By Ian Batty

# The 6-transistor Motorola 66T1

**This little transistor radio from Motorola may not look anything out of the ordinary but it did have some very interesting features at this early stage of transistor development. The standout aspect would be the double-sided PCB.**


In 1928 the rapid uptake of domestic valve radios was being retarded by the cost and drawbacks of batteries.

Typically, the sets in this era had "A", "B" and "C" batteries. While it was possible to provide the "A" supply with a car battery, "B" and "C" batteries were expensive. But with more and more homes getting mains power, enterprising designers were coming up with the "battery eliminator", a mains-powered supply able to deliver a variety of high tension and bias supplies.

Chicago brothers Paul V. & Joseph E. Galvin then bought the bankrupt Stewart Battery Company's plans and plant at auction. Beginning with battery eliminators and looking to expand, Paul Galvin challenged his engineers to design a new product: an inexpensive car radio.

Galvin coined the name "Motorola" from "motor" and "ola", a common suffix of the day roughly meaning "little" and seen elsewhere in Moviola, Victrola and other proprietary names of the period.

Moving on to equipment for government customers such as police, Galvin gained lasting fame as the designers and manufacturers of the revolutionary BC-611 "Handy-Talky". Battery-powered, using the just-released all-glass B7G valves and able to be carried and used in one hand, the BC-611 became the mainstay squad radio for United States' forces and set the standard for lightweight portable transceivers.

Motorola's offerings in the 1950s and 1960s ranged from car-mounted radio-telephones to radios and televisions. Catching the solid-state wave of the 1950s, Motorola offered the first high-power germanium transistor in 1955.

Neil Armstrong's famous "One small step for man..." was relayed to the Lunar Excursion Module over a Motorola transceiver.

## Transistor portables

Although not first to market with a transistor set, Motorola were in there early. Their first five-transistor 56T1 used a transistor demodulator, directly driving a single-transistor Class A output stage. Class A output stages were a common feature of many manufacturers' first outings.

The audio circuit of the 66T1 is similar to the GE675, previously covered in September 2015 (www.siliconchip.com.au/Article/9015).

This Motorola 66T1 was made in 1957, 61 years ago! It's a six-transistor design using a similar RF/IF section to the GE675 but with a transformer-coupled Class-B push-pull output circuit.

Given Motorola's innovative heritage, you'd expect the 66T1 to be different from sets made by other manufacturers and it does not disappoint.

For example, the 66T1 is housed in a metal case, which would ordinarily prevent the use of any internal antenna, loop or ferrite rod. Motorola fixed that problem by putting the ferrite rod into the moulded plastic carrying handle. This handle can fold for compact stowage or be canted backwards to prop the set at an angle.

The overall dimensions of the case are quite small, with a total volume of some 500ml. This is partly achieved by having the batteries in the back shell, rather than accommodating them with the circuit board and speaker.

However, perhaps the most interesting aspect of this Motorola set is that it has a double-sided circuit board. Yes, it has tracks on both sides, although all the components are soldered to the visible side, as shown in the accompanying photos.

You might have thought that double-sided PCBs were a comparatively recent development in electronics, but here it is in a tiny transistor radio made over 60 years ago!

I have not included a photo of the underside of the PCB since it is soldered to the metal chassis and it would require major surgery to remove the PCB and expose its underside. This also makes it quite difficult to remove and replace components. Both sides of the PCB are depicted in a diagram on Ernst Erb's Radiomuseum site.

The double-sided PCB would have demanded careful design and precision manufacture. That PCB and the metal case have the advantage of improved shielding that reduces potential feedback, and the 66T1 is notable for not using neutralisation in its IF stages.

The tuning dial is large, and its knurled edge allows easy one-finger tuning. In common with US-designed sets of the era, the dial includes the Civil Defence Conelrad tuning markers at 640kHz and 1240kHz. I have discussed these in previous Vintage Radio articles, such as in January 2016 (www.siliconchip.com.au/Article/9780).

The 66T1 has a 6V supply coming from four AA cells, and the battery label shows insertion for carbon-zinc or mercury cells, the latter having reversed polarity on their terminals. Mercifully, mercury cells were a passing phase, as I've seen several fine "keychain" radios rendered unrepairable by leakage of the mercury cell's highly corrosive electrolyte.

## NPN germanium transistors

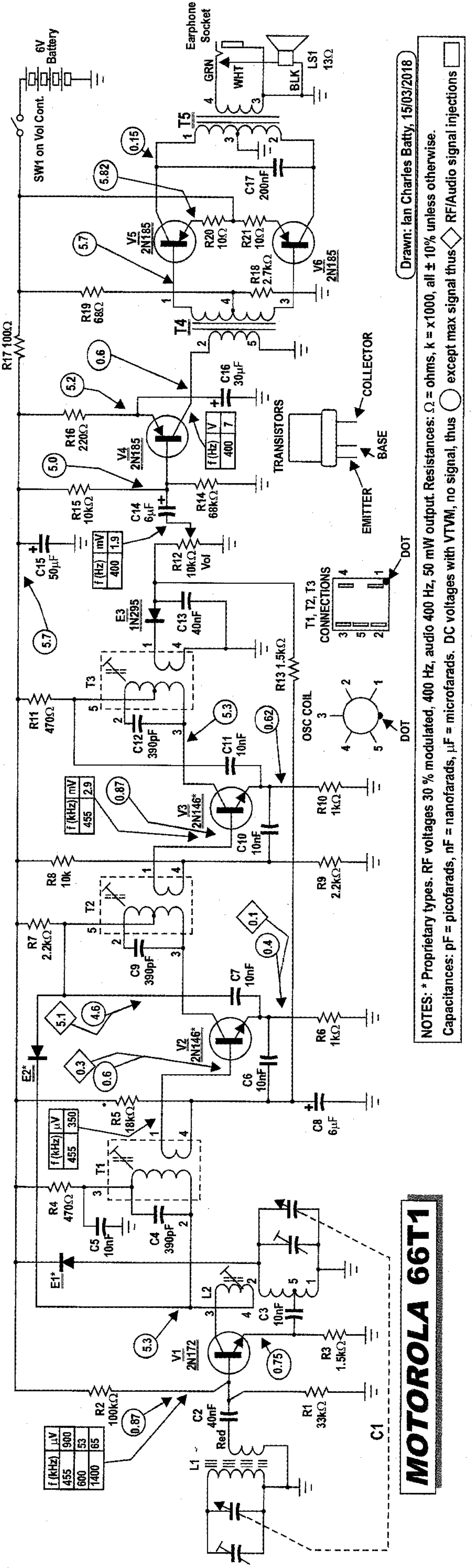
Like many early solid-state radios, the 66T1 uses grown-junction transistors in the RF/IF stages. The grown-junction process worked best when producing NPN transistors, and this technology dominated initial RF/IF transistor production.

Alloy-junction transistors which followed later, while offering simpler manufacture and better yields, could only be used for audio until full development was reached. Hence the 66T1 uses NPN transistors for the converter and both IF amplifiers, and three PNP types in the audio section.

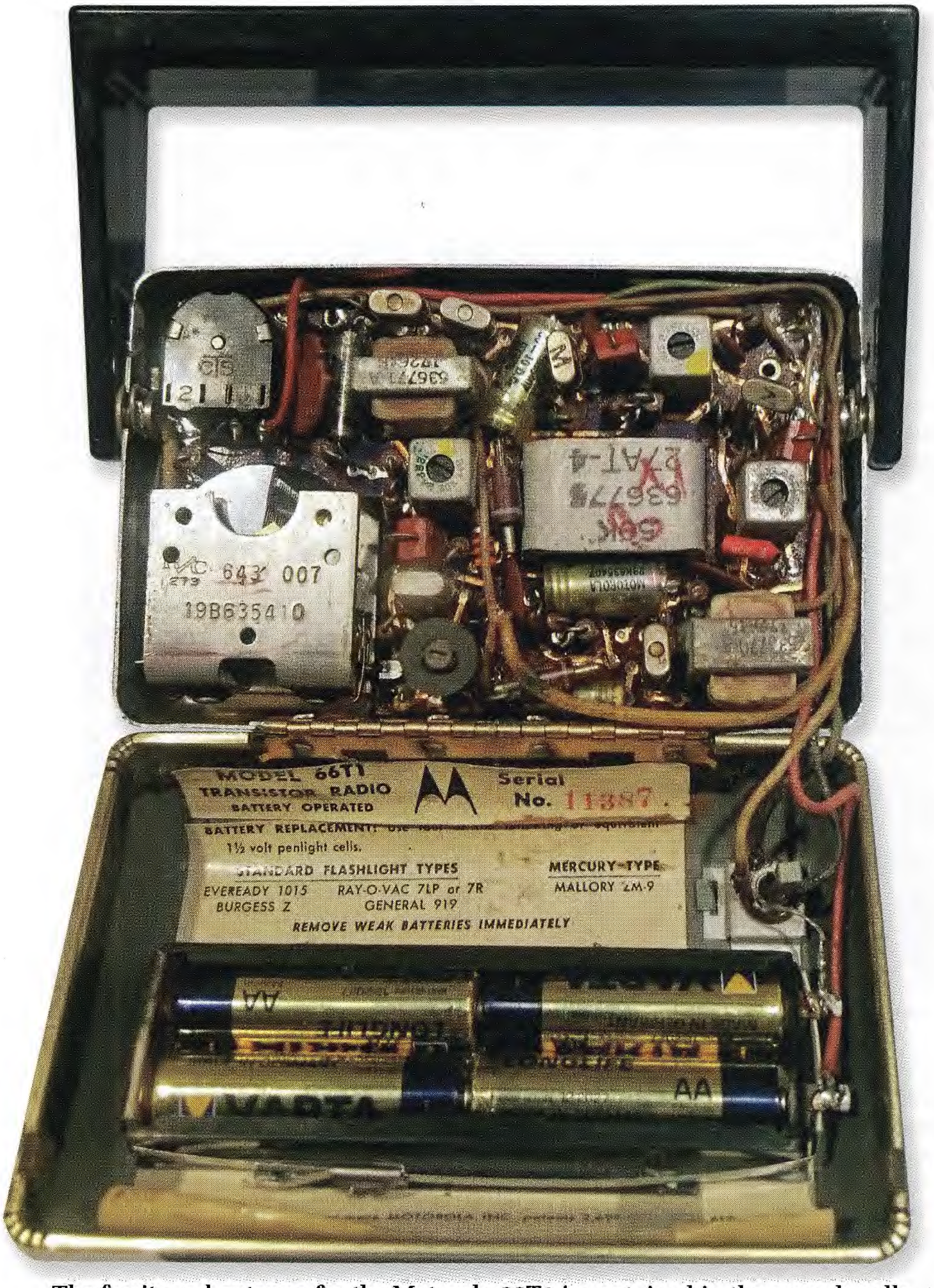
The circuit begins with transistor V1a, 2N172 mixer-oscillator (converter), with collector-emitter feedback. This design allows the ferrite antenna rod's tapping to feed the base with no combined local oscillator signal.

It works about as well as collector-base feedback but has the advantage of allowing signal injection directly onto the base for testing and alignment.

The tuning capacitor, as in most transistor sets, uses the cut plate design for the local oscillator, so there's no padder. E1, a proprietary germanium diode, connects between the top of the local oscillator's coil's tuned winding and the +6V supply. It's there to limit the local oscillator's activity; excessive oscillator output is prevented by E1's shunting effect if the oscillator voltage exceeds 6V on its positive excursion.




The three IF stage transistors (V1-V3) are NPN types, while the three 2N185 audio transistors (V4-V6) are PNP.




**The ferrite rod antenna for the Motorola 66T1 is contained in the carry handle, due to the metal case shielding any ferrite antenna. Unfortunately, this means that signal reception varies changes when you move or touch the handle.**

At only around 70mV, V1's biasing might seem much too low for operation. This voltage is measured with the self-oscillating mixer actually in oscillation. It's common for these circuits to "start" in Class-A (a bias of maybe 200mV), but then to shift into the Class-B operation that gives the non-linearity needed for mixer operation.

Killing the local oscillator saw the base voltage drifting up to give a more normal $V_{BE}$ of around 200mV (Remember, these are all germanium transistors, with much lower bias voltages than silicon types). I've tried this test for local oscillator activity on many sets, but with varying results.

I still recommend using the radiation test: tune a second set to the high end of the band and listen for the "swoosh" as you tune the suspect set over the band. It's more reliable and doesn't even require you to open the suspect set.

V1 feeds 1st IF transformer T1's tuned, untapped primary. Its untuned, untapped secondary feeds the IF signal to the base of 1st IF amplifier V2, a 2N146. V2 is biased by the combination of an 18kΩ resistor R5 and the 1.5kΩ resistor R13 connected to the anode of the demodulator diode, E3.

This negative-going rectified output from E2 forms the AGC circuit. With increasing signal pickup, V2's bias will decrease, reducing its collector current.

As collector current falls, the drop across the 2.2kΩ resistor R7 will fall, and the DC collector voltage will rise. This increase in voltage also appears at the anode of E2, the AGC extension diode.

E2's cathode connects into the converter's collector and E2 coming into conduction will partly shunt out the IF signal at the converter's collector.

This action greatly increases the range of AGC control. Without it, reduction of V2's bias can only give an AGC range of some 30dB.

V2's collector feeds the tapped, tuned primary of 2nd IF transformer T2. Its secondary feeds the base of 2nd IF amplifier V3, another 2N146. This works with fixed bias. Neither IF amplifier uses neutralisation and the set is stable without it.

Both IF amplifiers use bypassing back to their emitters rather than to ground. It's a method more often used in VHF designs and it no doubt comes from Motorola's extensive experience in RF circuitry.

V3 feeds the 3rd IF transformer T3's tapped, tuned primary, and T3's secondary feeds the demodulator diode E3. After IF filtering by 40nF capacitor C13, recovered audio is fed to the volume control. Audio filtering is performed by 6μF capacitor C8.

## Audio stages

As already mentioned, the entire audio section uses PNP transistors. Driver V4, a 2N185, uses conventional combination biasing. Its collector connects to the phase-splitter transformer T4 to provide out-of-phase signals to the 2N185 output transistors V5 and V6 which form the push-pull Class-B output stage.

The usual amount of forward bias (about 0.12V) is provided by resistive divider R17 & R18. Output transformer T5, shunted by top cut capacitor C17, combines the output transistor collector currents and delivers output either to the internal 13Ω speaker or to an earphone via the earphone socket on the rear case shell.

## Getting it going

This process started with the following steps: insert batteries; close case; switch on; be disappointed.

It's a pretty common story but one with a happier ending than many others.

Plugging in an external speaker rewarded me with sound, confirming nothing more problematic than an oxidised earphone socket. Then there was more disappointment. Sound from the set slowly faded to nothing. Turn off, turn on; the same thing happened.

My local oscillator test showed that the oscillator was dead. Great. A 60-year-old NPN germanium transistor is crook. I put the set aside for the time being.

That time finally ended and I thought I'd give this set another try. Let's say I was surprised that this time it just worked, with no weird fading or loss of signal.

I had been hoping the fault was in E1, the local oscillator limiter diode – at least a faulty germanium diode could be replaced easily. But with the set now working, even that simple plan was no longer necessary.

After the initial surprise, I put the radio on the test bench and checked it over. The alignment guide puts the low end of the tuning range at 530kHz. This implies that you can adjust the antenna tuned circuit to match. In practice, unless you can slide the antenna coil along the ferrite rod, the optimal adjustment is done at 600kHz.

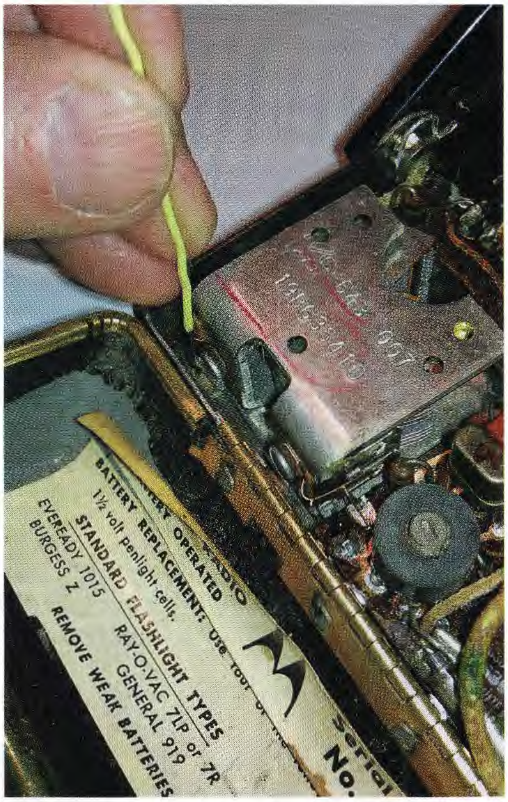
To adjust, set the dial to 600kHz and radiate a 600kHz signal. Now, oscillator adjustment should give maximum output. To check, screw the oscillator slug in slightly, readjust the generator and check the output.

If it has increased, continue with small adjustments of the oscillator coil until you get maximum output. If screwing the slug in reduced the output, try bringing it out a bit. Again, if there's an improvement, continue until you reach maximum output.

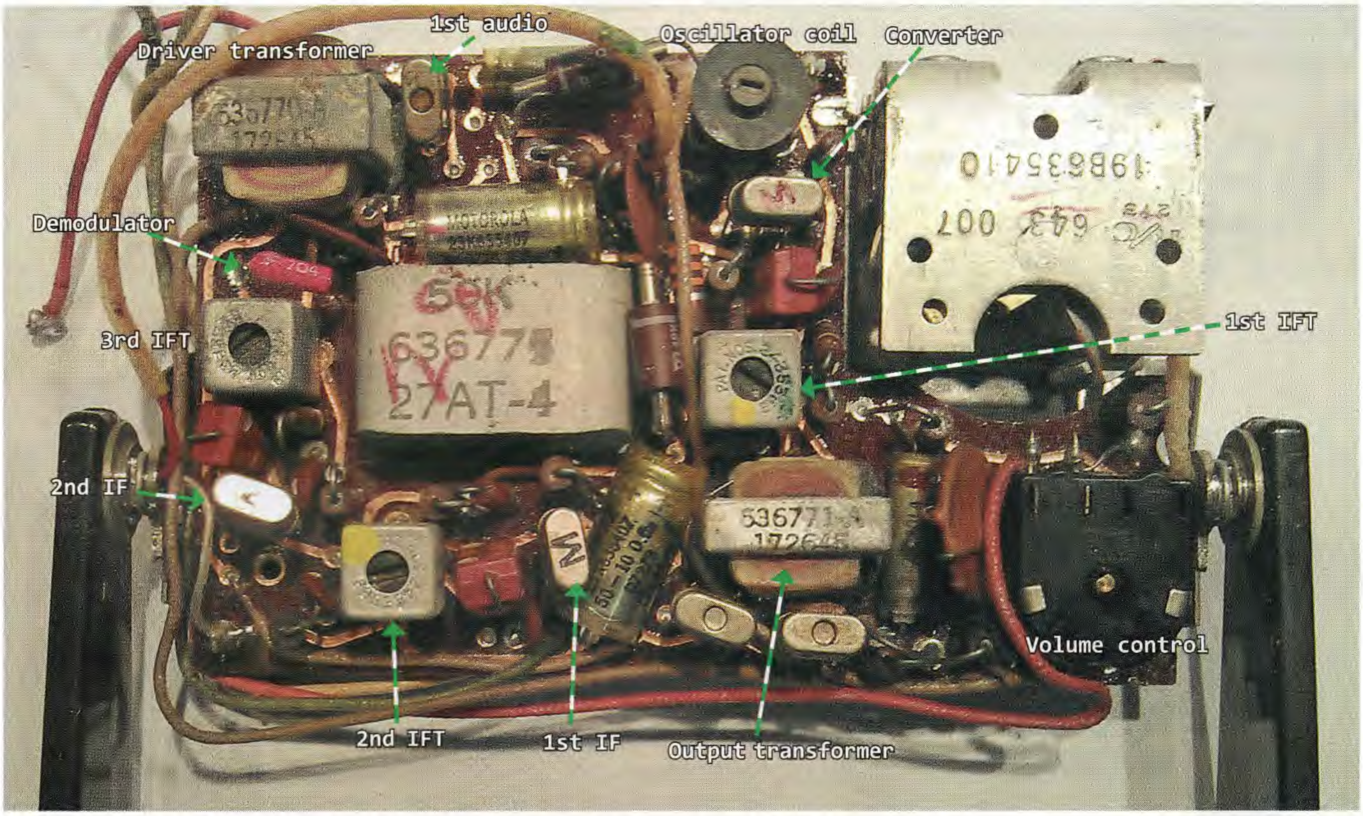
## Special handling

The service instructions advise that the 66T1 be aligned in its case. This works fine for the local oscillator slugs and the three IFs, but the local oscillator and antenna trimmers are obscured. A paperclip with a flattened end is recommended, as the photograph shows. Yes, it is fiddly.

Removal and replacement of parts in the radio is a bit tricky: the volume knob pulls off, but the tuning dial is held by a central knurled screw. Removing the knob exposes a Philips head screw to remove.




**The service manual recommends doing alignment with the PCB in the case. This means you'll need a piece of taut wire or a paperclip bent at 90° to adjust the tuning gang's antenna and oscillator trimmer.**




**While the PCB in the radio is double-sided, components are only soldered to one side.**

Now, turn the carrying handle backwards at 90° to the case. You may need to slightly compress the case lengthwise to allow the handle's pivots to clear the case slots and draw out.

So far, so good. I took it outside to pick up a few local stations and was successful, so I returned it to the test bench. Next day it would not give a peep. The speaker was open-circuit.

Great. Where was I going to get a 3-inch, 13Ω speaker? Careful probing showed there was a break in one of the braids that connects between the speaker's basket terminal and the voice coil. Careful resoldering restored the connection and allowed the speaker to work again, thankfully.

The battery carrier, made of black plastic, had suffered over time and one corner had broken so that it failed to hold the batteries tightly enough to make contact.

Attempts to glue it together were unsuccessful, so I used a cable tie to strap it. Plastic cable ties aren't very good for making sharp angles, but a stainless steel tie (left over from irrigation work) worked just fine.

## Performance

So how good is it? It's OK without being outstanding. Starting with the RF performance, for 50mW output, it needs some 1mV/m at 600kHz and 1.9mV/m at 1400kHz. Selectivity at -3dB down was ±2kHz and at -60dB down it was ±45kHz.

This performance mirrors the previously-described GE675 which also featured an unusually small ferrite rod antenna. Outside, it did manage to bring in ABC Western Victoria at Horsham but it needed the volume control "well advanced" for comfortable listening.

Its AGC performance was a bit puzzling. The circuit includes E2, an AGC extension diode. Other sets with this design easily exceed 45dB gain control for 6dB output rise but this set's AGC action was minimal at best. As the circuit voltages for V2 show, strong signals did bring extension diode E2 into play.

I suspect that the poor AGC action is due to the low resistance values in V2's bias network: in series, they supply diode E2 with some 270μA of forward bias. To provide any AGC action, there has to be enough rectified signal to counteract this current and it's considerably more than in other sets whose designs deliver much better AGC action, with circuit currents as little as one-fifth.

It's possible that the low values of bias dividers for the two IF amplifiers were over-designed to accommodate the wide production spreads of first-generation grown-junction transistors.

At 50mW output, total harmonic distortion (THD) was 3.7%, and only 1.5% at 10mW output, pretty good for a "first-generation" portable. It went into clipping around 90mW, hitting 10% THD at 110mW output. At half battery voltage, it clipped at 20mW, reaching 10% THD at 30mW.

Frequency response from volume control to speaker was 110kHz~7.5kHz, and from antenna to speaker it was 180Hz~2kHz.

## Would I buy another?

You can still find 66T1s around and they're respectable members of the "first wave" of portable transistor sets. It was also good to get a 56T1, just to be able to compare the two audio designs.

My only quibble with the 66T1 is the noticeable "hand effect" that detunes the antenna circuit, reducing signal pickup if you use the antenna as a handle.

## Further Reading:

For the circuit and servicing instructions, go to Radiomuseum: siliconchip.com.au/link/aajt

For a collector's description, and illustrations, try Phil's Old Radios at antiqueradio.org/Motorola66T1.htm

A general discussion, including "it's a bit deaf" can be seen at siliconchip.com.au/link/aaju **SC**