'Technical Shorts'

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'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.

(Early)
^ Semiconductor Lore

Introduction

What! I hear you say – these 'Shorts are for valve radios, not those radios with three-legged (or more) fuses pretending to be valves! What on earth is Gerry up to? Is nothing sacred anymore? Apparently not…

Well, not quite. I recently opened up my modest Eddystone collection to a couple of 'solid-state' sets: an EC958, mainly out of curiosity given comments in the QRG and Lighthouse that this receiver was considered by some as 'the finest set the company ever built', and a lowly EC10 MkI, mostly out of nostalgia, as it was the first Eddystone model I ever owned. Having delved into these sets a little (the EC10 more than the EC958, so far anyway) I got to thinking that there was now a bit of a hole in the 'Technical Shorts' series (pardon the pun)… Ok, well, what can I possibly hope to achieve in a 'Short on semiconductors I now hear. To be truthful, not a lot given the enormity of the subject – however, my objective here is not to delve into basic semiconductor theory (though references are given), nor is it to fully describe the evolution of various semiconductor types, and as for integrated circuits…. well, no, this is certainly not the place. My aim here is simply to provide a grounding in some of the semiconductor types and applications found in the earlier Eddystone solid-state offerings (before the use of microprocessors and other 'logic chips'), how these devices were used, some common faults, basic fault-finding/device-testing techniques and some tips on making substitutes

when necessary. Anything more than that is beyond such a 'Short and many contemporary texts and websites exist for those interested in finding out more about the various semiconductor device types, circuit design, fault conditions and test procedures.

For those that may have read my EC10 MkI restoration article, apologies for some repetition in this 'Short (in the context sections only), however, there is also much new material here that may be of use when servicing the earlier Eddystone solid-state receivers, so bear with me....

The Dawn of a New Age!

Following the development of the first transistor devices in the late-1940's, the first commercial application of this fledgling technology were in hearing-aid amplifiers around 1950. The first actual 'trannie' radio was reportedly developed by *Intermetall* in 1952, which they showed-off at the Dusseldorf Radio Show that year. This was followed by the first commercial transistor radio set in 1954, the 'Regency TR1', developed in the US as a joint project between the Regency Division of *Industrial Development Engineering Associates* and *Texas Instruments* (Texas Instruments manufactured the transistors and Regency designed and built the radio). This desirable gadget (bearing a remarkable likeness to the modern-day iPod) was marketed under the catchy slogan "*See it! Hear it! Get it!* – those that did get it though coughed up $49.95, around £200 ($400) in 2008 lucre. Meanwhile, over in Japan, the *Tokyo Tsushin Kogyo Company* (soon to be re-born under the moniker '*Sony*' for obvious reasons) followed close behind with their 'TR55' model, launched into the market in August 1955 (hey, that's when I was

produced also! - though I was made in the UK). Speaking of which, the first UK-made portable trannie was the 'Pam 710' (advert, left), manufactured by *Pam (Radio & Television Ltd)* of Regent (not Regency) Street, London and launched in March, 1956 for about £33. The rest as the saying goes, even including the Sinclair matchbox radio, is history - nothing would ever be the same again – except, of course, valved Eddystones…

Eddystone Adopts the New Technology… Albeit Slowly

Eddystone first experimented with transistors around 1960 (see the *Cooke Report*, p18), and the first transistor set having an Eddystone pedigree was reportedly the 'Stratton Portable' produced in 1961. Graeme Wormald in the QRG notes this set to be an:

> "*…All-band transistor radio… strictly speaking this was not an "Eddystone", but* [it] *was developed in Stratton's Eddystone laboratory...*

> *The Laughton family, owners of Stratton and its Eddystone Radio division before the sale to Marconi in 1965, had family connections with the John Myers mail order company.*
>
> *Transistor Radios were new and it was thought that an opening might exist. The radio covered Long, Medium and Short waves up to 30MHz as well as VHF/FM* [quite impressive for its day]. *It was built into a diecast box with ferrite rod aerial in a plastic handle and rabbits' ears for HF/VHF.*
>
> *Needless to say, the build quality was far too good for the cut-throat competition of the mail order market. Three sets were constructed. They were raffled off amongst those involve with the development. You never know; one day... But it gave Eddystone's their first experience of solid state design."*

Building on this knowledge, and staying within their more traditional and familiar territory of communications receivers, Eddystone launched their first all-solid-state general coverage communications receiver in 1962. This set looked identical externally to an S.940, though with transistor circuitry replacing the traditional valves. The S.960 sported 12 germanium transistors/7 diodes, had six ranges covering 500kHz to 30MHz and was powered by an internal 12 volt battery pack. The circuit had one RF stage and three 465kHz IF stages, including a band-pass crystal filter. Its performance was apparently (and very believably) not on a par with the S.940 however, and the S.960 was dropped from the Eddystone range after the Bath Tub manufactured only 150 of the sets over 2 years. It is worth noting that the transistors used in the first experimental Eddystone solid-state sets cost the equivalent of around £50 ($100) *each*.

The next solid-state set out of the Bath Tub was the famous EC10 in 1963 (photo, right) – one of the companies biggest successes in terms of total sales (over 16,000 MkI and MkII series sets combined). This set was an instant success,

receiving favourable radio press reviews and satisfying the need for a more 'modern' and compact communications receiver at a (fairly) reasonable price point. The EC10 was housed in a much smaller case (12" wide) than the S.960, while still retaining the famous Eddystone slide rule dial that made tuning the set a pleasure, as well as the hallmark Eddystone mechanical construction that made it *feel* like a quality piece of kit. The EC10 used an all-germanium PNP transistor line-up that shared many circuit design elements with the S.960 (its main features are described below), but was constructed on two 'Paxolin' printed circuit boards, with a zener-stabilized nominal 6.5 volt supply to the radio frequency (RF) amplifier, Mixer, local oscillator (LO) stages and the beat frequency oscillator (BFO). The set could be powered from a removable battery pack using 6 'D'

sized dry-cells to provide a 9.1 volts, positive-earth supply (positive-earth was the norm when using all-PNP transistor circuitry).

Spurred on by the success of the EC10, Eddystone introduced several other straightforward solid-state receivers during the 1960's, starting with the broadcast, general coverage shortwave and VHF FM model EB35 (photo, left) in 1965, with 13 germanium transistors/6 diodes, later upped to 14 transistors – the additional one for an extra FM IF amp, the very rare EB35A (covering the inshore narrow-band FM frequencies instead of the FM broadcast band) and its MkII and MkIIS versions in 1970 ('S' for Stereo, this model having 20 transistors), and finally the MkIII (the 'Statesman') in 1976, this version having a completely new circuit with silicon transistors, field effect transistors (FETs) and integrated circuits (IC's). The EB36 (photo, right) was introduced in 1966 (9 germanium transistors/5 diodes), with the EB36A, having a narrow IF bandwidth, in 1969 and then the MkII version in 1970. Yet another version in this lineage was introduced in 1971, the EB37, having 10 transistors/4 diodes

– this set marketed for ships cabin use and as a short wave tuner for HiFi units.

The most complex Eddystone sets not to use ICs were the S.990 series of professional receivers, introduced in 1967: the S.990/R for VHF, photo, below, and in 1968, the

S.990/S for UHF, these sets having 39 transistors/14 diodes and 33 transistors/9 diodes respectively (the S.990/R was in production through to 1981). Subsequent solid-state Eddystone sets
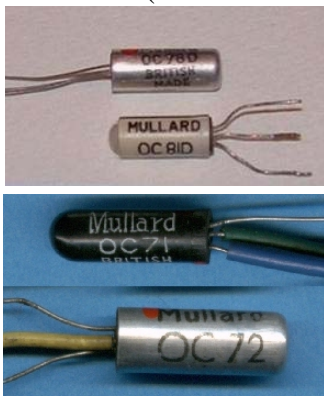
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in the late 1960's through 1970's, such as the EC958 series (eg. 958/3, photo, right), became increasingly more complex, using a combination of discrete devices: bipolar transistors, FETs, diodes and analogue ICs for the signal circuits, with logic ICs for digital frequency readout circuitry in the higher-end sets, before microprocessor control started to be employed in the 1980's with the introduction of the 1650 series. The early EC958 series sets used 41 transistors, 46 diodes and 12 ICs, but later and more complex variants, introduced in the early 1970's, eg. the EC958/E, had up to 75 transistors, 99 diodes and 70 ICs. The solid-state replacement for the venerable S.830 series valve receivers, the Model 1830, manufactured from 1971 to 1977, employed some 33 transistors, 21 diodes and one IC.

Semiconductor Devices Found in the Early Eddystone Solid-State Sets

The EC10 (MkI and MkII), EB35 series (except the MkIII version), EB36 series and the EB37, all used the same late-1950's/early-1960's germanium

transistor technology in their designs – predominantly PNP, though with one NPN type creeping into the mix as well. For broadcast AM and shortwave radio frequency (RF), local oscillator (LO) and intermediate frequency (IF) stages, the OC171 type was ubiquitous, with AF114s and AF115s used in the VHF FM RF stages in the EB35 (MkI and MKII). For audio frequency (AF) amplification, either the OC71, AC127 (the NPN type) or GET880 were deployed for low-level audio and either OC81's/OC81D, OC83's/OC83D or OC81/AC127 pairs in the driver and output stages (photos, left).

Diodes used in these sets' small-signal circuits are the OA70 (AGC detector, IF transformer damping), OA79 (FM discriminator), OA90 (AM detector) and the BA111 varicap for fine-tuning control in the EC10 MkII. Voltage stabilization for the RF and LO stages was effected by a simple zener diode, type OAZ203.

The above selection of semiconductors is ubiquitous in the early Eddystone solid-state receivers. Only in the late-1960's, when Eddystone were focussing on the professional and military markets did the selection expand to include silicon bipolar transistors, FET's and IC's. The EC958 for example used 17 transistor/FET types (all silicon), 16 diode types (including the 'ancient' germanium OA47 as its AM detector and meter rectifier) and 12 linear IC types in its analogue circuitry.

Typical Circuit Applications, Fault Conditions and Troubleshooting

As with the majority of Eddystone valve sets, the early Eddystone solid-state receivers were of generally conservative, almost 'textbook', designs, with the general receiver configuration mimicking that of the majority of their contemporary valve receivers: RF stage, Mixer, Local Oscillator, IF amplifiers, BFO, AM/FM/AGC detectors, AF amplifier and push-pull output stages – nothing too 'fancy' was tried in the early days. Indeed, the main changes made were to accommodate the different biasing, impedance-matching and power supply requirements of transistors versus valve circuitry. By the late 1960's however, significant circuit sophistication was beginning to appear in sets like the EC958 series – this set being based around the

My EC958/3 with the case removed– modular beauty at its finest… here viewed from the top

'Wadley-Loop' principle when in high-stability mode, and the level of sophistication, elegance of its circuit design and modular construction represented some of the best professional receiver design of that era.
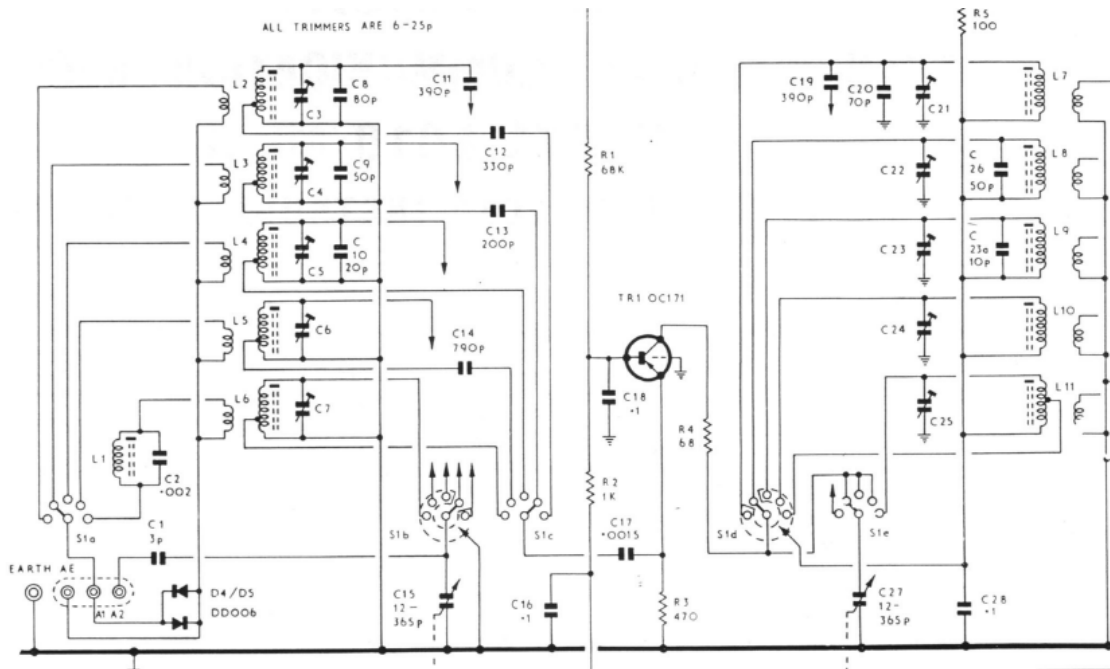
Performance limitations of the rather primitive transistor devices available to Eddystone in the early-1960's was overcome to some extent by careful circuit design, eg. using grounded-base circuitry in the RF stages, although the limited gain and relatively high noise figures of the OC171 transistors used still limited these sets performance compared with the contemporary valve sets. As in the Eddystones valve receivers, the use of high-quality double-tuned inductors helped performance and their solid mechanical construction promoted reliability and robustness.

Basic techniques for fault finding, as described in my 'Short on 'Receiver Fault Finding' though aimed at valve sets, generally apply to solid-state sets also. Signal-tracing and voltage-checking techniques are particularly applicable, with resistance measuring less so, as the presence of semiconductor devices in the circuit can affect the measured resistances by a considerable margin – unfortunately most semiconductors are hard-wired into circuits, so unless they are removed (not a good idea for fast troubleshooting), this may result in misleading results. Below, I use the EC10 and EB35 MkI circuits as examples to describe circuit design, typical operation, faults and troubleshooting techniques for early solid-state Eddystones. Also, test procedures applicable to semiconductor devices are described later in this article.

RF Amplifiers

The signal from the aerial is generally fed to an RF coil, usually a transformer – either with separate secondary and primary windings, tapped, or auto-wound (L2 – L6/C15), this being tuned to the desired receive frequency. This tuned aerial transformer adds some degree of selectivity ('pre-selection') and also matches the aerial impedance to the input impedance of the RF amplifier transistor. L1 – C2 is an IF trap. In many sets, including Eddystones (eg. the EC10, circuit diagram extract shown below), a grounded-base arrangement is used for the RF amplifier as this has the advantage of being inherently more stable as the grounded-base effectively shields the input signal from the output signal. This allows more gain from the RF stage without requiring some form of neutralization to counteract the internal capacitance feedback in the transistor. This configuration is almost universally employed in VHF receiver front-ends where such feedback is an even greater problem.

The RF amplifier transistor (TR1) is given the correct DC operating conditions via a number of resistors. In the grounded-base configuration, this is usually by a voltage divider across the supply lines to the base, and/or to the AGC line (R1, R2), in order to set the correct base bias (and hence gain) under a wide range of signal strengths. The base is grounded at signal frequencies by a capacitor (C18). A resistor (R3) is included in the emitter circuit to provide protective bias for correct operation of the transistor (an emitter resistor reduces the base bias if the total transistor current tends to increase) and the input signal is fed to the emitter from the secondary (low-impedance winding) of the RF tuned circuit via C17. The collector circuit of the RF transistor feeds through the second (tuned) RF transformer (L7 – L11/C27) to the Mixer stage.

RF transistors are particularly susceptible to damage caused by voltage spikes induced into the aerial circuitry, eg. from lightening or from a transmitter operating in close-

proximity to the set. Many solid-state receivers meant for operation with or near transmitting equipment have 'reverse-parallel' diodes fitted across the antenna input connections to mitigate this possibility (eg. a pair of DD006 diodes, D4 and D5, are included in my EC10 MkI – circled yellow on the photo at the top-right of page 23).
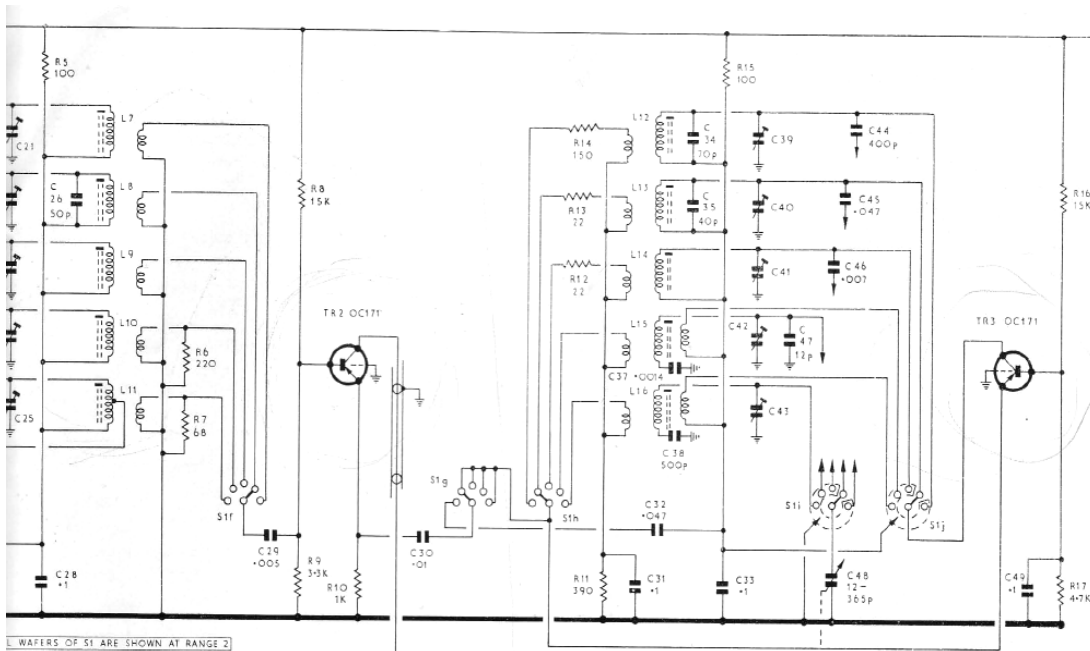
If the RF amplifier is defective, strong stations may still be received. A quick check for a faulty RF stage can be made with the receiver operating by touching the collector of the RF transistor with a screwdriver (and at the same time touching the metal blade with a finger) – if signals can now be heard or previously weak signals are much stronger, this indicated a likely problem in the RF stage of the receiver. Next, measure the emitter voltage of the RF transistor as this indicates the amount of current flow through the transistor (using Ohms law). If the emitter voltage is zero (or close to it), then little or no current is being drawn by the transistor. This could mean that the supply voltage is not getting to the collector (easily checked by measuring the collector voltage), the transistor is open circuit, or that there is insufficient base bias voltage being applied to turn the transistor on. Next check the base voltage: if it is found to be zero or thereabouts, check the base bias resistor from the negative supply line (for PNP transistors) and the AGC resistor/capacitor components. If the emitter voltage is too high (say above 4 volts), the likely problem is a short-circuit transistor or very leaky one (from collector to emitter). In this case, before fitting a replacement transistor, check the associated bias components, coupling and de-coupling capacitors for faults that could have caused the device to fail. Measuring voltages around a transistor amplifier should be undertaken with some caution, however, as sometimes the method of deriving the bias is more sophisticated and may rely on other directly-coupled semiconductors – check the circuit diagram for any such possibilities.

Mixer/Local Oscillators ('Frequency Converters')

Mixing the RF signal with the LO signal to derive the desired IF frequency can be undertaken either in a dedicated Mixer stage, with the LO signal being derived from a separate oscillator stage (as in Eddystone solid-state sets, eg. the EC10, circuit diagram extract shown on the following page), or by letting the Mixer stage oscillate to provide the LO signal – such a dual-function stage is often known as a 'frequency converter'. The RF signal, either directly from the aerial or from the RF amplifier stage(s), is usually fed to the base of the Mixer transistor (TR2), with the LO signal being fed to the emitter, the mixing occurring in the transistor's collector circuit, since both applied signals affect the transistor's signal bias voltages. If the mixer transistor is also the LO, then feedback is usually applied from the collector circuit to the emitter – this feedback is via a tuned circuit at the LO frequency, the capacitor tuning this circuit being ganged with the RF tuned circuits to allow tracking of the RF and LO frequencies.

If trouble is suspected in the Mixer stage, a good first check is again to measure the emitter voltage (across R10) as this indicates the amount of current flow in the transistor. If the emitter voltage is zero (or close to it), then little or no current is being drawn by the transistor. This could mean that the supply voltage is not getting to the collector (easily checked by measuring the collector voltage), the transistor is open circuit or that there is

insufficient base bias voltage being applied to turn the transistor on. Next check the base voltage: if it is zero or thereabouts, check the base bias resistor from the negative supply line (for PNP transistors), R8 in an EC10, and the AGC resistor/capacitor components if these are connected to the Mixer stage. If the emitter voltage is too high (say above 4 volts), the likely problem is a short-circuit transistor or very leaky one from collector to emitter. In this case, before fitting a replacement transistor, check the associated bias components, coupling and de-coupling capacitors for faults that could have caused the device to fail.
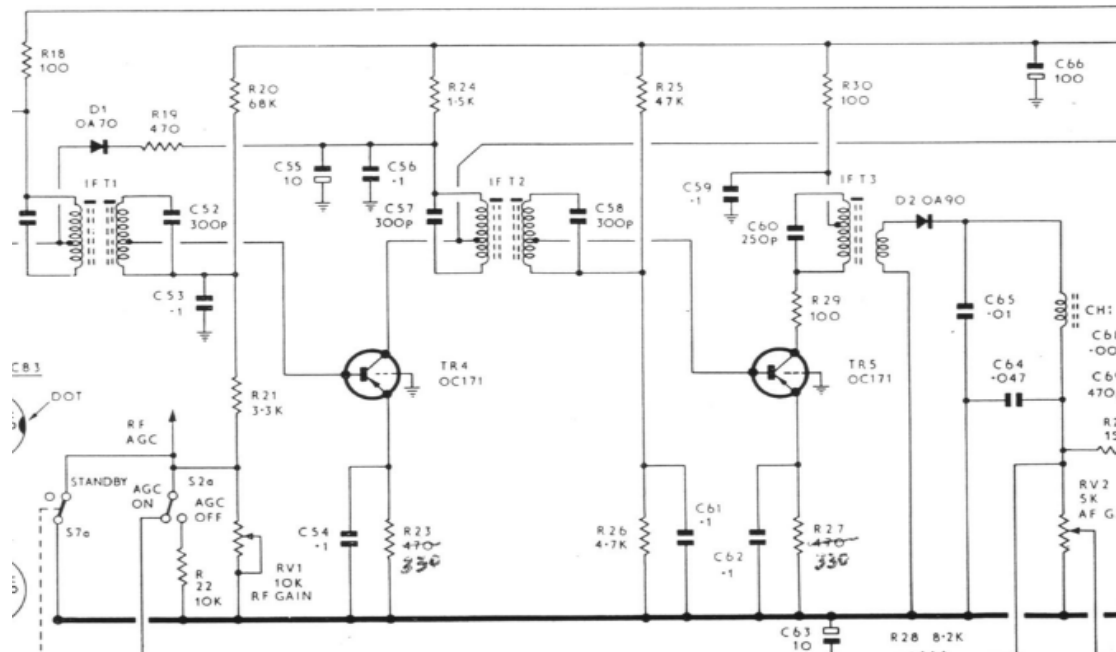

If all voltages seem to be within around 20% of what they should be (according to voltages indicated by the manufacturer on the circuit diagram or in a voltage table) and all that can be heard when tuning the radio is a hiss, assuming the IF and audio stages have checked-out ok, then it is likely that the LO is not oscillating. This can be determined by measuring the base bias voltage on the LO stage – between the base and emitter. Then slowly turn the tuning capacitor and if all is well you should observe a slow change in voltage as the strength of oscillation varies with frequency which reflects in the transistor's DC bias. Or, if you have another radio handy, listen for the LO of the faulty radio on it by tuning around the faulty radio's indicated dial frequency plus or minus the IF frequency of the radio: if the LO is working, a heterodyne beat will be heard. If the LO is found not to be oscillating, check the bias resistors and feedback components (coil/transformer and any capacitors in the LC circuit) – the latter can be quite complex in multi-band receivers. Also, double-check the bandswitch for poor contacts and clean with De-Oxit or similar switch cleaner. If these all seem ok, try replacing the LO transistor as its gain may have reduced with age.

IF Amplifiers

The IF amplifier is where the majority of the gain and selectivity occur within a superheterodyne receiver. Most of the AGC action also happens in these stages. The

early Eddystone IF amplifiers use OC171 PNP transistors and the DC biasing arrangements are simple (refer to the extract from the EC10 circuit diagram, below), maintaining the collector voltage negative with respect to the emitter and the base biased slightly negative (0.1 to 0.2 volts) with respect to the emitter.
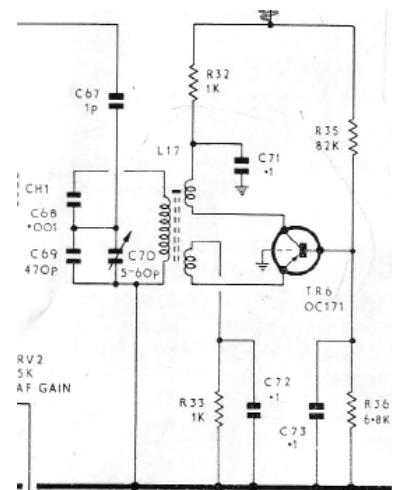

From the Mixer stage, the IF signal passes through the first IF transformer (T1), tuned to the set's IF frequency, to the base of the first IF amplifier stage (TR4). A step-down action is applied by the transformer which lowers the signal voltage and increases the signal current. The transistor is given the correct DC operating conditions via a number of resistors: usually by a voltage divider across the supply lines to the base (R20, R21, R25, R26) and resistors in the emitter circuits (R23, R27) to provide protective bias for correct operation of the transistors (an emitter resistor reduces the base bias if the total transistor current tends to increase). These resistors are bypassed to ground by capacitors (C54, C62) that prevent variations in signal voltage affecting the DC bias conditions. The collector circuit of the first IF transistor feeds through the second IF transformer (T2) to the base of the 2nd IF amplifier and so on, with the final IF stage transformer (T3) secondary being connected to the detector diode (D2).

If trouble is suspected in the IF amplifiers, similar fault-finding procedures as given above for the RF stage may be implemented, however, watch for inter-coupling of bias arrangements between IF stages: in such cases, a fault in one IF stage could affect the DC bias conditions in another.
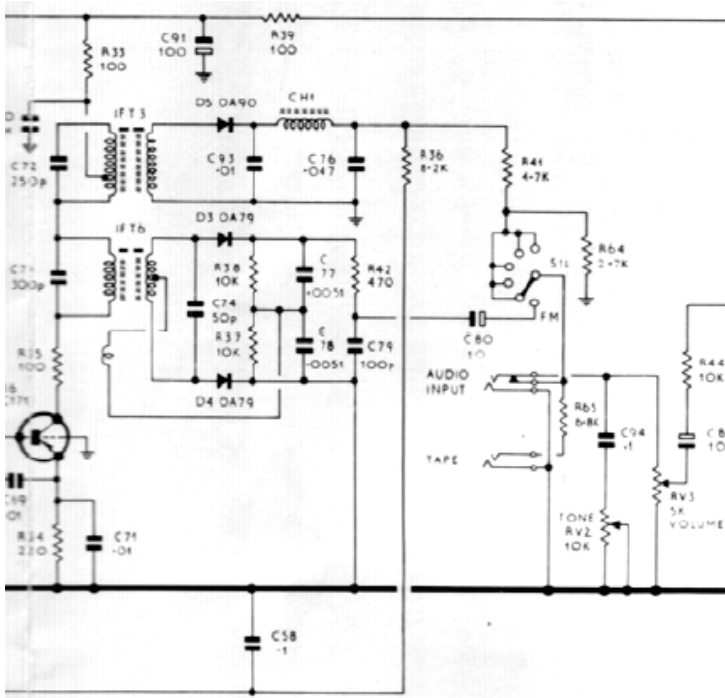
BFO

BFO circuits (diagram right, as found in an EC10) are normally a simple oscillator circuit – similar to the LO - with tuned feedback from the collector to either the base or emitter circuit,

however, the range of frequencies covered, being the IF +/- 5kHz or so, simplifies the design of the circuit. Fault-finding procedures are essentially as per the LO circuit described above.

Detector(s) and AGC

The AM detector circuitry generally comprises a simple point-contact germanium diode, eg. an OA90 and LC or RC filtering. This rectifies the IF signal, with the remnant IF component decoupled to ground via a small capacitor and the recovered audio being fed to the AF gain control usually by way of an electrolytic capacitor.

FM detectors, where present (eg. in the EB35, MkI, circuit diagram extract, left), are usually either of the Foster-Seeley (discriminator) or ratio detector types, both of these using a pair of point-contact germanium diodes. For example, a Foster-Seeley discriminator is used in the EB35 MkI employing a pair of OA79 diodes (D3 and D4).
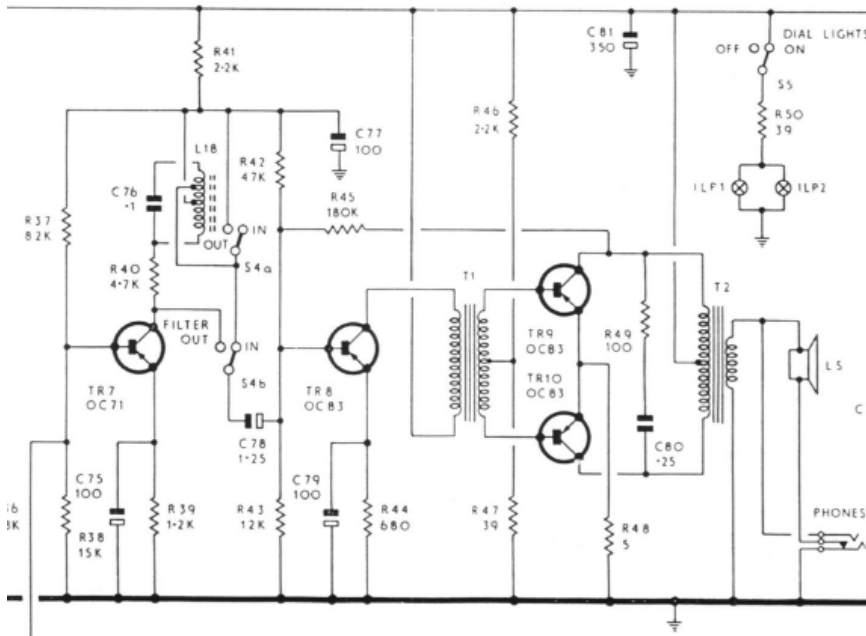
Both types of detector are normally very robust, although the diodes have been known to degrade in performance over many years or, quite rarely, fail. For FM-capable sets of unknown provenance, if a fault is traced to the detector circuit, suspect that a 'mad twiddler' has 'had a go' at the slugs in the detector transformer (IFT6 in an EB35 MkI), necessitating this to be re-aligned (see my 'Short on 'Detectors and Discriminators' for how to do this and for more detail on how these detectors work).

AGC action requires the generation of a DC voltage that varies with the signal strength. This DC voltage may be used to vary the bias conditions of the RF, Mixer and IF amplifier stages and thus regulate the gain of the receiver to maintain a sensibly constant output level for a large variation in input signal strength. This DC voltage can readily be provided by the AM diode detector or by a separate AGC detector diode. The DC voltage thus obtained is then fed to base of the RF/Mixer/IF stage transistors as required via a resistor/capacitor network (an 'RC Filter') to decouple any audio that may be present on the AGC line and to provide an appropriate time-constant for the signal ('fast' or 'slow' AGC action). Less negative bias applied to a transistors' base makes the transistor draw less current and lowers the gain. For IF amplifiers, the base bias for subsequent transistors may be supplied by the emitter of the preceding stage – thus the

AGC line voltage need only be applied to the first IF amplifier as by changing the bias conditions on the first IF stage will then also control subsequent stages.
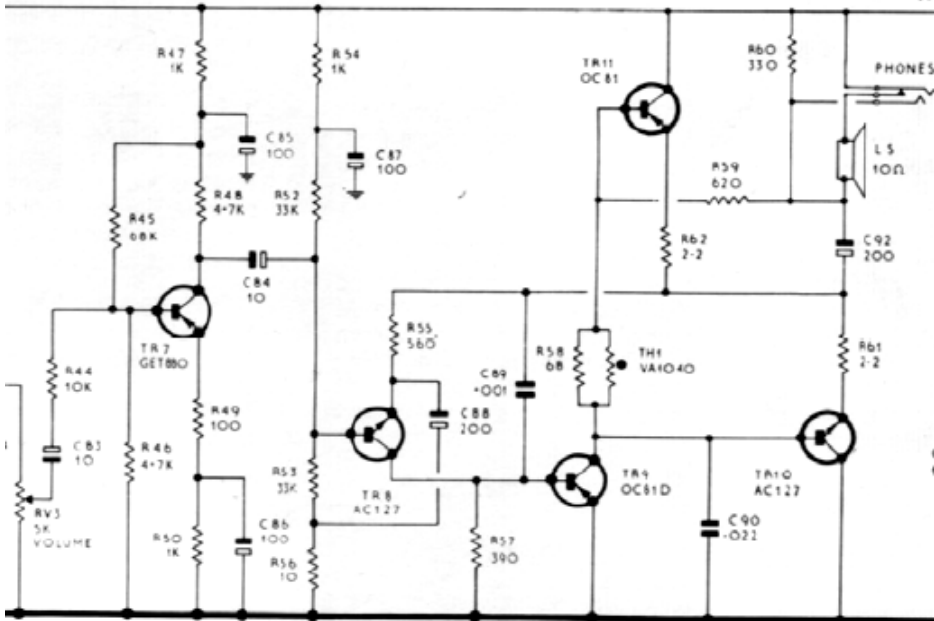
Audio Amplifiers

The audio signal from the detector stage is fed, normally by the AF gain control, to the first audio amplifier via a coupling capacitor (in order to retain an appropriate audio frequency response, coupling capacitors in AF stages of solid-state receivers tend to be of a larger value than in valve sets due to the lower impedance of the transistor base circuit). In sets of this era, there is usually a first AF amplifier stage followed by a driver and a push-pull output stage (refer to the circuit diagram extract above). A photo of the EC10 circuit board containing this circuitry is shown on Page 1.

The correct bias arrangements for the first audio and driver stages are again derived from suitable resistor networks. In germanium transistor circuits, the base bias is usually provided by a voltage divider across the supply lines as per the RF and IF stages (R37, R38, R42 and R43). This arrangement is used as it provides a low resistance to ground from the base which effectively prevents leakage between the collector and base of the transistor from being a problem - this leakage is much higher in germanium devices than in silicon ones. Again, protective bias is provided by emitter resistors (R39, R44), to mitigate thermal runaway, here bypassed to ground at audio frequencies (by electrolytic capacitors, C75, C79). If one of these bypass capacitors goes open-circuit, the gain of the impacted stage will drop significantly and the audio will likely become weak and/or distorted. A substitute capacitor may be tried across the suspect one in this case to see if an improvement can be effected.

The collector of the first audio transistor stage (if present) would normally be connected to the base circuit of the driver stage via a coupling capacitor (C78). In some sets, eg. the EC10 series, an audio filter (a tuned LC-circuit, L18/C76 in circuit diagram above) may be switched into this circuit to provide enhanced reception of CW signals. If transformer-coupled circuitry is used for the output stage, the collector circuit of the driver transistor is connected to the supply line via the primary of the driver transformer, the secondary of

which is centre-tapped to provide opposite-phase signals to the bases of the output transistors. In this common arrangement, the bases of the two output transistors (which are operating in class B, ie. a low bias condition is applied to the output transistor pair and each only functions during half of the audio cycle) are biased by a voltage divider across the supply lines feeding the centre-tapped secondary of the transformer (R46, R47). The (common) emitter resistor, R48, is necessarily of a low value as a higher value would limit the current draw of the circuit and hence reduce the available power output. However, this arrangement provides very little by way of 'protective' action to limit thermal runaway, and in some designs thermistors may be found in the output stage base bias circuit to provide such protection. An example of this (TH1) can be found in the transformer-less complementary push-pull output stage of the EB35 MkI (circuit diagram extract shown above).

Faults in transistor AF stages may result in no output, weak output, distortion or 'motor-boating', squealing or howling. In all cases, preliminary checks should be made to ascertain if the correct bias voltage is being applied to the stage(s) in question – first, check the emitter voltage of the stage. In RC-coupled stages (as in most first AF stages), also check that the coupling capacitor is not leaking as this can upset the bias conditions on the base of the subsequent stage. Audio transformers in solid-state sets tend to be very reliable, but should not be above suspicion – open circuits and shorted turns can occur. In the latter case, the stage may still function, but at a lower output level and/or with some distortion. 'Motor-boating' and 'howling' is usually a result of a faulty power-supply decoupling capacitor (eg. C77 or C81 in the EC10) – to test, try shunting a suspect component with a known good one. Another cause of this symptom can be a fault in any negative-feedback components and these should also be checked if present.
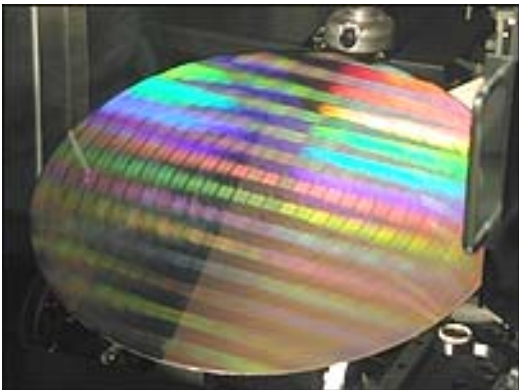
Also, don't forget to check the speaker and headset jack for faults: speakers can give 'rattely' or 'grating' forms of distortion, and corrosion or dirt on little-used headphone jack contacts can cause intermittent changes in volume and/or annoying crackling.

Semiconductor Faults and Component Testing

Device Failure

Semiconductor devices are generally very reliable provided they were designed and manufactured correctly. Indeed it may even be assumed that if they are operated correctly (within their design limits) there should be no reason for them to fail at all… In the real world though, they do fail and this can be for a variety of reasons, including poor design (especially very early transistors) - either mechanical or substrate design flaws, manufacturing faults, ageing effects, environmental causes - including heat and ingress of moisture, poor circuit design, electrical transients, or failure of other circuit elements leading to the device operating outside its specifications.

If there is a manufacturing defect in a new transistor, it will often show up in the first few hours of use. If the device operates correctly for this period then the chances are that it will continue to do so. A large proportion of manufacturing faults can be detected by 'soak-testing' new equipment, ie. running it on a test bench for a number of hours to detect early failures. Devices that survive these tests can be put into regular use with some confidence. Early transistors were manufactured in primitive conditions compared with modern-day semiconductors – this is true both for the semiconductor materials themselves ('wafers') and for their associated mechanical components/assembly (lead connections, encapsulation and sealing materials/techniques) – for example, the very common OC171-type transistors in early Eddystone solid-state receivers suffer from an age-related problem that appears to be the end result of a design flaw (method of construction/materials selection) – see sidebar on the next page.

On the face of it, there is no real reason that transistors should suffer from aging. A slice of germanium or silicon (photo, left) 40 years old should be the same as a 1 year old slice shouldn't it? Well, not necessarily – the semiconductor is subject to minute changes over time resulting from current flow, thermal and chemical diffusion effects, all of which may alter the properties of the semiconductor junction over extended periods. Mechanical stresses are also induced by thermal cycling – especially in higher-power devices. Other circuit components, such as resistors, may change their values with age - particularly the older, carbon-composition types - especially if they are subject to heating caused by high current flow. This may eventually result in a transistor operating outside its normal parameters, and for example, running at a higher than permitted junction temperature. It is then that transistors are more likely to suffer failure. In such circumstances it is wise to investigate the reasons for the failed transistor rather than just replacing it. For example, check the values of all associated DC bias components (with the faulty transistor removed from the circuit) and then the

voltages at the transistor terminals after replacement to make sure there are no abnormal readings.

Sometimes external causes may damage or even destroy transistors. Careless handling of MOSFETs for example can lead to damage by electrostatic discharge. Sometimes this will result in a device not working when fitted within a system, because the very thin insulating layers within the device have broken down completely due to high voltage static electricity inadvertently applied to the terminals of the device. However, such discharges do not always cause immediate destruction of the device, but damage the insulation to such a degree that the device fails sometime (hours or years) later. In mains (line) powered equipment, high voltage transients that occur from time to time can also damage semiconductors. Most mains-powered circuits have some sort of protection built in that prevents damage in most cases, but it is rarely 100% effective.
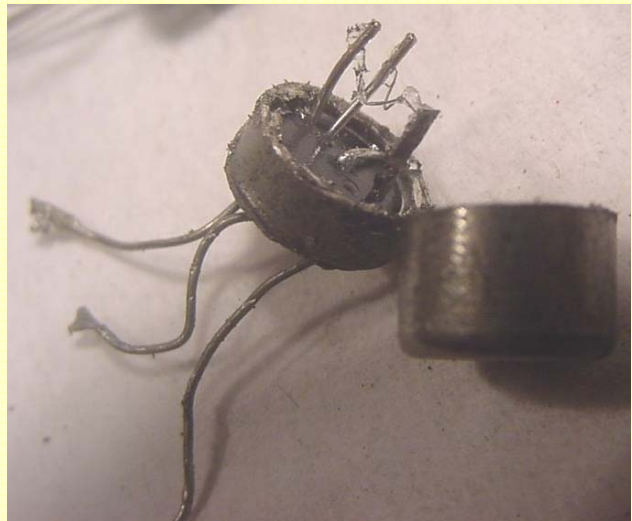
Increased reliability of any component (especially transistors) is inversely-proportional to the power it dissipates, ie. 'the hotter it runs the faster it fails'. Such a rule-of-thumb tells us that a failed transistor is more likely to be in the output stages of a circuit than the low voltage, low power stages that precede it. Any circuit which uses either high voltages, high current or both, puts much more stress on semiconductors than low voltage, low current operation. Although the devices used in these circuits are designed to withstand such use, they do so less well than those devices which have a relatively 'easy life' in low-power situations (unless there is a circuit

Transistors with Whiskers…

The first transistors suitable for use in RF applications used the alloy-junction fabrication process. However, Mullard followed the US-led technology direction by adopting the alloy-drift fabrication technique. The first RF transistors manufactured by Mullard that were available commercially in quantity were the OC169, OC170 and OC171, introduced in 1959. This range was supplemented in 1961 with the AF117 to AF118 series. All these transistors were housed in a TO-7 case style that included, in addition to the base, collector and emitter connections, a fourth lead, connected internally to the transistors' aluminium case to act as a screen.

The internal construction of this transistor family is illustrated below. The collector lead acted as the support post for the semiconductor substrate, with fine wire connections from the emitter and base leads to the substrate. The upper part of the can was filled with a gob of silicon grease (presumably to protect the internal assembly from moisture ingress and possibly to add some resilience against shock). Beneath the silicon grease is a small air space – ok, a bit crude but functional, but here is the weird part…

Over many years, microscopic metallic filaments develop inside this air space (these are reportedly only 0.008mm across). These filaments are noted as being 'tough, springy and electrically conductive'. Eventually one or more of these filaments contacts one or more of the leads inside the can, shorting it to the can – effectively 'killing' the transistor. This phenomenon (no explanation found) affects both used and new-old-stock (NOS) devices at random. A sharp tap on the transistor case can effect a temporary cure by dislodging the offending filament. Alternatively you can try cutting the screen lead.

transient, design error, malfunction, device design or manufacturing flaw). The more common problem areas in solid-state equipment are therefore power supplies and output stages.

A particular receiver design can have recurrent faults (ie. similar faults appear in many sets of the same design or model). This occurs due to either an electronic/mechanical design flaw or poor component selection/ batch manufacturing faults.   Some faults will occur due to the product exceeding its 'design life' whilst others will occur prematurely. Designing an electronic product for a particular life span, under conditions which will be very variable and over which the designers have no control (service conditions) is not a precise science – even today, let alone in the 1960's when semiconductor technology was still in its infancy. However such faults as do occur usually follow a distinct pattern, and careful recording of previous faults can be a good indication of future ones. These failures can affect transistors just as easily as any other component. Where faults occur prematurely, manufacturers often produce modifications to prevent similar failures occurring in the future.

When a diode or a transistor fails, one of two things usually happens:

- A junction (or junctions) go short circuit (its resistance becomes very low or zero); or
- A junction (or junctions) go open circuit (its resistance becomes very high or infinity).

Of course we could extend this list to say that a junction may become leaky (slightly low resistance), though this is relatively rare, as in practice this condition is usually followed fairly soon by the development of a complete short circuit. This suggests that diodes and transistors can be tested by simple resistance measurements and in most cases this is true – with the caveat that this is best done when the suspect junction on the device is disconnected from the circuit. A set of resistance measurements can tell us with a great degree of certainty whether a semiconductor is serviceable or faulty – these tests are described below.

Transistors can also become intermittent or noisy in operation: these effects are often affected by the temperature of the device and a simple test is to apply some heat (from a soldering iron tip for example – though be careful not to apply too much heat as you could damage a good device!) or chill the suspect using one of the spray cans sold for this purpose.

Testing Semiconductors

Most multimeters are suitable for testing transistors, JFETS and diodes and many have transistor or diode testing facilities built-in (left-hand instrument in photo, left). Dedicated transistor testers can also be bought (photo, left) – the more sophisticated of these will generally tell you more about a transistor than an ordinary multimeter will. In most fault-finding situations a transistor or diode that was apparently working well is now suspect – a go/no-go answer is needed rather than ascertaining subtleties of the device's characteristics.   A few simple resistance or voltage checks with your multimeter will tell you this.
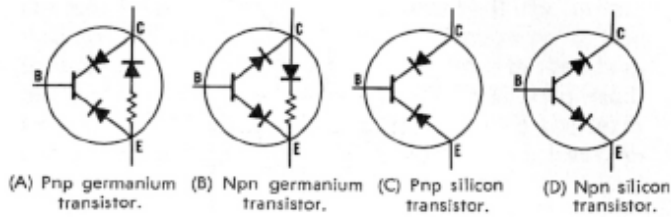
If you are using a digital multimeter (DMM) find the range marked with a diode symbol (circled red on photo, right) as this is the range you must use for testing transistors and diodes. Don't use any other range on a DMM as it won't test the device properly. This is because on resistance ranges the meter puts a small voltage across the probes tips, so that when you connect it to the component being measured, a current flows through the component. It's this current that the meter is measuring, displaying the result as resistance (in Ohms) to save you having to calculate it from voltage and current. The meter uses a low voltage, and likely a different value of voltage on different ranges, and in many cases with a DMM the meter voltage won't be enough to overcome the junction threshold voltage of the component under test - so the junction will measure as being open circuit even if it is fully-functional. The 'diode range' on a DMM is designed to supply just enough voltage to turn on the junction (just less than a volt), and pass a very small current through it. This gives a reasonably reliable indication of the condition of the junction without risk of damaging the device under test.

An analogue meter is better for testing semiconductors, as the visual indication provided is more readily (and rapidly) interpreted. However, when using the resistance ranges on many analogue meters, remember that on the Ohms ranges, the Red lead is negative and the Black lead is positive (what? I here you say – go on, check the polarity by measuring with another meter). My Triplett Model 630NA VOM (photo, left) does not suffer from this affliction, but all my other analogue meters do. This is very important

when considering a junction whose resistance depends on which side of the junction is positive (when testing junction's forward resistance the positive meter lead goes to the 'P' side of the junction and negative lead to the 'N' side). This is not the case for digital meters, where red is usually positive and goes to 'P' for the forward resistance test, and black is negative and goes to the 'N' side of the junction.

(A) Pnp germanium transistor. (B) Npn germanium transistor. (C) Pnp silicon transistor. (D) Npn silicon transistor.
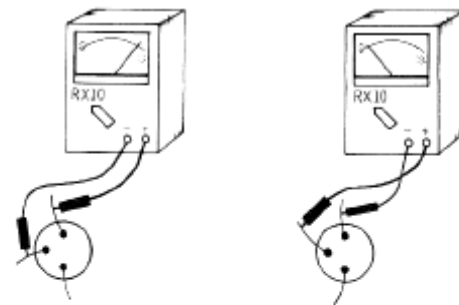
Another caution when using analogue meters (especially some of the more expensive ones) is to be careful which range(s) you use for the measurements. My Triplett Model 630NA for example has a 30v battery installed for the two highest resistance ranges - putting 30V across a small-signal semiconductor junction whose forward voltage is only 0.6V will more than probably destroy it.

A bipolar transistor has two junctions (diagram, above), which can be considered simply as two back-to-back diodes for testing purposes. To test a transistor you just need to check the forward and reverse resistance of both junctions, thus (refer to diagram, right):
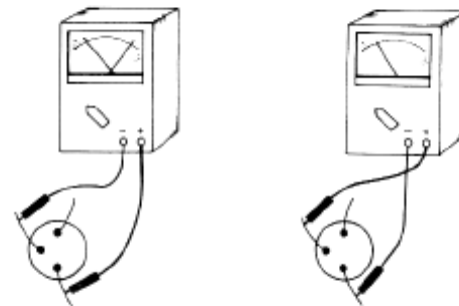
- Identify the correct pin-out for the device under test (refer to published information for the device – Eddystone manuals often have the pin-out on the circuit diagram pages)

- Test the resistance between collector and emitter

- Then reverse the positive and negative meter connections and test again

(A) Base-to-collector test.

(B) Base-to-emitter test.

If the meter reads zero or a few ohms in the above, there is a short circuit between collector and emitter and the transistor is faulty and should be scrapped. If both readings are (close to) infinity:
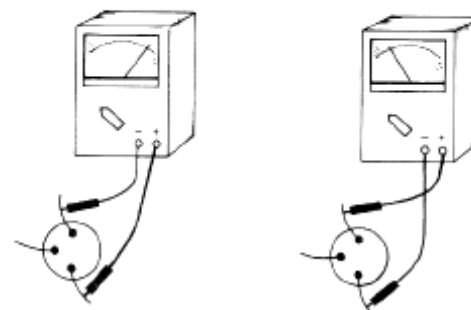
- Connect the positive meter lead to the base and test the resistance of both junctions by connecting the negative meter probe to one of the other two pins. It doesn't really matter whether this is the collector or the emitter, in the test we are simply testing a junction

- Leave the positive lead on the base and move the negative lead to the other

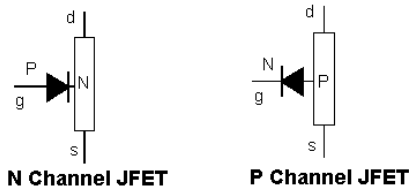(C) Emitter-to-collector test (see text).

untested (collector or emitter) pin and measure the resistance of this junction

In the above, a typical forward resistance reading of less than 1k Ohm should be obtained in both cases. Next:

- Connect the negative lead of the multimeter to the base and the positive lead to another pin (collector or emitter)

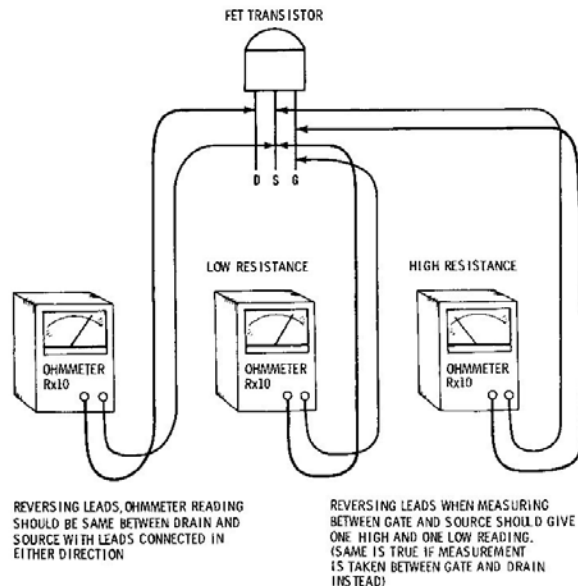- Connect the positive probe to the other untested pin (collector or emitter)

For the above two readings, both junctions should read infinity for a silicon device and at least several tens of k Ohms for a germanium device. If all of these six tests are ok you probably have a good transistor, otherwise you have a cat's plaything…

The results of resistance tests on FETs are generally not as easy to interpret as for bipolar transistors. Because of the high impedances involved for these devices, the results will be more variable and practice is needed to gain confidence in the results obtained. In addition, the handling requirements for IGFETS and MOSFETS with regard to electrostatic voltages mean that testing these devices out of the circuit is very likely to cause damage. The only effective test for these devices is by substituting a known good device, making sure that the manufacturers handling precautions are observed.

N Channel JFET   **P Channel JFET**

JFETs however can, with care, be tested with a multi-meter in much the same way as bipolar transistors. The figure, left, shows a junction model for testing a JFET. With this device we can consider that we are testing a single PN junction attached to a channel that is basically a resistor. The resistance of the channel between source and drain will be very high (several Megohms) but may vary considerably if the positive meter lead is connected to the drain and you then touch the (very high impedance) gate connection with your finger. This will put enough voltage on the gate to operate the FET. The actual results observed will vary depending on the device characteristics, the type of meter used, the resistance of your skin and even the humidity of the room. The PN junction can be tested by connecting the meter between gate and source, first one way and then reversing the polarity. The result should be a low reading of about 1k Ohms in the forward bias direction (positive to gate in the case of a N channel device) and infinity (open circuit) in the reverse bias direction (negative to gate) – diagram, above right.

The above transistor test methods assume you are going to test the device having first unsoldered it and removed it from the circuit (or at least two of the three leads).

Sometimes the above methods for testing transistors can be used in an un-powered circuit, provided that any resistors in the circuit around the transistor have high values, though the results can still be misleading. To test devices still in-circuit, voltage measurements with power applied are much better. There are some simple voltage measurements that can indicate if a suspect (bipolar) transistor is indeed faulty:

- More than 0.7 volts difference between base and emitter voltages indicates an open circuit base-emitter junction;

- The same voltage on two or more terminals may indicate one or more short circuit junctions;

- A lower than expected collector voltage generally means that the transistor is conducing heavily (is turned on); and

- A higher than expected collector voltage generally means that the transistor is not conducting (is turned off).
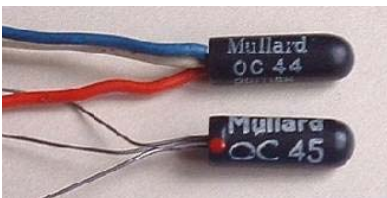
Device Substitution

Germanium Transistors

While germanium transistors have become mainly obsolete, a small range is still being manufactured and

available as new stock from several suppliers. In addition, like valves (but not to as great an extent), millions of

Junk box germanium small-signal transistors – some NOS, but mostly recovered from scrapped 'trannies'

these devices were manufactured and many can still be obtained as NOS. At a pinch, they may also be salvaged from scrap transistor sets, although you need to ensure you are not replacing a faulty component with another faulty component. Care is needed when removing devices from another set and it is advisable to test the part before installing it as described above. Luckily, most obsolete transistor types used in radios can be replaced from a small range of parts, eg. the alloy-drift 4-wire (TO-7 encapsulation) AF114-117 range can be replaced with similarly-encapsulated OC169, 170 and OC171 types (and vise-versa). Alternatively the AF125 and AF127 types can be substituted for these parts – these are alloy-drift devices electrically similar to the AF115 and AF117 respectively, but in the smaller TO18 (4-lead) and TO72 metal cans. A benefit of substituting the AF-series of transistors is that they don't suffer the collector-to-case short syndrome due to development of 'whiskers' that afflicts the earlier OC171 types (see sidebar on page 15).

'Medium-power' PNP audio transistors, eg, types OC72/81D/81/83, can be replaced with

the AC128, a relatively high voltage, high current device. Type AC127 is the NPN complementary version of the (PNP) AC128, but is used to complement an OC81 in the transformer-less output circuit of the EB35 MkI. Low-power AF amplifier transistors like the OC44 and OC71 types can be replaced with the still readily-available

AC125 and AC126 types. The PNP AC188 and NPN AC187 types are intended for use as a complementary pair in transformer-less output stages with somewhat higher power output (up to 3W). All these devices are packaged in metal TO1 cans.
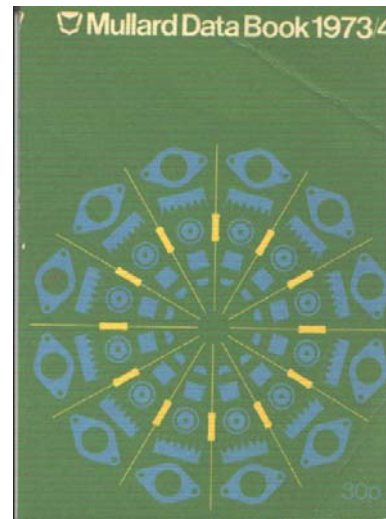
Typical applications for the early AF germanium transistors were as follows (source - Mullard Data Book, 1973/4, 'Mister Transistor' and other websites – see References):

- OC44: IF and low-level AF amplifier
- OC45: IF and low-level AF amplifier
- OC71: Low-level AF amplifier (black-painted glass case type SO-2)
- OC72: Higher-power version of OC71 (metal case)
- OC81D: AF output stage driver transistor
- OC81: AF driver and push-pull medium-power output
- OC83: AF driver and push-pull medium-power output
- AC126: AF pre-amplifier and driver stages
- AC127: High gain (NPN) AF output – complementary symmetrical Class B output stages
- AC128: High gain (PNP) AF output – either complementary to AC127 in push-pull, or as single-ended, Class A
- AC187: Higher gain and higher power (NPN) AF output for Class B push-pull output stages
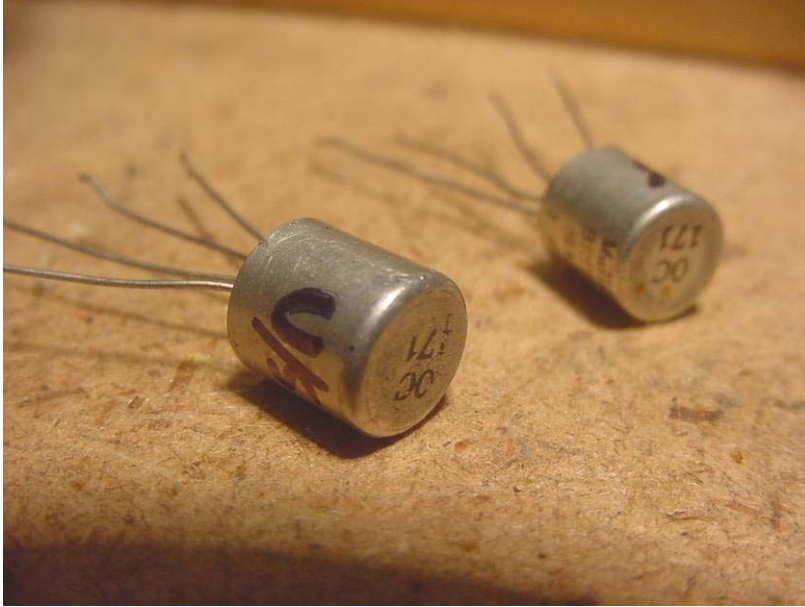- AC188: The (PNP) complementary transistor to the AC187

These medium-power output transistor types must be mounted on a suitable heatsink, particularly when run near their maximum dissipation. A thin smear of thermal compound should be applied to the heatsink/transistor/insulator contact when mounting replacements.

Typical applications for the early RF germanium transistors (all PNP) were as follows (source - Mullard Data Book, 1973/4, 'Mister Transistor' and other websites – see References):

- OC169: Earlier version of AF114
- OC170: Earlier version of AF116
- OC171: Earlier version of AF116/117
- AF114: RF pre-amplifier in VHF/FM front ends
- AF115: Mixer/oscillator in VHF/FM front ends.
- AF116: IF amplifier for 10.7MHz used in FM receivers.
- AF117: General purpose RF/mixer/IF amplifier in LW/MW/SW receivers.
- AF118: Higher voltage (75v) video amplifier for transistor TVs.

In practice, the AF125 can be used to replace AF114/115/116 series, however, there is no listed equivalent to the AF118. Alloy-drift transistors tend to be noisy at low frequencies and as such are not generally suitable for audio circuits. Another point to watch is that

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equivalent books often list the AF239S as a replacement for the AF114/115/116 range. However the AF239S is a UHF device designed for use in TV UHF tuners and has a relatively low gain compared with the AF114-118 types and is therefore not a good substitute. If a direct replacement or equivalent transistor cannot be located, or if you are replacing a transistor with a 'junk box special', the replacement can be tried out by temporarily tack-soldering it to the print side of the circuit board with the faulty device removed – this way several devices can be tried quickly and without damaging the circuit board.

The gain (hfe) of germanium transistors is generally lower and far more variable than silicon devices and is also strongly dependant on collector current and ambient temperature. The base-emitter voltage (Vbe) is also lower for germanium at 300mV compared with 600mV for silicon. For this reason a silicon transistor cannot normally be substituted directly for a germanium device without modifying the DC biasing arrangements, although some sources report that the (silicon) PNP type BF450 will often work quite happily without any circuit modifications in RF, LO and IF amplifier stages (I have not tried this myself).

Silicon Transistors and FET's

Silicon transistors tend to be rather more reliable than germanium types (especially more-so than the very early germanium types). However, they still fail for the reasons discussed in this article. As for germanium types, many early silicon transistors are now unavailable, and with the continuing trend towards surface mounted technology, there are even suggestions that transistors with leads are becoming scarce…
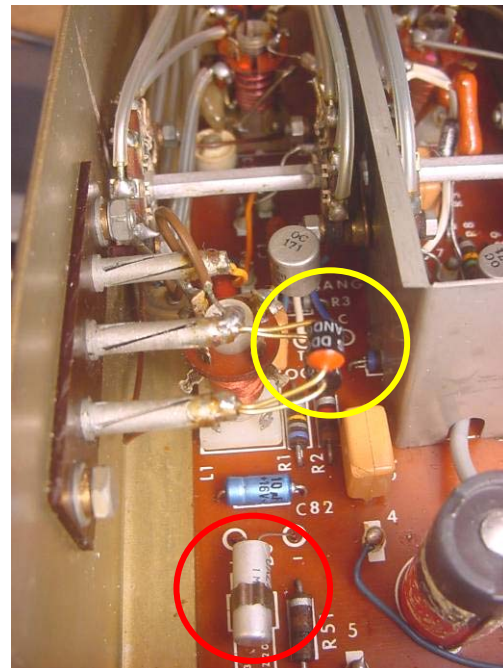
For small-signal AF and DC switching applications, the BC107, BC108 and BC109 range are good to have available. A good low-cost general-purpose RF NPN silicon transistor to have in your junk box is the 2N2222A. For FET's, the ubiquitous 2N3819 and J310 JFETs are a very common types, as is the 40673 dual-gate MOSFET - these may be useful to have in stock.

Diodes

Diodes used in early Eddystone solid-state sets' small-signal circuits are OA70, OA79 and OA90 point-contact types (photo, left). All these diode types are germanium point-contact diodes. The type OAZ203 6.5 volt zener diode (circled red in photo, right) was used for voltage stabilization and BA111 varicap was used for fine-tuning control in the EC10 MkII. The (still) readily-available general-purpose OA91 point contact germanium diode may be used as a substitute for the OA70, OA79 and OA90, though other point-contact diodes will also work well in most applications, eg. OA47, OA81 and GEX33-GEX55 types - these can also be readily salvaged from scrap transistor radios.

Characteristics of some germanium point-contact diodes is provided below – bear these in mind when making substitutions, especially the inverse voltage rating. In many applications small signal silicon diodes, eg. 1N914 or 1N4148 types, will also be found to work ok.

Type	Max Inverse Voltage Peak	Average	Max Forward Current Peak	Average
OA70	22.5v	15v	150ma	50ma
OA71	90v	60v	150ma	35ma
OA79	45v	30v	100ma	4 ma
OA81	115v	90v	150ma	50ma

Modern silicon zener diodes (eg. BZX series, 1N4735 series) may be substituted for the OAZ203. I have had success using small silicon rectifier diodes in varicap applications (all diodes exhibit varicap characteristics to some extent, ie. the diode junction capacitance varies depending on the level of reverse bias voltage applied), although if a 'real' varicap diode can be found with similar characteristics to the BA111, use one in preference.

Front-end protection diodes, when present, were usually the DD006 type (circled yellow in the photo, above right), though I have had success with fitting 1N4148 silicon types.

Other Considerations

It is not only the challenge of the semiconductor technology itself that can be off-putting for those more familiar with valve technology, but the actual construction method of the

circuits: instead of the easily-repaired point-to point or tagstrip wiring and easily-replaced valves, the vast majority of solid-state circuitry is built using printed circuit methods with the semiconductors 'hard-wired' into the circuit. The main issue here for successful servicing is that of careful de-soldering/soldering techniques. This comes down to practice and the use of proper tools. Some key points to bear in mind include:

- Purchase a good-quality temperature-controlled soldering iron with a fine chisel tip (the blue one in the photo, right) – it will pay for itself many-fold. This tool will result in better and quicker soldered joints;

- Practice de-soldering techniques on a scrap circuit board until you can do this successfully without damaging the tracks. Try different tools and de-soldering aids, eg. flux-impregnated de-soldering braid, de-soldering pumps and specialist de-soldering stations/irons (photo, right);

- Clean the leads of the new component by gently scraping with a knife before soldering (especially if the component is NOS or has been in your junk box for years);

- Don't trim component leads until they have been soldered – then use a pair of good-quality wire cutters to trim the excess;

- Speed is important – apply sufficient heat with the soldering iron to result in good solder-flow and a nice shiny joint, but not so much that the component you are soldering is damaged or the track detaches from the printed circuit board;

- Use a small-gauge rosin-cored solder – this allows the joint to be made quicker than larger-gauge solder;

- Traditional advice for soldering semiconductors often includes using a heat-shunt on a transistor or diode leads while soldering – I don't bother in most cases (especially if it is awkward) – instead, just use the advice above. If you *do* want to be extra-cautious and use a heat-shunt, try an alligator clip or a pair of locking tweezers so your hands are free for manipulating the solder and soldering iron.

Don't forget to re-install any insulation materials that may be present (eg. mica washer) and a dab of thermal compound when installing replacement output transistors - or any other sort of higher-power semiconductor device for that matter.

Many push-pull output stages employed 'matched' pairs of transistors – if replacement is undertaken without matching, you may find that the sets audio is distorted, particularly at low levels. In extreme mismatch cases, the DC operating conditions of the circuit may be impacted, resulting in premature device failure.
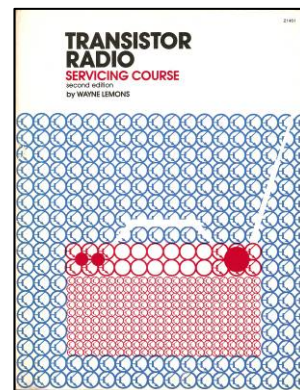
When an RF, mixer, LO or even an IF transistor has been replaced, the circuit alignment should be checked as different internal capacitances of the devices can affect the tuned circuits associated with the repaired stage.

An important point to remember with sets that use predominantly PNP transistors is that they (usually) have a *positive* common (ground) connection. We are so used these days of having the power supply line being positive and the common (ground) connection being negative that we are apt to forget this. Under normal operation of the set this is not a cause for concern, but when the set is out of its case for repairs/servicing and you connect a temporary power supply to perform checks, <u>BE EXTRA CAREFUL</u> and double-check the sets polarity before switching the power on. A moment of carelessness (or complacency) here can be expensive, time-consuming and more than a little annoying.

Experience is something we gain just after we needed it - but applying someone-else's experience can help a bit… Also, don't forget to drink some tea!

Closure

This 'Short only touches the tip of the subject of semiconductors used in Eddystone sets, focusing on the early (and simpler) ones that left the Bath Tub in the 1960's through 1970's. However, for those unfamiliar with the vagaries of the use and failure of semiconductors in earlier Eddystone (or other) solid-state receivers pre-dating the introduction of IC's, there is hopefully enough material here to get you working on these sets with some confidence (and, hopefully success!). Several suggestions for further reading are given below and I would particularly recommend the book by Wayne Lemons (photo, right) which includes an excellent section on troubleshooting solid-state radio circuits (this book is often for sale on Ebay). Also, several websites are suggested that cover semiconductor theory, substituting and fault-finding, as well as some that cover the development of solid-state technology from its inception in the 1940's.

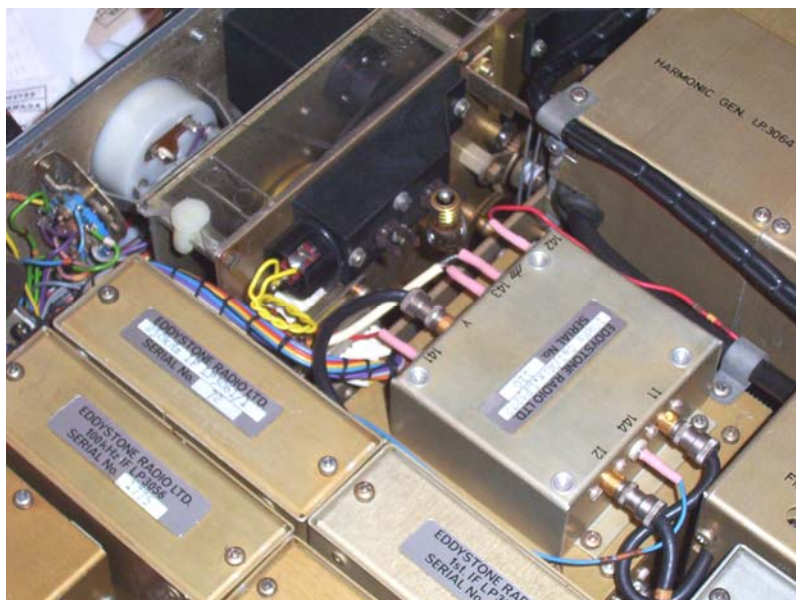© Gerry O'Hara, G8GUH/VE7GUH, Vancouver, BC, Canada, April, 2008

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- http://homepages.nildram.co.uk/~wylie/Mullard/Mullard.htm ('Mister Transistor')
- http://learnabout-electronics.org/index.php ('Learn about Transistors')
- http://users.arczip.com/rmcgarra2/index.html (Transistor Museum - excellent site)
- http://www.elexp.com/t_solder.htm
- http://www.kpsec.freeuk.com/components/tran.htm
- http://semiconductormuseum.com/Museum_Index.htm (Another transistor museum - also excellent)
- http://hometown.aol.co.uk/oldradioparts/semiconductors.htm
- http://www.uoguelph.ca/~antoon/tutorial/xtor/xtor8/xtor8.html

- http://www.eie.polyu.edu.hk/~ensurya/lect_notes/commun_cir/Ch2/Chapter2.htm#DualGateFET
- http://sound.westhost.com/trans.htm (Transistor terms and specifications, including OC44, OC45, OC70, OC71, OC72, AC125 - AC128, AC187, AC188, AF114 – AF118)
- http://vintageradio.me.uk/info/transistor1.htm (transistors information and data sheets)

Above: My EC958/3 – looking every bit as good as an Eddystone valve set (so much so that I get a surprise when I switch it on and it does not need to warm-up!). I mean, even the dials are lit-up to look like they belong in a valve radio… Right: Under the lid of the EC958/3 – hey, where did all those valves, er, I mean transistors, go?

Above: New old stock (NOS) 1960's-vintage germanium semiconductors resplendent in their original packing. Note the prices, ranging from 3 shillings (15p or 30c) for the OA90 point-contact diodes, to a whopping 8 shillings and 3 pence (42p or 84c) for that 'exotic' OC44

Above: the oft-dreaded printed circuit board construction – shown here is the print side of the RF board in my EC10 MkI following replacement of the Mixer and Local Oscillator transistors