1972 BWD Model 141 Audio Generator

By Ian Batty

The BWD 141 is an Australian-made sine and square wave generator, produced around the early 70s. It has an output frequency range of 1Hz to 1MHz, and is powered by mains or two 9V batteries, boasting a respectable 600 hours of battery life.

BWD, established in 1955 in Hawthorn, Victoria by John Beesley, Peter Wingate and Bob Dewey produced well-engineered and affordable test equipment for several decades. They eventually became McVan Instruments and currently work out of Mulgrave as Observator Instruments.

BWD's versatile and innovative 216A 0~400V power supply was described in the February 2019 issue of SILICON CHIP (siliconchip.com.au/Article/11419).

This article describes a simpler piece of test gear, but one with a much longer history in electronics.

You may be fortunate enough to have AWA's R7077 Beat Frequency Oscillator in your collection. Released in 1940, it used two ultrasonic oscillators: one fixed, and the other adjusted by the frequency control.

The oscillator signals were mixed, and the frequency difference was delivered as the audio output signal. This had the great advantage of a single-span dial covering the audio band from 30Hz to 13kHz. However, the need to zero it before use and its less-than-perfect sinewave output made it unsuitable for testing high-performance audio equipment.

Modern function generators do offer sinewave output, but they generally are modified square waves of indifferent purity. I recall a TAFE colleague who was teaching audio and hifi discovering this. With a few choice words, he returned the class set of function generators to storage and ferreted out every 'old-tech' BWD audio generator and MiniLab he could find.

Early signal generators

Frederick Emmons Terman is one of the giants of electronics. He was born in 1900 and gained his Doctorate of Science in 1924. His supervisor was another giant of American science, the man who would lead the Manhattan Project: Vannevar Bush.

Working at Stanford University, Terman designed a course of study and research in electronics, focusing on vacuum tubes. Terman's Radio Engineering was first published in 1934, and would become one of the most important reference works in the science of electronics. It remains an authority to this day.

The saying goes that "if you were doing radio or electronics engineering anywhere from the 'forties to the 'sixties, and you weren't reading Terman, you weren't doing engineering."

Terman's Stanford University students included Oswald Garrision Villard Jr. (ionospheric research and over-the-horizon radar), Russell and Sigurd Varian (inventors of the klystron), William Hewlett, and David Packard.

Those last two would founded one of the world's top makers of electronic instruments, and created the HP Way, a corporate model that has led innovation within the industry.

From thesis to product

Bill Hewlett's Master's thesis described a wide-range, low distortion audio signal generator. His supervisor was Frederick Terman, of course. Using the Wien Bridge filter, the HP 200A set aside tuned-circuit and other

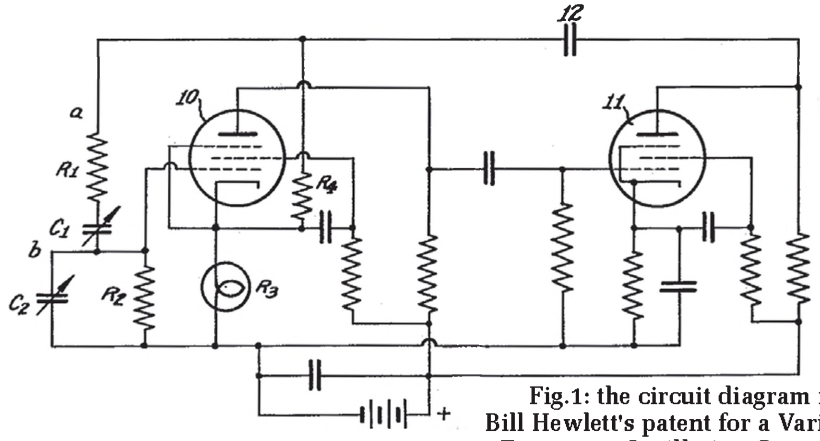


Fig.1: the circuit diagram from Bill Hewlett's patent for a Variable Frequency Oscillation Generator.

complex techniques and used a simple resistance-capacitance bridge that could easily deliver a 10:1 frequency ratio in each range.

It was named the 200A for marketing reasons. It gave the appearance of being one-of-a-number of products, rather than the very first.

The Wien Bridge (invented in 1891 by Max Wien) uses two resistors and two capacitors (R1, R2 and C1, C2 in Hewlett's diagram). For equal-value resistors and capacitors, there is a frequency ($f = 1 \div [2\pi \times R \times C]$), where the phase shift from input to output is zero. This is one part of the Barkhausen Criterion for oscillation, the other part being an overall loop gain of +1.0.

Notice that there are no exponents in the formula; frequency varies directly as the inverse of resistance or capacitance, so a 10:1 change in either R or C gives a 1:10 change in frequency. This decade span allows just three switched ranges to cover the three-decade audio band of 20Hz to 20kHz. It's another advantage of the Wien Bridge principle.

Tuned-circuit oscillators see frequency vary as the square root of L or C, so a 10:1 change in L or C gives only a 1:3.16 change in frequency. This three-to-one ratio is characteristic of L-C tuned oscillators.

An oscillator circuit can be built by putting the Wien Bridge filter in the positive feedback path between the output and input of an amplifier. The amplifier only needs moderate gain to make up for the small losses in the filter circuit; a gain of about three is adequate.

In practice, the circuit (shown in Fig.1) uses two feedback paths: the positive feedback circuit that contains the frequency-determining filter, and an adaptive negative feedback circuit that regulates the oscillator's output and produces a sinewave of low distortion. Hewlett used a low-power light bulb, R3 in the circuit. More on this below.

Hewlett opted to vary the capacitances in his filter circuit. This had the great advantage of reliability, using a four-gang capacitor. Variable resistors rely on sliding contacts with their attendant noise and possible interruption due to wear or corrosion. But the only moving contacts in a variable capacitor are the ball-bearing supports for the shaft, which ground the shaft on which the moving plates are mounted.

A variable capacitance system, though, struggles to exceed a frequency range of six decades, and more commonly offers only four or five. With the HP 200A's maximum capacitance of 1.05nF (1050pF) for each two paralleled sections of a practical four-gang 525pF capacitor, they needed 8.24MΩ resistors to get down to 20Hz.

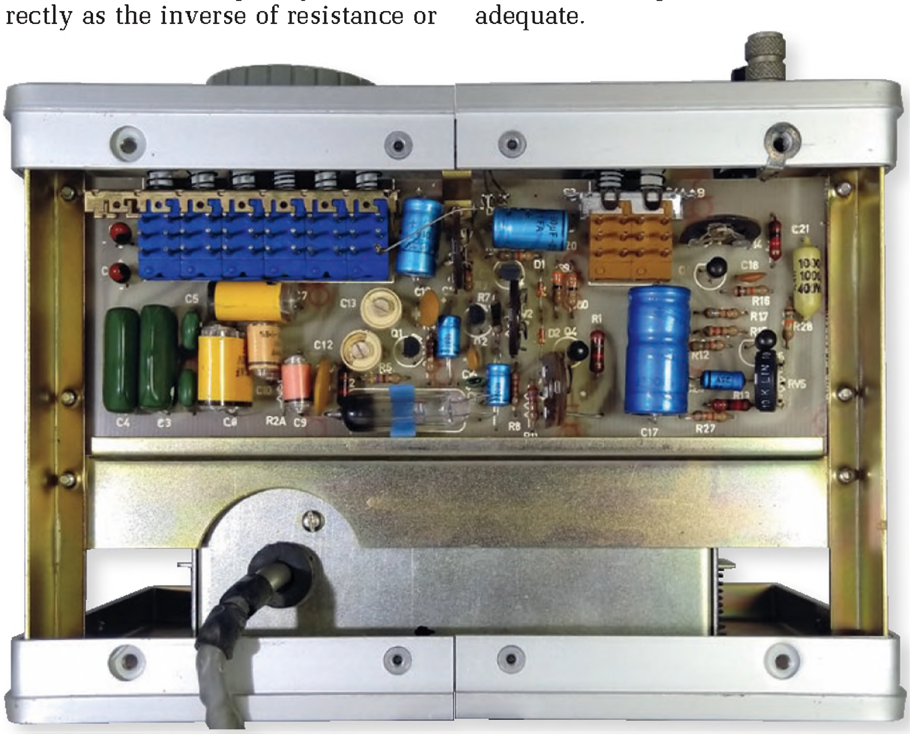
That's approaching the point where a valve's contact potential and other input phenomena affect circuit operation.

The high-frequency end can use low-value resistors, but now we find that the minimum capacitance of the gang itself, combined with circuit capacitances, conspire to limit the highest practical frequency of operation.

Variable capacitors, however, can have their plates cut to a non-linear capacitance-versus-rotation profile, giving a linear frequency dial. It's more difficult to build the non-linear high-precision variable resistors that would be needed for a linear scale.

HP's 200A offered three ranges: 35~350Hz, 350~3500Hz and 3500~35,000Hz. The successor HP200B shifted the ranges down to 20~200, 200~2000 and 2000~20,000Hz while output power was 1W into 500Ω, with distortion less than 1%.

Using ordinary 'radio' components, and weighing in at just over 8kg (18lb), it really could be built by two young men in a garage. Against this, General Radio's much more complex beat-frequency oscillator weighed in at over 42kg (93lb). It's not hard to guess which instrument the average technician preferred.



The single-sided PCB is mounted on the underside of the chassis. Interestingly the thermistor (TH1) is mounted in a glass tube with blackened top, and can be seen around the bottom centre of the PCB.

William Hewlett said that "…an oscillator of this type can be laid out and constructed on the same basis as a commercial broadcast receiver, but with fewer adjustments to make. It thus combines quality of performance with cheapness of cost to give an ideal laboratory oscillator."

BWD's design rework

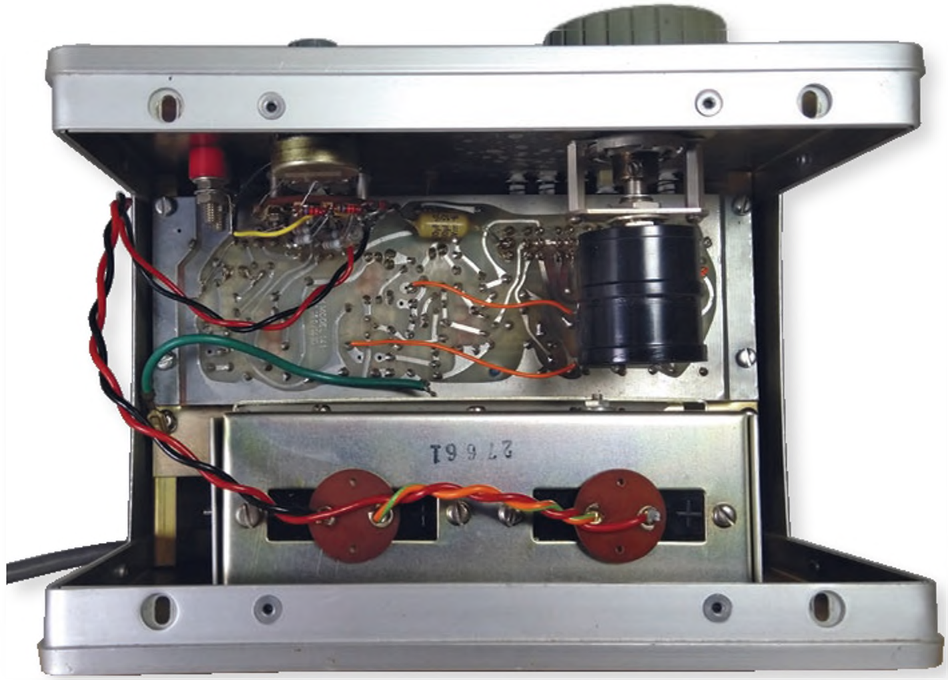
The BWD 141 updates the classic HP design. It's all solid-state, and works economically from two 9V batteries or a regulated mains supply. It also changes the variable element, using a two-gang potentiometer. Reliability is ensured by using a wirewound type, much less likely to suffer contact degradation and noise than a carbon pot. This change gave a six-decade range: 1Hz to 1MHz.

The third change is to replace Hewlett's low-power incandescent lamp with a negative temperature coefficient (NTC) thermistor, the venerable R54. If you've built yourself a Wien Bridge oscillator, you probably used the R54 (or its R53 cousin) as well.

A square wave output was added. This was useful for testing the transient response of high-performance audio circuitry.

BWD 141 outline

The 141's Wien Bridge circuit comprises three functions: a frequency-determining filter, a positive feedback amplifier and negative feedback stabilisation. Positive feedback is vital; without positive feedback, there will be no oscillation. The filter's purpose is also clear; it controls the oscillator's frequency.

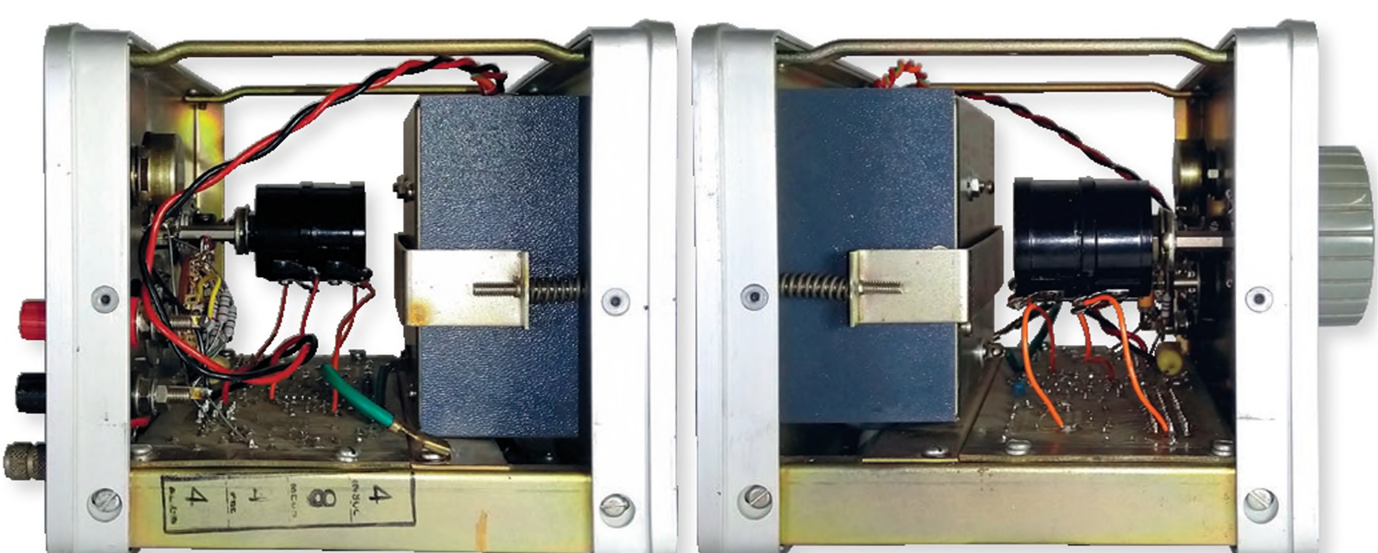


The large black device at upper right is the rotary adjustment knob used to adjust frequency (RV1A/B). The knob at upper left is the amplitude range selector (RV3/6). The big metallic container at the bottom is the AC power pack, since the BWD 141 could be operated using two 9V batteries (type 216P).

The positive feedback must be sufficient to ensure reliable starting and operation for all settings of the filter's controls (range and frequency), and to handle reasonable variations in load, temperature and supply voltage. It also needs to make up the filter's loss.

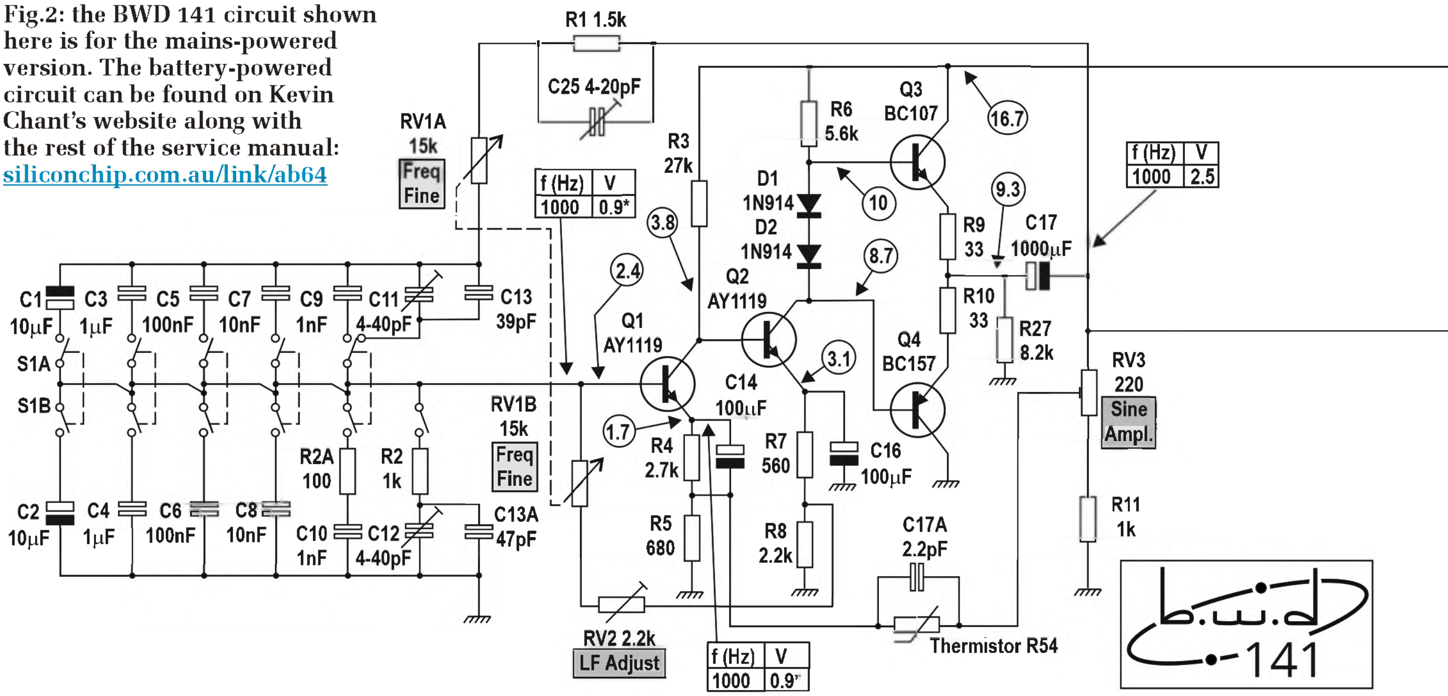
A sufficient amount of positive feedback will ensure fast, reliable starting, and the 141's gain is around 70 times. This ensures startup, but it also drives the amplifier into clipping, giving a square wave output. Many tuned-circuit oscillators do just this, relying on their inductance-capacitance tuned circuits to reject the square wave's harmonics and produce something approaching a pure sinewave.

If you check out the specs for low-cost RF signal generators, you'll discover that many of them have a top range that relies on the second harmonic from the oscillator, which is evidence that their sinewaves are not totally pure. It's the negative feedback circuit that gives the Wien



A side view gives a better look at the wiring for the front panel controls. You might be able to see that the cables from the power pack connect to the underside of the single-sided PCB.

Fig.2: the BWD 141 circuit shown here is for the mains-powered version. The battery-powered circuit can be found on Kevin Chant's website along with the rest of the service manual: siliconchip.com.au/link/ab64



Bridge its pure sinewave output.

The BWD 141 significantly betters the HP200A in terms of distortion too, delivering less than 0.1% total harmonic distortion (THD) over the audio spectrum.

Circuit description

The BWD 141 circuit is shown in Fig.2. NPN transistors Q1 and Q2 form the gain block, with complementary emitter-followers Q3 (NPN) and Q4 (PNP) forming a buffer to drive the load and supply the positive feedback path (via R1/RV1A/C3) and the negative feedback path (via RV3 and thermistor R54).

DC conditions are set by negative DC feedback from Q2's emitter, via RV2 and RV1B, to the base of Q1. This feedback sets the output emitters to about half-supply.

The output stage operates in Class-B, with biasing set by the forward conduction voltages of series diodes D1/D2.

On startup, the output from the emitters of Q3 & Q4 rises rapidly to half-supply. This rise is conveyed back, via R5-RV1A and the range capacitor (C1, C3, etc – let's take C3) to the base of Q1. C3 (and its companion C4) will be charging, and its charging current is what draws Q1's base positive from its 'resting' DC position.

Q1's base will be more strongly forward-biased by this positive feedback action, so its collector voltage will fall, allowing Q2's collector voltage to rise, pushing the emitters of Q3 & Q4 even higher.

The circuit will eventually saturate as Q3 turns on fully. At this point, the voltage at the emitters of Q3 & Q4 can rise no further, and C3/C4 cannot charge any more. C3's charging current into Q1's base will fall, so Q1's collector voltage will rise.

Now, Q2's base current will rise, as will Q2's collector current, and Q2's collector voltage will drop. This will bring the emitters of Q3 & Q4 towards ground, along with the top end of C3, reducing Q1's base current.

Once these voltages drop low enough, Q1's bias circuit can begin to charge C3/C4 again, pulling Q1's base positive and allowing base current to flow again. The cycle will continue at a rate determined mainly by the values of RV1A/C3 and RV1B/C4. The output will be pretty much a square wave due to the high gain of the circuit.

Negative feedback

Now, let's consider the feedback path via the thermistor, and let's just consider AC conditions. Any signal passing from the output (emitters of Q3 & Q4) back to Q1's emitter will reduce the circuit's gain.

The thermistor has a negative temperature coefficient, with a 'cold' resistance of around 40kΩ and a 'hot' resistance (with only 3mW applied) as low as 500Ω. So any applied power will increase the circuit's negative feedback and reduce its overall gain.

Since the output signal is applied to the thermistor, a high output signal will force its resistance to fall.

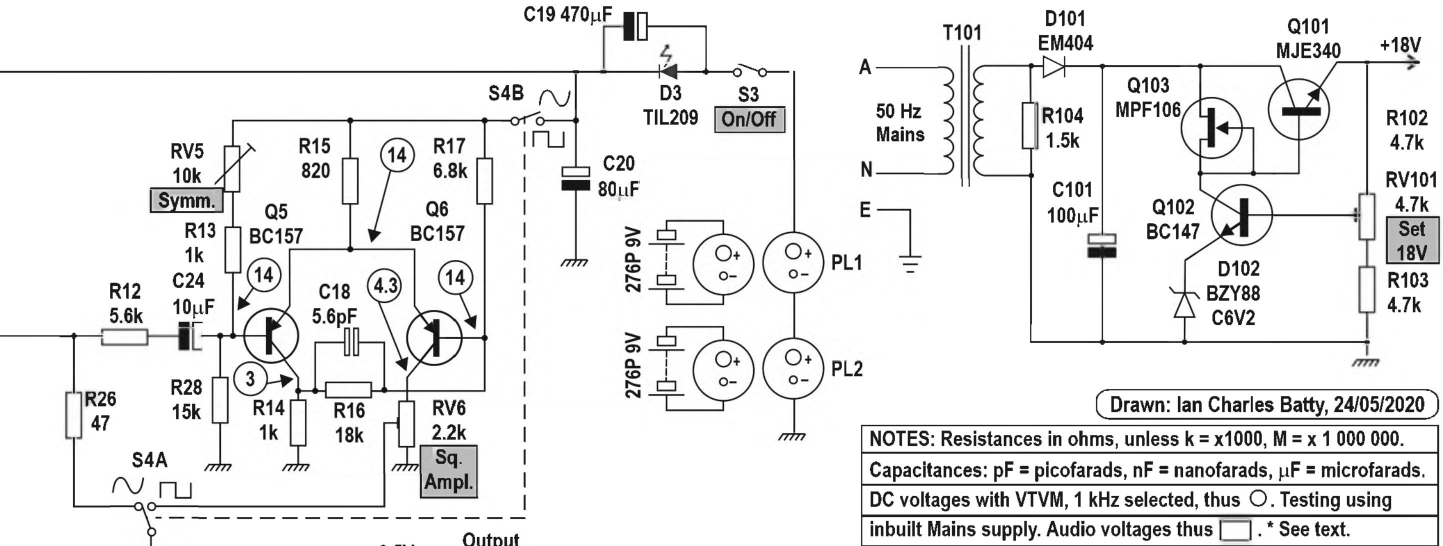
And that's what happens. As soon as the circuit goes into oscillation, the output signal will cause the thermistor's resistance to fall, and negative feedback will increase. The combination of thermistor characteristics and the value of Q1's unbypassed emitter resistor will cause the oscillator to settle at an output voltage of around 8V peak-to-peak, ie, 2.5V RMS.

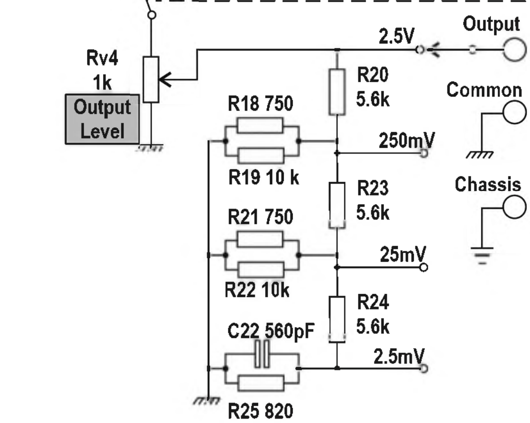
It's important that the time constant of the negative feedback path is significantly slower than the rate of oscillation, due to the thermal inertia of the thermistor. Otherwise, it would modulate the signal and thus introduce significant distortion.

As the entire circuit operates in the linear mode, distortion is low; no harmonics (ideally) are generated, and the output sinewave is of high purity. A recent advanced laboratory design of a similar circuit yielded a THD level of –140 dB (0.00001%)!

Notice that the circuit diagram shows almost identical voltages indicated at Q1's emitter and base for a 1kHz signal (marked with asterisks*). It's working as a differential amplifier, and the amplifier's open-loop gain of 70 times means that, for an output signal of 2.5V RMS, the difference between the two input signals only needs to be about 36mV (2.5V ÷ 70).

Such a small difference was not apparent on the oscilloscope screen,





hence the two identical voltage readings on the circuit.

The square wave section uses a schmitt trigger driven by the sinewave, and this is the preferred method for generating square waves from pretty much any waveform. Its hysteresis allows the output square wave to have very rapid rise and fall times, regardless of the slopes and frequency of the input.

It's one of those simple circuits with a complicated description. If you're interested in exploring it further, see the "further reading" section at the end of this article.

Cleaning it up

Upon receiving this BWD 141 signal generator, I found that it had no output signal. I jiggled a few controls and got something, but it still didn't seem quite right.

Cleaning the output attenuator pot and the range switches brought it back to life. I didn't bother to clean the dual-gang frequency pot, as it worked just fine. It was a bit off calibration, but a few minutes with a frequency counter and a DVM had it back in spec.

A quick clean of the cabinet, and it was ready for the photo session.

How good is it?

For a simple, cheap and cheerful instrument, it does the job. The frequency setting is accurate to the dial, but the output attenuator's rudimentary scale could have been made more precise. Be aware that the thermistor loop does take a little while to stabilise after switch-on, and after changing frequency or ranges.

THD across the audio band from 20Hz to 20kHz (at 1V RMS output) was less than 0.1%, agreeing with the BWD specifications. Square wave rise time (10% to 90%) was 200ns, fall time (90% to 10%) was 150ns at 100kHz and 1MHz.

Frequency drift seemed absent in my workshop at 20ºC. It started at 19.448kHz cold, and that's what I got for the next ten minutes.

So I got out the hot air gun and cheekily warmed things up to around 35ºC, getting a frequency shift from 19.448kHz to 19.469kHz (about 0.1%). It's a bit academic, as this kind of signal generator is not expected to give extreme frequency stability.

Frequency accuracy is within dial setting, bettering 1% in each case.

The output voltages varied a little with range. Selecting full sinewave output (2.5V/250mV/25mV/2.5mV) gave 2.4V, 260mV, 26mV and 2.5mV. The 1.5V, 150mV, 15mV & 1.5mV settings were similar, but the 0.5V, 50mV, 5mV & 0.5mV settings gave only about half their indicated values.

Any selected output voltage was constant within specification across any one band.

It benefits from the mains supply, as distortion rises rapidly with low voltage. With a 16.5V supply (ie, 8.25V x 2), distortion increases to around 0.9%, with visible flattening of the negative sinewave peak. If using batteries, it would be sensible to check them before taking measurements needing a low-distortion signal.

Would I buy one?

I already have a very nice Kikusui 433 that includes an output voltage meter. It has served me well for ten years, so I'll be returning this fine Aussie product to its generous owner to enjoy.

The review set was Serial No. 26125, so I reckon there are still plenty around if you need a piece of test gear that combines Australia's tech history with decent performance.

Special handling

The power supply is wholly contained in a separate section within the case, so there are no hazardous voltages in the case when you open it up for basic maintenance. While the circuit board is not too cramped, be careful when using an oscilloscope probe with a grounding ring behind the tip. A bit of tape or heatshrink over the ground ring is good insurance against accidental shorts to ground.

Further reading

- The HP200 (including manual!): siliconchip.com.au/link/ab3z
- Thermistor data (look for R series): siliconchip.com.au/link/ab40
- Low distortion (-140dB) Wien Bridge design by Vojtěch Janásek: siliconchip.com.au/link/ab41
- Schmitt trigger: https://w.wiki/3AEH

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