Design and development of a GPS Disciplined Oscillator

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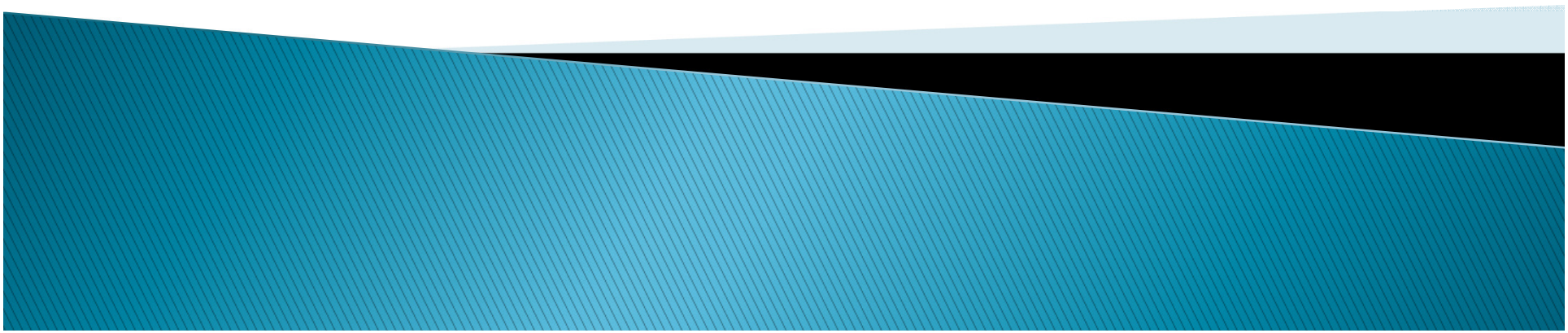
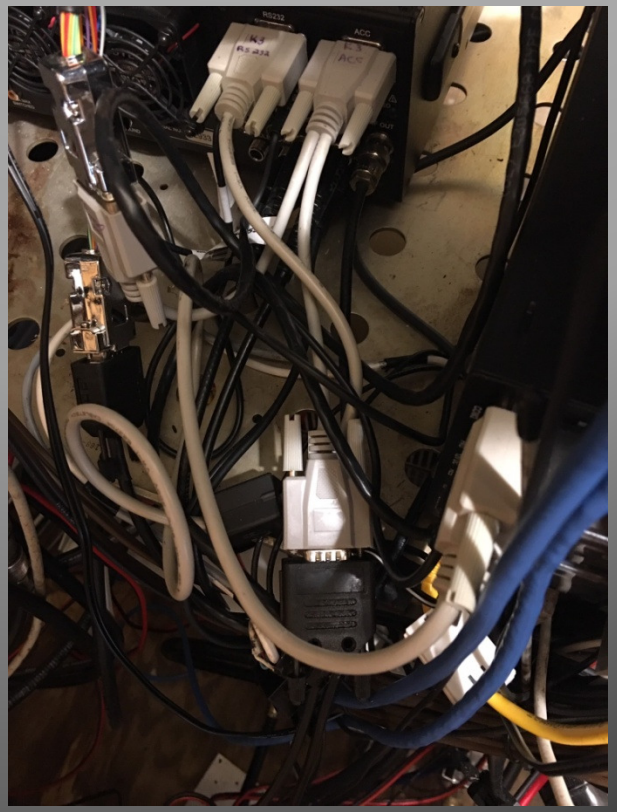


GPSDO – Time to update the transverters

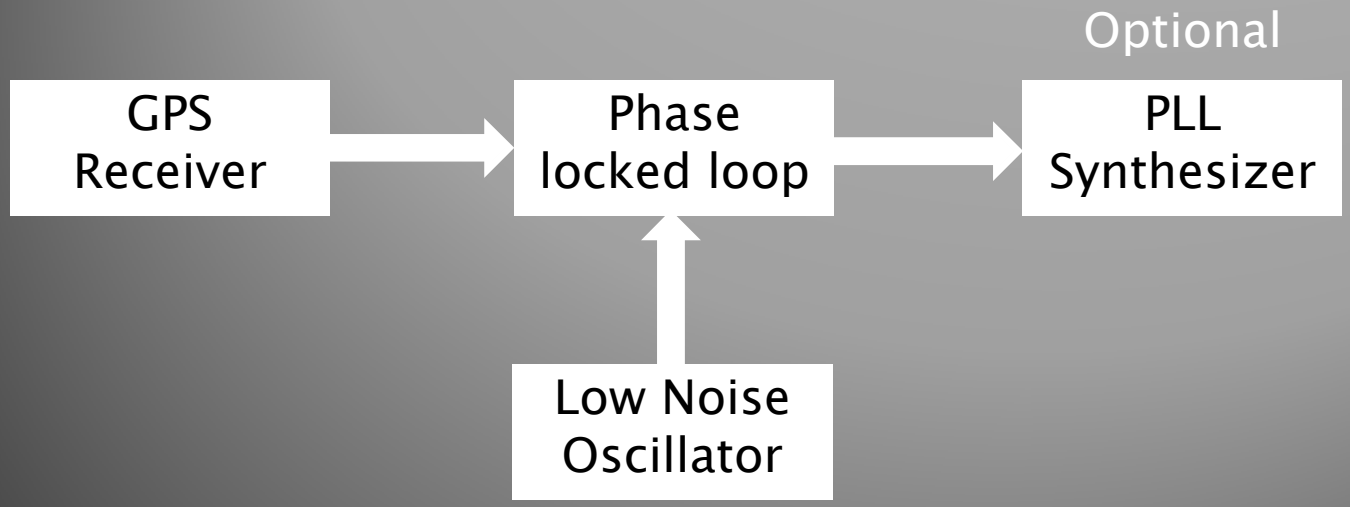
- LOs need more stability
- LOs need more accuracy
- Always want better phase noise
- Shack is too cluttered already



How do we “get on frequency” and stay there?

- Something GPS based is the answer
- Anything else seems to be a bandaid
  - Try to rebuild your existing crystal oscillator or oven controller and figure out what is not in the book
  - Calibrate (often) to an external beacon that you hope is really GPS locked

GPSDOs – disciplined oscillators



GPSDO – what is it?

- Best of both worlds
  - Long term stability derived from the GPS cesium clocks
  - Short term stability (phase noise) from high quality on board crystal oscillator

GPSDO – a bit of history

- Military uses – expensive boxes by companies like Symmetricom
- Commercial uses – cell phone frequency standard – remember the Z3801 with its 6 channel GPS receiver?

GPSDO – more recent history

- New chip vendors
  - UBLOX – small GPS receivers with integrated RF output
  - Silicon Labs – clock oscillators and jitter attenuators
- Leo Bodnar

- SV1AFN

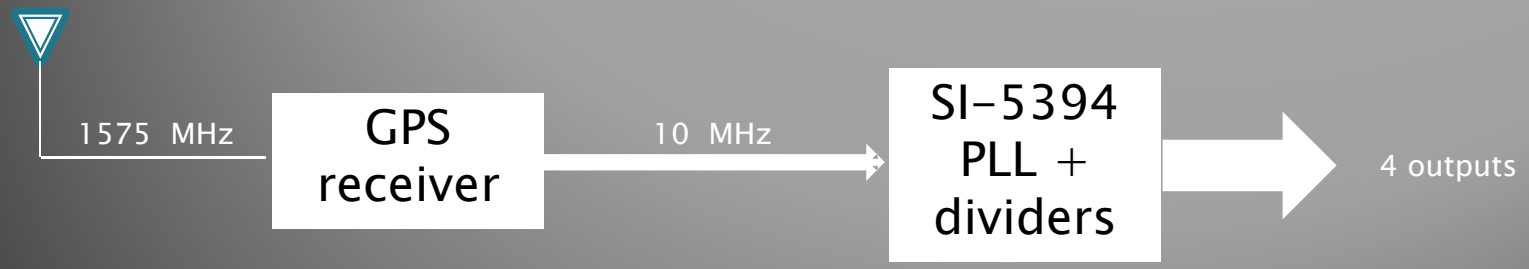
GPSDOs – where are they applicable?

- Local oscillators for transverters
- Beacon transmitters
- Reference oscillator for HF receivers, signal generators, spectrum analyzers
- Weak signal sources

GPSDOs – what's new?

- More independent channels
- Lower phase noise
- Latest generation components
- SI5394 – 4 channels
- Crystal filter following TCXO
- Ublox M8 GPS receiver

GPSDO – simple block diagram



GPSDO – what should we expect?

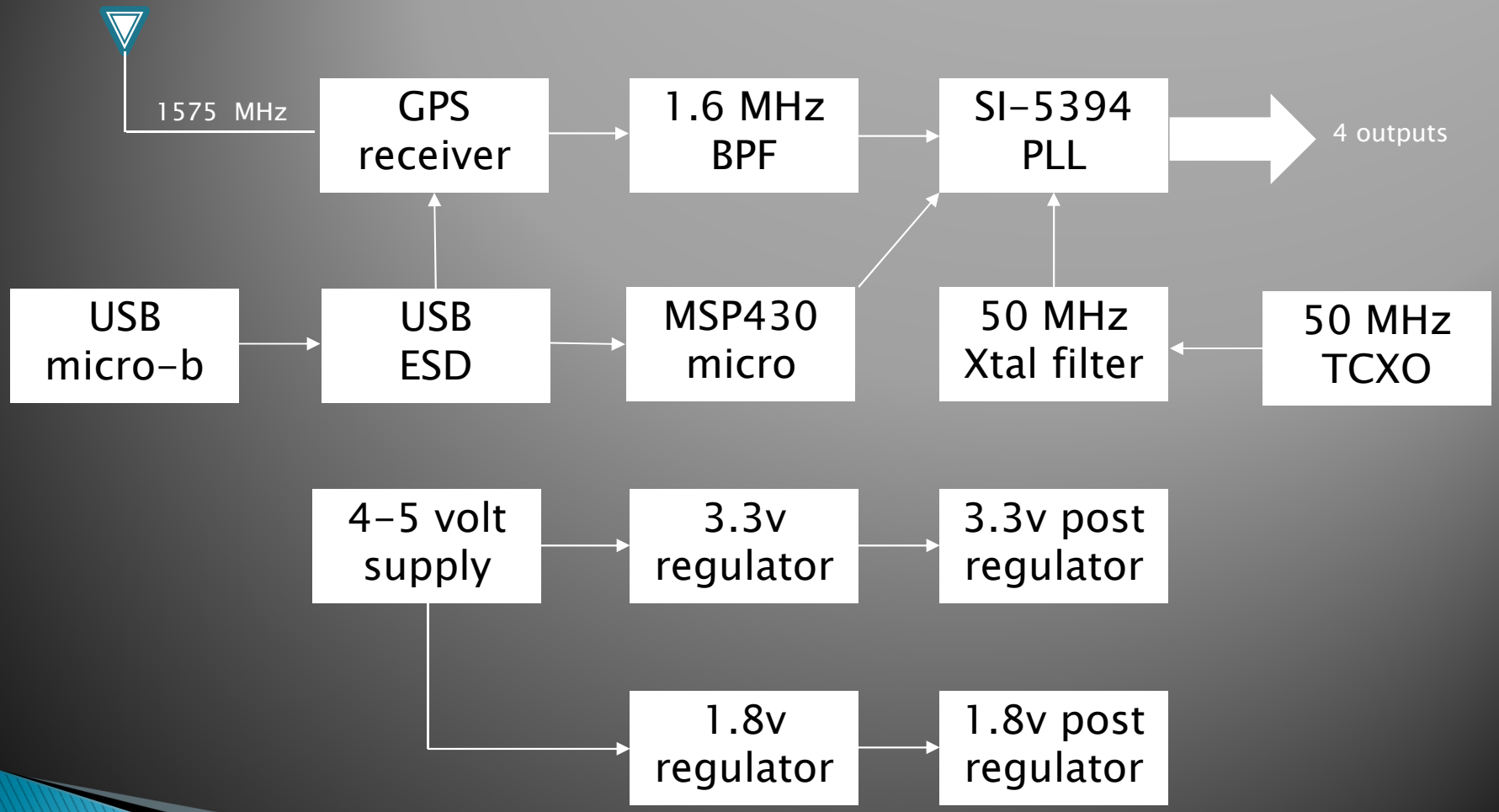
116 MHz Phase noise Measurement	Wenzel (FSWP)	116 XO (FSWP)	SI5394 Datasheet	LB Mini* phase detector	DigiLO Datasheet	VHF ApolLO Datasheet
100 Hz	-123.7	-123.4	-96.6	-105.0	-97	-85.7
1 KHz	-152.7	-149.7	-123.6	-122.0	-112	-104.7
10 KHz	-164.7	-157.3	-139.6	-127.0	-115	-108.7
100 KHz	-167.7	-163.5	-147.6		-120	

* Results obtained using battery power source, USB results will be worse!

GPSDO – real life

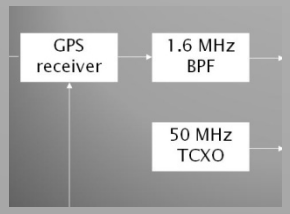
	BEACON case				Contest station case 1			Contest station case 2		
Frequency			144.3	Mhz		144.3	Mhz		144.3	Mhz
Transmit power (watts)		10	40	dBm	1000	60	dBm	1000	60	dBm
Cable loss			-1	dB		-1	dB		-1	dB
Transmit antenna	halo		1	dBi	12 el yagi	14.5	dBi	12 el yagi	-6	dBi
Effective radiated power			40	dBm		73.5	dBm		53	dBm
Path Loss (1.0 mile)			79.8	dB		79.8	dB		79.8	dB
Receive antenna			10	dB	12 el yagi	14.5	dB	12 el yagi	-6	dB
Cable loss			-1	dB		-1	dB		-1	dB
Carrier Power to receiver			-30.8	dBm		7.2	dBm		-33.8	dBm
100 Khz offset			-147	dBc/Hz		-147	dBc/Hz		-147	dBc/Hz
100 KHz offset absolute			-177.8	dBm/Hz		-139.8	dBm/Hz		-180.8	dBm/Hz
Receiver noise bandwidth			500	Hz		500	Hz		500	Hz
Receiver noise bandwidth			27	dB		27	dB		27	dB
Phase noise power at receiver			-150.8	dBm		-112.8	dBm		-153.8	dBm
Receiving system noise floor 3 dB noise figure (500 Hz BW)			-144.0	dBm		-144.0	dBm		-144.0	dBm

GPSDO – not so simple block diagram

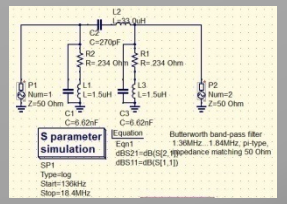


GPSDO – the build process

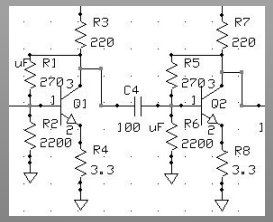
- Design – block diagram
- Design – circuit simulation
- Design – schematic capture
- PCB layout – 2 layer board



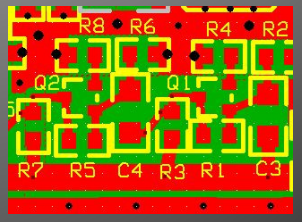
Power Point



QUCS



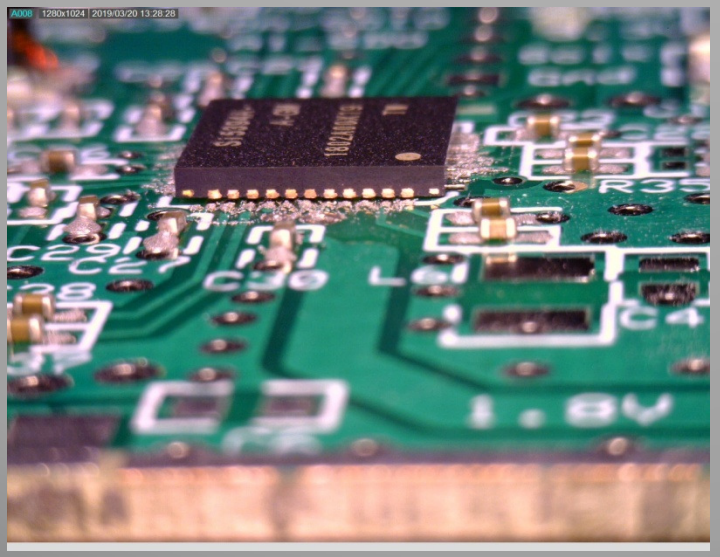
Express PCB



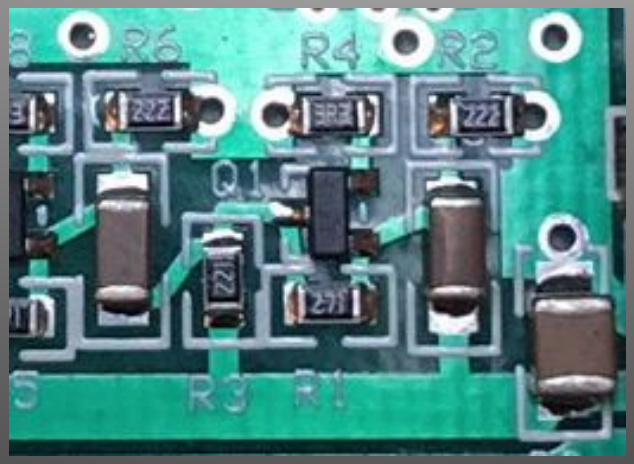
Express PCB

GPSDO – the build process

- Solder paste

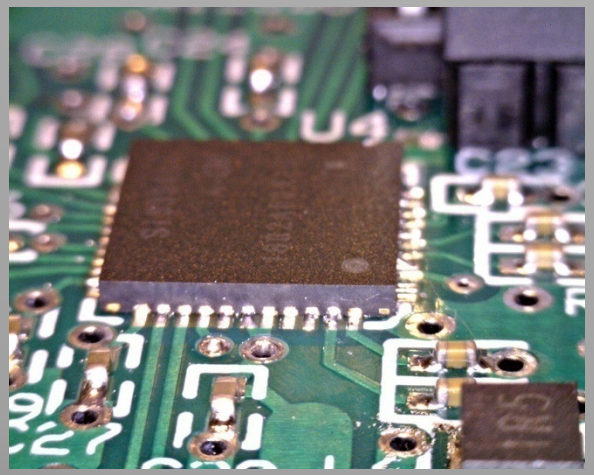


- Toaster oven



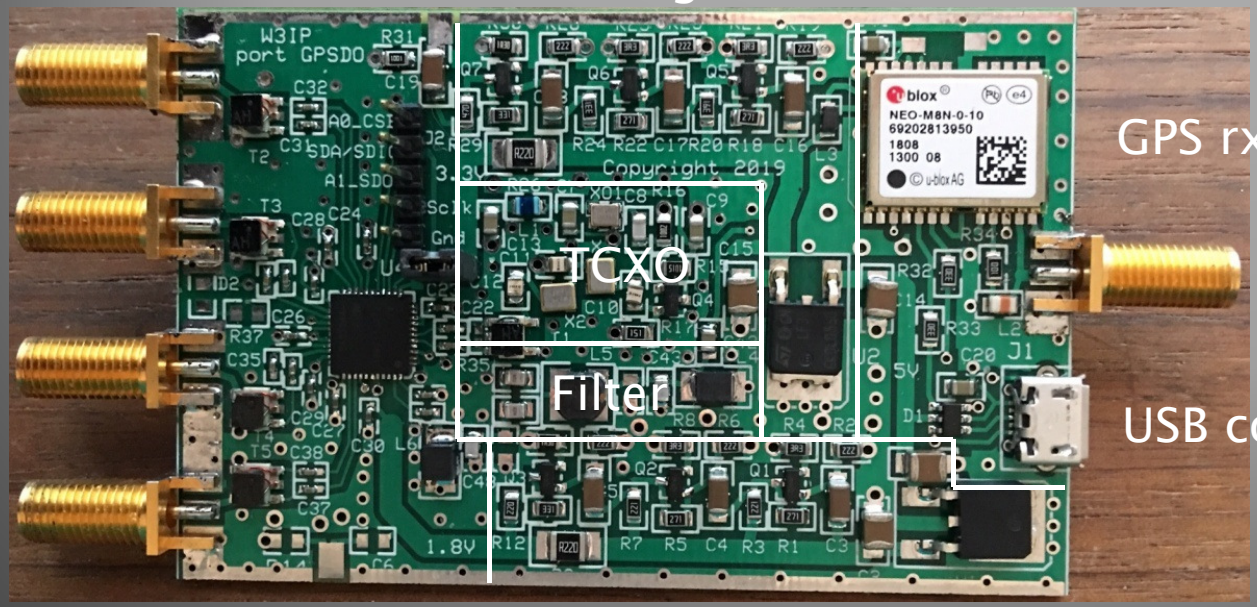
GPSDO – the build process

- Inspection

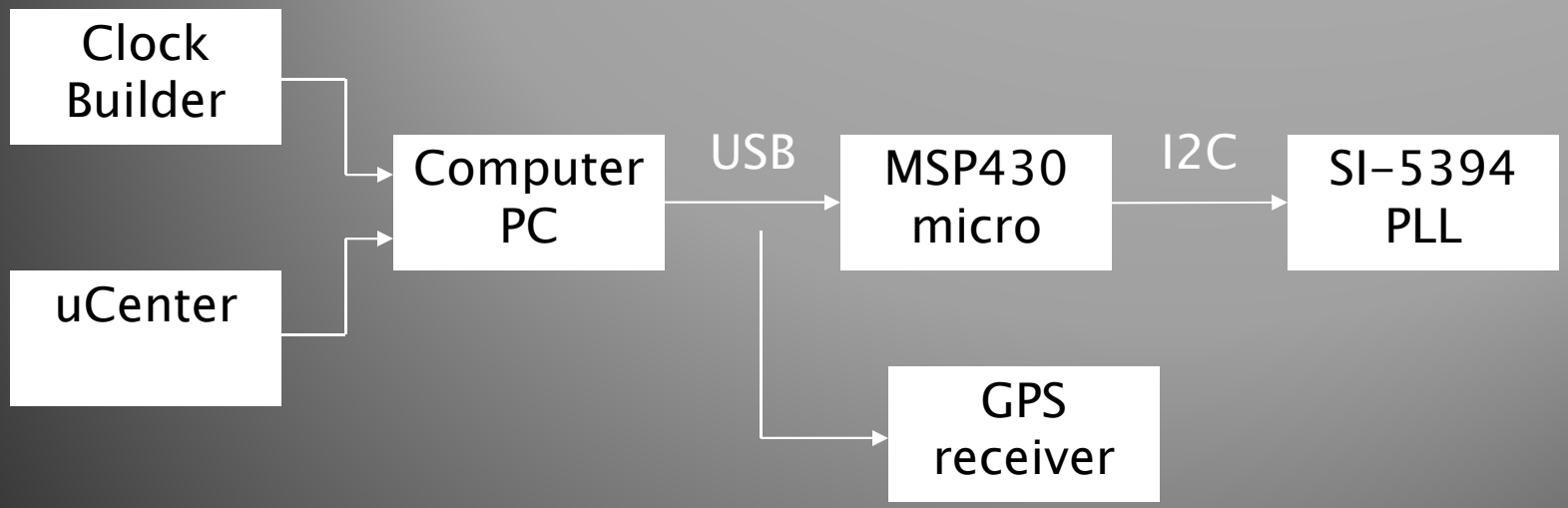


- Mechanical

GPSDO –Prototype 2



GPSDO setup – Digital Data Flow



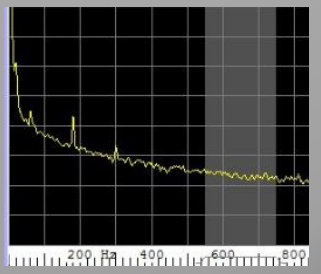
GPSDO – Microprocessor selection

- USB and I2C compatible
- Must have factory bootloader
- Small pin count
- MSP430F 5xxx/6xxx
- Lots of code
- Eliminates the inexpensive PICs
- Wishful thinking – 48LQFP
- CCS code bloat

GPSDO – Testing 1,2,3

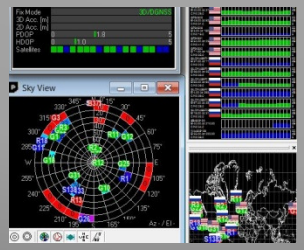
- Regulator – function

- Regulator – performance



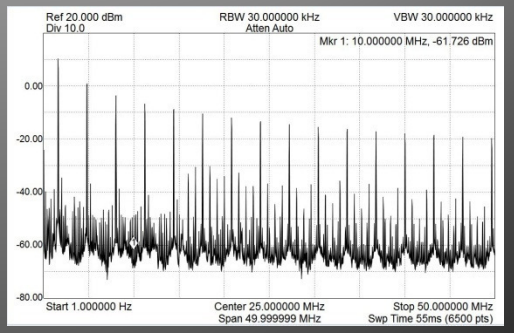
Spectrum Lab

- GPS receiver – function



U-Center

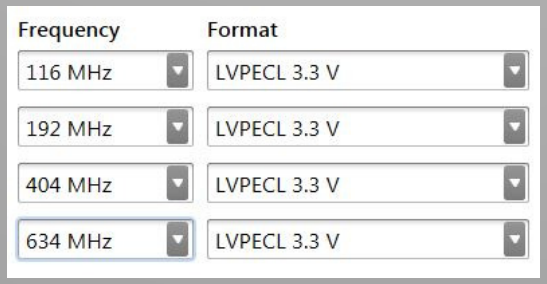
- GPS receiver – performance



SignalHound

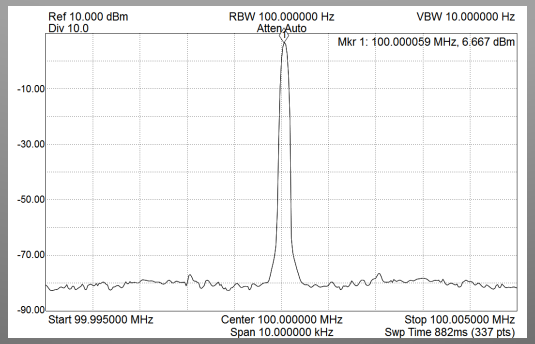
GPSDO – Testing 1,2,3

- Clock multiplier – function



ClockBuilder Pro

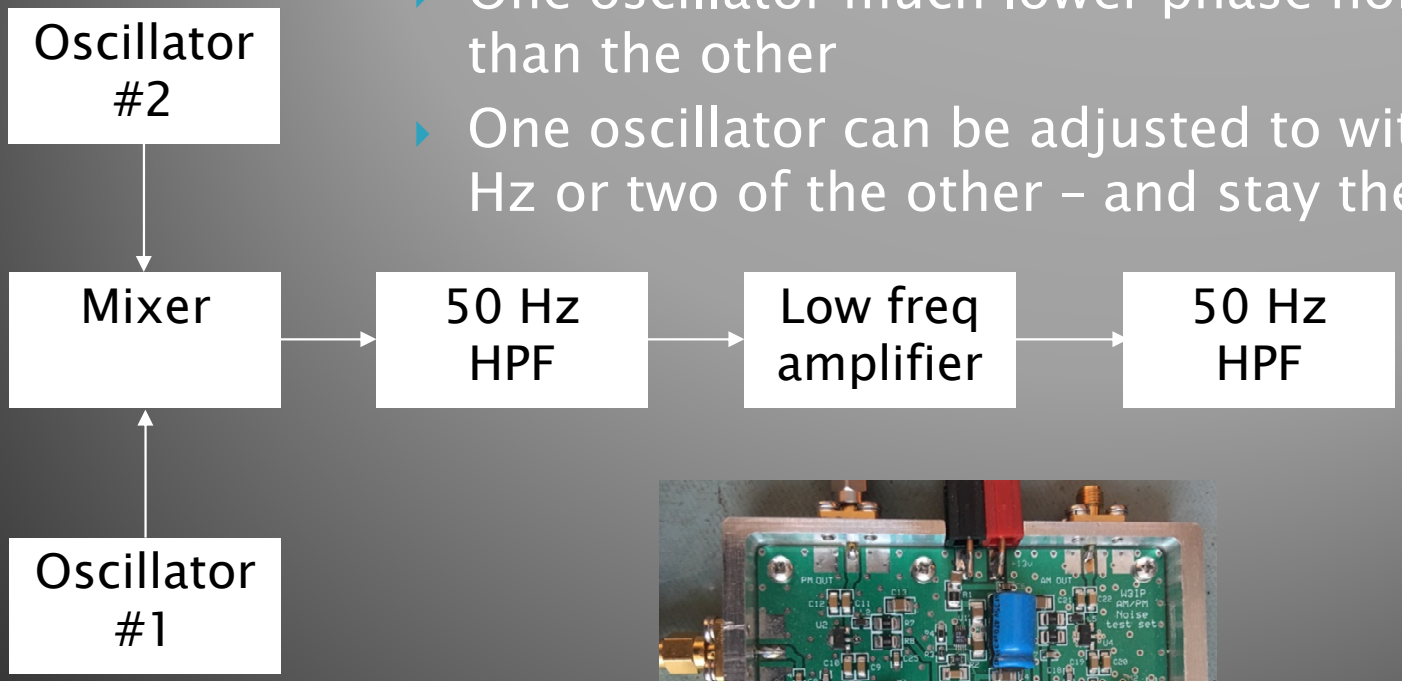
- Clock output – levels
  - +6.5 dBm typical

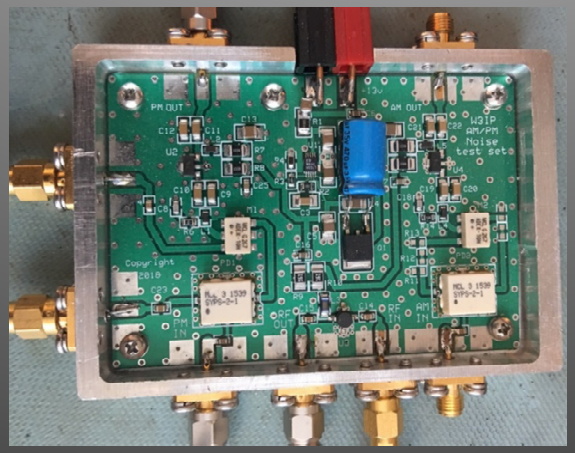


SignalHound

GPSDO – Phase noise testing

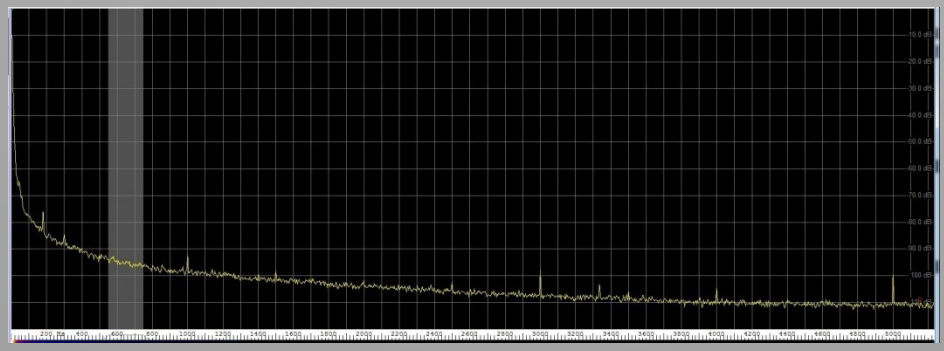
- Assumptions
- One oscillator much lower phase noise than the other
- One oscillator can be adjusted to within a Hz or two of the other – and stay there





GPSDO – Testing 1,2,3

- 100 MHz output – phase noise



Spectrum Lab

- Prototype-2 Phase noise performance

100 MHz Phase noise	Wenzel (FSWP)	W3IP Phase det.	SI5394 Datasheet
100 Hz	-125.0	-97.8	-97.9
1 KHz	-154.0	-120.8	-124.9
10 KHz	-166.0	-135.8	-140.9
100 KHz	-169.0		-148.9

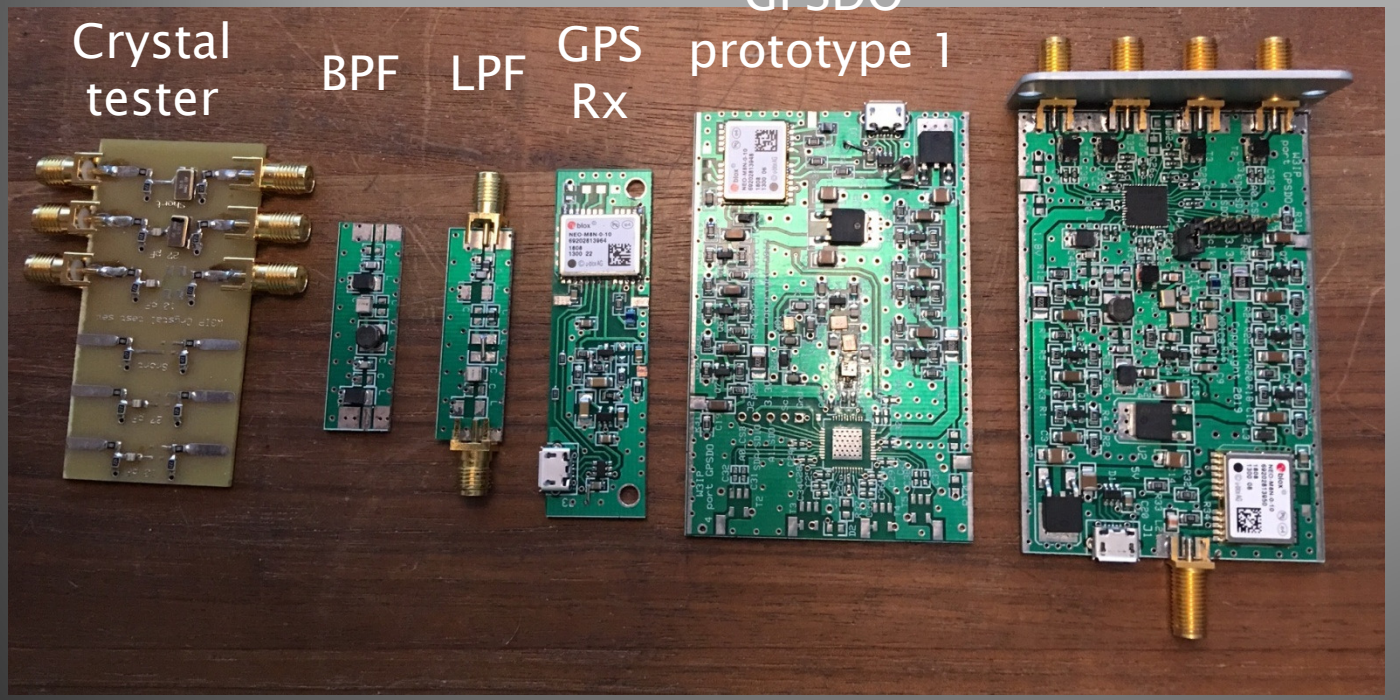
GPSDO – PLL power consumption

Assumptions
Total Power: 1.030 W, **On Chip Power**: 960 mW, **Tj**: 91 °C
Note:
•On-chip power excludes power dissipated in external terminations.
•Tj is junction temperature. Tj must be less than 125 °C (on Si5394 Revision A) for device to comply with datasheet specifications.
•Total power includes on- and off-chip power. This is a typical value and estimate only.

VDD:	1.8 V
Ta:	70 °C
Airflow:	None

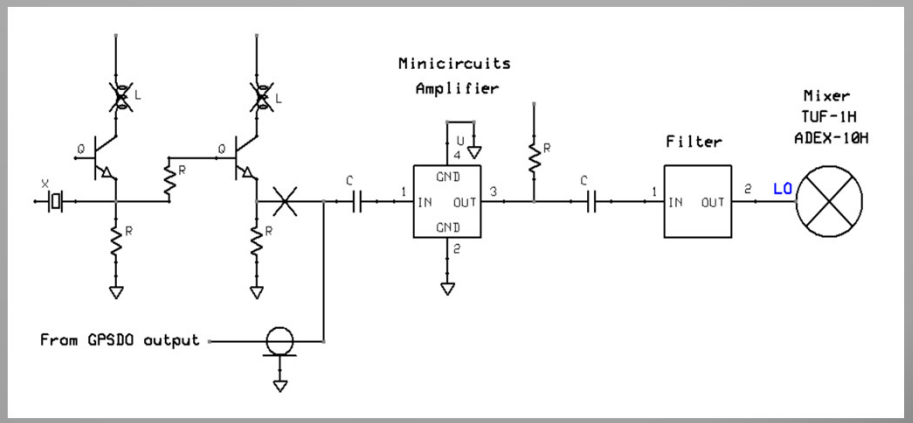
	Frequency	Format	Voltage	Current	Power
VDD			1.8 V	187.3 mA	337 mW
VDDA			3.3 V	117.4 mA	387 mW
VDDO0	116 MHz	LVPECL	3.3 V	22.6 mA	74 mW
VDDO1	192 MHz	LVPECL	3.3 V	23.1 mA	76 mW
VDDO2	404 MHz	LVPECL	3.3 V	24.5 mA	81 mW
VDDO3	100 MHz	LVPECL	3.3 V	22.5 mA	74 mW
			Total	**397.2 mA**	**1.030 W**

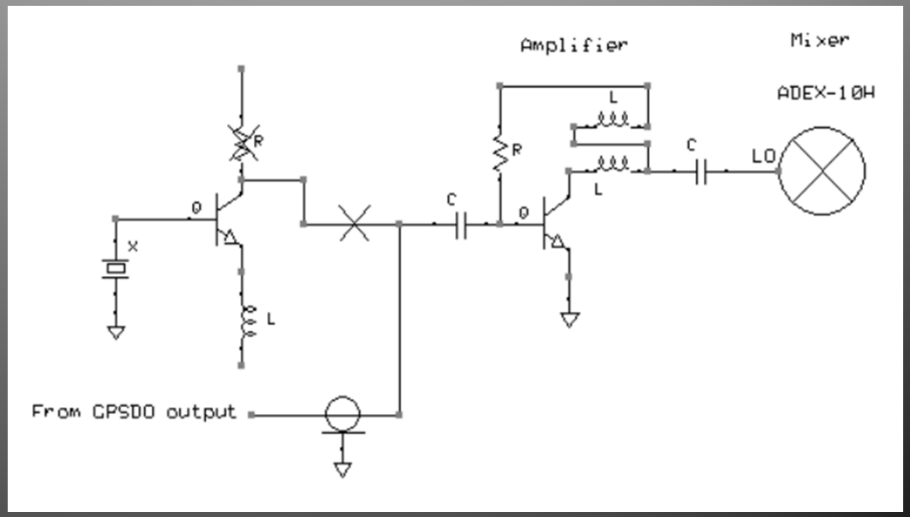
GPSDO – development boards



GPSDO – Transverter Integration

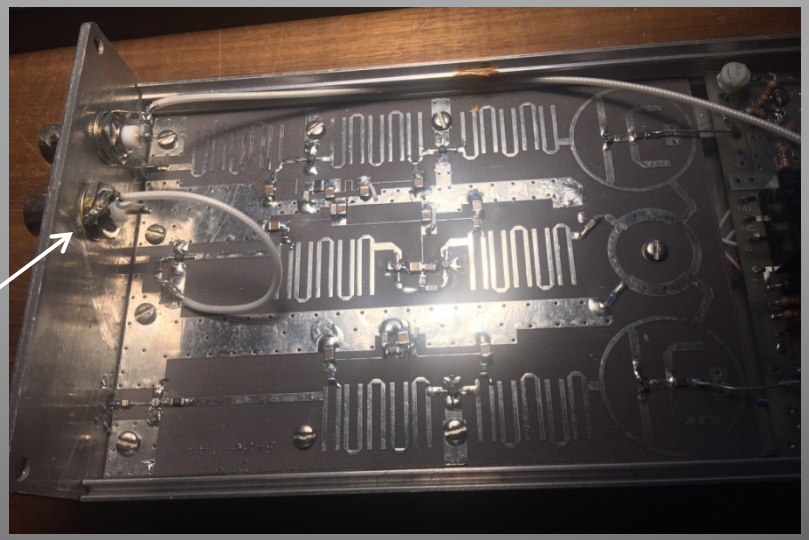
- VHF transverters
  - Many mixers want +17 dBm
  - Remove DC power from oscillator and oven (PTC)
  - Feed GPSDO signal into driver amp, ac coupled





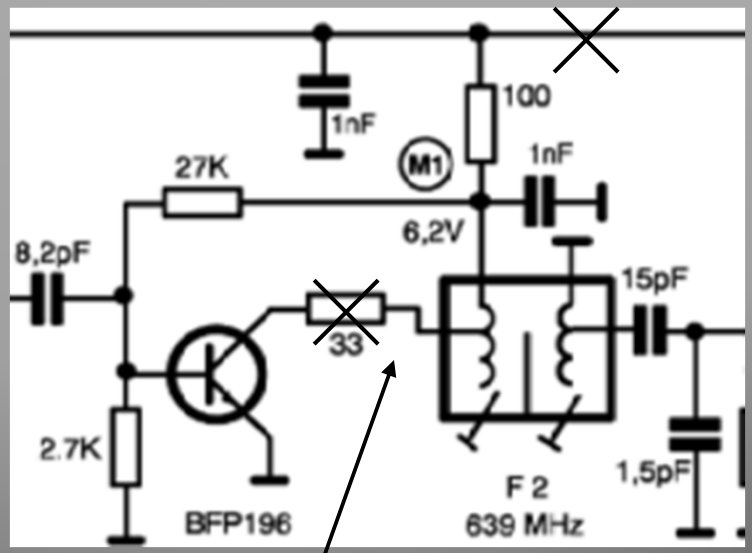
GPSDO – Transverter Integration

- Microwave transverters
  - Multi PCB transverters – Disable the crystal oscillator and lower multiplier stages
  - Feed GPSDO signal into multiplier on micowave board, ac coupled



GPSDO – Transverter Integration

- Microwave transverters
  - Single PCB transverters (DB6NT) – Analyze block diagram and schematic, find highest frequency in LO chain supported by the GPSDO
  - Remove DC power from oscillator and lower level multipliers
  - Feed GPSDO signal into next multiplier



AC coupled at 639 MHz

4 channel GPSDO – in the box

GPSDO – Prototype-2 Datasheet

- Number of channels: 4
- Frequency range: 10-720, 734-800, 825-1028 MHz
- Power output: 6.0 dBm minimum 1-500 MHz
- 2.3 dBm at 1024 MHz
- Channel to channel Isolation: 50-85 dB
- Phase noise at 100 MHz (clean power source)
  - -98 dBc/Hz at 100 Hz
  - -121 dBc/Hz at 1 KHz
  - -136 dBc/Hz at 10 KHz
- Size: 3.2 by 2.1 by .91 inches (excluding connectors)
- Power consumption: 5 volts, .67 amps max

GPSDO – Summary

- Described the design process for a 4 channel GPSDO
  - Evaluated existing hardware
  - Identified areas for improvement
  - Tested circuits in phases
  - Developed circuit values, schematic, PCB, BoM, mechanical package
  - Tested key parameters – channel to channel isolation, phase noise