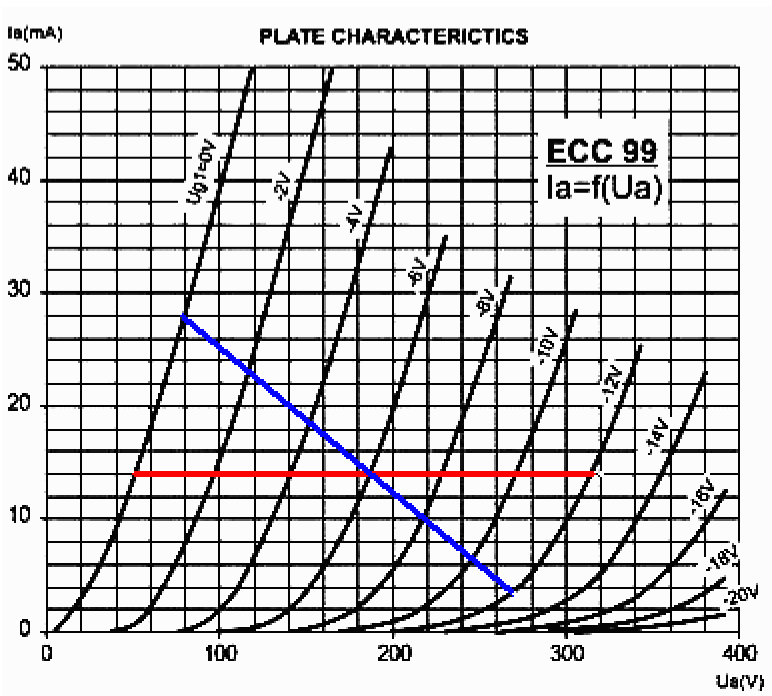
Active loads and signal current control

The use of active loads (CCS's) in vacuum tube amplifiers has several advantages over resistive loads. These including full mu of the tube, lower distortion, and greatly improved power supply noise rejection.

When using active loads the load line presented to the triode is a horizontal line versus the diagonal line seen by resistive loaded stages. Transformer and choke loading also provides a horizontal load line in the midrange frequencies but goes reactive at low frequencies where the inductance limits the performance and at high frequencies where the inter-winding capacitance limits the performance.



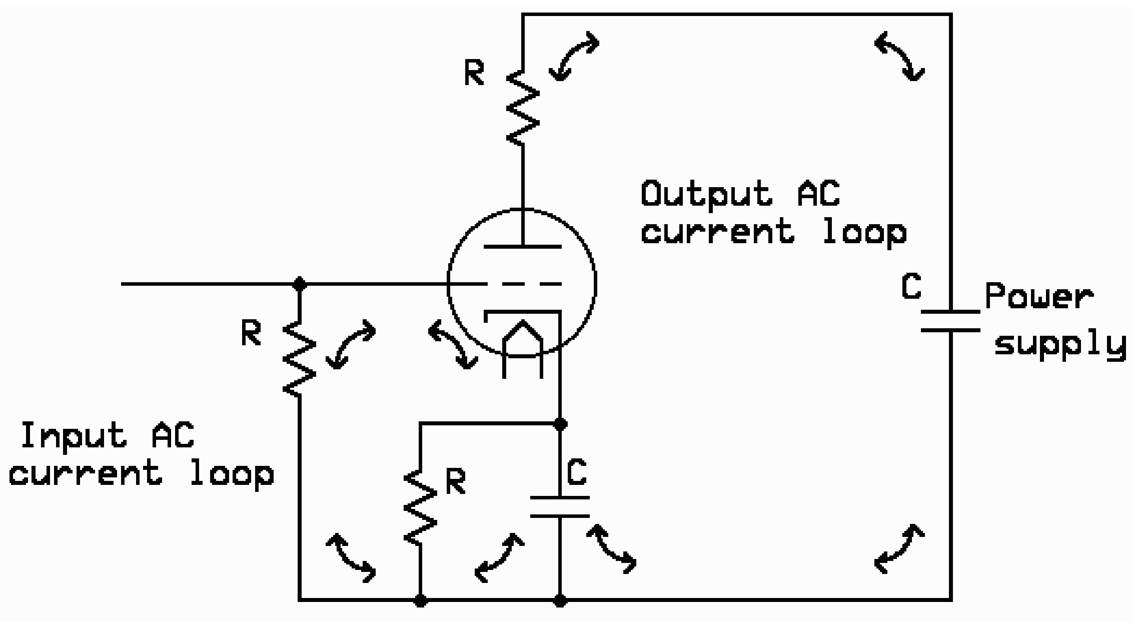
The horizontal line represents the load line when using a CCS plate load. The diagonal load line represents a 15K resistive plate load. Working off the too small graph we can determine roughly that with a 12 volt P-P input signal the resistive load would give an output voltage of 188 volts P-P where the CCS load would give an output voltage of 269 volts P-P. If you compare the spacing of the grid curves you can see that with the CCS load the lines are much more evenly spaced.

Active loads are also very good at increasing power supply isolation. The CCS appears as a very high impedance low reactance load. The ratio of the high impedance of the CCS against the plate resistance of the triode determines the power supply isolation (ripple rejection). I prefer the use of the term power supply isolation instead of ripple rejection as it offers a more comprehensive view of workings of the amplifier. The low reactance means the CCS will remain a high impedance load over a very wide range of frequencies.

Active loads are also a tool that can be used to control where the AC signal current flows. When active loads are coupled with shunt regulators, the use of large capacitors in the signal current loop can be avoided.

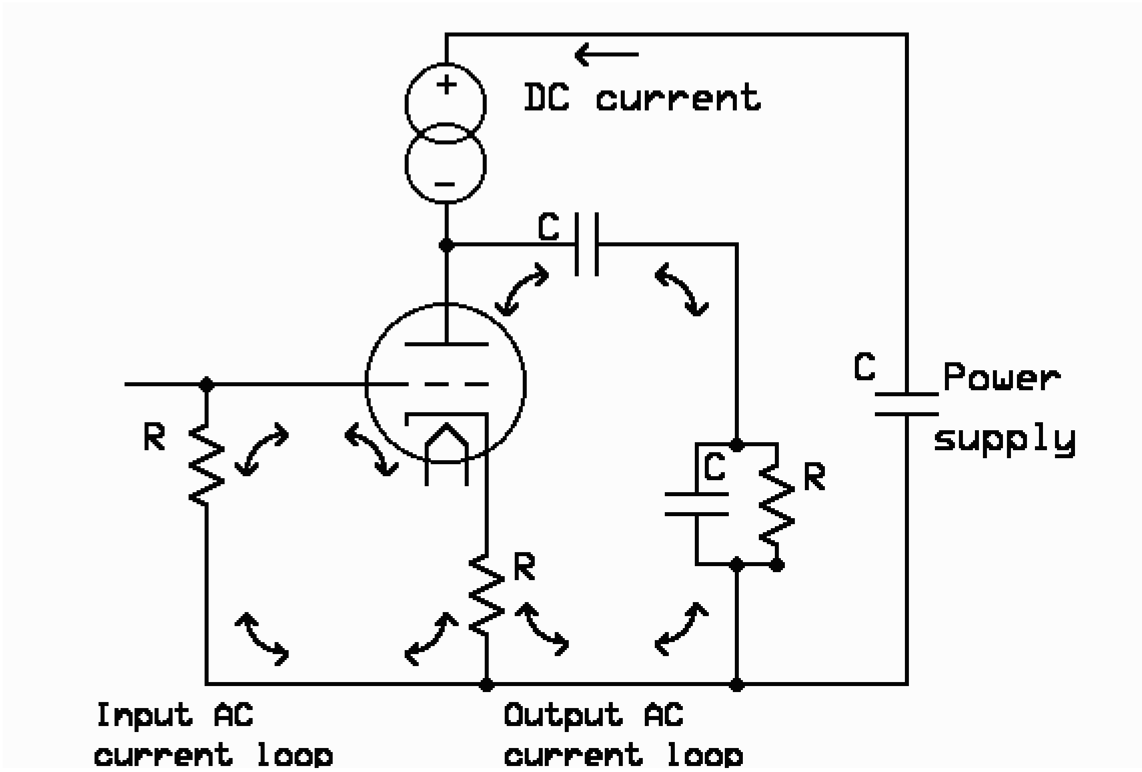
One of my design goals is to have the power supply responsible only for supplying DC current for the operation of the stages and to have the AC current paths separate from the power supply.

Conventional SE stage



In conventional SE circuits the power supply is an integral part of the signal current loop. This makes for a signal loop that has at minimum, 4 components in the AC path, the plate load, power supply capacitor, cathode bypass capacitor and the triode. In most cases, the cathode bypass cap and the final capacitor in the power supply are large capacitors, usually electrolytics that have less than stellar sonics. Another problem that plagues conventional SE circuits is poor power supply isolation.

SE stage with active load



When we add an active load the basic operation of the stage changes. Now the power supply only provides DC operating current as the CCS provides isolation between the power supply and the triode. With the CCS holding the current drawn from the power supply steady the demands on the power supply are greatly reduced.

The great power supply isolation provided by the CCS makes the design of the power supply much less critical. Depending on the performance of the CCS, power supply isolation of over 100dB is possible. It is not necessary to have super low ripple and noise with this kind of isolation available.

Another feature of having the current through the triode held constant by the CCS, we can dispense with the cathode bypass capacitor. The constant current flowing through the cathode resistor provides a constant DC voltage to bias the stage. Effectivly the stage operates with fixed bias.

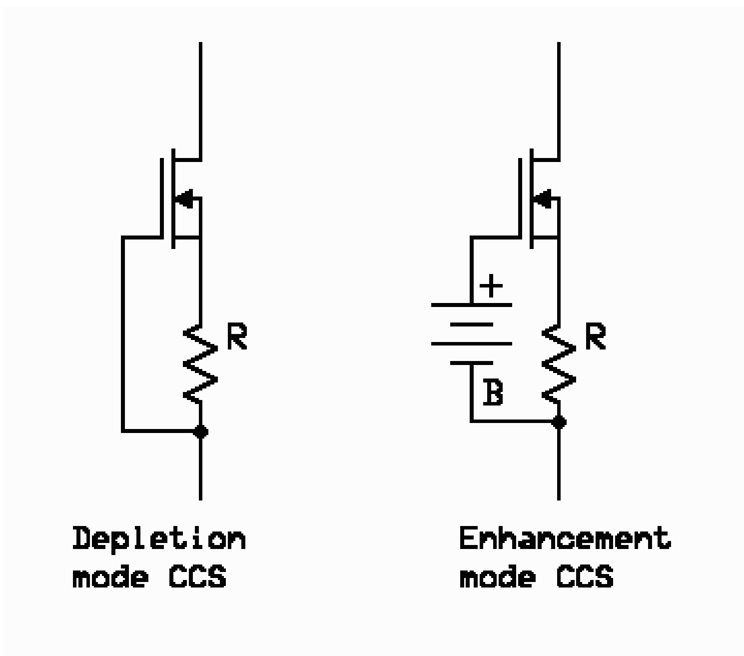
This holds for light loads driven by the stage. If the next stage is a heavy load requiring current to be delivered the tube will come out of constant current operation. In RC and DC coupled circuits the predominant load is usually the miller capacitance of the next stage. The capacitive load causes the horizontal load line to become elliptical at high frequencies increasing the distortion. This could be one of the contributors to harsh, strident, grainy high frequency sound.

To overcome the loading issues a follower circuit can be used to isolate the load from the triode. The CCS's I have designed have the capability of performing as a source follower without any modifications. This could be viewed as an advantage to having the voltage reference and current setting hardware at the bottom of the CCS.

Before moving on to the follower ideas, a basic understanding of CCS operation is necessary.

Overview of a simple CCS

One of the simplest CCS's to setup uses a single mosfet. There are 2 kinds of mosfets that can be used to build CCS's. Depletion mode mosfets are normally "on" and enhancement mode mosfets are normally "off". It only takes a single resistor to make a CCS with a depletion mode part where it takes a voltage source (battery) and a resistor to build a CCS from an enhancement mode mosfet.



To use a depletion mode mosfet as a CCS the fist step is to refer to the part's data sheet. Find the performance curves plotting current Vs drain voltage. They will look like nice pentode plate curves. Look for the bias voltage at the current you want the CCS to operate at. The value of the current set resistor will be the bias voltage divided by the operating current. The value may need to be adjusted slightly to get due to turn-on voltage variations in the mosfets.

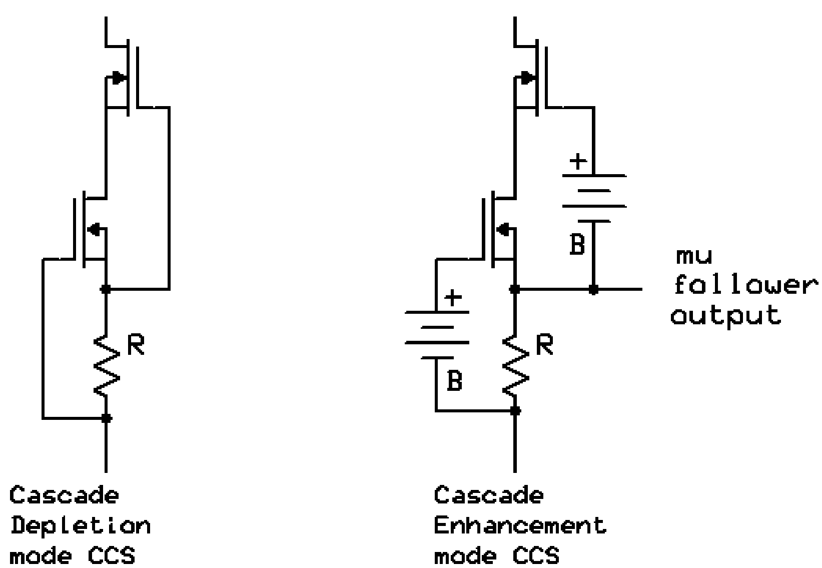
To use an enhancement mode mosfet as a CCS we need to provide a bias voltage (battery) to turn the mosfet on. You will need to refer to the data sheets to find what the turn-on voltage is at the required current. The value of the current set resistor will be the battery voltage minus the turn-on voltage of the mosfet.

The disadvantage to single mosfet depletion mode CCS’s is relatively poor performance. When using the depletion mode mosfet as a CCS the bias voltage available to set the current is usually 1 volt or less. The low bias voltage does not provide good feedback to stabilize the operating current.

When using enhancement mode mosfets with batteries to provide bias the voltage can be up to the gate voltage limit of the mosfet, typically 20 volts. The higher voltage provided by the batteries provides much better internal feedback in the CCS. This increases the performance by a large margin. Batteries can also be used with depletion mode mosfets to improve the performance of the CCS.

Another poor performance aspect of single mosfet CCS’s is high shunt capacitance. Mosfets look like great parts until you take into account their high capacitance issues. I suspect that the shunt capacitance is the source of most of the sound coloration’s that make CCS’s sound different.

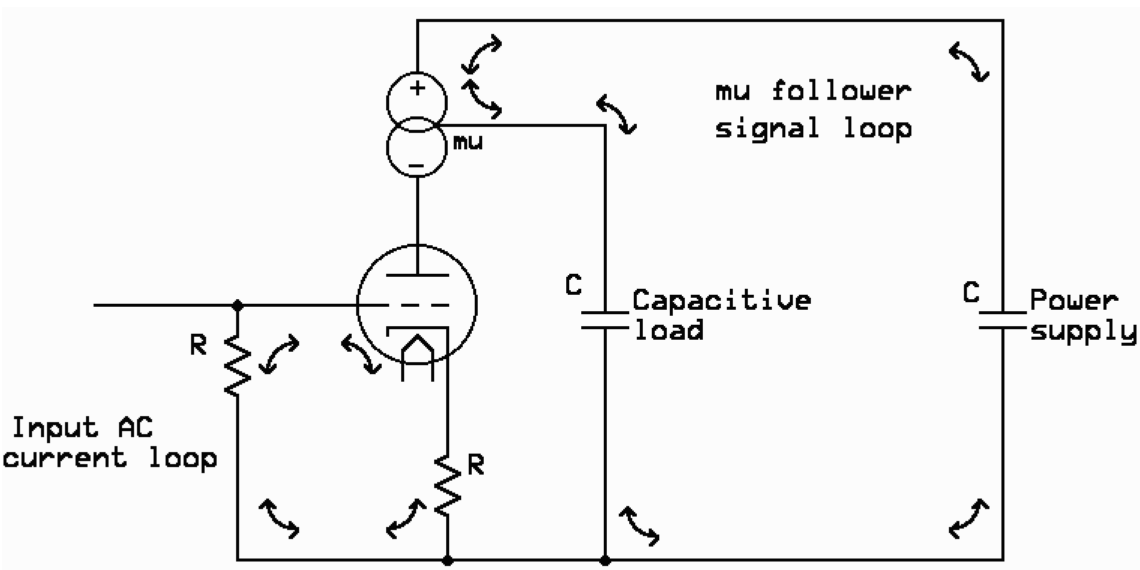
The use of a cascade circuit configuration will greatly reduce the shunt capacitance and improve the DC performance of a CCS.



Performance in a cascode circuit improves because the upper mosfet isolates the lower mosfet from voltage variations. At higher frequencies where the capacitance issues come into play the AC leakage current that couples across the drain to the gate of the upper mosfet is routed back into the current summing node of the CCS, the source of the lower mosfet. There will be very little AC leakage current from the drain to gate of the lower mosfet, as it is isolated from the AC signal by the upper mosfet. With the upper mosfet handling the AC signal voltage the lower mosfet basically operates at DC.

Using a CCS as a combined CCS and mu follower

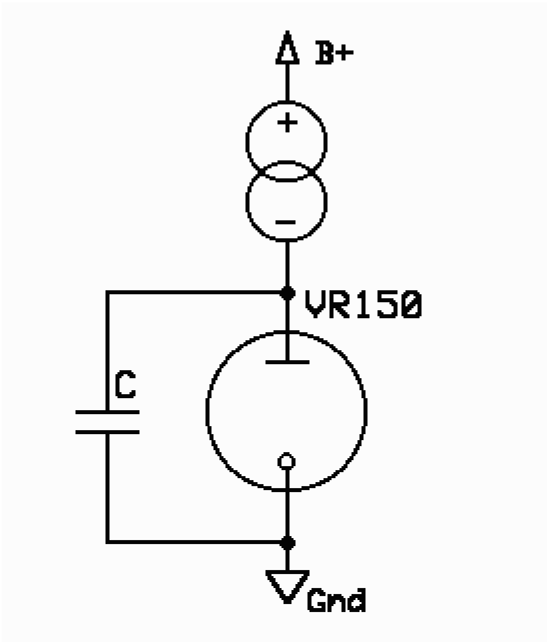
When an n-channel mosfet is used for a CCS we have an opportunity to get a second function almost for "free". The output signal can be taken from the source of the lower mosfet instead of the plate of the triode. Refer to the schematic above to see the circuit detail of where the signal is taken from.



When driving output triodes or interconnect cables that are high capacitance loads, this arrangement works very well. The driving triode is isolated from the load capacitance to maintain constant current operation at high frequencies and the next stage is driven from low source impedance.

The drawback to this arrangement is the current to drive the next stage comes from the power supply, it violates the design concept of separate paths for AC and DC.

CCS fed shunt regulators



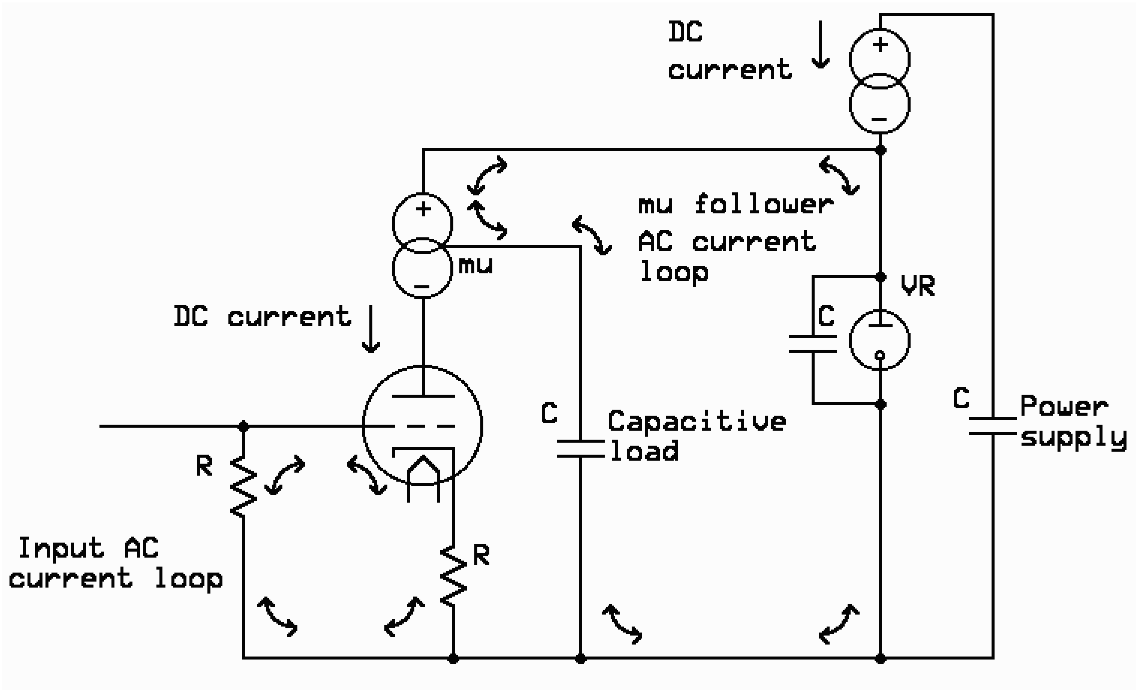
A CCS feeding a VR tube forms a simple shunt regulator circuit that has excellent performance (and the glowing VR tubes look great too).

Shunt regulators work by varying the current they draw from a circuit to maintain a fixed voltage. If the voltage tries to increase the shunt regulator increases the current it draws. Conversely, if the voltage starts to decrease the shunt regulator decreases the current draw to hold the voltage stable. The simplest shunt regulator is the VR tube or "gas zener".

Depending on VR tube family the operating current can be from 3ma to 40ma. The miniature tubes generally are 3 to 30 ma while the octal tubes are 5 to 40 ma.

VR tubes are quite inductive. To improve the high frequency performance a small capacitor can be added in parallel with the VR tube. Most VR tubes have a maximum capacitance specification of .1uf. If the capacitance is increased above .1uf the VR tube and capacitor can form a relaxation oscillator and will start to oscillate. I have been using .056uf capacitors with good results.

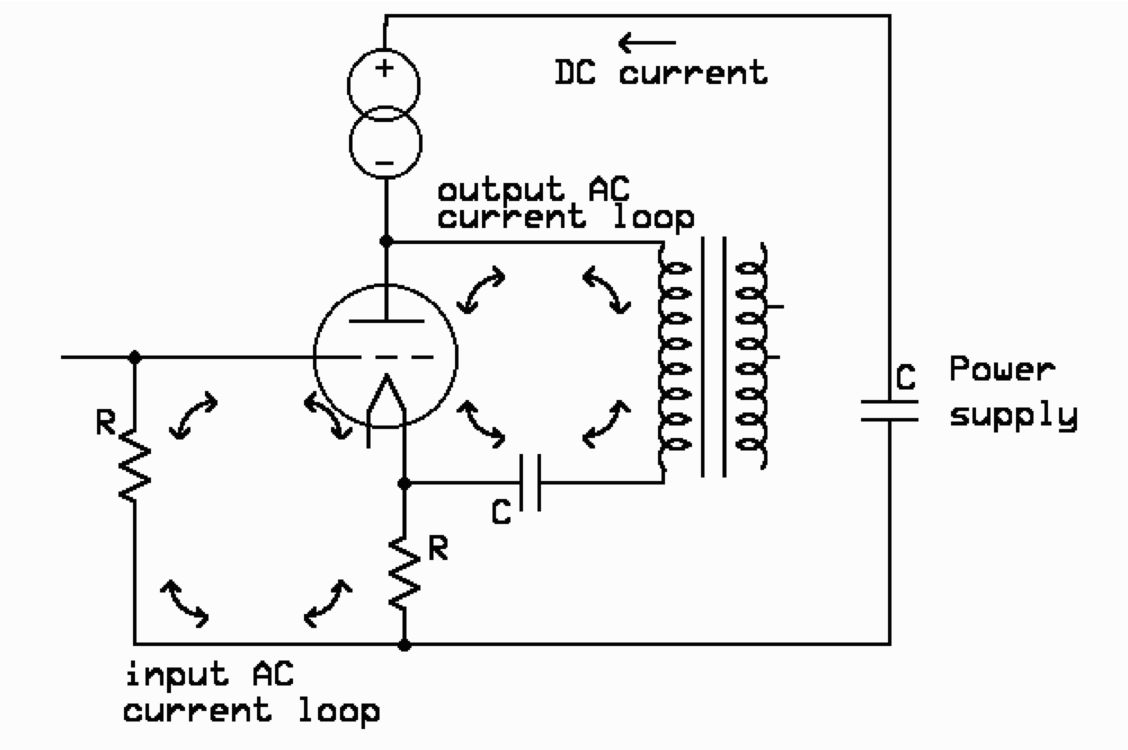
A CCS fed shunt regulator is placed between the power supply and the CCS feeding the triode. This isolates the signal path from the power supply.



To setup a CCS fed shunt regulator in this application you set the upper CCS for the current that the lower CCS is set for plus the current to bias the VR tube. Assuming the lower CCS is set to deliver 10ma to the triode and the current desired in the VR tube is 15ma, the upper CCS would be set to deliver 25ma.

It is interesting to note that only the circuits using the mu output have the triode operating in true constant current mode. In the other variations of CCS loaded triodes where the signal is taken from the plate, the plate current varies in proportion with the load current.

CCS loading of output stages



Output stages are a different case. The CCS is used as a high performance replacement for the plate choke. The CCS offers performance that is simply not achievable with inductors.

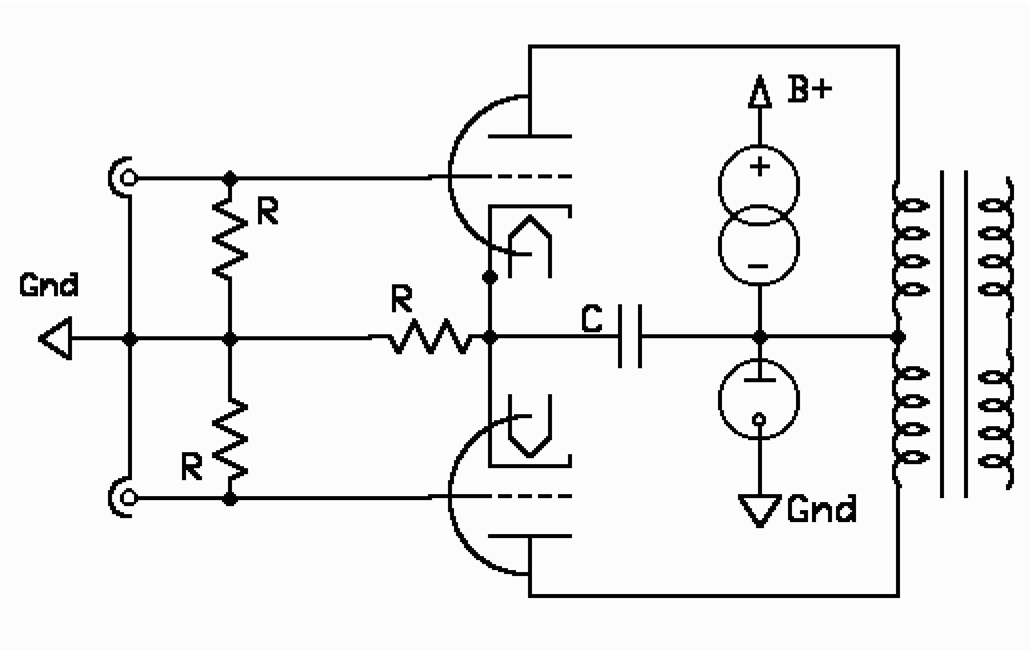
The object is not to operate the triode at constant current but to provide the output stage with a constant bias current that does not change over the operating frequency range of the amplifier.

In this arrangement the output stage as a whole operates at constant current. With the triode working into the load presented by the output transformer. The sum of the AC currents through the triode and the primary of the output transformer will equal the DC current set by the CCS.

The use of CCS's use in P-P stages

There are a couple of ways that CCS's can be used in P-P stages.

CCS fed shunt regulator to feed the plates. This provides a stable clean supply for the stage.



A CCS can be used on the cathodes of a P-P input stage. This allows the input stage to perform the phase splitting duties.