Vintage Radio

By Ian Batty

Anything you can do – Raytheon's T-2500 7-transistor radio

Raytheon's T-2500 (left) was considerably larger than the Regency TR-1 shown below and was a much better performer.

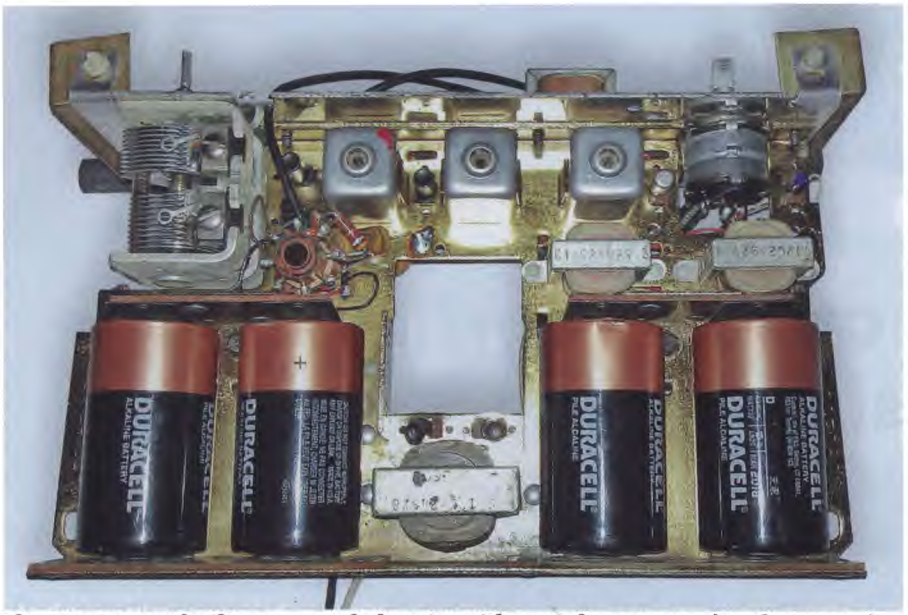
Electronics giant Raytheon (light of the gods) made it to market with their 8TP transistor radio just a few months after the first "trannie" – Regency's TR-1 (see April 2013). It was quickly followed by the T-2500. So was Raytheon's offering better?

TEXAS INSTRUMENTS, Raytheon and Tokyo Tsushin Kogyo (soon to become Sony) were among the front-runners in domestic transistor radio development. As a large, specialist manufacturer of military hardware and other high-tech products, Raytheon held an enviable position. The company pioneered sub-miniature valves and had developed a number of highly-specialised applications, such as proximity fuses for artillery shells.

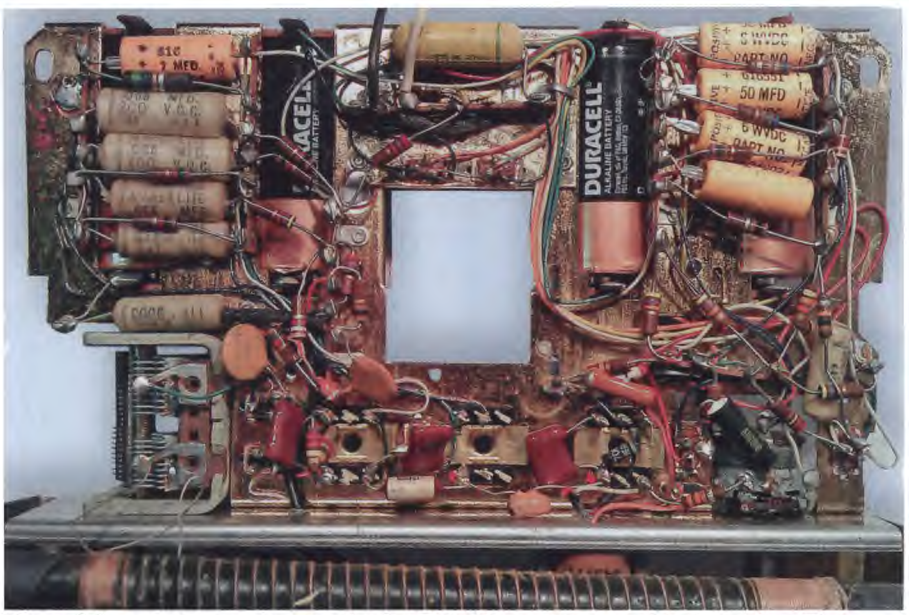
Raytheon's business was founded in 1922 by the redoubtable Vannevar Bush. The first electronic product marketed under the Raytheon brand was a 1925 cold-cathode helium gas rectifier used in "battery eliminators". Bush went on to administer the Manhattan Project (which developed the atomic bomb during WW2) and to invent "memex", an adjustable microfilm viewer with a structure that can now be compared to the World Wide Web.

The subsequent Apollo Guidance Computer that took Neil Armstrong and his crew to the Moon was a joint MIT-Raytheon project – "the most reliable computer of its time". Why, then, did the much smaller Texas Instruments, in partnership with the Regency Division of Industrial Development Engineering Associates, beat Raytheon to the transistor radio market, given the latter's outstanding manufacturing and engineering resources?

The reason for this was mainly due to the different types of transistors used by Texas Instruments and Raytheon in their early transistor radios. TI's laboratories had managed to bring the grown-junction technique to reality before Raytheon's alloyed-junction design. But although grown-junction



The T-2500 was built on a metal chassis, with transformer coupling between the various audio stages. Power came from four D-cell batteries.



Most of the minor components in the T-2500 are connected to tagstrips. The seven transistors were mounted in sockets on the other side of the chassis.

transistors were far superior to first-generation point-contact devices, they struggled to operate at broadcast radio frequencies.

In fact, the grown-junction transistor's limitations are confirmed by the Regency TR-1 being forced to use an IF (intermediate frequency) of only 262.5kHz. What's more, it required a 22.5V supply (close to the maximum rating) in order to operate at even this low frequency. In short, Regency's transistors did not have enough gain to operate at the standard 455kHz IF and from more normal supply voltages of 6-9V.

By contrast, Raytheon's engineers and scientists pinned their hopes on the newer alloyed-junction design. This was easier to manufacture and offered superior performance, as evidenced by the famous "CK" transistor types that the company developed.

Raytheon wanted to release a transistor radio that was at least as good as comparable valve portables. However, using the transistors of the day, this required six or more active stages.

Although the Regency TR-1's superhet design is electrically sound, its low gain, low power output and short battery life led one commentator to describe it as "a toy that didn't come at a toy price". However, Raytheon's initial offering was more ambitious. Designated the 8TP, it used the 8RT1 chassis design and boasted a total of eight transistors, used as follows: oscillator, mixer, two IF amplifiers, a detector, an audio driver and a push-pull audio output stage. It sold for $79.95, over half as much again as the cost of the TR-1 and the equivalent of around $683 today.

Ironically, the TR-1 had also initially been designed with eight transistors but an aggressive cost-cutting, "man overboard" program cut that down to four. In terms of value from money though, Raytheon's design was more than "one and a half times" better. Those extra transistors really made a big difference to the performance!

The 4-transistor TR-1 has a maximum sensitivity of about 500μV/m for a meagre 3mW output and its maximum audio output is just 6mW. By contrast, the 8TP's sensitivity for 3mW is easily 10 times better. And with its large speaker and 100mW push-pull output stage, the 8TP provides good listening levels, even against normal background conversation. The TR-1, however, demands "quiet room" conditions for comfortable listening.

Timber cabinet

Raytheon's 8TP was housed in a handsome timber cabinet with leatherette veneer and also featured brass knobs and brass or anodised trim. Power came from four "D" cells (giving a 6V supply) and the battery life was about 350 hours, compared to the TR-1's meagre 20 hours. The four "torch battery" cells in the 8TP cost about 60 cents in 1955, for a running cost of around 17 cents per hundred hours.

By contrast, the TR-1's 22.5V "hearing aid" battery cost about $1.25 and the running cost was around $6.25 per hundred hours. So it was no contest here either.

Following its release in March 1955, Raytheon's 8TP gained universal approval from reviewers, the only criticism being its large size although some reviewers also complained of low sensitivity. The sensitivity reservation is curious. Valve sets of the time were rarely much more sensitive. And a 1960 Mullard article refers to a 5-transistor portable (using the next generation of alloy-diffused transistors) with 200μV/m sensitivity as being

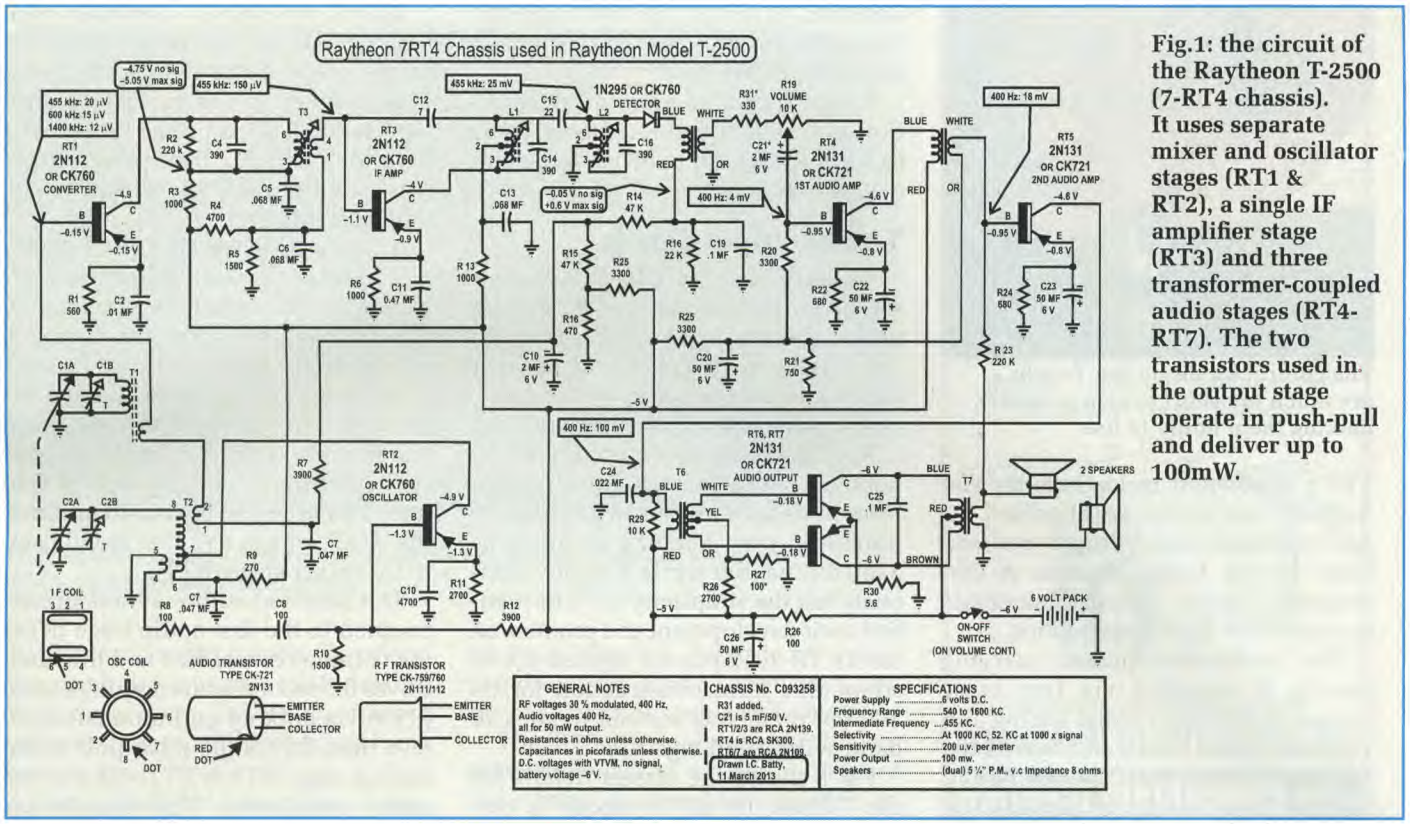


Fig.1: the circuit of the Raytheon T-2500 (7-RT4 chassis). It uses separate mixer and oscillator stages (RT1 & RT2), a single IF amplifier stage (RT3) and three transformer-coupled audio stages (RT4-RT7). The two transistors used in the output stage operate in push-pull and deliver up to 100mW.

"economical", adding that including an extra IF stage (for a sensitivity improvement of about 10 times to 20μV/m) would make it "outstanding".

AGC, IF stages & detector

The original 8RT1 chassis applied AGC to the two IF stages. The IF intercoupling technique used was perfectly standard, ie, a tapped, tuned primary matching to a low-impedance, untuned, untapped secondary.

This configuration allowed a high-Q IF-coil primary to match its driver transistor's medium-high output impedance. At the same time, the low-impedance secondary closely matched the following transistor's low input impedance.

The detector operated in class-B, working pretty much as a "diode with gain". Since it would conduct more heavily with signal, strong signals would force its collector voltage to fall. This collector voltage formed part of the bias network for the two IF amplifiers, thus providing AGC.

The 7RT1 chassis

The basic 8TP transistor radio went through several changes before being eventually discontinued. Raytheon then reworked the 8RT1 chassis design and released it as the 7-transistor 7RT1 while retaining the 8TP's case.

The 7RT1's chassis dispensed with one IF amplifier stage and the transistor detector but added an extra audio stage. This resulted in four transistors being used in the audio stages (ie, two audio amplifiers plus the push-pull output stage). Another two were used in the preceding RF/IF chain, while the seventh was used in the local oscillator.

The low signal from the 7RT1's diode detector was apparently unable to generate sufficient AGC to be applied to the remaining IF amplifier's base. As a result, the 7RT1 (unusually) uses AGC on the mixer. Because this changes the stage bias, and thus its collector current and input impedance, applying AGC to a single-transistor mixer-oscillator (as used in the TR-1 and most other transistor superhets) can cause unwanted oscillator frequency changes with changes in signal strength.

However, Raytheon's 7RT1 uses a separate oscillator design, so it is unaffected by AGC. Applying AGC directly to the mixer reduces overload due to strong signals in this stage and is quite effective.

Another unusual design aspect is that the 7RT1 uses transformer coupling between the detector diode and the first audio stage. This matches the detector to the low-input impedance of the audio stage and in fact, the entire audio section uses transformer-coupling between stages. While this gives the maximum possible power gain, it comes at the expense of extra transformers and their limitations on frequency response.

Negative feedback

Negative feedback is used in the audio stages, and is applied via a resistor connected from one side of the speaker pair to the base of the second audio driver stage. This helps reduce crossover distortion in the output stage, especially at low volume levels.

The three amplifying stages result in an audio sensitivity of about 4mV for 50mW output. This does, however, make the audio section somewhat noisy at low volumes.

T-2500 receiver

The 7RT1 chassis was used in the author's T-2500 set. With two 5.25-inch loudspeakers and a cabinet measuring some 310 x 150 x 230mm (including rubber feet), it's really about the size of a small car battery so it's hardly compact.

The T-2500's timber cabinet is soundly constructed and like the

The control knobs on the T-2500 are much too short to grip properly, making them fiddly to use.

TR8's, is covered in leatherette. The front and rear grilles are anodised expanded aluminium, with an anodised bezel for the front speakers. A cast enamelled badge and cast nameplate complete the front presentation.

The leatherette-covered carrying handle is attached via two brass screws and the cast-metal tuning and volume control knobs sit towards the top rear of the cabinet. The tuning and volume "zero" marks are provided by flat-topped, engraved brass screws. Being a US-made set, the dial has "Civil Defense" arrowheads at 620kHz and 1240kHz (as has my Regency TR-1).

The main chassis is cadmiun plated and passivated steel, with aluminium brackets. Unlike the TR-1, with its printed circuit board, the T-2500 uses sockets for the transistors, tagstrips for the minor components and point-to-point wiring. The IF and audio transformers, the ferrite rod and the volume control have all been custom-designed to match the low transistor impedances but no other specialised components are used.

Basically, the standard of construction is excellent and Raytheon seems to have spared no expense to ensure a quality product.

T-2500 circuit details

Unlike Regency's TR-1, Raytheon's sets used conventionally-sized components, as used in the valve sets of the day. Raytheon's military equipment at the time was at the forefront of technology, a place it holds to this day.

Raytheon subsequently piloted the hobbyist use of transistors with the release of its famous CK722 germanium transistor, now fetching as much as $250 online. But while Regency obviously felt the simplicity of PCBs justified their development and production for its TR-1, Raytheon elected not to adopt this form construction for its T-2500, preferring instead to stick to hand-wiring and tagstrips.

Fig.1 shows the circuit details for the T-2500. Its RF/IF circuit is distinctive: a mixer with AGC applied, a separate oscillator stage that is unaffected by signal strength and a single IF amplifier stage.

The circuit voltages indicate that the mixer ("RT1") has virtually no base-emitter bias. That's because mixers must operate by swinging into cut-off (Class-B operation). The oscillator coil is air-cored, with no ferrite adjusting slug, and there's no oscillator adjustment at the low-frequency end of the broadcast band.

RT3 is the sole IF amplifier stage but there are three IF transformers – a carry-over from the 8RT1 with its two IF amplifiers. In this case, the "missing" second IF amplifier is replaced by a top-coupled "bandpass" circuit using two coils, each with a single tapped winding.

As in the Regency TR-1, the T-2500's IF amplifier uses neutralisation feedback (C12) to combat the regenerative effect of collector-base capacitance. A conventional diode detector follows the IF stage and the demodulated audio is then fed to the first audio stage via an audio transformer. The signal at the bottom of the primary of this transformer is also filtered to produce the AGC voltage and this is fed back to the mixer stage (RT1),

The detected audio is transformer-coupled to the first audio stage (RT4) via volume control R19 and this then drives the second audio amplifier stage (RT5) via another audio transformer. RT5 then drives the push-pull audio output stage (RT6 & RT7) via another audio transformer. This transformer has a centre-tapped secondary and acts as a phase splitter.

The push-pull output stage drives two series-connected speakers, again via a transformer, making four audio transformers in total.

The end of the line

With its four audio transformers, its cavernous case and dual 5.25-inch speakers, it's perhaps not surprising that the T-2500 was the end of the line for Raytheon's attempts to penetrate

The T-2500's volume and tuning controls are mounted on the top of the cabinet and are awkward to use.

the domestic radio market. Raytheon also produced several smaller sets but even these were unable to create a sufficiently profitable line to continue production.

The T-2500 did leave one legacy, though. Moulded plastic cases are specialised items whereas timber cases are relatively easy to make, even at home. The *Radio, TV & Hobbies* "Transporta" series subsequently mimicked the Raytheon line with their generous timber cabinets and 5-inch speakers.

The author's T-2500

The author's Raytheon T-2500 (chassis number C093258) was purchased online for $375. Cosmetically, it was in very good condition, with acceptable wear on the case and no battery corrosion. A "506" date stamp on the tuning gang indicates that it was made in the sixth week of 1955.

The original 8TP's control layout on the top of the cabinet was carried over to the T-2500. These are awkward to use because the knob bosses are too short to grip properly. In addition, the small diameter of the calibrated dial ring on the tuning control does not indicate the station frequencies with any great accuracy.

The tuning does, however, have a slow-motion dial movement, which eases the task somewhat.

Despite this, the T-2500 is more difficult to tune than the TR-1. The latter's large dial face is easily read, it indicates frequencies more accurately and the dial can easily be used as a thumbwheel. The TR-1 also wins out on design. Its sleek, "post-deco" styling stands out, even today, from any number of anonymous transistor portables.

The T-2500's volume control is another drawback of the design. It has a slow onset, followed by a sudden increase in volume from about 90° of rotation. As a result, setting the required volume level can be rather fiddly.

Performance

The T-2500 easily meets its published specifications. Its sensitivity is 150μV/m at 600kHz for 50mW output, rising to 200μV/m at 1400kHz. The selectivity for 60dB signal attenuation is around ±30kHz at 600kHz and ±40kHz at 1400kHz.

The audio performance is modest by today's standard, with some 13% THD (total harmonic distortion) at the rated output of 100mW and a more respectable 4.6% THD at 50mW output. The frequency response of the audio stages (measured by feeding a signal into the volume control) is 230Hz to 2.3kHz. By contrast, a modulated RF signal fed into the aerial socket gives an overall frequency response (ie, for the entire receiver) of 580Hz to 2.3kHz.

Compared to the valve portables of the day, the T-2500 has similar audio fidelity but less than half the output power (ie, 100mW versus 250mW). However, this equates to a difference of just over 3dB which is hard to pick. The T-2500's sensitivity is equal to all but the best valve portables using RF stages.

As mentioned previously, the set's battery life (and thus its running cost) is excellent. At today's battery prices, the set costs just two cents an hour to run. And although I've not carelessly left it in the sun, I suspect that the T-2500's timber cabinet would survive such mistreatment much better than any plastic cabinet.

It may seem that I've been unduly harsh on some design aspects of the Raytheon T-2500. However, as an engineering design, it's an excellent performer, especially when judged by the standards of the day.

Schematic errors

Some corrections to Raytheon's original circuit schematic for the T-2500 should be noted. First, the detector diode was shown connected in reverse (the AGC would not operate if the detector was connected as shown in Raytheon's circuit). Second, the schematic also shows incorrect DC voltages for first audio stage based on RT4. The circuit diagram published here (Fig.1) is correct.

Finally, the Howard W. Sams "Photofact" (Set 329, Folder 11) also shows the detector connected in reverse. It also shows incorrect emitter and base voltages for mixer RT2. **SC**