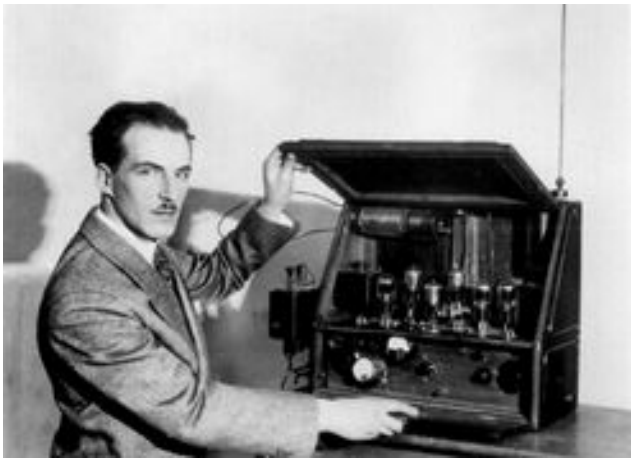
Genius shows most clearly from behind

Artist friends tell me that one of the reasons that student artists repeatedly copy the work of great masters – I mean as a learning exercise, not for fraud – is that their failures to copy the spirit of the original highlight new features they had not noticed before, and illuminate all the more clearly the genius of the original creator. I think that the last couple of months have given me a scientist/engineer's version of that experience, though the story comes not from my official laboratory at work but from the chaotic interior of my shed at home, far from Edinburgh in a tiny hamlet on Scotland's east coast. The story centres on a mad idea for an unusual Christmas present for Katie. A present that ended up being given to her six weeks after Christmas, which is why I am writing this in February.

Katie is very musical, playing several instruments and singing to a high standard in some of Scotland's most impressive choirs. A while ago, over at my house, she heard a CD of Clara Rockmore playing a Терменвокс ('Termenvox'), or 'Theramin' is it and its inventor are more usually known in the West. For anyone who has not come across this device, it is a musical instrument invented in by Леев Сергеевич Термеен (Lev Sergeivich Termen) in 1920 as a by-product of research on electrical properties of gases. What makes the instrument unusual is that playing it involves no physical contact. Instead, the player alters the position of his or her right hand

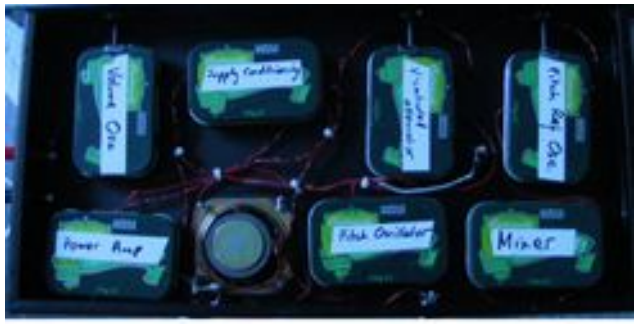
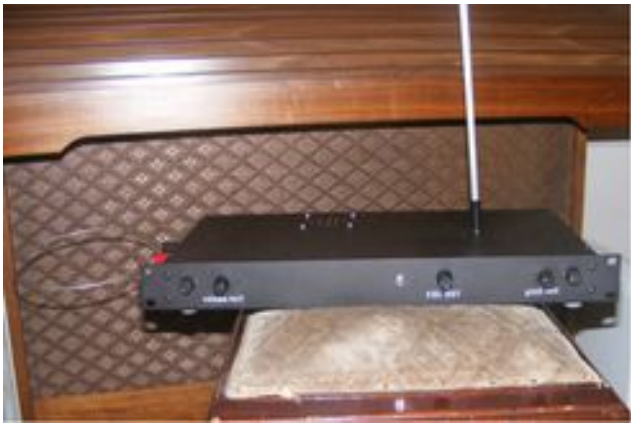


Leon Theramin, as he called himself while living in the USA, and his Theraminvox. The left-hand image shows how it is played.

to control the pitch of a note, and left hand to control the volume, the hands moving in empty space near two metal projections.

The sound of the instrument is unique, a little like a stringed instrument but very subtle as the harmonic structures change with pitch. Unlike many simple electronic toys, this can be played as a real musical instrument and anyone who doubts this should look up Clara Rockmore on YouTube. Given that Katie was fascinated by device, I thought one might be an unusual present. It is of course possible to buy them, but those that are available seem either to be very cheap novelty versions, usually without the volume control and with a terrible tinny tones, or fancy digital versions that have stepped beyond the elegant simplicity of Lev Sergeivich's original vision. Building one seemed the obvious solution. Much as I love 1920s circuitry and adore making things using valves ('tubes' in the USA), I could not copy the original design for two reasons, the first of which was its physical size (Katie lives in a small flat) and the second was safety: while I am happy to play about with 600V across 50-year-old components in devices I make for myself, I felt that if I were to build something for Katie that had metal arms sticking out of it connected to the circuitry, solid-state circuitry running at 12V in a relatively small box would be altogether more sensible. The principle of the instrument is simple and there was a design based on transistors available on the net. How hard could it be?

It turned out that building something that kind-of-worked, in the sense that moving a hand near one metal projection changed the pitch and the other changed the volume, was easy and took about a day. Building something that had the stability and predictability of a real musical instrument was not: it took me about 3 months, off-and-on, first to locate and iron out the causes of instability in the system and then to analyze, ever more carefully, Lev Sergeivich's original design. Some features of this, such as his way of controlling volume by varying the heater current in a thermionic valve, could not be directly translated to the solid-state world and I had to find different solutions that generated similar relationships between hand position and volume. Other features, such as the shapes of the metal projections that seemed merely aesthetic choices, turned out on mathematical analysis to be very subtle and clever ways of generating relationships between hand position and metal that mapped to the logarithmic physiology of musical conventions and the human ear.

	
Part of the solution to mutual interference between different parts of the circuit: enclosing each element in a Marks and Spencer's mint tin.	*The finished instrument, resting on an organ stool.*

The harder I looked at the designs, the more obvious it became that almost all accounts of how the original worked were wrong (Robert Moog's analysis being an insightful exception). I read and read: one quote on a forum I found said

> *I have never undertaken anything which has educated me more - Back in the 80's I took on a design to control the deposition of a one molecule layer of phospholipids onto a substrate - it had to maintain precisely one layer of lipids on the surface of a trough while the substrate was dipped... I never imagined that I would find something as "simple" as a theremin could pose any challenge after having achieved that! - But that job took less than a year - and here I am after having spent at least 5x as long on theremin R+D. But I have learned more about electronics in this time than over the entire 30+ years preceding it.*

This at least made me feel less stupid about the problems I was having, and I felt better that I too felt that I was learning a huge amount about basics of electronic design that I thought, wrongly, that I had fully understood years ago on the evidently spurious grounds that I could get the right answers to text-book problems. Part way through, I realized that I was in fact having enormous fun!

In early January, when everything was stable but the pitch was covering too few octaves and the volume control still had too small a dynamic range for real musical use, I had a visit from our friendly local Bobby one Sunday evening, with news about a campaign that we residents had for a speed limit through our little hamlet. Approaching the back of the house from a neighbour's, he saw the light on where I was working so knocked and came round the half-open door. Ranged around the chassis of the instrument, and all live and working, were three oscilloscopes (one 60 years old,

one 30 years old and one about 10 years old, all obviously military surplus), two radio-frequency signal generators, an audio-frequency signal generator, two 'bench' digital voltmeters, one old enough to have glowing 'nixie' tubes, a hand-held digital voltmeter and two frequency meters. Oh, and a teapot keeping warm on a gently humming power supply (obviously there was a teapot: I was not going to tackle a job like debugging a Theramin without taking steps to maintain my blood tea levels!). Beyond, not switched on, was the permanent messy paraphernalia of welding gear, lathes etc, with which I just about manage to keep my ageing vehicles on the road. The policeman stopped in his tracks, his face wide-eyed horror. Puzzled by the reaction of this normally cheery man, I suddenly saw the scene from his point of view, in this era of paranoia about terrorism. Fortunately, the instrument was in working condition, bar the small faults mentioned above, and it was a matter of a moment to show him the benign function of what clearly looked, to a non-engineering type, like some very sinister technology indeed. MI5 were not called – not this time, anyway.

The analyses and experiments paid off and I did finally get the thing working as it should, with several octaves' range for pitch and a 26dB dynamic range in volume, both comparable with what one can hear measure from a CD of Rockmore's recitals. It is now with Katie. For anyone else interested in building one of these things, I have placed on the web a 51-page document giving the final design and explaining not only how it works, but also the reasons for each choice of architecture and component, and in some cases giving the results of mathematical analyses. But the point that struck me very forcibly, when putting away all of the test equipment, is that almost none of it existed in the 1920s, when Lev Sergeivich Termen invented his instrument. He came up with an amazing, subtly clever design from first principles, he got it working without any fancy modern test gear, and most critically of all, he did all of this without knowing in advance that such as thing *could* be made to work. I had always thought of him as an interesting, original inventor. Having tried to follow him, with the full knowledge that the goal is attainable, with accurate instruments to measure performance, and a computer to model designs before I even put solder to iron, I have come to the conclusion that he was a far greater technologist than ever I realized.

In technology, as in art, genius is easiest to see from behind, when we try to follow in its path.

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February 2015

Links:

My notes on the build: http://golgi.ana.ed.ac.uk/Davieslab/NotesOnTheramin.pdf - 51 pages long.