'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.

Inductor Lore

Introduction

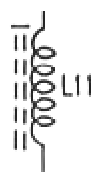
The purpose of this 'Short' is to identify what coils, chokes and transformers, collectively termed 'inductors' are, why and where they are used in Eddystone receivers, some considerations in their design for particular purposes, and to identify problems that may develop and how to identify them. The article assumes the reader has a basic understanding of AC theory, the principle of inductance and terms such as 'reactance' and 'resonance'. For information on such fundamentals, the reader should refer to standard texts on radio and electronics theory , eg. Terman, and manuals such as those published by RSGB and ARRL (see reference section at the end of the article).

Sid couldn't give a cat's whisker about inductors - dozing in the winter sun is much more fun – oh come on, they aren't that boring…

Inductors in radios fall into three broad types: coils, chokes and transformers. Coils and chokes are used where a circuit is required to have frequency dependant characteristics, sometimes with a capacitor in series or parallel, sometimes without. Transformers, however, whilst also being able to have frequency-related performance, exhibit other properties that are exploited in circuits where frequency-dependence is not necessarily required or even desired. That said, it must always be remembered that the value of the reactance in either a coil, choke or transformer depends not only upon its value of inductance, but also on the frequency at which the circuit that contains it is operating. It should also be noted that the inherent distributed capacitance of a coils windings, ie, capacitances between adjacent windings and surrounding components, can form a resonant circuit with its inductance value. For RF applications, this effect limits the highest frequency to which the coil can be tuned.

Coils and Chokes

A coil is what it suggests: a coil of wire, usually copper wire wound around a former, though at HF and higher frequencies coils may be self-supporting. Coils and chokes are really the same thing, though the term 'choke' is used to indicate that the coil exhibits a significant amount of reactance at the frequency (or range of frequencies) the circuit within which it is deployed is operating at: the coil will thus have a large effective resistance to those frequencies, ie. it will *choke* them. Also, chokes are normally fixed in inductance value, whereas a coil may have its value of inductance varied.



Coils and chokes can be broadly divided into high frequency (RF/IF) and low frequency (AF and power-supply) types. RF/IF coils or chokes may range in inductance from a fraction of a uH to a few tens of mH, whereas AF and power supply chokes (the term 'coil' not normally being used for these lower frequency inductors) may range from 0.1 to 500H. The former are usually wound on hollow formers, ferrite or iron dust cores, whereas the latter are generally wound on laminated iron, ferrite or special alloy formers.

RF Coils and Chokes

For greatest efficiency, an RF coil should have a length not less than half and not greater than twice its diameter. In a perfect

'Q' – the Magic Quality of Coils

In a tuned circuit comprising a coil, a capacitor and a resistor, the voltage across the coil, or the capacitor, can be much greater at its resonant frequency than the applied AC signal. The current at resonance is determined by the resistor, whereas the voltage across either the coil or the capacitor is determined by the product of the current and the appropriate reactance of the component, which may be many times the value of the resistor. The ratio of the voltage across the coil or capacitor to that across the resistor is termed the 'magnification factor', 'quality factor' or 'Q'.

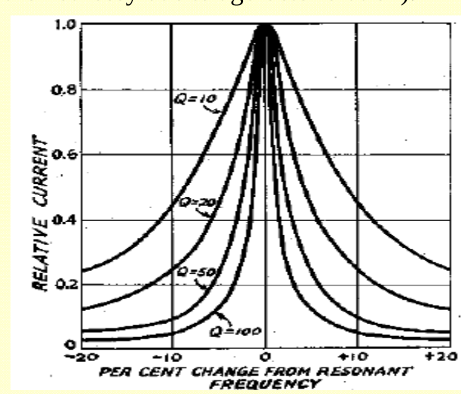
$$Q = \frac{X}{R}$$

where Q = Quality factor
X = Reactance of either coil or condenser, in ohms
R = Resistance in ohms

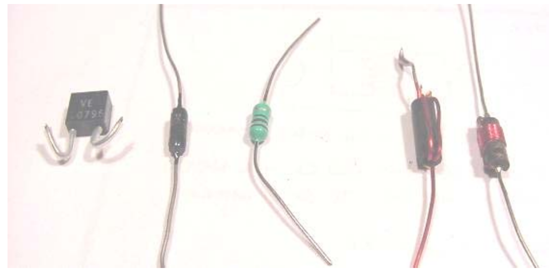
Example: The coil and condenser in a series circuit each have a reactance of 350 ohms at the resonant frequency. The resistance is 5 ohms. Then the Q is

$$Q = \frac{X}{R} = \frac{350}{5} = 70$$

In practice, a high Q tuned circuit will be more selective than one of a lower Q (diagram below) – this quality is thus very important in receiver circuitry – and one that Eddystone paid due attention to in their receiver designs. The Q of a tuned circuit is determined mainly by the coil, since the capacitors used for these circuits have negligible losses (providing they are functioning to their specification and are not lossy due to age-deterioration).



Eddystone even took out a patent on RF chokes in their early days: the novel idea was in the way the wires connected to the windings of the choke coil. Normal practice of the period was to solder the connection wires to solid metal (lead alloy) ends on the coil former. The folks at Eddystone realized that this could act like a shorted turn on either end of the choke, thus lowering its Q. By simply passing the connection wires through the former and eliminating the solid metal rings, the chokes had a higher Q – and the start of a long lasting reputation...



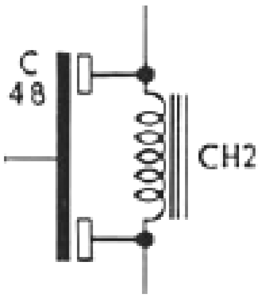
world, an RF inductor would have negligible DC resistance, exhibit only inductance, the current through it and the voltage across it would be 90 degrees out of phase (referred to as *quadrature*) and no power would be lost in the inductor. Of course we don't live in a perfect world, and neither do inductors: they may have a significant effective series resistance and power is dissipated in the coil. The efficiency of a coil at RF is indicated by its 'Q' (sidebar on previous page) – a high Q coil would have relatively low loss. The losses in an RF coil are due to eddy currents in surrounding metal, including the core of the coil (if present), the 'skin effect', whereby RF currents tend to travel only in the outer surface of a wire, thus increasing its effective resistance at RF frequencies compared to low frequencies or DC, and dielectric losses in the (insulating) coil former. Low inductance RF coils are usually wound on low-loss hollow formers, eg. Paxolin (phenolic), ceramic, glass/glass fibre, certain plastics, or are even self-supporting (ie. in air).

Above: selection of iron dust cores and a silver-plated brass core
Below and top of page: selection of RF chokes
Bottom of previous page: selection of RF coils

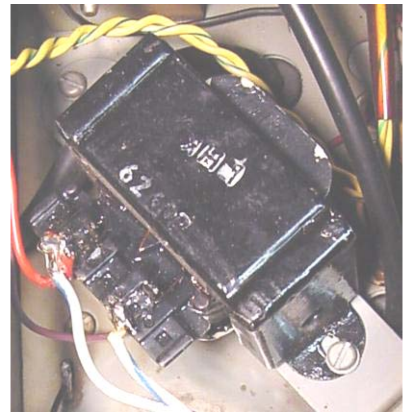
Larger inductance RF coils, eg. those used at broadcast frequencies and IF circuits, are usually fitted with a 'dust' core, the permeability of which allows fewer turns of wire to be used for a given value of inductance – this reduces the resistance of the wire and hence increases the Q. Such cores are formed of an iron alloy dust moulded in an insulating medium so that eddy currents do not form and thereby reduce the Q. Ferrites, which are non-metallic magnetic materials of high resistivity (and hence low in eddy currents) can be used for even higher Q in many applications.

Varying the position of the core in the coil varies the inductance, increasing it as it is placed further into the coil in the case of iron dust or ferrite, but reducing it in the case of brass, this acting as a short-circuiting turn on the coil. This effect can be very useful as the tuned frequency of the coil can be varied – a process called *slug tuning*.

The type of wire used also has an effect on the performance of RF coils. For higher values of inductance, where more turns are required, 'Litz' wire - derived from the German word "litzendraht" meaning woven wire - is often used. This is formed of many fine strands of wire that maximizes the surface area available for the RF currents to travel within, which reduces the effective resistance of the coil and thus increases the Q. For smaller values of inductance, single copper wire, often enamel coated, is used as the effective resistance of a few turns is comparatively small.



AF and Power Supply Chokes



Power supply choke in an S.830/4

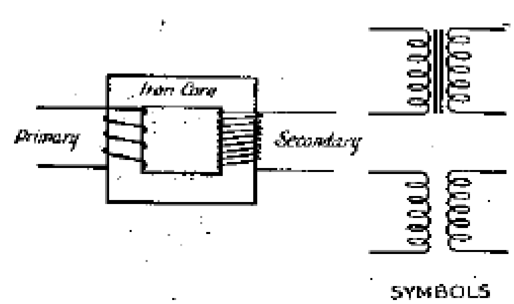
Low frequency chokes designed for audio frequencies and power supply applications are significantly different from the RF types described above. At these lower frequencies, the inductance values needed to have significant reactance are much larger. Also, the power levels used are significantly higher than used in RF receiver circuits. These requirements result in the use of more turns, heavier gauge wire and better insulation, together with different core materials and construction techniques. Chokes for these applications are usually wound on laminated iron alloy formers or steel pressings. They therefore tend to be much bulkier and heavier than their RF counterparts. Permalloy powdered cores or ferrite cores may also be used in certain applications, particularly in audio filters, where an accurate value of inductance is required.

The inductance of a choke is determined by the flux density in the core – a function of the AC current and limited by allowable temperature and core material saturation. Q is determined by the inter-winding capacitance and the effective resistance of the inductor, a function of the winding resistance, hysteresis and core losses due to eddy currents.

Transformers

Two coils having mutual inductance form a *transformer*: the coil connected to the source of energy is normally termed the *primary* coil (or *winding*) and the other coil is the *secondary*. Transformers exhibit several uses in ac circuits from low frequency, eg, in power supply circuits, to microwave frequencies, these being:

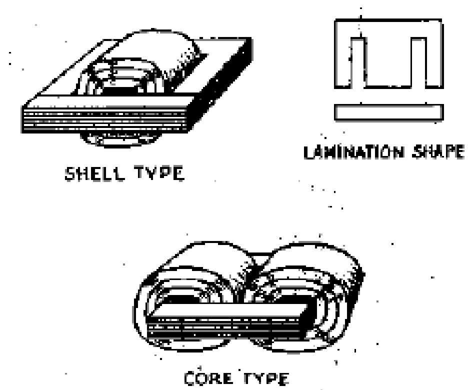
- Electrical energy can be transferred from one circuit to another without a direct connection;
- They can change one voltage level to another by varying the ratio of the number of turns on the primary and secondary coils;
- They can change the relative impedances of the primary and secondary circuits;
- When capacitors are added to form tuned circuits of the primary and/or secondary windings, the resultant tuned transformer exhibits resonance and therefore may be used to provide selectivity in receivers at RF, IF and AF frequencies; and



- The degree of mutual inductance can be varied in some transformer designs and this can provide variable selectivity in RF and IF circuits.

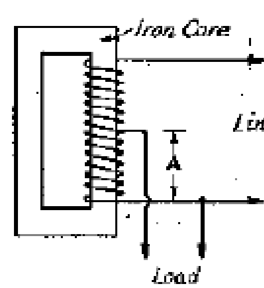
Transformer Construction

Transformer coils may be wound on different types of former (or 'core'), depending on their application (see below). These may range from hollow plastic, fibre glass, Paxolin, or solid powdered iron or ferrite for RF/IF applications, and laminated iron alloy - normally a silicon-steel - or ferrite for low frequency applications (note: there are many grades of ferrite available and the appropriate one must be selected for the frequency range being used for efficient operation and high Q).



Transformers are normally designed so that the magnetic path around the core is as short as possible for maximum efficiency – this maximizes coupling, reduces the number of turns and reduces flux leakage. In solid core transformers, such as used for audio and power supply applications (see below), the number of turns required is inversely proportional to the cross-sectional area of the core. Core shapes used for solid-core transformers are usually either 'shell' type, where both primary and secondary windings are placed on the inner leg of an 'E-shaped' core, or 'core' type, where the windings are placed on either end of a 'U-shaped' core. In both cases the open end of the core is closed with a bar of laminated core material. This type of transformer is usually wound in layers with a thin layer of insulating material between each, the wire normally being enamel-coated copper.

Toroidal transformers have a doughnut-shaped core, usually made from ferrite or compressed parmalloy powder. Higher values of Q and smaller size can usually be obtained than conventional 'bobbin' transformer construction for the same application. An added advantage of this form of construction is that pickup of extraneous magnetic fields (eg. RF interference or hum) is very low because of the symmetry of the windings and closed pattern of the electromagnetic field. This effect also results in low mutual conductance between adjacent toroids used in close proximity. A typical RF application of a toroid is a balun (*bal*anced to *un*balanced) transformer and typical low frequency applications include power supply and AF output transformers (often used in audio amplifiers to minimize hum and stray signal pickup).



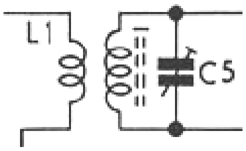
Autotransformers have only one winding that acts as both primary and secondary: the entire winding may be the primary, with a tapped part of the winding acting as the secondary for a

A 1kVA power autotransformer

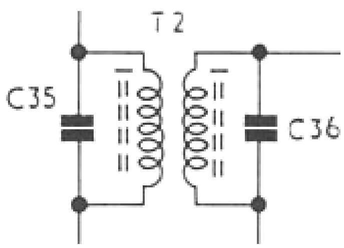
step-down voltage ratio, or vice-versa for a step-up. The advantage of an auto-transformer is that it is generally cheaper to manufacture than a conventional transformer. A disadvantage is that it provides no electrical isolation between the primary and secondary. They may be used at RF/IF, AF and power supply frequencies.

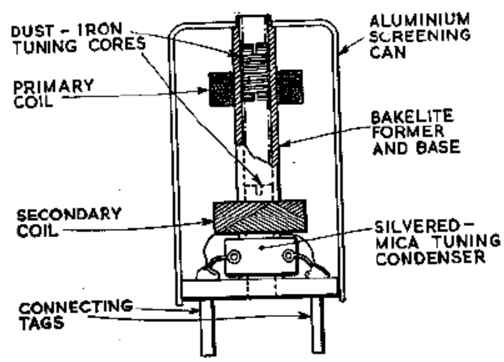
The number of turns required on the primary of a transformer for a given applied voltage is determined by the frequency, size, shape and type of core material used. For power transformers, this is typically 6 to 8 turns per volt on a core of 1 square inch cross section.

RF and IF Transformers



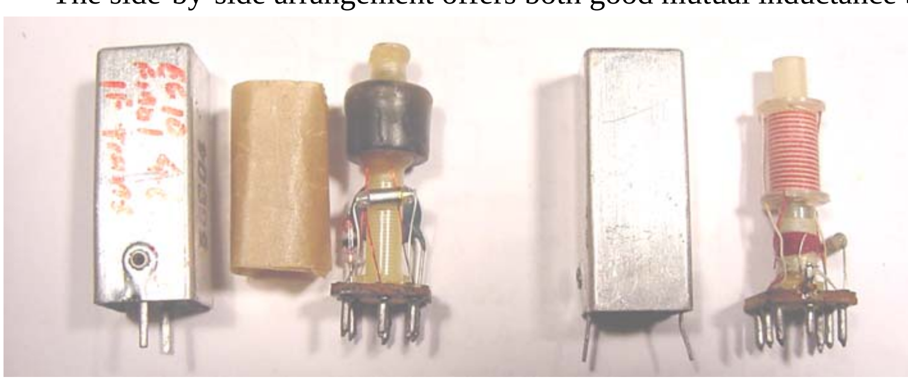
These are used to provide selectivity, electrical isolation, impedance and voltage transformation in RF and IF circuits in receivers. 'Conventional' RF transformers, as described in this article, can be made to operate efficiently at frequencies from tens of kHz through to UHF frequencies (several hundred MHz), though at the latter frequencies the transformer 'coils' may be one turn or less and the inductance of the connections becomes a very significant part of the total inductance.





Typical IF transformer construction

Important considerations for RF transformers are similar to those described for RF coils above: low loss/high-Q are normally paramount, with both coils usually being wound side-by-side on a single hollow former, using Litz wire for higher values of inductance and single-strand copper for lower values. The side-by-side arrangement offers both good mutual inductance between the coils and the opportunity to vary the coupling to the optimum value for the circuit in hand by separating or closing the gap between the primary and secondary coils. Eddystone exploit this effect in many of their sets to provide variable IF



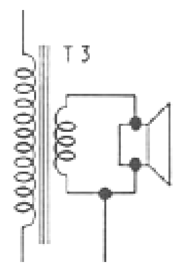
Typical RF/IF transformer construction: the one on the left is a 465kHz IF transformer from my EC10 (been in my junk box for over 30 years!)

selectivity, eg. in models S.750, S.680X and the S.830 series. Variations to this 'norm' do exist, with some arrangements – particularly in sets of the 1920's and early '30's, having the coils adjacent to each other, or even arranged such that a mechanism turns one relative to the plane of the other to allow variation of mutual inductance.

Again, as for individual RF coils, the inductance value of an RF transformer winding may be adjusted by inserting or withdrawing a core, usually made from iron dust or ferrite material – normally by virtue of the core being threaded – with a special insulated tool used to screw the cores in or out of the former to attain the desired resonance.

AF Transformers

These are designed to operate efficiently at audio frequencies (20Hz to 20kHz), but similar designs may be used at frequencies up to 100kHz or so. They are used to connect change voltage levels and match impedances (eg. the high impedance anode circuit of a valve audio stage to a low impedance loudspeaker or 600 ohm line output), invert signal polarities (eg. as a phase splitter in a push-pull audio amplifier), form part of an audio filter circuit and provide electrical isolation between AF stages.



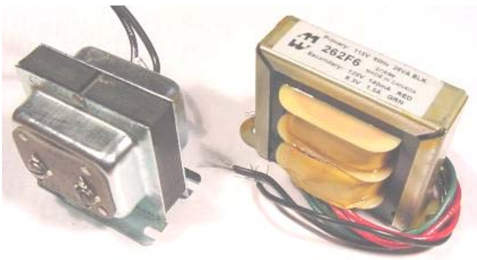
Important considerations for audio transformers are the frequency response characteristics and the power rating. Wide frequency response and low waveform distortion is desirable in high fidelity audio amplifiers, but in communications applications, as in Eddystone receivers, where intelligibility is paramount over fidelity, a narrower frequency range is desirable. In low signal-level transformers (<1mW) the primary design issue is to obtain good transmission at low frequencies: this requires high inductance as the gain reduces due to a decrease in primary reactance. At higher frequencies, leakage reactance, shunt capacitance and the winding resistance forms a low-Q resonant circuit, above the resonant frequency of which the response falls away rapidly. Higher power applications require higher inductance and heavier gauge windings to maintain efficient operation, particularly at lower frequencies, hence the much larges size and weight of these units.

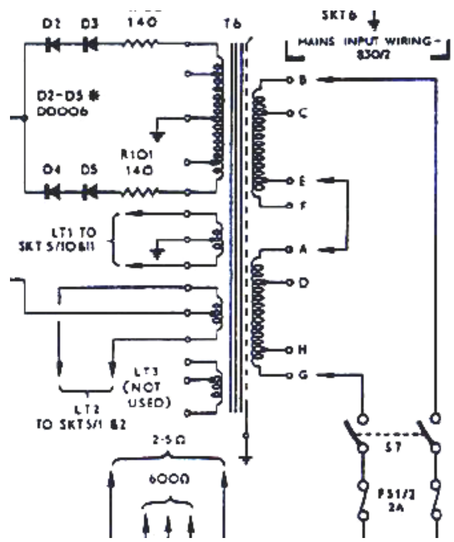
Push-pull audio output transformer from an S.940. Note the 600 ohm line output

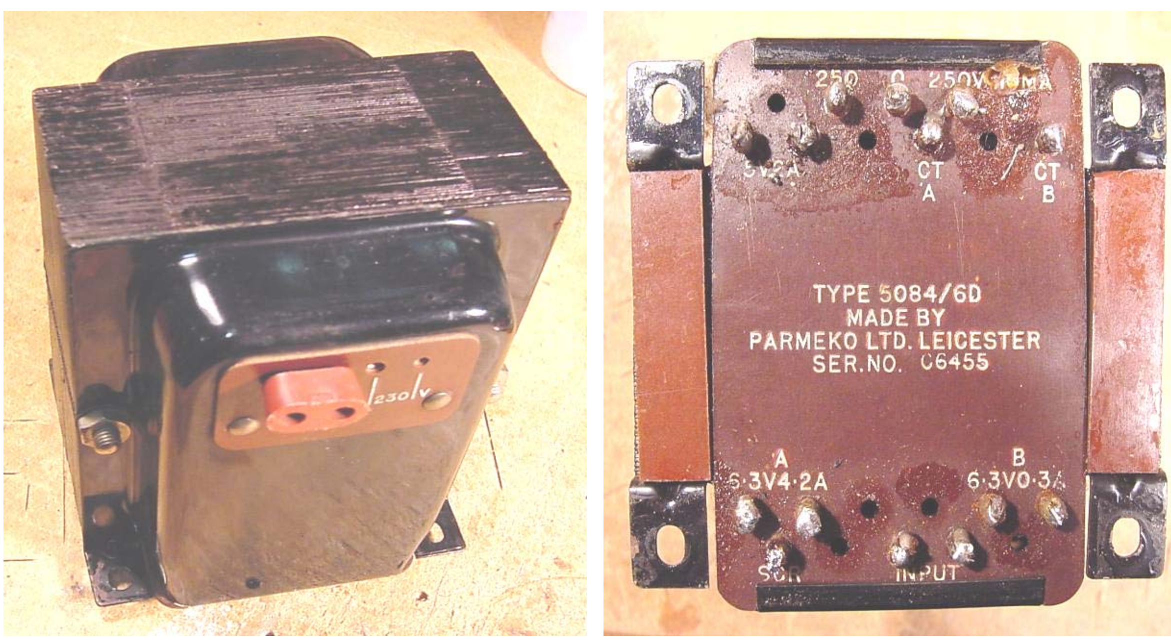
The operating level restricts the selection of core material and determines minimum physical size of the transformer. The cores of audio transformers are usually laminated iron alloy.

Power Supply Transformers

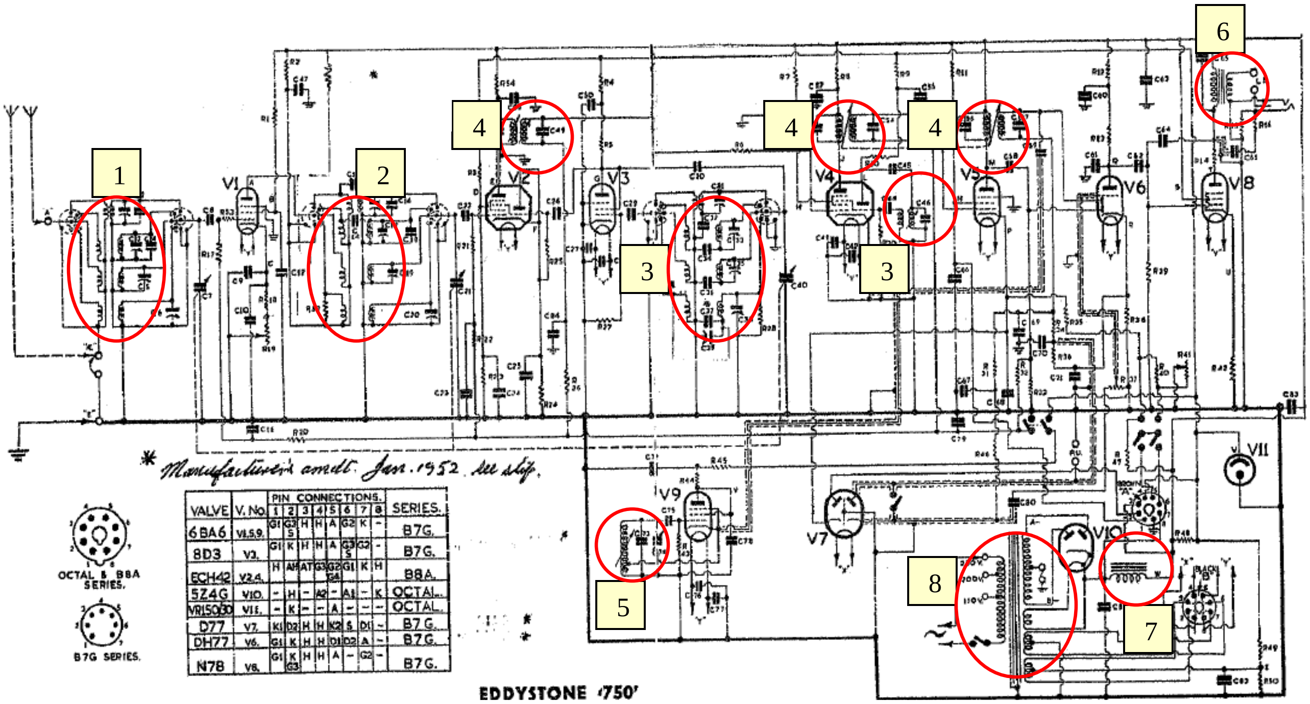
These are designed to operate most efficiently at a single frequency, usually 50 to 60Hz. Operation at these low frequencies necessitates a high inductance, usually requiring large laminated iron alloy cores. The power levels needed for this application, coupled with (often) multiple secondary windings, mean more coils and/or thicker wire used for the coils. Higher voltages also require thicker insulation - hence these transformers tend to be bulky and heavy. High efficiency, long life, good regulation and safety in power supply transformers therefore usually equate to large, heavy and expensive: skimping on wire thickness and core size usually means the transformer will run hotter and have a reduced life before a failure occurs. Most power transformers operate at temperatures up to 80C during normal operation, above which insulation starts to age prematurely and heat/cooling stresses can lead to open-circuit windings over time. Sealed, shrouded steel-cased transformers, such as those used in Eddystone sets are expensive to buy – but the quality is built in and hence they still work after decades of use.







Above: Parmeko Ltd. power transformer Type 5084/6D, alias Eddystone Part No. 3937P. This same transformer type was used in several Eddystone valve receiver models from the early 1950's (eg. S.750) through the early 1970's (eg. S.940)



Typical Applications of Coils, Chokes and Transformers in Eddystone Sets

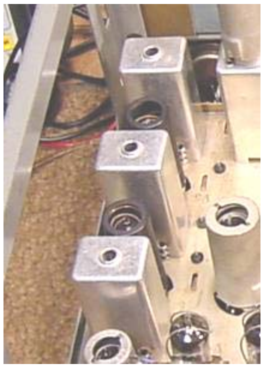
A selection of applications of a variety of inductor types in Eddystone valve receivers is given below, accompanied by photos to illustrate some types and locations in an indicative circuit (S.750, above – a double-conversion superhet design from 1950):

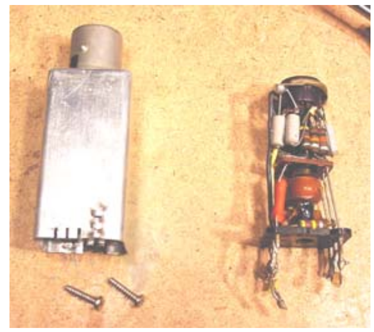
Aerial transformers (1): needed to match the low impedance aerial circuit (50 to 400 ohms) to the higher impedance grid circuit of the RF amplifier valve (or mixer valve) and to provide a degree of selectivity prior to the RF/mixer stages to help prevent amplification of unwanted signals and the development of cross-modulation. Examples from an S.940 are shown right.

Mixer transformers (2): provides electrical isolation and impedance matching between the anode circuit of the RF amplifier stage and the grid circuit of the mixer stage, plus an additional degree of selectivity.

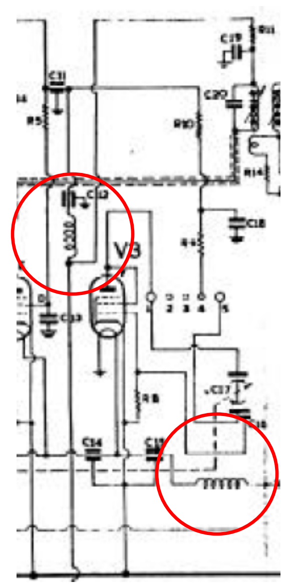
Local Oscillator coils (3): forms part of the local oscillator tuned circuit(s). In this application high stability is very important, particularly at the higher frequencies, to prevent oscillator drift.

IF transformers (4): provides electrical isolation and impedance matching between the anode circuit of the mixer stage and the grid circuit of the subsequent IF amplifier stage/between IF amplifier stages, plus a high degree of selectivity. Multiple IF stages can be tuned to provide the desired frequency response envelope shape, and, as noted above, many Eddystone sets included variable coupling between the transformer windings, this being done either by mechanical means, as in the S.830 series, or by electrical means, using a switchable tertiary winding on one or more IF transformers, or both, as employed in the S.940.





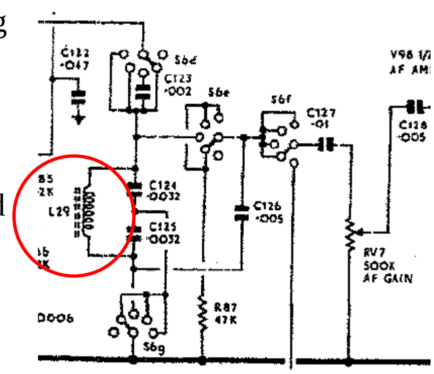
BFO coil (5): forms part of the BFO tuned circuit (photo, right). Centering of the BFO to the IF is normally undertaken using the slug in the coil, the front panel control being a variable capacitor (or a potentiometer varying the DC voltage applied to a varicap diode) in parallel with the coil.



RF choke: actually not used that frequently in Eddystone HF sets, though they may be found in many RF circuits to block the passage of RF currents where they are not desired. One example that comes to mind is in an S770R, where they are used to prevent stray RF coupling at VHF through the heater and HT supply circuitry to the RF stages (circuit extract, right).

AF choke: often used to form part of an AF filter circuit, as in the EA12 (circuit extract, below right) and the (solid state) EC10.

AF transformer (6): needed to match the high anode impedance of the AF power amplifier (several thousand ohms) to either the 600 ohm line or 2.5 ohm loudspeaker impedance.



Power supply choke (7): used to provide efficient filtering of the HT supply. Eddystone used some very neat choke designs – look at the photo from the S.680X at the end of this article.

Power supply transformer (8): Only the best quality used here in Eddystone sets – many models sharing the same transformer design from Parmeko, eg. the S.750, S.680X and S.940 all use the Eddystone Part No. 3937P design, over a span of around 25 years (photos on previous page).

Faults in Inductors

Apart from mistuning by the 'mad-twiddler' which can be corrected by a re-alignment in an ordered manner according to the manual (see the 'Short' on receiver alignment), the most common faults that occur in inductors of any type are age-related corrosion faults and latent dry-joints, or fatigue due to mechanical stress (eg. heating/cooling cycles). Corrosion, usually resulting from condensation forming on the coil wires – often exploiting a pin-hole gap in the enamel coating – leads to the dreaded 'green lurgy' or 'green spot' condition, so-called because of the colour of the corroded copper wire. These defects normally result in one of the transformer windings going open-circuit. Fault-finding is usually best undertaken by identifying the faulty stage by signal tracing (see the 'Short' on fault finding and repair) and then undertaking resistance checks on the suspect coil, transformer or choke. Repair is effected by carefully removing the insulating from the corroded wire, cleaning it to shiny bare metal and then re-soldering. When Litz wire is involved however (not often a green lurgy problem, but more likely mechanical stress), this can be problematic – I have met only limited success in trying to re-make joints with Litz wire as it does not like to be cleaned and tinned.

A second fault condition is when one of the inductor coils has burned out forming an open-circuit due to excessive current passing through it – most likely as a result of a fault in an associated downstream component. Similar fault finding techniques can be used as described above, however, sometimes evidence of the burned condition can be observed by blackening of the inductor or, particularly in that case of power supply transformers and chokes, by a sickening (and expensive) smell. It is of course essential that the root cause of the inductor failure is identified prior to repair or replacement of the inductor. The photo (right) shows the typical appearance of a burned-out power transformer winding. The transformer can be re-wound professionally (usually at a significant cost: our local company here charges by the hour) or by the owner, however, I would express concern over the latter for power transformers on safety grounds unless you really know what you are doing – in which case you probably wouldn't be reading this article....

Other faults are of the purely mechanical variety, eg. broken or jammed tuning slug, loose wire or cracked former. Broken slugs can be carefully removed – though if the slot or hex hole has been badly damaged you may have to resort to the use a darning needle, drill bit or similar to coax the remnant part(s) of the slug out of the former – patience is paramount here if you are to avoid damage to the former. In extreme cases, total destruction of the slug and its removal in fragments is the only answer – the critical thing is to preserve the coil and former intact (replacement slugs are relatively easy to obtain). When there are two slugs in the one former and one has a gnarled slot, first try to remove the slug in the opposite end of the former and then remove the jammed one with the gnarled slot in its upper end from beneath using its (hopefully still) good slot in its lower end. Broken formers can be repaired by using a light application of an appropriate glue and jigging the former together, although the degree of success in doing this depends on how substantial the former is and the material it is made from.

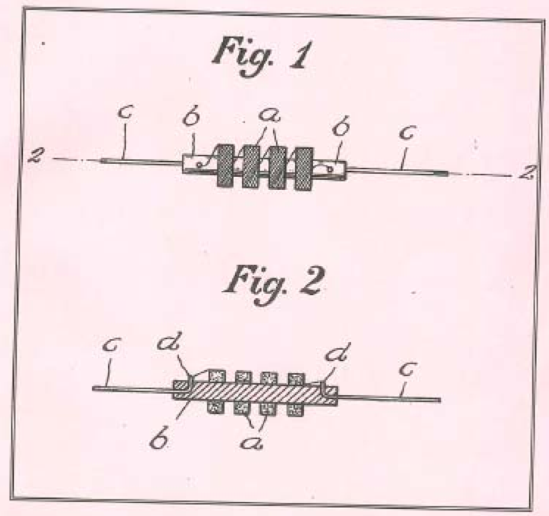
Conclusion

The use of high quality inductors is paramount to efficient and reliable receiver design: use of such in the various stages of a receiver will provide high levels of RF and IF selectivity, audio fidelity, accurate filtering, and reliable power supply circuits. Eddystone built a reputation from their earliest days for either manufacturing or specifying only the highest quality inductors for use in their receivers. Even today, many decades after they were manufactured and in use for extended periods since, often in adverse environmental conditions (eg. hot/cold cycling, high humidity), they continue to provide excellent service, allowing these venerable old sets to perform to their factory specifications using the original inductors.

Gerry O'Hara, G8GUH, Vancouver, BC, Canada, February, 2007

Lighthouse Issue 96, April 2006

Eddystone's Patent High Frequency Choke



What's so special about these?, you may ask. They look like any other RF Choke, you may say. Actually they only look like any other Eddystone RF Choke and the reason is this: - Rival manufacturers had Lead alloy ends (at points 'b' and 'd' on these drawings) rather like some 1920s and -30s carbon resistors. This was so they would fit in a standard resistor clip of the period.

But the boffins at Eddystone *(sounds like one of technical director Harold Cox's bright ideas)* realised that a solid block of metal at either end would have exactly the same effect as a shorted turn on the choke and thus reduce that magic property, the "Q" or quality of the inductor.

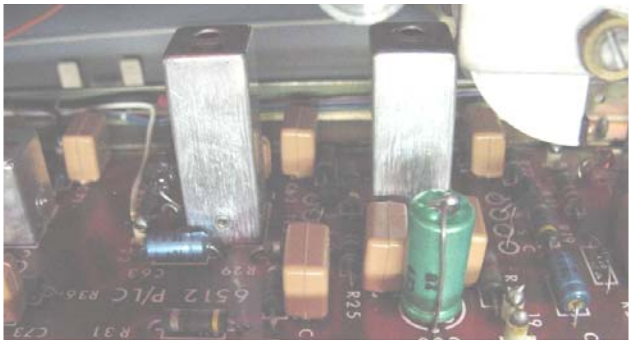
And sure enough, the British Patent Office agreed with them. This means that if you use an Eddystone RFC you will get optimum performance from your circuit due to the very high "Z" or radio frequency impedance of the choke.

Some Useful References

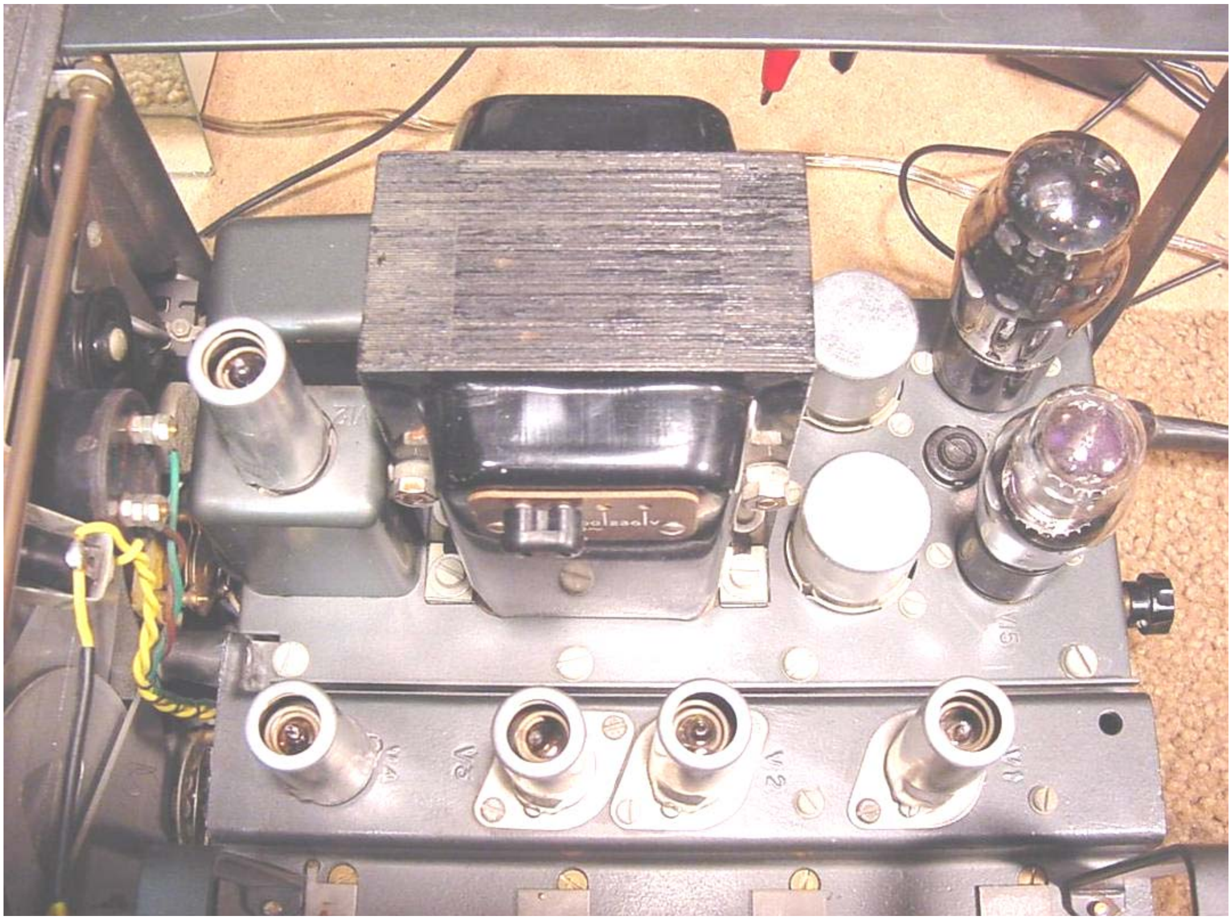
- Radio Communications Handbook, RSGB (eg. 4th Ed, Ch.s 1 & 17)
- Radio Amateurs Handbook, ARRL (eg. 31st Ed. Ch. 2)
- Radio Engineering, F. Terman, 1947, (3rd Ed. Ch.s 2 & 3)
- Radio Servicing: Theory and Practice, A. Markus, 1948 (Ch.s 1 & 12)
- Electronic Components Handbook, T. Jones, 1978, (Ch. 3)
- Various sections of Eddystone manuals downloaded from the EUG web site and specific articles in Lighthouse including:

Subject	***Issue***	***Page***
Toko i.f. coils	68	34
transformers & cores, damaged	85	25
i.f. transformers		
cannibalised	56	16
query as to substitute	61	39
replacement effected (Jim Duckworth)	66	15
substitutes, care as to	67	8

- Some web-based articles/resources on subjects covered in this article include:
    - http://www.rac.ca/tca/RF_Coil_Design.html
    - http://www.wiretron.com/litz.html
    - http://www.radiodaze.com/transformers.htm
    - http://www.tubesandmore.com/
    - http://www.jensen-transformers.com/
    - http://www.shure.com/ProAudio/Products/us_pro_ea_audiotransformer
    - http://www.antrimtransformers.com/catalogue.php?sec=631
    - http://www.parmeko.co.uk/html/transformers.html
    - http://www.hammondmfg.com/5cindex.htm



Ok, I know these articles are on valve Eddystones, but I did mention and EC10 in the text so here is the IF/AF strip out of one… Above: two of the three IF transformers (in-situ this time) and the BFO coil at far left. Right: the AF filter choke (shiny round thing with a TCC 0.1 uf capacitor soldered across the top), circled yellow



Above: that popular 3937P mains transformer again, this time in an S.680X (my latest restoration project – yet to be written-up). To its left (top) is a very neat power supply choke and below it the BFO coil unit – pure Eddystone beauty - come on Sid, show some interest! Below: AC/DC mains power supply choke (circled yellow) and coilpack in an S.870A