Figure 22 illustrates a design for a vinyl disc preamplifier that I designed and which ran in my own hi-fi system (Brice 1985). It is a slightly unusual design in that it incorporates a *cascode* input stage (**V1a** and **V1b**). The more usual choice for a high-gain valve stage is a pentode but these valves generate more shot noise than triodes because of the action of the cathode current as it splits between the anode and screen. An attractive alternative is to use a cascode circuit.

Like so many other valve circuits this has its origins in radio. Its characteristics are such that the total stage noise is substantially that of triode **V1a**. But the gain is roughly the product of the anode load of **V1b** and the working mutual conductance of **V1a**. In other words it works like a pentode but with lower noise! The design of the lower valve stage in the cascode is straightforward and the standing-current and bias is set in the same way as for a common-cathode amplifier. The anode load is chosen - along with the decision of the standing current for the stage - to set an appropriate operating point. From a design point of view, the only decision lies in the choice of the upper grid supply voltage since this sets the operating voltage for the anode of the lower valve.

Artzt circuit (a.k.a. the SRPP and the µ-follower)

Figure 23 illustrates a circuit which has found great favour with designers of valve hi-fi equipment in recent years. Variously known as the *Shunt-Regulated Push-Pull* (*SRPP*) configuration or (in a variation of the circuit) as the *µ-follower*, the circuit is ingenious; combining the virtues of high input impedance with low output resistance, high gain and good linearity. The origin of the term *µ-follower* is uncertain; although it was presumably coined because the stage topology provides a very high voltage-gain; close to the theoretically maximum gain for a triode stage of **gm** × ***ra*** = **µ**. The term *shunt-regulated push-pull* is confusing too, as the circuit doesn't really contain anything shunt-regulated!

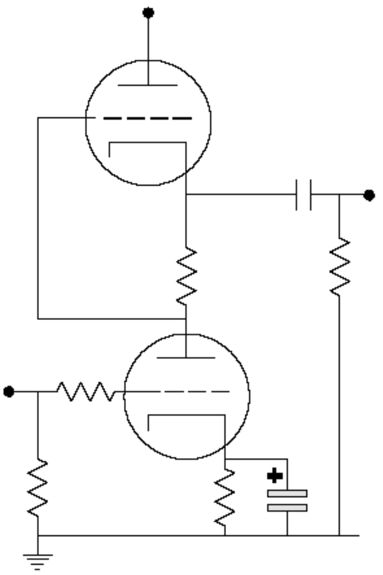

Figure 23 - The Artzt (or SRPP) circuit

Some authors in explaining the action of this circuit refer to the upper valve as a current source. But this is not correct, as this valve has a signal voltage between its cathode and grid which varies due to the signal current change through the resistor load of the lower triode. (Incidentally, if it were true that the upper valve in the *SRPP* stage was a current-source, then the circuit wouldn't be shunt-regulated *or* push-pull!) Part of the confusion surrounding this circuit arises because it has been used in various different ways. One application is as a symmetrical driver of a low impedance load, like driving the surge-impedance of a coaxial cable with an analogue, video signal; as shown in Figure 24.

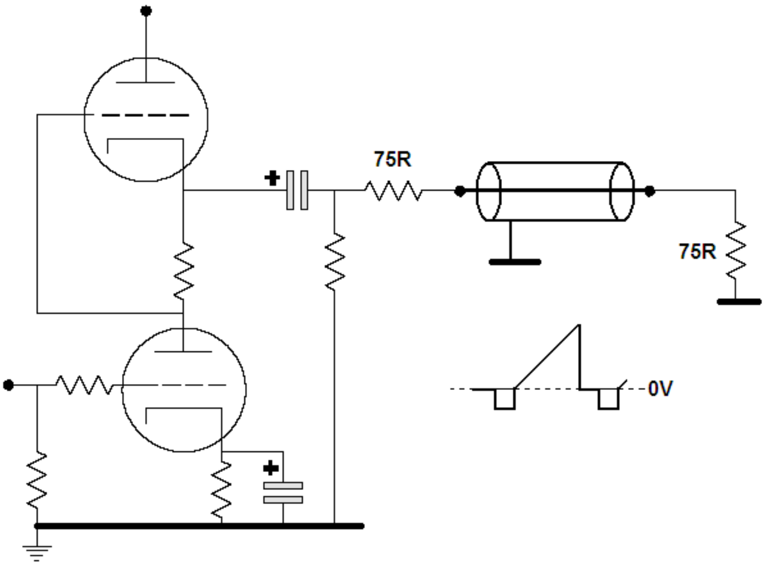

Figure 24 - Artzt circuit used as a video (or pulse) driver for a cable and matched termination load

In this application, the circuit is truly push-pull. However, when used in modern, audio applications and driving a subsequent stage with high impedance, envisaging this circuit as a push-pull stage makes analysis unnecessarily complicated and I prefer to see this circuit as a high-gain stage and a subsequent buffer stage, cleverly combined together.

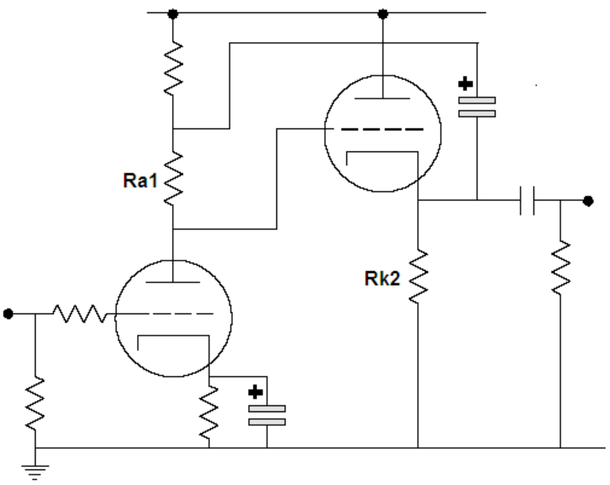

Figure 25 - The Artzt circuit (*SRPP*) deconstructed

Figure 25 illustrates the SRPP, unfolded into a two-stage amplifier, very familiar from transistor circuitry in which the gain of the first stage is increased by *bootsrapping* the anode load from the output of the following buffer stage - in this case, a cathode-follower. In the SRPP stage, this bootstrapping is accomplished by the action of the upper valve whose cathode follows its grid voltage, thereby bootstrapping the upper end of the anode load of the lower valve. The efficiency of this bootstrapping is dependant on the stage gain of the buffer, because the gain is increased by the fraction **1/ (1 - *A*)**, where ***A*** is the "gain" of the buffer stage. Unlike an emitter-follower, which has a gain very nearly equal to one, a triode-based cathode-follower has a gain which only approximates to unity when the cathode load is a very high value; ideally, a current-source[3]. Looking back at the SRPP diagram (Figure 23), in this respect, the circuit is very ingenious because the performance of the cathode-follower stage is greatly enhanced by the fact that the lower triode acts as its current-source cathode load. So, this circuit embodies the rather wonderful symbiosis of the upper valve bootstrapping the lower's anode load efficiently because the lower valve is enhancing the upper valve's cathode loading!

One minor disadvantage of the SRPP stage which it shares with the cascode is that the cathode of the upper valve is at an elevated positive voltage with respect to the heater. Inside an indirectly heated valve, the heater is electrically insulated from the cathode. But this insulation is very thin so as to remain closely thermally coupled and thereby to maximise electron emission. Elevated voltages can "punch-through" the dielectric and destroy the valve. For this reason, SRPP stages often have a separate, floating or biased supply for the heater of the upper valve. This fact also accounts for a renaissance of interest in the larger, octal versions of double triodes like the 6SN7 instead of the later, B9A, ECCnn, 12An7 series valves. Octal valves, which originate from the nineteen-thirties, have a more substantial heater/cathode insulation layer, meaning that they can stand more elevated heater/cathode voltage differentials and are more suitably employed in this type of circuit than their nineteen-fifties' cousins.

The SRPP or the μ-follower stage was patented by a Maurice Artzt of RCA in a US Patent titled, *Balanced Direct and Alternating Current Amplifiers* (#2,310,342) which was applied for in 1940 and granted three years later. Given the confused (and confusing) nomenclature of this amplifier configuration, would it not be appropriate to honour its inventor by adopting his name to identify the circuit as I have done above?

Real-world valves

So far we have considered rather abstract valves which look like a light bulb with an extra plate in the top - just like the valve circuit symbol. It's true that the very first valves were of this form. However fifty years of research and development led to valves of much greater sophistication. This section is devoted to the structure of the valves we see inside guitar amplifiers and other audio equipment, most of which were developed in the nineteen-fifties at the end of the age of valves.

Figure 26 is an illustration (taken from engineering documents of the time) showing the structure of a beam-tetrode valve at the end of the valve era. As you can see, practical valves are always concentric, with the heater in the centre, surrounded by wire structures which form the grid (or grids), the entire arrangement being encapsulated in a folded metal structure which forms the anode.

There is much to be learned from dissection of a valve and a dead component should always be regarded as an opportunity for an instructive autopsy. Photographs of the internals of various valves revealed in this way are given below.

[3] Actually I prefer the term, *current-sink* for a source which is "sinking" current into ground, rather than "sourcing" it from the positive rail. However I accept this is not universal usage.

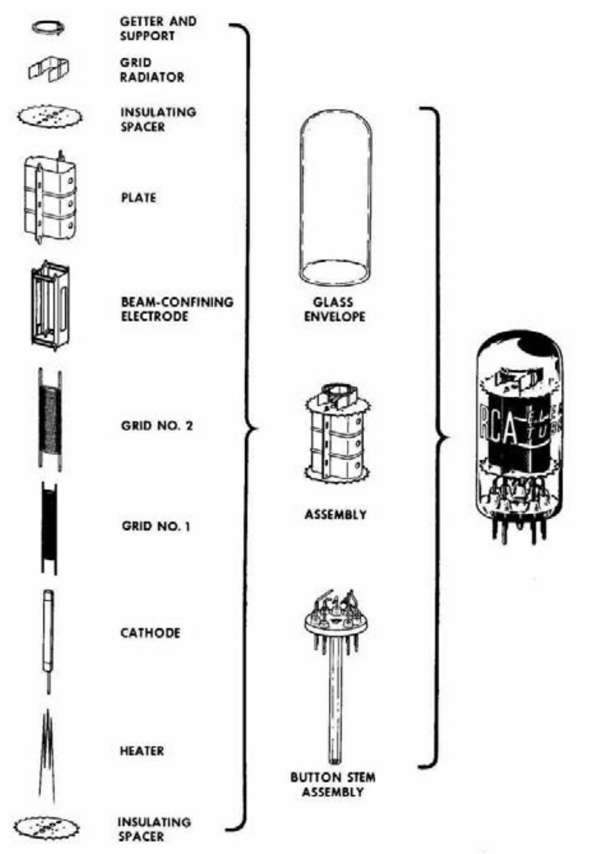

Figure 26 - Construction of a beam-tetrode from the end of the valve era

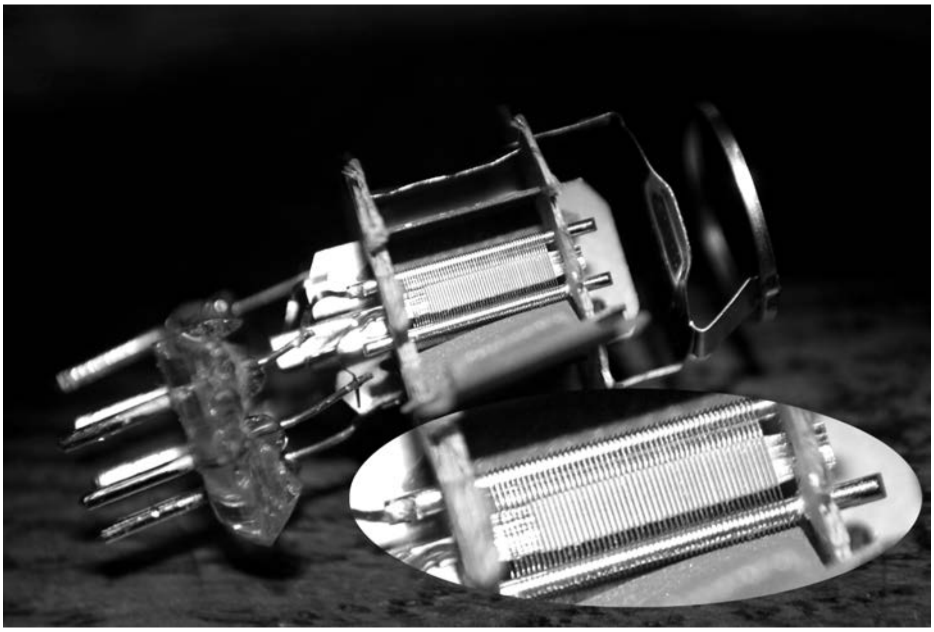

Figure 27 - Internals of 12AX7 valve with anode structure cut away to reveal detail of cathode arrangement and surrounding grid

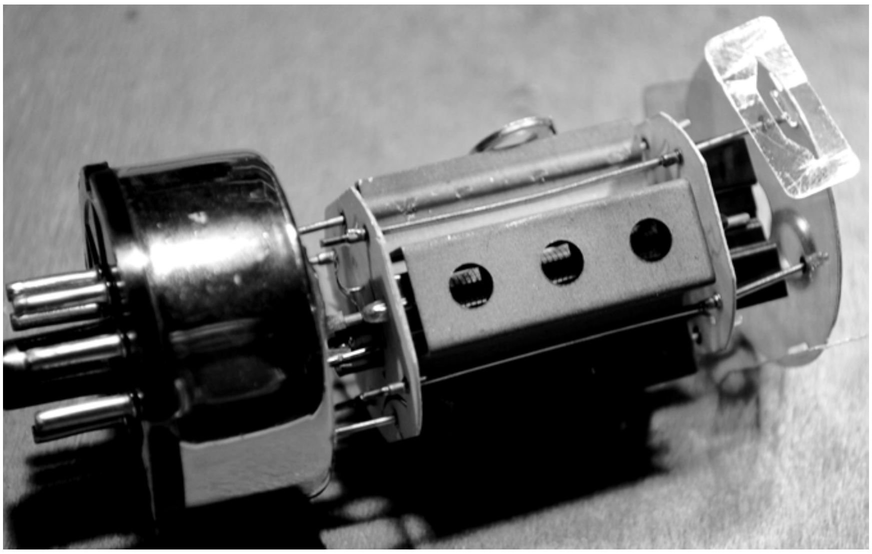

Figure 28 - KT100 (KT88) valve with glass envelope removed

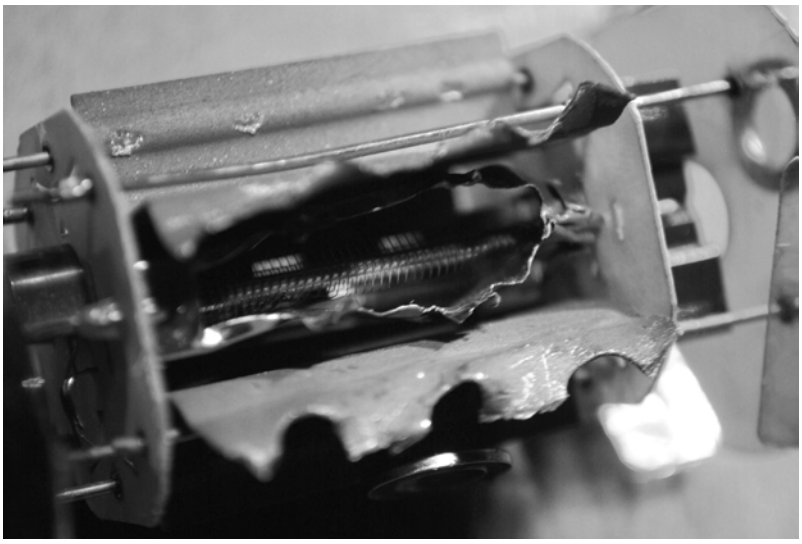

Figure 29 - KT100 with anode structure and beam-forming electrode cut away to reveal screen and control grids

The cathode and the work function

The metal cathode is heated in a modern valve by a dedicated heater. All metals are crystalline, made from a lattice of atoms in a more-or-less regular structure. If, by some means, the electrons in the valance band of the metal atoms are given greater kinetic energy, they may be able to escape the electrostatic forces of the atoms in the lattice and escape the surface of the material. This extra energy may be supplied by heating (as is the case in the cathode of a valve), by photons or other particles falling on the surface of the material (as in secondary emission), or by a powerful electrostatic field.

The amount of energy (or *work*) required to get electrons to reach the critical escape velocity varies from metal to metal and is defined by a measurement known as the *work function*. It is measured in electron-volts (**eV**). There is a relationship between the density of the crystal lattice and the work function such that, the looser the atoms are packed together in the lattice, the lower the work function. The metal with the lowest work function is caesium, so we might conclude that this would be a good metal for the cathode. But it's not, because the temperature at which it melts is just above room temperature. Instead - where a pure metal cathode is required - the favourite choice is tungsten; just like the filament of a light bulb. Tungsten has rather a high work function, but it has the