VK3CV / WQ1S 122GHz Transverter Assembly and Operation

Ver 1.03

Introduction

In this document we describe the theory, construction and operation of a 122GHz Transverter system based on the Silicon Radar TRA_120_002 transceiver I.C.

Please use the Dropbox link below to get the most current versions of all data and diagrams etc.

https://www.dropbox.com/sh/oesw3j4jwrf1pb2/AAA06dkaindVJy8k0dbw82B9a?dl=0

It is possible that fully assembled PCB's and waveguide chip couplers may be made available by a third party manufacturer. Keep a watch on the DropBox archive for any up to date information.

System overview

The 122GHz Transverter PCB is based on the Silicon Radar TRA_120_002 I.C. The PCB contains all the components necessary for transverter operation with an external I.F. receiver.
Note that there is no requirement for the external I.F. to transmit, it is receive only so any suitable receiver can be used. All transmit functions are implemented on the PCB.

The transmitter and receiver frequencies are separated by the I.F. frequency under the control of a programmable Phase Locked Loop (PLL). The I.F separation ensures that no communications can occur due to direct I.F leakage as may be the case in a mixing style of Transverter.

The I.F. separation of the TX and RX frequencies also allow for full duplex operation in FM voice mode as the TRA_120_002 is capable of simultaneous transmit and receive operation.

In Transmit mode, the design allows for Keyed FM Tone, Beacon Keyed FM Tone, FM Voice, Keyed pseudo CW and Beacon Keyed pseudo CW.
Pseudo CW is generated by shifting the TX carrier frequency onto the TX frequency while keyed, and away from the TX frequency when not keyed. This type of pseudo CW can also be termed Frequency Shift Keying (FSK). This is done because the TRA_120_002 is not directly capable of ON/OFF keying. It's internal local oscillator (L.O.) is running at all times. The pseudo CW frequency shift used is equal to the I.F. frequency. The PLL is able to lock so quickly (120uS typically) that little or no keying chirp is noticeable on the keyed transmissions

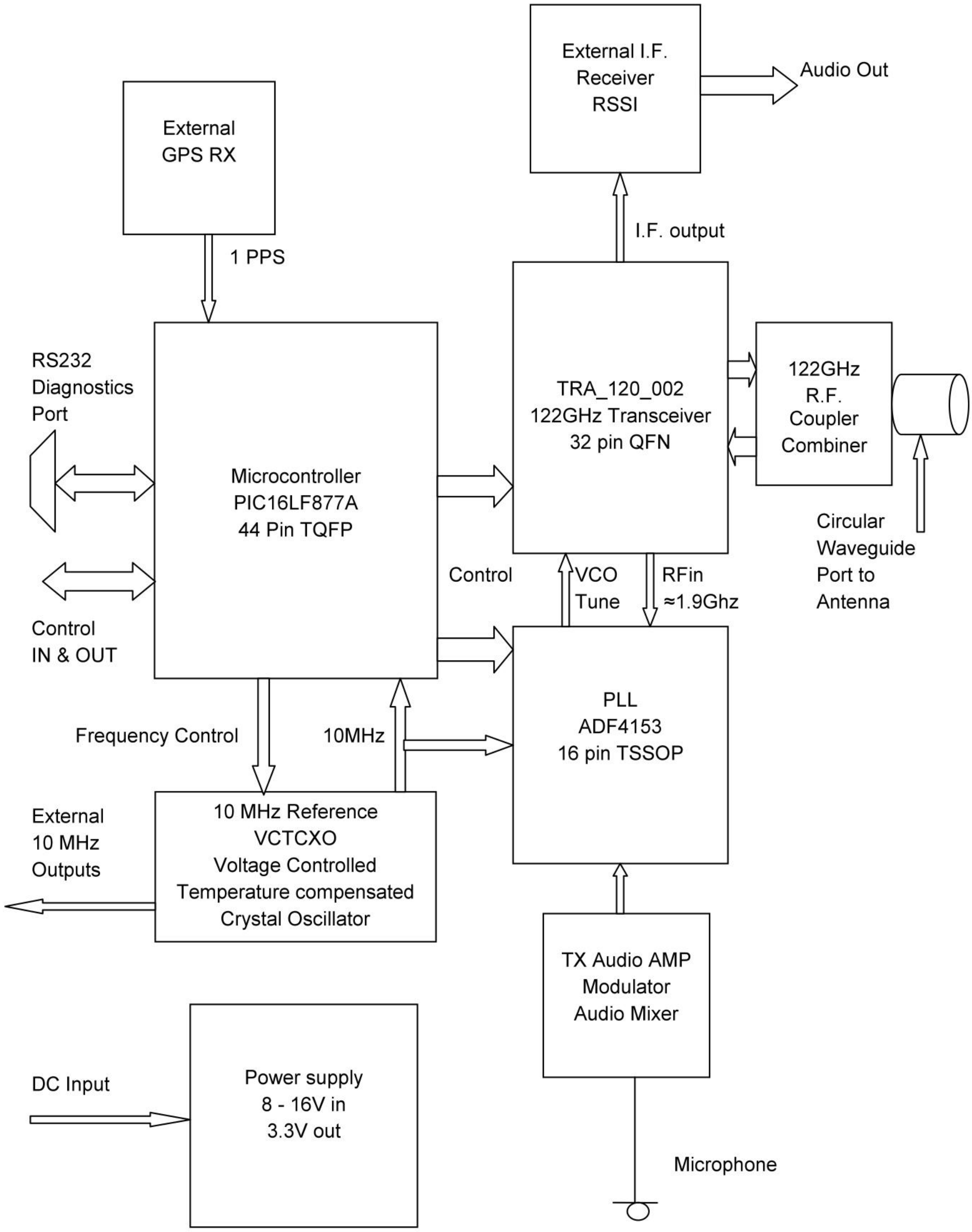
On receive the system will support any modulation mode the I.F. receiver is capable of receiving. It is simply a receive down converter in the receive mode.

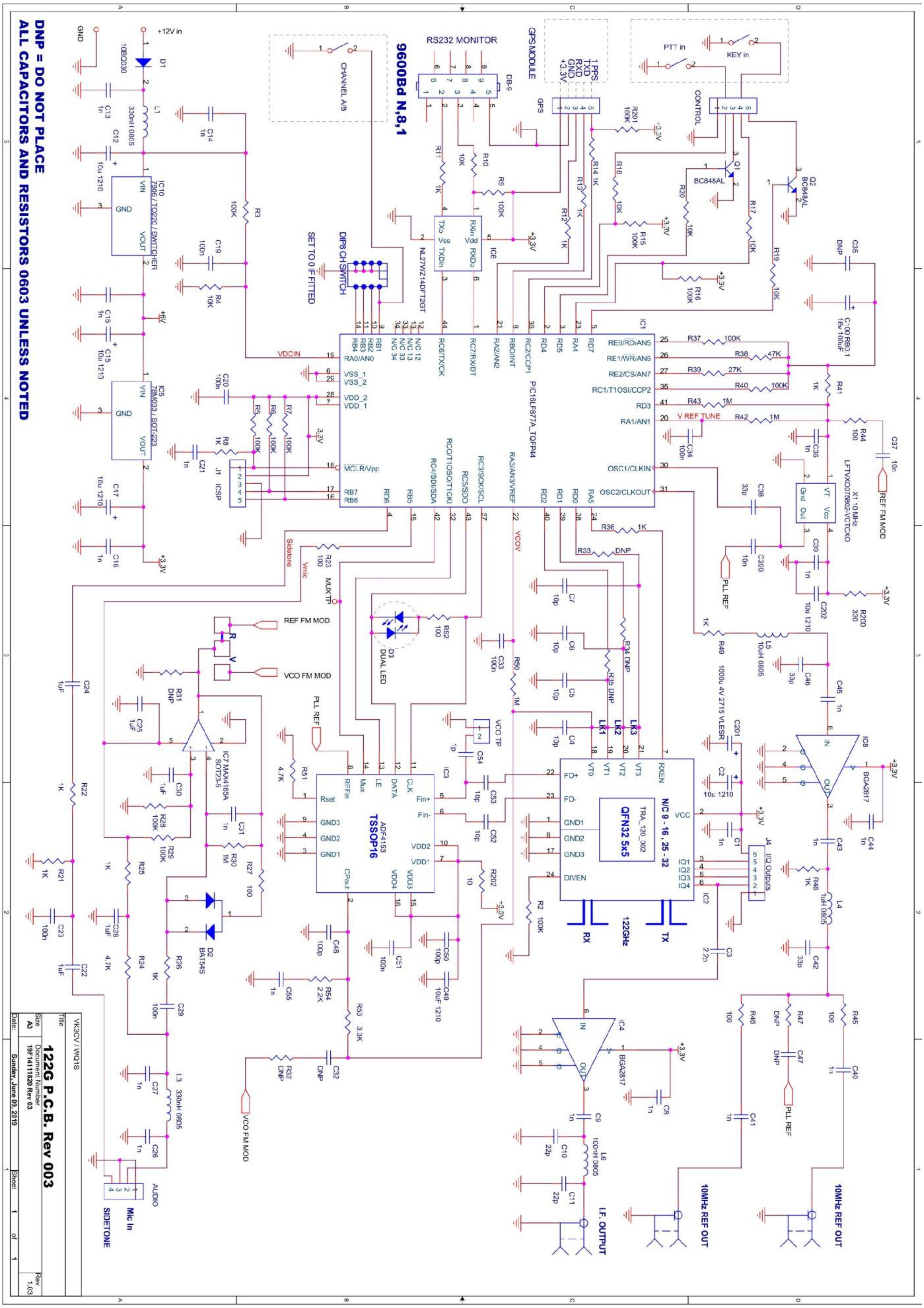
The Transverter design includes a waveguide RF coupler that combines the separate transmit and receive functions of the TRA_120_002 into a common path allowing easy interface to an antenna.

More information on the TRA_120_002 is available at the following public domain link :

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

Simplified Block Diagram of the 122GHz Transverter




DNP = DO NOT PLACE
ALL CAPACITORS AND RESISTORS 0603 UNLESS NOTED
+12V in
GND
RS232 MONITOR
9600Bd N,8,1
GPS MODULE
1PPS
TXD
RXD
GND
+3.3V
CONTROL
PTT in
KEY in
CHANNEL A/B
DIP8 CH SWITCH
SET TO 0 IF FITTED
PIC16LF877A_TQFP44
IC1
IC6
NL27WZ14DFT2GT
IC10
7806 / TO220 / SWITCHER
IC5
78M033 / SOT-223
J1
ICSP
X1 10 MHz
LFTVXO075802-VCTCXO
REF FM MOD
PLL REF
VCO FM MOD
DUAL LED
IC3
ADF4153
TSSOP16
IC2
TRA_120_002
QFN32 5x5
N/C 9 - 16 , 25 - 32
122GHz
RX
TX
I/Q Outputs
IC7 MAX4165A
SOT23-5
IC8
BGA2817
IC4
BGA2817
I.F. OUTPUT
10MHz REF OUT
10MHz REF OUT
AUDIO
Mic In
SIDETONE
VK3CV / IW01S
122G P.C.B. Rev 003
Size A3
Document Number
Rev 1.03
Sunday, June 09, 2019
Sheet 1 of 1

Circuit theory of operation

With reference to the simplified block diagram and circuit schematic, An external power supply of a nominal 12V DC is applied through a reverse polarity protection diode to a 5V regulator then to a second 3.3V regulator which supplies all the active circuits. All functional control for the board is handled by a PIC16LF877A Microcontroller. The clock for the microcontroller and reference signal for the Phase Locked Loop (PLL) is provided by a Voltage Controlled Temperature Compensated Crystal Oscillator (VCTCXO) running at 10MHz.

The 122GHz transceiver chip is controlled by the Microcontroller in addition to being frequency locked by the PLL (ADF4153). The 122GHz TX and RX circuitry is all contained within the TRA_120_002 chip. A divided by 64 output of the internal 122GHz Voltage Controlled Oscillator (VCO) in the TRA_120_002 chip is fed to the PLL which can then lock its internal VCO to the desired operating frequency. The VCO in the TRA_120_002 is always operating either on the TX or RX frequency and its frequency is determined by the control data sent to the PLL chip by the Microcontroller.

Note that the PLL operates in the region of 1.9 GHz. A test point is available to observe this 1.9GHz signal to allow testing of the system. The PLL phase comparator output is fed via a loop filter to the VCO tune inputs of the TRA_120_002. This voltage is monitored by the Microcontroller as well as the PLL lock signal to ensure the PLL is correctly locked.

Modulation inputs are included in the PLL circuit to allow modulation of either the VCO error voltage or of the reference tune voltage resulting in FM modulation of the VCO. There are selection links to choose which modulation path is used, Normally the reference signal path is used giving a nominal 5 KHz of FM deviation. The modulation signal is supplied from a simple modulation limiting microphone amplifier which is connected to an external electret type microphone.

The VCTCXO tune voltage is derived from a resistive voltage summing network. Inputs to this network are provided from the Microcontroller to provide frequency error locking to an external GPS signal as well as FM tone Modulation. An external GPS derived one pulse per second (1PPS) signal is fed to the Microcontroller which under software control, uses this to lock the 10MHz internal reference to the external 1PPS signal resulting in a frequency error much less than 1Hz when locked. The frequency locked 10MHz signal is also available externally and can be used as a reference for other equipment.

The TRA_120_002 chip has two separate internal linearly polarized antennas for TX and RX which are separated physically within the structure of the chip. The TX and RX signals are combined in a specially designed external chip to waveguide coupler which sits directly over the TRA_120_002. The coupler external antenna port is a 2mm diameter circular waveguide which is then fed to an external antenna. This approach ensures that no errors in the antenna main lobe direction occur between TX and RX which would be very significant if a high gain antenna were used without the coupler . The coupler feed waveguide is circular but the polarization remains linear. See the marker arrow on the PCB for the linear E field polarization direction. Two types of antenna have been made, A Chaparral™ type with 10dBi gain for use as a offset type dish feed and a 21dBi Gain Conical horn for beacon use. When the dish feed is used with a 600mm dish, a gain of over 50dBi is possible.

Received Signals from the internal chip RX antenna on 122GHz are first amplified and then converted down to the I.F. frequency by a mixer inside the TRA_120_002 chip. The I.F. signals are available as I/Q differential signals for use by an external Software Defined Radio (SDR) or in an analogue format via a buffer amplifier for use by an external I.F. receiver. The I.F. frequency is nominally 144.4 MHz. This can be changed to anywhere in the range from DC to 200MHz under software control. There is a significant amount of degradation in the FM received signal to noise performance of the system due to the inherent phase noise on the TRA_120_002 local oscillator. Use of the narrowest I.F. bandwidth FM I.F. demodulator available will give the best results. Note that as the VCO in the TRA_120_002 is always running, Full duplex operation is possible in FM mode. This is done by having the local system and the remote system operating on frequencies separated by the I.F. See the following mode control section.

Transmit signals on 122GHz originate from the VCO inside the TRA_120_002. They're then fed via an internal TX amplifier and then on to the internal chip TX antenna.

Software Operation

The Microcontroller takes inputs from several sources which it then uses to control various features and functions of the system under control of the internal software. The Microcontroller has control of the following : Bi-Colour RED/GREN LED, FM modulation tone generation, External sidetone generation, GPS frequency locking, Microphone amplifier enable, PLL RF frequency, RS232 diagnostics port, TRA_120_002 mode, External mode control inputs, External mode outputs and Channel selection. Note that only 2 channels are currently used being A and B corresponding to "0" and "1" on the least significant bit of the channel selection lines. If a channel switch is fitted to the PCB, the DIP switches must be set to all open or position "0" for a rotary HEX switch

The system software is contained in Flash memory within the Microcontroller. Software programming is achieved via the provided In Circuit Serial Programming (ICSP) port on the board. Refer to the relevant Microchip data sheets for information and software programming details.

On power up, The microcontroller configures all the required inputs and outputs and initializes the required internal registers and external peripherals. A dual colour LED is available to give operator feedback on operation. The LED will initially be RED during power on an then change to GREEN to show correct operation and that the PLL is locked. If the PLL is not locked, The Led will remain RED and flashing. The LED will also go to RED when the system is in the TX mode. An rapidly alternating RED/GREEN LED flash indicates low DC input voltage. (less than approximately 10V).

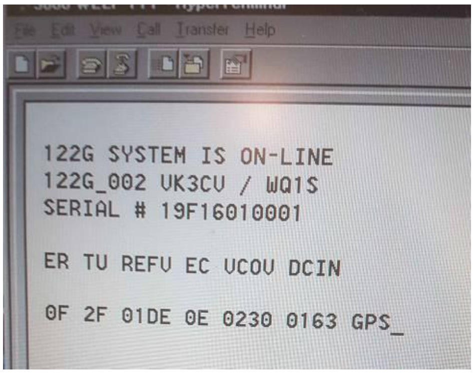
Depending on the selected mode of operation, the Microcontroller has a built in Morse Code Keyer available which can provide a continually repeating Morse code message such as a call-sign on the transmitter to aid with testing and for use as a beacon. The transmitted string can be changed in the Software as desired. It is located in the string definition section near the end of the assembly language file.

The full Assembly language source code file is also available in the DropBox archive. All information in this document is provided free of charge and without any implied or direct warranty.

Diagnostics Port

An RS232 port is available which outputs data to allow monitoring of the system during operation.
The port is set to a 9600 Baud rate, No parity, 8 data bits, and 1 stop bit, I.E. 9600,N,8,1.
The port is an output only at this point although device command and control is possible if suitable software changes are made in future software revisions.

The RS232 port initially outputs a series of strings at power on to show the identity of the unit and the software revision. After this a continuous stream of data is output at roughly a 1 second rate showing the internal operation.



The RS232 output string is in the following format :

ER TU REFV EC VCOV DCIN _> "Appended Strings"

The values are in Hexadecimal and are as below :

ER = GPS Locking current Error Result
TU = Current 10MHz VCTCXO reference error TUne value
REFV = Current 10MHz VCTCXO reference tune voltage
EC = VCTCXO error count since last correction, (Lock Quality indicator)
VCOV = Current VCO error Voltage
DCIN = Current DC Input Voltage

_> dummy command cursor, Not currently used.

"Appended Strings" = Data that may be appended to the end of each string, These are a "GPS" indicator that shows 1PPS GPS data has been received, And "PLL Lock Error" which indicates the PLL is out of lock.

For best results use an RS232 terminal program in ANSI mode to receive the data from the RS232 port.

Mode and Frequency Control

There are 3 control inputs which determine the mode of operation and RF frequency of operation of the system. These are : "PTT in" , "Key in" and "Channel A/B". It is suggested that locking toggle switches be connected to "Channel A/B" and "PTT in". In the case of "Key in", It is suggested to use a locking toggle switch in addition to bringing the "Key in" control line out to a connector for connection to a Morse Code Key.

The "PTT in" input controls the internal microphone amplifier and enables the PCB for FM voice operation. Note that this line is also used in conjunction with the "Key in" line to select beacon mode.

The "Key in" input controls the CW keying functions of the PCB, The CW keying will be either carrier of modulated FM tone depending on the state of the "Channel A/B" input,
Note also that this line is also used in conjunction with the "Key in" line to select beacon mode.

The "Channel A/B" input controls the RF channel selection and also sets the transmission mode to either FM or CW. See the following Operating mode table.

Note that all of the control lines have internal pull up resistors to 3.3V on the PCB. Simply connect a switch between the control lines and ground. This means that switch open = 1 and switch closed = 0 in the following mode table. DO NOT connect an external voltage to these control pins.

The RF channel frequencies currently used are :

Channel A = 122,500.400 MHz
Channel B = 122,356.000 MHz (Channel A-144.4MHz)

Any frequency from 122.25 to 123 GHz is possible as the TRA_102_002 will cover the entire band. A frequency table is present in the assembly language software which can be modified to give the desired frequency. Refer to the ADF4153 data sheet for PLL register programming details. Note that the minimum channel step is currently 400KHz.

OPERATING MODE TABLE

CH A/B	PTT in	KEY in	Operating mode
1	1	1	RX mode on Channel A (FM, SSB or CW mode receive on I.F.) LED GREEN, Microphone Not Active
0	1	1	RX mode on Channel B (FM, SSB or CW mode receive on I.F.) LED GREEN, Microphone not active
1	1	0	TX mode Channel A, (TX CW), Side tone on LED RED, Microphone not active
0	1	0	TX mode Channel B (TX FM Tone), Side tone on LED RED, Microphone not active
1	0	1	TX mode Channel A (FM Audio), RX mode FM Duplex LED RED, Microphone Active
0	0	1	TX mode Channel B (FM Audio), RX mode FM Duplex LED RED, Microphone Active
1	0	0	TX mode Channel A, Beacon CW (TX CW), Side tone keying LED Flashing RED keying, Microphone not active
0	0	0	TX mode Channel B, Beacon FM (TX FM Tone), Side tone keying LED Flashing RED keying, Microphone not active

1 = switch open
0 = switch closed

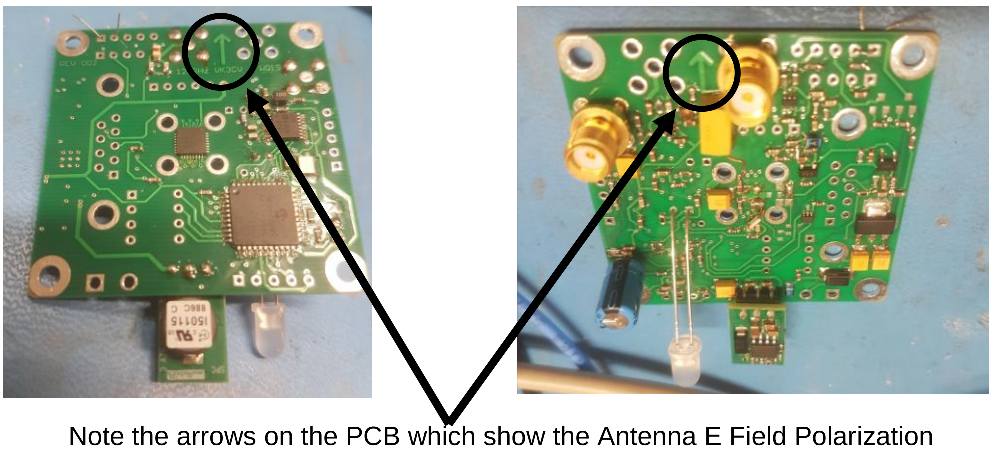
Construction

Use the Gerber Files in the DropBox archive to get the artwork for the PCB, Note that the design is a 4 layer board with an almost continuous internal ground plane to keep all the signals where they're supposed to be. Most multilayer PCB manufacturing companies will be able to take the Gerbers as they are and produce good quality boards.

The Bill of Materials (Parts List) and component placement legends (Component Overlays) are also available in the DropBox Archive.

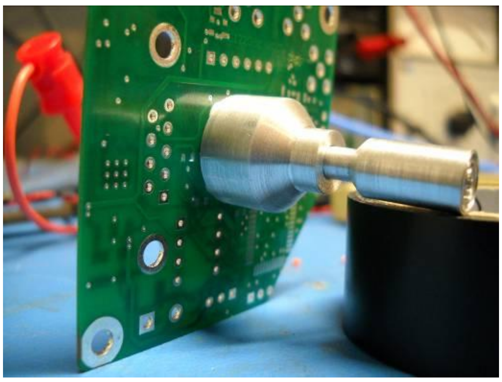
Mounting the TRA_120_002 chip itself can be challenging, good optical magnification, a steady hand and a heat gun or reflow oven are required, there's many YouTube videos on how to do it. It is suggested to place the TRA_120 chip first, observe basic anti-static practices but the chip is quite robust in this respect. Once the chip is down, as a connection check, look with a multi-meter at all the chips signal pins to ground to check if there is a diode junction present on all the connected pins. (The diodes seen are ESD protection diodes on all the pins) Reflow 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. If the part value is DNP then do place this part. Ensure the required option links are placed in accordance with the latest version of the circuit schematic.

Completed PCB Top and Bottom



Note the arrows on the PCB which show the Antenna E Field Polarization

Coupler and Antenna Feed



Drawings for the coupler and Chaparral™ Feed are also to be found in the DropBox Archive.

The coupler hole pattern in the PCB and coupler is a 8.38mm square, centered on the centre of the PCB. The PCB is square at 50.8 x 50.8mm with the PCB mounting holes in a 44.46mm square. The mounting holes in the coupler or horn antennas are all 6mm deep drilled and taped M2x0.4.

Testing and adjustments

Firstly use a current limited power supply set to 200mA at 13.8 VDC. Apply power and verify the 5V and 3.3V power supplies are present. Check that there is a signal present at 10MHz from the reference oscillator.
Connect a Microchip programmer and program the PIC Microcontroller. After programming, The board LED should now operate and diagnostics data will be present on the RS232 port.

If suitable equipment is available, use the VCO test point to check that there is a signal at the RF output frequency divided by 64 (1.9 GHz approx). It's level will be around -20-30dBm.

L.O. Frequency = 122.5004 GHz , VCO T.P. Frequency = 1.91406875 GHz
L.O. Frequency = 122.356 GHz , VCO T.P. Frequency = 1.91181250 GHz

If all is well then attach the chip coupler with 4 pcs M2x5mm screws. The Coupler and dish feed are made from Aluminium. The coupler and feed were manufactured on a small Lathe. Special tooling was also purpose made to cut the de-coupling rings in the feed. Most small Lathes are suitable for manufacturing these parts. It is possible these parts may be available pre-manufactured by a third party, see the DropBox archive.

The 10 MHz reference frequency will automatically adjust itself as soon as a 1PPS signal is seen, Initially this can take up to 20 minutes. This only needs to be done once. Use any GPS receiver that has a 1PPS output and feed this into the 1PPS input on the board. Observing the adjustment locking progress is possible on the RS232 port. Once you see the TU value stop changing every few seconds and the EC value getting larger than 9 then all is well. It is recommended to always have a GPS 1PPS signal connected to ensure the system is always on the correct frequency. If it is left unconnected the system will revert to the last measured value which is stores internally in EEProm.

Coupler Adjustment

The 122GHz Coupler needs to be adjusted to give the best performance. This is easily achieved with another system acting as a beacon. Separate the 2 systems by some distance and adjust the coupler by unlocking the adjustment screw on the front of the coupler and slide the feed waveguide in and out to achieve maximum RX signal. Lock it in place when best received signal is achieved. This position is usually when the end surface of the adjustable feed waveguide section is sitting approximately 1-1.5mm above the surface of the TRA_120_002.

Completed Systems

The completed board is intended to be mounted in a small enclosure at the focal point of an offset dish. A second enclosure is used to hold a power supply, control switches and associated connections. Mounting a Optical Telescopic sight on the enclosure aligned with the antenna is a very useful aid in pointing the system in the correct direction especially when using a high gain dish.
Bracing of the dish will also improve the repeatability of aiming.
A portable / Test / beacon system was also built in a self contained configuration, see below.

System usage

Here are some examples of how the system is used in a practical contact.

We will assume there are 2 identical systems, System #1 and System #2, Separate the systems by a small distance of around 10 - 30 Metres. Align the 2 systems antennas so they are pointing directly at each other. Once a signal has been received the antenna pointing directions can be peaked for maximum received signal level on the I.F. receiver.

CW Beacon Test

On System #1, Set the DC Power to ON , Channel to A , PTT to ON, KEY to ON , Connect a GPS 1PPS signal. This will put System # 1 into a CW beacon TX mode.

On System #2, Set the DC power to ON, Channel to A, PTT to OFF, Key to OFF, Connect a GPS 1PPS signal. This will put the system in an RX mode, Connect an I.F. receiver to the I.F. port on the PCB and tune the receiver to 144.3985 MHz. Set the receiver mode to USB or CW

A 1.5Khz CW beacon tone should be received on the I.F receiver

FM voice Contact

On System #1, Set the DC Power to ON , Channel to A , PTT to ON, KEY to OFF , Connect a GPS 1PPS signal. This will put System # 1 into an FM Voice TX/RX mode. Connect an electret microphone to the Microphone input on the PCB. Connect an I.F. receiver to the I.F. port on the PCB and tune the receiver to 144.400 MHz. Set the receiver mode to FMn.

On System #2, Set the DC power to ON, Channel to B, PTT to ON, Key to OFF, Connect a GPS 1PPS signal. This will put the system into an FM Voice TX/RX mode, Connect an electret microphone to the Microphone input on the PCB. Connect an I.F. receiver to the I.F. port on the PCB and tune the receiver to 144.400 MHz. Set the receiver mode to FMn

Full Duplex Voice audio should be heard by both operators.

CW Contact

On System #1, Set the DC power to ON, Channel to A, PTT to OFF, Key to OFF, Connect a GPS 1PPS signal. This will put the system in RX mode, Connect an I.F. receiver to the I.F. port on the PCB and tune the receiver to 144.3985 MHz. Set the receiver mode to USB or CW. Connect a CW Morse Key to the Key in line on the PCB.

A 1.5Khz CW tone should be received on the I.F receiver when the CW Key is pressed at System #2

On System #2, Set the DC power to ON, Channel to A, PTT to OFF, Key to OFF, Connect a GPS 1PPS signal. This will put the system in RX mode, Connect an I.F. receiver to the I.F. port on the PCB and tune the receiver to 144.3985 MHz. Set the receiver mode to USB or CW. Connect a CW Morse Key to the Key in line on the PCB.

A 1.5Khz CW tone should be received on the I.F receiver when the CW Key is pressed at System #1

Once all is working then get out to a mountain top and make some real DX contacts.

The following images will give some construction ideas.

QSY to 2.4mm , 73's VK3CV / WQ1S