

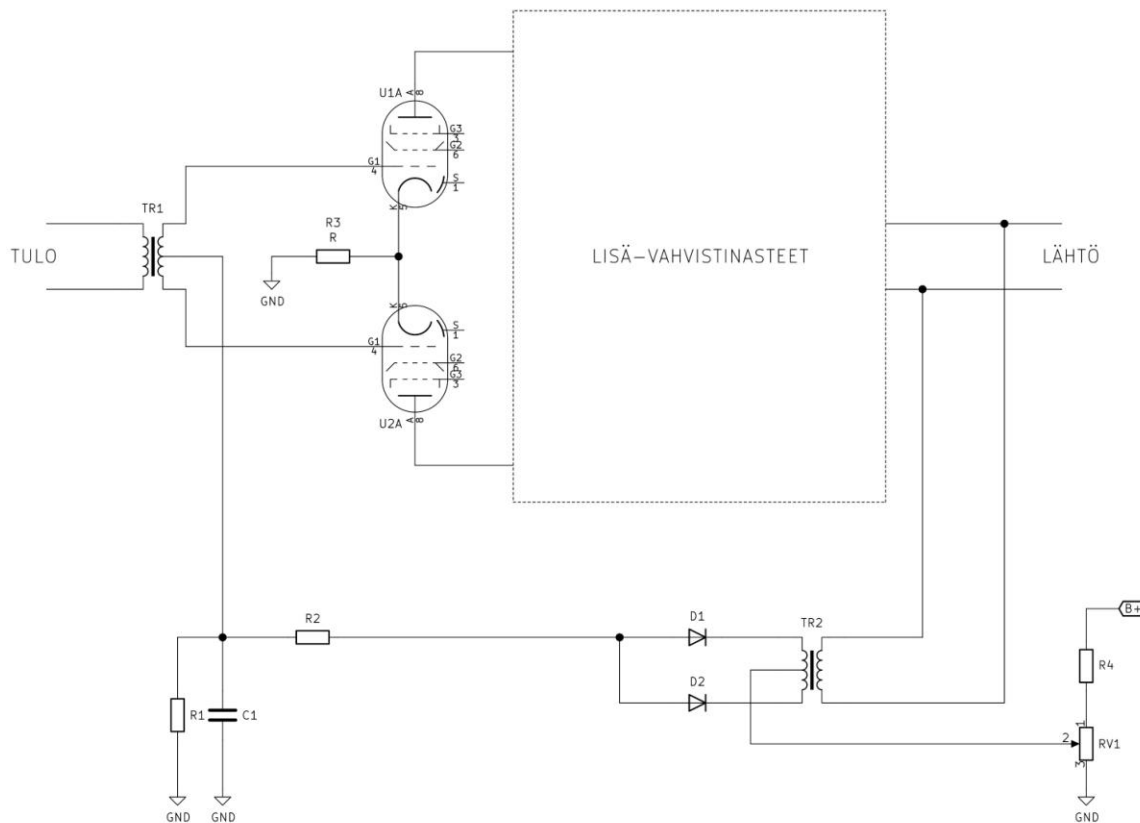
Tube compressors

Control tube compressors

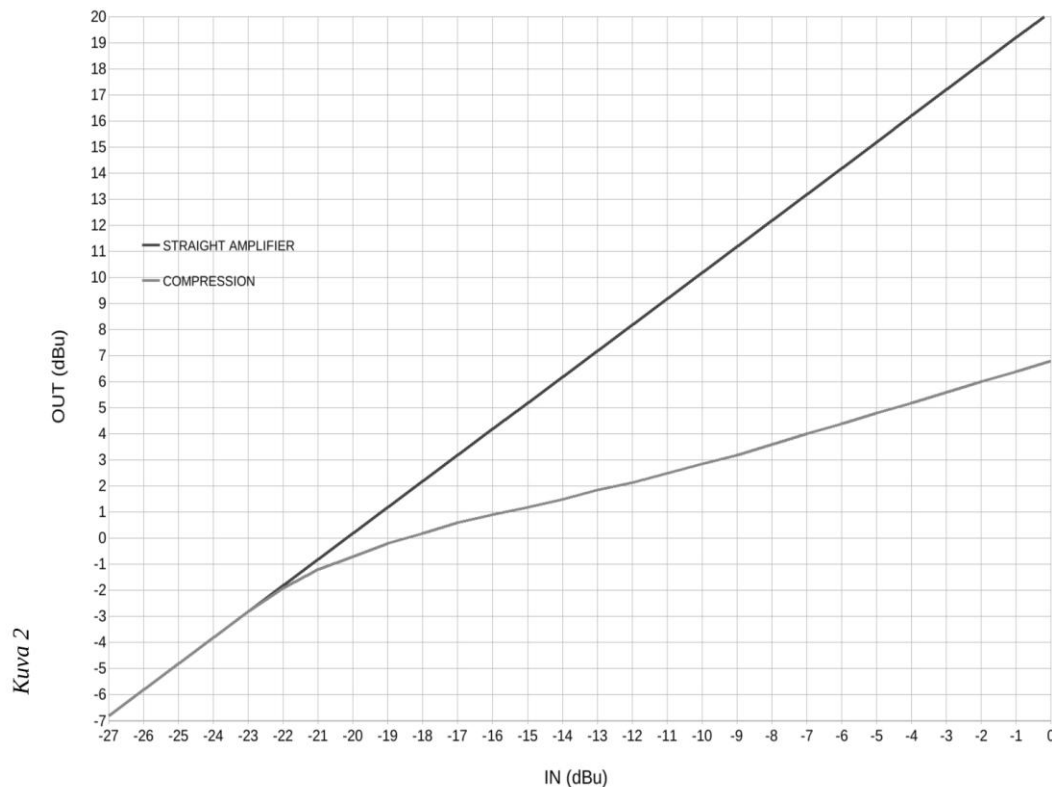
Activities

In electron-tube compressors, compression is accomplished with control tubes, also known as a variable-gain tube, known as "variable-mu," "remote-cutoff," or "super-control". By changing the gate bias voltage, the gain of the amplifier can be changed using control tubes. When the voltage of the control grid is made more negative with respect to the cathode, the anode current and transfer conductance of the tube decrease.

The connection of the compressor does not differ much from a conventional alternating amplifier, but an additional control circuit is created to create a variable gate bias voltage for the tubes (control voltage). Figure 1 is a simplified circuit diagram of a compressor showing the components essential for compression. U1 and U2 are control tubes that form a phase amplifier. The transmission conductance of the tubes and thus the gain depends on the bias voltage of the control grid. It is therefore a voltage-controlled alternating amplifier. A variable gate voltage is applied to the control gates of the tubes from the RC circuit via the center tap of the input transformer TR1, which is connected to the anodes of the diodes D1 and D2. The audio signal is applied to the cathodes of the diodes. The threshold level is determined by the threshold voltage of the diodes and the voltage controlled by potentiometer RV1.



When a signal is applied to the input, the compressor operates like any amplifier and amplifies the signal. If the signal is large enough, diodes D1 and D2 begin to conduct. Signal peaks that exceed the diode threshold voltage charge capacitor C1 to negative. The voltage of the capacitor C1 determines the gate bias voltage of the tubes U1 and U2. The more negative the voltage of the control grids, the lower the gain. Figure 2 is an example of a compressor input / output characteristic. The compressor operates like a linear amplifier until the signal exceeds the threshold at which compression begins and the gain of the amplifier decreases. It is also common for tube compressors that the compression ratio is not constant, but changes as compression increases. The ratio of compression steepness is thus gradually gentle (Soft knee).



The compressor response time (Attack) depends on how fast the capacitor C1 charges. The rise time can be expressed as an RC time constant where $C = C1$ and R is all resistance in series with capacitor C1, including the output impedance of the amplifier at which the diodes are driven. The release time can be expressed as $C1$ and $R1$ RC time constants. However, there is no standard for how compressor response and return times are reported. After the voltage-controlled alternating amplifier, there may be one or more additional amplifier stages. The control circuit may include its own amplifier stages at which the control voltage is generated, or in a multi-amplifier compressor, the control voltage may be rectified directly from the anodes of the last phase amplifier. A good example of a compressor with only one amplifier stage and a separate amplifier for the control voltage is the Fairchild 660. An example of a compressor without a separate control amplifier is the RCA BA-6A. Tube compressors are commonly known as Vari-Mu. The name Vari-Mu would seem to suggest that the gain of the tube, i.e. (μ), would change. However, the gain of the tube remains almost constant even with large changes

in the anode current, while the transfer conductance (g_m) and the anode resistance (r_a) change much as the anode current changes. The operation of control tube compressors (Vari-Mu) is based on the change in transmission conductance and not on the change in the gain. The gain also changes somewhat with the anode current, but never enough to be useful. There are also tube compressors such as TRIMAX A.30 where the series resistor and the cathode resistance of the tube form a voltage divider, and the signal can be attenuated by changing the bias voltage of the tube. The operation of such a compressor is also based on a change in transmission conductance. Like the transmission conductance, the anode resistance is a function of the control grid voltage. In a triode with a low gate bias voltage, the anode resistance is relatively small, as the gate bias voltage is changed to negative, the anode resistance increases. In this way, the attenuation of the signal can also be realized by a voltage divider formed in the anode circuit. The gain of the amplifier can also be controlled by a feedback circuit. The feedback circuit has a tube whose anode resistance determines the amount of negative feedback from the amplifier. However, most tube compressors are implemented with a control tube connection and are generally considered to be the best way to implement a tube compressor.

Distortion in Control Tube Compressors

Traditionally, for best results, a voltage-controlled amplifier has had to be an output-transformer-switched amplifier. In an AC amplifier, the even harmonics are canceled out of the distortion, although not completely, and with a transformer connection, the common-mode DC change does not reach the output or the next amplifier stage. The gate bias voltage is changed by the control circuit and the control voltage at the gates can be many times higher than the audio signal. The control voltage changes the anode current of the tubes suddenly, if the anode currents of the tubes of the phase amplifier are not in balance, rapid changes in the anode current will give the output a low frequency transient (“thump” sound). Achieving perfect balance is impossible, but with a good fit, the signal-to-thump ratio is large enough. In a poorly balanced compressor, large signals at fast attack times may also be over compressed. It will then take some time for the amplifier to stabilize and the signal to return to the correct level. In a bad case, it can take tens or even hundreds of milliseconds to get back to the right level. However, with adequate tube fitting and good control circuit design, overcompression and “thump” sounds are prevented. Figure 3 illustrates what can happen to a signal in a poorly balanced compressor.

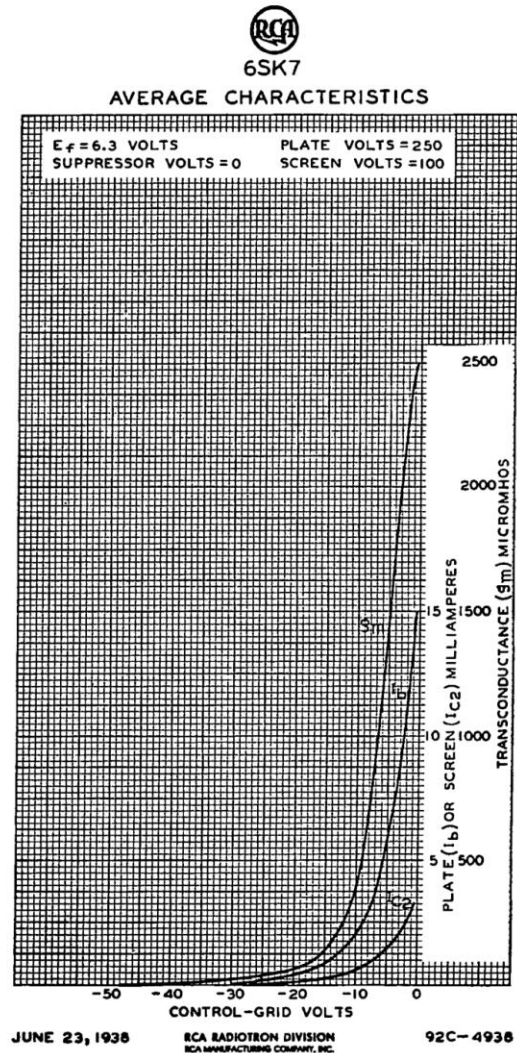
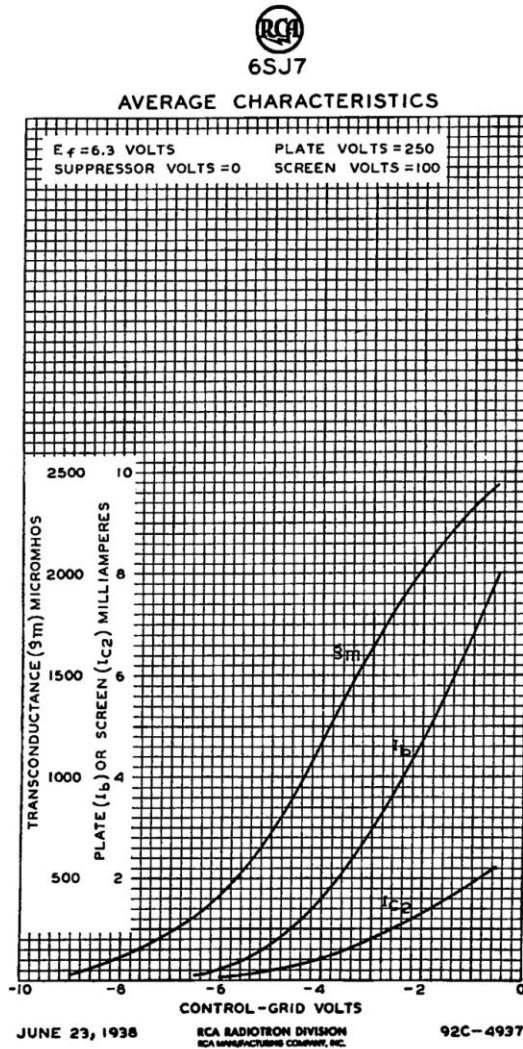


The RC circuit does not filter the control voltage to completely pure DC voltage. The variation in the tube bias caused by the ripple voltage modulates the signal, causing distortion. This distortion is not removed even by a perfect fit of the tubes. This distortion occurs at low frequencies and increases as the frequency decreases. For this reason, slow return times should be used when compressing material that contains a lot of low frequencies. The total harmonic distortion and the central modulation distortion depend on the amount of compression. The distortion is due to the anode current being reduced to effect compression and the signal being at its highest in the compressor amplifier stage with hard compressions. In particular, the central modulation distortion can become very large with hard compression. Many current tube compressor manufacturers do not report central modulation distortion at any compression level because a high IMD with even a few decibels of compression does not look good in device performance. The adjustment of the control tubes is very important so that both halves of the phase amplifier are in the best possible balance. The fit should remain as good as possible as the anode current changes. Tube compressors usually have one or more balance adjustment trimmers that can be used to fine tune the balance.

Control Tubes in Compressors

The less the transfer conductance changes with the anode current, the more linear the tube. In a compressor, the gain is desired to change with the anode current, so a tube is needed in which the transfer conductance changes. In ordinary (Sharp-cutoff) tubes, the anode current drops rapidly with the gate voltage and low current and large signals are not a good equation. In control tubes, the current does not cut off even at high negative gate voltages. Compression can be performed with triode, pentode or heptode tubes. The advantage of a heptode is that the audio signal can be applied to a different gate than the control voltage. Also in the pentode, the control voltage can be applied to the brake lattice and the audio signal to the control lattice with a fixed gate bias voltage. When the control voltage is applied to a different gate than the audio signal, the problem is that the compression amplifier is overdriven by large signals. The best result is usually obtained when the control signal a control voltage is applied to the control gate. The control voltage can also be applied to the cathode of the tube, in which case the control voltage is positive. In the era of electron tubes, it did not make sense to introduce a cathode because the impedance of the cathode is very low, while the impedance of the control gate is very high. With a control amplifier currently implemented with semiconductors, the control voltage can be applied to the cathodes and thus the need for an input transformer can simply be eliminated. Production of control tubes has been discontinued, with the exception of the JJ 6386 double triode, but the availability of many NOS tubes is very good. Russian versions of the 6SK7 and EF93 pentodes are very cheap. However, it is not necessary to use control tubes. For example, 12AU7 double triodes have been used in several new tube compressors instead of control tubes. The difference between a standard tube and a control tube can be seen in Figure 4. The 6SJ7 tube loses power at about five times the gate bias voltage compared to the 6SK7 tube. The characteristic curve of the control tube is very non-linear and is therefore not suitable for an amplifier operating at audio frequencies. In radio receivers, the gate bias voltage is changed according to the radio station being received, and nonlinearity is beneficial because the transmission

conductance changes along the entire curve and the current is not interrupted. At radio frequencies, the distortion caused by nonlinearity is insignificant because the tube load is the tank circuit. However, if the control tubes are used as an audio amplifier, then the phase switching operates linearly.



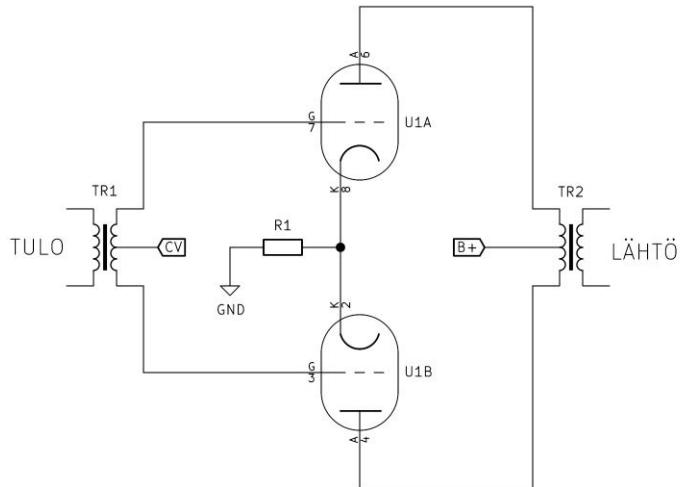
Compressor Design

Tube gain $A_v = g_m * r_p \parallel R_L$, where g_m is the transmission conductance of the tube, r_p is the anode resistance and R_L is the load seen by the tube. If a pentode is used as the tube, then the gain $A_v \approx g_m * R_L$ because $r_p \gg R_L$.

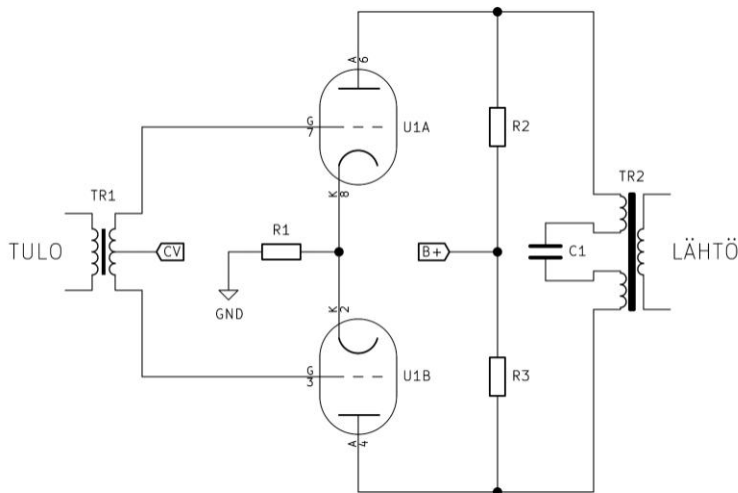
Figure 5 shows a typical way to implement a voltage controlled tube amplifier. The disadvantage is that the resistance of the source and the inductance of the transformer primary form a high-pass filter.

The output transformer TR2 is perhaps the most demanding part of a tube compressor. In the primary of the transformer, the resistance of the source and the inductive reactance of the primary form a voltage divider. As the frequency decreases, the reactance decreases

and the voltage decreases in the primary. At a frequency at which the inductive reactance and source resistance are equal, the signal is attenuated by 3dB. The anode resistance increases as the anode current decreases and the inductance of the transformer primary must be large enough so that the low frequencies are not attenuated during compression. The transformer must also withstand direct current in the primary or else the transformer core will saturate and the inductance will drop if the tubes are unbalanced.

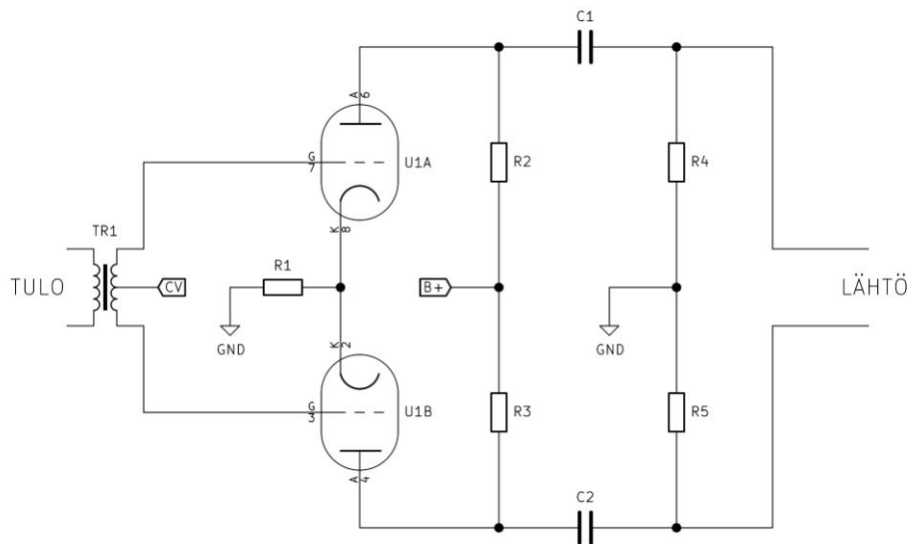


In Fig. 6, the direct current is kept away from the transformer by means of a capacitor C1. When the DC current is kept away from the transformer, even the poor balance of the tubes does not cause low frequency attenuation. The anode resistors R1 and R2 determine the maximum source resistance at which the converter is driven. In this connection, the load seen by the tube is the load reflected by the transformer in parallel with the anode resistor



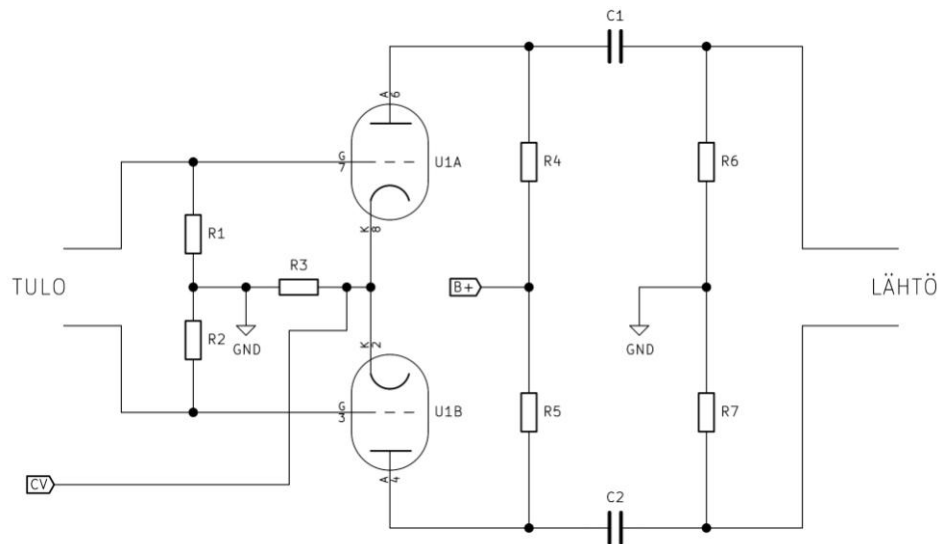
However, it is not necessary to use a transformer at the output of the compression amplifier, but an RC connection can also be used. The problem with RC connection is the high common mode voltage that goes to the next amplifier stage. If the anode current of both tubes in the circuit shown in Fig. 7 is 5 mA, the anode resistors R2 and R3 are 10k, and if, for example, the anode currents drop to one milliamperere during compression, it

produces a 40V common-mode voltage. The next stage of amplifier requires a high common mode voltage attenuation ratio and the ability to handle large common mode voltages.

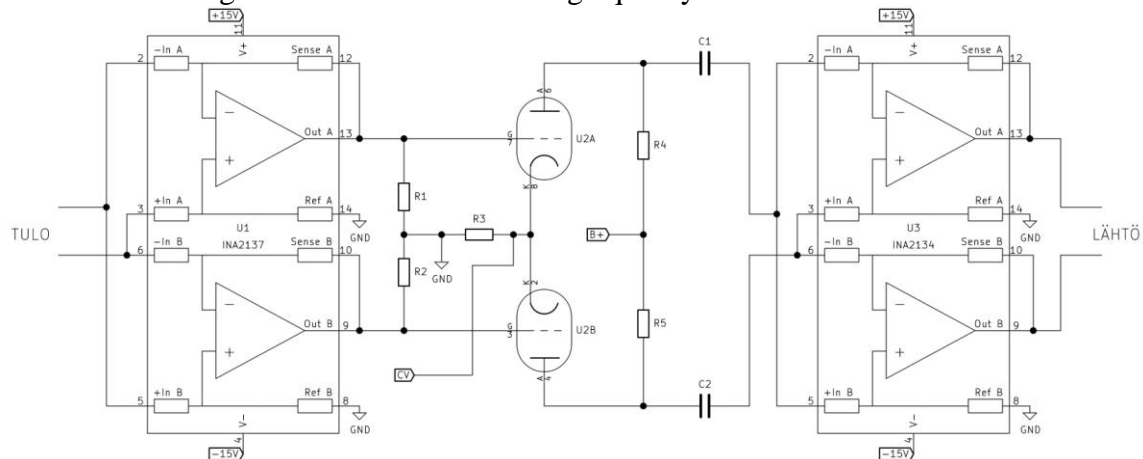


Transformerless compressor

Tube compressors are usually expensive. The reason for the high price is largely due to the expensive audio transformers. The mono compressor has 2 or 3 audio transformers and the stereo compressor has 4 or 6 transformers. However, the number of transformers can be reduced if semiconductors are used in the control circuit and in some amplifier stages. Traditionally, there is a transformer coming into the compression amplifier stage. The input transformer provides a symmetrical input signal for the compression stage and the impedance for the control voltage is practically infinite. The input transformer can be eliminated if a control voltage is applied to the cathodes of the tubes. When applied to cathodes, the impedance to the control voltage is low, in which case the control amplifier must be implemented with semiconductors. In Figure 8, a symmetrical audio signal is applied to the gates without a transformer and the control voltage is applied to the cathodes.



When the control voltage is applied to the cathodes, the input transformer can be replaced with a cross-connected INA2137 differential amplifier. The output transformer can be replaced with a cross-connected INA2134 differential amplifier. The maximum common mode voltage of the INA2134 inputs is about 25V, so the common mode + differential voltage must be kept below 25V or the amplifier will be overdriven. The INA2134 common mode voltage attenuation ratio at low frequencies is 90dB, so it attenuates common mode signals almost as well as a high quality transformer.



Control Circuit

Figure 10 shows the control circuit. The audio voltage is applied between the terminals 5 and 8 of the transformer T1. Diodes D2 and D3 convert the audio voltage into negative pulses with respect to the voltage V +. When the negative pulses exceed the threshold voltage of the transistor Q4 base, it amplifies the Q4 signal and turns the pulses positive. The potentiometer RV4 can be used to change the gain of transistor Q4. Transistor Q3 acts as a buffer. The pulses charge the capacitor to the positive voltage of capacitor C2. R6 + RV2 determine how fast C2 charges and RV3 + R8 + R6 + RV2 determine how fast C2 discharges. Transistors Q2 and Q1 form a Darlington circuit from which the control voltage is applied to the cathodes of the tubes.

