Neutralizing grid driven amplifiers de-mystified part 2

This paper is part 2 of understanding neutralization. Part 1 is a prerequisite for part 2 and can be found at http://www.k9axn.com/_mgxroot/page_10873.html

The intent of part 2 is to provide a comprehensive understanding of the concepts surrounding **neutralization and negative feedback in multiband grid driven amplifiers.**

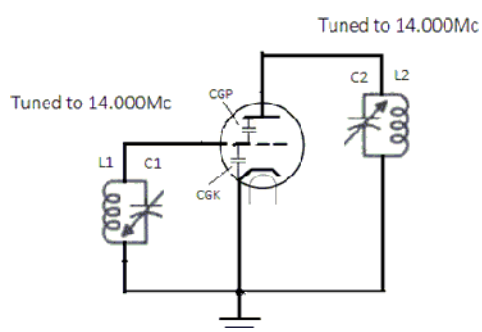
Most grid driven tube type transceivers and amplifiers use the Bruene single ended neutralizing technique invented by Warren Bruene in the early 50's.

The design provides two benefits; Neutralization for stability and Negative Feedback to improve linearity and IMD. The natural negative feedback available in grid driven amplifiers is seldom exploited because so little is written to describe the concept. Both benefits will be addressed in depth using schematics, explanations, and limited math.

With a comprehensive understanding of the circuits, it will become apparent that precise neutralization on all bands is important for stability and linearity, not just for the 10 Metre band. Understanding these concepts will enable you to choose for yourself what to believe and what to expect from the radios that you work with.

1. UN-NUTURALIZED GRID DRIVEN AMPLIFIER *

Schematic 1 is an un-neutralized, tuned grid – tuned plate (TGTP) amplifier.



SCHEMATIC 1

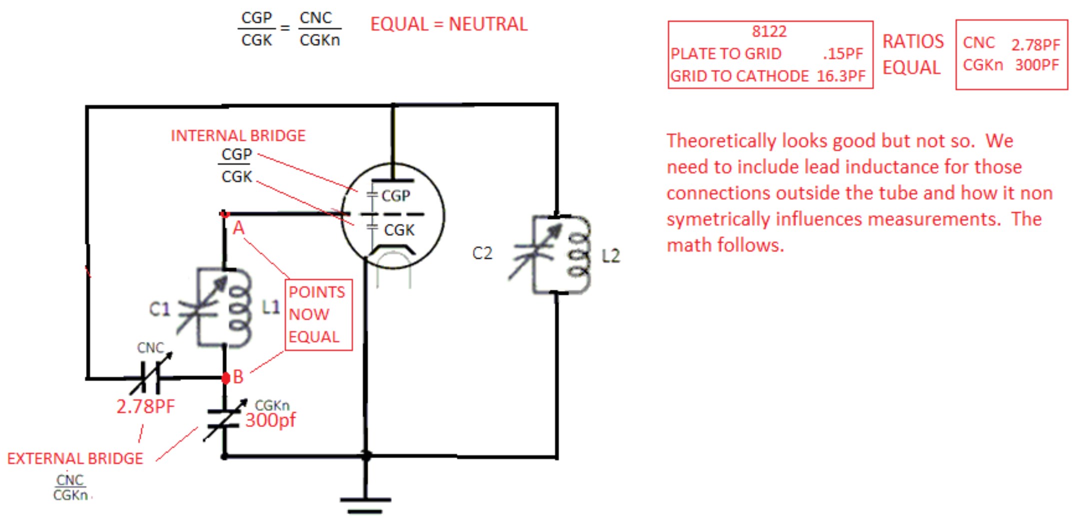
Note the internal voltage divider consisting of the plate to grid (CGP) and grid to cathode (CGK) capacitors. The center of the internal voltage divider CGP/CGK represents a fraction of the plate voltage coupled back to the control grid. At resonance it will be 180 degrees out of phase with the grid drive, effectively representing NEGATIVE feedback. When the plate is not resonant the feedback effect will be negative and phase shifted. Un-neutralized, this amplifier will be difficult to drive, non-linear, and unstable due to the **parasitic Hartley effect** which was explained in part 1.
http://www.k9axn.com/_mgxroot/page_10873.html

The plate to grid feedback **will not cause** the amplifier to oscillate at the **tuned frequency** because it is degenerative. It can however, oscillate slightly below the tuned frequency, again, because of the Hartley effect which was explained in part 1. Important to remember is the ratio of CGP/CGK determines the level of feedback not just CGP alone.

2. NEUTRALIZED GRID DRIVEN AMPLIFIER *

Schematic 2 represents the same amplifier using an 8122 tube, adding the external neutralizing bridge**.** There are two capacitive bridges; one internal to the tube and one external. The internal bridge is within the 8122 consisting of (CGP .15pf and CGK 16.3pf) and the external bridge consists of capacitors (CNC 2.78pf and CGKn 300pf). The ratios of both bridges are 108 and equal based only on the capacitive values in the schematic.

Theoretically, if the ratios of the internal and external bridge capacitors are equal the amplifier will be neutral because the voltage fed back from the plate will be equal at points A and B.



SCHEMATIC 2 --- NEUTRALIZED

This schematic would have you believe the capacitive ratio in the external bridge to be equal to the internal bridge and they are for 10 through 80 Meters --- **in the absence of inductance**.

The note in the schematic refers to the inductance in the external bridge and the influence it has on the overall functioning of the neutralizing design. You will see it to have a profound effect on multi band amplifier design.

To prove this, calculate the correct values for CGKn and CNC including the inductance of the components and connections. The intent is to understand why the above bridge component values will be patently incorrect for the 29Mc band when considering only capacity.

Then using the corrected component values for 29Mc, calculate how they will work at 3.7Mc. You will see the corrected values used to neutralize 29Mc will be patently incorrect at 3.7Mc. The components will work perfectly at 29Mc and become progressively over neutralized at 3.7Mc.

3. Calculate the values of the external bridge corrected for inductance *

Assumptions used to calculate the design of the external bridge:

*Wire has approximately .020uh per 1 inch.
*The **bypass** capacitor, CGKn, will have a diameter of $^1/_2$" with $^1/_4$" leads for a total of 1".
*The **neutralizing** capacitor, CNC, will require a total of 6 inches to connect.
*The internal bridge ratio for the 8122 is 108 thus the ratio for the external bridge must be 108.
*The anchor for the external bridge is CGKn, the 300pf bypass capacitor which is fixed.

Calculations for 29Mc integrating lead and component inductance

Capacitive and inductive **reactance** will be used to design the external bridge in order to integrate the inductance of the connections. The calculated capacitive and inductive reactances at 29Mc will then be combined to calculate the **effective capacity of the combined components.**

***First determine the effective capacity of the fixed 300pf anchor capacitor CGKn at 29Mc.**

To do this, calculate the affect that inductance has on the capacitive reactance of CGKn. Subtract the inductive reactance of CGKn from the capacitive reactance at 29Mc. CGKn is a $^1/_2$ inch disc ceramic with $^1/_4$ inch leads for a total of 1"; One inch has .020uh of inductance. The capacitive reactance is 18.3 ohms and the inductive reactance is 3.64 ohms. Combine the capacitive and inductive reactance 18.3-3.64=14.66 ohms capacitive.

Now calculate the effective capacity for 14.66 ohms at 29Mc; 1/(6.28x14.66x29,000,000) = 375pf. The inductance of a 1" length of wire changed the effective capacity of the 300pf capacitor to 375pf at 29Mc. The ratio needs to remain 108 so the effective capacity for CNC the neutralizing capacitor needs to be recalculated; 375pf/108 = 3.47pf. We now know the corrected effective capacity, 3.47pf for CNC and need to calculate the real capacity. The inductance for the 6 inch lead to connect CNC is .120uh rendering 21.85 ohms of inductive reactance @ 29Mc. The effective capacity of CNC will be 3.47pf and is 1582 ohms of capacitive reactance.

The corrected real capacity of CNC will need to be 1582+21.85 = 1604 ohms. The capacity will be 1/(6.28x29,000,000x1604) = 3.42pf. The inductive reactance will decrease the capacitive reactance causing the 3.42pf cap to appear as a 3.47pf capacitor. The new capacitive values for the bridge will be 300pf/3.42pf for 29Mc not 300pf/2.78pf. If you use the new capacitive values to calculate the bridge ratio, it will be 88 not 108. The added inductance renders a ratio of 108 at 29Mc not 88.

Note how the inductance radically changed the capacitive value of CGKn and barely nudged CNC. Look at the ratio of the real capacitors ignoring inductance, 300pf/3.42pf = 88 and the corrected ratio of effective capacity 375/3.47 = 108. The ratios for the internal and external bridges will be equal using a 300pf cap for CGKn and 3.42pf cap for CNC at 29Mc. Remember this is at 29Mc.

We've seen how the lead inductance affected CGKN and CNC on the 29Mc band. Now determine how the ratio is affected when using the same components and switching to the 3.7Mc band.

Calculations for 3.7Mc integrating lead and component inductance

The same capacitors used for the 29MC band, CGKn 300pf and CNC 3.42pf will be used for the 3.7Mc calculations to demonstrate why the amplifier will become progressively over neutralized as you descend to the lower bands.

CGKN:
300pf @ 3.7Mc. The capacitive reactance is 143 ohms and the inductive reactance is .465 ohms. Capacitive reactance is 143 - .47 = 142.5 ohms. The effective capacity of CGKn is 301.7pf at 3.7Mc. The capacity is essentially unchanged.

CNC:
3.42pf @ 3.7Mc. The capacitive reactance is 12582 ohms. Inductive reactance is 2.79 ohms. The capacitive reactance 12582 - 2.8 = 12579. The effective capacity is 3.42pf --- virtually unchanged.

CONCLUSION:
The external bridge ratio is 108 at 29Mc and 88 at 3.7Mc. It is progressively over neutralized on the lower bands. The inductance of the 1" length used to connect CGKn to the circuit has an extraordinary effect on neutralization with the lower bands when using the 29Mc values.

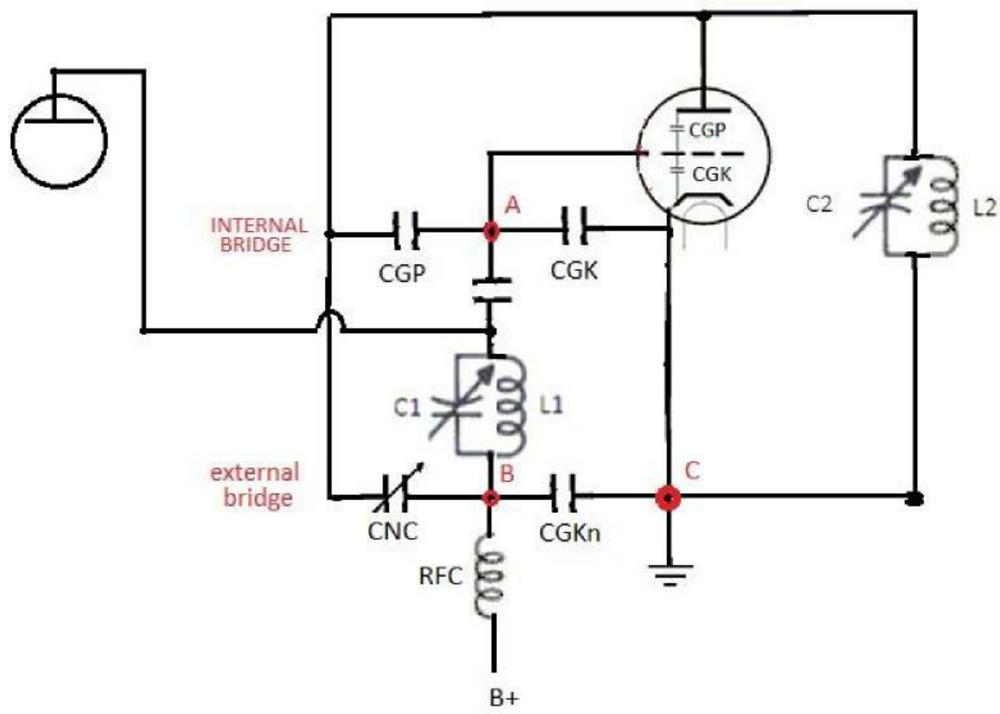
Is there reason to care? Yes, over neutralizing is REGENERATIVE feedback which can provoke oscillation and damage linearity and IMD numbers.

4. How neutralization affects the stability, linearity, and IMD of a grid driven amp

The single ended Bruene neutralizing bridge in schematic 3 provides two benefits, neutralization and negative feedback to improve linearity and IMD.

NOTE: PRINT SCHEMATIC 3 TO FOLLOW ALONG.

SCHEMATIC 3



Neutralizing and negative feedback redrawn to simplify circuit logic.

NEUTRALIZATION:

Point A, the top of the input tuned circuit is connected to the center of the internal bridge (CGP/CGK) which is drawn outside of the tube for clarity. Point B is connected to the center of the external bridge. The ratios, being equal, neutralize the effect the plate feeds back to the **tuned circuit** because both ends have exactly the same feedback voltage applied.

The **balanced voltage and any phase differences** fed back to point's A and B leave the input tuned circuit unaffected by plate feedback. **You can dial the plate tuning capacitor wherever you like and the grid tuned circuit will remain unmolested. The earlier video clip demonstrates this point**. Many papers written stating that the input circuit is neutral only when resonant with the plate are incorrect.

NEGATIVE FEEDBACK:

The single ended Bruene neutralizing circuit has one other very significant benefit. It exploits the plate to grid capacity to generate negative feedback that can be used to improve linearity and IMD. The negative feedback is generated across points B and C.

CALCULATE THE AMPLITUDE OF NATURAL NEGATIVE FEEDBACK:

The attainable natural negative feedback in a tube can be determined PRIMARILY by the ratio of CGK/CGP. There are other important influences but for the moment we'll focus on the CGK/CGP ratio. The Burle 8122 has a ratio of (108), the 6146 (61), and the 6KD6 (50); the lower the ratio the greater the negative feedback. This contradicts the notion that sweep tubes are less linear than the 6146.

The formula 20log (Voltage between A B/A C) is used to calculate the level of negative feedback in db. The number of db calculated will be very close to the improvement in IMD numbers.

To make sense of it, assume the drive voltage is 5.0 vpp across the tuned circuit A B and the feedback is 1.0 vpp across point B C. The voltage across B and C is 180 degrees out of phase with the drive voltage applied to the tuned circuit points A and B. The result, point A to C will be 5.0v - 1.0v = 4.0v PP.
20 log 5.0/4.0 = 1.94db --- It would have been 3db if it was 10.0vpp/7.0vpp or 6db if 10.0vpp/5.0vpp.

HOW TO SEPARATE AND MEASURE THE DRIVE AND NEGATIVE FEEDBACK

Run this video http://k9axn.com/_mgxroot/img_1323988130_15155_1454557028.avi --- **it is a correctly neutralized** Hallicrafters SR-2000 transceiver.

The top trace is the grid voltage to ground and the bottom trace is the plate voltage. The plate is tuned back and forth through resonance. Make special note, the phase of the plate is deviating close to 90 degrees from resonant yet the grid voltage remains symmetrical and unchanged except for a dip at resonance.

The tuned circuit in the grid will be unaffected by the plate voltage or phase because the plate and all of its properties are coupled to both sides of the tuned circuit and canceled.

NOTE: THE TUBE WILL BE NEUTRAL WITHOUT REGARD FOR HOW IT IS TUNED; RESONANT OR NOT RESONANT. THERE IS A COMMON THREAD THAT SUBSCRIBES TO THE NOTION THAT THE TUBE IS NEUTRAL ONLY AT RESONANCE, IT IS NOT TRUE.

The grid dip at resonance is a result of the negative feedback impressed across points B and C. It's always been said the **grid voltage** should be unmolested when tuning the plate through resonance if the amp is neutral. More accurately stated, the drive voltage across the **tuned circuit** points A and B will be unmolested and it is shown in this video. However the measurement from **grid to ground** will be depressed at resonance due to the added negative feedback across points B and C.

To separate and measure the drive and negative feedback, tune the amplifier into a dummy load at a comfortable level, then detune the plate and measure the grid voltage. Now tune the plate to resonance and re-measure the grid voltage. It will be reduced by the level of negative feedback across B and C . With that ratio you can calculate the negative feedback in db.

THIS IS THE NEUTRAL STATE AND THE POINT AT WHICH MAXIMUM NEGATIVE FEEDBACK IS ACHIEVED AND AN INDICATION THAT THE TUBE IS PRECICELY NEUTRAL. If there is no grid voltage depression at resonance, the tube is over neutralized resulting in positive regenerative feedback.

PRECISION NEUTRALIZATION:

Precision neutralization on all bands is often trivialized because of the notion that only the 10 and maybe 15 meter bands require it. Remember the lower bands will go progressively over neutralized resulting in positive regenerative feedback if they aren't neutral.

Positive feedback is caused by excessive feedback from the neutralizing capacitor. This feedback is fed to point B, the bottom of the **grid tuned circuit** which is 180 degrees from the grid side and regenerative to the tuned circuit.

Excessive neutralizing feedback will cause poor linearity and can cause the amp to oscillate. This oscillation will occur at the tuned frequency whereas under neutralizing can cause oscillation just below the tuned frequency.

One way to implement Precision neutralization for all bands is to replace CGKn with variable capacitors for all bands except 10 meters. This way every band will be precisely neutral without regard for what tubes you install. Sweep tube amplifiers generally have individual fixed CGKn capacitors for each band.

FALSE RESULTS IN IMD TESTING:

IMD measurements performed on class AB1 transceivers are seldom accurate or comprehensive. In order to acquire accurate IMD measurements the radio must be aligned properly and precisely neutralized. Any deviation from precise neutralization can result in a variation in IMD of up to several db. A slight variation in the synchronized plate dip and max out will decrease the linearity of the radio markedly. The design of the transceiver limits what you can expect and what you can do if anything to improve performance.

Other neutralizing configurations