

'Technical Shorts'

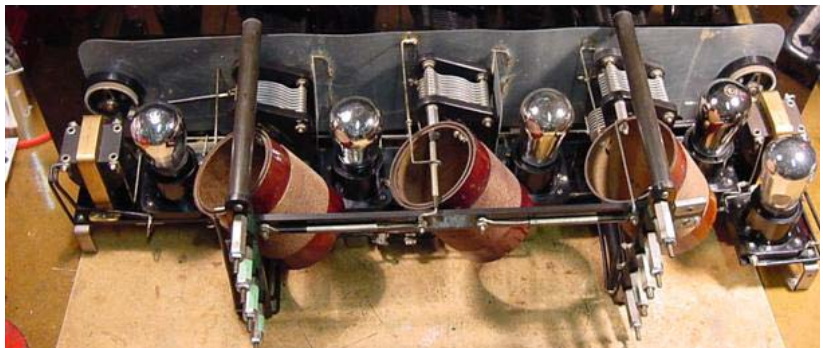
by Gerry O'Hara, VE7GUH/G8GUH

'Technical Shorts' is a series of (fairly) short articles prepared for the Eddystone User Group (EUG) website, each focussing on a technical issue of relevance in repairing, restoring or using Eddystone valve radios. However, much of the content is also applicable to non-Eddystone valve receivers. The articles are the author's personal opinion, based on his experience and are meant to be of interest or help to the novice or hobbyist – they are not meant to be a definitive or exhaustive treatise on the topic under discussion.... References are provided for those wishing to explore the subjects discussed in more depth. The author encourages feedback and discussion on any topic covered through the EUG forum.

Receiver Front-Ends

Introduction

Every radio receiver has a 'front-end': by this I mean the circuitry formed by the aerial, radio frequency (RF) amplifier(s), tuned circuits, mixer, local oscillator, attenuator etc. It can be argued that this is by far the most critical section of a conventional



receiver as it directly affects important receiver characteristic, specifically sensitivity, selectivity (especially in how it relates to image frequency rejection in superhets), frequency stability, signal to noise ratio and cross-modulation performance, even though subsequent stages in a superhet receiver provide the bulk of the gain and adjacent channel selectivity (both of these predominantly in the IF stages in a superhet), and other functions, such as BFO and audio filtering etc. This 'Short' focuses mainly on conventional front-end circuitry as found on valve receivers such as those in 'broadcast band', and 'All-Wave' domestic receivers of the mid-1930's through WWII, and the Eddystone range from the 1940's through to the early-1970's. However, it is certainly not a technical treatise and does not deal with theoretical concepts of front-end design.

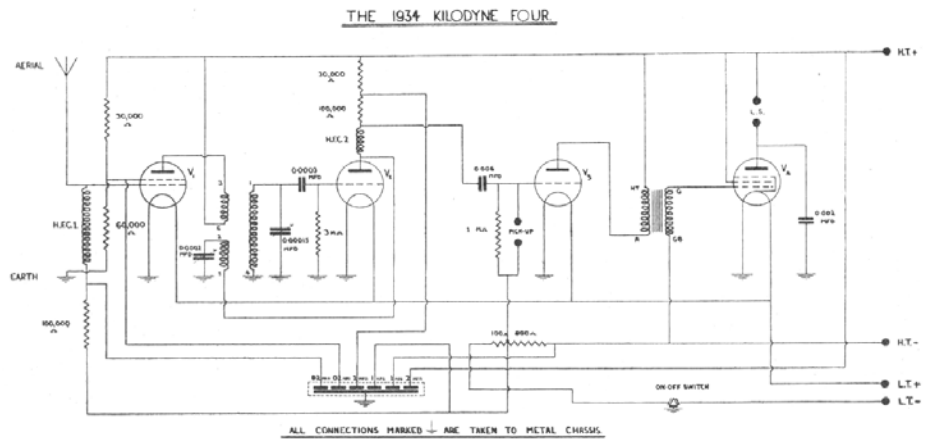
Types of Receiver Front-End

The earliest valve radios in the first quarter of the Twentieth Century were fitted with the only type of amplifier valve available at that time – directly heated triodes (indirectly heated valves were developed in 1924 to allow AC power to be used for the heater

circuits). Some designs used these triodes simply as audio frequency (AF) amplifiers following the detector, with the only RF tuned circuit being present between the aerial and the detector. Where amplification at RF was used, this was in a 'tuned radio frequency' (TRF) configuration, often referred to as a 'straight' design. Sometimes the aerial circuit was un-tuned (known as 'aperiodic', as in the Eddystone 'Kilodyne Four' kit design – circuit shown below, right), with only the detector grid circuit being tuned. All Eddystone sets up to 1936 (except the mythical 1924 'Regional One' that apparently only had a tube

detector) were of this topology, with varying permutations of RF and AF amplifier stages. This included all designs (kits and built receivers) from the 'Eddystone Two' in 1926 (detector

and AF amplifier only), through the various 'Atlantic', 'Scientific', 'All-Wave' and 'Kilodyne' models, the 'Homeland', 'Empire', 'Sphinx', 'Overseas' and 'Quadradyne' sets, culminating in the 'All World Four' and 'Homelander' designs of 1934/35. The 'Super Six', introduced about 1934, was Eddystone's first superhet design (not too successful by accounts in Lighthouse¹), followed by the 'All World Eight' in 1936, the latter having a tuned RF stage, mixer, local oscillator, two intermediate frequency (IF) stages, detector and a push-pull AF stage – quite a leap forward in technology. The RF or detector stage was often made to be 'regenerative' in TRF designs, ie. positive feedback at RF could be applied to the stage concerned using a 'reaction' control to increase



Eddystone All World Four

sensitivity and that could bring the stage into oscillation so CW signals could be detected. Eddystone were rather 'conservative', in that if RF amplification was used in their TRF designs, only one stage was provided. Other manufacturers, especially in the US, frequently used two or more stages of RF amplification in lieu of the extra gain afforded by the 'fiddly' regenerative detector stage.

The RF amplifier stage(s) in TRF designs suffered from instability due to inter-electrode capacitance (Miller

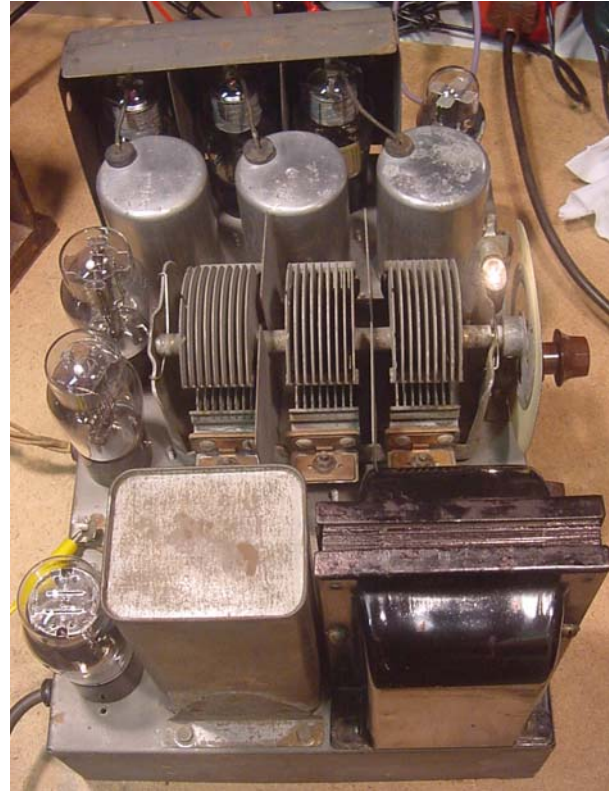
¹ Not mentioned in the QRG, but see Lighthouse issues 71 (p15), 80 (p20) and 96 (p44). Very few made.

Effect) causing self-oscillation when too much gain was attempted. The first techniques to overcome this problem were either based around neutralizing the internal valve capacitance, eg. as in the 'Neutrodyne' circuits popular in the mid-1920's in the US (used in my Freed-Eismann TRF set, photo on page 1), and/or very careful layout and screening of the RF stages. It was with the introduction of the screen grid valve² (tetrode) around 1927 that a significant improvement in front-end stability was achieved (used in the RF stage of the 1930 Eddystone 'All-Wave Four' and the Philco Model 20, photo, right).

This was followed by the general introduction of superhet technology shortly afterwards, whereby the receiver amplification distribution changed to having the majority of the gain performed at a single, lower (IF) frequency, which was an inherently more stable design. The tendency for the RF or tuned detector stage of a receiver to oscillate was, however, exploited in some receiver designs as noted above, whereby control of this was

exercised to increase gain and selectivity in 'regenerative' designs. Such designs tended to be simple (one or two valves) and were more for the enthusiast than for those who simply wanted to switch on, tune in and listen to radio programs. Another problem with regenerative designs is that they can become low-power transmitters if the regeneration is not well-controlled, interfering with nearby radios trying to listen to the same station.

Thus receiver designs by the early-1930's, were almost universally adopting the superhet topology with screen grid valves in the RF and IF stages over the TRF designs with screen grid valves. The introduction of the pentode allowed yet more gain and stability to be achieved, though with some additional noise at higher frequencies with earlier valve types. With the majority of the receiver gain now being at the IF frequency, the need for any RF amplification at all was becoming questionable for local broadcast band frequency reception, particularly with the increasing broadcast transmitter powers being deployed at that time. This meant that the front-end of most broadcast band receivers was a 'converter', ie. a valve performing both the mixing and local oscillator functions, with the only RF selectivity being performed by the aerial matching and tuned circuits ahead of the mixer grid. While this arrangement was adequate for general listening in the broadcast band (Medium Wave) at the onset of the 1930's, by the middle of that decade,



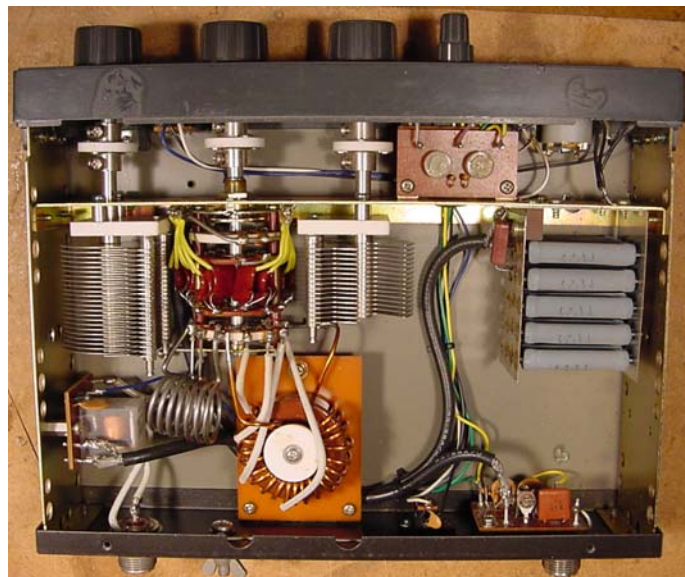
Philco Model 20 chassis – a 'straight' TRF design using screen grid valves and careful screening for stability

² Screen grid valves much-reduced the Miller Effect, giving higher gain/more stable TRF designs without the need for neutralizing. They were developed in 1919, but not introduced into general use until 1927.

sets sporting 'All Band' specifications were becoming popular as the interesting shorter wave bands were being explored by the more radio-savvy public and many more stations were also cluttering the broadcast band. The generally weaker and variable-strength signals on shortwaves meant greater receiver sensitivity, signal to noise ratio and image frequency rejection was desirable, spawning the need for better front-end design/performance. The valves used in the 1930's converter/mixer stages were inherently quite noisy, these being 'pentagrids' (heptodes) - as a general rule, the more grids a valve has, the more noise it generates. Thus tuned RF amplification gained a new lease of life in superhets capable of shortwave reception. This trend was most apparent in the new 'communications receivers' being developed in the early-mid 1930's, where maximum performance on the shortwave bands was being sought. One or even two stages of RF amplification ahead of the mixer stage became the norm for any 'serious' communication receiver from this period through to the end of the valve era of receiver design (though there were a few exceptions, eg. where high performance balanced mixer designs and those using the 7360 or 6ME8 beam deflection mixer valves dispensed with an RF amplification stage as techniques aimed at improving signal to noise and cross modulation performance).

Importance of Aerial Matching

One component of the receiver front-end often brushed over is the aerial matching arrangement, or indeed, the aerial itself. Correct aerial matching is one of the most misunderstood and ignored issues affecting front end performance of a receiver. As Peter Lankshear notes in Lighthouse Issue 72, p22 *"...Matching is to electronics what a gearbox is to a motor car. If you cannot have the right gear ratios your car won't go as well, and by the same token an unmatched feeder will cause an aerial installation to be very inefficient."* Equally, good matching is not much use if the aerial is inappropriate for the type of reception you are interested in. However, rather than entering into discussion on these topics here, my Technical Short on 'Aerial Matching' should be referenced – that article provides discussion on matching basics and some suggested simple aerials for use with general coverage shortwave receivers. Suffice is to say that it is rare for the front-end of a receiver to be perfectly matched to an aerial/feeder system by its internal circuitry. Instead, some form of external matching is usually employed (an aerial matching unit, or 'ATU') and again, the 'Aerial Matching' Technical Short provides some simple examples



A professionally-built ATU – part of my 1980's vintage Yaesu transceiver setup

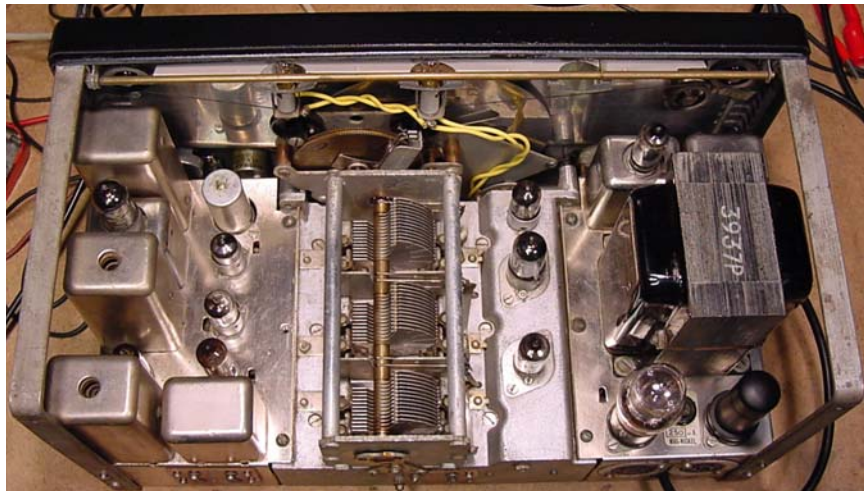
from 'Lighthouse' and elsewhere in this regard. There are many methods of coupling the aerial into the RF stage (or mixer/converter stage) of a receiver, the most common being a form of mutual inductance coupling as this lends itself to applications of balanced and unbalanced aerial/feeder types. Eddystone sets generally use this form of coupling and a simple arrangement is usually provided on the receiver rear panel to allow either balanced or unbalanced aerials to be connected by simply changing a link.

A device, sometimes fitted in receiver front-ends, but which can also be easily added externally, is a simple step-attenuator. This comprises a network of resistors and a switch, connected such that the signal (and noise) being applied to the receiver aerial connections is reduced by varying degrees, such that overloading of a sensitive front end can be avoided in the presence of very strong signals. A simple attenuator can be incorporated into the ATU.

Another device often ignored in the receiver front end (and not always present, though found in several Eddystone models) is an 'IF trap'. This is usually a simple series or parallel tuned circuit that is tuned to reject the set's IF frequency (or harmonic thereof) to reduce the possibility of unwanted heterodynes occurring in the receiver circuits.

Purpose of an RF Stage

As noted in the introduction, in a conventional receiver the front-end directly affects important receiver characteristic, specifically sensitivity, selectivity (especially in how it relates to image frequency rejection in superhets), frequency stability, signal to noise ratio and



My S.750 – note the die-cast RF sub-chassis (centre)

cross-modulation performance. The purpose of an RF stage in a receiver front-end arrangement may be summarized as being to provide:

- Increased sensitivity (greater gain). This will necessitate use of a valve that has a fairly high value of mutual conductance and that has low grid to anode capacitance for stability (eg. a pentode);
- Improve the signal to noise ratio by amplifying the RF signal ahead of the (noisy) mixer stage. To this end, the noise generated in the RF stage valve must be considerably less than that generated in the mixer (or converter) valve.

The above benefits can be provided by an un-tuned (aperiodic) RF stage, however, if the RF stage is fitted with a tuned circuit(s), the following additional benefits can be realized:

- Increased selectivity (actually, more of a reduction in adjacent-channel sensitivity) by rejecting signals other than at the (desired) tuned frequency;
- Improved image frequency rejection;
- Lessens the effects of spurious frequency combinations;
- Minimizes radiation of the local oscillator frequency; and
- Can reduce cross-modulation, ie. the interference of stronger, unwanted, signals with the signal of interest, if the RF stage is well-designed.

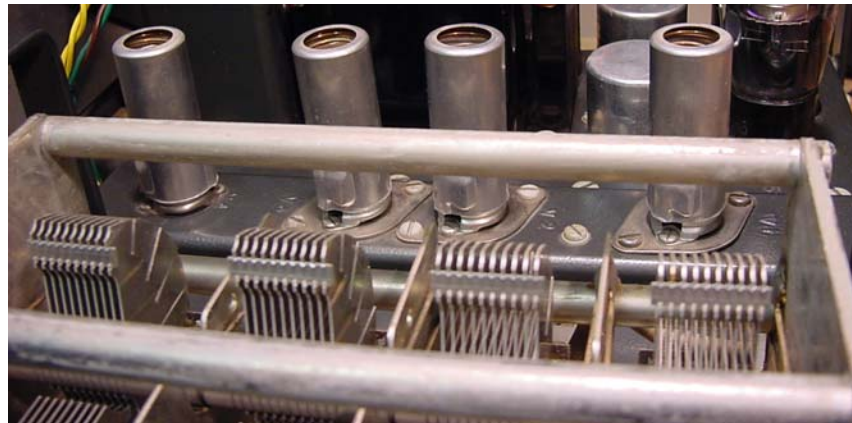
The design of an RF stage is thus a compromise between providing adequate amounts of selectivity and gain, but not excess noise or such an amount of gain that the stage(s) become unstable or overloads the mixer. The use of high-Q tuned circuits is critical to good tuned RF amplifier performance as this helps minimize noise and increases front-end selectivity (and rejection of unwanted signals).

RF Stage Design

Regenerative or neutralized RF stages were discussed briefly in the introduction and I will not discuss further here as they are not found in the more common (post-WWII) Eddystone receivers.

The majority of RF

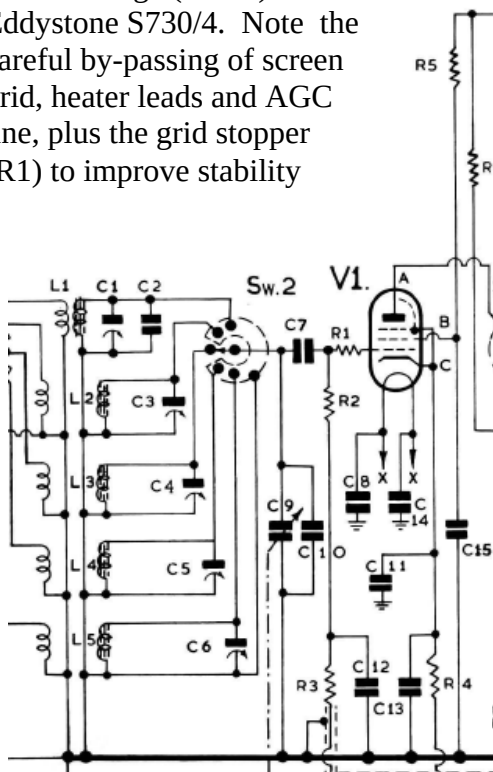
amplifiers found in valve receivers use variable-mu pentodes, eg. 6BA6 or similar, however, occasionally triodes may be found in the cascode configuration (most-often a dual-triode valve such as a 6ES8/ ECC189), or even a combination of both a cascode and pentode stage, as in the S940³.



The 'stalwart' RF sub-chassis line-up in an S680X - including two 6BA6 RF amplifier stages, a 6BE6 Mixer and 6AM6 local oscillator

³ The RF stages in the Eddystone S940, comprise a tuned aerial circuit feeding a cascode (dual triode) first stage, tuned coupling to a second RF stage (pentode) and tuned coupling to the mixer stage - this is a heavy-duty front end by any standards. Although this arrangement provides significant gain, its main purpose in my view is to act as a high-performance pre-selector to this single-conversion superhet design, that would otherwise suffer from poor adjacent-channel selectivity and images. It actually works very well (see Table 1 on page 19), although stronger stations can swamp it and result in cross-modulation and blocking in extreme cases – the price to be paid for using this technique. However, judicious use of the RF gain control and an attenuator with this set can mitigate this adequately in most circumstances.

First RF stage (6BA6) in an Eddystone S730/4. Note the careful by-passing of screen grid, heater leads and AGC line, plus the grid stopper (R1) to improve stability



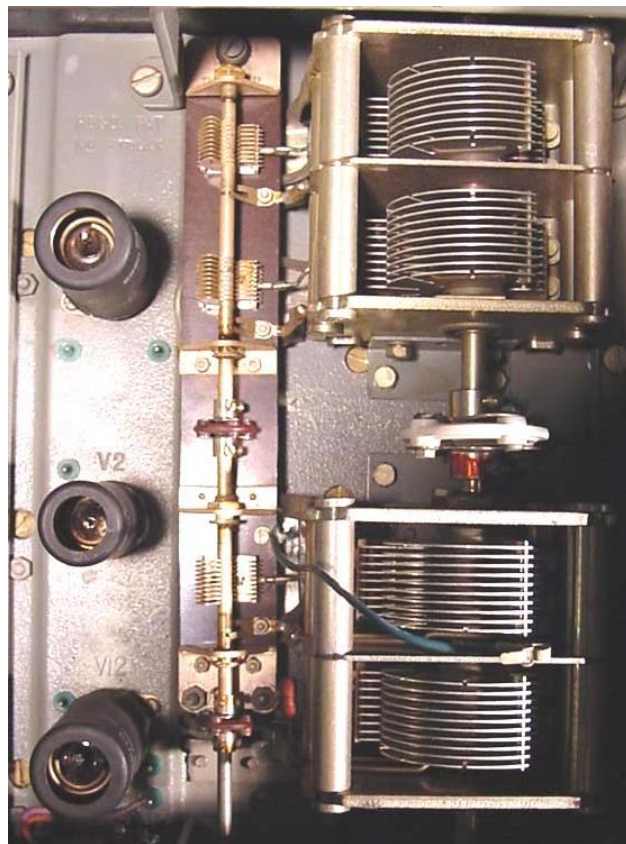
A typical pentode RF stage is shown in the schematic, left (this the first RF stage of the two present in the S730/4). The use of variable-mu pentodes, such as the 6BA6, allows the best use of AGC and manual RF gain controls. The designs of pentode RF stages in Eddystone HF receivers from the late-1940's through the early 1970's were very similar, although the valves used changed from the Octal-based EF39 in the S504 and S640 in the mid-1940's, through the B8A-based EAF42 in 1950, eg. in the S.740, to the ubiquitous B7G-based 6BA6 in the early-1950's through 1970, eg. as in the S750, both RF stages of the S680X and S730/4, and as the second RF stage in the S940.

Provided the gain offered by a single RF stage is sufficient (x10 to x15) to overcome the mixer (or converter) noise, little further improvement in receiver signal to noise ratio is obtained by adding additional stages of the same type. The main advantage of adding more than one stage of RF amplification lies in improved selectivity,

however, it is most common for additional gain and selectivity to be achieved instead by additional amplification at the IF frequency(s) where the tuned circuits are operating at a fixed (and generally much lower) frequency. Indeed, there are a number of disadvantages in adding more stages of RF amplification, including:

- Increased construction complexity;
- Potential for instability;

Right: RF sub-chassis in an S830/4 – note the small tuning gang to the left of the main tuning gang, this is the 'Peak RF' control used to trim the three front-end RF amplifier tuned circuits. The RF amplifier stage is a cascode ECC189 (6ES8), with 6AK5 (pentode) 1st mixer and 6U8 1st local oscillator (pentode section)



- Susceptibility to tracking problems (and more circuits to align); and
- Complex (wafer) switching in multi-band receivers that can be problematic, especially with ageing.

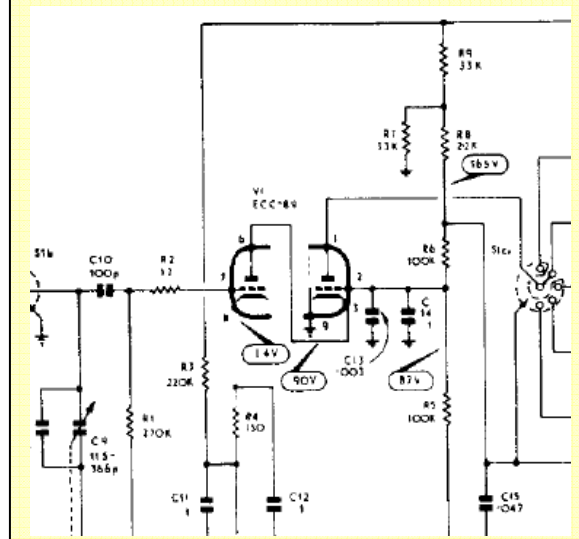
At higher frequencies (above 50MHz), grounded-grid triodes tend to provide better signal to noise ratios than grounded cathode pentodes, but at the expense of lower gain and selectivity. Following its description in the Proc. I.R.E. article in June, 1948 by Wallman et al., the cascode RF amplifier (sidebar, right) became popular in the early 1950's, initially to provide a low-noise, stable amplifier for TV sets operating at VHF. A typical cascode circuit uses a dual-triode, the first in common cathode mode, directly coupled (in series) to the second, operating in a grounded grid configuration. This arrangement has a high input resistance and low equivalent noise, and can be considered to be a single grounded-cathode triode having virtually zero grid to anode capacitance and a mutual conductance and noise resistance equal to that of the input triode. The benefits of the cascode arrangement are also present at HF, eg. noise figures of <0.25db at 6MHz and <1.3db at 30MHz are noted, a higher resistance to cross-modulation and to strong-signal overload. This circuit was introduced into the Eddystone range in the early 1960's - in the S830 professional series, the EA12 high-end amateur bands model, and the popular general-coverage S940 - to increase front-end specifications of this new range of higher-performance HF receivers.

A design problem with aerial and RF stages is that of obtaining satisfactory performance over a large tuning range. The L/C ratios obtainable with a variable capacitor giving an incremental capacitance range of 9:1 are satisfactory on the broadcast band, but not so on the shortwave bands. This is usually overcome by various arrangements of series and parallel fixed capacitors switched in/out of circuit depending on the selected band, thus giving the desired

The Cascode Circuit

Developed around 1950 and used in some early TV (VHF) front-ends, this circuit comprises a grounded cathode triode stage followed by a grounded grid triode stage, effectively in series – ie, *cascaded triodes* or '*cascode*'.

Normally, direct coupling is effected between the two triode stages with the input circuit of the second stage acting as the output load for the first stage. The need for neutralisation, otherwise required for triodes in grounded cathode RF applications due to the Miller Effect, is dispensed with because the feedback voltage through the plate to grid inter-electrode capacitance of the first stage (operating at low anode volts and low gain) is too low to cause oscillation, and the second stage, connected in grounded-grid configuration, is inherently stable. The total gain of the two stages approximates to that of a pentode, but with the lower noise characteristics of a triode and with better cross-modulation characteristics. Typical valves used in this application include the ECC189/6ES8 (as in the S940 and S830), ECC84/6CW7 and 6BQ7.

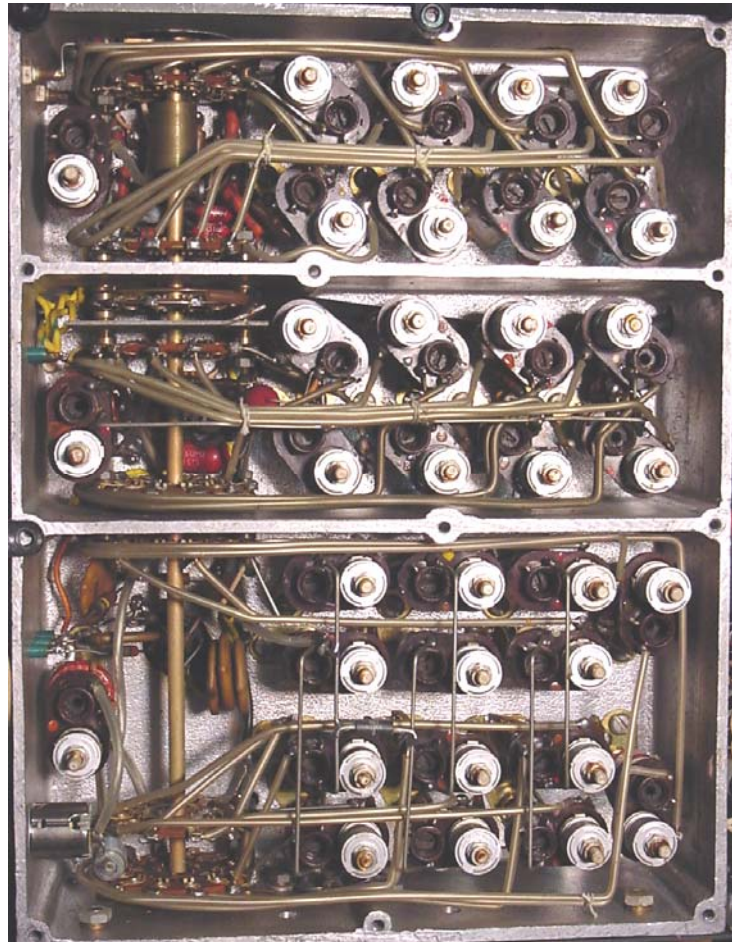


amount of band-spreading for the particular band in use.

The RF stage is usually coupled to the mixer (or converter) stage using a form of mutual inductance coupling by means of a tuned transformer. The primary winding (in the RF stage anode circuit) resonates with the valve output capacitance, transformer winding capacitance, stray wiring capacitances and sometimes an added capacitor. The coupling transformer secondary is usually tuned via one gang of the tuning capacitor, with tracking being accomplished by a slug in the coil and a trimmer capacitor in parallel with the tuning gang (permeability – variable inductance – tuning is sometimes used).

Image rejection deserves a special mention: if there were no tuned circuits ahead of the mixer (or converter) stage, a signal lower in frequency than the local oscillator frequency, and which differs from the oscillator frequency by the value of the intermediate frequency would pass into the IF amplifier stages, as would a signal higher in frequency by the same amount. One of these two frequencies is the desired signal, the other is termed the 'image'. Thus the desired and undesired signal frequencies are separated by twice the IF. The aerial tuned circuit provides some selectivity between these two frequencies, however, this is usually not that great, as significant damping can occur due to poor matching, reducing the effective Q of the aerial tuned circuits. A tuned RF stage allows looser-coupling and higher effective Q values of the tuned circuits to be realized, and for an additional tuned circuit to be placed in front of the mixer

(or converter) stage. These effects combined provide significantly higher selectivity at the desired signal frequency, providing good tracking can be effected across the tuning range of the receiver. These considerations are particularly important at higher frequencies, when the IF frequency is a much smaller percentage of the signal frequency.



Coil box in an S830/4 – note the careful layout, plus the excellent inter-stage screening and mechanical robustness afforded by the diecast construction

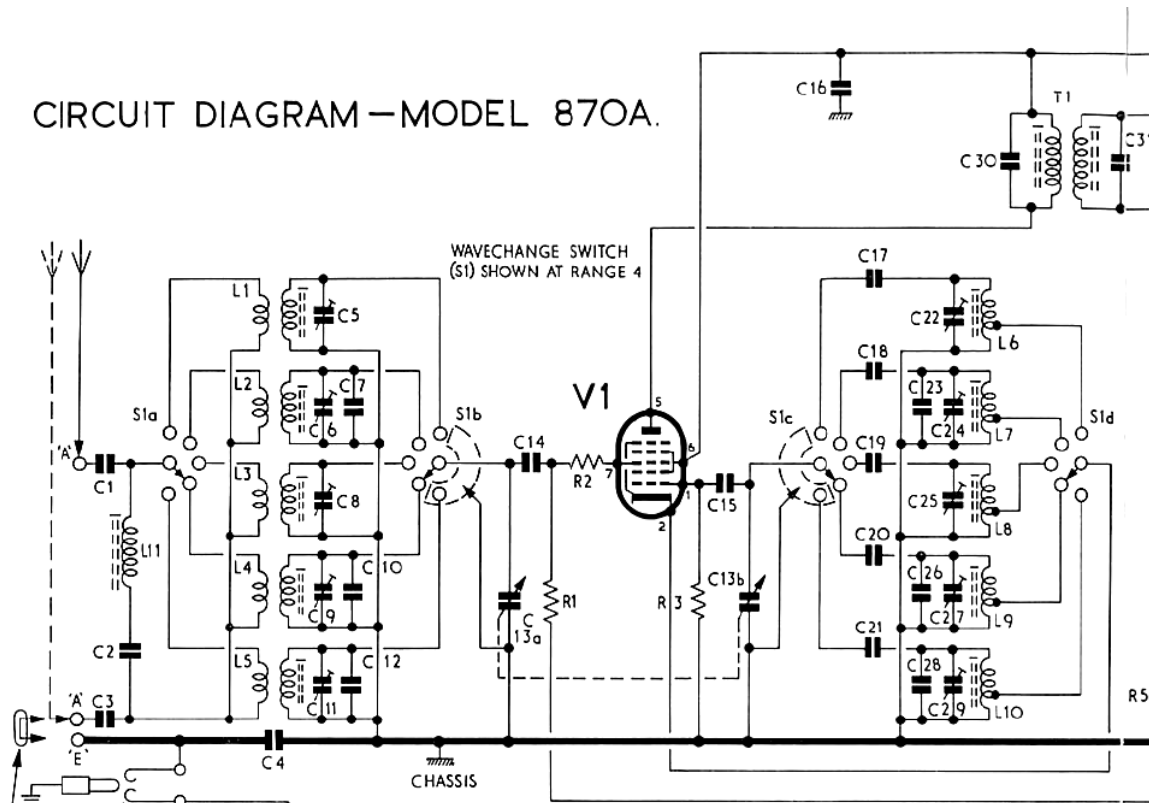
Instability in RF stages can be a problem. As noted above, selection of the correct valve type and circuit configuration are paramount in order to avoid the internal capacitances in the valve from giving undesired positive feedback. Lack of adequate shielding or care in placement of coils and signal leads can also lead to instability, as can inadequate decoupling of power supplies (including the heater leads), and poor ground connections.

Cross modulation distortion is an effect that can happen when two signals are applied to any non-linear circuit element (such as a valve under certain operating conditions) and modulation of the weaker signal by the stronger one occurs. The effect is most noticeable when a strong (eg. local) signal is present when listening to a much weaker signal. Good linearity and selectivity in the RF amplifier help to combat this effect – however, no amount of selectivity in the IF stage can remove the undesired signal once cross modulation has occurred in the RF amplifier or mixer (or converter) stage. Good linearity can be achieved by careful selection of the bias conditions of the RF valve and with good bypassing at all frequencies of the cathode circuit (in a pentode RF stage).

Mixer (or Converter) Stage

Mixers operate by performing the trigonometric function of multiplying two sine waves. Specifically, $2(\cos A)(\cos B) = \cos(A+B) + \cos(A-B)$, where A and B are changing angles (frequencies) with possibly different time origins (phases). If A and B are different frequencies, two new frequencies are produced, one of which is at the IF frequency. The most important attributes of a good mixer stage are efficient mixing, low noise and a high overload threshold. Valve mixers tend to be multigrid valve designs, as higher mixing efficiencies can be obtained, as well as greater isolation between the local oscillator and the mixer circuits (whether the local oscillator valve is integral with the mixer or not). As noted earlier, however, more electrodes in a valve generally means higher noise factors, so, as per the RF stage, a compromise is made, here between stage gain, isolation (to avoid 'pulling'), cross modulation performance and noise level. If an RF stage(s) is present, gain in the mixer stage is much less important, and the designer can instead focus on reducing the noise factor, susceptibility to oscillator 'pulling' (when strong signals entering the mixer vary the local oscillator frequency due to poor isolation in the valve and/or circuit layout/design), mixing efficiency and dynamic range.

The most satisfactory early multigrid valves were known as 'pentagrid converters' (heptodes). A similar valve, having an additional suppressor grid was also frequently used (octode). Here, two of the grids (closest to the cathode) were generally used in the local oscillator circuit and the others to introduce the signal and perform the mixing function. The general use of a low intermediate frequency in shortwave receivers (usually around 455kHz) meant that the local oscillator frequency was separated from the signal frequency by only around 2%. A phenomena known as 'space-charge coupling', found in the simple pentagrid converter valve, meant that severe pulling of the oscillator frequency could occur (by as much as 50kHz), especially when strong signals were encountered and/or when AGC was applied to the converter stage. One development to overcome this issue was the introduction of the triode-hexode, where a separate triode within the same envelope and having a common cathode assembly to the hexode, was



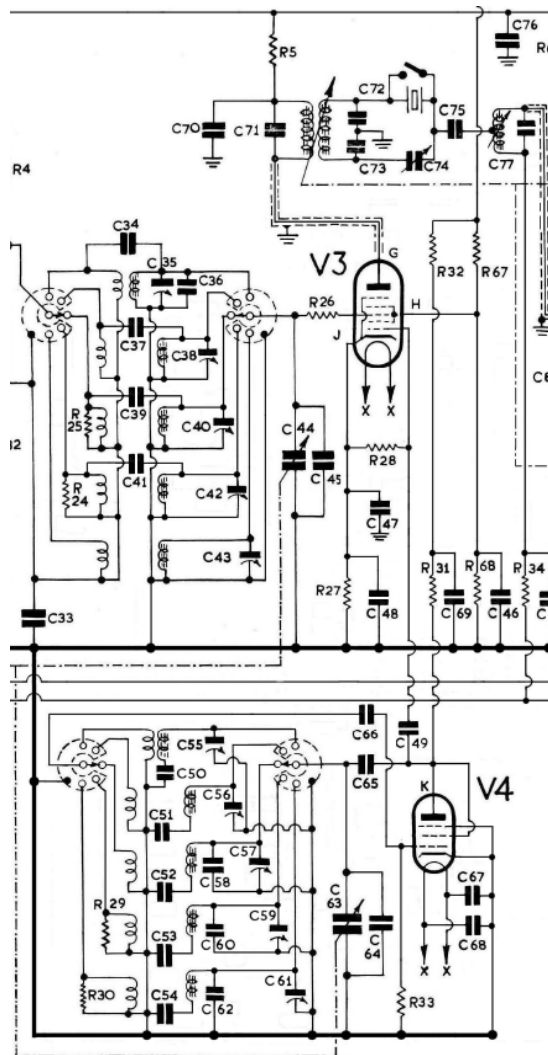
Above: Front-end from an S870A. Points to note include the series-resonant IF trap (L11, C2) effectively grounding signals at the IF frequency, grid stopper (R2) to prevent parasitic oscillations, use of a 12BE6 (12v heater version of the 6BE6) as a frequency converter, with grid1 used in the electron-coupled local oscillator circuit, the signal injected to grid 3, AGC applied to grid 1 via R1, and the flexible aerial and ground switching arrangements

used in the local oscillator circuit. Here, the triode grid is connected internally to the third grid of the hexode section – in this way, by applying the oscillator voltage to an outer grid and the signal grid to an inner grid, space charge coupling was significantly reduced and AGC could be applied to the valve with less effect on the oscillator frequency. Other solutions were also introduced, including adaptations of the pentagrid with changes to the internal construction to allow physical separation of the mixer and oscillator grids relative to the common cathode, but retaining the usual inner grid oscillator injection of the pentagrid design.

An important characteristic of a mixer (or converter) stage is its conversion transconductance, this being the ratio of IF output current to the signal grid input voltage. A rule of thumb is that 30% of the maximum signal grid to anode transconductance of the valve can be obtained during mixing. There are three basic modes of operation of a mixer valve – the oscillator voltage may be placed on:

- the same grid as the signal voltage. Examples of this would be the use of a triode or pentode as a mixer, with the oscillator voltage introduced in series with the signal voltage using inductive, capacitive or conductive coupling, or even introduced into the cathode circuit. An example of a pentode mixer is the 6AC7;

- an inner grid, with the signal applied to an outer grid. In this configuration, the cathode current is modulated at the oscillator frequency, with the signal serving only to change the distribution of current between the grids and the anode (a screen grid is usually placed between the two control grids to reduce the undesirable coupling between the oscillator and signal circuits). Examples of valves used in this configuration include the 6A8, 6BE6, and 6SA7 (all pentagrids), and the 6K8 (triode-hexode); or
- an outer grid, with the signal applied to an inner grid. Here, the cathode current is modulated by the (small) signal voltage, with the (large) oscillator voltage altering the current distributing between the anode and screen grid (again, a screen grid is placed between the control grids for isolation). Examples of valves used in this configuration include the 6L7 (pentagrid), ECH35 and UCH42 (triode-hexodes), and 6AJ8, 6J8 and 6AE8 (triode-heptodes).

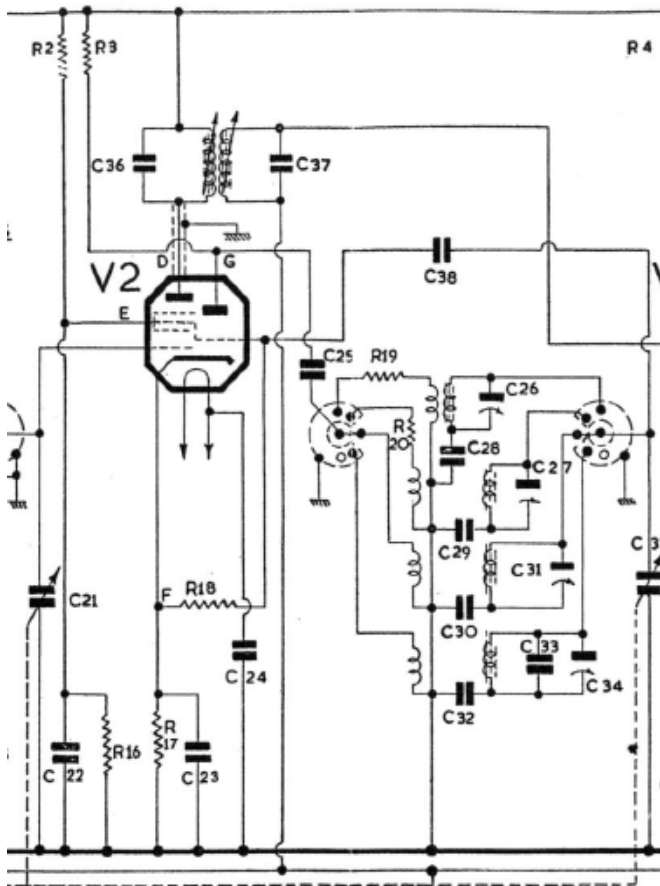


Mixer (6BE6) and local oscillator (6AM6) stages in an S680X. Note the local oscillator injection to the inner grid (grid 1), and signal injection to an outer grid (grid 3)

Each of these modes of operation have characteristics that depend on the mode rather than the valve type used. Also, not all pentagrid and triode-hexode/heptode valve types behave the same due to differences in internal construction, ie. geometry, layout and shape of the grids. In particular, some function better at higher frequencies than others and some work better (are more stable) than others with AGC applied. The early pentagrid valves, such as the 6A8, work well at broadcast frequencies through to around 15MHz, when the conversion transconductance falls away very rapidly, and when used in a converter application, the oscillator frequency and output vary with applied AGC voltage (most noticeably at higher frequencies) – use of a separate local oscillator valve can mitigate this effect somewhat. The (later) 6SA7 and 6SBY7 pentagrids improved upon the 6A8 by using different oscillator grid arrangements. The 6J8 and 6AJ8 (triode-heptodes), and the 6K8 and UCH42 (triode-hexodes) are less affected by the AGC action due to the greater isolation between the oscillator and mixer sections of the valve. These valves tend to have a lower conversion transconductance than the 6A8 at

broadcast band frequencies and provide greater conversion gain at higher frequencies. The 6K8 and other valves of similar construction also have a more stable oscillator section, making them particularly suitable for use as a converter in shortwave receivers.

The type of valve and method of operation must therefore be carefully chosen to meet the most important objectives of the receiver's function.



Above: Frequency converter stage of an S670A using a UCH42 triode-hexode

Local Oscillator

Frequency stability is the over-riding consideration when designing a free-running valve oscillator, however, phase noise is also an important consideration. The latter impacts the overall noise factor of the receiver and is particularly bothersome when receiving weak signals.

Oscillators '101'

Every oscillator has at least one active device (valve, transistor, FET or IC) acting as an amplifier. This device is arranged in a circuit such that a portion of its (amplified) output is fed back to its input in the correct phase such that this signal gets amplified and thus a sustained oscillation occurs. The frequency of the oscillation is determined by tuned circuit elements, eg. a crystal, or capacitors and inductors.

Frequency or phase stability of an oscillator is usually thought of in the long-term case – measured over minutes, hours, days through years... Of interest here are effects of component changes with ambient conditions, eg. temperature, humidity, mechanical stability and, over longer periods, component aging. Short-term stability is also of interest and the higher the 'Q' of the tuned circuit element, the higher the stability of the oscillator and the greater its ability to filter out undesirable harmonics and noise (which is amplified along with the desired oscillator signal frequency).

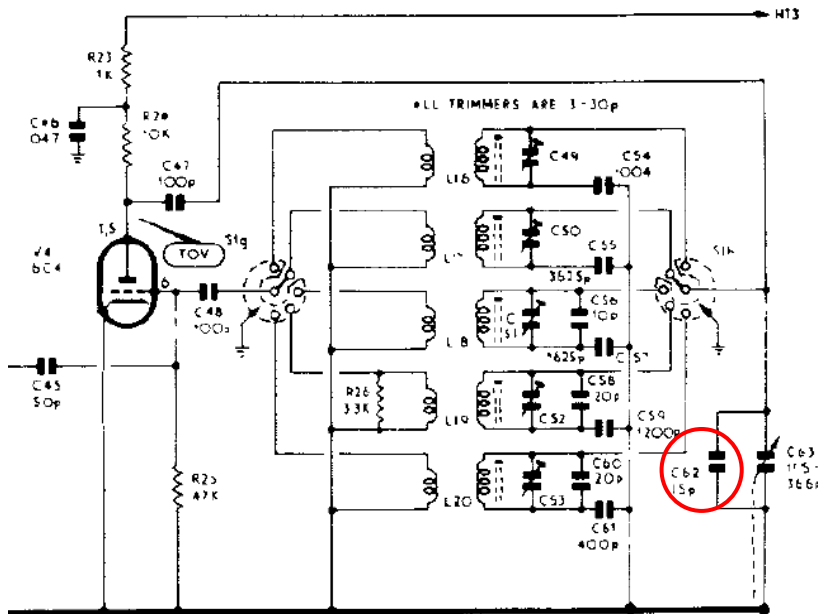
Frequency drift can be minimized by:

- Isolating the oscillator by using a buffer stage
- Careful choice of oscillator circuit
- Ensuring mechanical stability
- Maintaining constant ambient temperature/humidity
- Providing a clean, well-regulated power supply
- Minimizing circuit changes by selecting appropriate and high-quality components, eg. silver mica or polystyrene capacitors
- Using low-loss, high-'Q' coil construction
- Using negative temperature ceramic 'drift-cancelling' capacitors to compensate for temperature changes
- Selection of a low-noise active device and operating it at a low power level
- Use of a low L/C ratio: maximise reactive energy

Attaining highly-stable free-running oscillators is a combination of art and technology and was the 'holy grail' of receiver designers before the availability of low-cost frequency synthesisers and digital electronics (see the HBR receiver reference below).

The easiest way to make a stable oscillator is to use a crystal as the frequency-determining component. Although still subject to frequency drift with temperature changes of the crystal element, the stability of a well-designed crystal oscillator is an order of magnitude or more better than a well-designed free-running oscillator (usually termed a variable frequency oscillator or 'VFO'), ie. one that does not incorporate a crystal as its frequency-determining element. Of course using a crystal in an oscillator is rather limiting unless you are interested in only one (or a few) frequencies or their harmonics. Even given that a crystal can be made to oscillate slightly off-frequency by varying its operating conditions, eg. loading with a variable capacitor, tuning across a wide range of even spot frequencies would be impractical. So, what if we focus on improving a free-running oscillator? eg. by using rigid mechanical construction, selection of one of the more stable oscillator types (eg. Hartley, Colpitts or Vackar) and apply good design/construction practices - see sidebar on the previous page. At HF, these techniques can certainly reduce drift to very acceptable levels <200Hz per hour or so – and certainly more than adequate for AM, SSB and even CW reception using very narrow filters. The reader is referred to my EC958 article ('The Best Receiver Eddystone Ever Built?') for

further discussion on making VFO's more stable than this.



Many Eddystone models used a separate local oscillator valve, usually a triode (eg, 6C4), though in other models a pentode was used, as in the S830 series (half of a 6U8). Temperature compensation was usually simple: a small-value negative temperature coefficient capacitor in parallel with the oscillator tuning capacitor (eg. C62 in the S940, circled

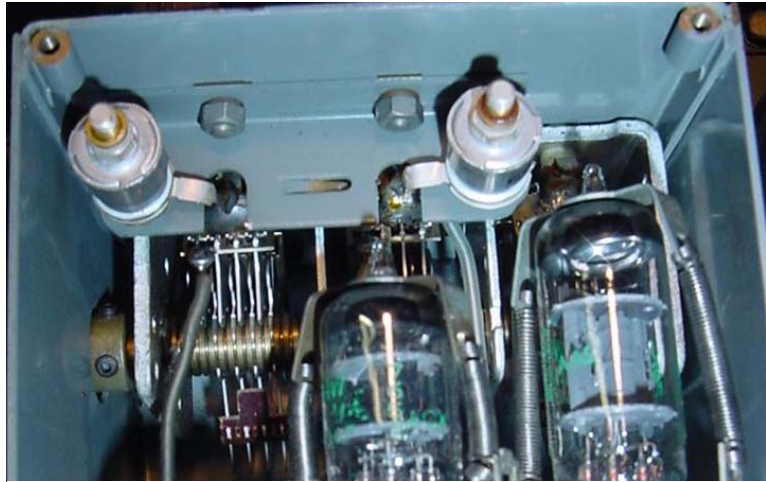
The simple local oscillator circuit from the S940 using a 6C4

red on the schematic, left). Mechanical stability of the local oscillator tuned circuits is afforded in most Eddystone sets by the use of a diecast coilbox/RF chassis and the use of heavier gauge, solid core wiring. Circuit layout is important, with heat-producing components, eg. valves and higher-wattage resistors, being placed above the chassis or outside the coilbox. Stabilized power supplies feeding the local oscillator (or converter)

stage helps, as does keeping the oscillator valve grid current as low as possible consistent with stable and reliable operation. Selection of appropriate components, especially capacitor types, is critical – important in RF and mixer stages, but especially so in the local oscillator stage – and use of silver mica capacitors and temperature-compensation ceramic capacitors when needed. Good circuit design and selection of an appropriate circuit configuration pays dividends (eg, Hartley up to 50MHz and either Hartley or Colpitts above this), as well as techniques such as connecting the valve into only part of a coil in a tuned circuit ('tapping down') and arranging the L/C ratio to be as small as possible.

Long-term frequency stability of the local oscillator is only one issue though – oscillators can suffer from other problems. These include:

- flutter – rapid minor variations in oscillator frequency (usually a power-supply issue);
- squegging – variation in output level or even intermittent stoppages of oscillation due to 'blocking' of the oscillator (occurs at an audio or ultrasonic rate). This is usually caused by incorrect bias conditions and/or excessive grid voltage amplitude in the oscillator stage, and/or incorrect proportioning of the values of the grid resistance and capacitance. It can be frequency-dependant, often occurring only at the high end of the tuning range. Reducing the level of feedback and/or installation of a grid stopper resistor can effect a cure if the oscillator valve all other components test ok;
- Hum – can be caused by poor heater-cathode insulation in the oscillator valve or insufficient power supply filtering;
- Frequency modulation – at audio frequencies due, for example by a speaker being fitted in the receiver case and causing vibration of the tuning capacitor plates – especially at bass frequencies. Use of an external speaker or improved isolation of the speaker and/or the tuning capacitor from the receiver chassis/cabinet can help;
- Microphonics – poor valve design and faults, eg. variations in heater-cathode capacitance (this problem can be cured by connecting one side of the heater to the cathode (where possible) and using an RF choke in the other heater lead); and
- Parasitic oscillations – these are undesired oscillations in a circuit. Any circuit will contain tuned circuits (of low Q) formed by component leads inductances, valve and stray capacitances. As the values of these 'incidental' components tend to be small, the resonant frequency tends to be high. They can become problematic, with dead spots and/or variations in oscillator amplitude occurring



Second local oscillator compartment in my S830/4 – again, excellent screening and mechanical robustness afforded by the diecast construction

in the tuning range as a result. Parasitic oscillations can be cured by using grid stopper resistors, careful circuit design and layout/screening techniques.

Conclusions

The front-end is arguably the most critical section of a receiver, in terms of circuit design, component selection, construction, alignment and maintenance: get only one of these things wrong and your set will become 'deaf', drift or be plagued by unwanted whistles, distortion or high noise levels. Most of these issues had been resolved to an acceptable level by the time the post-WII Eddystone HF receivers were being manufactured, with the communications and professional receivers incorporating features such as miniature, low-noise RF pentodes, high-Q tuned circuits, die-cast coil boxes/RF chassis, stabilized power supply to the local oscillator, separate local oscillator and mixer stages (allowing greater choice in selection of mixer valve and greater isolation), etc. Dual-conversion designs were introduced around 1950, allowing some relaxation of the selectivity requirements on the front-end, as its job in minimizing image rejection was lessened.

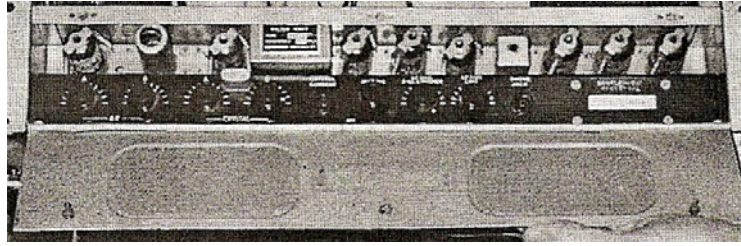


High-stability oscillator designs were introduced into some high-end receivers in the mid-1950's, eg. the RACAL RA-17/RA-117 receivers (photo, left), using the Wadley Loop system, and by using crystal-controlled first local oscillators and tuneable second local oscillators (eg. as in the Eddystone S880 in 1959). The cascode RF amplifier design was introduced around 1950, 'combining the gain and stability of a pentode with the low

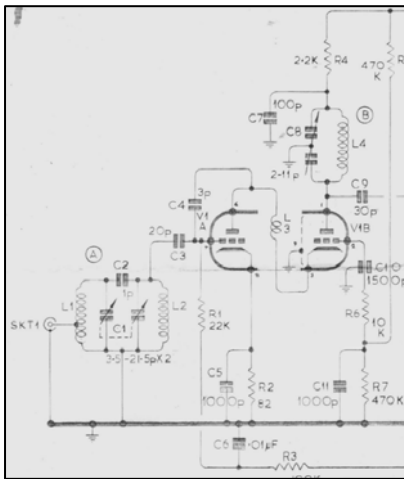
noise of a triode'. It was adopted in HF receiver designs for the same reasons it was used in VHF TV tuners of the day (I could never understand why it was not more widely adopted at HF as the additional circuit complexity and/or valve cost was rather trivial).

The pinnacle of valve receiver front-end technology had been reached by the early-1960's, with the design employed in a particular receiver generally being selected depending on the market/use the receiver, rather than by introducing new techniques. By that time, manufacturers research and development focus was firmly upon solid-state technology. However, it would take another decade before performance of solid-state receivers started to compete with that of well-designed valve sets – especially in the front-end department, as early semiconductors were noisy, easily overloaded, susceptible to damage from nearby transmitters and static discharges, etc. A brief summary of the published front-end performance specifications for a number of Eddystone HF/LF valve receivers is provided in Table 1 (page 19). These were taken from a brief review of the manuals, specification sheets and data sheets posted on the EUG website and are not comprehensive. Most of the sensitivities and signal to noise ratios quoted are for AM reception and will tend to be higher for CW and SSB modes.

By the time valve sets were finally exiting production in the early-mid 1970's, most of the failings of the early solid-state front ends had been resolved... but valve radio front-ends had (have)

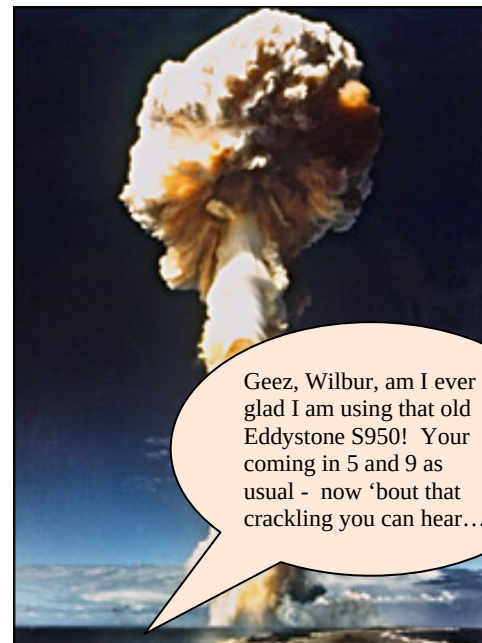


one additional bonus – they are relatively ‘bomb proof’ (literally). An article by Graeme Wormald in ‘Lighthouse’, Issue 93 (pp31 to 33, entitled ‘Eddystone and the Bomb’) discusses the Eddystone S950 – the last valve Eddystone receiver ever made (photo, above). The purpose of this receiver, a crystal-controlled single conversion superhet



operating in the 110 – 130MHz range, was apparently to allow the armed forces to evaluate the immunity of tube technology receivers to electro-magnetic pulse (EMP), such as released by a nuclear explosion. Only a prototype and a handful of evaluation models of this design were manufactured according to the article, with possibly only the pre-production prototype surviving, located at Alan Ainslie's ‘Eddystone Museum’. The receiver block diagram in the article (and the ‘provisional’ manual for this set on the EUG site)

shows that it had an ECC189 cascode RF amplifier (schematic, above), a 6AK5 mixer and separate 6U8 crystal-controlled local oscillator as its front-end – I didn't see a ‘proton and neutron trap’ though... Graeme's article also notes that valve radios were used in ‘Operation Desert Storm’ as solid-state sets could not cope with the high levels of static discharge generated by hot, dry sand moving at speed across the vehicle aerials (acting like a Wimshurst machine) – no doubt those sets had ‘sand traps’ installed in their front-ends?



Geez, Wilbur, am I ever glad I am using that old Eddystone S950! Your coming in 5 and 9 as usual - now 'bout that crackling you can hear...

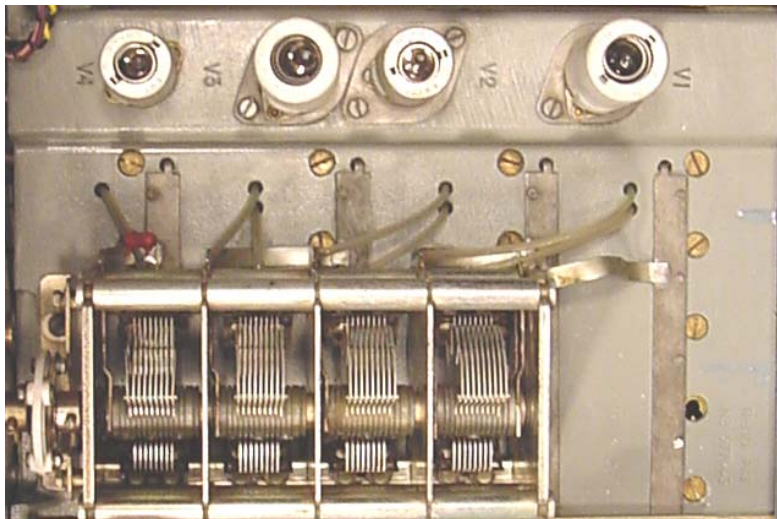
Gerry O'Hara, VE7GUH/G8GUH, residing in ‘Nuclear-Free’ Vancouver, BC, Canada, November, 2009 (...seems like it is also almost ‘Eddystone-Free’ at times).

PS: Did you notice that I managed to write this article without once mentioning the terms ‘third-order intercept point’ or ‘IP3’⁴ – damn, now I have, shame on me...

⁴ In a nutshell, the ‘third-order intercept point’ (IP3) expresses how well a receiver separates two closely spaced signals. Generally speaking, the higher the quoted number the better the receiver is at doing this – the IP3 may range from around –10dB to around +40 dB. Eddystone valve set specs never quoted IP3s.

Some Useful/Interesting References

- Radio Communications Handbook, 4th Ed. RSGB, 1968, Chapters 2 and 4
- Radio Engineering, F. Terman, 1947, (3rd Ed. Chapter, 6, 7 and 8)
- Radio and Television Receiver Circuitry and Operation, Ghirardi & Johnson, 1951 (Chapter 4)
- Radiotron Designers Handbook, RCA, Langford Smith, 3rd Ed. 1940 (Chapters 14 and 15)
- Radiotron Designers Handbook, RCA, Langford Smith, 4th Ed. 1953 (Chapters 23, 24 and 25)
- Electronics One-Seven, Edited by Harry Mileaf, Hayden Book Co., 1967, Chapters 3 and 5
- 'Receivers' (1949) and 'Valve Technique' (1948), RSGB, Reprinted 2006
- A Low Noise Amplifier, Proc. I.R.E. June, 1948, H Wallman et al.
- Recollections of a Radio Receiver – The W6TC (SK) Adventure 1956 – 2009. A collection of Observations, Remembrances, Letters and Notes, e-book by Jay Helms, W6HHT, available from www.w6HHT.com (568pp on a CD about the HBR homebrew receivers - packed with interesting stuff – all for \$10)
- Some web-based articles/resources on subjects covered in this article include:
 - o http://www.clarisonus.com/Archives/TubeTheory/SG_Arrives.pdf ('A Shielded Grid Tube at Last Arrives', Radio News, January, 1928)
 - o http://en.wikipedia.org/wiki/Tuned_radio_frequency_receiver (some good hyperlinks from this)
 - o <http://en.wikipedia.org/wiki/Neutrodyne>
 - o http://urgentcomm.com/mag/radio_receiver_frontend_characteristics/
 - o <http://electronbunker.sasktelwebsite.net/TwoTubeSuper.html>
 - o www.ppraa.org/downloads/tech.../Third%20Order%20Intercept%20Point.rtf (as simple an explanation of IP3 as I have found anywhere)
- Eddystone User Group website (<http://eddystoneusergroup.org.uk/>):
 - o Technical Short #13 on 'Aerial Matching'
 - o 'The Best Receiver Eddystone Ever Built?'
 - o "Eddystone and the Bomb", 'Lighthouse', Issue 93, pp31 to 33
 - o 'Quick Reference Guide' ('QRG'), 2nd Ed. Graeme Wormald, 2002



Left: the S940 front-end sub-chassis – with a cascode ECC189 first RF (V1), 6BA6 pentode second RF (V2), 6AJ8 triode-heptode mixer (triode section not used) and 6C4 triode (V4) local oscillator. Quite a potent combination!

Model	RF Amplifier	1 st Mixer	AM sensitivity (for 50mW output @30% mod	Signal to Noise	Image Rejection	Frequency Stability ⁵
S358X	Pentode (EF39)	ECH35	<3uV >1.5MHz <8uV <1.5MHz	Not quoted	33:1@20MHz 500:1@3MHz	Not quoted
504	Pentode 1 st and 2 nd RF (both EF39)	ECH35	<2uV	Not quoted	75dB@2MHz 60dB@5MHz 50dB@10MHz 35dB@20MHz	Not quoted
556	Pentode 1 st and 2 nd RF (both EF39)	ECH35	2uV	Not quoted	75dB@2MHz 60dB@5MHz 50dB@10MHz 35dB@20MHz	Not quoted
S640	Pentode (EF39)	ECH35/6K8	<2uV	Not quoted	90dB@2.5MHz 60dB@10MHz 45dB@30MHz	Not quoted
S659	Pentode (EF39)	6K8	<10uV@6Mhz <60uV@28MHz	Not quoted	Not quoted	Not quoted
S680X	Pentode 1 st and 2 nd RF (both 6BA6)	6BE6	3uV	15dB	>90dB@2.5MHz 65dB@10MHz 30dB@30MHz	Not quoted
S730/4	Pentode 1 st and 2 nd RF (both 6BA6)	6BE6	<5uV	15dB	Not quoted	150ppm in 1hr after 2 hours warm-up
S740	Pentode (EAF42)	ECH42	<10uV	15dB	Not quoted	Not quoted
S750	Pentode (6BA6)	ECH42	<5uV	20dB	>40dB@30MHz	<300Hz ⁶
S830/7	Cascode triodes (6ES8/ECC189)	6AK5	3uV	15dB	50dB to 1.5MHz 70dB 1.5 – 10MHz >50dB@30MHz	<4MHz 4 in 10 ⁴ >4MHz 10 in 10 ⁴
S840	Pentode (UAF42)	UCH42	<10uV	15dB	Not quoted	Not quoted
850/4	Pentode (6BA6)	6AJ8	<5uV (above 100kHz)	15dB	>75dB@600kHz	Not quoted
S880/2	Cascode triodes 1 st RF (6ES8/ECC189), Pentode 2 nd RF (6BA6)	6AK5	<3uV (<5uV below 1.5MHz) ⁷	15dB	>90dB 1.5-15MHz 60dB >15MHz and <1.5MHz	<100Hz in 1 hour after 2 hours warm-up
S888	Pentode (6BA6)	ECH42	Not quoted	Not quoted	Not quoted	Not quoted
S940	Cascode triodes 1 st RF (6ES8/ ECC189), Pentode 2 nd RF (6BA6)	6AJ8/ECH81	3uV	15dB	90dB @1MHz 75dB@8MHz 40dB@20MHz	Not quoted
EA12	Cascode triodes RF (6ES8/ ECC189)	6AJ8/ECH81	2uV ⁸	10dB	>50dB all ranges	<100Hz/hour

Table 1: Selection of Eddystone HF/LF Valve Receiver Front-end Specifications⁵ After 1 hour warm-up unless otherwise stated⁶ For +/-5% change in mains voltage⁷ 'Absolute sensitivity' quoted as <1uV⁸ 0.5uV for 20dB signal to noise on CW