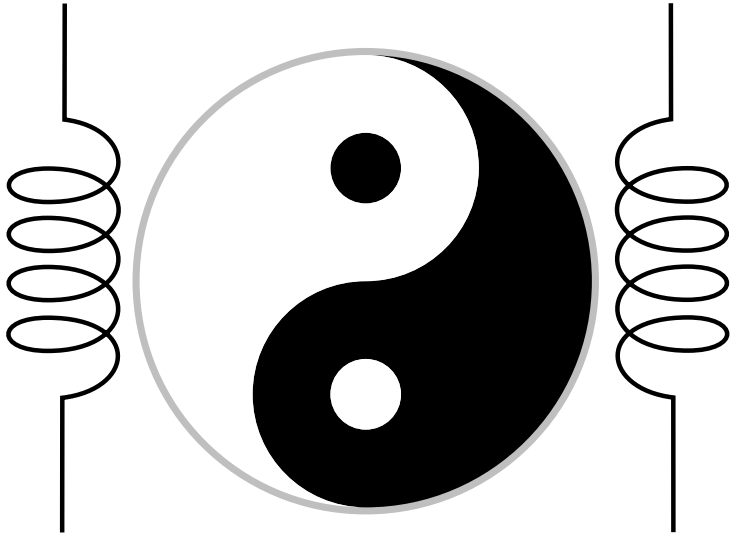
YIG & YANG
(Yet ANother yiG driver)



Dimitri Stolnikov
OsmoDevCall #5
23 April 2021

Agenda

- Brief intro into YIG technology
- Applications & examples
- Driver board requirements
- Driver circuit & layout
- Outlook
- Discussion (not recorded)

Yttrium Iron Garnet

$Y_3Fe_2(FeO_4)_3$ or $Y_3Fe_5O_{12}$

Image Source: Wikipedia

- Transparent over 600nm
- Ferrimagnetic (resonance, hysteresis)
- Low loss (high Q) at microwave frequencies
- Foundation for wideband tunable microwave components since mid-60's – it's "retro" µ-wave
- Still interesting for experimenters because
  - Plenty of scrapped T&M gear available
  - Mostly connectorized modules were used in the old days…
  - Tuned with DC current over a multi-octave range (for example 2-10 GHz)

YIG Applications

- Filters – used as pre/postselectors

YIG Bandpass

- For a bandpass the coupling coils are in rectangular alignment
- The resonance of the YIG sphere(s) is tuned into position where coupling shall happen

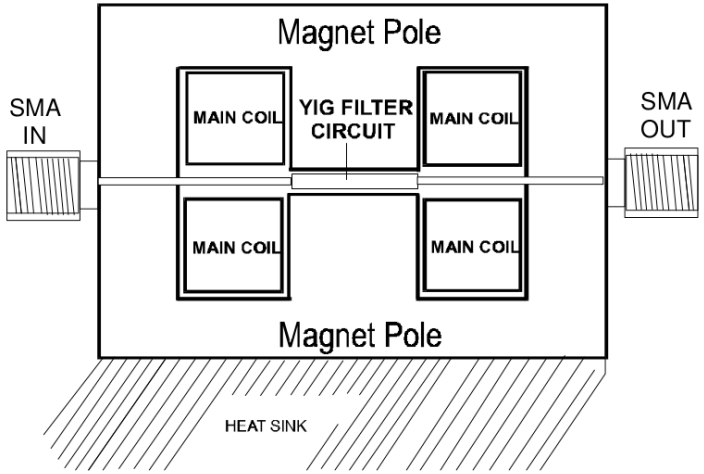


Image source: Micro Lambda Wireless

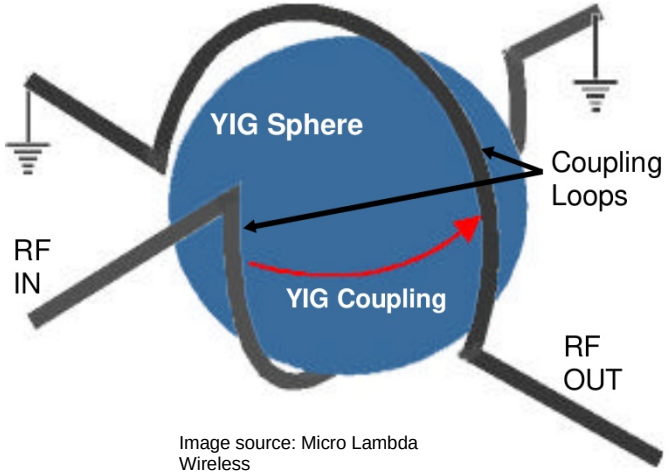


Image source: Micro Lambda Wireless

YIG Bandstop (notch)

- For a bandstop the coupling coils are in series with In/Out
- The resonance of the YIG sphere(s) is tuned into positi where attenuation shall happ

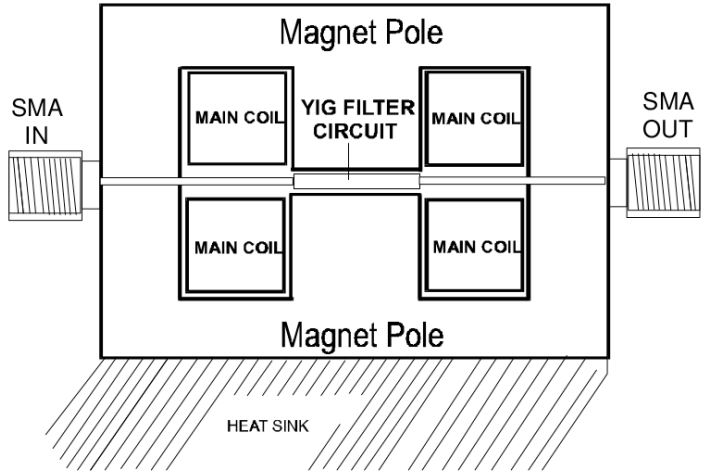


Image source: Micro Lambda Wireless

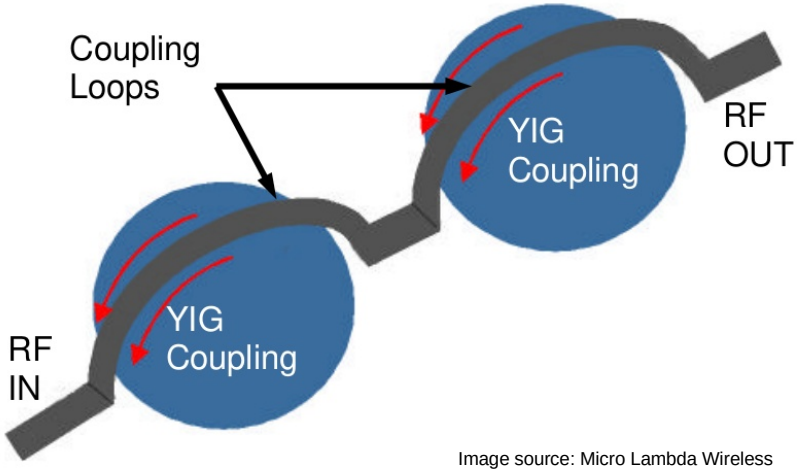
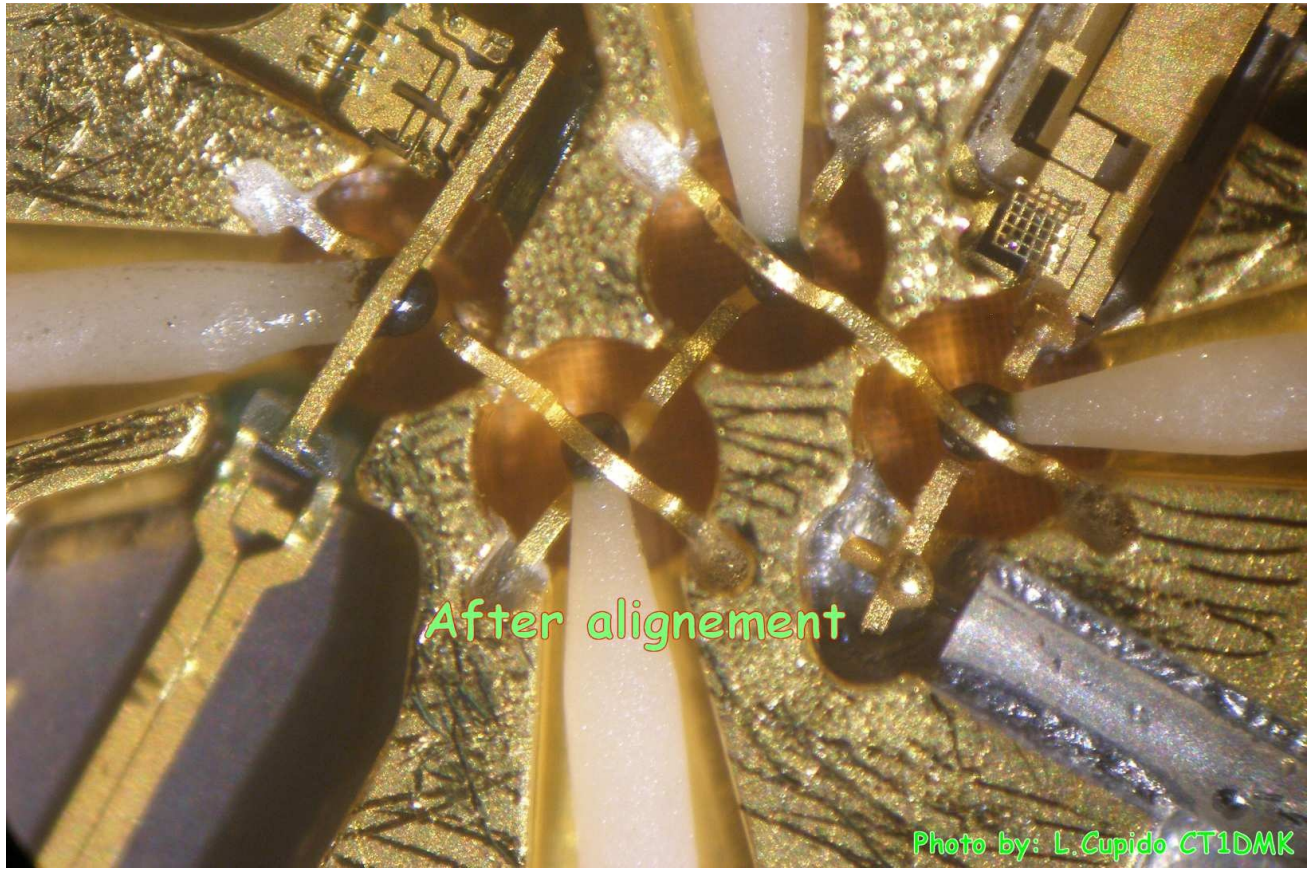


Image source: Micro Lambda Wireless

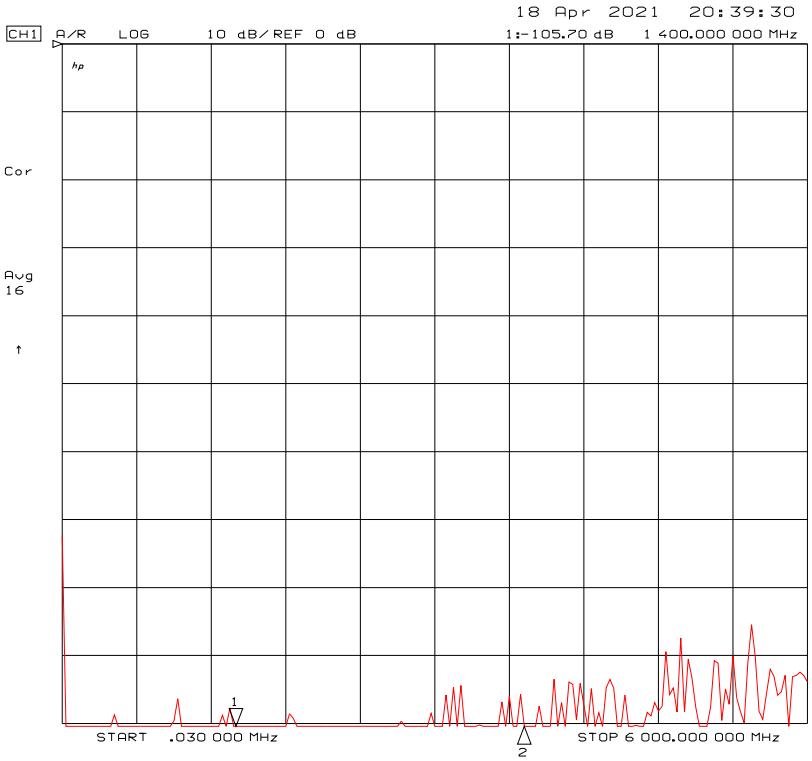
https://www.qsl.net/ct1dmk/wbond_ex.html

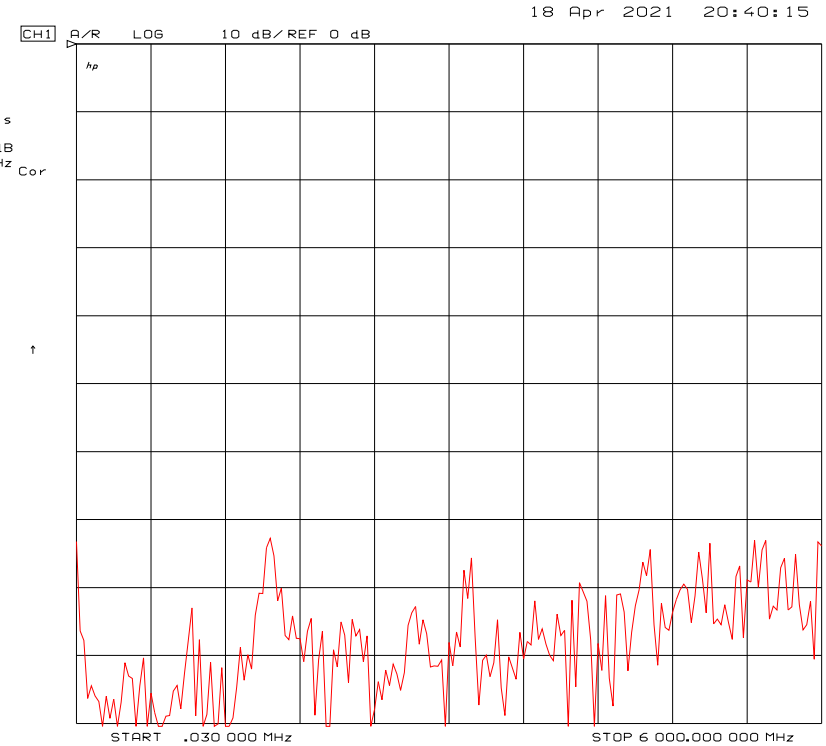


YIG Applications

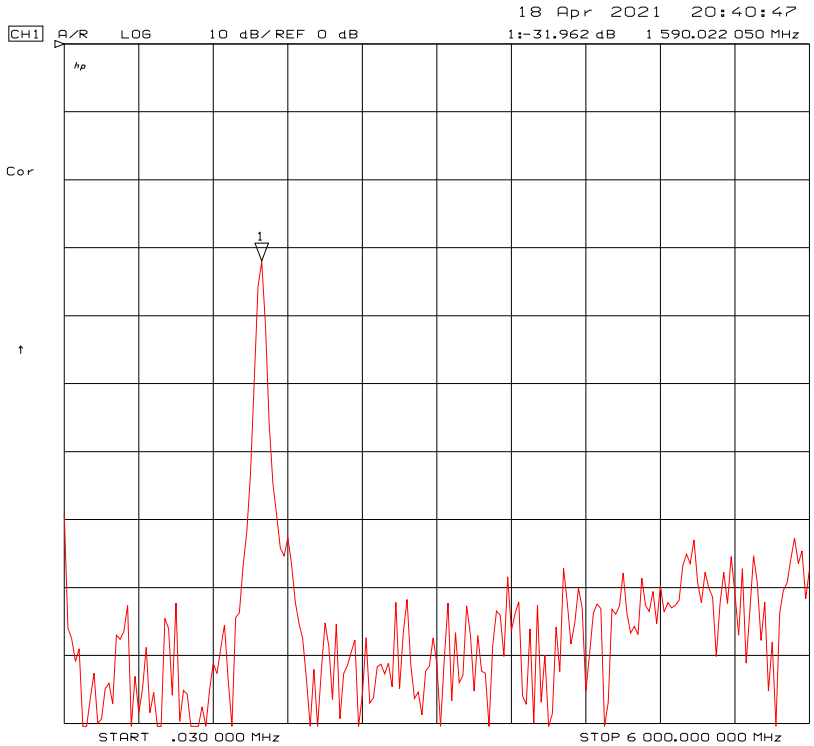
- Filter example

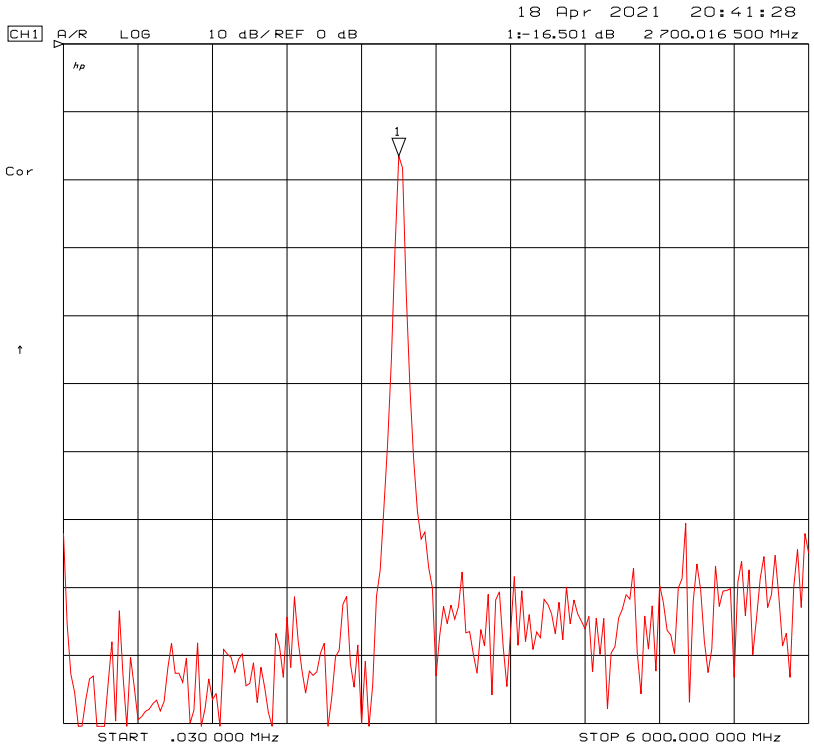
0mA and 50mA


18 Apr 2021 20:39:30
CH1 A/R LOG 10 dB/ REF 0 dB
1:-105.70 dB 1 400.000 000 MHz
hp
Cor
Avg
16
START .030 000 MHz
STOP 6 000.000 000 MHz

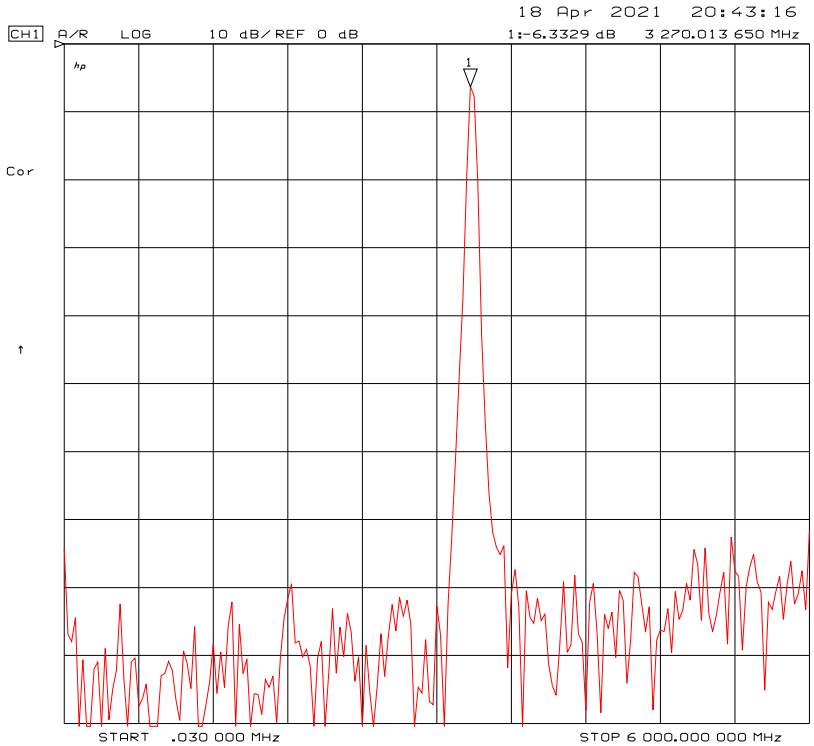

18 Apr 2021 20:40:15
CH1 A/R LOG 10 dB/ REF 0 dB
hp
CH1 Markers
2:-100.56 dB
3.72001 GHz
Cor
START .030 000 MHz
STOP 6 000.000 000 MHz

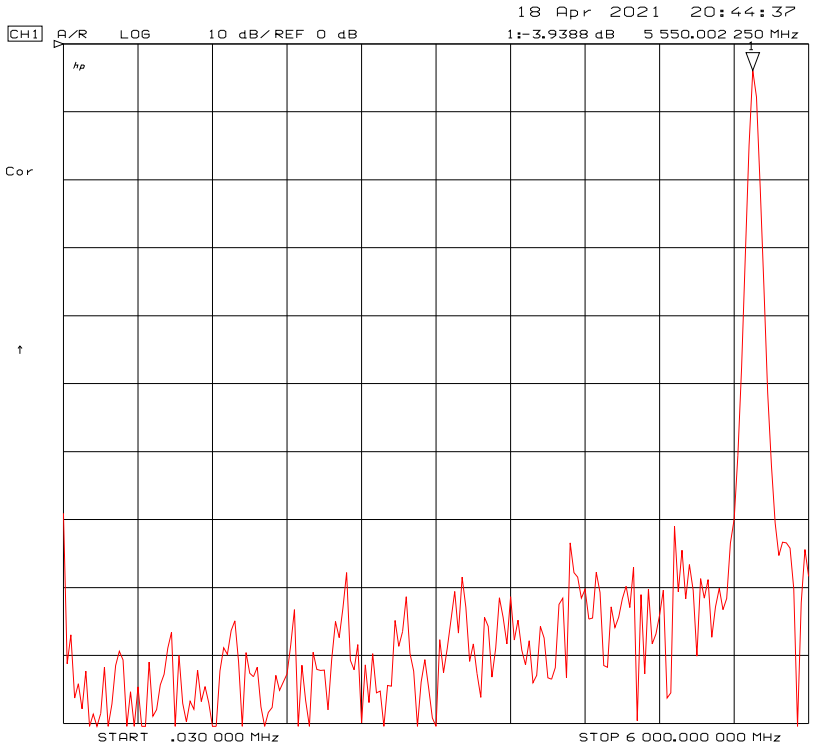
60mA and 100mA



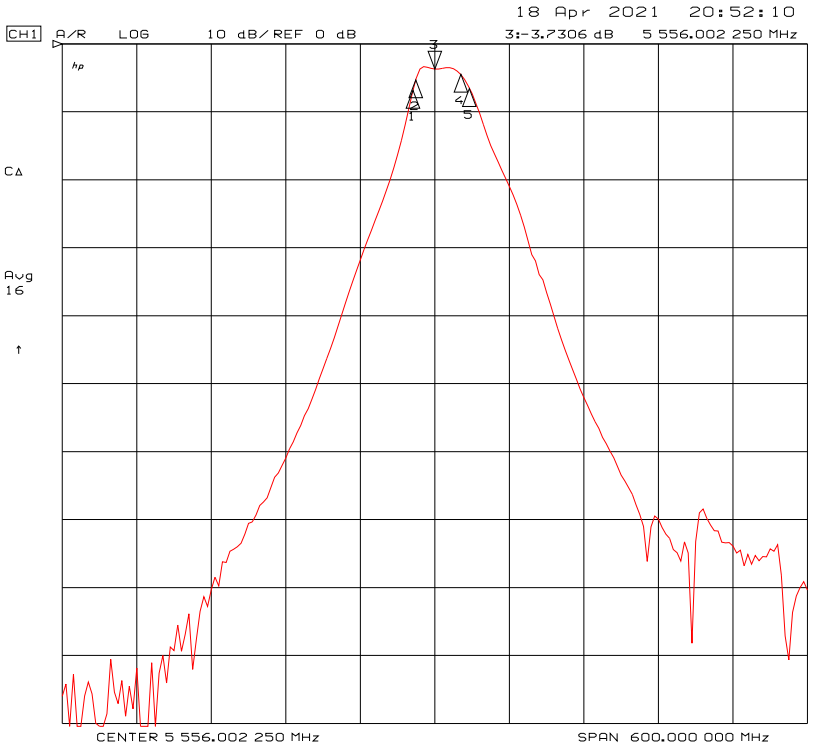


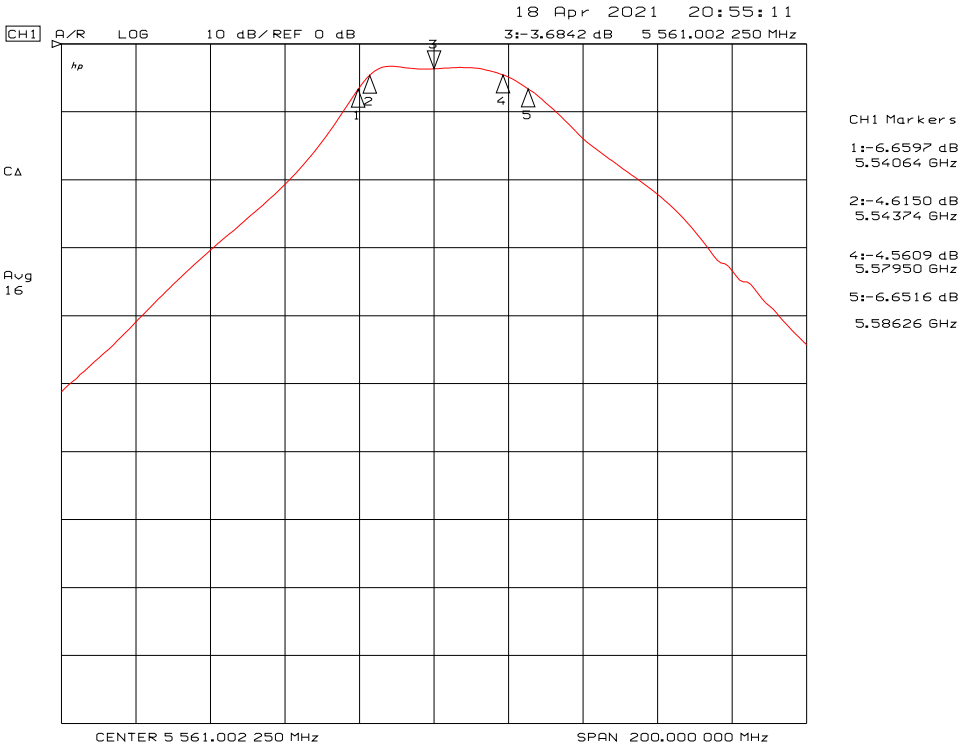
120mA and 200mA

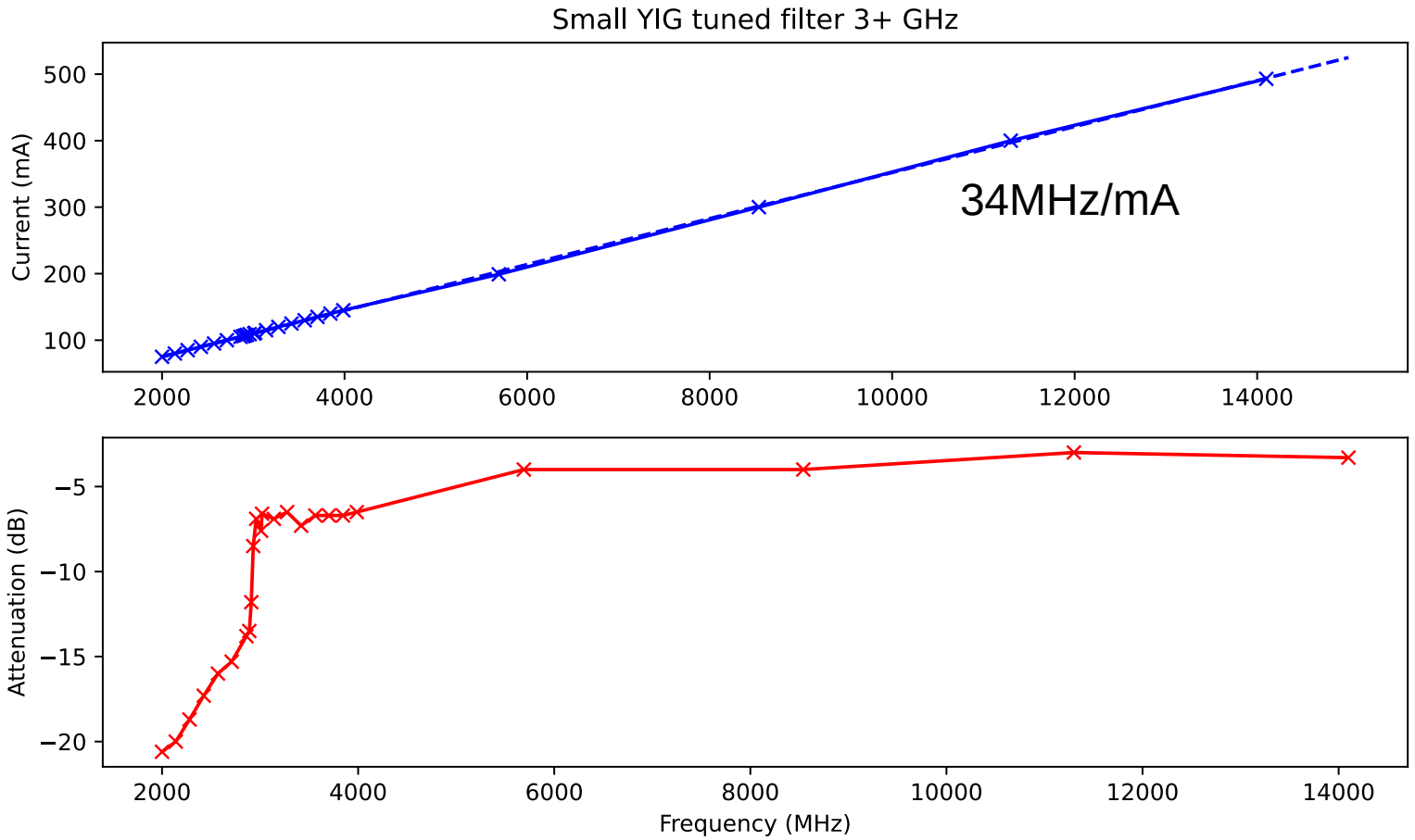




Passband: -1dB 36MHz, -3dB 46MHz





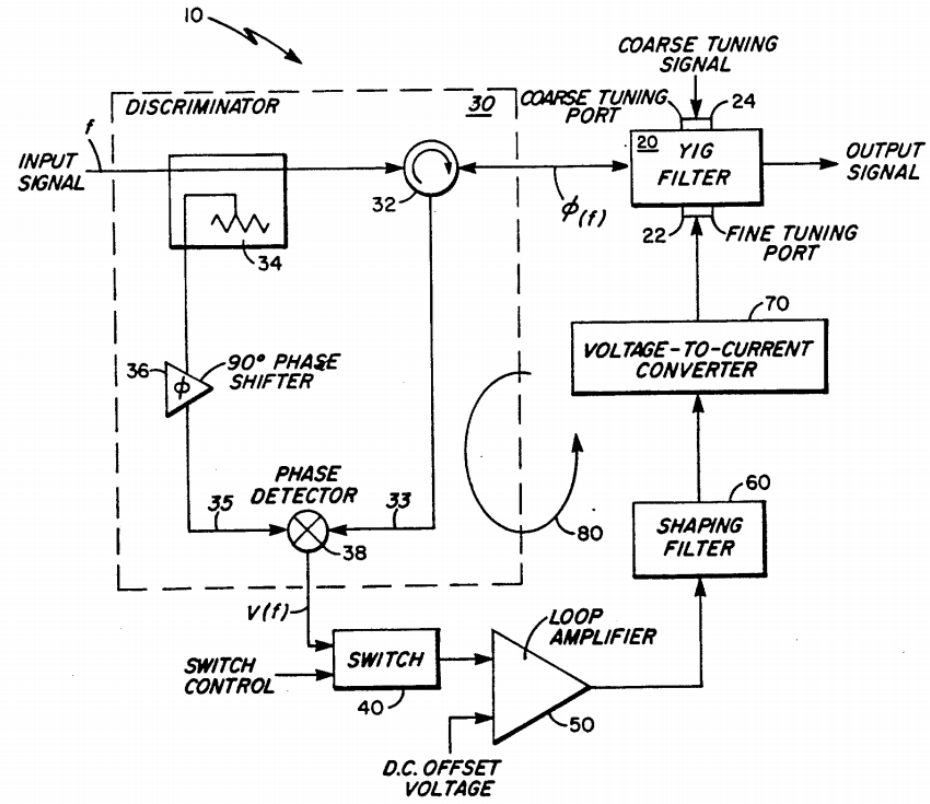

Small YIG tuned filter 3+ GHz
Current (mA)
500
400
300
200
100
34MHz/mA
2000
4000
6000
8000
10000
12000
14000
Attenuation (dB)
−5
−10
−15
−20
Frequency (MHz)

Summary

- Usable from approximately 2.7GHz (at 100mA) and up
- Not sure what the spec is, but at 500mA into 20 ohms of the tuning coil is $P = I^2R = 5W$ already!
  - It gets worse once the coil copper heats up
  - The YIG sphere operates best at a nominal temperature
    - So ironically you have to cool the YIG down, but also heat it up with an internal heater to keep the temperature stable
      - Heater current in this case was 80mA at 24V, 105mA at 15V

Tracking filter (US5019792)

- When the filter is off-frequency the magnitude of the reflected signal (33) increases
- Error signal V(f) from phase detector is then used to fine-correct the tuning error of the filter

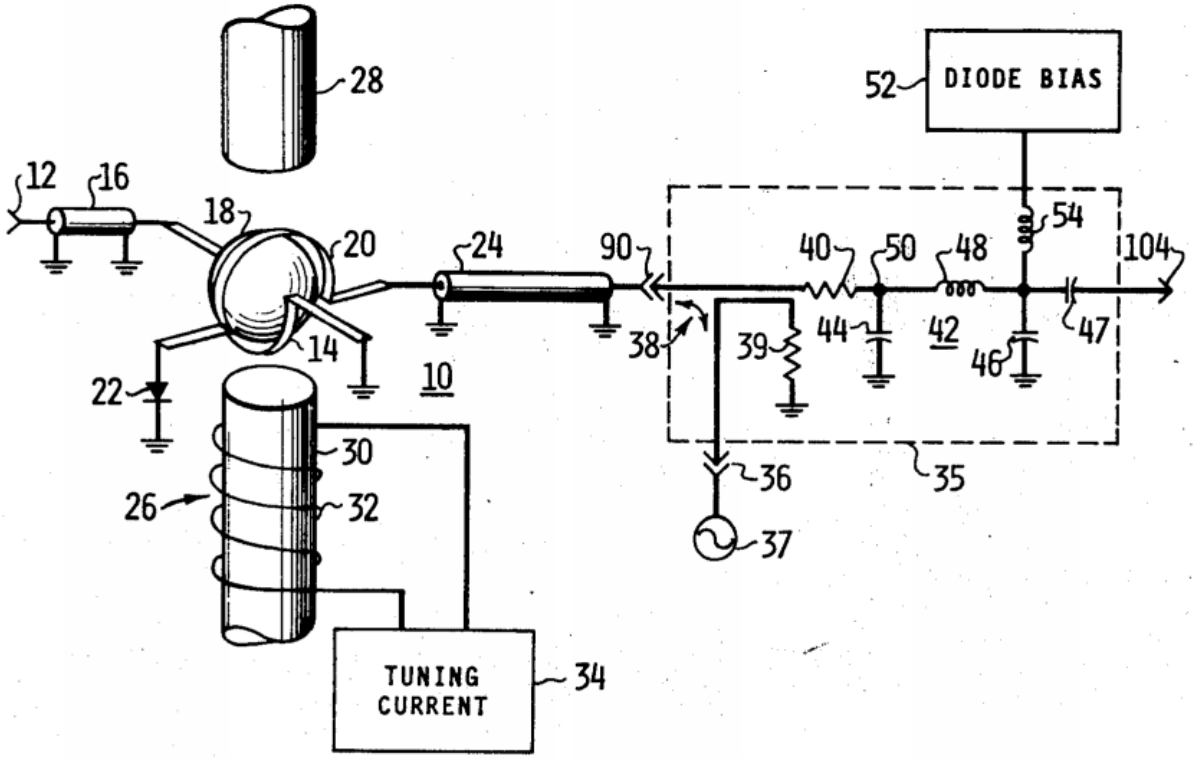


YIG Applications

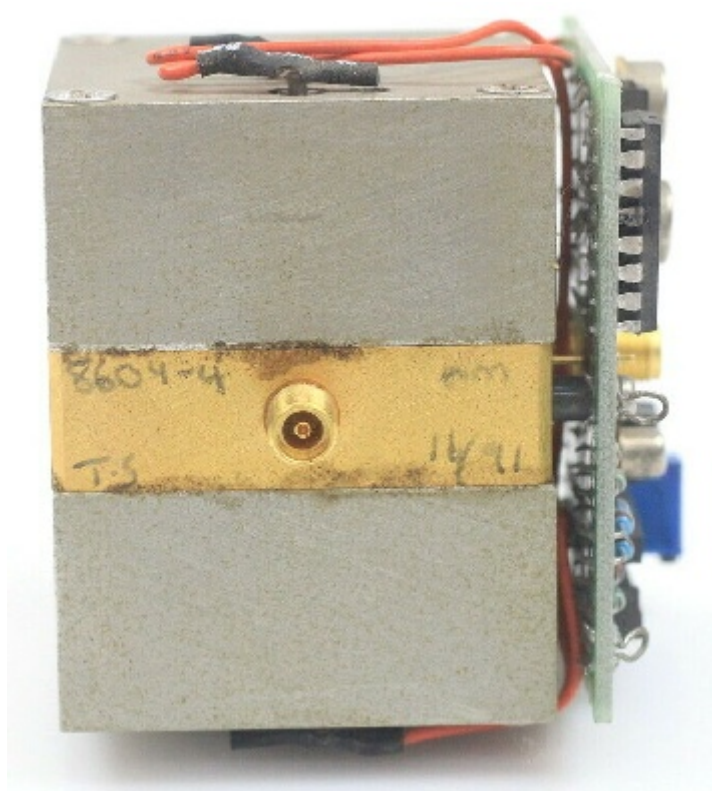
- Multipliers (mixers) – used in signal generators and receivers (spectrum analyzers)

YIG Tuned Mixer (US3973204)

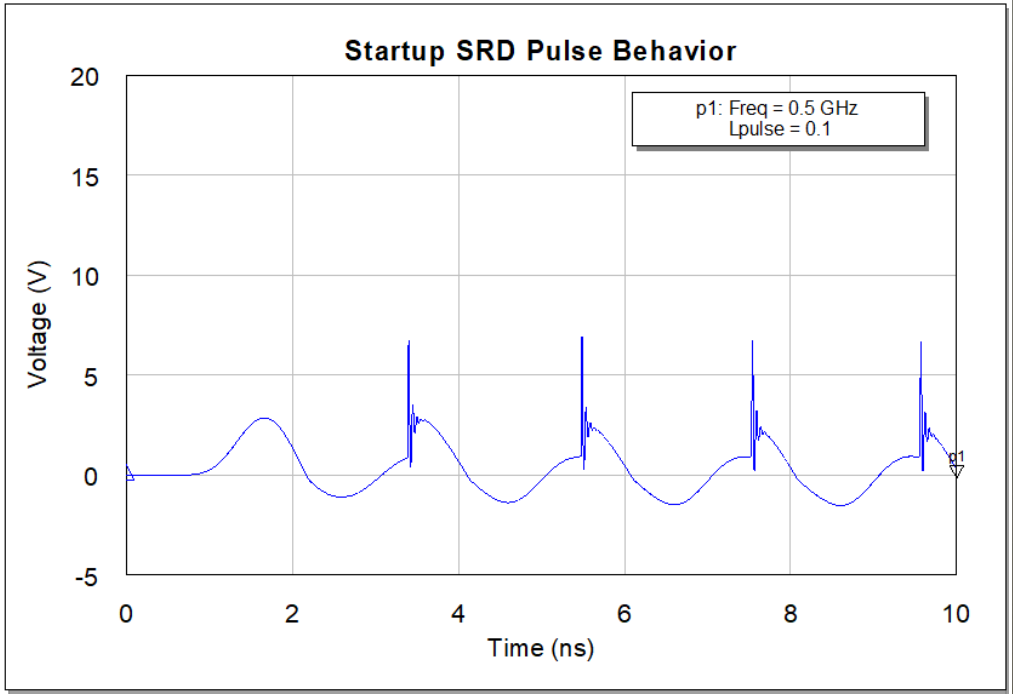
- 12: RF input
- 36: LO input
- 104: IF i/o



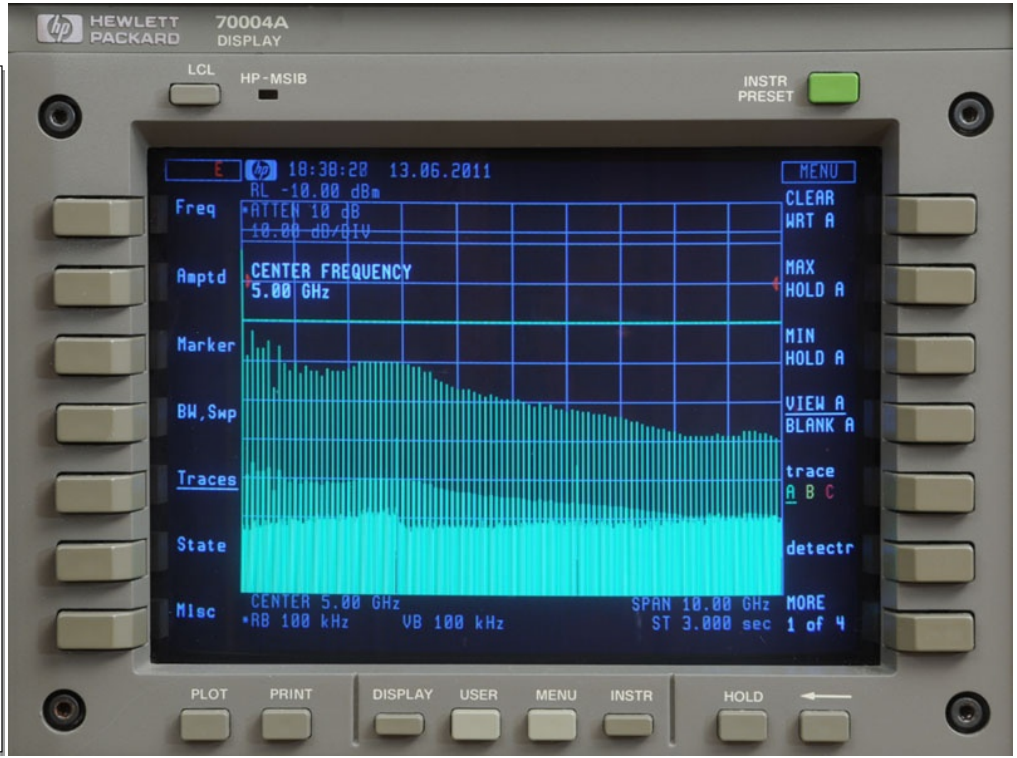
YIG Miltiplier = Comb Gen. + YIG Filter



Comb Gen.: Step Recovery Diode



https://kb.awr.com/display/examples/Sampling_Gate



https://www.hpmemoryproject.org/wb_pages/wall_b_page_10e.htm

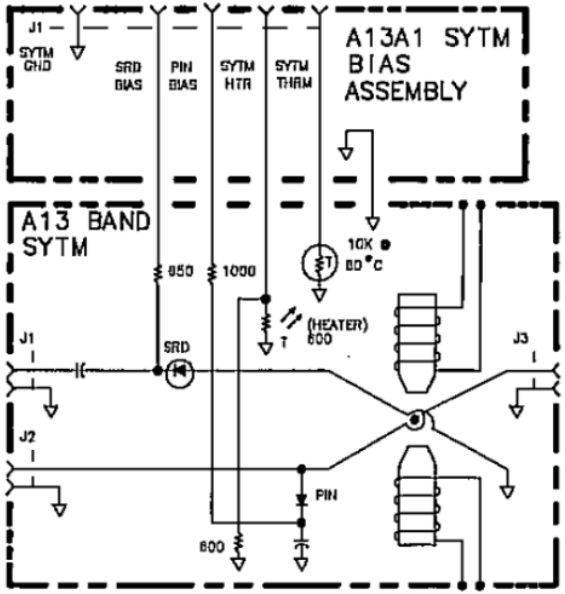
YIG Applications

- Multiplier example

Switched Yig Tuned Multiplier (SYTM)

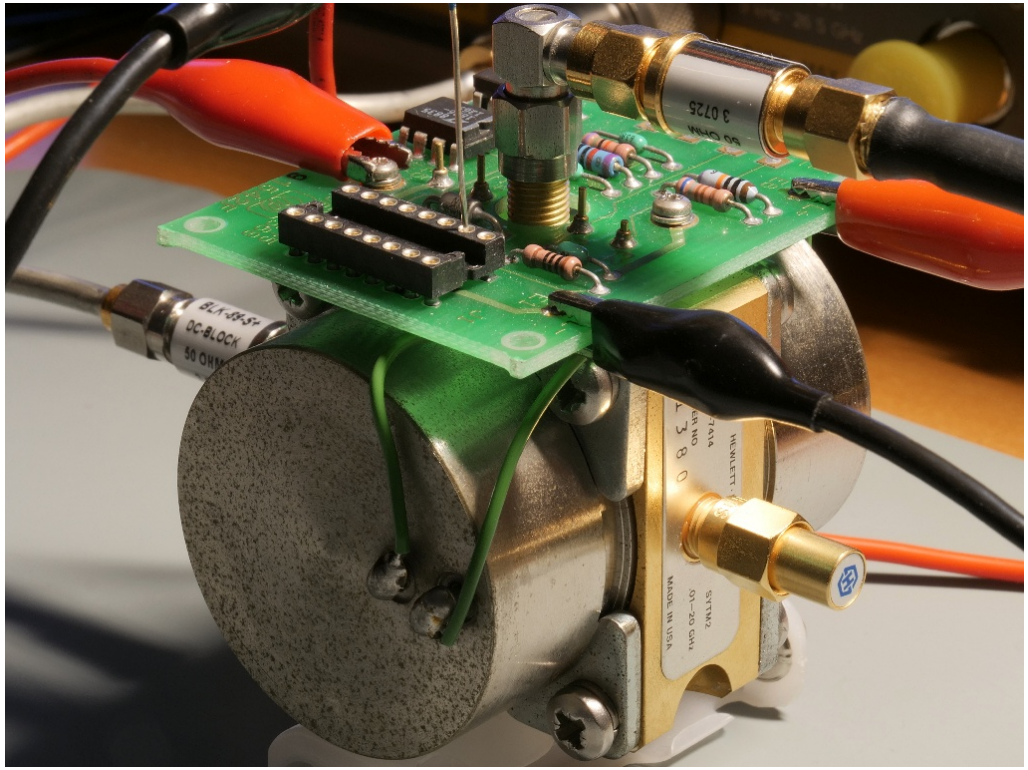
High band in
2.3 –7.0 GHz

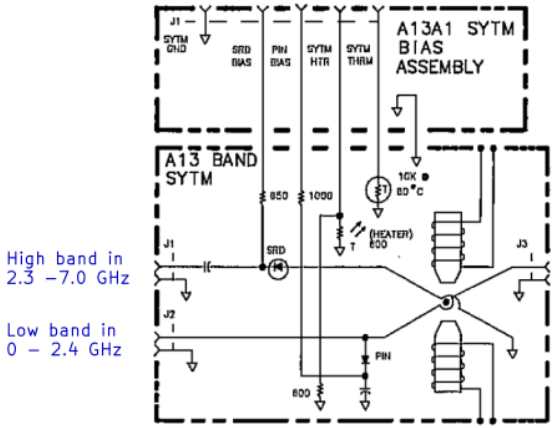
Low band in
0 – 2.4 GHz



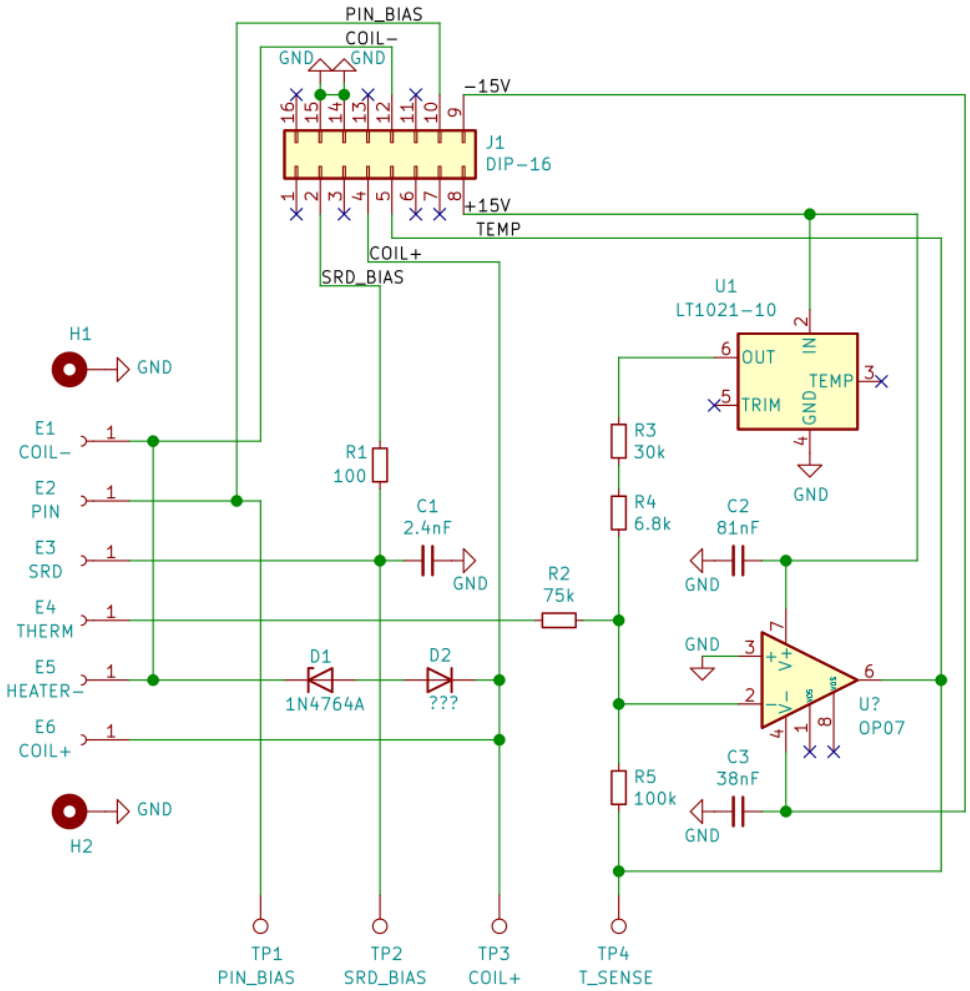
Output
0 – 20 GHz

HP 5086–7414
Coil: 50 ohm (15 mA/GHz)
Heater: 295 ohm to GND



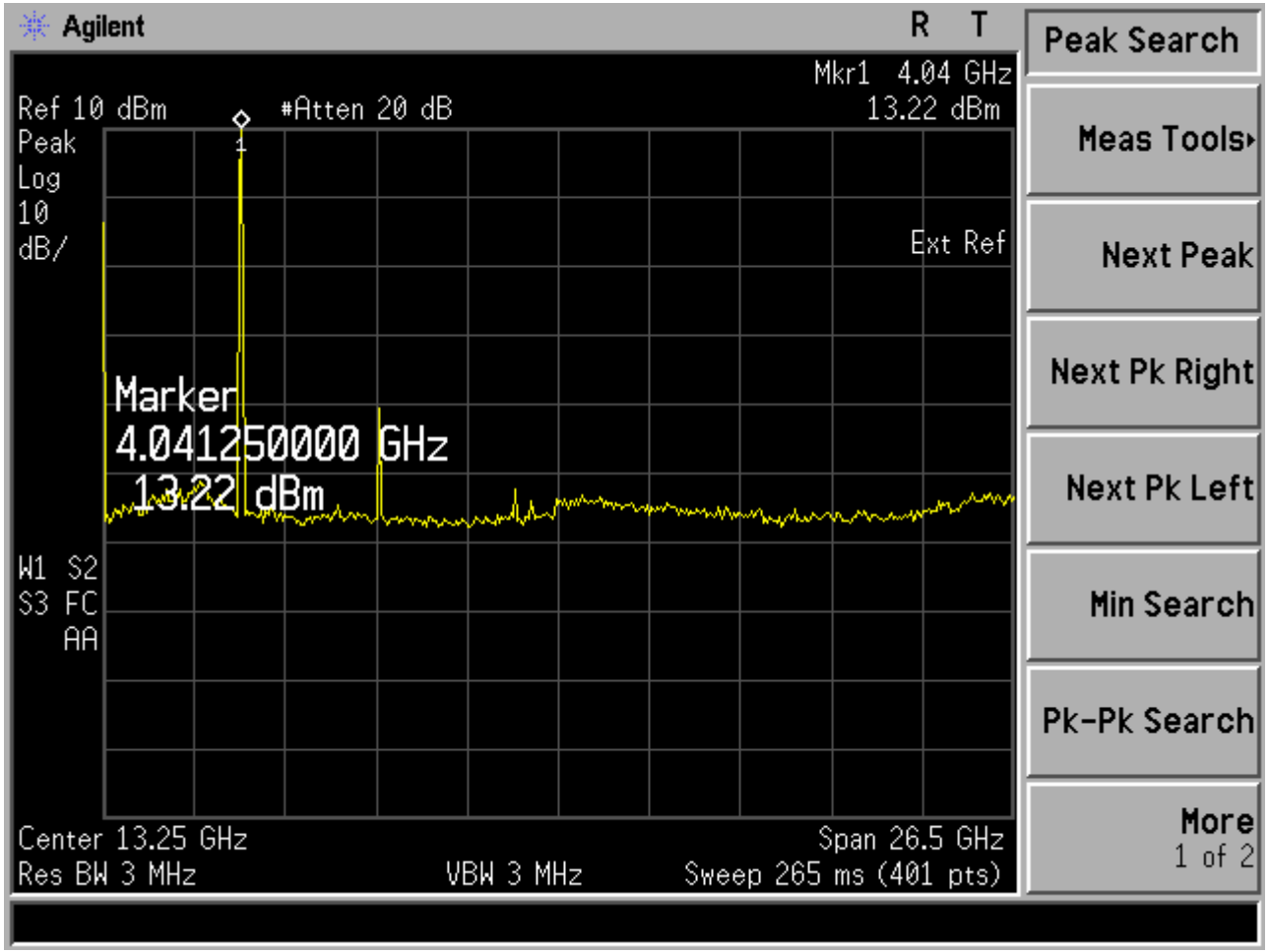


HP 5086–7414
Coil: 50 ohm (15 mA/GHz)
Heater: 295 ohm to GND



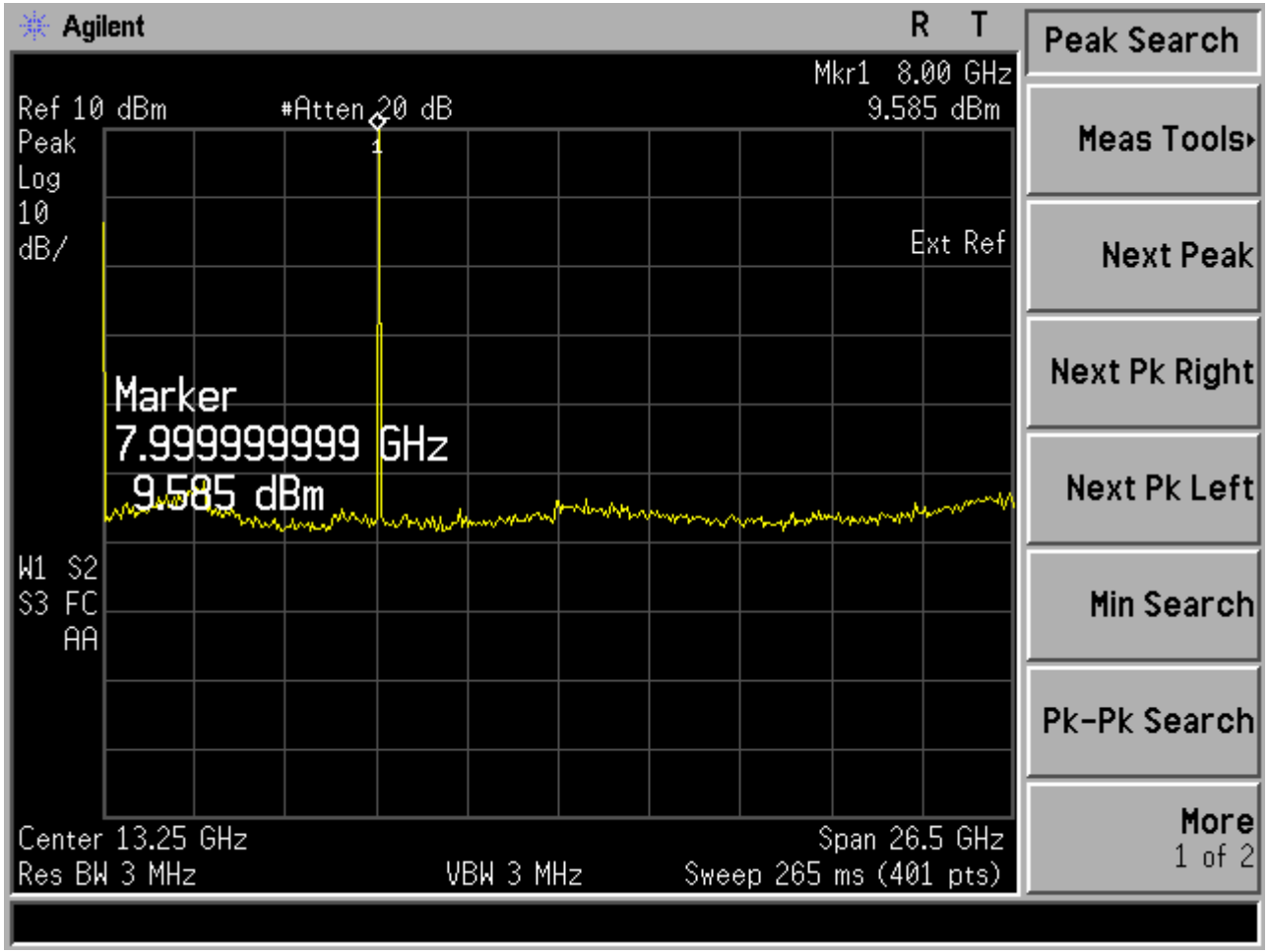
4 GHz out

- 4 GHz in
- at 25dBm
- Heater off



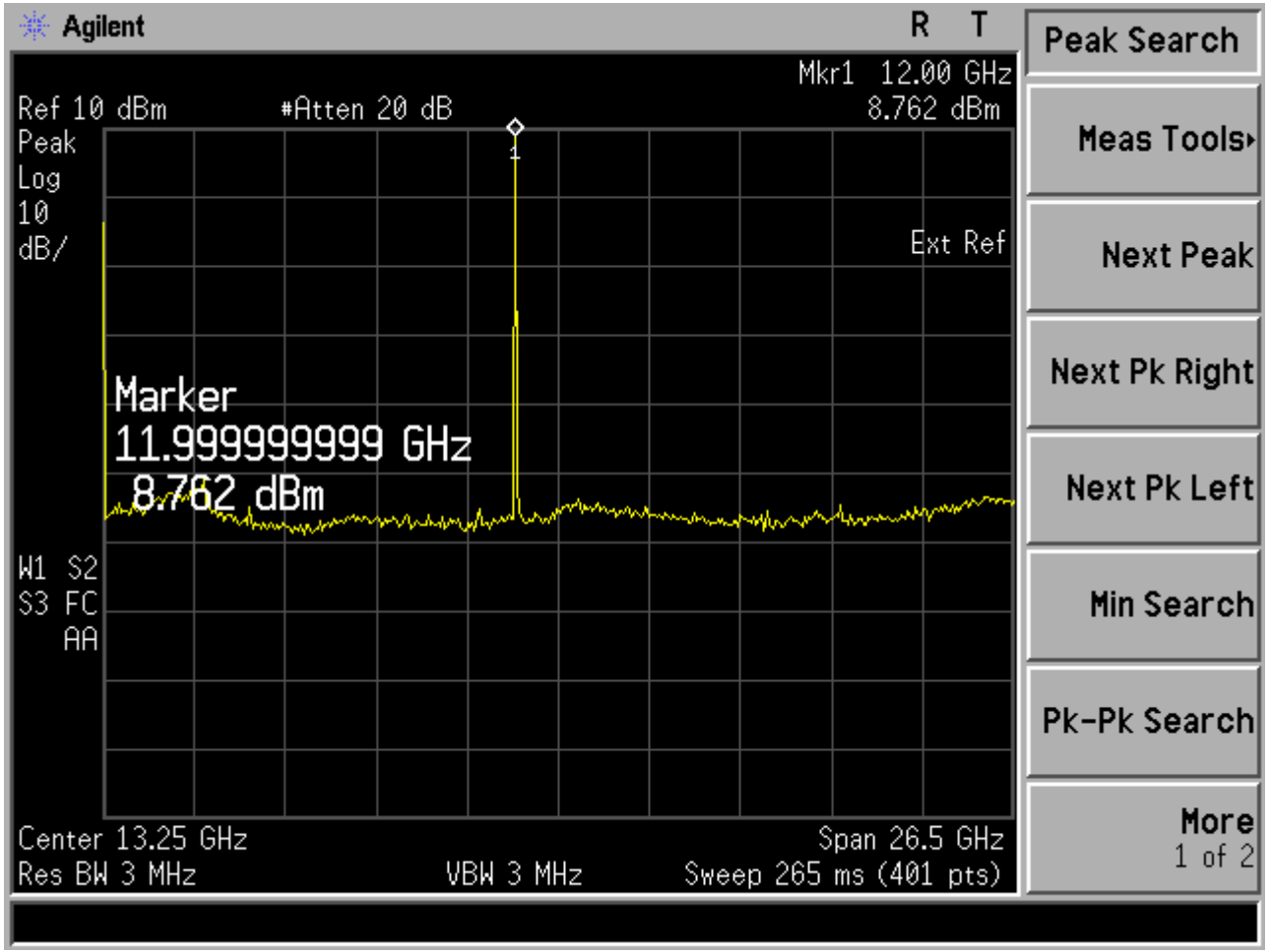
8 GHz out

- 4 GHz in
- at 25dBm
- Heater off



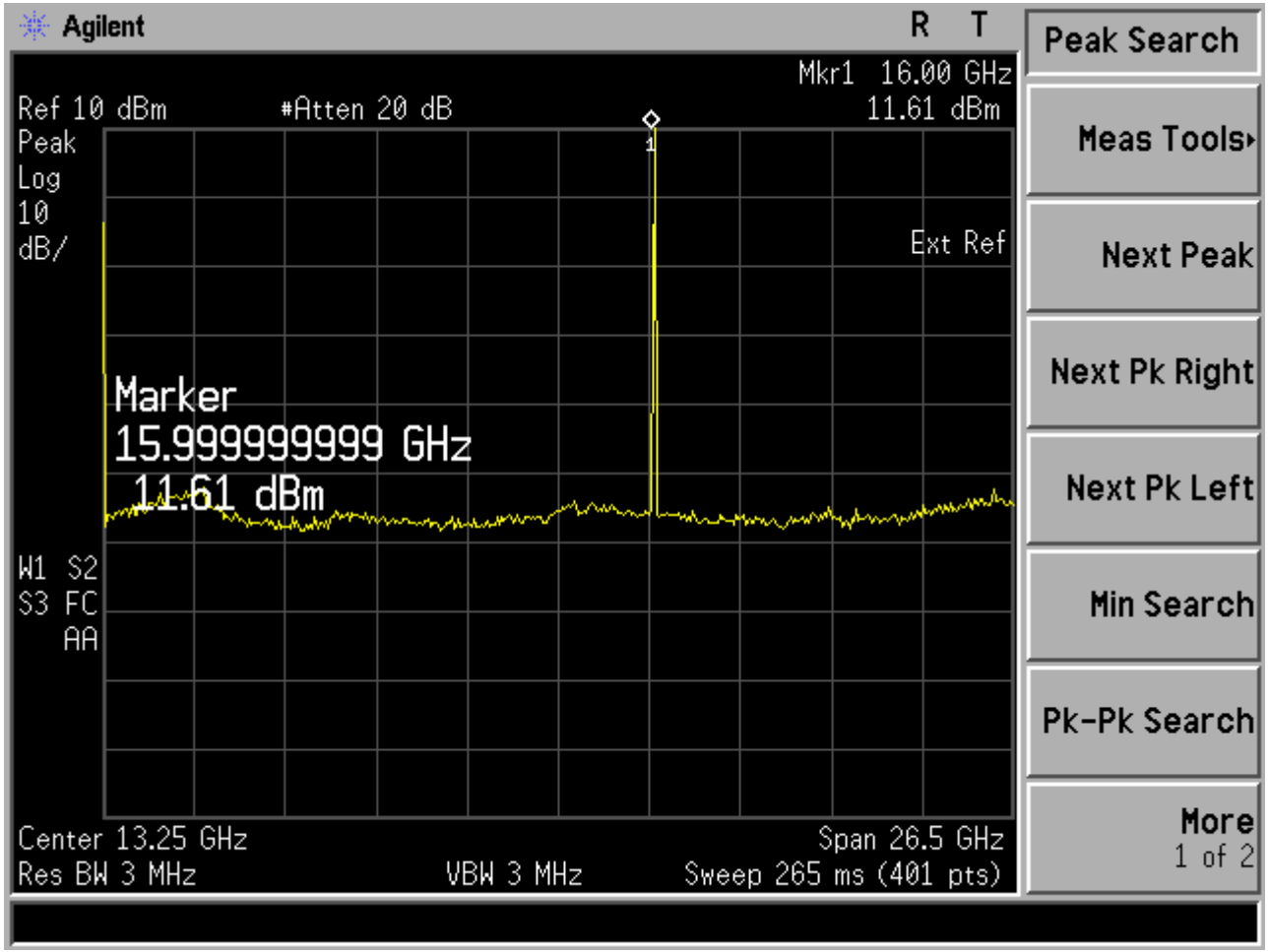
12 GHz out

- 4 GHz in
- at 25dBm
- Heater off



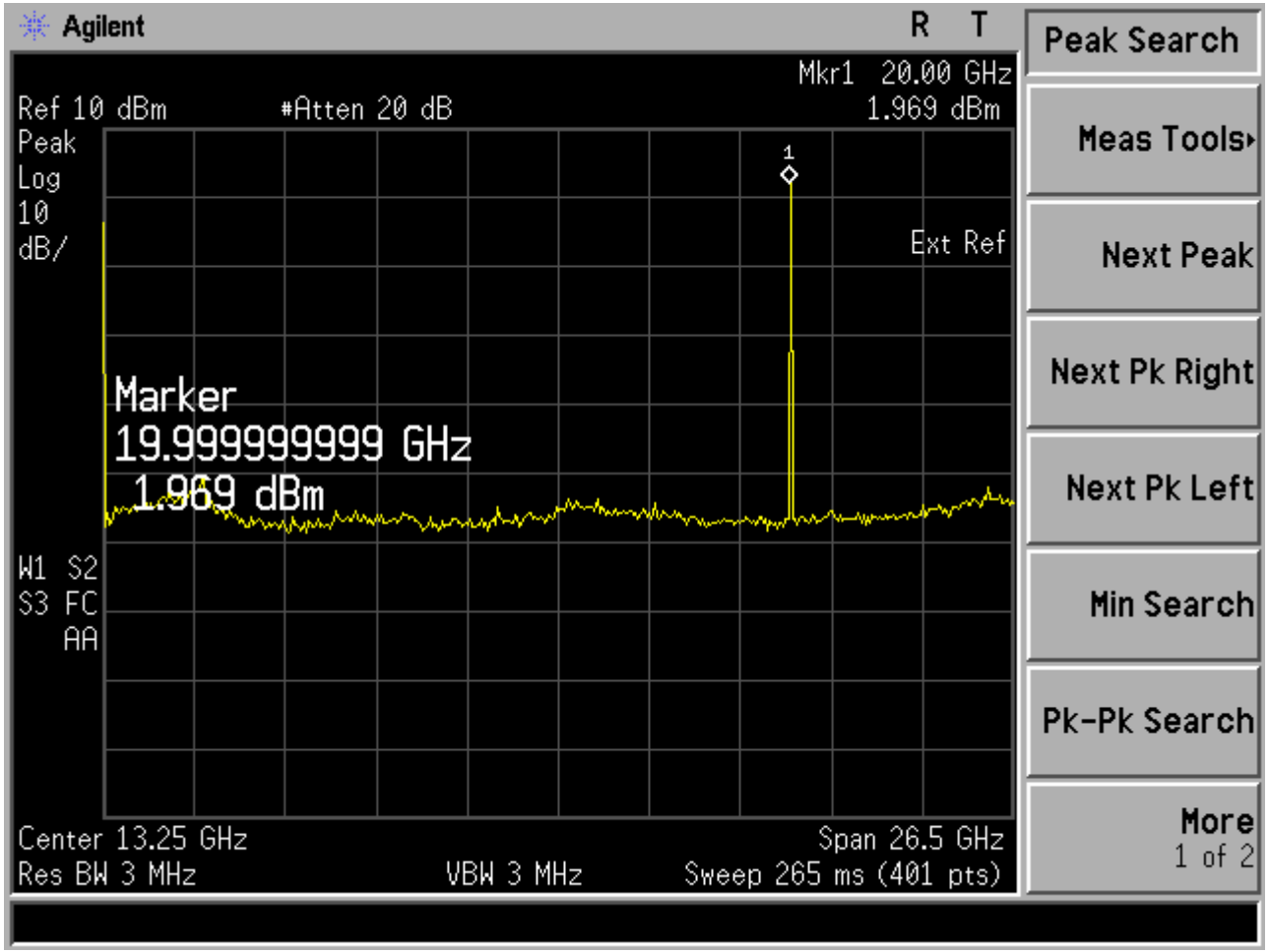
16 GHz out

- 4 GHz in
- at 25dBm
- Heater off



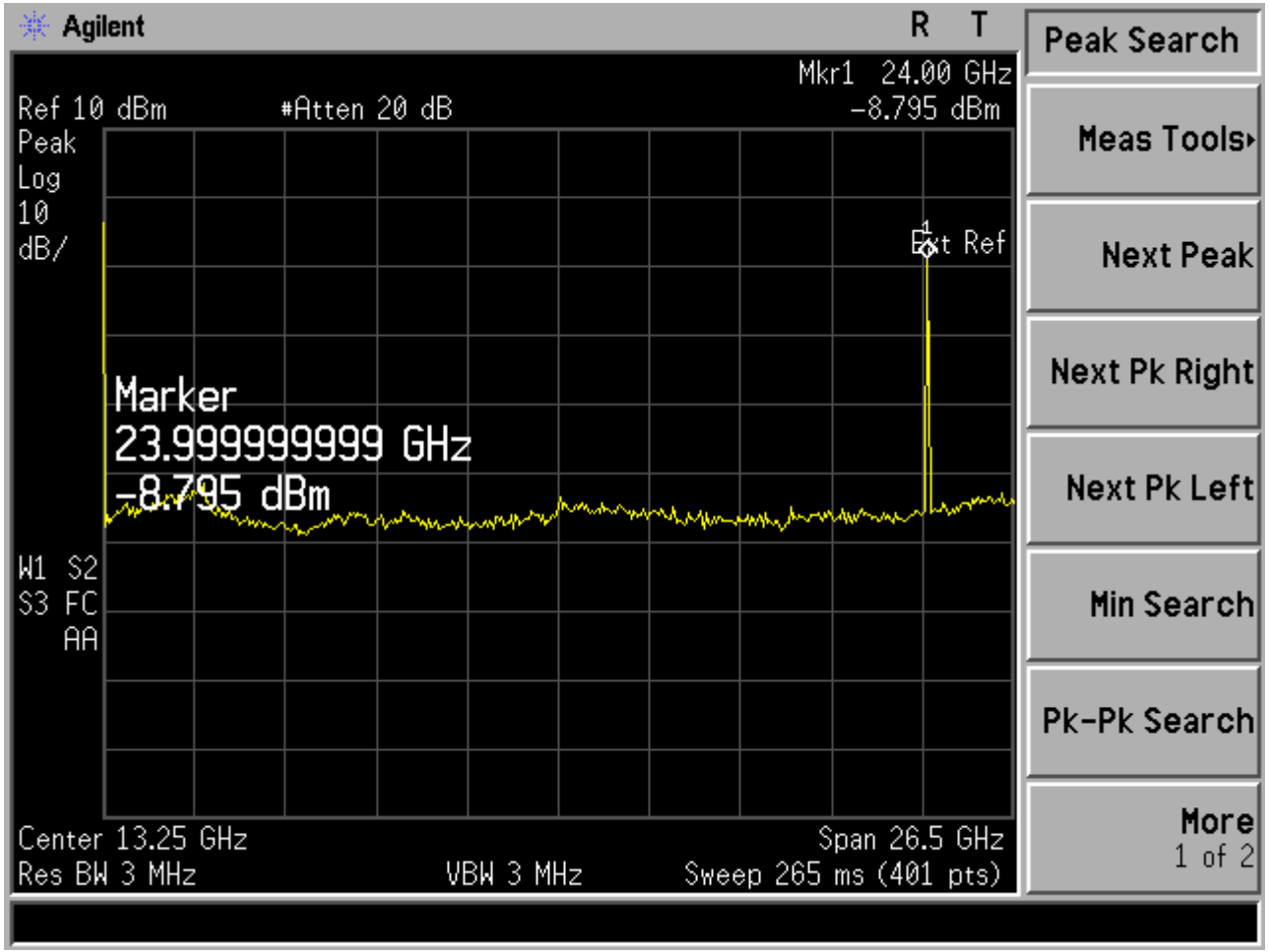
20 GHz out

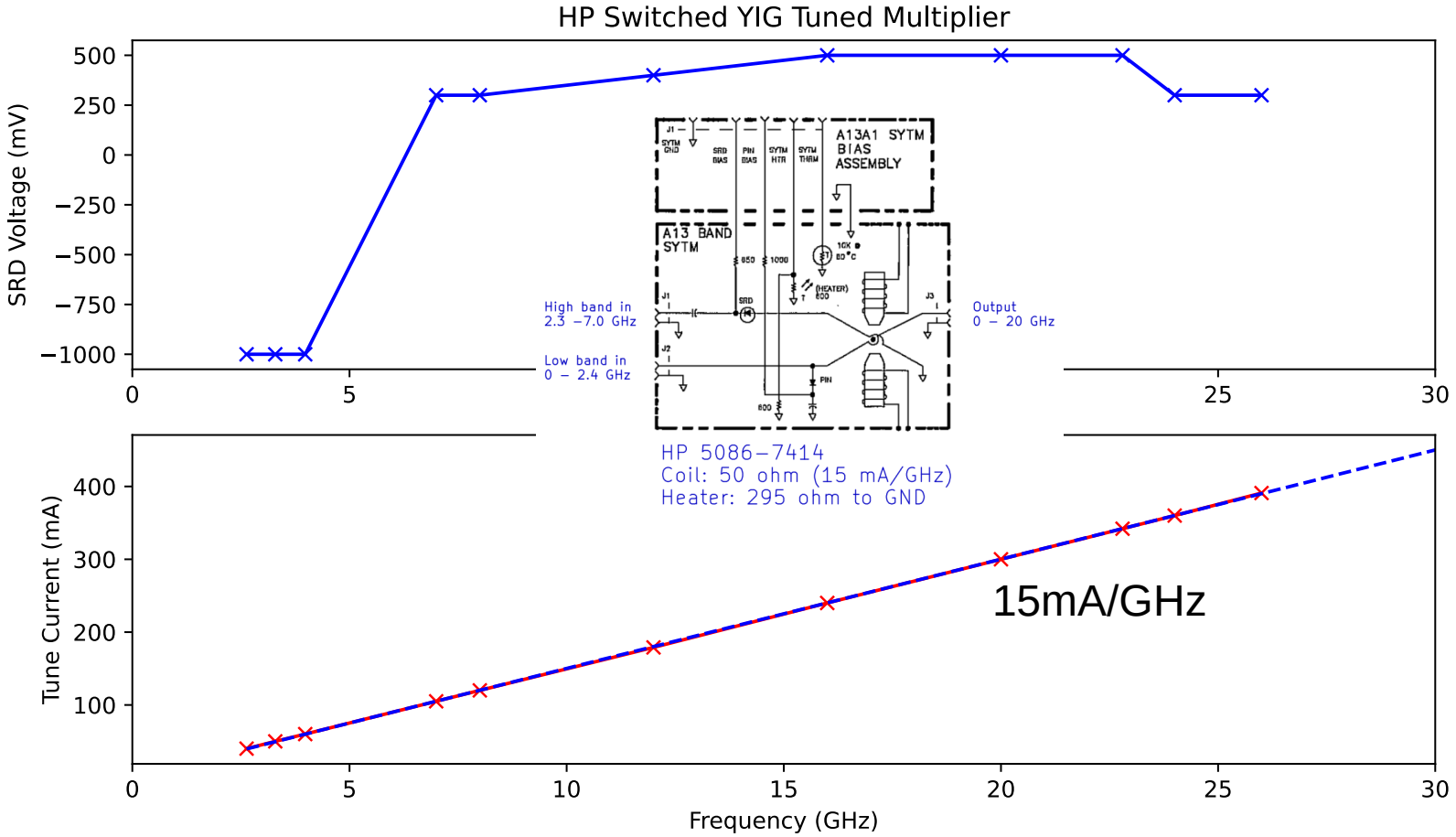
- 4 GHz in
- at 25dBm
- Heater off



24 GHz out

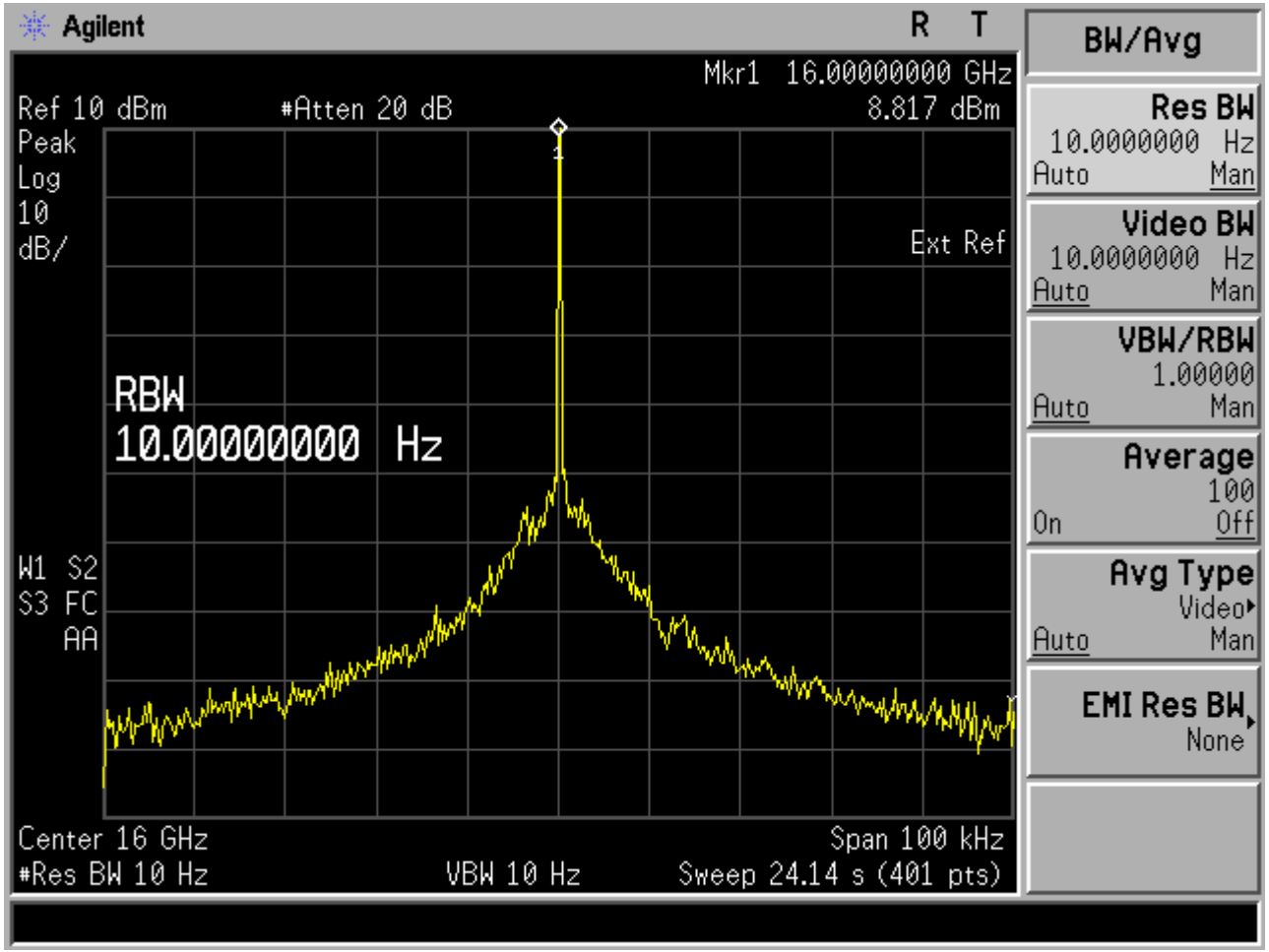
- 4 GHz in
- at 25dBm
- Heater off




HP Switched YIG Tuned Multiplier
SRD Voltage (mV)
500
250
0
−250
−500
−750
−1000
0
5
25
30
A13A1 SYTM
BIAS
ASSEMBLY
A13 BAND
SYTM
High band in
2.3 −7.0 GHz
Low band in
0 − 2.4 GHz
Output
0 − 20 GHz
HP 5086−7414
Coil: 50 ohm (15 mA/GHz)
Heater: 295 ohm to GND
Tune Current (mA)
400
300
200
100
0
5
10
15
20
25
30
Frequency (GHz)
15mA/GHz

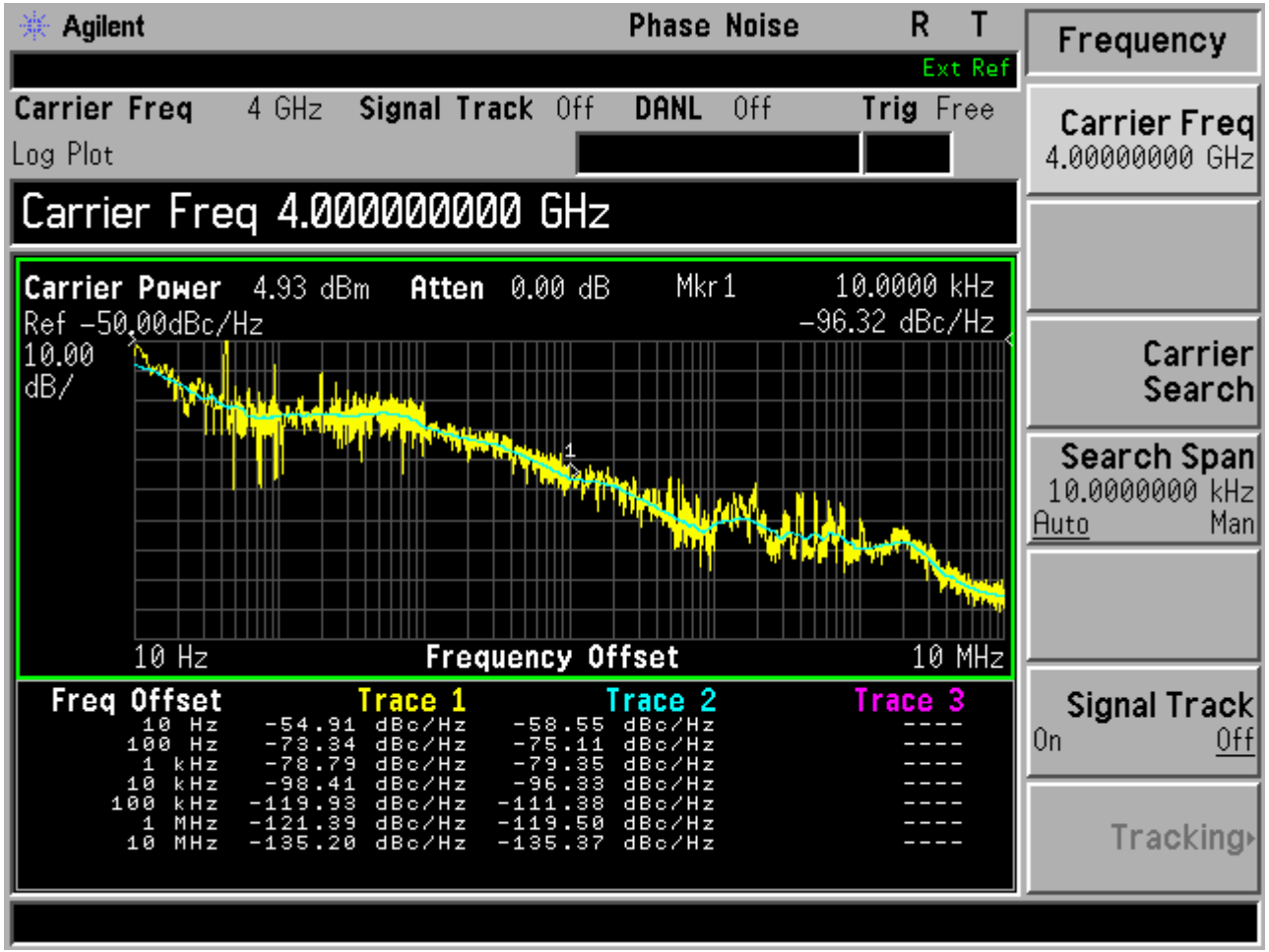
16 GHz

- Phase noise of the source gets multiplied 4 times == gets worse by 20*log(4)=12dB



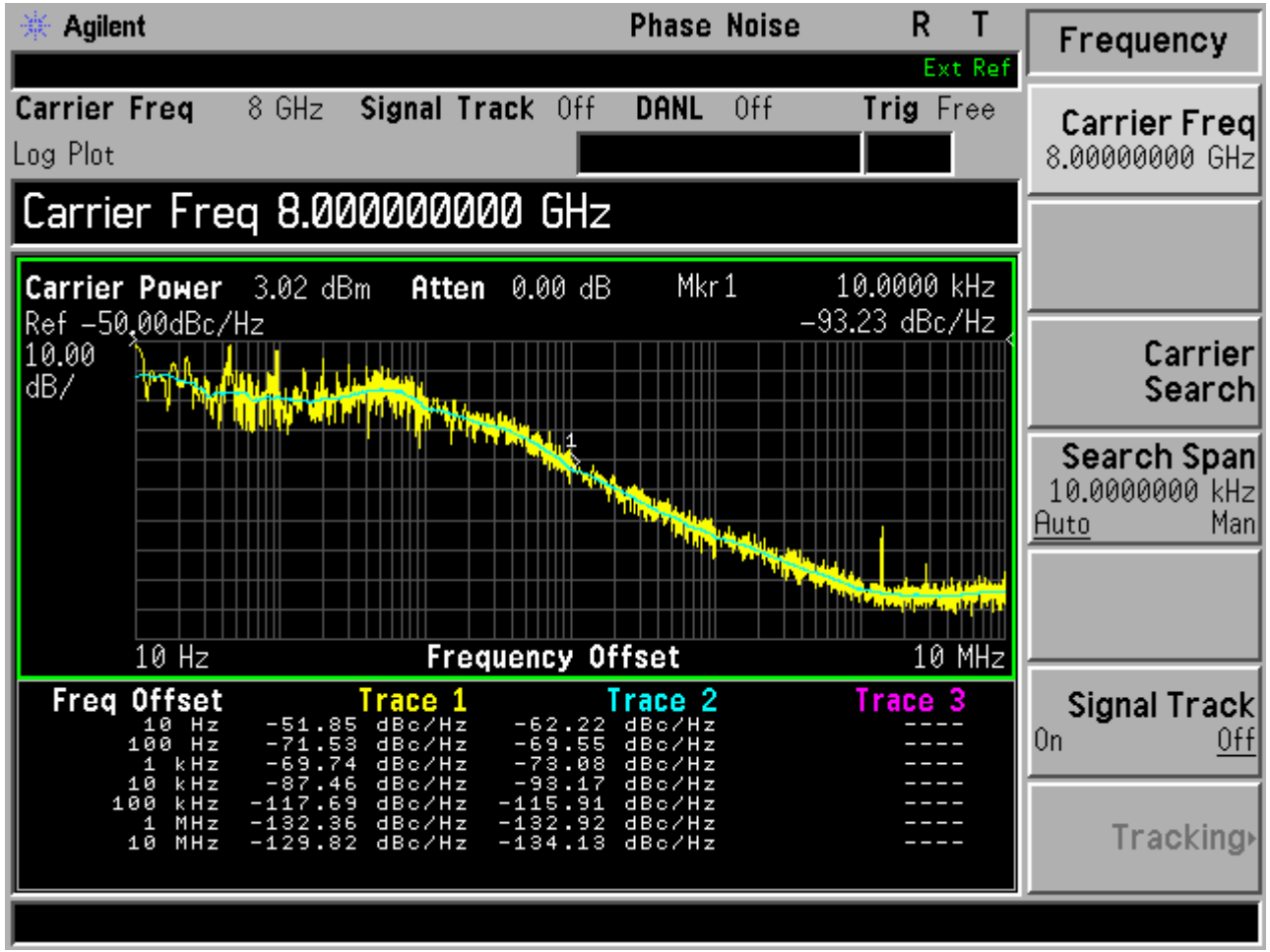
4GHz out

- 4GHz in



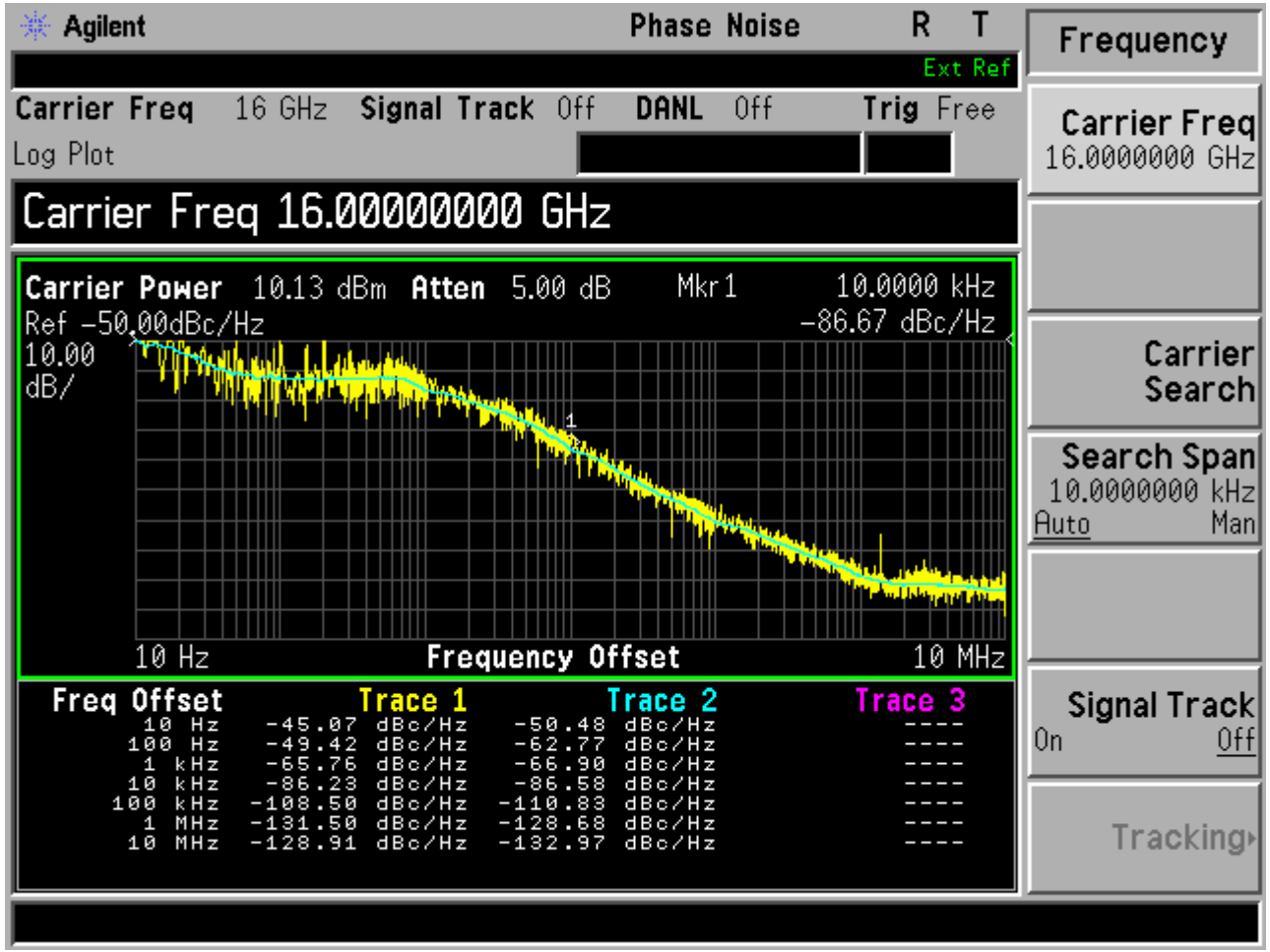
8 GHz out

- 4GHz in



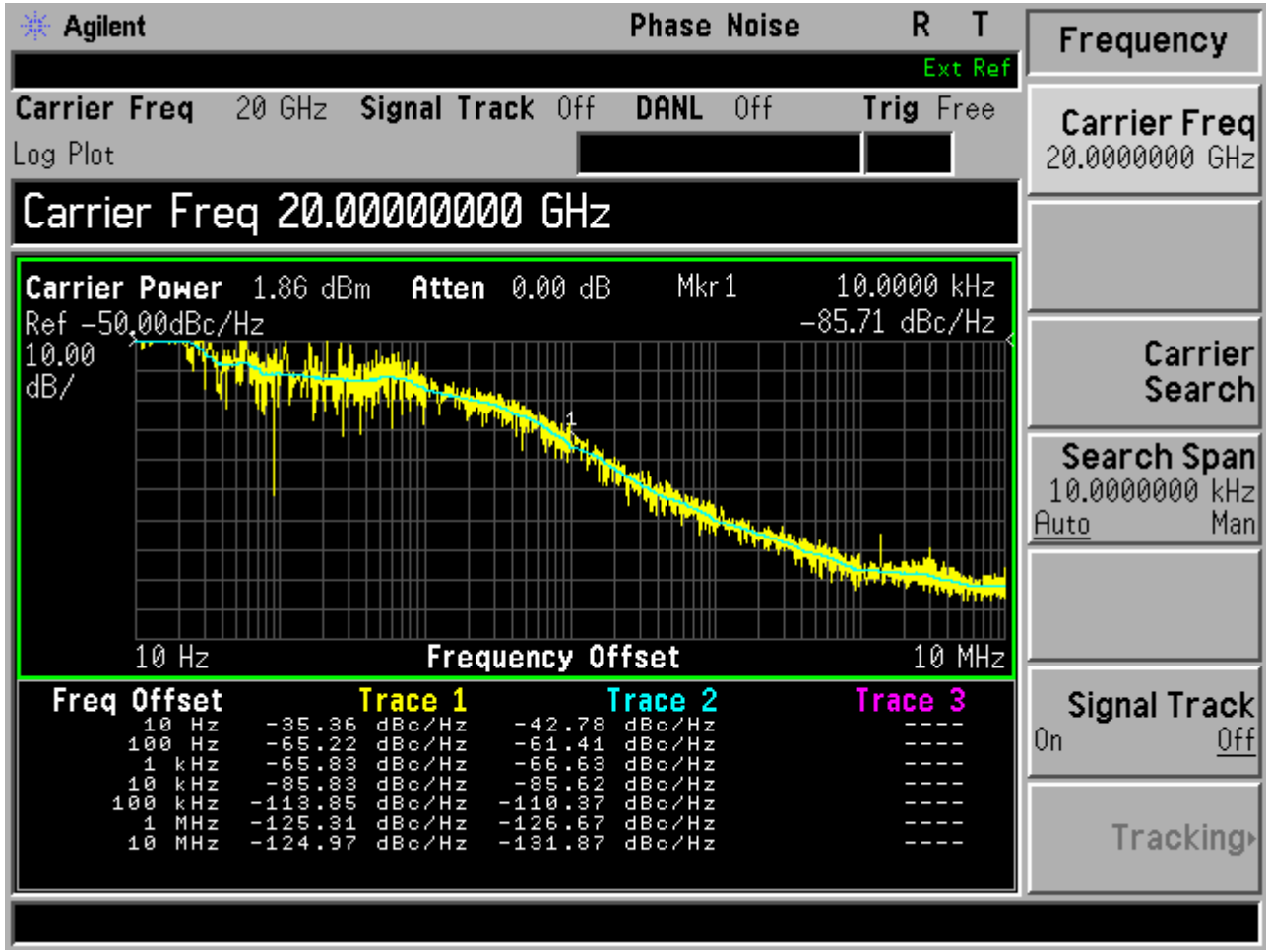
16 GHz out

- 4GHz in



20 GHz

- 4GHz in



Summary

- Usable from approximately 2.6GHz (at 40mA) and up
- Spec is 20 GHz, at 390mA (for 26GHz output) into 50 ohms of the tuning coil is $P = I^2R = 7.6W$ already!
  - It is wise to stay in-spec (approx. 300mA, 4.5W)
  - It gets worse once the coil copper heats up
  - The YIG sphere operates best at a nominal temperature
- Although linear freq. response, it becomes very difficult to manage band switching and compensation of nonlinearities (such as hysteresis) when used in a swept signal generator

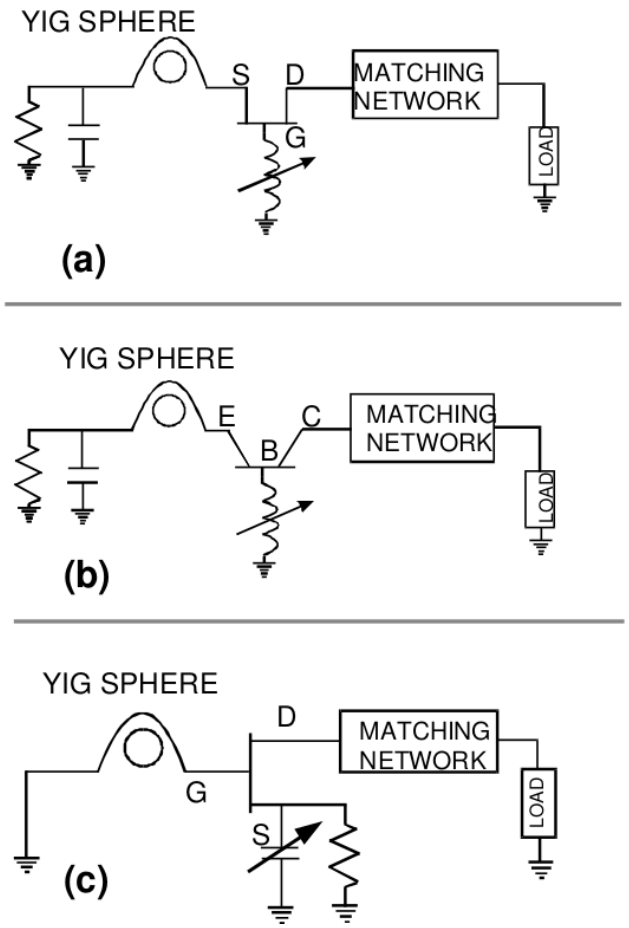
YIG Applications

- Oscillators – used in signal generators, network analyzers and receivers (spectrum analyzers)

YIG Oscillator

- YIG sphere used in the feedback loop of the amplifier
- Low phase noise because of the high Q of the YIG sphere
- Usually dual supply (+15V, -5V)
- Some models are biased to ~center frequency with a permanent magnet
- A smaller coil is used for fine frequency control (modulation, phase locked loop etc.)

Image source: Micro Lambda Wireless

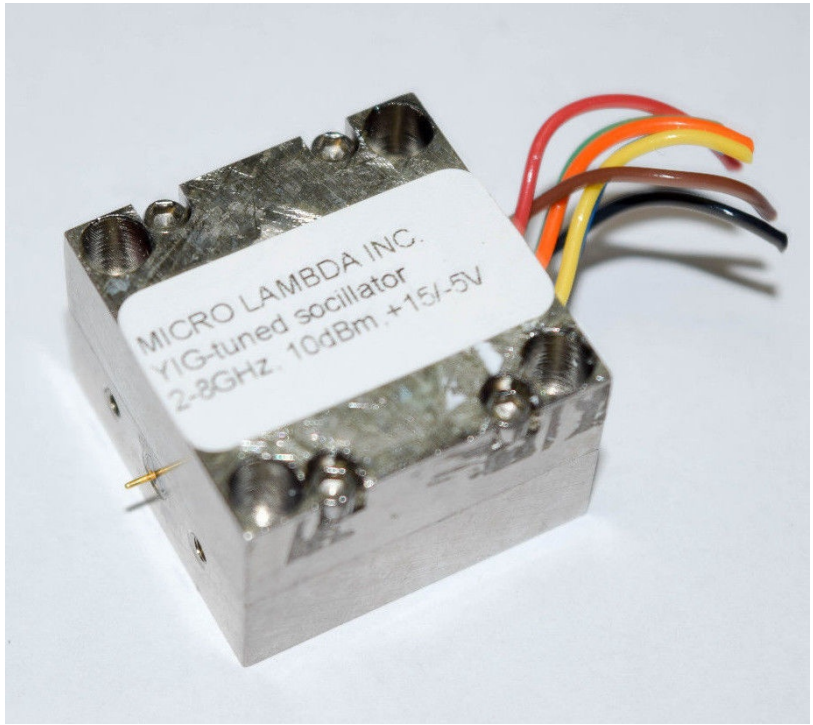


YIG Applications

- Oscillator example

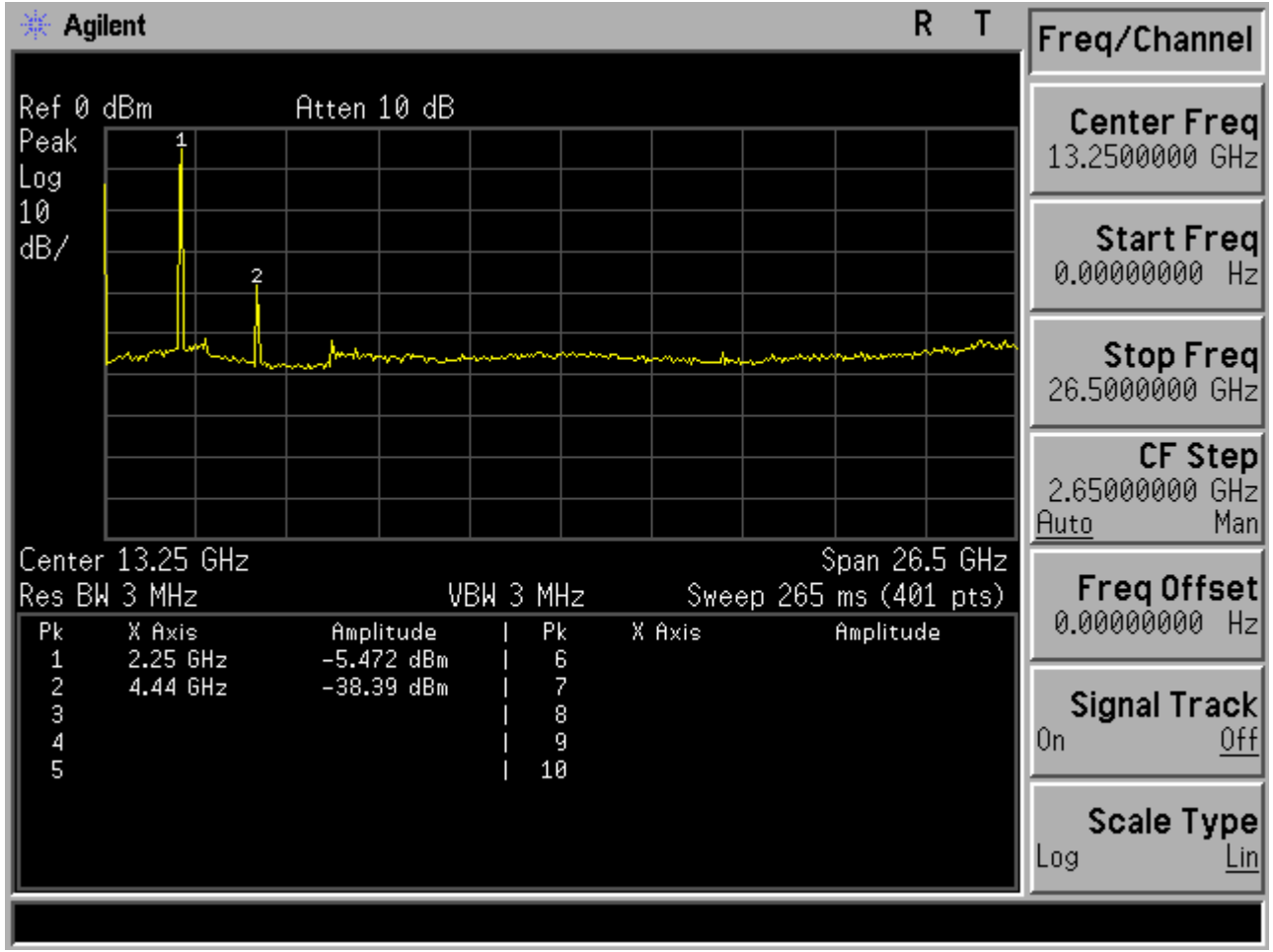
Micro Lambda Wireless “MLMH-0208”

- Tune coil 10 ohm
- FM coil 0.5 ohm
- Heater 138 ohm
- 15V @70mA, -5V @17mA



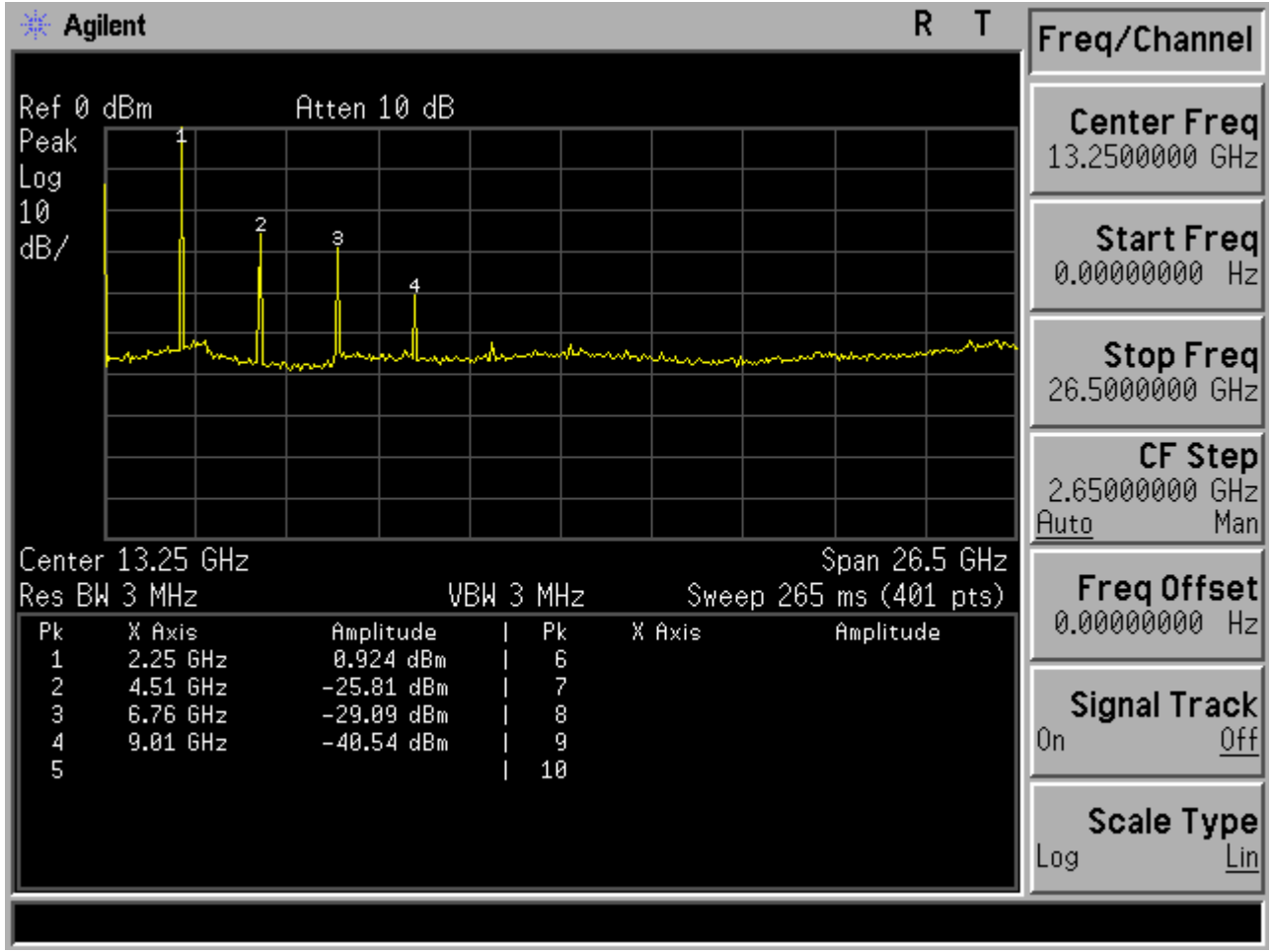
107 mA

- 2.25 GHz
- -5.4 dBm
- with 10dB att.



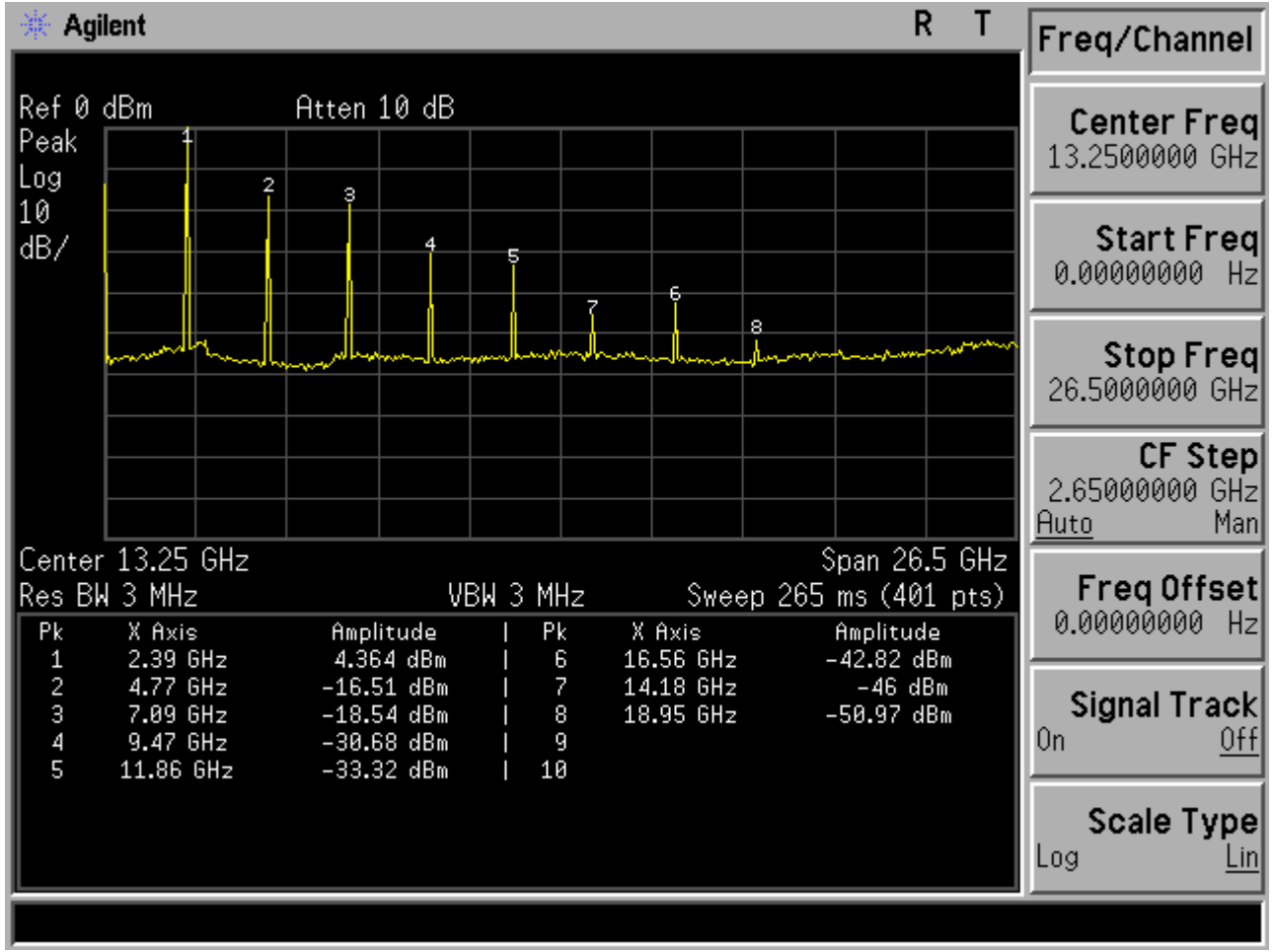
109 mA

- 2.25 GHz
- 0.9 dBm
- with 10dB att.



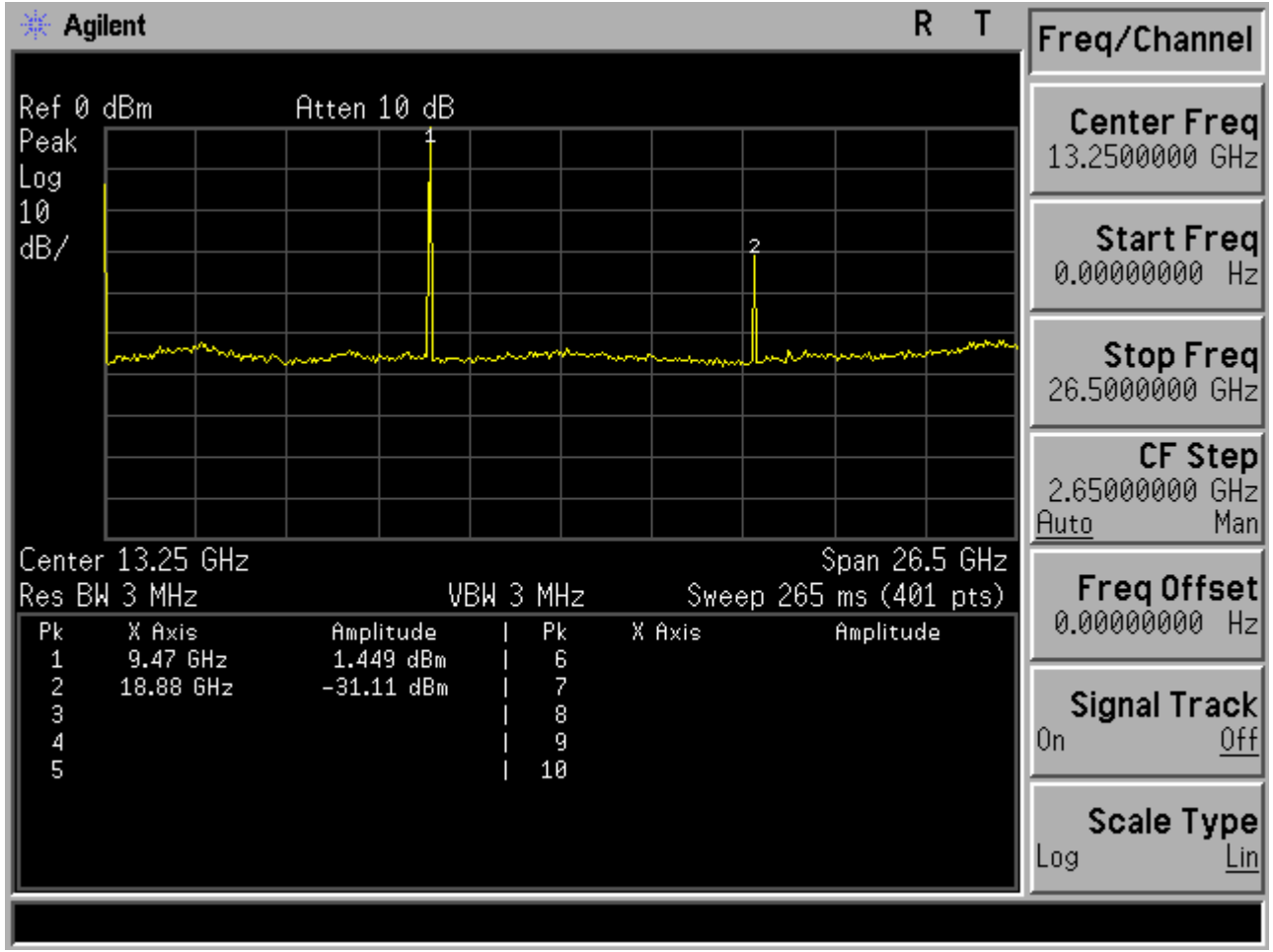
115 mA

- 2.39 GHz
- 4.3 dBm
- with 10dB att.



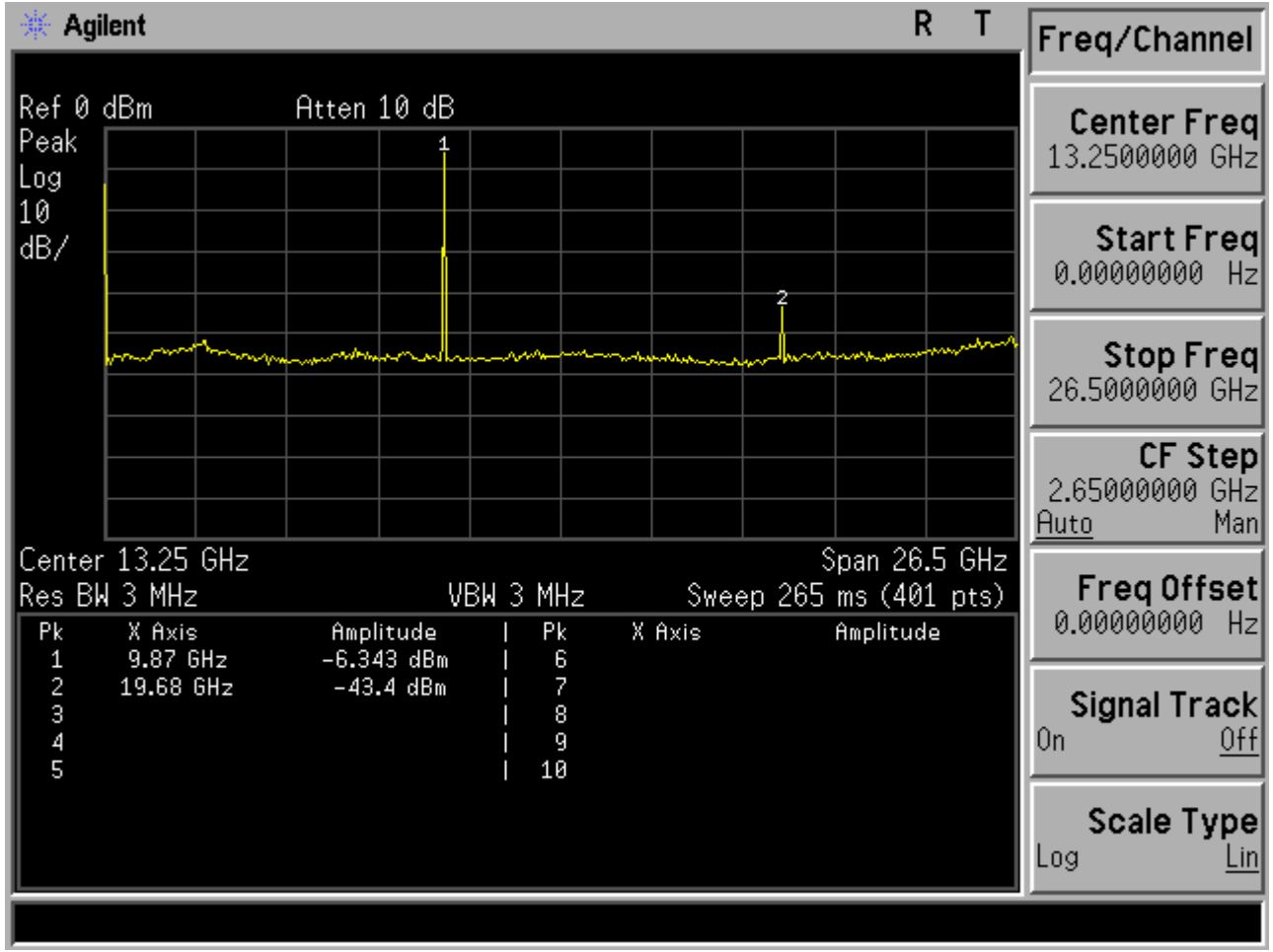
469 mA

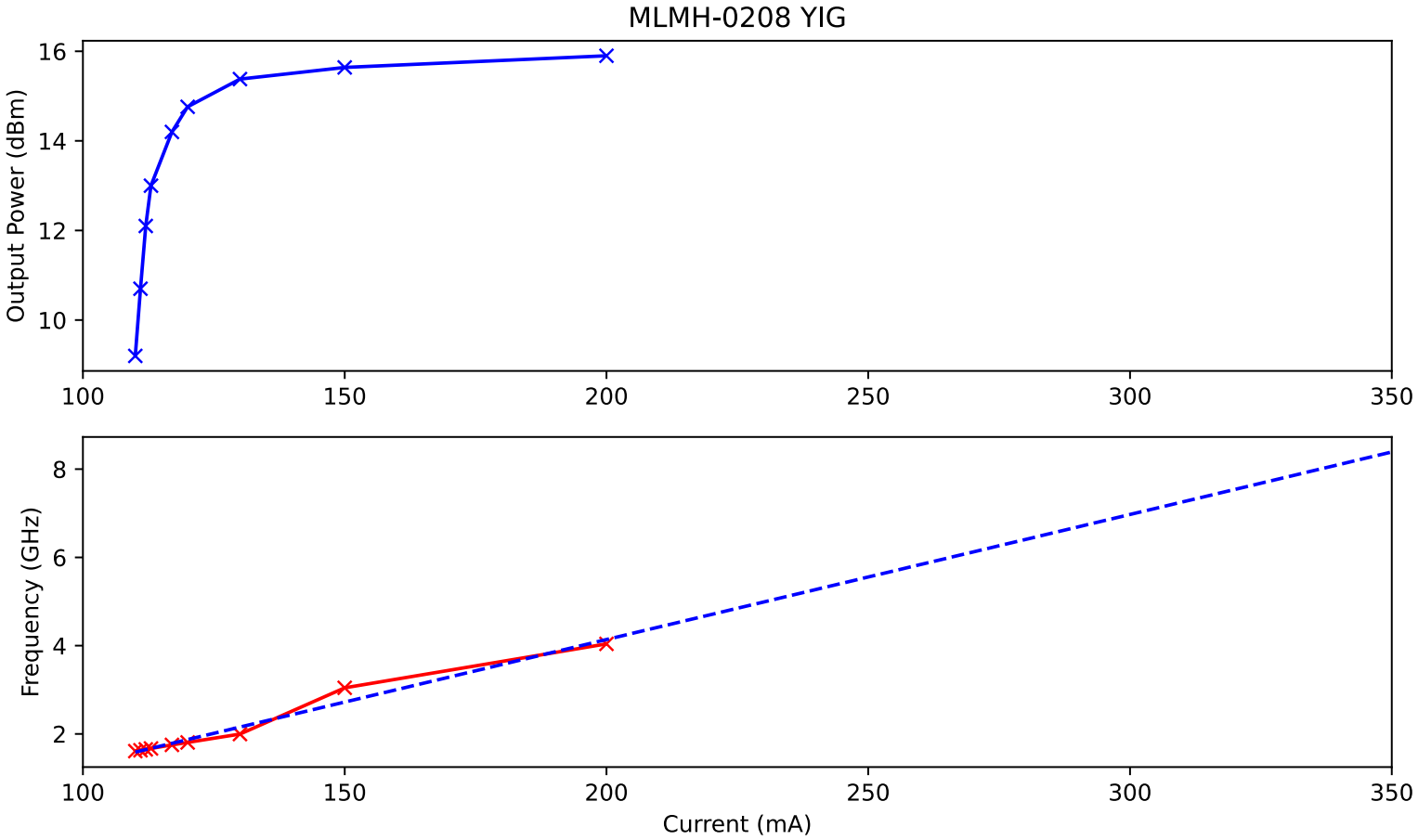
- 9.47 GHz
- 1.4 dBm
- with 10dB att.



489 mA

- 9.87 GHz
- -6.3 dBm
- with 10dB att.




MLMH-0208 YIG
Output Power (dBm)
16
14
12
10
100
150
200
250
300
350
Frequency (GHz)
8
6
4
2
Current (mA)

Summary

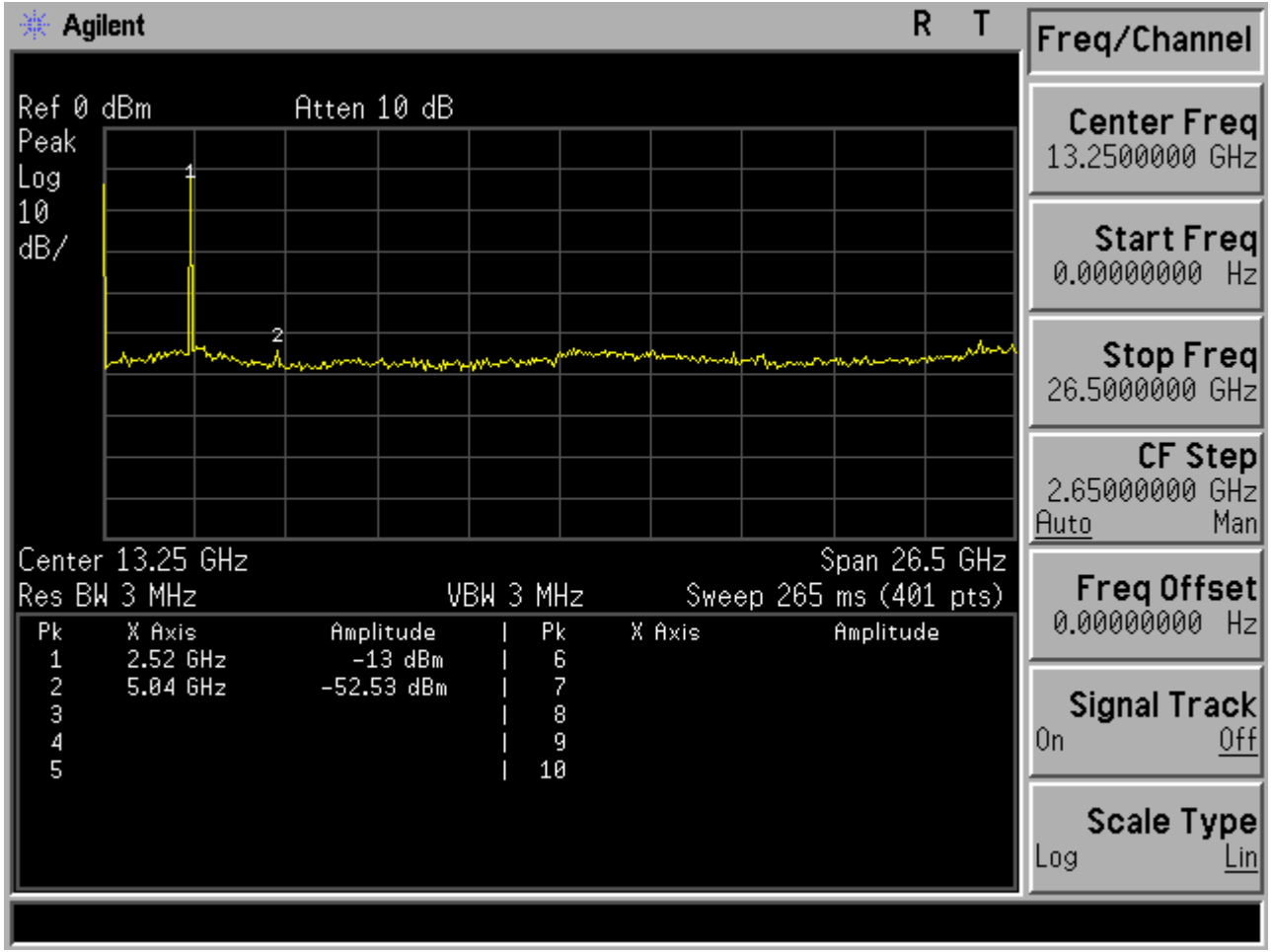
- Usable from approximately 2.25GHz (at 107mA)
- Spec is 8 GHz, at 470mA (for 9.5GHz output) into 6.45 ohms of the tuning coil is $P = I^2R = 2.2W$ already!
  - It gets worse once the coil copper heats up
  - The YIG sphere operates best at a nominal temperature
- Harmonics present
- Open loop sweeping is likely difficult due to drift/nonlinearities, but a PLL would compensate for that...

Watkins Johnson WJ-6703-14

- Specified for 4-8 GHz
- Tune coil 6.45 ohm
- FM coil 1.2 ohm
- Heater 375 ohm
- 15V @70mA, -5V @30mA

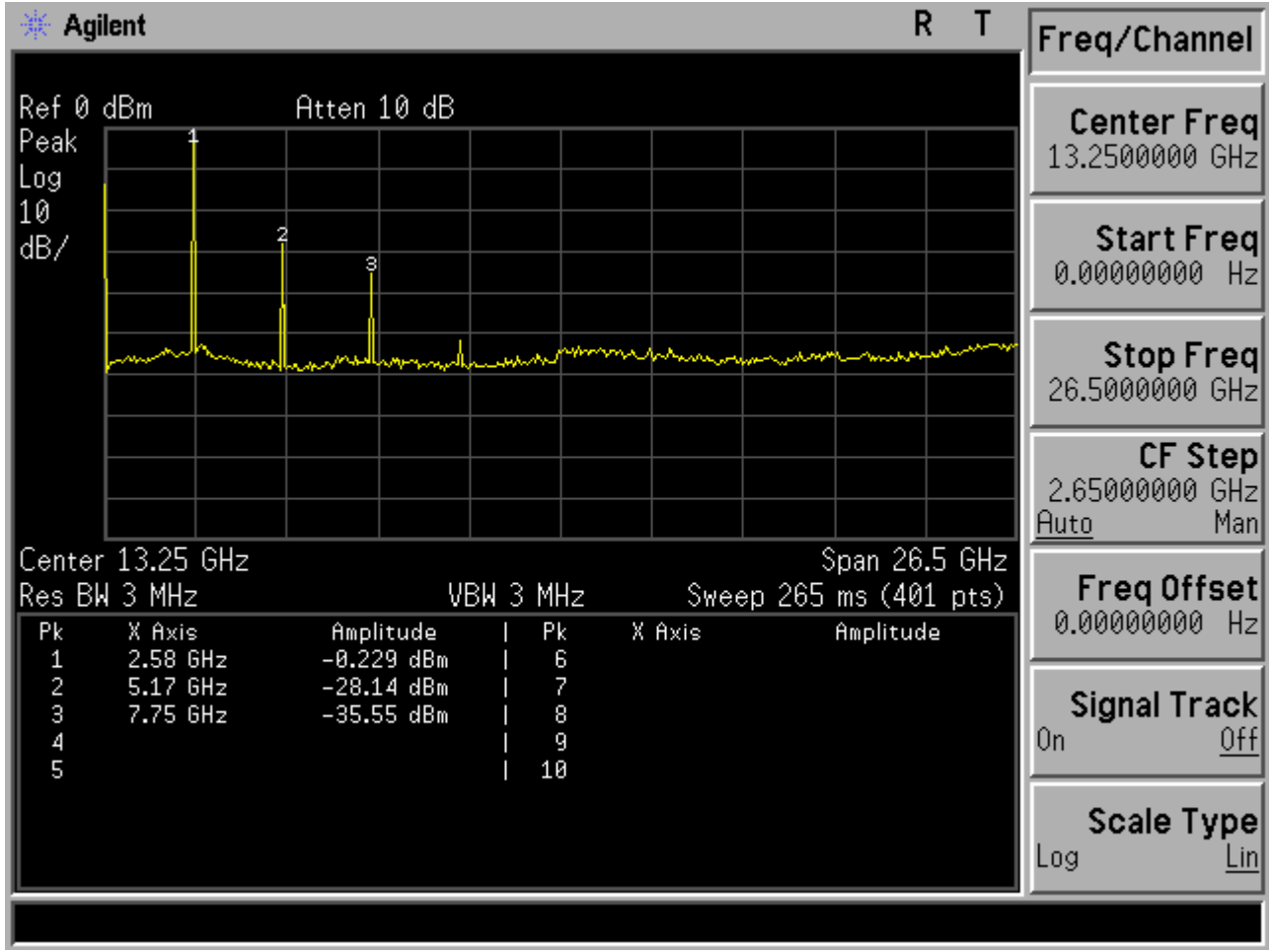
164 mA

- with 10dB att.



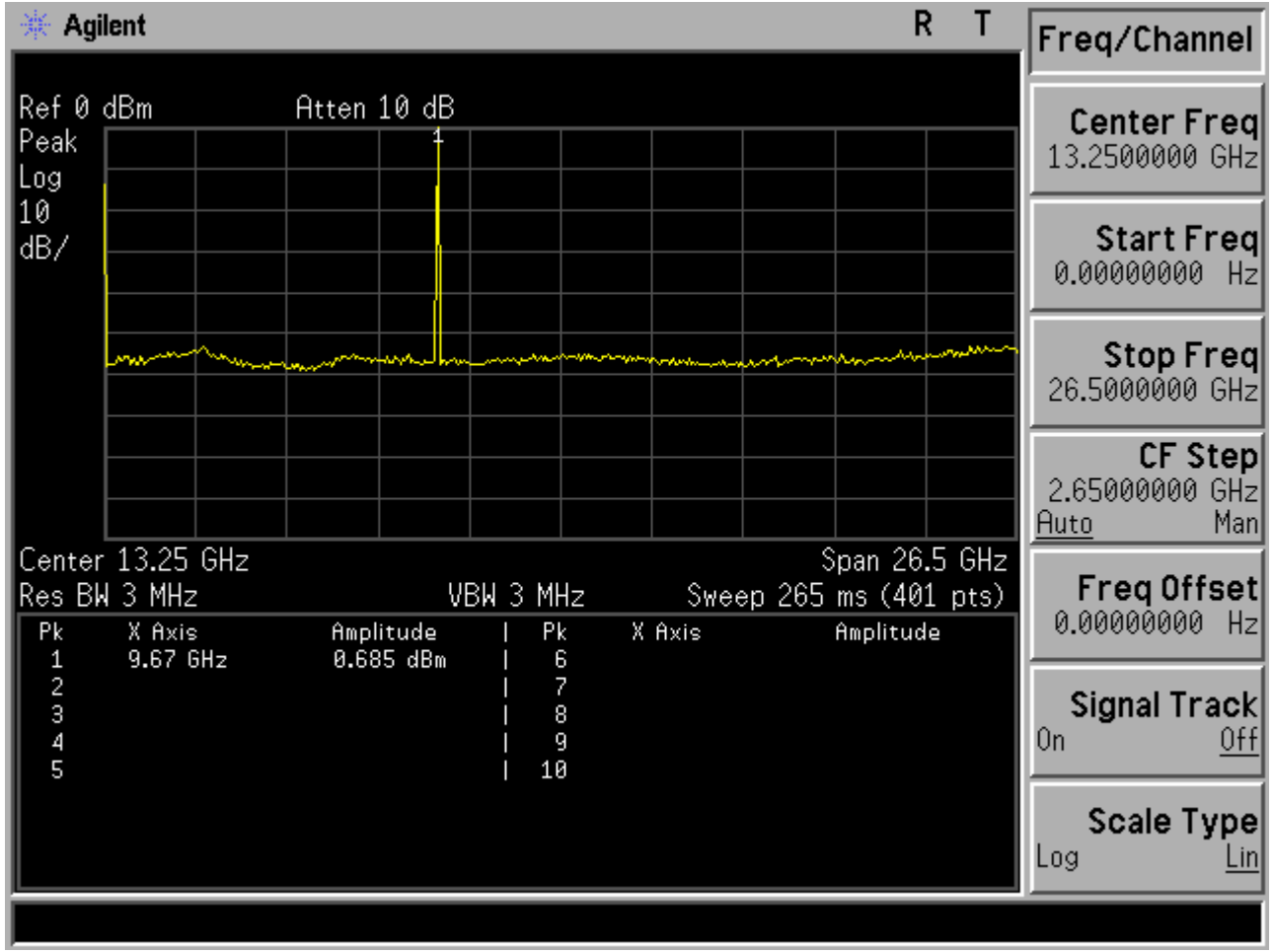
169 mA

- with 10dB att.



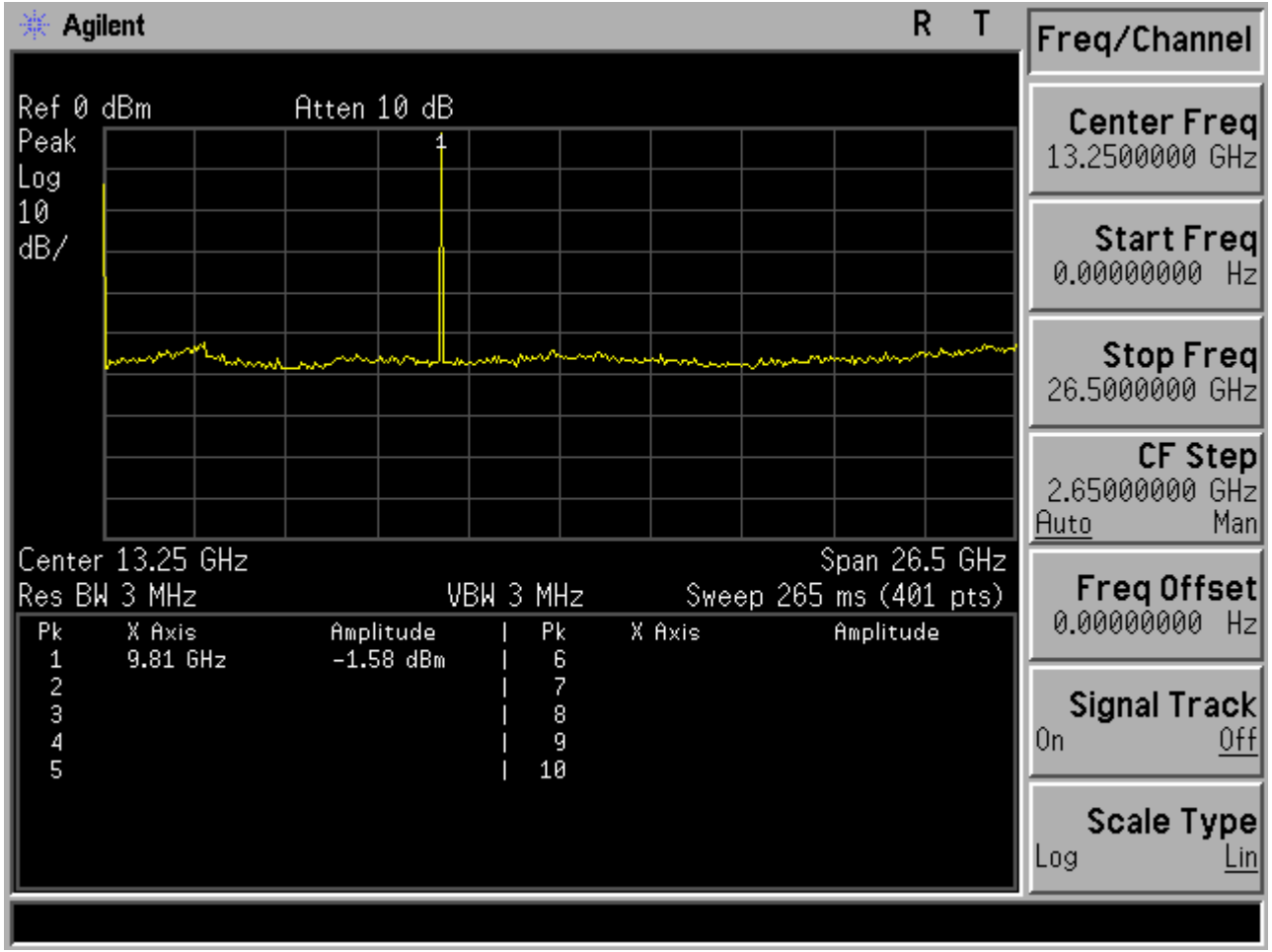
639 mA

- with 10dB att.



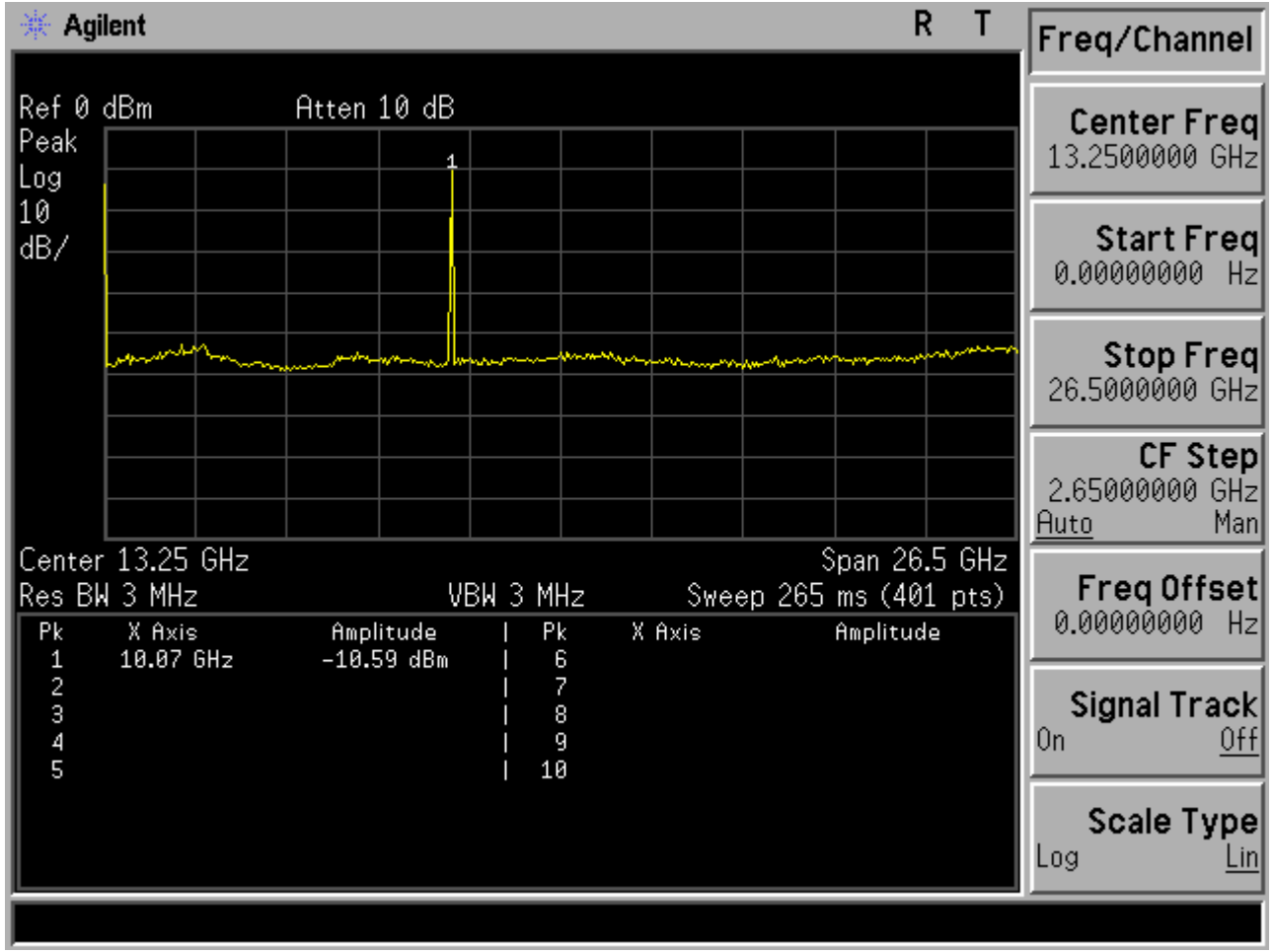
649 mA

- with 10dB att.



669 mA

- with 10dB att.



Summary

- Usable from approximately 2.6GHz (at 170mA) and up
- Spec is 8 GHz, at 650mA (for 9.8GHz output) into 6.45 ohms of the tuning coil is $P = I^2R = 2.7W$ already!
  - It gets worse once the coil copper heats up
  - The YIG sphere operates best at a nominal temperature
- Lower harmonics than the Microlambda type
- Open loop sweeping is likely difficult due to drift/nonlinearities, but a PLL would compensate for that...

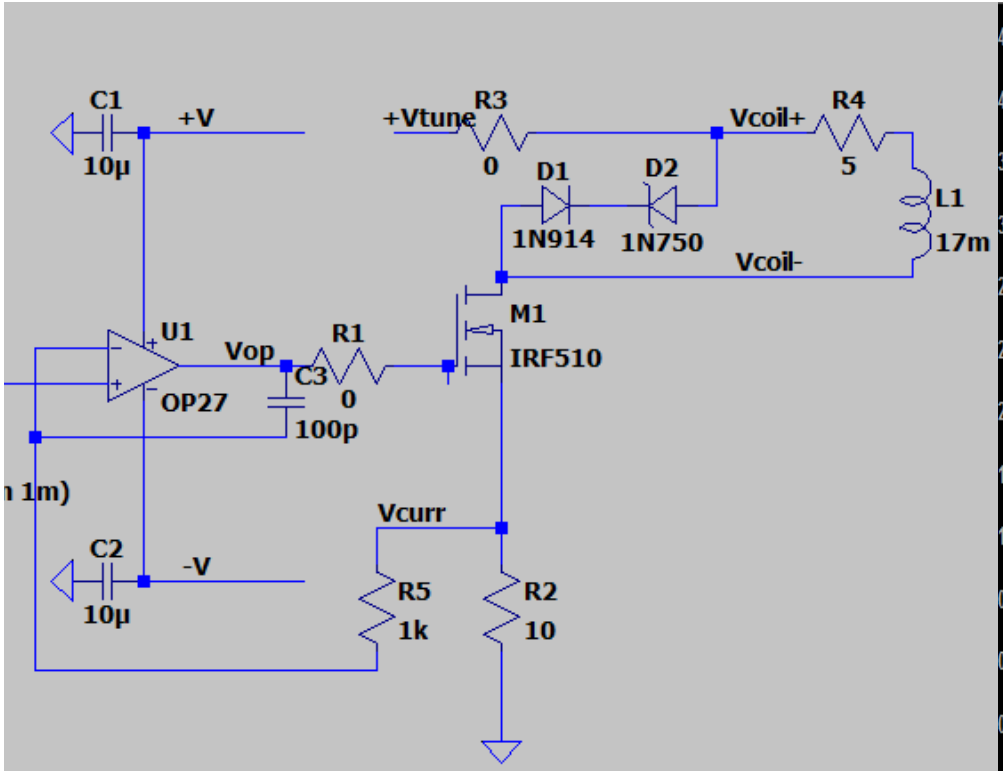
Osmocom YANG

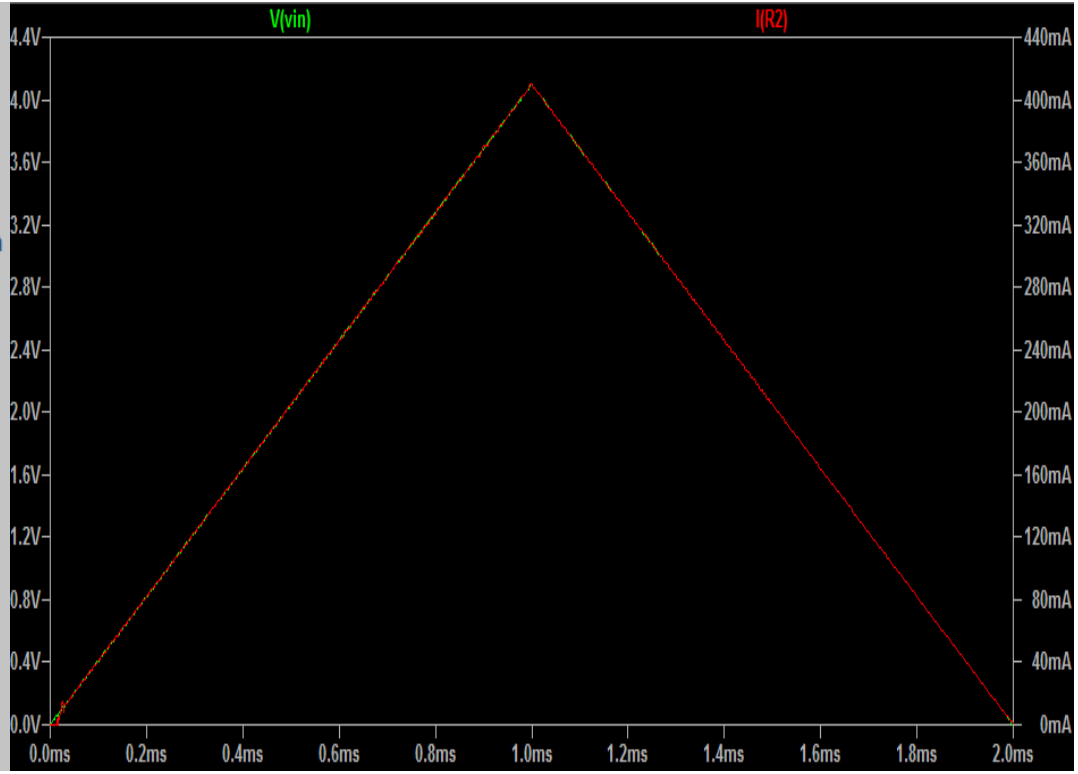
- Yet ANother yiG driver...

Osmocom YANG Requirements

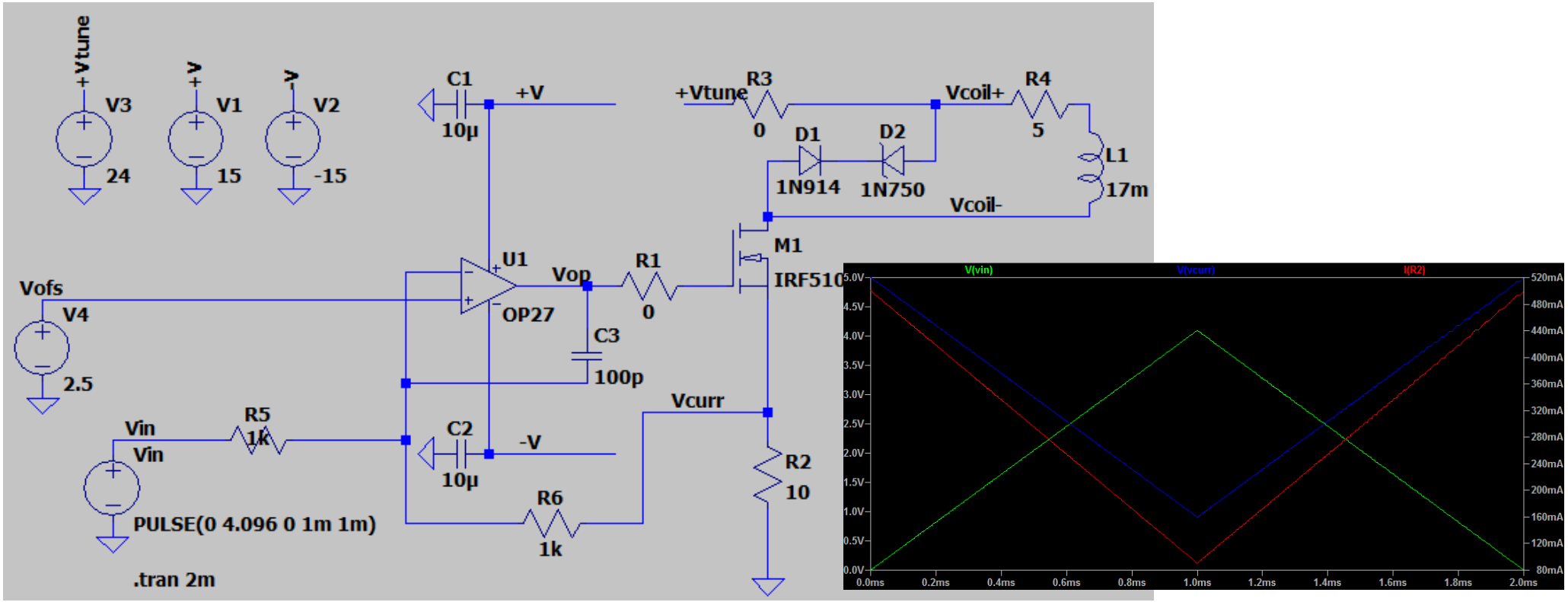
- Customizable to fit most surplus parts
  - optional circuit paths & components
  - switchable bandwidth for tune & FM coils
- Offset (50-500 mA) and slope (GHz/V) adjustment
  - up to 500mA into tune coil (but only positive currents here, so no support for permanent magnet YIGs)
  - +/- 100mA into FM coil (no offset here)
- Onboard DAC for direct filter/multiplier/mixer control
- But no PLL onboard because:
  - it depends on the actual frequency of interest, also loop BW...
  - requires quality substrate for low insertion loss (low reflection)
  - detached RF/Driver allows more flexibility when mounting “hot parts”
- Small form factor, cheap 2 layer FR4
- KiCad!

Simulation: Tune driver #1 (default)

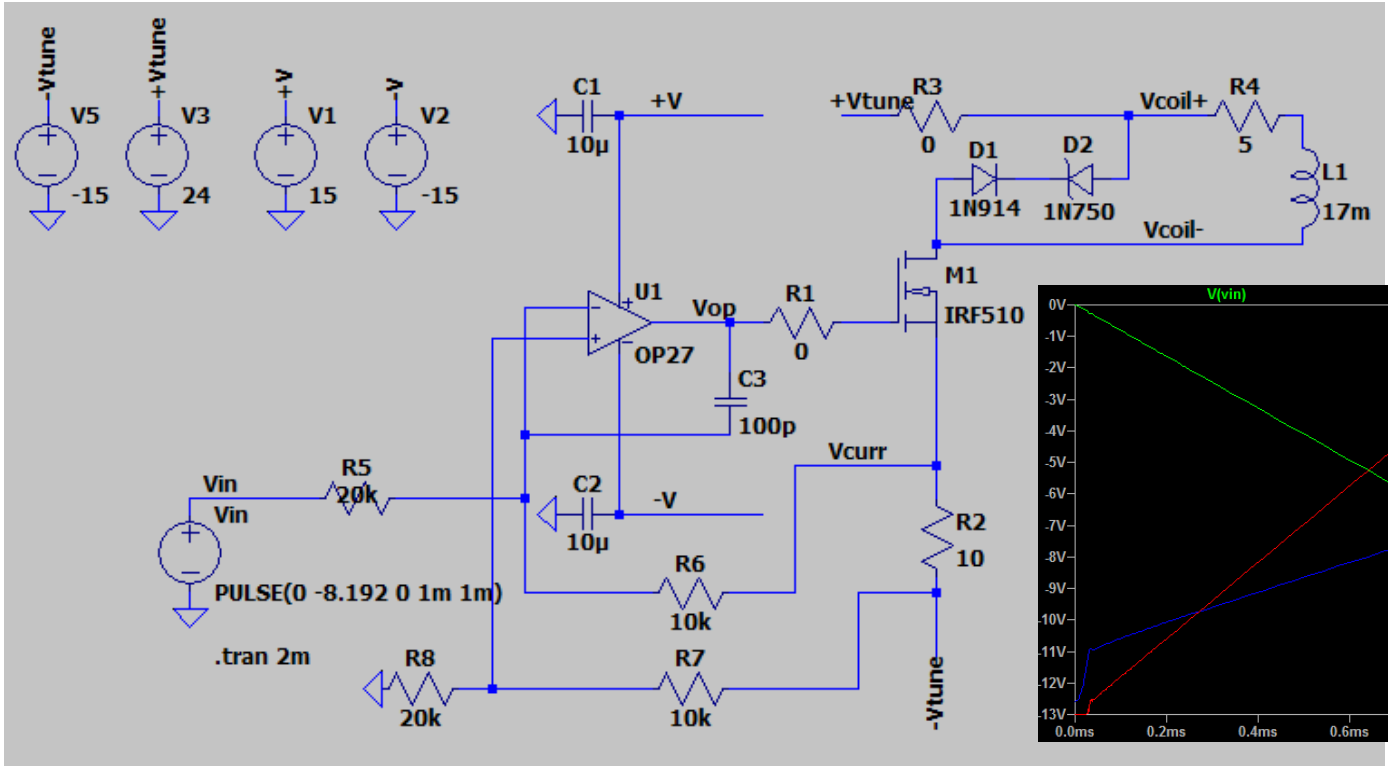


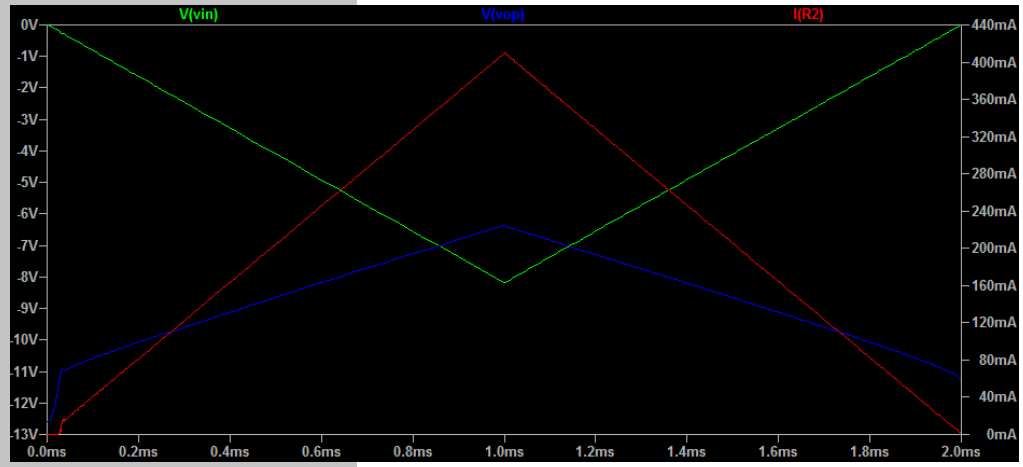


Simulation: Tune driver #2 (inverted)

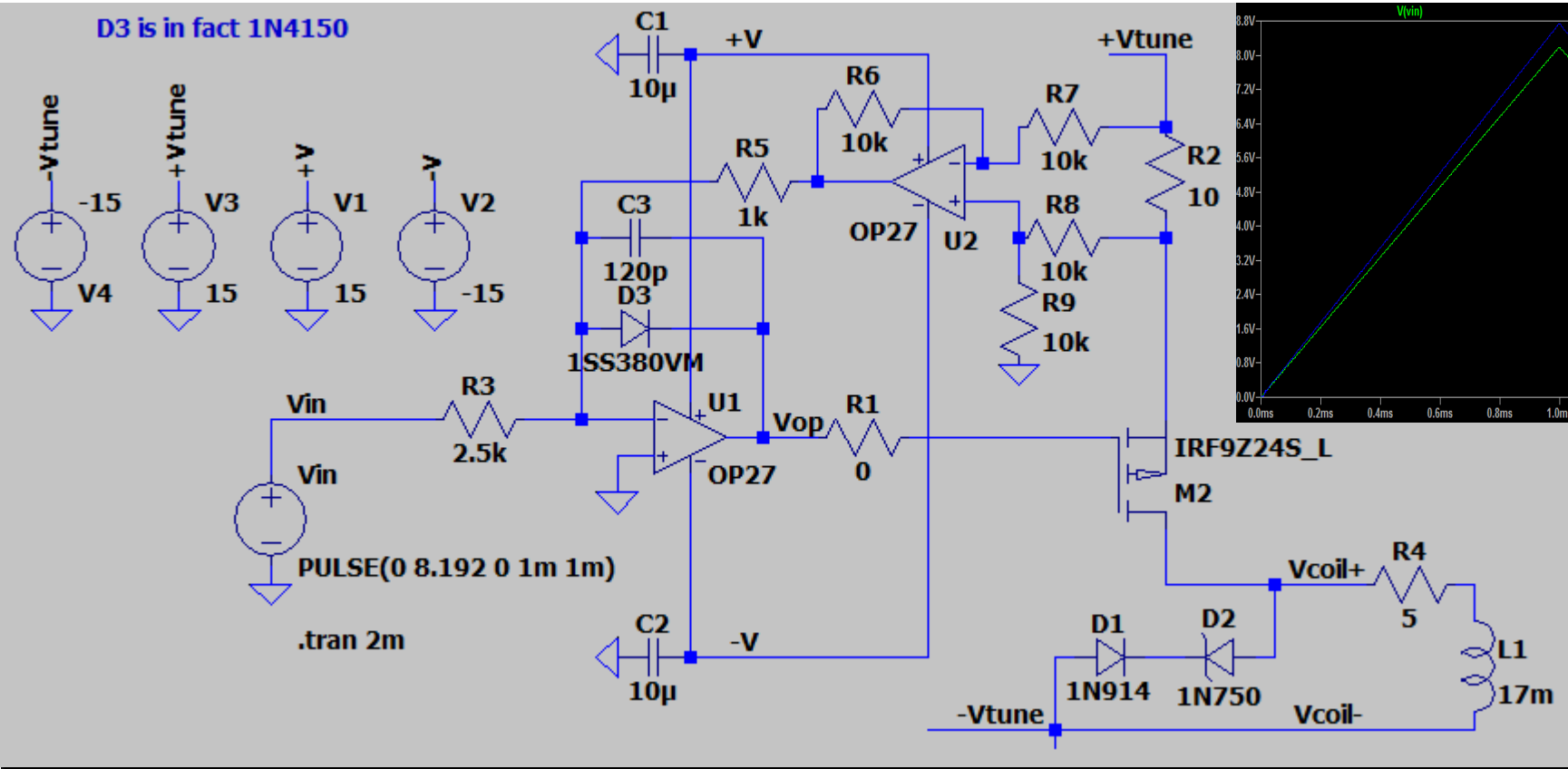


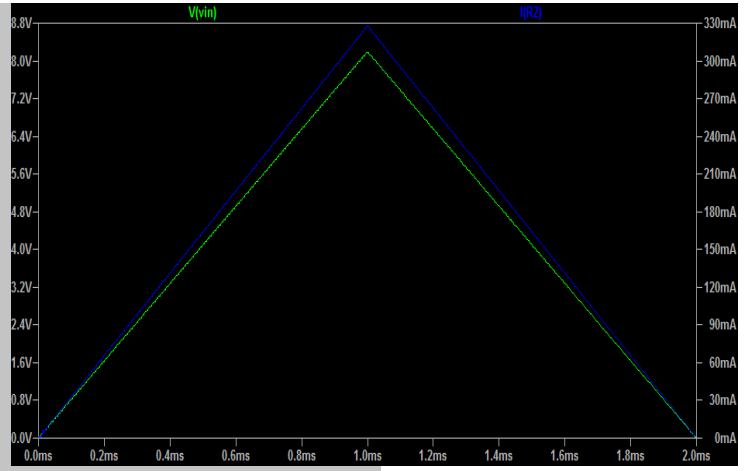
Simulation: Tune driver #3 (Option 2)



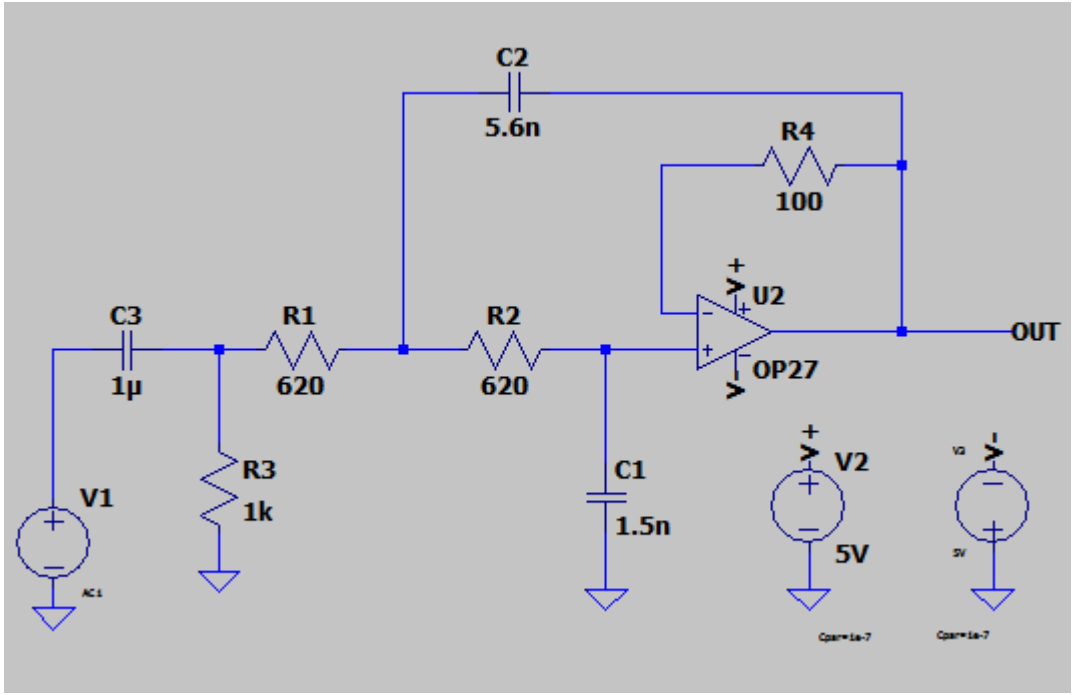


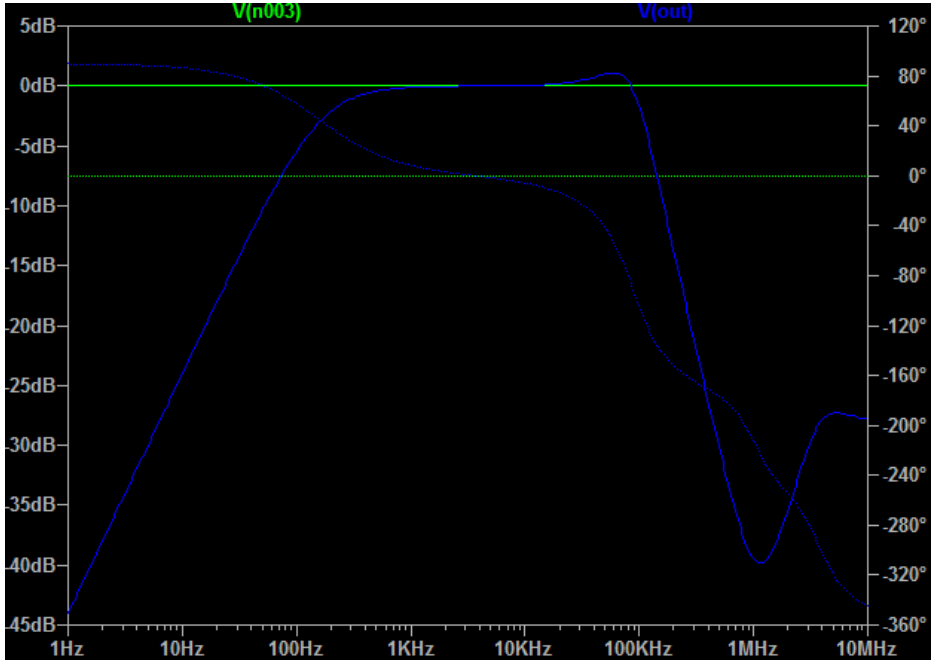
Simulation: Tune driver #4 (high side)



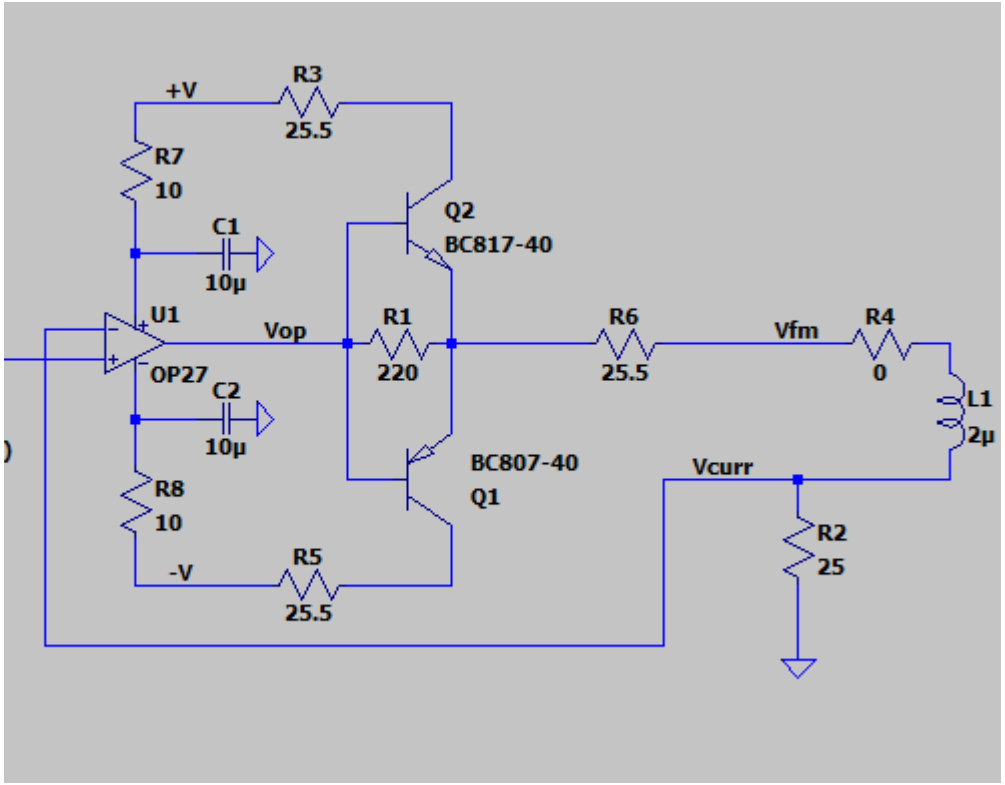


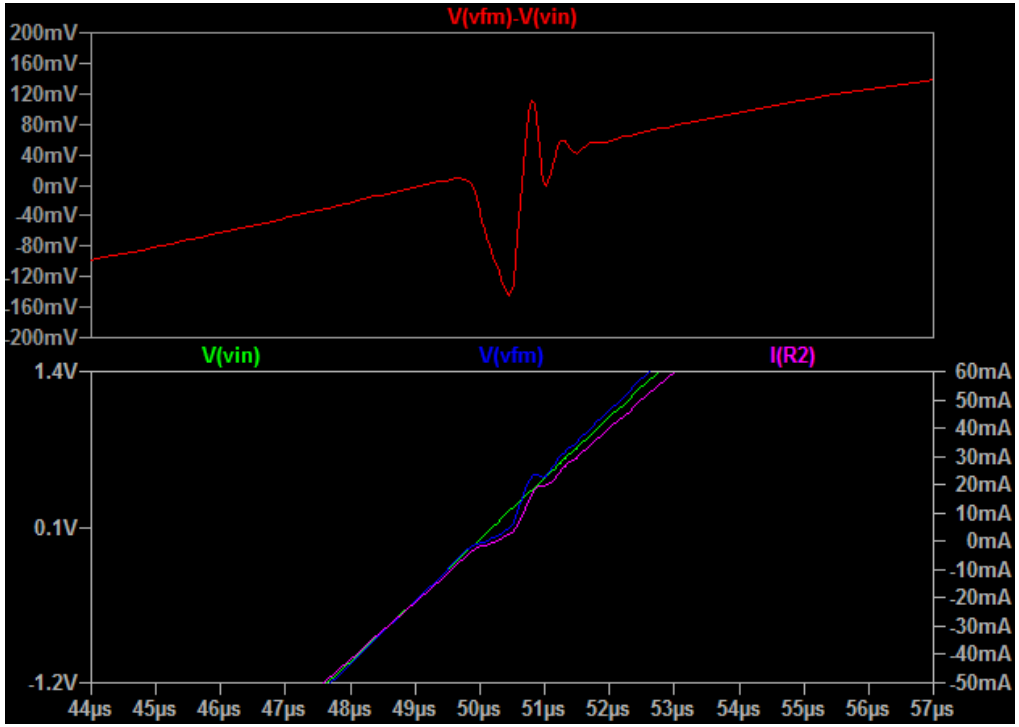
Simulation: FM lowpass filter



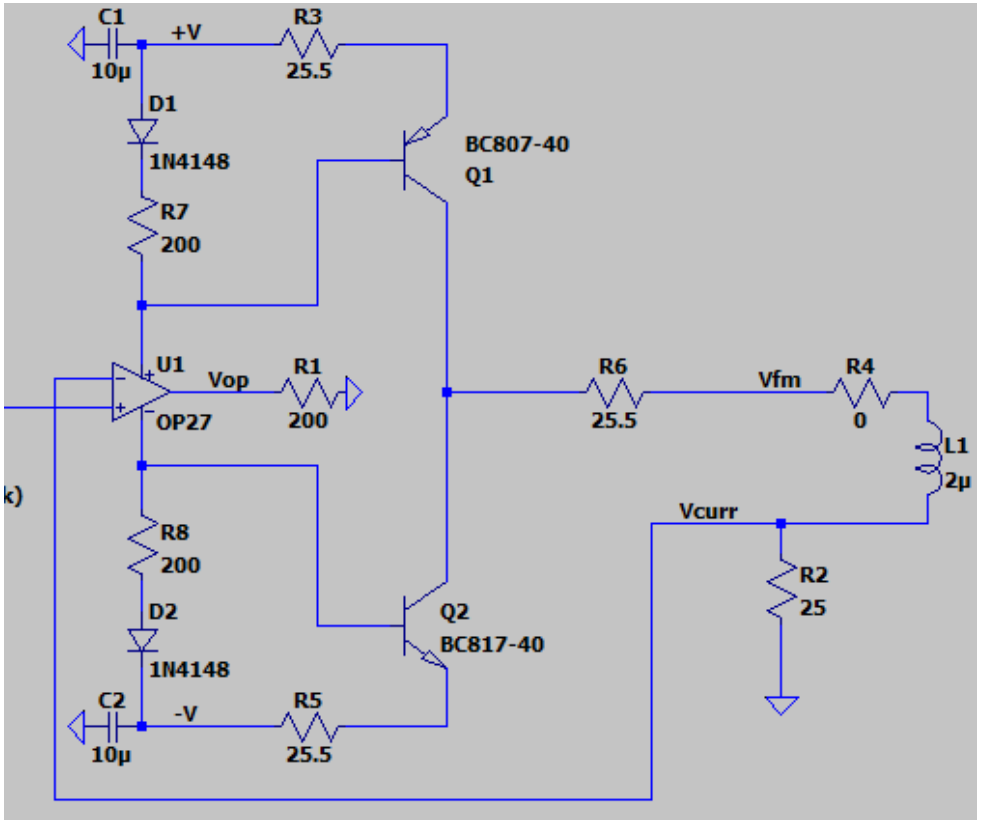


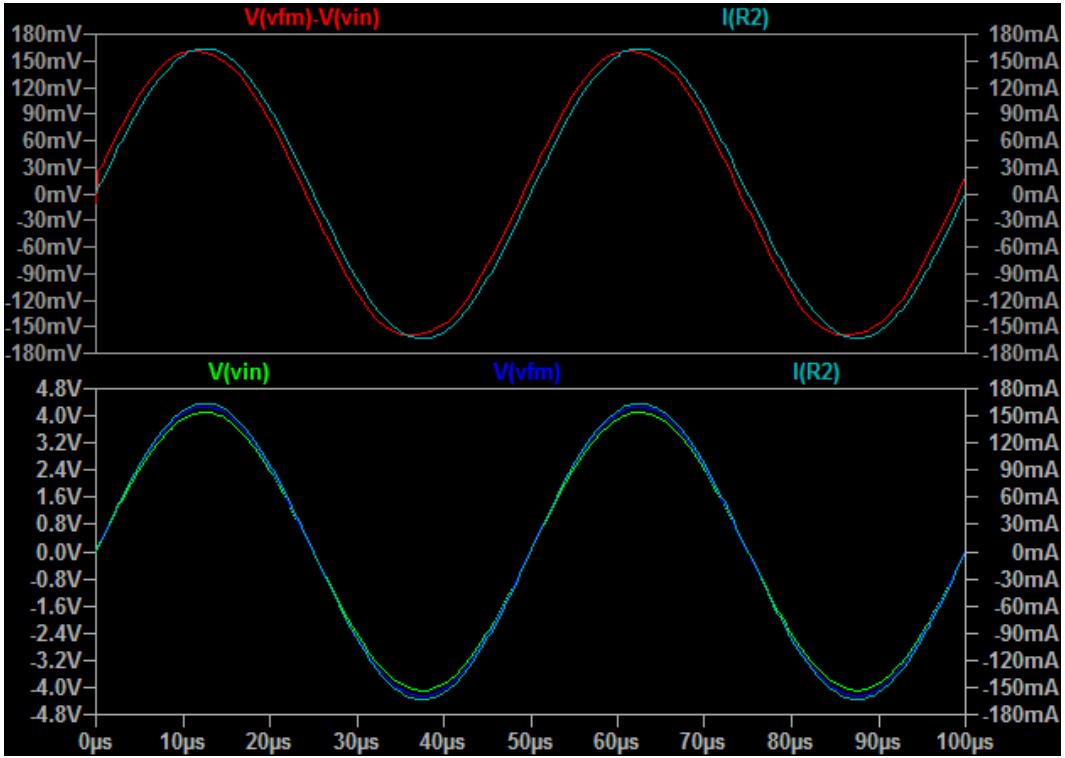
Simulation: FM driver #1



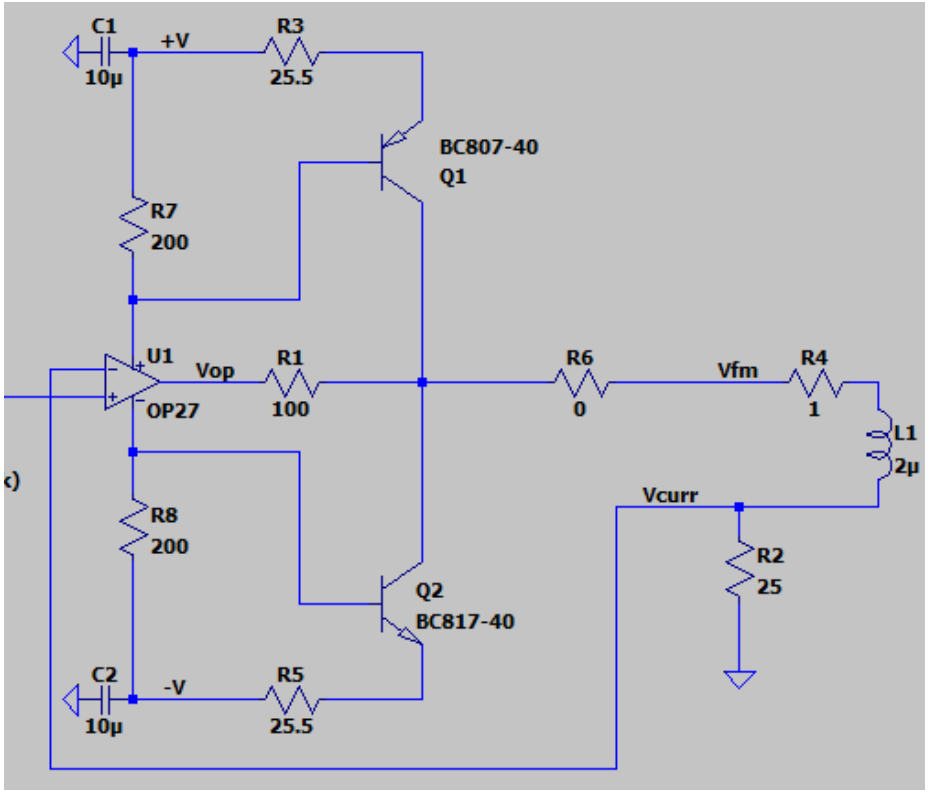


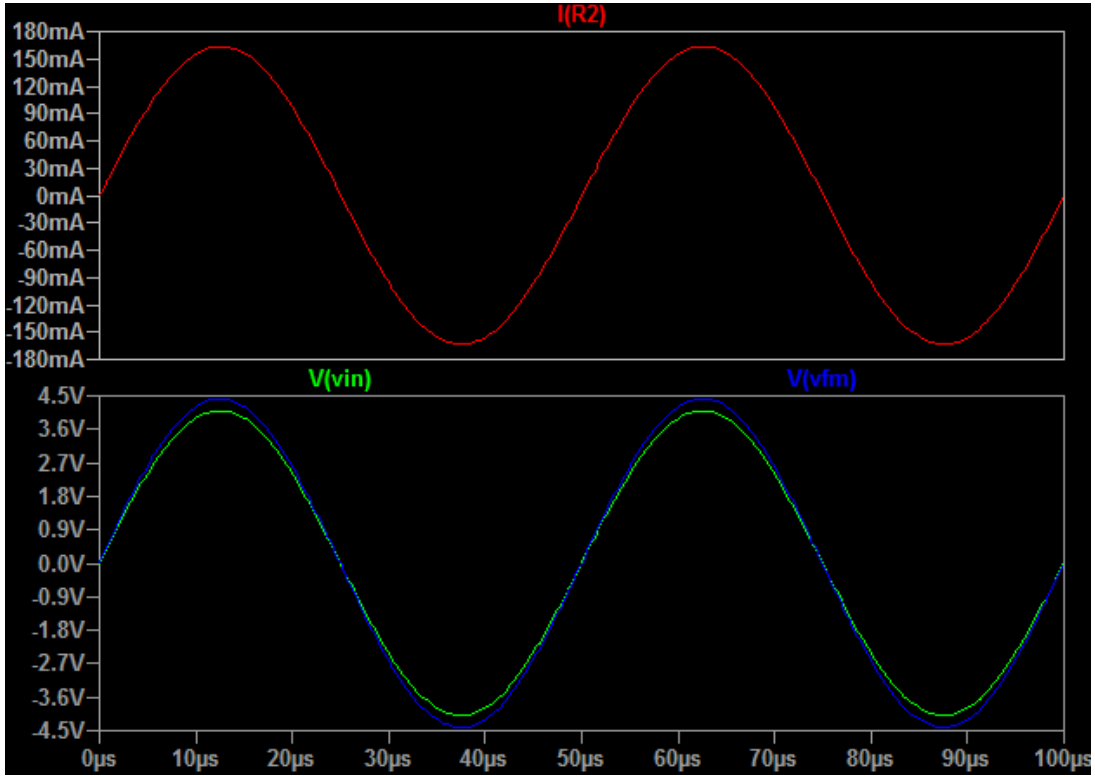
Simulation: FM driver #2



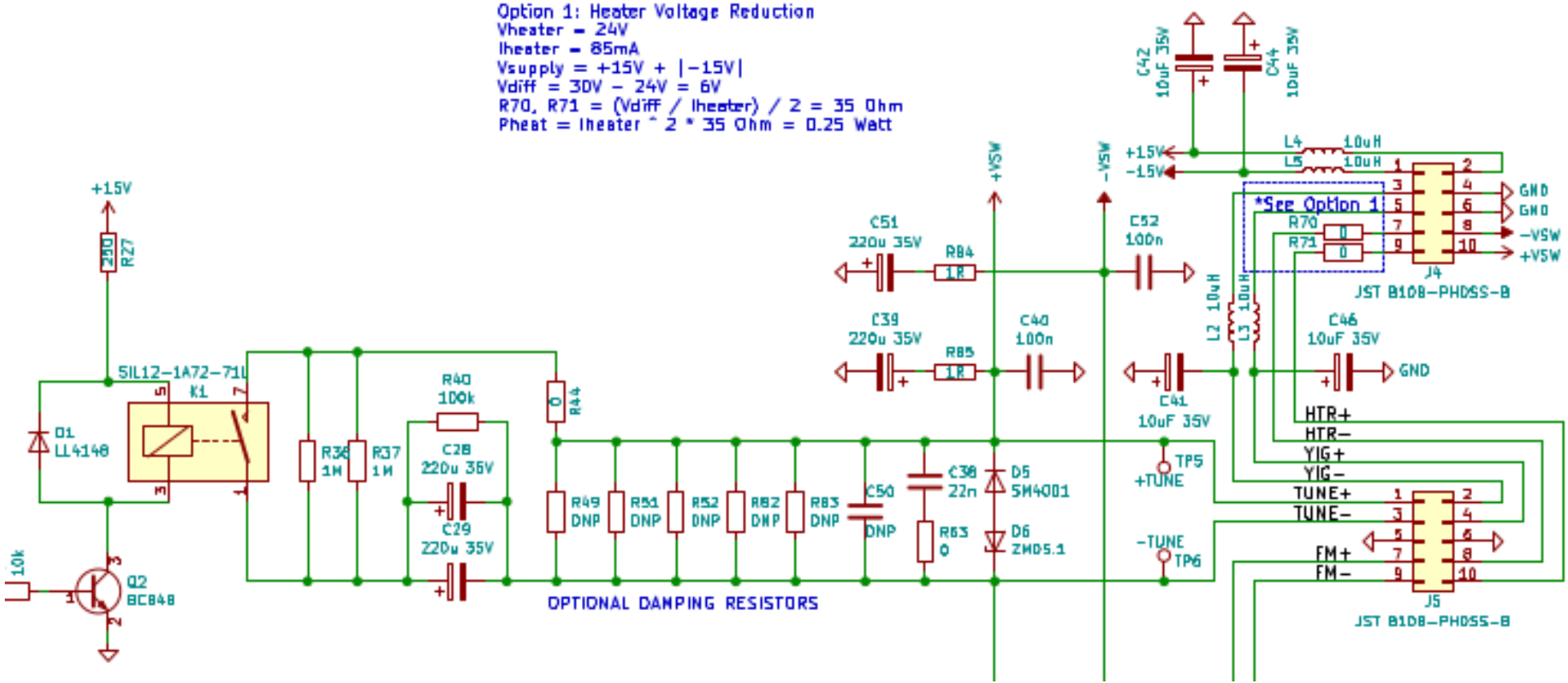


Simulation: FM driver #3

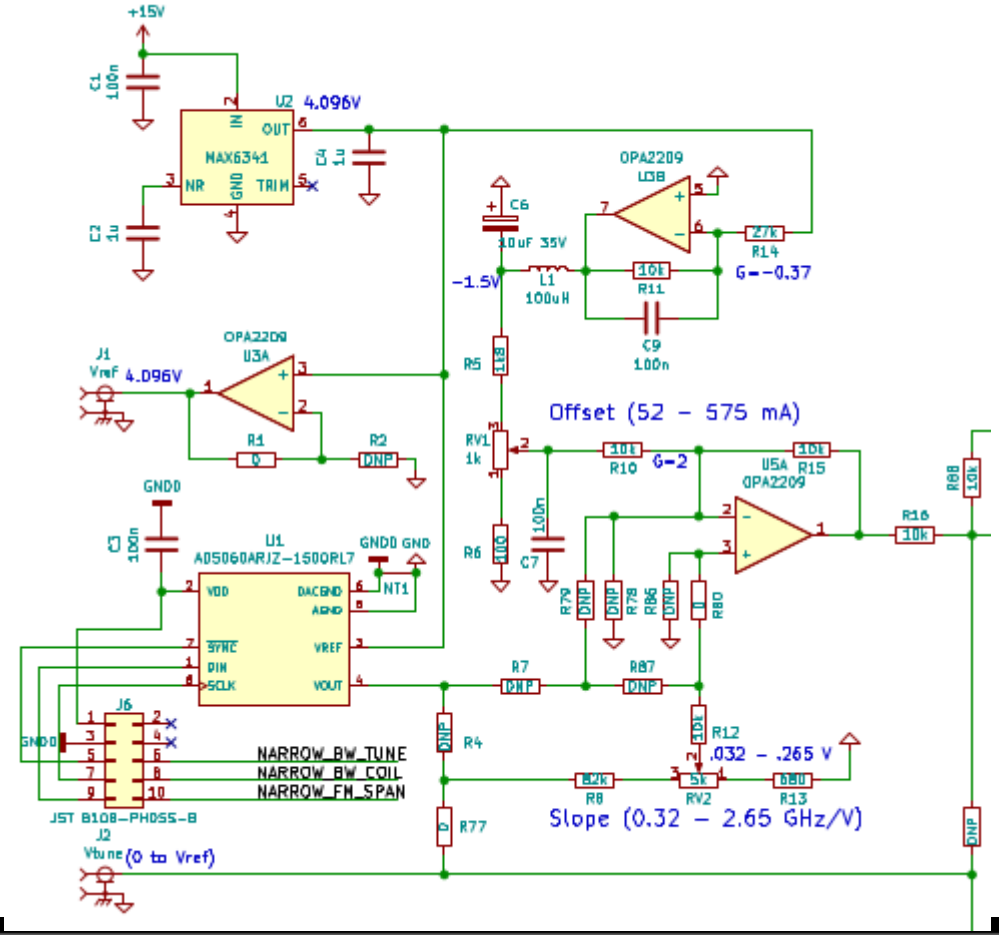




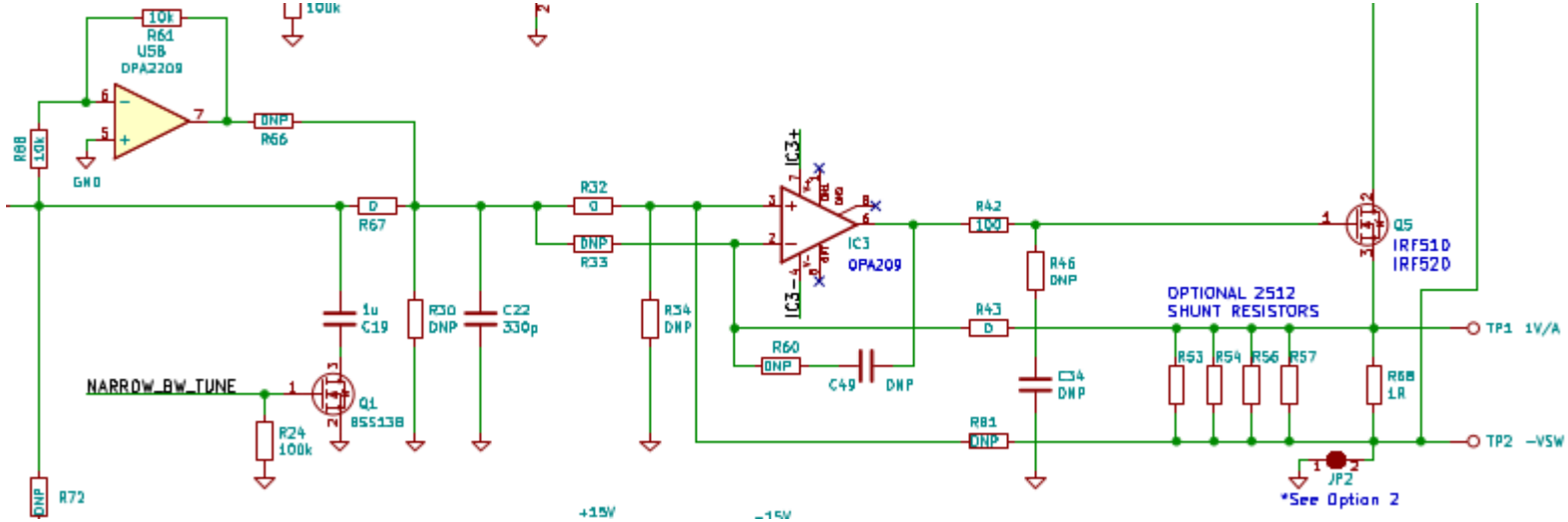
Schematic: Connectors



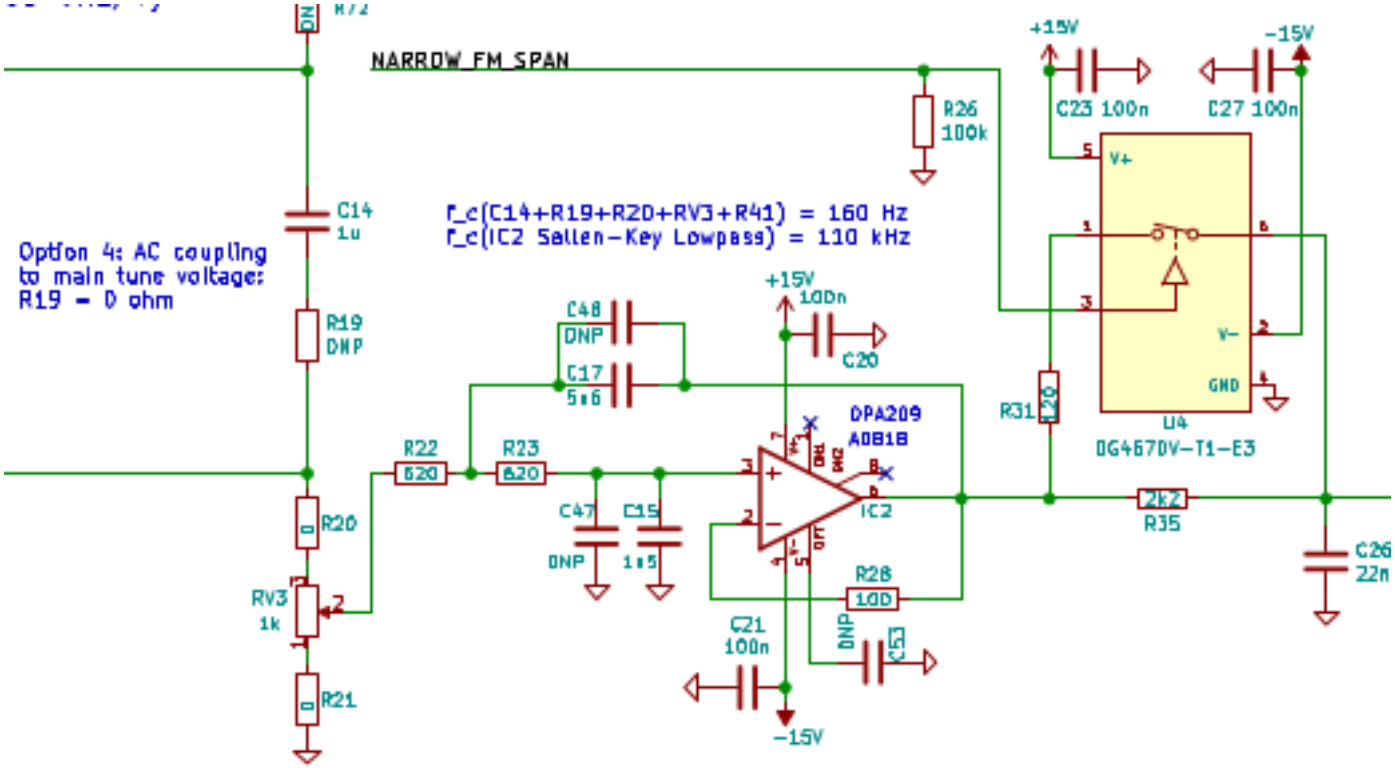
Schematic: Ref, scale, offset, DAC



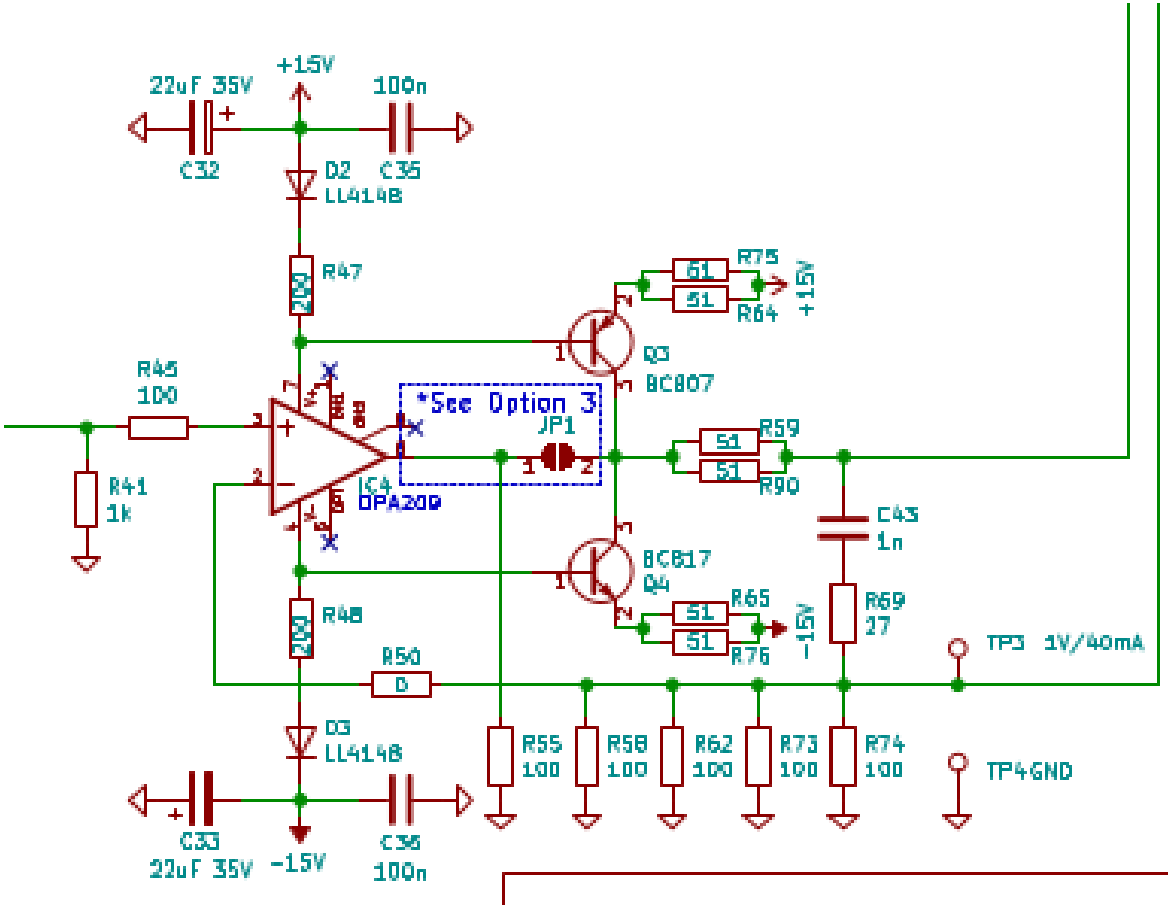
Schematic: Tune coil driver



Schematic: FM coil filter & BW switch



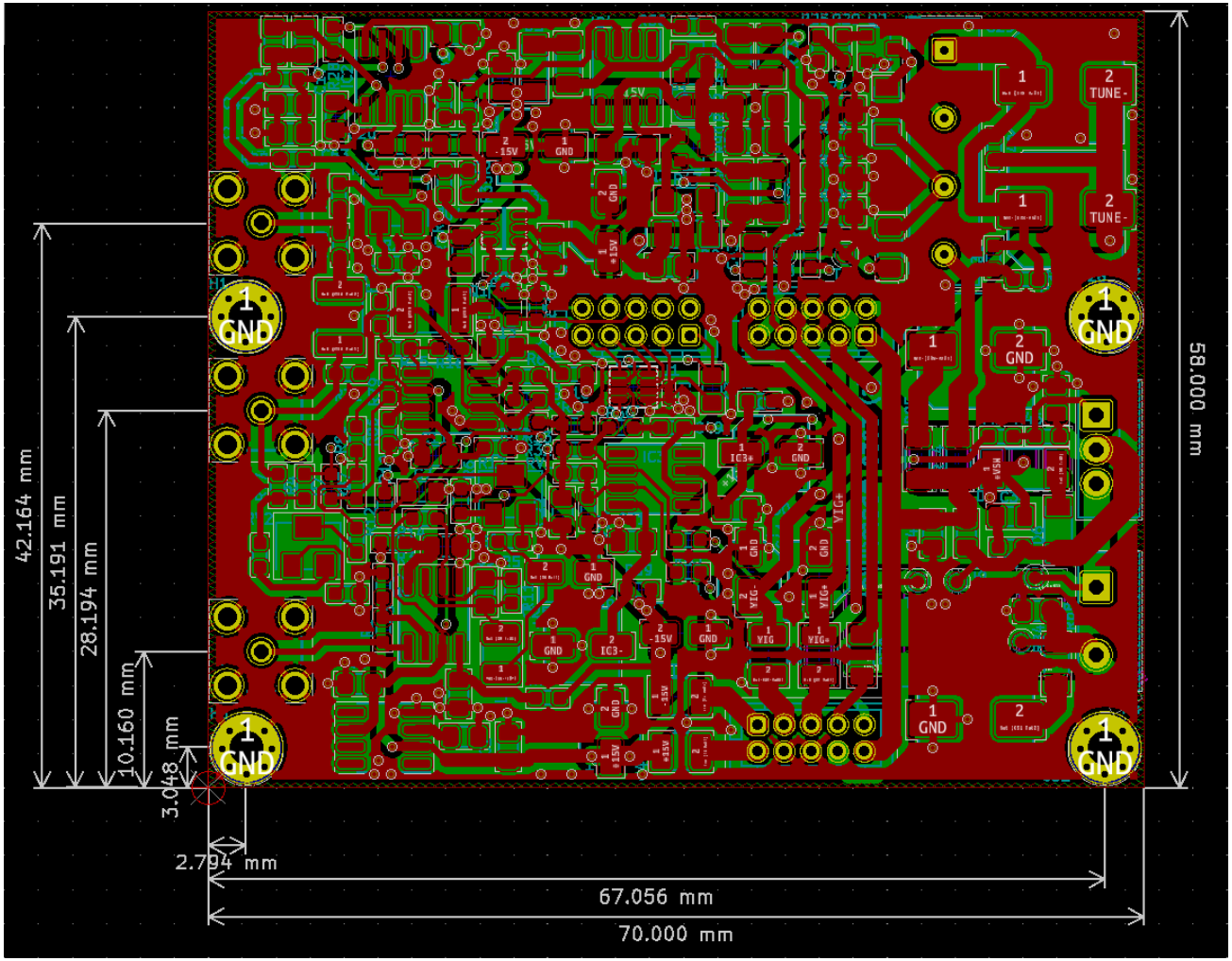
Schematic: FM coil driver

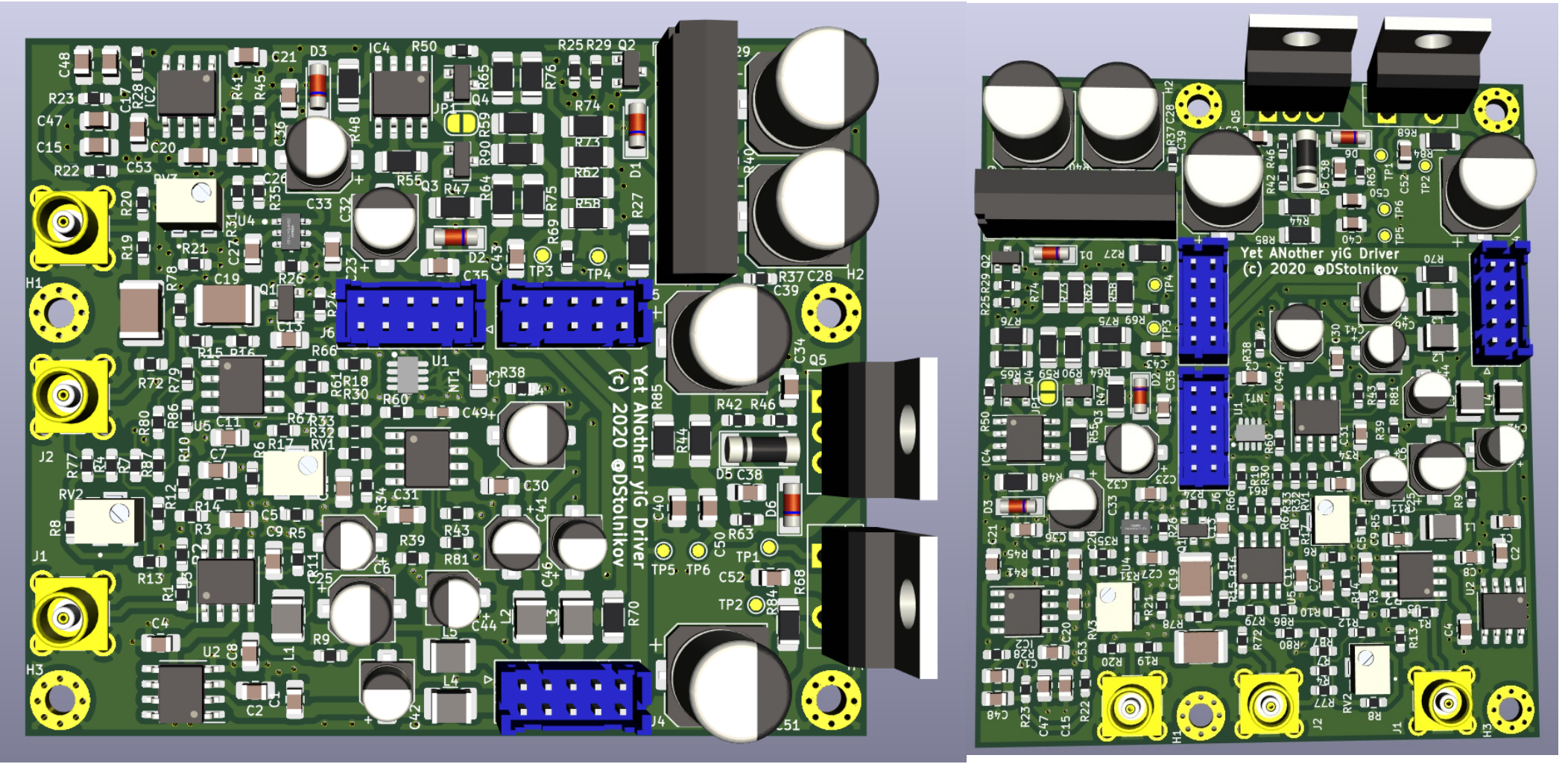


Option 3: Low FM Current
Solder JP1 connection
Bridge D2 and D3
R47, R48 = 0
Q3, Q4, R55 = DNP
R64, R65, R75, R76 = DNP
R59, R90 = 470

Layout 2020

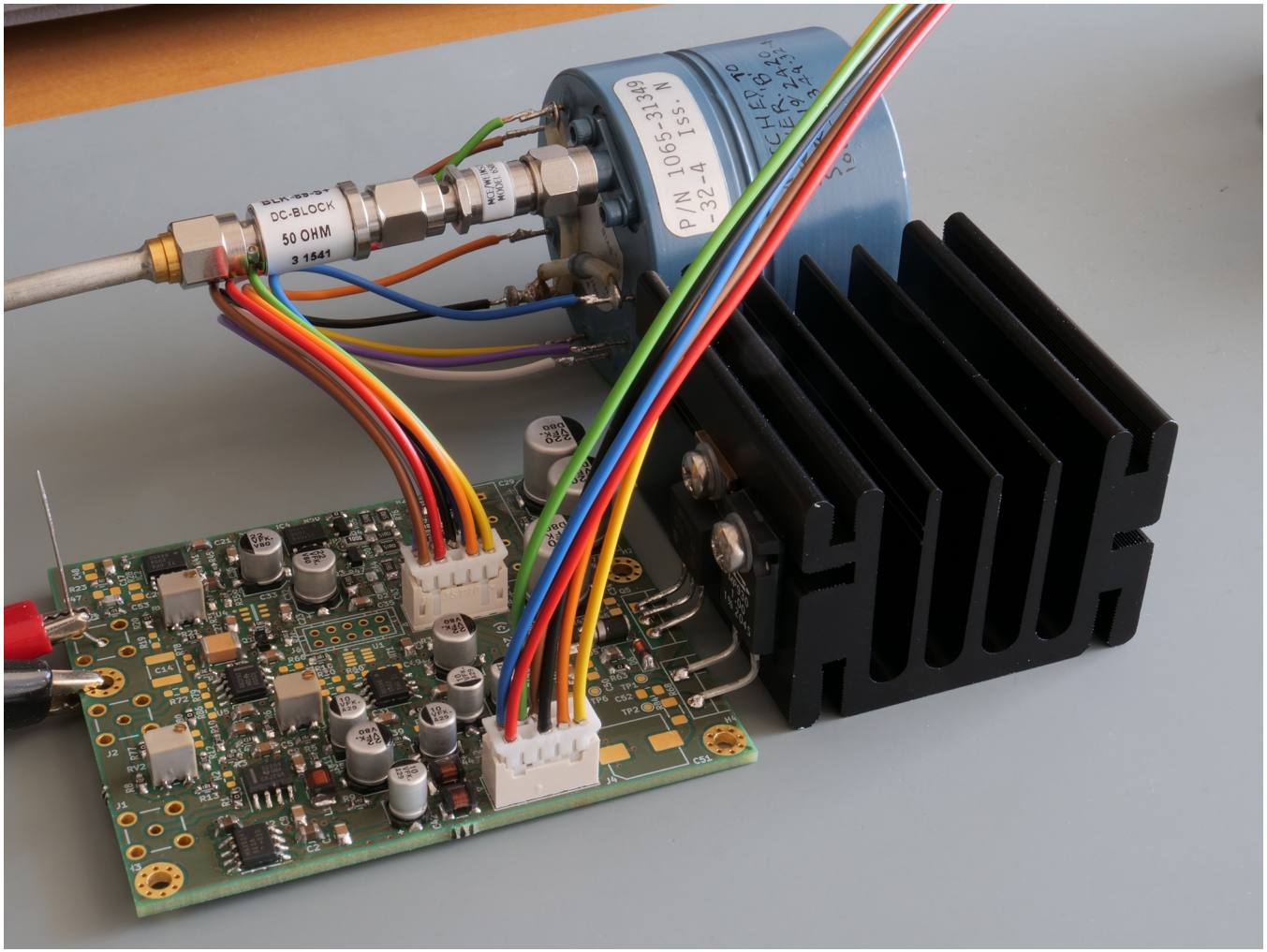
- 70 x 58mm
- Upper part could be cut away if FM / BW limitation is not needed (filter use case)




Yet ANother yiG Driver
(c) 2020 DStolnikov
Yet ANother yiG Driver
(c) 2020 DStolnikov

Test Setup

- +/-15V, -5V
- No heater supply
- Tune with 0 to Vref (4.096V)



Project ideas

- Filter:
  - Tracking filter for ADF5355/ADF5610/LMX2820
- Multiplier:
  - CW signal generator 10MHz – 20+GHz
- Oscillator:
  - Scalar network analyzer
- Your idea here...

Outlook

- PLL board to control the driver? (help welcome)
- Second version without FM driver for exclusive filter/miltiplier/mixer control (different pinout)
  - High side MOSFET with high-side shunt
  - A second DAC for SRD voltage control
  - PIN diode “output driver” (= comparator opamp)
  - ADC for YIG built-in thermistor readback

Tips

- When bringing up a YIG, start around 50-100mA tune coil current to find where it begins to operate
- Use the YIG linearity in your favor – no need for microwave test gear to get started – 2~4 GHz siggen/SDR/diode detectors are sufficient to start
  - Don’t forget to protect your test gear when interfacing to unknown DUT
    - Use DC blocks, attenuators, limiters potentially...
- Be careful with the FM coil (very low resistance)
  - it could be burned easily!
- Search for YIG parts from: HP, Agilent, Micro Lambda Wireless, Omniyig, Avantek, Watkins-Johnson, Teledyne
- Use Keysight Find-A-Part: https://www.keysight.com/my/fapHomePage

Links

- https://en.wikipedia.org/wiki/YIG_sphere and the documents linked there
- https://www.microlambdawireless.com/resources/apppmytos.pdf
- https://worldradiohistory.com/Archive-DX/VHF-Communications/VHF-COMM.2007.2.pdf
- https://publications.drdo.gov.in/ojs/index.php/dsj/article/view/6283
- git://git.osmocom.org/osmo-small-hardware/yang (in the next days)

Thank you!

And thanks to Y, Fe and especially O!

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