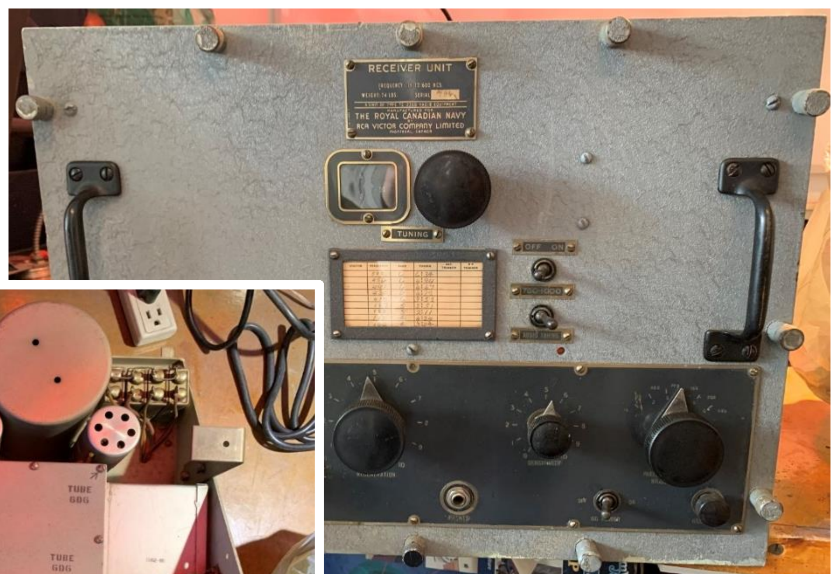
Refurbishment of Two Sophisticated WWII Era Tuned Radio Frequency, Very Low Frequency Receivers (Part 2) – Gerry O'Hara

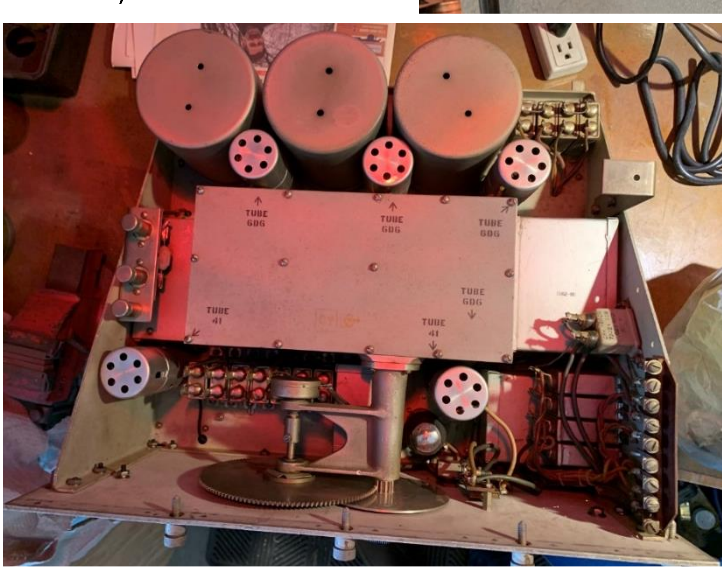
A friend asked me to refurbish two very low frequency (VLF) receivers: a Marconi B29[1] and an RCA TE-236-B. These are both sophisticated tuned radio frequency (TRF) sets dating from the early-1940's[2], and although sharing the same basic topology as TRF sets from the 1920's, their standard of construction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

RCA TE-236-B

Preliminary Inspection



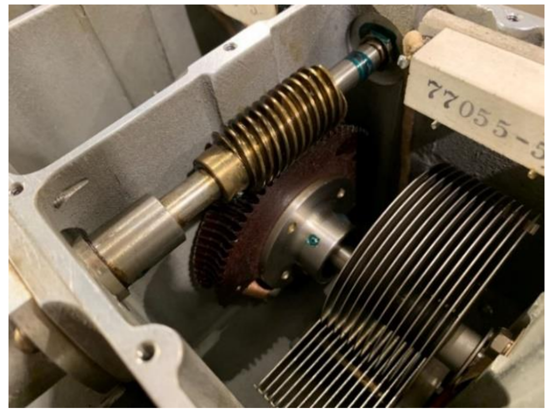


`An initial 'once-over' of the formidable, nay, mighty, RCA TE-236-B (RCA) chassis (photos right and below) showed that its construction quality is second to none and in a completely different league to the Marconi B29. As far as I can tell, both receivers were designed to do very similar jobs, covering the VLF bands from 15KHz through to the lower

[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

end of the Broadcast Band (600KHz in the case of the RCA). As well as the construction quality, the electronic topology of the two sets is somewhat different, even though they are both tuned radio frequency designs: the RCA has two RF amplifier stages, like the B29, though uses the earlier 6D6 pentodes[3] (the B29 uses 6K7s), with a simpler, tapped RF coil design. It dispenses with the separate BFO oscillator that the B29 uses and, instead, an 'autodyne' regenerative detector is used in the RCA (another 6D6 pentode) to generate the tone for CW reception - in theory, this could provide some additional sensitivity and selectivity over the B29 arrangement. Like the B29, the detector is followed by two stages of audio amplification (a 6D6 and a #41 tube), with selectivity enhanced by a high quality audio filter – the RCA filter is a more sophisticated four-section Pi filter that is switchable between 750Hz and 1KHz (this is a scaled-down version of the filter fitted to the very similar RCA RAK-7 receiver which has ten audio filter frequency selection options). The RCA also sports an active Automatic Volume Control (AVC) circuit (#41 tube) fed from the audio output signal. When switched in, this limits the audio output level to an amount set by the AVC control on the front panel.



The RCA chassis does not have an integrated power supply and requires an external power supply providing an HT voltage of 180vDC (45mA), a 90vDC (stabilized) supply for the screen voltage on the regenerative detector tube, and a 6.3v (2A) heater supply. The chassis contains no electrolytic capacitors and, apart from several silver mica parts, all the capacitors are top-quality chassis-mounted metal-clad paper-in-oil types, mostly 0.5uF and 1uF values. The chassis is an all aluminum/alloy construction using thick castings/plates, and all mechanical parts are extremely heavy-duty: the worm gear drive for the tuning gang is of particular note and is massively 'over-engineered' using a huge brass worm gear engaging a concave-faced helical gear on the tuning gang shaft – photo, above. The 2nd RF stage and detector grid coupling capacitors, located in the tuning gang compartment, are an unusual oblong ceramic bodied design that resemble 'modern' power resistors (see part marked '77055-5' at the top right of the photo, above). Most resistors are mounted on tagstrip(s) and, thankfully, most of the wiring is cloth-covered, though some rubber-insulated wiring is present, eg. in the tuning gang compartment/RF coil connections (photo, left), the 6D6 tube grid connections, and audio output stage.

[3] The 6D6 and #41 tubes were both introduced in the early-mid-1930's. The use of these rather 'long-in-the-tooth' tubes in a high-end 1940's receiver for military use reflects the origin of the basic TE-236-B design in the mid-1930's RAK line of receivers

The preliminary inspection of the chassis identified some very minor weeping of oil around some of the capacitor seals – photo, right (which is typical for a 70+ year old parts of this type), and degradation of the rubber insulation on the grid cap wires to the RF amplifier, detector and 1st audio stage tubes (photo, below left). The form of construction of this set makes replacement of the capacitors problematic: I did not relish gutting and re-stuffing the many paper-in-oil capacitors (around 20 in number), as it is a time-consuming and messy task to cut each one open, and as it is possible they contain PCBs, precautions must be taken accordingly. Instead, I planned on testing several critical ones for leakage and if reasonably low, would leave them in place for preliminary power-up. Any that show excessive leakage would be replaced externally (leaving the old capacitor in place though disconnected from the circuit).

Refurbishment and Troubleshooting

I checked all the readily accessible paper-in-oil capacitors in circuit and made allowances for any parallel resistances. Where these capacitors had no parallel resistance paths I measured leakage at around 20Mohms (or higher) using a Triplett 630 VOM on its highest resistance range. This applies 30vDC across the component – about a sixth of the maximum potential that would be applied in the circuit, though many would have less than this potential across them. In most applications, this high resistance would have little to no adverse effect on the operation of the circuit. I therefore decided to leave all the capacitors in circuit for preliminary testing.

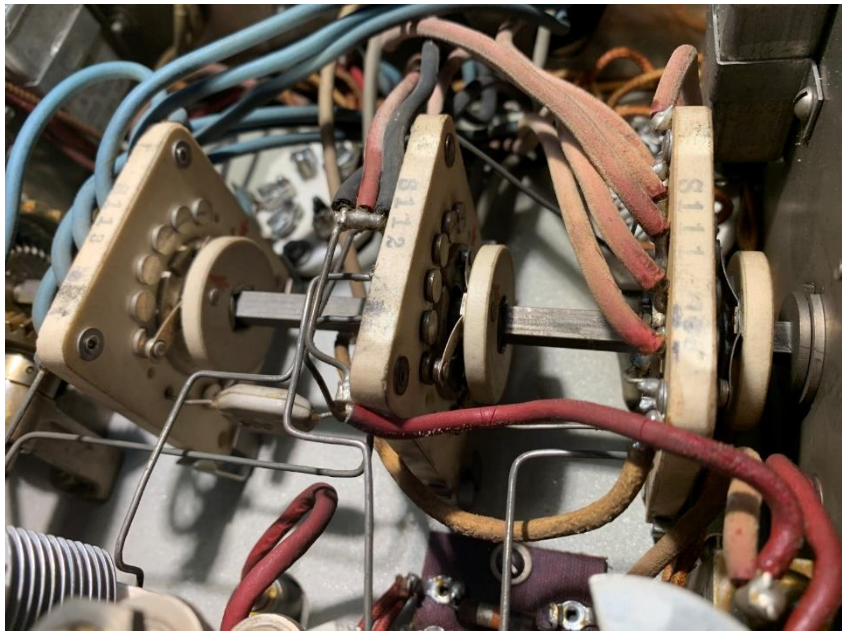
Next, I removed the cover from the tuning gang compartment to access the connections to the two RF tube and detector tube grid wires. Replacing the grid wires that had crumbling insulation was not straightforward for the 2nd RF and detector stages as the connection is made on the underside of a small sub-assembly attached to the inside of the compartment with limited access to the securing screws that must be removed to gain access – very fiddly and needing a very small 'stubby' screwdriver (photo, right). The inside of this compartment revealed the worm gear drive part of the tuning mechanism: the elongated worm gear on the tuning control shaft engages with a very large scalloped (concave face) helical gear mounted on the tuning gang shaft. A truly massively over-engineered construction designed for minimal backlash.

With the capacitors checked and the grid leads replaced, I connected power to the chassis (180vDC HT and 6.3vAV). It is interesting to note that the ground side of the 6.3vAV supply is coupled to ground via a 1uF capacitor, so there is no DC path through the heater circuit when configured for AC operation. The chassis also requires a stabilized 90vDC supply for the screen supply to the regenerative detector stage[4], however, Jerry Proc, who worked on this model of receiver some years ago, vouched that they work ok without this supply – he asked for me to check if this one did and whether connecting a separate 90v supply to the detector circuit made any difference. So, I initially powered the set on without the 90vDC connected.

The set came to life on switch-on (sort of…) – I could tune in a very strong signal on the top three bands, though there was little audio strength, and there was a lot of crackling and other noises present – all the controls generated noise when operated and some were intermittent in operation, the band change switch was very stiff in operation, and the sensitivity and AVC controls were non-functional. Clearly all was not well!

I decided to clean all the controls and switches as a first step in troubleshooting and then check resistor values. This entailed removal of the band change switch compartment cover from the base of the chassis. This revealed one of the strangest band change switch arrangements I have ever seen in a radio – both unusual in design/construction, and massively constructed (of course!). Like the tuning drive mechanism, the mechanical drive parts of the band change switch are over-engineered, comprising a couple of large bevel gears (photo, right) used to turn the switch action through 90 degrees, combined with a large indented metal wheel that engages with a spring-loaded pin so that the slot locations define each band as the front panel band change switch is rotated. The switch shaft extends across the full width of the radio parallel to the front panel, passing through a total of seven large ceramic switch wafers. The upper edge of these wafers are secured in place with spring clips attached to the chassis, and the lower edge is positioned using adjustable screws and locknuts attached to plates located under the switch. Instructions on how to adjust these screws is printed on the plates – adjustment being to within 5 thousands of an inch(!) – photo, left. Why this arrangement was adopted is not clear, though I

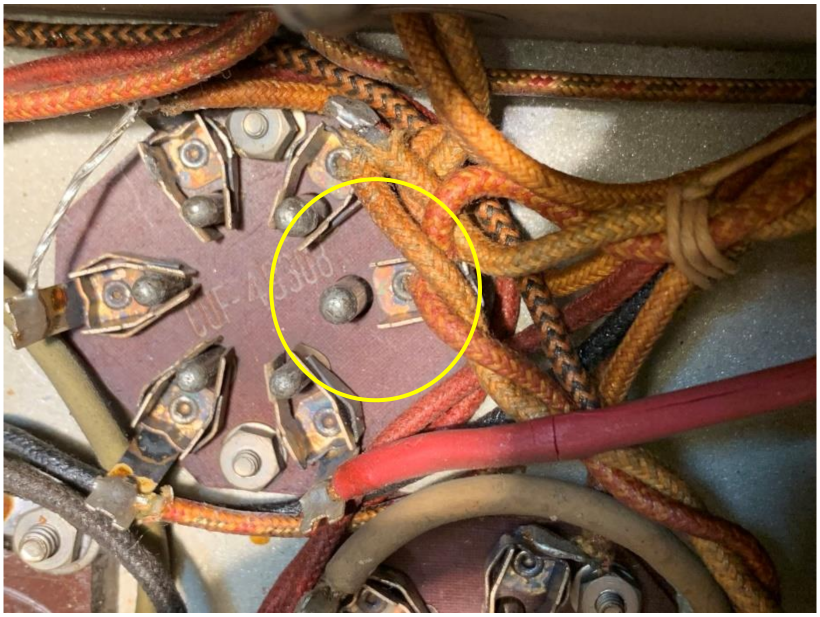
[4] Supplying a stabilized 90vDC supply to the regenerative detector stage screen would be more important for the higher frequency RAL receiver, covering 300KHz to 23.0MHz, that was paired with the RAK receiver in a typical navy installation



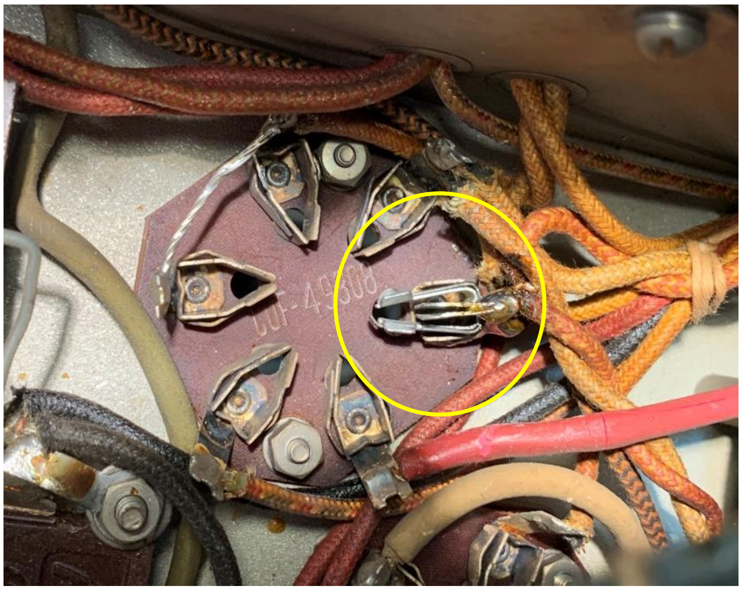
concluded it was to both assure good alignment of the contacts and minimize stresses on the ceramic wafers to avoid cracking of the wafers under heavy vibration/impact conditions that could be present onboard a ship. The switch contacts themselves are huge compared to a standard wafer switch, comprising ¼' diameter discs mounted on the wafers (photo, right), with large contact wipers connected to dual large concentric wiper tracks. The metal parts appear to be silver-plated, though they had significant grime build-up on them. I spent a couple of hours painstakingly cleaning all the contacts and wiper surfaces on the switch assembly, freeing the gummed-up lubricant from the bevel gears and re-lubricating where needed.

With the band change switch refurbished, I turned my attention to the front panel controls, removing the backs of all the wire-wound pots ('AVC Level', 'Sensitivity', 'Regeneration' and the gain compensation pot linked to the tuning mechanism,) and cleaned the wirewound tracks and sliders with a Q-Tip soaked in Deoxit (photo, left). The AVC Level pot still felt a little rough when rotated, but was now working reliably. I also sprayed Deoxit into the toggle switches and worked the switches several times until their operation was reliable. Next, all resistors were checked - around two-thirds were out of tolerance and were replaced – photo, right.

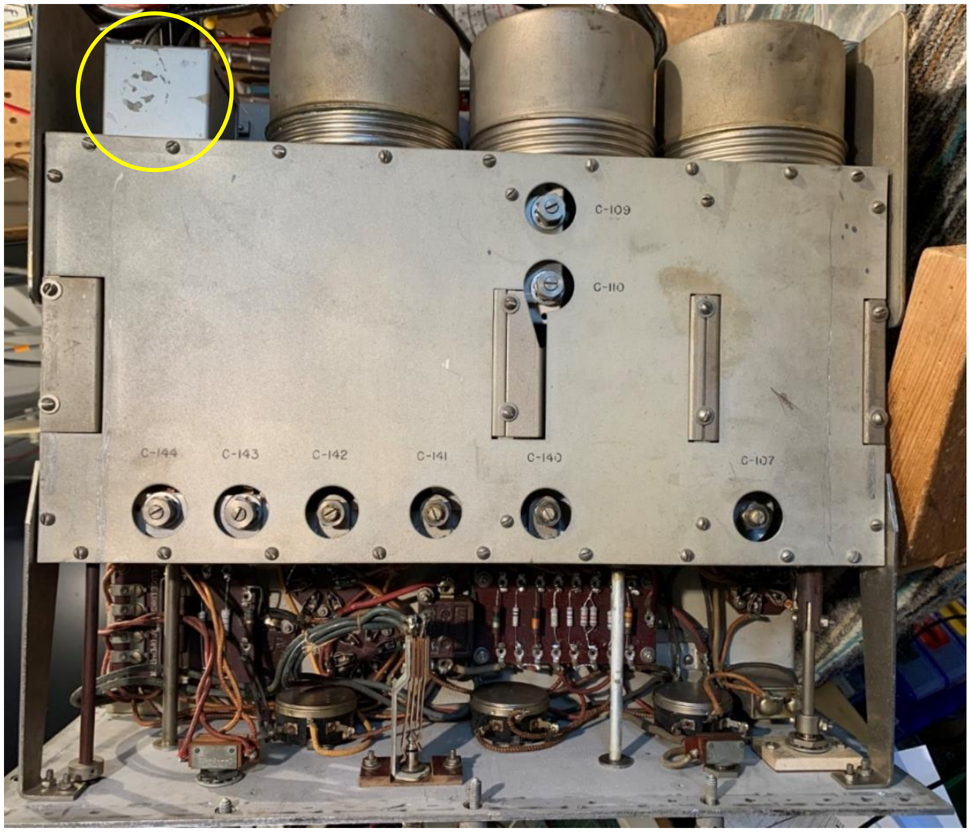
On powering-up the set again, a slight increase in sensitivity was noted and the noisy control issues had gone, however, the 'Sensitivity' control still had no effect on the receiver gain, which remained well below par. Further troubleshooting was needed, starting with checking the tubes, followed by signal tracing.



The two RF amplifier tubes and the regenerative detector tube (all 6D6s) tested in the 50 – 60% emission range – not the best, but should function reasonably well. The 1st AF tube (another 6D6) tested over 70% emission, and the second audio and AVC tubes (both #41s) tested over 55% emission. I decided to replace the two RF amplifier and detector tubes with higher emission ones from my stock, at least to prove if the tubes were an issue or not. Changing out these tubes made little to no difference, so I also tried swapping out the 1st AF tube (6D6). Inserting another tube in this position resulted in complete silence of the set(!), as did re-installing the original tube(!!). An under-chassis inspection soon found the problem: one of the heater pin socket connections had failed when removing/installing the tube – circled yellow in photo, above). I did not have a suitable 6 pin socket in stock, so I butchered a 4 pin socket and removed one of its larger (heater) connections. I then cleaned-up the remnant part of the broken connector, installed the tube, placed the connector part over the heater pin to ensure proper orientation of the connector, then secured the connector with a loop of wire and a generous glob of solder – photo, left. The repaired 6 pin socket worked well and the set came back to life on switch-on.



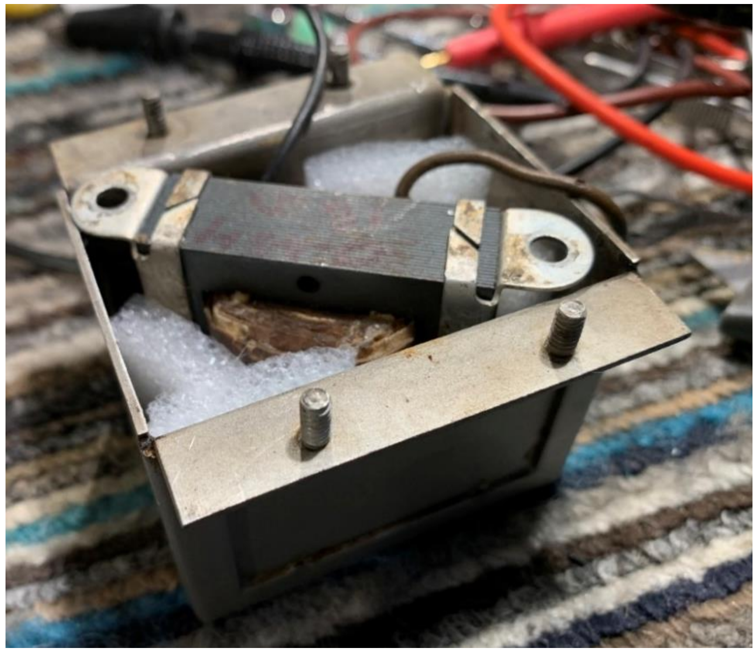
That repair did not help with the lack of sensitivity though – the set remained very 'deaf', with several tens of millivolts needed to hear a signal. As the 'Sensitivity' control was non-functional, I suspected a problem in the cathode circuit of the two RF stages as this control, together with a gain compensation potentiometer coupled to the tuning mechanism, control the bias on these tubes. A quick continuity check soon identified the problem – a low frequency choke between the Sensitivity control pot wiper and the cathode resistors of the RF amplifier tubes was open circuit, so neither of these tubes were working(!). I quickly jury-rigged a bypass for the choke using a 220 ohm resistor in place of the choke (as this is the DC resistance the parts list states for this choke), and the set burst into life, the Sensitivity control now working correctly and the set sensitive on CW down to levels well below 1uV[5].



The failed choke ('L109') is located in a metal enclosure bolted to the rear apron of the chassis (circled yellow in photo, right), from which emerges two rubber-insulated wires. I cut the wires close to the choke and removed the choke enclosure from the chassis. The choke was potted into the metal enclosure using tar – I carefully dug out the tar to expose the connections from the rubber-insulated wires to the choke winding (magnet wire) as these connection points can be the source of open-circuits over time due to corrosion, a dry joint and/or fatigue. Unfortunately, these connections were intact (photo, left), so the open circuit was buried within the winding, and therefore much more difficult to deal with. Instead, I decided to replace the choke – but what with? (and what purpose does it serve? - most sets do not include such a part in the RF gain control circuits). The circuit description in the manual for the similar RCA RAK-7 set does not identify the purpose of this choke, however, the parts list identifies its function as "*Choke used as Filter in Cathode Bias Supply to 1st and 2nd R-F tubes*", describing it as "*Reactor, iron core, impregnated and sealed in can*

[5] It should be noted that the set is designed primarily for CW reception, though if the regeneration is backed off so the detector ceases oscillating, single tone modulated carrier wave (MCW) signals can be received at reduced sensitivity, however, the audio filtering circuits render speech reception very poor quality – the manual noted this limitation of the sets design.

consisting of 5500 turns AWG#36 wire, coil traverse 31/32", impedance 3800 ohms at 3V 60 cycles with 0.12 amp d.c., d-c [sic] *resistance 220 ohms +/-7.5%*". This describes a typical 10H power supply filter choke, which would have an impedance of around 3800 ohms at 60Hz and a similar DC resistance. I concluded that the purpose of this choke is to mitigate audible hum resulting from the presence of any remnant low-level 60Hz (or 120Hz) ripple on the HT supply entering the cathode circuits of the RF tubes via the cathode bias circuit. I was using a stabilized and well-filtered HT supply for my testing, and hence I could not detect any such hum when subbing a 220 ohm resistor for the choke, but this may be a problem if a less sophisticated power supply is used[6]. I decided to install a suitable choke into the metal enclosure and also replace the rubber insulated wiring to the Sensitivity control and cathode circuits, as disturbing it weakens the degraded rubber insulation, however, I did not have any 10H chokes in stock that would fit the enclosure. I did have a 0.5H choke that would fit, so I installed that, using a little stiff foam packing (photo, above). The DC resistance of this choke was only 20ohms, so I added a 180ohm resistor in series with it to bring the DC resistance approximately in line with the original components resistance specification. This seems to work ok, and at least with the stabilized power supply there is no discernable hum[7].



Alignment Checks

Next, I decided to check the receiver operation on all six bands and tweak alignment only if necessary. This receiver does not have a dial calibrated in frequency, only numbers, and reference must be made to a chart to obtain the received frequency (similar to a National HRO receiver). Each TE-236-B receiver likely had a factory calibration chart unique to that set, however, if so, these are often lost with time (as this one has been). Instead, a generic ('average' or typical) chart is included in the manual, so I used that as a starting point[8]. I tried coupling a digital frequency meter (DFM) to the regenerative detector stage to provide a direct readout of the autodyne detector signal, but the oscillation amplitude was too low for the DFM sensitivity, so that idea was abandoned.

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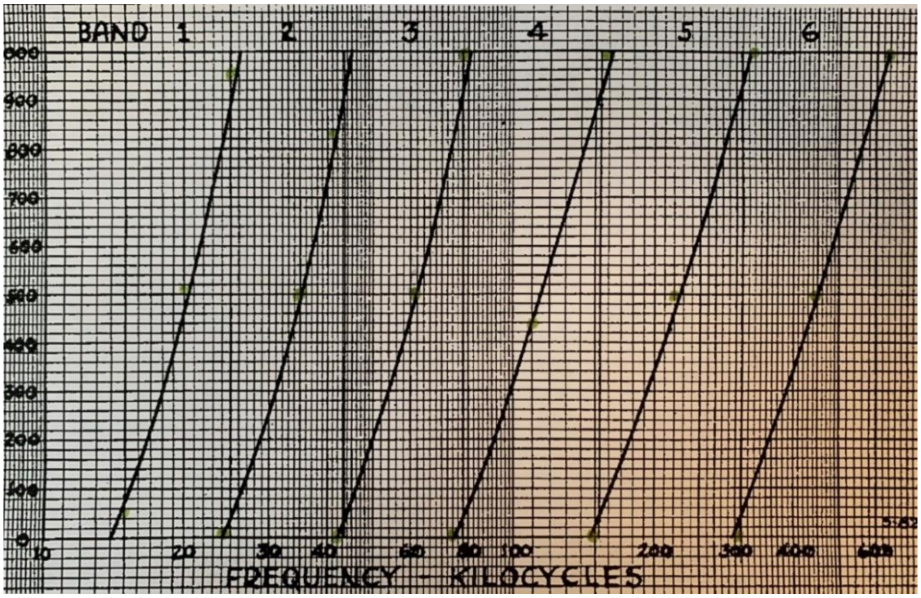
[6] Interestingly, Tom Brent mentions a hum issue with the TE-236B in an article here, though relating to the detector and 1st audio stages, stating "*A few collectors I know have gone to the trouble of supplying DC to the filaments in an effort to cure 60 Hz hum. I have a US Navy technical bulletin that advises that only RCA 6D6's should be used for the detector and first audio stages. Ken-Rad and Tung-Sol brands could used only in the first and second RF stages. The hum was caused by the construction of the filament in the 6D6 tube*.".

[7] The owner wanted me to build a suitable power supply and, if so, I will check if hum appears, and, if so, try to obtain a suitably-sized 10H choke.

[8] If there was significant discrepancy to the curves on the chart I could generate a set of receiver-specific charts for the owner.



I checked the receiver operation on all six bands (15KHz - 600KHz). The receiver was almost 'spot on' all frequencies on all bands – quite remarkable, and it was completely stable. The sensitivity was pretty much even across all bands also. A photo, right) of the 'average' calibration chart with the green dots representing the actual frequency/dial reading coordinates measured at the bottom, (approx.) mid point, and top of each band. Given this I did not tweak any of the RF trimmers.

Closure on the RCA TE-236-B

During its final soak testing, I experimented a little with alternate tubes to see if performance was impacted: I re-installed the original 6D6 RF and detector tubes back into the set to see what effect they would have on performance. These tubes tested between 50% and 60% emission compared with the three tubes I installed for testing (all around 80% emission and borrowed out of other sets). This resulted in around 2 – 3db reduction in output level for the same input signal (1uV), though I think in practice this would not make much difference – there was still ample gain and the minimum received signal level is limited by tube noise and QRM. A video demo of the RCA set operating can be viewed here.

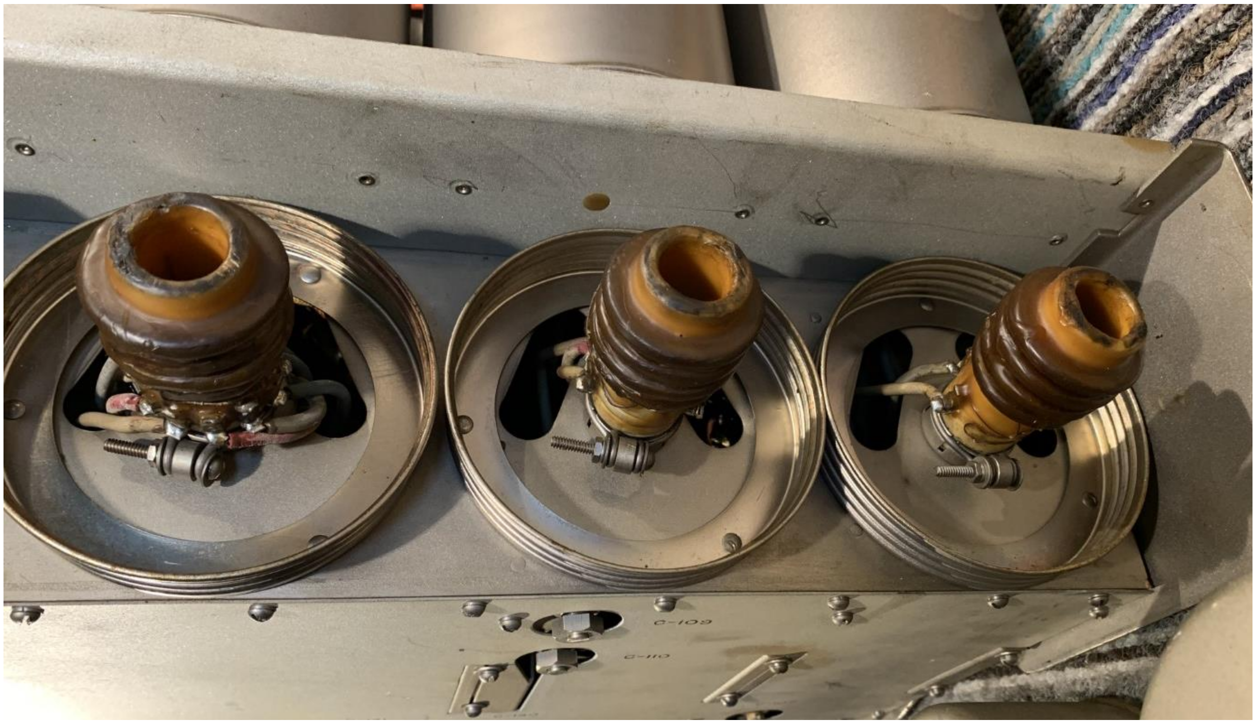
I should note that the audio output level is such that it will not drive an 8ohm speaker directly[9] (it's a 600ohm phones output). This could be modified to enable speaker output either by adding a line matching transformer (600ohms/8ohms), or by changing the output transformer.

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

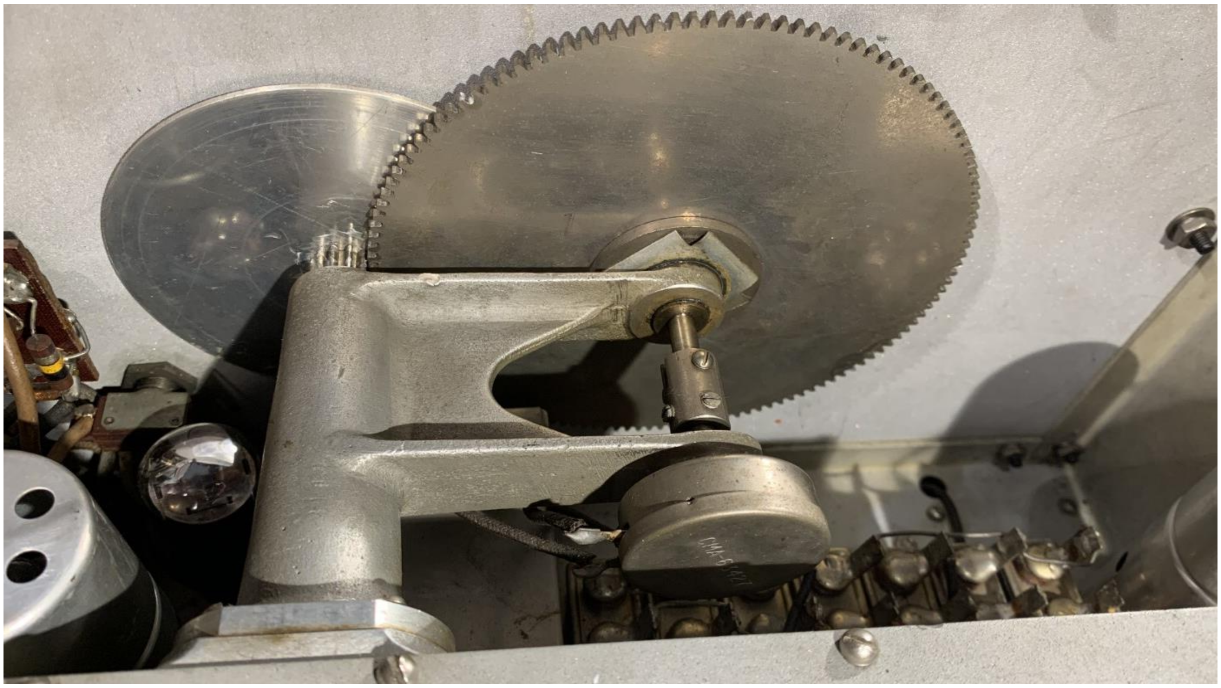
Note: please refer to Part 1 of this article for the Marconi B29 refurbishment.

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 AVC 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.

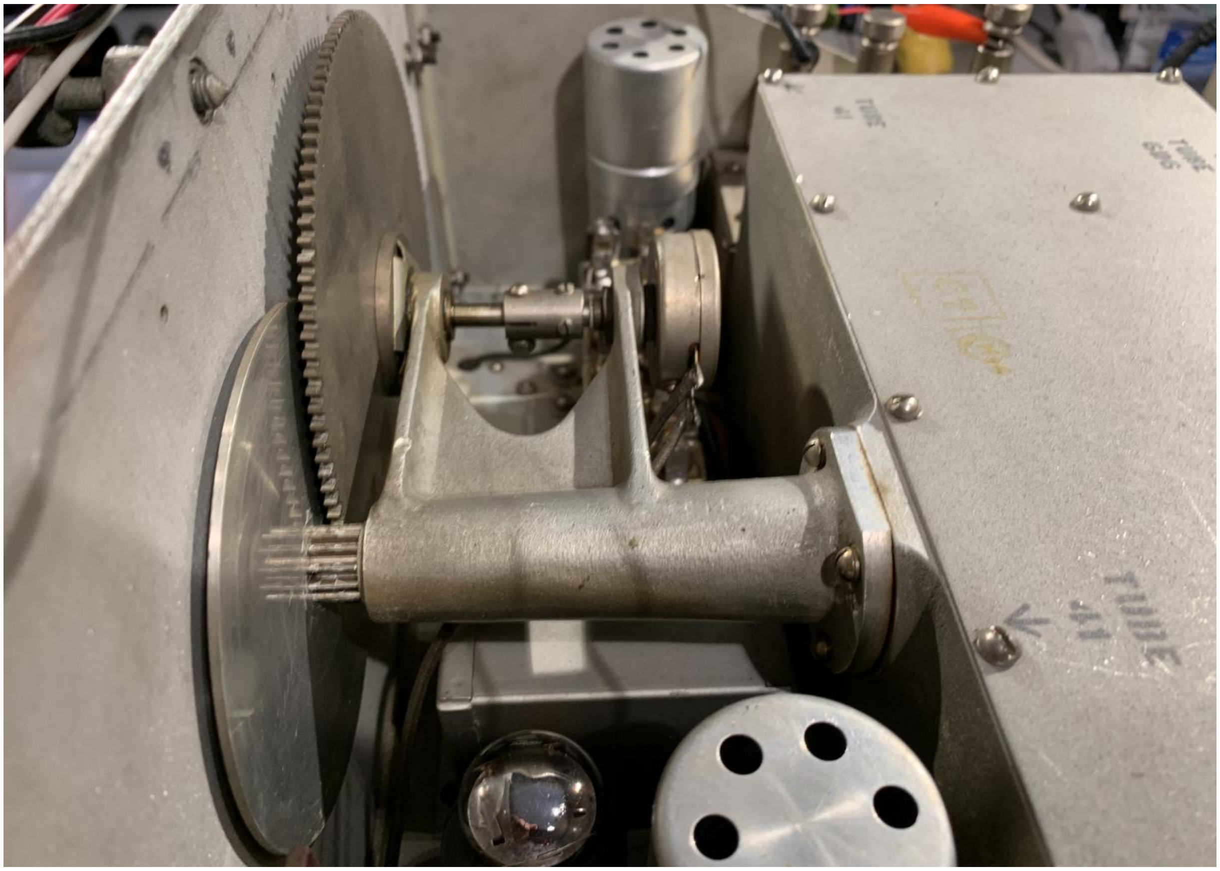
[9] I had been using an amplified speaker connected to the 'phones output during testing



Above: left to right – the TE-236-B detector, 2nd RF and 1st RF tuned circuit coils for Bands 4, 5 and 6. Below: left to right - the TE-236-B detector, 2nd RF and 1st RF tuned circuit coils for Bands 1, 2 and 3 (these are physically huge for receiver coils!).

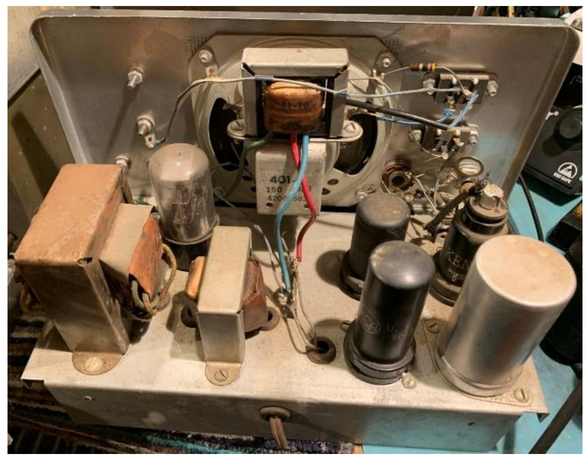


Two views of the TE-236-B tuning mechanism (external to the tuning gang compartment). Above: the gain compensation pot is mounted on the 0-10 division shaft (right) driven by a pinion and gear drive from the tuning control shaft (left). Below: note the heavy-duty nature of the pinion and gear drive, and the substantial aluminum casting forming the shaft carriers, attached to the tuning gang compartment



Postscript to the RCA TE-236-B Receiver

The RCA sets' owner wanted a power supply to go with the radio. So, I went around to a friends house and sorted through his vast collection of 'iron' (transformers and chokes). Unfortunately most of it was on the 'extra large' size (and EXTRA HEAVY!), though I brought a tray of the smaller parts back with me to see if any could be used. I also spotted a scruffy Heathkit T-3 signal tracer unit that I thought may be suitable for the power supply chassis/cabinet (photos, right), and the bonus was that it includes a speaker that could be used with the receiver. Unfortunately the power transformer in the Heathkit unit would not be suitable for the power supply as it has 12v heater tubes (except the rectifier, which is 6.3v) - the RCA receiver needs 6.3v for the tube heaters, and the HT voltages indicated on the Heathkit schematic were much too high for the RCA.



I stripped and cleaned the Heathkit chassis and case and filled unwanted holes on the front panel with JB-Weld, reinforcing the large hole (eye tube hole) with a piece of plastic card, and then spray painted it and the case satin-grey to smarten it up.

I decided to use a very simple power supply circuit using a bridge rectifier (4 x 1N4007s) and a filter comprising a twin 32uF can capacitor and a 10H choke (the photo, left, shows the above-chassis view of the completed power supply). As the case included a speaker (3 ohm), I included the wiring for it in the umbilical cable between the power supply and the receiver, however it is a severe mismatch to the receiver's 600 ohm line output circuit and would 'kill' the output when connected directly without a matching transformer. I was going to try the output transformer that was in the Heathkit signal tracer unit, but its primary was open circuit - typical. I found a Hammond 262F6 power transformer in my junk box that was (almost) correct for this supply design: 130vAC @140mA plate and 6.3vAC @1.5A heater - this is a bit lower heater amperage than needed by the receiver (6.3v @ 1.8A), but I tested it for a few hours on the 1.8A load and the transformer temperature was barely warm (37C) and the voltage under this load was just over 6vAC. The HT current draw from the set is only around 40mA, so that is well-within the capabilities of the transformer. On operating the receiver, I found that the voltages at

the radio terminal strip were a little low (164vDC plate and 6.1vAC heater), but these are both within the normal 10% tolerance for tube receiver voltages. I used a 10H choke from my friends iron collection – a neat old Hammond 10H 65mA part.

On testing the supply, hum was only noticeable on the receiver output (through an external amplified speaker) when the output circuit was not loaded correctly – with a 680 ohm resistor across it the hum level was low. I also tried a few different 6D6s in the 1st AF and detector stages and retained the ones with the lowest hum level. Given this I figured it was not worth changing the (0.5H) choke in the RF stage cathode circuit for a 10H one, as what hum there was did not seem to be coming from the RF stages anyway.

I found an audio matching transformer in my junk box – it was not 600 ohms to 3 ohms, but had a 250 ohm DC resistance primary and 25 ohm DC resistance secondary. This worked reasonably well and the speaker in the power supply now worked ok, though the volume was likely less than would be obtained with the correct matching transformer (easily swapped out if one becomes available).

Next, I installed a slide switch on the power supply front panel to select the speaker or dummy load, to allow for when high impedance 'phones are plugged into the receiver front panel 'phones jack socket and a speaker is not needed - I used a 680 ohm dummy load resistor to approx. match the output impedance of the receiver. I also installed a switched ¼" jack socket on the front panel of the power supply to allow low impedance 'phones to be used (when phones are plugged in to this socket it disconnects the speaker automatically). I found a suitable (black) metal handle for the top of the power supply case - looks the part (photo, above).

I strapped the short length of cable ('flying lead') from the receiver terminal strip to the male Cinch connector to the chassis to prevent strain on the wires, and insulated the HT terminal to prevent accidental shocks (its easily touched!), or shorting to the adjacent terminals.

I placed the power supply and receiver on soak test for a day, receiving <1uV at 500KHz (Band 6, at 6.56 on the dial) and it was rock steady with a very clear tone. I also re-checked its operation on all bands and all seemed good. The power supply case did not even get warm to the touch after many hours powered-up.

Finally, I made and applied some labels to the power supply and also to the side panel of the receiver to identify the connections. I also added a small tuning chart label to the receiver side panel for info. I also laminated the full-sized (letter) marked-up tuning calibration curves for the owner to keep with the set.

A short video of the power supply under test on the receiver can be viewed here.