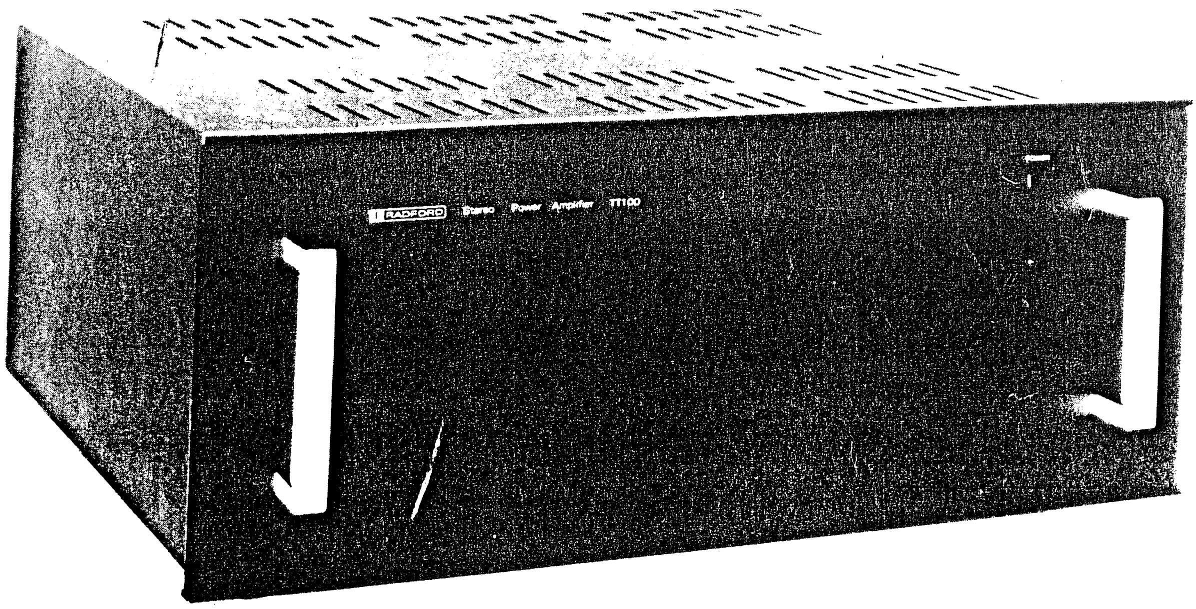
RADFORD

TT100 Power Amplifier

Leaflet A35. 981



THE TT100 VALVE AMPLIFIER

THE TT100 IS A DUAL CHANNEL AMPLIFIER OF HIGH POWER OUTPUT INTENDED FOR SOUND REPRODUCTION OF THE HIGHEST QUALITY.

IT HAS BEEN DESIGNED WITH A VALVE POWER OUTPUT STAGE TO SATISFY THE REQUIREMENTS OF THE PROFESSIONAL USER AND ENTHUSIAST AUDIOPHILE. IT IS A TRANSISTOR/TUBE HYBRID EMPLOYING THE DESIRABLE FEATURES OF BOTH TECHNIQUES.

1. INTRODUCTION

It is not uncommon that design techniques made obsolete by later developments and fashion, re-emerge after a period when weaknesses in the new technique are discovered. So it is with the valve power amplifier. The transistor amplifier completely replaced the valve amplifier after its inception, except in isolated cases, and production ceased.

Recently, however, enthusiasts and the technical staffs of magazines, have been comparing the subjective performance of the better valve amplifiers (Radford, Quad, etc.) of a decade or more ago with present day transistor amplifiers. The advantages claimed for the valve amplifier over the transistor amplifier are that:

It produces a more pleasing and satisfying overall sound quality.

It handles high level transients more effectively.

It can be operated nearer the overload point without noticeable distortion.

It produces a higher apparent sound pressure level than transistor amplifiers for a given rated power output.

2. HISTORICAL

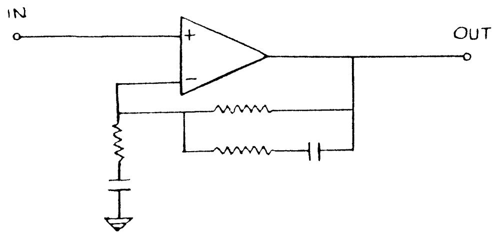
Radford Audio Limited has had considerable experience in the design and production of valve *and* transistor amplifiers which has enabled the company to design a new amplifier incorporating a state of the art valve output stage, together with semiconductor drive circuits in a direct coupled circuit with a performance never previously achieved in a valve amplifier.

At the time of ceasing production on the STA25 and STA100 valve amplifiers, a provisional patent was granted to Radford for a system of crossover feedback which provides high stability with reduced distortion and higher power at high frequencies. This technique was never used in a production amplifier, but has now been successfully applied in the TT100.

Negative feedback was introduced in the 1930's but was mainly confined to the output and driver stage only. Usually feedback (6-10dB) was applied from the output secondary winding to the cathode of drive valve. The first *overall* negative feedback amplifier was described in the Wireless World by Williamson in 1947. Marginal stability was achieved by high sectionalisation of the output transformer and careful choice of time constants. Considerable improvements have been made in the ensuing years in lower phase-shift circuits – particularly in the phase splitter. The introduction of the ultra-linear output stage with an improved design output transformer enabled a high amount of negative feedback to be applied for lower distortion with higher stability.

The Radford STA25 was one of the first amplifiers to apply a large amount of negative feedback with unconditional stability. It used a new triode/pentode phase splitter and an output transformer using high permeability grain oriented laminations. This amplifier was followed by the STA100 which used two video pentodes in a balanced long tailed pair circuit as a phase splitting output stage driver with a cascode input stage.

Fig. 1 Input stage schematic



3. VALVES v. TRANSISTORS – COMPARISONS

3.1 Output stage

The output stages of the valve and transistor amplifier are fundamentally different and the following comments may explain the preferences outlined above.

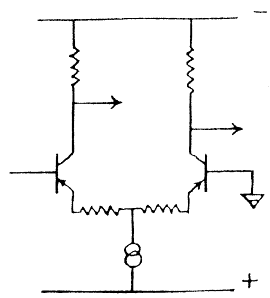
High order harmonic distortion

The distortion produced by good valve amplifiers consists mainly of low order harmonics. A push-pull output stage properly balanced cancels even harmonics and produces a very small amount of high order harmonics. Transistor amplifiers generally produce high order harmonics in abundance as well as 2nd and 3rd etc. High order harmonics, particularly odd orders (7th, 9th, 11th etc.) have a high irritation factor and produce listening fatigue. (It should be noted, however, that the best high quality transistor amplifiers produce virtually no distortion up to overload level. The Radford ZD50 and ZD100 amplifiers produce less than 0.005% total harmonic distortion right up to the overload point.)

Overload characteristics

The valve amplifier has a slow and smooth overload characteristic whereas the transistor amplifier overloads suddenly. This means that the transistor amplifier must be operated well within its rating to avoid distortion on peaks. The reduction in apparent available power output is effectively demonstrated with music having a high ratio of peak to average level, such as choral works and the piano.

Fig. 2 Phase splitter schematic



Transient power into reactive loads

The overload characteristic condition is exacerbated by other differences in the operating characteristics of the transistor power output stage. The emitter/base junction of a transistor has a low mass and thermal capacity and is easily destroyed by transient overheating. Transistor amplifier output stages are, therefore, fitted with high speed protection circuits to prevent this. The switching circuit is designed to operate when the output load is unsuitable.

The transistor power amplifier ideally likes a resistive load. Loudspeakers, however, are reactive and have a varying impedance characteristic with frequency. High reactive currents operate the protection circuits leaving little power to do work. The valve amplifier does not need a protection circuit and is able to satisfy a high instantaneous reactive current demand.

Summarising then, the weaknesses of the transistor power output stage relative to the valve power output stage are:

Rapid overload characteristic.

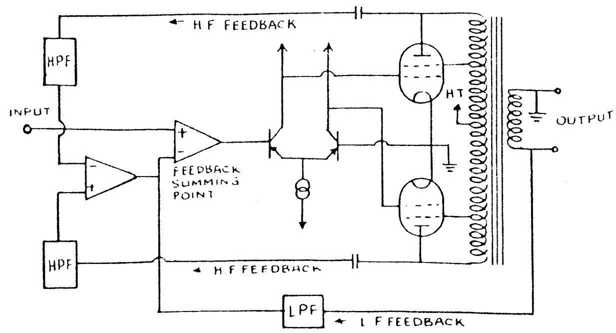
Generation of high order harmonic distortion products near and at overload point.

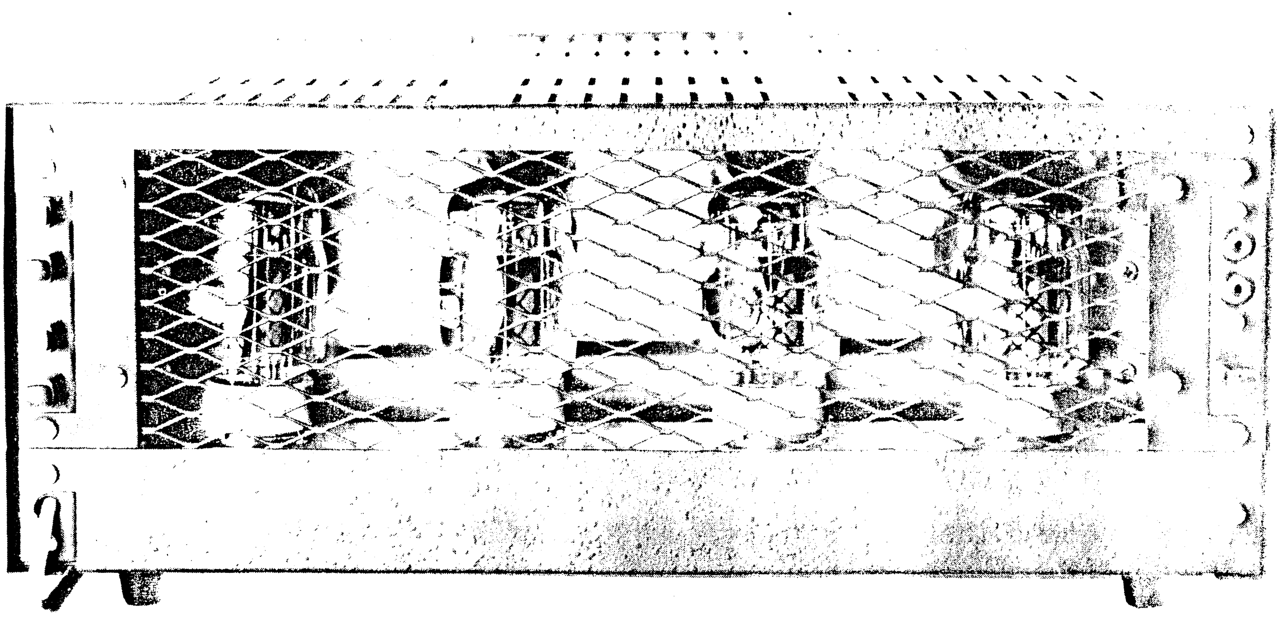
Generation of distortion products by protection circuit switching transients.

Poor reactive load capability which precipitates early overload.

The valve power amplifier has a more acceptable overload/distortion characteristic and is less sensitive to the load characteristics of the loudspeaker. Nevertheless, high quality transistor amplifiers can be designed to provide high reactive currents and work into relatively low impedance loads before the protection circuit operates. Leaflet A30.976 describing the ZD50 and ZD100 amplifiers gives information on the design of such amplifiers.

Fig. 3 Amplifier overall feedback schematic





3.2 **Input and drive stages**

Valves used for amplification in the input and drive stages of a power amplifier are relatively high impedance and, therefore, have a poor bandwidth and phase characteristic in a practical amplifier compared with transistor stages. The 'miller' effect of reflected capacitance from a valve output stage has virtually no effect across the very low source resistance of a driver stage using power transistors.

Transistor gain stages are low impedance having a good bandwidth and lower noise with higher stability than valve gain stages.

Transistor input and drive stages are ideal for driving valve output amplifiers.

4. **TT100 CIRCUIT DESIGN DETAIL**

4.1 **Input Amplifier**

The basic requirements of the input amplifier include two inputs; one of reasonably high impedance for the signal and the other for negative feedback. The TT100 input amplifier is direct coupled and has a wide bandwidth with low noise and distortion. The high performance is obtained by using a high slew rate low noise operational amplifier with a large amount of negative feedback. See Fig. 1.

4.2 **Phase Splitter**

A wide bandwidth low distortion 'long tailed pair' phase splitter has been developed for the TT100 using high voltage p.n.p. transistors to provide adequate voltage swing and to permit direct coupling to the output valve grids. Local feedback is introduced to reduce distortion and the constant current source in the tail is returned to a positive supply to enable the inputs to be at ground potential – obviating the need for input coupling capacitors. See Fig. 2.

4.3 **Output Stage**

A pair of high power beam tedrodes are used in class AB2 push pull. This means that under normal music conditions the amplifier will be running in Class A and moving into Class B only to provide the extra power required for the clean reproduction of transients. The valves are coupled to the load via a multi-section output transformer wound in our own factory and specifically designed for the TT100 to obtain optimum performance over a wide range of load conditions. Distortion in the output stage itself is reduced by the ultra linear connection using 43% taps.

4.4 **Power Supplies**

To eliminate feedback through the power supplies from large current swings of the output stages, separate power supplies are provided for the voltage amplifying and phase splitting stages. Two power transformers are used: one providing 600V for the output stages and the other 250V for the long tailed pair drive stage, +15V, +15V, −15V; and 6.5V for the output valve heaters. The high voltage circuit uses a bridge rectifier and a choke capacitor filter. It has very low internal resistance in order to meet the demands of the output stage for high transient power. The 250V supply transformer also energises a silicon diode bridge rectifier with choke capacitor smoothing. The ±15V supplies for the input stage and the feedback summing amplifier are regulated.

4.5 **Overall Schematic Arrangement**

It is conventional in valve amplifiers to apply negative feedback from the secondary winding of the output transformer to the input amplifier. The disadvantage of this arrangement is that the phase correcting networks have to commence rolling off in the middle of the audio band, reducing the amount of overall feedback at high frequencies. The phase shift in the forward gain path is mainly due to the leakage inductance and self capacitance in the output transformer. In amplifiers using a valve drive stage, phase shift also takes place due to the reflected capacitance of the output valves into the phase splitting circuit.

To overcome the phase shift due to miller reflected capacitance, a very low output resistance transistor drive circuit is used. A new and novel arrangement is used to avoid the phase shift at high frequencies, due to the output transformer. High frequency feedback is taken from the anodes of the output valves, but as the push pull anodes are 180° out of phase, inversion of the signal from one anode is necessary. In addition, these two feedback paths must be integrated with the overall feedback signal from the secondary of the output transformer. This is achieved by using high-pass filters in the high frequency feedback paths, and a low-pass filter in the low frequency feedback path. The output from the inverting and non-inverting high frequency feedback amplifier is summed with the low frequency feedback into the second input of the signal input operational amplifier. The high frequency and low frequency feedback filters are carefully integrated as a feedback crossover network. The schematic diagram (Fig. 3) illustrates the general arrangement of the amplifier design and power supplies.

5 PERFORMANCE CHARACTERISTICS

5.1 Load flexibility

In order to provide high power output without distortion over a wide impedance range normally found in practice, the output transformer ratio has been set to provide maximum power into 4 ohms. This enables a power output exceeding 100W into impedances from 1½ to 8 ohms peaking at 135W per channel into 4 ohms (Fig. 4).

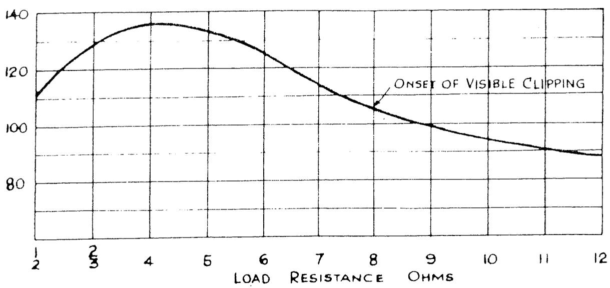
5.2 Distortion versus frequency

It will be seen from Fig. 5 that the distortion over the audio band is 0.25% rising to 0.5% at 20Hz and 1% at 20kHz for 100W output into 6 ohms both channels driven.

5.3 Distortion versus power output

Fig. 6 shows that at 1kHz and 6 ohms load, each channel provides an output of 120W at 0.5% distortion. Distortion follows a linear curve to zero distortion at zero power output.

Fig. 4 Load resistance v. power output characteristic



6. THERMAL CHARACTERISTICS

Valve amplifiers are conventionally designed with a perforated cover for convection cooling by natural upward air flow. This is a considerable disadvantage as the amplifier must be located with a large air space above it to prevent overheating and consequent unreliability. The thermal engineering design of the TT100 was approached with the same thoroughness as the circuit and guidance was sought from the M.O. Valve Company, the makers of the Gold Lion tubes used in the amplifier. Cooling is achieved by a combination of radiation and increased velocity air flow. A polished aluminium reflector is situated at an optimum distance from the anodes of the KT88's (similar to a reflector type electric fire) and heat is transmitted into the wall or room at the rear of the amplifier. The anodes are oriented for maximum reflection radiation. An air duct is provided between the sub chassis (on which the tubes are mounted) and the reflector and the air inlet is arranged to increase the air velocity over the tubes and reflector. The main power supply electrolytic capacitors are located behind the reflector away from heat with a cooling gap around the circumference. The printed circuit boards are fitted below the main chassis cooled by the input air stream.

Fig. 5 Distortion v. frequency characteristic

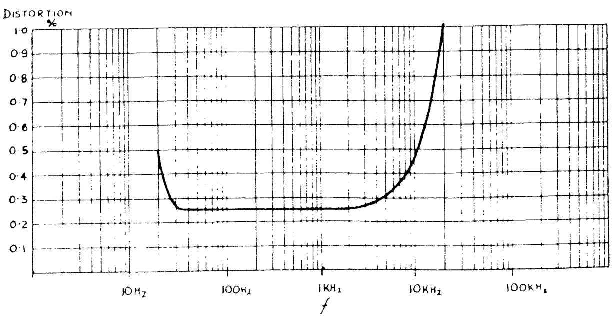
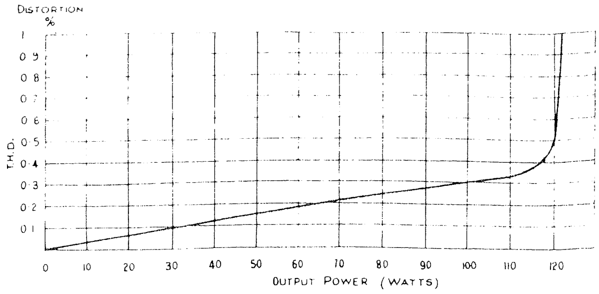


Fig. 6 Distortion v. power output characteristic. 6 ohms load



7. OPERATING CHARACTERISTICS

7.1 Transformers

Transformers are manufactured to the highest possible standard by Radford Transformers Limited. Bobbins are made from synthetic resin bonded paper and coils are wound with a vinyl-acetal covered wire. No oleo-resin enamelled wires are used. Polyester film is used as insulation between high voltage windings and between sections in output transformers. Wound coils are impregnated with a thermo-bond varnish and cured by baking at 120°C for 10 hours. Copper screens are used between the primary and secondary windings in mains transformers. Assembled transformers are sealed with a tropical enveloping varnish making it virtually failure-proof under normal working conditions.

7.2 Tropical climates

All Radford equipment is designed for satisfactory operation continuously in ambient temperatures and humidities experienced indoors in tropical climates, providing adequate ventilation is arranged in accordance with the operating instructions.

7.3 Reliability

The TT100 is designed on a very generous basis for continuous duty operation with minimum maintenance. Once installed and adjusted after a running-in period it should be necessary to replace valves at regular intervals only depending on the operating duty cycle.

The amplifier is substantially constructed, is totally enclosed and able to withstand the rigors of frequent handling and transportation in commercial vehicles.

8. MAINTENANCE AND REPAIR

As a backup to the considerable effort in design and manufacture for reliability, the engineering construction has been arranged for easy fault finding and speedy replacement of a component part or module. Technical Instruction B/C 35 provides a circuit and parts list together with information on the maintenance and repair of the TT100 amplifier.

9. SPECIFICATION

Power output rating	100W average power (continuous r.m.s. sine wave per channel into resistive load)
Voltage frequency response	±0.5dB 20Hz to 20kHz
Power frequency bandwidth	20Hz to 20kHz, matching 4 to 8 ohms nominal
Stability	Unconditional
Input sensitivity	1 volt at rated power
Signal to noise ratio	Better than 100dB
Cross talk	80dB

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