THE WILLIAMSON AMPLIFIER

Experimental audio amplifiers were first made about 75 years ago. Since then, a vast amount of work and research has gone into improvements. A major advance came in 1947, when a new design that raised standards of performance considerably was described in the British magazine *Wireless World*.

Although during the period prior to 1950, there were luxury receivers using elaborate audio systems, few qualified as being genuinely 'High Fidelity'. As professional equipment was neither affordable nor readily available to the private user, enthusiasts and small manufacturers usually 'rolled their own', often using designs that appeared in *Wireless Weekly* and later *Radio & Hobbies*, A.W.V's *Radiotronics*, *Wireless World* from the UK and numerous American magazines.

Two philosophies

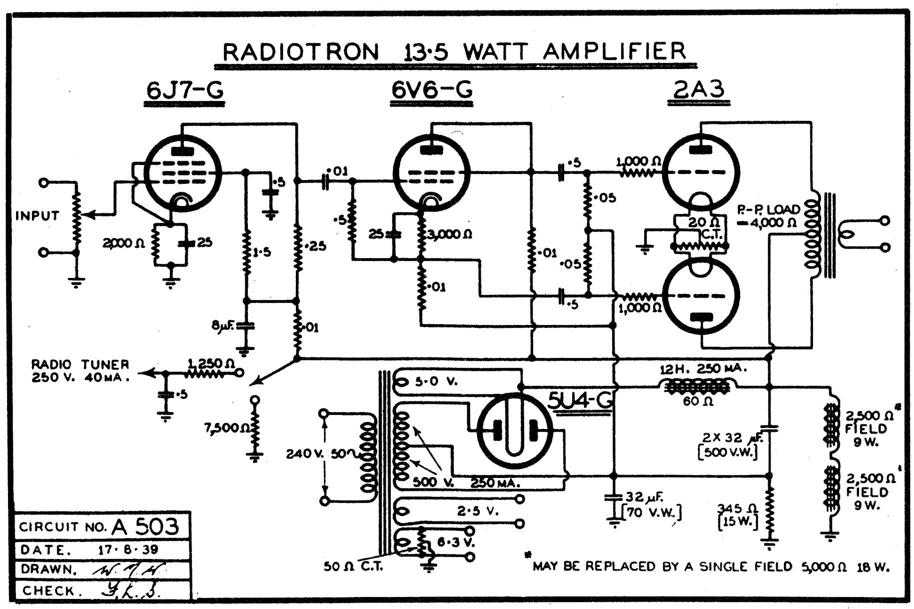
Pentode and beam tetrode output valves with their advantages of high sensitivity and efficiency had become standard in receivers, but they had the serious shortcomings of high distortion and the inability to damp down bass resonances in loudspeakers, due to high output resistance.

Quality conscious enthusiasts continued to insist on triode output stages, the ultimate valves being the American 2A3 and its British equivalents. A pair of these could provide around 10 watts, but required upwards of 100 volts drive between grids. Interstage driver transformers were strongly recommended, but suitable types required complicated winding configurations and were very expensive. One solution was to use a large driver valve, as in the AWV circuit in Fig.1.

Tetrodes suspect

Multiple grid output valves simplified design considerably. Their grid drive requirements were less demanding than those of triodes and they were more efficient. By using negative feedback, amplifier performance could be made to be equivalent to a good triode amplifier, but without a lot of care, the beam tetrode was hard to stabilise against parasitic oscillations. Fig.2 is an example of a well designed beam tetrode equivalent of the amplifier in Fig.1, again from AWV.

The test curves show that the two amplifiers had similar performances and in operation would have produced indistinguishable results. The deterioration at low frequencies in the triode amplifier can be attributed to an inadequate output transformer rather than the basic design.



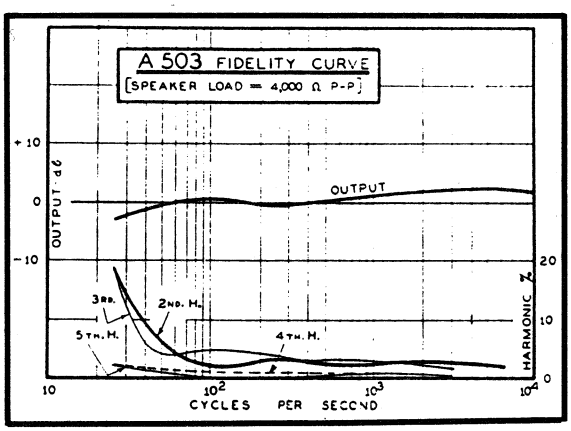


Fig.1: This AWV triode amplifier circuit of 1939 shows the performance achievable without negative feedback. Note that the circuit was drawn by Neville Williams, and checked by F. Langford-Smith.

Two factions

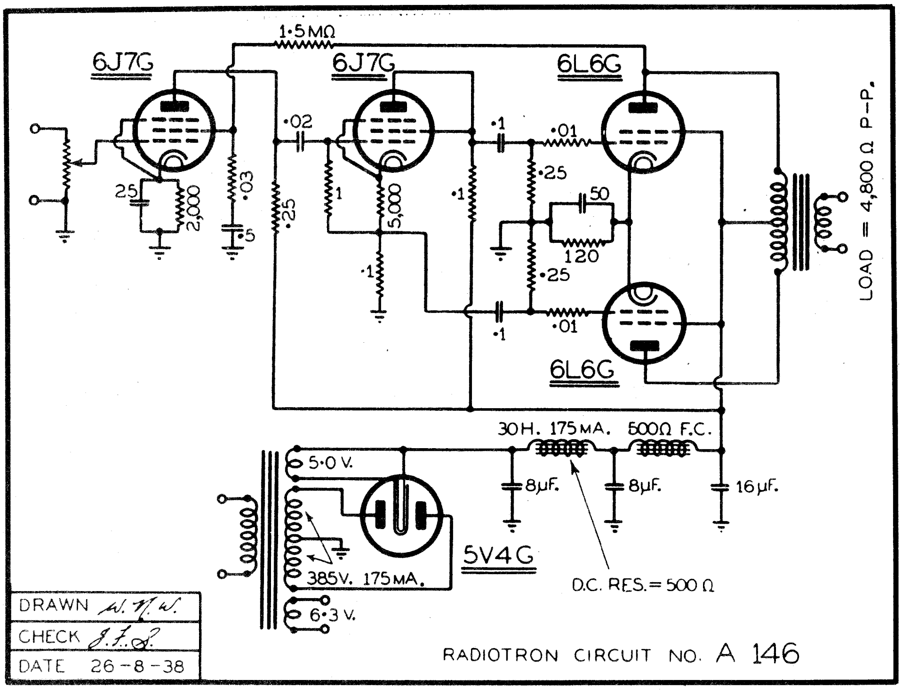
Sound reproduction technologies have a history of attracting opposing opinions, and recent arguments in *EA* show that this spirit is still alive. The triode versus tetrode debate became quite heated, so much so that early in 1946, the redoubtable Australian authority, F. Langford-Smith took a hand and wrote an article in *Radiotronics* putting the whole thing into perspective. He reported on the work done by the American authority J.K. Hilliard, whose conclusions were that beam power valves could deliver the same audio power as triodes with the same or less distortion.

New standards

By 1947, a typical high quality amplifier would have had a frequency response varying by no more than 1.0dB from 40Hz to 10kHz and, above 100Hz, harmonic distortion at 10 watts output of between 1% and 2.0%. With the 78rpm shellac records and radio transmissions then available as programme sources, these specifications were adequate, but improved methods were forecast.

Wartime developments had been incorporated in Decca's 'FFRR' recordings, improved pickups and speakers were becoming available, FM transmissions were planned and German developments in tape recording were being revealed. It was time to improve amplifier performance.

One solution was obvious. If negative feedback improved beam tetrode amplifiers, it should make a good triode amplifier even better. However in practice it was not quite this simple.



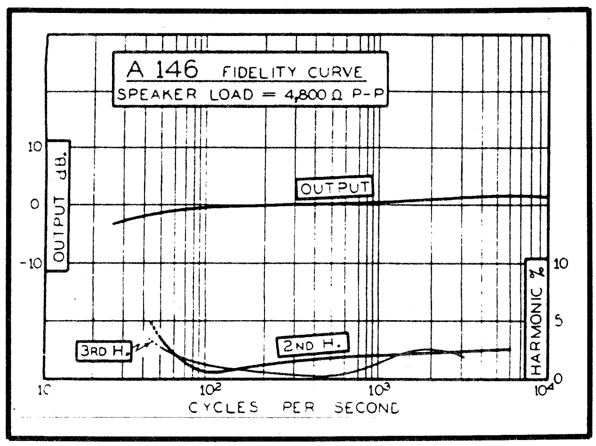


Fig.2: The tetrode equivalent of Fig.1, also from AWV, with negative feedback taken from the anode of the upper 6L6G to the screen grid of the first valve.

Transformer problem

In the amplifier of Fig.2, feedback is taken from the anode of the upper output valve to the screen of the input valve. but it was not sufficient simply to substitute low mu power triodes for the 6L6G's. Apart from there now being insufficient gain, some distortion could be produced by the output transformer. Furthermore, it may be seen from Fig.2 that because feedback came from the upper output anode only, any incomplete coupling between the two primary sections would result in there being a smaller feedback component from the lower output valve.

For there to be any worthwhile progress, the entire amplifier including the output transformer would have to be included in the feedback chain. This had been tried often enough, but the problem was that serious limitations were imposed by conventional output transformers, causing the amplifier to become unstable before a worthwhile amount of negative feedback could be applied.

Low frequency transformer response could be degraded by insufficient primary inductance, as the graph in Fig.1 shows, whilst the high frequency end was restricted by inadequate coupling between windings. These limitations introduced sufficient phase shift at each end of the audio spectrum for the feedback to become positive, with disastrous results.

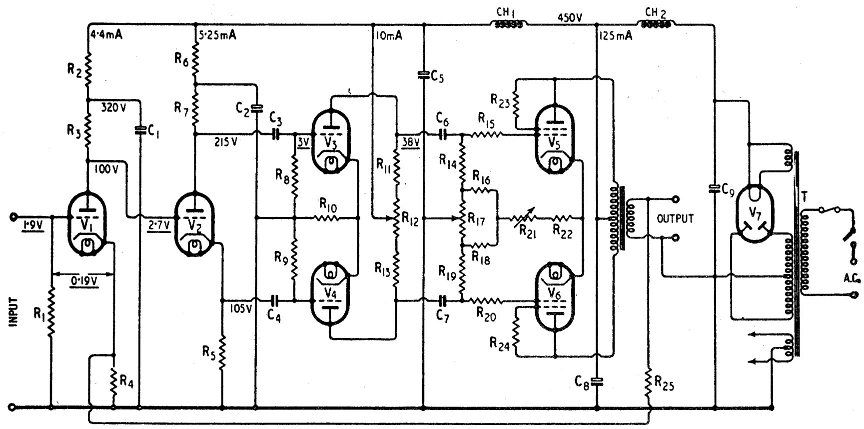
To avoid instability with a worthwhile amount of feedback, a transformer would need to have a frequency response wider than that of its associated amplifier. Without careful design, adding extra voltage amplifier stages to compensate for the loss of gain could also increase the phase shift problems.

Williamson's answer

In articles published in the April and May 1947 issues of *Wireless World*, D.T.N. Williamson of the Marconi Osram Valve Company dealt at length with these problems and their solutions. He concluded by giving constructional details of an amplifier which produced 15 watts with 0.1% distortion, and a frequency response that was absolutely flat between 10Hz and 100kHz, a remarkable standard of performance.

Williamson tackled the transformer problem head on. He produced a design that permitted its inclusion within the feedback loop operating with a 10 times (20dB) gain reduction, with a stability margin of a further 10dB.

The lack of inductance was countered by the use of no less than 4400 turns of wire for the primary, on a core as big as



Circuit diagram of complete amplifier. Voltages underlined are peak signal voltages at 15 watts output.

CIRCUIT VALUES

R_1	1 MΩ $\frac{1}{4}$ watt ± 20 per cent	R_{15}, R_{20}	1,000 Ω $\frac{1}{4}$ watt ± 20 per cent	C_8	8 μF 550 V, wkg.
R_2	33,000 Ω 1 watt ± 20 ,,	R_{16}, R_{18}	100 Ω 1 watt ± 20 ,,	C_9	8 μF 600 V, wkg.
R_3	47,000 Ω 1 watt ± 20 ,,	R_{17}, R_{21}	100 Ω 2 watt wire-wound variable.	CH_1	30 H at 20 mA (min.)
R_4	470 Ω $\frac{1}{4}$ watt ± 10 ,,			CH_2	10 H at 150 mA (min.)
R_5, R_6, R_7	22,000 Ω 1 watt ± 10 ,,	R_{22}	150 Ω 3 watt ± 20 ,,	T	Power transformer.
R_8, R_9	0.47 MΩ $\frac{1}{4}$ watt ± 20 ,,	R_{23}, R_{24}	100 Ω $\frac{1}{2}$ watt ± 20 ,,		Secondary 425-0-425 V
R_{10}	390 Ω $\frac{1}{4}$ watt ± 10 ,,	R_{25}	1,200$\sqrt{\text{speech coil impedance}}$, $\frac{1}{4}$ watt.		150 mA (min.) 5 V. 3A, 6. V. 4A, c.t.
R_{11}, R_{13}	39,000 Ω 2 watt ± 10 ,,				
R_{12}	25,000 Ω 1 watt wire-wound variable.	C_1, C_2, C_5	8 μF 450 V, wkg.	V_1 to V_4	L63
		C_3, C_4	0.05 μF 350 V, wkg.	V_5, V_6	KT66.
R_{14}, R_{19}	0.1 MΩ $\frac{1}{4}$ watt ± 20 ,,	C_6, C_7	0.25 μF 350 V, wkg.	V_7	U52

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Fig.3: Williamson's circuit. It achieved a dramatic improvement by using a large amount of negative feedback, with the output transformer included in the loop. A complex and specially designed output transformer was needed to achieve stability.

Fig.4: The Williamson amplifier's performance curves. Note that they cover from 1Hz to 1MHz – three decades wider than those for the earlier AWV amplifiers.

that of a large power transformer – providing a minimum of 100 henries inductance. To overcome the high frequency coupling problem, the windings were divided into no less than 10 primary and 8 secondary sections, all interleaved in two balanced halves.

Simple amplifier

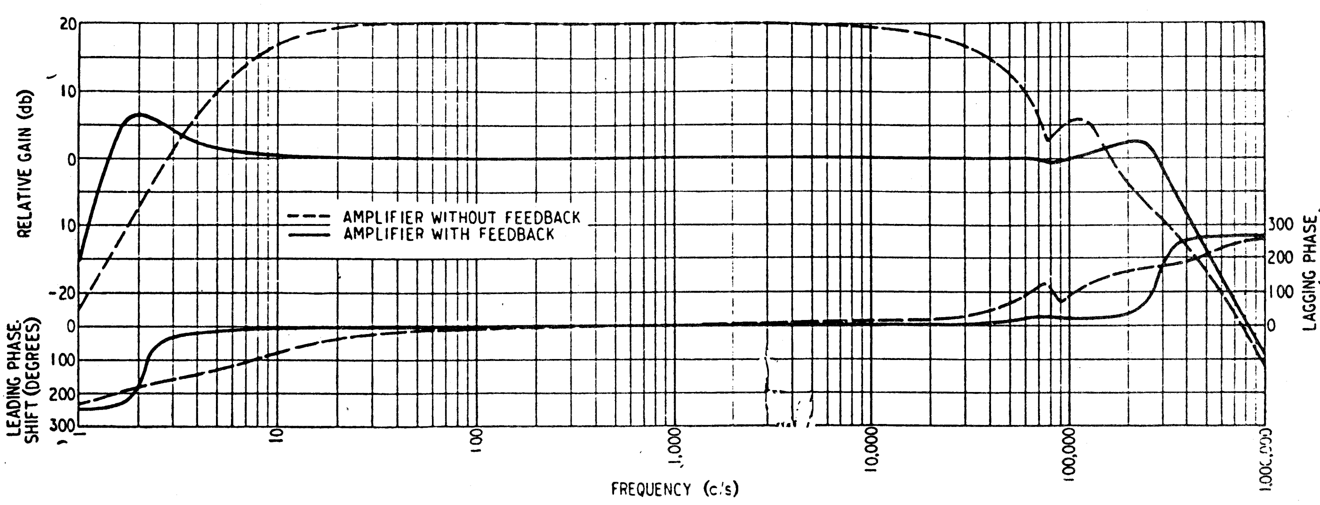
No tricks were employed in the amplifier circuit itself. Just as in the circuit of Fig.1 there was a voltage amplifier (V1) and phase splitter (V2), but to provide the additional gain needed, there followed a push pull driver stage (V3/4). To minimise low frequency phase shifts, the voltage amplifier stage was direct coupled to the phase splitter and there were no cathode bypass capacitors.

The output stage used triode connected KT66 beam tetrodes. These needed about half the drive of 2A3 triodes, but required a greater HT voltage. KT66 valves were similar to the American and Australian 6L6G and 807, but had much higher screen voltage ratings. The L63 general purpose triodes used for the amplifier stages were identical to the 6J5 or one half of a 6SN7GT.

Instant success

Within a very short while, Williamson amplifiers were being built by enthusiasts world wide. Many with lots of patience wound their own transformers, but manufacturers soon produced them, admittedly at a price.

In Australia, AWV adapted it to their own valve types and F. Langford-Smith himself published a very full report in the October 1947 edition of *Radiotron-*



Loop gain and phase-shift characteristics of the amplifier.

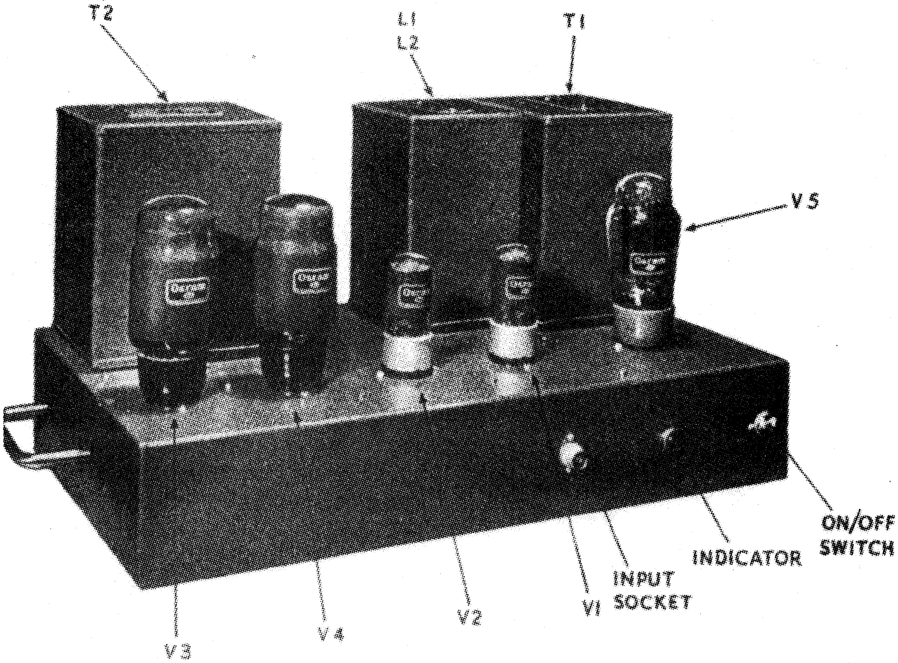


Fig.5: This version of the Williamson design was made by GEC. Note that the output transformer T2 was at least as large as the power transformer T1. Valves V1 and V2 were here B65 (6SN7) double triodes, replacing the original L63 single triodes. V5 is the rectifier.

ics. Although they were themselves leaders in amplifier design, it is to their considerable credit that AWV were unstinting in their praise of the Williamson design. The report summed up their opinion by stating "This amplifier is by far the best we have ever tested. It not only gives extraordinary linearity and lack of harmonic or intermodulation distortion, but is comparatively simple and involves no special problems except the choice of output transformer."

Uprated 807

A possible problem with the Australian version was that the 807 had a rated maximum screen voltage rating of only 270 volts. AWV found that triode connected, it could with cope the 425 volts of the Williamson amplifier without distress, and placed some samples on long term test. Some months later they reported that there had been no problems, and the ratings of the 807 were officially increased.

Radio and Hobbies reprinted the AWV report in full in its January 1948 issue, and gave complete constructional details in the March issue, using locally made transformers – but strangely, without any reference to Mr. Williamson as the originator. Ferguson and Red Line advertised their versions of the output transformer at six pounds, which is more than $120 at today's values. In New Zealand, Beacon Radio made a very respectable transformer.

Americans impressed

Traditionally, American constructors had tended to favour their own home grown designs, but they adopted the Williamson design with enthusiasm. Some even took the unprecedented action of importing transformers and KT66 valves! It can be said that the Williamson amplifier revealed to many Americans the quality of British equipment and opened the market for a range of British high fidelity products.

During the 1950's, American manufacturing of high fidelity equipment boomed. Each edition of the magazine *Audio* carried reviews of commercially available amplifiers, and a significant number used the Williamson circuit. I doubt if D.T.N. Williamson gained any financial benefit from this development, but he did achieve immortality with his landmark design. Amplifiers that followed, such as Quad, Leak, Mullard, Baxendall and the *R&H* 'Playmaster' series showed that with the use of large amounts of stable negative feedback, similar results were possible with other configurations.

The real importance of Williamson's work was that he demonstrated that extremely low distortion was achievable by using plenty of negative feedback, combined with carefully designed output transformers. His design set a standard of performance that is still acceptable today. After 43 years, that's a pretty good record.