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
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.

<table>
<thead>
<tr>
<th>Frequency Band*</th>
<th>RX</th>
<th>TX</th>
<th>LO</th>
<th>LO/12 (input)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.600GHz</td>
<td>22.592GHz</td>
<td>23.600GHz</td>
<td>21.236GHz</td>
<td>1769.66MHz</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Synthesizer 1 ADF 1</th>
<th>1819 MHz</th>
<th>x 12 mult</th>
<th>21828 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthesizer 2 ADF 2</td>
<td>2220 MHz</td>
<td>+ 144 MHz IF</td>
<td>2364 MHz</td>
</tr>
</tbody>
</table>
External view of module
Signal Flow & Components Inside the Wavelab Module

- Tx IF Input
- Tx IF BPF (2364)
- Rx (I/Q) Down Converter
- Tx RF Output
- 2W PA
- PIN Attenuator
- Tx BPF (23 GHz)
- Tx Up Converter
- LO Splitter
- Rx RF Input
- Rx IF Output
- LO/12 Input (1.8 GHz)
- LO/6 (3.6 GHz)
- LO Multiplier Chain
- LO/2 (10.9 GHz)

Photos and schematics from YO4HFU website
Module schematic
Add on board by PA0MHE

- 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
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

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.

<p>| | |</p>
<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Customers</td>
<td>800,000+</td>
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<tr>
<td>Orders Daily</td>
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<tr>
<td>Factory Area</td>
<td>450,000m²</td>
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<tr>
<td>Production Capacity/Month</td>
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<tr>
<td>PCBs Produced/Year</td>
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<tr>
<td>Countries Covered</td>
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<tr>
<td>Employees</td>
<td>3000+</td>
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<tr>
<td>Years Founded</td>
<td>15</td>
</tr>
<tr>
<td>On-time delivery</td>
<td>&gt;99.97%</td>
</tr>
<tr>
<td>Quality Complaint Rate</td>
<td>&lt;0.23%</td>
</tr>
<tr>
<td>PCB Prototype</td>
<td>1 Day</td>
</tr>
<tr>
<td>Online Service</td>
<td>24/7</td>
</tr>
</tbody>
</table>

* 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

- Shipment timeline. From payment to shipment < 6 days

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
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<tbody>
<tr>
<td>Submitted</td>
<td>2022-11-14</td>
</tr>
<tr>
<td>Paid</td>
<td>2022-11-14</td>
</tr>
<tr>
<td>Reviewed</td>
<td>2022-11-14</td>
</tr>
<tr>
<td>In Production</td>
<td>2022-11-15</td>
</tr>
<tr>
<td>Shipped</td>
<td>2022-11-20</td>
</tr>
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</table>

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

Shipped

Tracking #: 1248274300
DHL Express Worldwide
Photos of package:
V5 changes from V4

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

![Schematic diagram of V5 changes from V4](image-url)
Remaining parts
Soldering technique

Small I/O footprint before placing
Soldering technique

- 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.
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
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)
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
Building tips

• Use a checklist for initial checkout
  • [https://ntms.org/files/Feb2023/Wavelab power up testing.pdf](https://ntms.org/files/Feb2023/Wavelab power up testing.pdf)
Building tips

• 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

- 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

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

- Mon(itor) port

Measure varies from -0.5 to -3.5v (J2 pin 1)
Program ATTINY

- 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

- 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)
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

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

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<td>2220 MHz</td>
<td></td>
<td>2220 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>24048 MHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>144 MHz</td>
<td>IF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24192 MHz</td>
<td>Final</td>
</tr>
</tbody>
</table>

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

- Pertinent register values are the first two hex strings

Reg 1 will control Integer and Fractional values

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

- There's an app for that!!
High Hawk proving ground – Feb 3, 2023
WA5JAT unit

- Passes all tests and measured +32 dBm output
KI5EMN unit

Uses latching relay driver with SMA latching relay
KM5PO unit
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
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 offset dish
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
Inside the module

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Value</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>12x1700+2364</td>
<td>22764</td>
<td></td>
</tr>
<tr>
<td>12x1633+2364</td>
<td>21960</td>
<td>down 804 -3db</td>
</tr>
<tr>
<td>12x1774+2364</td>
<td>23652</td>
<td>up 888 -3db</td>
</tr>
<tr>
<td>12x1807+2364</td>
<td>24048</td>
<td>up 1284 -6db</td>
</tr>
</tbody>
</table>
SMM5845

Output Power vs. Frequency
VDD=6V, IDD(DC)=1400mA
PIN attenuator
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
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).
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.
Testing
Testing
IF drive vs RF out ATT1 = +5v
IF drive vs RF out ATT1=0.5v
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
Resources

Wavelab24GHz@groups.io | Home

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

YO4HFU Wavelab 23 specs, schemas, 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

1. NEGATIVE -5V voltage MUST be always present (also on RX)

2. 6V and -5V on both connectors must be connected externally

3. TRY NOT TO OPEN it is hard to assemble

- tx mon
- +6V TX !!! 1.4A Vatt1
- +5V TX&RX 400mA
- -5V (always)
- 5V TX&RX 275mA
- - LO IN 5dbm min.
Additional resource
Add on board schematic pages
Questions?