Front-end Design of the Read-Out System for Micromachined Sensors

Eng. García, Manuel

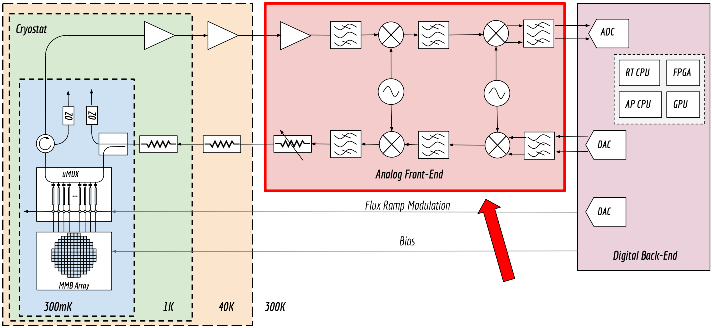
HIRSAP Workshop 2021
Universidad Nacional de San Martín - Karlsruher Institut für Technologie
Directors: Prof. Dr. Platino, Manuel - Prof. Dr. Weber, Marc.
Scientific Supervisor: PD. Dr. Sander, Oliver.

manuel.garcia@iteda.cnea.gov.ar

November 2, 2021

Workplan and Previous Work

Workplan



Main Objective

Design a compact and scalable RF Analog Front-End for the readout system of Low Temperature Detectors using frequency division multiplexing in the range of GHz.

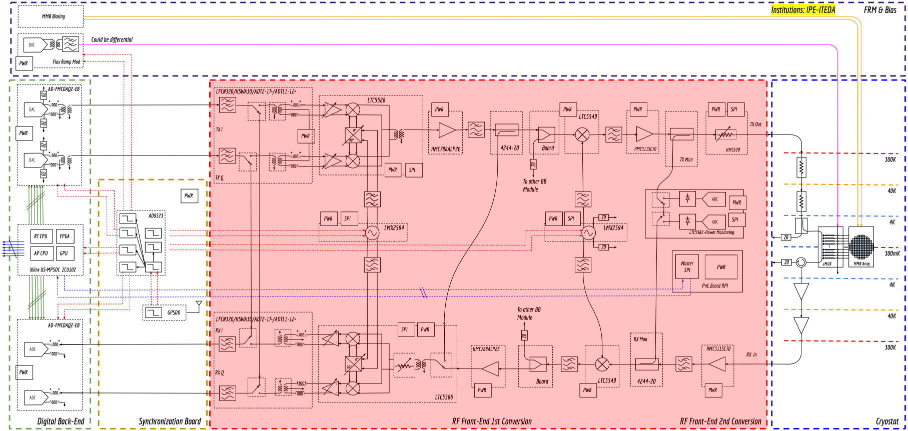
Previous Work

- **Key Points**
  - Read-out Powers.
  - Multiplexing Factor.
  - Signal to Noise Ratio.
  - Long Term Stability.

TABLE VIII. RF Front-End parameters for the QUBIC project.

Parameter	Symbol	Unit	Minimum	Step	Maximum
DAC Number	N_{DAC}	Unit	5	-	-
DAC Sample Rate	f_{DAC}	MHz	1000	-	-
DAC SFDR	$SFDR_{DAC}$	dBFS	60	-	-
DAC ENOB	n_{DAC}	bits	16	-	-
DAC Full Scale	FS_{DAC}	Volt	0.5	-	-
ADC Number	N_{ADC}	Unit	5	-	-
ADC Sample Rate	f_{ADC}	MHz	1000	-	-
ADC ENOB	n_{ADC}	bits	10.6	-	-
DAC SFDR	$SFDR_{DAC}$	dBFS	60	-	-
ADC Full Scale	FS_{ADC}	Volt	0.5	-	-
Clock Jitter	τ_{jt}	fs	-	-	125
IQ Phase Control	$\Delta\theta_k$	^{o}	-	0.1	-
IQ Amp. Control	ΔA_k	dB	-	0.05	-
DC offset Control	ΔV_{DC}	μV	-200	2	200
Rx Gain	G_{Rx}	dB	17	0.5	37
Tx Gain	G_{Tx}	dB	-25	0.5	-5
Gain Slope	G_{Tx}	dB	-	-	5
Gain Ripple	G_{Tx}	dB	-	-	3
Rx Noise Fig	NF_{Rx}	dB	2	-	18
Tx Noise Fig	NF_{Tx}	dB	10	-	30
Rx IIP3	$IIP3_{Rx}$	dBm	13	-	30
Tx IIP3	$IIP3_{Tx}$	dBm	30	-	47
Rx IIM2	$IIP2_{Rx}$	dBm	20	-	-
Tx IIM2	$IIP2_{Tx}$	dBm	20	-	-
Rx IP1dB	$P1dB_{Rx}$	dBm	3	-	-
Tx IP1dB	$P1dB_{Tx}$	dBm	20	-	-
LO Frequency	f_{LO}	MHz	4000	0.1	8000
Frequency Stability	δf	ppp/h	-	-	10
LO Phase Noise	$\mathscr{L}_{0.1Hz}$	dBc/Hz	-	-	-7
LO Phase Noise	$\mathscr{L}_{10Hz}$	dBc/Hz	-	-	-47
LO Phase Noise	$\mathscr{L}_{100Hz}$	dBc/Hz	-	-	-67
Power Stability	δP	dBm/h	-	-	0.1
Phase Stability	$\delta\theta$	$^o/h$	-	-	1

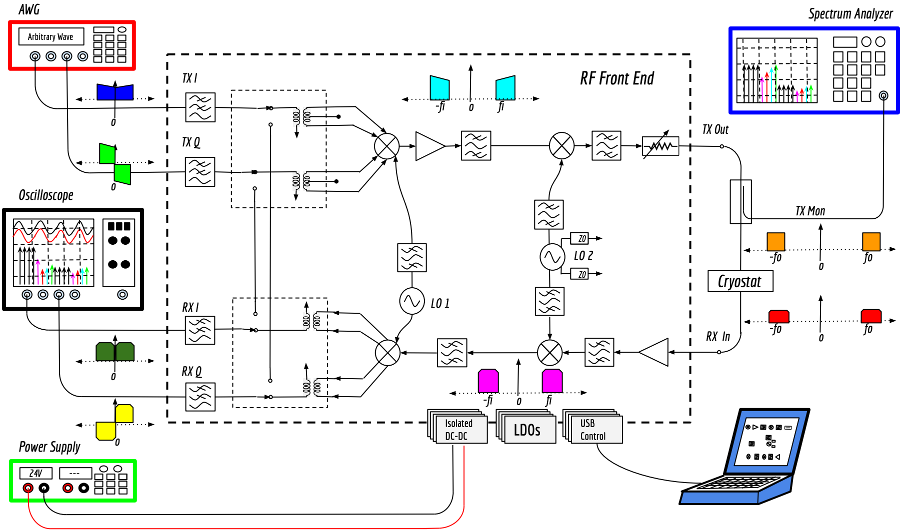
Work Progress



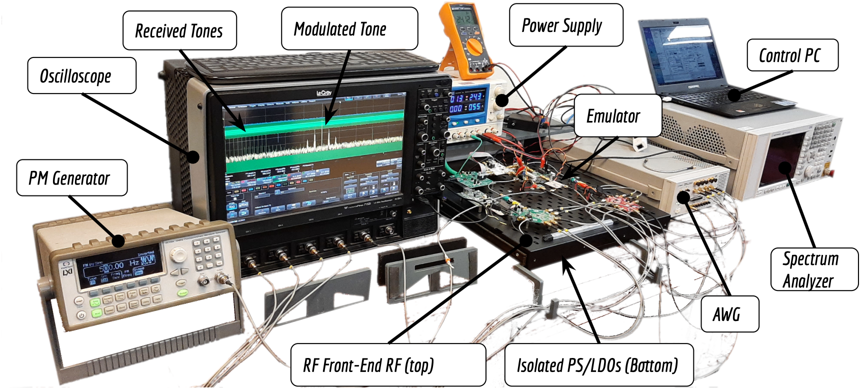
Reduced Front End

How does the RF Front end Degrades Signal Quality?.

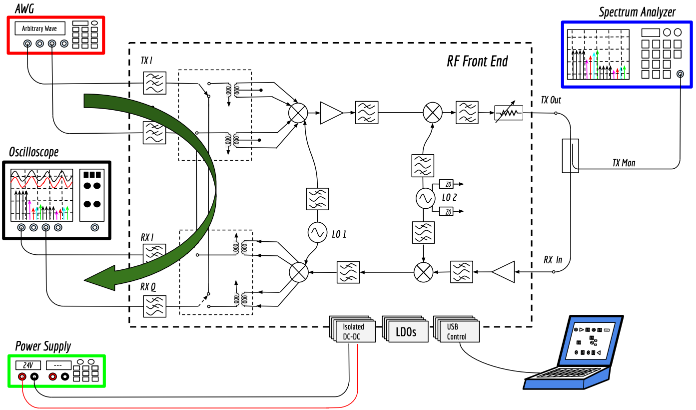
Reduced RF Front-End Characterization.

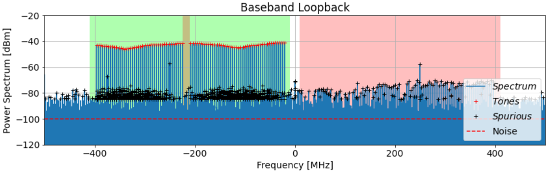


Characterization Set-Up.

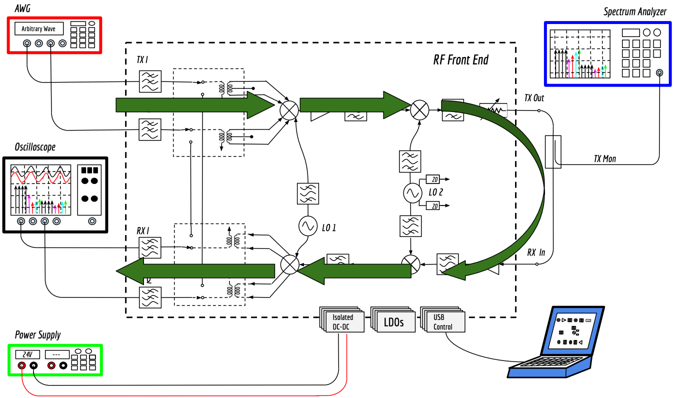


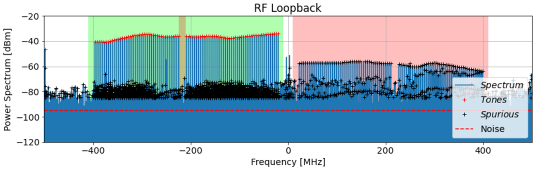
Baseband Loopback.



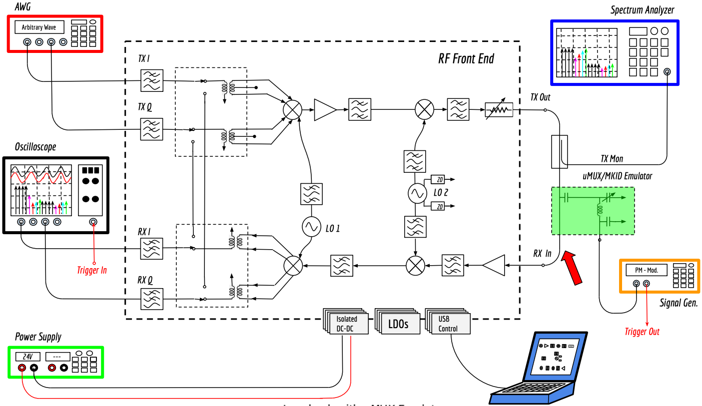


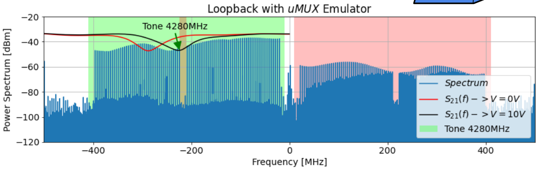
RF Loopback


AWG
Arbitrary Wave
Spectrum Analyzer
TX I
RF Front End
TX Out
TX Mon
Oscilloscope
LO 2
LO 1
RX I
RX In
Isolated DC-DC
LDOs
USB Control
Power Supply
24V

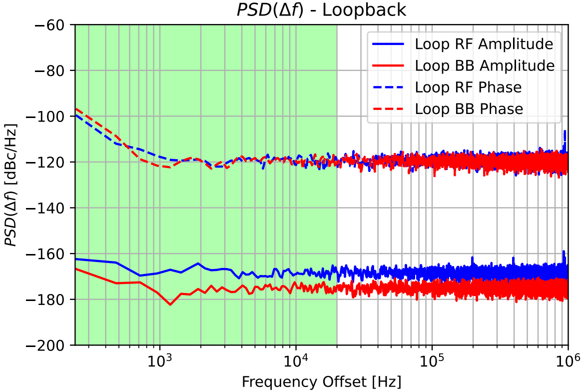

RF Loopback
Power Spectrum [dBm]
−20
−40
−60
−80
−100
−120
−400
−200
0
200
400
Frequency [MHz]
Spectrum
Tones
Spurious
Noise

uMUX Emulator

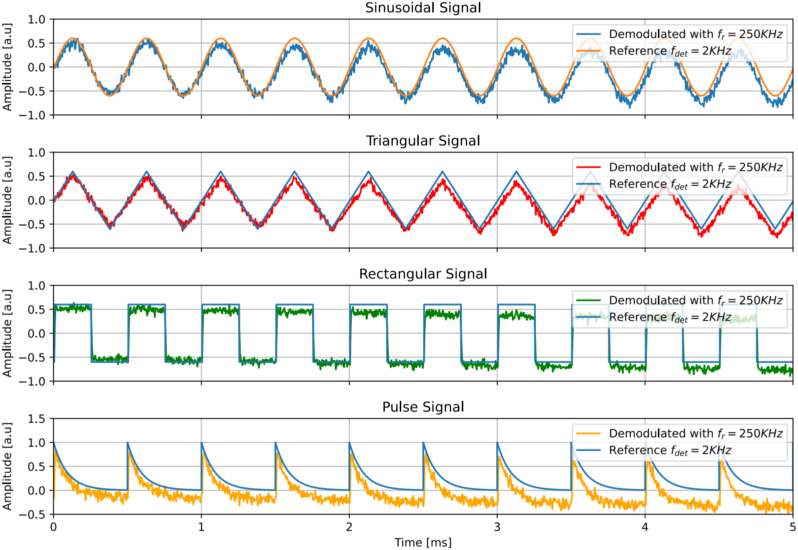




Preliminary Results.



Preliminary Results



Publications, Events and Courses

- **Events**
  - 7th MT Meeting DTS mirror agenda - February 2021.
- **KSETA Courses**
  - Introduction to Quantum Physics - October 2021.
  - Low-Temperature (Superconductive) Detectors - October 2021.
- **Languages**
  - Deutsch A2.1 (UNSAM).
  - Deutsch A2.2 (UNSAM) (in progress...).

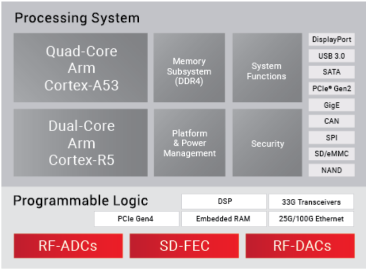
QUBIC Integration LAB

Future Work

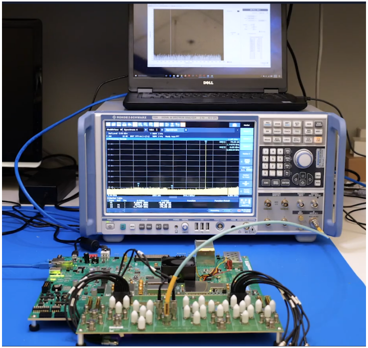
Measurements Processing and Validation.

- **Signals**
  - Spectral and Temporal Characteristics.
  - Amplitude Distribution and Powers.
- **Signal to Noise Ratio Vs. Number of Tones.**
  - Additive Noise.
  - Multiplicative Noise.
  - Spurious and Synchronization.
- **Integration.**
  - Include a Frequency Reference.
  - Integration with other Sub-systems.
  - Buy/design Missing components.

RF SoC Characterization



(a) RF SoC Architecture



(b) RF SoC Evaluation board.

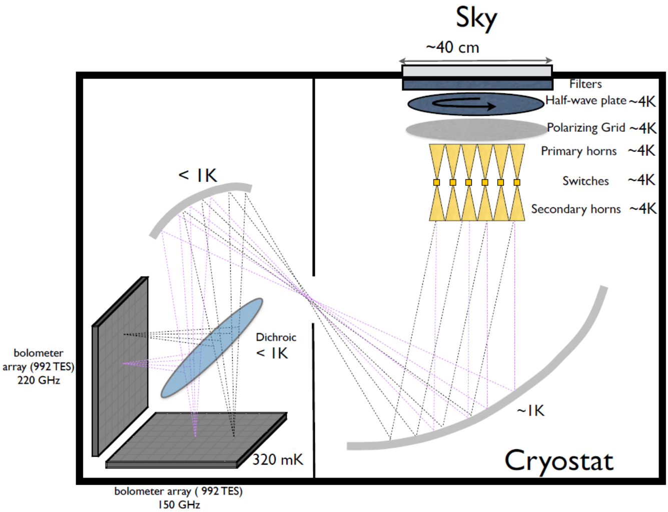
Possible Improvements:

- Integration and Low Power Consumption
- Bands Combining/Splitting
- Synchronization and Stability

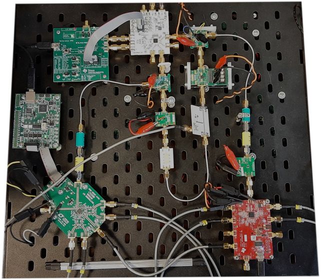
Thanks!

Questions?

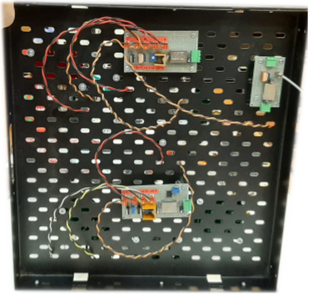
Backup - Telescope



RF Front End

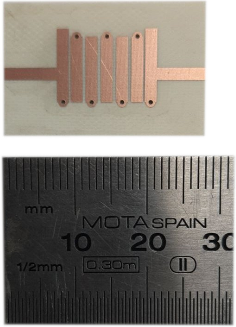


(a) RF FE Top (Radio-frequency)

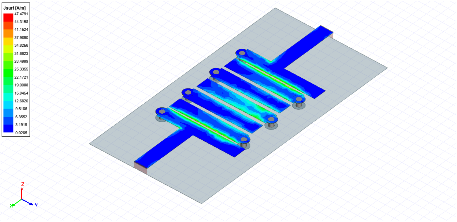


(b) RF FE Bottom (Power Supplies).

Filters Design

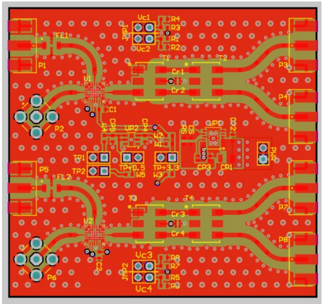


(a) Intedigital Band pass Filter.

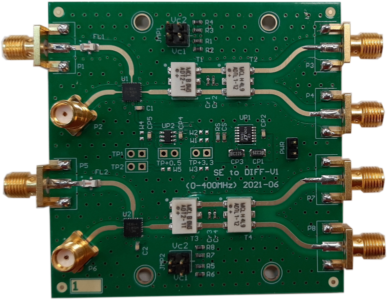


(b) EM Simulation.

SE to DIFF Converter

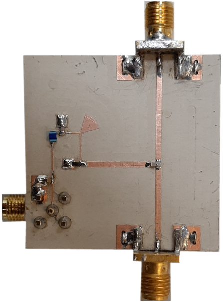


(a) SE to DIFF Converter CAD.

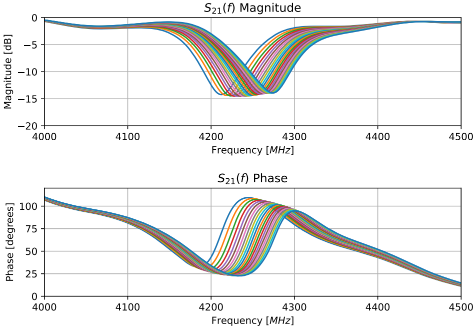


(b) SE to DIFF Board.

uMUX Emulator



(a) MKID/μMUX Emulator.



(b) $S_{21}(f)$ Vs. Voltage.

uMUX Emulator Bias

$$V_{gen}(t) = V_{dc} + V_{ac} \cdot \sin[2\pi f_r t + \beta \cdot x_{\mathrm{det}}(t)] \tag{1}$$

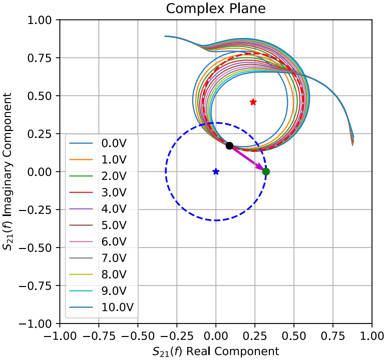
$$V_{gen}(t) = V_{dc} + V_{ac} \cdot \sin[2\pi f_r t + \beta \cdot \sin(2\pi * f_{det} t)] \tag{2}$$

$$f_{res}(t) = \frac{1}{2\pi\sqrt{LC_0 + LC[V_{gen}(t)]}} \approx f_0 + \Delta f \cdot V_{gen}(t) \tag{3}$$

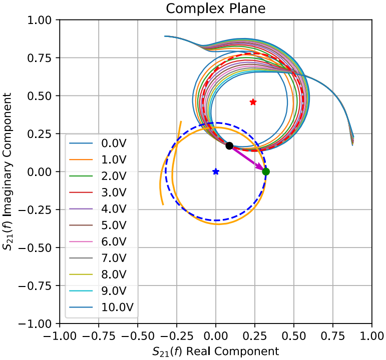
Attention

More detailed model should use Taylor's series due to the non-linearity frequency vs. voltage.

IQ Plane

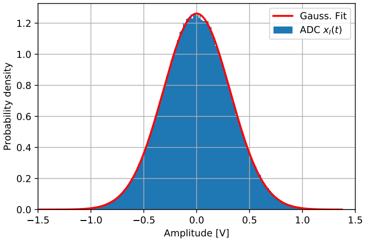


(a) Resonator Complex Plane.

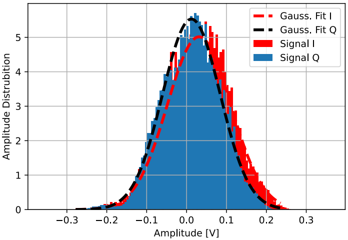


(b) Complex Plane Transformation.

Signal Distribution

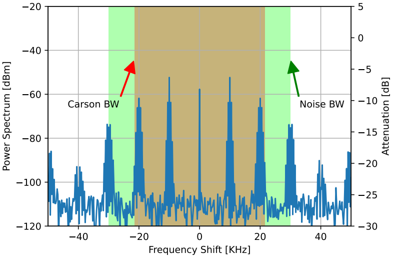


(a) Baseband distribution Simulation.

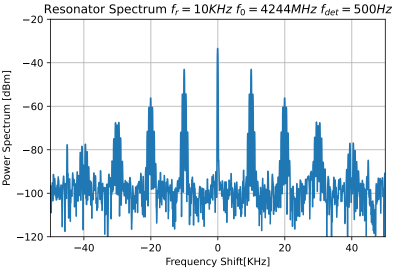


(b) Baseband distribution Real Data.

Signal Spectrum



(a) Simulation.



(b) Real data.

RF Cryo-circuit

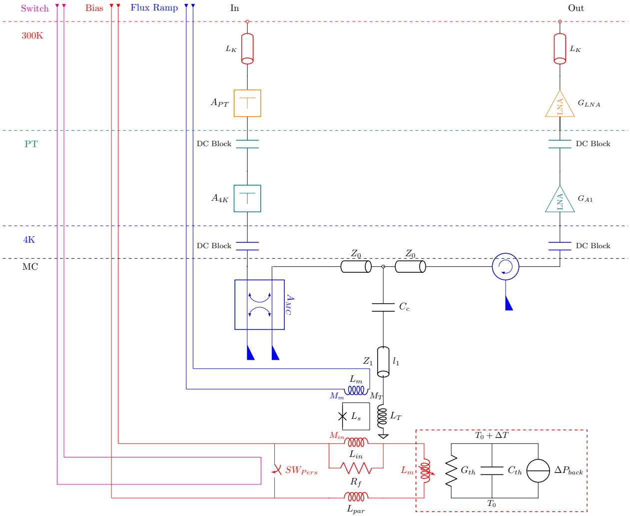


Figure: RF Chain inside Cryostat.

Extra Spectrum

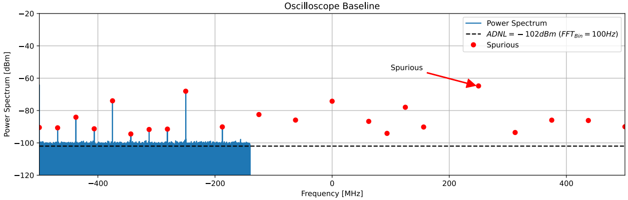


Figure: Scope Baseline.

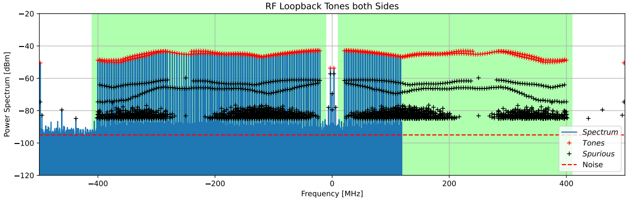


Figure: Two Sided Spectrum.