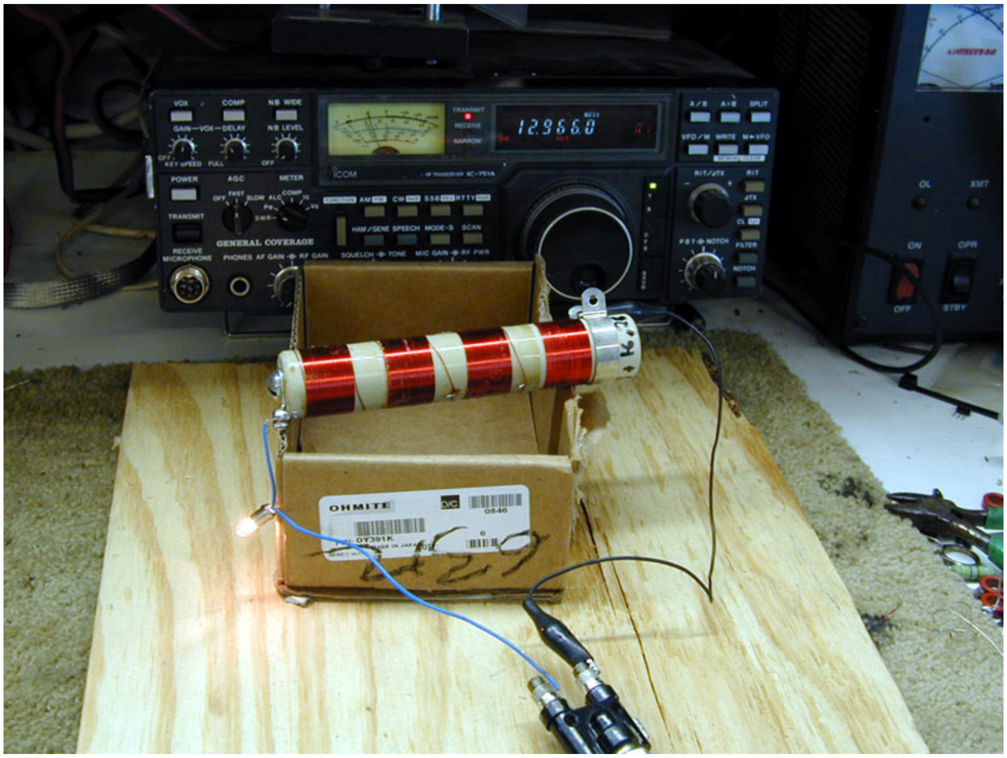
Keep lamp close to coil
or trap under test

A standard transmitter, dummy load, and 12 volt lamp can be used to effectively test an RF plate choke.

Electrically, keep the TL from the "T" point to the choke and lamp very short. Less than five electrical degrees (one-half foot at upper HF) is generally short enough.
The other two TL lengths are not critical.

The best place to test the choke is in the actual operating location, with the choke cold end bypassed to ground normally, but the top end disconnected from the tank system and tubes. The lamp would go between the disconnected top choke end, and the TL supplying RF. The lead above the lamp to the TL can be somewhat longer, even 5 inches is unlikely to have a large effect. The lead from the lamp to the choke must be short.

TL from the tap point on the transmission line must be short, as in the bench setup below!



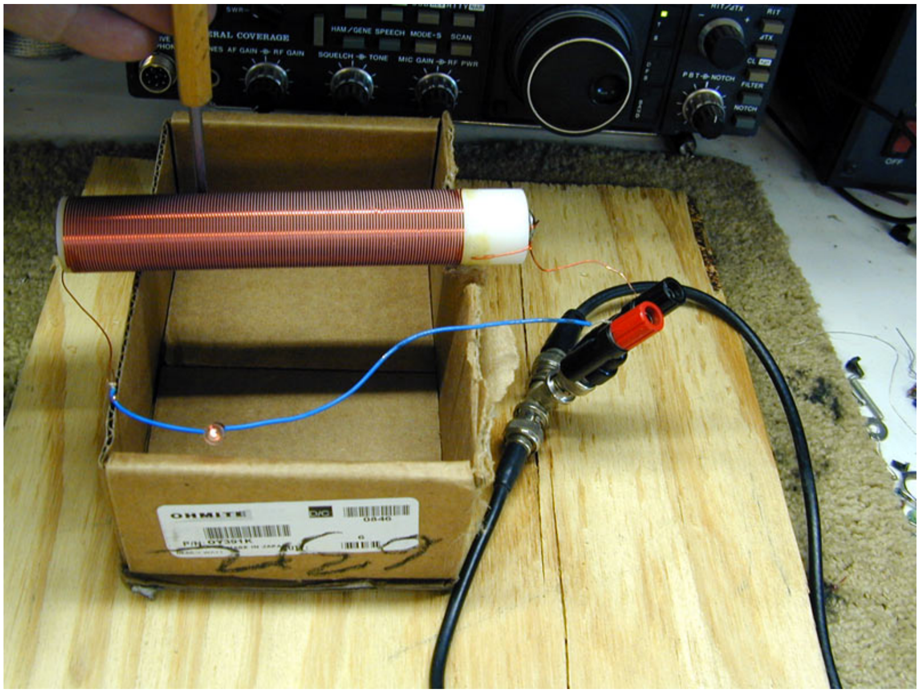
4-section choke under test for series resonance. The transmitter is set at 25 watts and the VFO swept up through the frequency range until the lamp glows. Adjust power so the lamp lights, but does not burn out. In this case series lower resonance was at 12.985 MHz.

The width of frequency range for the glow roughly indicates Q based on selectivity, while brightness at a given power also indicates Q based on Rp. A brighter glow generally means higher Q, and that's a very good thing.

Spinning the VFO up, we find the upper resonance around 16.8 MHz.

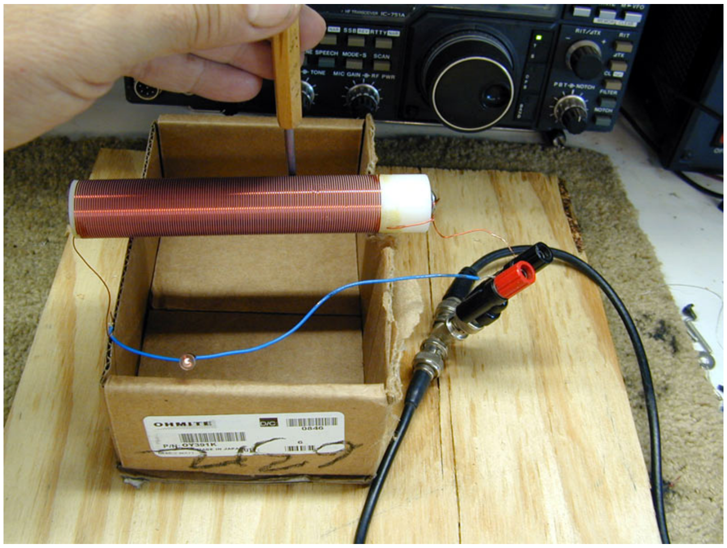
Finding the problem area:

By sliding a well-insulated metal tipped tool along the choke, the "hot spot" or "hot spots" can be located.



Adjust the radio's frequency to find maximum lamp brightness. Without adjusting the radio, move the insulated tool's metal tip along the choke and watch for the spot where the bulb dims the most. This is the "hot spot" where voltage peaks.

If you remove wire in this hot area, the series resonance will shift upward the maximum possible amount for a minimal effect on overall inductance. To lower self resonant frequency, either add dielectric (a thick coating of insulating varnish) or rewind with closer turns spacing.



The higher frequency resonances will be in two or more places, and are out near the ends of the choke. The lowest frequency resonance is near the choke center.

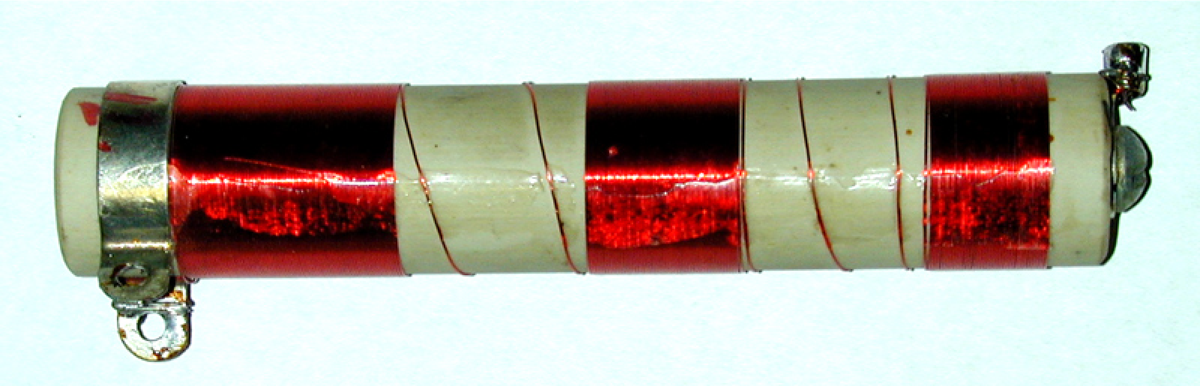
When you find a frequency with the largest hand effect near the center of the choke, you can be pretty sure you have the lowest self-resonant frequency.

Minimum required Inductance and Choke Current

The minimum necessary choke inductance in an amplifier or other RF system is dependent on five things:

- RF voltage across the choke's impedance
- Choke Q and ability to dissipate heat
- Bypass capacitor's ability to handle current
- Q increase that can be tolerated in the PA anode system
- The extra plate tuning capacitance available

RF choke impedance varies widely with frequency. At low frequencies the choke looks like an inductor either shunting (parallel equivalent) or in series (series equivalent) with a resistance. Let's look at a Heathkit and Ameritron choke I designed in the late 1980's.



This choke has the following characteristics (from an Excel spreadsheet I used in AL80B design work):

F MHz	L or C	Xs	Rs	Xp	Rp	Q
1.8	255 μH	2550	22	2550	295590	116
3.5	275 μH	6060	85	6061	432127	71
7	.36 pF	-315000	3851	-327203	26764200	82
10.15	2.3 pf	-6900	79	-6901	602737	87
12.1	0	0	504	0	504	0
14	.6 pF	-19200	380	-19952	1008110	51
15.7	0	0	550	0	550	0
18.2	.6 pF	-14300	220	-14357	933205	65
21	1 pF	-7800	126	-7846	486452	62
24.8	1.25 pF	-5240	87	-5368	467250	60
28	1.37 pF	-4130	69	-4229	291096	60
			$R_p = R_s + X_s^2 / R_s$			
			$X_p = X_s + R_p^2 / X_s$			

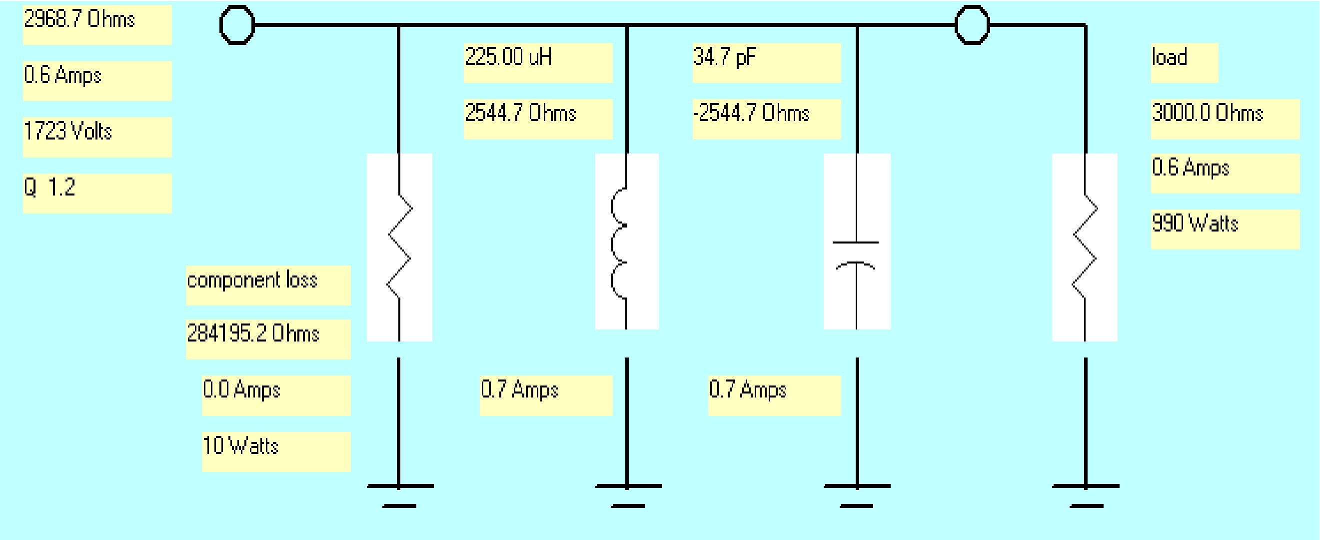
Note: L, C, and some other values will not be textbook perfect because they are subject to measurement tolerance and rounding errors. Values at or near parallel resonance (40 and 30 meters) may be subject to impedance measurement errors because measurements of extreme impedances is difficult.

Choke Heating and RF Current

Choke RF dissipation can be determined by voltage across the choke and Rp of the choke. The standard formula E^2/R applies. The above choke on 160 meter looks like:

From the above table let's use Rp (parallel equivalent choke resistance).

Using E^2/Rp and assuming an RMS tank voltage of .6 times dc voltage, at 2800 volts dc supply we would have a maximum choke RF power dissipation of (2800*.6)^2 / 295590 = 9.55 watts



The model to the above ***approximates*** these values, and is what we would expect for a 1000 watt output class AB power amplifier with 2800 volts dc on the anode.

We can see how critical choke Q becomes. We can reduce choke impedance if choke Q is high, but we have to be mindful of low choke impedances with low Q. In other words, choke Q becomes increasingly critical as choke impedance is reduced. This, and saturation problems, are why magnetically-soft iron-core chokes are generally a bad idea in high-impedance circuits of high-power multiple band amplifiers.

Below are typical choke dissipations based on an amplifier plate voltage of 3000 volts for 160-10 meters. Spreadsheet like this show why operation on or near series-resonant points is catastrophic! Also, heat dissipation is not spread over the entire length of the choke. On higher frequencies, and especially near series-resonance, heat (or loss) is concentrated in certain areas of the winding. This is why calculations or series-resonance measurements alone will not prove safe operation, although they clearly will indicate unsafe operation.

Below is a copy of an excel spreadsheet showing worse case dissipation (Pd) calculations used in my AL80B amplifier design:

Freq	Rp	Q	Ep	Pd
1.8	295590	116	3000	11.0
3.5	432127	71	3000	7.5
7.0	26764200	82	3000	0.1
10.15	602737	87	3000	5.4
12.1	**504**	**0**	**3000**	**856**
14	1008110	51	3000	3.2
15.7	**550**	**0**	**3000**	**844**
18.2	933205	65	3000	3.5
21	486452	62	3000	6.7
24.8	467250	87	3000	6.9
28	291096	69	3000	11.1

Note:

Higher frequency heating, especially above 21 MHz, can be predominately in dielectrics and not copper.

Series resonant frequencies (in red) assume tube can deliver full power to 800 ohm loads. Power won't reach that level before the choke catastrophically fails.