High Frequency RF Power Amplifier Stability at VHF

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HF Amplifier Stability at VHF

While most areas of Troubleshooting and Engineering follow logical steps, a great deal of Empirical or Voodoo Engineering surrounds amplifier instability. Few builders follow logical planned steps to understand, test for, and correct instability problems. Much of the problem surrounds the abstract nature of flaws causing instability, lack of visualization of component and layout VHF behavior, and the lack of good articles about causes of instability. The absence of readily available information creates a vacuum, and that vacuum causes builders to rely on some well-written but, regretfully, Pathological Science. When we couple the natural human desire to have a fast, simple, universal answer or simple instruction to solve every complex problem, we become targets for some very bad science.

VHF Impedances

The intelligent discussion of VHF systems requires a feel for VHF systems, and how VHF energy moves through a system. At VHF, wavelength is very short. Wavelength in feet is found by the formula (Wavelength = Frequency divided by 983.6 divided by 4). A typical 150 MHz system would have a quarter wavelength of 19.67 inches. This wavelength formula does not include velocity factor of dielectric, or unevenly distributed series inductances or shunt capacitances, which can make electrical distance along a conductor appear much longer than it is.

The general rule of thumb is two electrical degree length paths will have a negligible effect on system impedances. While that is 3 feet on 160 meters, two electrical degrees is roughly 1/2 inch on 150 MHz.

A 10-inch long conductor, in particular a thin conductor with a dielectric, is just like having no path at all for VHF, yet we see Internet suggestions of adding thin wires from Control Grid pins up to tuning capacitors to beneficially alter the path from tuning capacitor to Control Grid in some amplifier layouts!

VHF paths must be short and very wide, and ideally would be smooth surfaces. A wide path acts more like a ground plane, instead of a transmission line. For example, a 20-inch metal radius makes a very low impedance ground path at VHF, yet a 20-inch thin wire can look like no ground connection at all between two points! If we want reasonable results, we have to stop following unreasonable logic or junk science when making changes. If a tuning capacitor is poorly connected back to the Control Grid at VHF, because the path through 10-inch wide sheet is too long, we are NOT going to improve it with an additional several inches length of .060 inch wide conductor in parallel. The notion something so thin in parallel with a wide ground plane helps reduce path impedance is silly.

To actually improve things, we must stop treating VHF systems like they were DC systems, or HF systems.

A similar error occurs in a west coast amateur's discussions of VHF suppressors. He treats the VHF suppressor as an isolated component that solely determines Anode system "Q". The Anode suppressor is actually one small section of a much longer path that behaves like a transmission line. The suppressor "Q", in isolation, means very little to overall system behavior. We have to look at the suppressor in full context of how it modifies a much more complex system's overall impedance. This is why every suppressor, when optimized, must be optimized for a particular system. As we see when we look at commercial designs, one size does not fit all. In many cases no suppressor at all is required, and when required, depending on application and layout, a variety of styles are used. There is no single right way and wrong way.

Circuit Configuration

We might assume, because of a certain circuit configuration or descriptive system name, the system behaves like that configuration on all frequencies. More often than not, there are exceptions to that assumption. Within a certain frequency range, things do behave as schematics and descriptions might indicate. Beyond those frequency limits things change. Let's consider the case of a grounded grid amplifier.

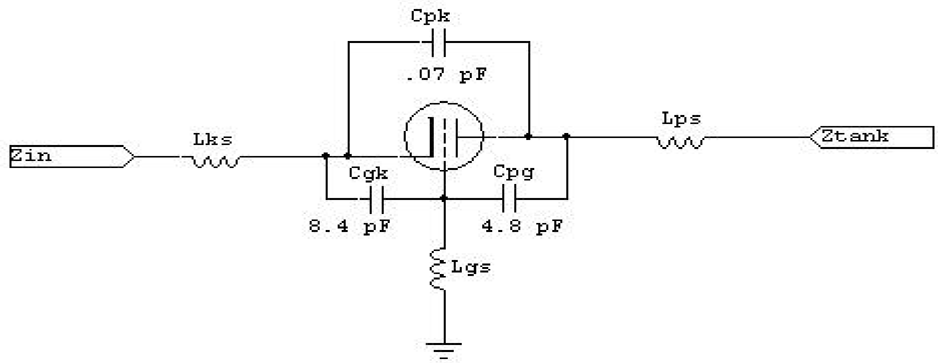
A grounded grid amplifier only acts as if the Control Grid were grounded over a certain range. The range where the system behaves as expected is determined by how the Control Grid is grounded, both with components and wiring the builder or designer can control, and by things inside the tube that only the tube manufacturer can control. Grounded grid amplifiers are theoretically unconditionally stable, because they have extremely high negative feedback from output-to-input. This negative feedback, determined by the ratio of output load impedance to input impedance, normally swaps out any regeneration. The Control Grid or Control Grids, in theory anyway, also shield the input from the output.

Unexpected problems occur when the system does not behave as the schematic implies. This is because the schematic does not show stray impedances. These stray impedances can reconfigure the amplifier stage on various frequencies, making it change modes anywhere from stable grounded-Control Grid operation, to a mode where the Control Grid floats. 3-500Z Tube Dominant capacitance is Control Grid-Anode and Control Grid-Cathode.

These capacitance ratios are loosely typical for most transmitting tubes. The Control Grid-to-chassis impedance is why the Anode-control Control Grid path, not the plate-Cathode path, dominates VHF stability.

At HF and lower, a different effect can occur. The plate-Cathode feed through can allow regeneration from Anode to Cathode. At high frequencies with long thin Control Grid leads, they might not appear grounded at all.

This mixture of effects varies with input and output networks, layout, tube, socket, and wiring.



When the impedance of Lgs becomes large enough, either resistive, inductive, or capacitive, the tube is effectively no longer in grounded grid operation. We now have the makings of a Tuned Plate Tuned Control Grid (TPTG) oscillator, with feedback through Cpg. This is why it is important to ground the Control Grid as well as possible.

Cause of Unwanted VHF parasitic Oscillations

The most sensitive control element in the tube is the Control Grid and generally has the largest influence in determining oscillation frequency. The Control Grid often controls if, when, and where the system oscillates. Small changes in Control Grid and screen grid voltages, with respect to Cathode, dominant tube operation. This is why primary frequency control elements of VFO's or crystal oscillators are normally placed in the Control Grid's circuitry.

The Anode system normally has the highest RF voltage swing in the system. The Anode-Cathode path through the tube has the largest time-varying current, the current being primarily regulated by the Control Grid. If the Anode system presents a high impedance at radio frequencies, small changes in Anode current will cause significant RF voltages to appear. With large Anode voltage changes for relatively small Anode current changes, a very small amount of Anode-to-Control Grid capacitance can be enough to form an oscillator. Logically, the

Control Grid-Anode path and circuitry at the Control Grid and Anode by far are most likely to dominate an unwanted oscillator system.

An oscillator also must have enough gain to overcome feedback loss, and feedback has to be the correct additive phase. If positive or regenerative feedback does not exceed system losses, the system cannot oscillate. The Control Grid-to-Anode path generally has the highest possible unwanted gain in the amplifier system, and that is why this part of the system is by far the most problematic area for unwanted VHF stability problems in lower frequency amplifiers. The normal mode of VHF oscillation in HF Power Amplifier's is where the tube becomes a Tuned-Plate Tuned-Control Grid Oscillator. The frequency of this oscillator is mostly determined by the Control Grid system, from the Control Grid inside the tube, out through the Control Grid terminal, to whatever is outside the tube.

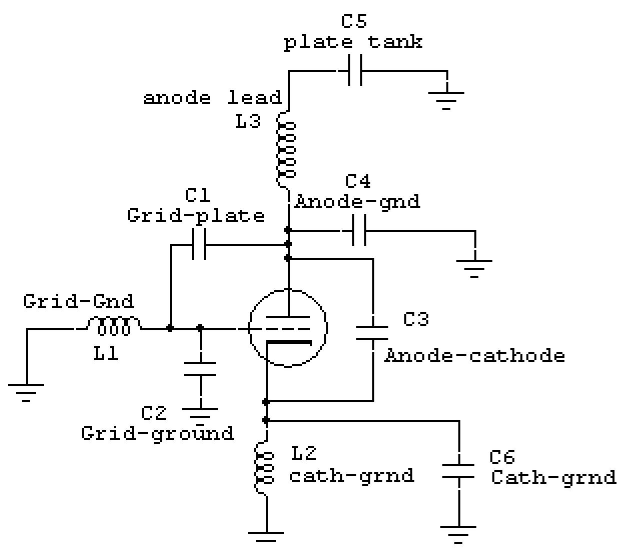
Inside the Tube

The Control Grid system has considerable stray capacitance to the Cathode and other low VHF-impedance elements. The Control Grid also has a conductive path connecting the Control Grid to the socket Control Grid pin. The combination of Control Grid-to-Ground Shunt Capacitance and Control Grid-to-Ground Series Inductance through the Control Grid Lead-to-Chassis path forms a parallel resonant circuit with fairly high "Q". Since this circuit mostly exists inside the tube, there is very little we can do externally to reduce Control Grid Impedance at Very High Frequencies (VHF). Most of that impedance is inherent in tube construction. Every Control Grid, deep inside the tube, behaves like it is connected to the Control Grid Pin or Control Grid Ring through a parallel-tuned circuit. At some frequency, internal Control Grid stray-capacitance parallel-tunes the total inductance of the Control Grid-to-Ground conductor path.

L1 and C2 primarily determine optimum frequency for unwanted oscillations. The parallel resonant combination of L1 and C2 "float" the Control Grid off the chassis. Unfortunately we cannot greatly affect L1-C2, they are mostly inside the tube. Optimally, L1/C2 should be resonant as far above the highest desired working frequency as possible. L1 should have the lowest possible impedance below the operating frequency.

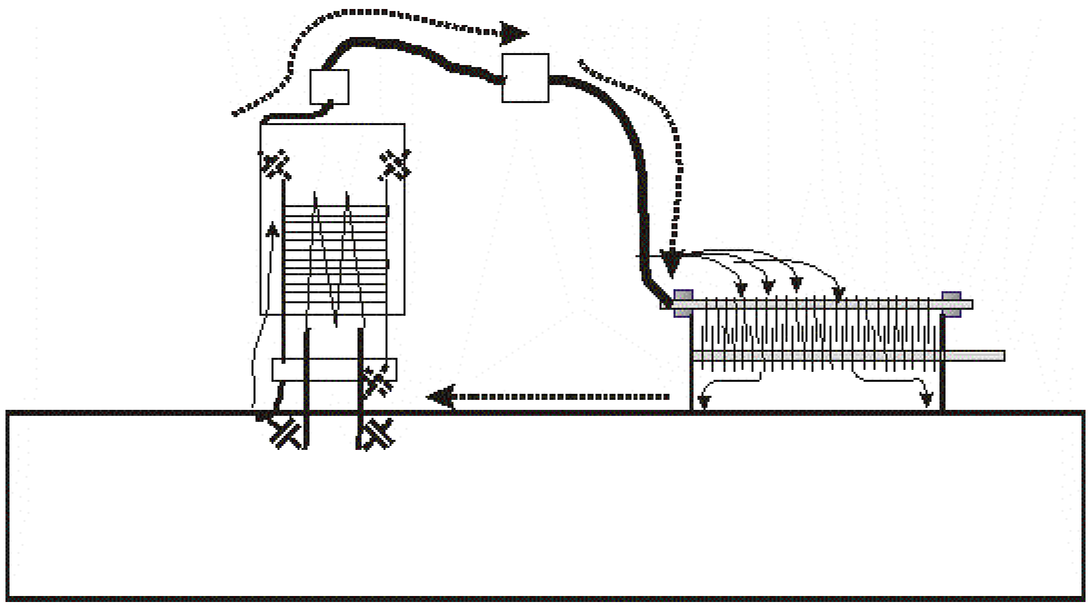
L3/C4 (including the C3+C6 path and C5 path) allows the Anode to easily change Anode voltage at VHF with small current changes inside the tube. We want L3/C4 to be resonant *below* the Control Grid resonant frequency, with the lowest possible reactance. Ideally we would want the Anode to see zero impedance at the frequency where the Control Grid is resonant, but that is impossible. The next best choice is to load the Anode with a perfect termination, like a dummy load, that has low-to-modest resistance to ground. For maximum operating efficiency we want L3 to have minimum series resistance at the desired operating frequency.

The unwanted VHF feedback path, creating an undesired oscillator is through C1.



Anode system path

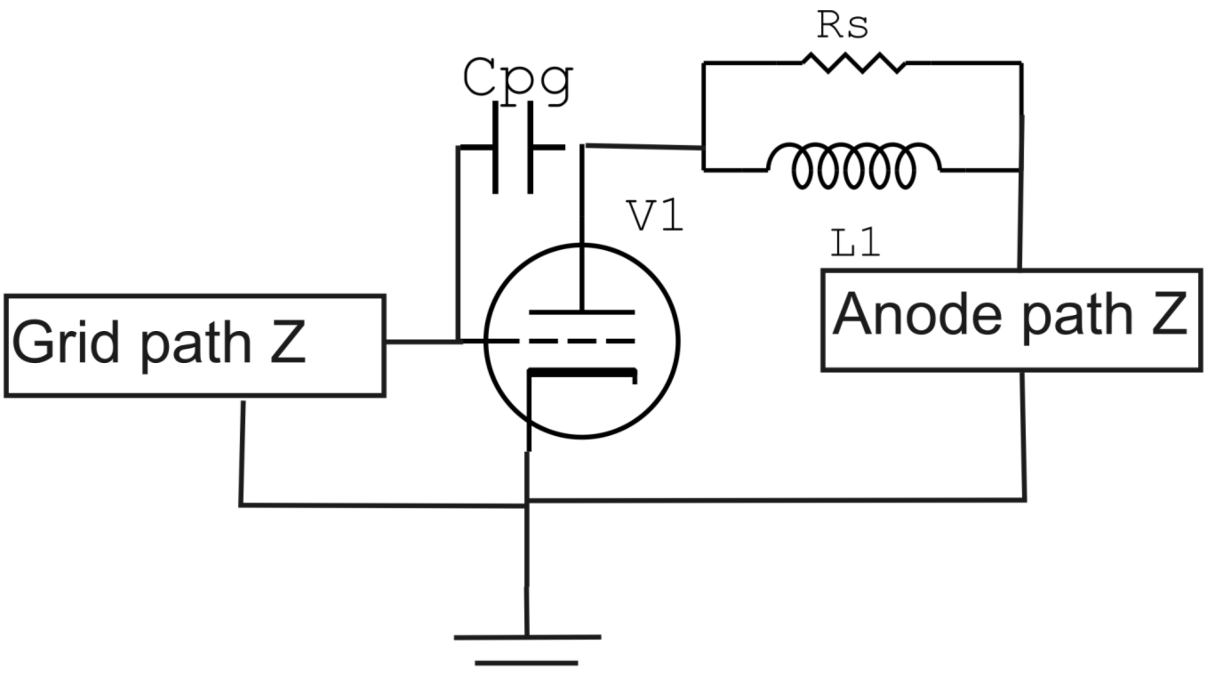
The Anode has stray capacitance to chassis and to Control Grid. The long RF connection from Anode-to-Chassis has Series Inductance. This is the Anode's "VHF Tank Coil". Stray capacitance from Anode-to-Ground parallel-tunes the Anode wiring's Inductance. This forms a complex resonant circuit with the Anode components and Anode Capacitance.



Control Grid system path

The Control Grid has inductance in the connection path from Control Grid-to-Chassis. This is the Control Grid circuit's "VHF Tank Coil". The Control Grid has stray capacitance to chassis and filament. This parallel tunes the Control Grid's Inductance. The Control Grid also has significant internal capacitance to the Anode which forms the unwanted oscillator's primary feedback path. With all of this, the circuit has everything needed to become a Tuned-Plate Tuned-Grid Oscillator if tuning and feedback conditions are right. If feedback loss (attenuation) from Anode-to-Control Grid capacitance is less than tube gain at some frequency, the tube *may* oscillate. The final requirement is the phase of unwanted feedback must be an angle value that produces regenerative or positive feedback. These requirements are the same in any oscillator.

The Cathode drive system is normally not part of VHF instability. With a proper input system, the Cathode system has low enough impedance to be considered "grounded".



The suppressor, Rs and L1, in combination with the existing Anode path Z, becomes the Anode-to-Chassis path impedance. This forms the plate load resistance at every frequency. The impedance must be analyzed at every frequency.

The Control Grid path impedance can also be varied, and again must be analyzed at every frequency of concern.

In a Grounded-Grid amplifier, Control Grid Z should be as low as possible at every frequency.

For maximum stability we want the resonant frequency of the Anode, at every frequency where there is significant internal tube gain, to be lower than the resonant frequency of the Control Grid.

Conditions for Instability

Once again, the conditions required for instability are:

- Gain from Control Grid to plate must exceed attenuation or loss in the feedback capacitance path from plate-to-Control Grid
- The Control Grid must have a sufficiently high impedance for the amount of available feedback to cause a stability problem
- The Anode must have a sufficiently high impedance near the same frequency as Control Grid resonance to cause instability
- Feedback phase must be correct to provide *positive* or additive voltage feedback. This best occurs when the plate is resonant near or above the Control Grid's parallel resonant frequency

If any one of the above four requirements are not met, the tube will not oscillate! This is true no matter how high "Q" is in any individual path, or if the tube has suppressors or not. What this means is, we cannot just look at "Q". The problem, while we would like it to be simple with only one possible cause and one universal solution, really involves four distinct but easily understood areas. This is the same with any oscillator, whether the oscillator is desired or unintentional!

The Myth of Parasitics Causing Bandswitch and Tube Failures

Claims have been made that tubes will remain stable for years, and a "sudden event" (like a photon striking a tube) will make the tube break into an uncontrolled oscillation. Oddly, these claims all come from one source with nothing but the fact "something bad happened" as evidence of parasitics. His evidence of a cure is someone installed his kit and was happy.

We all know, or hopefully we understand, that Oscillators are Oscillators. Oscillations that start cannot stop unless one or more of the four important system parameters above significantly change. Also, an uncontrolled oscillation cannot suddenly start, especially one that has so much feedback it reaches catastrophic levels, unless all of the above conditions are met. These conditions are either met, or they are not met, unless we change something. The notion a healthy system can go along for hours, weeks, or years and suddenly break into an uncontrolled oscillation that damages components is highly unlikely unless a major component significantly changes characteristics.

Conversely, if the system is stable, one or more of the above parameters must change in a way that allows oscillation. If that happens the tube will oscillate continuously until operating voltages are removed. We can actually intentionally try to create optimum oscillation conditions. I do that to test for stability. Even creating intentional oscillations, nearly all of the time, oscillations are not damaging.

Exploding VFO's Anyone?

Consider the oscillator in a transmitter. The oscillator rapidly comes up to a state of equilibrium and stops increasing in amplitude. We never find an oscillator that can output more power than the same tube can provide operated as an amplifier, as a matter of fact power is always less!

Any claim an amplifier tube that saturates at a few amperes Cathode current can provide 50 or more amperes of "big-bang" current from accidental oscillation is profoundly ridiculous. The Cathode can't magically produce more current as an oscillator than the saturated emission would permit in any other service. Such big-bang claims might make good fictional theater, but they aren't factual.

The most common effect of unwanted VHF oscillations are creation of spurious signals and odd meter readings; *not* bangs, pops, or arced band switches. Bangs and pops are caused by gassy tubes or other problems, while arced band switches (if caused by an oscillation) are generally caused by oscillations at or near the desired operating frequency!

Location of VHF Suppressor

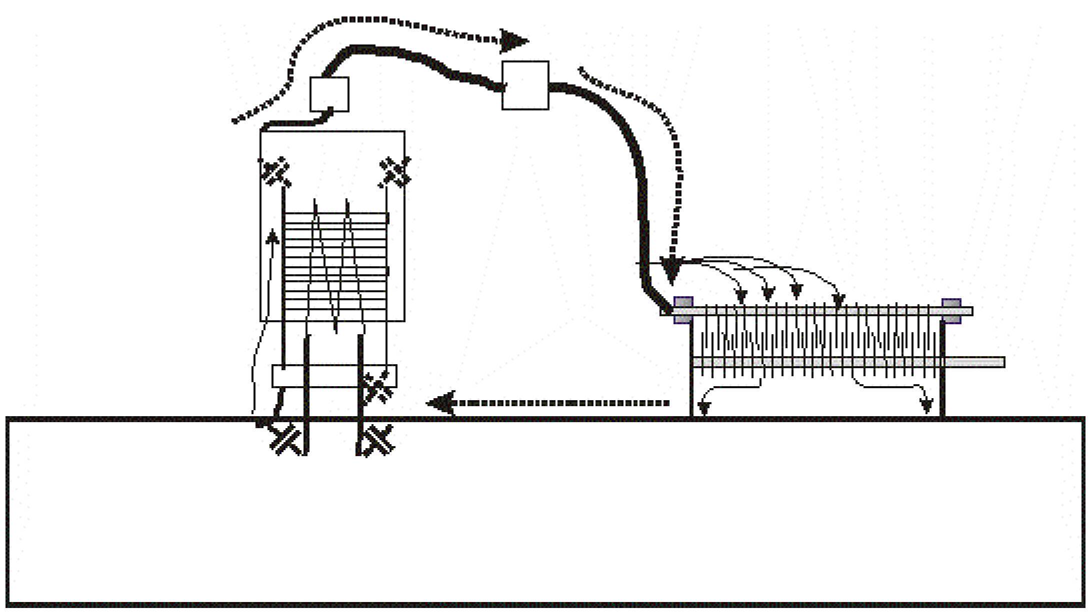
Most of our modern Power Amplifiers are Grounded Grid (GG) Cathode Driven (CD). Cathode Driven operation requires that one or more Control Grids be directly grounded to the chassis (at least for RF) with the lowest impedance possible.This is necessary to shield the output from the input, and assure operating frequency stability and purity of emissions.

A VHF oscillation, if it happens to occur in an HF Power Amplifier, is almost always rooted in the system behaving like a "Tuned-Plate Tuned-Grid" oscillator. To be most effective, a VHF suppressor must be located between the tube element and a low-impedance path to ground at

VHF. This allows the best loss-loading of the unwanted internal oscillator circuits. The actual working circuit causing a VHF oscillation is almost always entirely different than what appears on the actual component-based schematic. The Cathode, an element commonly involved in low-frequency instability is rarely involved in VHF oscillations, other than supplying electrons and stray capacitance to ground.

Even though the Anode is the second most problematic area, it is an area most easily altered and modified. This is because virtually every Anode has much shorter and wider connection paths to outside tube terminals. Suppressors are normally found in Anode systems, even though other locations can work to suppress oscillations. Locating the suppression in the Anode path generally works best because the Control Grid or Control Grids can remain well-grounded for RF, provided the best operating frequency performance, and because the Anode connector is often the shortest access point to tube internals.

To be most effective, the suppressor has to dominate the Anode path impedance to chassis. This means the suppressor inductance must be large compared to Anode-chassis path impedance. Short and wide Anode leads, a low VHF impedance plate tuning capacitor that is well-grounded to the main chassis, and compact layout, work in concert to minimize required suppressor inductance.



The Most Unstable Troublesome Tubes

The most problematic tubes for VHF oscillation have relatively large elements and long thin leads. Tubes of this type have low gain or are unusable at VHF. This is because elements in the tube (shunt internal capacitance combined with series lead inductances) are actually resonant or connected to outside pins through high VHF impedances.

Internal connecting leads diameter and length are almost always the major concern for parasitic instability. Longer and thinner internal (and external) leads produce less stable and more difficult to use tubes. Long and thin leads move a tube element's natural self-resonance lower in frequency and increase element impedances. This causes unwanted self-oscillation even with tiny amounts of Anode-Control Grid feedback capacitance.

A few examples of troublesome tubes with common instability are the 811A, 572B, 833, 4-1000A, 3CX1200A7, and 3CX1200D7.

A few examples of troublesome tubes with moderate instability are 3-500Z, 3-1000Z, and 4-400A.

Examples of tubes having virtually unconditional VHF stability are the 3CX800A7, 3CX1200Z7, 3CX1500A7/8877, 3CX3000F7, 3CX5000, 3CPX5000, YU-156 series.

Looking at the above, tubes with thinnest and longest leads are most troublesome. These tubes also provide poorest intentional VHF performance.

The most troublesome tubes listed above tend to oscillate in the lower-VHF range, between 40 and 120 MHz. The typical instability frequency of an 811A or 572B is around 80-100 MHz, assuming Control Grid leads are short and direct to the chassis.

A very important thing to remember! The closer a tube's instability frequency is to the operating frequency, the more likely it is to have tank-damaging oscillations. This is because the tube might actually oscillate on or very near the tank circuit's resonant frequency. It also is much more difficult to stabilize a tube with a low Control Grid-frequency resonance without severely impacting desired operating frequency efficiency and gain.

Anode Circuit Layout

Anode circuit layout can contribute to VHF instability. Long thin leads from the tube Anode connector to the chassis at VHF are a problem. Problems can occur when thin and long plate blocking capacitor leads, thin and/or long wiring, and poor mounting of the plate tuning capacitor are used. The Anode path, from tube through blocking capacitor and through the plate tuning capacitor to the chassis, is also an important VHF path. This is true even if the amplifier only *intentionally* operates on HF.

To maximize stability:

- Use wide Anode circuit leads from the tube to the tuning capacitor.
- Mount the tuning capacitor directly on the chassis, or on a large metallic ground plane area that is thoroughly bonded to the chassis at many points.
- Use a low-inductance plate blocking capacitor.
- Keep all leads as short as possible, even if it is at the expense of "looking pretty" with perfectly aligned 90-degree wiring angles.
- Use the chassis as a ground plane and as an input-to-output shield. Keep the tank circuit's ground connection point common to the Control Grid ground point in a grounded grid amplifier, but NEVER by using long leads. Use the chassis, or any large wide ground plane, for this path. Not wires!
- Don't ground tank capacitors exclusively or primarily to a front panel. Ground them to the same metal as the Control Grid, if possible.

Control Grid Circuit Layout

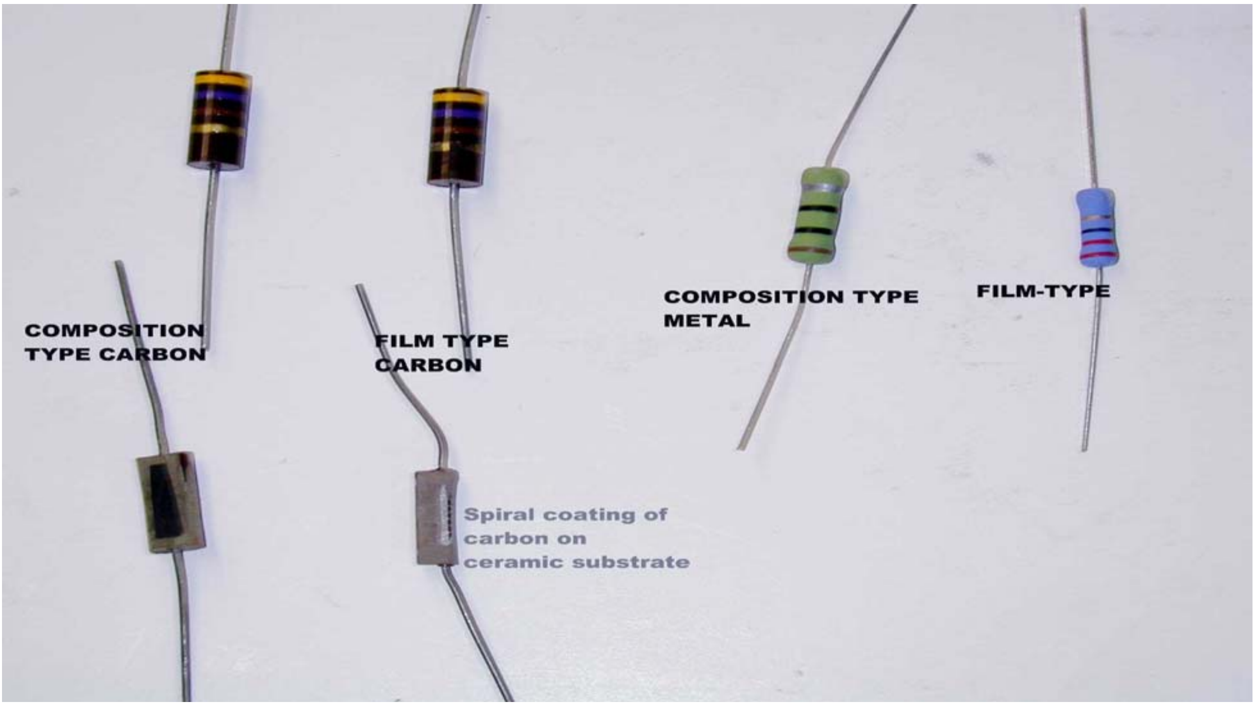
The Control Grid circuit layout is probably the single most important area for insuring a stable design. Long thin leads from the tube Control Grid connector to chassis are a problem at VHF. Problems often occur from physically thin and long bodied Control Grid capacitors or thin and/or needlessly long Control Grid wires or wiring. The best idea is to ground Control Grids directly to the chassis through ground lugs mounted directly on the chassis immediately adjacent to Control Grid pins. Always think "zero length Control Grid leads"!

To maximize stability:

- Use wide low-inductance Control Grid leads from the tube socket directly to the chassis, connecting Control Grid grounding leads to the closest possible point. Ideally use ground lugs right at the Control Grid pins (rather than using socket mounting screws) for grounding.
- Use Low-Pass Filter Pi-Network or Parallel Tuned Networks as input matching circuits.
- Mount any Swamping or Control Grid Load Resistors right at or on the tube socket so leads are very short.
- Mount the Low-Pass Filter or Band Pass Filter input matching system near the tube, or use exceptionally low-impedance transmission lines to reach the input matching system.
- Keep all Control Grid connections as short as possible, even if it is at the expense of having wiring "look pretty" with all perfectly aligned 90-degree angles.

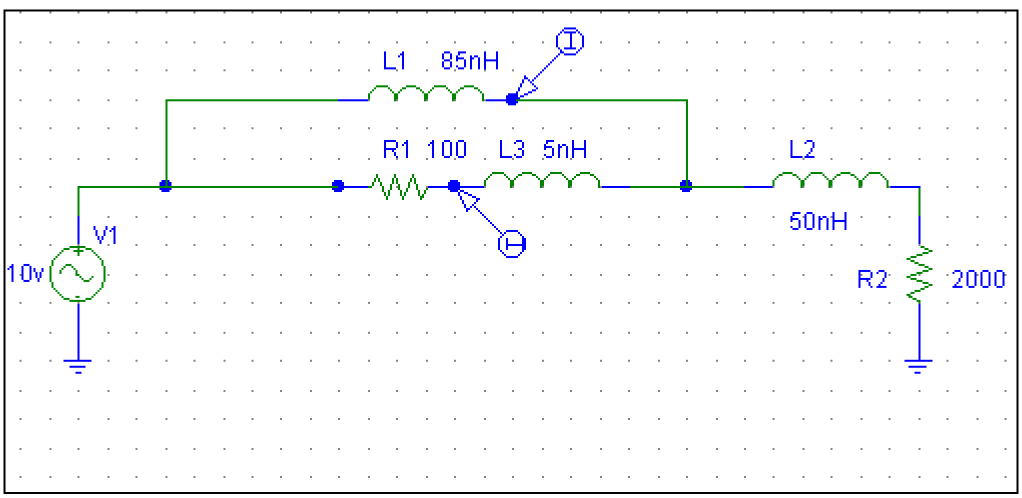
What Does the Parasitic Suppressor Do?

The parasitic suppressor normally has two components in parallel, a Resistor and an Inductor. At Low Frequencies, the path through the inductor dominates the system. At Very High Frequencies, the resistor dominates the system (assuming it is a low-inductance resistor). One common problem is people assume brown carbon resistors are non-inductive.



All of the spiral-conductor resistors above have significant inductance at VHF, and make very ineffective suppressors unless the reactance is cancelled. Only the "true carbon composition" resistors are useful in non-resonant standard suppressors.

This is a typical suppressor system, including inductance of the Anode lead:



In this case V1 represents the tube. The following is a simulation of currents in the suppressor:

The green curve is current through the inductor, the red curve shows current through the resistor. Starting at 30MHz, the ratio of current in the inductor to current in the resistor is:

Frequency	I(L1)	I(R1)
30MHz	0.0047	0.0015
60MHz	0.0041	0.0026
90MHz	0.0034	0.0034
120MHz	0.0029	0.0037
160MHz	0.0024	0.0041
190MHz	0.0021	0.0042
220MHz	0.0018	0.0043

This tells us something very important. The INDUCTOR dominates only at low frequencies. At 30MHz, current in the inductor is three times current in the resistor.

At 190MHz, in the range of the instability frequency of a 3-500Z, the resistor has twice the current as the inductor.

This tells us any changes in INDUCTOR design or inductor "Q" (such as use of nichrome wire) mainly lowers low frequency "Q". It would have virtually no effect on very high frequency "Q" of the system.

The dominant factor in controlling VHF "Q" is the resistor value, and any reactance in the resistor path.

The dominate factor in determining HF "Q" and performance is the inductor value, and any changes in inductor "Q".

This has been my point all along with the Richard Measure's nichrome suppressor. Richard Measures claims, incorrectly, his suppressors provide lower VHF "Q" while, in fact, they do exactly the opposite! A typical Richard Measures hairpin suppressor actually produced significantly *higher* system "Q" in the Anode of a 3-500Z (nearly twice the VHF "Q"), because the equivalent Rp of the suppressor in *series* with the Anode lead was *lower*!

Reducing VHF "Q"

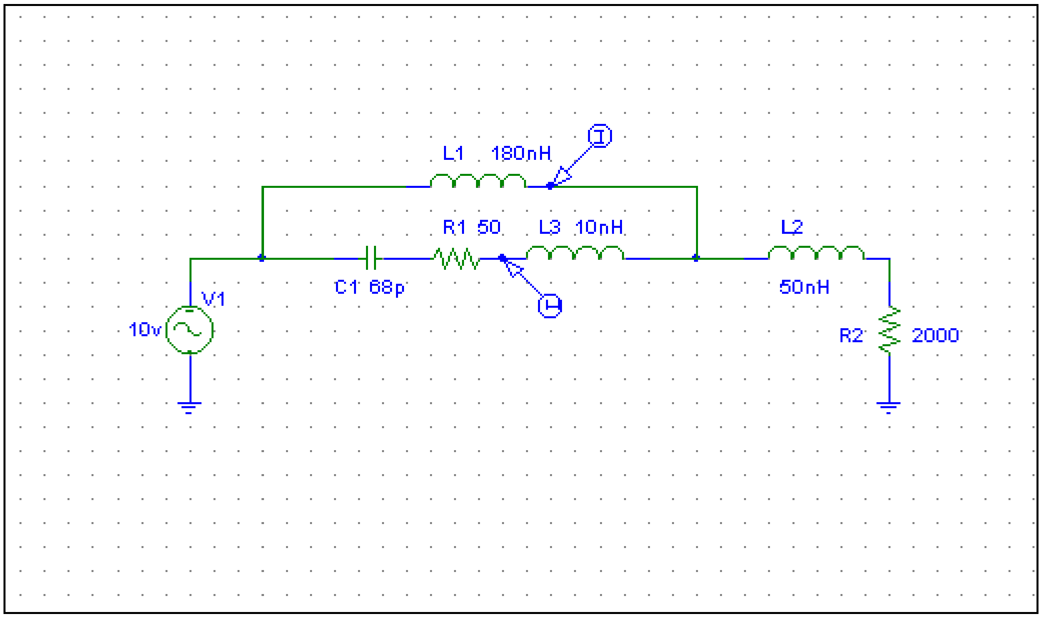
If we want a lower VHF "Q", while maintaining high HF "Q" and efficiency, the system must shift current into the resistor faster as frequency increases. The suppressor must also have higher Rp, so it dominates the Anode path inductance that is in series with the suppressor.

While Richard Measures openly touts his "low-Rp suppressor", the fact is a low Rp suppressor results in higher Anode system "Q"!

A Truly Improved Parasitic Suppressor

In order to improve VHF stability by reducing VHF "Q" and reduce VHF gain, we must have a series resistance dominate the Anode system's impedance at VHF. This means, in a frequency sweep simulation, the ratio of currents in the resistance to current in the inductance must be as high as possible. Let's call that slope *the rate of transfer.*

The rate of transfer can be increased by adding a small value of capacitance in series with the resistor:



The old suppressor was:

Frequency	I(L1)	I(R1)	Ratio
30MHz	0.0047	0.0015	3
60MHz	0.0041	0.0026	1.6
90MHz	0.0034	0.0034	1
120 MHz	0.0029	0.0037	.78
160MHz	0.0024	0.0041	.58
190MHz	0.0021	0.0042	.5
220 MHz	0.0018	0.0043	.42

The new one:

Frequency	I(L1)	I(R1)	Ratio
30MHz	0.0069	0.0026	2.6
60MHz	0.0050	0.0055	.9
90MHz	0.0027	0.0052	.52

120MHz	0.0019	0.0050	.38
160MHz	0.0013	0.0048	.27
190MHz	0.0011	0.0047	.23
220MHz	0.0009	0.0047	.19

Graphically we see the currents are:

The green curve is current through the inductor, the red curve shows current through the resistor. Notice how flat current is in the resistor, and how sharp roll off of current in the inductor becomes.

This means we will have very low *Anode SYSTEM "Q"* starting at a low VHF frequency of 50-60MHz, and continuing up to UHF. Dissipation in the resistor is still reasonable at HF, efficiency and tank "Q" at the operating frequency remain high, yet VHF suppression is greatly improved.

Optimum resistor value can be determined by network analyzer measurements, or determined empirically.

If the Anode path to chassis is long and thin, the VHF impedance will be very high. A high Anode path impedance (thin or long leads) requires higher values of resistance, because we want the resistor to dominate the Anode system impedance. The best value for a resistor is generally one that is approximately equal to, or slightly higher than, the Anode path reactance at the frequency of instability. This ensures an upper-VHF "Q" approaching 1, and a broad dampening bandwidth.

That impedance can be measured on an impedance test set, or through other methods by creative engineers or technicians. As a general rule in good HF tank systems, long, thin, Anode leads (i.e. 811A's) require 100-150 ohms of resistance while shorter thicker Anode leads (i.e. 3-500Z) require 30-100 ohms of resistance. Stable tubes with external Anodes can often use natural Anode lead resistance of brass or other materials, or even hairpins, to adequately dampen Anode path reactance. Exceptionally stable tubes with short internal Control Grid leads exiting on a Control Grid ring often require no suppression at all, if the Control Grid ring is grounded directly to the chassis.

At the frequency of instability, the suppressor inductor must present significantly higher reactance than suppression resistance values. The high inductive reactance causes the majority of current to flow through the suppressor resistor at very high frequencies, not through the inductor.

Looking at amplifier designs, we will find tubes like 811A's generally have higher resistor values and many turns in the suppressor inductor. Tubes like 3-500Z's have significantly fewer turns, especially when Control Grid leads are kept very short and direct to the chassis, and can use lower value resistors.

The less stable the tube at low VHF, the larger the inductor must be.

The longer and thinner the tank leads to the tank input variable capacitor and the longer the capacitor to chassis path, the higher suppressor resistance and inductance must be.

One way to view this is to consider the frequency response of a Hi-fi amplifier. Larger values of plate load resistors in amplifier stages reduce higher-frequency gain. The same is true in RF power amplifiers. Lower frequencies of instability require larger inductors, so the RF path is shifted over to the resistor at a lower frequency.

Uses For Improved Suppressors

Series-resonant suppressors are used with slightly inductive resistor paths, and larger-than-normal shunt inductors. A small capacitor is placed in series with the slightly inductive resistor path, and this capacitor series-tunes the resistor path to a very broad VHF resonance. This results in a very rapid shift of current into the resistor as frequency is increased. This works well with amplifiers operating at 1/3 to 1/2 the instability frequency. It minimizes resistor heat on upper HF while providing perfect lower or mid-VHF stability.

Typical amateur applications for shunt L series R-C suppressors are 3CX1200A7, 3CX1200D7, 572B and 811A tubes.

Shunt suppressors with series-resonant tuning to ground are also sometimes used, the normal application is very high power stages with substantial Anode-to-tank currents. These suppressors consist of a series R/L/C system, where the C is normally just stray capacitance to the tube Anode. Sometimes these suppressors take the form of a ferrite block placed between the Anode and chassis. The inductance of the block series-tunes stray capacitance, and the losses act like a damping resistance in series with the Anode-to-chassis path. I've stabilized 50-100kW VHF transmitter designs using shunt suppression.

Other Instability

Some Power Amplifier systems are prone to oscillation at low frequencies. Yaesu and Dentron amplifiers using 572B's, and the Collins 30L1 amplifier using 811A's are good examples of production amplifiers with stability problems. These amplifiers tend to oscillate NEAR the operating frequency. All of these amplifiers, except the Yaesu, use tubes with high Anode-to-Control Grid feed-through capacitance and no neutralization. Worse, the Collins floats the

Control Grids for RF, reducing the already poor isolation of Anode-to-Cathode feedback path in the 811A.

Yaesu uses one of the poorest engineered feedback systems of all, with a capacitor from the output of the Pi section back to the Cathode! Phase shift in that path would vary wildly with tank circuit tuning and load impedance on the PA, as would the amount of feedback!

The Yaesu amplifier is a particular problem with Chinese 572B tubes, because Control Grid mu is lower. Negative Control Grid bias has LESS of an effect on Cathode current, so the Chinese (and Russian) tubes draw extra quiescent current when the antenna relay is open. This additional current allows the tube to amplify while the amp is in standby. Since the antenna and input source are removed in standby, and the improperly designed feedback path to the tank output remains in place, the PA oscillates near the operating frequency with no load! Voltage in the tank builds up to many thousands of volts because energy is not extracted to a load. The fact the oscillation is at a low frequency allows the bandswitch to see the full voltage, and it often fails.

Amplifiers can create extremely large voltages when RF is applied and a load is not present!

All of the amplifiers discussed above would be greatly improved by:

- Adding a proper bridge neutralization circuit like Heathkit, Ameritron, and Gonset used in 811 amplifiers.
- Grounding the Control Grids either directly or through low reactance very-short-lead capacitors, directly between the socket's Control Grid pin and chassis.
- Using the improved suppressor outlined above to de-"Q" the amp at lower VHF.

A Bad Control Grid Idea commonly used called the "Super Cathode Drive"

Floating Control Grids on capacitors to add "Negative Feedback" is one of the *'worse things'* every done in Grounded-Grid Triode Power Amplifier's. This bad idea appears in the Collins 30L1, 811A RF Power Amplifier, and Japanese manufacturers copied the bad idea into their

Power Amplifiers. Heathkit was also a victim of this engineering gaff in the SB-220 and SB-221 amplifiers. Here is how it started and filtered through Ham gear:

When I was designing Power Amplifier's in the late 1970's and early 1980's, an employee of Eimac (who was also an author of many articles and a popular Radio Handbook) put considerable pressure on me to float the Control Grids of 3-500Z Power Amplifier's through small mica capacitors. He called the circuit a "Super-Cathode Driven" amplifier. He wrote letters and called frequently, asking why I would not float the Control Grids through small mica capacitors.

This quite likable fellow creatively "borrowed" this idea from the Collins 30S1, which was actually a proper application for this type of system. This system works in the 30S1 because it is a class AB1 Cathode-Driven 4CX1000A Tetrode. The 30S1 with it's Tetrode, using the floating-Control Grid circuit, has zero Control Grid current, unlike later Triode "copy-cats". The Control Grid has very high impedance all through the RF cycle. The high Control Grid-Cathode impedance does not shunt the upper capacitor divider with the low drive-varying Control Grid resistance of stages with Control Grid current. Essentially R1 (see the circuit below) is infinite in the Collins 30S1. The 30S1's Tetrode, unlike Triode copy cats, has a directly grounded screen. The screen shields the RF input (Cathode) from the RF output (Anode).

The theory seems pretty simple on the surface. Floating Control Grids through small mica capacitors forms a capacitive voltage divider, with the small Control Grid-to-ground bypass capacitors forming the grounded half of a capacitive voltage divider. The small internal Cathode-to-Control Grid internal tube capacitance forms the upper leg of this voltage divider. Driving power requirements are increased by this negative feedback (the Control Grid partially follows the RF Cathode voltage, reducing effective Control Grid/Cathode voltage and reducing effective driving power applied to the Control Grid). In theory, the amplifier should be "cleaner" and, with reduced power gain, be a closer match to higher power exciters.

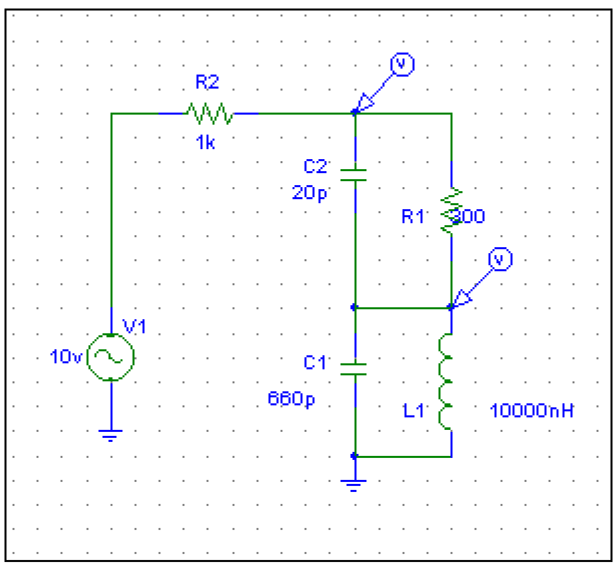
After some thought, experiments, and questioning other engineers, I found no one actually measured performance or calculated feedback over a wide range of operating frequencies and

Control Grid currents. It was assumed since everyone did it and an Eimac staffer endorsed it, super-Cathode was already confirmed technically sound.

Good Feedback Dividers

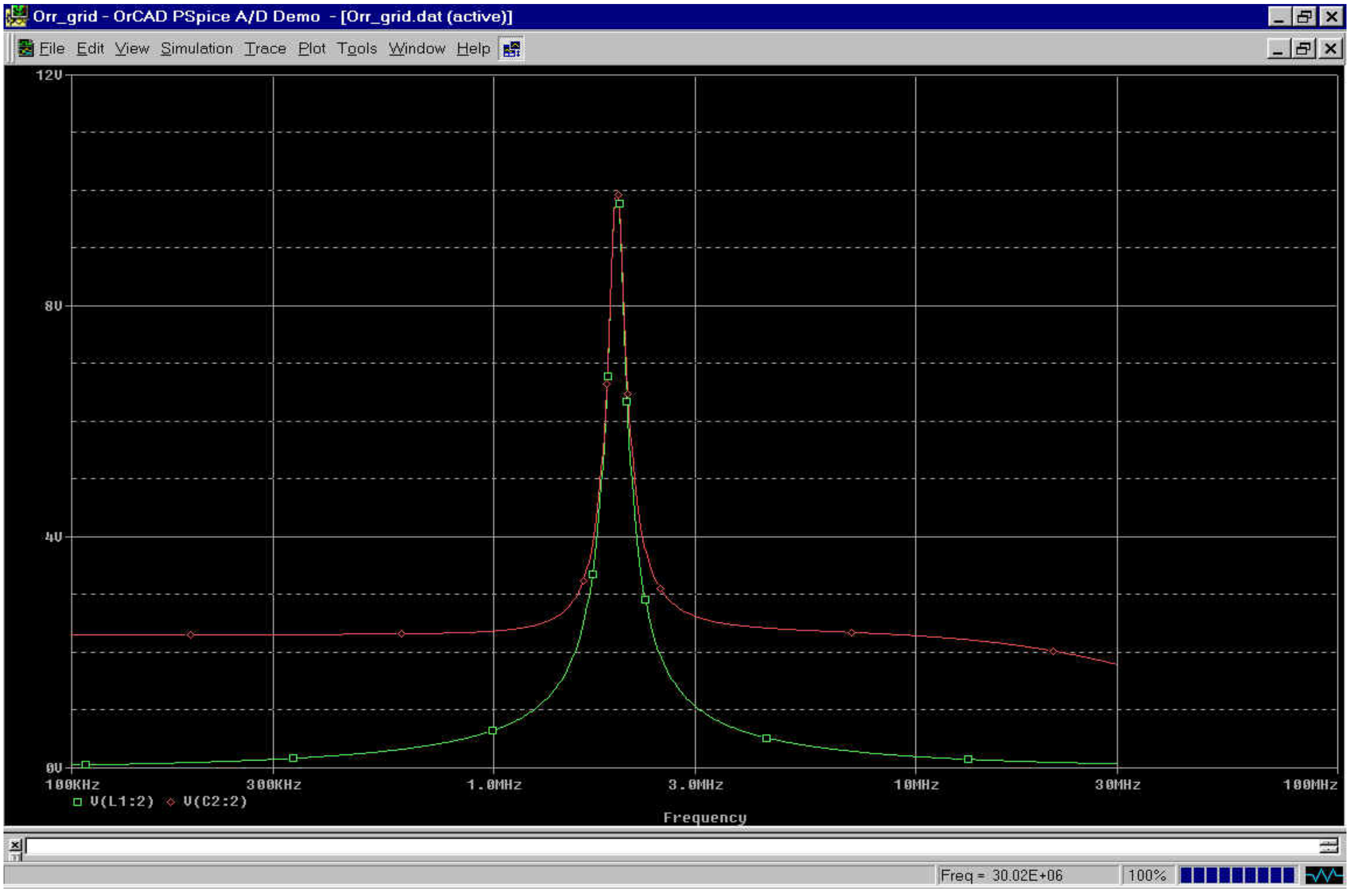
In a good capacitive divider, sampled feedback voltage would be constant in both amplitude and phase regardless of frequency, power levels, and tuning. To be a "good" capacitive divider, the reactance of capacitors C1 and C2 would have to totally dominate system impedances. This is where the wheels fall off "super Cathode drive".

The basic circuit the Eimac marketing engineer and prominent handbook author promoted, and that Heath and others used, was similar to this circuit:



- The Control Grid connects at the junction of C1 and C2, while the Cathode connects to the top of C2.
- C2 is the internal stray G-K capacitance of the tube
- R1 is the time-varying Control Grid to Cathode impedance
- R2 is only added to allow us to see the input impedance change of the divider on the SPICE model.

Sweeping the system from 100KHz to 30MHz shows the following:



We find a huge spike in Control Grid-to-ground impedance at 2MHz, and very uneven response above that range. By manipulating the value of L1 (the Control Grid chokes) we can move the spike around, but we are ALWAYS left with some low frequency where the Control Grid isn't grounded! The Heathkit SB-220, for example, peaks below the 160-Meter band.

This is a very *serious* violation of good engineering practices in any Grounded-Grid Power Amplifier, and is actually at the root of VHF and HF stability problems in a few popular Power Amplifier's. Collins, for example, had a series of field modifications to the 30L1 Control Grid system. They kept moving the spike around, trying to stabilize the amplifier. The best idea for the 30L1 Collins would have been to abandon the silly notion this system adds stable controlled negative feedback, and change the amplifier back to a true grounded grid with neutralization. If Collins wanted negative feedback in the 30L1, the *PROPER* method would have been the addition of a resistor in series with the Cathode feed point near the tubes! We never want to float the Control Grids in a Grounded-Grid Triode amplifier.

There are obviously several major flaws with the super-Cathode drive concept. Control Grid current causes Control Grid-to-Cathode impedance to constantly vary with drive level. When Control Grid current is absent, the Control Grid-to-Cathode impedance is nearly an open circuit. Control Grid-to-Cathode capacitance dominates the upper half of the divider, and everything appears to work as planned. Unfortunately, a problem appears whenever the Control Grid draws current. Even the tiniest amount of Control Grid current causes Control Grid-to-Cathode impedance to decreases rapidly. With only a few dozen milliamperes of Control Grid current, Control Grid impedance drops to a few hundred ohms or less. As Control Grid current is drawn, the decreasing Control Grid impedance dominates the upper leg of the voltage division circuit!

There are also new potentially destabilizing resonances added in the Control Grid path.

This system causes four major problems:

- Control Grid drive is effectively reduced as operating frequency is increased. This is the opposite of what we need! We need more drive to offset system inefficiencies on higher frequencies.
- Feedback starts to show significant phase-lag with increased drive, especially on lower bands.
- Control Grid-to-chassis impedance at VHF and LF is increased, making the amplifier much less stable. An SB-220 Heathkit amplifier for example required nearly twice the parasitic choke inductance when the "super Cathode" circuit was used. Still, because of pressure from this person, the circuit was added!
- Protection for the exciter and Cathode system, in the event of a tube arc, is greatly reduced.

When I tested several amplifiers with this alleged "super-Cathode" system added, IMD performance became *significantly worse* under some operating conditions. Stability also significantly decreased. Several Power Amplifiers I tested using 572B, 3-1000Z, and 3-500Z tubes all had higher Intermodulation distortion and required larger parasitic chokes when this super-Cathode system was added!

Unless you have a Class AB1 Tetrode or Pentode Power Amplifier, ground the Control Grids directly with short heavy leads or use low-inductance high-value capacitors with very *short leads* to ground the Control Grids! The "super Cathode drive" system does not belong in any Grounded Grid Triode Amplifier. Get rid of it!

Summary

I hope this information is useful, and helps people understand what really goes on in a parasitic suppression system. As time permits, I add more articles about curing unique problems in amplifiers, and diagnosing amplifier failures. I hope these pages are a good start.