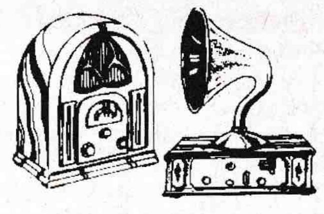
Vintage Radio

by PETER LANKSHEAR



RF gain control and variable-mu valves

This month we take a look at the problems of controlling the gain of an RF amplifier, while not detracting from its ability to handle signals without distortion and other unwanted side effects. This is an ongoing problem with solid state technology, but it was largely solved in the valve era with the development of the variable-mu valve in late 1930.

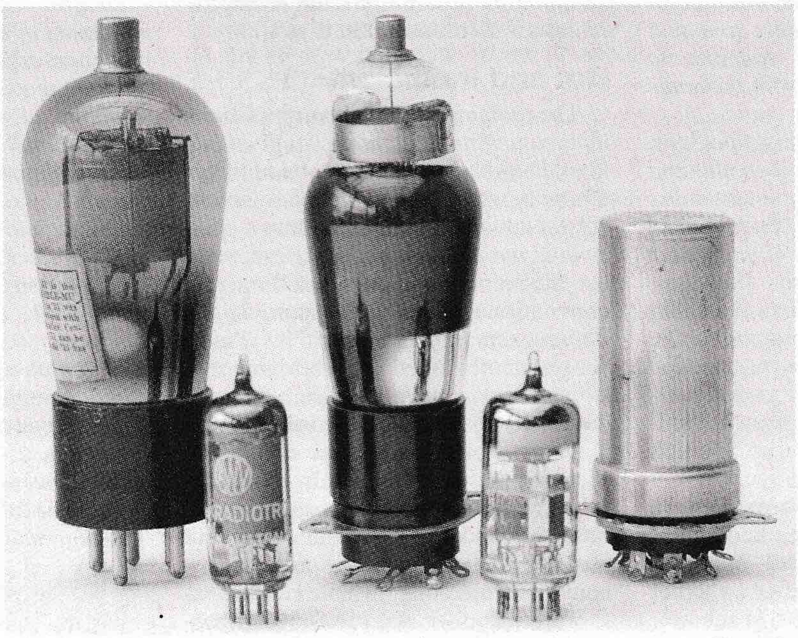
Tom Moffat's story in the January 1996 issue of *EA* about the Hobart receiving station at Quoin Ridge was of special interest to me, as many years ago I worked in a similar station at Quartz Hill near Wellington. To tune across the spectrum with a good receiver connected to a real aerial at such a location is a memorable experience.

Tom mentions the superior performance of an old GEC BTR400 receiver, when compared to a state of the art Icom R-9000. By an odd coincidence, as my term at Quartz Hill was finishing, we were preparing to make room for some new receivers — GEC BTR400's no less — and more recently I have owned one of these monsters.

The BTR400 is a fine receiver, but many of the final generation of valve communication receivers can provide a similar performance. Two such sets, the Hammarlund SP600 and the Eddystone 940, have been previously described in this column, and there were others, including superb models from Racal and Collins. But can Tom Moffat's claim for superior results from equipment designed 40 years ago be substantiated? The short answer is yes.

Back in the late 1950's as semiconductor diodes and transistors became increasingly available, it became evident that in time, these devices would be able to do anything that valves could do, but better. This has of course proved to be so, and today solid state technology is infinitely more efficient and versatile than that of valves. Modern electronics and integrated circuits especially, would just not be possible with 'hollow state' devices, and there is no equivalent to much solid state technology, such as complimentary PNP/NPN operation.

There is one exception, however. To this writer's knowledge, as yet there is no solid state equivalent device to the variable-mu or 'remote cutoff' valve, and this is what provides the superior valve receiver performance quoted by Tom Moffat. In this column I'll try to explain why this is so.



Variable-mu valves came in a wide range of shapes and sizes. At left rear is an original Arcturus 551, on which the '35 was based; centre rear is a 6U7G, long used in Australian receivers; right rear is a Loctal based WB1/EF22, as used in the GEC BTR400 receivers. The small valve at left front is a 6BA6/EF93, developed in 1945 and a standard type until the end of the valve era, while that at right front is a 6ES8/ECC189, a high performance variable-mu twin triode.

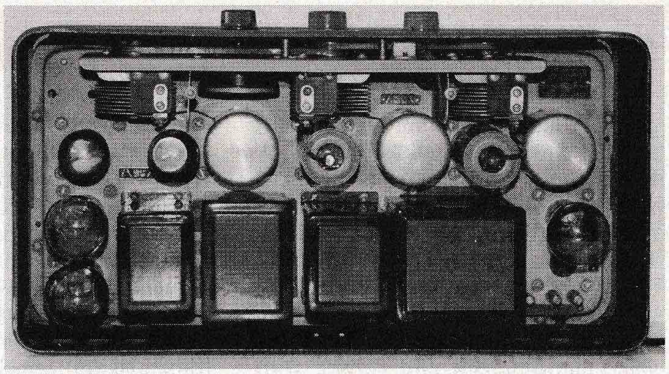
Decades of gain control

This story really starts about 75 years ago. In the earliest multi-valve receivers, gain was controlled simply by switching amplifier stages in or out as required. With the growth of broadcasting however, something a bit more refined was required and a smoother control was found to be possible by varying valve filament voltage. This was fine, especially with thoriated tungsten filaments, but with the advent in 1927 of the UX226 AC heated valves, as described in this column last November, a new method of gain control was required.

The '26 was essentially the standard '01A type with a low voltage high current oxide-coated filament. But with just over an ampere required for each valve, gain control by means of a filament rheostat was no longer practical. Volume control of the first generation of AC receivers was therefore achieved by nothing more sophisticated than a variable aerial attenuator! This was a simple and effective method, but it did mean that the receiver was running at full gain the whole time — which did nothing beneficial for signal to noise ratios.

By the following year, the indirectly heated type '27 had replaced the '26 and with it came a far better method of gain control — that of

The 1929 Atwater Kent model 55 was one of the first receivers to use the mains powered screen grid type '24 valve. In an effort to overcome its sharp-cutoff characteristic, A-K varied screen voltage to control gain; but the real answer came with the development of the 35/51 variable-mu valve in 1930. Although the model 55 had a single tuning knob, the separate tuning capacitors were ganged using phosphor-bronze drive belts — visible at the top of the interior picture at right.



varying the grid bias of the RF stages, usually by means of a simple variable resistor connected between the cathodes of the RF stages and ground.

As an RF amplifier, typical operation of the '27 was at 180 anode volts with around -15 volts grid bias. Increasing this bias progressively up to -30V or more provided reasonably smooth and satisfactory control of receiver gain, although a local/distance switch, generally some sort of aerial attenuator, was usually provided to cope with very strong signals.

Progress in receiver development around this time was very rapid, with each season bringing features that made previous models obsolete. For broadcast band operation, with suitable stabilisation or neutralisation, the general purpose triode was a reasonably satisfactory RF amplifier, but there were significant shortcomings. Stage gain was limited, and the low anode impedance compromised selectivity; stability was often marginal and triodes were unsatisfactory as shortwave RF amplifiers.

The need for neutralisation and stabilisation was due to unavoidable grid to anode capacitance, which enables tuned triode RF amplifiers to become oscillators. The solution was, in retrospect, simple enough. By inserting an electrostatic shield between the grid and anode, inter-electrode capacitance could be sufficiently reduced to achieve stable amplification. Of considerable benefit too was the considerably higher amplification factor of the tetrode.

There were development problems however, and it was early 1929 before a really satisfactory AC heated screen grid valve, the tetrode '24, was produced in the US — to be closely followed in Europe and England by equivalent valves.

The characteristics of the tetrode proved to be considerably different from those of the triode. Whereas the amplification factor of a general purpose triode might be about 10, that of the '24 was more like 400! Although the full potential of this could not be realised in practice, a stage gain of 50 was readily achieved, a very significant improvement over the 10 or so of a stabilised general purpose triode RF stage. Further advantages were shortwave capability and, in a well designed amplifier, better stability.

SHARP CUTOFF	VARIABLE MU
24A	35/51
57	58
77	78
6C6	6D6
6J7	6K7
6J7g	6U7g
6SJ7	6SK7
6SH7	6SG7
KTZ63	KTW63
EF37	EF39
6AU6/EF94	6BA6/EF93

***Table 1:** RF pentodes were often designed as sharp- and remote-cutoff pairs. Here are some of the more common types.*

However, although the screen grid valve may have permitted stable RF amplification, difficulties were experienced once again with *controlling* receiver gain; and this time there were undesirable side effects.

The problem was the large amplification factor of the tetrode valve. A relatively small change in grid bias voltage meant a significant change in anode current. Increasing the grid bias would certainly reduce the gain of an amplifier stage, but the problem was that, although the anode current might be practically cut off, the amplification factor itself was unaffected, so that even quite small signals overloaded the valve. Consequently, the level of signal that could be handled before the onset of serious distortion was very limited.

Several methods tried

Another method of reducing the gain of a tetrode RF amplifier was to control the screen voltage, but the signal handling ability still remained inadequate.

One well known manufacturer's efforts to solve the gain control problem illustrate the ongoing difficulties. For their 1927/28 receivers using filament-type '26 amplifier valves, Atwater Kent used an aerial attenuator. In 1929, they were one of the first to use the new '24 tetrode and settled for a screen voltage gain control in their TRF receivers. This receiver series went rapidly through several developments, culminating in the impressive type L chassis, used in the 1930 model 70, incorporating a dual volume control controlling both aerial and screen grids. Although an improvement, this method was abandoned for the first A-K superhets. For these, a standard volume control potentiometer was connected between the mixer and the 125kHz IF stage!

It can be said that there was no really satisfactory method of controlling the overall gain of receivers fitted with sharp-cutoff screen grid valves, without creating undesirable side effects.

The problem therefore with the tetrode was that control by grid bias variation certainly reduced stage gain, but in the process crippled its signal handling ability. In one example given at the time, with the transconductance reduced to 10 micromhos, a '24 could deliver only about 0.3 volt of signal without serious distortion.

An ongoing problem

Distortion products from amplification of RF signals have several serious effects, and the problem is not confined to valve receivers. Three of the problems are: modulation rise, cross modulation, and intermodulation — all effects noted in the solid state receivers in Tom Moffat's tale.

Modulation rise is, as its name indicates, an apparent increase in modulation percentage. With signals that have already high levels of modulation, the result is serious audio distortion of the detected signal.

In a crowded band, several signals may be present within the passband of the input circuits of a receiver, but if the amplifying stages are completely distortionless the unwanted signals will be filtered out without any ill effects. However, where there is non-linear amplification, a strong adjacent signal may have damaging effects before being eliminated, and no amount of subsequent selectivity will rectify matters.

By interacting with the wanted signal, the modulation of the unwanted transmission appears in the background of the desired signal. This is cross modulation. Intermodulation is a bit more subtle, and occurs when two transmissions beat together to create spurious signals, and whistles.

Wanted: variable gain

So the situation was that low-mu general purpose triodes could handle strong signals fairly well, but had limitations as RF amplifiers. On the other hand high-mu tetrodes were good RF amplifiers, but could not cope with a wide range of signals.

Basic valve design is simple enough: a fine winding pitch for the control grid provides a high amplification factor or mu, and a coarse pitch a low mu. What was needed therefore was a valve with an adjustable amplification factor — high for weak signals and low for strong transmissions. But how can the effective grid winding pitch be altered in an operational valve?

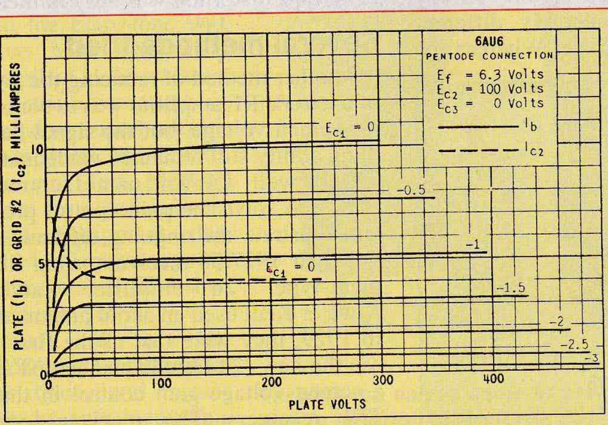
Like so many good ideas, the solution — although not immediately obvious — was in retrospect quite simple. In November 1930, Stuart Ballantine and H.A. Snow of the Boonton Research Corporation presented a paper to the Institute of Radio Engineers in which they described a *variable-mu* tetrode. What they had done was to take a standard '24 valve and fit it with a control grid having a winding which varied in pitch over its length.

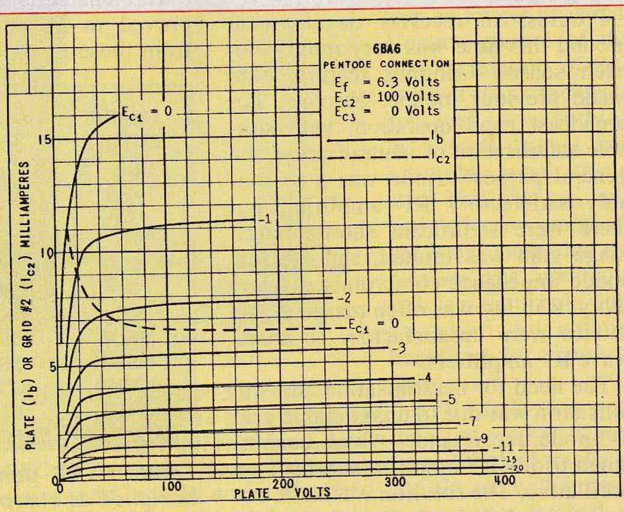
At small values of bias, the entire grid was in control and the valve behaved like a standard screen grid valve. As the grid bias was increased, the electron stream was progressively cut off by the fine pitch portions of the grid; but it required a bias of the order of -30V before the anode current was reduced to something less than 1mA. At this stage only the coarse section of the grid was in operation, and the valve now had the characteristics and signal handling ability of a low amplification factor type. Under high bias conditions, the new valve could handle a signal some 30 times stronger than the '24.

Worked well

The variable-mu grid worked well, and in one stroke the various problems of RF amplifiers using sharp cutoff valves were solved. Indeed, it was so successful that the variable-mu valve rapidly became standard for conventional valve-equipped AM receivers thereafter.

Several major manufacturers produced the variable-mu valve immediately, and exhibited examples early in 1931 at the Chicago Radio Trade Show. For some unexplained reason, two type numbers were selected. One, the '51, was made by Arcturus as type 551 and by DeForest as the 451.





These graphs of the characteristics of the variable-mu 6BA6 (right) and the equivalent sharp-cutoff 6AU6 (above) show clearly how the grid bias needed to cut off a variable-mu type is much greater. Here it is around -20V compared with -3V.

The other type was the '35. RCA made the 235, but with the Cunningham label it became the 335. National Carbon (Eveready/Raytheon) and Sylvania both called their versions type 235. To have several names for the one device was confusing, and within a short time the variable-mu tetrode was listed by most makers as the 35/51.

Receiver manufacturers were quick to make good use of the new valve, and were able to take advantage of its features by incorporating in receivers such refinements as effective automatic gain systems.

Technical progress was rapid during this period, and the RF tetrode's days were numbered. Britain's Cossor had produced an RF pentode, the MS/PenA in 1930, and in the US at the beginning of 1932 the type '39 pentode was released. This was the first American RF pentode and was significantly a variable-mu type. (A very similar valve, the '44, was an alternative offered by some makers and the two types were later combined as the 39/44.)

Popular pentodes

Later in 1932, there appeared a pair of RF pentodes which will be familiar to many collectors as a mainstay of the infant Australian radio industry. These were the sharp-cutoff 57 and its variable-mu partner, the 58. Eventually, given an octal base and 6.3V filament, the 58 became the 6U7G — for many years virtually the standard Australian RF pentode.

It became regular practice to develop sharp-cutoff and variable-mu pentodes as complimentary pairs, and some of the more common examples are listed in Table 1.

Although a feature normally restricted to multi-grid valves, there were triodes intended for VHF RF amplifier service with variable-mu characteristics. One, used by Philips in TV tuners and known in Europe as the ECC189 and in the US as the 6ES8, was a twin triode intended as an AGC controlled cathode coupled 'cascode' low noise amplifier.

With an impressive transconductance of 12.5mA/volt, the ECC189/-6ES8 needed a bias control range of about 10 volts. According to the RCA tube manual, it could be biased back to only 125 micromhos conductance, and still cope with a 0.5V signal with negligible distortion.

Although not primarily intended for HF and MF service, this valve proved to be a very successful 'front end' for the Eddystone 940 receiver described in this column for November 1993. Tested alongside an expensive 'state of the art' solid state receiver, the 940 exhibits a similar interference immunity to that of the GEC receiver observed by Tom Moffat. Significantly, unlike modern solid state communication receivers, the Eddystone and its kind have no need for an aerial attenuator — made obsolete by the variable-mu valve 65 years ago!

About valve life

One frequently expressed concern about older type equipment is that of valve mortality. Although valve life is finite, it can be much greater than is generally realised. For non-commercial service, exact figures are hard are hard to come by, but recently I was able to get an indication.

In 1992, I set up a 'MATE' mini transmitter to relay my favourite FM transmission 24 hours a day. With the exception of a couple of holiday breaks, operation has been continuous, and after 3-1/2 years total service, the 12AU7 and 6AV6 valves were tested. In both cases, mutual conductance had dropped to about 2/3 of the new figure and performance was still quite adequate.

This service works out at 30,000 hours, or more than 10 years at eight hours a day. Admittedly, the MATE valves are conservatively run and there can be failures from causes other than wearing out; but the conclusion is that there needs to be no concern about using valve equipment for protracted periods. ❖