Semester Project – LNA Design and System Test - Radio Design 401, Episode 8

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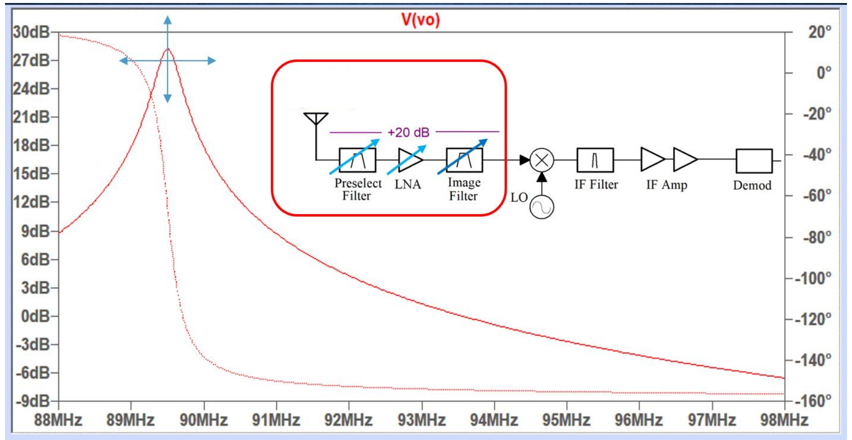
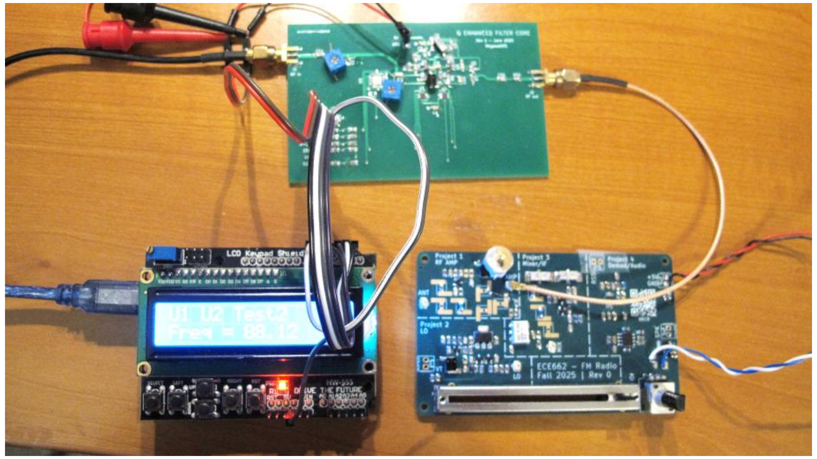
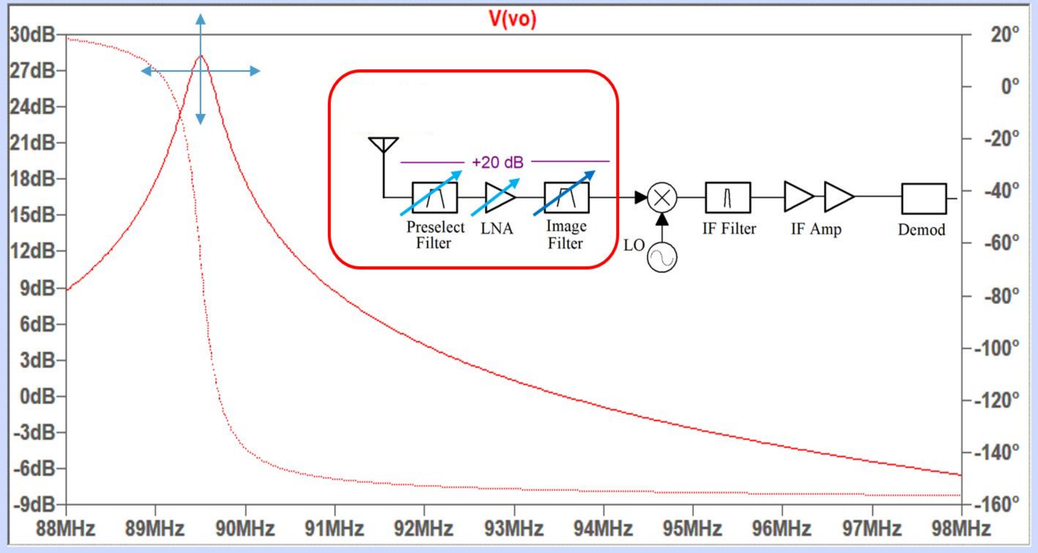
This is Episode 8 - the final episode in the Radio Design 401 series. In it, we validate that the Q-enhanced LNA technology introduced in Episode 1 together with the improved overall receiver architecture from Episode 5, outperforms some of the best commercial receivers, while operating at 10 times lower power consumption. The full system is tested in various spectral environments and compared to a modern automobile radio receiver. The goal is to receive weak signals in the presence of strong interferers as discussed throughout this series.

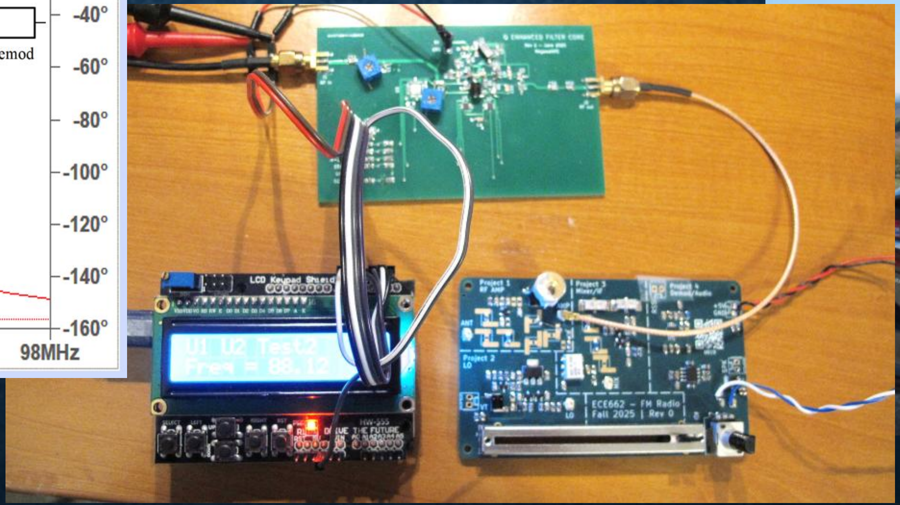




Radio Design 401 – Episode 8

LNA Design and System Testing





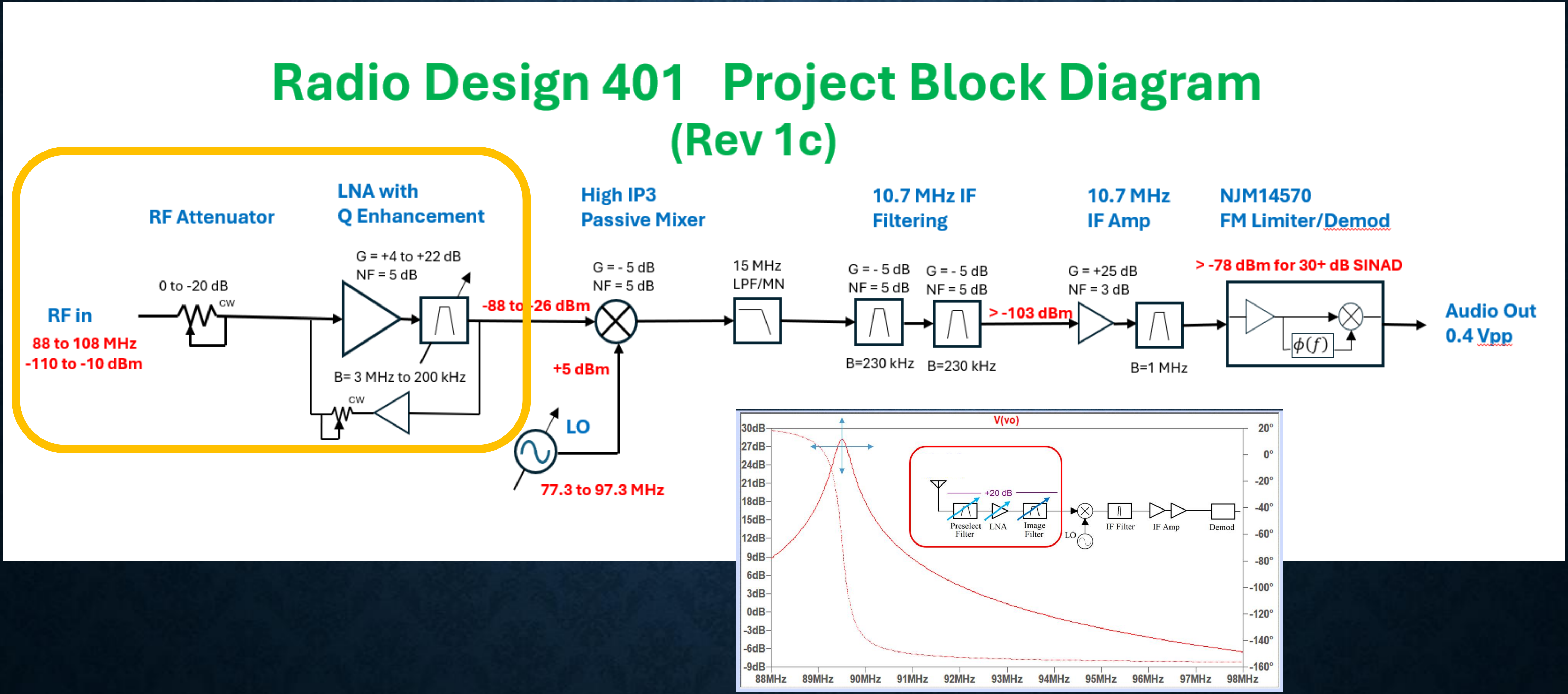
Overview

lna design and system testing

AI Overview

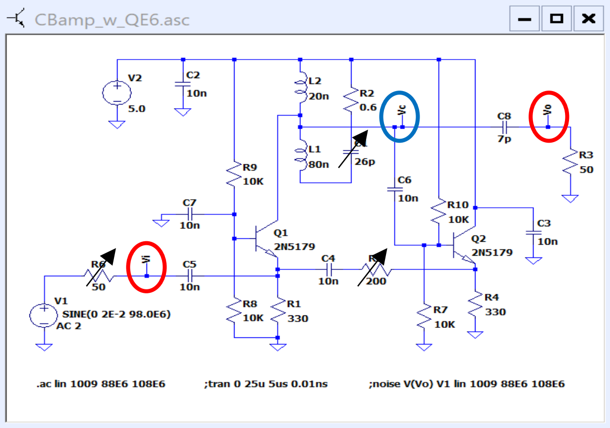
LNA design involves a systematic process of selecting components and topologies to **amplify very weak RF signals while adding minimal noise**, ~~to achieve~~ and achieving specific performance goals (gain, noise figure, stability, linearity, etc.). **System testing** then verifies that the fabricated LNA meets these specifications and functions correctly within the overall receiver system, often using sophisticated RF test equipment.

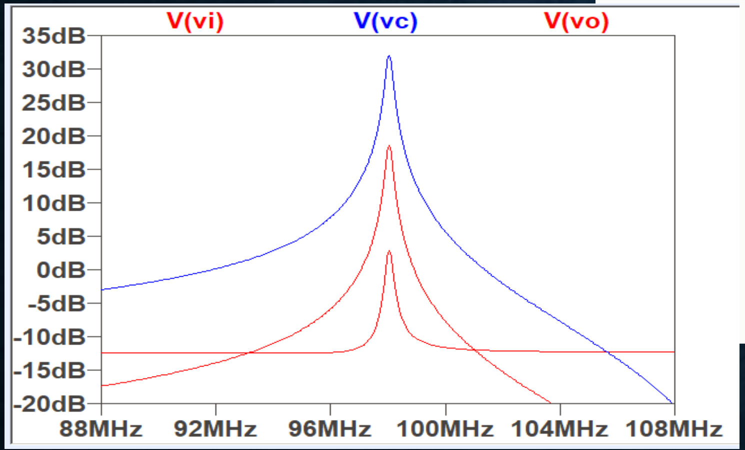
RD401 LNA in Receiver Context

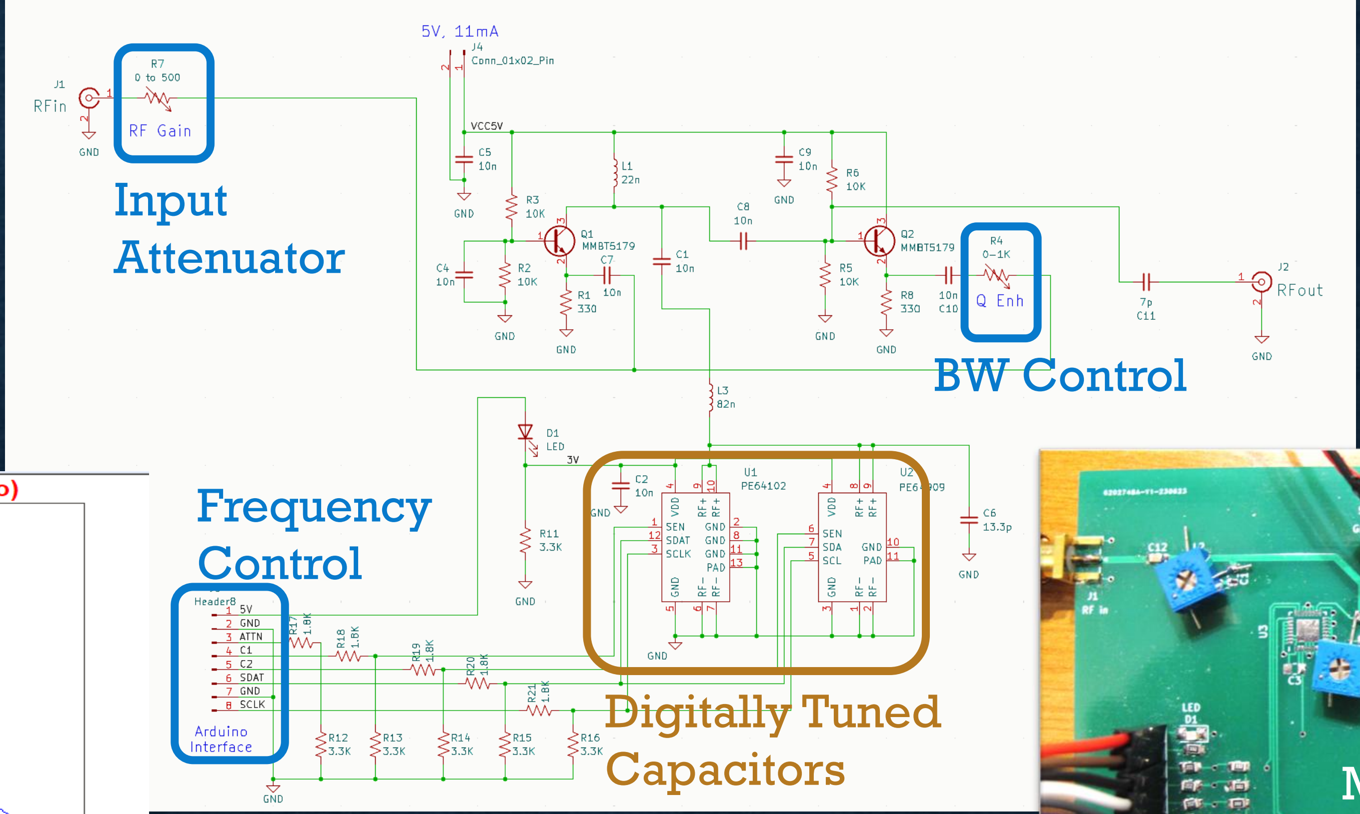


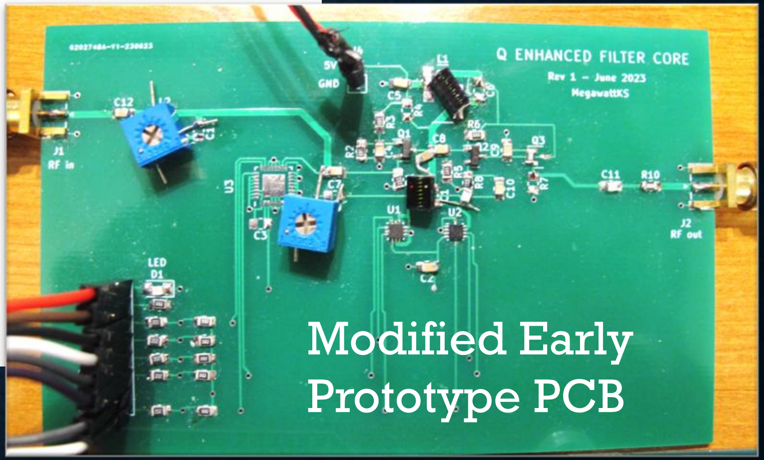
Q-enhanced LNA Design

See also Episode 1









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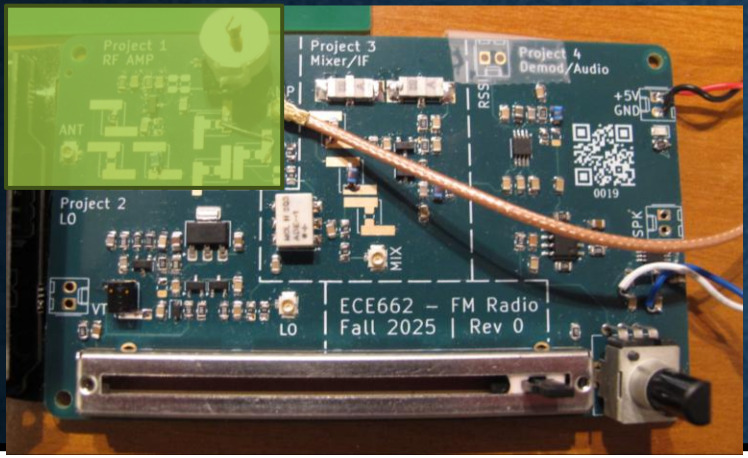
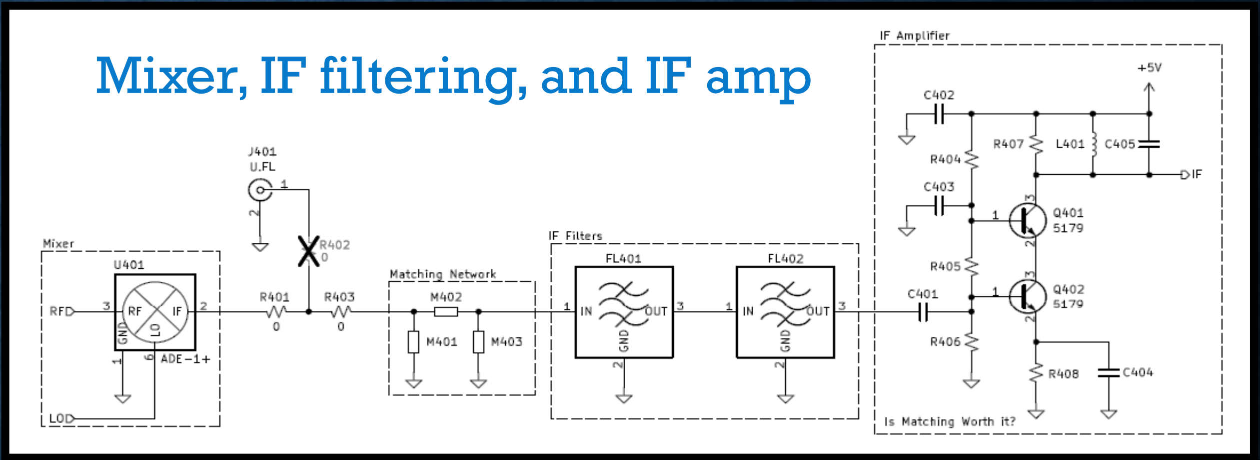
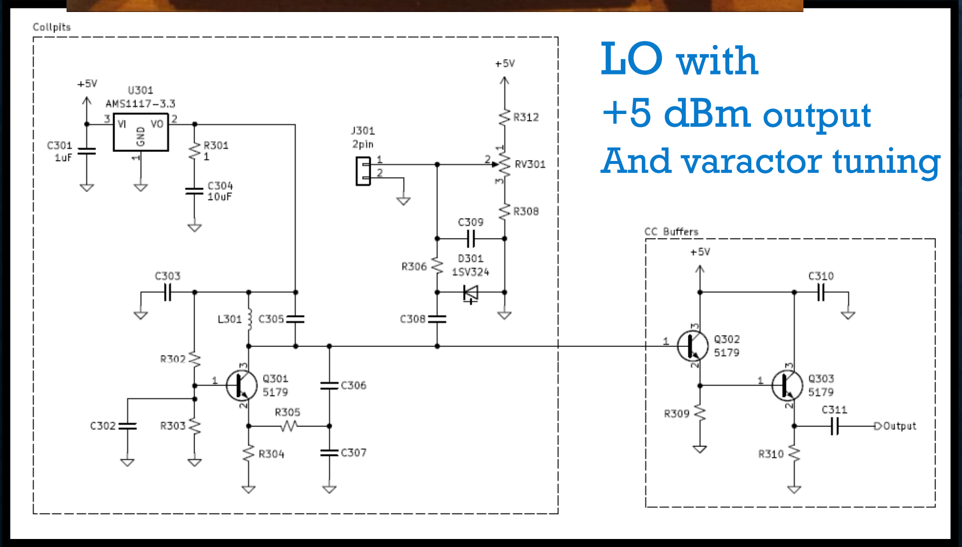
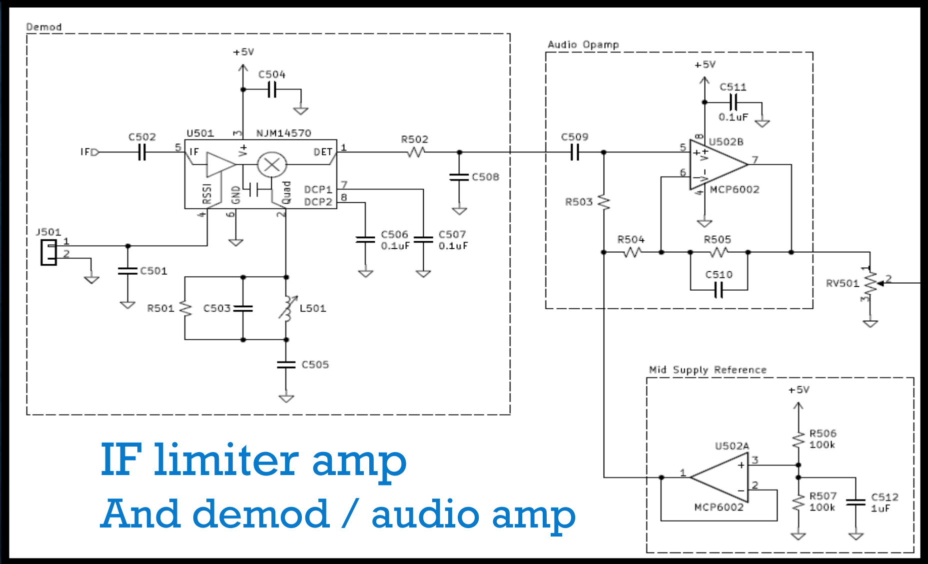
LO, Mixer, IF, Demod

(KiCad Drawings and PCB Courtesy of Garrett Peterson)









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Testing (vs Car Radio)

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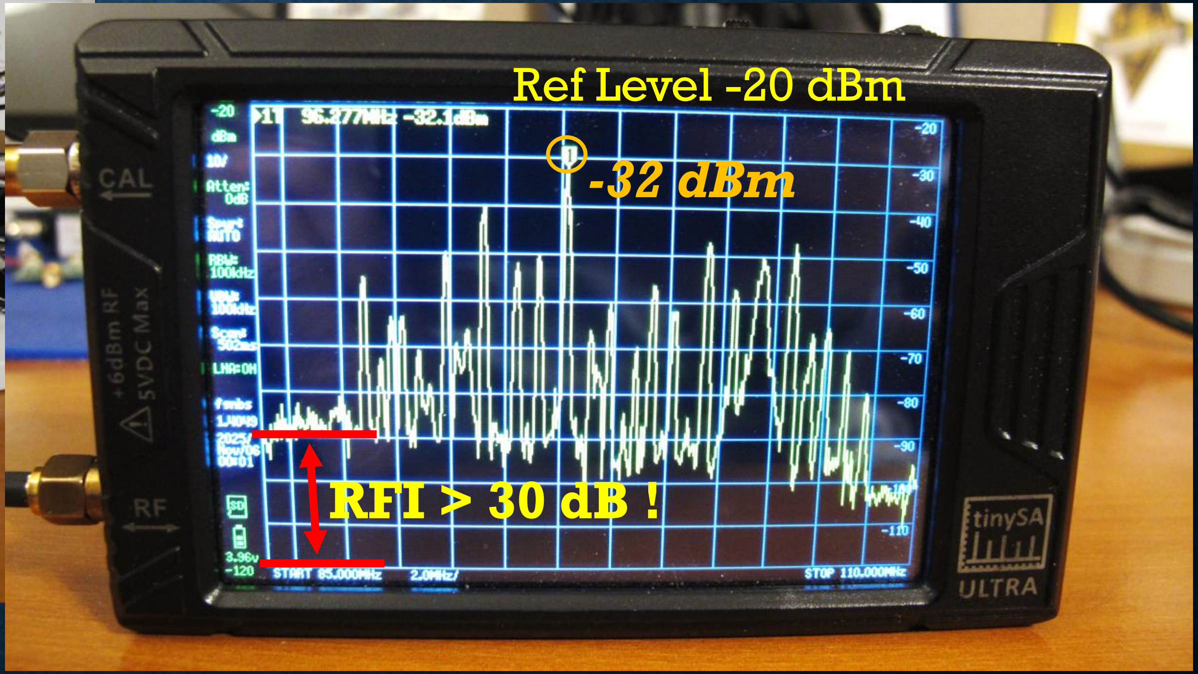
Testing (at the Top of the World)

Presentation Outline

- Signal Environments
- Background and Prior Episodes
- LNA Design
- Classic Lab Testing (Gain, NF, P1dB, Pdc)
- Real-World Test Results
- Conclusions and Future Directions

Noise in Indoor Environments

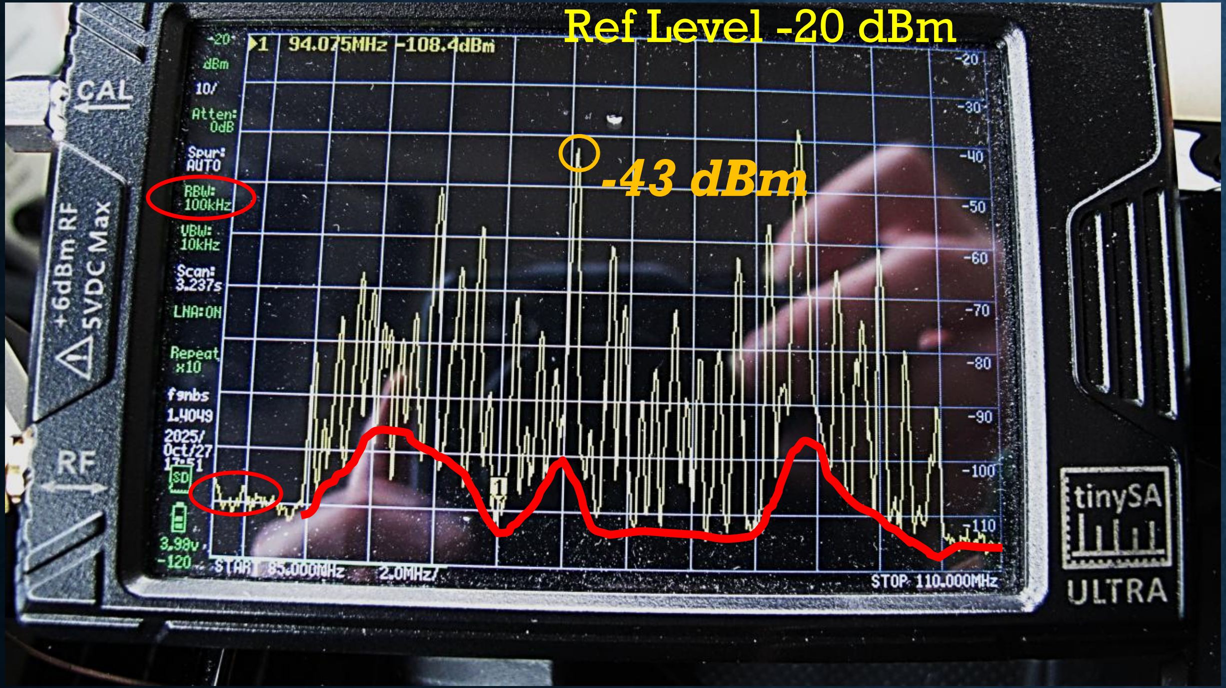
Noise Floor is RFI-Limited



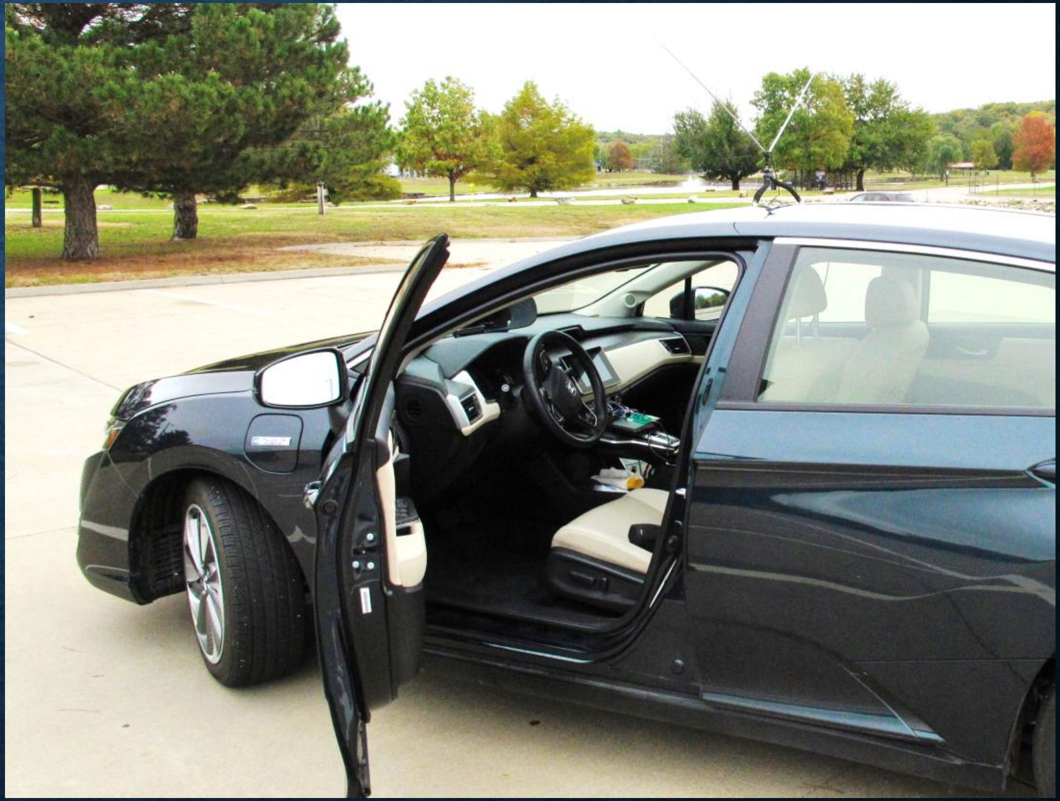
TinySA LNA is ***ON***

Crowded *Outdoor* Environments

Noise Floor is Intermod / IF Filter Limited



TinySA LNA is ON



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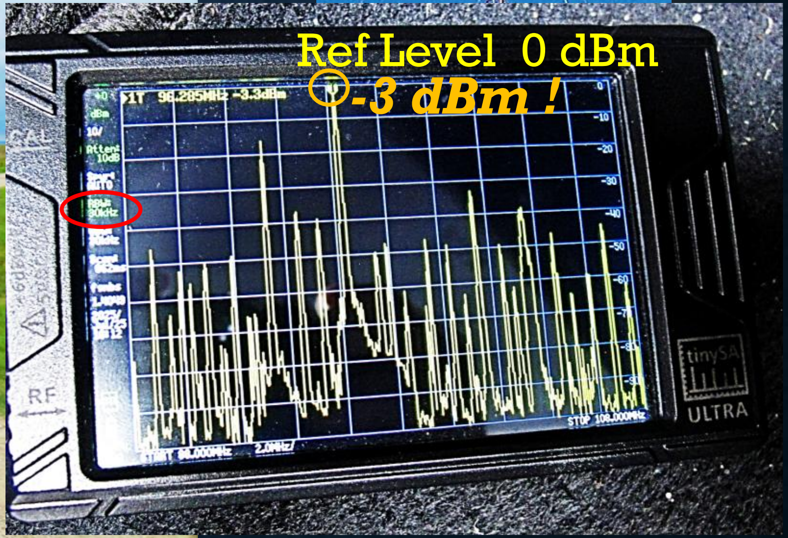
Testing at the "Top of the World" !

Noise Floor is Dynamic-Range and Spurious-Emission Limited

6-element Vertical Array

Pt = 7.5 kW
EIRP=21 kW



LNA is OFF

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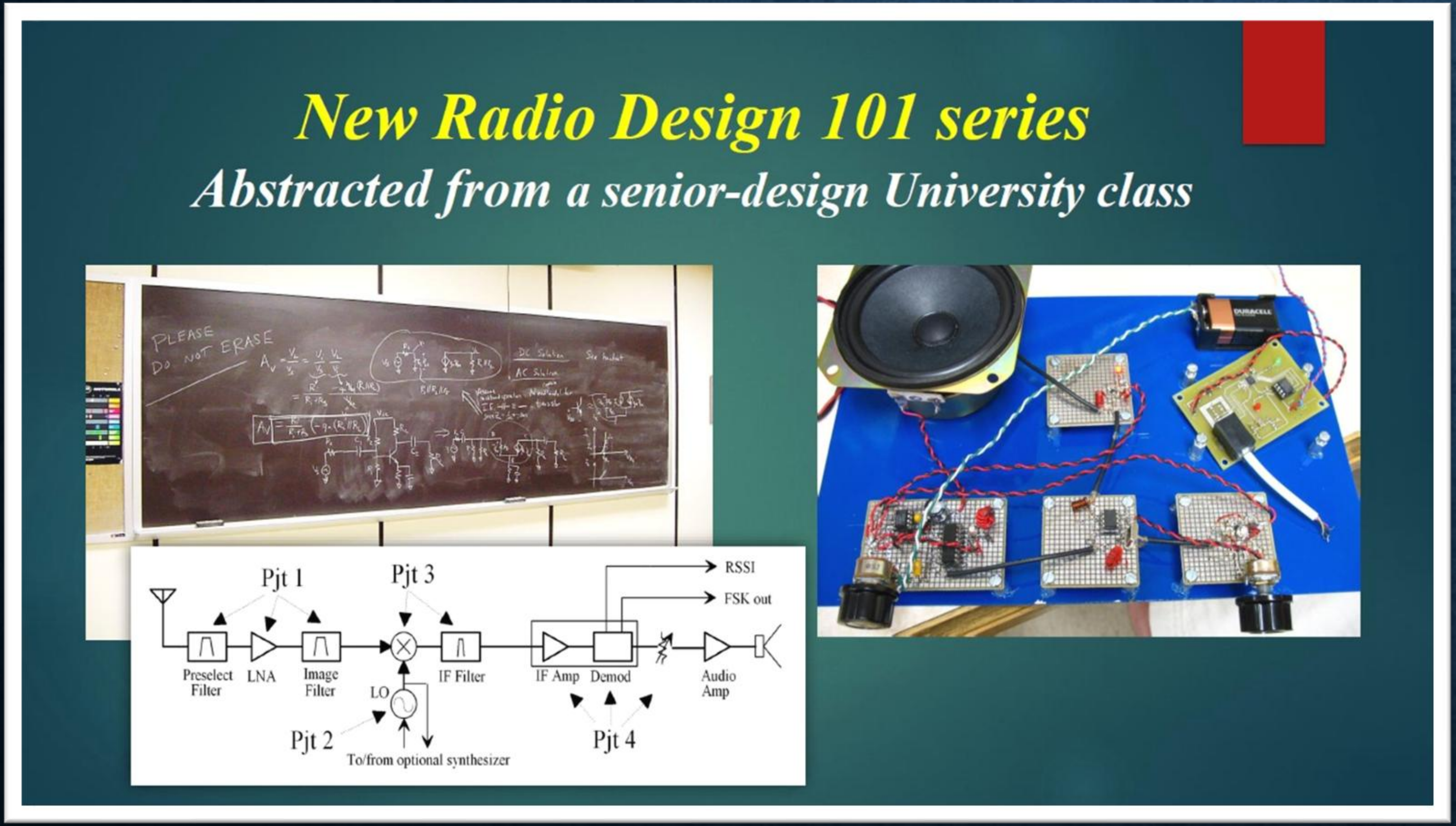
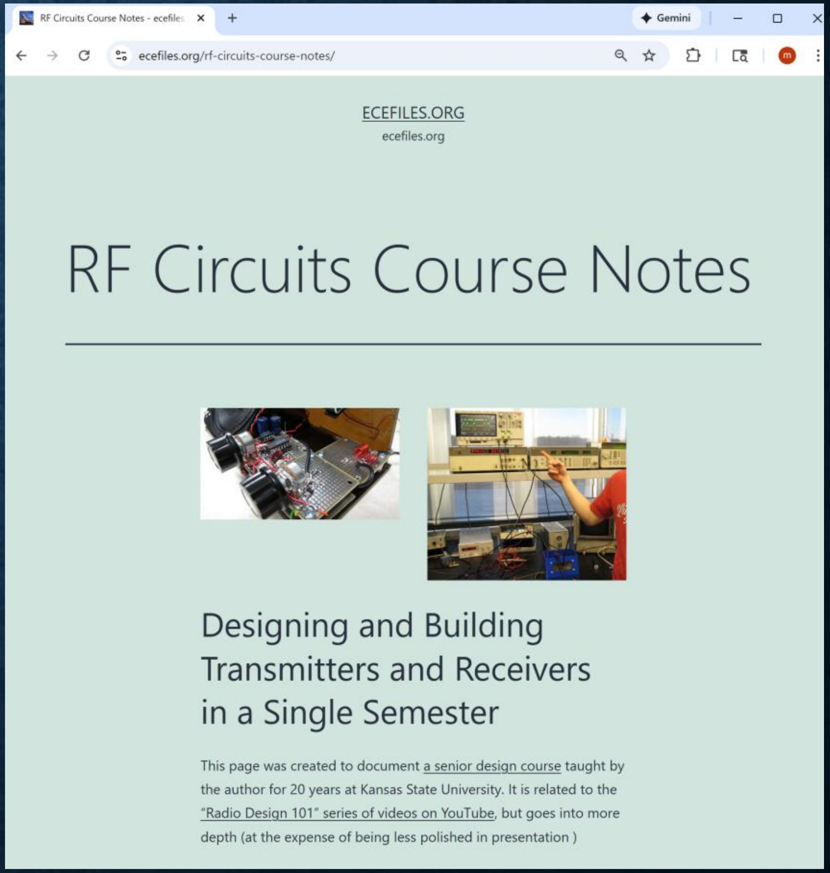
Background

University Class and Radio Design 101 YouTube Course





End of Semester Checkoffs

ECE 662 Final Exam – Fall 2015

Your "Final Exam" will consist of demonstrating and explaining (during the question/answer session of the final) your FM broadcast-band / Purpletooth receiver built from projects 1 through 4. Due date is:

Complete on or before the end of exam week (Friday, Dec 18, 5pm).

There will be a signup sheet in the lab with 60 minute timeslots (20 minutes demo, 30 minutes quiz).

Demonstration

Demonstrating your receiver will include actual "off-the-air" tests showing that you can receive strong and weak FM stations alike. In the demonstration, you must also show that you meet the following specifications using suitable laboratory-generated signals (***with you doing the tests and your instructor observing***). You must also show proficiency in operating the test equipment to verify these specifications.

- Tuning range — 88 MHz to 108 MHz
- Threshold sensitivity — Better than -110 dBm (12 dB SINAD at 98 MHz)
- 30 dB quieting sensitivity — Better than -100 dBm (98 MHz)
- Audio frequency response — 100 Hz to 10 kHz or better (+-3 dB) after accounting for 75us equalization rolloff
- Audio output power — > 2.5 Watts with 75 kHz peak deviation
- Distortion (at 1 Watt) — < 2% THD for 1 kHz sinewave with 75 kHz peak deviation
- Purple-tooth support — FSK and RSSI outputs functional
- Power consumption — < 70 mA at 9V (zero volume)

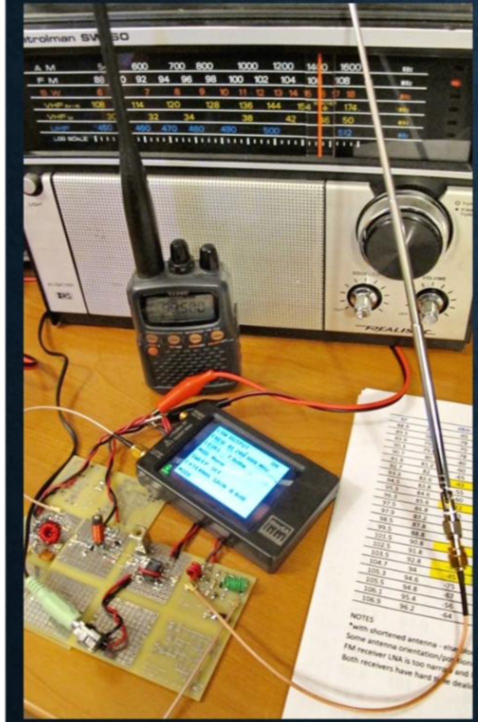
Quiz

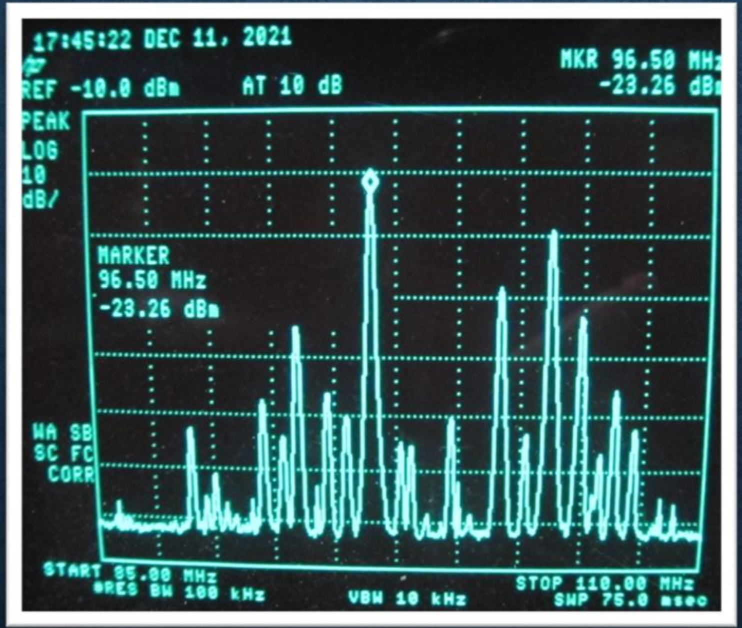
The quiz is designed to check your knowledge of all aspects of radio theory and circuits we have discussed in class. You should bring your project schematics and circuits with you. I will start by asking some basic questions and then increase the difficulty to try to see the depth of your knowledge. The questions may cover material from any of the projects as well as other material presented in class.

DC power	Tuning Range	Thresh Sens	Audio Freq Response	Audio Pout	Distortion	FSK demod	RSSI	Notes
✓ 52mA	✓ 88-108+	✓ -90 dBm / -114 dBm	✓ 2.2 kHz corner	✓ 2.4 Vrms	✓ 0.4%	✓ Working	?	✓ 17 stations, Great Sound
63mA	✓	-102 dBm / -118 dBm	2.3 kHz	✓	<1%	✓		21 stations, Great Sound, [illegible]
✓ 72mA	88-108	-95 / -112	65 - 3.1K	1/2 W	0.7%	◯		LM386; 17 w/20dB atten; 5 unique, Lots of interference
72mA	88+-108	-100 / -112	370 - 4.4K	OK	1.7% ✓	✓ AC coupled?		20+ stations, Very clear :) But serial/small issue
56mA	88-108	-82 / -108	14 - 12K	Low	✓	✓		12ish (distorted [illegible] stations) x2; Demod likely off freq
61mA			Not yet working					Demod problem
69mA	✓	-50 / -88	10Hz - 30Hz	Low	—			5; Very low sound - looking at pot
68mA	88-108	-96 / -108	1K - 16K	✓	1.6%	X		15 stations ✓
No board		Pj 1, 2 accepted before						
53mA	88-108	-90 / -110	500 - 5.9K	✓	1.2%	✓		21 stations
			Not yet working					
57mA		Pj 1 working?	Pj 2 oscillates, but low output		Pj 3?	Pj 4 X		No 6V regulator; No sound, Osc not large
—	92-108	-70 dBm	10 - 3.X K	—	~10%			No hiss, Distorted audio, Very weak audio, Osc issue
52mA	✓	-100 / -112	30 - 2.5K	✓	✓	✓		20 Stations good audio
—	88-108	-95 / -116	30 - 2.9	✓	✓	✓		20 Sounds good!
74mA	90-108	-90 / -106	25 - 2.9	✓	✓	✓		16 Sounds good

Radio Design 101 Testing

See Epilogues 1 - 3

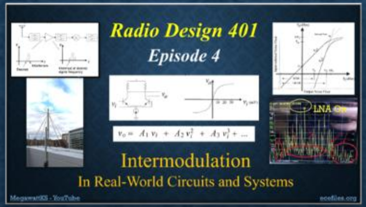


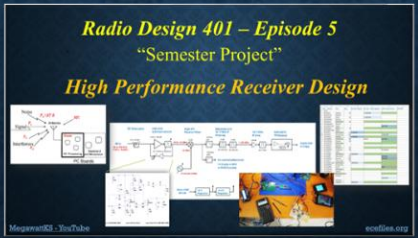


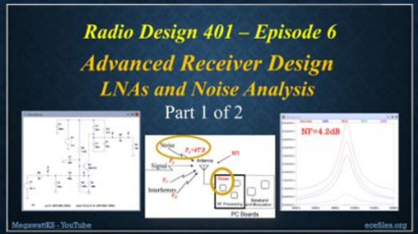
RF	LO	dBm	FMrx	FMrxFixed	VR120	VR120atten	Old Radio
88.9	78.2	-65				yes	yes
89.5	78.8	-78			yes		yes
89.9	79.2	-70	quiet	quiet	yes	yes	yes
90.3	79.6	-78		quiet		yes	yes
90.7	80	-80					yes
91.9	81.2	-60	quiet	good	yes	yes	yes
92.7	82	-65		good		yes	yes
93.3	82.6	-43	excellent	excellent	yes	yes	yes
94.5	83.8	-55	quiet	good	yes	yes	yes
95.3	84.6	-60	quiet	good	yes	yes	yes
96.3	85.6	-22	excellent	excellent	yes	yes	yes
97.5	86.8	-65		good		yes	yes
97.9	87.2	-67	quiet	quiet	yes	yes	yes
98.5	87.8	-80					?
99.5	88.8	-61	?	excellent*		yes	yes
101.5	90.8	-40	excellent	excellent	yes	yes	yes
102.5	91.8	-62					yes
103.5	92.8	-30	excellent	excellent	yes	yes	yes
104.7	94	-45	good	excellent	yes	yes	yes
105.3	94.6	-75					yes
105.5	94.8	-67			yes	yes	yes
106.1	95.4	-56		very quiet	yes	yes	yes
106.9	96.2	-64			yes	yes	yes

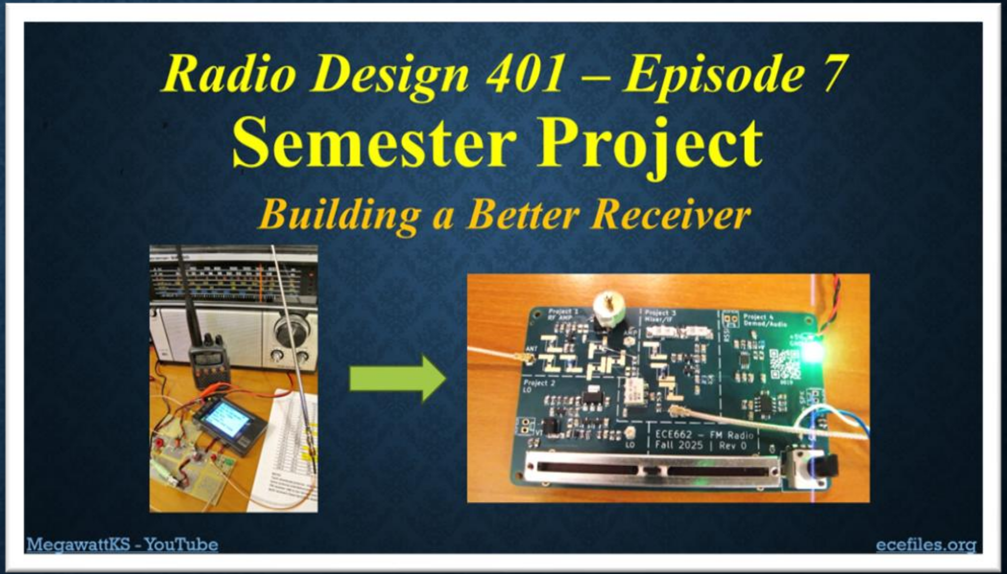
NOTES
*with shortened antenna - else blocked by 96.3
Some antenna optimization done to get best signal for all cases

Radio Design 401 - Prior Episodes









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- Signal Environments
- Background and Prior Episodes
- ➡ LNA Design
- Classic Lab Testing (Gain, NF, P1dB, Pdc)
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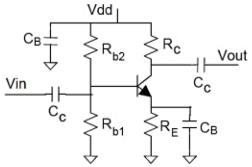
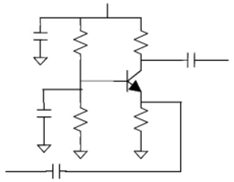
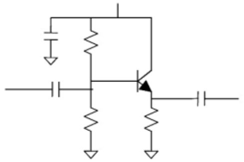
Amplifier Design Basics

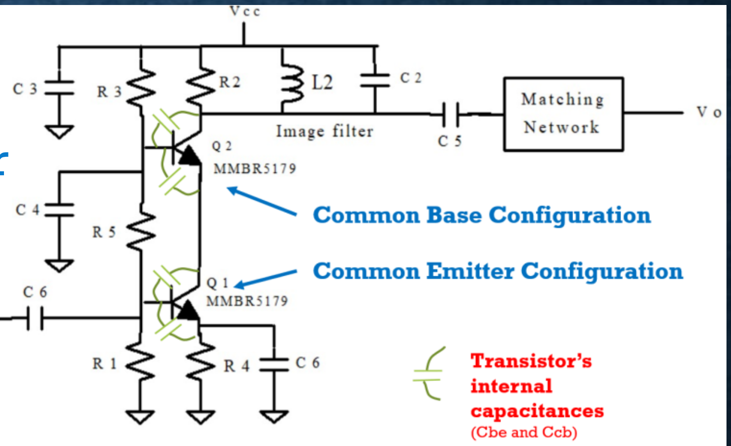
See Radio Design 101 (esp. Episode 3)

BJT Amplifier Configurations

Configuration	Representative Circuit	Approx. Formulas	$A_{Vno\text{-}load}$	R_i	R_o
Common Emitter		$A_{Vno\text{-}load} = -g_m(R_c \| r_o)$; $R_i = r_\pi \| R_{b1} \| R_{b2}$ where $r_\pi = h_{fe}/g_m$; $R_0 = R_c \| r_o$	High	Med	Med
Common Base		$A_{Vno\text{-}load} = +g_m(R_c \| r_o)$; $R_i = 1/g_m \| R_E \| r_\pi$; $R_o = R_c \| r_o$	High	Low	Med
Common Collector (Emitter follower)		$A_{Vno\text{-}load} \approx 1$; $R_i = R_{b1} \| R_{b2} \| r_\pi(1+g_mR_E)$*; $R_o = 1/g_m$**	Unity	High	Low

* Assumes unloaded output
** Assumes low source R

Cascode Amplifier



UHF Fully Integrated LNA

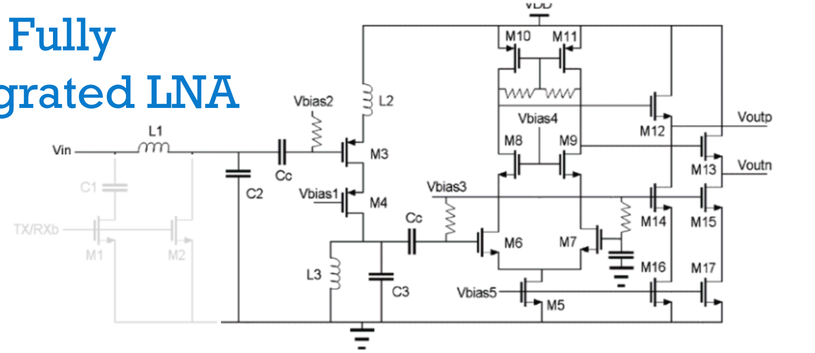


Fig. 23. Schematic diagram of LNA with integrated T/R switch circuits.

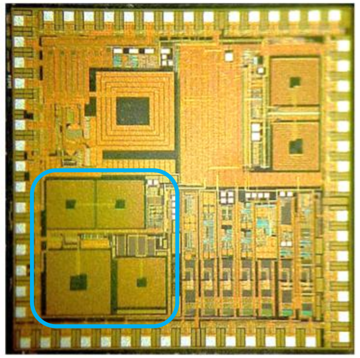


Fig. 39. Die photo of fully integrated single-chip 100-mW transceiver.

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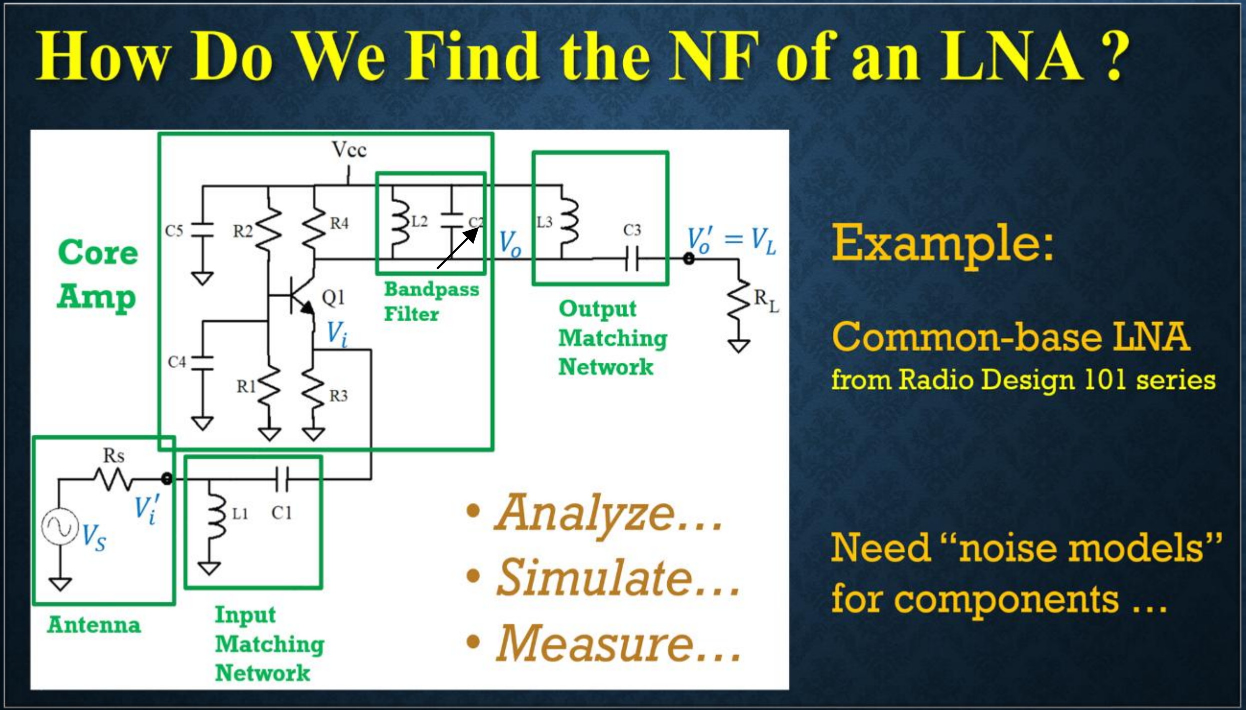
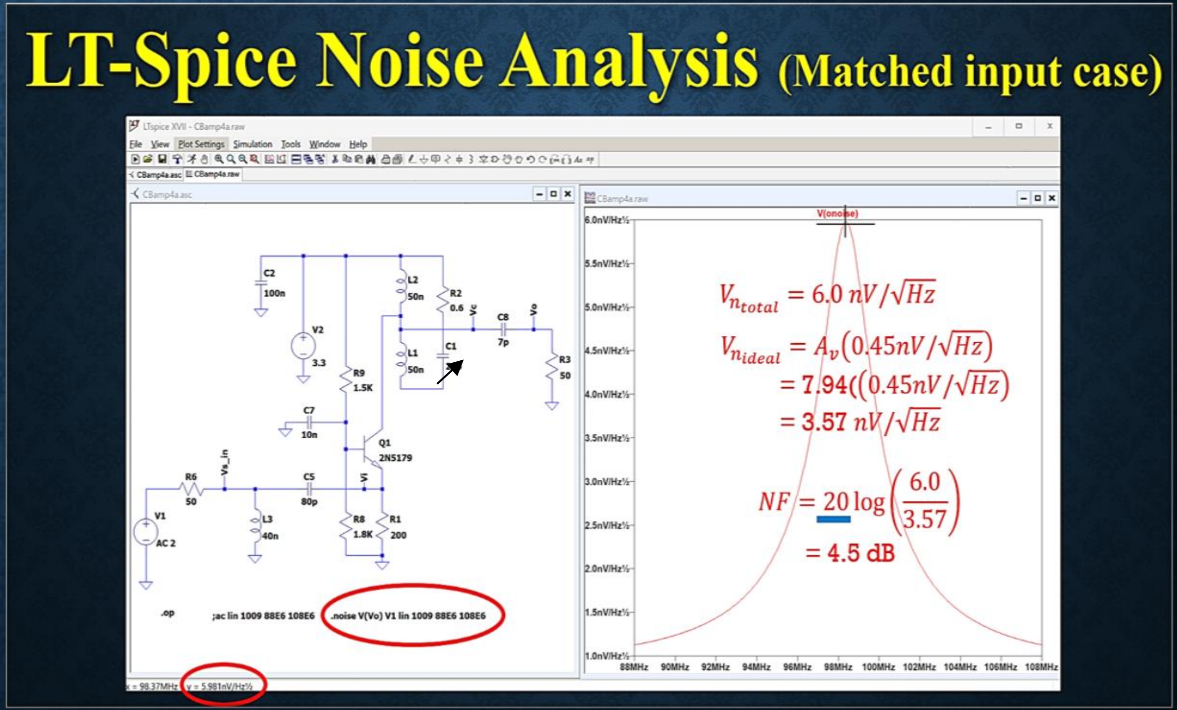
Common-Base LNA Examples

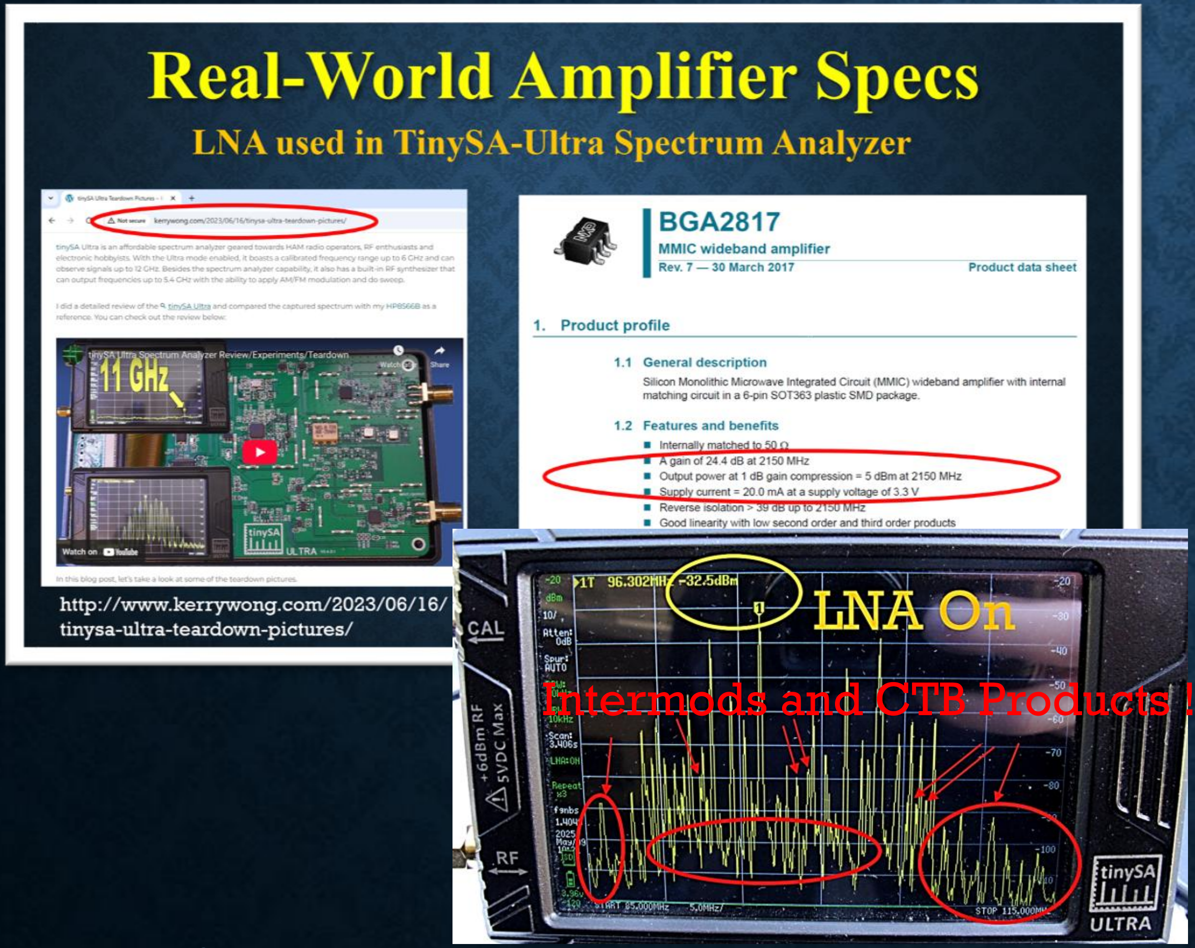
See Radio Design 401, Episode 6

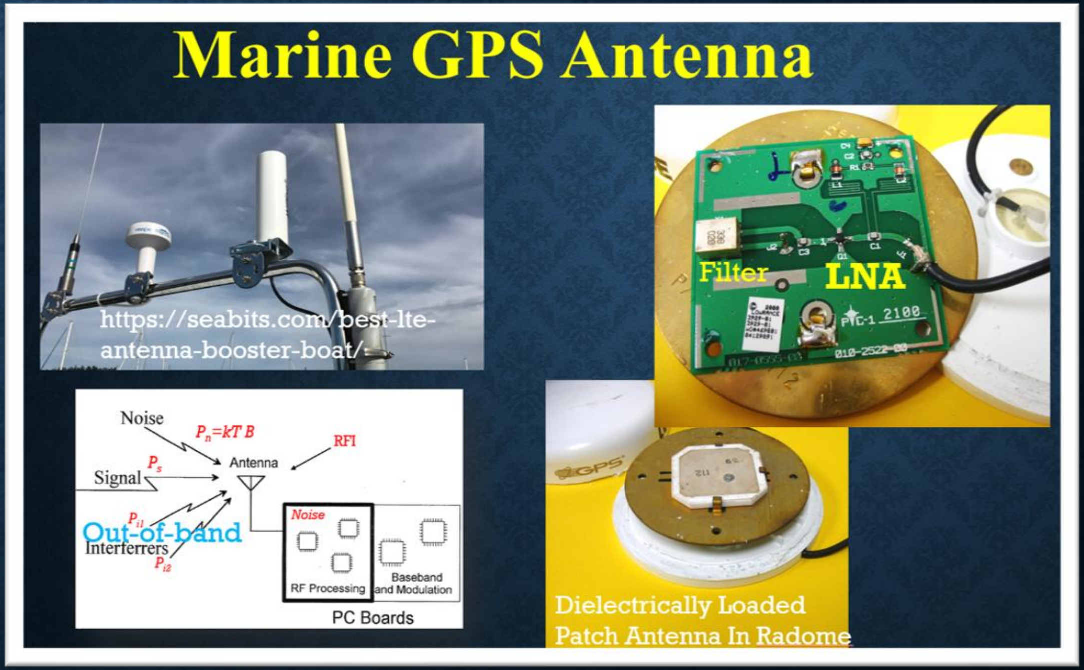




Commercial LNA Examples

See RD401, Episodes 4 and 6





Ideal Low Power Receiver

Reduce Preselect Filter bandwidth to signal bandwidth !

See Episode 1

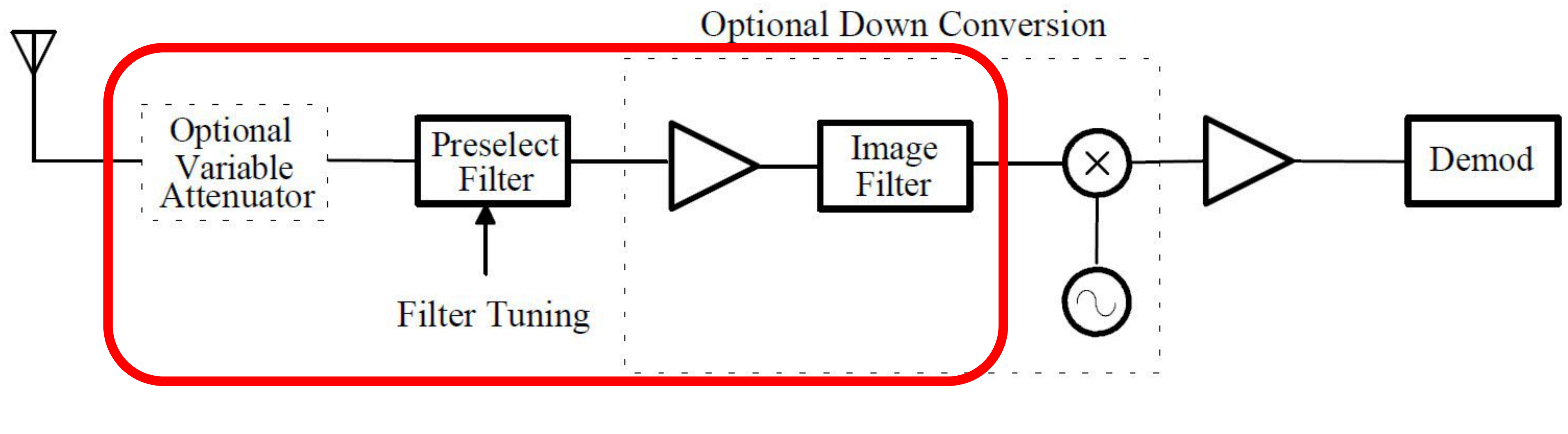


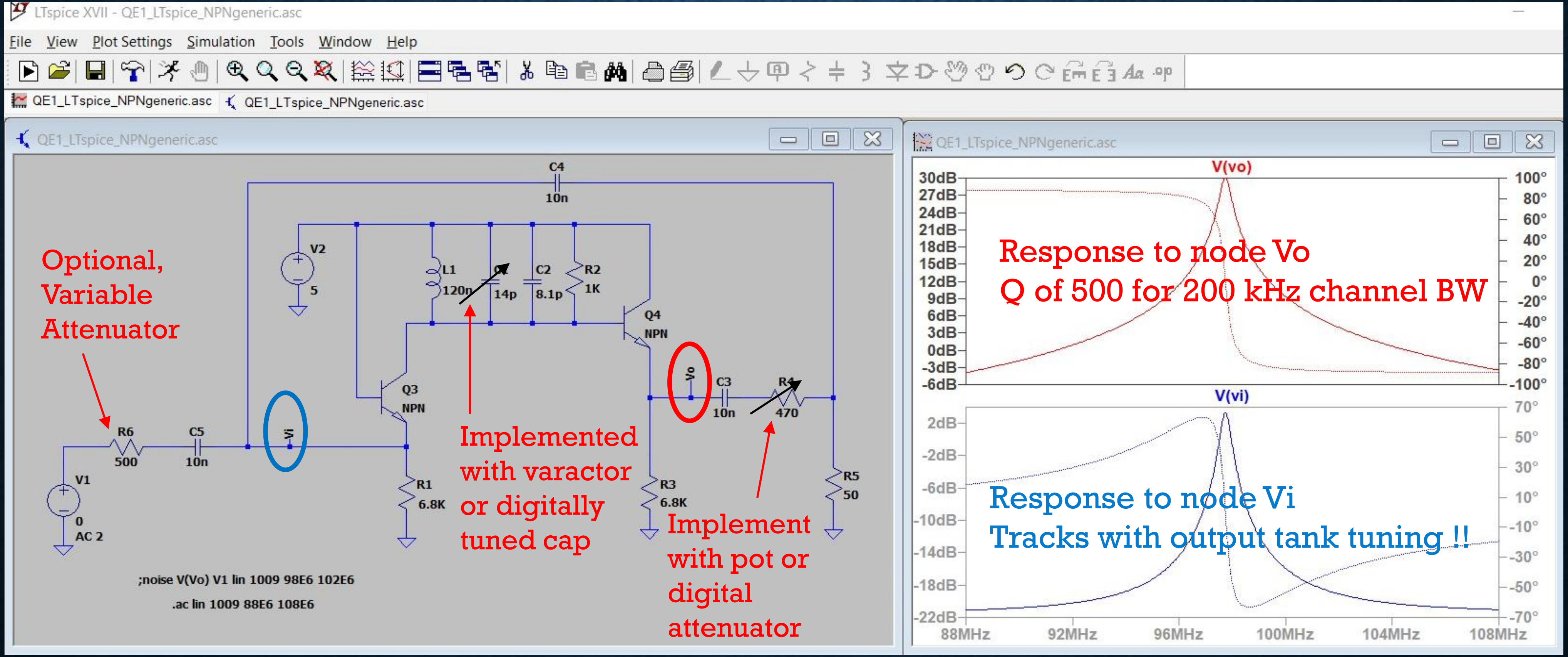
Figure 4.16: Ideal receiver architecture.

From: "Design of Integrated, Low Power, Radio Receivers in BiCMOS Technologies", PhD dissertation, Virginia Tech, 1995

Q-enhanced LNA 1st Prototype

Provides narrow BW and tracking-preselect filtering

See Episode 1

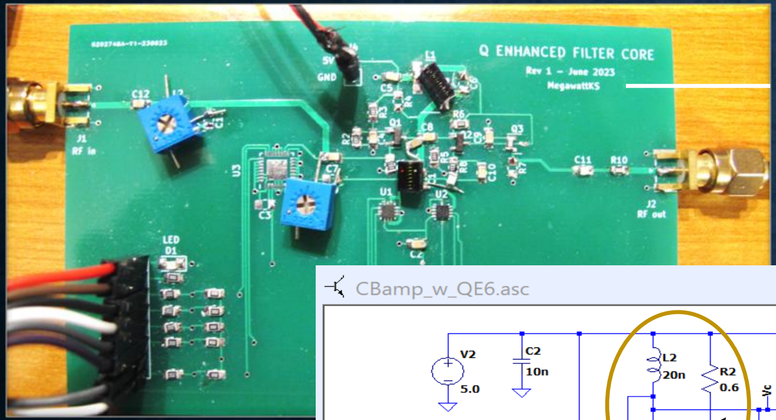


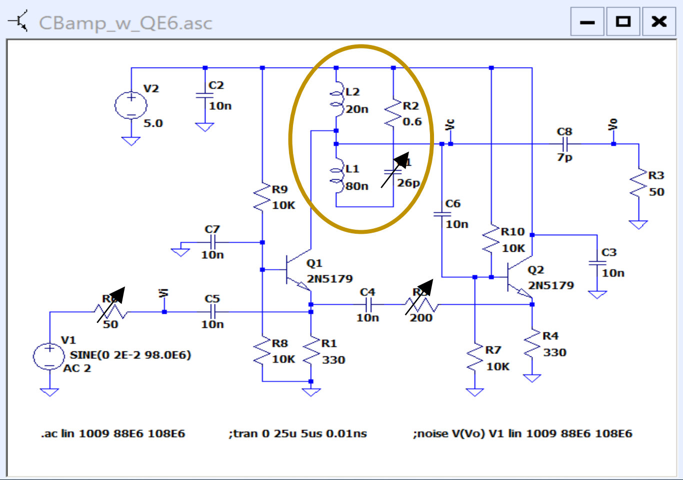
1.2 mA at 5 V (6 mW)

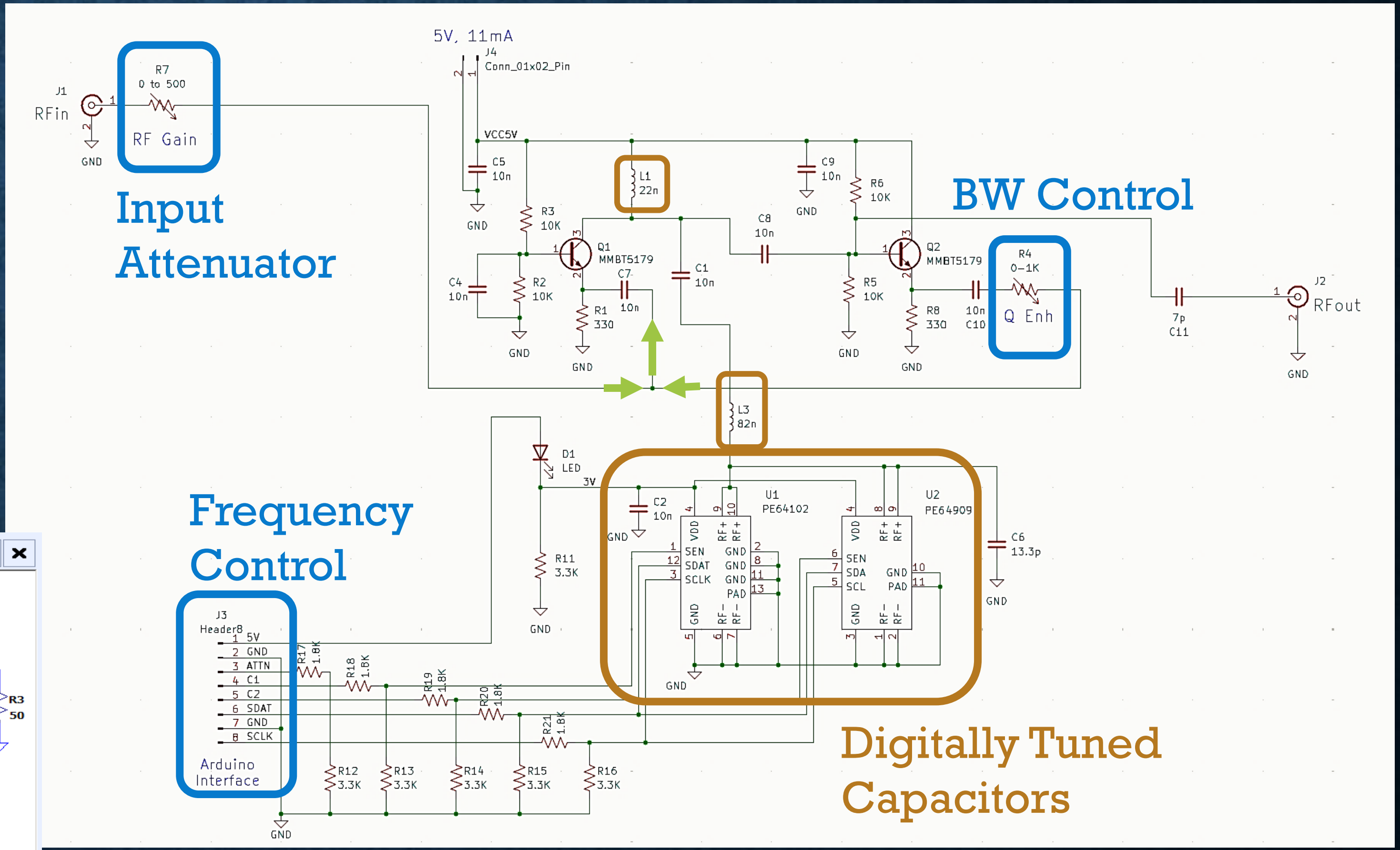
Latest Q-enhanced LNA

Uses original Rev 1 board and firmware, but…

Modified for lower gain using split-L tank circuit, and higher Pdc







11 mA at 5 V (55 mW)

Presentation Outline

Signal Environments

Background and Prior Episodes

LNA Design

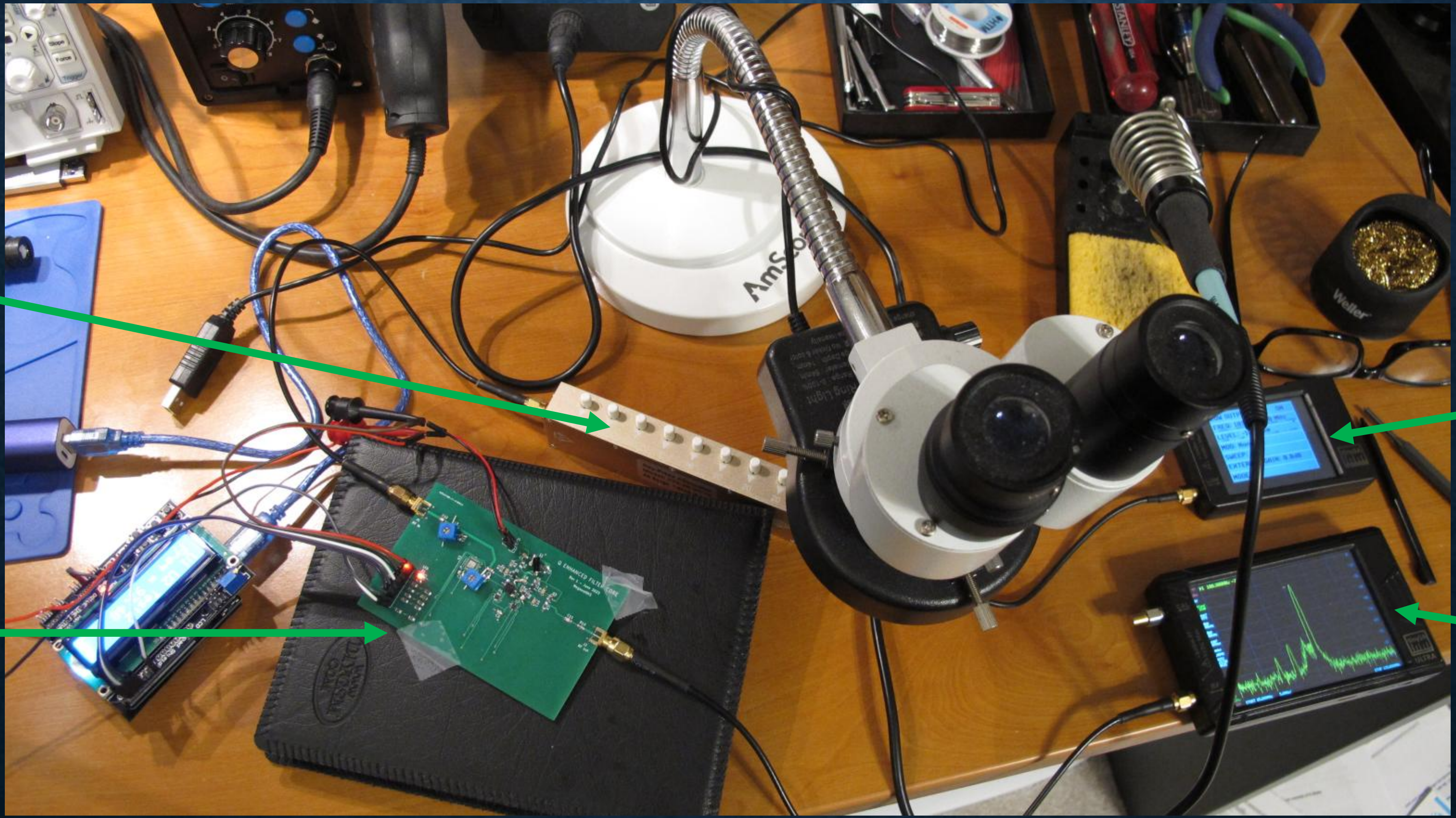
Classic Lab Testing (Gain, NF, P1dB, Pdc)

Real-World Test Results

Conclusions and Future Directions

Lab Testing Setup

Kinda Messy …



Lab Test Results

(with filter BW adjusted to 200 kHz)

Pdc = 11 mA @ 5V (55mW)

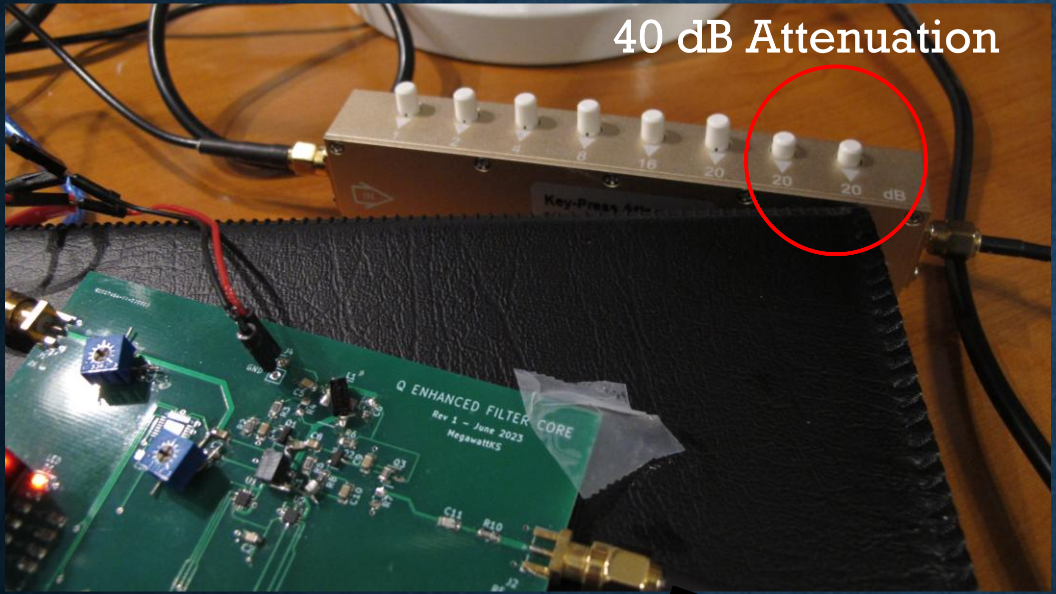
G = 18 to 22 dB (22 dB during NF checks at 109 MHz)

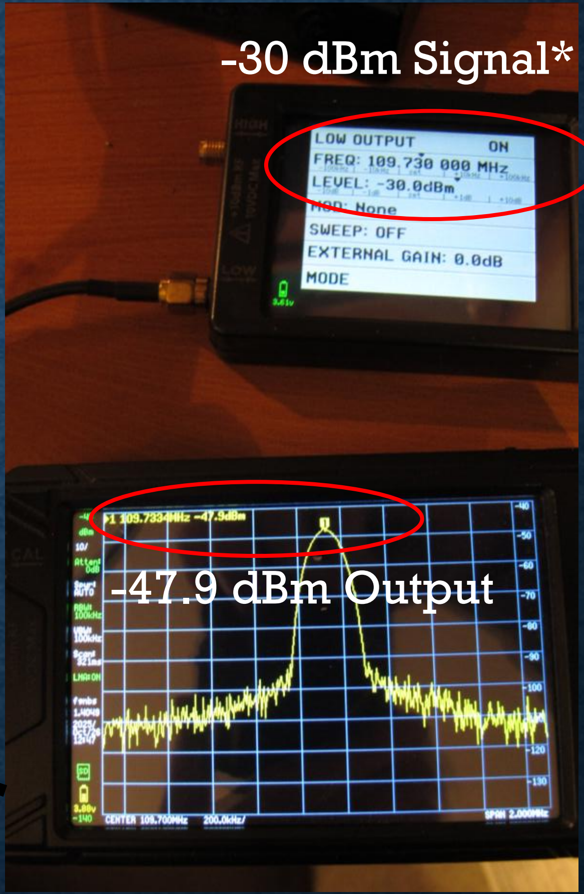
NF = approximately 5 dB

P_{i1dB} = -30 dBm on-channel

P_{i1dB} = -10 dBm at 2 MHz above

Insertion Gain Testing



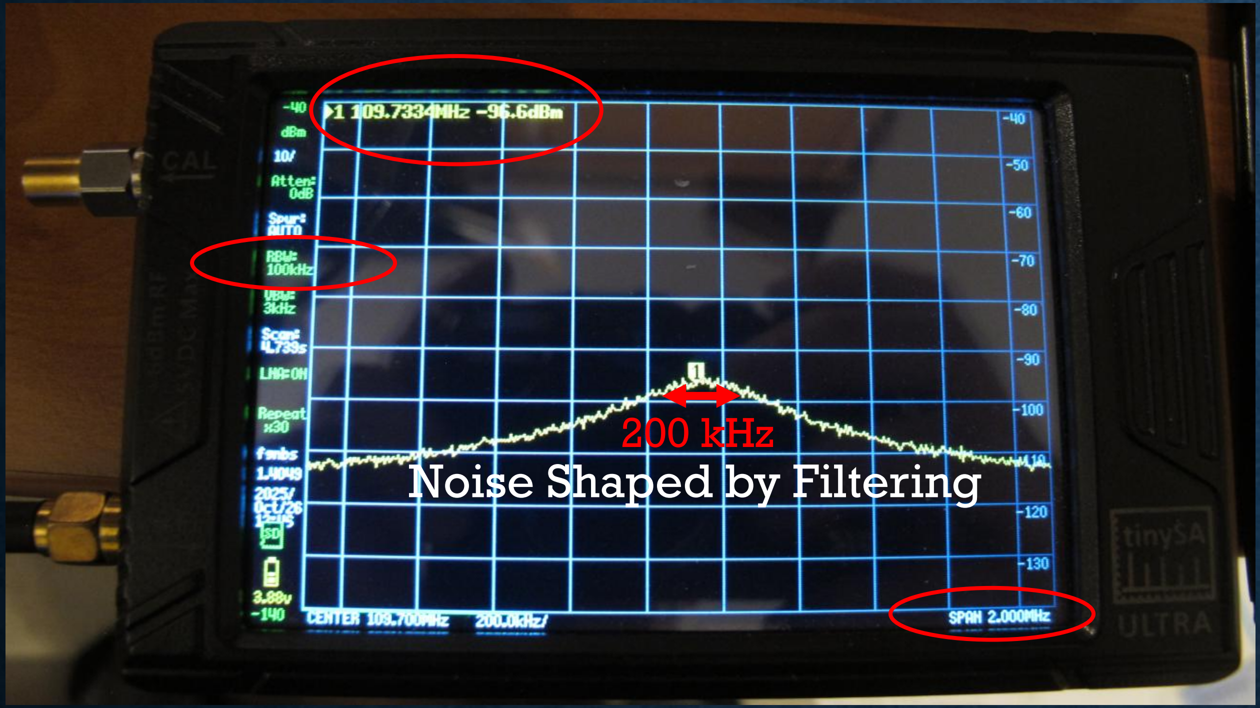


* Level confirmed in testing

Gain = - 47.9 dBm - (-30 dBm - 40 dB)
= 22.1 dB @ 109.73 MHz
(with filter BW adjusted to about 200 kHz)

Output Noise and NF

(with input terminated in 50 Ohms)



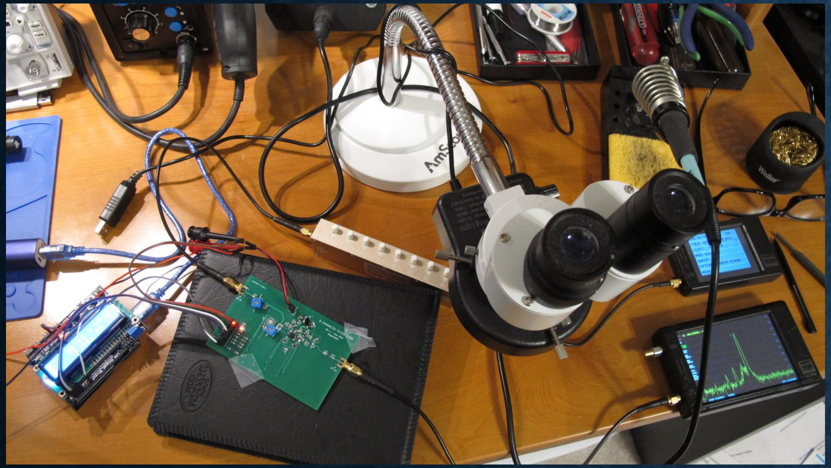
Theoretical Output Noise
in 100 kHz RBW
= -174 dBm + 10 log(100k) + Gain
= -174 + 50 + 22.1
= -101.9 dBm

Measured Output Noise
= -96.6 dBm

NF = -96.6 dBm – (-101.9 dBm)
= 5.3 dB
(+/- a dB or two ;-)

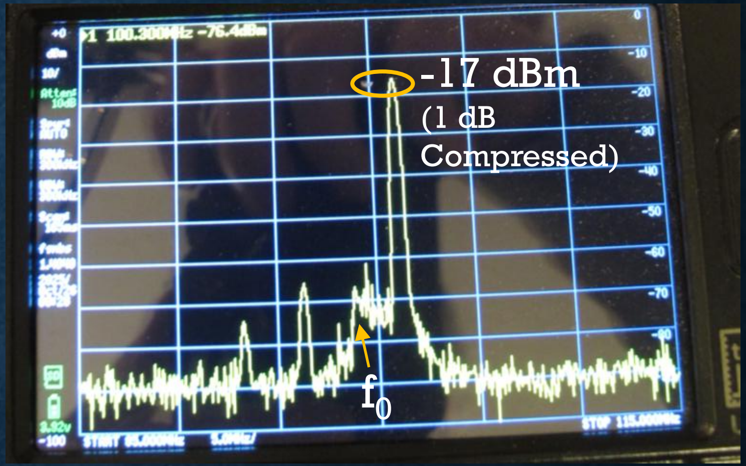
P_{1dB} Input Compression Point(s)

(with filter centered at 99.2 MHz and BW adjusted to 200 kHz)



Step attenuator used to find P1dB
(if 4dB attenuation removed and output increases by only 3dB, we're there)

Tests run at 99. 2 MHz and at 101.2 MHz (2 MHz above f_0)



-17 dBm output with -10 dBm signal at 2 MHz above f_0.
Expect -26 dB gain from filter rolloff
(-10 dBm + 20 dB – 26 dB = -16 dBm ☺)

P_{i1dB} = -30 dBm on-channel

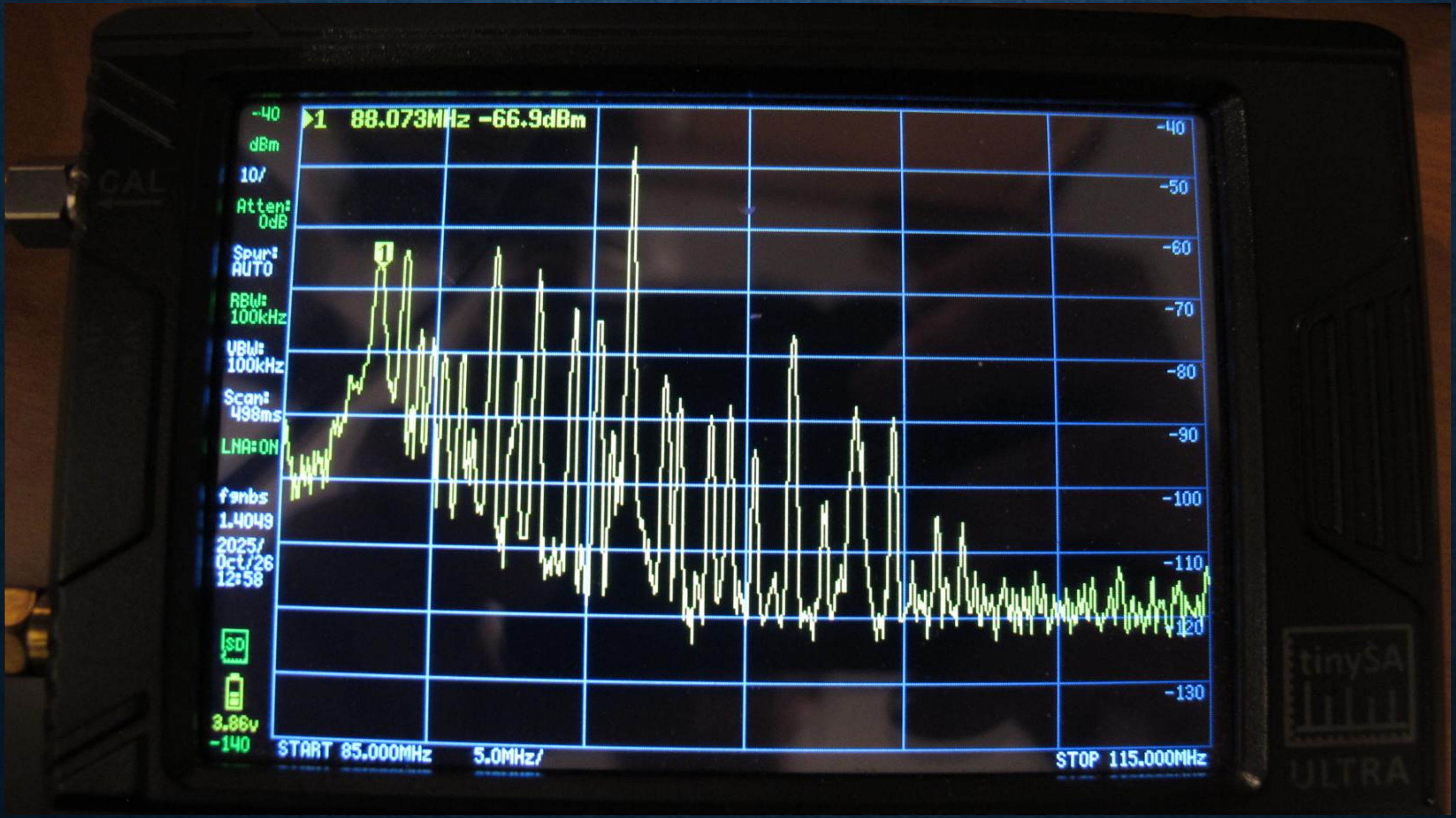
P_{i1dB} = -10 dBm at 2 MHz offset

Presentation Outline

- Signal Environments
- Background and Prior Episodes
- LNA Design
- Classic Lab Testing (Gain, NF, P1dB, Pdc)
- ➡ Real-World Test Results
- Conclusions and Future Directions

Off the Air (Indoor) Test

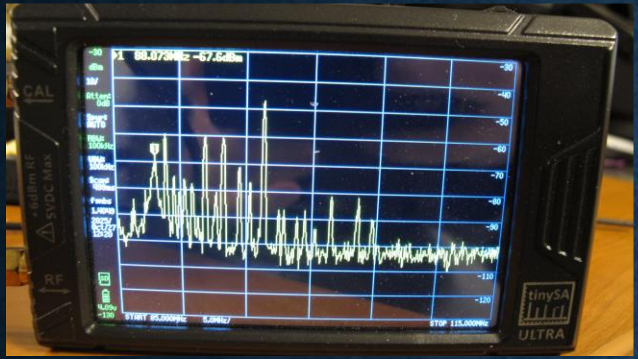
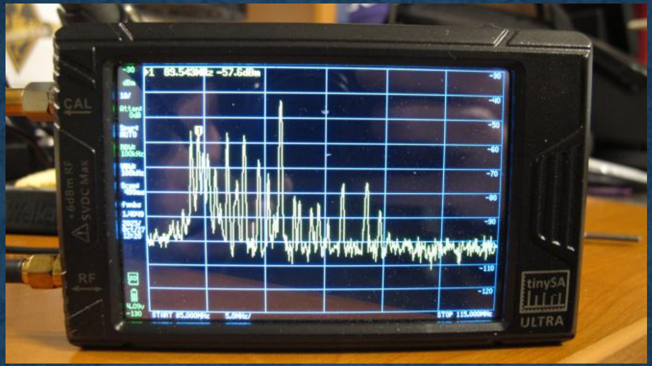
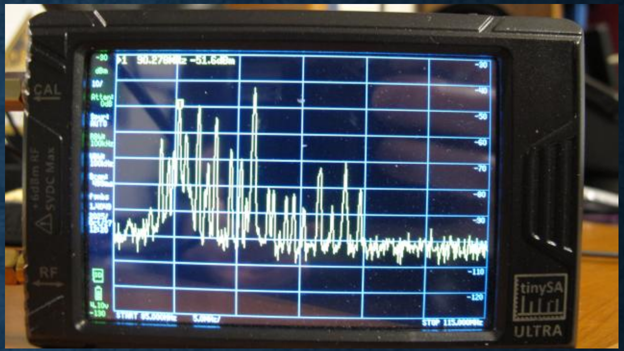
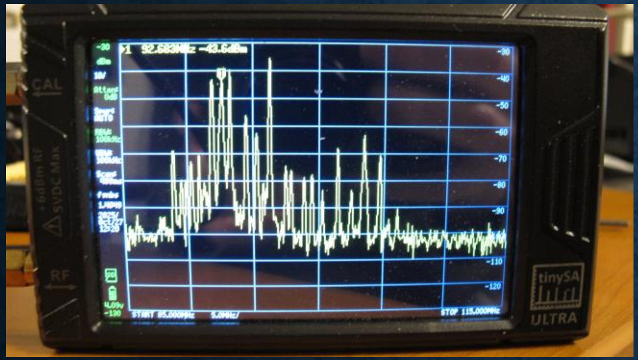
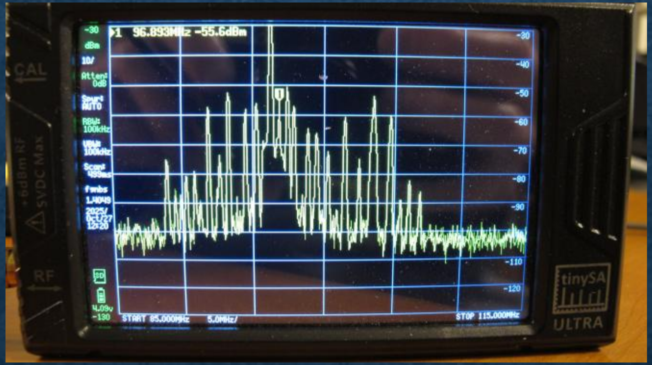
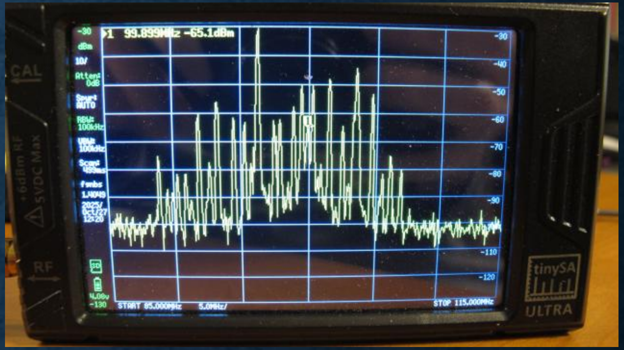
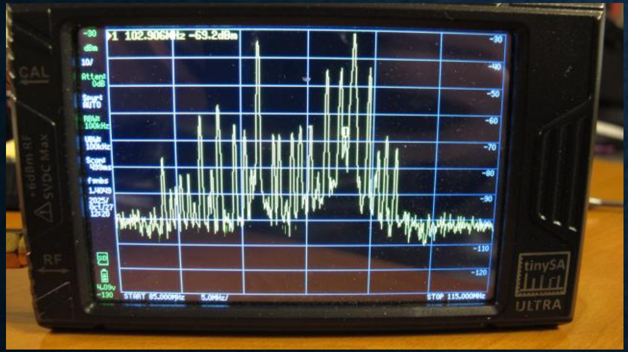
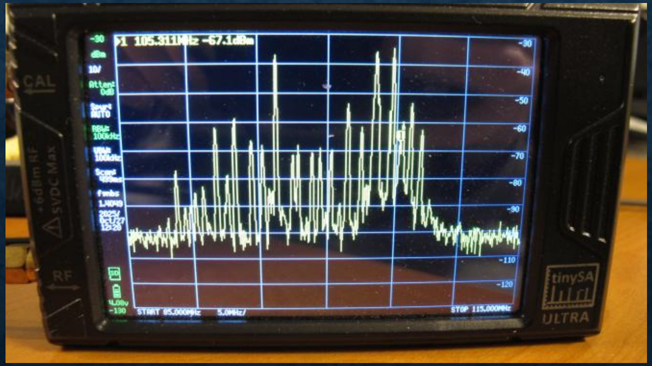
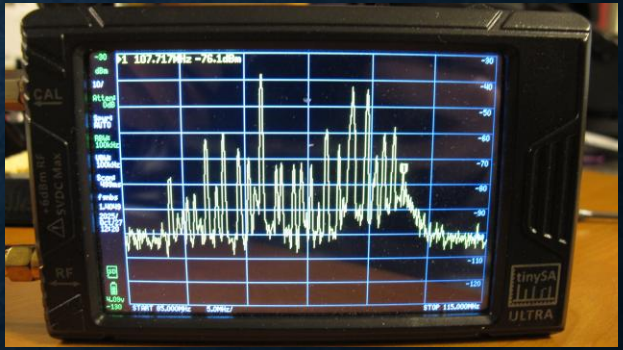
(with filter centered at 88.1 MHz and BW adjusted to 200 kHz)



MegawattKS - YouTube

ecefiles.org

Tuning Through the Band

Testing (in Local Park)

Testing (at the Top of the World)

Presentation Outline

Signal Environments

Background and Prior Episodes

LNA Design

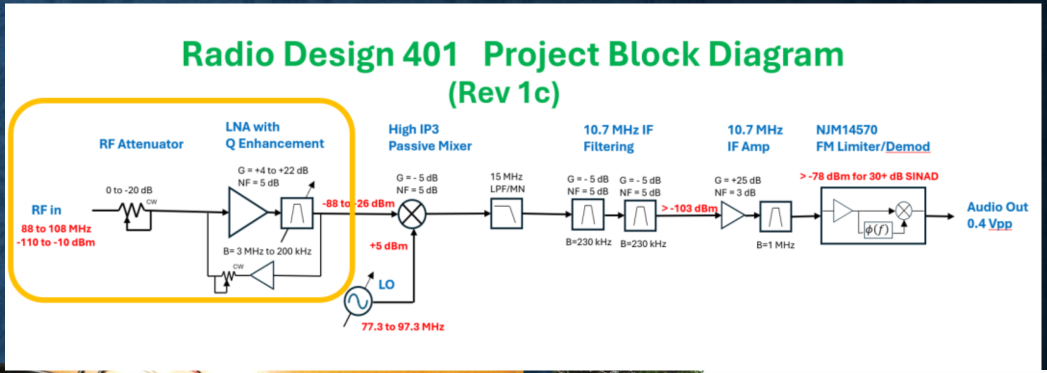
Classic Lab Testing (Gain, NF, P1dB, Pdc)

Real-World Test Results

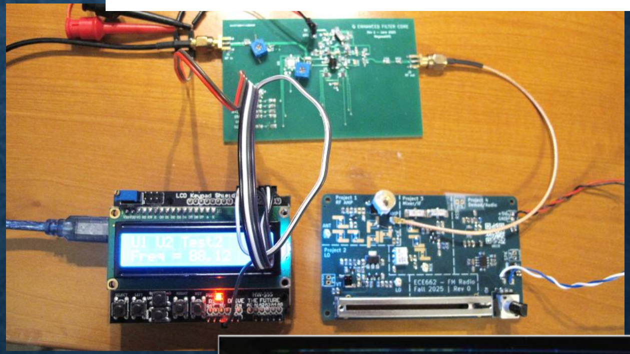
Conclusions and Future Directions

Conclusions

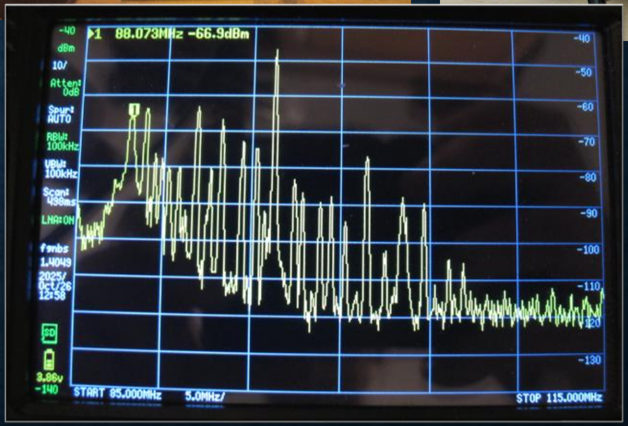
Radio Design 401 receiver with QE LNA meets or exceeds performance of the best commercial receivers in automobiles



Narrowband preselect filtering allows operation in harsh, crowded spectrum environment at 1/10th the power



Field tests in real-world environments validate the "white paper" theory from episode 1 ☺



Future Directions

Radio Design 401 receiver with QE LNA approaches the realization of an Ideal Receiver ☺

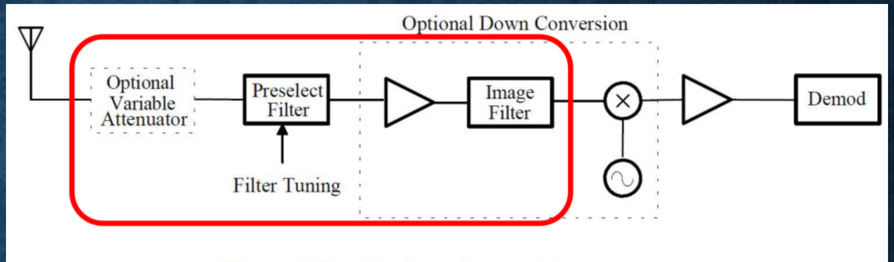
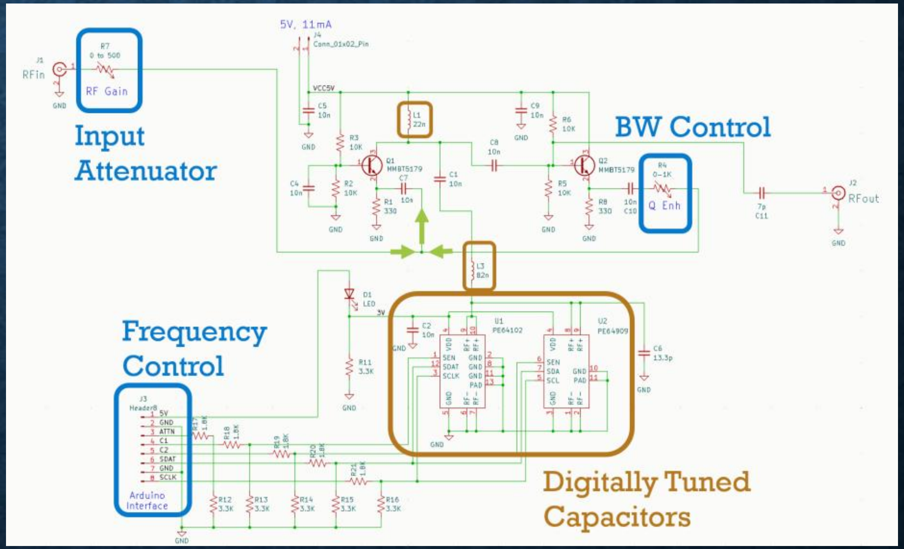
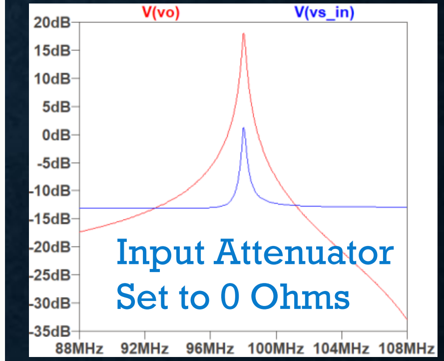


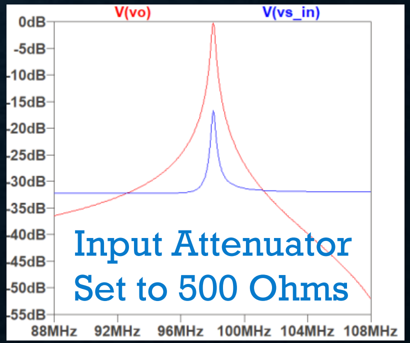
Figure 4.16: Ideal receiver architecture.

Still requires attenuator for very strong signals due to single-pole bandpass response and limited preselect-filter off-channel attenuation





Future work on additional filtering before amplifier could improve results further



The End …

Thanks For Watching !