Improved Anode-Circuit Parasitic-Suppression for Modern Amplifier-Tubes

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This is an unexpurgated, pre-edited version of the article "Improved Anode-Circuit Parasitic-Suppression for Modern Amplifier-Tubes" that appeared on page 36 in the October 1988 issue of *QST*. A more recent treatment of the subject appeared in the September and October 1990 issues of QST; the article is titled "Parasitics Revisited."

The traditional copper-inductor/carbon-resistor anode [plate] parasitic-suppressor has been used in vacuum-tube amplifiers for at least 50 years. Information on anode-circuit VHF parasitic suppressors first appeared in the 1926 Edition of The Radio Amateur's Handbook however, this information was inexplicably omitted from post 1929 editions. The earliest record of an anode parasitic-suppressor used in production equipment was in a transmitter built in the early 1930s by the Collins Radio Company.

Much of the reason for Collins' early success can be attributed to their understanding that, where RF is concerned, there is no such thing as a zero-potential "ground" and that:

- any wire or strap was a capacitor-inductor VHF tuned-circuit as well as a conductor,
- an "RF-choke" acted like a short-circuit at certain frequencies, and
- sometimes a resistor would make a better RF-choke than an RF-choke!

Anode parasitic-suppressor design has not changed during the last 50+ years while vacuum-tube design has changed markedly. In the 1930s, 40s and 50s, a "high-Mu triode" had a (voltage) amplification factor of 40. Today, a "high-Mu triode" usually indicates an amplification factor of 100 to 240. A fifty+ year-old parasitic suppressor design that was usually successful at preventing oscillation in an amplifier tube with an amplification of 40, may not be as successful on a modern amplifier tube that has much more gain.

Modern amplifier tubes have another factor, in addition to higher voltage gain, that makes the job of the traditional inductor/resistor VHF parasitic suppressor more difficult. That factor is higher frequency capability. Ancient amplifier tubes could barely be coaxed into amplifying at 28MHz. The 203A that was used successfully in the Collins 150B transmitter had a full power rating of 15MHz.

Modern Amplifier Tube Performance

The popular 8802/3-500Z triode has an average amplification factor of 130 (Eimac) to 200 (Amperex). The Amperex version appears to be electrically equivalent to the 8163/3-400Z with the exception of the anode dissipation rating. The maximum-input rating of the Eimac 3-500Z, for "radio frequency power amplifier or oscillator service" is 110MHz. 3-500Zs work well above 110MHz if the power is de-rated as frequency increases. Other types of modern amplifier tubes commonly used in HF-amplifiers have an even higher amplification factor and a frequency rating, some up to 500MHz. The 8874 is a good example of a high gain, 500MHz triode. It has an average amplification factor of 240! This is definitely a high-Mu triode.

Oscillators

If an amplifier tube can amplify at a frequency, it can usually be made to oscillate at that frequency. This is good news for oscillator builders and bad news for amplifier builders.

In addition to frequency capability there are some other prerequisites that must be met before oscillation can be achieved:

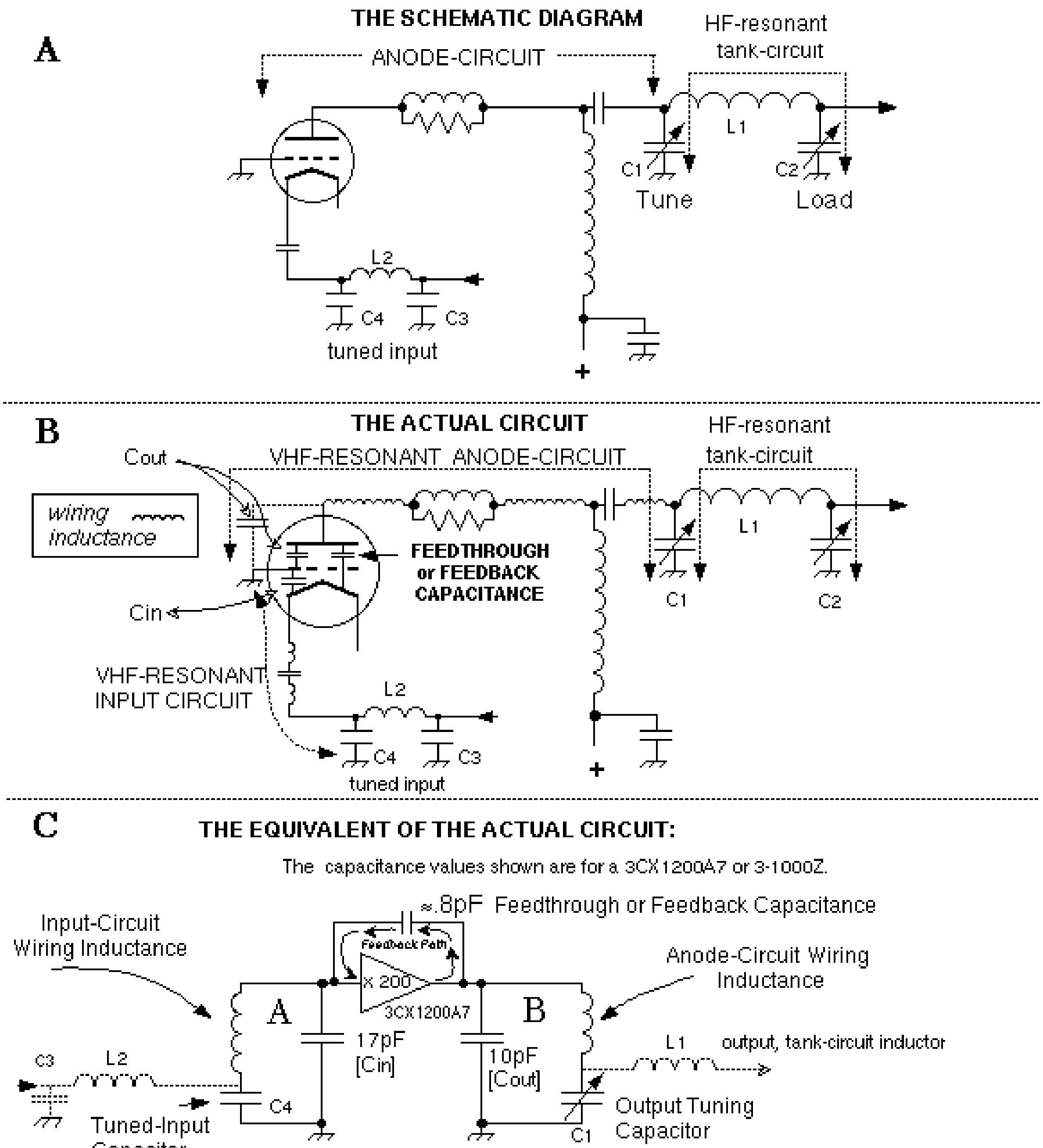
- a feedback path between the output and the input of the amplifier, and
- there must be two high "Q" resonant circuits, one in the output lead and the other in the input lead to the amplifier tube – both must be resonant near the same frequency.

The resonant circuits are essential because they act like a flywheel and sustain the oscillation during the portion of the cycle that the amplifier tube is not conducting and amplifying.

The (Incomplete) Schematic Diagram

Understanding the nature of the parasitic oscillation problem would be much easier if the schematic diagram of an amplifier circuit would show the interconnecting input and output leads to the amplifier tube for what they actually are: inductors. These incognito inductors, combined with the inter-electrode capacitances of the amplifier tube, form unavoidable VHF self-resonant circuits. See Figure 1, A-B-C below. The typical frequency range of these resonances is from 90MHz to 160MHz in 1500W HF amplifiers.

FIGURE 1 of 1 for: "Improved Anode-Circuit Parasitic Suppression For Modern Amplifier-Tubes"



The high-Q inductances and capacitances at A and B form high-Z, parallel-resonant, VHF circuits that cause the amplifier to exhibit a near-maximum VHF voltage gain. And so, the possibility of VHF regeneration and oscillation is enhanced. This problem can be corrected by reducing the VHF-Q at A and at B.

The Parasitic Oscillation Seed Voltage

The essential question is: Where does the initial VHF voltage come from that starts the self-resonant flywheels in motion that causes the parasitic oscillation to take place? It cannot come from the exciter because all exciters have a built-in low-pass filter that is very effective at blocking any VHF signal. This leaves only the amplifier itself as the source of the seed voltage.

The answer to this pivotal question involves “Q”. “Q” represents the "Quality" of a tuned circuit or a circuit component. More quality should be better. An old adage says: "more is not always better". Where amplifier design is concerned, more “Q” is certainly not always better. The appropriate “Q” for each part of the circuit is the best design. For example: HF tank circuit components should have a high “Q” and anode leads should have a low “Q”.

For the purpose of this discussion, the most important rule about “Q” is: The RF voltage that is developed across a resonant circuit is directly proportional to the “Q” of the resonant circuit.

This principle is best illustrated by the antique spark-transmitter. In a spark-transmitter, the transient currents from a motor driven rotary spark gap (a motorized switch) were passed through a high “Q” tuned circuit. This caused the tuned circuit to "ring" at its resonant frequency which produced a surprising amount of RF voltage and power. The tuned circuit acts like a flywheel after each impulse. It coasts a bit after each impulse and then stops, like the ringing of a bell. This is referred to as "flywheel-effect". Lowering the “Q” will reduce the flywheel-effect.

Amplifiers are routinely subjected to numerous turn on, switching, keying, and voice transient currents. These transient currents pass through the VHF self-resonant anode circuit and the VHF self-resonant input circuit. Each transient current causes the input and output self-resonant circuits to ring and generate an invisible, damped wave of VHF voltage that is proportional to the VHF “Q” of these circuits. This is the source of the VHF seed voltage that initiates the parasitic oscillation.

Part of this seed voltage will be fed back to the input of the amplifier by the feed through / feedback capacitance inside the amplifier tube. The VHF voltage will then be amplified by the amplifier tube and it will appear in the anode circuit where some of it will be returned to the input of the amplifier tube by way of the feedback capacitance.

If the amplified VHF voltage arrives with the right phase and amplitude, an even larger signal may be fed back to the input of the amplifier. When this occurs, the parasitic oscillation is off and running. This would not be a problem if the considerable energy that is generated by the VHF parasitic oscillation could be safely dissipated in the load that is connected to the amplifier. Unfortunately, the VHF energy cannot reach the output connector of the amplifier because it cannot pass through the HF tank circuit inductor. This inductor acts as an RF choke to the VHF energy. This traps the VHF energy in the anode circuit. With no load, the grid current and grid dissipation of a high Mu triode oscillator becomes excessive in a matter of milliseconds. This can start a chain reaction of events that almost simultaneously results in severe damage to the amplifier.

Grounded-grid Oscillators

Making a grounded grid amplifier oscillate is easier than it might seem. In a grid driven, grounded cathode amplifier, the output and input voltages are 180 degrees out of phase. They oppose each other. Before regeneration can occur, the output and input voltages must be made (forced) in phase, to aid each other, by adding a phase-shift circuit. In a grounded grid amplifier the output and input voltages are already in phase and aiding each other.

For many years it was assumed that grounded grid amplifiers were inherently stable because the "grounded" grid acts as a shield between the input and the output circuits, thereby blocking regeneration and oscillation. At HF this logic is true but at VHF, the logic is false because no matter how carefully an amplifier tube is designed, at some frequency the "grounded" grid will become self-resonant. This is due to the unavoidable, combined inductances of the grid structure, the internal leads, external leads, and the tube socket resonating with the capacitance of the grid structure. In a 3-500Z triode, the directly (as is possible) grounded-grid will self-resonate at about 95MHz. As frequency increases above grid self-resonance, the grid exhibits inductive reactance and the grid is no longer "grounded".

When the grid is not truly grounded there is no shield to block regeneration. And, to make matters worse, as the frequency increases into the VHF region, the feed through capacitance from the input [cathode] to the output [anode] of the amplifier has fewer and fewer ohms of capacitive reactance.

In other words, as the frequency increases above the grid self-resonant frequency, the "grounded grid" behaves progressively less as though it were grounded and the feedback, or regeneration, path between the input and the output of the amplifier tube becomes more and more conductive to RF current. This combination is not desirable in an amplifier.

Anti-Parasitic Techniques and “Q”

Another important rule is: “Q” is equal to Reactance divided by Resistance, or Q= X/R. “Q” can be decreased by increasing the resistance, or by decreasing the reactance, or both.

One obvious way to lower “Q” is to use resistive or low “Q” conductors. Silver plated copper strap has the highest VHF “Q” known to science at room temperature and yet silver plated copper strap is commonly used for anode circuit wiring and for VHF "parasitic suppressors" in HF amplifiers. *A more accurate name for a silver plated parasitic suppressor would be a parasitic supporter.*

The “Q” of copper is about 94% of the “Q” of silver, so copper does not provide an appreciable improvement in “Q” reduction over silver. Trying to build a low “Q” circuit using high “Q” silver or copper conductors is about as sensible as trying to make a pencil eraser using Teflon®.

Reducing the inductive reactance by shortening lead lengths may improve stability IF the shortened lead places the cathode and anode-circuit self-resonant frequencies farther apart.

Another method of improving stability is to tune out some of the inductive reactance in the grid structure by bypassing the grid to the chassis with small capacitors. This increases the self-resonant frequency of the grid circuit to a point where the amplifier tube will have less oscillating and less amplifying ability.

The first grounded grid amplifier to use this technique used (4) 811As and was built by the Collins Radio Company. Many currently produced commercial grounded grid amplifiers still use this technique. There is an interesting discussion on this technique in an article about parasitic oscillation in grounded grid amplifiers titled "Grounded-Grid Amplifier Parasitics", on page 31 of the *Ham Radio Magazine*, April 1986 edition.

Grid inductance cancelling capacitors are most effective when used with older design amplifier tubes like the 811A that have a considerable amount of internal grid inductance to cancel. This technique should not be used on modern amplifier tubes that have inherently low grid inductance.

Another anti parasitic technique is the use of an input parasitic suppressor resistor, to lower the VHF “Q” at the self-resonant frequency of the input (cathode) circuit. Input suppressor resistors also reduce intermodulation distortion (IMD) with the tradeoff of a slight increase in the drive power requirement to the amplifier. This technique is moderately effective but not always 100% successful. The only area left for improvement is the anode circuit.

In Search Of a Better Anode Parasitic-Suppressor

The trouble with trying to troubleshoot a parasitic oscillation problem is that the crazy things are not always predictable. It may be that just the right transient or rapid sequence of transients needs to come along to get the ball rolling. For example, you can change something like a conductor length in a marginally stable amplifier and it will behave for months. When you are beginning to believe that the problem is "fixed", and you confidently put the rest of the screws in the cabinet, it will unexpectedly arc or burn-up the parasitic suppressor resistor; or worse.

The perfect amplifier to experiment with would be one that has an unusually high gain amplifier tube or tubes that consistently exhibited instability problems even with input suppressors installed. There is just such an amplifier from a well-known manufacturer which uses a pair of 3-500Zs with either 2200V (CW) or 3200V (SSB) on the anodes. This amplifier sometimes makes an arcing sound, but the operator is told on page 14 of the instruction manual that this arcing sound is "normal". After a few months the "normal arcing" will burn off some of the contacts on the output section of the band switch. The missing contacts made the amplifier inoperative. This was not an isolated case as many hams have had to replace the output band switch on this model amplifier.

The factory authorized service technicians say that the output band switch was damaged by: “…someone who had rapidly switched the band switch while transmitting at full power”. No competent HAM would be stupid enough to try band switching an amplifier while transmitting.

Since the actual breakdown voltage of these components is above 5000VDC at sea level and the maximum RF voltage is only about 2600V peak, nothing inside an amplifier should arc over unless the amplifier was operated at an extreme altitude that would probably cause the operator to pass out because of anoxia.

As the frequency of a specific AC voltage increases, its gas ionization ability also increases. This effect can be seen in the manufacturer's voltage versus frequency ratings for RF rated relays: the rated RF peak operating voltage always decreases as frequency increases. This is one of the reasons why the waveguides of high-power radar transmitters are pressurized with dry nitrogen gas.

The presence of an unwanted AC voltage, with a frequency that was much higher than the normal 29.7MHz maximum, was indicated in this amplifier. The most likely source of this voltage is a VHF parasitic oscillation.

The recommended fix is to install some input suppressor resistors consisting of a pair of 10 ohm, 2W metal{oxide}film [MOF] resistors in series with the RF input connection to the 3-500Z cathodes and then replace the band switch.

If after replacing the original band switch and adding the input suppressor resistors, there is still arcing in the general area of the band-switch then check then inspect the damaged band switch. If the damaged band switch reveales that the most severely burned/vaporized switch parts were the anode tuning capacitor padder contacts for the 3.5MHz and 1.8MHz positions; and the next most-roasted contacts were for the 28MHz tank coil tap; and the 21MHz tank-coil tap contacts were burned less than the 28MHz contacts; and the 14MHz contacts were not burned. Then the pattern is clear: only the contacts that were close to the anode were damaged; and of those the contacts that were *the closest to the anode were damaged the most*. Thus, it may be concluded; the voltage that did this damage had a remarkable ability to jump an air gap and deteriorated very rapidly as it tried to travel through the inductance of the tank-coil. HF energy would have no problem traveling through the inductance in the tank-coil. The only kind of voltage that fits this profile is a high-voltage with a frequency in the VHF range.

The solution here is to install a 5.1 ohm, 2W MOF resistor in series with the HV positive lead. The resistor will act like a HV fuse and current limiter if a full-blown parasitic oscillation occurs. This limits the discharge current pulse from the considerable number of joules of stored energy in the HV filter capacitor bank. If unlimited, this current pulse can disturb the grid to filament alignment in the amplifier tube[s] which can cause fatal, grid to filament shorts. A ceramic 10 ohm, 7W to 10W wire wound resistor would provide even better protection. A higher wattage resistor should be used only if justified by increased anode current demand because the resistor is supposed to burn out quickly during a circuit fault and stop the flow of current.

If this happened to your amp, as a precaution before firing-up the amplifier, check the 10W cathode bias Zener diode. As is often the case after a parasitic oscillation and its accompanying large current pulse, the Zener diode gets shorted. The Zener diode can be replaced with another identically rated Zener or it can be replaced by a series string of (7) ordinary, Perf-board mounted, RF bypassed, 1A, >50piv silicon rectifier diodes with the polarity arrows pointing opposite that of the original Zener. This provides about 5 volts of cathode bias voltage during transmit. The polarity is opposite because the new diodes will be operated in the forward conducting (.75v/diode) direction instead of in the reverse, Zener-breakdown direction.

It is not unusual for this amplifier, even with input suppressor-resistors installed, to oscillate reliably with only 2200V on the anodes on the 14MHz and 28MHz bands! With 3200V applied, the amplifier was unstable on some additional bands as well.

With new 3-500Zs these amplifiers can have remarkably high gain. Using 100 Watts drive at 3.8MHz, they will deliver 780v p-p [1520W PEP] into a Bird 50 termination. This does not necessarily mean that they would have also had abnormally high VHF gain as well, but it is probably a safe assumption. There is a solution.

In every HF amplifier design, there is an unavoidable VHF tuned circuit formed by the anode to ground capacitance and the total inductance of the wires or straps between the anode and the output tuning capacitor. The resonant frequency of this anode-circuit can be varied only slightly by adjusting the output tuning capacitor.

Measure the anode-circuit's self-resonant frequency, with a dip-meter coupled to the wire between the HV blocking capacitor and the anode-choke. Look for a very sharp, high-Q dip at 130MHz. Next measure the self-resonance of the center-conductor of the coax that delivers the input signal to the cathodes and you'll see that the input circuit is self-resonated near the same frequency. This is not good.

Much of the inductance that formed the resonance in the anode circuit appears in the 50mm [2 inches] of "U" shaped #12 copper wire that connects the HV blocking capacitor to the top of the anode RF choke. This #12 wire has about 39nH of inductance. At 130MHz this inductance has a reactance of +j32. Soldering a 5.1 ohm non-inductive MOF resistor, with "zero" lead-length, across the "U" shaped #12 wire will dampen the "Q" of the tuned circuit.

The extremely sharp dip at 130MHz and the high "Q" of the anode-circuit are other contributing factors. This problem is exacerbated by the high VHF "Q" silver-plated strap that is used for the combination anode-suppressors/anode-leads. The obvious choice for a low "Q" conductor is Nichrome ribbon or wire. It has 60 times the resistance of copper or silver. "Q" measurement tests on a VHF "Q" meter, confirmed that Nichrome produces a much lower "Q" than any other commonly available conductor material. Unfortunately, Nichrome wire and, especially, flexible Nichrome ribbon, is not easy to find or inexpensive. Soft stainless steel makes a good second choice because it has 10 times the resistance of copper and it is commonly available.

Anode-Circuit Modifications

The #12 copper wire must be replaced with a strip of Nichrome ribbon about 3mm in width and 35mm long. A three-turn inductor, with an inside diameter of about 6mm to 7mm, made from #18 [1mm] soft stainless steel wire was connected in parallel with the ribbon in order to stagger-tune the circuit. This increases the self-resonant frequency of the anode circuit to about 150MHz and also lowers its apparent "Q".

It is not possible to connect a VHF “Q” meter to the anode-circuit of an amplifier; however, a good measure is how closely the dip meter has to be coupled to the anode circuit to obtain a 10% meter dip at resonance for each type of conductor material.

The factory-original, silver-plated, high VHF “Q” L/R parasitic-supporters, must be replaced with low VHF “Q” L/R suppressors made from two 100 Ohm, 2W metal{oxide}film [MOF] resistors in parallel, shunted by a 70nH inductor made from #18 stainless-steel wire. The inductor has 3-turns. A 9/32" drill bit shank can be used as a winding-form. To keep the circuit's VHF “Q” as low as possible, #18 stainless steel wire should also be used for the leads at the ends of the anode suppressor assembly. The ends of the wire leads can be bent into circles for mounting with the original screws. For an even lower Q and better parasitic-suppression, the conductors could be made from Nichrome wire in place of the stainless-steel wire.

Construction Notes

1: The inductor and each MOF resistor should be parallel to each other and separated by a cooling air gap of about 2mm.

2: To avoid a short circuit and to facilitate cooling the inductor must not be wound on top of the resistors because the conducting part of these resistors is on their outside surface.

If an amplifier shows signs of instability with the 3-turn suppressor inductors, try 3 1/2 or 4-turn inductors.

> ***Caution***, the inductance cannot be arbitrarily increased because too-much inductance will cause the inductor's voltage drop to be too great for the parallel 100 ohm, 2W resistors on the 28MHz band. The reason for this is that, on the 28MHz band, with an anode voltage of 3KV, there is approximately 1.8a of RF current circulating through each 3-500Z anode lead due to the 4.7pF anode to grid (ground) capacitance of each anode.

In amplifiers with longer anode-circuit lead lengths, two or more of these suppressor assemblies can be connected in series with each anode lead for an even lower Q.

Results

The unruly KenwoodTL-922 amplifier will show no signs of instability after modifying the anode circuit with low “Q” conductor. The output power will remain unchanged on a wattmeter (although it is probably about 10 – 20 watts lower at 29MHz as a result of using the low “Q” anode circuit conductors).

The same anti-parasitic technique can be used on the Heathkit SB-220 amplifiers; the two, Henry Radio Co. 3CX1200A7 amplifiers and on the notoriously unstable Viewstar amplifier.

A Closer Look at How and Why a Successful Parasitic-Suppressor Works

A successful parasitic-suppressor must perform two, interrelated tasks. The first task is to reduce the flywheel-effect of a VHF self-resonant circuit by reducing the “Q” of that resonant circuit. The flywheel-effect is essential to oscillation. Reducing the flywheel-effect will reduce the chance of a parasitic oscillation. The second task of a suppressor is to reduce the VHF voltage gain of the amplifier stage.

The voltage gain of an amplifier is approximately proportional to the output load resistance (RL) placed on the amplifier-tube. High RL means high voltage gain and low RL means low voltage-gain. If the VHF voltage gain of an amplifier tube can be made low enough, by decreasing the VHF RL, the VHF voltage gain of the amplifier will be so low that it cannot oscillate at VHF. If a high-Q conductor inductor is used to connect the anode of the amplifier tube to the, essentially VHF-grounded, tuning capacitor, a high “Q” parallel-resonant circuit will be formed. The capacitance in this parallel resonant circuit is the output capacitance of the tube and the inductance is the built-in inductance in the leads between the anode connection [plate cap] and the tuning capacitor. A high “Q” parallel resonant circuit acts like a very high resistance at its resonant frequency. Thus, the amplifier has a very high RL and a very high voltage gain at the VHF resonant frequency which greatly increases the risk of a VHF parasitic oscillation. See Figure 1, C above.

A low “Q”, parallel resonant circuit will have a relatively low resistance at its resonant frequency. If two, low “Q”, paralleled, conductor/inductors of slightly different inductance are connected in parallel and to the same capacitor (C-out) a dual resonant, broadband effect and an even lower “Q” will result. This is similar to the broad banding effect that is achieved when the primary and secondary of an IF transformer are tuned to different frequencies. This technique lowers the VHF “Q” even further and decreases the VHF output RL which further decreases the VHF voltage gain of the amplifier. The goal of parasitic suppression is to reduce the net (VHF) voltage gain, by lowering the VHF “Q”, which lowers the VHF load resistance on the amplifier tube, so that the amplifier tube cannot oscillate.

In a typical parasitic suppressor, the two, low “Q” paralleled conductor inductors are: the suppressor's resistor, which makes the lower inductance current path, and the Nichrome inductor, which makes the higher inductance current path. Both of the inductances in a parasitic suppressor can also be constructed solely out of low “Q” wire or ribbon as was the case for the low “Q” replacement for the #12 copper bus-wire in the TL-922.

The "Bottom Line"

High “Q” conductors, such as silver and copper, are the best choice for the anode circuit/tank-circuit conductors in a VHF amplifier or VHF oscillator.

Copper is the best material for the conductors in a HF tank circuit or tuned input circuit. Silver plating the copper will improve the appearance but not the performance at HF.

Nichrome exhibits a very low VHF “Q”. Thus, it is a suitable material to use for anode circuit, input lead and suppressor conductors in an HF amplifier. Round conductors exhibit a lower VHF “Q” than flat conductors due to skin effect.

Appropriate Conductor Sizes

1/4 inch [6.35mm] Nichrome ribbon conductor is satisfactory for anode-circuits carrying up to about 8A of RF circulating-current. The circulating-current through the anode-lead of a typical 1500W amplifier is usually much less than this. The conductor width should be held to a minimum to lower the VHF "Q" for better stability. It would not be good engineering practice to use 1/4 inch Nichrome ribbon if a smaller conductor will carry the current. Bigger or wider conductors are not appropriate unless a smaller conductor is overheating from the RF circulating current during 10 meter band operation.

The safe RF current carrying capacity of #18 gauge Nichrome wire, in free-air, is approximately 3 amperes at 30MHz.

Construction Tips

Nichrome and stainless-steel can be easily soldered with an ordinary soldering iron by using a special flux that is made for soldering nickel chromium alloys and 430ºF tin silver solder. These materials are sold in hobby shops and in welding supply stores.

Notes

There is no single "sure-cure" for every case of amplifier instability.

1. Taming especially unruly amplifiers may require the intelligent use of a dip meter, several anti-parasitic techniques, more than one L/R parasitic suppressor per anode lead and a VHF "Q" lowering, metal film [MF] resistor in series with the L/R parasitic-suppressor.
2. In some cases, it may help to add a low "Q", series resonant L/R/C suppressor between the cathode and ground. The resonant frequency of this series circuit should be at, or slightly higher than, the self-resonant frequency of the anode circuit. The resistor should be a 1 – 5 ohm, 2W MOF or MF type and the capacitor is 25pF. The inductance is controlled by adjusting the lead lengths on the resistor and the capacitor. The resonant frequency of this circuit is difficult to check because the cathode must be directly shorted to ground and the resistor must be bypassed with a straight wire in order to find the dip on a dip meter.
3. In rare cases, a VHF self-resonance in the anode HV RF choke or in the filament choke can become a player in a parasitic-oscillation. This problem can be overcome in these ways:
    a. A filament-choke can be effectively isolated by placing a VHF attenuator rated ferrite bead (Mu850) over each filament lead on the filament side of the filament-choke.
    b. An anode HV RF choke can be effectively isolated by placing an un-bypassed 10 - 15W, wire wound resistor in series with either end of the choke.