‘TECHNICAL SHORTS’

by Gerry O’Hara, G8GUH

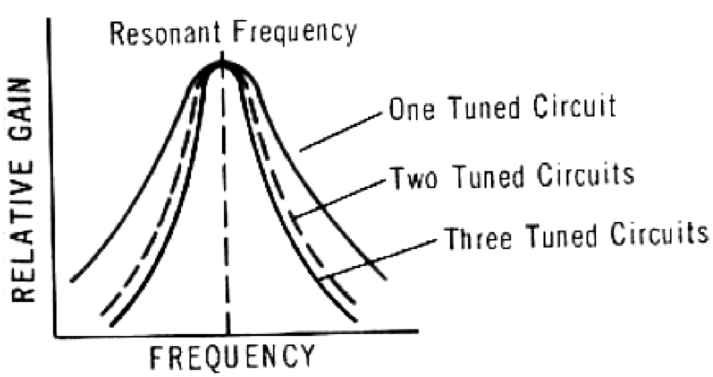
‘TECHNICAL SHORTS’ is a series of (fairly) short articles prepared for the Eddystone User Group (EUG) website, each focussing on a technical issue of relevance in repairing, restoring or using Eddystone valve radios. However, much of the content is also applicable to non-Eddystone valve receivers. The 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 Selectivity and Crystal Filters in Valved Eddystones

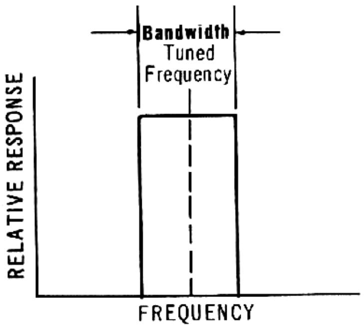
Introduction

It’s great having a nice sensitive receiver, but high sensitivity is of little use if the set cannot separate the signal you want from those you don’t want: attaining the correct degree of selectivity appropriate to the type of signal being received and the prevailing band conditions is critical. The earliest valve radios (the tuned radio frequency or ‘TRF’ sets) achieved selectivity by separately tuning several RF amplifier stages – not an easy task for the non-technical listener. In those days of course, the number of stations and man-made interference was much lower and so selectivity was a secondary consideration to sensitivity for most listeners. Later TRF sets ‘ganged’ the RF tuned circuits and provided a high level of screening between the stages to improve both stability and selectivity, as well as to make tuning easier. Other techniques at that time, especially in the ‘homebrew’ radio enthusiast scene, were regenerative and super-regenerative designs using an adjustable level of positive feedback at the desired signal frequency to increase both sensitivity and selectivity. However, the widespread use of the superheterodyne (superhet) circuit by the early-1930’s represented the largest leap forward in providing the level of selectivity we now take for granted (and is needed!) for today’s conditions.

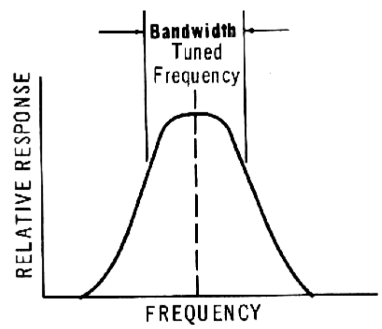
The superhet receiver derives its selectivity from both its RF and the IF tuned circuits, however, the greatest degree is from the IF circuits, as these are designed to operate at a fixed, relatively low frequency, whereby high gain and stability are easily achieved. Increasing the number of tuned circuits does not greatly affect the peak (level) of the IF response curve but steepens the sides of the curve (figure, right) – this results in a



sharper response with the output signal decreasing rapidly for small changes in frequency of the input signal above and below the resonance frequency of the tuned circuits (assuming that they are all tuned to the same frequency). The range of frequencies allowed to pass through the IF amplifier is termed the 'bandwidth' and the optimum width of this 'passband' depends on the type of signal and degree of interference from stations close in frequency to the one desired. The selectivity and the passband requirments are somewhat contradictory: whereas good selectivity is required to avoid adjacent-channel interference, the passband must be sufficiently wide to allow all the desired sideband frequencies of the signal to be amplified to provide appropriate fidelity. For example, an AM broadcast signal will require a nominal 10kHz bandwidth to allow the upper and lower sidebands of the signal to pass in order to maintain good-quality audio, whereas for AM speech of communications quality, 5kHz would be sufficient, with 2.5kHz or even less being adequate for an SSB signal, and CW may be read with a passband of less than 100Hz.

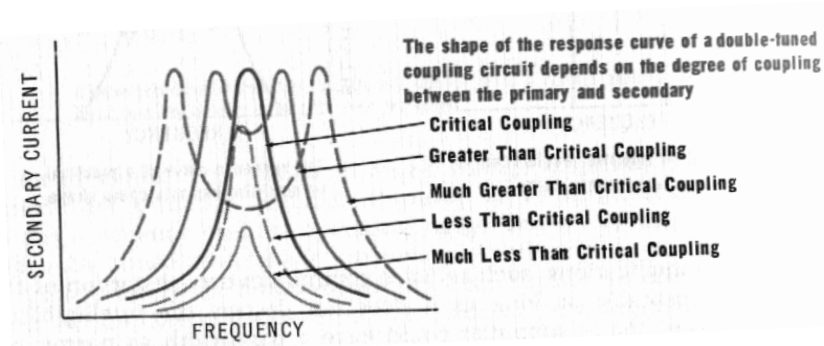


An ideal i-f amplifier would have a rectangular response curve



The response curve of a practical i-f amplifier has this basic shape

Specially-designed inter-stage coupling circuitry can be incorporated into the IF stages that allow the passband to be adjusted to suit the listening requirments as noted above. Double-tuned coupling is normally used and the shape of the resulting IF response curve depends on two main factors: the 'Q' of the tuned circuit, a measure of efficiency, determined by the ratio of the tuned circuit's reactance to resistance, this being dependant on the materials used, physical design and layout of the circuit, and the degree of coupling between the two tuned circuits, the latter being termed the 'mutual inductance', and is determined by the proximity of the two transformer coils. 'Critical' coupling is reached when the resonant current induced in the secondary coil is at its maximum: less than this value is termed 'undercoupling' and when above the critical value the condition is termed 'overcoupling'. Undercoupling results in narrower bandwidth whereas overcoupling results in a twin-peak response curve, giving distortion of the audio output due to non-linear amplification across the bandwidth, together with very steep sides or 'skirt' to the response curve (see diagram above). The desired response curve(s) in a receiver can be provided by careful design, alignment and operator adjustment of the IF circuits.



The shape of the response curve of a double-tuned coupling circuit depends on the degree of coupling between the primary and secondary

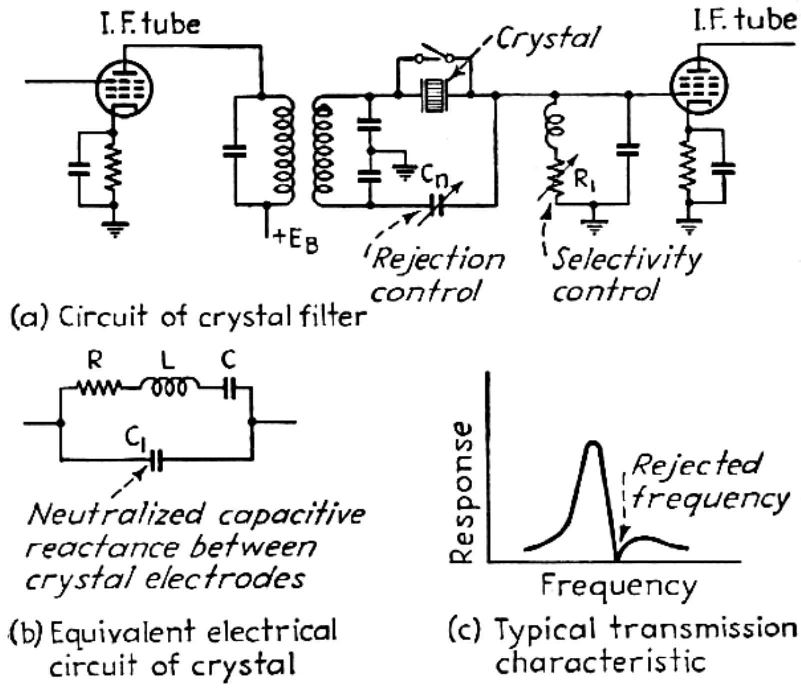
Many broadcast superhet radios of 'conventional' design incorprate only a single RF tuned circuit coupled directly to the frequency converter (first detector) stage, and a single IF amplifier between two double-tuned IF transformers operating at an IF of around 465kHz for HF bands and 10.7MHz for VHF bands. This arrangement provides adequate selectivity for the job in hand and good audio fidelity for speech and music. Where more selectivity is required, one or maybe even two, tuned RF amplifier stages are normally added, together with an extra stage or two of IF amplification, each coupled with double-tuned transformers. A number of techniques may be used to provide variable selectivity where desired, ranging from varying the level of coupling (eg. physically moving the transformer coils) or the circuit's Q (eg. by placing 'shunt' resistors across the tuned circuits). Another, more elaborate technique, which became popular in the 1950's, was the use of 'Q-multipliers': an amplifier stage with tunable positive feedback, which allowed a variable depth and frequency peak, and/or an amplifier stage with tunable negative feedback, allowing a variable depth and frequency notch to be added to the IF response curve, thereby allowing an interfering signal to be suppressed and/or the desired signal to be enhanced. Another twist on this theme for control of selectivity was the 'Q-Fiver' – spurred on by the availability at that time of low cost WWII-surplus receivers covering low frequencies, where a separate receiver able to tune across the IF of the first (primary) receiver was used to increase selectivity – cumbersome but reportedly very effective if done right…

Many communication receivers also include a single or double (bandpass) crystal filter arrangement for CW and/or SSB reception. First introduced into radio circuits in 1929 by Dr. J Robinson, a British scientist, a crystal represents a series inductance/capacitance/ resistance circuit with its thickness, angle of cut, shape and material (eg, quartz or ceramic) determining its resonant frequency. A typical quartz crystal can have a Q between 10,000 and 100,000, compared with 300 for a high-quality conventional coil/capacitor tuned circuit. A crystal used as a filter in a receiver is usually connected between two conventional tuned circuits in the input to the first IF stage. To frequencies within its resonant bandwidth (usually in the order of 50 to 200 Hz), the crystal offers a very low impedence, and to those outside its resonant bandwidth, a very high impedence. In a single crystal filter circuit (see diagram on the next page), a variable capacitor is used to neutralize the capacitance of the crystal holder and in use, this 'phasing' can be used to enhance a wanted or reject an unwanted signal close in frequency to the desired signal (up to 45db of

rejection is typical). When a wider passband is required than a single crystal can provide, two crystals differing in frequency by the desired bandwidth (say 2 kHz), may be employed to provide a steep-sided 'bandpass' response curve having the required bandwidth. This can be extended into a 'lattice' arrangement using multiple-cascaded crystal pairs to further define the passband and steepness of the skirt. A disadvantage of the single crystal filter when peaked at maximum selectivity is that it may tend to 'ring' or 'echo', making it difficult to copy weak CW signals – effects caused by the crystal oscillating for a short period after being excited by the signal. The degree of selectivity of a crystal filter is also affected by the impedence of the input and output circuits: raising these impedences will make the Q of the filter appear less, thus broadening the filter response curve. This effect may be obtained in practice by detuning the secondary of the filter input or output transformer/coupling circuits.

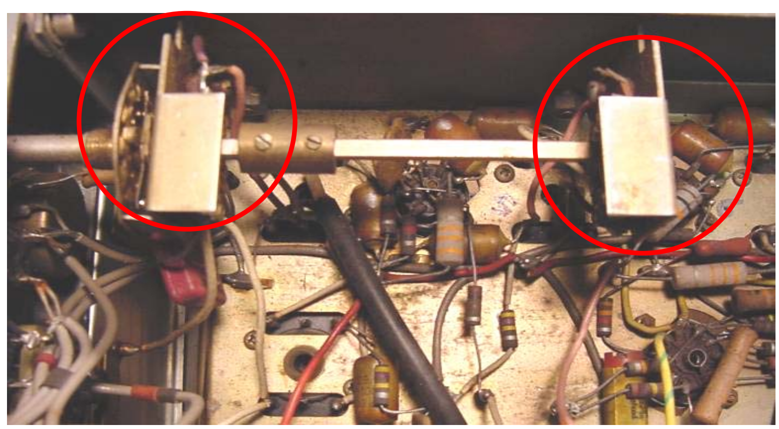
Selectivity Provisions in Eddystone Valve Receivers

Post-WWII Eddystone valve receivers followed the conventional routes as described above for superhet receivers to provide optimum performance and operational flexibility. Some of the circuits and mechanical arrangements used are described below.



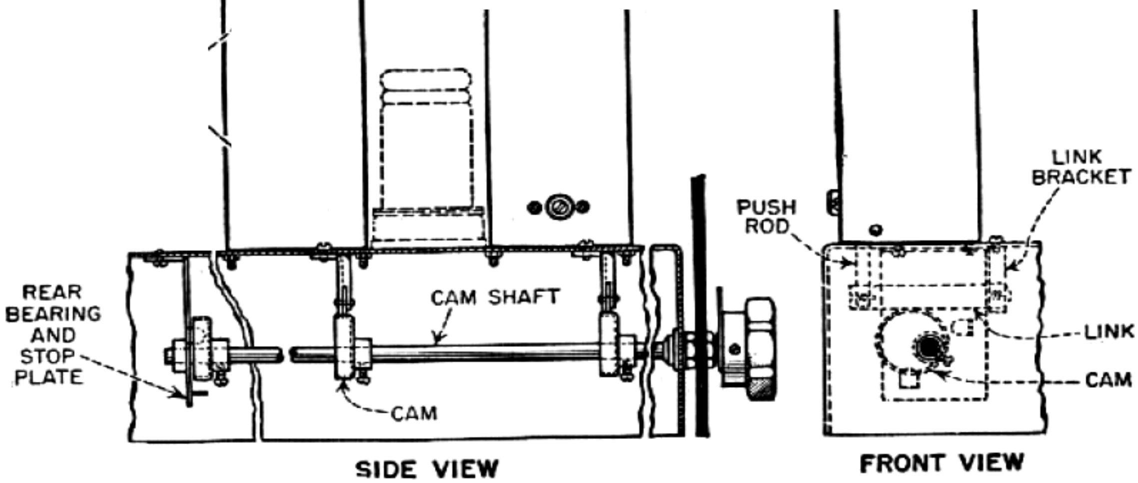
Variable Selectivity

This was provided in many Eddystone receivers either by switching in/out tertiary windings in the IF transformers (eg. as in the S.940) or by physically changing the degree of coupling between the primary and secondary windings by mechanical means in the IF transformers (eg. as in the S.750 and S.830 series).



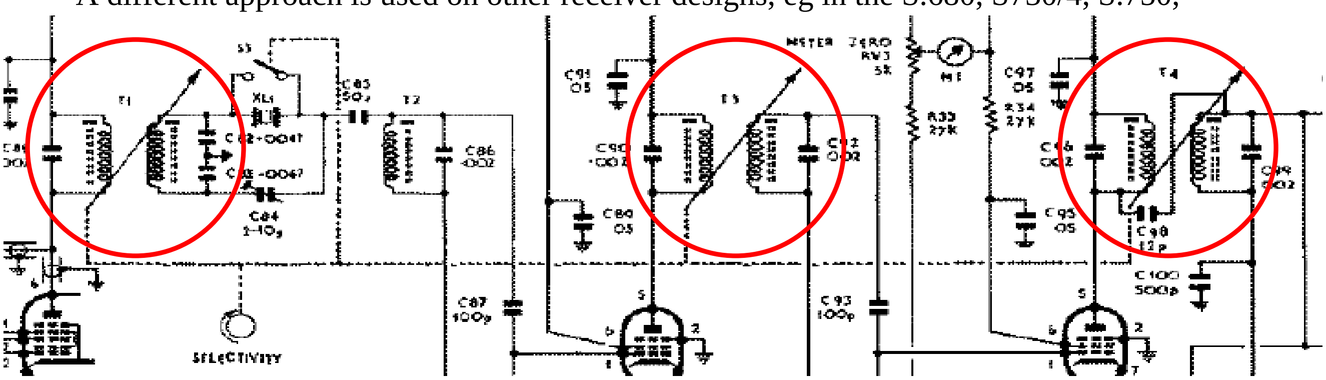
S.940 IF strip showing switches controlling selectivity

Mechanical system for varying selectivity (here as deployed in a Hammarlund Super-Pro receiver)



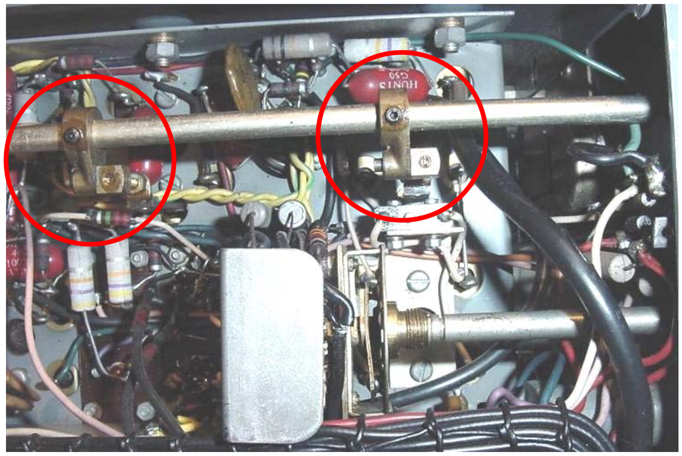
The S.940 uses tertiary windings on the first and third IF transformers that are connected into the secondary of the double-tuned IF transformers by the use of the ‘selectivity’ switch on the front panel (circuit on Page 7). In the ‘min’ position, both tertiary winding are connected, providing a degree of over-coupling and hence wider bandwidth. In the ‘max’ position, the tertiary winding in the third IF transformer is disconnected, providing an overall narrower IF passband. A third position of the selectivity control then disconnects both tertiary windings and allows a crystal to be introduced between the first and second IF transformers for CW operation (see below). This is a very effective and simple to use system.

A different approach is used on other receiver designs, eg in the S.680, S730/4, S.750,



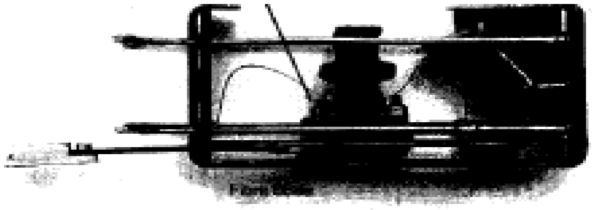
S.830/4 IF strip showing crystal filter and three-section mechanically variable selectivity arrangement (circled)

‘No-frills’ front panel control of selectivity on an S.750 – simple but very effective in use…



and S.830 series. In these sets, the front panel selectivity control operates cranks/eccentrics that move rods into/out of two or more IF transformer cans underneath the chassis (diagram and circuit above and photo, right). These rods move one of the IF transformer coils relative to the other in the same IF transformer, thus physically altering the degree of coupling between the transformer primary and secondary circuits. In the S.750, this is claimed to be 'variable from 30 to 60db down for 5kHz off resonance'[of the IF tranformers], and in the S.830, bandwidths of 12 kHz, 8kHz and 5kHz at 50db down from resonance are claimed for pre-set positions of 'AM', 'SSB' and 'CW' on the continuously variable scale, and 2kHz when the crystal filter is switched in (50Hz at 6db down).

Above: Part of the S.830/4 variable selectivity 'mechanicals' (eccentrics and actuating rods circled). Below: Inside the variable-coupled IF transformers.



Eddystone 680/2 Variable Selectivity I.F. Transformer

Crystal Filter Arrangements

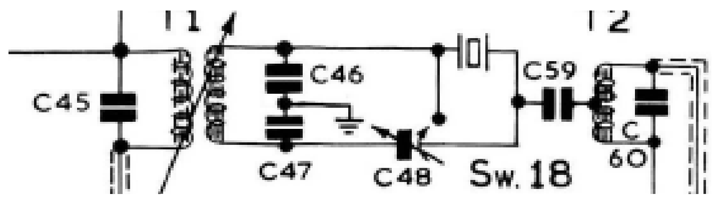
Many Eddystone sets intended for the non-commercial market (ie, that were intended for the 'professional' or 'amateur' market) have a single crystal filter installed, primarily for the reception of CW signals, eg. as in the S.640 (1.6MHz), S.730/4 (450kHz), S.830 (100kHz), S.940 (450kHz, except my set which is tuned to 455kHz) and EA12 (100kHz). The circuit used is fairly standard across all these recievers (similar to the design shown on Page 4), although in the EA12 the crystal filter is supplemented by a 'slot' filter – a separate parallel-tuned ('bridged-T') rejection filter with variable notch depth, inserted between the crystal filter and the first IF stage.

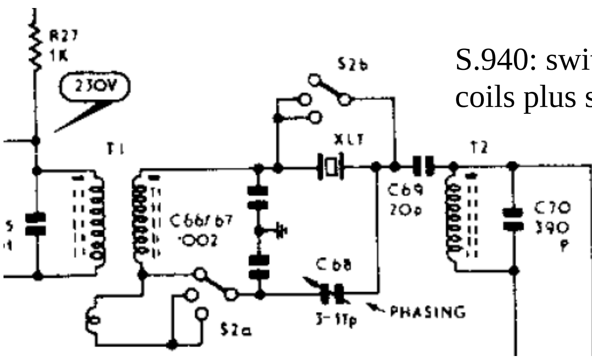
Several Eddystone single crystal filter arrangements are shown in the figures below: in all cases, the crystal is installed in the secondary tuned circuit of the first IF transformer (or first stage of the second IF in double-conversion sets such as the S.750 and S.830 series). The arrangement is such that the phasing capacitor can be used to neutralize the capacitance of the crystal holder and so the crystal can be switched in/out of circuit by shorting out when not in use. Also shown is the more unusual (for Eddystone) dual crystal bandpass filter arrangement as found in some variants of the S.830 model.

A set of actual IF bandpass curves, as published for the S730/4, illustrating the effect of introducing the crystal filter and adjusting the phasing control, is included after the References.

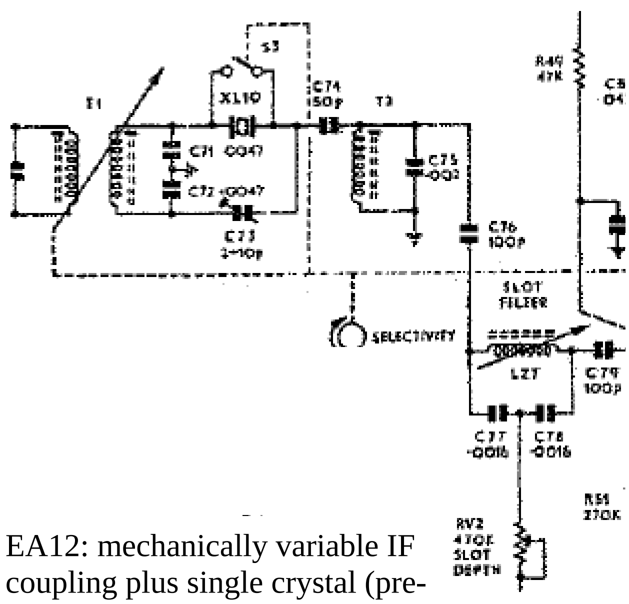
S.640: single crystal with phasing

S.730/4: mechanically variable IF coupling plus single crystal with phasing

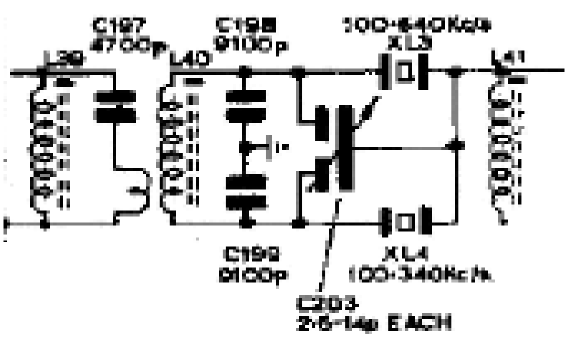




S.940: switchable IF coupling by tertiary coils plus single crystal with phasing



S.830/9: mechanically variable IF coupling plus bandpass ('Piccolo') crystal filter



EA12: mechanically variable IF coupling plus single crystal (pre-set phasing) and slot filter

A selection of crystal filter circuits from late 1940's (S.640) through early-1970's (EA12 and S.830). Note: the S.830/9 circuit is a bandpass dual-crystal arrangement (330Hz bandpass designed for the tonal frequencies used in the UK 'Piccolo' diplomatic service encoding system in the 1960's). The more usual single crystal circuit is represented by the 830/4 as shown on Page 5.

Some Useful References

- Radio Communications Handbook, RSGB (eg. 4th Ed, Chapter 4)
- Radio Amateurs Handbook, ARRL (eg. 31st Ed. Chapter 5)
- Electronics One-Seven, H. Mileaf, 1967, (diagrams from Chapter 5 included herein)
- Radio Engineering, F. Terman, 1947, (3rd Ed. Diagram from Chapter 15 included herein)
- Radio Servicing: Theory and Practice, A. Markus, 1948 (Chapter 10, pp410-412)
- Radio and Television Receiver Troubleshooting and Repair, Ghirardi & Johnson, 1952, (sketch from Chapter 9 included herein)
- Radio and Television Receiver Circuitry and Operation, Ghirardi & Johnson, 1951 (Chapter 4)
- Various sections of Eddystone manuals downloaded from the EUG web site, including:

Subject	***Issue***	***Page***
variable bandwidth system	34	14
variable bandwidth system fault (in a 680)	83	7
Crystal filters		
phasing, reversed to eliminate QRM	31	2
filter switch	62	9
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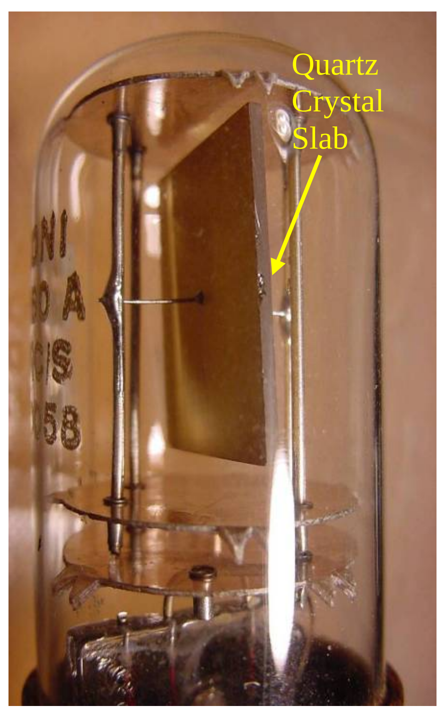
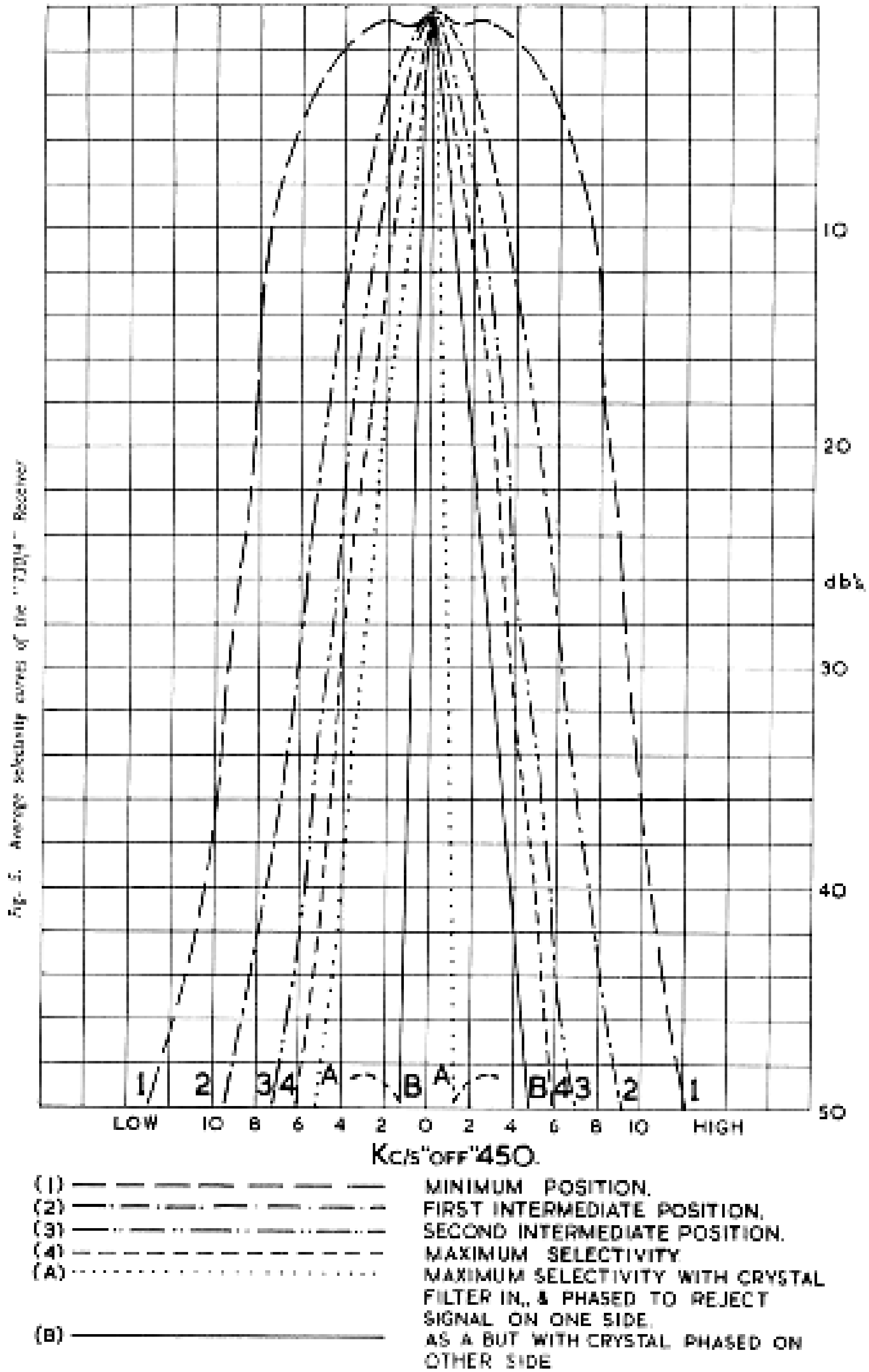
Piccolo		
filter removed	9	24
	37	2
microswitches	57	11
reception of	23	15
selectivity switch not connected	6	5

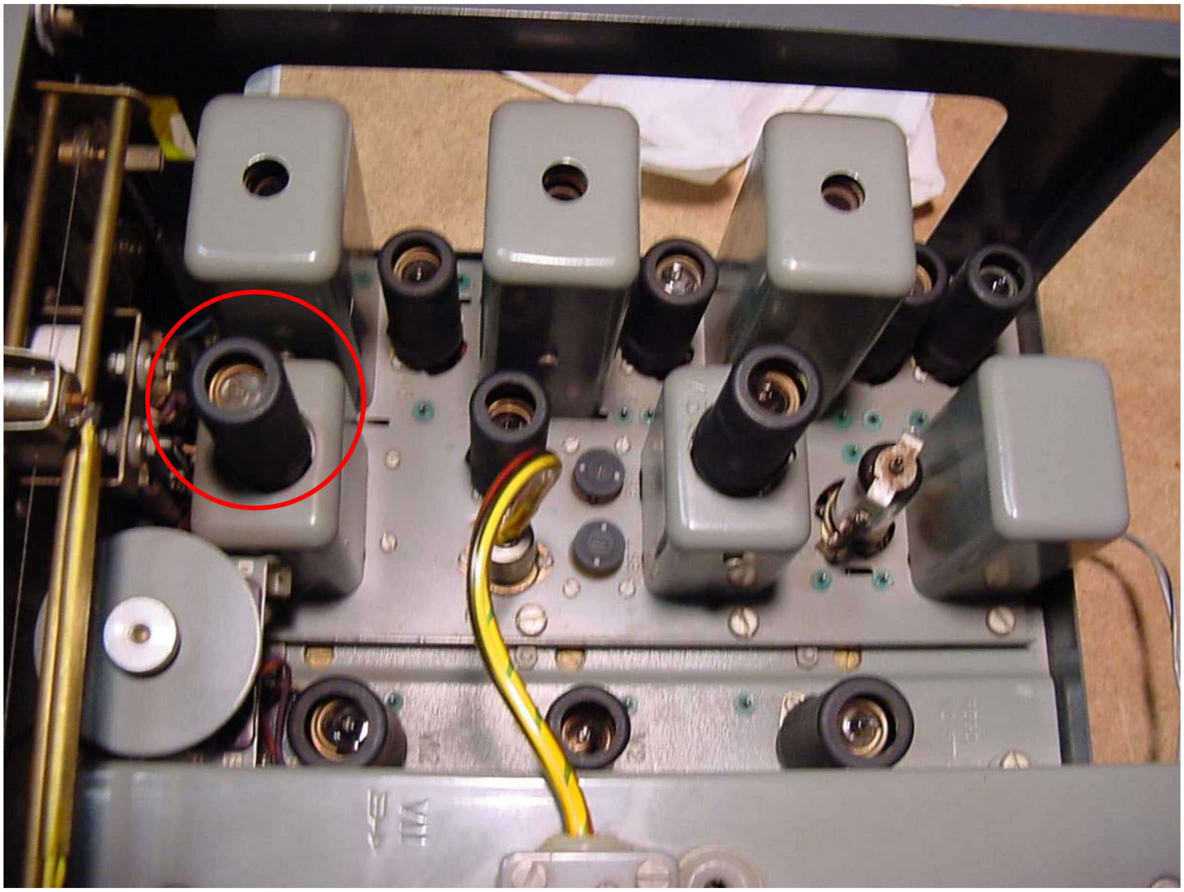
- Some web-based articles/resources on subjects covered in this article include:
  - http://www.monitoringtimes.com/html/selectivity.html
  -
  - http://www.networksciences.com/A%20Crystal%20Filter%20Tutorial%20for%20the%20Customer%20.htm
  - http://www.ieee-uffc.org/freqcontrol/crystal.html
  - http://www.radio-electronics.com/info/data/crystals/monolithic_crystal_filter.php



A 100kHz quartz crystal showing mount



S.730/4 IF response curves



Above: S.830/4 with B7G-cased 100kHz second IF crystal filter circled.
Below: Selection of crystal package styles from my junk box