Introduction to Hifi

Power amplifiers

The development of the power output section of domestic hifi amplifiers adds up to a quite intriguing study, although not one that can be pursued at length in this present series. It should be helpful, however, to mention certain notable configurations — both valve and solid-state — that have culminated in present-day technology.

In actual fact, most of the fundamental principles governing the operation of amplifier output stages were identified and documented during the establishment period for domestic hifi, from the early 30's to the late 40's, in the context of valve-based technology.

Typical of such research was a landmark paper presented by the late F.Langford-Smith to the 1938 IREE World Radio Convention in Sydney entitled: "The Relationship between the Output Stage and the Loudspeaker". The author, at the time, was Chief Applications Engineer for the Amalgamated Wireless Valve Company.

When solid-state technology took over in the '60s and '70s, it brought radical changes in methodology, but the critical design parameters that had been identified by Langford-Smith and others, 30 years previously, still applied: source impedance, load impedance, distortion, frequency response, damping, feedback, stability, etc.

The inclusion of a segment on valve type power amplifiers therefore offers more than mere historic or nostalgic interest. It should serve to highlight considerations which apply with equal force to modern solid-state designs, while also bringing a touch of reality to those who choose to regard valve-based amplifiers as a race apart.

From the seemingly endless — and often misguided — arguments in the '30s about triodes, tetrodes and pentodes, about operating conditions, biasing arrangements, direct coupling, negative feedback, and so on, a basic configuration that earned early and unfailing respect from the then-hifi fraternity is shown in Fig.5.

Reproduced from the June 1937 issue of *Radiotronics*, the particular example shows a pentode voltage amplifier, followed by a triode-connected pentode as a phase splitter, driving a pair of push-pull 2A3 power triodes — a valve broadly equivalent to two old-time 45s in parallel. The available power output is quoted as 7W RMS with the distortion, mainly second harmonic, ranging from 0.25% at low output levels to 2.5% at full volume — said to be substantially below that of then available program sources.

Measured across a resistive load at voice coil impedance, and dependent on the particular output transformer, the frequency response was shown as –2dB at 35Hz, virtually on reference from 42-1000Hz, a gentle rise to +3dB at 4kHz, falling back again through reference just above 10kHz — again, an acceptable result for the period.

(A contemporary alternative approach was to use a pair of triodes as a

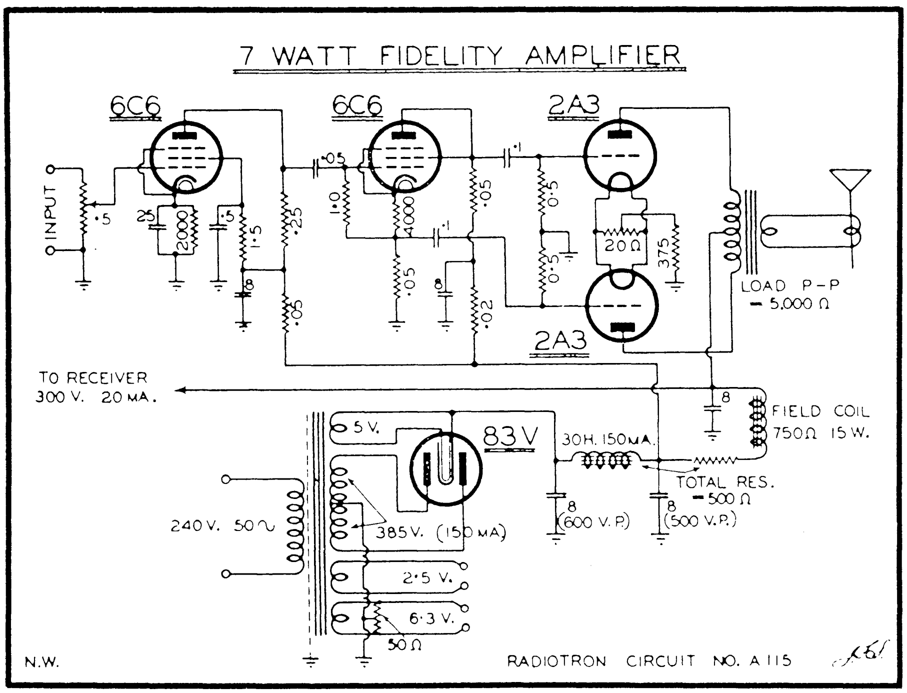

Fig.5: The circuit for a 7-watt pure class-A push-pull 2A3 amplifier comes from the A.W.Valve Co technical bulletin "Radiotronics" for June, 1937. A class-AB version delivering 13.5W was described in "Radiotronics" for August 1939.

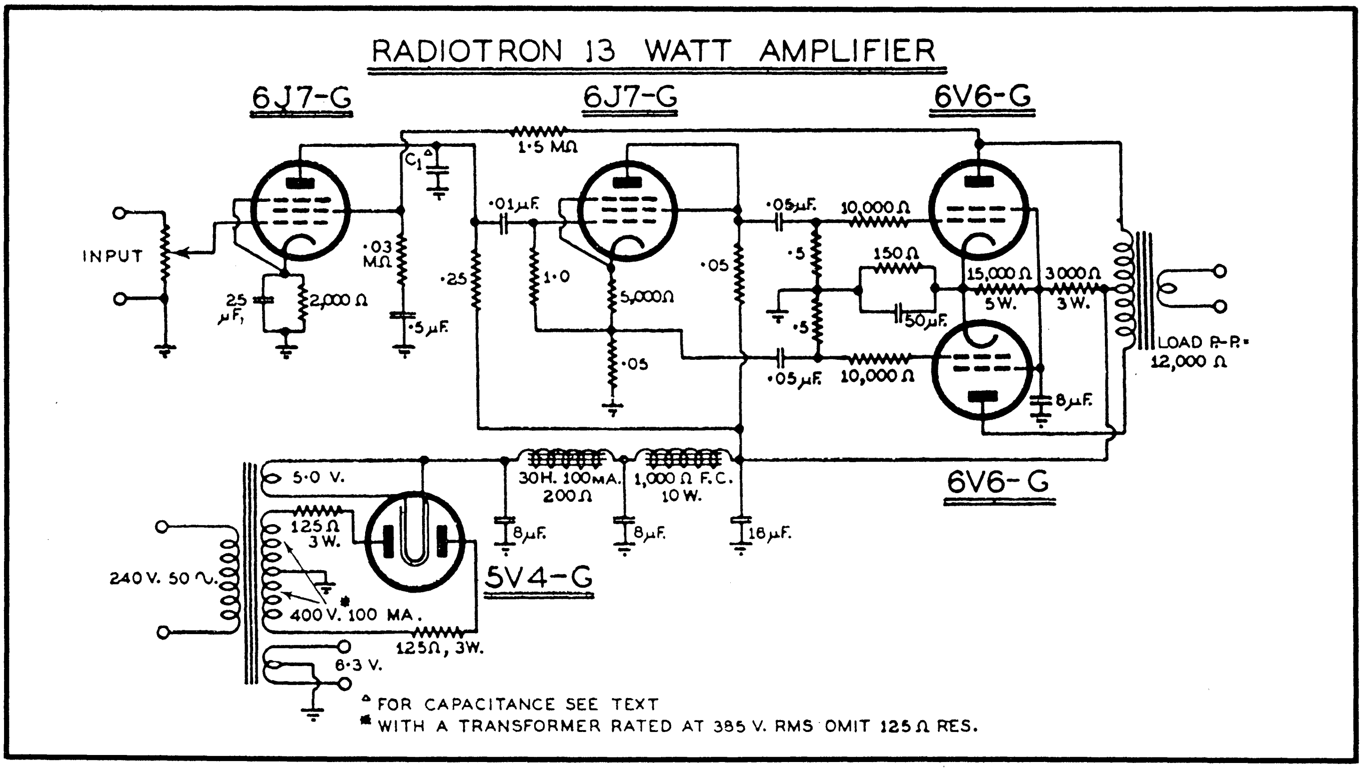

Fig.6: When the importation of 2A3 triodes was restricted on 1940, attention turned to the use of 6V6-G tetrodes using, initially, a simple system of negative voltage feedback — from one side of the output transformer to the screen of the pentode voltage amplifier.

phase inverter ahead of the output valves, preceded by a triode voltage amplifier).

Either way, the merit of the overall approach rested, very largely, on three basic performance criteria:

(1) All stages operated under class-A conditions — near the centre of their dynamic characteristic — thus minimising harmonic distortion.

(2) Because of their intrinsically low output resistance (e.g. 800 ohms) 2A3 output triodes could operate into typical reactive loudspeaker loads, without exhibiting unduly increased harmonic distortion or non-linear frequency response.

(3) When stepped down by the output transformer, the valve output resistance assumed a value well below the nominal loudspeaker voice coil impedance, thereby ensuring good loudspeaker damping, particularly at the bass resonant frequency.

Admittedly, the 7W RMS power output available from a pair of 2A3s was modest by present standards but, in those days, such amplifiers were commonly used with large and expensive mono hifi loudspeaker systems, designed with a special emphasis on acoustic efficiency. The sound pressure level available could be much the same as from a less sensitive modern system driven by a 20-30W amplifier.

Push-pull 2A3 amplifiers were still being used — by choice — right up into the mono LP era although, well before then, designers had managed to obtain increased power by pushing them to their dissipation limits and even adding a few dB of negative feedback to keep the measured performance abreast of other evolving technology.

For example, *Radiotronics* for August 1939 carried details of an amplifier broadly similar to Fig.5 but using the 2A3s under maximum class-AB conditions, driven by a triode-connected 6V6G phase splitter. No provision was made for negative feedback, but the design offered an output of 13.5W RMS at a distortion figure ranging from very small at low signal levels to about 3% at full output.

Tetrodes and pentodes

In terms of published characteristics, power output tetrodes and pentodes invariably appeared to have a marked advantage over contemporary power triodes, in terms of both gain and power output; hence the urge to use them. In the early '30s, for example, a single 47 offered 2.7W output against 1.5W from the 45 triode, for a comparable DC power input and distortion level and about one-third of the grid drive signal.

The 47 was followed by a whole string of pentodes and beam-power tetrodes, from the 59 to the 6V6 and 6L6, offering progressively higher gain and improved input/output efficiency for a distortion level ostensibly similar to that of power triodes.

The catch was/is that, in practice, with their high intrinsic output resistance (30,000-60,000 ohms) tetrodes and pentodes perform very poorly into complex reactive loudspeaker loads. The distortion level rises way above the published figure for a resistive load, while the acoustic output also varies widely with load impedance, and therefore frequency. In addition, the output stage imposes little in the way of damping on the voice coil.

As a result, from the very outset, tetrode and pentode output stages gained a reputation for louder signals (higher sensitivity and output), a harsh sound (increased distortion), a strident quality (rising treble response), and "boomy" bass (poor loudspeaker damping).

To reduce the effective output resistance and thereby counteract these inadequacies, it was/is essential to use negative (voltage) feedback around the output stage. In broad terms, around 10-12dB of feedback or a gain reduction of 3-4 times is necessary to achieve performance parameters comparable to those of a triode power stage *without* feedback.

This presents no special problem in

simple audio systems and, over the years, generations of mass produced valve-based receivers and record players were sold, using single-ended tetrode and pentode output stages with roughly that order of negative feedback to lower effective output resistance and hence to reduce distortion, linearise frequency response and improve damping with loudspeaker loads.

A similar approach to hifi system design became more urgent in 1940 when wartime import restrictions effectively cut off the supply of 2A3 power triodes, for other than replacement purposes. While "2A3" type amplifiers could still be simulated using locally made type 45s in push-pull parallel, the Amalgamated Wireless Valve Co suggested a push-pull 6V6G design, with feedback, as being more economical and probably more reliable.

Two such circuits were suggested: a 9-watt amplifier in *Radiotronics* for November 1940 and a very similar 13-watt version in May 1941 (Fig.6), offering much the same performance as the 13.5W 2A3 amplifier mentioned earlier. For those requiring higher power levels, circuits using 6L6 tetrodes in push-pull class AB1 offered up to 32W RMS.

Those were the good old days, when a designer's lot was a relatively happy one but . . .

Feedback & Stability

With the emergence of improved signal sources — FM broadcasting, microgroove discs and magnetic tape recording — amplifier designers had to come up, fairly smartly, with something a lot better than the reliable old triodes, or tetrodes with a modest amount of negative feedback.

If frequency response was to be truly flattened, distortion reduced by an order of magnitude, and damping made really effective, it would be necessary not only to increase the amount of negative feedback but to extend it so as

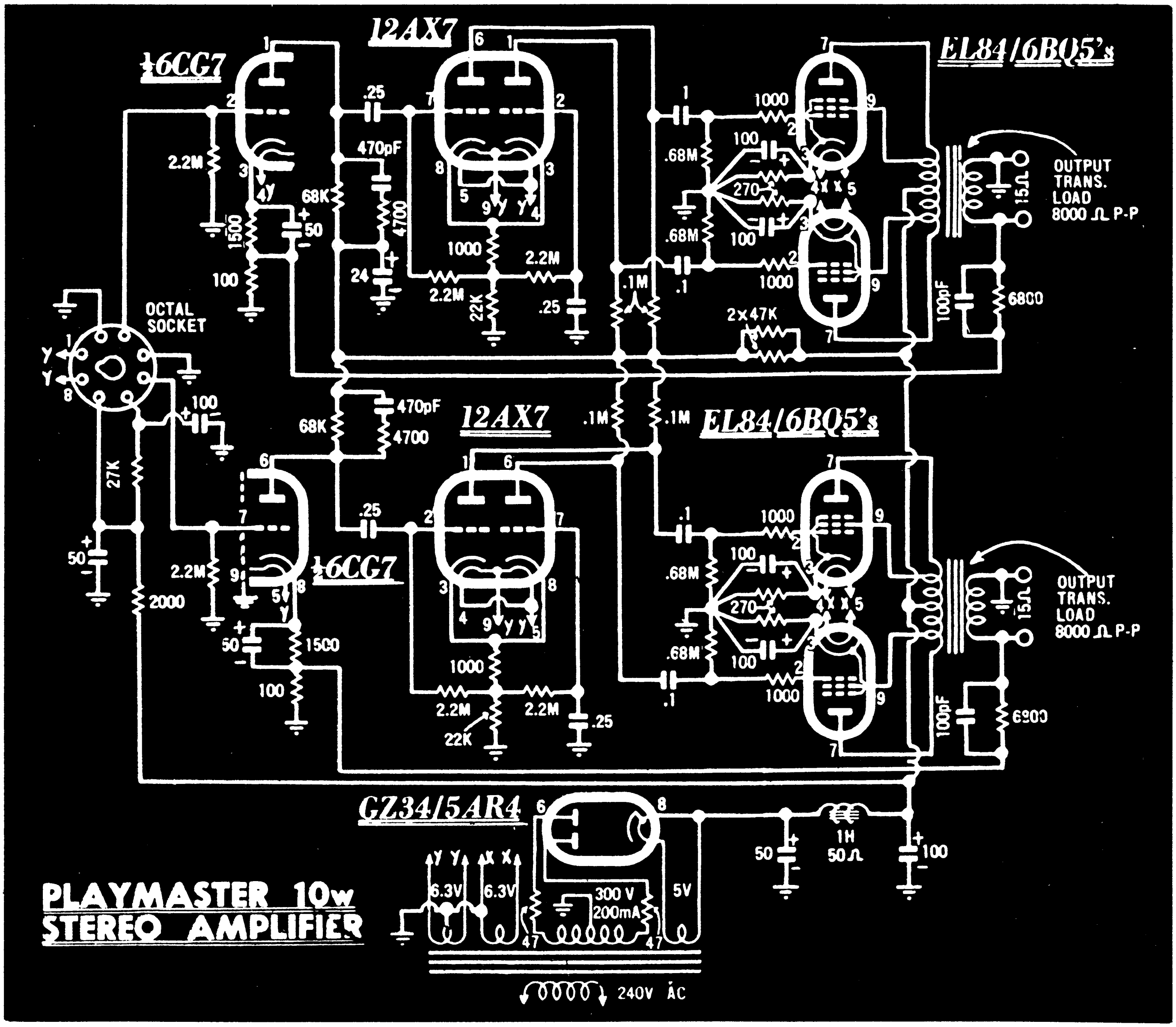

Fig.7: Combining economy with performance: the first of the stereo ultra linear valve Playmasters. Note the 100pF capacitor across the 6800Ω feedback resistors and the 470pF/4700Ω "step components" across the 6CG7 anode loads, all serving to tweak the phase.

to include the voltage amplifier, the phase inverter stage and the output transformer as well.

This would typically involve grounding one side of the transformer secondary winding and taking a feed from the other side back to a suitable early point in the signal chain as, for example, the cathode circuit of the voltage amplifier. Needless to say, the connections would be so arranged that the feedback would be negative, rather than positive.

It sounds simple enough but, unfortunately, the likely presence of coupling capacitors within the feedback loop, along with bypass and stray shunt capacitance and the complex reactive qualities of the output transformer, all conspire to rotate the phase of the original and the feedback signal at subsonic and supersonic frequencies.

Even the reactive qualities of the loudspeaker system can have an effect, as also can the capacitance and inductance of the loudspeaker cable.

Given sufficient feedback and negative-to-positive phase rotation, an amplifier can all too easily become marginally or completely unstable. At best, the sound quality may suffer; at worst, the amplifier may "motorboat" at a very low frequency, or oscillate so violently at a supersonic frequency as to endanger the tweeter loudspeaker.

The practical outcome of this is that, in designing a high performance tetrode or pentode power amplifier, extreme care is necessary with the circuitry and layout — and especially the choice of output transformer. It may also be necessary to tweak the phase shift with supplementary resistors and capacitors, in the interests of stability.

A well designed high-feedback, high-performance amplifier can be mass produced quite successfully, or duplicated in the case of a do-it-yourself project. Problems can arise, however, if a given circuit is built up using other components, and particularly a different output transformer. Variants really need to be checked with a CRO and a sine/-square wave audio generator, to determine whether or not they are intrinsically stable.

The "ultralinear" circuit

The climax to the audio valve era came with a development credited to Hafler and Keroes, reported in the Feb.'52 issue of this magazine (then *Radio & Hobbies*). They discovered that pentode and tetrode valves could be made to assume triode-like characteristics, by feeding the screens from a tapping part way up the respective halves of the output transformer primary winding.

For example, their work with an amplifier using push-pull 6L6s showed a clear optimum tapping position at 80% of the plate load impedance — about 10% down the winding from the respective anodes, expressed in turns.

At this point, the available power output was the same as for tetrode operation (20W RMS) but the effective anode resistance, referred to the 16 ohm secondary winding, had dropped from 145 ohms to less than 20 ohms. Low level distortion, even into a resistive load, had also fallen markedly.

It took a while for the message to get through, the more so because the authors' choice of the term "ultra linear" tended to suggest just another gimmick. In fact, the mode very effectively combined the sensitivity and efficiency of pentodes or tetrodes with a vitally important low output resistance, not too far removed from that of a triode.

It also took a while to verify optimum tapping points for other output valves, and for manufacturers to produce transformers with suitably interwound sections. This done, however, an ultra linear amplifier could be produced at virtually the same cost as its pentode/tetrode equivalent. It could use a similar order of feedback, but with the advantage that it would be operating around a much better basic amplifier — with a much better end result.

The mode really came into its own in the late '50s, with stereo demanding a new generation of compact, efficient, high performance, two-channel amplifiers. The first of this new breed was the Playmaster 10+10W stereo amplifier, described in the January 1959 issue (See Fig.7) using a specially designed kit of A&R transformers. It set the style for others which carried through to the end of the valve era, a few years later.

According to the accompanying article, written by the late John Moyle, the negative feedback was checked out up to 32dB but finally set at about 20-22dB — this around an already impressive basic amplifier. No figure is quoted for distortion, although this would inevitably have been very low compared with earlier tetrode/pentode designs using less feedback.

The response, however, is shown as dead flat from 10Hz to 100kHz, falling away above that in a relatively smooth, controlled fashion. Photographed off a CRO screen, the square wave response was totally free of overshoot or ripple.

Derivatives of this circuit, and of the larger version using EL34s did a good job in their day, driving the large and efficient Rola, Goodmans and Wharfedale loudspeakers. They ran into problems, however, when loudspeaker manufacturers found it necessary to trade off acoustic efficiency in an effort to produce smaller, wide-range systems.

It became necessary to produce amplifiers capable of much higher power output and, in the ultimate, transistors offered the most practical means to meet that requirement.

There are still those who credit valves with the ability to produce a more "musical" sound than transistors but, having in mind the limited sensitivity of modern loudspeakers and the extended dynamic range of compact discs, something much more pretentious is necessary than even the best ultra linear designs of the '60s.

Currently, more pretentious designs certainly are available at the top end of the marketplace — similar basic thinking but scaled up in size, weight, complexity and specifications, with cost almost an afterthought. Whether the end result is better than, equal to, or even as good as the best solid-state equivalent is something that hifi enthusiasts argue about with considerable spirit.

(To be continued)