How it Works

The amplifier is a three-stage, single-ended output (SE), stereo design, using thermonic valves (also known as tubes). The circuit uses a combination of classic valve and modern solid state technology. Valves are used exclusively in the audio path and solid state technology is used for the power supply module and an optional Bluetooth connectivity module. There are ample opportunities to experiment with this circuit using different valve and output transformer combinations.

Each channel uses a triode voltage amplifier followed by a cathode follower stage and a class-A power output stage. The first two stages form a constant current draw amplifier (CCDA); a common-cathode voltage amplifier followed by a DC-coupled cathode-follower. The output stage can be configured as either an ultra-linear or triode power amplifier. It is also possible to configure it as a standard pentode/tetrode stage though Ultra-Linear is recommended. Two slide switches on the rear panel select either a nominal 4 Ohm or 8 Ohm speaker impedance and switch in or out global negative feedback.

The output transformer is the most critical and expensive component in any valve amplifier, and a large variety were tested. The transformer supplied with the kit is epoxy potted into an attractive metal housing and provides excellent performance for its price. The cost of some output transformers can rival the cost of the entire amplifier, but their sonic improvement is marginal at best. Some audiophiles may wish to use the alternative output transformer.

Input Switching: The input source is selected between two pairs of RCA sockets on the rear panel, or an optional Bluetooth wireless module. One set of RCA inputs is also connected to a 3.5mm stereo jack on the rear panel; if a 3.5mm jack plug is inserted, (say from a smart phone), its associated RCA input is automatically disconnected. Relay switching simplifies the input selection and allows an attractive miniature toggle-switch to be used on the front panel, rather than a large hand-wired rotary switch with a bundle of shielded cable terminations.

The Input Amplifier Stage: After input selection the signal passes through an audio-grade volume control and is DC coupled to the grid of a 12AT7 twin-triode. The input is DC coupled to avoid using of a second coupling capacitor in the audio signal path, (coupling capacitors can add unwanted sonic characteristics). V1 is configured as a constant current draw amplifier (CCDA) consisting of two cascaded DC-coupled triodes. The first triode is configured as a common-cathode amplifier with an amplification factor (gain) of about 45, and the second triode is a cathode-follower providing no gain but a low output impedance to drive the grid of the power output stage.

The main benefits of the CCDA are low output impedance and a constant DC current drain from the power supply. When the input signal at the grid of the first triode goes positive and its conduction increases, its anode voltage will fall. As a result, the voltage on the grid of the DC coupled second triode will fall in line with the anode of the first triode, and its conduction will decrease, and its anode voltage will rise. If both triodes are set-up to have the same anode currents in the zero-signal state, they act as a see-saw; as the anode current through the first triode rises the anode current through the second triode falls. The total current supplied to both triode stages is therefor constant throughout an entire input signal cycle. A reverse diode prevents exceeding the maximum cathode to heater voltage on the second triode during the warm-up period after switch-on, when the valve is not fully conducting.

The Power Amplifier Stage: The power amplifier is a single-ended (SE) class-A amplifier which can supply about 5 Watts RMS power @ 10% distortion into an 8 Ohm load, using a 12.5VDC power supply. Distortion falls off quickly as signal power is reduced. See the specifications download on this website.

In a class-A amplifier, a constant current (called a bias current) continuously flows through the valve from cathode to anode, even when there is no signal. Class-A is a very inefficient type of amplifier, only achieving about 25 - 30% efficiency for a pentode or tetrode, and even less with a triode. The output valve dissipates all the constant unused electrical energy as heat in its anode, so for optimum valve service-life it's important not to exceed the manufacturers maximum anode power rating. Class-A is used almost exclusively in small valve amplifiers due to its simplicity and perceived superior sonic characteristics.

The amount of bias-current flowing through a valve is inversely related the negative voltage on its grid with respect to its cathode, (called the negative grid-bias voltage). Electrons leaving the cathode are repelled by the negative charge on the grid, and as the negative grid voltage is increased fewer electrons successfully reach the anode. So, in short, the negative voltage on the grid controls the current flow through the valve from cathode to anode.

In this circuit, the grid-bias voltage on is derived from the voltage developed across a cathode resistor. The constant bias current flowing through the valve (and through the cathode resistor) develops a DC voltage with the cathode being positive with respect to DC ground. As the grid is tied to DC ground potential through a high value resistor, the grid is then negatively-biased with respect to the positive cathode.

As a valve ages less electrons are emitted from the cathode and, without some sort of self-regulating bias arrangement, the bias voltage on the grid would need to be periodically adjusted to maintain the correct bias current through the valve. Cathode bias is a simple self-regulating (negative feedback) mechanism which strives to hold a constant DC bias current through the valve as the valve characteristics vary with usage and age. (If the current through the valve decreases the voltage developed across the cathode resistor would also decrease, which in turn would reduce the the negative grid-bias voltage. The lower negative grid-bias voltage will then try to force the valve to conduct more. Naturally there is a limit, and eventually the valve's conduction would fall to a point where it can no longer be successfully regulated). Because the cathode resistor is bypassed by a large value electrolytic capacitor, which presents a near short circuit to audio frequency AC signals, there is no noticeable effect on the audio signal.

The output valve can be either be a pentode (like the EL34) or a beam-tetrode (like the 6V6, and KT77, or a 6BQ5 if a conversion socket is used). The maximum power output is mostly determined by the power supply voltage, the characteristics and limitations of the valve, and the design of the output transformer.

Power Amplifier Mode: The screen grid (G2) of the output valve accelerates the flow of electrons from cathode to anode, and how it's configured will slightly change the sound characteristics. Either ultra-linear, triode, or pentode modes can be selected by rearranging the screen grid connections on two 4-way screw terminals mounted on the PC board for terminating the output transformer primary windings. Each mode has it's advantages and disadvantages as shown below. The recommended mode for this amplifier is ultra-linear mode where the screen grid is taken to a tapping point on the output transformer. Audiophiles with very efficient loudspeakers may prefer triode mode which is generally accepted to be sonically superior (but only about half the power).

1. **Pentode mode**; where the screen grid is connected through a resistor to the amplifiers high voltage power supply. This mode gives the maximum amplification and maximum power output, but also the highest amount of distortion and the highest output impedance. The sound is rich in odd-order harmonics, and higher output impedance results in lower loudspeaker damping and more ‘colouration’ of the sound. For pentode mode strap the screen grid (G2) to B+.

2. **Triode Mode**; where the screen grid is connected directly to the anode, so the output valve is configured as a triode. This is the mode favoured by audiophiles as it has predominantly even-order harmonic distortion, and a lower output impedance. Its disadvantage is lower gain (lower input sensitivity) and lower power output. Use this mode if you have a smallish room or spend most time listening through headphones.

3. **Ultra-Linear (UL) Mode** (not avaliable with Audiophile OPT); where the screen grid is connected to a tap on the primary of the output transformer. This mode is really a blend of pentode and triode modes and is said to achieve the best characteristics of each. However, care must be taken to avoid oscillation, especially when the speaker is disconnected, so a small capacitor is connected from plate to screen for stability purposes.

The Output Transformer (OPT): The main task of an output transformer in a valve amplifier is to transform the high voltage/high impedance at the anodes of the output valves to a low voltage/low impedance AC voltage suitable for driving low-impedance loudspeakers. Importantly, it also provides voltage isolation for the loudspeakers which is important for safety. The OPT is the single most important contributor to the performance of a valve amplifier, and also the heaviest and most expensive component. Two OPT options are available for this amplifier, standard and audiophile.

In a perfect lossless transformer, voltage and current are transformed up or down by exactly the turns ratio of the primary and secondary windings. However, as impedance is the product (multiplication) of an AC voltage and an AC current, impedance is transformed up or down by the square of the turns ratio. Impedances specified for an OPT are really only nominal impedances that match the square of the turns ratio - any two impedances (within practical limits) can be matched by the same transformer. When using the 8 Ohm speaker setting, the Red Roo OPT has a turns ratio of about 21, so an 8 Ohm loudspeaker connected to the secondary winding will reflect a 3500 Ohm primary impedance onto the anodes of the output valves. The same OPT could be used with an 8Ohm loudspeaker connected to the 4 Ohm secondry and would reflect a 7000 Ohm primary impedance (for 6V6 or 6BQ5 output valves).

An OPT needs to be designed and manufactured very carefully for both good low-frequency and high-frequency performance. Generally, the bigger the better - the larger the metal core volume, and the higher the primary inductance (more turns of wire), the better the low frequency performance. However, as size increases, high frequency performance usually suffers. Complex (and expensive) winding arrangements called sectioning are used to improve high-frequency performance, where the primary and secondary windings are split into sections and inter-leaved in order to minimise internal capacitance and magnetic ‘flux-leakage’, (called leakage-inductance). Output transformers range from a few tens of dollars, to many hundreds or even thousands of dollars for hand-wired examples. The two OPT options supplied with this kit are at differing price/performance points, the audiophile option having better specifications on paper.

Negative Feedback: Feedback is where a sample of an output signal from a system is fed back to the input, in order to modify the total response of the system. Feedback occurs in areas such as electronics, engineering, economics and finance, climate, and our own biology - everywhere really.

If the feedback signal is of the opposite polarity (out of phase to the input signal) it is called negative feedback, and it partially cancels-out the input signal. Errors in the output of a system (distortion) are reduced by negative feedback. Negative feedback is widely used in amplifiers to reduce distortion, and lower the output impedance to the loudspeaker (which increases the damping or suppression of loudspeaker resonance's). Negative feedback also reduces the overall amplification (gain) of the circuit.

If the output signal is fed-back in the same polarity as the input signal (in-phase with the input signal) it is called positive feedback and it will reinforce the input signal. If an amplifier has positive feedback the signal will quickly increase in amplitude to a point where the whole system will oscillate strongly at some frequency; usually at some resonant frequency where amplification is highest. You can hear the effect of positive feedback when a microphone is placed too close to a loudspeaker.

Amplifiers with a large amount of negative feedback can have impressive specifications on paper, but the feedback could be masking some serious underlying design issues. A good amplifier should be designed for the best possible price/performance without any negative feedback, and then a modest amount of negative feedback applied to make it even better.

Additionally, the entire system must be carefully designed ensure that the feedback doesn't swing from negative to positive at some frequency within the systems frequency/amplification range (called the gain-bandwidth). An amplifier may have a large phase-shift, or resonance, where the feedback swings positive at some frequency well outside the human hearing range and, although everything may appear normal to the ear, a powerful oscillation may be slowly frying the loudspeakers.

There is another important reason why a large amount of global negative feedback is not a good idea, especially when applied to valve amplifiers using output transformers: The slowest responding component in a valve amplifier is usually the output transformer and, as the output transformer is usually within the feedback loop, it mostly determines the speed (response time) of that feedback-loop. Imagine a circuit where there is 20dB of negative feedback, so the voltage amplification (gain) of the entire circuit is reduced by 10 times. During the feedback delay period, the gain of the circuit would be 10 times higher, and the amplifier could be forced into into overload and hard distortion (clipping) by a very modest input signal.

Music and human voice are rich in fast transients. So, common audio signals could drive an amplifier with large amounts of negative feedback into hard distortion easily, before the global feedback has time to come into operation to reduce the gain. This can cause transient distortion in the loudspeaker output, and may be the reason why some amplifiers are said to sound harsh or fatiguing even though they have super-good specifications on paper.

Global feedback is where the feedback-loop is placed around the entire system, from the output right back to the input. This amplifier uses a small amount of global negative feedback that can be switched in or out using a slide switch on the rear panel. The amount of negative feedback is set by a resistor to be about 6dB in ultra-linear mode and about 4dB in triode-mode.

Amplifiers without global negative feedback still have feedback loops, but they are less obvious. Negative feedback also occurs in isolated loops around each stage, called 'nested' feedback loops. An un-bypassed (by a capacitor) cathode resistor is a common example of a 'nested' feedback loop. A Triode amplifier stage has an inherent 'nested' negative feedback loop within the operation of the valve itself (another reason why triodes are popular with audiophiles).

The Power Supply: Power supplies in valve amplifies are large, heavy, and very expensive compared to modern solid-state amplifiers. Because mains power transformers operate at very low mains frequencies (50Hz or 60Hz) they have high inductance windings (lots of turns), and large heavy cores in order to avoid magnetic core saturation. Toroidal transformers (those with a closed-loop steel or ferromagnetic core in the shape of a doughnut) offer a significant improvement, but they are still comparatively large and are even more expensive.

The output of a full-wave rectifier is 100Hz or 120Hz pulsating DC. Turning this into smooth DC suitable for an audio amplifier requires a multi-stage low-pass filter using large value filter capacitors, and often one or two large and expensive iron cored inductors (chokes). Additionally, the stray pulsating electromagnetic field emanating from such large transformers and chokes is often difficult to contain and can easily interfere with sensitive circuitry. This presents significant difficulties at high voltages.

The power supply in this valve amplifier is different and, along with the Bluetooth option, we believe a highly worthwhile concession to the 21st century. The input to this amplifier is 12V DC @ 5.5 Amps, and the 12V DC is then up-converted to about 280V DC using a small and efficient voltage-boost inverter module. There are significant advantages to this approach:

1. The inverter converts 12V DC from a commonly available in-line or bench power supply to a high frequency AC waveform, which is then transformed up to the high voltage using a very small, lightweight, and inexpensive ferrite-cored transformer. (This is possible because of the high switching frequency, about 25kHz, or 50kHz after full-wave rectification in the inverter module).
2. As the switching frequency is well above the human hearing range, there is no audible power supply noise (hum) in the loudspeakers.
3. The filter components following the rectifier in the inverter are small and inexpensive. (Again due to the high switching frequency).
4. The inverter is supplied as a pre-assembled module. The resulting amplifier is smaller and lighter. (The 150 Watt inverter used is loafing along).
5. And, possibly most important of all - there is no need to work on mains power wiring. The external 12V DC power supply is commonly available in most countries and, if purchased locally, will carry all the necessary regulatory approvals and the correct power plug for the country of purchase.

There are some excellent resources for those who wish to learn more about valve audio technology. For those starting out www.valvewizard.co.uk is excellent, or for those up for a challenge John Broskie's TubeCad Journal at www.tubecad.com is our favourite. Morgan Jones' Valve Amplifiers, Third Edition ISBN: 978-0-7506-5694-8 is required reading.