Updated 122/134 GHz Transceiver

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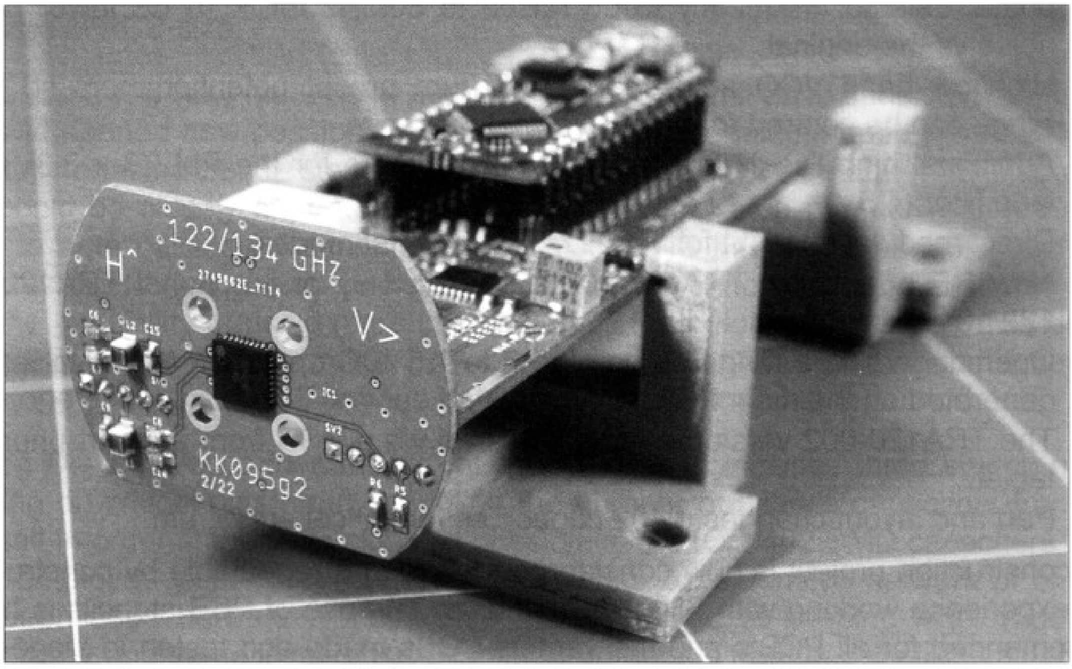

Fig. 1: Front view 122/134 GHz transceiver

Introduction

This article is a follow up from the "An Advanced 122 GHz Transceiver" published in Dubus 02/2020. Adapting a mmWave transceiver module intended for distance measurement over 10 – 20 metres to one that can communicate over fifty or more kilometres has many challenges. Like all projects, the process of experimentation continues to the point where the collective improvement makes the original design obsolete. With newer 120 GHz modules now released, it was also time to update the base project. This article details the updated V4.0 main PCB and new RF PCBs all using the same footprint of the original V2.0 design. The hardware changes have improved phase noise, transmit and receiver performance as well as adding direct digital modulation and the option of 134 GHz. Unfortunately, widespread part shortages continue to hamper many projects in 2022. This has required changes to the design allow alternatives, the parts lists are updated with suggestions to help.
This project has progressed in collaboration with Iain VK5ZD who has suggested improvements and done confirmation testing on all prototypes as well as further development of his software that makes the project work. Input from amateurs who have experimented with various Silicon Radar designs as well as advice from professional users of the modules has also been valuable.

Improvements to the 122 GHz transceiver

The general description and construction steps of the original article still apply so this article will focus on the changes made and any variations to construction. In summary the following hardware changes have been made:

- Change from ADF4159 to new ADF41513 PLL for better phase noise & sub hertz frequency resolution
- An optional 40 MHz 0.28 ppm VCTCXO daughter board PLL locked to 10 MHz that is mounted on the underside of the main PCB. This enables the phase detector frequency to be raised to 80MHz for ~ 10 dB lower phase noise vs the original
- High/low band VCO adjustment via 5 turn preset potentiometers so VCO range can be centred for better thermal tolerance
- Additional high PSRR low noise LDO regulators for the PLL (3 x 3.3V) and loop filter (4.5V)
- Direct modulation input for WSJTX JT4xx digital modes
- New RF boards for TRA120-002 122 GHz only and optional TRA120-045 122/134 GHz variant
- Operating voltage range reduced to 6 to 7.5VDC operation to minimise heat generated on the main PCB.
- The TRA120-002 version can be powered via a USB from a smart phone or tablet.
- Part and layout changes, 0402 capacitors for critical areas, etc

The construction project is now considered mature and repeatable by constructors with experience working with SMD components. The use of PCB stencils is highly recommended for all PCB's and the various PCBs made and tested in stages described in the original article.

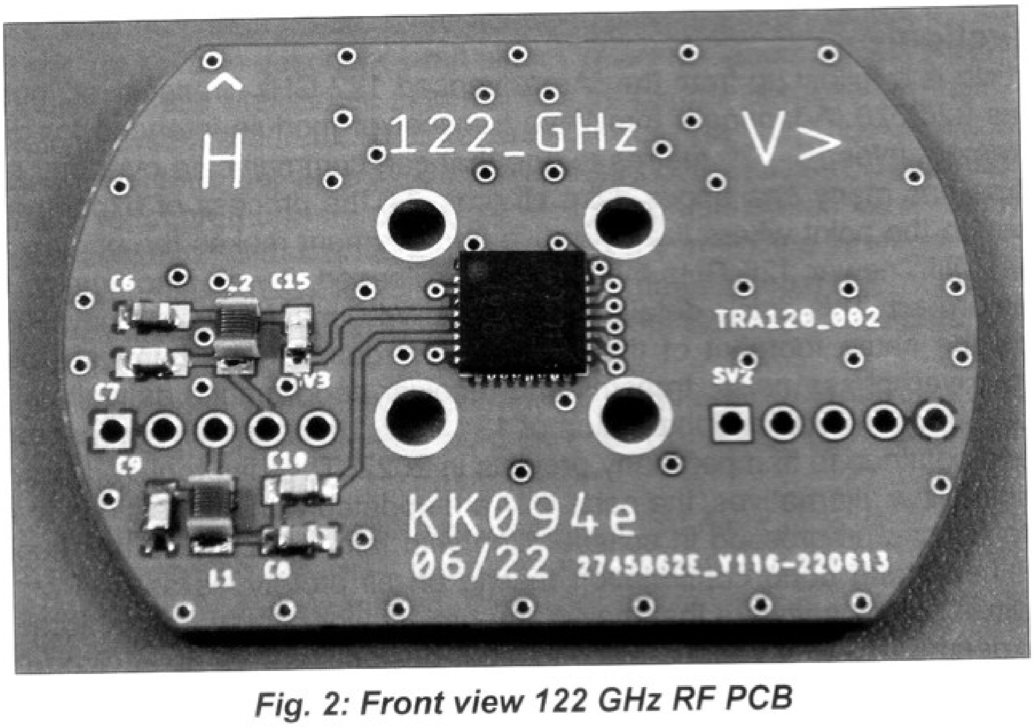

Fig. 2: Front view 122 GHz RF PCB

New Version 4 Transceiver Main PCB

The main change for the new main board is replacing the ADF 4159 with a the newer ADF41513 PLL [1]. The ADF41513 is an ultralow noise frequency synthesizer that can be used with local oscillators as high as 26.5 GHz. The ADF41513 is designed on a high-performance silicon germanium (SiGe), bipolar complementary metal-oxide semiconductor (BiCMOS) process, achieving a normalized phase noise floor of −235 dBc/Hz. This is >10 dB better than the ADF4159 specification and contributes to the better phase noise seen in prototypes. The pinout is relatively similar, so I have been able to keep the same basic layout as the original with no increase in PCB size.

There are a few new features of the ADF41513 PLL that have simplified configuration and opened new possibilities. The 25-bit fixed modulus mode of the ADF4159 originally enabled 38 Hz steps at 122 GHz. This meant JT4 steps (multiples of 40 Hz) could be closely approximated however the odd step number required extra code to auto calculate frequencies. The ADF41513 has 49-bit variable fractional modulus mode that gives sub hertz resolution making calculations easier in code and the possibility of using more complex multi tone digital modulation. The development of software would need a direct port from WSJTX to do that and is beyond the scope of this project. If anyone has ideas, please contact the author!

Analog Devices recommendations for the ADF41513 includes three stages of bypassing on critical pins nearly doubling the number of bypass capacitors from the original! In order fit these as close as possible to the IC, 0402 SMD capacitors have been employed in the first row around this chip. An extensive network of chokes has been used between various pins, mostly aimed at keeping high frequency noise away and some level of RE (Radiated Immunity) from nearby transmitters we experience on high mountains. Installing small components does require a steady hand and a good magnifier but using a solder stencil makes the job much easier.

As we are using a 5V logic Nano, a single NVT2006 6 channel bi-directional level converter is used to convert logic to 3.3V. This has simplified the original arrangement where we had to cope with 1.2V, 1.8V and 3.3V logic. It also provides good protection of the ADF41513 should the Nano fail.

The PLL loop filter design has remained the same using an OP184 low noise Op-Amp but has revised filter values for each of the TRA120 module types and phase detector frequencies. Many experiments have been conducted to model filter requirements that are repeatable with device variation, it is essential that the correct values are used to obtain best results. For the TRA120_002 module, optimum CP is between 2.1 -2.7 mA. Feedback of the VCO voltage is now provided to the Nano so the VCO locking voltage can be displayed as well as enabling several diagnostic tuning tools in software. A precision LPV821 Op-Amp is coupled to the output of the OP184 CP filter and connected to analogue A6 input on the Nano.

The original scheme of digitally switching the TRX120/TRA120 RF module VT1/2/3 inputs has been dropped in lieu of switching in multi-turn trim pots. For the TRA120_045 chip, there is an even simpler solution (see further).

The same ADM7154ACPZ-3.3-R7 low noise regulator is used for to provide 3.3V to the TRA chip with an additional 3 x ADM7160ACPZN3.3-R7 3.3V regulators to separate isolated analogue and digital supplies to the ADF41513. As the TRA120_045 module requires 0 - 4.5 V for VCO tuning an additional TPS7A2045PDBVR 4.5V regulator is installed. All regulators have high PSRR (power supply ripple rejection) and choke decoupling between stages. A single 5V LDO regulator has been used to supply all regulators.

It is possible to run the TRA120_002 transceiver from the USB port depending on a smart phone/tablet's ability to supply 5 volts @ ~ 300 mA. Filtering has been added to the 5V rail so there is no degradation in performance or phase noise. Using USB power, the 5V rail only runs at ~ 4.3V. This OK for all 3.3V regulators but in the TRA120_045 version the 4.5V regulator will not work.

A newer Mini Circuits ADQ-180+ 90-degree hybrid has been used on the new PCB. While this part has similar specifications but is far easier to obtain than the original. Either side image can be rejected by changing the JMP1 or JMP2 links, normal configuration is to pass the high side although be aware that this will place the LO outside of the amateur bands if you use the lowest pre-set frequency on each.
A new feature added is an input on pin 8 of X-3 to enable WSJTX JT4 transmission. This can be connected directly to the audio output of a PC or laptop, just how this works is described further.

Manual frequency control is also available to select 1 of 4 pre-set frequencies via a rotary or toggle switch. Pin 6 of X-3 is connected to analogue input A1 of the Nano which has its internal pullup set high. Frequency choice is achieved by detecting different voltages on this pin using a resistor to ground, figure 6 details the values used. Note if you are not using a manual switch R129 (10K) must be in place.

Additional RF boards TRA120 modules

The original article used the TRX120-001 QFN56 module with external patch antenna in lieu of the TRA120_002 module that has RX/TX dipoles on the silicon die. This module bare is quite capable of 20 km and found to be useful as a directional beacon. However, whilst the TRX module has ~ 8db antenna gain advantage, its narrow beamwidth limits its use to offset fed dishes with some method to reposition the focal point between RX and TX. The TRA120_002 module on the other hand is a smaller chip with a broad beamwidth and only 1.5 mm RX/TX focal difference.

Andrew VK3CV's 122 GHz Project [2] detailed two types of antennae for the TRA120_002, a chaparral for F/D ~ 0.38 dishes and a 25 dBi horn feed. In experiments, the chaparral feed was found to be no better than the bare chip itself however the horn feed gave close to the predicted 25 dB gain over the bare chip on VK5ZD's range tests. After a few requests, a new RF board was created for the TRA120 QFN32 modules with the hole pattern to suit the VK3CV horn feed. This RF PCB has become the template for creating two more RF PCBs for the TRA120_031 and TRA120_045 115 to 135 MHz modules.

The new RF boards have been made to the same dimension of the original and use the specified 2mm pitch 90-degree header pins. As each RF module has slightly different pin outs and some reversed functions each board has different circuitry. The I/Q IF outputs have a simple pi network match to 50 ohms, measured rejection of the unwanted image is 18 – 20dB without any further adjustment. The construction technique is the same as before, when the RF PCB is attached to the main PCB the ground plane is soldered on both sides behind the TRA chip for good thermal and mechanical stability. A small dob of solder at the corner joints then completes.

The new RF PCBs are interchangeable between all V2, V3 or V4 main PCBs to make possible swapping and reusing on different main boards for experimenting. The differences between the module configurations (002, 031 or 045) can be selected Iain VK5ZD's software.

For those interested, Gerber files for a revised version of TRX120 RF PCB (KK083e) that can be used with the new main board are available. This PCB has level conversion from 3.3V control voltages used by the TRA modules and the new main PCB to the 1.2V logic used with the TRX module.

The horn feed can be used for 10 – 20 km or used with a Cassegrain reflector (to be described in a future article). Alternatively, the bare RF PCB's can be used to directly feed a 0.38 F/D dish if you are prepared to adjust the focal point. VK5ZD/VK5KK have used a pair of these with 600 mm dishes up to 52 km under non ideal conditions. The pattern is skewed and the gain ~ 6 db worse than a good Cassegrain but still very usable.

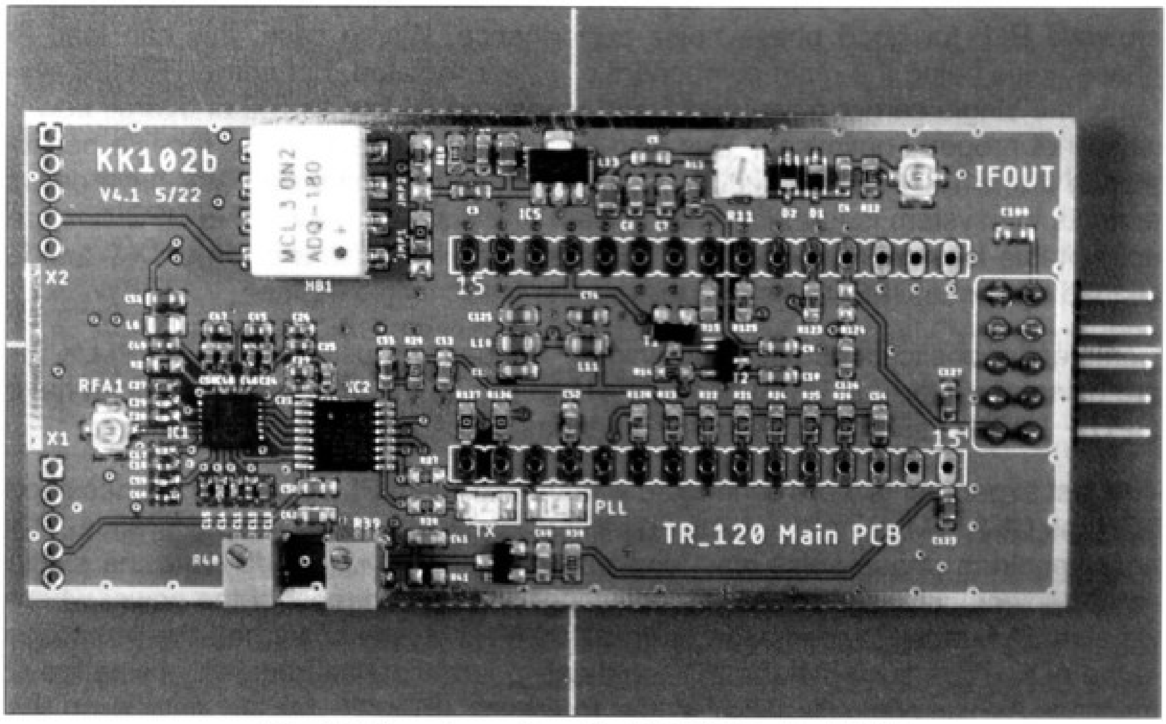

Fig. 3: Top view of main PLL & Control PCB