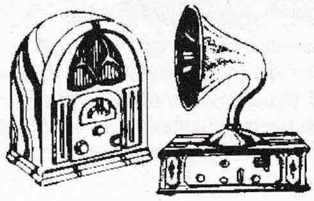
Vintage Radio

by PETER LANKSHEAR



Converters, first detectors, or 'mixers'

For the past 65 years, the superheterodyne has dominated radio receiver technology. Although there has been a wide range of systems and configurations, all superhets change the frequency of the received signal by combining it with a locally generated oscillation, using devices known variously as mixers, first detectors, converters, modulators and translators.

As would be expected, given its wide use and long history, the mixer has taken many forms and has varied in complexity from simple diodes through practically every valve type to specially made *octodes* with six grids. Many converter valves also had oscillator triodes in the same envelope. Some of these multi-grid mixers were the most complicated conventional valves made.

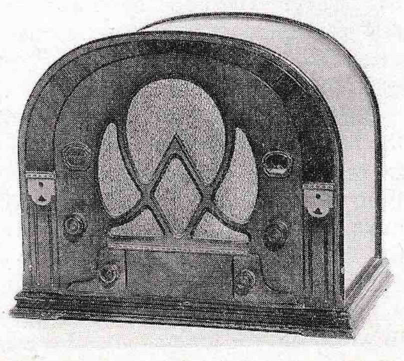
At first, mixers were simply standard detectors connected to an aerial by way of the usual tuned circuits to provide preselection, and coupled — often by means of a small coil — to the local oscillator. It is not surprising that a common name for the valve where frequency conversion took place was the 'First Detector', while the IF demodulator was the 'Second Detector'. Although diodes could be used, it was natural for the ubiquitous grid leak detector to became the standard superhet mixer.

These elementary converters needed considerable taming. In the early period following World War I Edwin Armstrong, following on his wartime work, set about making a practical superhet for RCA — who by now practically monopolised the patents. In 1923 Armstrong produced the prototype of the first RCA superhet, the model VIII, which as can be seen from Fig.1 was remarkably complex. In fact without a few clues, the circuit operation is difficult to analyse.

Briefly, the first valve is reflexed, functioning as both an RF and first IF amplifier. The next valve also combines two operations, as a self-oscillating or 'Autodyne' mixer. The reason for this complication was economy. TRF receivers at the time had at most five valves, but a straight superhet needed eight — far too expensive to be competitive. Armstrong therefore countered this by the doubling up on valve functions, and got the count down to six.

As these early superhets used a very low frequency IF, typically about 50kHz, a self-oscillating mixer had considerable problems from strong signals pulling the oscillator off tune. Armstrong's remedy was to use the second harmonic of the oscillator. This cured the pulling problem, but as higher harmonics will also beat with a carrier, and with no ganging of the tuning capacitors, or image rejection, it was possible with one of these sets to tune a transmission above about 1250kHz at six settings of the oscillator dial!

Another problem of harmonic mixing was excessive noise generated by the mixer stage, creating a background hiss. Consequently, to minimise these problems in the next series of RCA superhets, separate inductively-coupled oscillator and mixer valves were used.

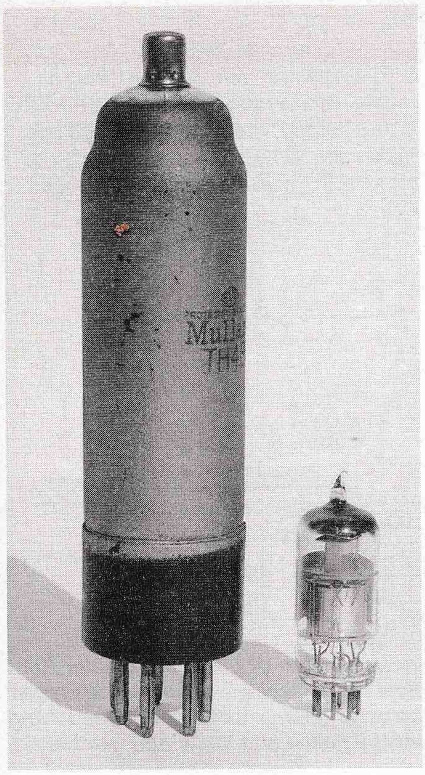


In the course of one year (1933/34), American manufacturer Atwater Kent produced receivers using three different conversion systems. Above is the five valve model 165, with a pentode autodyne converter; at upper right is the model 206, with a 2A7 pentagrid converter; and at right the 217, which had a triode oscillator and separate pentode mixer.

Tetrode, pentode mixers

In 1930, RCA was obliged to issue superhet licences freely. Tetrodes had become available and were shortly to be overtaken by pentodes. When biased to near cutoff, these valves proved to be good frequency converters.

Oscillator injection could be into the control grid, along with the received signal, and a common method was to wind



the oscillator and grid tuning circuits on the same former. This could lead to oscillator radiation from the aerial, and optimising oscillator injection over a wide range of frequencies could be difficult.

Although grid injection via a capacitor was not much used at low frequencies, for VHF services, including TV and FM reception, it proved to be very successful. For this service, several high performance combined triode and pentode valves, including the 6U8, ECF86, and 6BL8/ECF80 were developed.

Converter valves came in a variety of shapes and sizes. These are both triode-hexodes, but the 1937 Mullard TH4A dwarfs the Osram X78 made about 15 years later. For all their differences in size, their performances are similar.

Oscillators were normally very basic Hartley types, with a tuned grid coil and feedback provided by a small winding connected to the anode. Cathode injection proved to be the most successful for broadcast receivers using tetrode and pentode mixers. Fig.3 is of a typical application of this type, used by Atwater Kent in their model 217.

We do not always appreciate how expensive valves were during the early 1930s. It is difficult to translate prices into present day values, but at a time when a week's wages could be less than five pounds ($10), the list price of a typical valve was 17/6 ($1.75). Little wonder, then, that there was a reluctance to use two valves for a mixer if one would do. The autodyne was therefore resurrected using tetrodes and later, the new RF pentodes, and proved to be quite successful for broadcast band work. A typical application was the Atwater Kent model 165 as shown in Fig.4.

The Dynatron

Early electronics engineers were fond of what has been termed techno-Greek: titles made up from classic words. Two favourites were 'Dyne', meaning force and 'Tron', an instrument. Put the two together and we have the 'Dynatron', but in reality, one device so named was not as potent as its title implied.

The Dynatron was an oscillator in vogue for a short while and associated with a single valve type, the 224 screen grid tetrode. Tetrodes have the habit of being very unstable when operated with the screen voltage higher than the anode, for they can exhibit negative resistance characteristics, whereby the anode current actually increases as the voltage is reduced!

This is normally a nuisance, and one reason why basic tetrodes were rarely used as power amplifiers. However, if a valve is operating under negative resistance conditions with a tuned circuit connected to the anode, the system will oscillate. There is no need for external feedback and all that is required is a single untapped winding, an attractive situation for budget priced receivers. However, dynatron autodyne converters were temperamental and were soon abandoned.

There was at this time an increasing interest in shortwaves, but the small difference between signal and oscillation frequencies meant that pulling again made autodyne mixers unsatisfactory above a few megahertz. A separate oscillator valve as in Fig.4 was a partial solution, but expensive. What was needed was a purpose-built valve combining an oscillator and a mixer, but with as little interaction between the two as possible. A pair of conventional valves in the one envelope would still have the shortcomings of the triode-pentode mixer. What was needed was a new type of valve, with two independent control grids in a common electron stream.

The first Pentagrid

The pentagrid converter came from RCA in early 1933. Produced with both 2.5 volt and 6.3 volt heaters, the 2A7/6A7 had, as its name suggests, five grids surrounding the cathode. The inner two operated as a triode oscillator, modulating the electron stream from the cathode. Then followed two screen grids, with the signal control grid sandwiched between them. Around the first screen grid was a cloud of electrons or space charge, modulated by the oscillator frequency, and acting as a virtual cathode for the signal grid.

The second grid was in reality an anode for the oscillator, and, so as not to impede the main anode current flow,

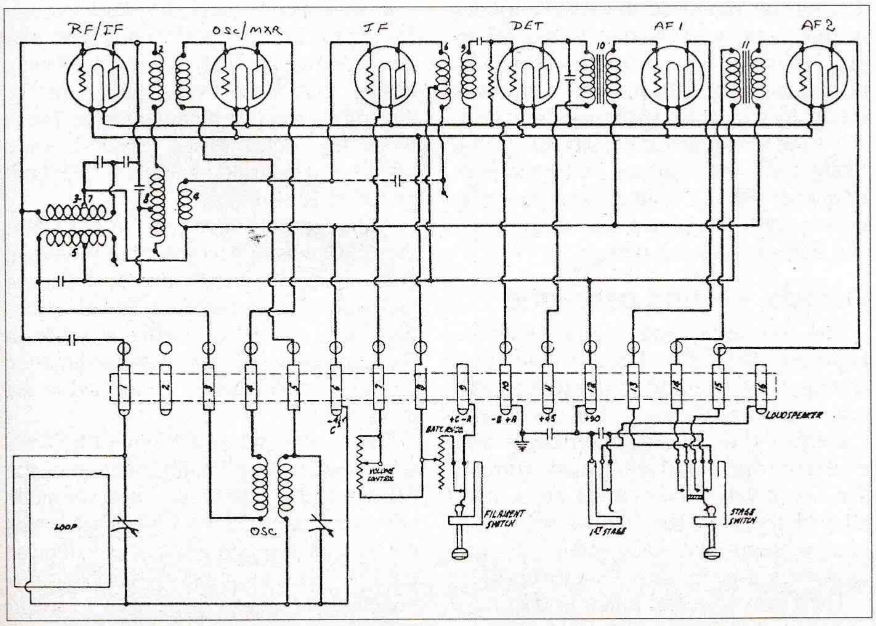
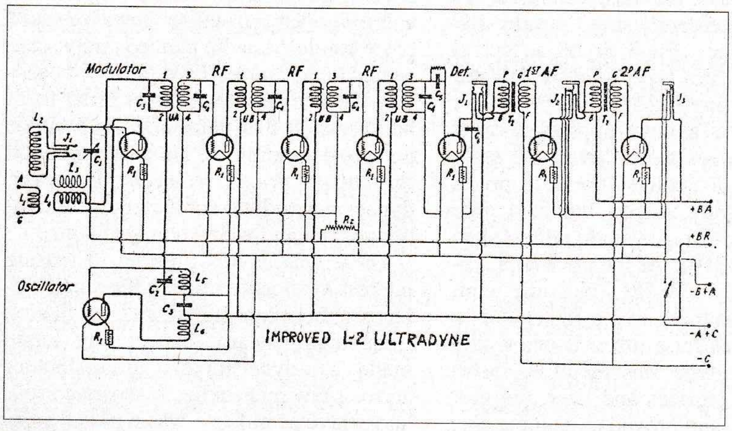


Fig.1: The first commercial superheterodyne was the Armstrong developed Radiola model VIII, using an autodyne mixer and released in 1924. Reflexing the input stage created a very complex circuit, made all the more daunting by many of the components being encased in a sealed 'catacomb'.

Fig.2 (below): Although during the 1920s, RCA had the manufacturing of superheterodynes tied up, they did not control the sale of kitsets and some rather interesting superhets were available to home constructors. Most followed more or less the Armstrong pattern, but designs like this one turned out by R.E. Lacault had novel, and by all accounts, effective mixer stages. Tracing out the mixer stage (modulator) reveals that there was no connection to the HT supply; instead the valve was energised by the oscillator.



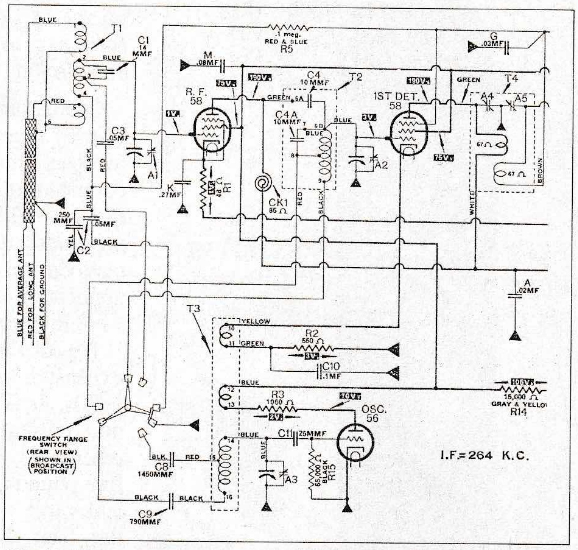


Fig.3: The converter section of the 1933 Atwater Kent 217, using a typical triode oscillator and pentode mixer combination. The wave change switch permited tuning to 3MHz, to cover the police and lower amateur bands.

could not be a solid element. It was found that even a minimal number of conventional grid turns was too restrictive, and in the final development the anode-grid consisted of just the two grid support rods, without any grid wires at all! The anode area was, of course, very small, and proved ultimately to be a limitation.

For a first effort however, the pentagrid proved to be remarkably successful, and was an industry standard until the 1940s. Within a few months of its American debut, it was introduced to Britain by British Ferranti as the VHT4. When RCA's range of metal valves was launched, the original pentagrid valve was repackaged unmodified as the 6A8, and in 1939 America's Sylvania incorporated the same valve in their Loktal valve range as the 7B8.

Different terminology

American terminology used for the early converters differed from European. At first, US identification was by the number of grids, whereas the British and European system was based on the total number of electrodes. Therefore the American pentagrid was the British and European *heptode*, but individual valves differed considerably.

The original pentagrid design had some imperfections. A fair degree of oscillator activity was required, but was made difficult at high frequencies by the restricted area of the anode-grid. Difficulties were also experienced in tuning above about 15MHz by strong signals pulling the oscillator frequency, and AGC applied to the control grid could also affect stability.

A combined triode-pentode, the 6F7 was intended to be a useful and versatile valve. One proposed function was as a pentode mixer with a triode oscillator, but this method of frequency conversion had already been tried with no advantages over the pentagrid and the 6F7 was therefore rarely used as a mixer.

Meanwhile, the Europeans had been doing their own research, and in 1934, Telefunken produced the ACH1 triode-hexode, somewhat similar to the pentagrid but with a separate triode. There was no anode grid and the innermost grid was internally connected to the oscillator grid. The triode-hexode had the advantage of a lively oscillator with less pulling at high frequencies than the other types, and was eventually to become a major European and British converter design.

Octode, second pentagrid

The Europeans were also busy with the pentagrid-heptode. They found that adding a suppressor grid between the screen grid and the anode had the beneficial effect of decreasing internally generated noise and of reducing anode current. This new valve they called an *octode*. One of the first, the Philips AK1, and later versions, the AK2 and EK2 were frequently used in Australian receivers.

There was a second mixer in the original 1935 metal valve series. This was the 6L7, another pentagrid but with a quite different internal structure from the 6A8, and which required a separate oscillator. The inner element of the 6L7 was now the main control grid. Then there were two screen grids, surrounding the oscillator injection or second control grid; a suppressor grid; and finally the anode.

Intended for high performance receivers where the cost of an extra valve was of little consequence, the high frequency characteristics of the 6L7 were superior to the other mixers.

In their house magazine *Radiotronics* for April 1938, AWV announced two new converter valves of American design that were to be important for Australian receiver manufacturers. These were the octal based triode-hexode 6K8G, and the triode-heptode 6J8G, both priced at 18 shillings.

Although not much used in the USA, the 6J8G was to become widely used in Australian sets during the next decade and will be described first. It was essentially a 6L7 with an oscillator triode in the same envelope, and with the heptode injection grid internally connected to the triode grid.

The European terminology of heptode was used for the pentagrid section of the 6J8G, which by the way, was never made with a metal or GT envelope; but it was put by Sylvania into a Loktal envelope as the 7J7. This adoption of European terminology seems to have been to avoid confusion with the *third* type of pentagrid, to be described shortly.

About the only real weakness of the 6J8G was its low conversion gain, of about half that of many converters; but in practice this was hardly discernable. This minor problem was overcome later in an improved triode-heptode, the 7S7.

USA's only triode-hexode

Europe may have had reasonable success with the triode-hexode, but America seems to have had but one solitary example: the 6K8 (and its 12 volt companion the 12K8). Not only was it the sole American triode-hexode, but it had a most unusual construction. In fact, it could almost be described as a pentagrid with an outboard triode!

A close inspection of a 6K8G or GT will show that whereas conventional

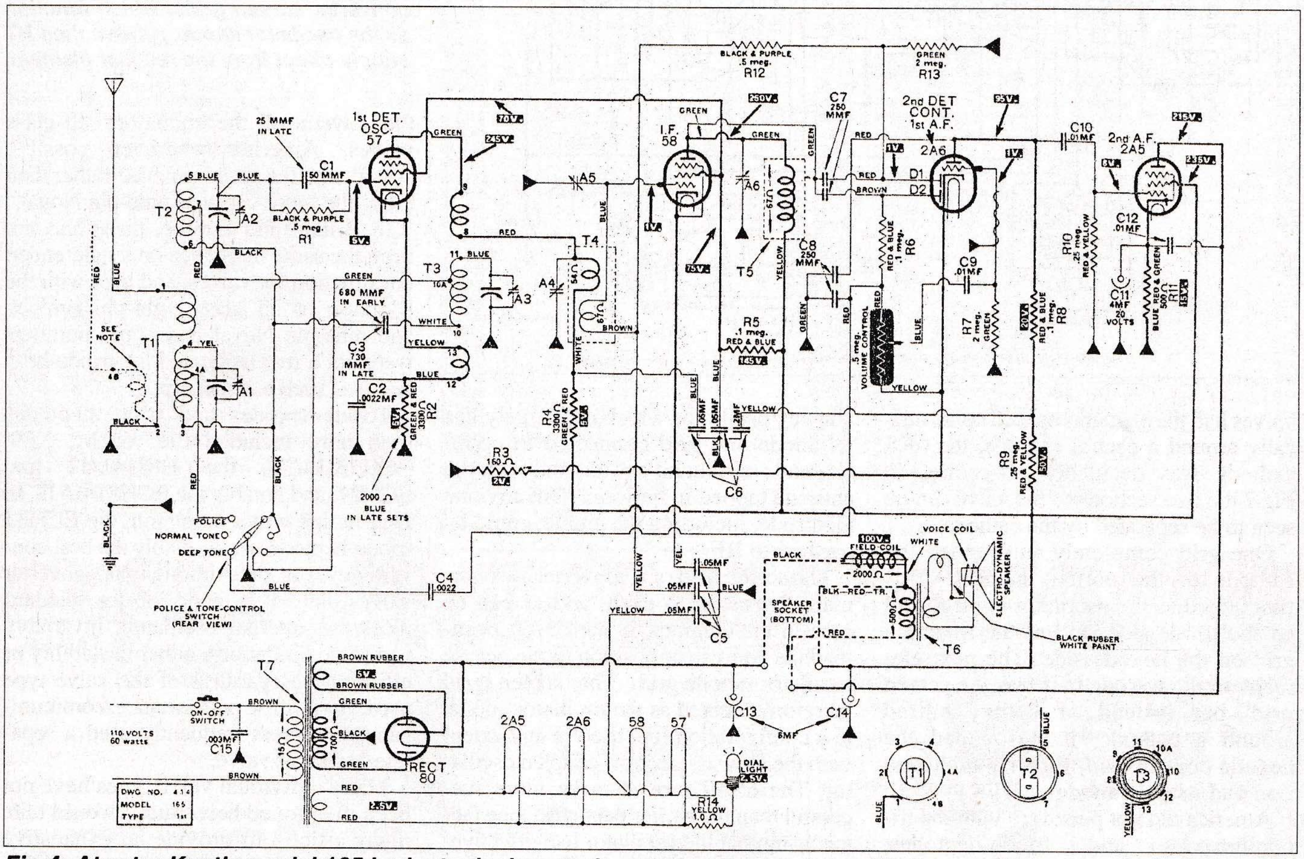


Fig.4: Atwater Kent's model 165 had a typical pentode autodyne converter, with the oscillator tuned winding closely coupled to the anode and cathode by way of similar windings on the same former. In several of their smaller sets, including the 165, AK combined the police band wavechange and tone switches.

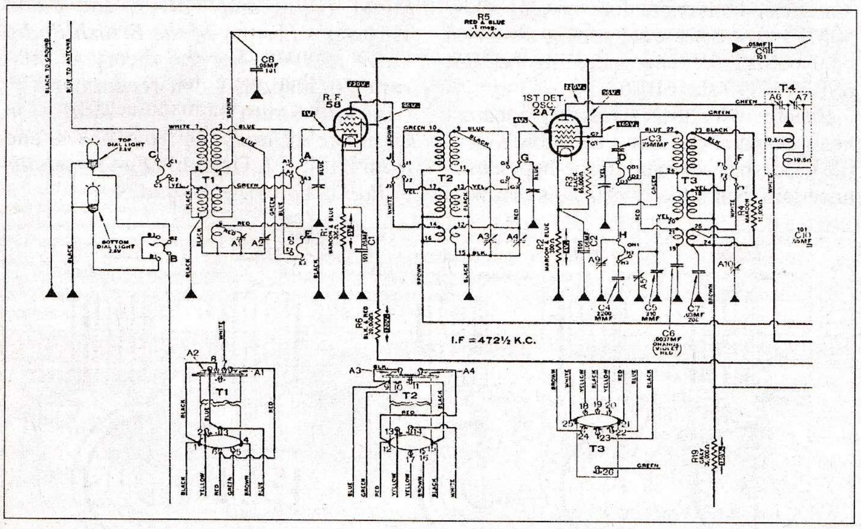


Fig.5: The first converter valve, the 2A7 pentagrid was used for the three band 1934 Atwater Kent 206. To improve stability, the oscillator HT was derived directly from the rectifier filament.

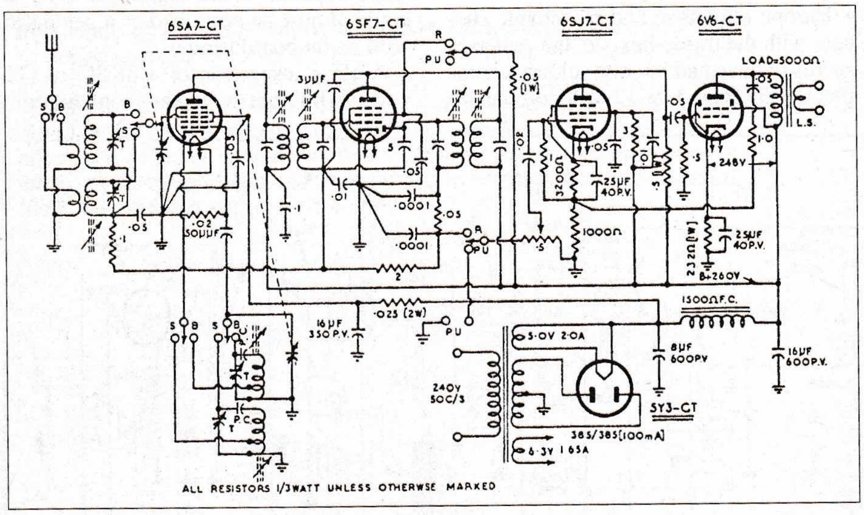


Fig.6: Just 50 years ago, Australia's AWV Co published this circuit using the American 6SA7GT 'third generation' pentagrid converter. The oscillator coils are single tapped windings and the converter screen grids, which function as the oscillator anode, receive their HT supply direct from the rectifier filament.

valves had the elements spaced concentrically around a central cathode, the 6K8 cathode was decidedly off-centre. In Fig.7 the two sections of the valve can be seen to be separated by the cathode.

One grid completely surrounded the cathode in the normal manner. This functioned as the oscillator control grid on the triode side, and as the injection grid on the hexode side. The next element on the hexode half was the screen grid, but instead of being centred around a cathode, it surrounded the hexode control grid. Finally, each section had its own anode.

America did not persevere with the triode-hexodes and triode-heptodes, although they were very successful across the Atlantic. The availability of only seven active socket pins on a single-ended metal valve may have been a factor. The original concept of the metal valve was for single-ended construction, but this was not properly realised until 1938 with the release of the series that included the 6SK7 and 6SQ7 — and yet another pentagrid, the 6SA7.

A third, US pentagrid

The pin shortage was circumvented in the 6SA7, by eliminating the oscillator anode. But how can a mixer oscillate without an anode in the oscillator section?

Fig.6 is an example of how it was done. Most converter systems, including even the Lecault circuit, used a Hartley oscillator which effectively has its anode and grid connected to opposite ends of a tuned circuit, and with the cathode tapped in between. But any one electrode, including the anode, could be earthed to RF.

The screen grid of a converter was normally bypassed to earth, and as can be seen in the diagram, in the 6SA7, occupied the equivalent position to the octode oscillator anode/grid. The screen grid therefore doubled as the oscillator anode, in a configuration first used to any extent with the Dow or electron-coupled oscillator. The 6SA7 proved to be more successful than the earlier pentagrid, one factor being that the oscillator had effectively a far greater anode area — although it is arguable whether it was as good as the European triode-heptodes. All new American converters for service below 50MHz thereafter were pentagrids based on the 6SA7, the range including the 1R5, 6SB7Y, 7Q7 and 6BE6.

Exactly why there was this apparent xenophobia about using the more versatile triode-hexodes and triode-heptodes is uncertain. But a likely reason is that with the advent of the miniature all-glass valves, America wherever possible stayed with the seven-pin base rather than using the more versatile nine-pin Noval.

In Britain and Europe, there had not been the same insistence on single-ended construction for valves, and later with the adoption of all glass eight-pin rimlock and nine-pin Noval bases, pin numbers were not a restriction and the triode-hexode was used extensively.

Triode-hexodes and triode-heptodes seen here included the X61M, X79, ECH33/34/35, the ECH41/42 and ECH21, and notably the ECH81/6AJ8. In fact, in this writer's opinion, the ECH81 triode-heptode was arguably the best converter ever made. Although the converter valves did a very good job for standard receivers, internal oscillators invariably had some limitations, either in stability or efficiency. Regardless of the valve type used, to optimise performance, communication receivers frequently used a separate oscillator valve.

Many individual valve types have not been mentioned here, and it would take many articles to provide an exhaustive treatment of the converter story. In-depth historical information will be found in John Stokes' book *70 Years of Radio Tubes and Valves*, and Keith Thrower's *History of the British Radio Valve to 1940*. For the theory of converter operation, I can recommend F. Langford-Smith's *Radiotron Designer's Handbook* from AWA, and from Philips, J. Deketh's *Fundamentals of Radio-Valve Technique*. ❖

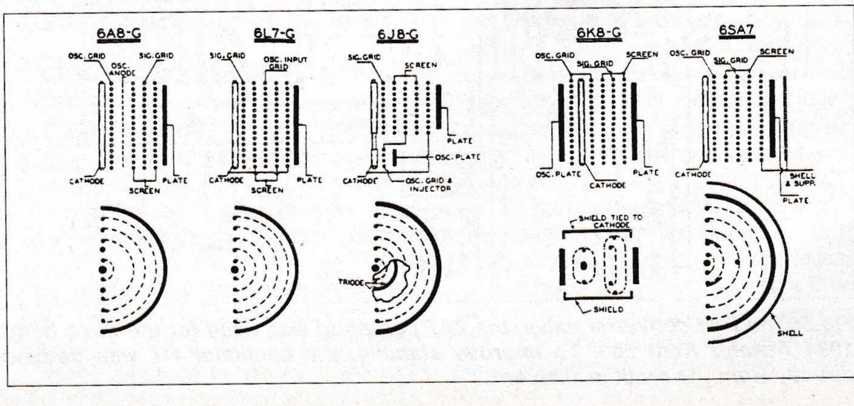


Fig.7: These drawings, showing clearly the different internal details of the American pattern converters, are from the 1940 edition of the 'Radiotron Designer's Handbook'.