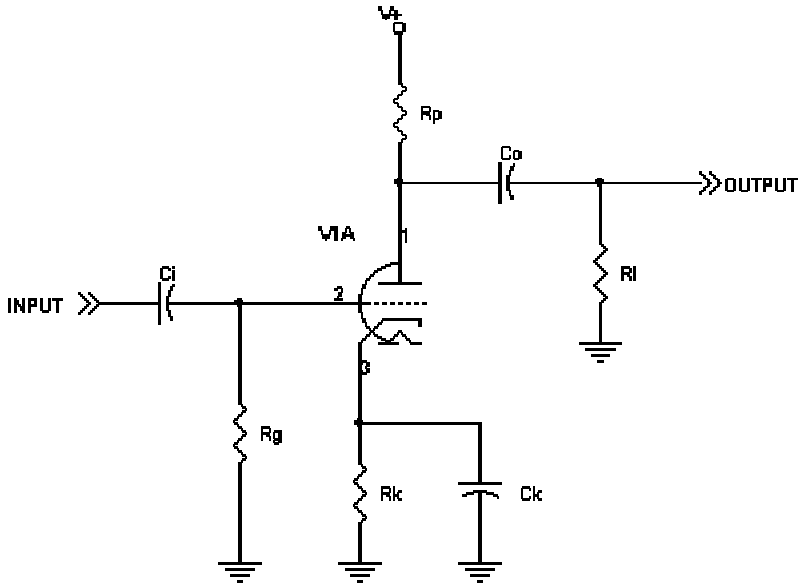
Vacuum Tube Amplifier Circuits and Equations

General

Following is a collection of tube amplifier circuits and equations. It will be updated regularly as new papers on different tube circuits and configurations are added to the website (beh ormai l'ho stampato).

Common-cathode stage, fully-bypassed cathode:



Voltage Gain:

$Av = (mu * Rp)/(Rp + r_a)$

Input impedance:

$Rin = Rg$

Output impedance (plate):

$Rout = (r_a * Rp)/(r_a + Rp)$

Output impedance (cathode):

$Rk' = (Ra+r_a)/(mu+1)$
$Rout = Rk'||Rk$

Input capacitance:

$Cin = Cgk + Cgp*(Av + 1)$

Frequency response:

f1 = 1/(2*pi*Ci*Rg) - highpass breakpoint due to Ci/Rg

f2 = 1/(2*pi*Co*(Rout + Rl)) - highpass breakpoint due to Co/Rout/Rl

f3 = 1/(2*pi*Ck*Rk'||Rk) - highpass breakpoint due to Ck/Rk

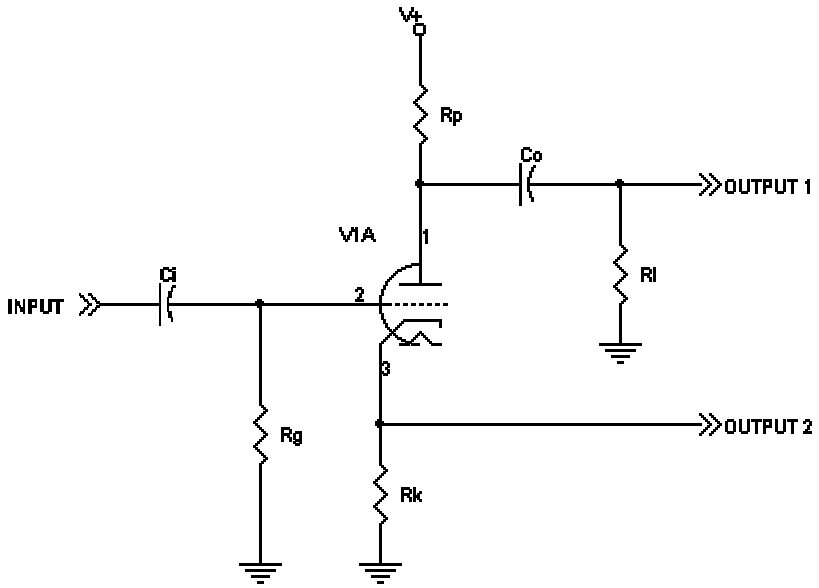
f4 = 1/(2*pi*Rout*Cin) - lowpass breakpoint due to Rout of previous stage and Cin

Where:

Rg = the grid resistor
Rp = the plate resistor
Rl = the load resistance, or the input resistance of the next stage
Ra = the total load resistance, which is Rp in parallel with the input resistance of the next stage, Rl. If there is no Rl, Ra = Rp.
r_a = the internal plate resistance of the tube
mu = the mu of the tube
Cgk = the grid-to-cathode capacitance
Cgp = the grid-to-plate capacitance
Av = the stage voltage gain

Note that Rl is ignored in the output impedance calcuations for the output, not because it doesn't affect output impedance of the overall circuit, but because output impedance is traditionally the impedance of the output of that gain stage looking back into the output. Rl is the input impedance of the following stage, so it is not included. Of course, when calculating overall gain in an amplifier, the loading effect of Rl must be taken into account. In the case of the cathode impedance, Rl must be included because it will affect the impedance seen looking back into the cathode.

Common-cathode stage, unbypassed cathode:



Voltage Gain (Output 1):

Av = (mu * Rp)/(Rp + r_a + (mu + 1)*Rk)

Input impedance:

Rin = Rg

Output impedance (Output 1):

Rout = [(r_a + (mu + 1)*Rk) * Rp] / [(r_a + (mu + 1)*Rk) + Rp]

Output impedance (Output 2):

Rout = [(Ra + r_a)/(mu + 1) * Rk] / [(Ra + r_a)/(mu + 1) + Rk]

Frequency response (Output 1):

f1 = 1/(2*pi*Ci*Rg) - highpass breakpoint due to Ci/Rg

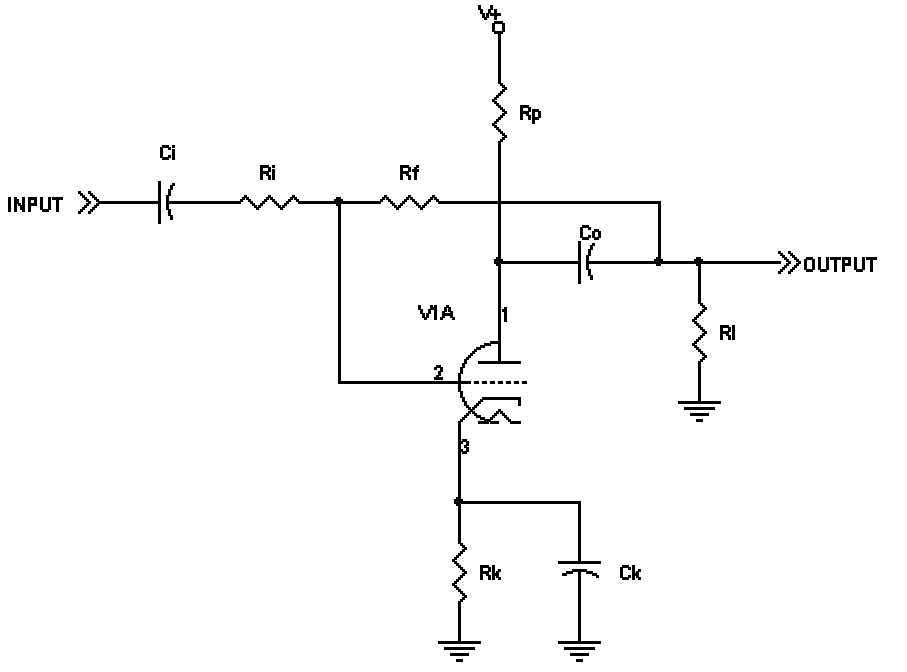
f2 = 1/(2*pi*Co*(Rout + Rl)) - highpass breakpoint due to Co/Rout/Rl

Where:

Rg = the grid resistor
Rp = the plate resistor
Rk = the cathode resistor
Rl = the load resistance, or the input resistance of the next stage
Ra = the total load resistance, which is Rp in parallel with the input resistance of the next stage, Rl. If there is no Rl, Ra = Rp.
r_a = the internal plate resistance of the tube
mu = the mu of the tube

Note that Rl is ignored in the output impedance calcuations for output 1, not because it doesn't affect output impedance of the overall circuit, but because output impedance is traditionally the impedance of the output of that gain stage looking back into the output. Rl is the input impedance of the following stage, so it is not included. Of course, when calculating overall gain in an amplifier, the loading effect of Rl must be taken into account. In the case of the output taken from the cathode, Rl must be included because it will affect the impedance seen looking back into the cathode.

Single-stage inverting feedback amplifier:



Gain:

Acl = (Ro + A*Rf) / (Ri + Rf + Ro - Ri*A)

Input impedance:

Rin = (Ri * A - Ri - Rf - Ro)/(A-1)

Output impedance:

Rout = (Ri + Rf) * [Ro / (Ri + Rf + Ro - Ri*A)]

Frequency response:

f1 = 1/(2*pi*Ci*Ri) - highpass breakpoint due to Ci/Ri

f2 = 1/(2*pi*Co*(Rout + Rl)) - highpass breakpoint due to Co/Rout/Rl

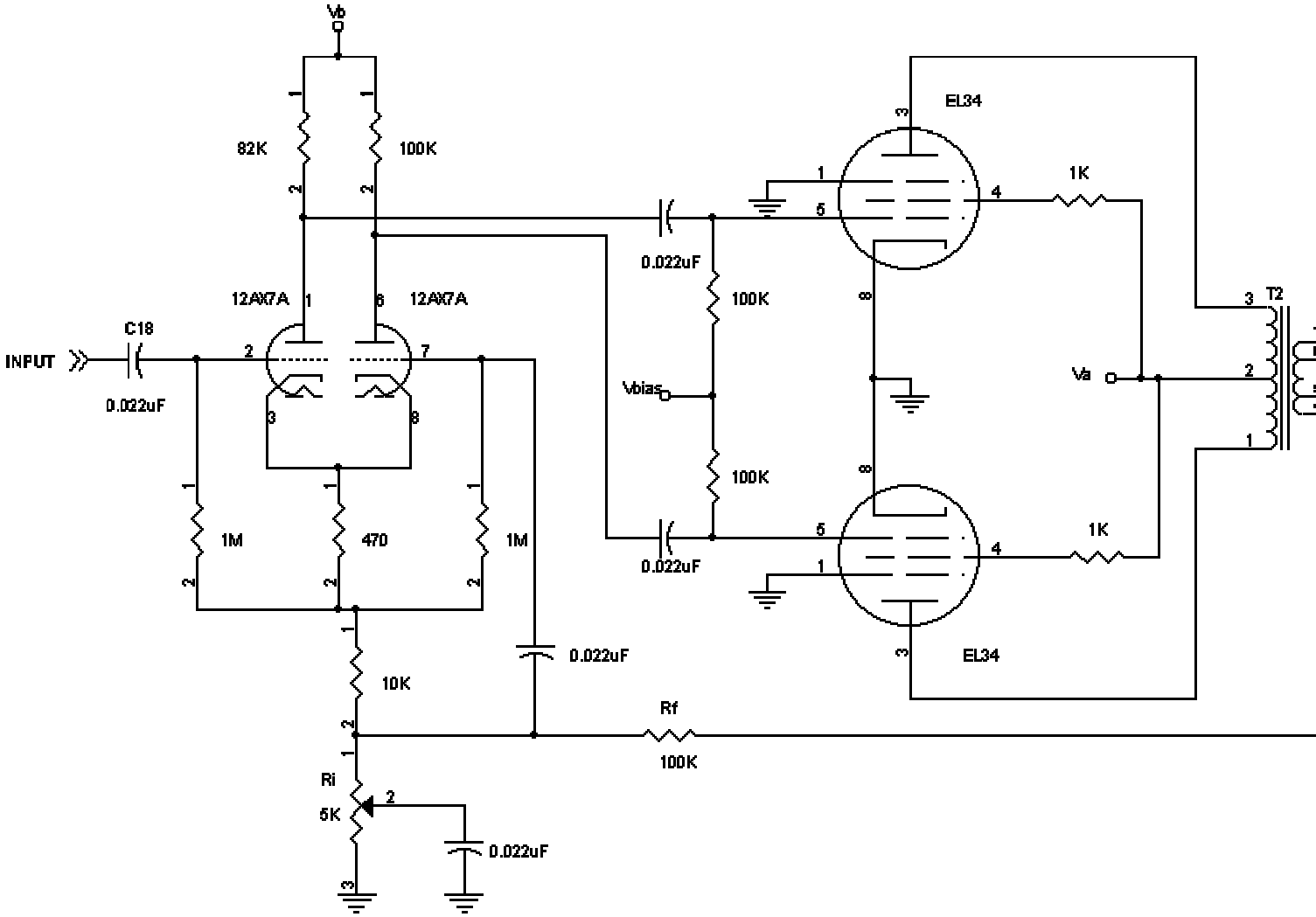
Where:

Acl = closed loop gain
A = open loop gain
Ri = input resistance
Rf = feedback resistance
Ro = internal output resistance of the stage (the plate load resistor in parallel with the internal plate resistance, r_a, of the tube, plus the reactance of Co, if not negligible at the frequency of interest)

Note that for negative feedback, A must be a negative quantity. If A is positive, the feedback will be positive. The value of A can be calculated by using the equations for the common cathode amplifier stage.

Note that Rl is ignored in the output impedance calcuations, not because it doesn't affect output impedance of the overall circuit, but because output impedance is traditionally the impedance of the output of that gain stage - Rl is the input impedance of the following stage, so it is not included. Of course, when calculating overall gain in an amplifier, the loading effect of Rl must be taken into account.

Global negative feedback amplifier:



Gain:

Acl = A*(Ri+Rf) / (Ri + Rf + Ro + Ri*A)

Note: if Ro is assumed zero, Acl= A / (1 + A* Ri / (Ri + Rf))

Input impedance:

Rin = Rg / (1V - Acl*Ri/(Ri+Rf))

Note: If closed loop gain is high enough, Rin is essentially infinite

Output impedance:

Rout = ((Ri + Rf) * Ro) / (Ri + Rf + Ro + Ri*A)

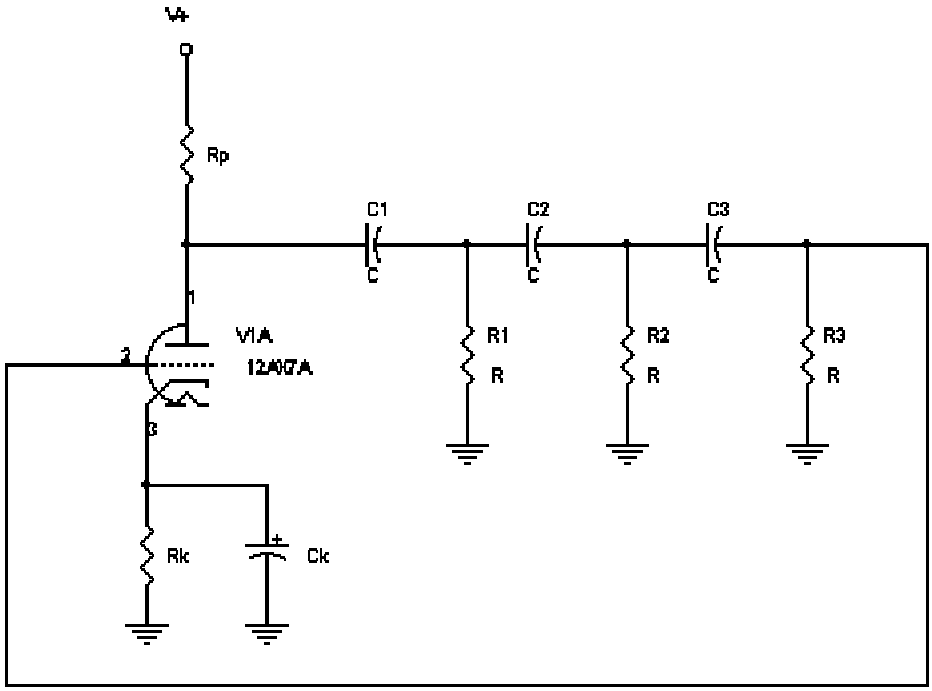
Note: if Ro is assumed zero, Rout = 0.

Where:

A = open-loop gain
Acl = closed-loop gain
A = open loop gain
Ri = input resistance
Rf = feedback resistance
Ro = internal output resistance

Note that for negative feedback, A must be a positive quantity. If A is negative, the feedback will be positive. The value of A can be determined by opening the loop and measuring the output voltage and dividing by the applied input voltage.

Phase-shift oscillator:



Minimum gain required for oscillation:

A(min) = 29

The value of A can be calculated by using the equations for the common cathode amplifier stage. It must be 29 or greater to sustain oscillations. A gain of exactly 29, or just enough to sustain oscillations, will produce the lowest distortion sine wave at the plate of the tube.

Oscillation frequency:

$f_o = 1/(2*Pi*Sqrt(6)*R*C)$

Impedance and frequency scaling

Impedance scaling

Impedance scaling is accomplished by first calculating an impedance scaling factor, ZSF, as follows:

ZSF = Znew/Zold

The impedance-scaled values are then calculated using the following formulas:

R' = R*ZSF
L' = L*ZSF
C' = C/ZSF

Frequency scaling

Frequency scaling is accomplished by first calculating a frequency scaling factor, FSF as follows:

FSF = desired frequency/existing frequency

The frequency-scaled values are calculated as follows:

R' = R
L' = L/FSF
C' = C/FSF

Frequency and impedance scaling

Both frequency and impedance scaling can be accomplished in one step with the following equations:

R' = R*ZSF
L' = (L*ZSF)/FSF
C' = C/(ZSF*FSF)

where

R', L', and C' are the resistance, inductance, and capacitance values after impedance scaling