As easy as 1...2...2 GHz ?

An easier way onto the 122GHz mm-wave band.

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Inspired by Les Jenkins VK3ZBJ (Silent Key)

July 2019

Fig 1 Finished system

Introduction

The 2.4mm Amateur band at 122.25 to 123 GHz is considered totally out of reach to most operators. This is because the equipment is complex and requires a lot of experience to build, It requires hard to find and often very expensive components and the test equipment is as rare as hens teeth.

Why would you bother ? the challenge of it. The 2.4mm band is actually a very dumb place to try to achieve long distance communications. This is due to the high atmospheric absorption from oxygen and water vapor, hence the attraction to use the 122GHz band to try to break the laws of physics, or at least try to bend them a bit. We want cold, still, low pressure, low humidity air, We don't want atmospheric pressure highs with thermal ducting and other high altitude atmospheric propagation enhancers as with VHF. 122Ghz is more like light than R.F.

In the past, most 122GHz equipment was based on high order multipliers which are low in efficiency, very low in power output and the receivers rarely have pre-amplification which means the receive sensitivities are not that hot. Generating any detectable signal at all on 122GHz is a challenge.

This article presents a simpler and lower cost way to get operational on the band using an off the shelf, fully integrated transceiver chip designed for proximity and collision avoidance Radar.

There's a lot of different disciplines crammed into this article so there's not a lot of depth in any of them here, this project needs : Electronic design, R.F. Waveguide design, Circuit board layout, Software development, Antenna design, Antenna Field measurements, Mechanical design, Fitting and turning, Tool making, etc. I've done the harder bits so now it over to you to have a go.

The single chip approach , Pro's and Con's.

The Silicon Radar TRA_120 series Radar transceiver is a device containing a complete 118 - 126 GHz transceiver with separate integrated antennas for TX and RX.

Here's a public domain link to the TRA_120 data sheet for those interested in the fine detail :

https://siliconradar.com/datasheets/Datasheet_TRA_120_002_V0.8.pdf

The TRA_120 has some really nice features such as a high power output of around 0.5mW that's milliwatts not Megawatts or watts. At 122GHz, half a milliwatt is QRO (High Power). The chip also has a preamplifier in the receive path with respectable gain and a not too shabby noise figure as well. It's also frequency agile as the internal oscillator is a Voltage Controlled Oscillator (VCO). Using an external Phase Locked Loop (PLL), the internal VCO can easily be frequency locked.
The external PLL only has to work at around 1900 MHz as the TRA_120 has a built in R.F. pre-scaler which is pure magic. Our P.C.B's don't have to work at 122GHz, It's all inside the Chip !!!!

This all sounds great but there are some problems to solve first. As Uncle Les would say, "The difficult we achieve immediately, The impossible takes slightly longer".

Other Amateurs have also used this TRA_120 chip, K6ML et al. but have quickly realized a major hurdle with the two antennas in the chip, they're not in the same exact physical place. This is great if the chip is used bare as it was designed, or with a low gain external antenna. A bare chip is fine if you just want a QSO across the street but if you want some real range, you'll need a bigger antenna. If a higher gain antenna is added, because the chip TX and RX antennas are in different places, then the TX and RX antenna patterns end up occurring at different directions resulting in huge difficulties. This means having to either re-position the chip or the antenna when swapping from TX to RX. High gain antennas also introduce another challenge of getting them pointed at each other in the first place.
As the antenna gain is very high, the antenna beamwidth becomes very small, Pointing it exactly at the other station is a real challenge.

To quote from Uncle Les, "That antenna's pattern is as narrow as a fowls face".

Because we don't have much TX power and our RX's are "as deaf as a post" (A highly technical term describing poor RX sensitivity), High gain antennas are about the only easy way to add system gain. We must use high gain antennas to get any significant range performance, So we have to find a way to deal with the high gain antenna pitfalls.

We also need to be very careful with what is called Oscillator Phase Noise. My first prototypes ran afoul of this and my signals sounded like total garbage in a narrow band I.F.
Phase noise is, in simple terms, tiny oscillator wobbles that occur in all oscillators (It's Physics JIM). Quartz crystals are way better than L. C. or other lumped element oscillators. Phase noise is, in another analogy, short term frequency stability, We'll get to long term frequency stability (Frequency Drift) in a moment. Very careful PLL design, correct component selection, screening and noise source de-coupling are required to minimize phase noise. The PLL itself also multiplies the phase noise of the reference oscillator so that needs to be the cleanest, lowest phase noise oscillator we can get, definitely a Quartz crystal. The TRA_120 internal VCO also adds phase noise as does the PLL chip itself and how it's configured. In the end, after many hours of "Gingerbeering" (Engineering), it's all quiet enough to give a pretty good sounding tone in a narrow SSB receiver.
There's another little detail we need to be really careful about, frequency stability (Drift). As we'll need a PLL for the TRA_120 chip, this means we need a frequency reference which could just be any old Quartz Crystal. On crunching a few numbers you find that an error of 1Hz with a 10MHz reference gives an error of over 12KHz at 122 GHz. We'd better use a GPS locked reference to at least be on the same frequency as the other end just to be safe, More expense and complexity..... GASP !!
I chose a lower cost (and lower DC power) VCTCXO (Voltage Controlled, Temperature Compensated Crystal Oscillator) to give me reasonably low phase noise, An Voltage Controlled OCXO (Oven Controlled Crystal Oscillator) would be even better but uses way more power and more € £ $. If you already have a good 10MHz external reference you could always just use that.

By the way, On the TX side, We can't even begin to generate SSB with this TRA_120 chip. This is because we can't modulate the TX amplitude except for on and off channel. We can however easily generate FM, or FSK or other types of angle modulation. We generate pseudo Morse CW via FSK.

Don't give up, There's a way.

Let's attempt to solve the problems, Firstly the antenna pointing, With a bit of lateral thinking and hours of simulation on the computer, an R.F. chip coupler and combiner was developed, you could also call it a diplexor. This coupler combines the R.F. from the TX and RX antennas on the chip into a single waveguide path without the need to have to re-position the antenna on from RX to TX, Viola !!!, problem solved but....the downside is that we will lose some performance in both TX and RX.
The TRA_120 comes in two versions, I chose the 002 version, which suits the coupler approach.
K6ML has very successfully used the 001 version with a feed re-positioner.

I've made my coupler adjustable to allow optimization of the coupling and isolation.
You don't need test gear on 122GHz you can do it all with the S meter and an attenuator on your RX.
The output of the coupler is a circular waveguide, It's non standard and I call it WG-AA, it is in fact just a 2mm diameter circular hole, Not that difficult. By the way, even though the guide is circular we are exciting it in a linear mode so we are still using linear polarization.

This reminds me of the waveguide Les and I used for 10GHz way back when, a random brass rectangular section of suitable dimensions for X band which was meant to be used to make office furniture, It worked a treat. Les and I held the 10GHz distance record back in 19hundred and January.

How about that huge high gain antenna we need to make this all work, We'll that sounds very expensive and difficult I hear you say, Well not at all actually, Surplus Satellite TV 600mm offset feed dishes are often to be found for free in roadside hard rubbish collections. Many microwave amateurs scoff at these but as I can attest, They work really nicely even at 122GHz if you take the time to set them up properly. The fine surface accuracy is good which is exactly what we need for 2.4mm wavelengths. Who cares if the gain is a few dB down on what the theory says because of minor shape errors, They're free and give over 50dB of gain. One of these junked antennas at each end gives us a overall system boost of 100dB, NOW YOUR TALKING ! , The TX E.R.P now becomes 0.5mW+50dB = 50Watts, you're going to hear that alright.

Build it and they will come.

Ok, so now there seems to be a practical way forward lets set to work building the thing.
As with a lot of chips these days there is a development kit available for the TRA_120 but as Uncle Les would say .....mumble mumble digitologists Bull#@%$, It's meant to highlight the Radar capabilities of the chip, It's expensive and you're stuck with whatever the P.C. computer program will let it do. So that's a NO to the development kit, I've designed my own board to use the chip.

Some features of the board layout are : See figures 2,3 & 4

- Mounting of the TRA_120 chip in a PCB pattern to allow direct connection to a waveguide transition.
- I.F. Output with cable driver to an external receiver. DC to 200 MHz, I/Q output capable.
- Small PCB (50x50mm) to allow mounting directly at the feed point of a dish.
- Lowish power consumption to allow portable battery operation, 12Vdc nominal, reverse protected !
- On board Microcontroller (PIC16LF877A) for control of the TRA_120 and PLL.
- 10MHz XTAL GPS locked frequency reference with extra outputs for other gear if required.
- On board PLL and channel switch for easy channel change.
- Mode switching for FM Voice, FM tone, Psuedo CW with a built in morse beacon Ident.
- RS232 diagnostics output for status monitoring and GPS data output to give you a LAT and LONG.

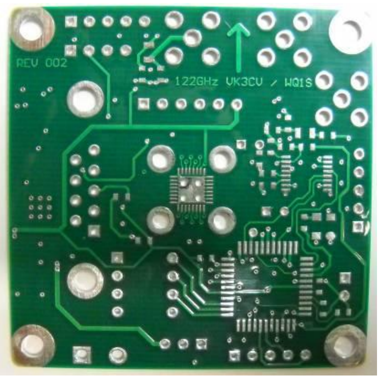

Fig 2 Bare PCB

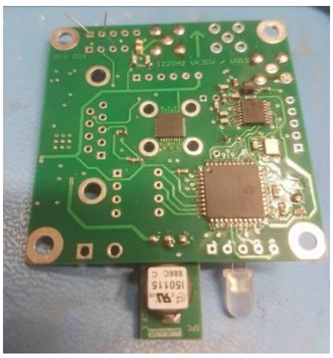

Fig 3 PCB Front , (Note the the TRA_120 chip in the centre square hole pattern)

Fig 4 PCB Rear

VK3CV/WQ1S 122 GHz TRA_120_002 Simplified Block Diagram

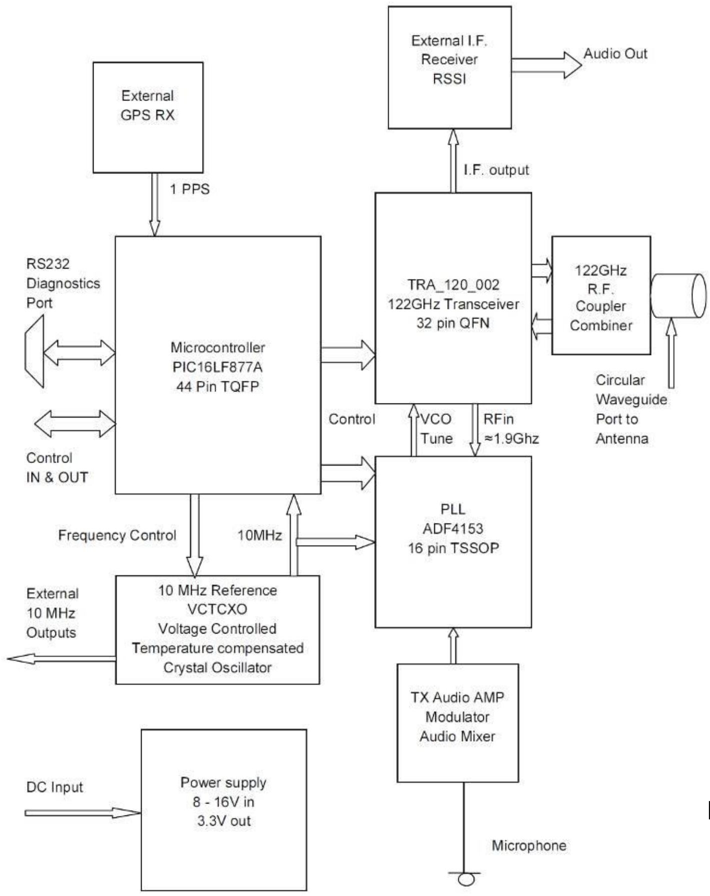

Fig 5 System Block Diagram

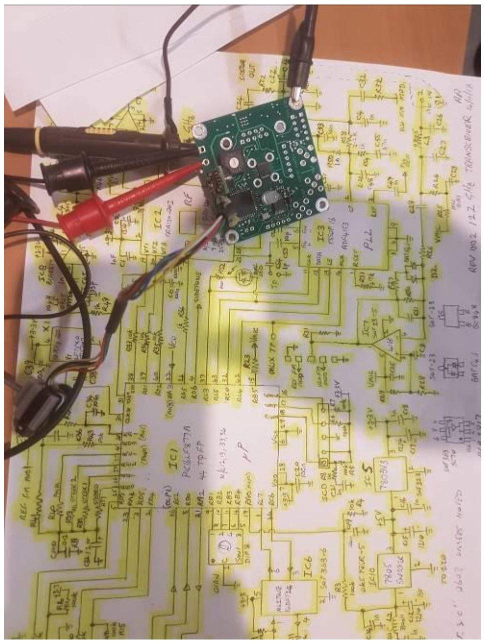

Fig 6 Assembled PCB and schematic

For the circuit diagram, PCB artwork, construction details, mechanical drawings and microprocessor code see :

https://www.dropbox.com/sh/32iznukohqnpjsz/AADXslP2AEr8md9e9Eg_tHEGa?dl=0

We'd need the whole magazine to put it here. Fig 5 shows the simplified block diagram.

On this point I'm going to throw it out there to ask for any interested entity, being an individual, Club or Commercial enterprise to take the design and manufacture a batch for distribution to a wider audience. I can be contacted at VK3CV_WQ1S@yahoo.com.

I've laid out the artwork for the PCB to allow easy interface to the TRA_120 chip, Note that my design is a 4 layer board with an almost continuous internal ground plane to keep all the signals where they're supposed to be. Mounting the chip itself is challenging, you'll need good optical magnification, a steady hand and a heat gun, there's plenty of YouTube videos on how to do it. I suggest putting the TRA_120 chip down first, observe basic anti-static practices but the chip is quite robust in this respect. Once the chip is down, as a sanity check, you can look with a multi-meter at all the chips signal pins to ground which check if there is a diode junction present on all the connected pins. (The diodes you see with the meter are ESD protection on all the pins) Reflow it again if there are any issues. Everything else can be placed and soldered manually using a small tip iron with the assistance of optical magnification.

Now that we had a piece of hardware, I set to work debugging and optimizing the hardware and writing the software for the microcontroller. The code I've written is in Assembly language.....I hear a HEAVY SIGH from the digitologists..... Sorry but I'm a dinosaur and I don't do C or C# or D minus, I get to bang around the bits to generate tones and PWM waveforms to control the VCTCXO so easily in assembly, How does the GPS reference disciplining work I hear you ask ? Very nicely, and thanks for asking. That's for another article. Anyway I've done it all for you so there's nothing to worry about.

The external GPS board is from Ebay and can be anything that has a one pulse per second output (1PPS). I mounted the GPS receivers in a small external plastic box which plugs into the control box.

Now to do the fun stuff. Firstly I get it working bare chip to chip across the shack, wooo hooo, I see signals and audio, the thing actually works. It's easy to see the 1.9GHz PLL signals and check that everything is locked and stable. Again you don't need any test gear on 122GHz. Diagnostics data is also available on the RS232 port at 9600Bd N,8,1.

I then set about improving the range firstly with horns that I made on the lathe. I had to make the tooling for the horns first as it's difficult to bore out internal tapered holes which start from almost zero diameter. This gets me out to over 400m range. The horns have the 122Ghz R.F. coupler/combiner built in. A 23mm diameter horn gives me around 21dBi gain, Things are small but potent on 122GHz. The machining of the Chaparral™ feed is a real challenge, special tool from a broken 2mm tap (Fig8)

Fig 7
Horn boring

Fig 8
Tiny Multi Choke Ring dish feed
Commonly known as a Chaparral™
(The centre hole is 2mm Diameter)

Fig 9 Horn, Adjustable and fixed feeds

Then I went to the final step and got the re-purposed Satellite TV dishes up and running. Note that you'll need good stable tripods and telescopic sights when you get to this point. I then designed and made a multi choke ring feed (commonly known as a Chaparral™ feed) for the dishes, they are so tiny and cute. I did a fixed and later an adjustable version of the Chaparral™ feed. The adjustable version allows optimization of the chip coupler. The chip coupler/combiner is built into the PCB waveguide mounting flange. The dish feeds have ≈9dBi gain to suitably illuminate the dishes.

As a sanity check I compared my Chaparral™ feed to the bare chip and the difference is around 1dB which suggests the feed is working very well indeed. The bare chip antenna gain is around ≈10dBi.

Fig 10 Above : Feed point and Telescopic sight

Fig 11 Below : Control Box with GPS unit (Black Box)

FIG 12 Ready for action

Setting up the dishes is time consuming and you need to be patient and methodical. I set up one of my boards with a bare chip just out past the R.F. near field at 25 metres from the dish system, put it on TX and in beacon ident mode if you like the sound of morse. Try to have the test area clear of reflective objects which at 122GHz is just about anything. Connect your I.F. receiver to the test unit and put an adjustable attenuator in the line if you have one. The attenuator is handy to keep the S meter on your receiver in a useful range. The I.F. can be anything up to 200MHz, I've used 144MHz.

The optimum feed point of the dish needs to be correctly identified in all 3 dimensions X,Y and Z. A good starting point is the original position of the old satellite feed. I then used trial and error by peaking for maximum signal from the remote beacon board. Accuracy and stability is important here, The feed positioning accuracy needs to be less than a millimeter in all X,Y and Z planes to realize peak gain, Also each time you move the feed, the dish needs to be re-peaked to see the effect, It took me a few days to do both my dishes. The way I did it was to make a temporary mounting bracket with slotted holes to hold the TRA_120 board in the dish focus point to allow everything to be adjusted. Make small changes then record the peak result and also the size and number of significant side lobes. You'll generally find more and larger side lobes when the feed is not in the right place. It's just like focusing an optical lens, The image needs to be sharp, not fuzzy. Lots of side-lobes indicate bad focus. When correctly focused, The dish is by design meant to have few, and smallish side-lobes. A 600mm dish should realize over 50dB of gain and have a 3dB beam-width of around 0.3 degrees. See that I've used some optical telescopic sights which are available at reasonable cost again on Ebay. They are essential in getting the systems pointing at one another when dishes are used. Set them up after you've got the dish feed peaked in the field by using a far field test, you'll need a 600metre dish to dish distance to align the sights correctly.

The dish itself as you'll see in the pictures will end up at an angle in the vertical plane when the actual main lobe is perfectly horizontal, The angle is normally around 20 to 30 Degrees. This is due to the whole offset feed arrangement. Imagine playing pool or billiards, The angle a ball hits the cushion is the opposite and equal of the angle at which the ball leaves the cushion. It's the same for the R.F. wave-front hitting the dish surface, It bounces off at the opposite but equal angle. Not all satellite dishes are created equal. Don't assume that just because you have two dishes which visually look similar, that they are exactly the same as far as the optimum feed position is concerned. Offset feed dishes like these give better gain than a prime focus dish because there is no feed obstruction.

Note that on my dish systems I've added adjustable stabilizing rods to the sides of the dish and back to the feed point. This assists in keeping everything stable, especially when you go into the field to try to make some contacts. The adjustment rods also assist in realizing a few more dB of gain by slightly changing the shape of the dishes to be closer to the ideal shape. Again careful adjustment and trial and error to get peak gain and thus efficiency.

My final systems are all nicely housed in a box with the control switches, a rechargeable battery, attached telescopic optical sights, and a bubble level to get the system perfectly horizontal to aid pointing in the right place. Note that the arrow on the PCB shows the polarisation sense.

I've built three systems so far, two dish systems (Fig 12) and a development system which is useful as a test beacon and also as a mobile station (Fig 13).

Fig 13 Development Unit

Fig 14 Inside the dish feed box

Does it actually work ?

The results in the field are impressive. We've made contacts from dish to horn at over 4km with plenty of margin to spare at sea level. We've done a mobile contact at over 2.8Km just for a bit of fun. The next step was 19km dish to dish in good conditions with more than 30dB of margin. More mountain top sites are yet to be conquered but we're now out to over 59 Km. We're probably not going to break any world distance records with this gear here in Australia but we're expecting to be able to push the range out to something above 80Km in ideal conditions, Maybe more with very tall mountains but we don't have any here in VK land. The system as described is programmed to be full duplex, I.E. Each end is offset in frequency by the I.F. A headset with an attached boom microphone is ideal to chat away for hours. Some really interesting propagation effects due to air movement QSB, Doppler chirps from passing cars and just dealing with the extra losses due to water vapor and air pressure are some of the charms of 122GHz. The system as described supports NBFM and CW. The residual phase noise will be evident on FM.

Future work to be done includes using the I/Q outputs of the TRA_120 to go directly to a SDR (Software Defined Radio) I.F. and demodulator. TX with Digital Modes such as WSJT is also a possibility. There's lots of experimenting and further development yet to be done. Better phase noise will also improve the system. Any suggestions and comments are welcomed.

Get with the program,
Have a go,
Have some FUN,

QSY to 2.4 mm.

73's Andrew VK3CV / WQ1S

Fig 15
Operating from the Cerberus Car Park ,
Black Rock, Victoria

Acknowledgments.

Silicon Radar for making the "Magic" chips for all this to be possible, and for their excellent support.
Sally, my YL for helping with field measurements and for keeping me watered and fed.
Ken Anderson, my late Dad, who taught me how to use my brain, my hands and a lathe.
Les Jenkins, VK3ZBJ (Silent Key), My mate and mentor, what Uncle Les didn't know about RF isn't worth knowing.
Karl, VK3LN, for field operations, assistance and sourcing the surplus dishes.
Noel, VK3NH, for field operations and assistance.
Mike K6ML, Alan VK3XPD, Dave VK3HZ, and others for ideas and peer review.

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