AUDIO OUT

By Jake Rothman

Ge-mania – Part 1

History

On 17 November, 1947 John Bardeen and Walter Brattain at AT&T's Bell Labs performed experiments and observed power amplification of a signal applied to a semiconductor crystal. Together with William Shockley they had invented the transistor, and in 1956 the trio were awarded the Nobel Prize in Physics 'for their researches on semiconductors and their discovery of the transistor effect'.

So what was in this special crystal – silicon? Definitely not – it was germanium, and for a short period the future looked germanium flavoured. However, as we all know, there is no Germanium Valley and we don't use germanium chips. Commercially, the germanium era only lasted from 1957 to around 1972, a mere 15 years, and even then it was dominant for just a few of those years – but it did usher in modern electronics – the germanium era was the first stage of the transistor solid-state age, which coincided with the moon race and the arrival of transistor radios.

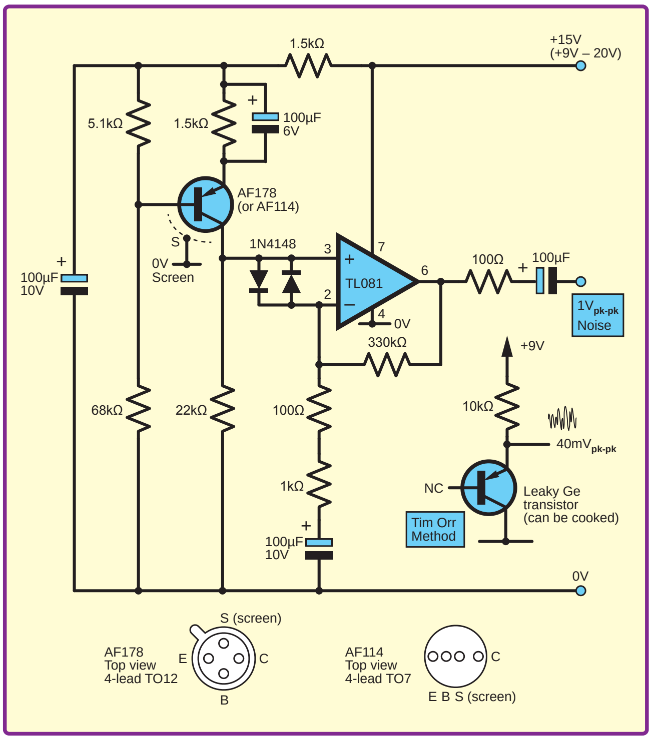

Fig.1. RF Germanium transistors make excellent white noise generators. Some often have a 'spluttery' noise character, they are useful for analogue drum units, since every 'hit' sounds different.

Who still uses germanium?

Like many lost technologies, germanium devices have their adherents. 'Who would want a temperature-sensitive, inconsistent, obsolete, scarce and expensive device in their designs?', I hear you ask. Well, it's the retro-loving, valve-hugging music buff! I used to call it 'germania' – although strictly speaking it should be 'ge-mania', since 'germania' is simply Latin for Germany, the original source of the element's name. Anyway, satisfying the demand for ge-manophiles is part of my job, and I do my best to give ge-maniacs the gear they want!

It's difficult to get germanium devices today. Most are Cold War legacy, 'new-old-stock' from electronic shops and specialist component suppliers, such as Cyclops, often in the north of England. Because the stock can be over 50 years old, 20% of what I buy doesn't even work. Some specialist germanium devices are still made in the States, but for their infra-red optical properties – not for audio use. Apparently, Doug Dunlop had some made recently for 'Fuzz Face' guitar effect pedals; they must have been expensive, since the price of raw germanium today is 80× that of silicon. Interestingly, the germanium used to be extracted from the soot of flue gasses of coal-fired power stations. There were also ores available from a few conflict zones. It was the difficulty in refining high-purity silicon at elevated temperatures that initially precluded its use, despite it being the second most common element in the Earth's crust. In 1958, a typical germanium small-signal transistor cost around £1.40 retail (today's money).

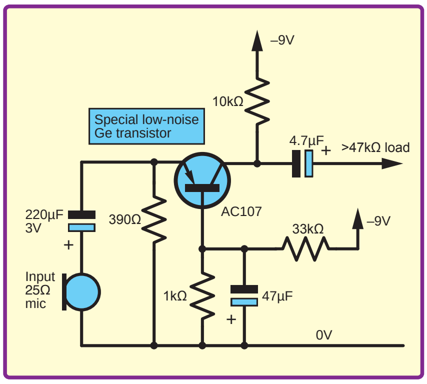

Fig.2. Common-base germanium microphone pre-amp. Used in the sixties to connect low impedance moving-coil microphones to high-impedance valve inputs.

I have some old germanium alloy-diffused RF transistors (AF128) that produce the most sonically interesting noise (I suspect there are some radioactive contaminants from the coal and crystal defects at work here) and I use these in analogue drum synthesisers – see Fig.1. In theory, germanium-alloy transistors, such as the 2N508A, can give the lowest voltage noise, giving lower noise than silicon planar devices with low impedance sources, such as ribbon microphones. However the poor manufacturing of old devices means you would have to manually select from a large number to get good results.

In my practical experience, modern silicon devices are generally quieter. Fig.2 shows a common-base preamp, which has a low input and high output impedance. It uses an AC107, a special low-noise germanium transistor designed for tape recorders in 1964. Hooking it up to a 25Ω moving-coil microphone gave good results – acting like a matching transformer. There are some germanium pre-amps and compressors

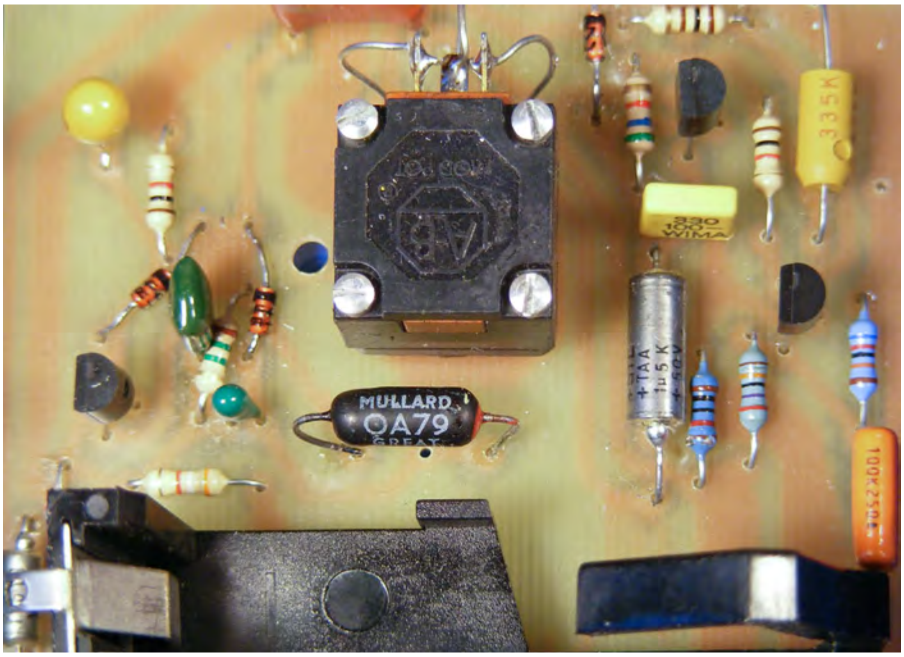

Fig.3. The earliest mass-produced semiconductor, the point-contact diode. Here, a 1960 OA79 is used in a Colorsound Single Knob Fuzz effects box, along with a silicon diode to give asymmetrical clipping action.

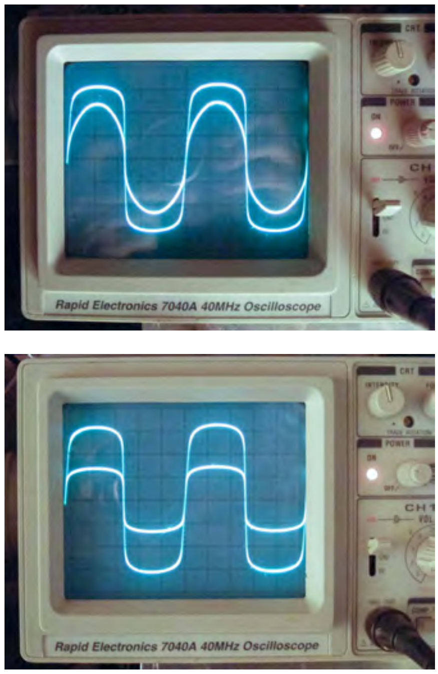

Fig.5. Clipping waveforms of various diodes. (Top) 1N4148 silicon compared to OA91 germanium, note the more rounded shape and lower amplitude of the germanium diodes. (Bottom) Comparison of silicon with BAT42 schottky diodes – the schottky diodes have lower amplitude, reflecting their lower forward voltage drop

on the market, such as those by Chandler Ltd. There is renewed interest in germanium for heterojunction bipolar transistors where germanium is combined with silicon in the base region of the device. They are used in very low-noise microwave applications.

Germanium vs silicon

The first mass-produced semiconductors were germanium point-contact diodes, such as the OA81 and OA79. I use OA79s in the latest version of my Colorsound Single Knob fuzz box, see Fig.3. These large-case glass SO-25 types were then miniaturised down to the DO-7 glass-case OA91 and AA119 devices. There is also a popular US germanium diode, the 1N60, which is still available, albeit at high cost, from companies such as Tayda. Their advantage is the low turn-on voltage of around 0.25V and their 'soft knee', the point where forward conduction begins. It gives a 'soft' distortion when used for fuzz boxes. They are also still the most sensitive device for crystal sets (although gallium-arsenide types can have a lower forward voltage). Today, these are often replaced by the more consistent schottky diodes, such as the BAT42, but to a discerning guitarist, nothing sounds quite as good as selected germanium devices. (I find musician's ears are finely tuned to distortion changes with level). Fig.4 shows a clipping circuit using various diodes. The resulting waveforms are shown in Fig.5.

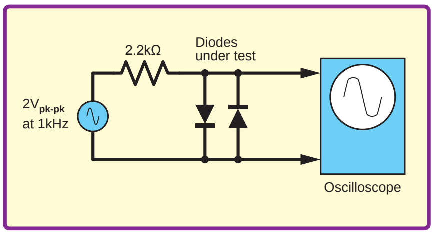

Fig.4. Clipping circuit to test different diodes

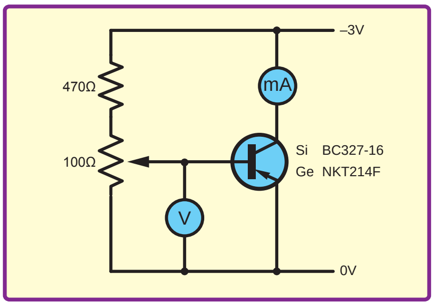

Fig.6. Transistor test circuit to compare the transconductance (base voltage vs collector current) of germanium and silicon transistors

With transistors, guitarists can also hear the differences between germanium and silicon. You can't 'see' it on a 'scope, but open-loop (with no negative feedback) they are supposedly more linear than silicon, reputedly having a less abrupt turn-on. Being a born sceptic, I distrusted the curves given in previous articles and amplifier books, so plotted my own, using the test circuit in Fig.6. This resulted in the collector current (I_c) vs base voltage (V_{be}) or transconductance curves given in Fig.7

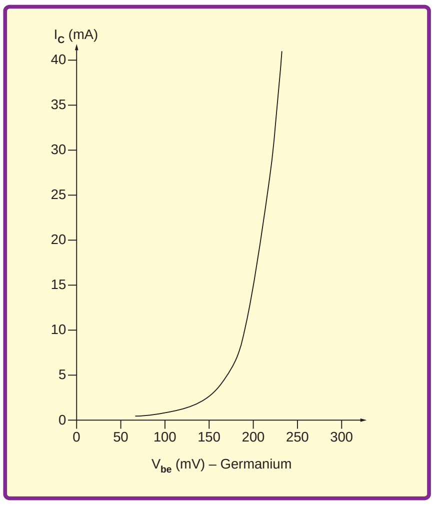

Fig.7. Germanium transconductance curve

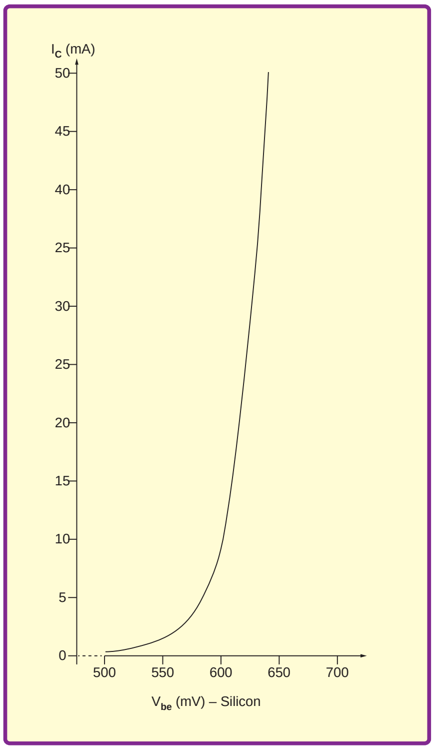

Fig.8. Silicon transconductance curve

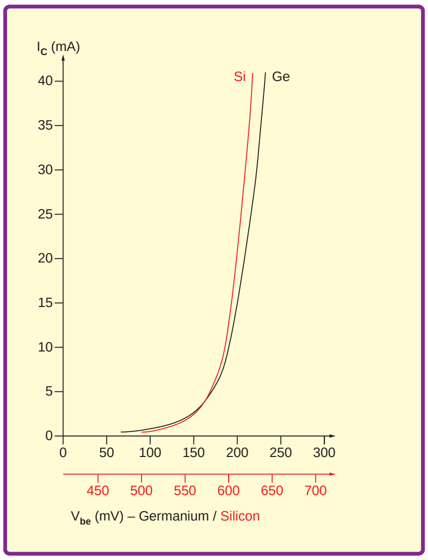

Fig.9. Comparison of silicon vs germanium transconductance curves

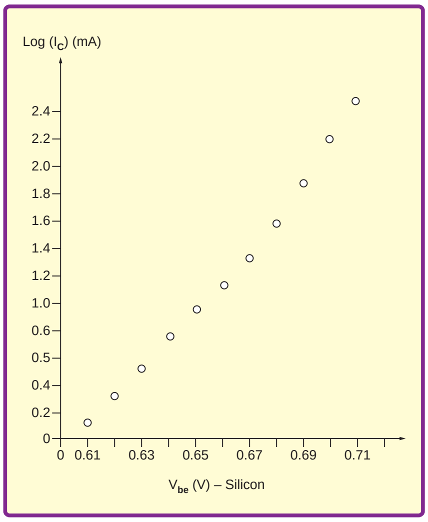

Fig.10. Logarithm of collector current vs base-emitter voltage gives a straight line with silicon. Germanium is the same but slope drifts badly with temperature.

and Fig.8. Using typical germanium and silicon audio 'driver' transistors (NKT214F and BC327), I found the germanium 'knee' to be only slightly softer. Overlaying the curves to take into account the different threshold voltages shows the difference in Fig.9. Both curves follow the usual logarithmic increase in I_c with increasing V_{be} in accordance with the physics of normal bipolar transistor action. I started to plot this, logging the current to see if I got a straight line, which I did (Fig.10) although I did feel like I was back at school! (As an aside, it was the improved stability of silicon transistors that allowed proper logarithmic signal conversion, which paved the way for Moog's analogue synthesiser.)

The Bailey amplifier

In November 1966, AR Bailey published a transformer-driven class AB Hi-Fi amplifier in *Wireless World*. It had low total harmonic distortion and it

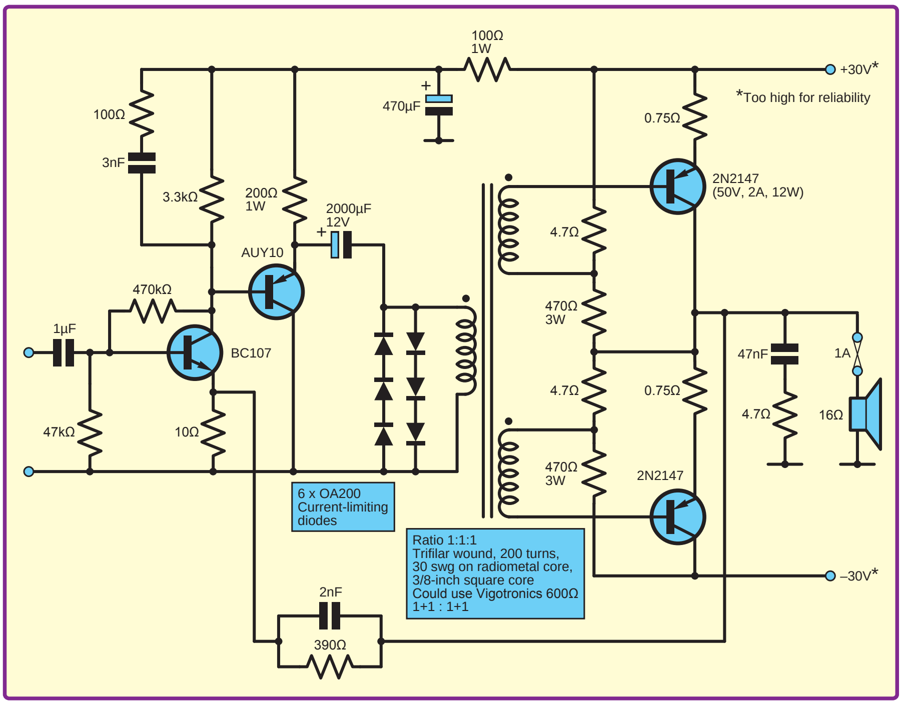

Fig.11. AR Bailey's 1966 transistor power amplifier used a driver transformer to give phase splitting and deal with leakage currents. Distortion was much worse with silicon transistors.

used germanium, not silicon transistors (see Fig.11). Then, in November 1969, John Linsley-Hood published another amplifier in *Wireless World*, and he also found lower distortion with germanium transistors in a standard common-emitter amplifier (Fig.12). (I tried but couldn't replicate this result. His circuit seemed to clip softer, rounding off square waves, but I suspect this was due to high internal feedback capacitances. Of course, the higher open-loop gain obtained with multiple silicon transistors, means silicon distortion can be made much lower when high negative feedback is applied.)

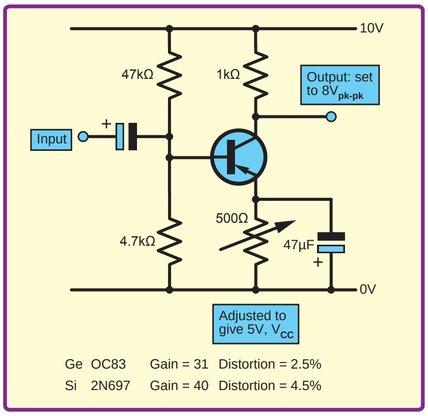

Fig.12. Common-emitter amp for comparing silicon and germanium transistors.

Germanium Hi-Fi

The first transformerless Hi-Fi amplifier was germanium-based, developed by HC Lin at RCA in 1956. It used a quasi-complementary output stage with a single low-power NPN device, the rare 2N35 – see Fig.13. The elimination of audio transformers was essential to allow high levels of negative feedback and the consequent reduction of distortion. Later, this circuit was developed by Toby and Dinsdale for a constructor's version in *Wireless World* in 1961. It was actually a rehash of a Lin-derived guided missile servo amplifier they had designed earlier, which they found also sounded rather good! The single NPN, now a 2N388A, again caused sourcing problems, with the only UK NPN device available at the time – the OC140 – tending to blow up. Later, Mullard produced the AC127Z, a selected AC127, which had sufficient V_{ce} rating.

That's all we have space for this month – more on *Ge-mania* in the next issue!

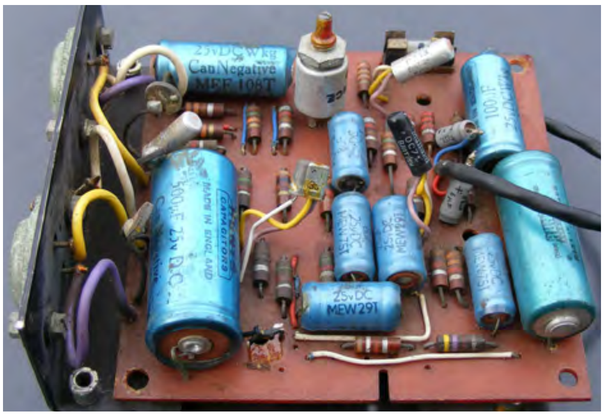

Fig.13. Power amplifier based on the Lin design from the early 1960s. The three-lead 2N35 in the silver can (dead centre) was one of the first NPN germanium transistors, allowing elimination of transformers in amplifiers.