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Wavelab 24 GHz project

Converting Surplus Wavelab 23 GHz radios to 24 GHz Ham Band using PA0MHE Wavelab Add On PCB

June 6, 2023

KM5PO
Jim McMasters

North Texas NTMS Microwave Society

Wavelab 23 GHz ODU

Wavelab module

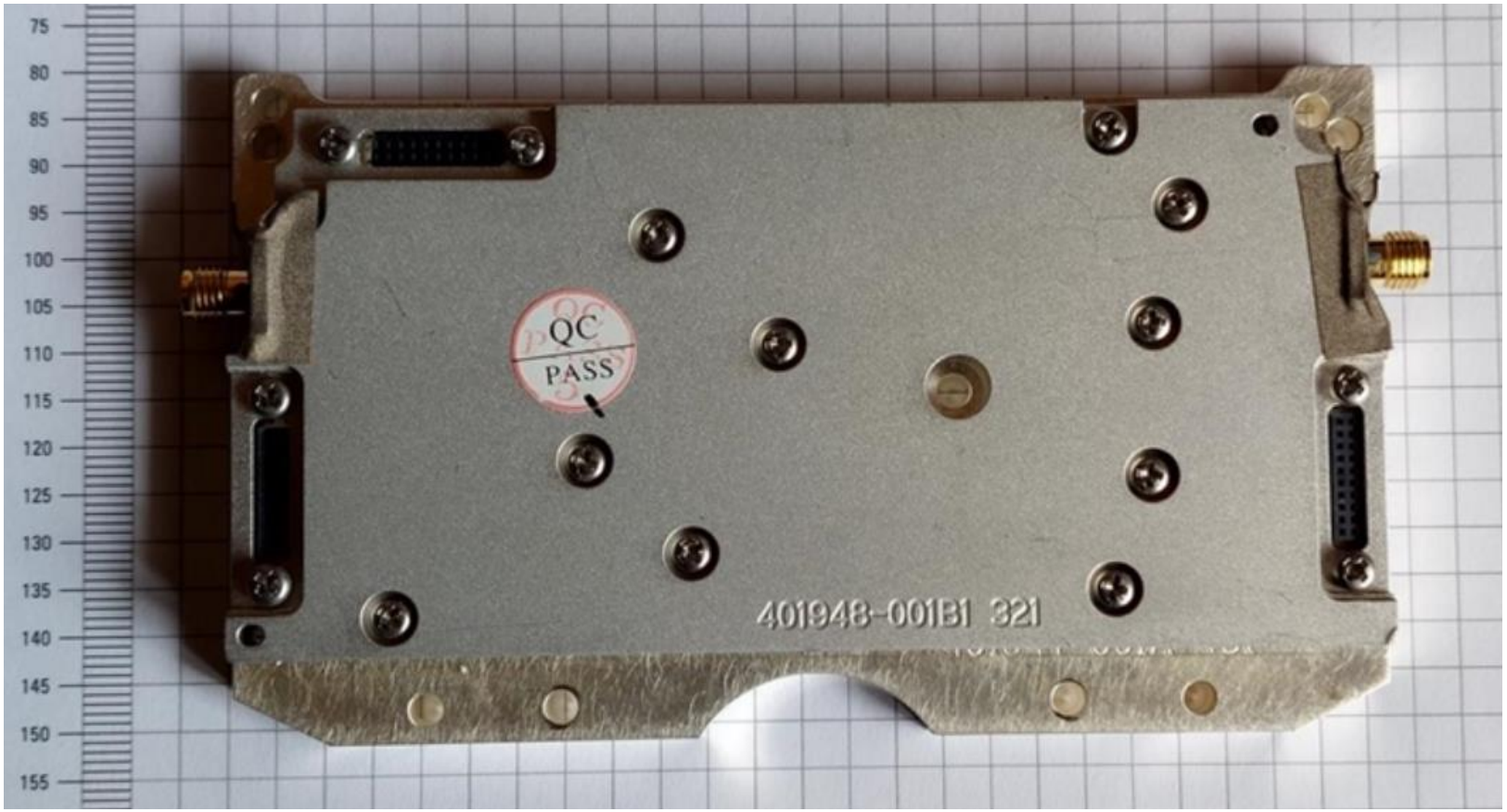
- According to Wavelab ODU brochure, frequency range is 21.2-23.6GHz but original PCB LO can't reach 21.2GHz. TR spacing is 1008 MHz
- Warning: The 23X1008XP module is our unit of interest. Do not purchase the “XN” module.
- The advantage of the XP module is that it can be converted to 24 GHz by simply changing the external input frequencies. It is not necessary to open it up or do any precision surgery on the millimeter wave circuitry.

23X1008XP TR space 1008MHz (IF Tx 2364MHz-IF Rx 1356MHz); RX=LO+IF Rx; TX=LO+IF Tx; TX= RX+1008MHz Motherboard ADF4153 PLL; VCO CRO1728T-LF; LO Range 1670-1770MHz				
Frequency Band* 23.600GHz	RX 22.592GHz	TX 23.600GHz	LO 21.236GHz	LO/12 (input) 1769.66MHz

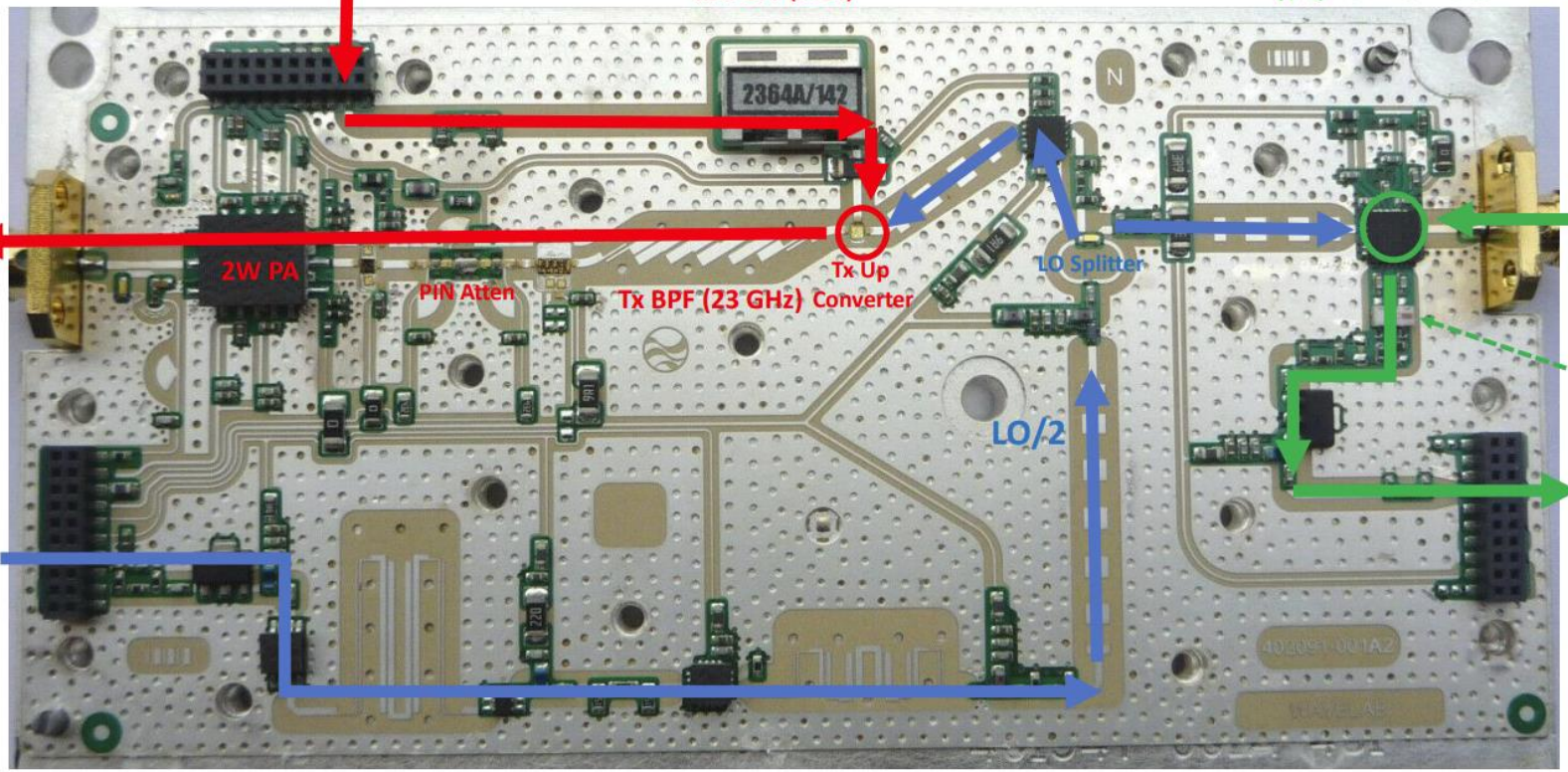
- The plan to put the module on USA terrestrial 24192 MHz

Synthesizer 1 ADF 1	1819 Mhz	x 12 mult	21828 Mhz
Synthesizer 2 ADF 2	2220 Mhz	+ 144 Mhz IF	2364 Mhz
			24192 Mhz

External view of module



Signal Flow & Components Inside the Wavelab Module



LO/6 (3.6 GHz) LO Multiplier Chain LO/2 (10.9 GHz)

Photos and schematics from YO4HFU website

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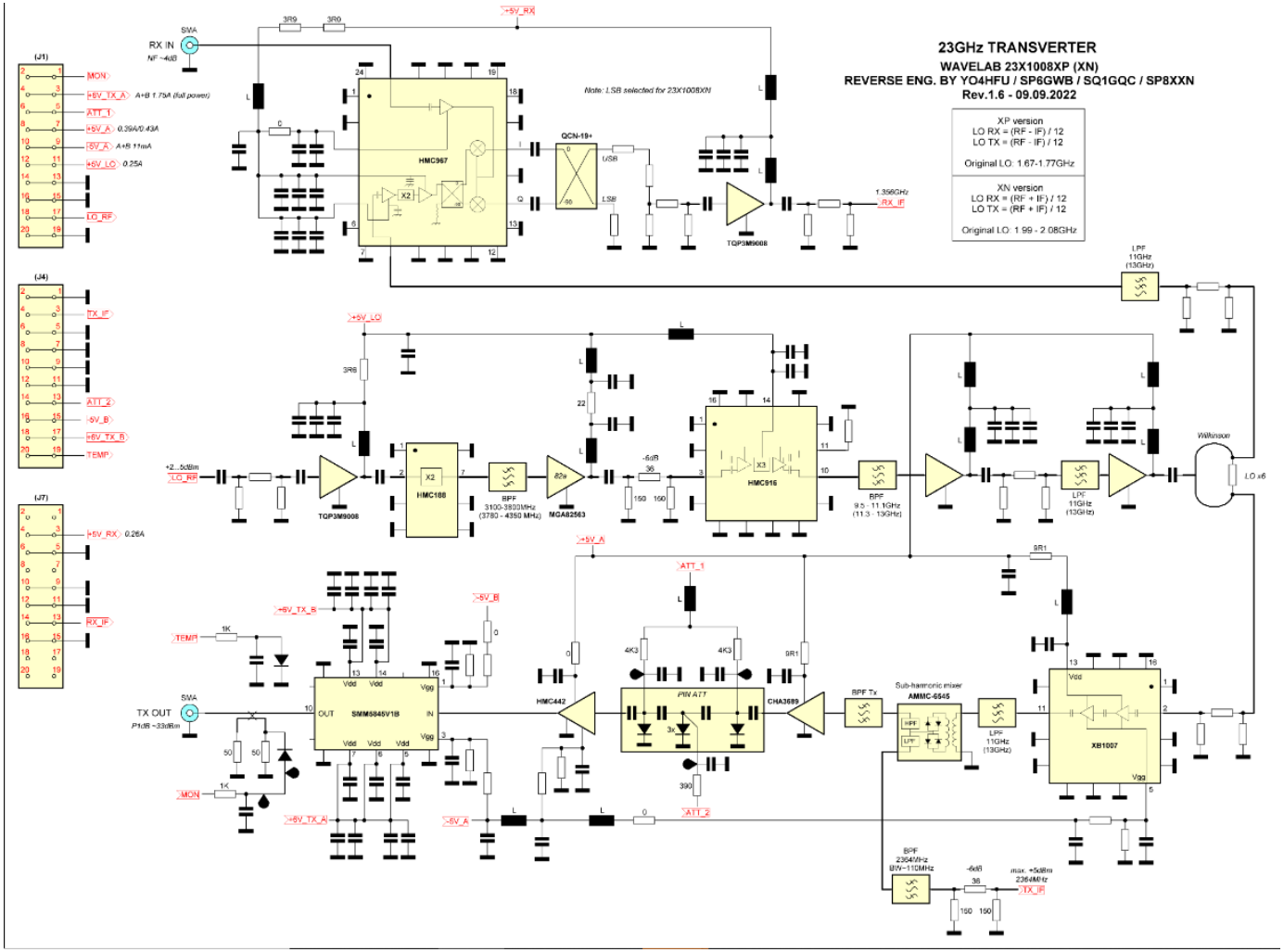
Module schematic



Add on board by PA0MHE

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- Board provides:
  - - all voltage regulators needed by the wavelab module and the add on circuits; supplied by a single 6.5-7 volt external input
  - - first LO synthesizer (~1.8 GHz) to drive the wavelab module's 12x LO multiplier chain
  - - first IF Tx and Rx amps and first IF (2364 MHz) band pass filter
  - - up/down conversion mixer from first IF to second IF (144 or 432 MHz ham transceiver)
  - - second LO synthesizer (~2.2 GHz) for 1st to 2nd IF conversion mixer
  - - second IF attenuators
  - - ATTINY microcontroller to program the two synths (both ADF4351)
- Support:
  - NTMS Group PCB order
  - Wavelab groupsio -https://groups.io/g/Wavelab24GHz

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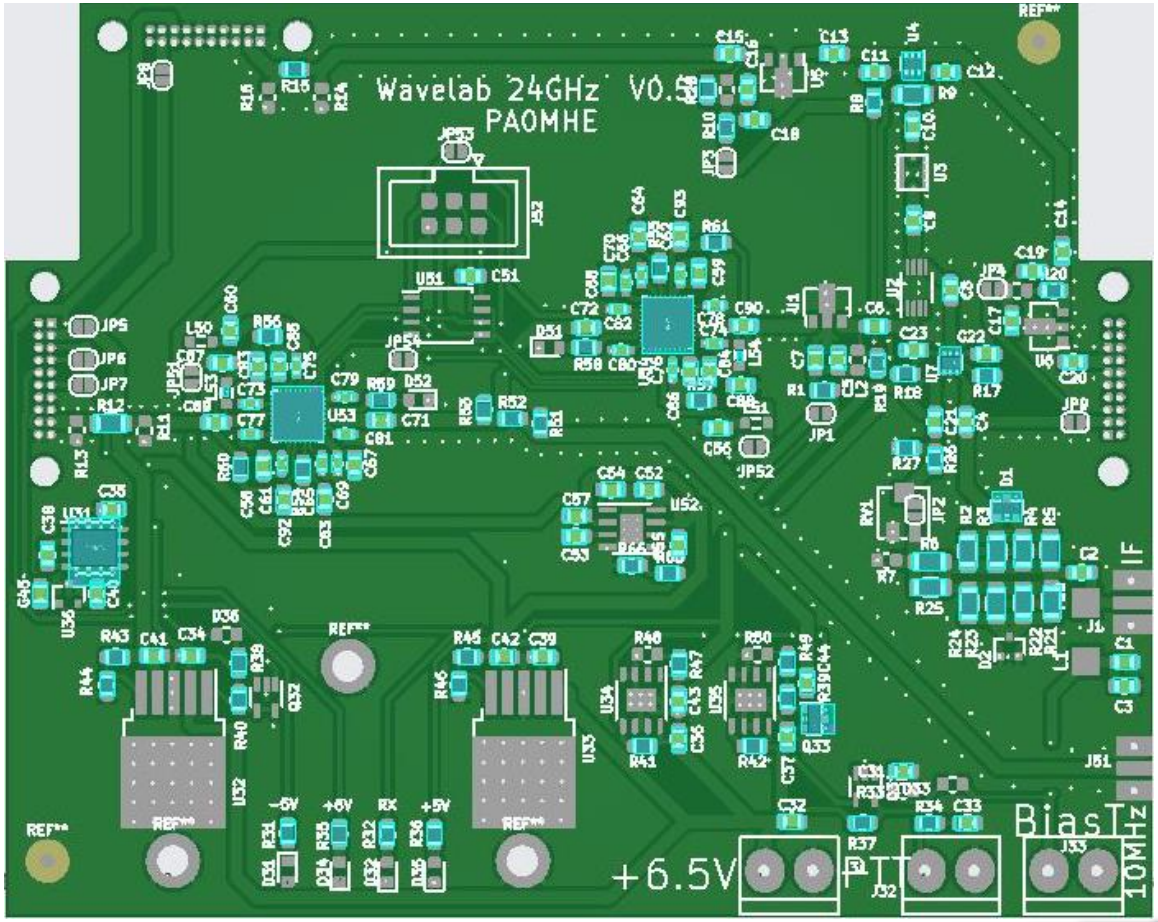
JLCPCB order

Confirming parts placement via website image



Board interest

- History
  - 11/14/2022 20 boards
  - April 2023 – eBay seller lists more modules
  - 4/21/2023 5 boards (NTMS#1 build)
  - 4/29/2023 30 boards (NTMS#2 build)
  - 5/31/2023 75 boards (NTMS#3 build)
    - Interest from VE, VK, PA, G, 9H1, ON

JLCPCB order

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Most Efficient, Economic, Innovative PCB Solutions

Founded in 2006, JLCPCB has been at the forefront of the PCB industry. With over 15-year continuous innovation and improvement based on customers' need, we have been growing fast, and becoming a leading global PCB manufacturer, who provides the rapid production of high-reliability and cost-effective PCBs and creates the best customer experience in the industry.

800,000+	20,000+	450,000㎡	620,000㎡
Customers	Orders Daily	Factory Area	Production Capacity/Month
6 Million+	170+	3000+	15
PCBs Produced/Year	Countries Covered	Employees	Years Founded
>99.97%	<0.23%	1 Day	24/7
On-time delivery	Quality Complaint Rate	PCB Prototype	Online Service

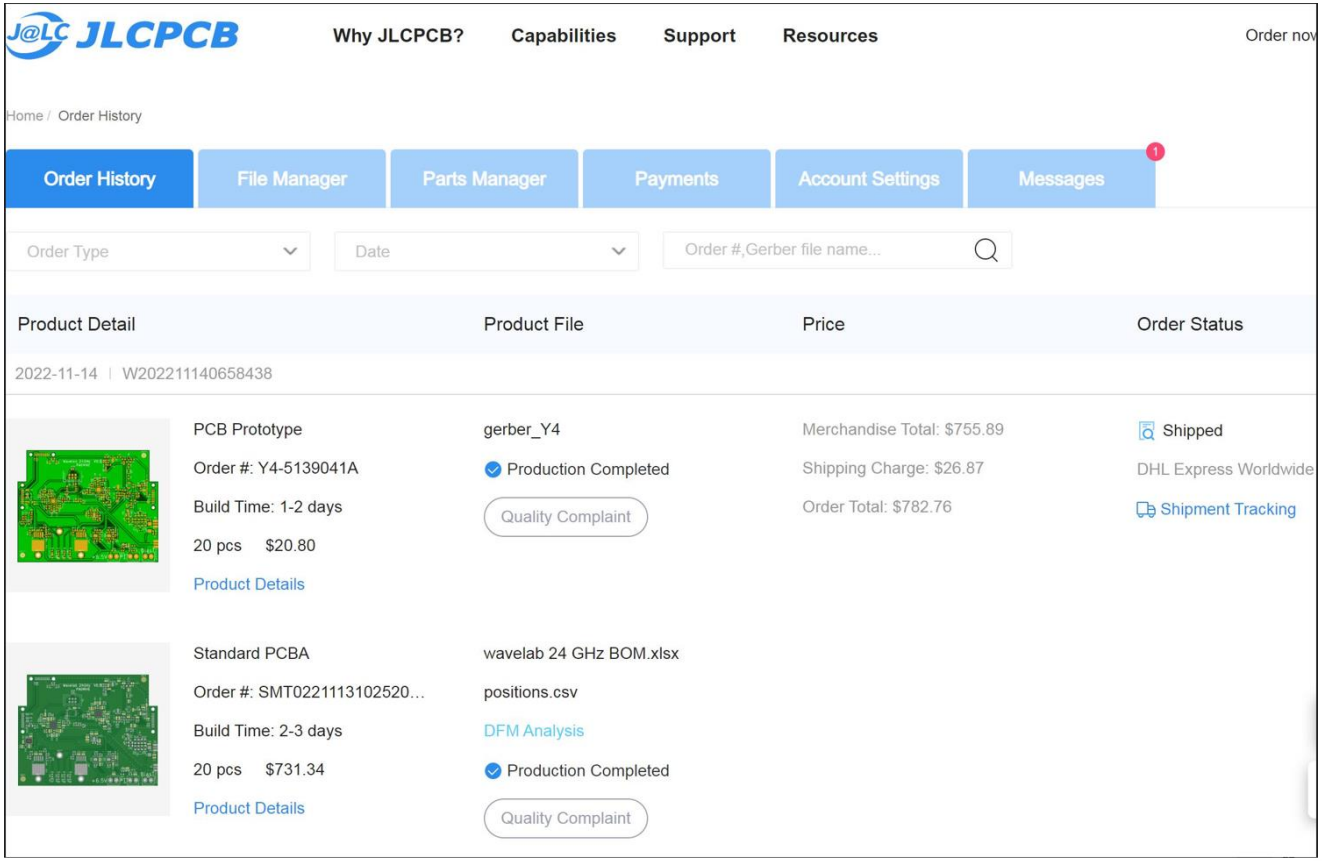
* As of January 2021

JLCPCB order

- Create an account on the website
- Upload the gerber, BOM, positions files
  - Wavelab-24G-Addon-module/Kicad/V05 Kicad6/Wavelab24GHz_v05/production at main · PA0MHE/Wavelab-24G-Addon-module · GitHub
- Review component placement and jlcpcb inventory shortages
  - Using search features you may find replacement parts
- Place the order

JLCPCB order

- Initial cost of PCBs was about a buck each.



JLCPCB order

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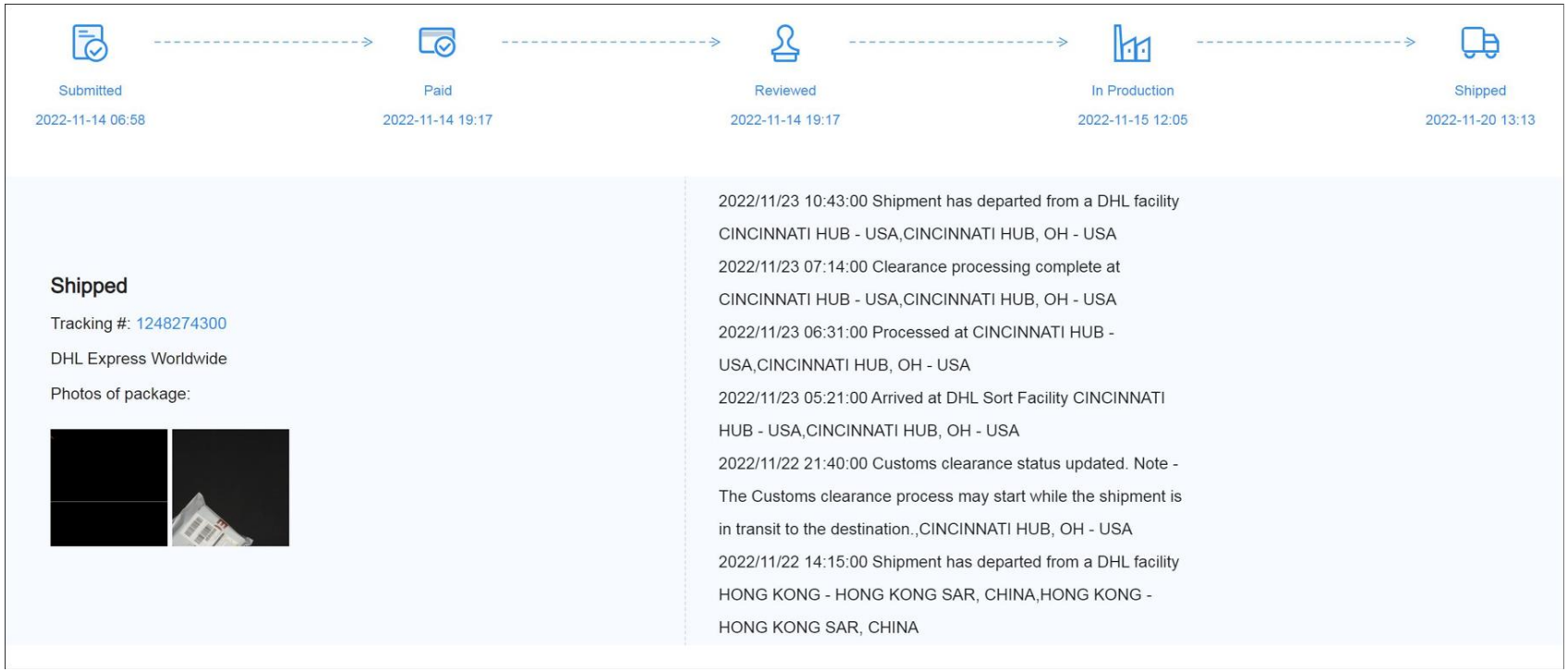
- Shipment timeline. From payment to shipment < 6 days



Submitted 2022-11-14 06:58 → Paid 2022-11-14 19:17 → Reviewed 2022-11-14 19:17 → In Production 2022-11-15 12:05 → Shipped 2022-11-20 13:13

Shipped

Tracking #: 1248274300

DHL Express Worldwide

Photos of package:

2022/11/23 10:43:00 Shipment has departed from a DHL facility CINCINNATI HUB - USA,CINCINNATI HUB, OH - USA

2022/11/23 07:14:00 Clearance processing complete at CINCINNATI HUB - USA,CINCINNATI HUB, OH - USA

2022/11/23 06:31:00 Processed at CINCINNATI HUB - USA,CINCINNATI HUB, OH - USA

2022/11/23 05:21:00 Arrived at DHL Sort Facility CINCINNATI HUB - USA,CINCINNATI HUB, OH - USA

2022/11/22 21:40:00 Customs clearance status updated. Note - The Customs clearance process may start while the shipment is in transit to the destination.,CINCINNATI HUB, OH - USA

2022/11/22 14:15:00 Shipment has departed from a DHL facility HONG KONG - HONG KONG SAR, CHINA,HONG KONG - HONG KONG SAR, CHINA

V5 changes from V4

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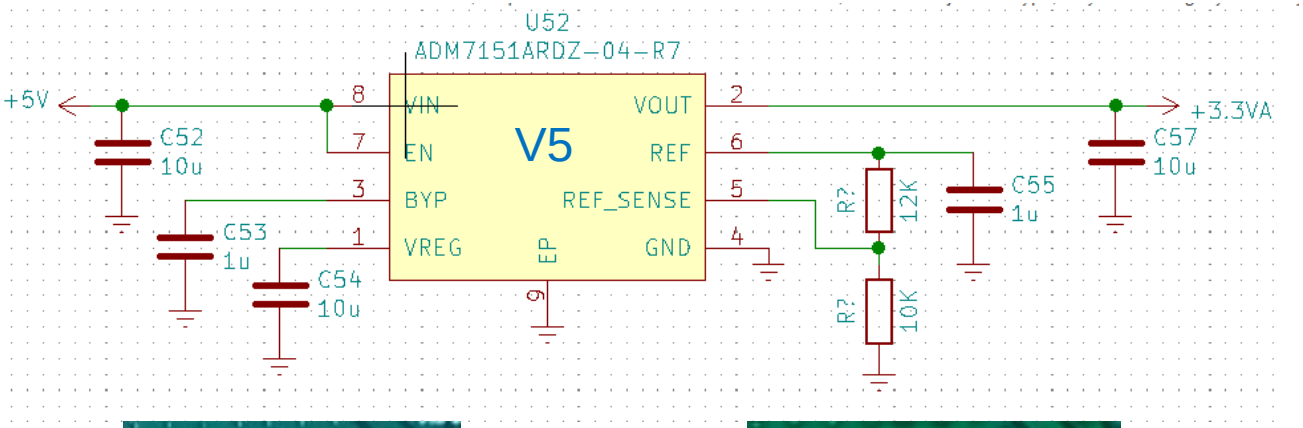
R65, R66 added as option for U52 ADM7151 (chip shortage)

R36 update service print to "+5V"

U6 changed footprint to MGA-86576 (still possible to mount PGA103+, but too little gain)

J31, J32, J33, J1, J2, J3 No solder paste



V4

V5

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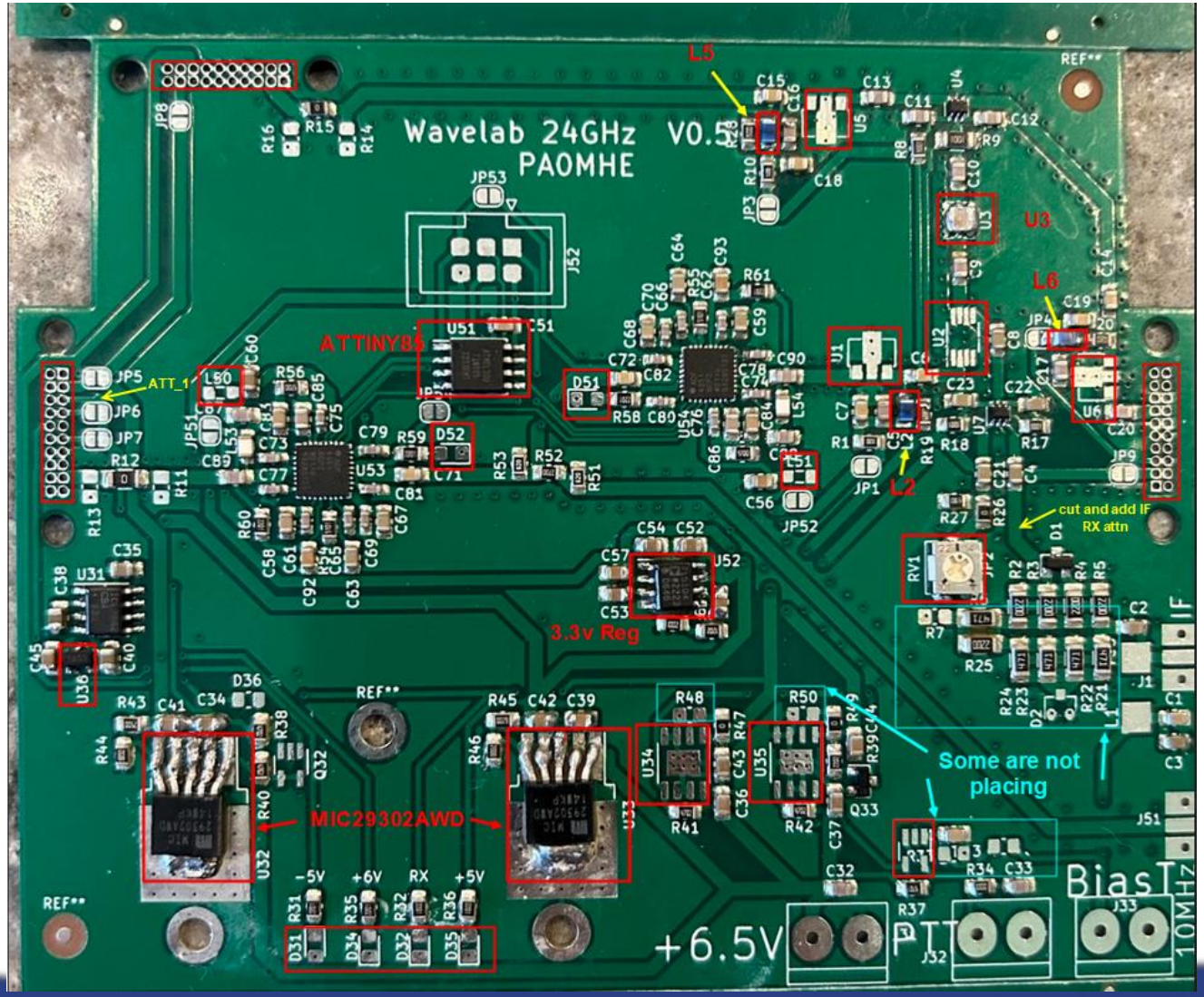
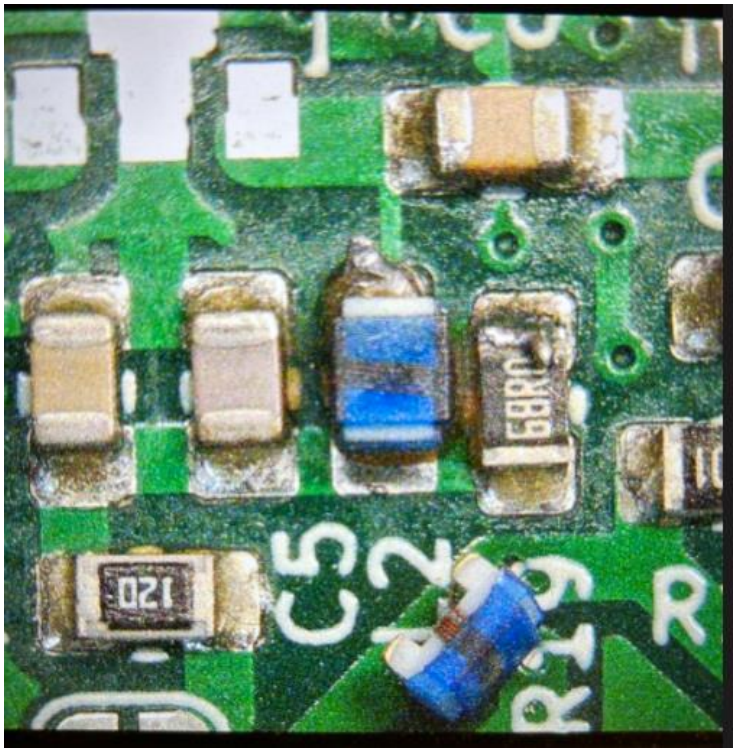
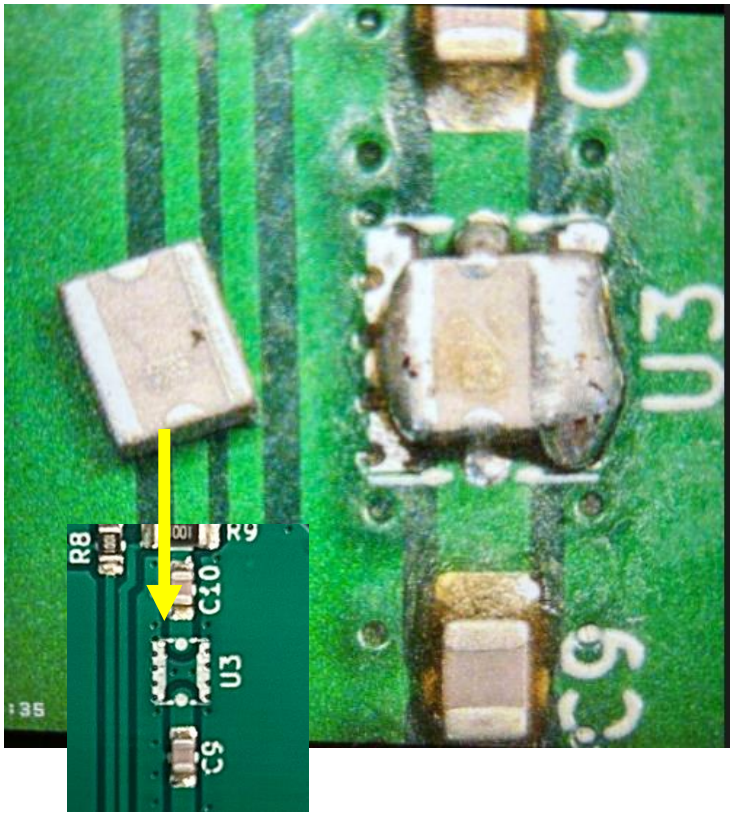
Remaining parts



Soldering technique





Small I/O footprint before placing

Soldering technique

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- Solder pin strip headers after DC checks are performed and validated
  - Rough up pin hole connections with light sandpaper
  - Tack one pin in place while insuring connector is aligned properly.
  - Start with J3/upper left -TX IF. 5 ground conns ganged together. 1 edge n/c and 1 edge ground.
  - Next is J4/right side - RX IF. 2 ground conns ganged. 2 other ground, 3 edge are n/c.
  - Last is J2/left side – LO. 2 ground conns ganged. 1 edge ground, other edge is MON but “n/c” on schematic.

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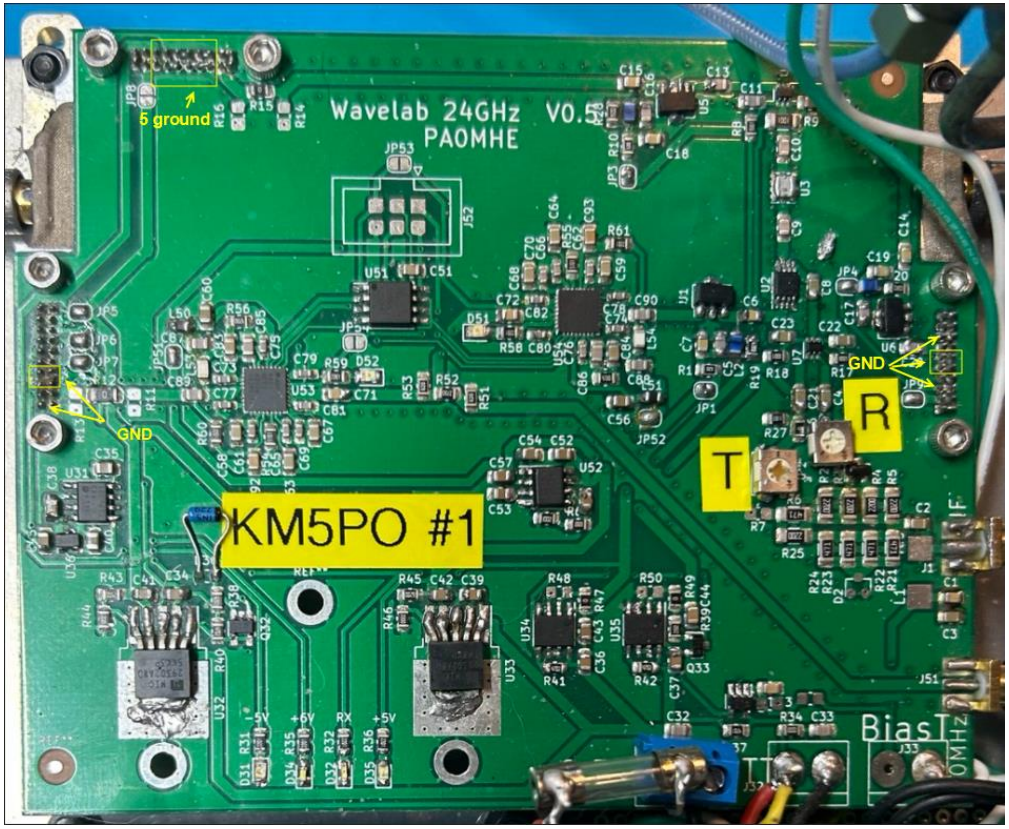
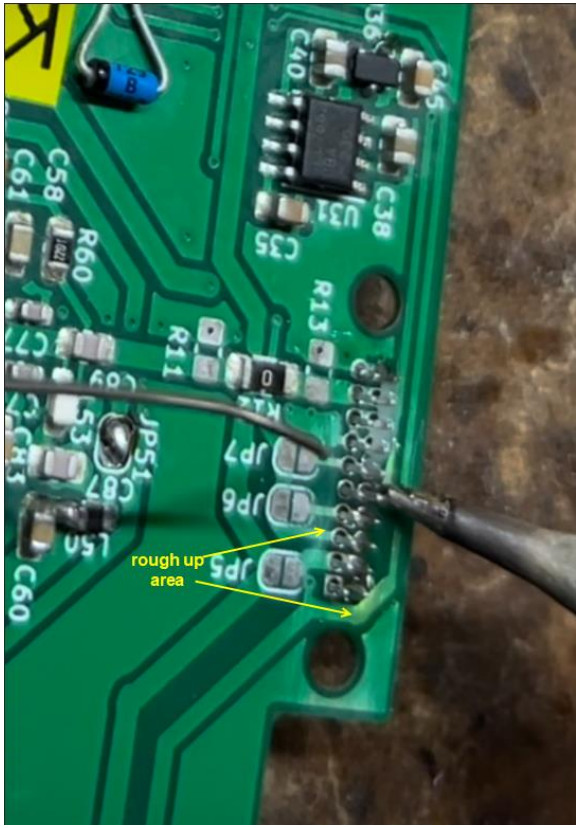
Soldering technique





Inspect solder joints

- Ohm out parts from other connecting parts
  - Filter U3 is easy to short to ground.
    - Through filter resistance is slightly lower than filter in/out ports to ground.
  - L2, L5, L6 – do not overheat. Verify through coil resistance is ~ .27 ohm
    - I pre-tin the pads but do not leave a build up of solder on the pad
  - The mixer sanity checks:
    - *IF port ~ 340 ohms to ground*
    - *RF port 10-14 ohms to ground*
    - *LO port 8-9 ohms to ground*

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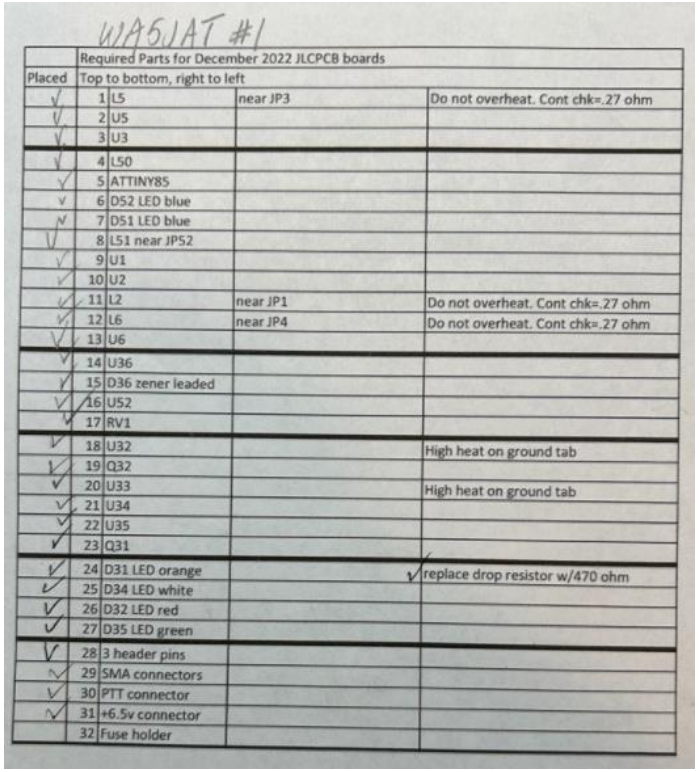
Building tips

- Use a checklist of parts placement
  - For the NTMS December 2022 PCB order, a checklist is available here:
  - Parts detail v5.pdf (ntms.org)



WA5JAT #1

Placed				
	Required Parts for December 2022 JLCPCB boards			
	Top to bottom, right to left			
✓	1	L5	near JP3	Do not overheat. Cont chk=.27 ohm
✓	2	U5		
✓	3	U3		
✓	4	L50		
✓	5	ATTINY85		
✓	6	D52 LED blue		
✓	7	D51 LED blue		
✓	8	L51 near JP52		
✓	9	U1		
✓	10	U2		
✓	11	L2	near JP1	Do not overheat. Cont chk=.27 ohm
✓	12	L6	near JP4	Do not overheat. Cont chk=.27 ohm
✓	13	U6		
✓	14	U36		
✓	15	D36 zener leaded		
✓	16	U52		
✓	17	RV1		
✓	18	U32		High heat on ground tab
✓	19	Q32		
✓	20	U33		High heat on ground tab
✓	21	U34		
✓	22	U35		
✓	23	Q31		
✓	24	D31 LED orange		✓ replace drop resistor w/470 ohm
✓	25	D34 LED white		
✓	26	D32 LED red		
✓	27	D35 LED green		
✓	28	3 header pins		
✓	29	SMA connectors		
✓	30	PTT connector		
✓	31	+6.5v connector		
	32	Fuse holder		

W5HN

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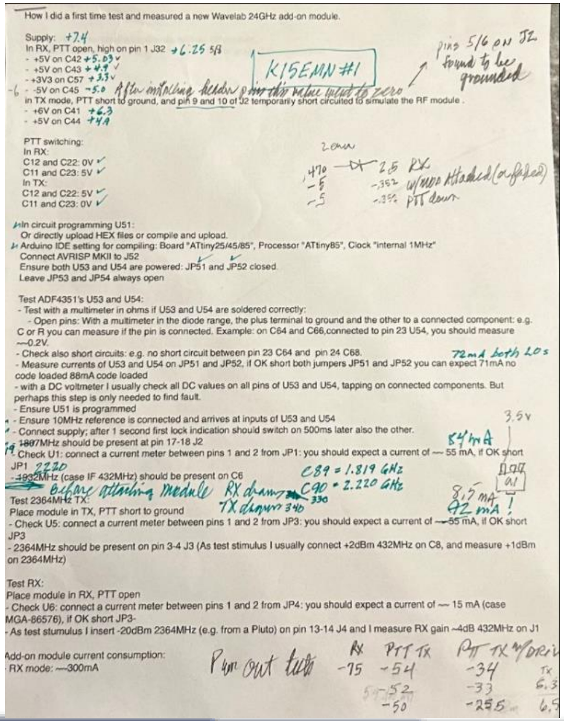
Building tips

- Use a checklist for initial checkout
  - Test sequence from Maarten/PA0MHE and modified for NTMS PCB with substituted parts is here:
  - https://ntms.org/files/Feb2023/Wavelab power up testing.pdf



24 GHz PA0HME checklist for testing PCB. Modifications by KM5PO .

How I did a first time test and measured a new Wavelab 24GHz add-on module.

I use a step by step approach:
- The pinstrips J2, J3 and J4 I only mount afterwards.
- Optically check if everything is present and well soldered.

Supply: (KM5PO- My supply was set t 6.8v)
In RX, PTT open, high on pin 1 J32
- +5V on C42
- +5V on C43
- +3V3 on C57
- -5V on C45

in TX mode, PTT short to ground, and pin 9 and 10 of J2 temporarily short circuited to simulate the RF module .
- +6V on C41
- +5V on C44

PTT switching:
In RX:
C12 and C22: 0V
C11 and C23: 5V
In TX:
C12 and C22: 5V
C11 and C23: 0V

In circuit programming U51:
Or directly upload HEX files or compile and upload.
Arduino IDE setting for compiling: Board "ATtiny25/45/85", Processor "ATtiny85", Clock "internal 1MHz"
Connect AVRISP MKII to J52
Ensure both U53 and U54 are powered: JP51 and JP52 closed. (KM5PO: measure current across these two jumpers first – see below – then close jumpers)
Leave JP53 and JP54 always open

Test ADF4351's U53 and U54:
- Test with a multimeter in ohms if U53 and U54 are soldered correctly:
  - Open pins: With a multimeter in the diode range, the plus terminal to ground and the other to a connected component: e.g. C or R you can measure if the pin is connected. Example: on C64 and C66, connected to pin 23 U54, you should measure ~~0.2V.
- Check also short circuits: e.g. no short circuit between pin 23 C64 and pin 24 C68.
- Measure currents of U53 and U54 on JP51 and JP52, if OK short both jumpers JP51 and JP52 you can expect 71mA no code loaded 88mA code loaded (KM5PO: all units have measured 73-75 mA code loaded)
- with a DC voltmeter I usually check all DC values on all pins of U53 and U54, tapping on connected components. But perhaps this step is only needed to find fault.
- Ensure U51 is programmed
- Ensure 10MHz reference is connected and arrives at inputs of U53 and U54

- Connect supply; after 1 second first lock indication should switch on 500ms later also the other.
- 1807MHz should be present at pin 17-18 J2 (KM5PO: for U.S. Terrestrial use this should be 1819 MHz)
- Check U1: connect a current meter between pins 1 and 2 from JP1: you should expect a current of ~~ 55 mA, if OK short JP1 (KM5PO: expect ~ 80 mA due to substituted part)
- 1932MHz (case IF 432MHz) should be present on C6 (KM5PO: 2220 MHz case IF 144 MHz)

Test 2364MHz TX:
Place module in TX, PTT short to ground (KM5PO: apply <= 1 watt 144 MHz IF drive at J1 or inject +5 dBm at C8 note: TX IF attenuation pot is at minimum value fully CCW and placed resistors on pad make up 20 dB of attenuation from J1)
- Check U5: connect a current meter between pins 1 and 2 from JP3: you should expect a current of ~~ 55 mA, if OK short JP3 (KM5PO: expect ~ 80 mA due to substituted part)
- 2364MHz should be present on pin 3-4 J3 (As test stimulus I usually connect +2dBm 432MHz on C8, and measure +1dBm on 2364MHz) (KM5PO: with drive supplied as noted above, expect ~+5 to +8 dBm 2364 MHz on pin 3-4 J3)

Test RX:
Place module in RX, PTT open
- Check U6: connect a current meter between pins 1 and 2 from JP4: you should expect a current of ~~ 15 mA (case MGA-86576), if OK short JP3 (KM5PO: expect ~85-90 mA due to substituted part)
- As test stimulus I insert -20dBm 2364MHz (e.g. from a Pluto) on pin 13-14 J4 and I measure RX gain ~4dB 432MHz on J1 (KM5PO: inject -20 dBm 2364 MHz on C20 and measure RX 144 MHz output -28dBm at J1 also 2nd test: inject DigiLO 24192.1 harmonic into wavelab module RX port and measure -46 dBm 2364 MHz on C20 and measure -40 dBm 144 MHz at C8)

Add-on module current consumption:
- RX mode: ~~300mA
- TX mode: ~~335mA

Finally I mount the pinstrips and mate with the RF module.
Then step by step I verify the currents via the solder jumpers and close them.

KM5PO: Fully assembled PCB board to module current consumption:
RX mode:
TX mode:

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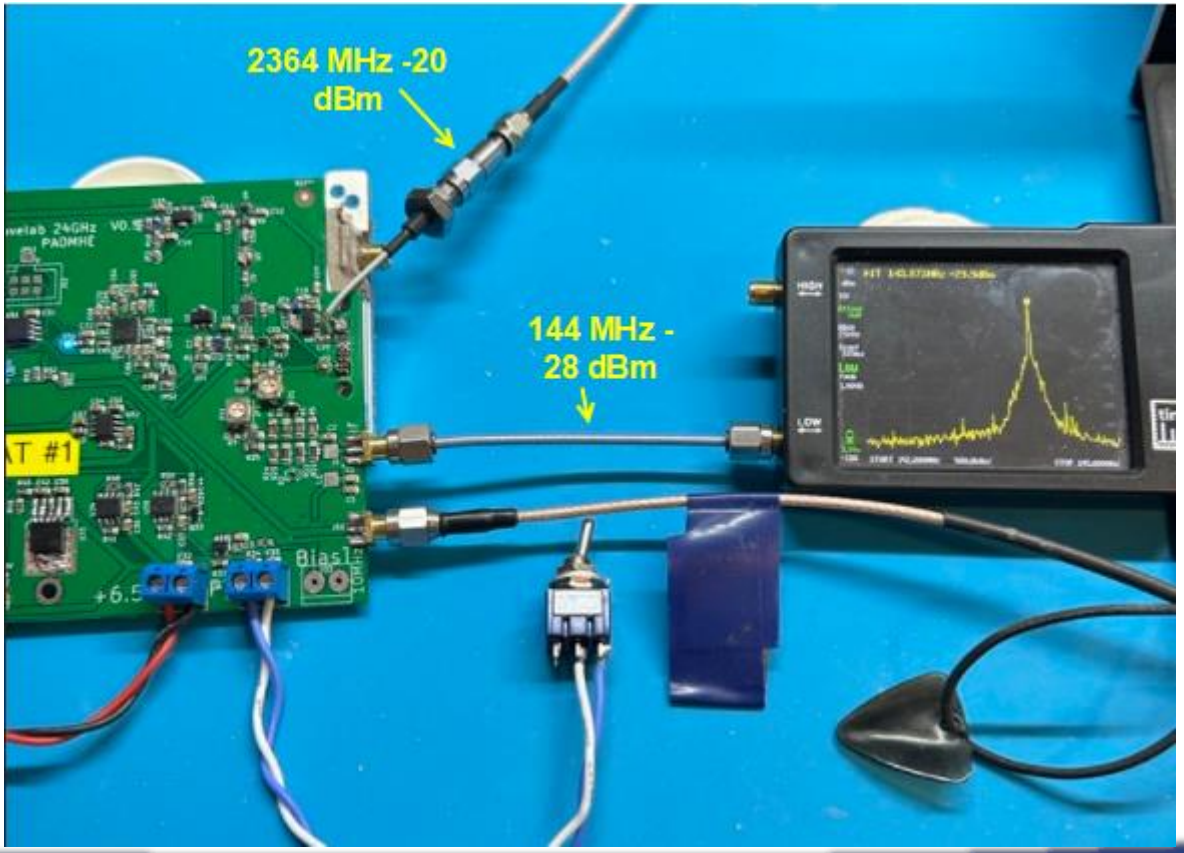
Building tips

- Use a checklist for initial checkout
  - https://ntms.org/files/Feb2023/Wavelab power up testing.pdf



Building tips

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- DC power reversal
  - Hook up the input DC power backwards and expect to replace:
  - U31 – Charge pump voltage inverter
  - U34 – LDO voltage regulator
  - U35 – LDO voltage regulator
  - Many ways to prevent this but at minimum install a 3 A fast blow fuse on +6.5 V line.
- D31 LED (- 5 V sense) place Anode on ground pad!
  - Opposite of the other three voltage sense LEDs…
- Even though LO synth LED “lock” lights up, if you see a big signal ~ 750 Mhz at LO #1 output (*should be 1819 MHz*) then you do not have 10 MHz ref lock.
  - Correct behavior of LO lock LEDs at power on is 1819 MHz lights first (left side of board), then 2220 MHz one second later.
  - I used 15 dBm reference in the shop for initial testing of the PCB boards.
  - Final build used McCoy OCXO with 13 dBm output + 3 dB attenuator ahead of ref input.

Building tips

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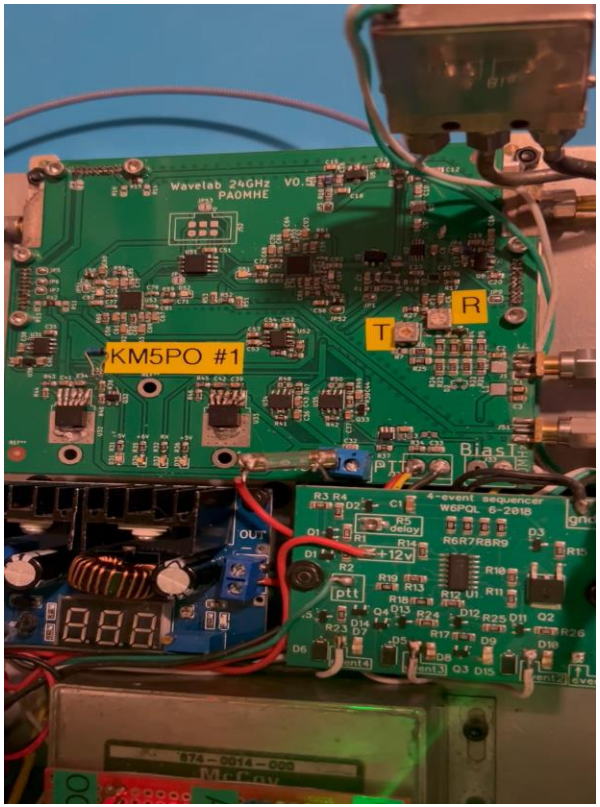
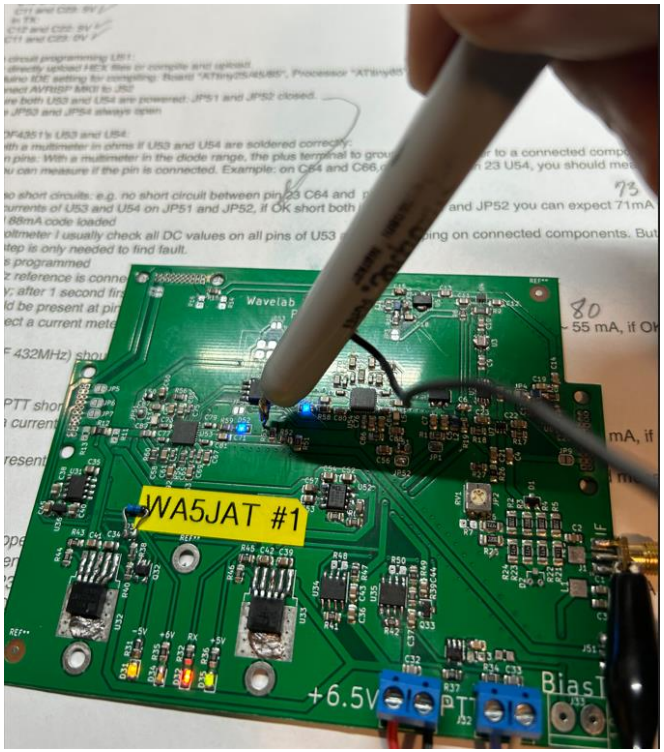
- Correct behavior of LO lock LEDs at power on is 1819 MHz lights first (left side of board), then 2220 MHz one second later.



Building tips

- Placing a probe between the LO LEDs will sample both LO frequencies



Building tips

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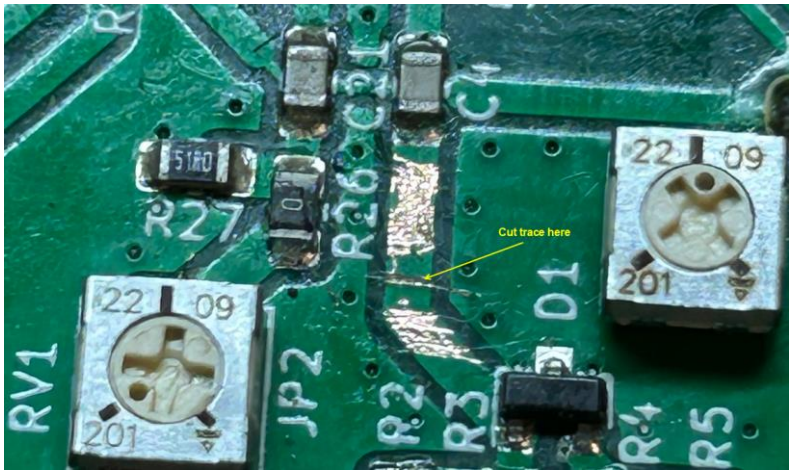
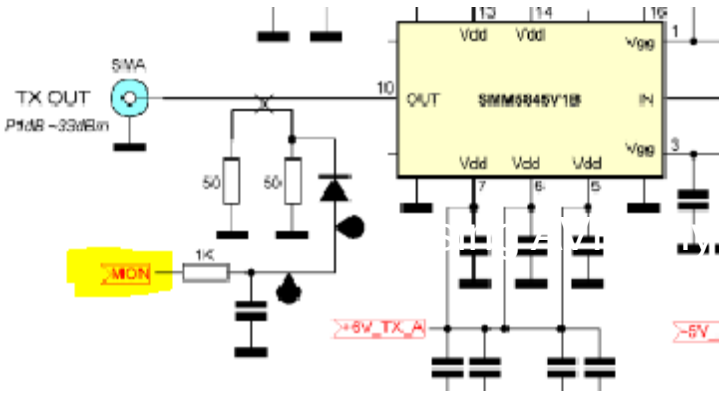
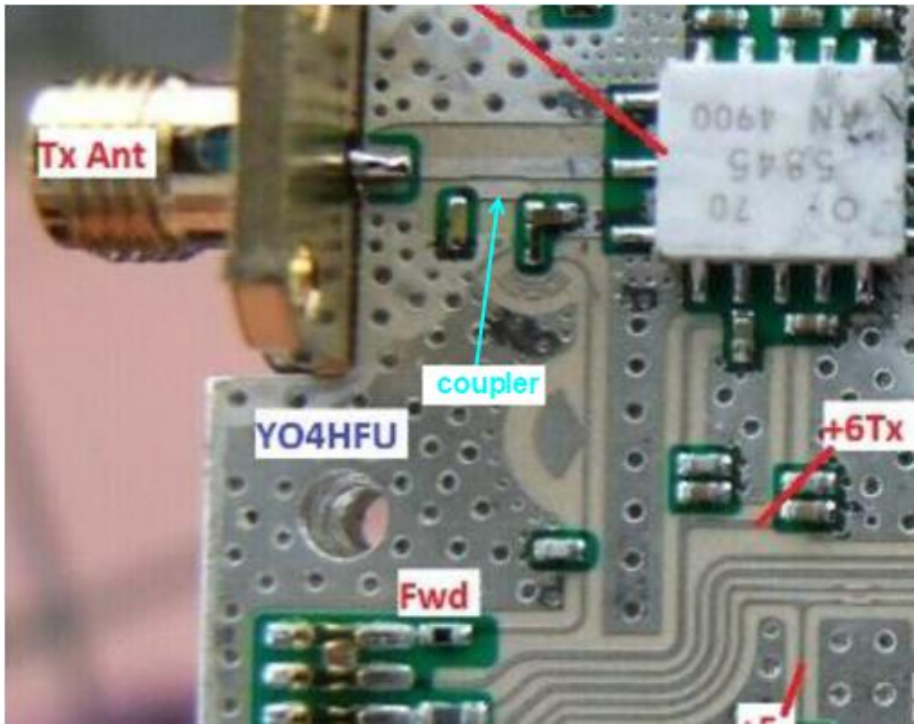
If you want to add receive side IF attenuation prepare the trace below C4



Monitor port

- Mon(itor) port





Measure varies from -.5 to -3.5v (J2 pin 1)

Program ATTINY

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- Arduino sketch is on GitHub
  - Wavelab-24G-Addon-module/ADF4351_fixed_tiny_24GHz.ino at main · PA0MHE/Wavelab-24G-Addon-module · GitHub
  - Arduino integrated development environment needed (Free)
- Use Arduino IDE to burn bootloader to Uno and then upload Wavelab sketch to ATTINY
  - Uno required, breadboards, patch wiring
  - Program an ATtiny With Arduino : 7 Steps (with Pictures) - Instructables
- Use sparkfun “AVR tiny programmer” and SOIC chip holder, install drivers, upload Wavelab sketch directly to ATTINY
  - This will be explained in the following slides

Programming tools

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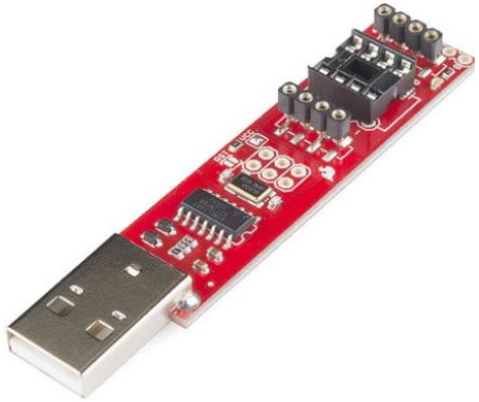
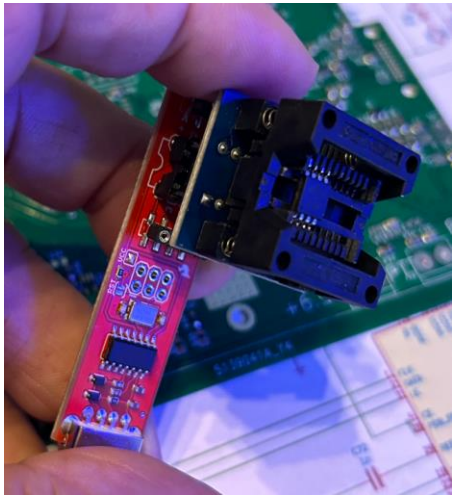
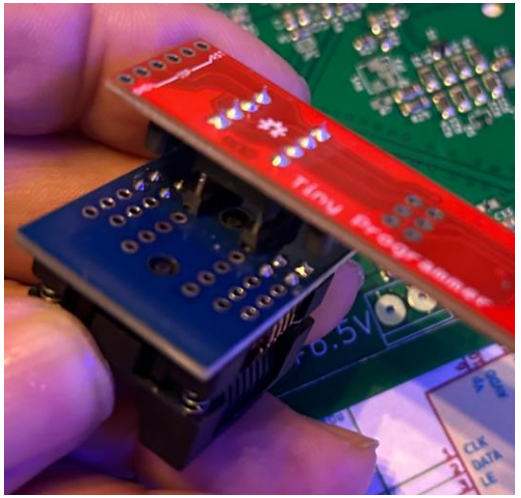
- Using AVR tiny programmer (windows)
  - Plug the programmer into your USB
  - If drivers are not found then download Zadig USBTiny drivers
  - Ref:https://learn.sparkfun.com/tutorials/tiny-avr-programmer-hookup-guide/all
  - Download the ATTINY addon to your Arduino IDE from GitHub
  - Configure IDE to use ATTINY85 (internal 1 MHz clock)
    - *Tools>Board>ATtiny85 (internal 1 MHz clock)*
  - Configure IDE to use ATTINY85 processor
    - *Tools>Processor>ATTINY85*
  - Configure IDE to use programmer USBtinyISP
    - *Tools>Programmer>USBtinyISP*
  - Plug in the ATTINY
  - Upload the code. (Use a blink sample sketch if you want to test 1st time)

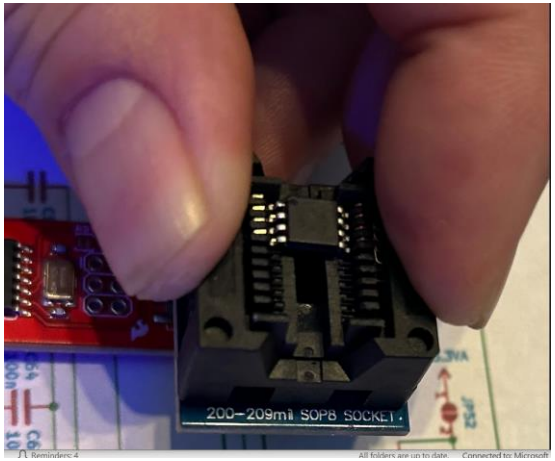
Programming tools







- On Amazon
  - AVR Tiny Programmer
  - SOIC8 SOP8 to DIP8 IC Programmer Socket Converter (verify the device will handle 200+ mil sizing)



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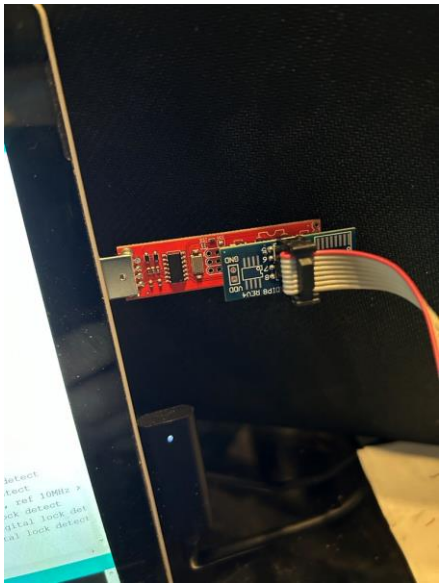
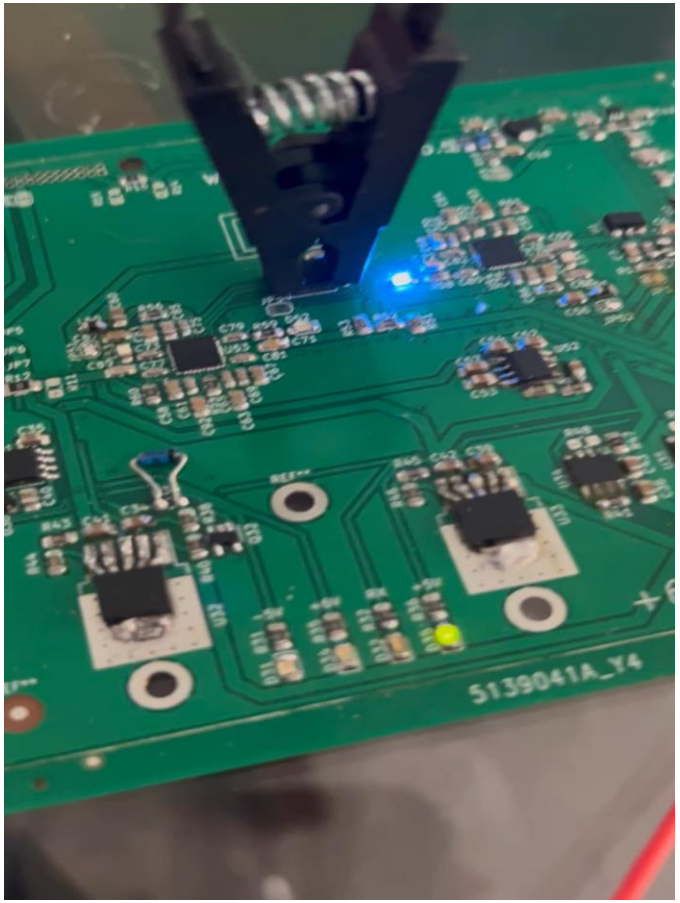
In circuit programmer (clip)





- I use the TinyProgrammer and plug in a cable with clip.
- Red wire in cable orients to pin 1 of the on-board chip to be programmed.

Video: +5v LED lights, #2 LO blinks, #1 LO blinks, then pause and #2 LO steady on.

LO frequencies

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- The plan to put the module on USA terrestrial 24192 MHz

Synthesizer 1 ADF 1	1819 MHz	x 12 mult	21828 MHz	
Synthesizer 2 ADF 2	2220 MHz		2220 MHz	
			24048 MHz	
			144 MHz	IF
			24192 MHz	Final

- For 144 MHz IF use the reg1 & reg2 lines below highlighted and comment out all others.

```
23    uint32_t reg1[6] =  {0x5A0038, 0x8008051, 0x1A004E42, 0x4B3, 0x9A003C, 0x580005} ; // 1807MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
24  + //uint32_t reg1[6] =  {0x5A8048, 0x8008051, 0x1A004E42, 0x4B3, 0x9A003C, 0x580005} ; // 1819MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
25    //uint32_t reg2[6] =  {0x378000, 0x8008011, 0x1A004E42, 0x4B3, 0x8A003C, 0x580005} ; // 2m, 2220MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
26  + //uint32_t reg2[6] =  { 0x600018, 0x8008029, 0x1A004E42, 0x4B3, 0x9A003C, 0x580005 } ; //438MHz, 1926MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
27    uint32_t reg2[6] =  {0x608008, 0x8008029, 0x1A004E42, 0x4B3, 0x9A003C, 0x580005} ; // 70cm, 1932MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
```

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LO frequencies

- Pertinent register values are the first two hex strings

```
23    uint32_t reg1[6] =  {0x5A0038, 0x8008051, 0x1A004E42, 0x4B3, 0x9A003C, 0x580005} ; // 1807MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
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27    uint32_t reg2[6] =  {0x608008, 0x8008029, 0x1A004E42, 0x4B3, 0x9A003C, 0x580005} ; // 70cm, 1932MHz, ref 10MHz x2, 5dBm, Muxout: digital lock detect
```

Reg 1 will control Integer and Fractional values

Enter hex number: 5A8048 (16)

= Convert | × Reset | ⇅ Swap

Binary number: 01011010100000001001000 (2)

Reg 2 controls Phase adjust, prescaler (8/9), Modulus value

Enter hex number: 8008051 (16)

= Convert | × Reset | ⇅ Swap

Binary number: 10000000000010000000001010001 (2)

ADF4351 Data Sheet

REGISTER MAPS

INTEGER REGISTER 0 **FRACTION**

RESERVED	Dec: 181 — 16-BIT INTEGER VALUE (INT)																Dec: 009 — 12-BIT FRACTIONAL VALUE (FRAC)												CONTROL BITS		
0 1 0 1 1 0 1 0 1																	0 0 0 0 0 0 0 0 1 0 0 1												0 0 0		
DB31	DB30	DB29	DB28	DB27	DB26	DB25	DB24	DB23	DB22	DB21	DB20	DB19	DB18	DB17	DB16	DB15	DB14	DB13	DB12	DB11	DB10	DB9	DB8	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	N16	N15	N14	N13	N12	N11	N10	N9	N8	N7	N6	N5	N4	N3	N2	N1	F12	F11	F10	F9	F8	F7	F6	F5	F4	F3	F2	F1	C3(0)	C2(0)	C1(0)

LO frequencies

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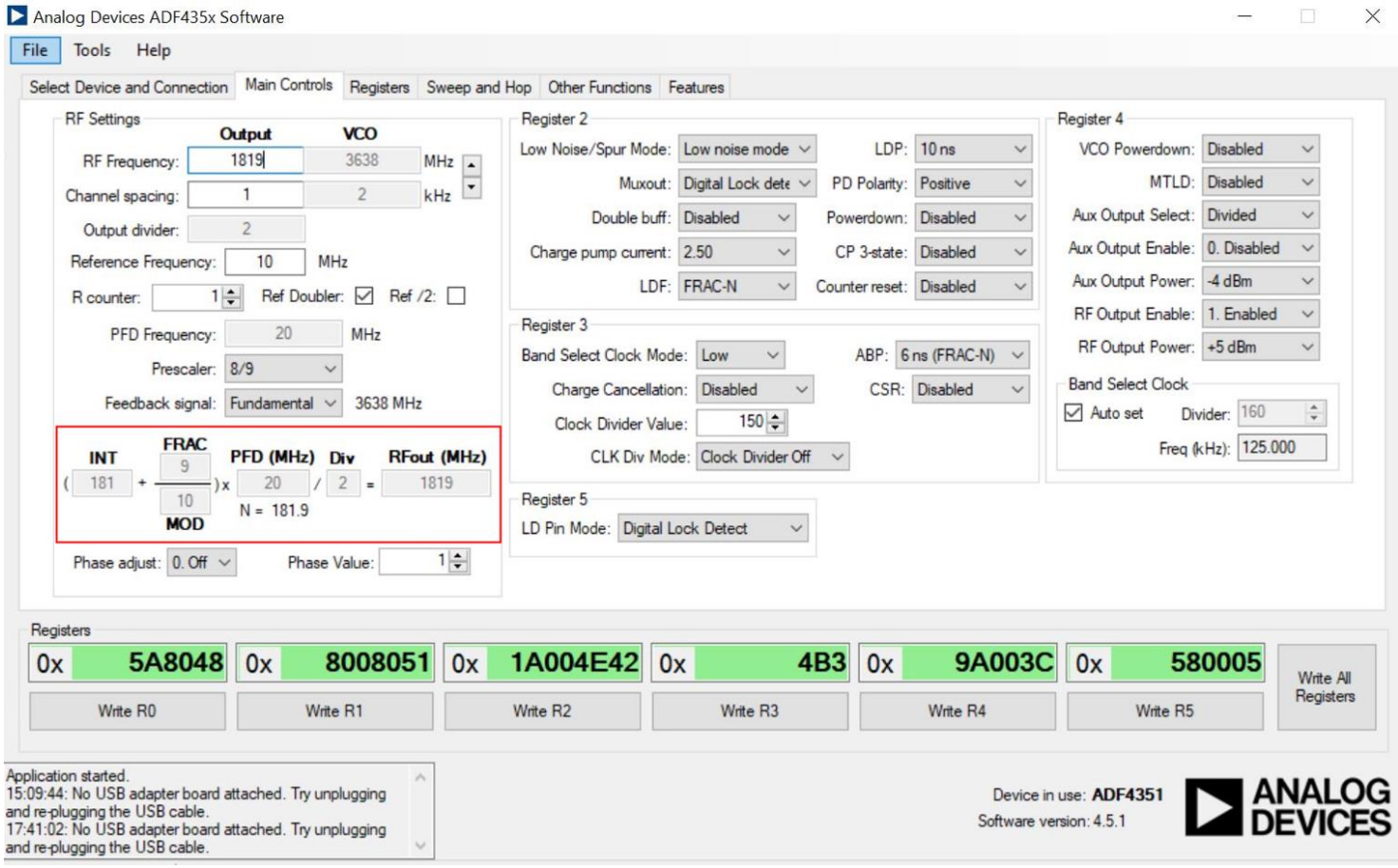
- There's an app for that!!



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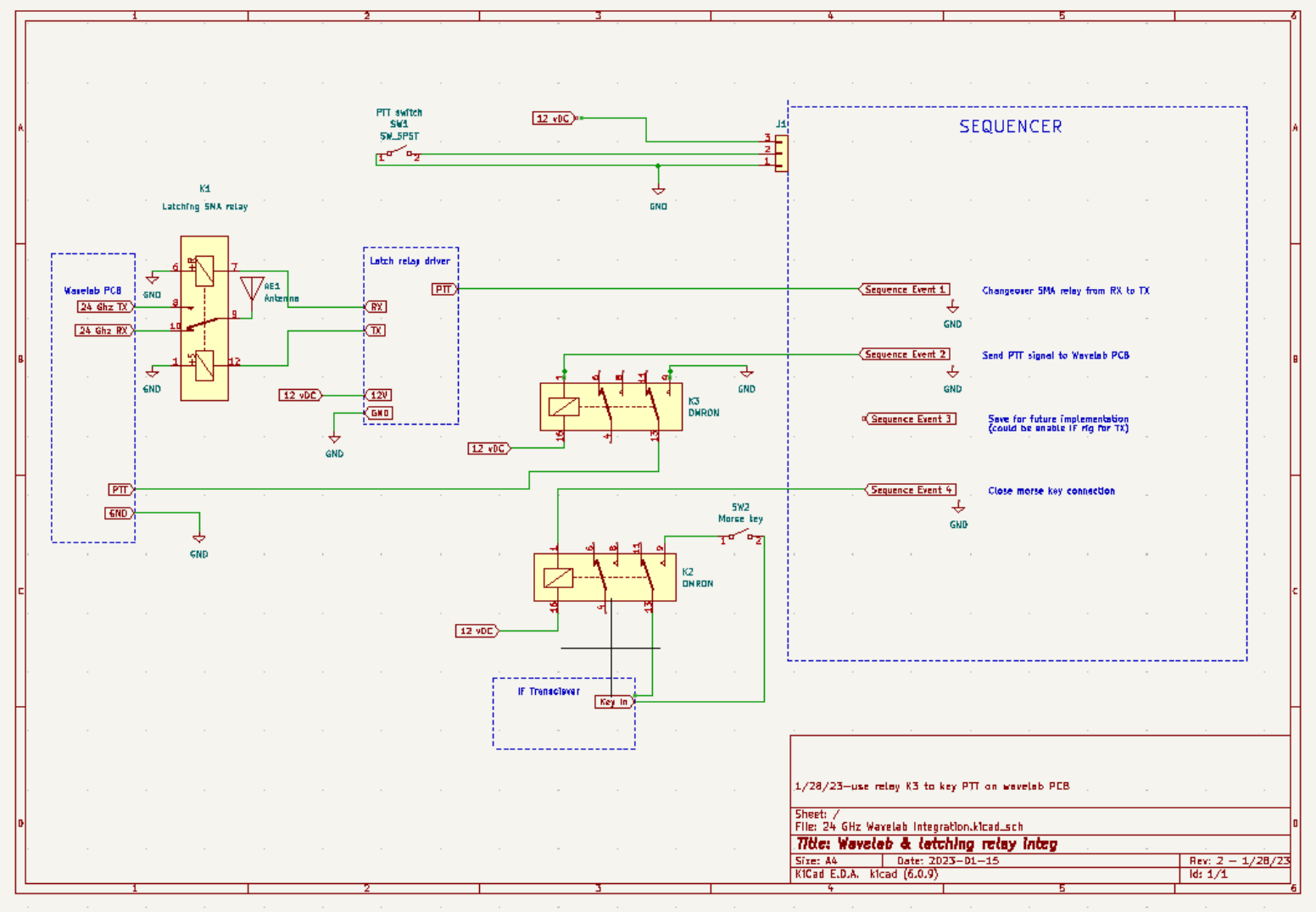
Integration



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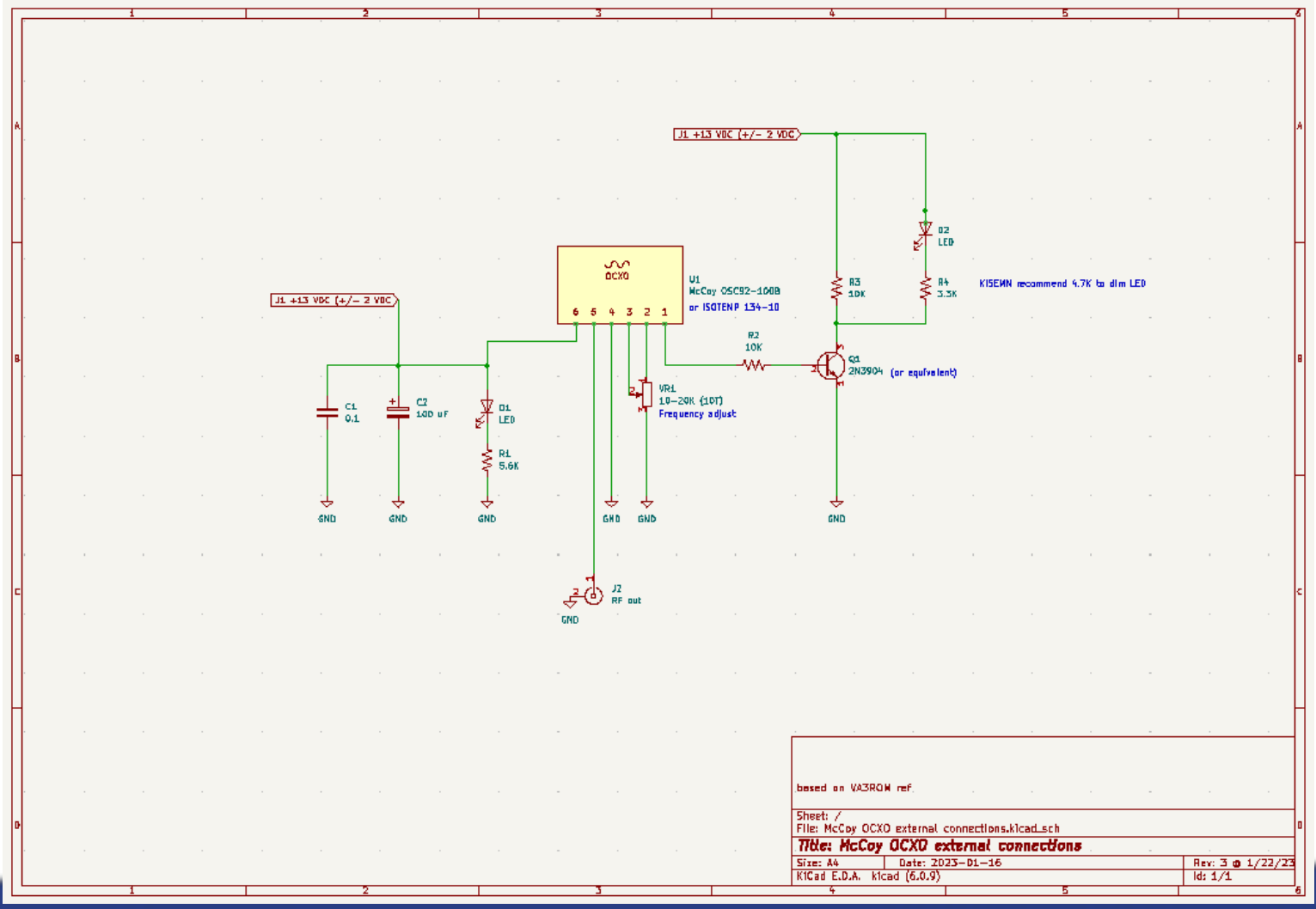
OCXO



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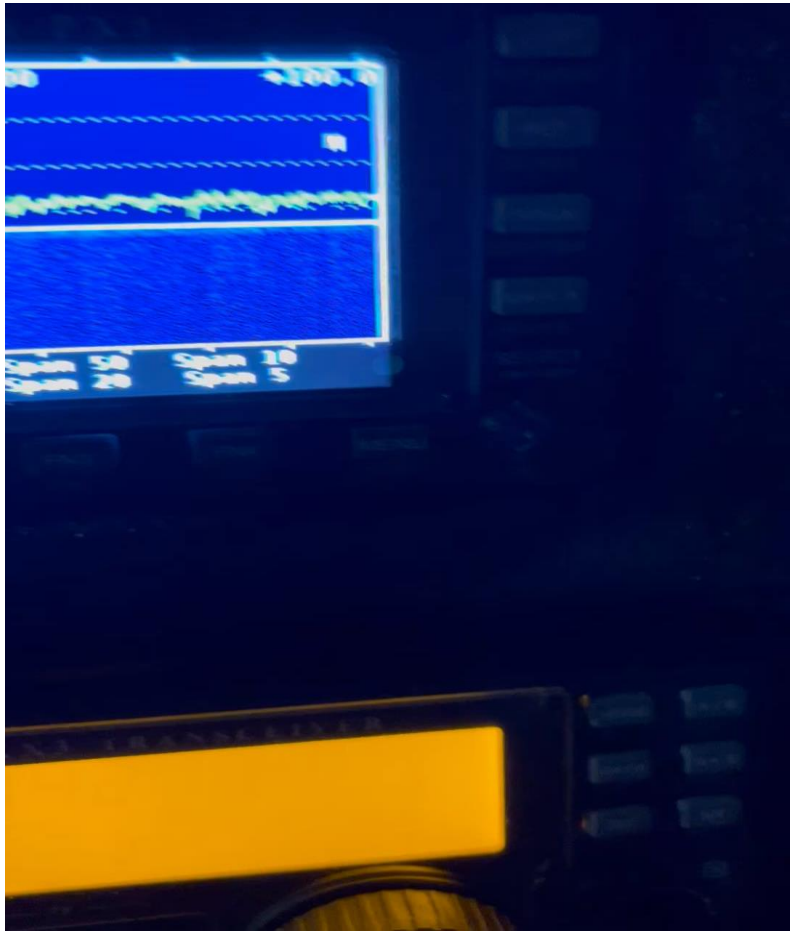
High Hawk proving ground – Feb 3, 2023



WA5JAT unit

- Passes all tests and measured +32 dBm output

KI5EMN unit

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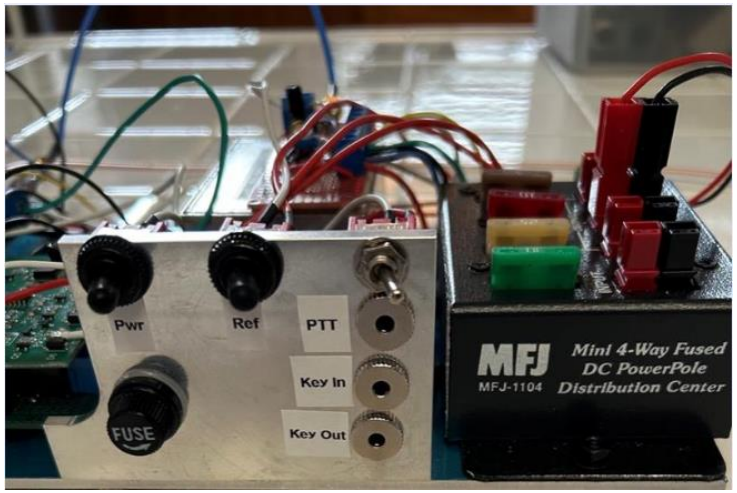

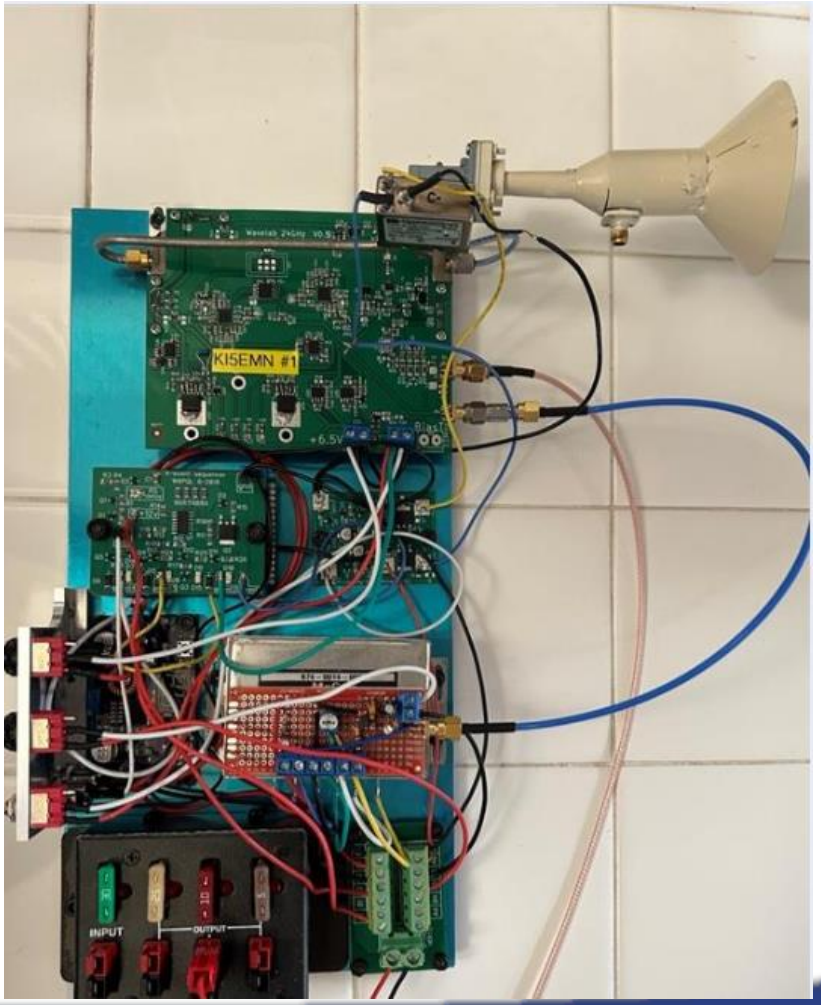

Uses latching relay driver with SMA latching relay

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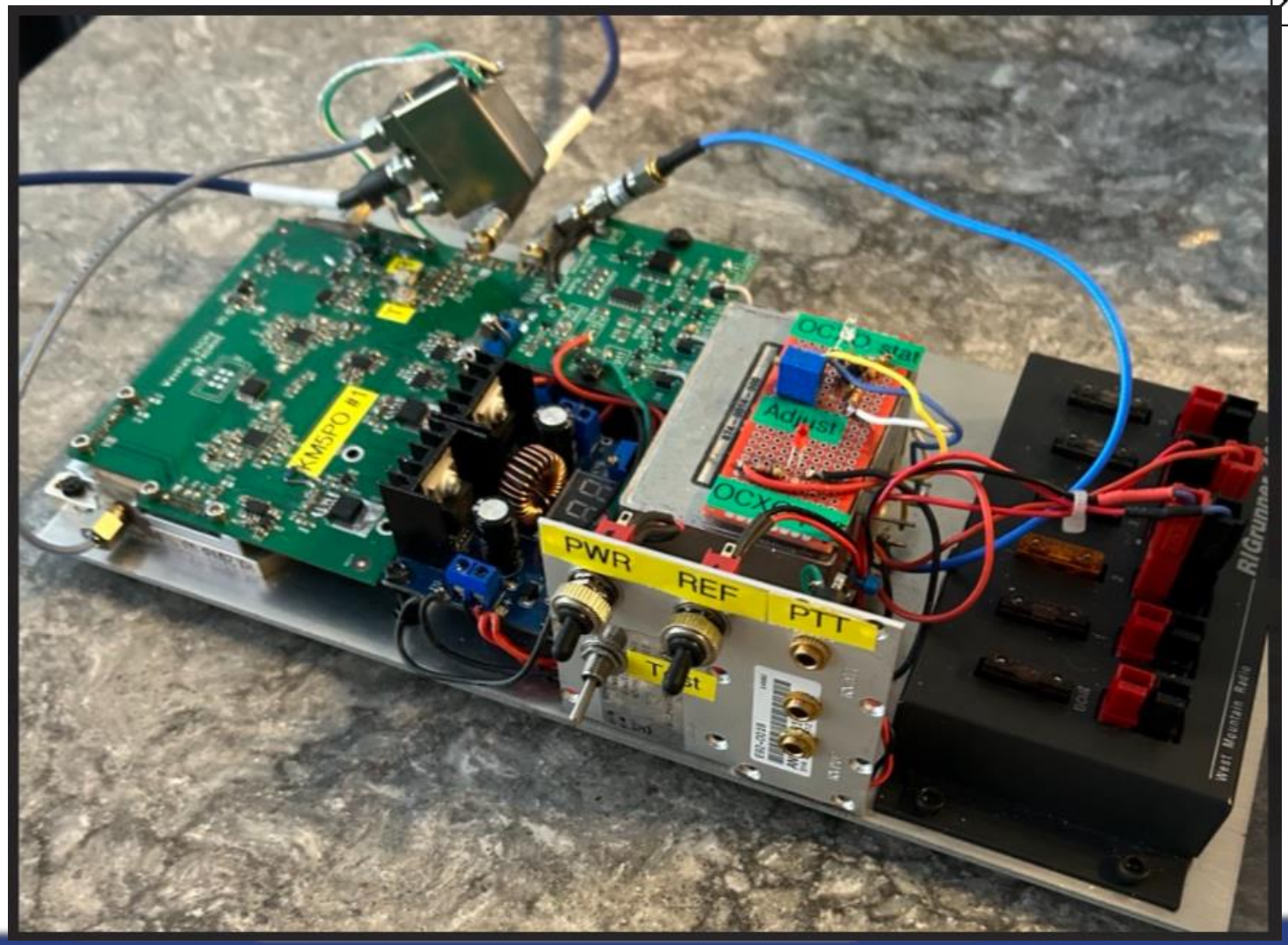
KM5PO unit



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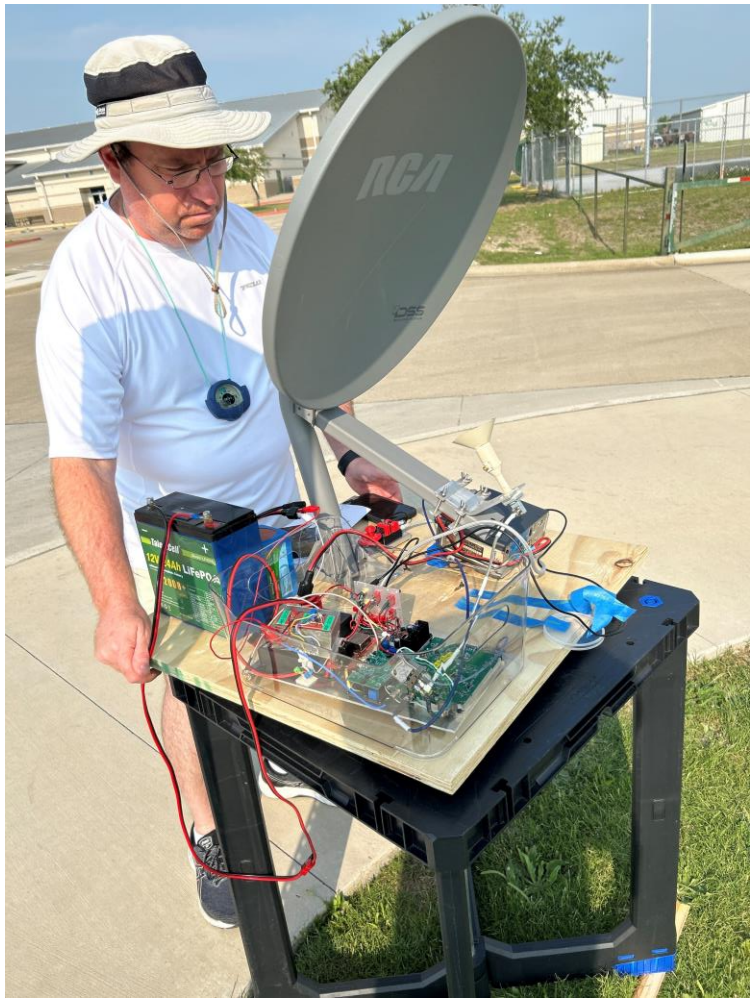
KI5EMN – Blue Ridge, Texas

- Recent on-the-air operation – NTMS MAD May 21, 2023



- Wavelab, PA0MHE add-on board, 18” dish.
- 30 km 599 contacts

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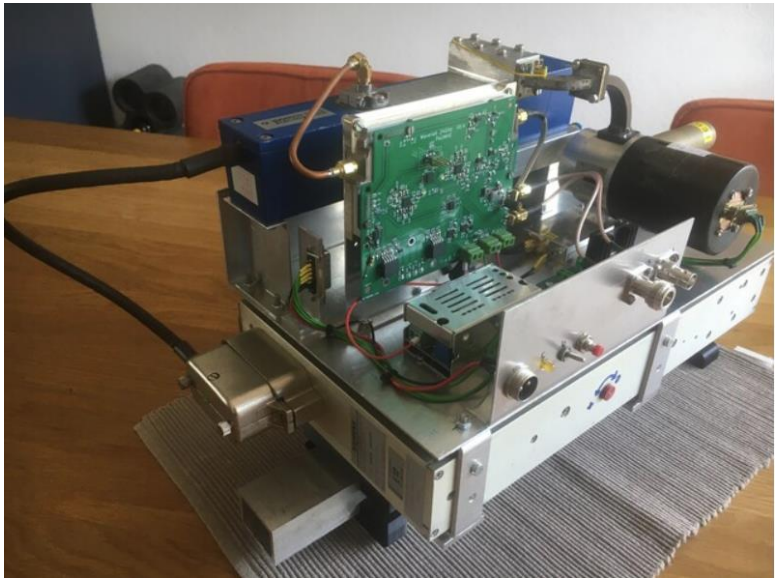
Wavelab 24 GHz EME

May 18, 2023- Hans PE1CKK worked PA0BAT via EME

- Wavelab with PA0MHE addon board
- RW1127 TWT 30W converted to 24G
- DU3T preamp nf 1dB
- WG switch
- Dualmode feedhorn calculated for f/D 0,8
- 1.8m Prodelin offest dish



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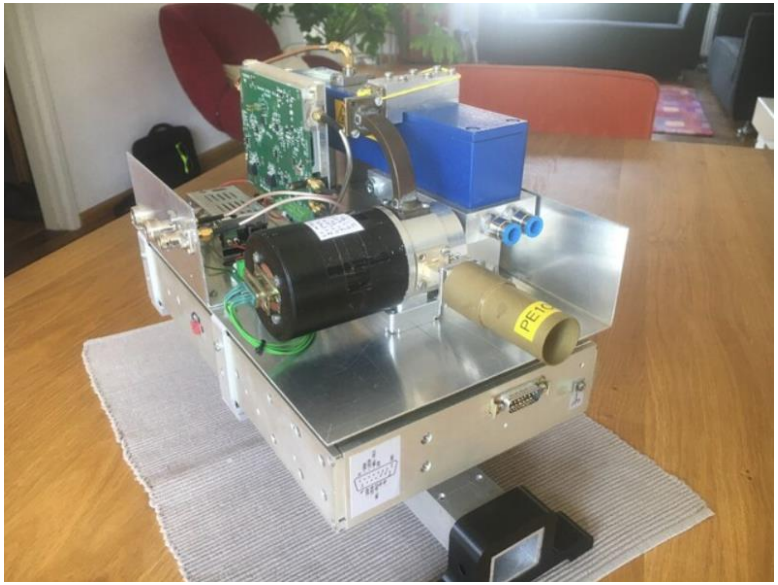
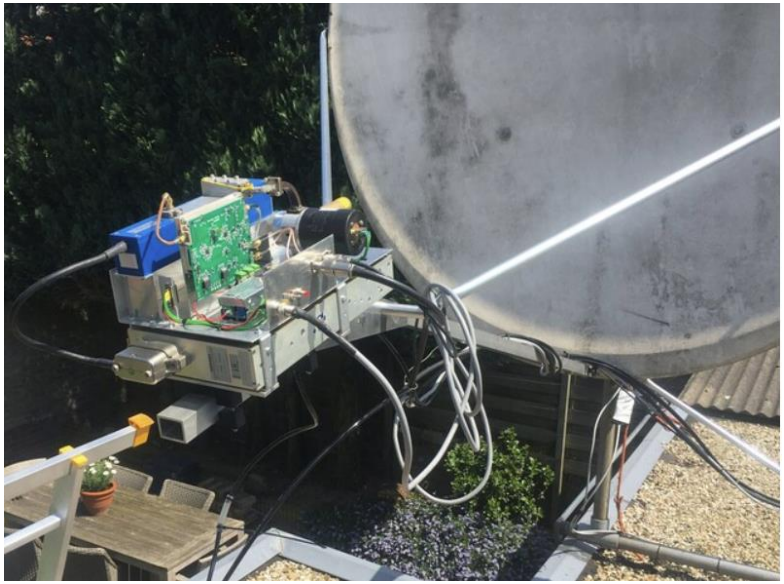
Wavelab 24 GHz EME

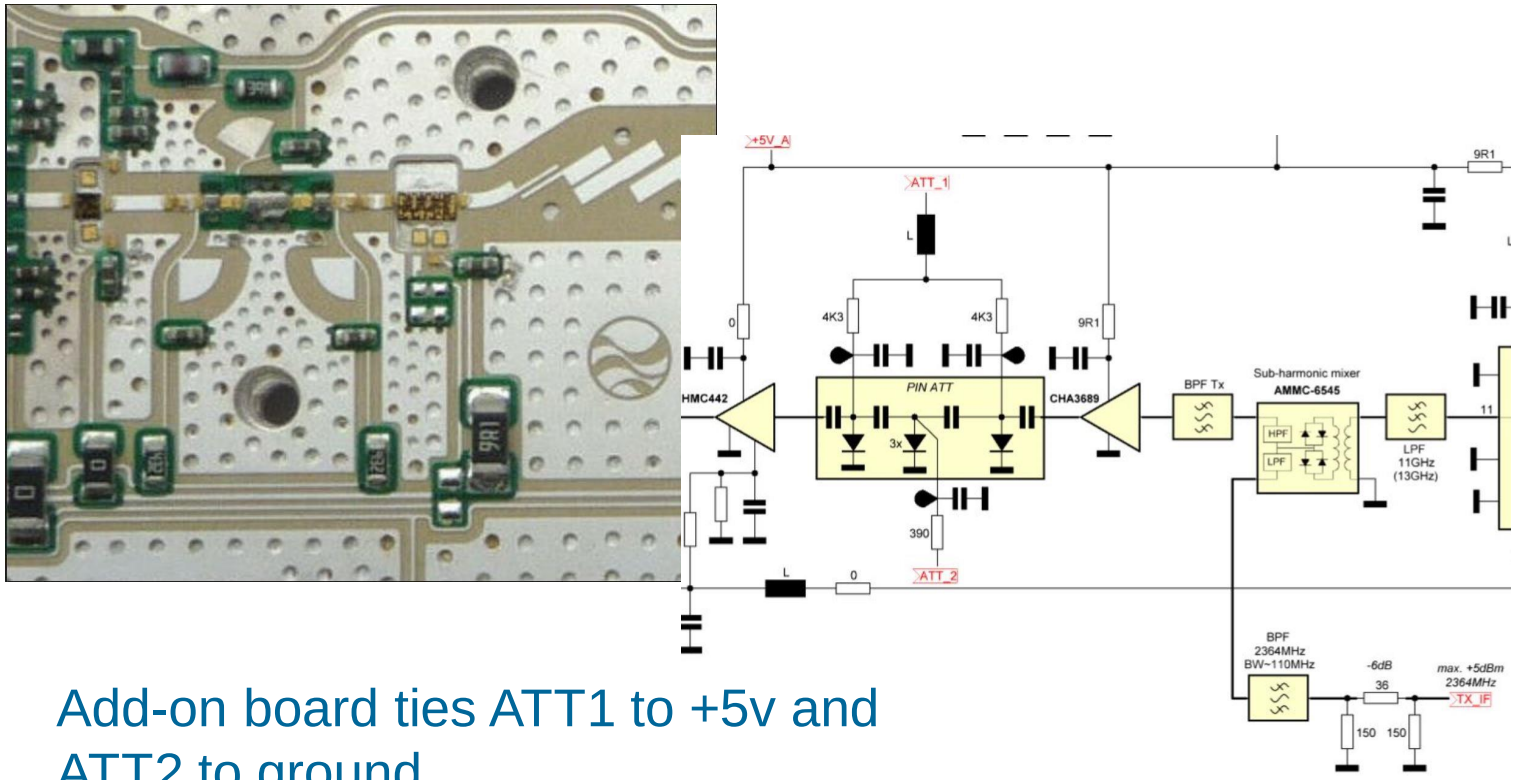
May 18, 2023- Hans PE1CKK worked PA0BAT via EME





Improving RF output

- Recall previous discussions around module-based PIN attenuator



Add-on board ties ATT1 to +5v and ATT2 to ground

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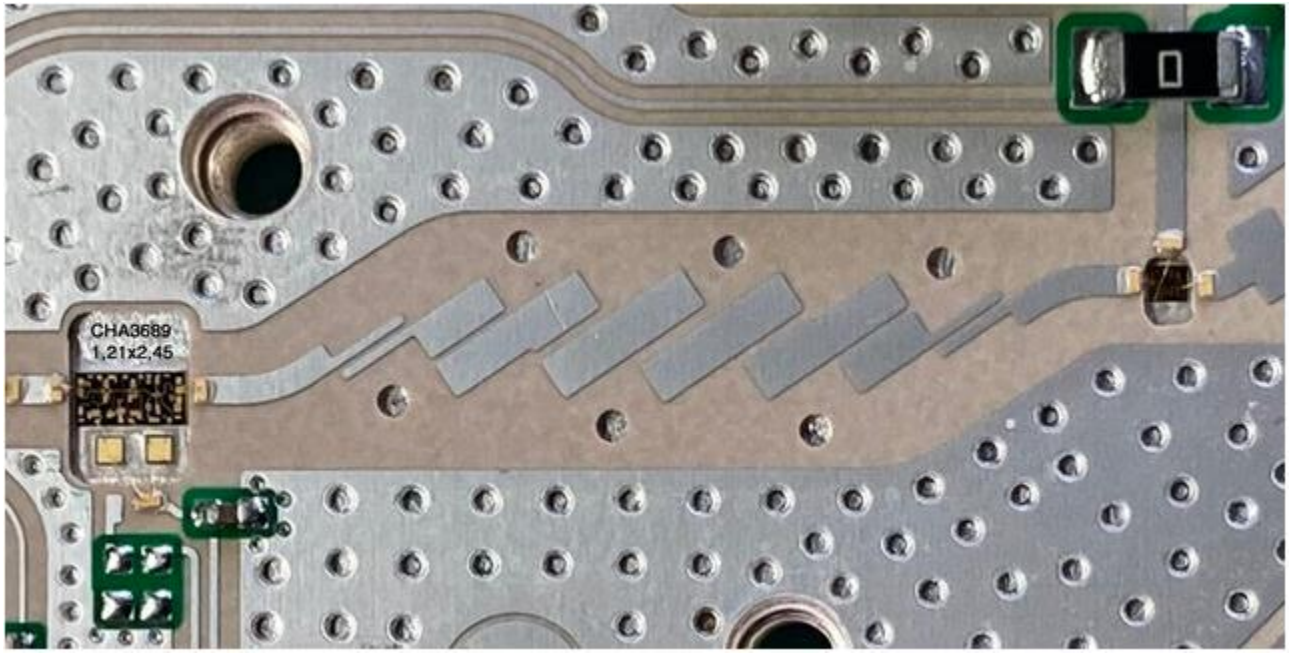
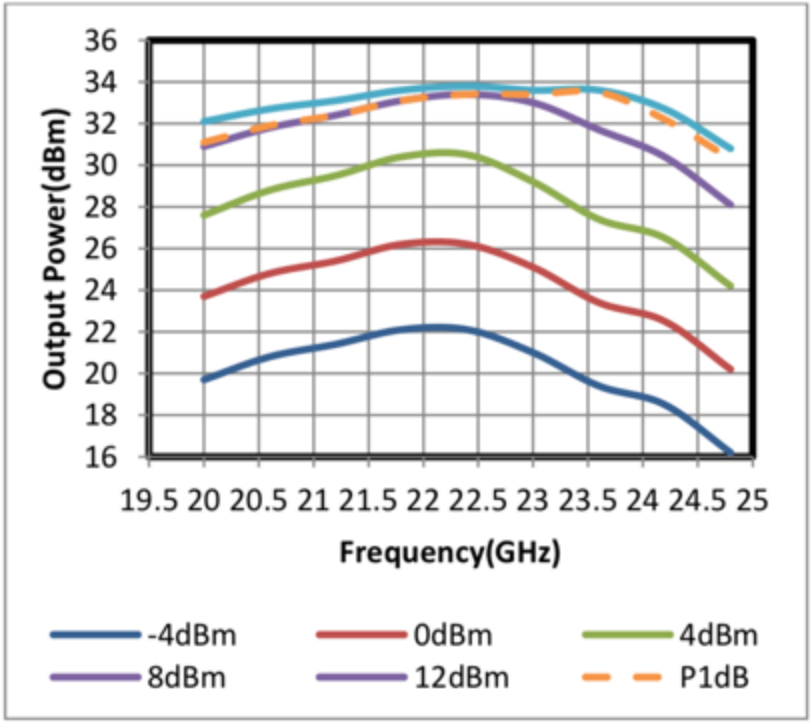
Inside the module



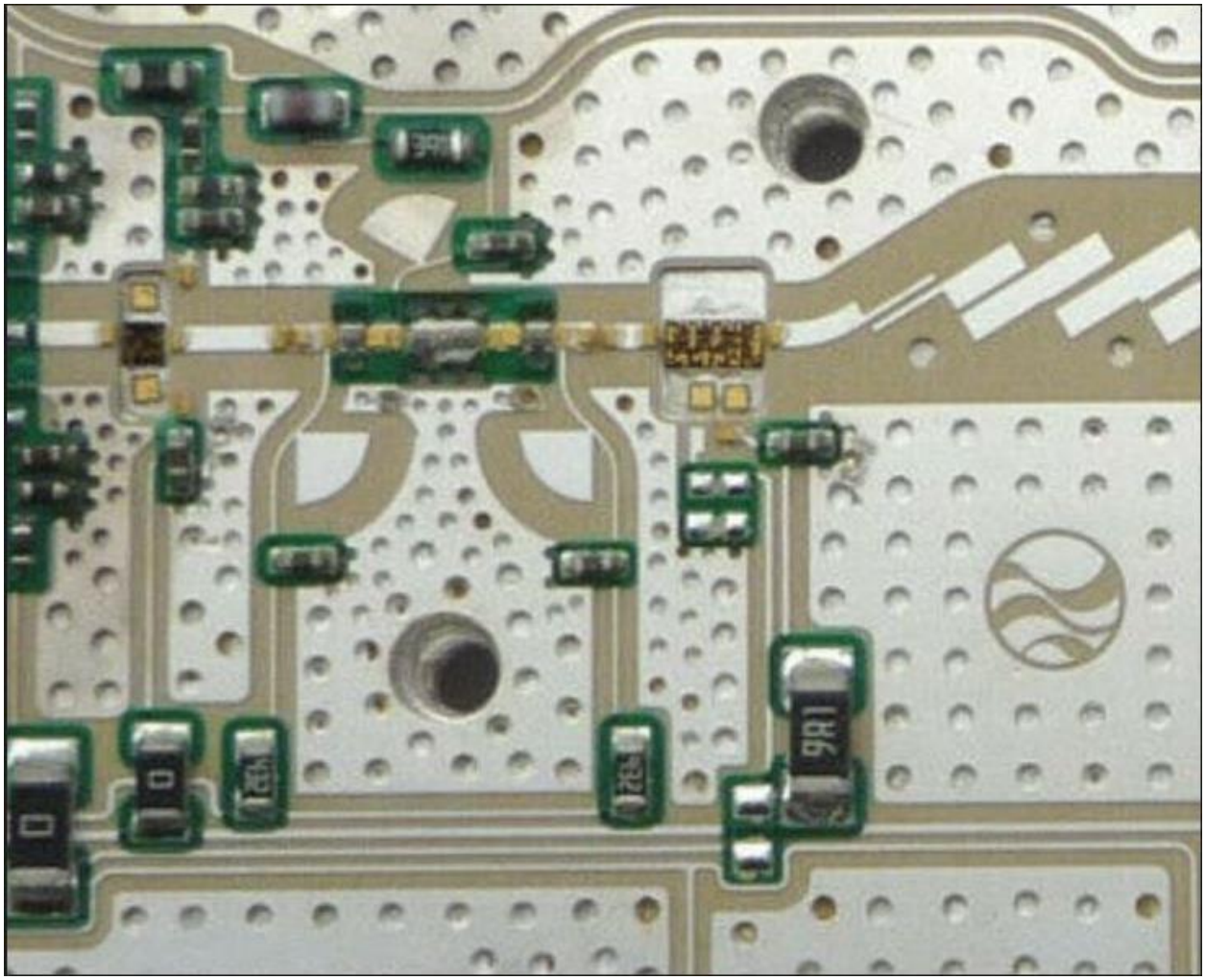
12x1700+2364=22764		Ref
12x1633+2364=21960	down 804	-3db
12x1774+2364=23652	up 888	-3db
12x1807+2364=24048	up 1284	-6db

SMM5845

Output Power vs. Frequency
VDD=6V, IDD(DC)=1400mA



PIN attenuator



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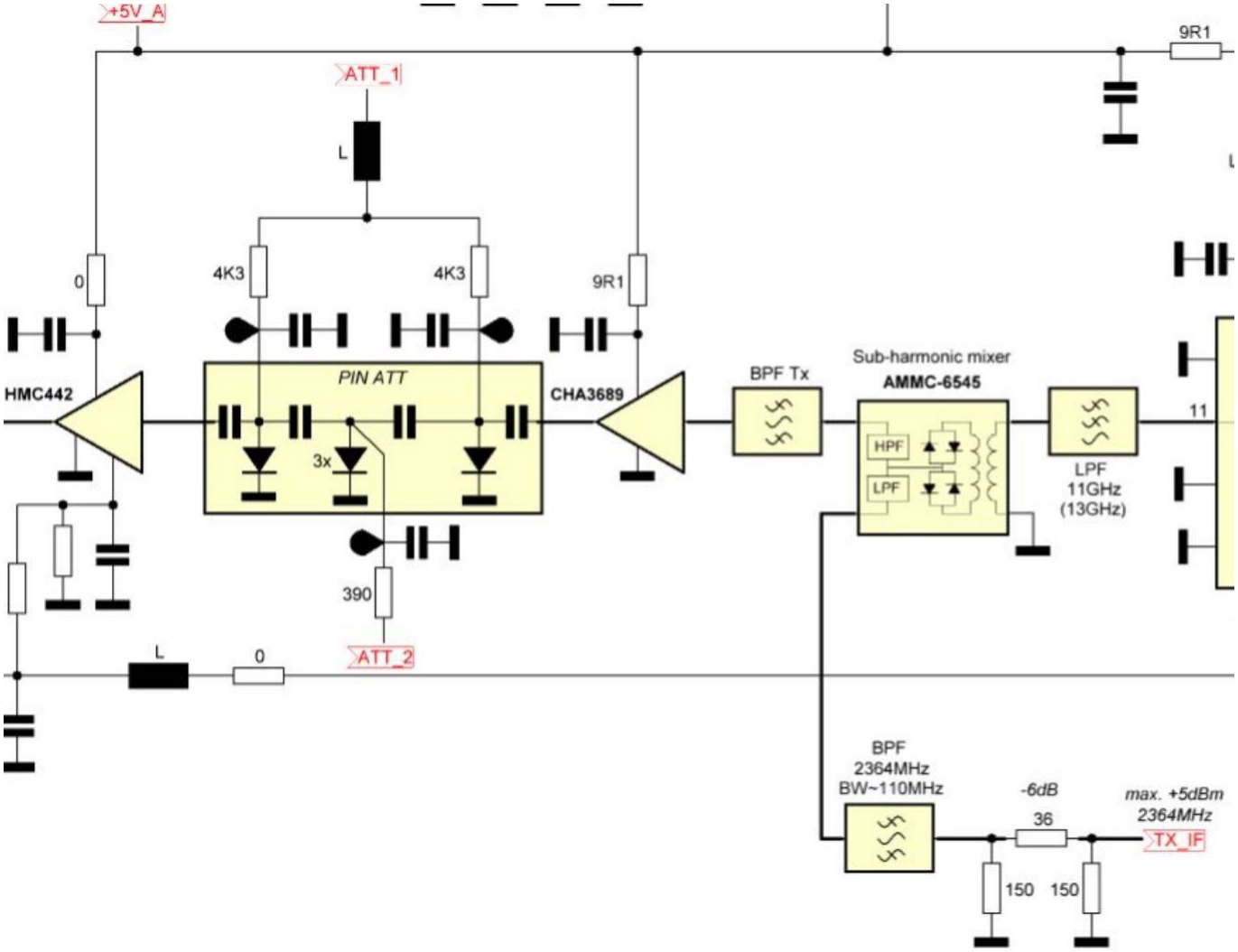
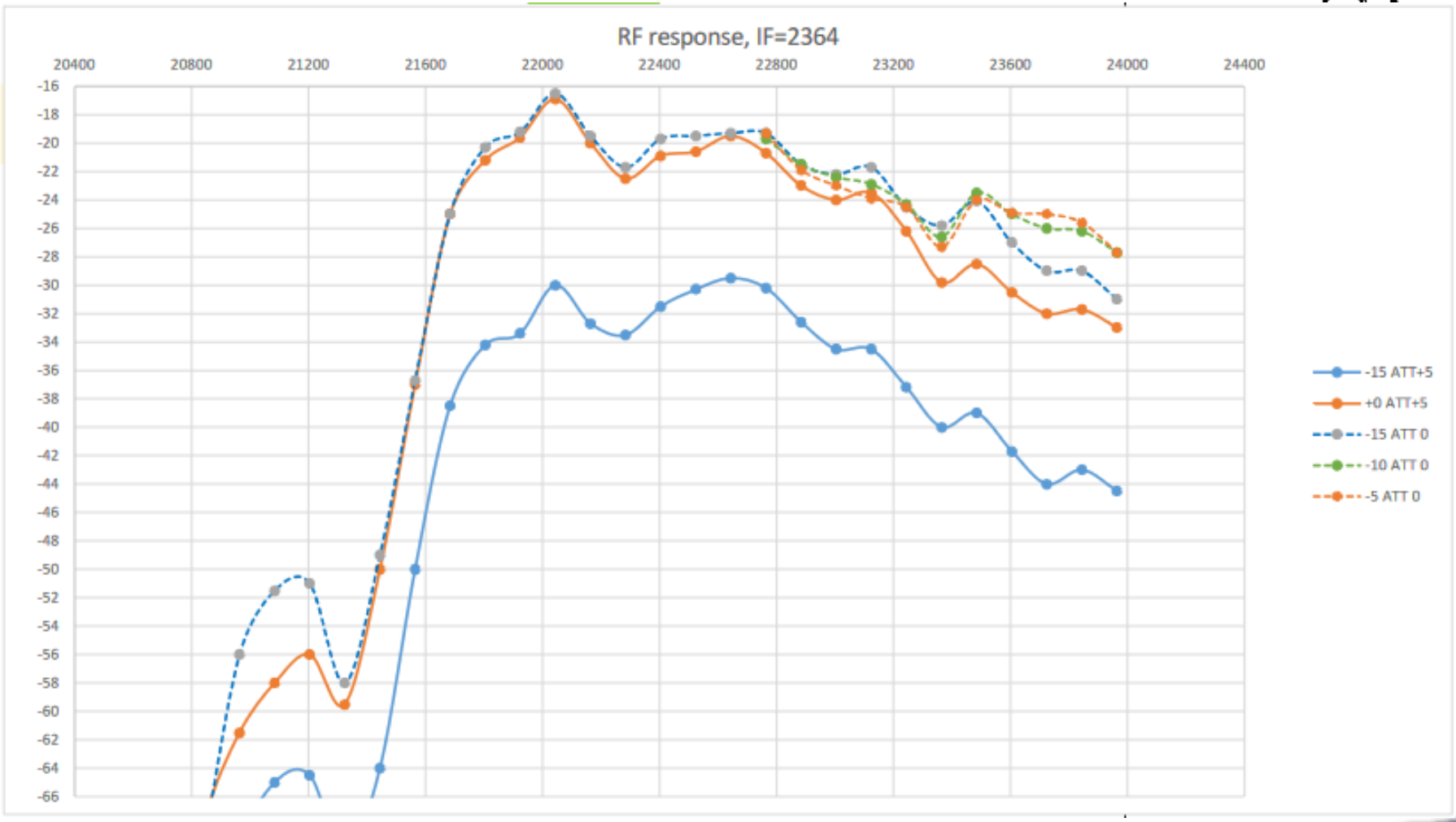
Pin closeup



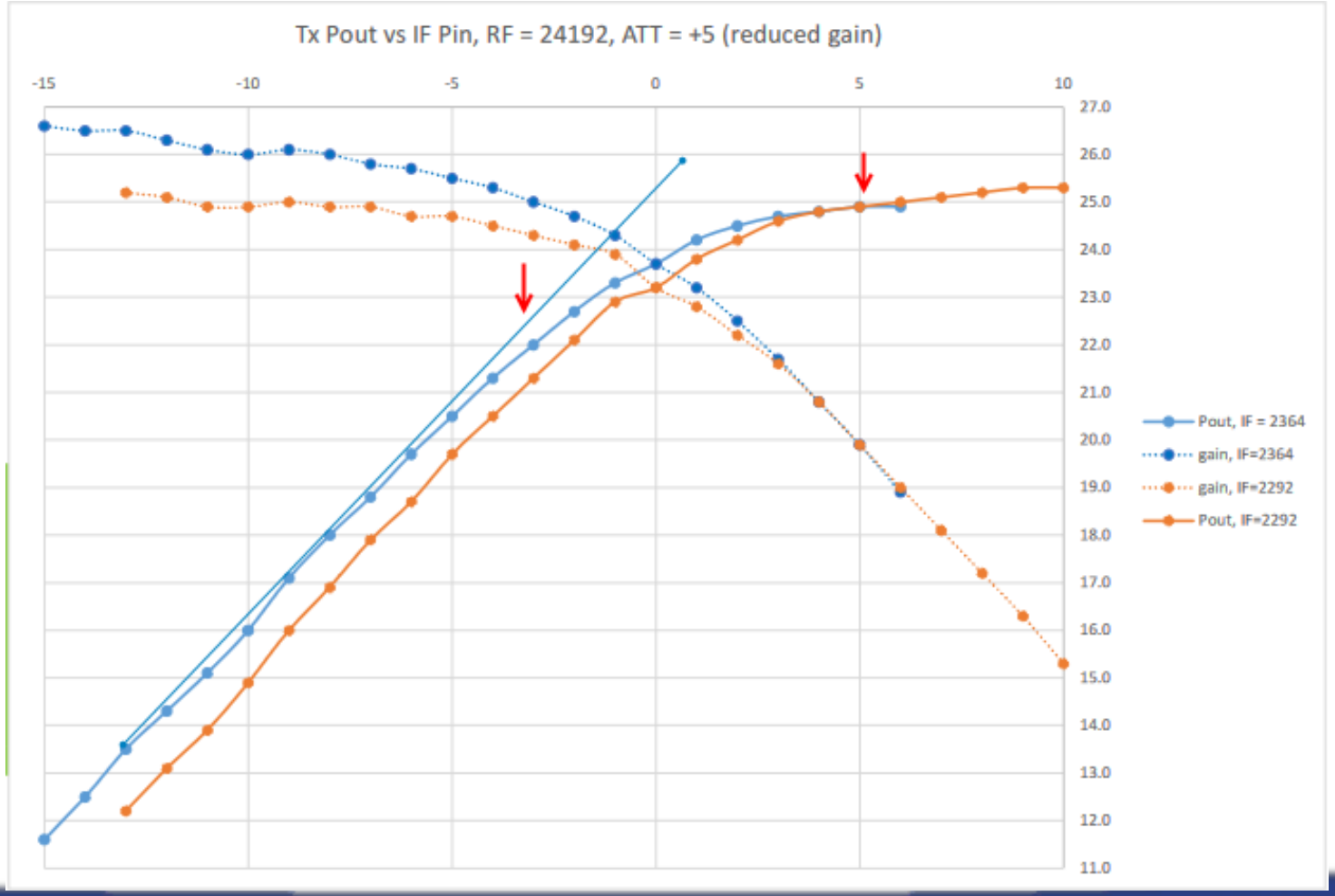
Improving RF output

- Mike Lavelle K6ML ran tests on the PA0MHE add-on board and Wavelab 23 GHz ODU module
  - He swept the LO1 frequency to determine the frequency response of the Wavelab's TX IF and RF band pass filters as well as the TX mixer and PA saturation points.
  - He then measured power in (after the PCB mixer) versus power out from the module to find the saturation point for the Wavelab module upconverter AMMC-6545 mixer for both conditions of ATT1 tied to +5v (stock PCB board design) and for ATT1 allowed to float.
  - The measurements demonstrate that eliminating most or all of the internal pin attenuation allows more drive in the transmit pipeline which provides full saturation of the final PA with less drive from the PCB. In theory this would enable more linear operation.
  - The modification will be described here and the measurement procedure if you would like to experiment with your Wavelab system on your own.

K6ML swept LO1



K6ML upconverter saturation test – ATT1=+5v



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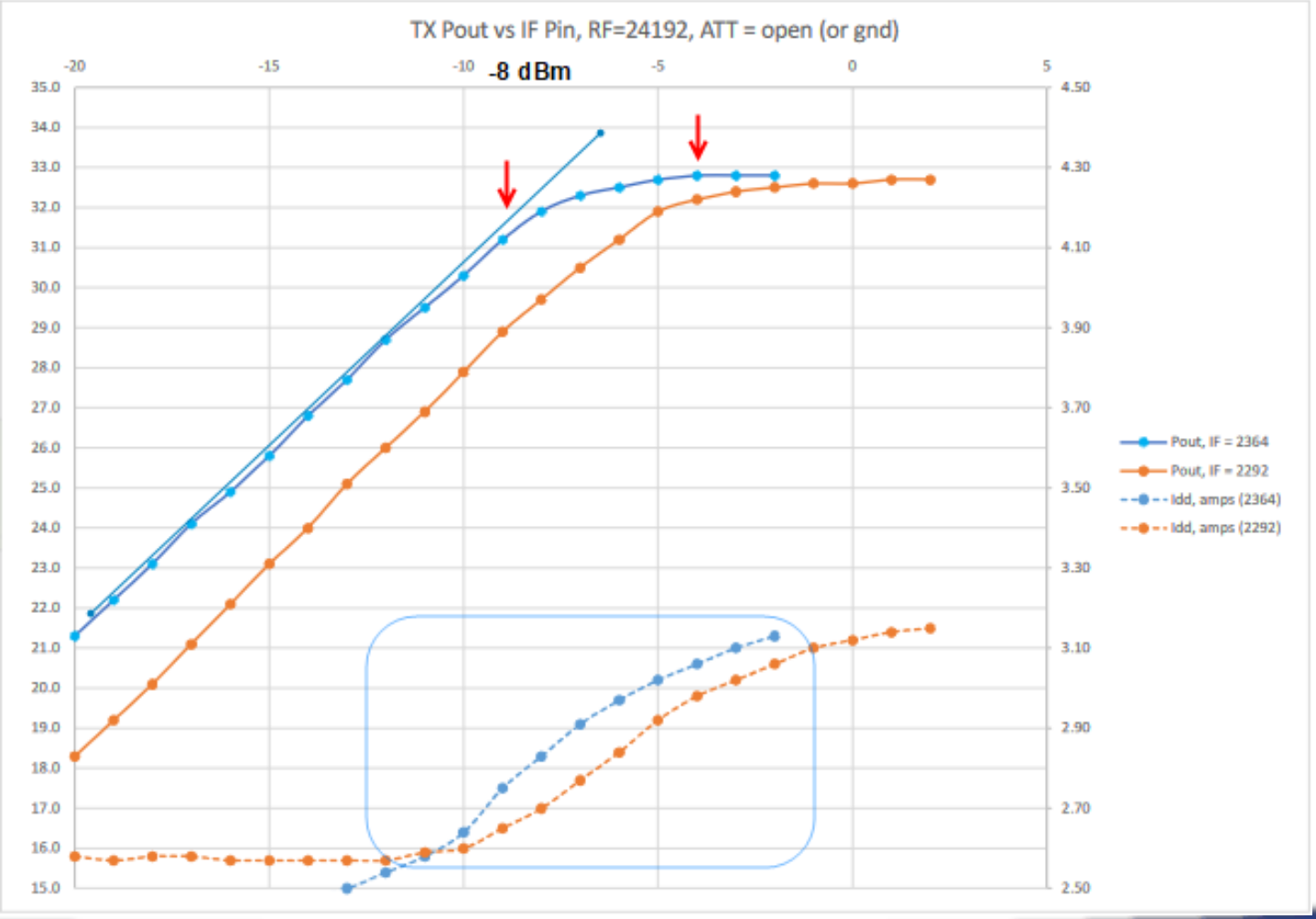
K6ML Pout/Pin ATT1 open



Improving RF output

Cutting ATT1 jumper adds about 14 dB gain to the internal path from Tx up converter to the PA input.

Without this extra gain, most units cannot reach full power at 24192. We can put a resistor across the cut trace to adjust the extra Tx gain by anywhere form 0 to 14 dB. Running wide open, we can supply less drive to the up converter and still drive the PA to P1dB (or Psat), but we might start to see LO leak thru at 21828 MHz. If we don't see too much LO leakage, an open trace is fine, but we can put some resistance across the cut to reduce the PA drive. The sweet spot would be to run the 2364 MHz Tx drive to the up converter at or just shy of P1dB for max LO rejection and then add enough gain using resistance at ATT1 to get the PA to P1dB (or Psat).

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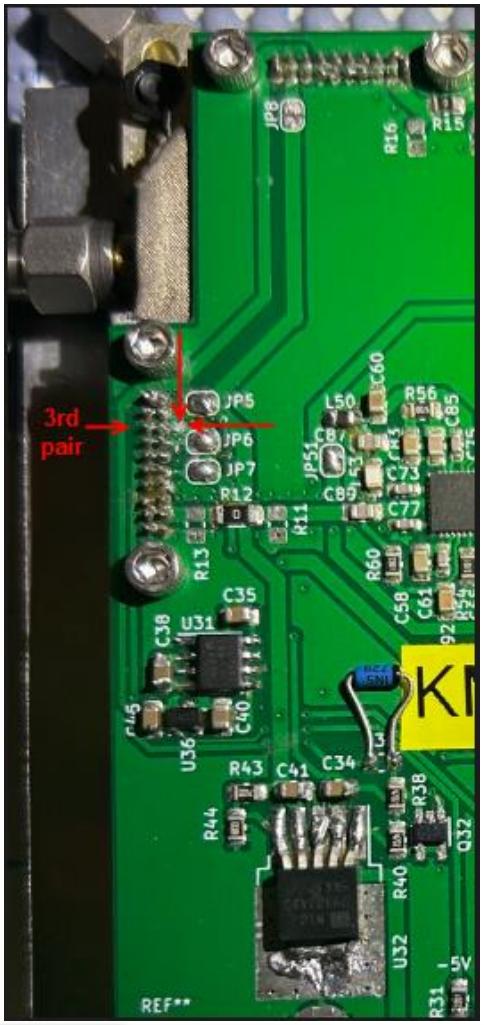
The modification



Turn the power off.

Make a vertical cut to the horizontal trace tied to the 3rd pair of pins on left side of board.

Check continuity from a +5v point like the +5v LED.

The 3rd pair of pins should now be open (not tied to +5v or grounded-although grounded will give the same results)

Testing

- Calibrate power meter to known source
  - DB6NT 24 GHz transverter = 2.5 watts = 34 dBm
  - 60dB attenuation to pad down to safe power head readings
- Calibrate or feel good about S.A.s for IF drive power readings
  - I tested a DigiLO (+2 dBm) an ADF 4351 development board (various outputs) using both the HP8566A and a TinySA Ultra.
- Attach a pigtail to C10 to read power levels of 2364 MHz drive
- Use RV1 pot to vary the drive level at approx. 1 dBm steps
- Record current, IF drive level, RF (24192 MHz) output level.

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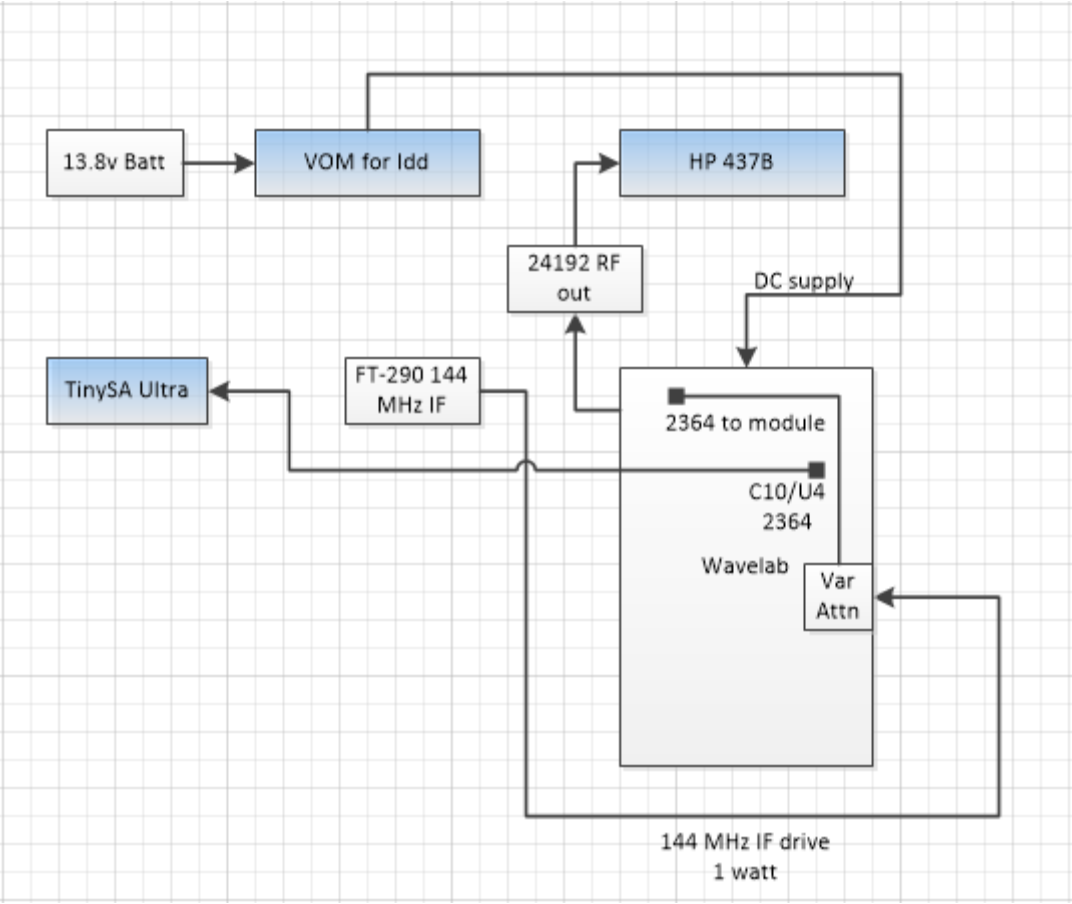
Testing



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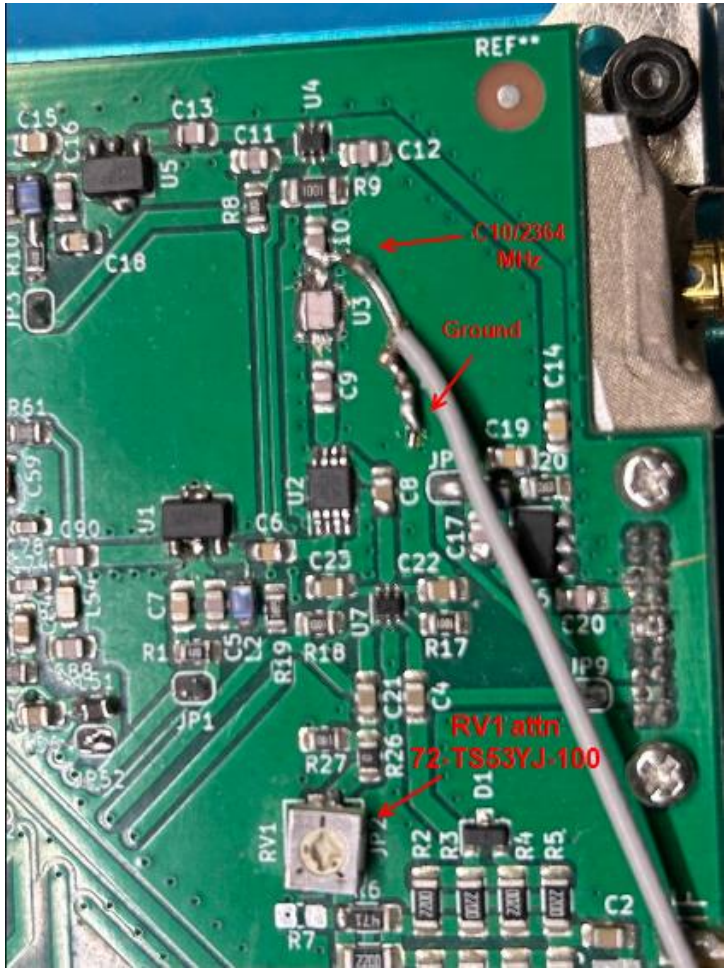
Testing



IF drive vs RF out ATT1=+5v

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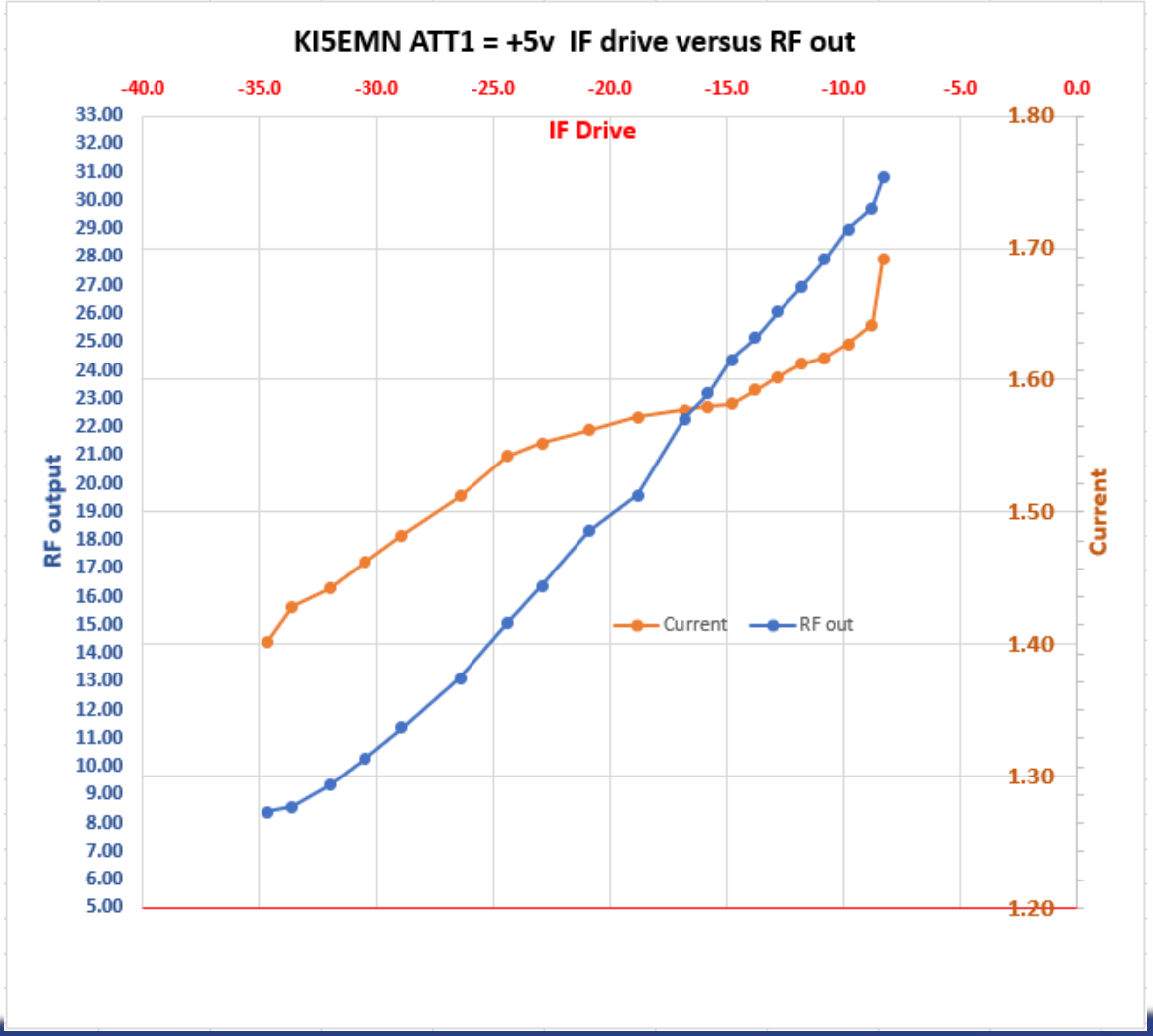

IF drive vs RF out ATT1=05v

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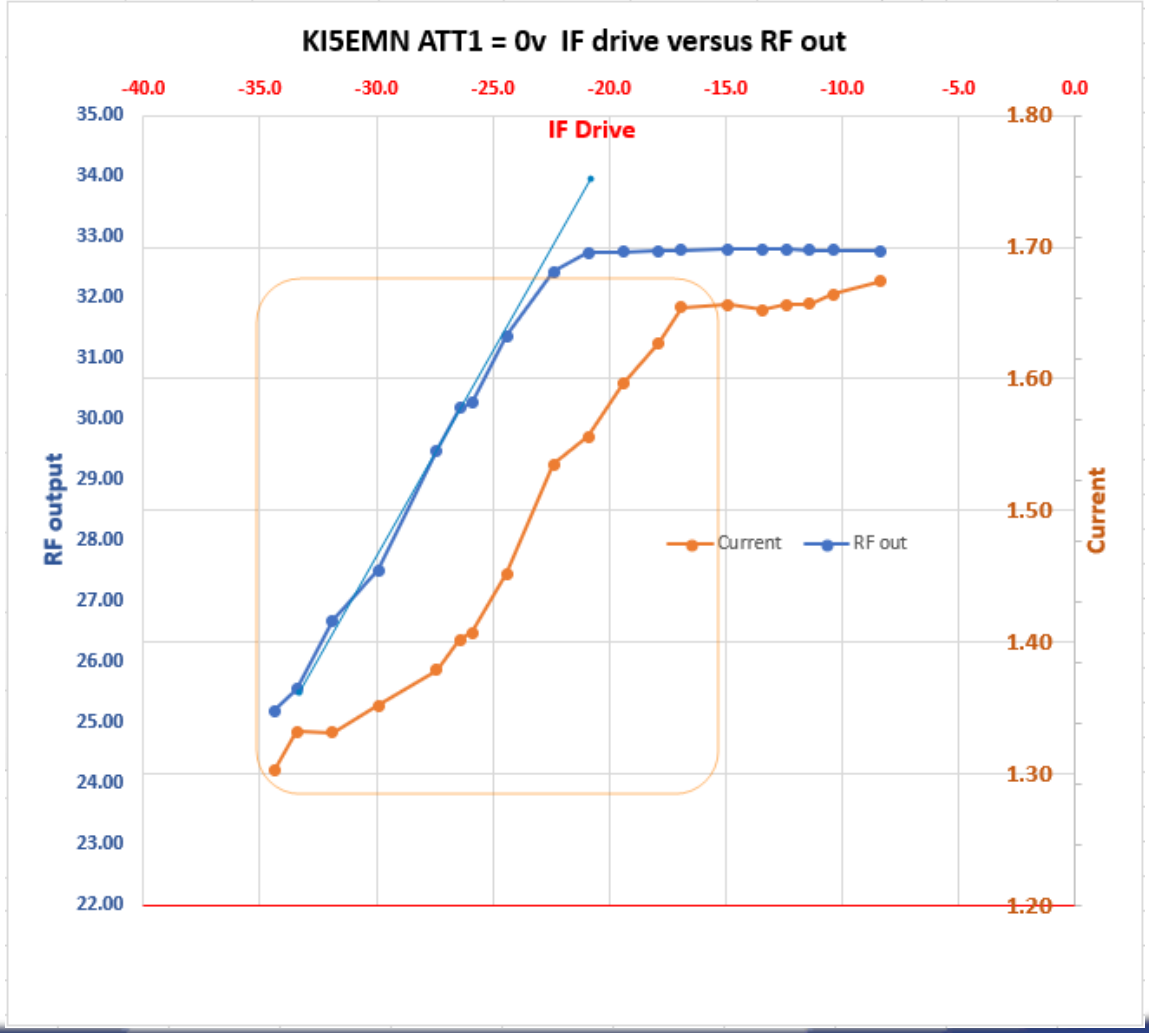

Next steps

- Obtain second set of accurate measurements:
  - Check spectral RF output
  - Verify power output
  - Measure receive sensitivity, noise figure
- Integrate improvements/optimizations.
  - More improvements may be coming as the user group expands
- In-field tests
  - Extend DX success
- Build a Wavelab beacon

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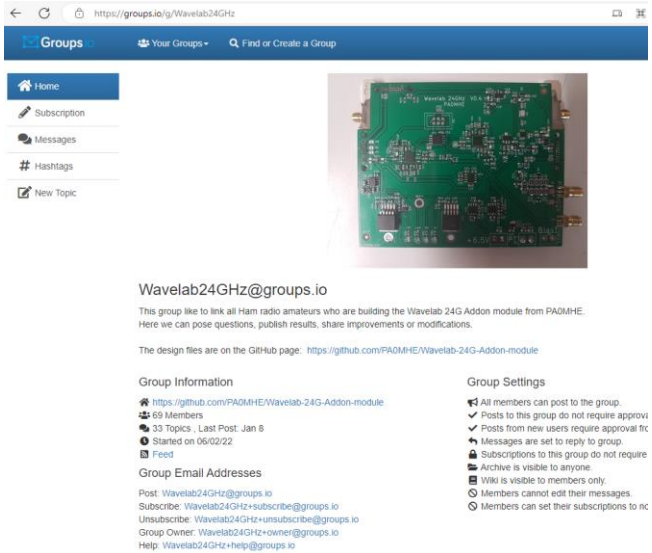
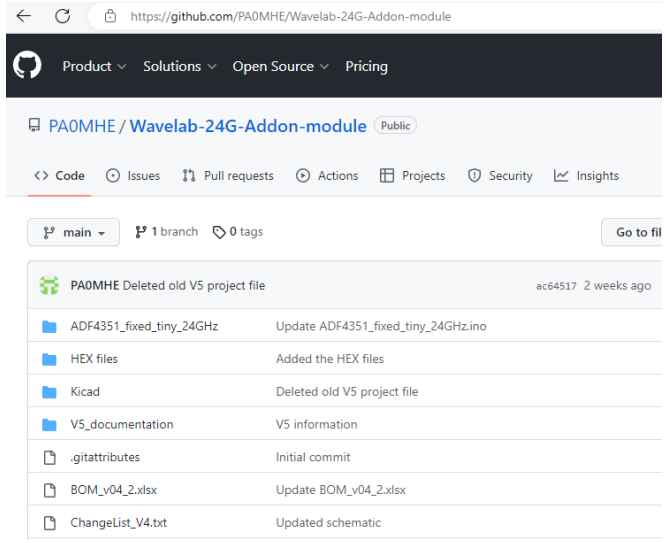
Resources

[Wavelab24GHz@groups.io | Home]

[GitHub - PA0MHE/Wavelab-24G-Addon-module]

YO4HFU Wavelab 23 specs, schems, photos, reverse engineering: [https://www-qsl-net.translate.goog/yo4hfu/Link_23GHz.html?_x_tr_sl=pl&_x_tr_tl=en&_x_tr_hl=en-US&_x_tr_pto=wapp]





Additional rev eng by SP6GWB

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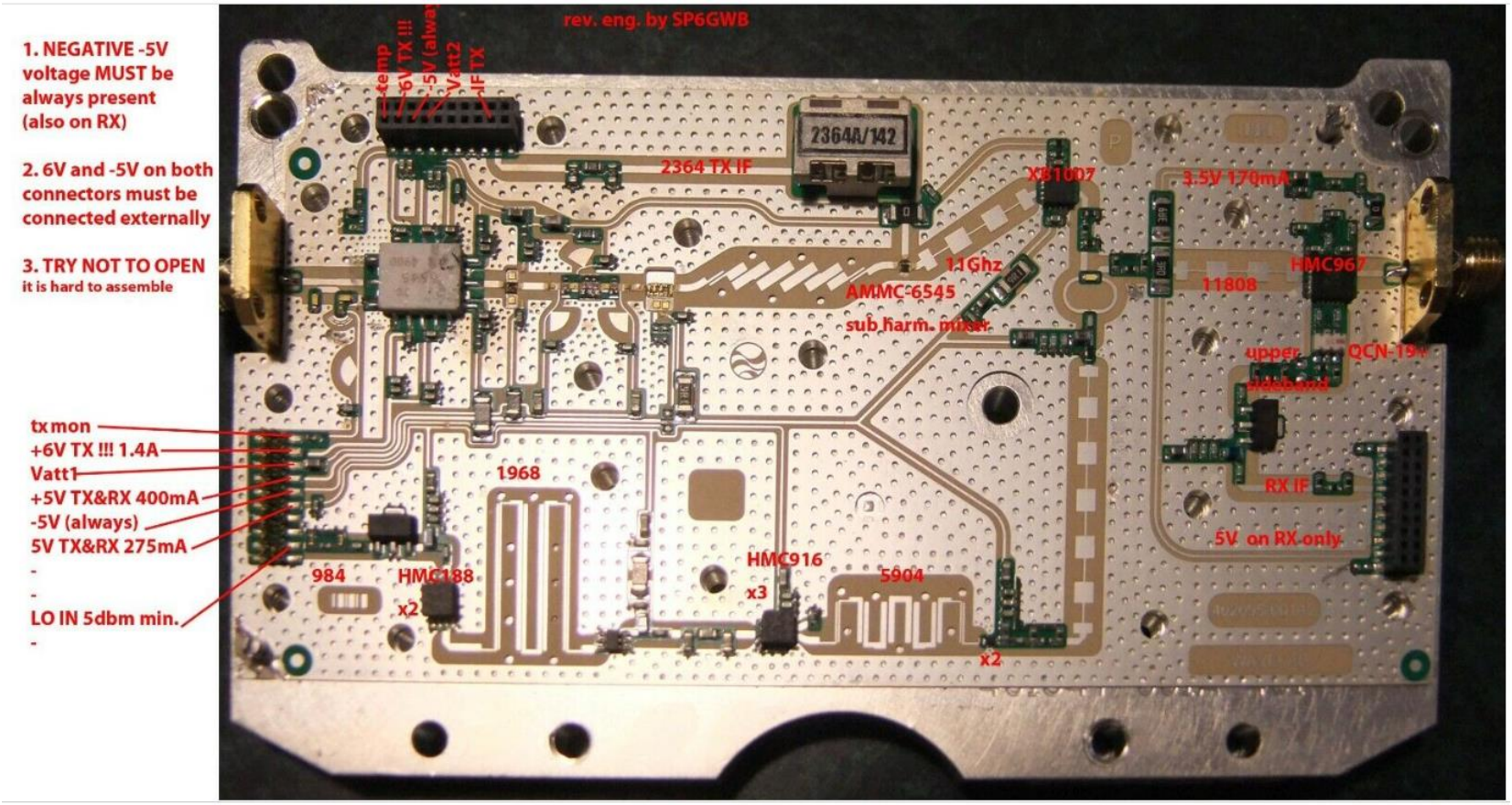

Additional resource

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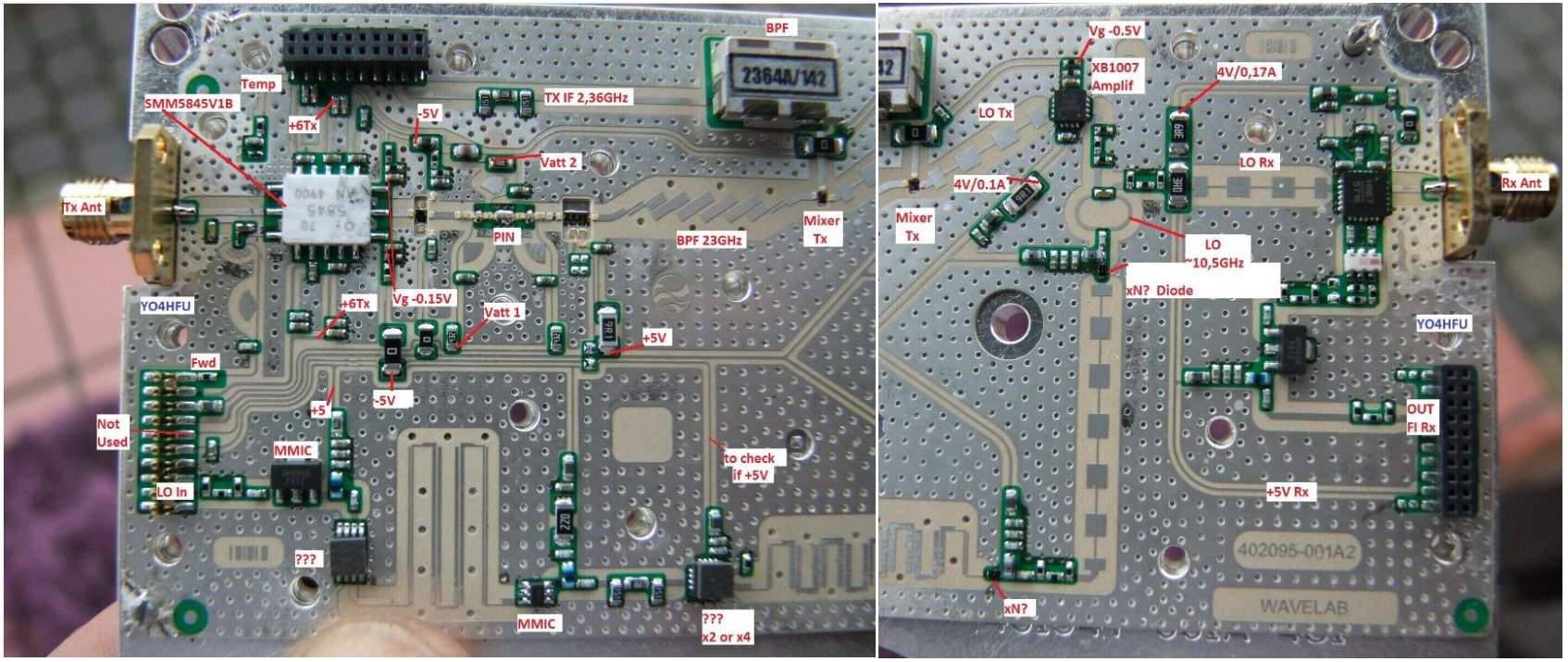
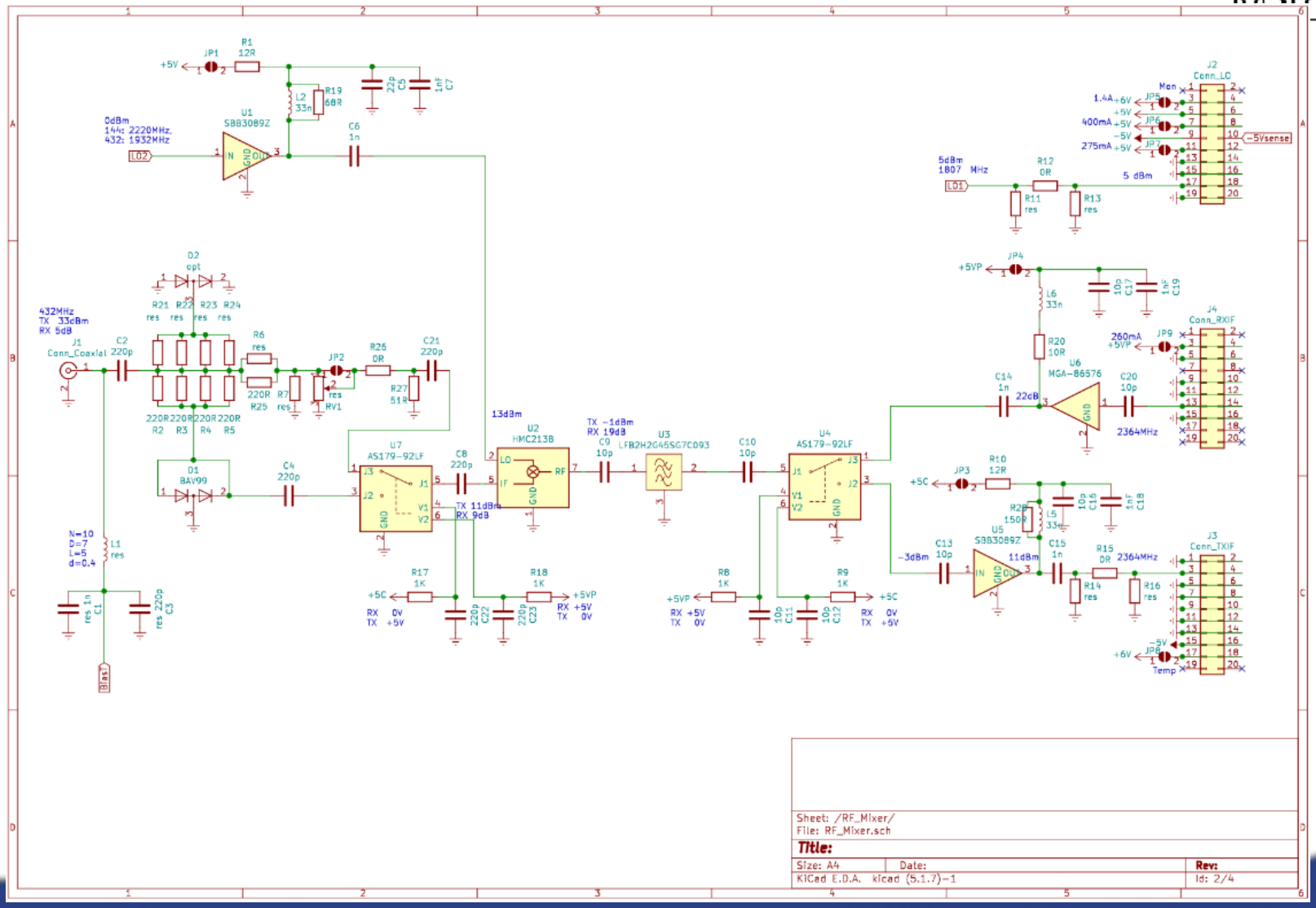
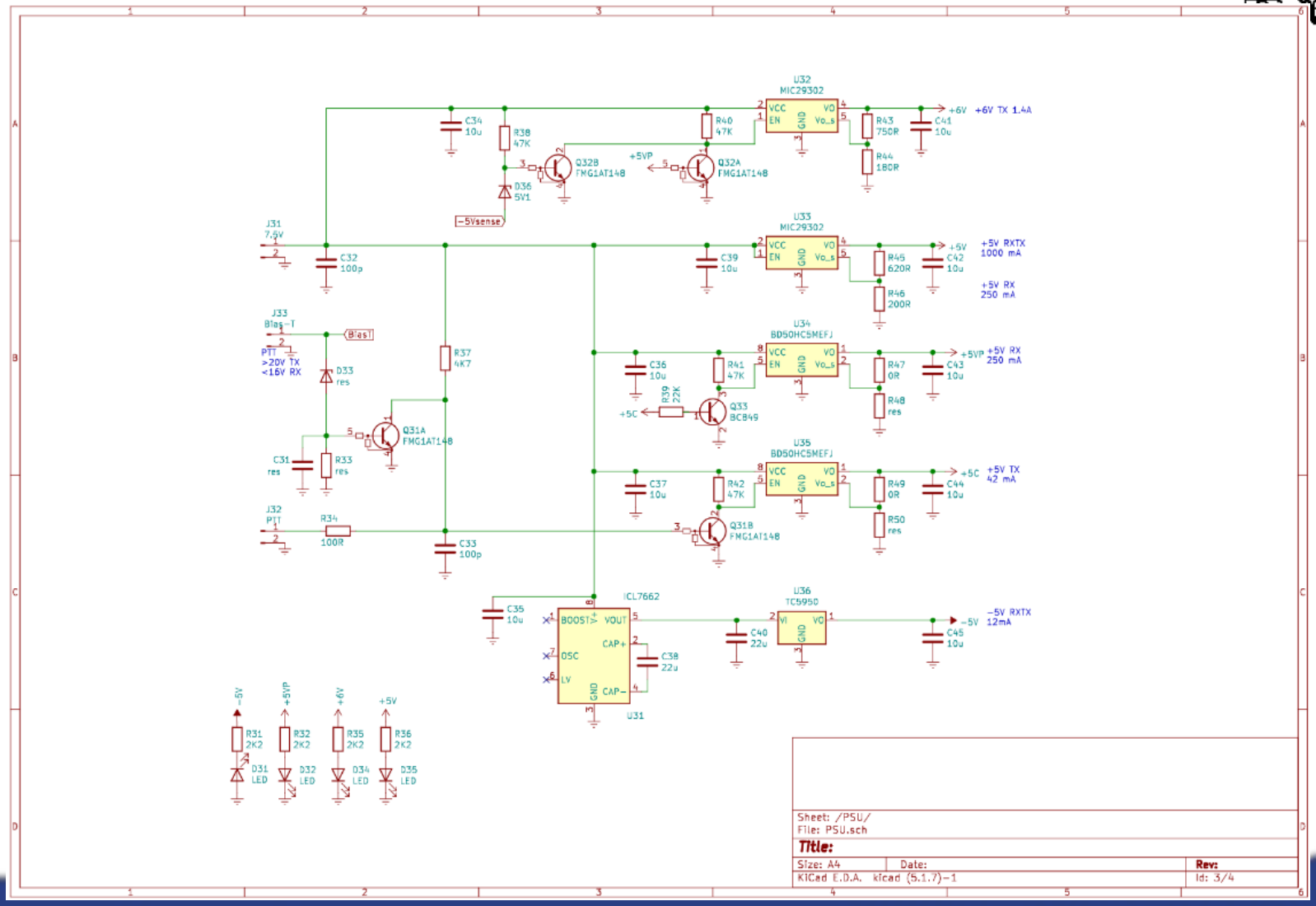


Add on board schematic pages

North Texas NTMS Microwave Society



Add on board schematic pages



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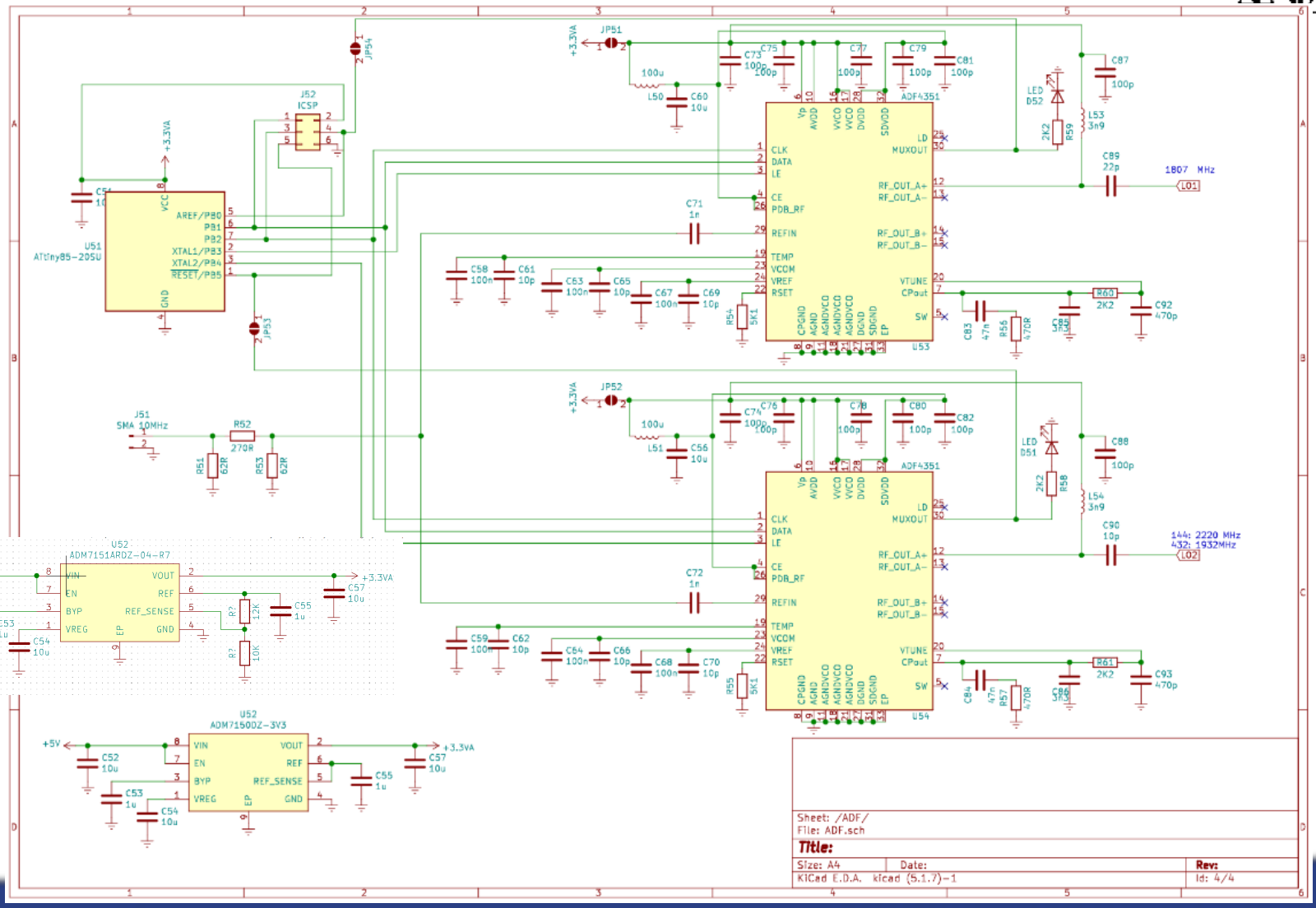
Add on board schematic pages



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Questions?