

CMOS Systems-on-Chip for NASA Millimeter-Wave & THz Space Instruments

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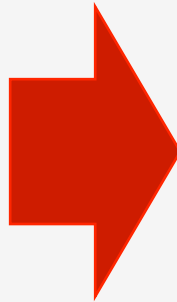
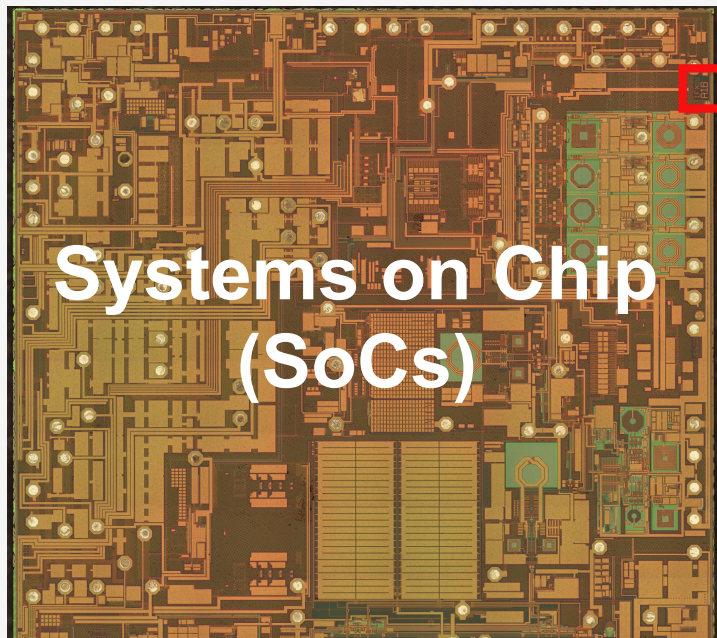


JPL

(and everyone else too)

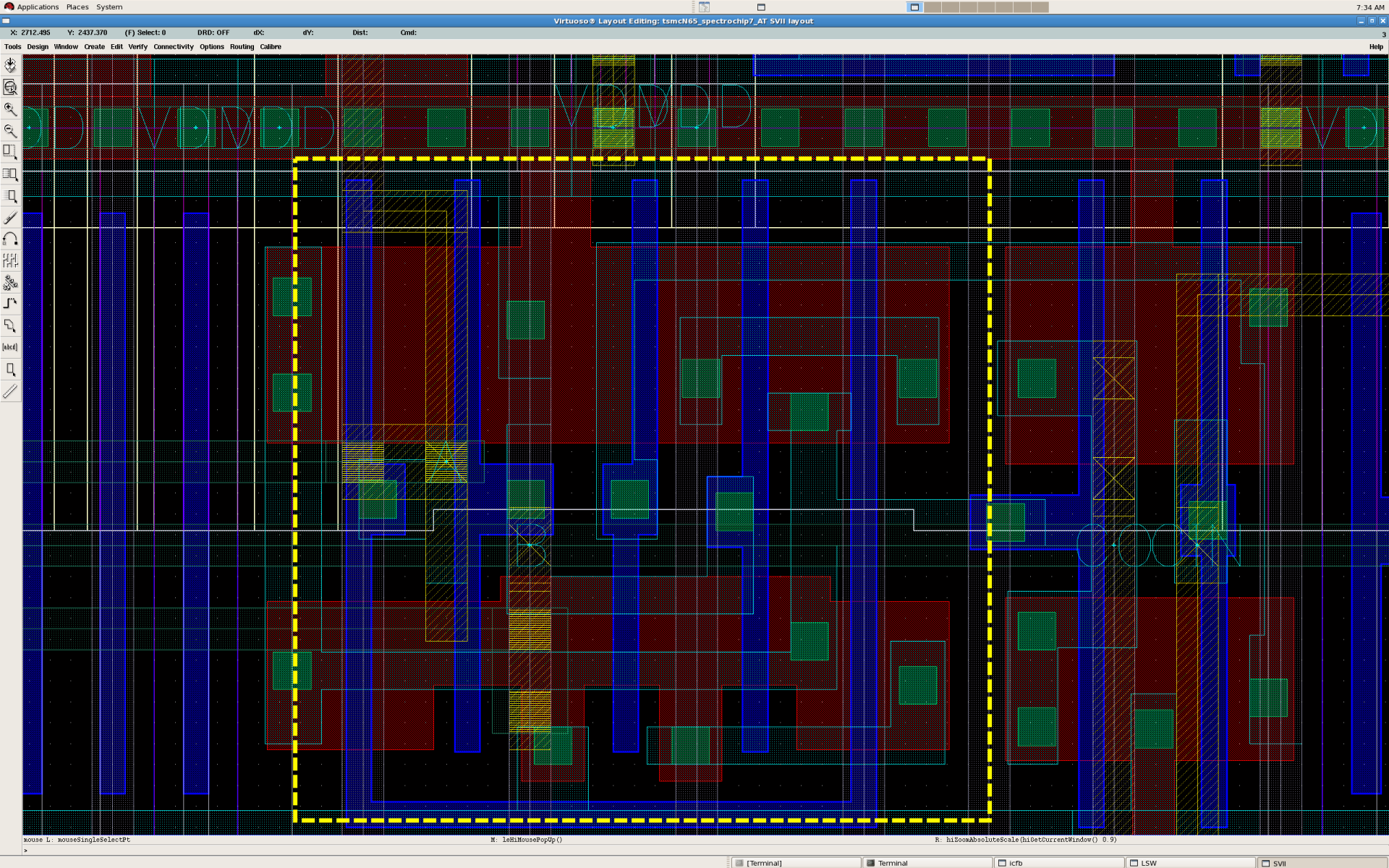
CMOS SoCs for Instrument Payloads

- ❖ The incredible integration ability of CMOS SoC technology is what enables modern electronics technology through reduction of system size/power.
- ❖ The ability to integrate 1000s of functions and sub-systems (analog, digital, mixed-sig, RF) onto a single-chip is what drives these industries.

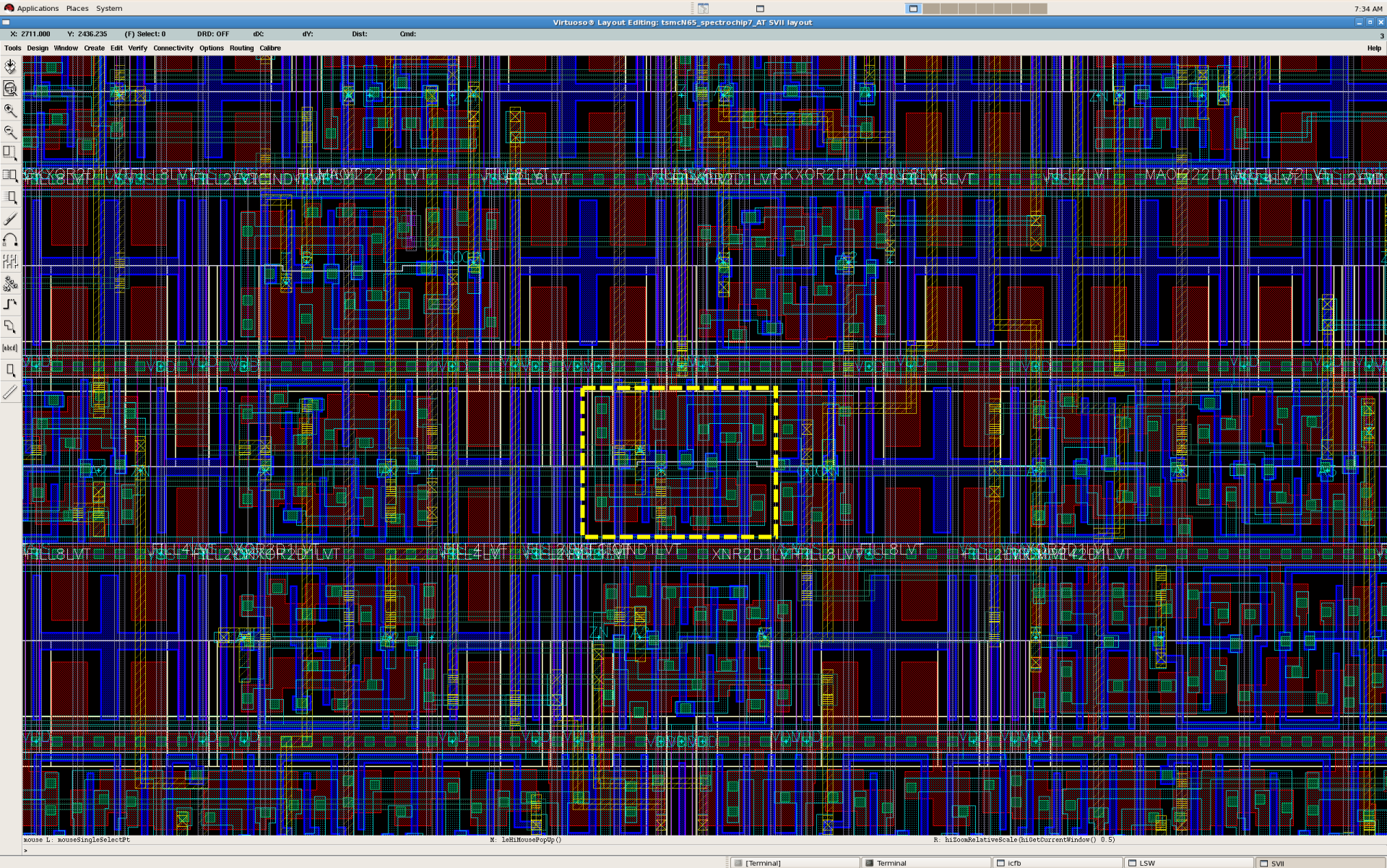


Can we use SoC technology to reduce the size weight and power of NASA space instruments?

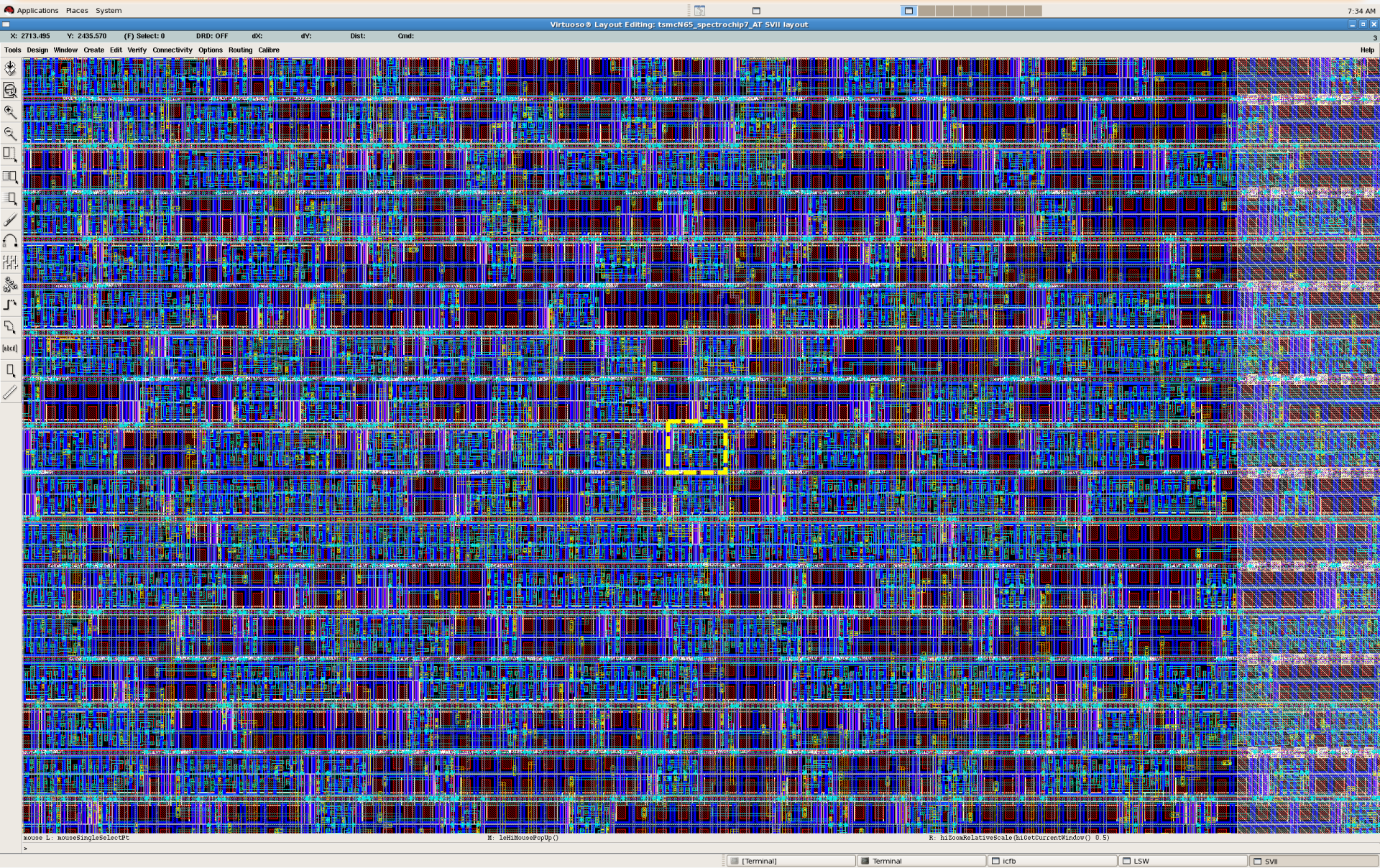
Example of a CMOS SoC



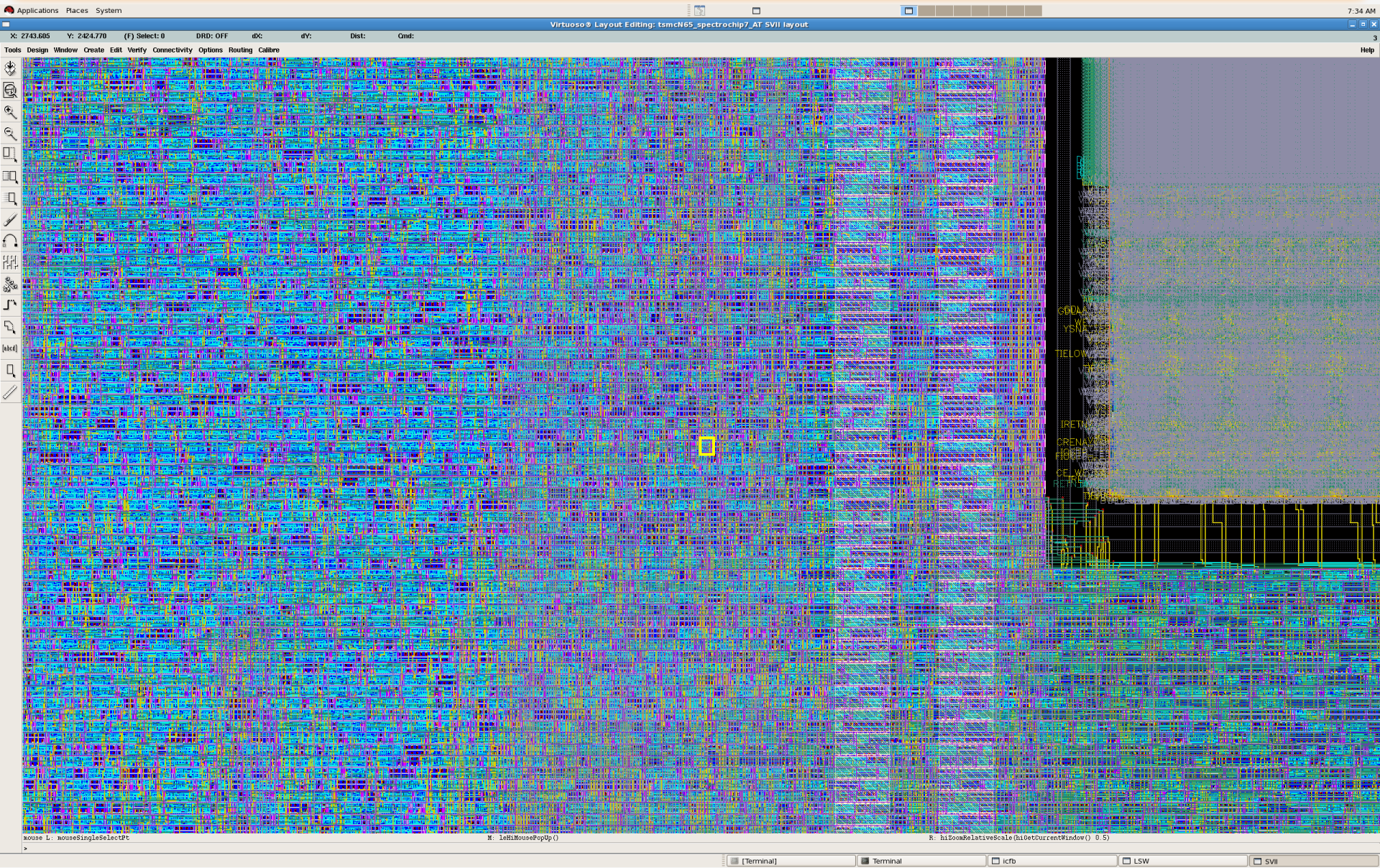
Example of a CMOS SoC



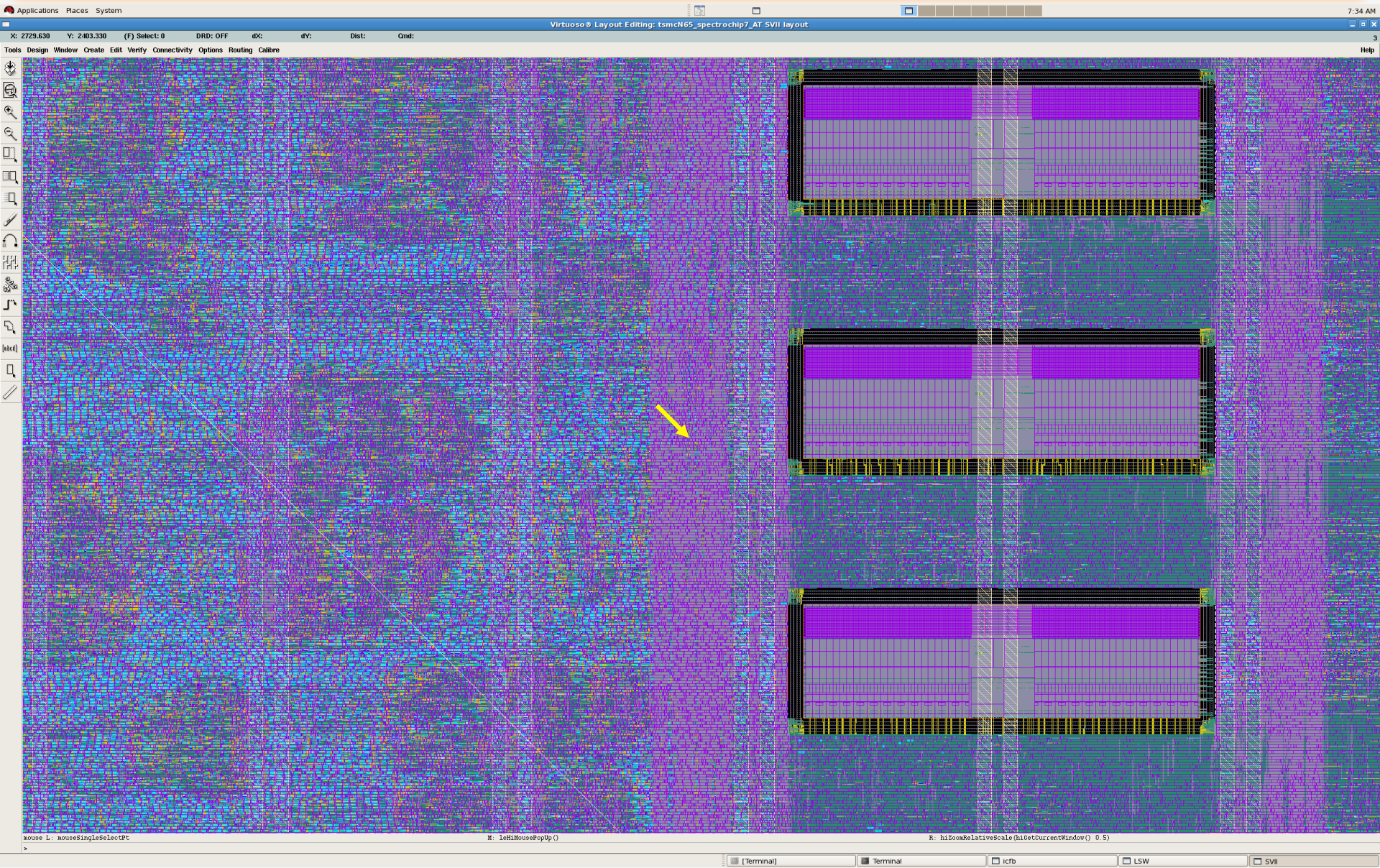
Example of a CMOS SoC



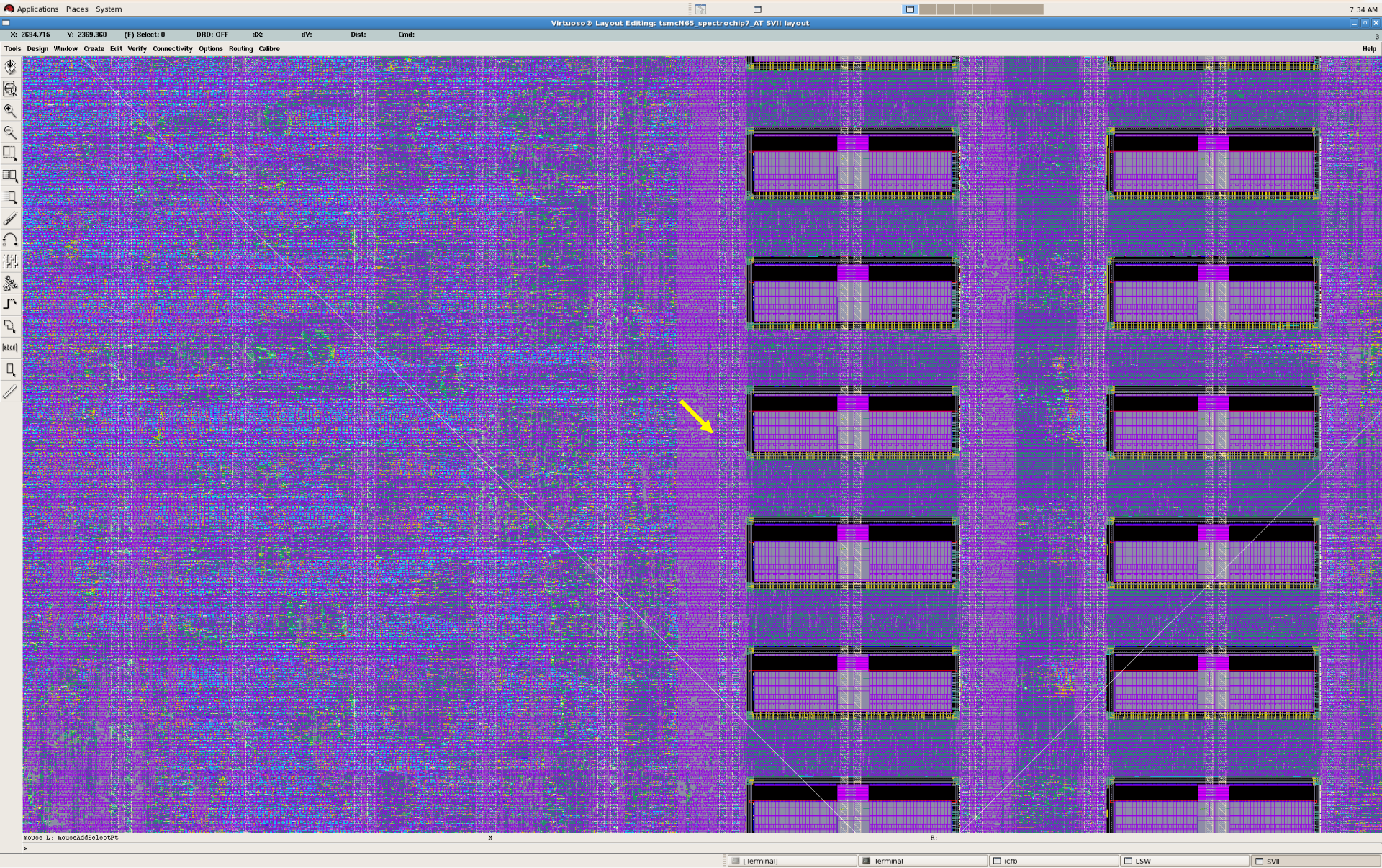
Example of a CMOS SoC



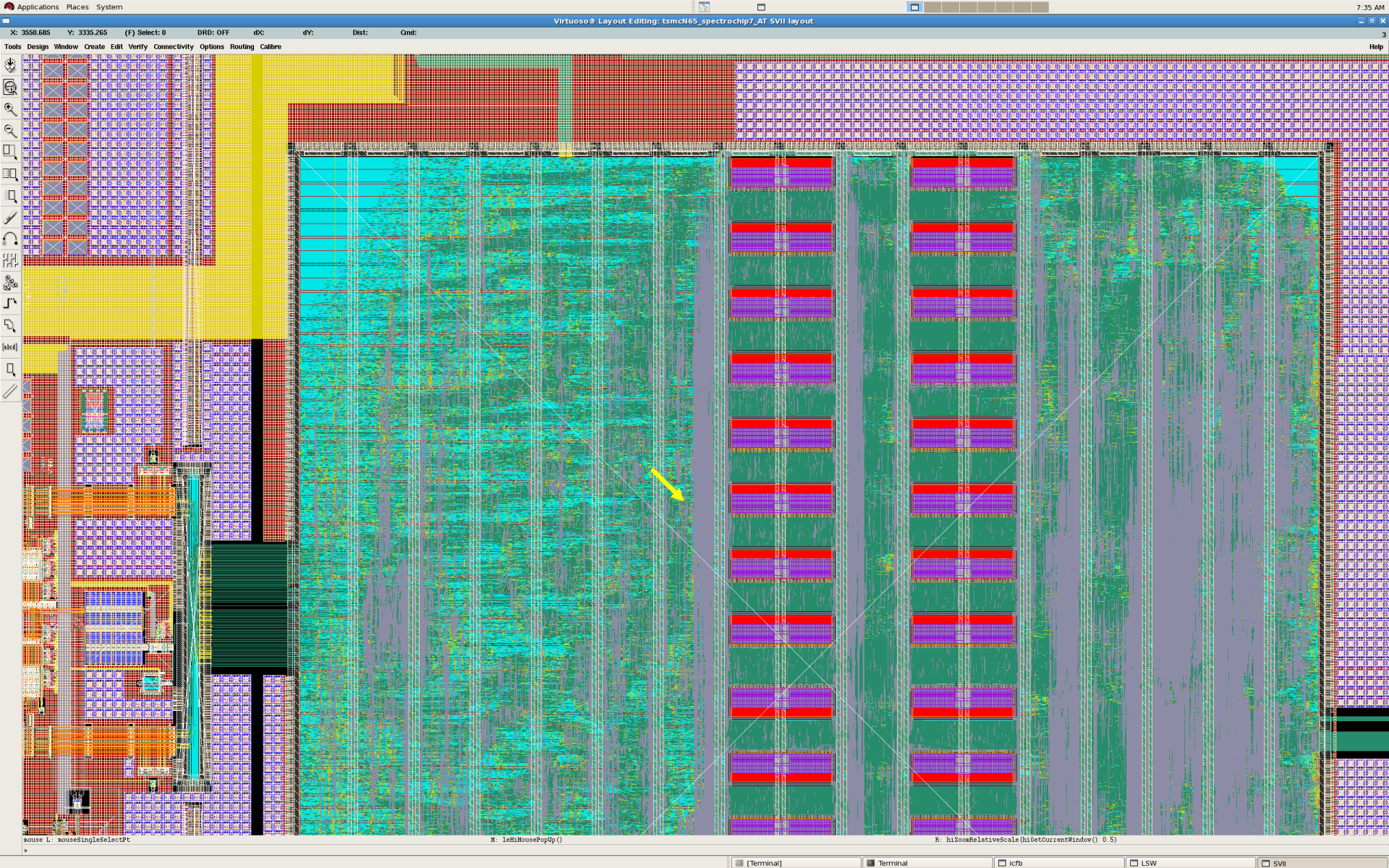
Example of a CMOS SoC



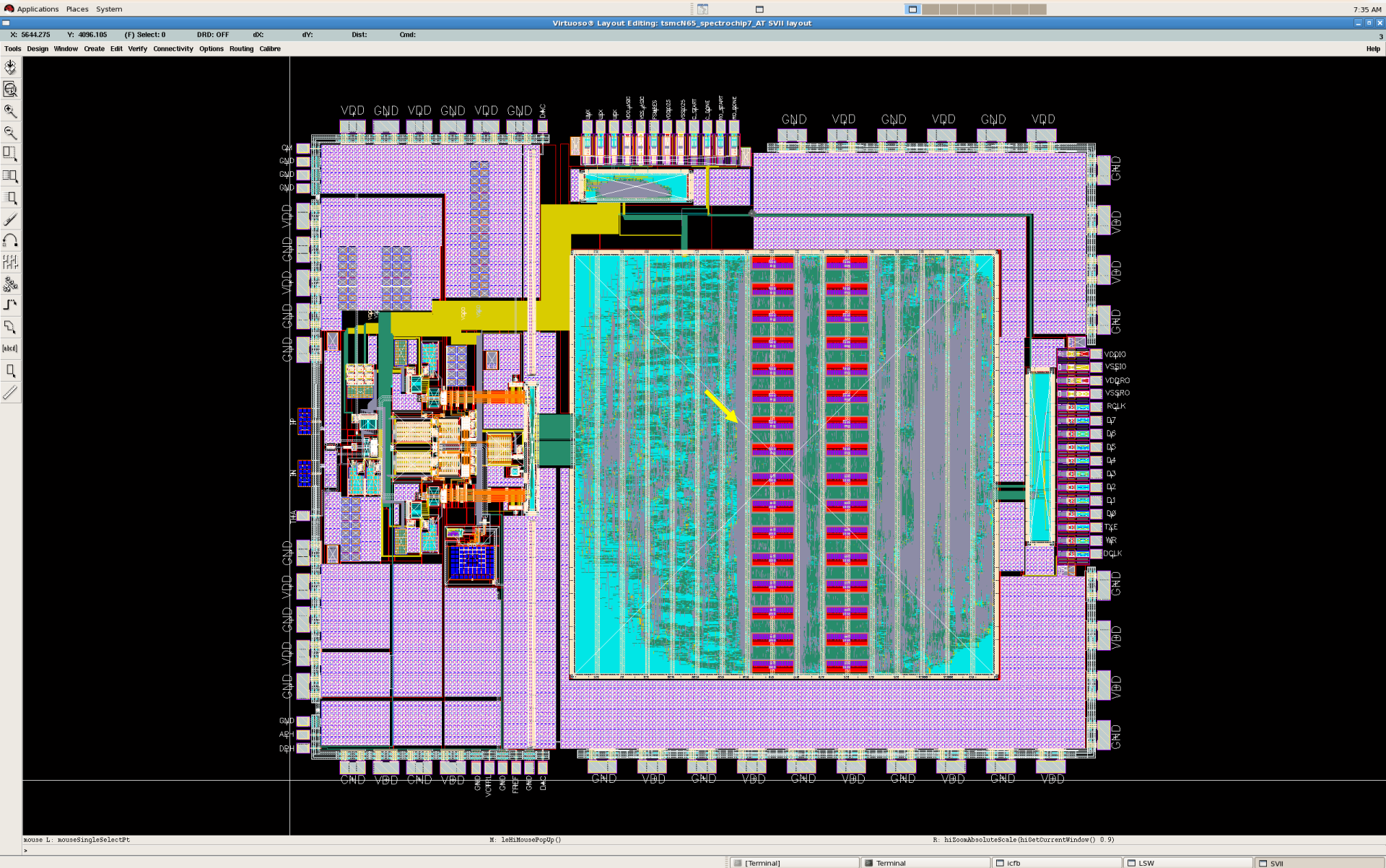
Example of a CMOS SoC



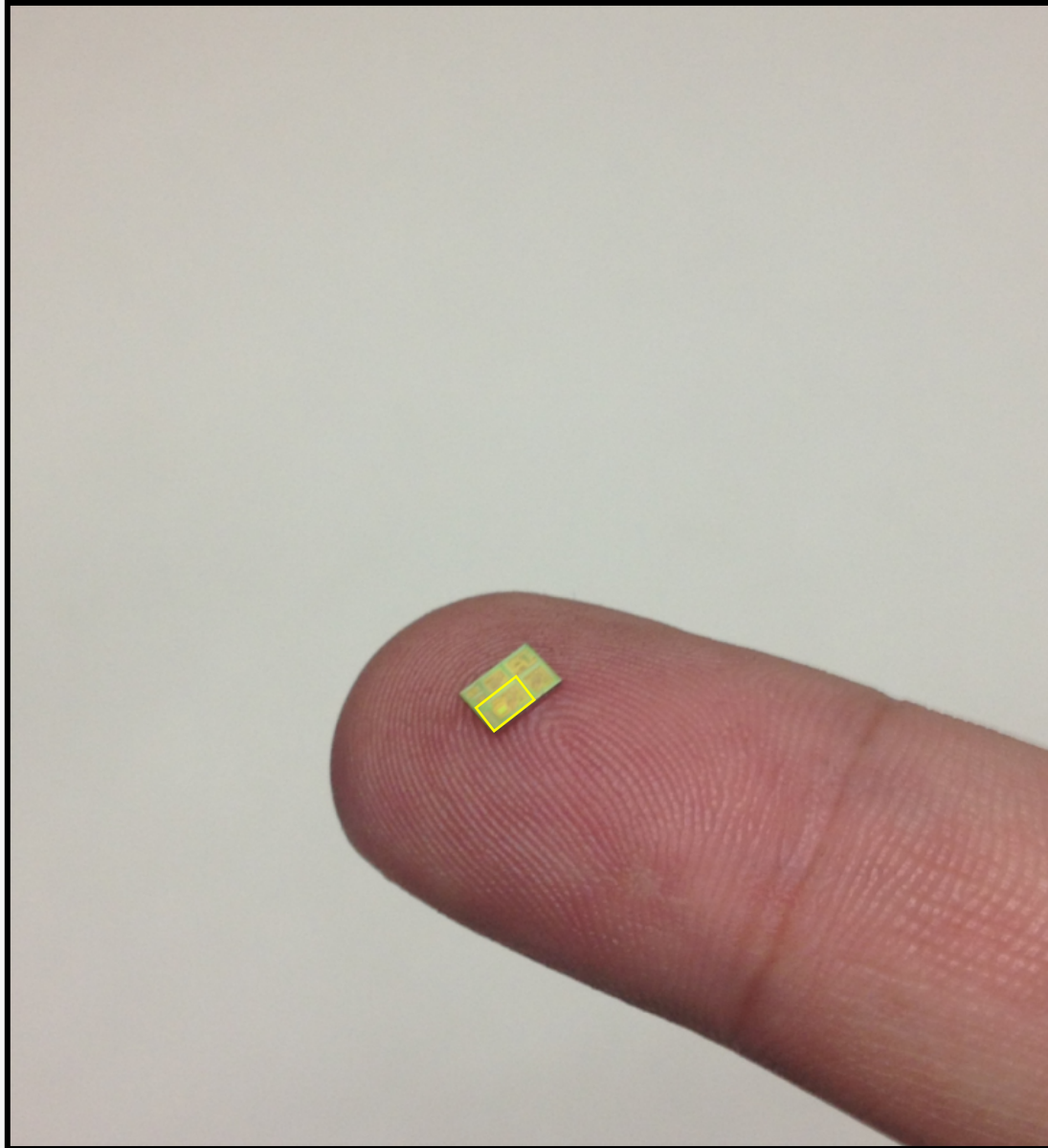
Example of a CMOS SoC



Example of a CMOS SoC

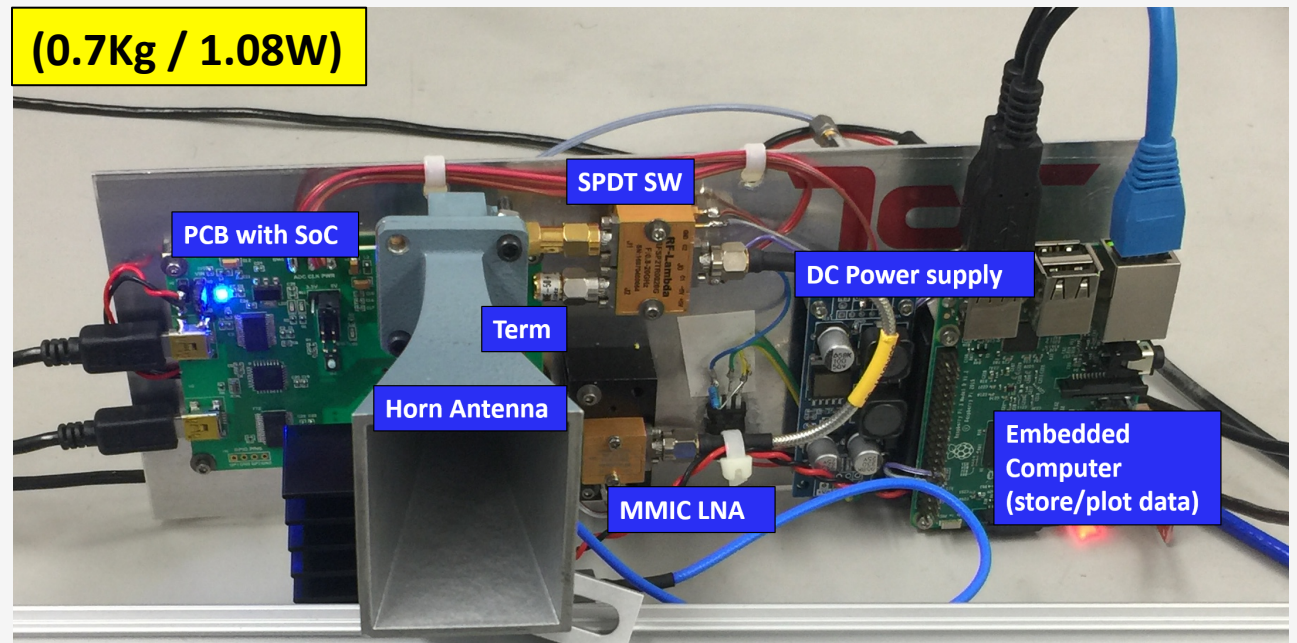
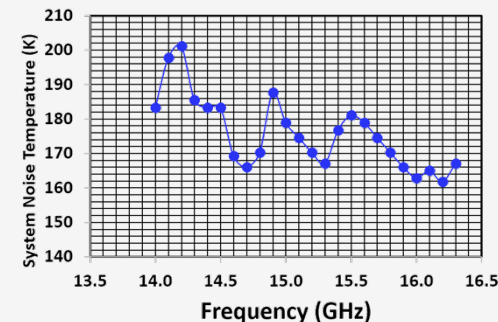
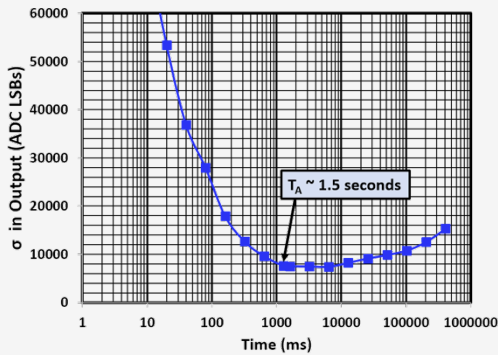
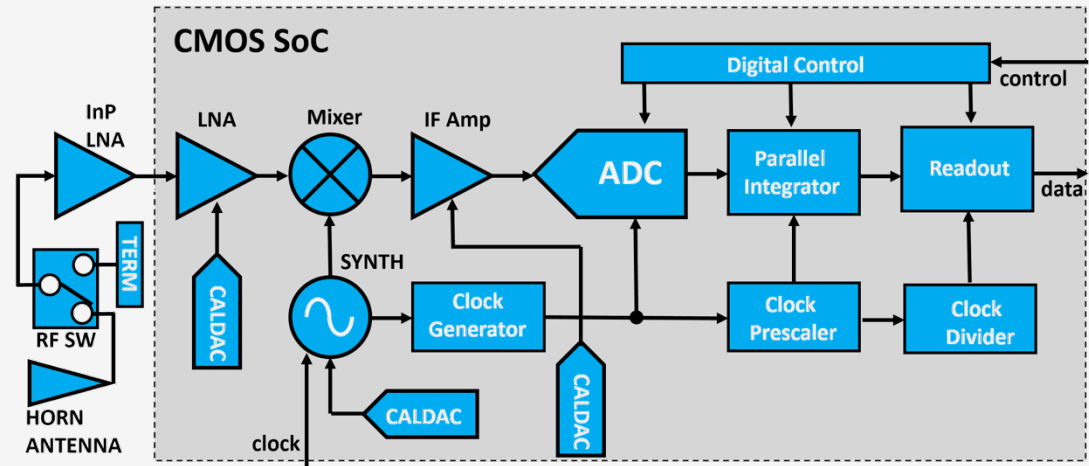
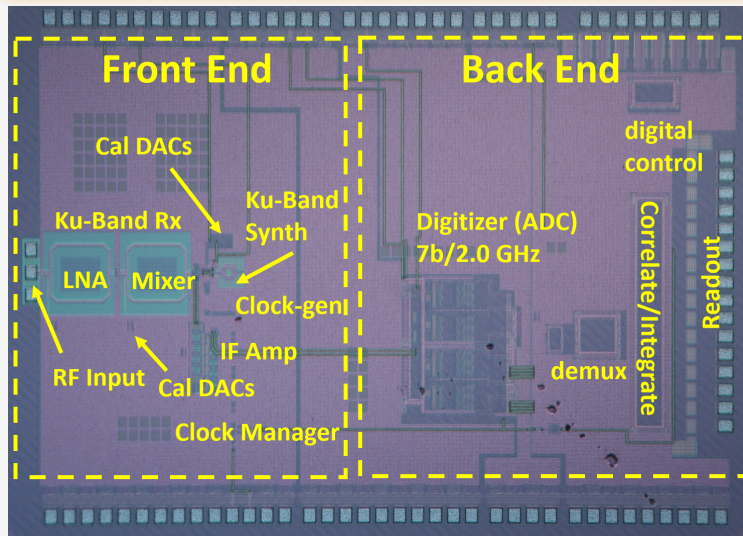


Example of a CMOS SoC

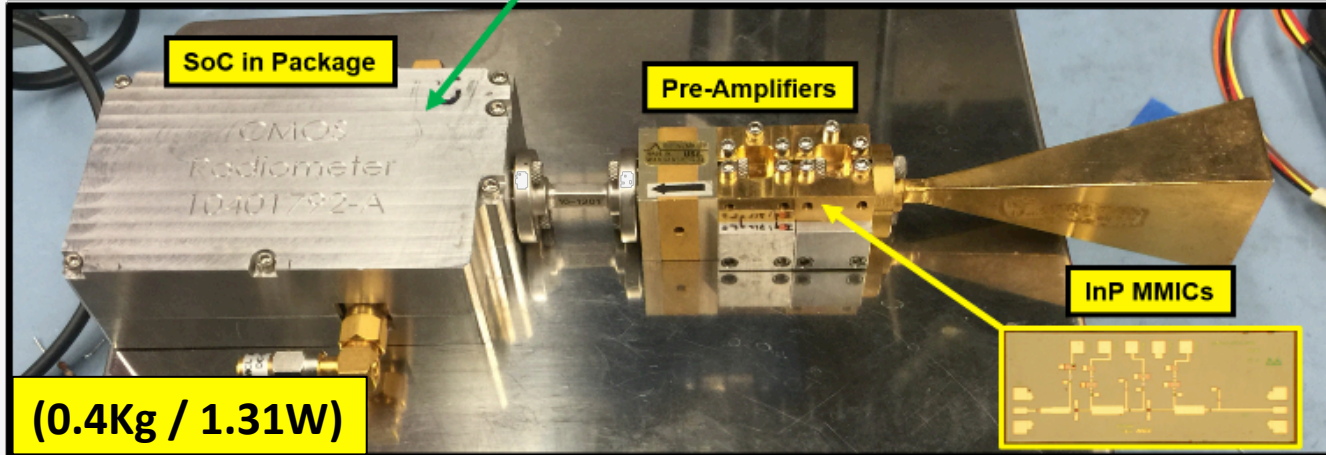
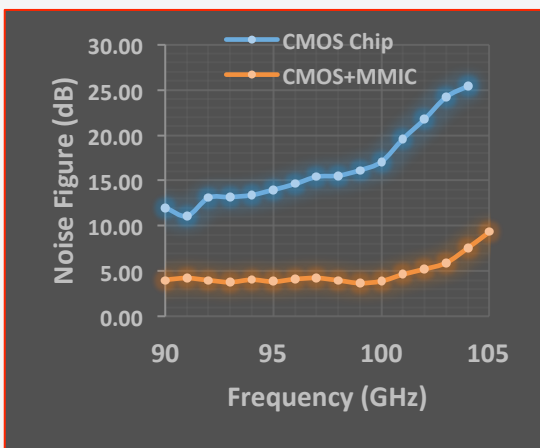
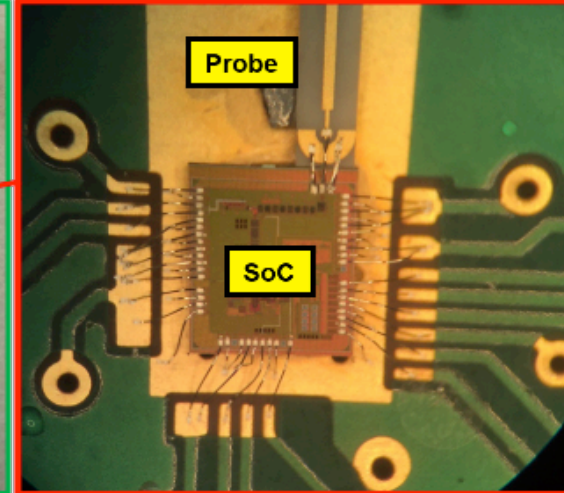
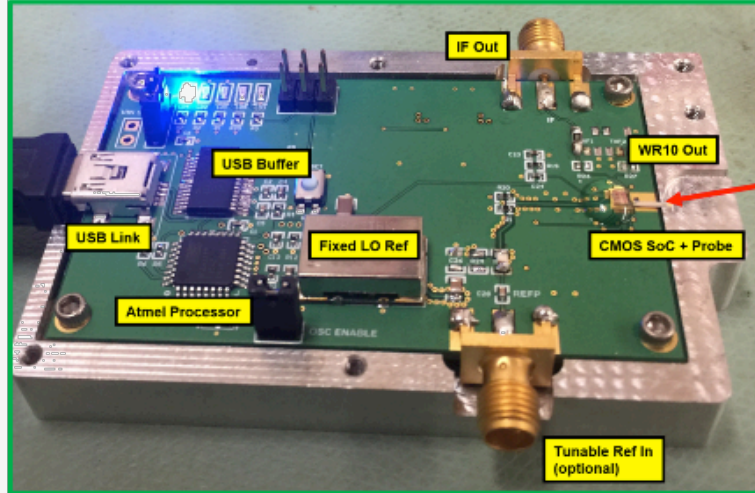
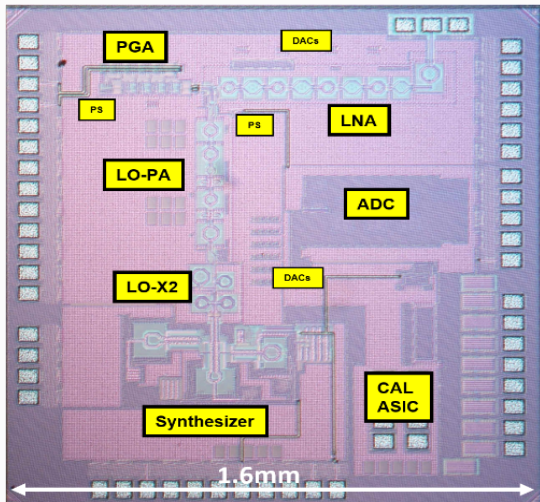


Radiometers!

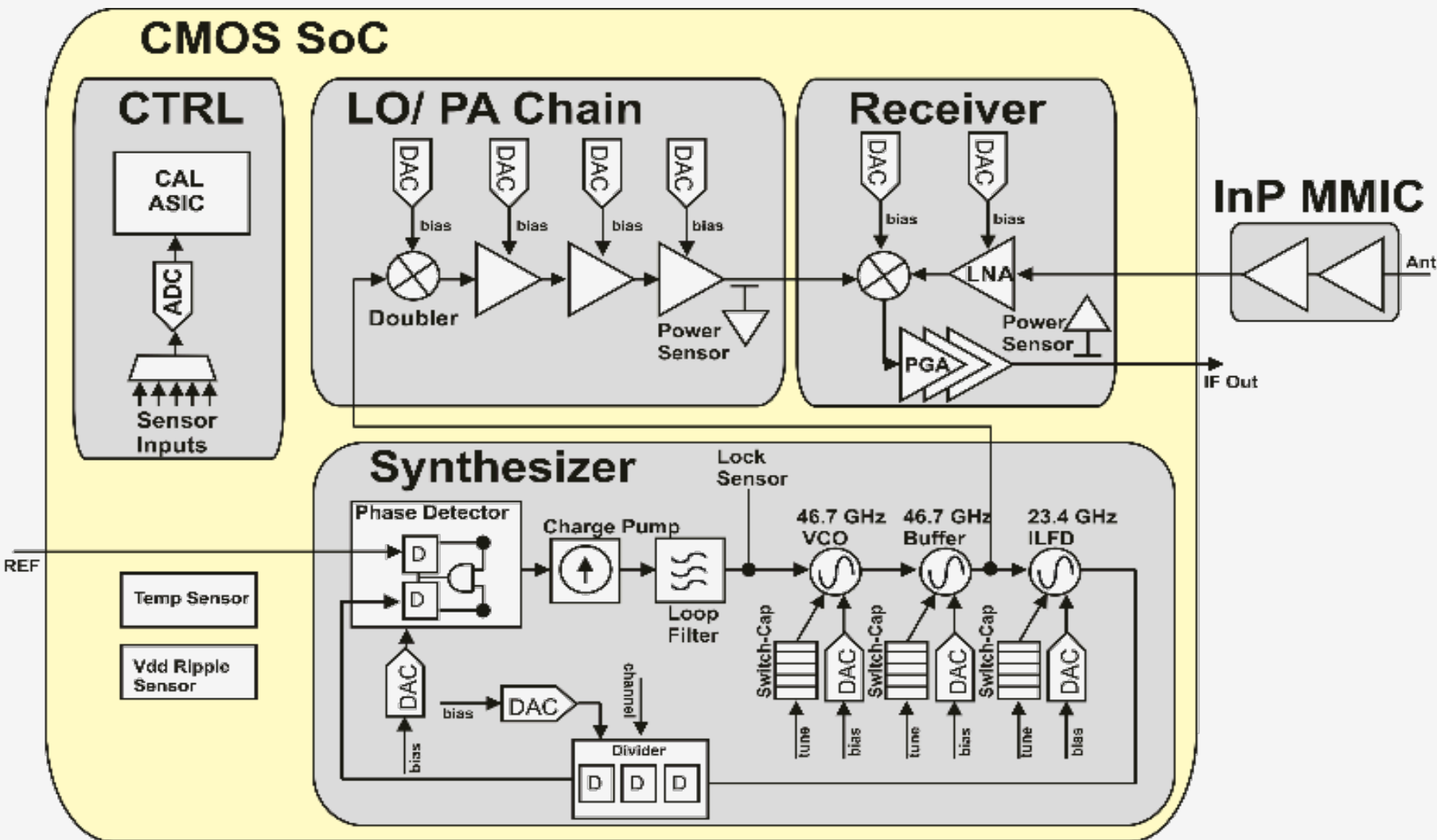
Hybrid (InP + CMOS) Ku-Band Radiometer



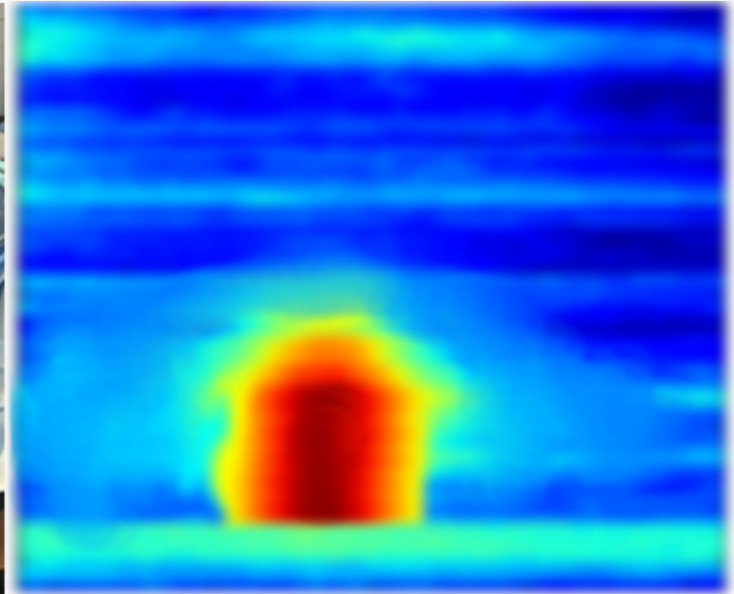
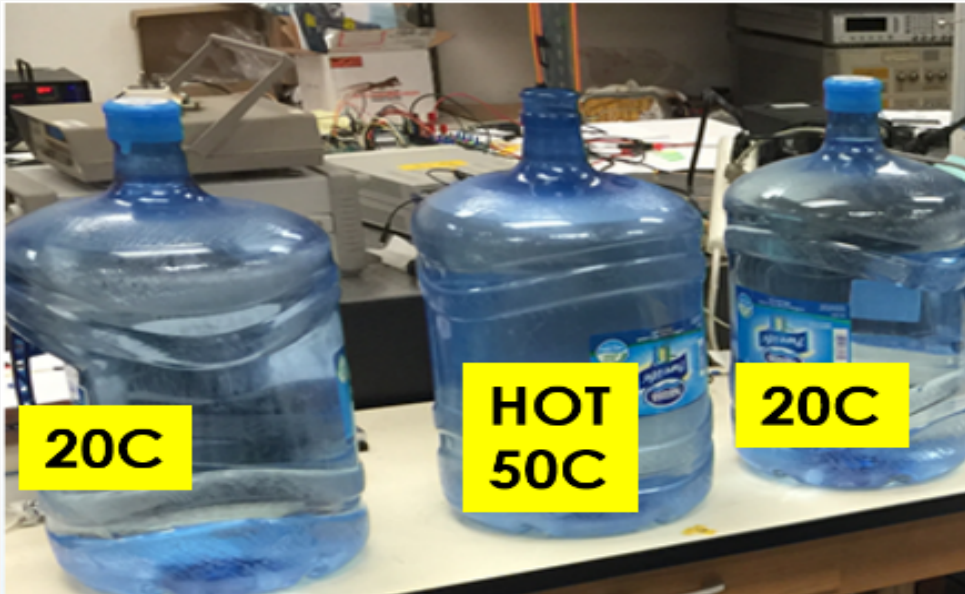
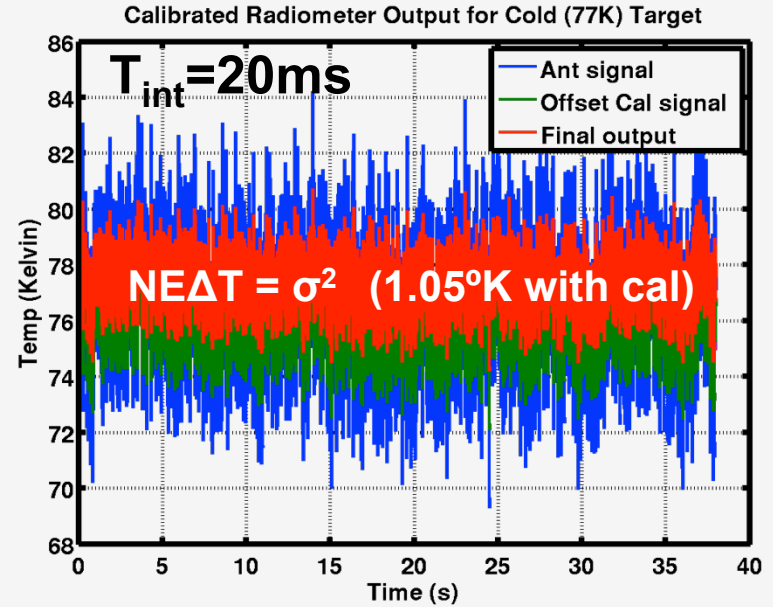
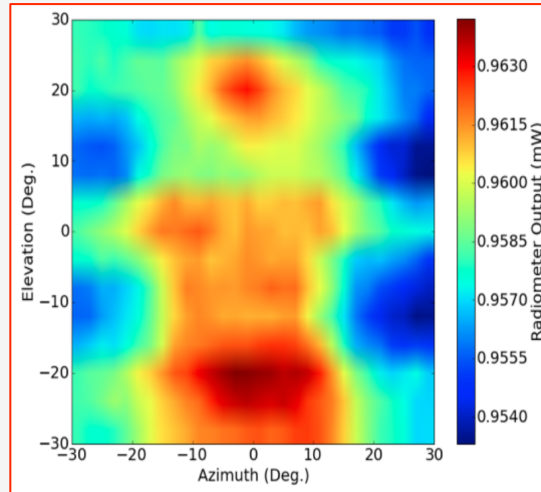
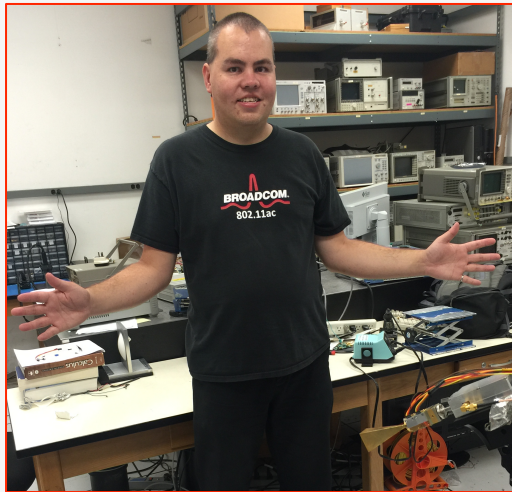
Hybrid (InP + CMOS) 100 GHz Radiometer



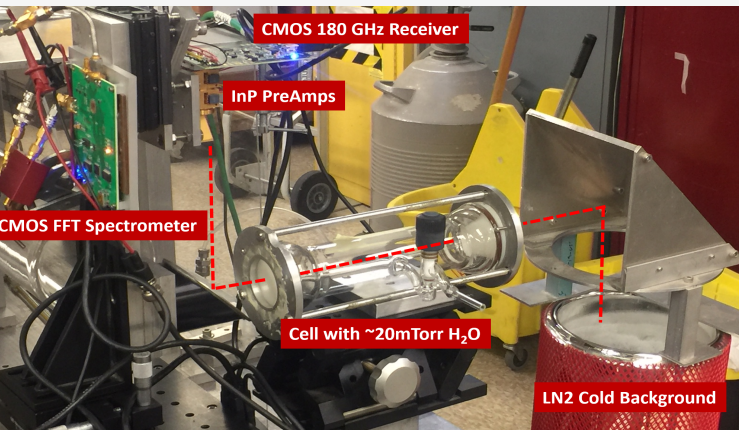
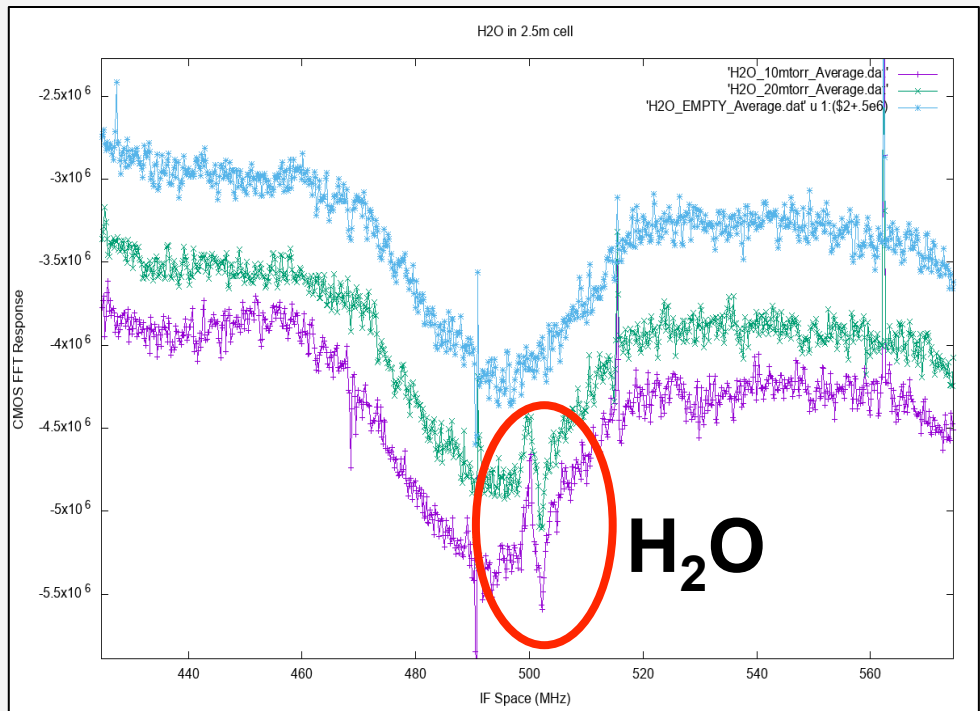
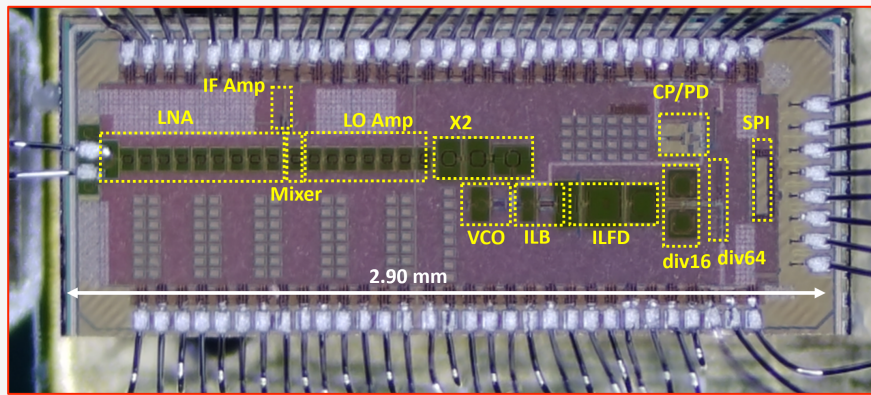
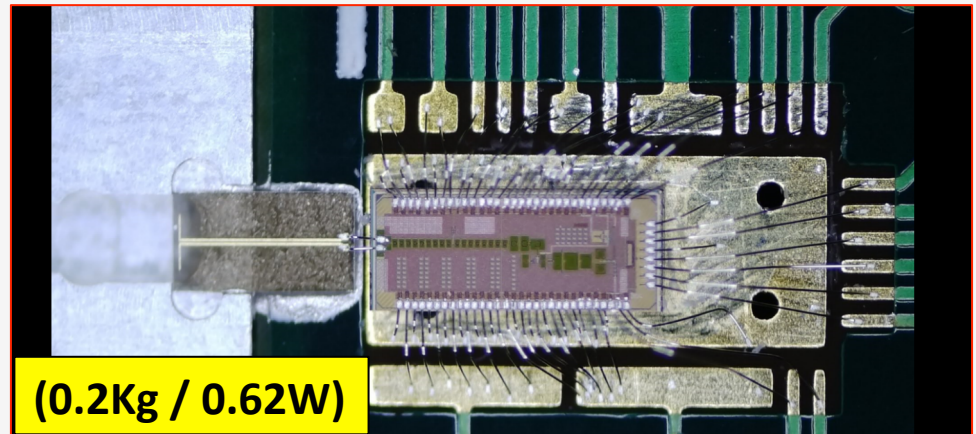
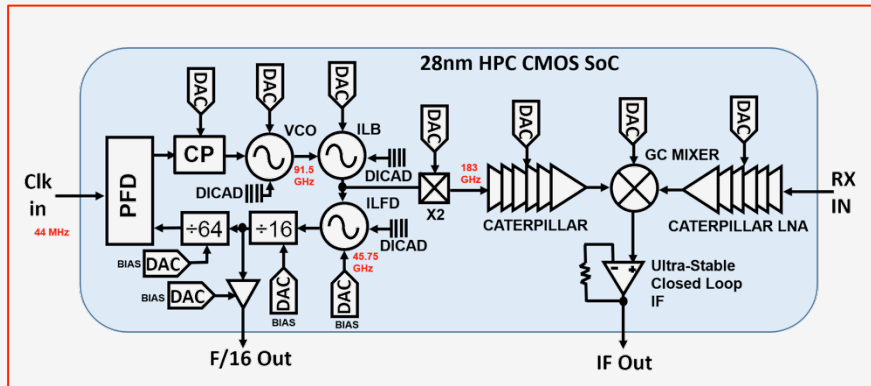
Hybrid (InP + CMOS) 100 GHz Radiometer



Hybrid (InP + CMOS) 100 GHz Radiometer



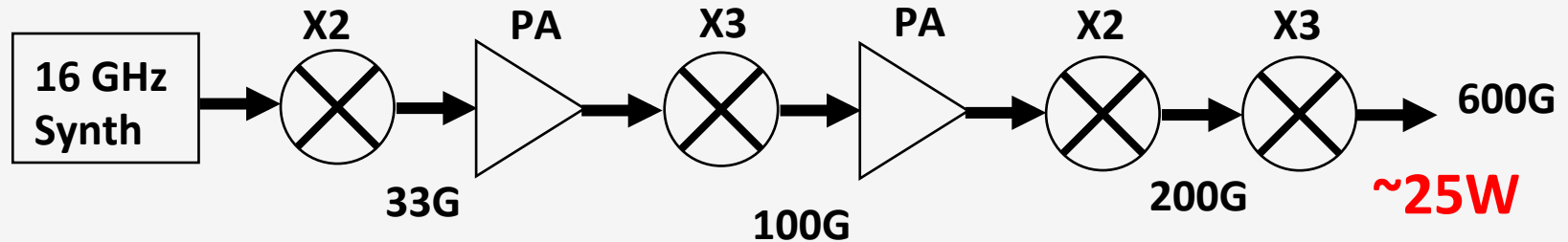
HP-CMOS 183 GHz Radiometer/Spectrometer



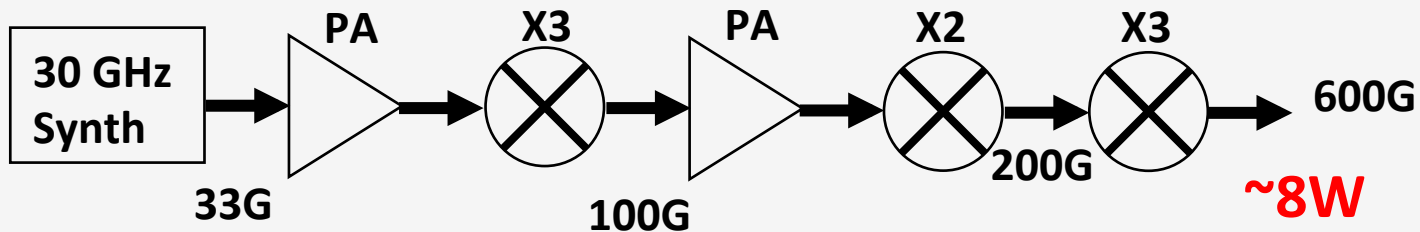
Spectrometer LOs!

Evolution of JPL's CMOS LO Chains

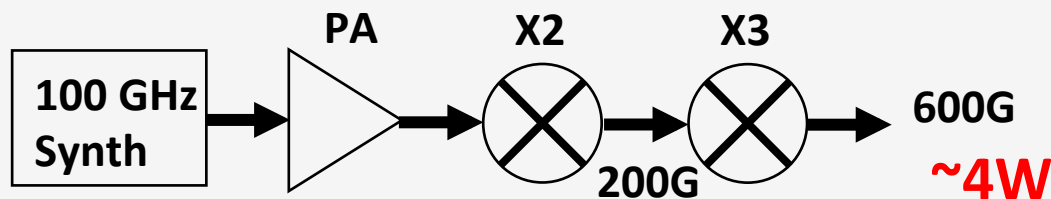
Pre-CMOS LO for a JPL 600 GHz Spectrometer (Before Adrian)



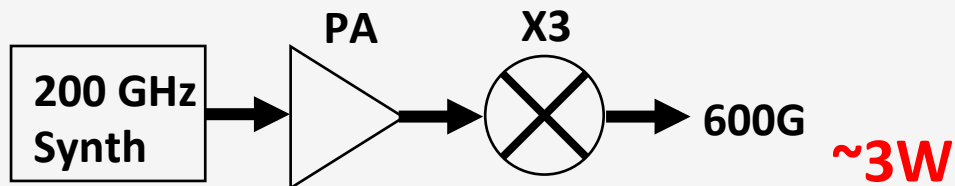
Phase 1: CMOS Based Solution (2014)



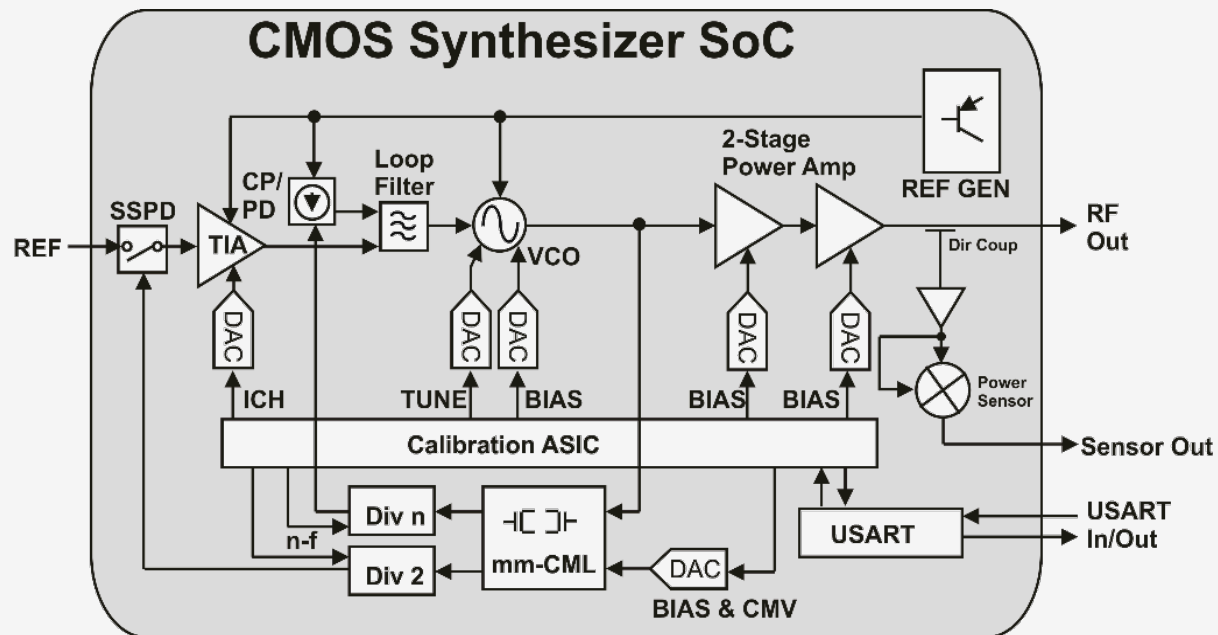
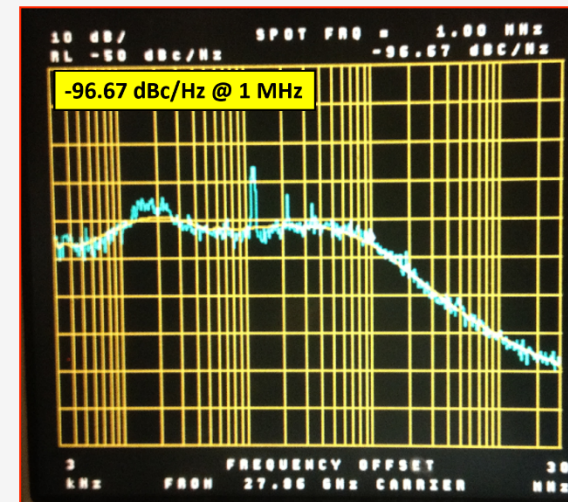
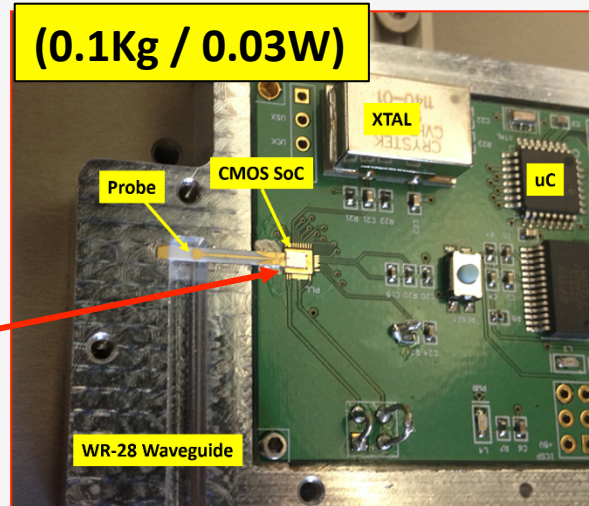
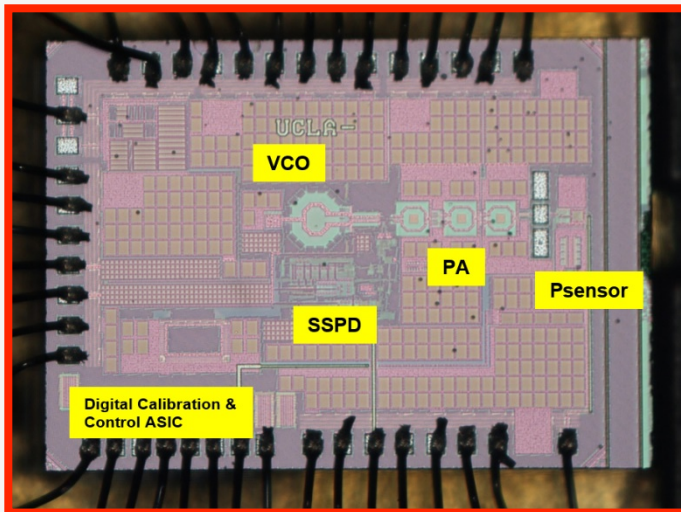
Phase 2: CMOS Based Solution (2016)



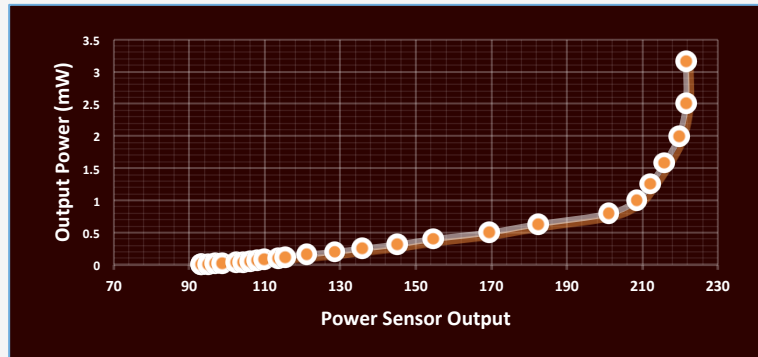
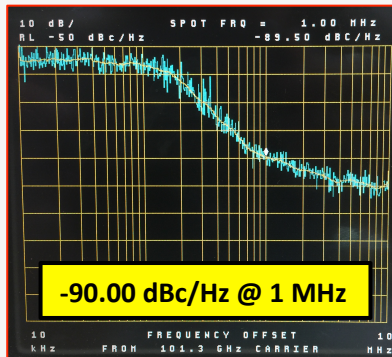
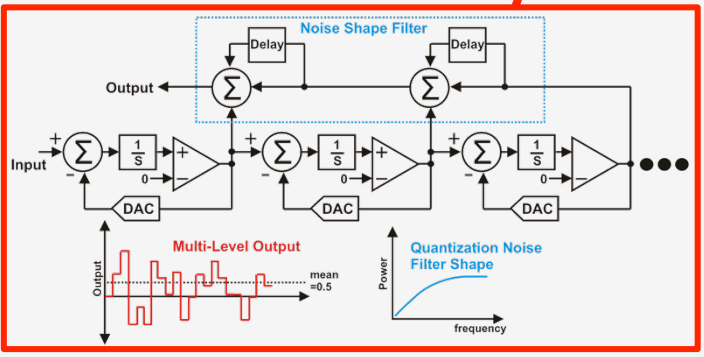
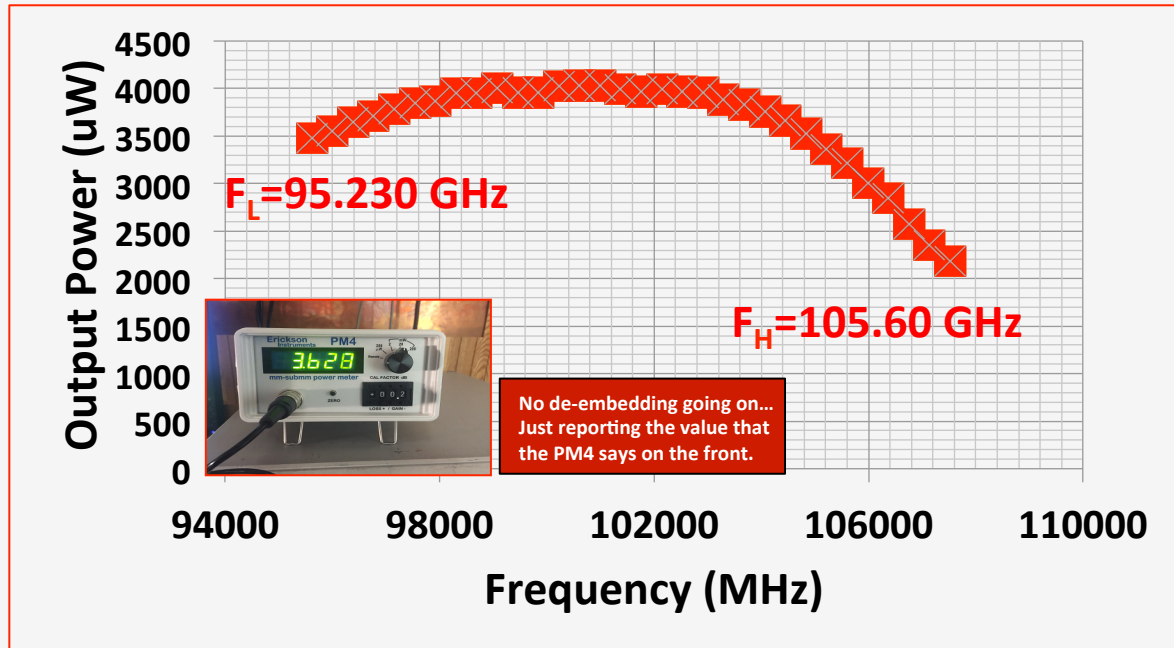
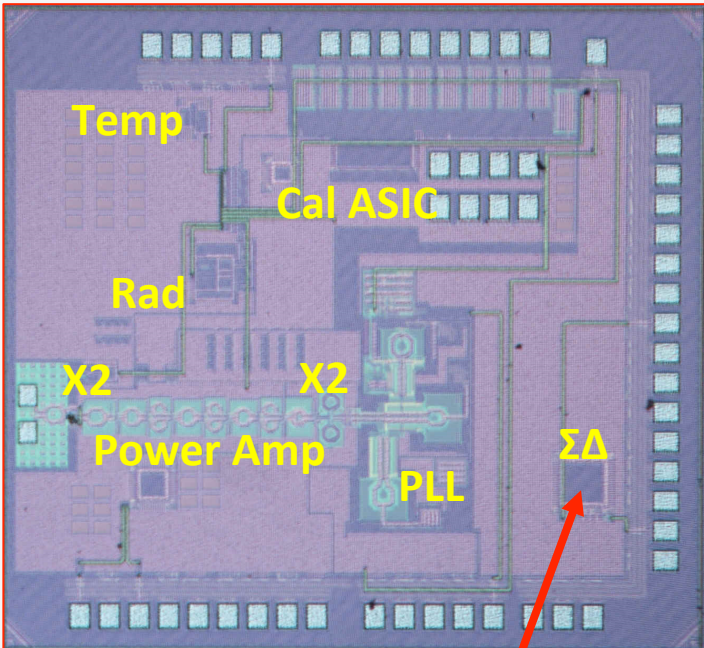
Phase 3: CMOS Based Solution (2018)



CMOS Synthesizer at 35 GHz

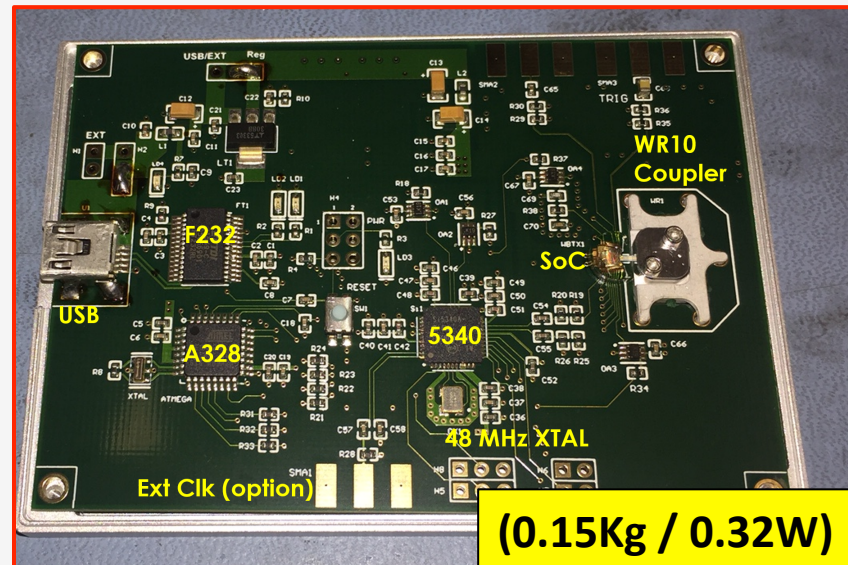
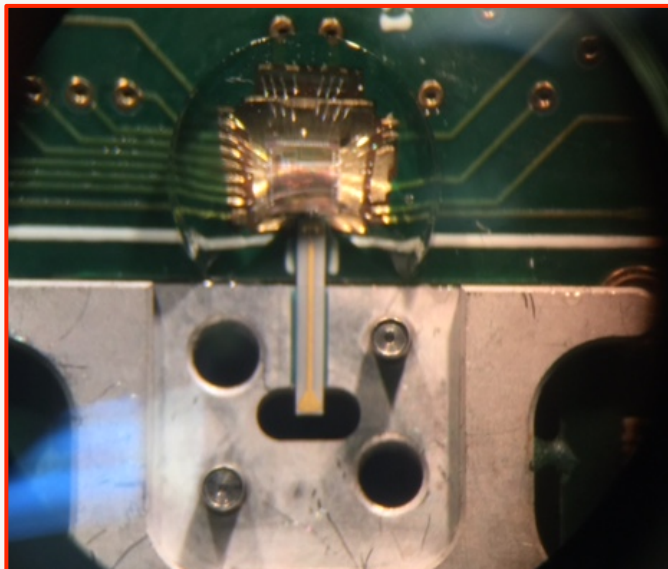
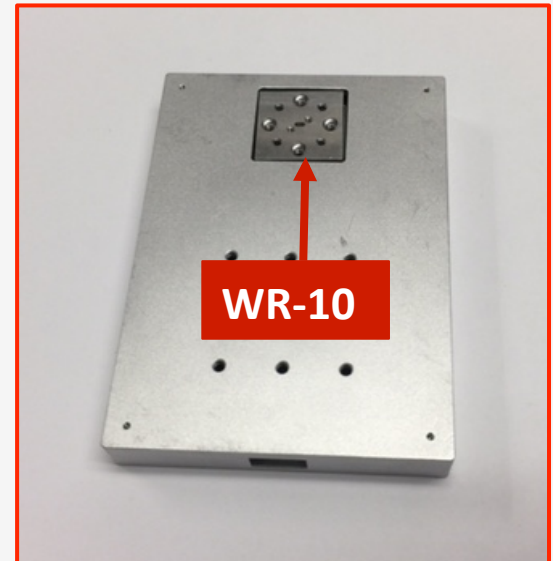
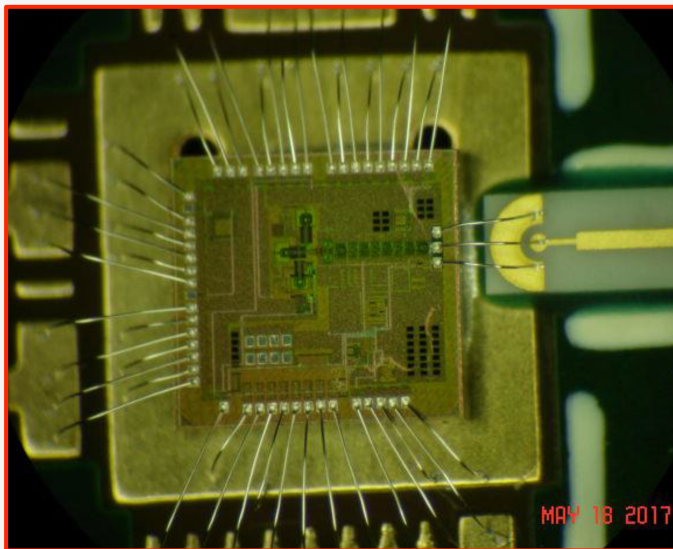


100 GHz CMOS Synthesizer

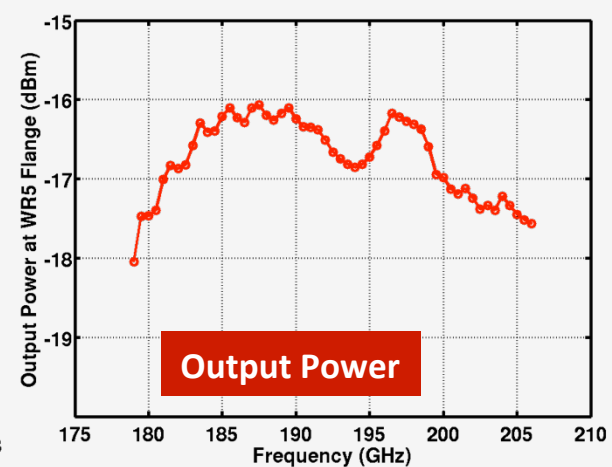
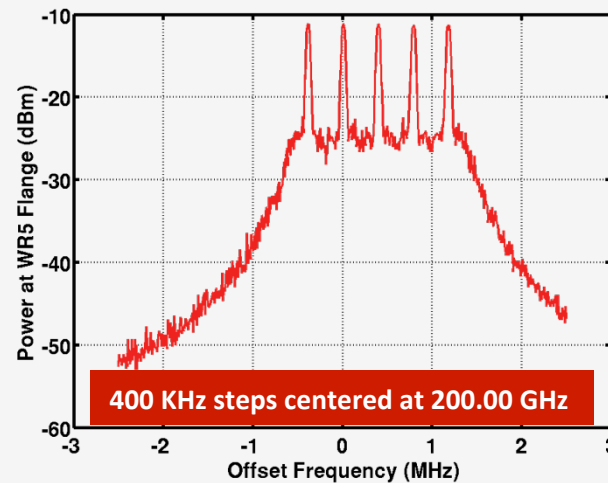
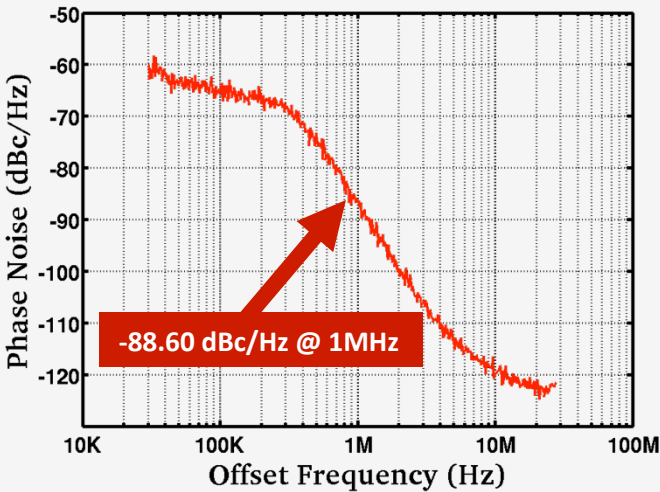
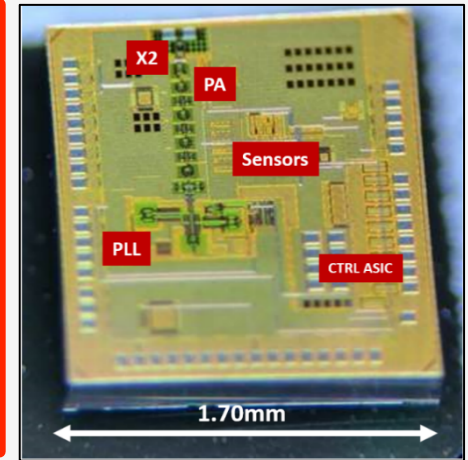
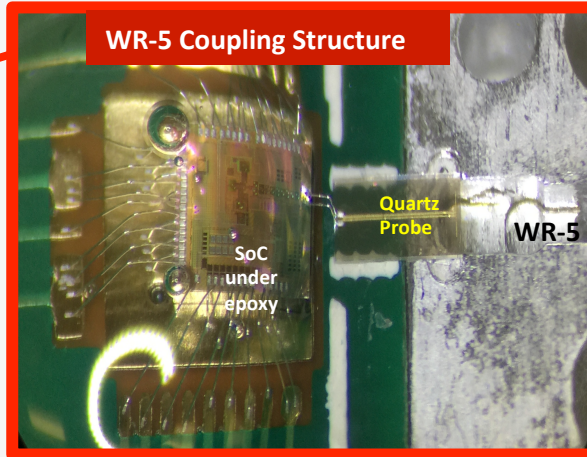
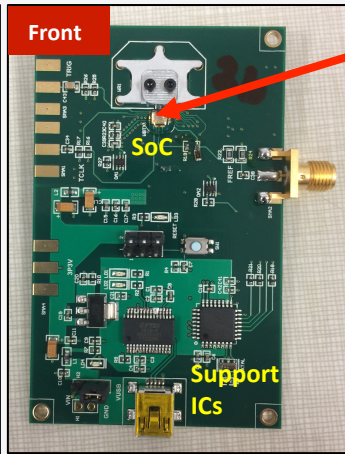


(0.1Kg / 0.08W)

100 GHz CMOS Synthesizer



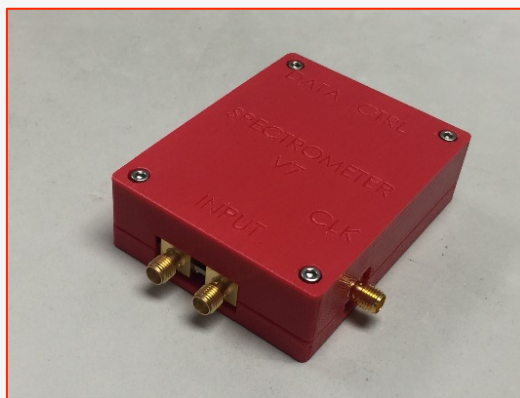
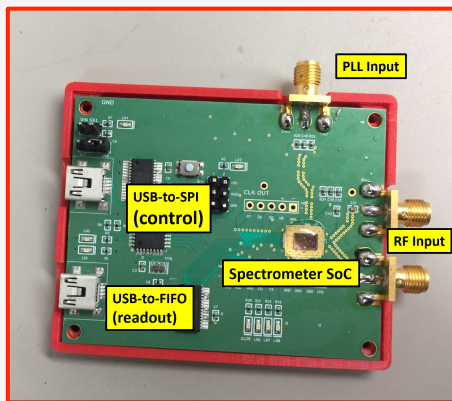
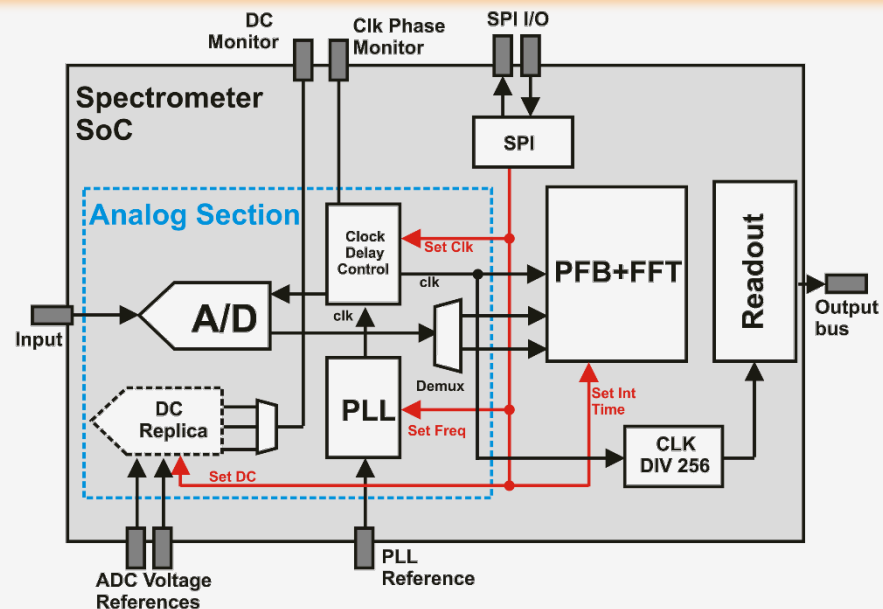
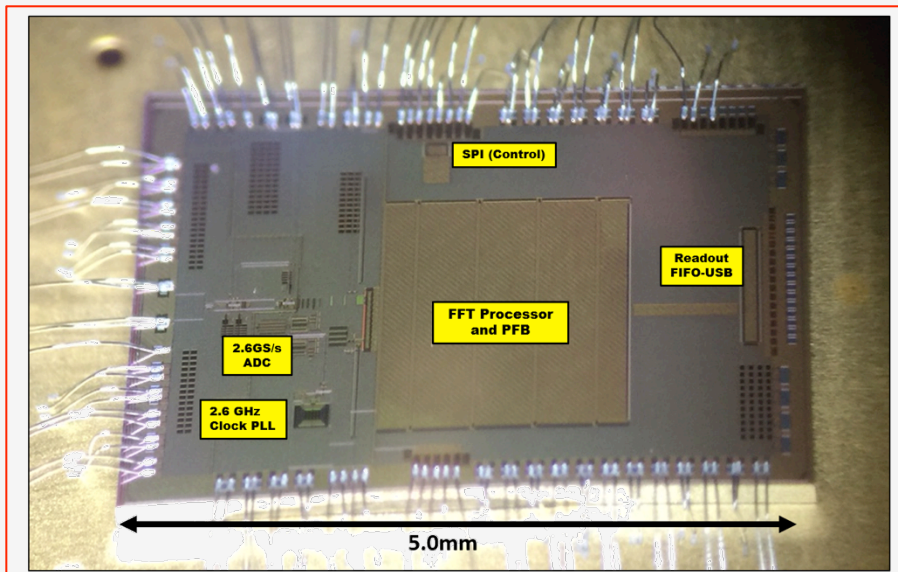
200 GHz Fractional Synthesizer



(0.15Kg / 0.40W)

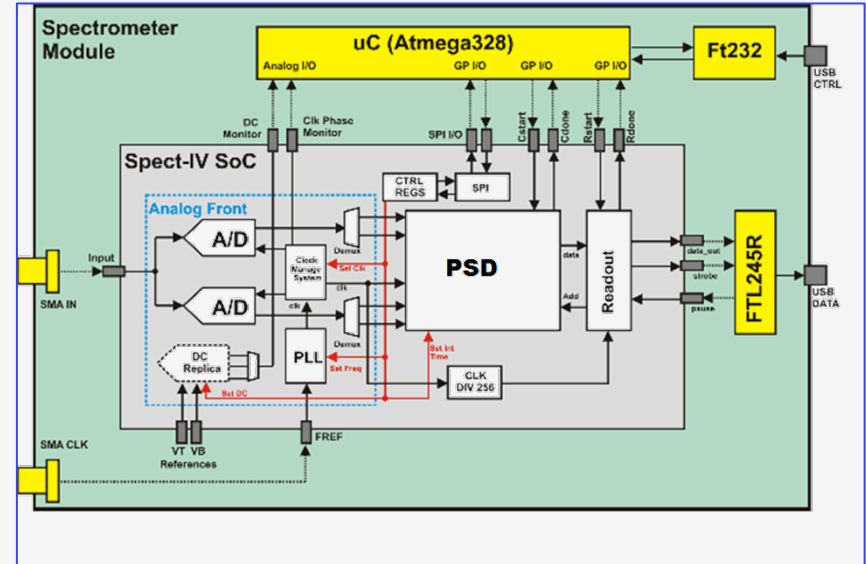
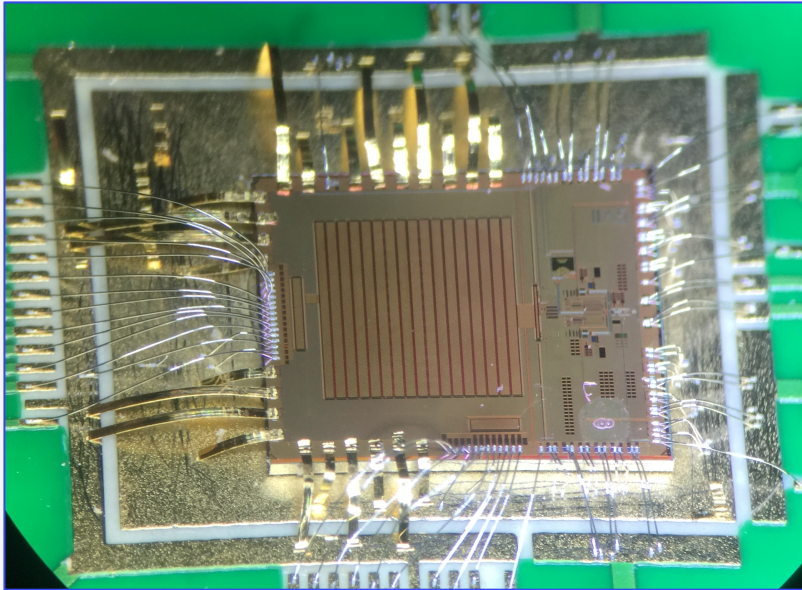
Spectrometer Back Ends!

Spectrometer Processor



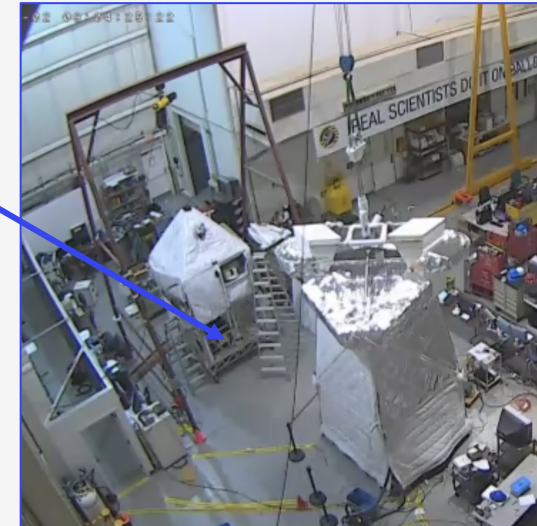
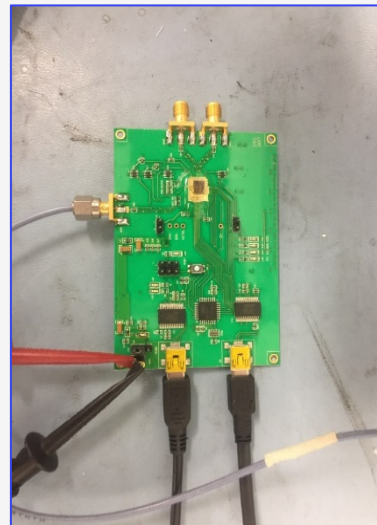
| JPL-UCLA SVI SoC Spectrometer | |
|-------------------------------|-------------------|
| Parameter | Value |
| Channel Count | 2048 |
| Bandwidth | 3.0 GS/s |
| Dynamic Range | 20 dB |
| DC Power Consumption | 900 mW |
| Volume | 22cm ³ |
| Weight | 105 g |

Spectrometer Processor II

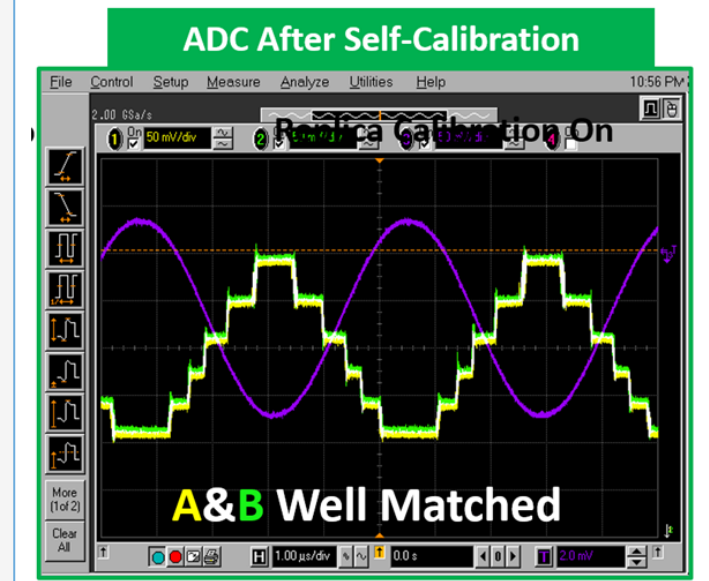
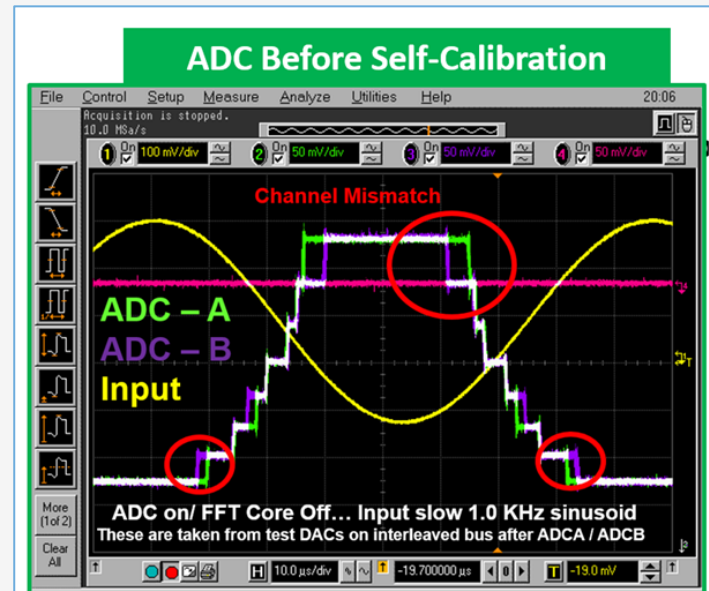
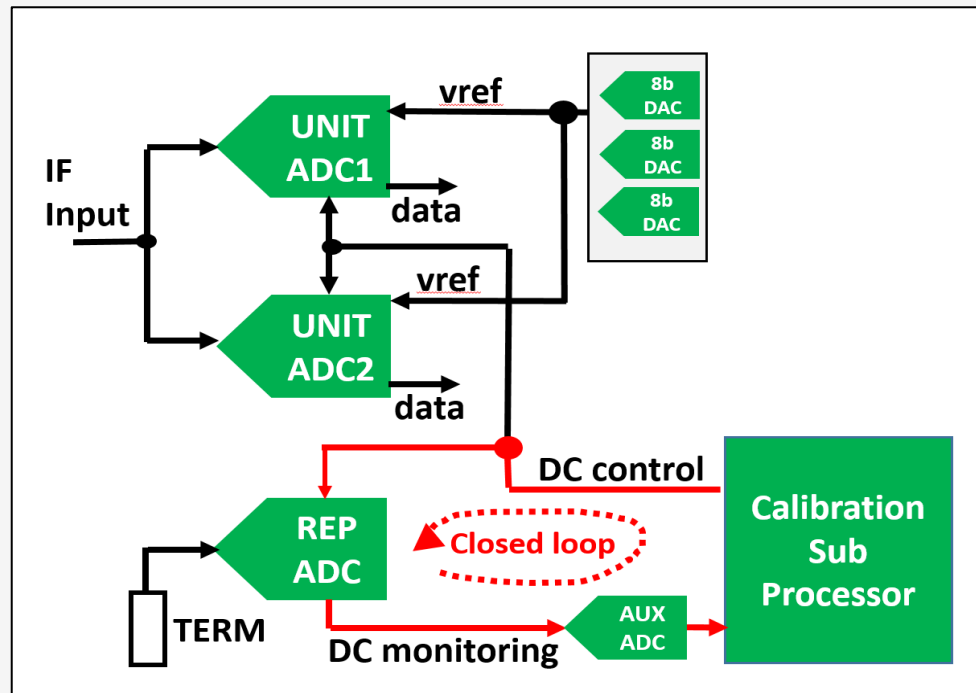
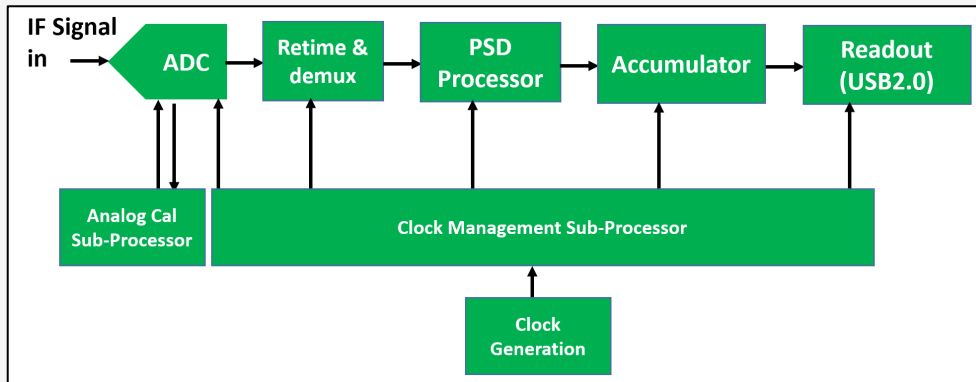


Spectrometer for NASA SLS Payload

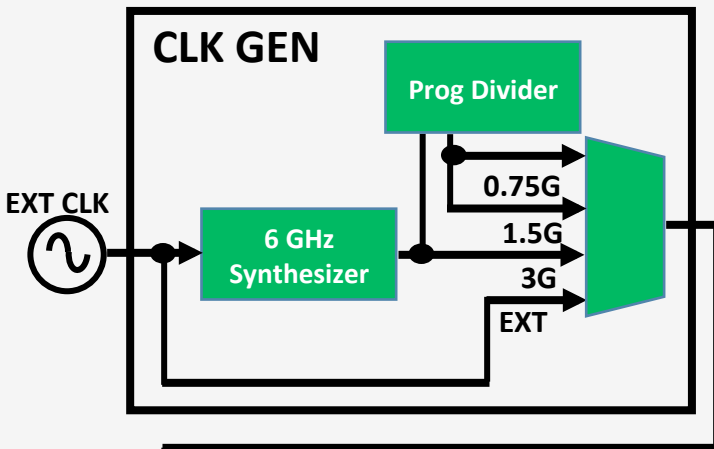
| JPL-UCLA SVII SoC Spectrometer | |
|--------------------------------|-------------------|
| Parameter | Value |
| Channel Count | 4096 |
| Bandwidth | 6.0 GS/s |
| Dynamic Range | 20 dB |
| DC Power Consumption | 1540 mW |
| Volume | 22cm ³ |
| Weight | 105 g |



Spectrometer Processor II

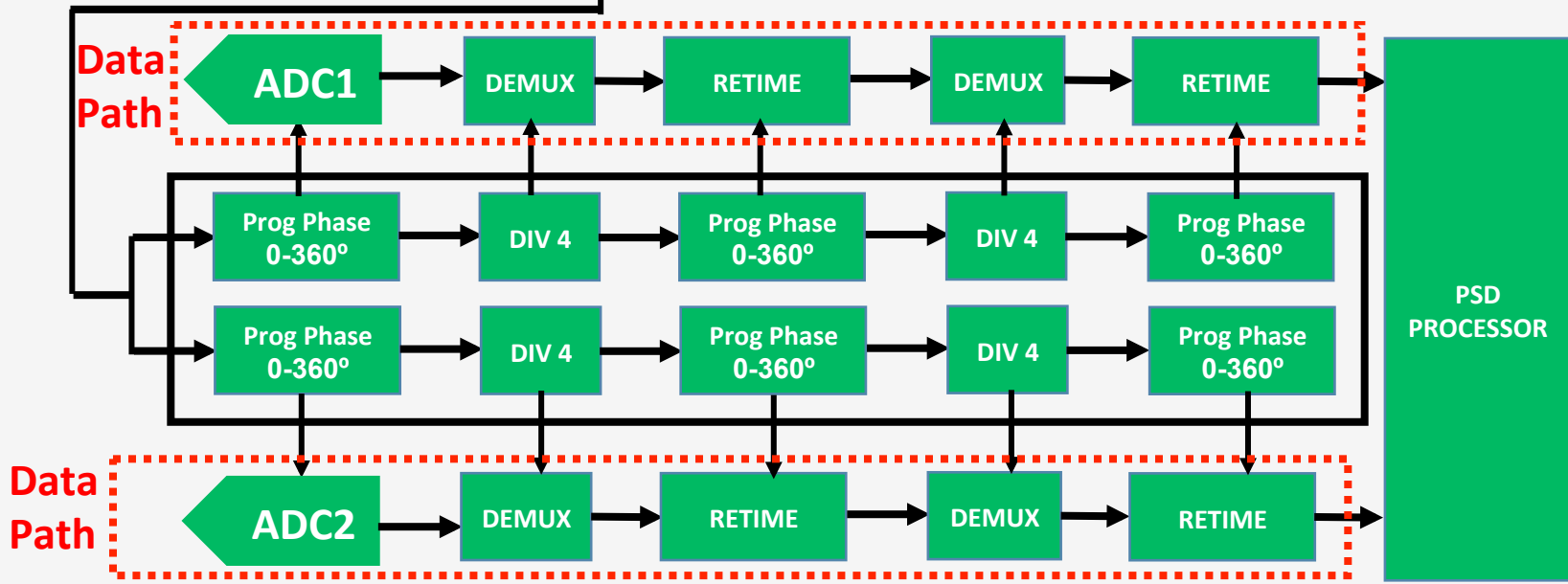


Spectrometer Processor II

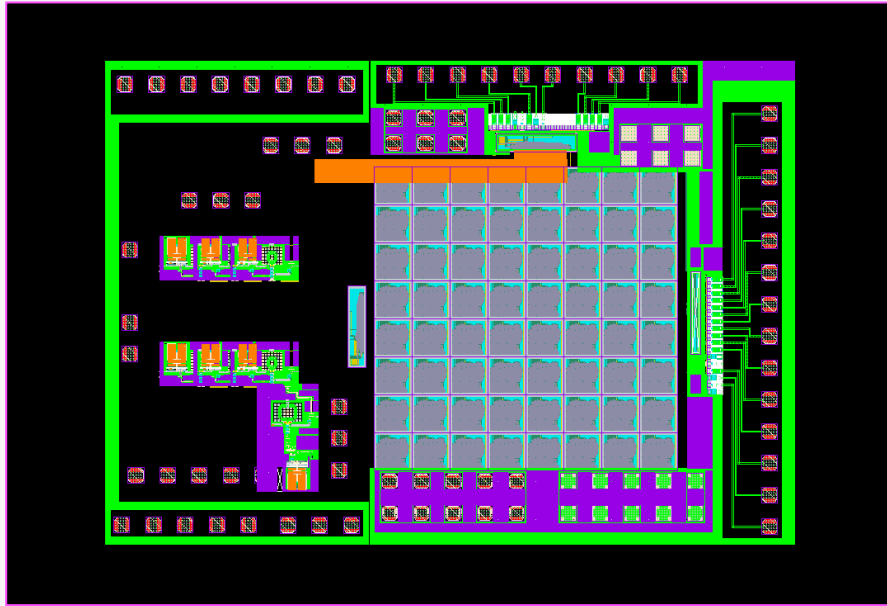


- ❖ At high speed, timing needs to be robust. We use an army of clock-tuners that adjust the clock phase throughout the chip to ensure setup and hold margins are met.

- ❖ Main clock is derived from an internal synthesizer and is selectable at full, half, quarter, or arbitrary EXT speed.

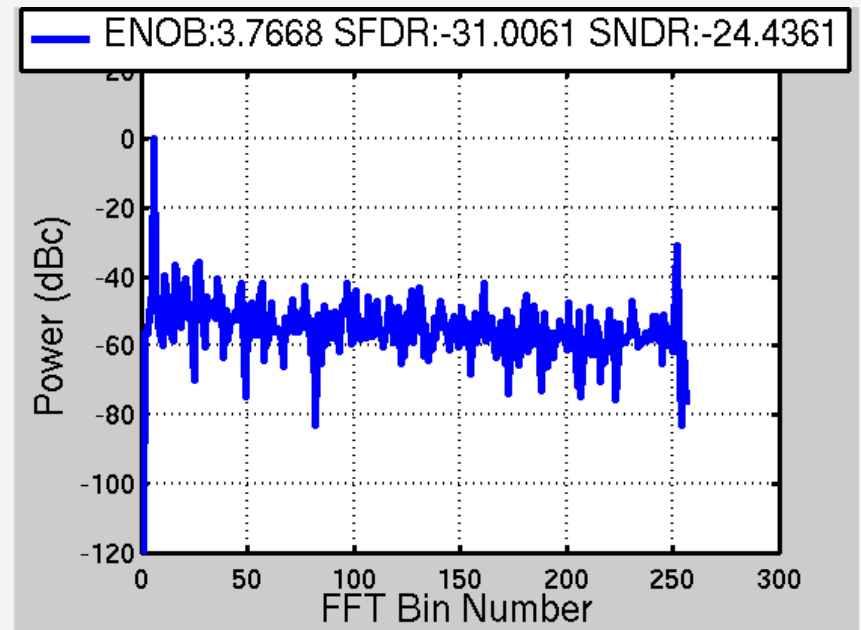


Spectrometer Processor III

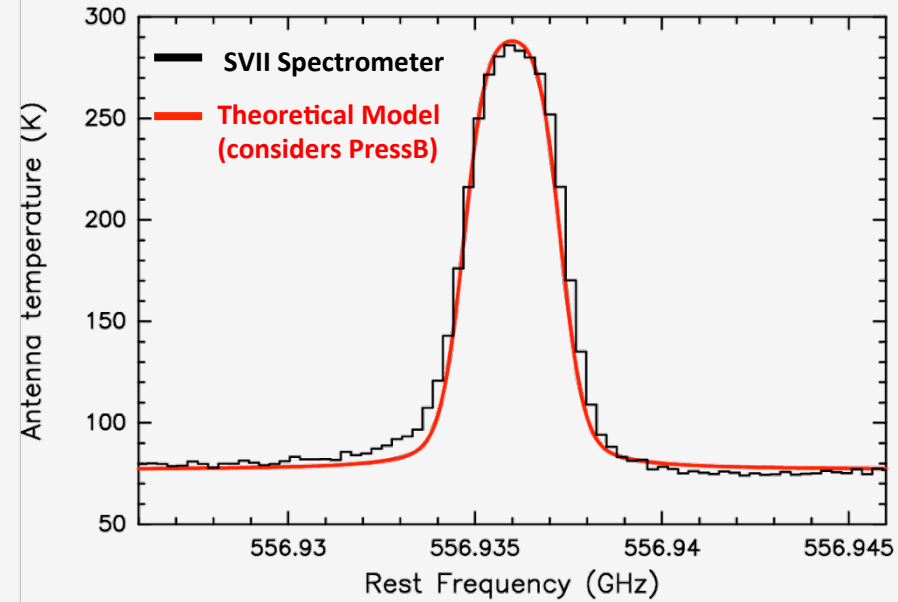
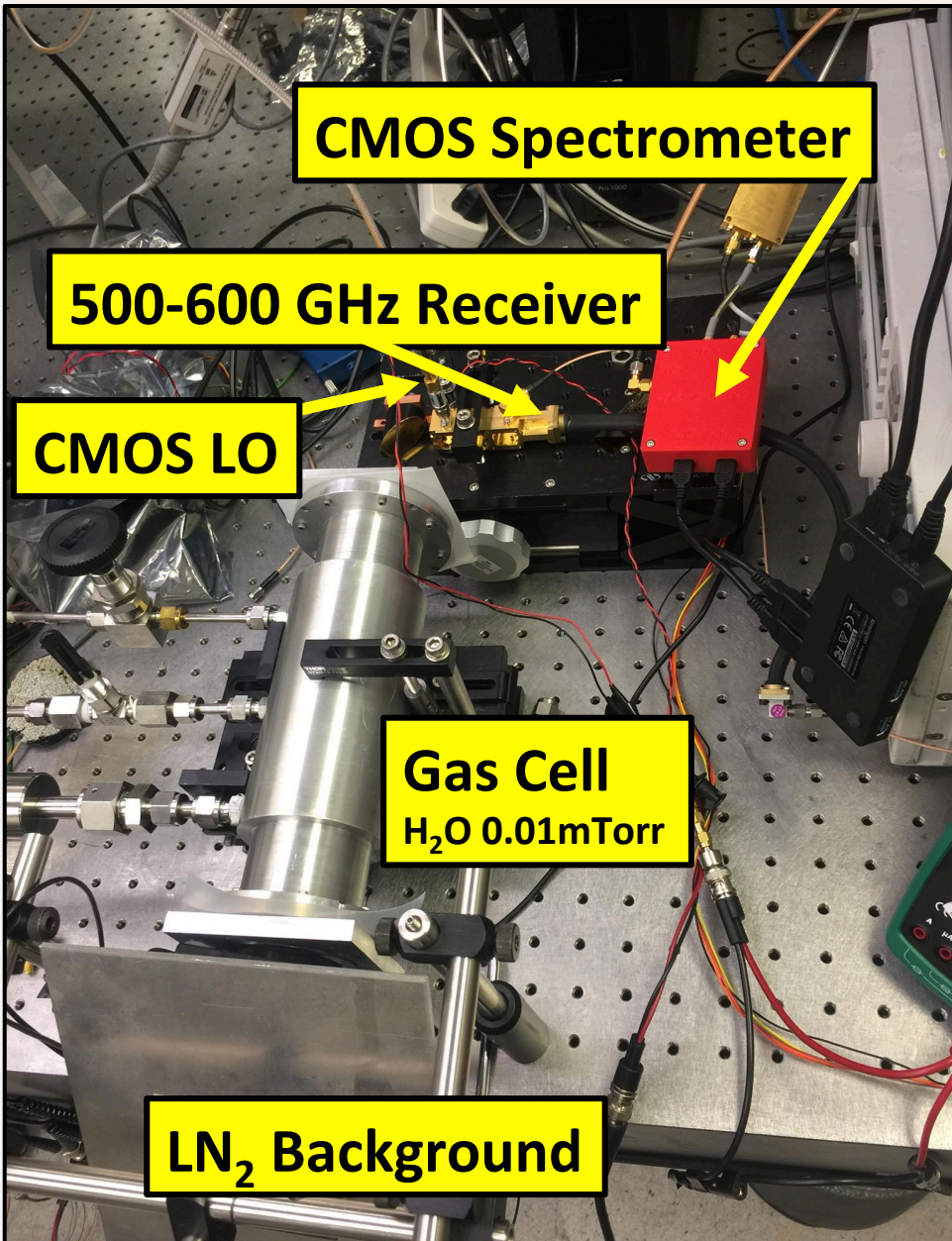


- ❖ More advanced version coming under the NASA APRA (astronomy) program.

| JPL-UCLA SVIII SoC Spectrometer | |
|---------------------------------|-------------------|
| Parameter | Planned |
| Channel Count | 8192 |
| Bandwidth | 12 GS/s |
| Dynamic Range | 20 dB |
| DC Power Consumption | 1400 mW |
| Volume | 22cm ³ |
| Weight | 105 g |



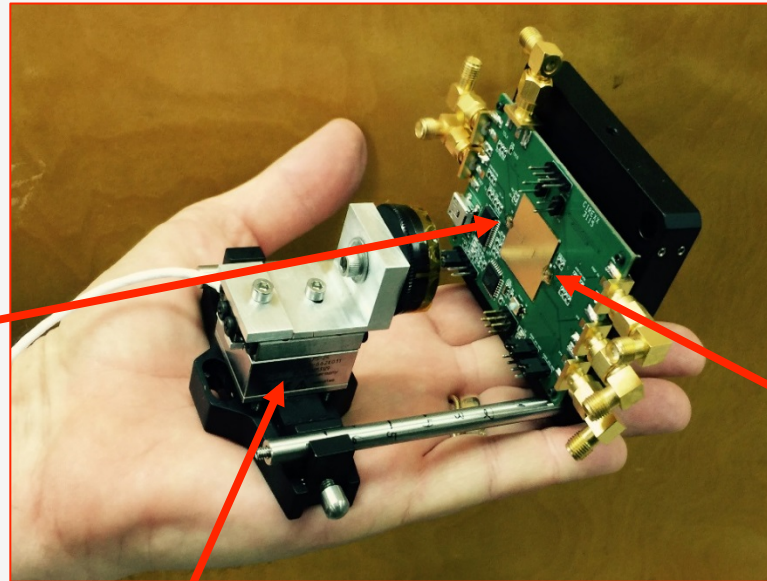
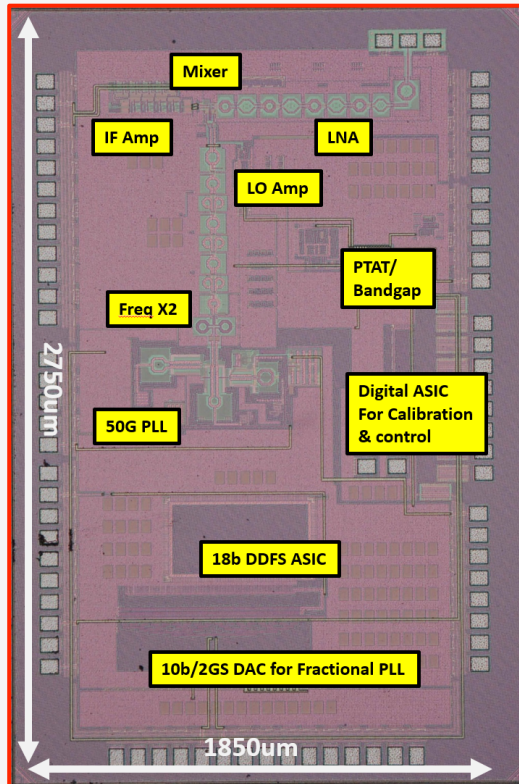
Example Full Instrument Test



- ❖ Was able to detect a few ppb of H_2O^{16} showing excellent sensitivity comparable with traditional technology.

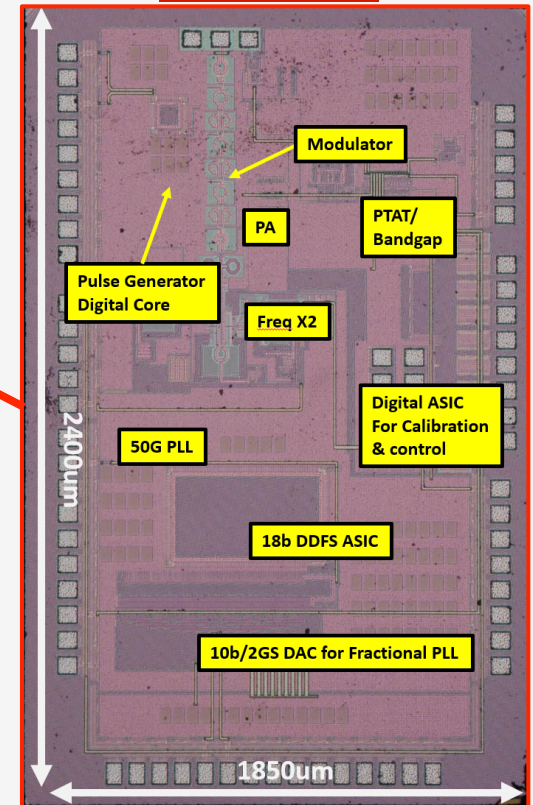
Cavity Pulse Spectrometer

Receiver



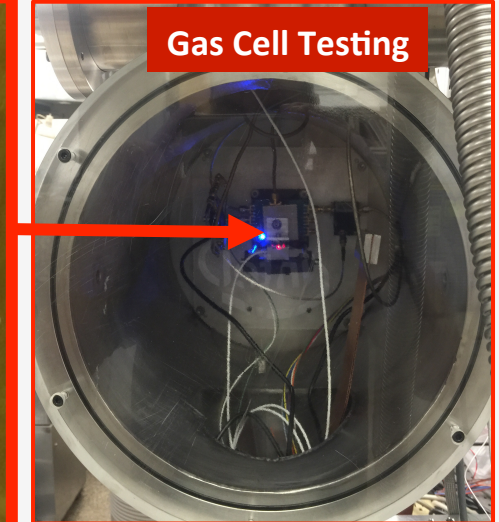
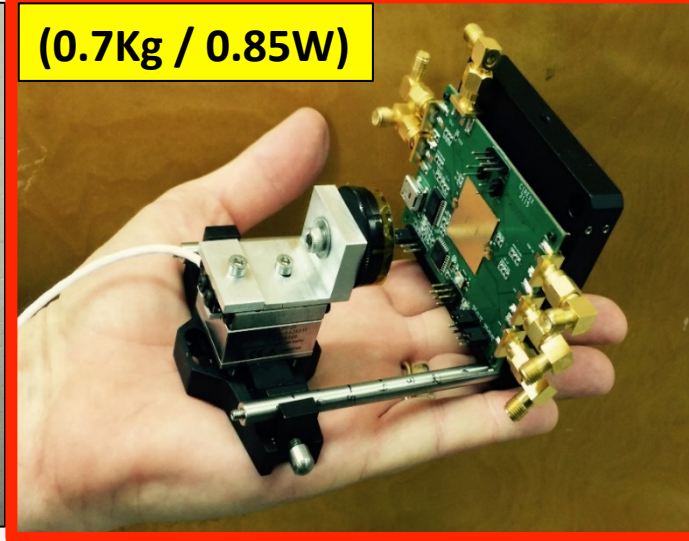
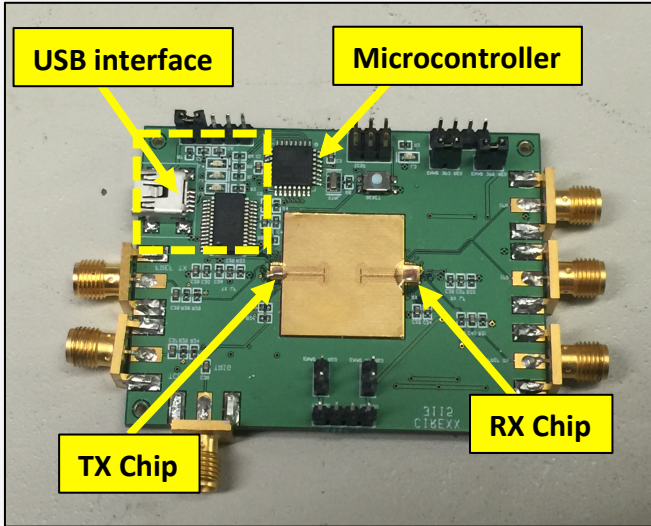
Space Compatible Piezo Motor

Transmitter

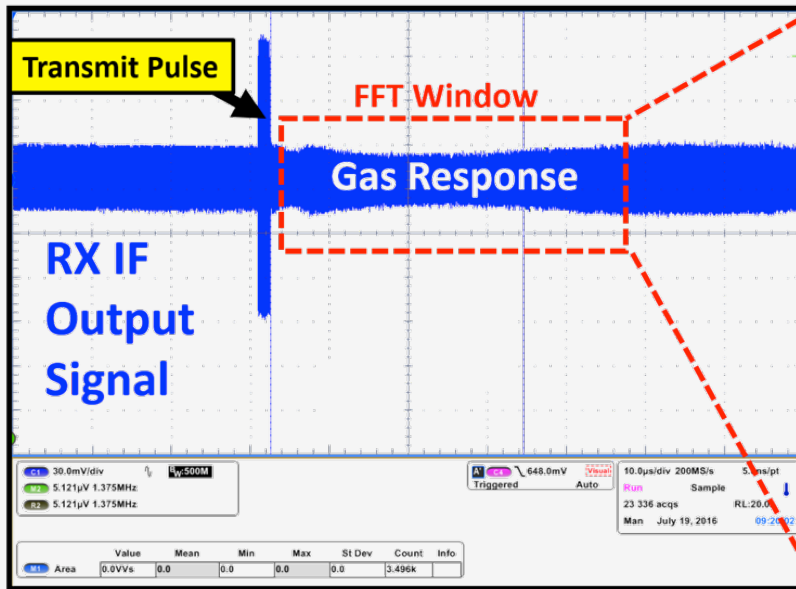


- ❖ Electronics are provided two CMOS SoCs and some support ICs for USB communications. Chips include up and down conversion, pulse generation and timing control, carrier generation and synthesis and calibration/acquisition.
- ❖ Don't need a vacuum chamber in space of course.

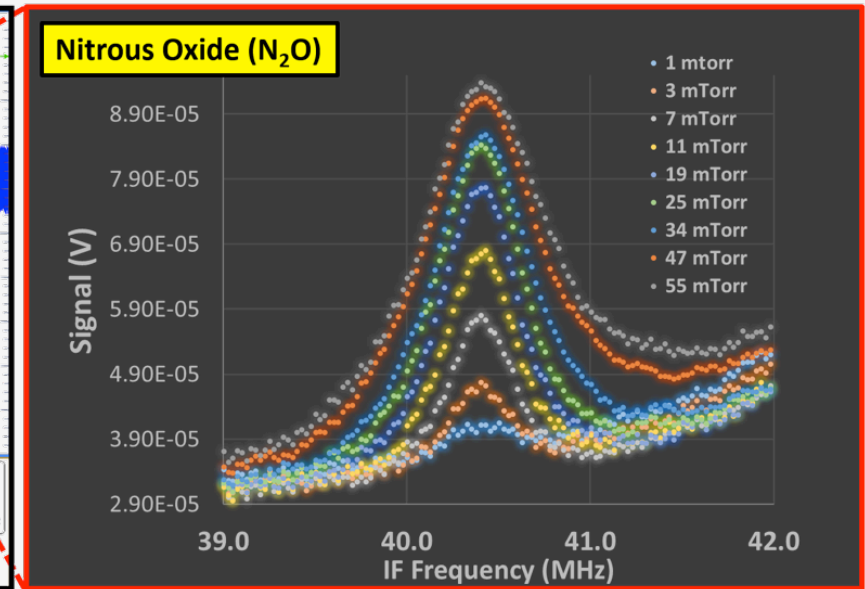
Cavity Pulse Spectrometer Testing



Time Domain IF Output

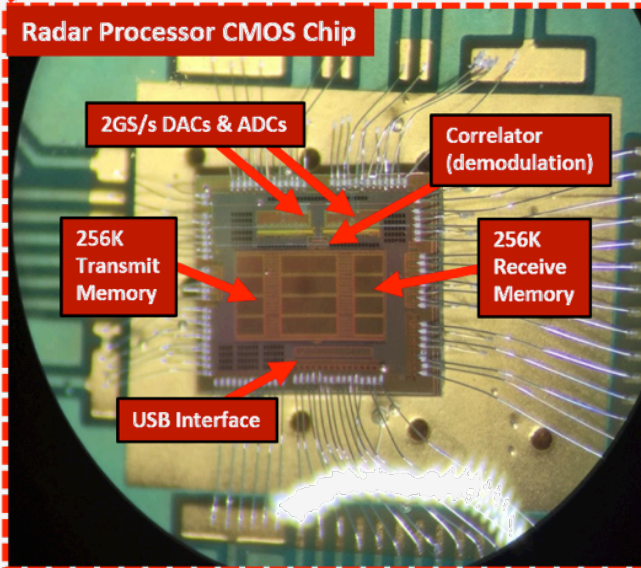
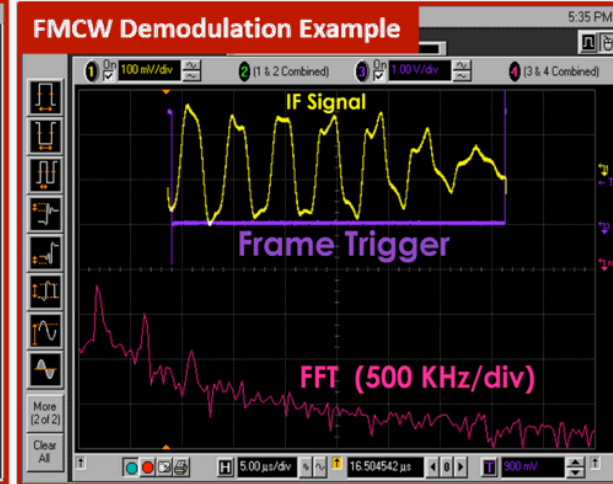
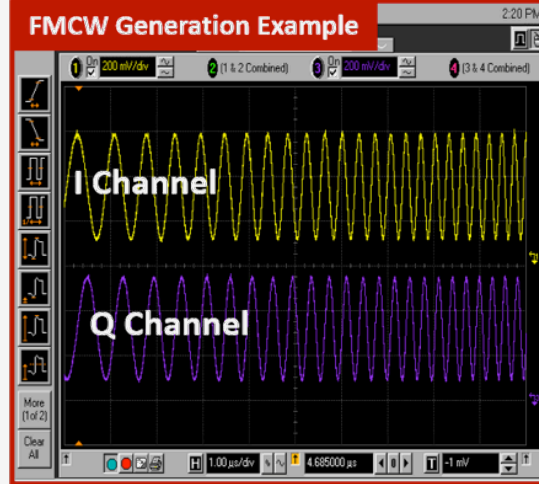
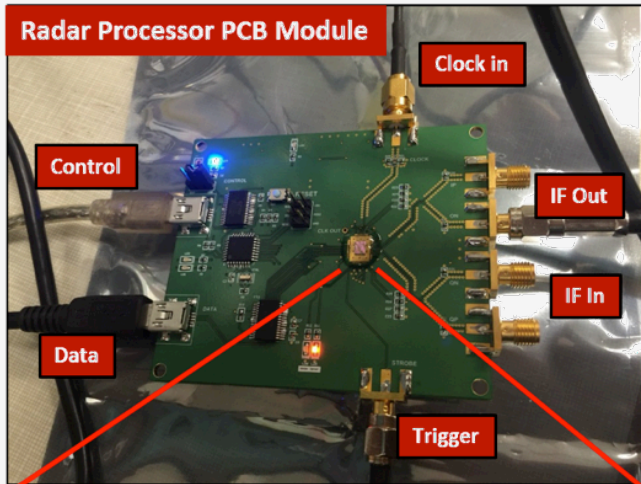


Computed FFT of Captured Echo Signal

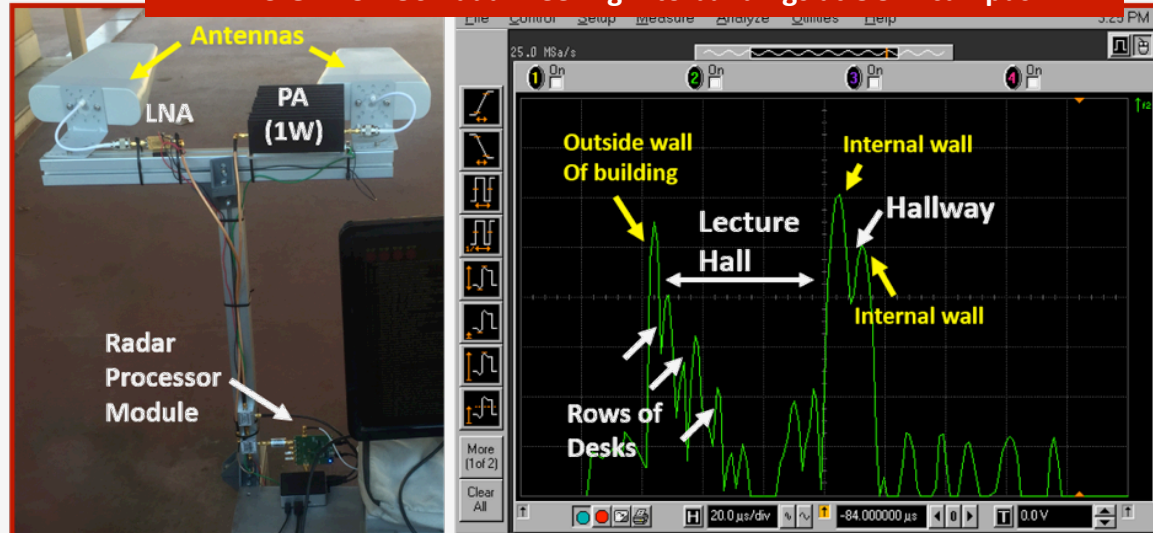


Radars!

CMOS 1-5 GHz Ground Penetrating Radar

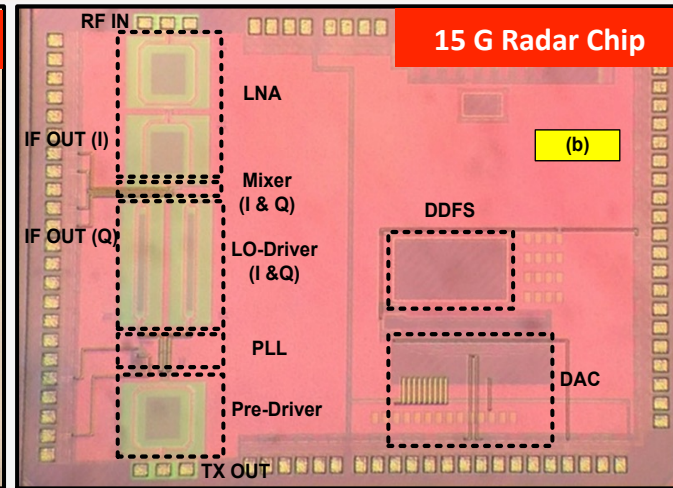
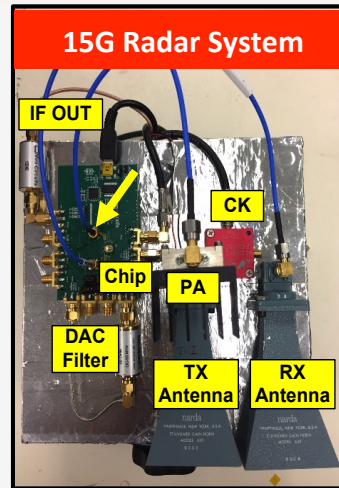
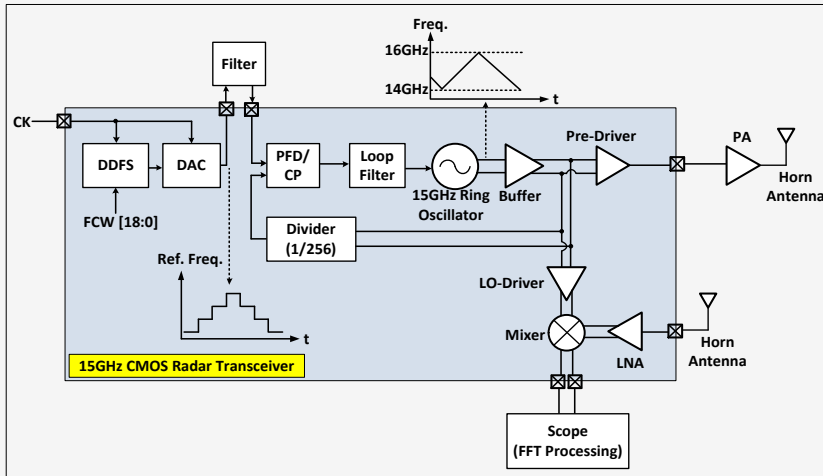


1-5 GHz CMOS Radar Peering into buildings at UCLA campus

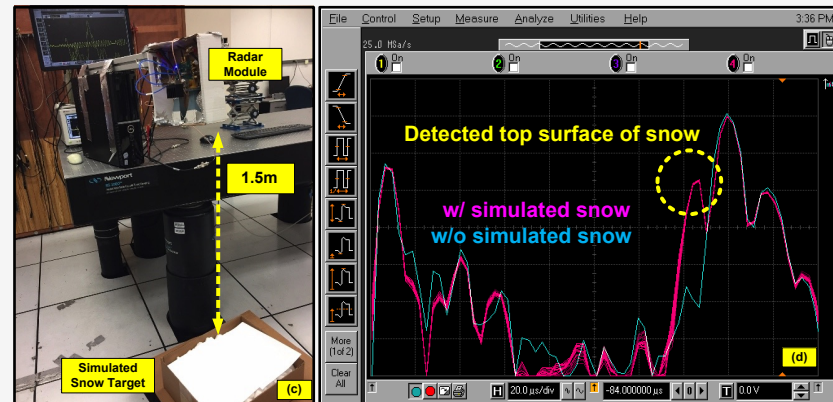
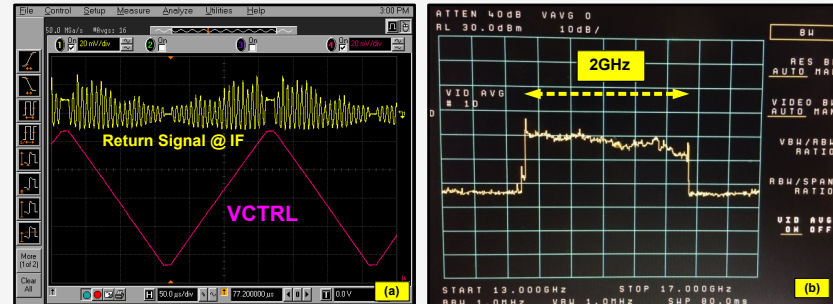


(1.5Kg / 9.1W)

CMOS 12-15 GHz (Ku-band) Snow Radar System

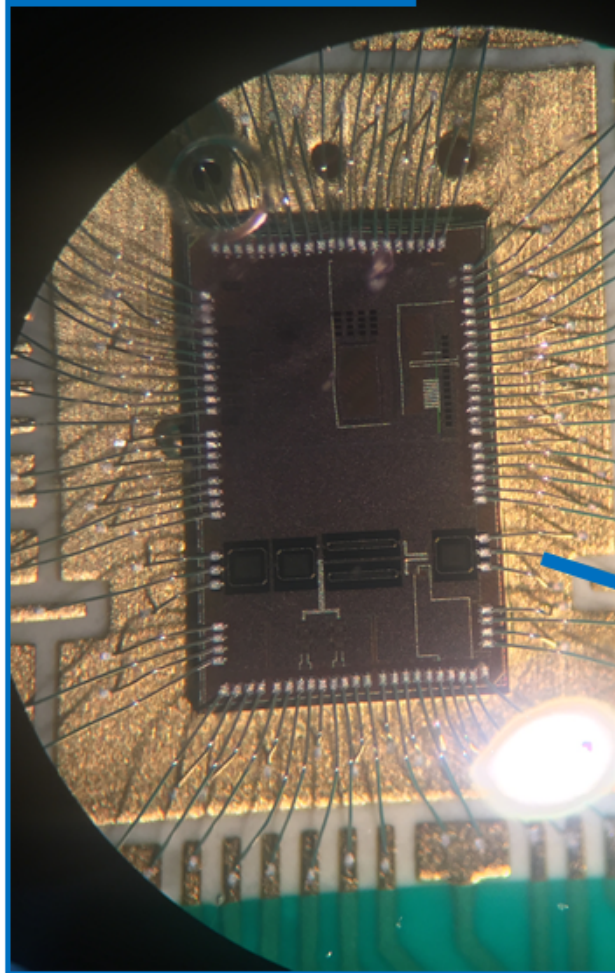


| JPL-UCLA KU-FMCW Radar | |
|------------------------|--------------------|
| Parameter | Value |
| Bandwidth | 12-16 GHz |
| Range Resolution | 5 cm |
| Dynamic Range | 62 dB |
| DC Power Consumption | 4450mW |
| Volume | 300cm ³ |
| Weight | 0.8 Kg |

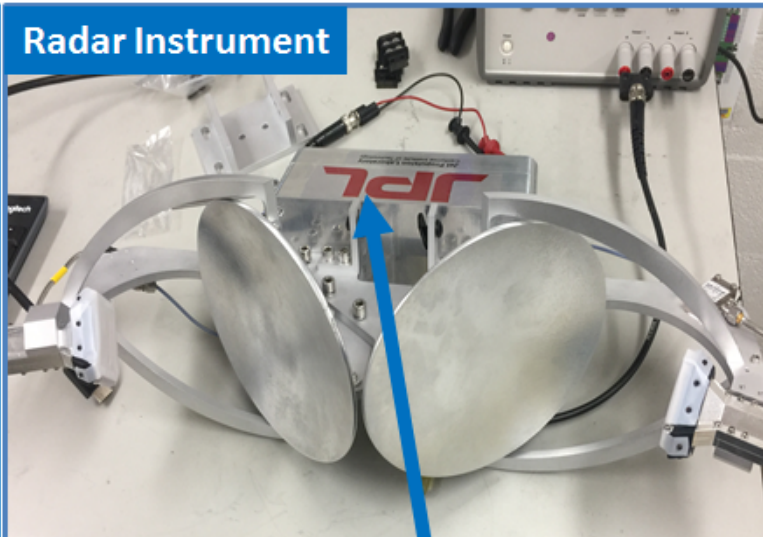


CMOS 12-15 GHz (Ku-band) Snow Radar System

CMOS Chip Assembly



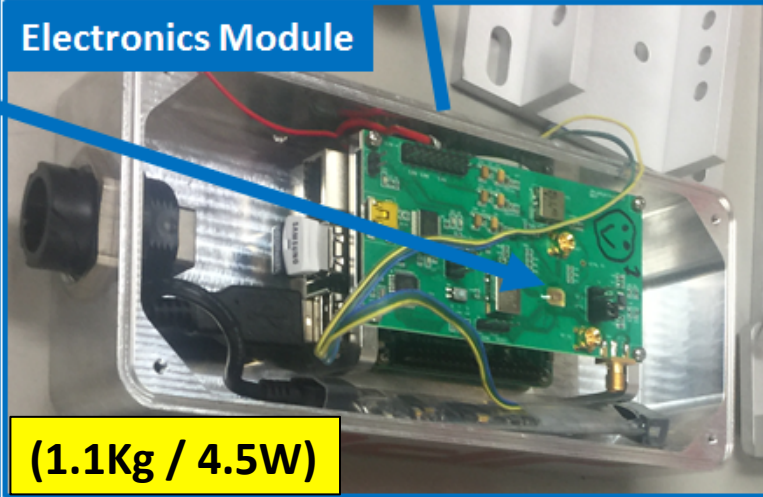
Radar Instrument



Deployment at CUES

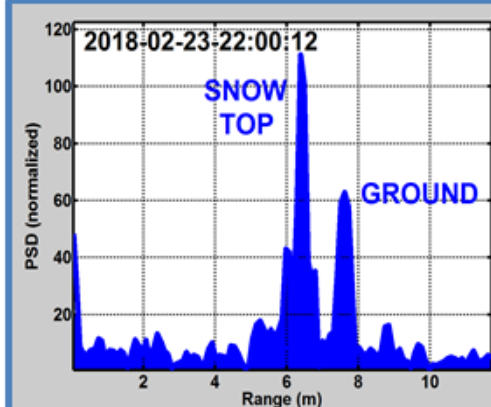


Electronics Module



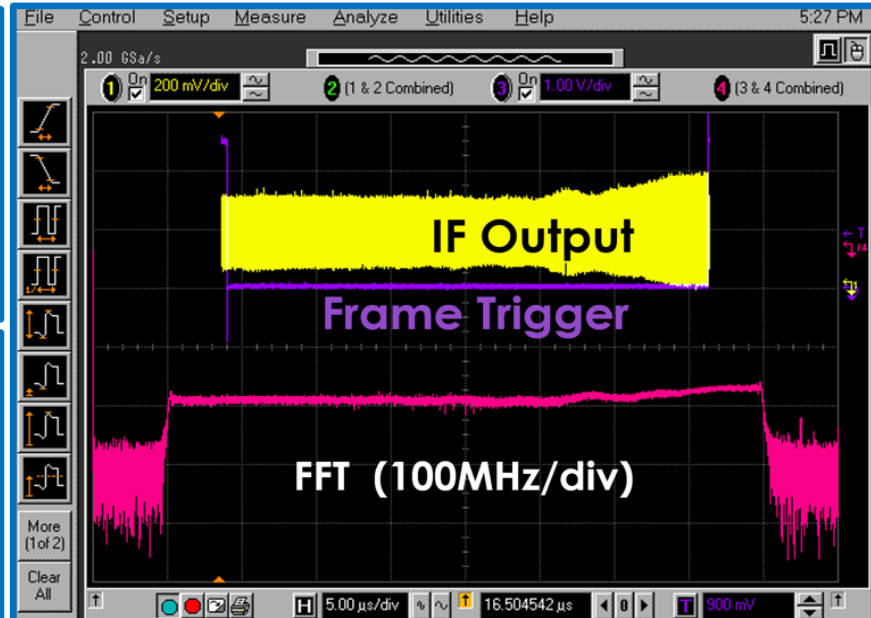
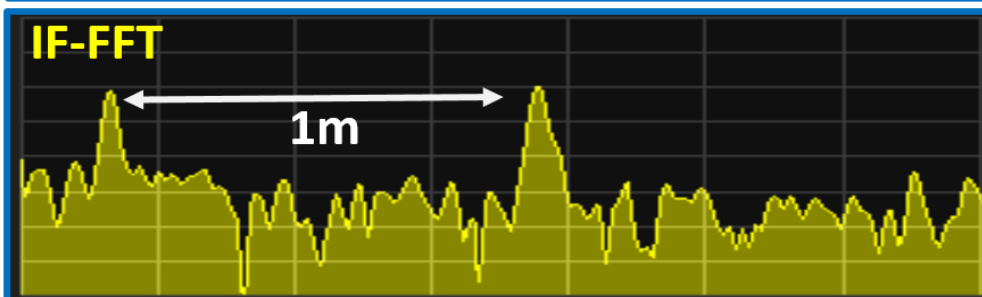
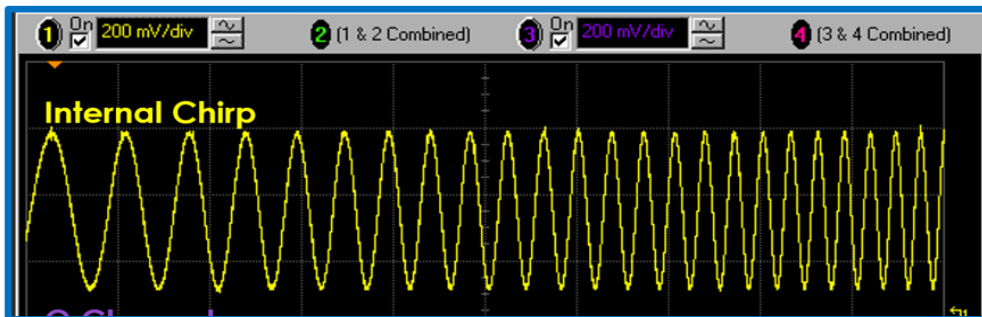
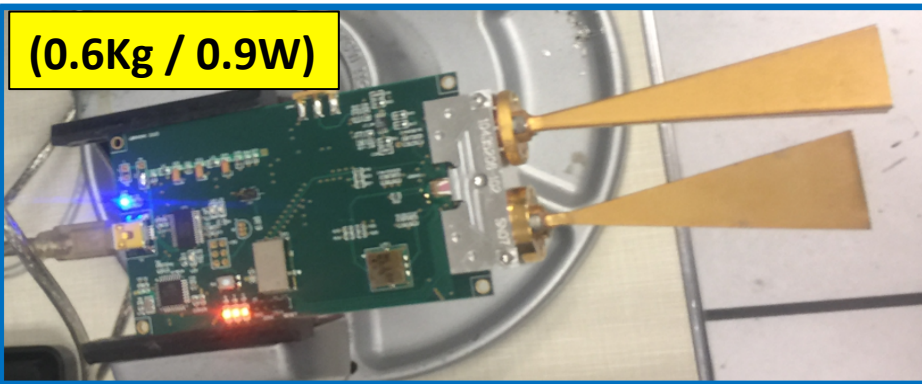
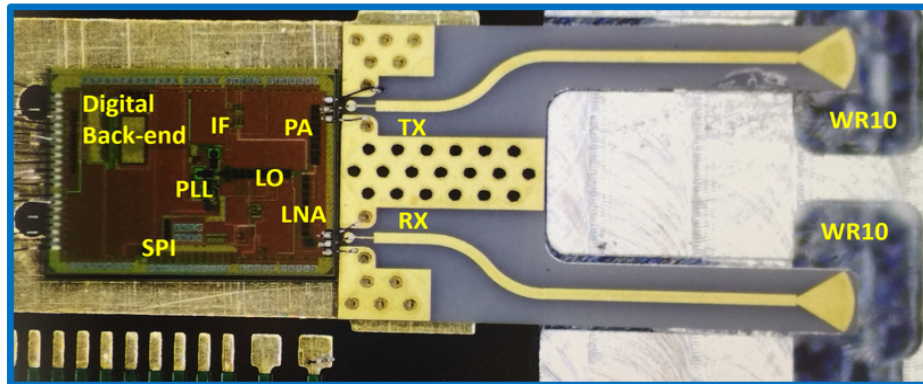
(1.1Kg / 4.5W)

Sample Measurement



- ❖ Has been deployed at Mammoth mountain resort (CUES) and providing them snow data for the last 12 months.

CMOS 90-100 GHz (W-Band) Radar Module



Thoughts to take away...

- ❖ CMOS enables compact and low power instruments that can offer comparable capabilities to existing sensing technology.
- ❖ CMOS is a good fit with most remote sensing instruments (Radiometers, Spectrometers and Radars)
- ❖ CMOS SoC technology evolves quickly. In 3 years we went from 15 GHz to 183 GHz in our receiver work because of how quickly the technology advances.

Acknowledgements

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NASA – Astrophysics Research and Analysis (APRA)

JPL's Research & Technology Development Program

DARPA's Healics Program

