When I Think Back...

by Neville Williams

Vintage Radio Receiver Design 4
How the superhet was 're-discovered'

In the early 1930s, superheterodyne receiver design was rationalised and simplified to such an' extent that it rendered the TRF principle virtually obsolete, for both domestic and professional applications. The progressive developments which brought this about will be examined in this and following articles.

In the Newnes-Butterworths Book *Radio, TV & Audio Technical Reference Book* compiled by S.W. Amos and published in 1977, there is apt reference to the 're-discovery' of the superhet in the early 1930s, and a subsequent period of progressive 'consolidation' that led up to the war years, which saw intensive development of a quite different kind.

Amos does not explain who or what led to the so-called re-discovery around 1930, beyond a brief reference to an unnamed company catering for the home construction market and 'massive' concentration on the subject of receiver design by the technical press.

I, personally, cannot recall ever having seen an article on the subject, but it appeals to me as one holding considerable potential interest as a paper or thesis for anyone having a mind to carry out the appropriate research of patent files and other literature.

In the meantime, I lean to the view that the radio industry worldwide desperately needed a configuration that offered a way around the inherent limitations of the TRF approach in the way of gain and selectivity; that, whatever the `trigger', sheer competitive commercial pressure maintained the on-going momentum that was evident in the consequent research and development.

In Australia, the motto of the radio industry was 'a set in every home', with individual manufacturers doing their level best to ensure that as many of the sets as possible bore their particular trademark.

However, without getting involved in the exact how, when, where or why, it is possible to nominate various developments which transformed a seemingly involved design concept into receivers that were relatively easy to mass-produce and eminently suitable for use by non-technical listeners.

If Australian manufacturers tended to incorporate similar technology in their respective models, it was because they had to evaluate each new development, irrespective of its source, as soon as it was publicised in trade literature or technical journals.

They simply had to keep abreast of their competitors, or be perceived as 'behind the times'.

Improvements essential

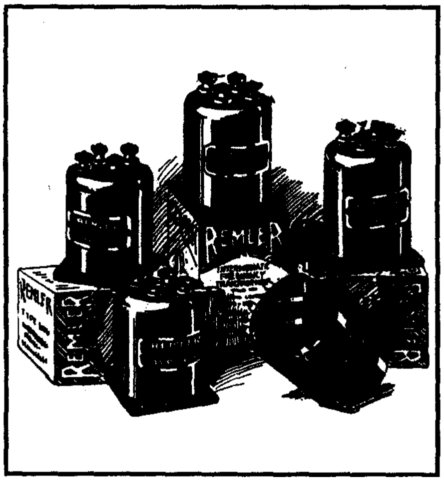
Back in 1925, despite their commendable gain and selectivity, early superhet receivers had peculiarities which, to say the least, were discouraging to potential non-technical buyers.

As explained in the June article, they exhibited double-spot tuning effects, image reception and spurious radiation from the inbuilt oscillator. A few manufacturers persisted with them, but most passed them by.

While the release of mains type screened-grid valves — sharp cutoff and variable-mu — significantly upgraded the design of TRF receivers (see last issue) they were no less a key element in the re-development of the post-1930 superheterodyne. For example, the provision of an RF amplifier stage ahead of the frequency changer became a routine option, isolating the local oscillator from the antenna and providing readily controllable gain, plus up-front selectivity to help deal with image and double-spot tuning effects.

In the frequency changing stage, a single sharp cutoff RF tetrode or pentode could fill a dual role as both mixer and local oscillator. (The so-called 'autodyne' frequency changer is explained later, in connection with Fig.4).

Again, in the IF (intermediate frequency) amplifier section, a single variable-mu tetrode or pentode could provide adequate and controllable gain, feeding into the detector and audio system. For such an approach, only one extra valve would be involved to achieve an order of gain and selectivity that would be unattainable from a comparably priced TRF. But the story does not end there.



Complete Remler coil kit for a 1920s-style superhet, as advertised in 'Wireless Weekly' (July 29, 1927) by Wiles Wonderful Wireless of Goulbum St, Sydney. The IF transformers carry terminals similar to those of audio transformers.

Higher IF

The tuning and radiation problems of the early superhets were compounded by the comparatively low IF (intermediate frequency) then being used — commonly in the region of 50-60kHz. As a manageable supersonic frequency, it was accepted as a natural choice in the quest for high selectivity.

A further consideration was that the early designs had to rely on triode valves, and the intrinsic grid/plate capacitance of these posed less of a problem in the supersonic frequency range, thereby making it easier to secure high, stable gain from a multistage IF channel.

Not surprisingly, perhaps, IF coupling transformers of the period were routinely styled like interstage audio transformers, with connecting terminals for P, B+, G and C- (Fig.1). The prime difference was that, instead of being responsive over the audio range, they were so wound as to be self-resonant at a supersonic frequency — hopefully one that was suitable.

Curiously, advertisements of the period make little or no reference to the *actual* resonant frequency of particular transformers, or to alignment precautions, if any. They simply suggested that constructors be careful to use only a complete matched set of IF transformers designed for the particular receiver.

With the release of screened grid (tetrode and/or pentode) valves, stability and gain ceased to be a problem in the RF and IF channels alike. As a result, engineers had the option of designing superheterodyne receivers around a much higher intermediate frequency, thereby making the image and double-spot tuning problems more manageable.

The first figure to emerge by industry consensus as a new IF standard was 170kHz — subsequently amended to 175kHz — and seen at the time as a radical departure from 50-60kHz. It meant that the oscillator frequency would differ from the signal by 175kHz and that potential tuning 'images' or `second spots' would be displaced by 2 x 175 or 350kHz. Compared with the previous 2 x 60kHz or 120kHz, the ability of the signal input tuning circuits to reject the unwanted images would be considerably enhanced.

Reasons for agreeing upon a new international industry standard IF included the following:

- The characteristic preference of engineers for an orderly, rather than a random design approach, particularly with an increasing international exchange of technical ideas and information.
- To facilitate the production of compatible coil kits and IF transformers by independent and/or international component suppliers.
- To avoid unnecessary confusion in the radio service industry, with a multiplicity of intermediate frequencies to which different receivers might need to be aligned.

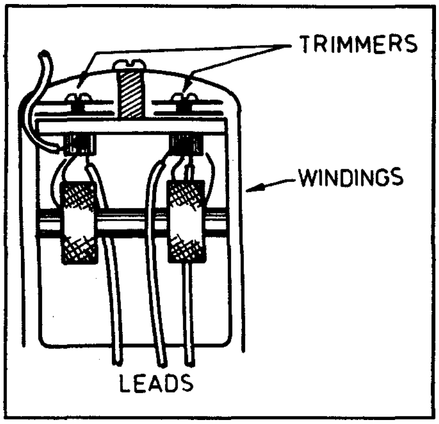


Fig.2: The construction of an early 1930s-style IF transformer. Two lugs on each of the alignment trimmer capacitors at the top provide rigid anchor points for the fine wires from the coils and for the heavier outgoing insulated leads.

Practical IF transformers

If the early 50-60kHz (supersonic) IF coupling transformers were patterned on their audio frequency counterparts, their 175kHz equivalents were unmistakeably envisaged as 'RF' (radio frequency) components, housed in a light-gauge aluminium shield can.

In a few early examples, the primary and secondary windings were simply jumble wound between bakelite cheeks on a common spacer, each being resonated by a separate compression type trimmer capacitor, accessable from outside the can. The two windings would be separated by just the right amount to ensure an appropriate order of signal transfer and selectivity.

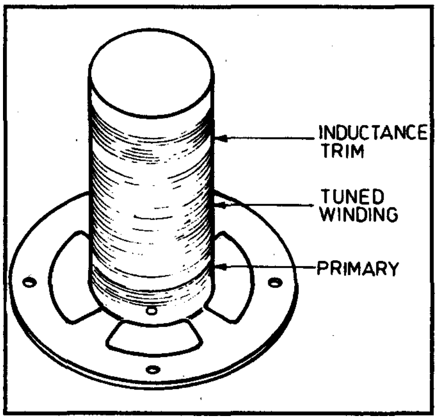


Fig.3: A simple 'solenoid' style coil wound on an Australian made Lekmek tubular former. The leads were anchored to metal clips fitted into holes around the lower end of the tube.

More commonly, the coils were honeycomb-wound towards either end of a composition or bakelised cardboard former, and subsequently stabilised by immersion in a low-loss wax or varnish. Mounted inside a common shield can, they were likewise resonated by compression trimmers, with leads running out through the top and/or down through the bottom of the can to the associated circuitry (Fig.2).

With all coils resonated deliberately and precisely to the one frequency — nominally 175kHz — after connection into circuit, the chances are that the selectivity curve would compare favourably with the 1920s-style IF channels, despite the greater complexity and lower frequency of the latter. This was because of the more casual approach to system resonance that was characteristic of the earlier designs.

Certainly, 175kHz superhets earned a reputation in the 1930s for high selectivity — too high, in fact for many listeners, who lamented the loss of upper treble by reason of sideband cutting.

The procedure for aligning the 'new look' superhet receivers, including the IF channel, will be detailed in a future article. In the meantime, one innovation led to another.

Single-dial tuning

A side-effect of selecting a higher IF was that it increased the discrepancy between the tuning range of the signal frequency and local oscillator circuits. For a broadcast band tuning range of 550kHz to 1600kHz, the frequency ratio was/is 1:2.9. For an IF of 175kHz, the required oscillator tuning range becomes 725 to 1775kHz, with a ratio of only 1:2.45.

To provide single-dial tuning — a prerequisite for family receivers in the 1930s — the designer of a superhet needed to arrange that, for a given rotation of the tuning mechanism, the oscillator would always be 175kHz above the selected incoming signal frequency. In other words, the respective circuits had to 'track' each other, right across the dial. The most obvious approach was to provide a ganged capacitor in which the oscillator tuning section used fewer and/or somewhat smaller plates, so shaped that the oscillator followed the required frequency law. This approach was, in fact, employed fairly commonly overseas, where the cost of designing and producing a customised ganged capacitor could often be absorbed in high-volume production budgets.

Fortunately for smaller production runs, a simpler alternative was devised. This involved the use of a conventional ganged capacitor with identical sections, and a specially selected 'padder' capacitor connected in series with the oscillator tuning section.

The oscillator coil would be designed with deliberately fewer turns such that, at the high frequency end of the band, it could be resonated 175kHz above the signal frequency using the normal alignment trimmer. At the low frequencies, the series 'padder' would reduce the effective maximum value of the tuning capacitor and, by making the padder adjustable in the manner of a compression trimmer, the oscillator frequency could be kept substantially in step with the signal tuning circuit(s) across the entire band.

That the series padder approach was vital in the design of domestic superhets is evidenced by the fact that some 25 engineering papers on this subject were published here and overseas, in the period 1931-41. These explored the principle, the mathematics and the potential accuracy of circuit tracking based on the use of a padder capacitor. It was certainly important in Australia where, for the minor cost of a compression type padder, local manufacturers could use perfectly standard two, three or four-gang capacitors, as might otherwise be used for a TRF.

The tuning dial would be calibrated to suit the brand of gang — Airzone, AWA, Stromberg, or whatever — and adjusted for the correct indication of frequency and/or station call as part of the alignment procedure, to be discussed in a future article.

Tuning coils

In regard to the associated tuning coils, the aerial input coil could well be identical for either TRF or superhet. With a somewhat higher inductance primary winding, RF coils could also serve in either type of receiver. Whereas, however, a family size TRF might typically use two RF coils, a 175kHz superhet would more commonly use only one, along with a special oscillator coil, as already mentioned.

In the early 1930s, tuning coils were mostly solenoids: wound with enamelled solid wire, single layer on 0.75 to 1.25" diameter cardboard or moulded formers (19-32mm). Depending on the inclination of the designer, primary windings would be wound adjacent to the earthy end of the tuned winding, or overlaying it with woven `cambric' insulation between.

Normally, the coils would be separately shielded by aluminium cans, of at least double the coil diameter and with similar clearance top and bottom. If the cans were too small this would reduce the inductance and efficiency of the coils; if they were too large they would be unnecessarily cumbersome and costly.

At my first job in Reliance Radio, we used coils wound on Lekmek moulded formers, about 35mm in diameter, with three integral moulded legs supporting the coil above a moulded base mounting ring. The inductance was finely trimmed during manufacture by manually spacing a few turns at the top, after which the winding would be stabilised with wax or varnish (Fig.3).

Lekmek style coils worked well, but they had one unfortunate weakness: they didn't like being bolted down to anything but a dead flat surface. Bolt them too firmly to a chassis with residual curvature and the base ring would crack, leaving the assembler with the option of confessing their aberration or saying nothing and hoping that the fine crack would pass unnoticed.

I/we were much relieved when Reliance went over to coils wound on waxed cardboard formers with metal-lug supports, which were much more tolerant of abuse!

As we shall see later, coils and IF transformers underwent a cycle of changes during the following years, aimed variously at making them more compact, more efficient, more economical to produce and, in some cases more amenable to advertising hype!

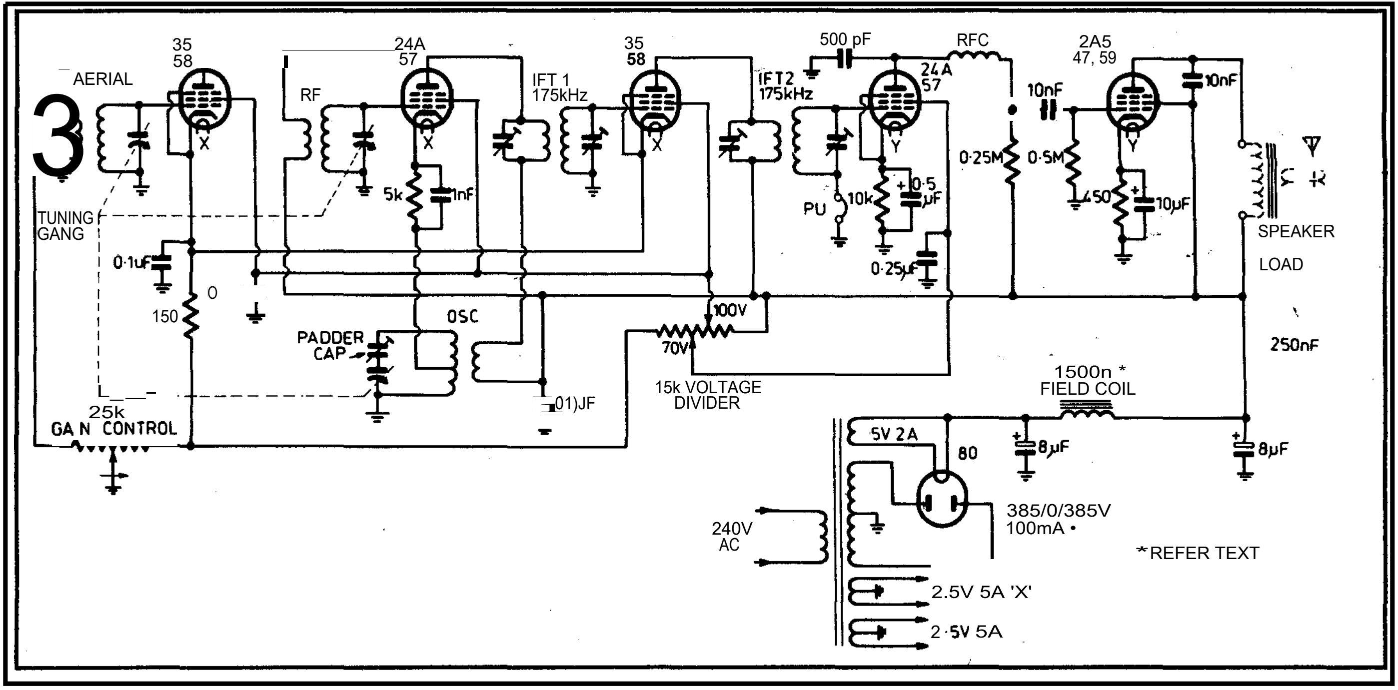


Fig.4: A circuit typical of five-valve mains powered 175kHz superhets from the early 1930s. Features like special-purpose frequency changing valves, automatic gain control and audio negative feedback had yet to appear.

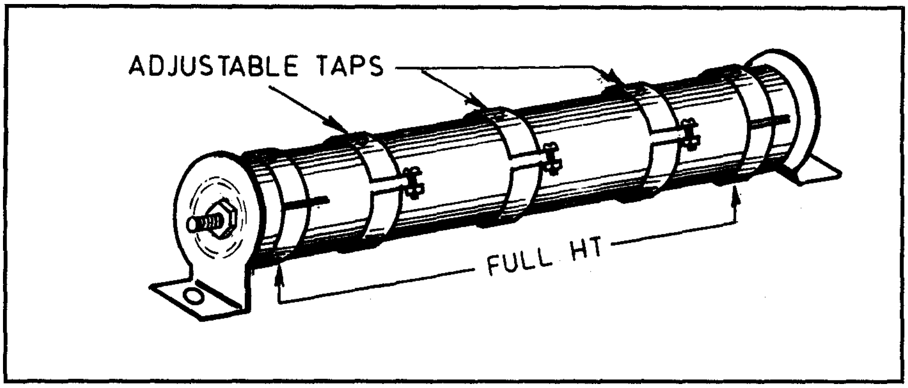


***Fig.5:* Commonly used in 19308-style receivers, voltage dividers were prone to troubles due to loose clips. Treat them gently, to avoid fracturing the fine resistance wire with which they are wound.**

Typical circuit

To gather together much of the foregoing discussion, Fig.4 suggests a typical circuit for a 5-valve mains powered 175kHz superhet receiver from the early 1930s. It is not a reprint but, rather, one cobbled together from circuit practices of the period, with the front-end configuration very like that of the much publicised *Wireless Weekly* 'Champion'.

Checking through the circuit from the front end, the aerial coil would normally have been of conventional solenoid design, as already mentioned, with a low impedance (e.g., 20-turn) primary adjacent to or overlaying the earthy end of the secondary. As such, it would have been appropriate for direct connection to a conventional outdoor antenna.

In the earliest examples of such a receiver, the RF amplifier valve would have been a type 35 five pin variable-mu tetrode. This was subsequently superseded by the type 58 six pin variable-mu pentode, with its suppressor grid (G3) tied externally, as shown, to the cathode. The cathode and screen feed will be discussed soon.

The RF coil coupling the RF amplifier to the frequency changer would have had a secondary identical to that of the aerial coil, plus a primary winding having at least twice as many turns as the aerial primary to be more compatible with the high anode impedance of the RF valve. Consistent with earlier *remarks,* the second valve is shown as an **'autodyne'** frequency changer — or self-oscillating mixer. In keeping with this dual role, it called for an overbiased, sharp cut-off valve such as the original five pin 24 or 24A, or the later six pin 57. Autodyne circuits could be configured in a number of ways, and a collector of vintage receivers has to be prepared for such variations. The arrangement shown was probably the one preferred by many designers, because the oscillator tuned circuit operated at cathode rather than anode potential.

Autodyne & IF channel

In this kind of stage the RF input signal is applied to the grid in the normal manner, with the cathode substantially inert at the signal frequency by reason of the cathode bypass and a low impedance tapping on the oscillator coil, which is resonant at an entirely different frequency. At the same time, the valve is operating as a cathode coupled oscillator, at a frequency determined by the oscillator tuned circuit — this time with the grid inert by reason of its own differentially tuned signal circuit. By very nature, the circuit depicted does not provide an inbuilt path for the oscillator signal back towards the antenna.

However, signal and oscillator energy are both present in the actual electron stream and, in consequence, because of the non-linear mixing or intermodulation that takes place, multiple frequencies appear as components in the anode current. These include the oscillator frequency (Fo), the incoming signal frequency (Fs), along with the sum and difference products (Fo+Fs) and **(Fo-Fs).** In addition, natural harmonics 2Fo, 3Fo etc., and 2Fs, 3Fs and so on are also present, plus their sundry sum and difference components.

Fortunately, the sharply tuned circuits in **IFT1** tend to reject all such components except the difference frequency (Fo-Fs) which, by front-end design, is 175kHz. This wanted signal is passed on to the IF amplifier — another 35 or 58 — and thence to **th** anode bend detector. The screen grid pins of the first three valves are wired together, bypassed to earth by a single **0.1uF** capacitor and fed from a 100V tapping on a 15k ohm, so-called 'voltage divider' resistor.

Voltage dividers

Connected across the HT supply, a voltage divider typically drew about 20mA and dissipated about 5 watts. Years before high wattage vitreous enamel resistors became commonplace, voltage dividers were mostly wound on cardboard formers with lightly insulated resistance wire, slightly turn-spaced, and lacquered to hold the wire in position. However, a narrow strip was masked off during lacquering to expose the wire along the former, the wire thereafter being lightly abraded so that adjustable clips could tap off intermediate voltages between 0 and (say) 270V — see Fig.5.

Voltage dividers served also to place a fixed load on the HT supply, thereby limiting the peak voltage from the directly heated rectifier at switch-on, before the remaining indirectly valves had time to warm up.

Unfortunately, voltage dividers also created their share of service calls — by reason of the generated heat shrinking the cardboard former and cracking the lacquer, causing intermittent contact between the clips and the wire. But in all fairness, fixed resistors in those days did not in themselves offer a very attractive alternative.

If replacement of a voltage divider is necessary in a vintage receiver, the most obvious course nowadays is to substitute a series string of 3W or 5W ceramic resistors, mounted on a tagstrip. Appropriate values, totalling about 15k, can be estimated from the position of the tappings along the original resistance element.

In Fig.4 the low potential end of the voltage divider returns to earth via the 2.5k gain (or volume) control. Depending on the setting of the control, the consequent cathode bias voltage for the RF and IF amplifier valves varies from the requisite minimum of 3V (maximum gain) to about 40V, where the gain of the variable-mu valves would be extremely low.

Furthermore, as the earthed contact in the potentiometer approaches the end remote from the voltage divider, it simultaneously shunts the aerial connection to earth in the manner of a local-distant switch. By specifying a 2.5k potentiometer, the shunting effect on the aerial circuit is less abrupt than it would be with a higher value control.

The audio system

The anode-bend detector calls for a second sharp cutoff **tetrode** or pentode — a 24A or 57 — with a modest screen voltage and a deliberately high bias, ensured by the 10k cathode resistor.

Operating close to the cut-off bend in the anode current current characteristic, the instantaneous current can rise with positive-going half-cycles of the RF signal but it cannot react to the same degree to negative half cycles. As a result, rectification takes place, with the valve responding principally to positive- going contours of the amplitude modulated carrier envelope.

In effect, an amplitude peak at the grid produces an upward surge of plate current and a downward surge of plate voltage. The 500pF bypass and RF choke in the plate circuit together suppress the RF or carrier component, such that the plate current excursions become a pure audio signal suitable for transfer to the output valve. Hence the term 'anode-bend' detector. Note that the lower end of the IFT2 secondary winding returns to earth via two pickup terminals, normally mounted on the rear of the chassis and bridged by a scrap of tinned copper wire. Although not taken all that seriously at the time, it was a facility costing next to nothing that provided a feed point for the rather primitive magnetic gramophone pickups of the day.

In older receivers, the output valve would most likely have been a 47, with a directly heated or filament type cathode. In the absence of a cathode, as such, the bias would have been provided by returning the centre-tap of winding 'Y' to earth through the 450 ohm resistor and 10uF bypass, instead of direct

Type 47 output valves had the advantage of drawing normal current almost from switch-on, but they were prone to grid current problems — resulting, in many cases, in gross distortion and a limited service life.

Type 59 valves were much better in this respect, but were less rugged than they should have been, suffering more than their fair share of internal shorts. By far and away the best of the three types shown on the circuit was the 2A5, which became the prototype of the popular 6.3V equivalents the 42 and 6F6-G.

Power supply

The power supply shown conforms to a basic configuration which was more or less standard throughout the 1930s and, as such, warrants comment beyond the mere addition of likely component ratings. The power transformer provides the requisite filament/heater windings, plus a centre-tapped high-tension secondary to feed a full-wave valve type rectifier. The pulsed DC output was/is delivered typically to an 8uF liquid or gel-filled can-type electrolytic capacitor and thence to the field coil of an electrodynamic loudspeaker, doubling as a filter choke. This is followed by a second 8uF electrolytic, which provides the final filtering, as well as maintaining the DC supply line at virtual earth potential in respect to audio frequencies. We shall have more to say later about loudspeaker field coils.

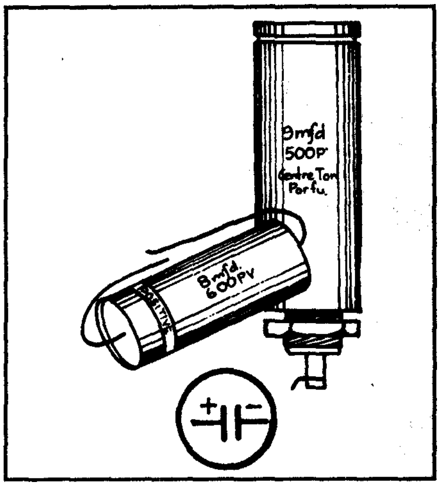


Fig.6: A traditional can-type electrolytic capacitor and its more recent, smaller gel-type tubular equivalent. If not earthed to the chassis, can types had to be insulated with large fibre washers.

In the early 1930s, power transformers were commonly supplied by specialist component manufacturers, who pro,oted selected 'catalog' lines, available from stock at the best price. Receiver manufacturers used them, wholesalers carried them on their shelves, and they were routinely specified in technical journals for home-built equipment.

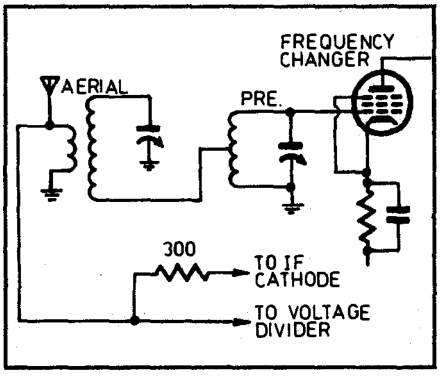


Fig.7: Pre-selector tuning offers similar selectivity to that of an RF stage, but without the gain or the gain control facility offered by a variable-mu valve.

For reasons which I can now only surmise, most stock power transformers carried a centre-tapped high tension secondary winding rated at 385-0-385V RMS and variously designed to cope with DC loads of 60, 80, 100 or 125mA, according to the nature of the receiver.

Voltage/current levels

Contemporary valve curves show that, under no-load (warm-up) conditions, a type 80 rectifier, fed with 385V RMS input, would deliver peak pulses of around 525V to the filter input capacitor.

Since 525 also happened to be the peak voltage (PV) rating of then-practical can-type electrolytic capacitors (Fig.6), it is reasonable to assume that 385 RMS represented the highest secondary voltage which could be countennced with a capacitor-input filter system.

While can-type electrolytics were said to be tolerant of high peak voltages, the 525PV rating would obviously been exceeded with an over-voltage mains supply. It was certainly not uncommon for liquid-filled electrolytics to 'sizzle' at switch-on, and one might even explode, on occasion, by reason of internal pressure. Perhaps that is why special 600PV types were in high demand for the filter input, when limited supplies ultimately appeared on the market

In the case of Fig.4, the drain of the voltage divider would lower the peak voltage across the input electrolytic to about 505, leaving a small safety margin. With a directly-heated 47 output valve, also having a similar warm-up time to that of the rectifier, the peak voltage across the first electro would be un-likely to exceed 425V — a very comfortable margin.

Depending on the ultimate DC supply voltage, the valve complement and the setting of the gain control, the DC load current of the receiver illustrated would be around 90mA, suggesting the choice of a power transformer rated at 100mA. At 90mA, the measured voltage across the input filter capacitor would be about 410. By subtracting from this figure the required 270V HT 'rail' voltage (250V + 20V cathode bias) we arrive at a desirable voltage drop across the field coil of 135V. Based on a current drain of 90mA, this works out at about 1500 ohms resistance for the field coil and a field wattage dissipation of just over 12W, which would be appropriate for an everyday 8" (200mm) diameter electrodynamic loudspeaker. These figures have been shown on the circuit as preferred values.

While loudspeakers with 1500-ohm field coils could be obtained from suppliers, they were less common than 2000 ohm or 2500-ohm fields. If, for a vintage receiver as in **Fig.4**, a collector needs to replace the original electro-dynamic loudspeaker, they may well have to make do with a higher resistance field.

Either of the abovementioned values should work out well enough. For sure, the voltage drop across the field would be increased, but not in direct proportion because, with a reduced supply voltage, the valves will draw significantly less anode and screen current. Based largely on 'guesstimation', I would expect the subsitution of a 2000-ohm field to result in a filtered HT voltage of around 255V at a current level of about 85mA. The field wattage would be something over 13. Repeating the exercise for a 2500-ohm field coil suggests a HT voltage of just under 250V at around 75mA, with a field wattage of just over 14. In short, increasing the field resistance as indicated would reduce the filtered HT supply and, with it, the available output power — but not to the point where it would seriously prejudice the subjective behaviour of the set.

Cutting costs

While the performance of a receiver along the lines of **Fig.4** was outstanding, relative to its cost, it raised the question as to whether there might be scope for an economy version with an adequate performance for non-critical areas. Accepting that it could be housed in a cheaper cabinet and powered from an 80mA transformer by cutting back on the HT current, could such a set also get by without the RF stage?

Superficially the answer was 'no', because reduced front-end selectivity could allow stations across the lower frequency end of the band to be affected by images from stations further up the band by twice 175kHz, or 350kHz.

As a compromise, RCS Radio and other coil manufacturers came up with a preselector coil which, in conjunction with the normal aerial coil, offered adequate up-front selectivity (**Fig.7**). It still called for a three-gang tuning capacitor, but eliminated the RF valve and the heater/anode load it imposed on the power transformer.

While preselector tuning was a well-known option at the time, receiver manufacturers came up with a preferred alternative which obviated the need for a special coil and a third section on the tuning capacitor: namely a still further increase in the intermediate frequency. How the new configuration evolved will form the subject of a future article.

(Tc be continued)•