Low-Cost WSPR with Raspberry Pi and SDR

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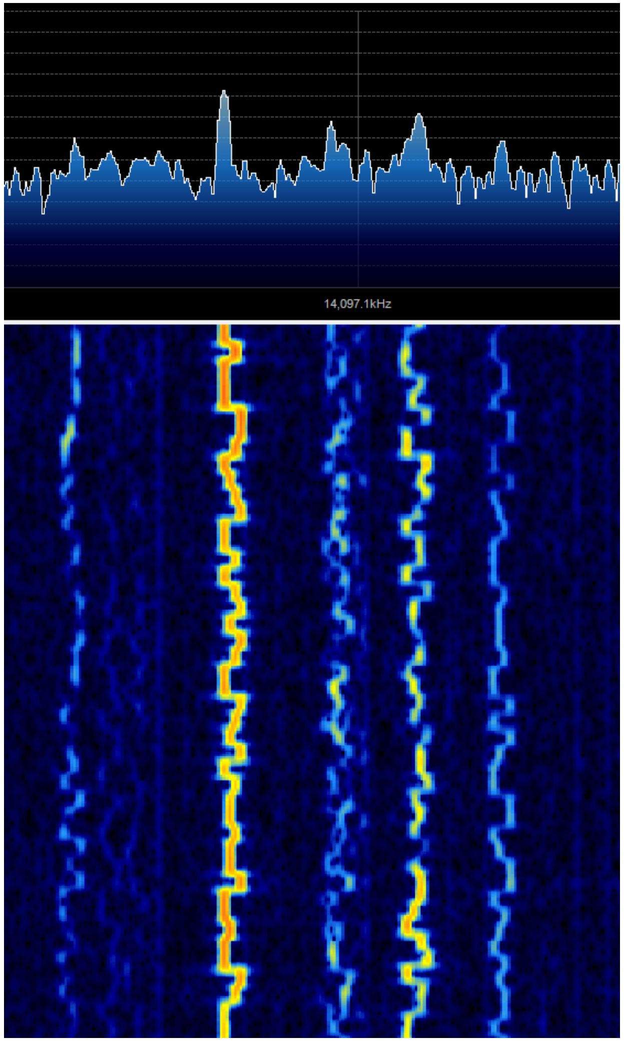
WSPR

Weak Signal Propagation Reporter

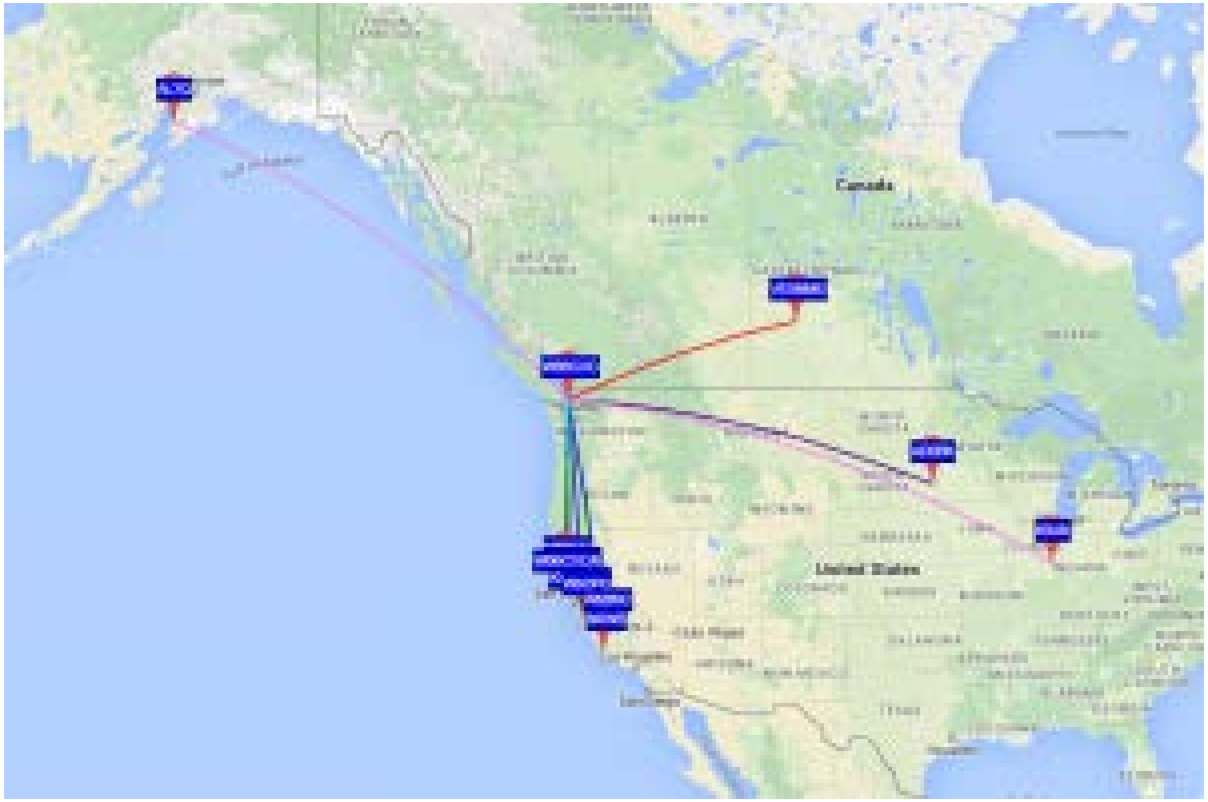
- Worldwide: 800 reporting stations, 1000 transmitting stations
- Operating on USB dial (MHz): 0.136, 0.4742, 1.8366, 3.5926, 5.2872, 7.0386, 10.1387, 14.0956, 18.1046, 21.0946, 24.9246, 28.1246, 50.293, 70.091, 144.489, 432.300, 1296.500
- Message: Callsign, 4-digit locator, power level in dBm: 50 bits
  - After Forward Error Correction = 162 bits
  - Plus a 162-bit synch pattern
- Modulation: 4-FSK, 1.4648 Hz tone separation, 1.4648 Baud
- Duration of transmission: 110.6 seconds
- Transmissions start on even UTC minutes

Modulation Detail



- Multiple transmitters share a common 200 Hz-wide band
- There is no frequency assignment, so interference can occur
- People (or radios) randomize their frequency, pick timeslots, repetition rates to reduce collisions
- We can see the four-level FSK modulation
    - 1.4648 Hz tone separation
    - 1.4648 Hz Baud
      (2.9296 bits/second)

20-Meter WSPR



- 5055 miles with 10mW – Friday Harbor to French Guiana
- 690 Miles with 0.1mW – Friday Harbor to Santa Rosa

Software-Defined Radios

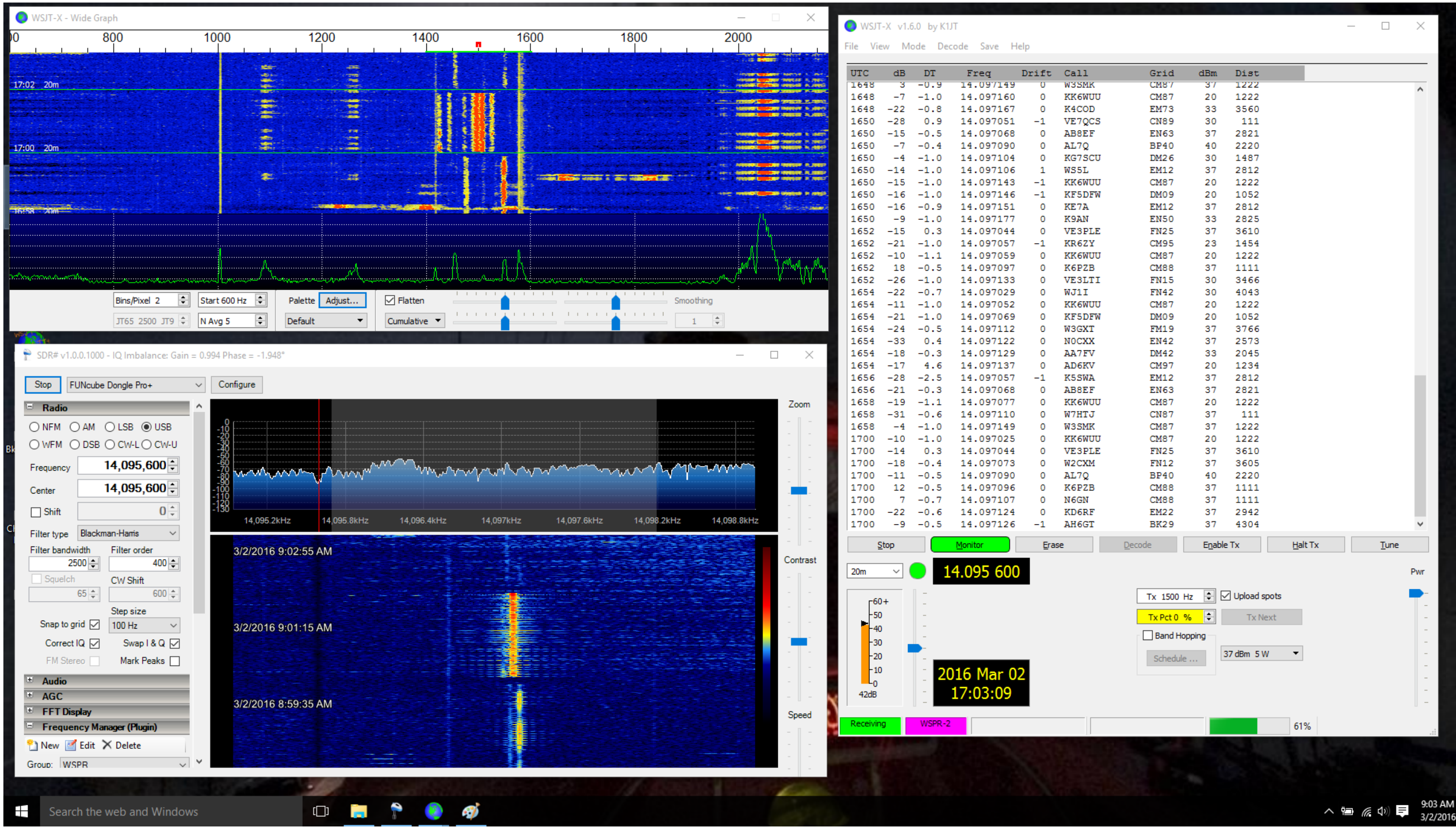
- Funcube Dongle Pro + ($175)
- SDRplay ($150)

- Icom 7200 – Not an SDR, but it has USB Soundcard interface and control

Receiving Software

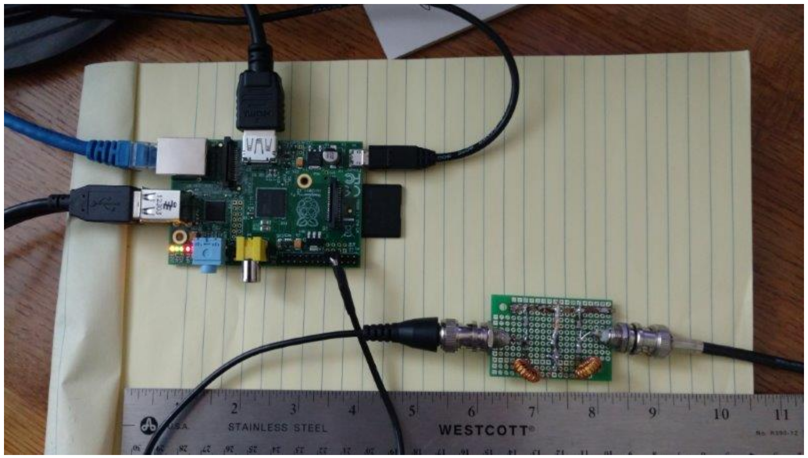
- SDR receiver control
  - SDR# (ver 1.0.0.100)
    - http://airspy.com/download/
  - HDSDR
    - http://www.hdsdr.de/
  - SDR-Radio
    - http://sdr-radio.com/Software/Download/Download-Kits
- WSPR decoding / reporting
  - WSJT-X v1.60, WSPR
    - http://physics.princeton.edu/pulsar/k1jt
- Using NTS or local GPS to keep computer time accurate
  - BktTimeSync
    - http://www.maniaradio.it/en/bkttimesync.html

Receiving WSPR

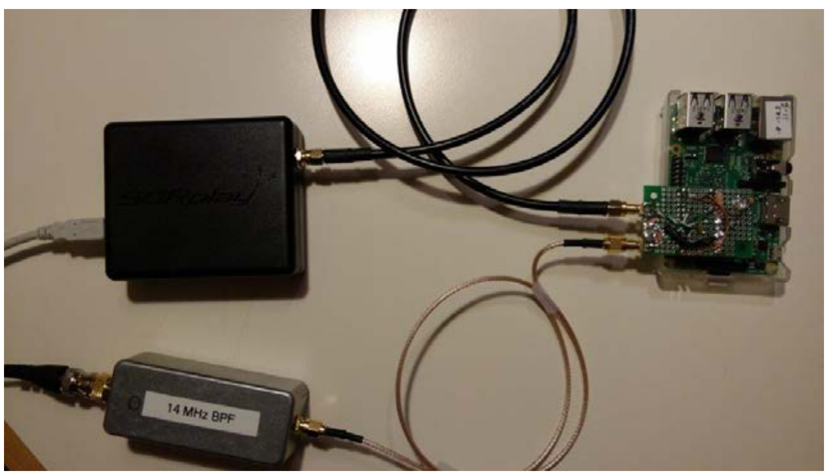


Using a $99 “Kangaroo” PC and Funcube SDR

Raspberry Pi WSPR Transmitter



- First version, Rpi Model B
- Transmit-only



- Second version, Rpi Model B+
- Transmit / Receive switch on plug-in card
- Nicer external filter package
- Shown with “SDRplay” receiver

Raspberry Pi and Software

- Raspberry Pi ($5 - $40)
  - Multiple versions available, Zero, 1 B+, 2 B, 2 B+, 3 B
  - Need USB power supply, output connector, RF filter, antenna
  - RPi runs “Rasbian” Linux
- JamesP6000 / WsprryPi
  - This is the program that turns the RPi into a WSPR transmitter
  - This version works with new and old RPi’s, and has more useful options
  - https://github.com/JamesP6000/WsprryPi
- OpenNTPD (Open Network Time Protocol Daemon)
  - Requires internet connection, or a local NTP server
- Chrony (flexible NTP implementation)
  - Can use GPS for local time source

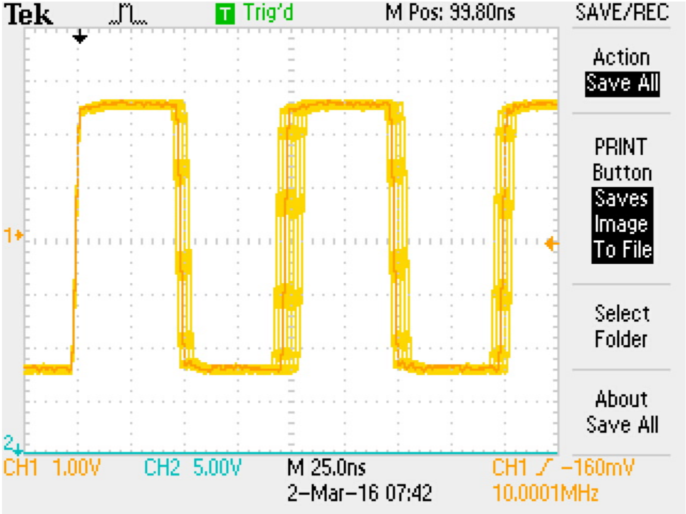
Many methods for digital clock synthesis

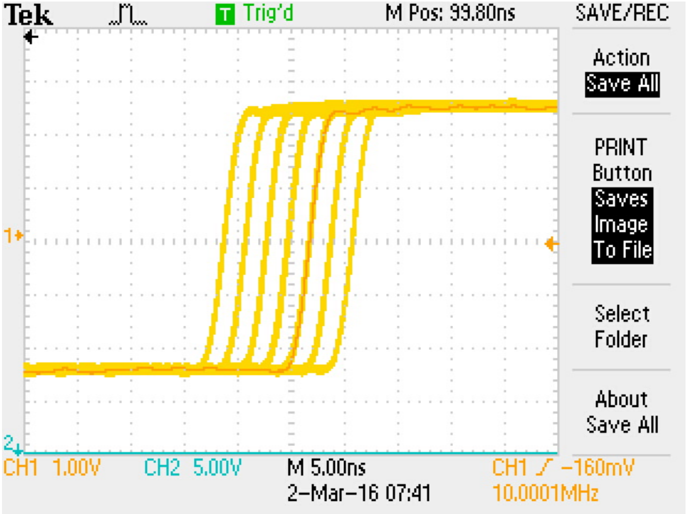
- Divide-by N
    - simple, limited resolution
- NCO (Numerically Controlled Oscillator)
    - Flexible, good resolution, wide output word
- The RPi uses a fractional (clock-dropping) divider, with fairly poor frequency resolution: At 14 MHz, the frequency step is about 400 Hz. It gets worse at higher frequencies

How do they get the 1.465 Hz frequency shift modulation?

- By very rapidly changing the divider divisor in software
- MASH noise-shaping hardware to further spread/smooth the transitions
- Software phase/frequency dither to spread/smooth spurious artifacts

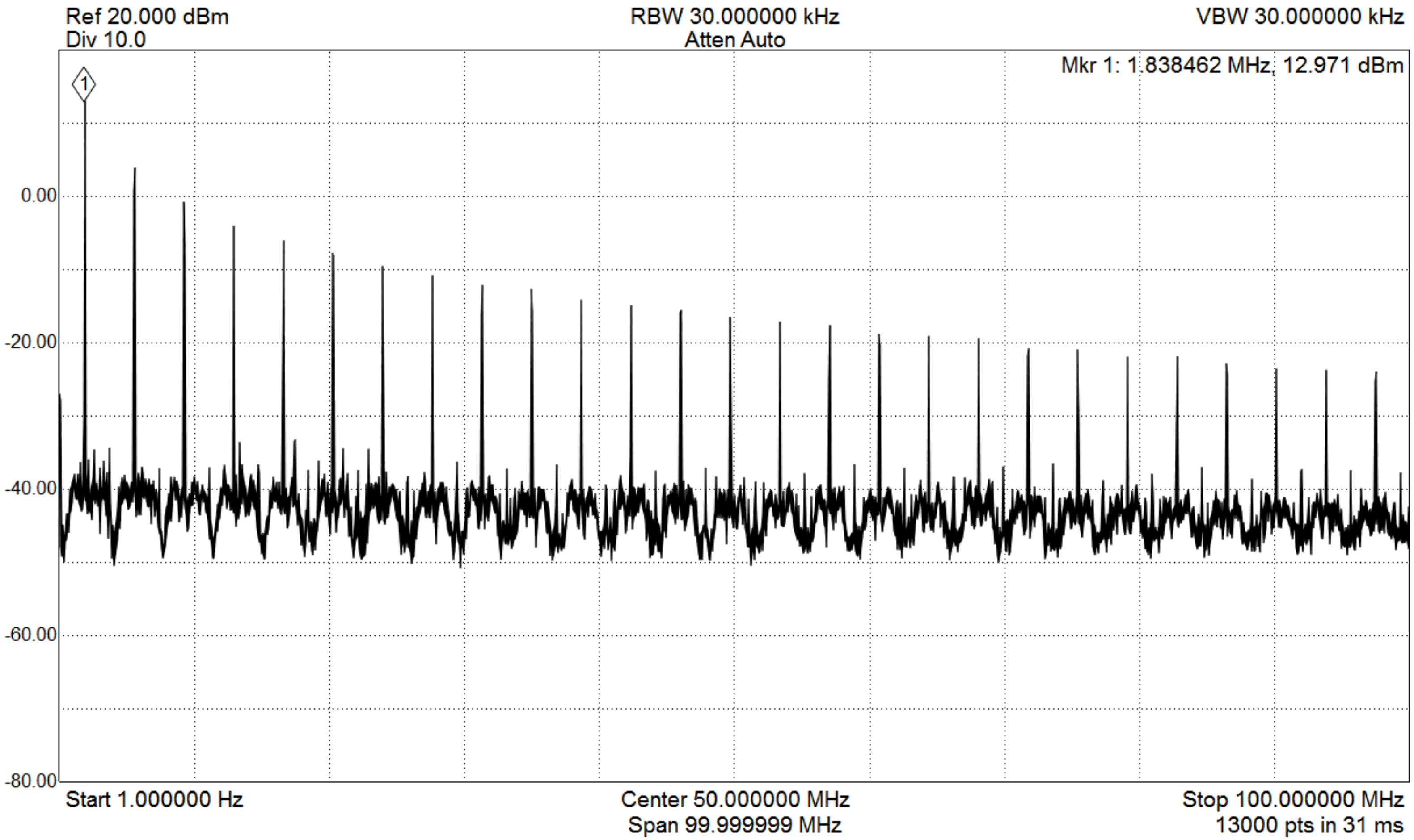
Raspberry Pi Timer Output





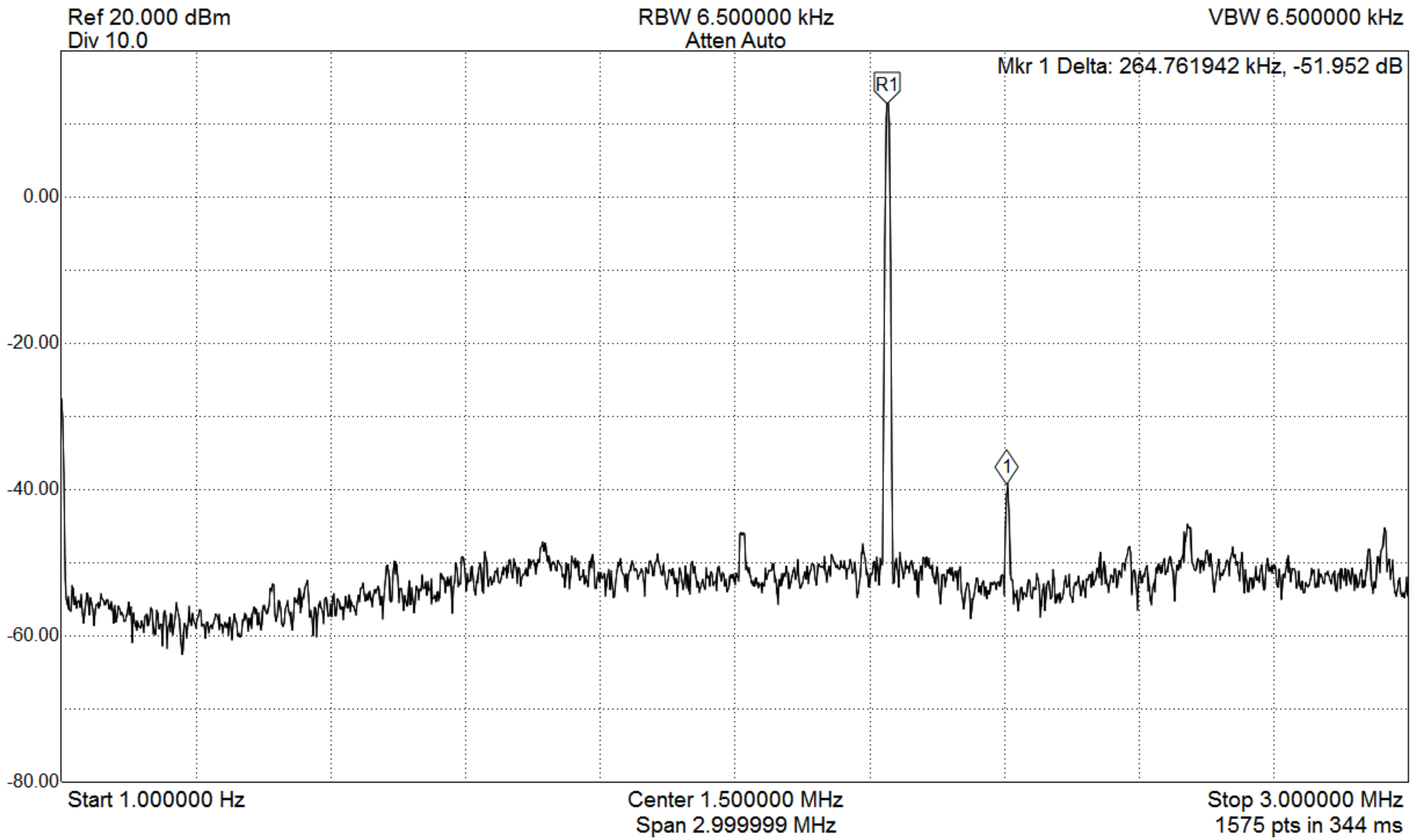
- Output is not a clean squarewave
- 2ns jitter “comb” due to 500 MHz internal clock.
- RPi has fairly symmetrical squarewave output with jitter, mostly odd harmonics
- Jitter noise-shaping for spur reduction – (maybe)

Raw Output @ 160 Meters



- Squarewave output gives strong odd harmonics, weak even harmonics
- These harmonics keep going…

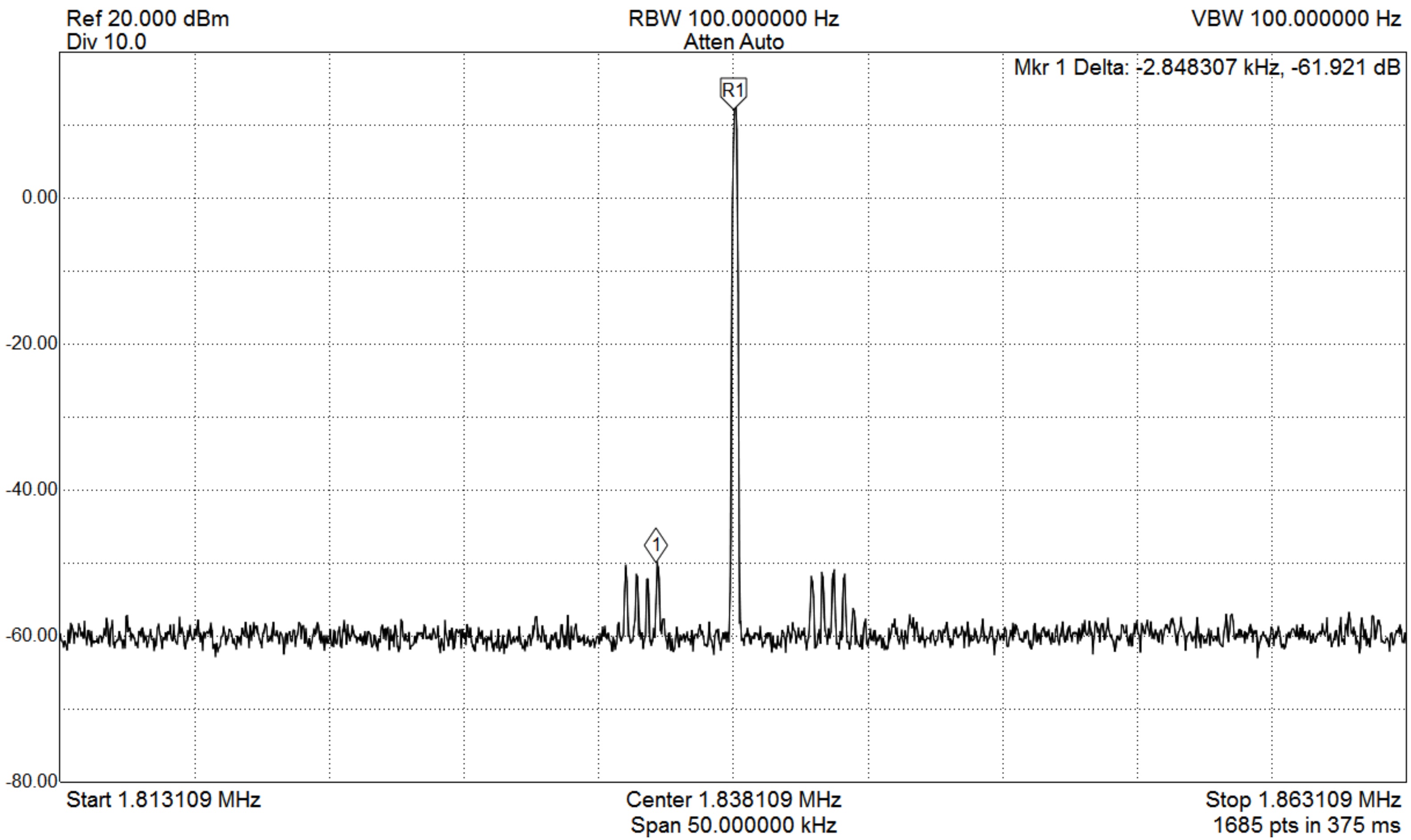
160 Meters Close-in Spur



-52 dBc is good

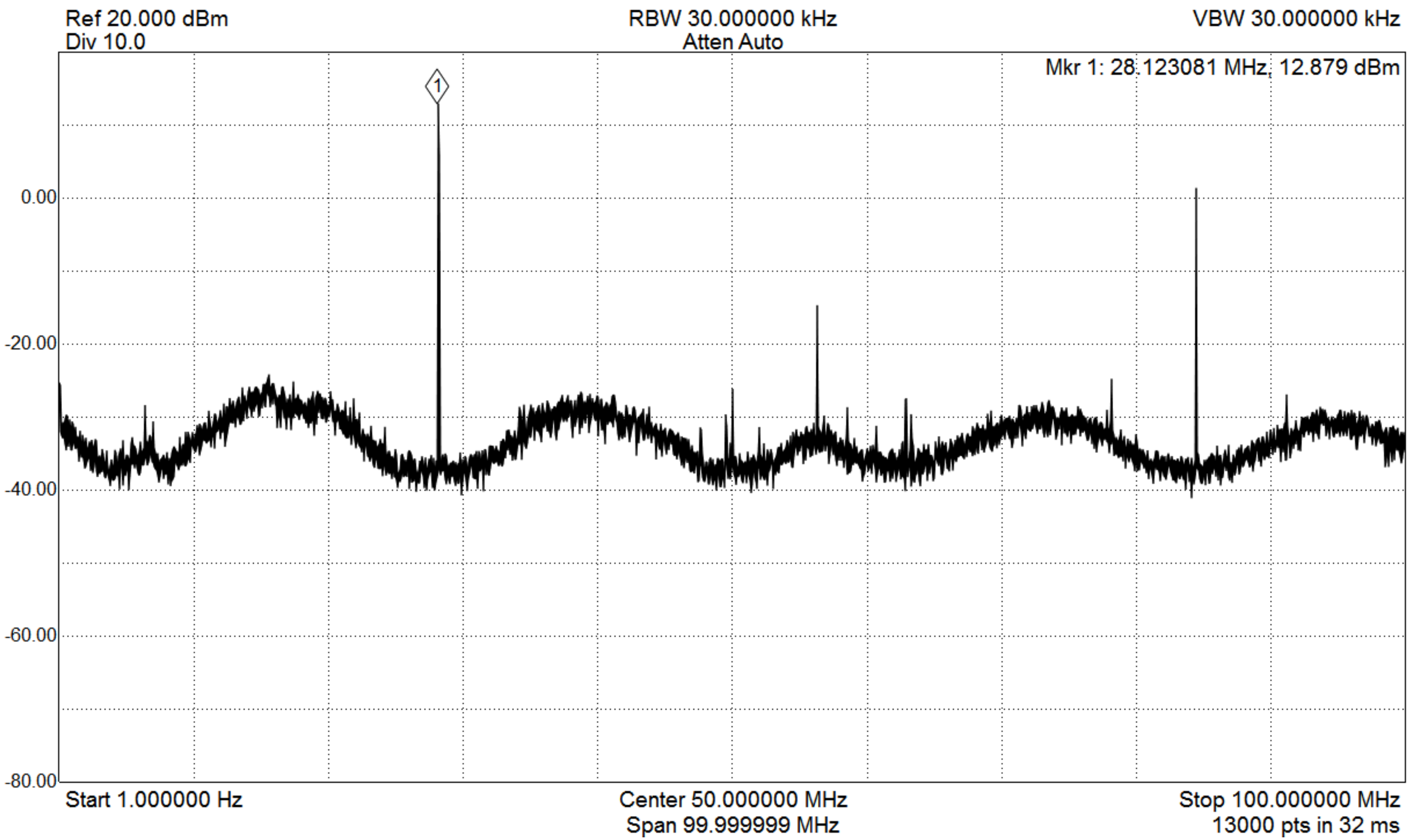
160 Meters

Interesting close-in low-level spurs

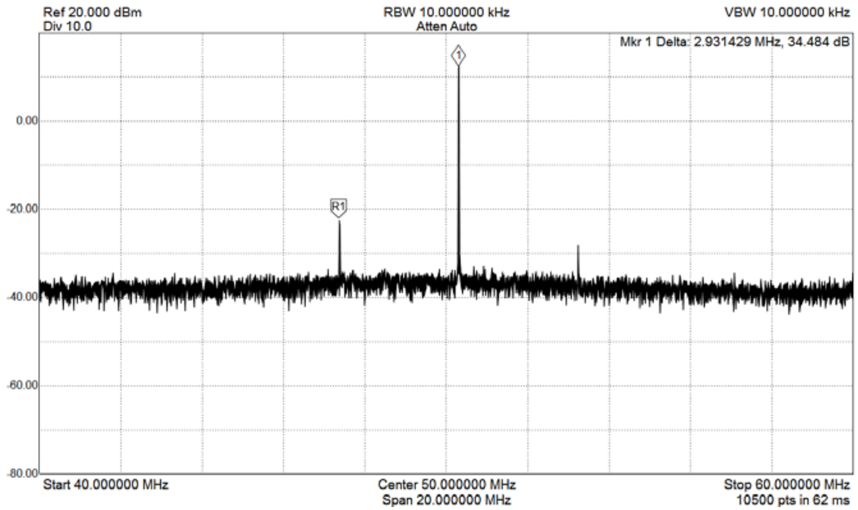


Raw Output @ 28.1261 MHz

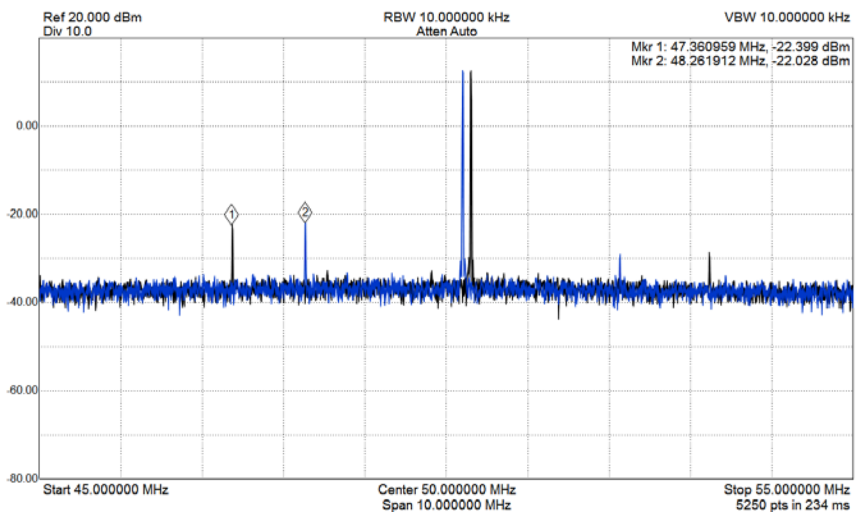
A simple low-Pass filter would be adequate



Raw Output @ 50.293 MHz



This close-in spur would be difficult to filter

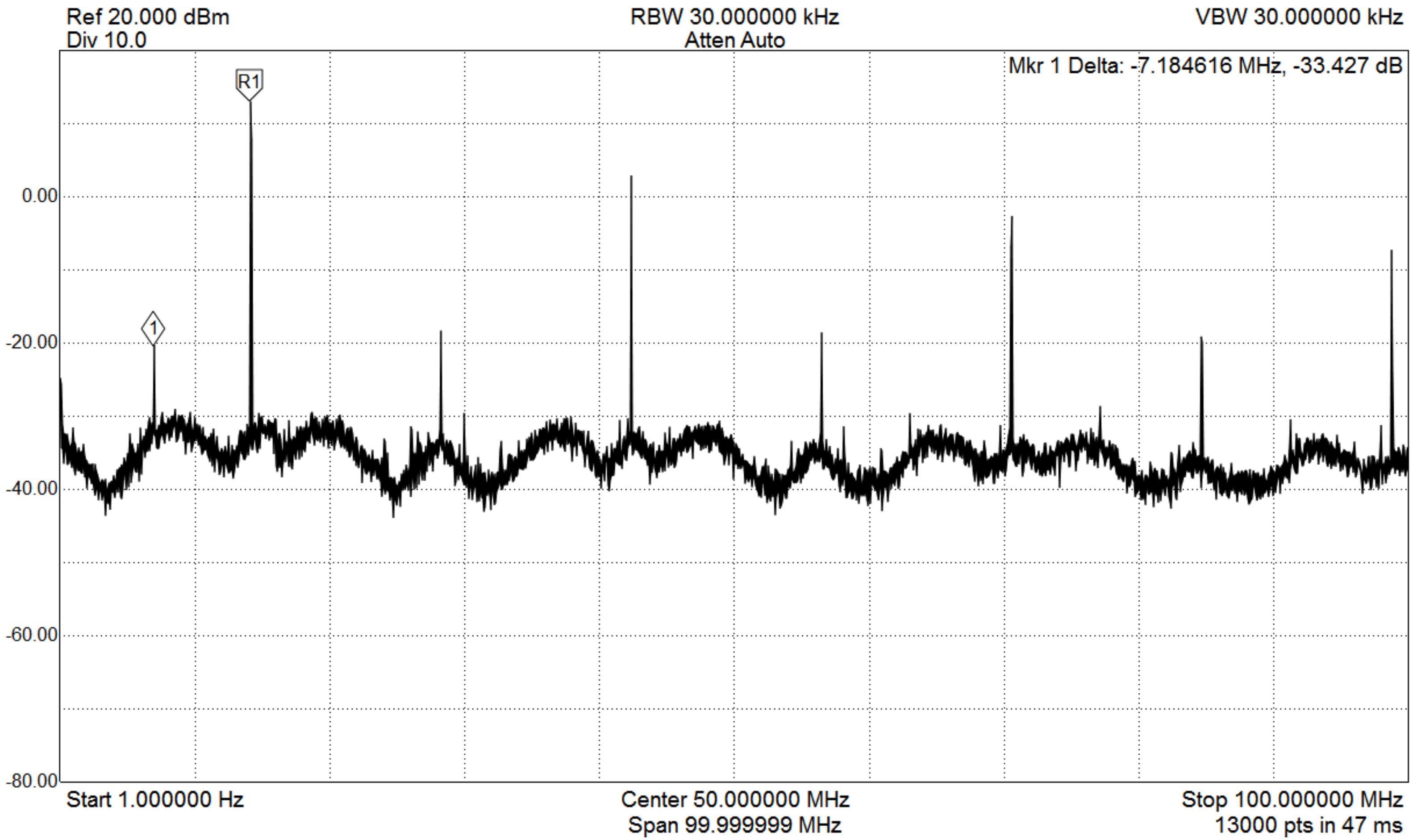


Shifting the carrier by +100KHz results in the spur shifting -900KHz

This tells us that the spur is the 9th harmonic, at approx 453 MHz, aliased back down by the 500 MHz sample clock.

Any harmonics above Fs/2 (250 MHz) will be aliased down in frequency.

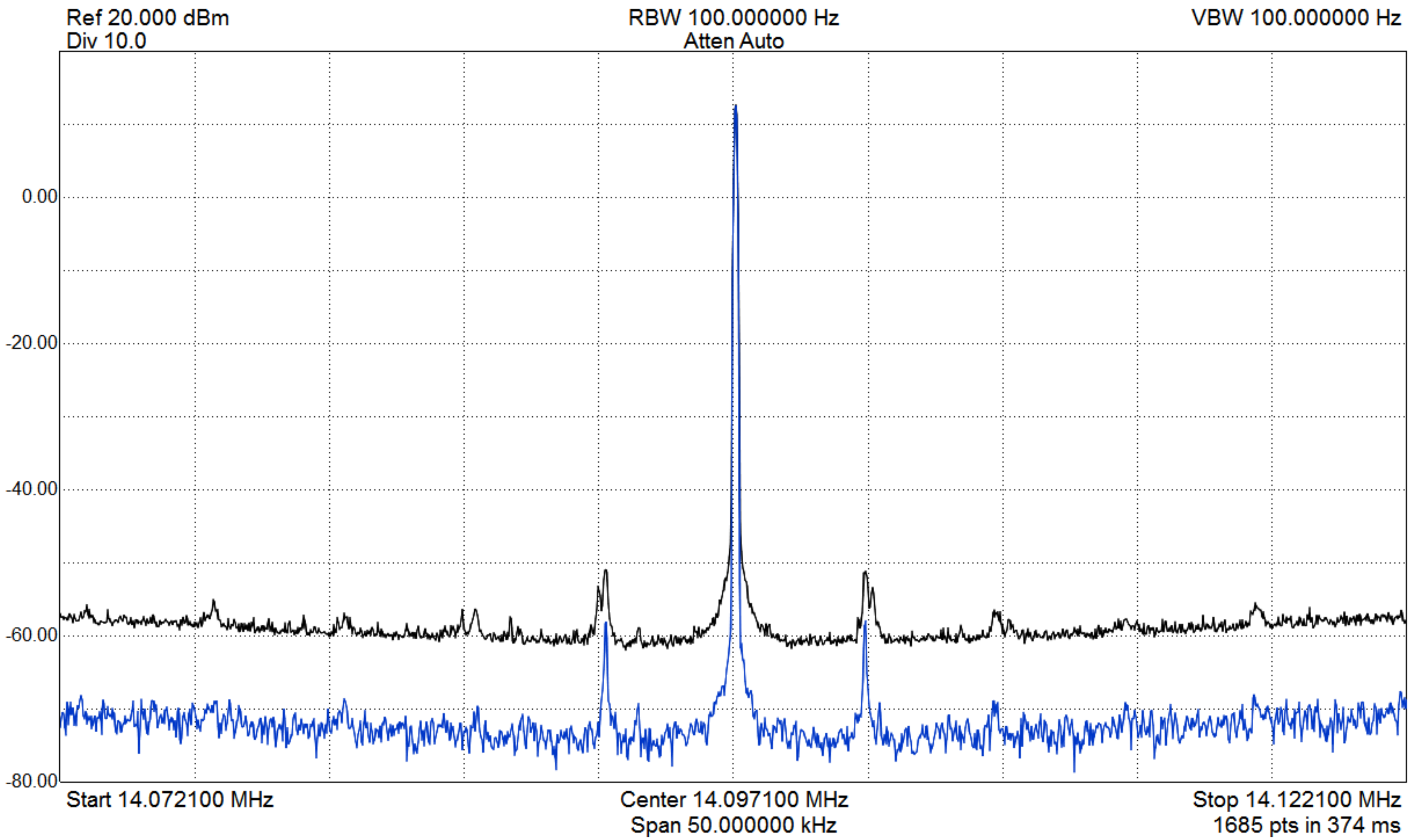
Raw Output @ 14.0971 MHz



- Spur at 7 MHz is only -33dB down – does not meet FCC -43dBc requirement
- This spur is actually the 35th harmonic of the 14MHz fundamental (493 MHz), aliased down to 7 MHz by the 500 MHz sampling clock.

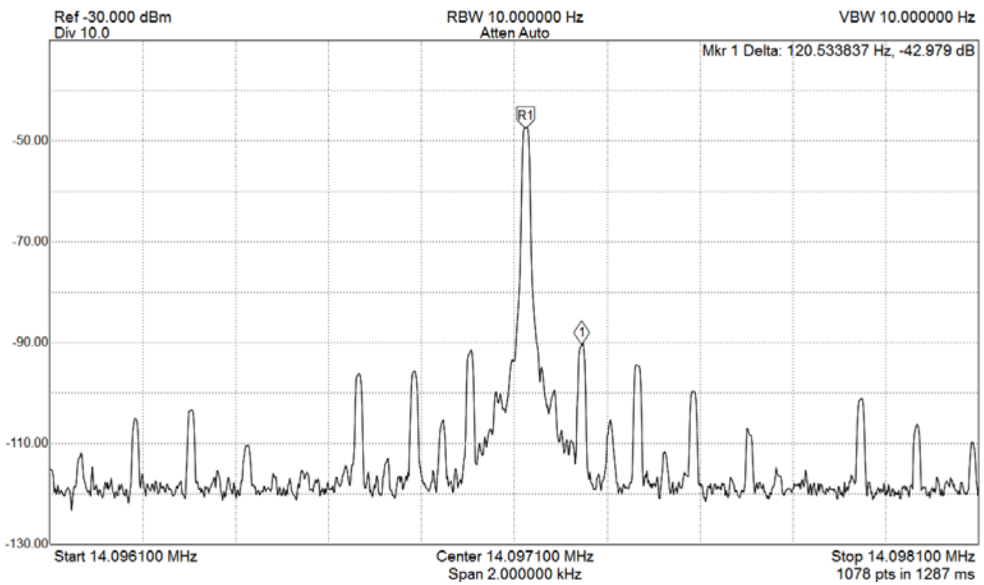
20 Meters

A clean close-in signal



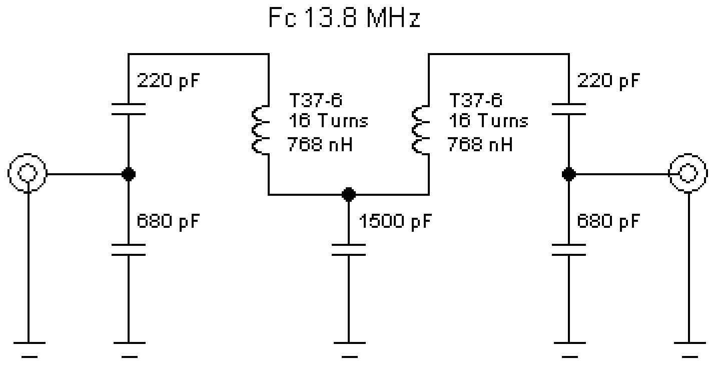
Blue = average, Black = peak-hold

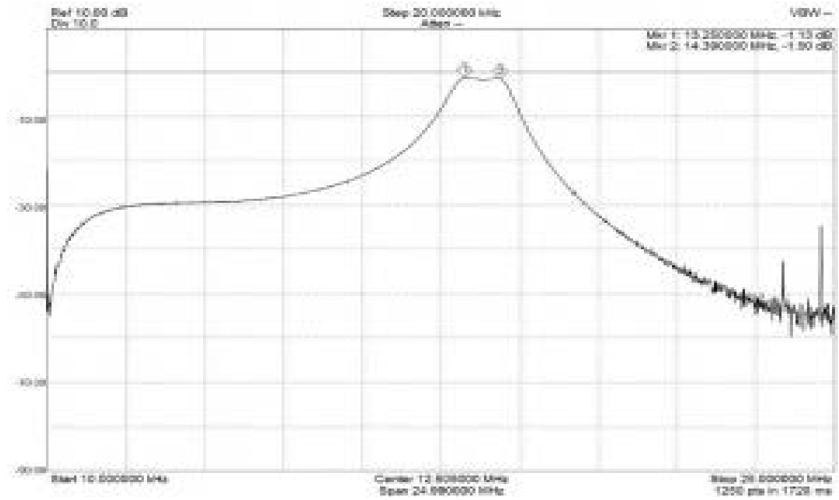
20 Meters Close-Up

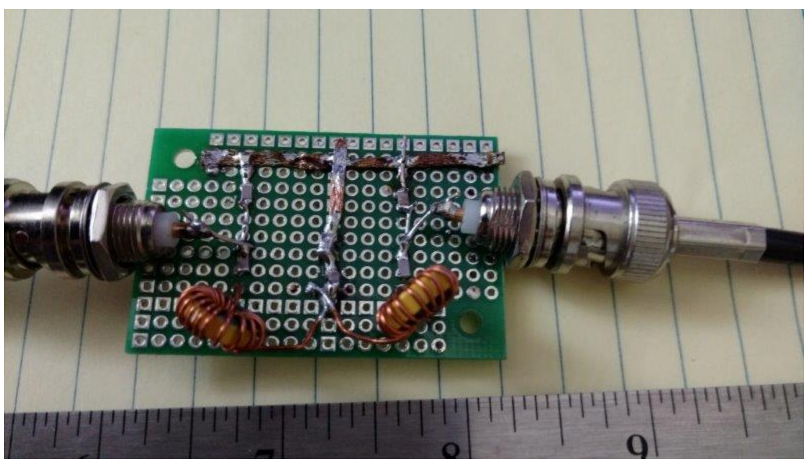


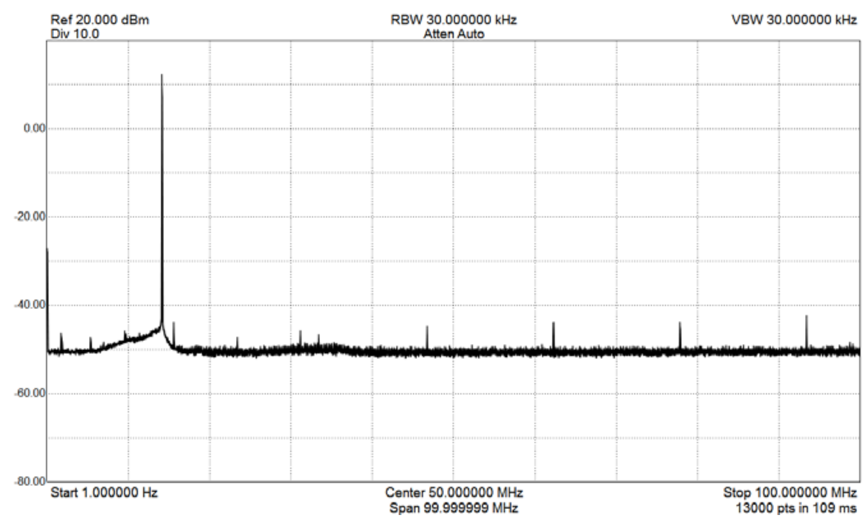
- 60 and 120 Hz sidebands
  - <= -43dBc
- May not be power-supply ripple
- About the same with:
  - Wall-wart USB charger
  - Bench supply
  - Custom linear regulator

Bandpass Filter on Output





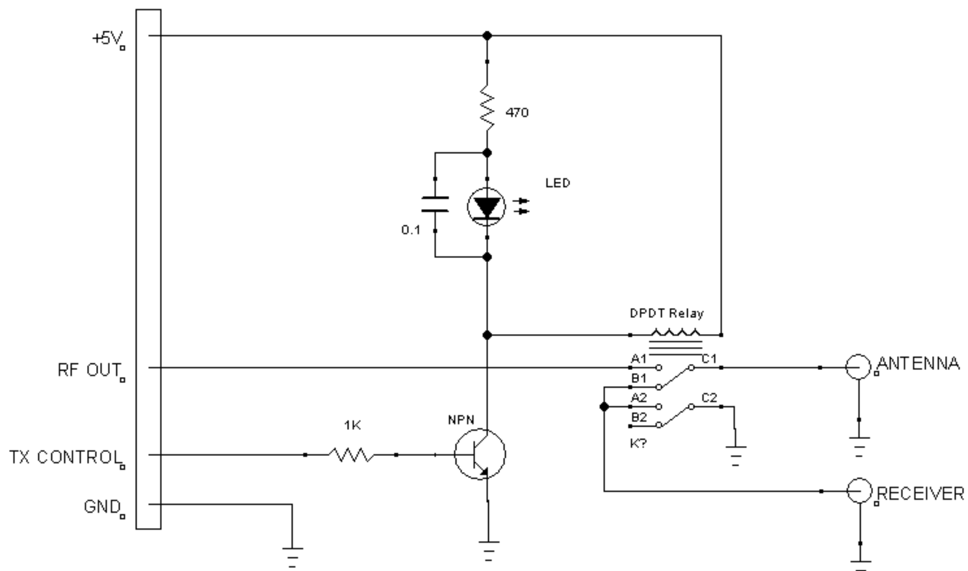




Frequency Stability

- Raspberry Pi uses a cheap, low-precision clock oscillator
- The WSPR band is 200Hz wide
  - At 14 MHz, 200Hz = +/- 7 ppm
  - At 50 MHz, 200 Hz = +/- 2 ppm
- The WsprryPi program allows for command-line frequency adjustment to correct for oscillator tolerance
- Measured frequency stability over temperature?
  - -16 °C : 14.000335 MHz
  - +22 °C: 14.000215 MHz
  - +45 °C: 14.000123 MHz
  - = 0.25 ppm / °C
  - @ 50 MHz, 16 °C max allowable temp swing (29 °F)
  - @ 14 MHz 56 °C max allowable temp swing (101 °F)

A Simple T/R Switch



- Lets us use a shared antenna for transmit and receive
- Built on Raspberry Pi plug-in card
- Program modified to drive TX CONTROL, with time-delay on transmit
- External bandpass filter connects to antenna jack, filters receiver input as well

More

- The Raspberry Pi transmitter costs less than the antenna
  - A bit more if you need a computer, GPS, etc
- WSPR 2.0 User's Guide: http://physics.princeton.edu/pulsar/K1JT/WSPR_2.0_User.pdf
- Linux commands used when running "headless" RPi
  - screen –S WSPR
  - sudo ./wspr –p -11.2 –r WB6CXC CN88LM 10 20m 0 0 0
  - screen -r
- Nyquist – sampling theory
- Shannon – channel capacity