Experiments with 1mW on 1296MHz

I started to explore what could be done with 1mW using homemade equipment on the 1296MHz band.

This article is in two parts. The first part is a description of some experiments using 1mW on 1296MHz and then the second part is some notes and thoughts about the 1296MHz band, which I hope will be useful for people relatively new to these frequencies and those who enjoy making radio equipment.

A lovely Spring day for radio experiments on a nearby hilltop (by the way, I am noting transmissions times on a pad while holding the pen lid in my mouth, not smoking a cigar!). The box mounted on the tripod contains the 1mW transmitter and dipole antenna.

Introduction

I recently set a quiz for my local radio club. One of the multiple-choice questions was "What is the farthest you can transmit on 13cm band using a couple of watts? a) 1km, b) 10km, c) 36km, d) 3,000km or e) 36,000km?

It was a bit of a trick question, as I use 2 watts with a homemade helical beam antenna to transmit up to the QO-100 geostationary satellite, which is about 36,000km away – so I know my signal is going at least that far! It's an amazing distance for such a low power and just shows what can be done when there is nothing in the way. This got me thinking: how far could I transmit with low power levels, say 1 mW, around where I lived?

As a teenager I absolutely loved F G Rayer's book *How to build Walkie-talkies* **[1]**; it was packed with fantastic projects that are still well worth trying. A highlight for me in those days was transmitting 2km or so using a homemade 100mW transmitter. These experiments used low power transistor transmitters and simple (but sensitive) super-regen receivers. They don't, of course, compare to modern digital techniques, but there was something marvellous about making all your own gear … with not a computer in sight to do the hard work.

There is a growing interest in 1296MHz, partly due to the introduction of superb radios such as the tri-band IC-9700 and partly perhaps to try to escape the growing noise problem that is even creeping up to the 144MHz band. I hope those considering starting on 1296MHz will find what follows interesting.

Making equipment and doing experiments is, to me, a big draw of amateur radio, so last year I started to explore what could be done with 1mW using homemade equipment on 1296MHz **[2]**. Those that have experience of 1296MHz won't be surprised by anything in this article – I have not broken any long-distance records, far from it, but I absolutely loved the whole process of building the equipment and exploring these frequencies. I had a great deal of fun, so I hope a little of this spirit might come through here.

A homebrew 1mW 1296MHz signal source

For my low power 1296MHz experiments, I built a signal source based on a ADF4351 PLL [2, **3**, **4**] development PCB from online sources such as eBay for about £20, **Photo 1a** and **1b**. You can discover a lot about these chips by searching on the internet – Andy Talbot's website also has details [3].

The ADF4351 can produce a signal from 40MHz to 4GHz and can form the basis of a signal source for 1296MHz. The unit does nothing by itself as it needs a microcontroller to send serial (SPI) data to 'program' it. F1CJN has described a complete frequency generator that uses a popular Ardunio microcontroller board and a readily available LCD shield (display and push switches). I won't go into any more detail here as it's all explained on his site [4].

The F1CJN device includes provision for memory storage of frequencies. The first memory

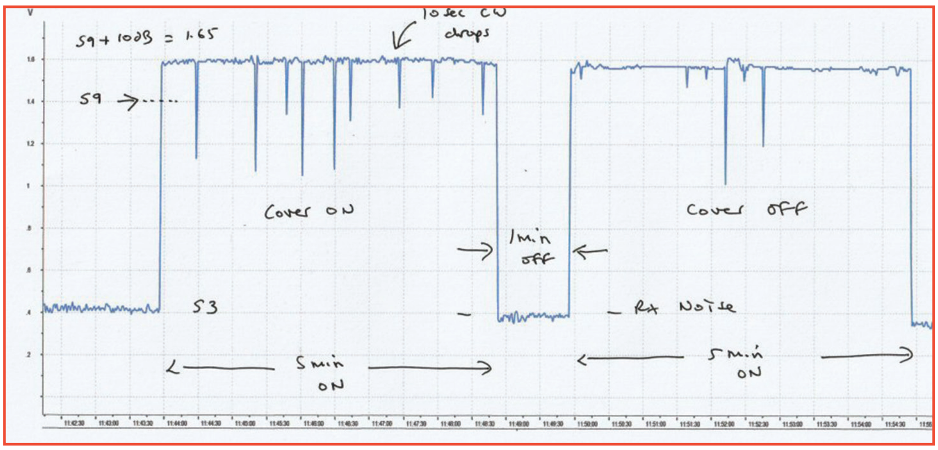
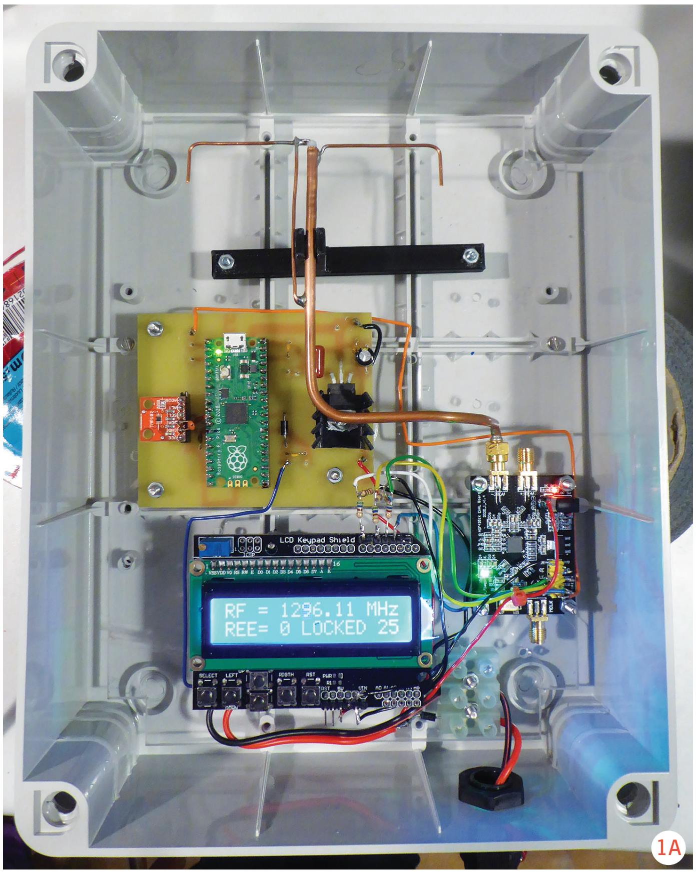


FIGURE 1: My first recorded data for the short 2km path from home to Hollingbury Hill showing signals of about 1.60V, which is S9 + 5dB or so (see text for more details).



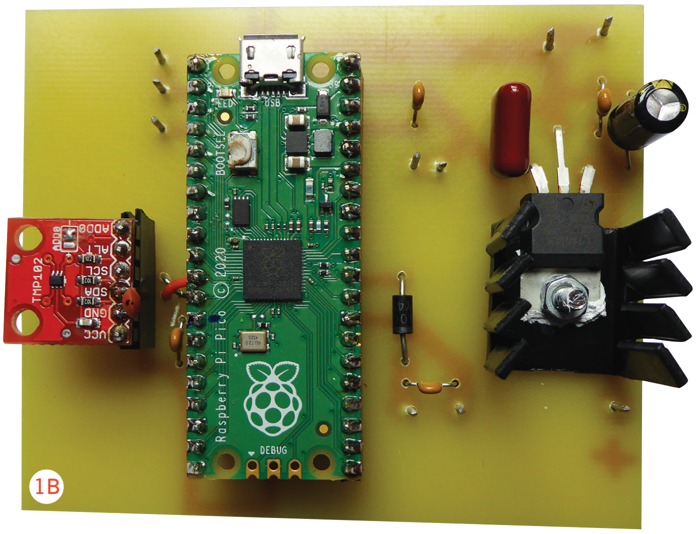


PHOTO 1A AND 1B: Inside my 1mW transmitter. The Arduino controller is under the liquid crystal display, while the ADF4351 PLL RF generator is to the right with the dipole antenna connected to it. Above the LCD is the Pi Pico modulator / keyer (with close up in Photo 1b). The red PCB is the temperature sensor (TMP102) the Pi Pico reads. Everything is fitted inside a 19 x 24 x 10cm waterproof case.

stores the frequency the unit will generate when powered up. Using the LCD shield buttons, I programmed the first memory with the frequency I wanted to use for my experiments, eg 1296.110MHz. With the memory saved, the unit was ready. The ADF4351 unit conveniently has an output enable pin on the PCB that can be used to key the transmitter.

A DC6ZM SWR/power meter (**[5]** and part 2) was used to confirm the output power of the ADF4351 to be just under 1mW.

Dipole antenna

My transmitter antenna was simply a dipole made using two lengths of 1mm diameter copper wire soldered to a piece of semi-rigid coax, **Photo 2A-D**. I made up a 1:1 balun using another piece of the same wire connected between the coax inner and the outer metal a quarter wave further down the coax [2]. In free space, the dipole will have an impedance of about 70Ω so I bent the dipole ends to give a better match to 50Ω (see Photo 2B). I don't think this is really necessary, but it does mean the antenna can fit into a smaller space.

A portable waterproof 1mW transmitter

Using the F1CJNs ADF4351 Arduino based generator and the simple dipole antenna, I built everything into a waterproof box that could be attached to a tripod to take out onto the local hills. The box has one gland fitted at the bottom for a 12V supply cable. In the photo, the Arduino board is under the liquid crystal display (LCD) and the ADF4351 board is to the right, with the antenna connected to one of the SMA output sockets.

Sprogs and birdies

I wanted to make sure my signal would be easily recognisable against any other that might be on the band, either from other amateur signals or 'noise' in the receiver. I was concerned that there may be noise or 'sprogs' that might make unambiguous detection of my signal difficult. So, rather than just make my transmitter send out a steady carrier, I decided to modulate it.

The ADF4351 unit has an output enable/disable pin that can be used to key the output stage. My first experiments used a simple 555 astable timer circuit to key the output stage 10 second ON and 0.5 second OFF, so that I could easily identify my signal. The 10 second ON periods being long enough to use the signal as a source to help tune-up antennas or for other experiments etc.

Pi-Pico keyer

The 555 worked well, but I realised it would be more fun to actually send real data rather than just simply keying transmitter on/off. So, I replaced the 555 circuit with a Pi Pico PIC microcontroller PCB to send out temperature data using a homemade CW slow-code I devised. The Pi Pico is a very economical and versatile microcontroller board that can be programmed in Python, C, assembler, etc. Dogan Ibrahim, G7SCU, has written a great starter book on the Pi Pico that I recommend **[8]**.

The current set-up uses the Pi Pico to send my callsign in CW and then send temperature data in a slow-code format. The Pi Pico reads a TMP102 temp sensor IC [8] to measure the temperature in the box. The unit still drops the carrier every 10 seconds, but now, each time it does, it sends 1 bit of a temperature slow code. If you don't want to know how the temperature data slow code works, you can skip the next section. Details of the temp slow-code can be found on the 1296MHz link on my website [2].

Temperature CW Slow code

The TMP102 sensor uses two 8 bit registers to store the temperature (two's compliment format so it can represent negative and positive values of temperature) [8]. The Pico reads the data and sends the temperature out via CW slow code. The sensor can read to 1/16°C resolution, far more than anyone needs, so I have ditched some of the bits and set the Pico to send out just 9 of the bits, which gives 0.5°C resolution. In this format, the least significant bit (bit 0) represents ½°C, bit 1 = 1°C, bit 2 = 2°C … bit 7 =

Jonathan Hare, G1EXG
jphcreativescience@gmail.com

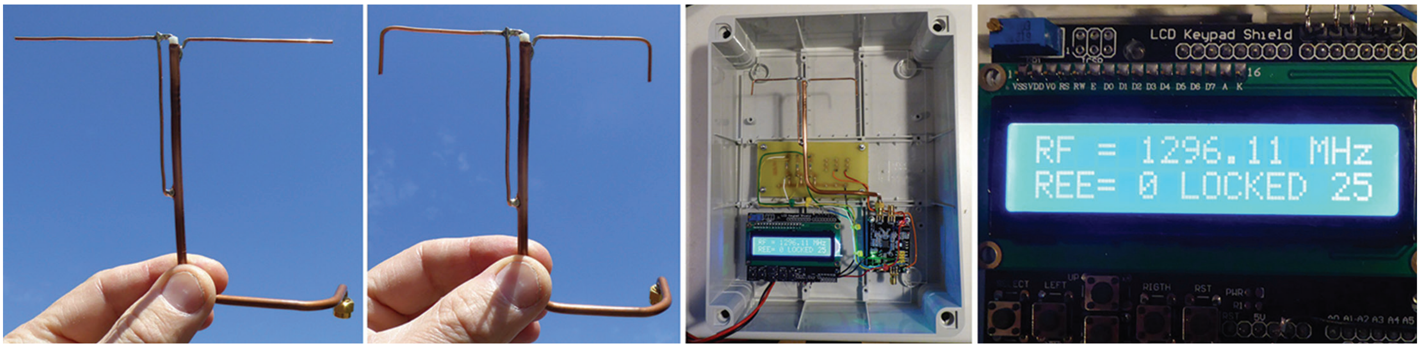


PHOTO 2: My transmitter antenna was simply a dipole made using two lengths of 1mm diameter copper wire soldered to a piece of semi-rigid coax. In free space, the dipole will have an impedance of about 70Ω so I bent the dipole ends to give a better match to 50Ω.

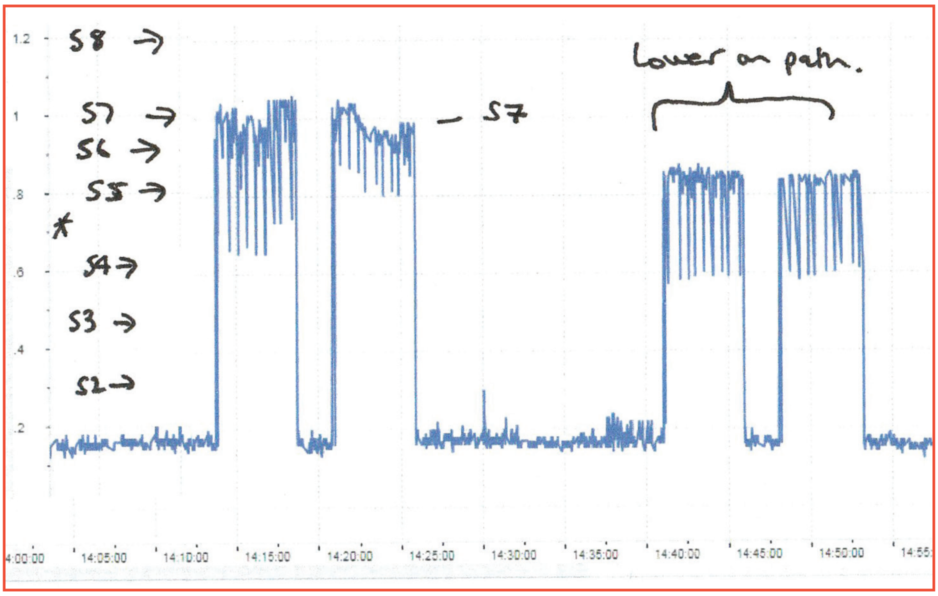


FIGURE 2: Received signal strength from Blackcap-home approximately 9km line-of-sight. Receiving on a 23 element Yagi. The drop-outs are some of the short slow-code temperature data bits (drops in carrier) showing up.

64°C and bit 8 (ninth bit) is 0 for plus °C or 1 for minus °C.

First, the Pi Pico sends my callsign in CW, then it creates a 'start bit' (four quick 200ms pulses) then every 10 seconds it sends out one of the nine bits corresponding to the temperature: a single 200 ms drop = 0, two 200 ms drops in quick succession = 1 (a bit like how MSF encodes the CW time signal on the 60kHz carrier).

Including the start bit, the complete temperature code takes 10 x 10 = 100 seconds to send. This data repeats for as long as the transmitter is on. The slow code should provide a very robust and high S/N ratio with narrow bandwidth receivers. I had envisaged using a Pi Pico to build a decoder, but if you listen to the slow code coming through on the receiver, it's quite easy to hear the difference between a 0 (single dip of the carrier) and a 1 (double dip) and you can jot them down on a piece of paper to work out the temperature. Details are on my website [2] and I've shown two examples here:

For example, if you note down the following bits after the start bit signal:

Example 1: 000101011

The first most significant bit (MSB) is zero, so this means it's a positive temperature. To work out the temperature we simply add up the rest of the scaled bits getting: 16 + 4 + 1 + ½ = + 21.5°C

Example 2: 111100110

As the first bit is 1 it means we have a negative temperature. To work out the value we ignore the 1 at the start (MSB) then invert the rest of the bits to give 00011001, which we add up as before to get: 8 + 4 + ½ = - 12.5°C

Note: In principle, to calculate a negative number using two's compliment, you ignore the MSB, invert the bits and add 1, but as the least significant bit only represents 1/16th°C, it's ok to miss out this last step.

Summary of equipment used

23 element 1296MHz Yagi (approximately 16dBd gain) at approximately 7m above ground

12m length of CLF-400 coax (approximately 2dB loss) between antenna and transverter

LT23S SSB Electronics transverter (1296 to 144MHz) or PE1CMO 1296 to 144MHz receive converter [6]

ICR7000 receiver (set to 144MHz) with data logger tapped into S-meter circuit.

Testo data logger type 175-S2

Note: The ICR7000 receiver was set to AM not CW, so that it would be as wide band as possible in case of drift (sunshine heating the transmitter etc.).

An eagled eyed reader might wonder why I needed the LT23S transverter as the ICR7000 can receive 1296MHz, but unfortunately the 1-2GHz converter is not working properly on my ICR7000.

ICR7000 S-meter and data logging

The ICR7000 is fairly old now (1990s) but is a very well made and respected receiver that covers all modes (AM, FM, SSB and CW) from 28MHz to 2GHz. Amateur radio astronomers still use the radio to detect hydrogen in space (the so-called H spin-flip transition, around 1420MHz).

The radio has a spare, unused phono socket on the back, which I modified to tap into the S-meter circuit so that I could feed the output voltage to a data logger. The S-meter circuit creates a fairly linear relationship between its voltage (0-2.5V) and the S-scale shown on the meter: S0 = 0V, S1 = 0.2V ….. S9 = 1.4V, to S9 + 30dB = 2.1V, which can be logged by my data logger (0-10V input).

I did not calibrate the S-meter voltage from a calibrated frequency generator, so the results should be treated as a guide only. However, you can use the data to see if a modification or change, improves or degrades a signal etc.

I used a professional stand-alone data logger (Testo 175-S2 used on the 0-10V input range) that can be set up and run, and then the data downloaded to a computer later on. I set the logger for the fastest rate which was 1 log/second. This was slow enough not to create too much data, but fast enough to catch most of the signal changes.

The S-meter o/p from the ICR7000 was simply wired into the data logger and no extra amplification or integrations (averaging) was required. Note: I set the receiver to AM rather than CW deliberately because AM is wider bandwidth so any slight drift (receiver or transmitter) won't adversely effect the recorded reception signal strengths.

PHOTO 3A-C: 23 element 1296MHz Yagi at home (ca. 60m asl) ii) view of Hollingbury Hill from my house in Brighton (hill top is slightly to the right of centre) and iii) the view back from the top of Hollingbury Hill (178m asl).

Note: As the slow code data drops are 100-200ms, not all the drops in carrier are visible at 1log / sec rate but in these experiments I was interested in recording the average signal strength rather than the slow code.

Experimental set-up and method

In these experiments, I set up my receiver at home with the data logger on the S-meter circuit. I rotated the receive antenna to line up as best as I could to the location I would be using on the hill. Before setting off, I started the data logger recording so that it would pick up my signal whilst I was away. I noted the exact time the transmissions took place, so that my signal might be more easily located on the logs.

Once up on the hill, I set up my gear to transmit in two 5 minute blocks with a 1-2 minute off period between. This was so that I could easily spot the data when I returned home, as a round trip might be an hour, so most of the logged data was simply no-signal 'noise'.

I never left the transmitter unattended at any location.

Measurement I

Home to Hollingbury Hill (178m ASL) – approximately 2km line of sight, **Photo 3a-c**.

In these measurements, I set up my data logger on the S-meter of my 1296MHz receiver with a 23 element Yagi, then put the 1mW transmitter on Hollingbury Hill approximately 2km line of sight distance. Note: In this experiment, my receive antenna could actually see the transmitter – so it really was a clear line-of-sight path.

I was delighted to record a S9 + 5dB signal on the equipment (see **Figure 1**).

The first 5 minute logs are with the plastic receiver cover on, while the last 5 minute logs were the signals recorded with the plastic receiver cover off. It looks like the signals are slightly different with the case on and off, this is actually due to the baseline (signal off) which, on this occasion, was drifting slightly downward due to the ICR7000 not having been given time to warm up properly. As the signals are the same with the plastic case lid on or off, it shows you can create a complete effective water-proof apparatus this way.

I have repeated these 2km line of sight measurements using the PE1CMO [6] converter (see part 2 next month), which gave similar signals strengths (but better noise levels).

Measurement II

Hollingbury Hill dipole-to-dipole communication, 2km line of sight.

In the last experiment we used a dipole on the transmitter and a 23 element Yagi on receive. Of course, it's helpful to have such a high gain antenna on receive (as long as it's pointing correctly at the transmitter) but in this second set of measurements I wanted to see what I could measure just using a simple dipole on the transmitter and receiver.

This produced a stronger than expected signal strength of between S8 and S9.

Using the 23 element Yagi I received S9 + 5dB. If one S-point is about 6dB, then the difference is about 1S-point + 2dB, about 8-9dB. That's less of a drop in signal than I would have expected switching from a 23 element (approximately 16dB gain) to a dipole (0dB).

I think there may be three reasons for this:

i) The ICR7000 S-meter circuit may not be very accurate and so we should not rely too greatly on the precise values we are measuring. The results are really intended to show trends. The ICR7000 is a professional

PHOTO 4A AND 4B: Brighton as seen in the distance from Blackcap (206m asl) approximately 9km. You can see the I-360 on Brighton seafront poking up. Although my house is too small to see, it's just to the left of the tower and still line-of-sight.

radio but I have not calibrated or checked the S-meter readings against known signal strengths.

ii) I pointed the 23 element Yagi by 'eye' in the direction of where my transmitter would be, so it's quite possible that the Yagi (with its relatively small beam width) might not have been pointing exactly in the correct direction. It is also possible that the elevation of the antenna may not have been accurately set.

iii) The Yagi measurements were made in summer whilst the dipole-dipole measurements were made in winter. Warm air can hold more water vapour than cold air so one might expect signals to be stronger in winter. But one would have thought it would not make a great difference for such a short-range measurement.

Whatever the case, it shows you don't actually need a large Yagi to make low power measurements on 1296MHz.

Measurement III

Home to Blackcap Hill (206m ASL) – approximately 9km line of sight, **Photo 4A** and **4B**.

Blackcap (East of Ditching Beacon) is about 9km from my home QTH and, if you use a pair of binoculars you could see my home from the top – so it is also a good line-of-sight path. In these measurements I used the 23 element Yagi to receive the 1mW transmitter (dipole) from Blackcap.

Again, I was surprised how strong the signal was with the 1mW transmitter so much further away over land (ie not free space), I was logging S7 signals while the transmitter was at the top of the Hill and even S5 signals when walking back at a lower level, **Figure 2**.

A rough calculation

My home to Hollingbury Hill is 2km, while home to Blackcap is 9-10km, so assuming for the moment that we use a simple inverse square law, the Blackcap signal should be down in signal compared to Hollingbury by about:

$(2/10)^2 = 0.04$ ie about a 1/25th of the signal, which is $10 \log(0.04) = -14$dB

Now 1 S-point is approximately 6dB, so -14dB should be slightly more than two S-points difference.

The S-meter readings were: S9 + 5dB from Hollingbury and S7 from Blackcap, about 17dB difference. This is slightly more than the theoretical 14dB, two S-points, but makes sense considering it's not true 'free space' and only a fairly good line-of-sight. As with the other experiments, I only guessed the beam heading for Blackcap by eye and, because I was out with the gear, I could not peak the beam for best signal.

On the way down from the hilltop at Blackcap, I set up the transmitter again, this was approximately 30-50m lower in altitude than the top, but where I could still see Brighton in the distance. In this location the logger still recorded about an S5 to S6 (which is the second set of peaks on the right-hand side of the data). This shows of course, that it's generally worth getting antennas as high as possible for best signals.

Summary and final thoughts

It is clear that on 1296MHz it is possible to communicate over many tens of kilometres with just a few mW, at least when you have a decent line-of-sight and good receive set up.

Despite possible problems from the extensive mobile phone network, noise levels are lower on 1296MHz than on other bands. From what I have measured, it would seem that as long as you have a good the line-of-sight then a considerable distance can be obtained using very low power levels (before reaching the noise floor).

There are many ways to go from here, for example:

I have reached the limit for clear line of sight high spots from my home location, but my home location has clear take off south out to sea. It would be fun to take the transmitter out on a boat southward and see how the signal fared with much further distances.

I could try using lower powers. If I lower the power considerably, I would have to make sure that no rogue signals are making it out from the wiring. This would probably not be an issue in this very low power set-up, but might be if you were using a 10 watt output with an attenuator from say a commercial rig or transverter.

Tiny, low power, 20dB gain, linear amplifiers (few pounds on eBay) are available [2] that can boost the 1mW to about 100mW. These might be useful if more power was required for longer distances or other experiments.

I am currently using the Arduino to program the ADF4351 and the Pi Pico to 'key' the output but I plan to use the Pi Pico to do both jobs. This will save power and space and might make the unit run from a small Li battery or even solar cells etc.

The quality of the output signal is not great – there is a bit of phase noise on the output that you can hear on the unmodulated carrier. It is not very serious for mW experiments but would need to be cleaned up for higher power work.

I plan to measure the temperature related frequency drift of the ADF4351 o/p using my temp slow code and a calibrated receiver.

Another option is to use a GPS atomic clock stabilised reference for the ADF4351 (and the microcontroller), so that both the Tx frequency and timing of the slow code could be much more precise. I could then use digital signal processing techniques, or a kind of phase sensitive detection technique (if I don't want to use a computer at all) to get very good signal to noise measurements.

Next month we'll look at some notes and thoughts about the 1296MHz band, which I hope will be useful for people relatively new to these frequencies and those who enjoy making radio equipment.

Websearch

1: *How to build Walkie-Talkies*, F G Rayer (G3OGR), Babani Books, 1981. ISBN 0 85934 046 5

2: G1EXG radio web page: www.creative-science.org.uk/g1exg.html

3: G4JNT PLL web pages: http://www.g4jnt.com/

4: F1CJN 1296MHz gen page (Note: English version further down page): http://f6kbf.free.fr/html/ADF4351%20and%20Arduino_Fr_Gb.htm

5: Measuring power, return loss and SWR at GHz frequencies, DL6ZM, *RadCom* March 2020, p. 30-32.

6: PE1CMO converter: https://www.hf-electronics.nl/PE1CMO-Converters

7: G1EXG 3D printing web page: www.creative-science.org.uk/3D.html

8: *Raspberry Pi Pico Essentials*, Dogan Ibrahim. 2021. ISBN 9783895764271