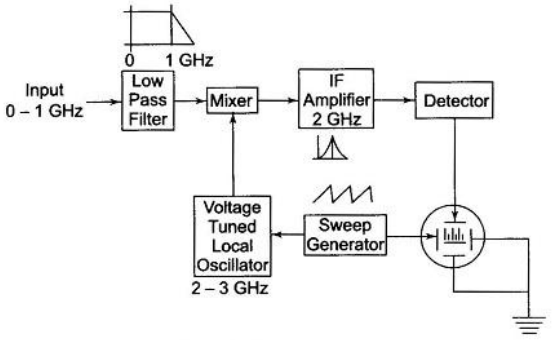
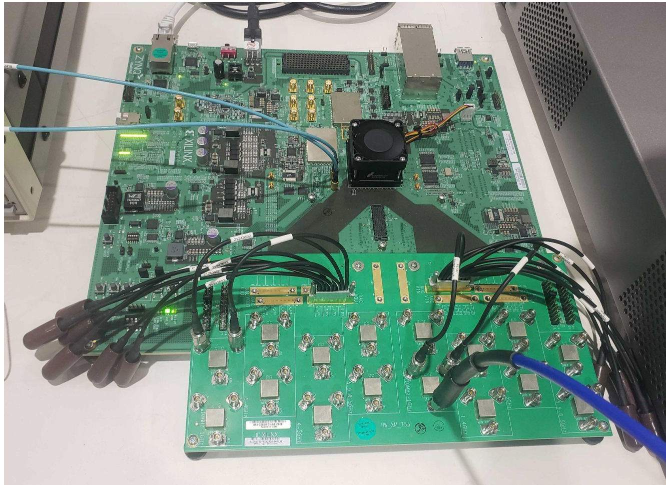
RF systems: analog vs. digital

- Analog circuits:
  - Analog components: capacitors, inductors, transistors, mixers, etc.
  - Analog signals, EM waves
- Digital Circuits:
  - Logic gates, FPGA’s
  - Digital signals, counts



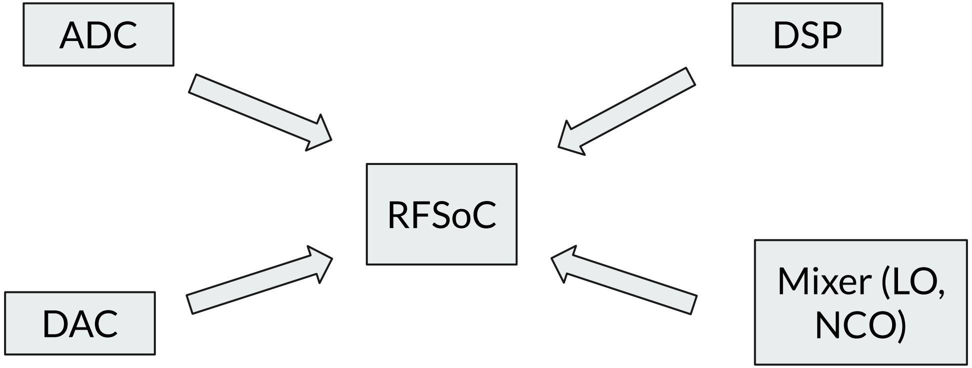
RFSoC Board basics

- Radio frequency system on chip
- Digital RF system (which includes signal converters, signal analyzer, etc.)
- Faster and more compact than analog signal analyzer
- Higher frequency limit than analog RF systems
  - Can analyze signals up to 2.7 GHz directly
- All-in-one RF system
  - Signal analyzer (integrated, multi-channel)
  - Digital signal generator (integrated)
  - Select external compatibility (network analyzer, external clocks, etc)
  - Programable

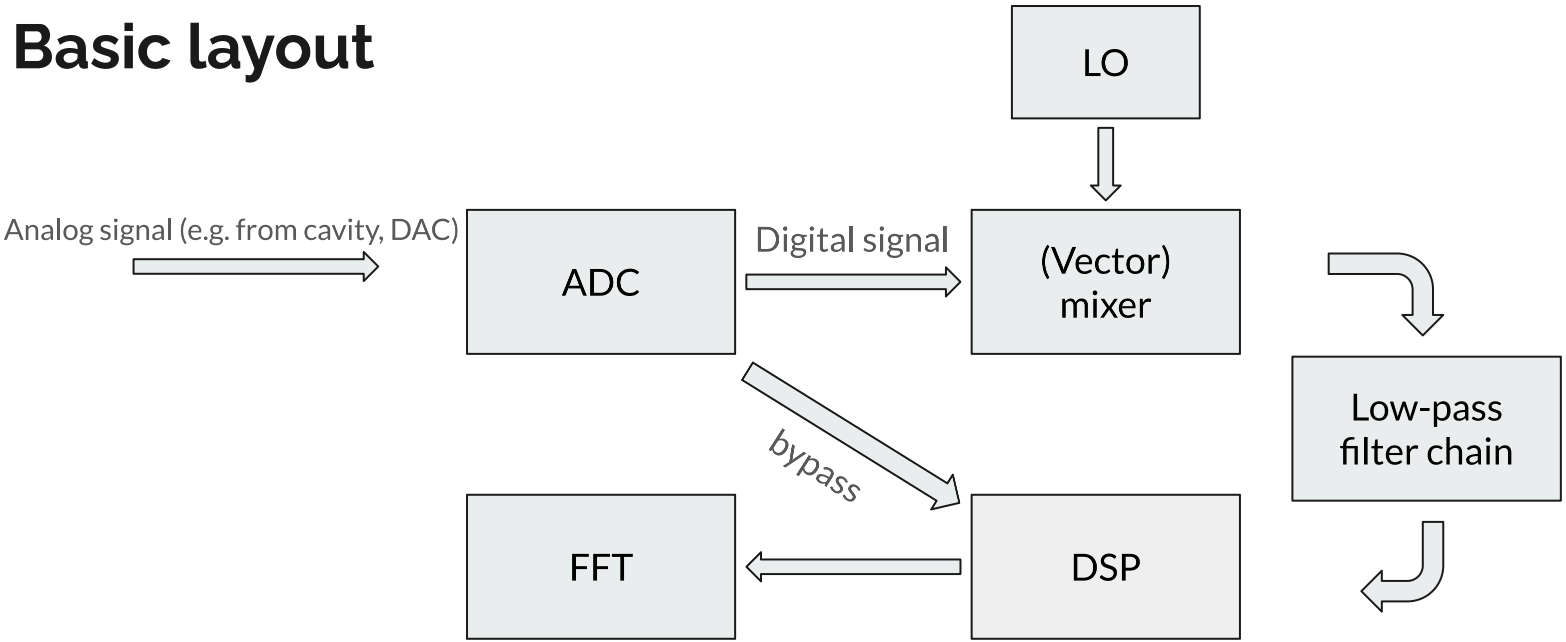


Single chip design

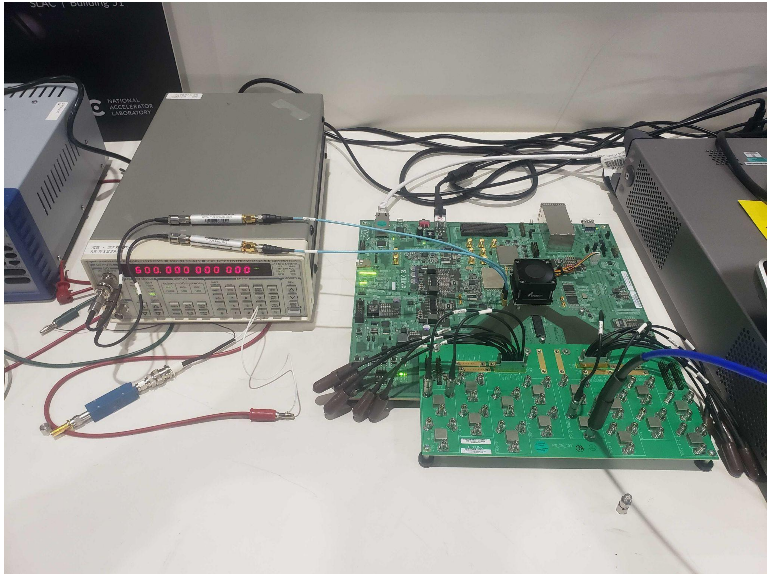
Integrates signal converters (analog-to-digital (ADC) and digital-to-analog (DAC)), digital signal processor (DSP), mixer and other components of the analysis chain into single chip, whereas analog signal analyzer the components are separate.



Basic layout

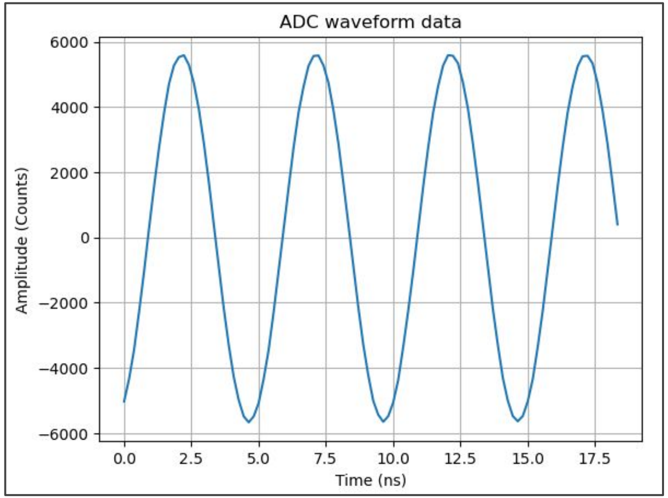


Lab setup



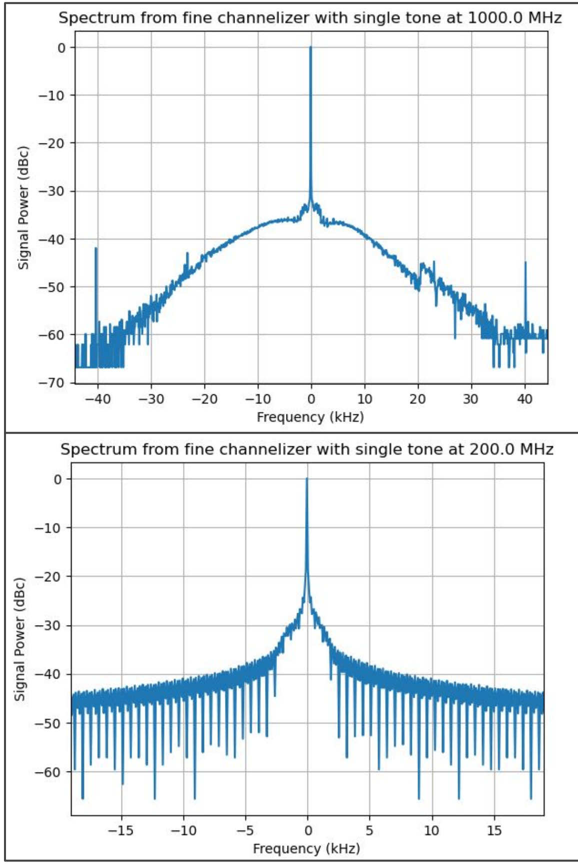
ADC and DAC Signals

- Input analog signal into ADC receiver
- ADC has a sample rate of 5.4 GHz (Nyquist frequency of 2.7GHz)
- DAC signal generator
- This data is then processed via FFT in DSP
- Beyond 2.7GHz, the firmware is designed to handle the aliasing signal generated by under sampling within the first Nyquist zone (by down mixing).



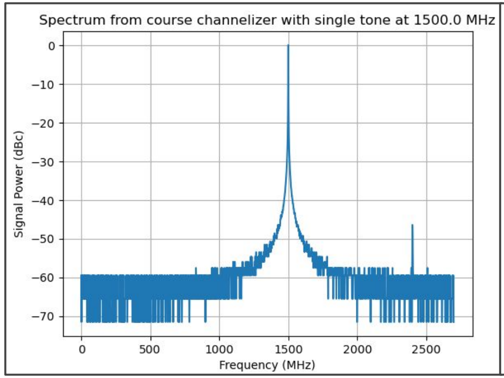
DSP

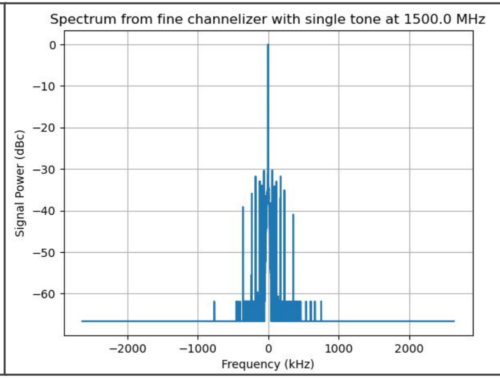
- Tell the LO in the DSP what frequency to analyze at
  - Can be offset form input frequency by up to ~2MHz
- Spectrum is centered on the LO frequency
  - Performs FFT over an interval around the LO frequency (~2 MHz radius)
- These steps produce a “pulse” in the spectrum
- Offsetting the LO frequency from the analog signal frequency causes two pulses:
  - a wider signal created by the analog input signal
  - a very narrow one generated at the LO frequency



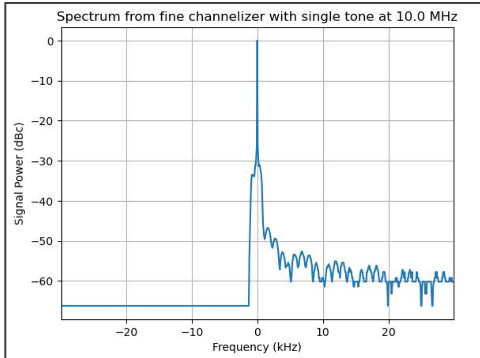
X-axis: frequency offset from LO frequency.

DSP - FFT





- Course and Fine FFT channels
  - Fine FFT uses a mixer to mix down the signal
  - Coarse FFT does not use a mixer and can analyze signals up to 2.2 GHz (limited by ADC processor)
- The lower frequency limit is claimed to be ~10MHz, but in reality it can go lower than this. The real limit requires more testing to find.
- Additionally, the lower power limit is unclear, but signal as low as -45dBm are detectable at room temp.
- Once FFT accumulation is finished, data is transmitted to the software.



Benefits over analog systems

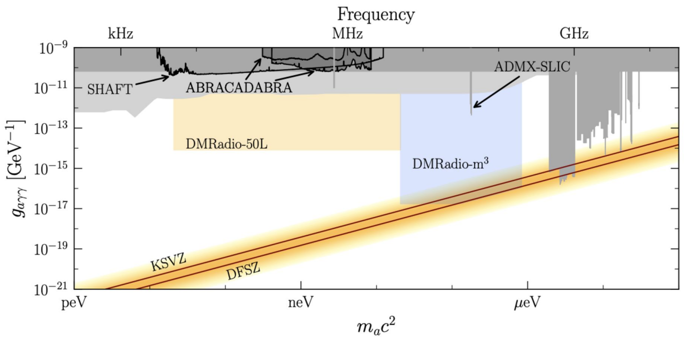
- On board processing.
- Converts analog signals to digital signals, easier to process.
- Can perform multiple tasks that would otherwise need multiple devices (signal conversion, mixing, signal analysis)
- Reduced power consumption

Cons

- Alterations to integrated analysis chain are difficult to integrate and are expensive as it requires reworking of chip design.
- Harder to work with/design as it requires knowledge of both RF and digital domains

Why should you care?

- On top of better optimized processing, it also offers a larger bandwidth for broadband analysis.
- High resolution (sub ~100Hz)
- The ADMX collab is greatly interested in working with these.
  - UW, Fermilab, PNNL: all interested in developing these boards to replace data acquisition system.



Bugs

- The RFSoC we are using uses special made firmware that may be causing issues, so the following are not necessarily general to all RFSoC boards.
- LO punchthrough.
- Uncertain units for power.
- Memory issues requiring frequent resets.
  - Causes distortion and “ghost” signals
- Window truncating effect
  - Distortions in the spectrum due to non integer periods of the signal in the acquisition time.
- Spurious free dynamic range is stable until ~-30dBm where it increases greatly (at 4GHz).