Refurbishment of Two Sophisticated WWII Era Tuned Radio Frequency, Very Low Frequency Receivers (Part 1) – Gerry O'Hara

A friend asked me to refurbish two very low frequency (VLF) receivers: a Marconi B29[1] and an RCA TE-236-B. These are both sophisticated tuned radio frequency (TRF) sets dating from the early-1940's[2], and although sharing the same basic topology as TRF sets from the 1920's, their standard of construction and performance is in a different league. **Part I of this article covers the B29 and Part 2 the TE-236-B.**

But why were TRFs being used in active service during WWII when the 1930's saw the proliferation in superheterodyne topologies, reaching a level of sophistication, features and performance that remained the standard for the following two to three decades? Surely their presence on the front line for critical ship to shore communications, including use on submarines, was an anachronism? Well, for VLF reception, there is no real need to convert the signal frequency to an intermediate frequency if care is taken in the electronic and mechanical design to avoid unwanted feedback and oscillation. The use of pentode tubes, plentiful bypassing of unwanted RF, care in component and lead dressing, and careful attention to screening the different stages from each other can accomplish this. The benefit is that a well-designed TRF using late-1930's components and design methods at VLF has sufficient gain and is inherently less noisy than a superhet as the mixer in a superhet introduces noise into the signal path. Also, if the radio is primarily for CW reception, which these sets were intended for in Navy service, adequate selective filtering could easily be accomplished at audio frequencies.

Marconi B29

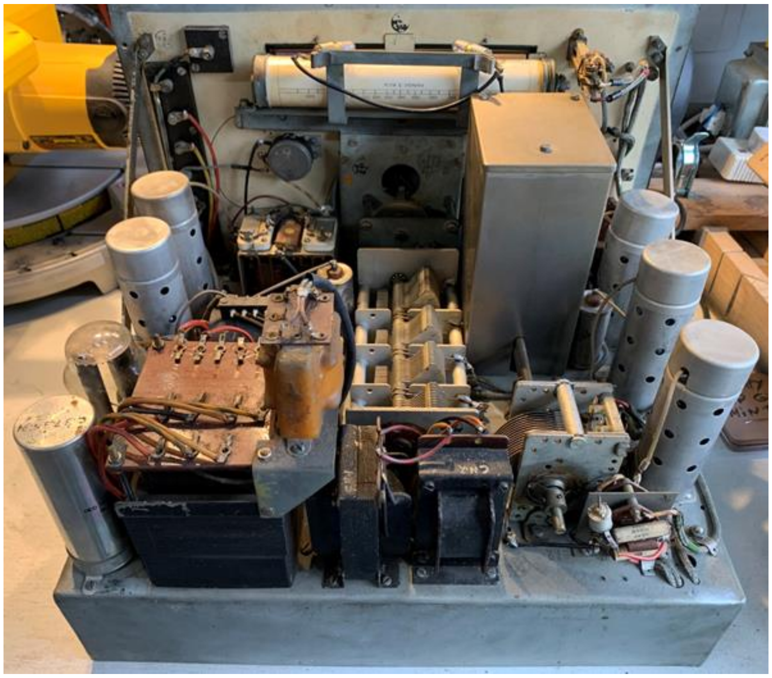
This set (photo, right) is really 'bomb proof' - constructed from heavy-gauge cadmium plated steel with lots of 'iron' (transformers and chokes) - I really struggled to turn it over on the bench.

Preliminary Inspection

Although being kept in a tight-fitting steel cabinet, the chassis (photo at top of page 2) was quite grubby and corrosion was present on several components, especially the metal-clad capacitor cases. Other than that, the chassis was in reasonable shape and the chassis looked complete. The construction style is interesting, with several unusual controls operating in novel ways, eg. the 'Input' control, which selects the coupling method to the antenna ('Tune', 'Standby', 'Loop 1' or 'Loop 2'), operates a twin wafer switch mechanism via a neat dual crank system, a radar interference suppression (RIS) control to blank out radar pulse interference, sporting a bright red knob, and a 'Het.

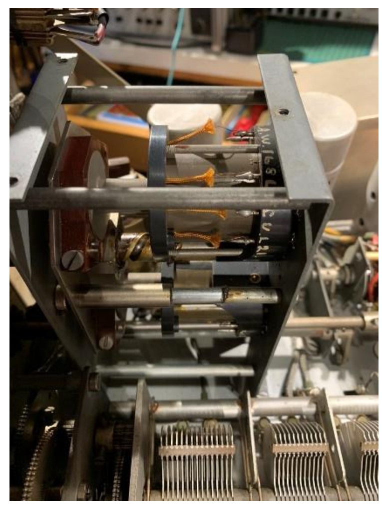
[1] I understand that this particular B29 receiver was operational on the cruiser HMCS Ontario

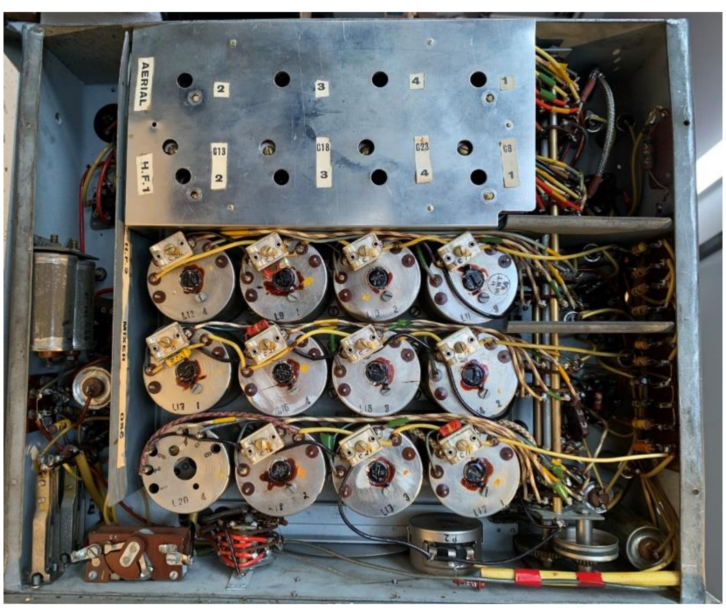
[2] The TE-236-B is based on the RCA RAK receiver design, the first contract for which dates from 1935



Vernier' control, used to detune any undesired heterodynes close to the desired signal - this operating a large helical screw that moves two large powdered iron slugs in and out of two coils. I noted that one of the two slugs in the Het. Vernier circuit was not present (photo below, right) - likely lodged in the corresponding coil former. The dial cord that operates the pointer was broken, but the band change cord was intact - this rotating the scale in the viewing window on the front panel when each band is selected.

The B29 circuit only has six tubes: two RF amplifiers (2 x 6K7G), detector and BFO (6K8G), 1st audio (6Q7G) and output (6J5G), with a 5U4G rectifier in the AC-operated power supply circuit - the set is designed for AC or DC operation, with the AC power supply integrated onto the chassis. As the set is not a superhet, the BFO must track close to the received signal, in this case 1KHz off, and this frequency is then selected by a 1KHz audio filter. This can result in annoying heterodynes with image signals 2KHz above or below the wanted signal frequency. To overcome this, a 'Heterodyne Vernier' (Het. Vernier) control is fitted that independently tunes the tracking BFO using a permeability tuning system that can be adjusted such that the unwanted heterodyne is outside the range of the 1KHz audio filter. The set is also fitted with a 'crash filter' (limiter) and a radar interference suppression (RIS) system – a sort of noise blanker synchronized to the radar system on the ship the set is being used on.





Much of the under-chassis 'real estate' is given over to the various tuned circuits (photo, left), which are large, due to the LF coverage, and well-screened, as is necessary in high-gain TRF receivers, plus a tag board mounted on the side of the chassis sporting a number of Erie ceramic bodied resistors. The upper chassis is home for the four gang tuning capacitor, a large box containing the 'Het. Vernier' permeability tuning mechanism, output transformer and the power supply components. Interestingly, almost every component had its circuit identifier hand-written onto it, including the resistors. The bypass and coupling capacitors in this set are all metal-clad types, many with relatively high values, eg. 1uF, required due to the low frequencies being bypassed (into the audio range at 15KHz). This needed some thought as to ways these could be replaced without re-stuffing each one, assuming they had failed/are failing. I was concerned these may be paper-in-oil types and that they could contain PCBs – the only way to find out for sure was to open one up, taking appropriate precautions (safety glasses, mask and nitrile gloves) and take a look.

Parts of the chassis were covered in white corrosion residues – presumably cadmium salts from the cadmium-plated steel. Cadmium and its residues are nasty stuff, so I donned nitrile gloves and used a rag and Q-tips moistened in rubbing alcohol to remove this before starting work, disposing of the rag, etc. afterwards. Little further cosmetic work was undertaken on the B29, though I did clean up the front panel and knobs as it looked like it had been sprayed with hot candle wax at some time! A short video of the initial inspection can be viewed here.

The set's owner wished the set to be functional and was not too concerned with the internal cosmetics, especially the under-chassis, thus straightforward capacitor/resistor replacement was ok (no component restuffing necessary). However, due to the form of construction used, some of the components, eg. some of the 1uF metal clad capacitors, often mounted vertically on the chassis, would not lend themselves to easy replacement and/or would look 'bodged' if not restuffed, especially if the replacement parts were located above the chassis.

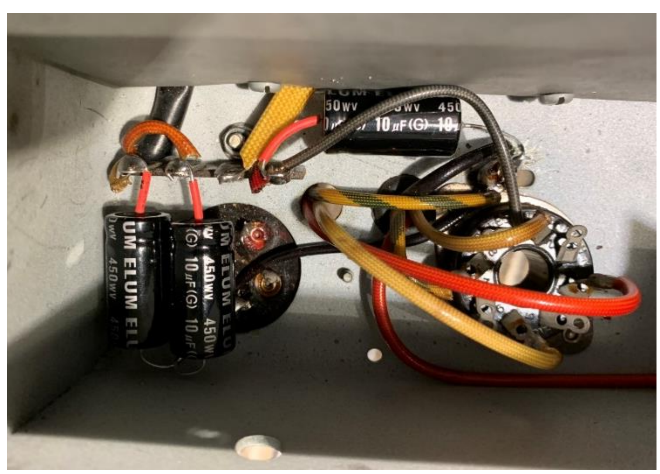
Refurbishment

I removed one of the metal-clad 1uF capacitors, and cut into the case with a hacksaw close to the upper end, taking precautions to catch any spilled oil – however, it turned out to be a 'dry electrolytic' type (photo, top right). The innards were a bit difficult to remove, but once they were out (photo, middle right), it was a simple job to restuff it with a new 1uF plastic film part (photo, bottom right): I added a solder lug to the fixing screw (on the inside of the metal capacitor case), and drilled a 1mm hole through the insulated top cap connection. One lead of the new capacitor was soldered to the solder lug (ground end) and the other lead threaded through the 1mm hole and soldered to the insulated top connection. A cardboard sleeve was glued around the inside of the metal case to help join and align the two parts, and a thin band of metal tape wrapped around the join before re-installing the capacitor onto the chassis.

I repeated this exercise for another above-chassis metal clad capacitor – this one was a coupling capacitor in the audio output circuit, not a decoupling one, so the insulated top cap had two solder lugs present where the capacitor leads were connected to instead of one being connected to a solder lug attached to the case (photos, right). Another chassis mounted metal clad coupling capacitor above the chassis, in the RIS circuit, could not be easily removed for re-stuffing as the nut securing it was located directly beneath part of the band change switch wafer stack and removal of that would have been extremely time consuming and prone to making a switch wiring error on replacement. Instead, I disconnected the original part, sleeved a yellow-bodied capacitor in black heat-shrink and tucked it out of sight behind the RIS potentiometer. This particular capacitor is not present on the schematic, where it is shown as a direct connection – I assumed this was a later modification to improve the RIS circuit which operates by applying a blanking pulse to the two RF amplifier suppressor grids, the level of which is adjustable by the front panel RIS pot. I doubt the owner will use this circuit, but as it may be used on a WWII tugboat that he owns, maybe he will…

While investigating the RFI circuit arrangement, I found that the pot could be rotated through 360 degrees and the resistance value remained the same(!) – it's a 100Kohm linear taper part. I removed it from the chassis, opened it up, and found that the control shaft had detached from the rotating slider. I cleaned-up the end of the control shaft, applied liquid flux and soldered it with the mighty 'Wall' solder gun (photo, left). I also cleaned the track with Deoxit before reassembling and refitting the pot to the set.

The remainder of the above-chassis metal-clad capacitors were replaced by components located under the chassis, along with replacement of the metal-clad capacitors located under the chassis. I left the original parts in place above and below chassis, and left 'dummy connecting leads' in place above the chassis (part of the conductor removed from inside the insulation) for appearances. I also disconnected the power supply 3 x 8uF filter capacitor and replaced it with three new 10uF capacitors mounted on a small tagstrip (photo, right).



Initial Testing

Following some resistance checks between key circuit nodes, I plugged a pair of 'phones into the set and powered-up the chassis using a Variac. It started to operate at around 90vAC.

I confirmed that the set was operating on all bands, and that the BFO, 1KHz audio filter, RF/AF gain controls, input selector, and the Het. Vernier control were all working (the broken permeability tuning slug was glued back onto the moving carriage). However, the antenna tuning control did not seem effective, though I figured that it likely required the correct impedance antenna to function correctly. The broken dial cord prevented confirmation that the set was tuning accurately, though checking at the low and mid-points of each band by positioning the tuning gang plates, showed that the receiver was working on all bands and was in reasonable alignment. Something was jamming the tuning mechanism around two-thirds from the low frequency end (tuning gang fully meshed), so I could not check the top of each band for accuracy (the broken dial cord was jamming in the gears).

Three videos can be viewed of the above initial testing:

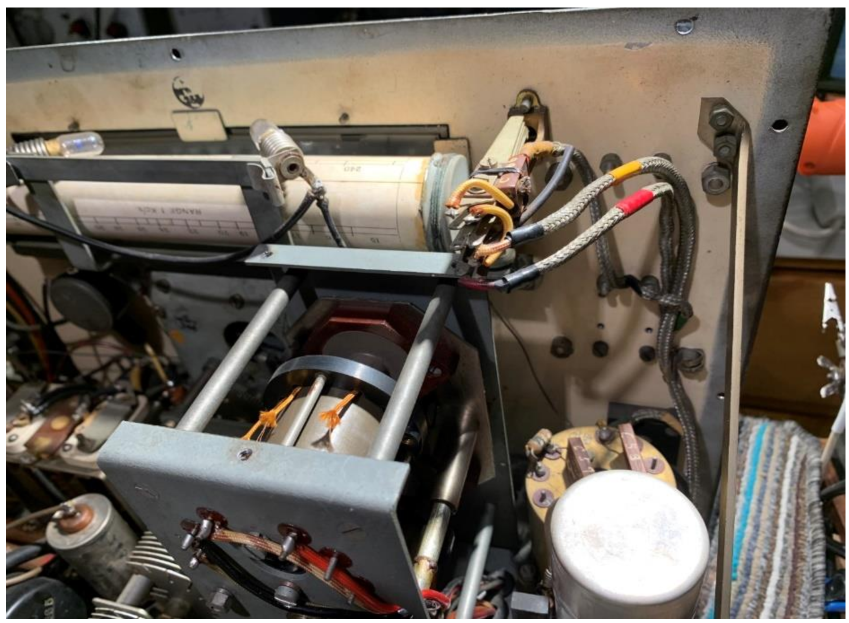
Function test part 1 (upper two frequency bands).

Function test part 2 (lower two frequency bands).

Permeability tuning mechanism ('Het. Vernier' control), dial cord problem and recap description).

Repairs and Workarounds

Replacement of the dial cord on a B29 is no mean task: it requires the removal of the front panel, which, in turn, requires the removal of many screws and controls (photo, right) – no big deal (apart from the inaccessibility of many), but also the removal of all the knobs – again, this should be no big deal, but it was(!). The band change and function switch knobs and the (metal) input



selector lever are held in place by a combination of set screws and small (tapered?) metal pins that pass through the knob and the shaft (circled yellow in the photo, left). These had all seized solid and after a couple of hours I gave up trying, concerned that I would damage the knobs… I have had similar issues with this type of arrangement before, but with larger, tapered pins that had seized, and that allowed a drift or punch to be inserted and the pin knocked out after application of penetrating fluid. These pins are so small that nothing I had in the tool chest would do the job. Options were to:

- persevere trying to remove the knobs/lever, taking more drastic action to remove the pins, risking significant damage to the knobs, ie. attempting to drill the pins out; or
- deliberately destroy the knobs, eg. using a Dremel tool and cutting wheels, and replace these with ones of similar design; or
- leave the pointer as non-functional and tap the BFO signal to feed to a digital frequency meter (DFM), giving the receiver a digital display - this would be 1KHz off the tuned frequency, however this should not be a significant issue in practice.

I discussed the front panel/dial restringing issue with the sets owner. After discussing the options, he thought the DFM readout option would be a good solution if it could be made to work. Also, he noted that he has a machinist friend that he thought may be able to make a suitable drift tool/press to remove the recalcitrant metal pins from the knobs without destroying the knobs in the process – this would best be done when the set is back in the owner's possession. If that is successful, the front panel could then be removed and I would then restring the dial to retain original functionality, but in the meantime the digital readout solution would allow the set to be used. I had also asked around to see if anyone I knew had similar knobs in their junk boxes to replace the originals if I simply cut the knobs up to remove them using a Dremel tool, but no one had, so that option was off the table as the owner wished to retain the original external appearance of the set.

I had undertaken a similar digital readout of the tuned frequency exercise on my Eddystone 940 receiver some time ago (see article here), using a small capacitor attached to the stator of the local oscillator. I had experimented with the capacitor value and found a 3pF silver mica part worked well in that case, providing sufficient coupling without loading the oscillator circuit significantly. For the Eddystone 940, I was reading the local oscillator signal up to 30.460MHz and the DFM unit I was using had a pre-set IF frequency (460KHz) offset, whereas In this case, I would be reading the BFO signal directly from around 15KHz to around 560KHz as this is a tuned radio frequency set with the BFO tracking around 1KHz away from the received signal frequency.

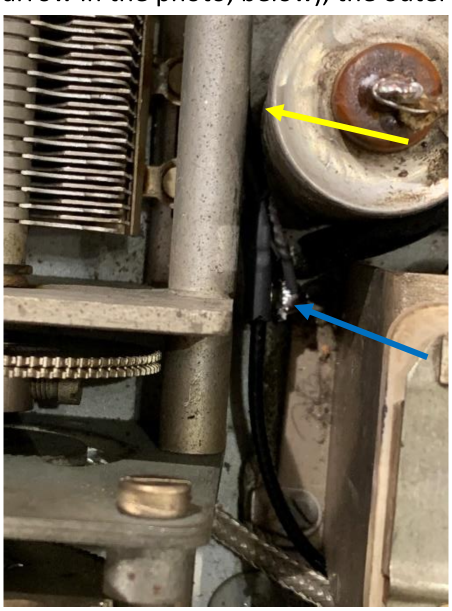
The connections to the BFO section of the tuning gang stator in the B29 are a little awkward to access, so I first tried a small capacitor attached to the oscillator (triode) grid of the 6K8 tube under the chassis. This worked ok with just the 'scope attached (10Mohms input impedance and around 15pF capacitance), but attaching the DFM (an old 1Mohm input impedance BK Precision DFM) stopped the oscillator working at the lower frequencies on each band. So, I persevered in attaching a small (10pF) silver mica capacitor to the tuning gang stator tag and connected this through some miniature coax to the 'scope and the DFM (photo, right). I added a 1Mohm resistor in series with the DFM to provide a little further isolation. I found that the signal at the DFM varied from around 2v p-p

(across the lowest frequency band) to around 200mV p-p at the upper end of the highest frequency band. The BK Precision DFM requires around 60mV p-p to provide a reliable frequency readout and can handle up to 200v p-p, so this was ok. A video showing this setup in operation can be viewed here.

Next, I experimented with the value of the coupling capacitor to the tuning gang stator until I had it optimized, ie. finding the correct balance of adequate coupling to the DFM with minimum pulling of the oscillator. The 10pF value was on the high side, causing some loading ('pulling') of the oscillator at its highest frequencies such that it was not reaching the highest frequencies on the dial. Once optimized, any remnant error should be removed during the alignment process.

I found that the optimum coupling capacitor size was between 2pF and 3pF. This very small capacitance value, used without the 1Mohm series resistor, provided around 2v p-p with only the (10Mohm) input of the 'scope attached, dropping to between 1v p-p and 1.5v p-p with both the 'scope and (1Mohm) input of the BK Precision DFM attached, with no noticeable change in oscillator frequency when connecting either instrument.

Given the very tight space for the coupling capacitor adjacent to the tuning gang, and the very small capacitance, I decided to use a 'gimmick' capacitor in place of a silver mica type. This was constructed from two lengths of very thin insulated wire twisted tightly together, with one end of each wire stripped of insulation. I inserted the leads into a capacitance meter and snipped short pieces of the twisted wires away until the capacitance measured 2.5pF (photo, above right). The 'gimmick' was then sheathed in heat-shrink (photo, below right), and I then soldered one of the leads of the 'gimmick' to the inner wire of a length of miniature coax and the other to the tuning gang stator (tip of the yellow arrow in the photo, below), the outer sheath of the coax being connected to the closest chassis ground (tip of blue arrow). The coax was threaded through an existing grommet to below the chassis. I removed one of the 'phones sockets from the front panel and replaced it with a BNC socket, then connected the other end of the miniature coax to the BNC socket. I insulated the removed phones socket and tucked it out of the way under the chassis, securing it in place with a plastic cable tie. This mod is therefore very easily reversed.

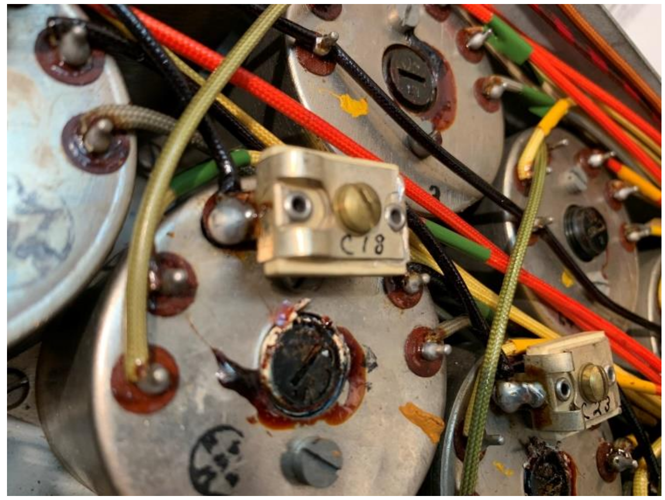


I tested the DFM operation again (photo, top of page 8), and found that it was working well and that the lesser loading on the oscillator allowed the highest frequency tunable on each band to be higher than previously, and only a few KHz below the analogue dial markings at the top end of the two highest frequency bands, and therefore certainly correctable during the alignment process.

The receiver was then placed on soak test for a day or so, before re-checking resistor values/replacing any that had drifted significantly out of tolerance, and clean the switch contacts and controls with Deoxit, before proceeding with alignment. In the meantime, I decided to improve the front panel antenna connection. There is provision for four antenna options on this receiver: a low impedance loop ('Loop 1'), a high impedance loop ('Loop 2') – these are both intended for use on the lower two bands when the receiver is installed in a submarine and single-turn loops are used for submerged reception, an 80ohm (balanced) input, using an Admiralty Pattern ('AP') 7151 3-point telephone plug phones-type jack socket, and a 'vertical' (unbalanced) antenna, connecting to the coaxial 'Antenna' connection (AP 1429) located on the front panel gas-gap spark arrestor housing on the left side of the receiver front panel. The 'Input' switch selects how these antennas are coupled to the 1st RF amplifier. Only in the 'Tune' position does the antenna tuning control become effective. I decided that the 'Tune' position of the input switch was the most appropriate for general reception purposes as this would allow the antenna tuning control to be used to peak the signal on a given antenna connected to the coaxial input. However, the AP 1429 connector is not generally available, so I decided to add an SO239 socked to facilitate connection using standard PL259 plugs (or BNC with an adapter). The gas-gap spark arrestor housing on the front panel has an inspection window for the glass gas-gap cartridge and the SO239 socket conveniently fitted this without any modification (photos, left). The SO239 socket was connected to either side of the gas-gap cartridge holder, making for a neat and easily reversible installation.

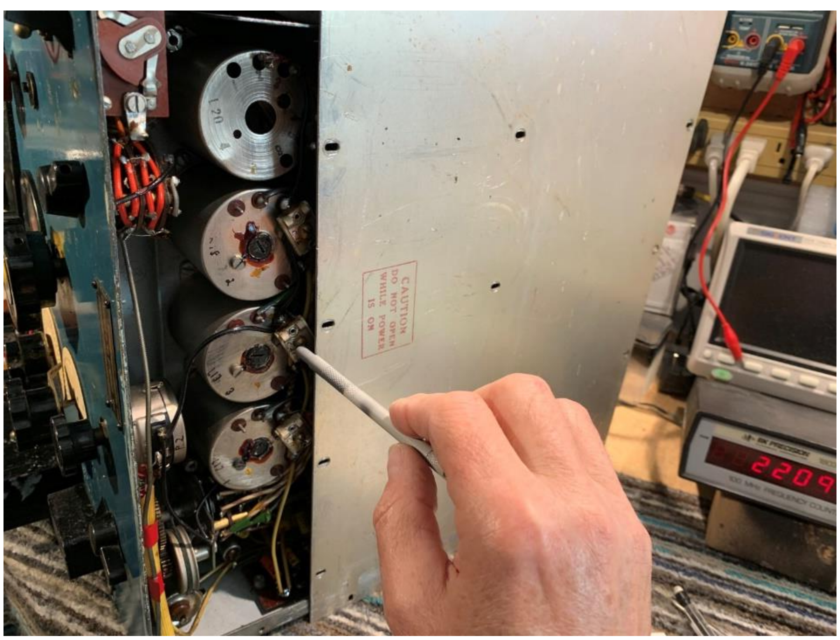
Alignment and More Refurbishment

Following installation of the SO239 socket, I undertook a preliminary re-alignment to check that the new socket was functioning correctly and that it was possible to re-align the set with the DFM connected.



During this, I found that there were two faulty sliver mica compression trimmers (photo, right) – one on Band 3 and one on Band 4 1st RF amplifier stages. I removed these trimmers, cleaned them thoroughly, and re-seated the moving plates correctly (they were shorting to ground during adjustment). This cured the problem. I noted in the alignment instructions that a "*false [metal] bottom pierced with holes for adjusting the various trimmers*" should be fitted to the chassis before alignment. There is such a 'false bottom' fitted over the antenna and 1st RF stage tuned circuits, but not the remainder. I decided to assess what effect a metal plate would have by placing a solid metal plate over the tuned circuits spaced approximately the same distance as the cabinet bottom away. Drilling a metal plate for a 'one off' use would be a lot of effort and I considered that I would do this only if the detuning caused by the plate was significant. In the meantime, I found that I could align all the stages correctly (no plate installed) and could achieve the full range on each of the bands. I noted that not all of the coils and trimmers were in the locations shown on the diagram in the service information. Thankfully, all coils and trimmers were marked with their correct part numbers – either hand-written or stamped onto the components.

I checked the values of all the resistors and most were well within the 20% tolerance rating, with only a couple close to tolerance, so none were changed out. Next, I cleaned all the switches and controls with Deoxit, paying special attention to the band change switch and input switch contacts. I also cleaned and re-lubricated the tuning gang and tuning drive gears. I also replaced a couple of the wires to the (unused) 'phones socket as one had snapped off, silencing the receiver when I was working on it (all the wiring in the set is thin tinned solid copper wire sleeved with phenolic-impregnated cloth – the thin solid wire is prone to snapping if bent a few times).



I then undertook a more careful alignment of the RF and BFO sections. To check what effect the presence of a metal plate (simulating the bottom of the steel case) would have on the receiver tuning, I used a plain metal sheet grounded to the chassis to check what effect this had when held across the underside of the chassis (photo, left). It had minimal effect across Bands 1 and 2 and only a slight effect at the upper ends of

Bands 3 and 4, shifting the frequency downwards by around 100Hz on Band 3 and 30Hz on Band 4, with no discernable drop in signal strength. I also found that I could place the metal sheet half-way over the BFO coil pack and then adjust the trimmers to compensate for the presence of the metal plate.

Closure on the B29 Refurbishment

I was impressed by the sensitivity of such a simple receiver (2 RF amplifiers, detector and two audio stages – sort of a 1920's TRF set on steroids) – it is able to detect a 1uV signal across all bands with the BFO operational. I think this level of performance is largely due to the relatively low noise level of the TRF design (no mixer noise), with gain maximised by careful design and use of high-Q coils. Selectivity is not as good as a superhet design, though with the 1KHz audio filter switched in it is remarkably good at picking an extremely weak CW signal out of the noise.

Before it left the bench I made a brief demo of the B29 receiving a ~1uV signal at 560KHz and how effective the 1KHz audio filter is for CW reception – check it out here.

Conclusions and Comparison of the Marconi B29 and RCA TE-236-B

Note: please refer to Part 2 of this article for the RCA TE-236-B refurbishment.

My conclusion on the RCA TE-236-B receiver (covered in Part 2 of this article) was that it is approaching the pinnacle of TRF design and performance - if not at the pinnacle – though that esteemed position may be reserved for the RAK-7 with its addition of metering and more sophisticated 10-position audio filtering circuitry, or the later RBA models. The RCAs superlative construction quality and 'brute strength' robustness are an easy win over the Marconi B29. The RCA also offers improved RF stage signal peaking, an AGC circuit, and switchable frequency audio filtering. That said, the B29 puts up a stalwart and very respectable performance too and either receiver would be up to the Navy's requirements for a robust, stable and reliable VLF set for CW operation.