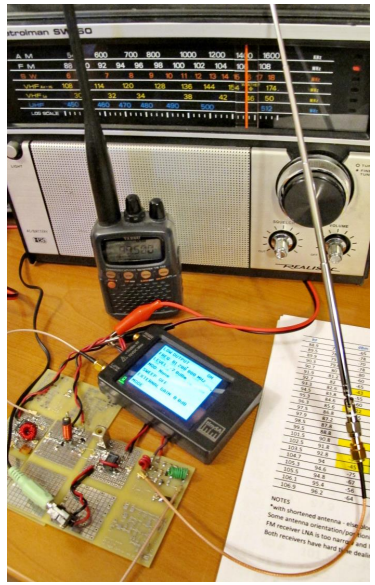
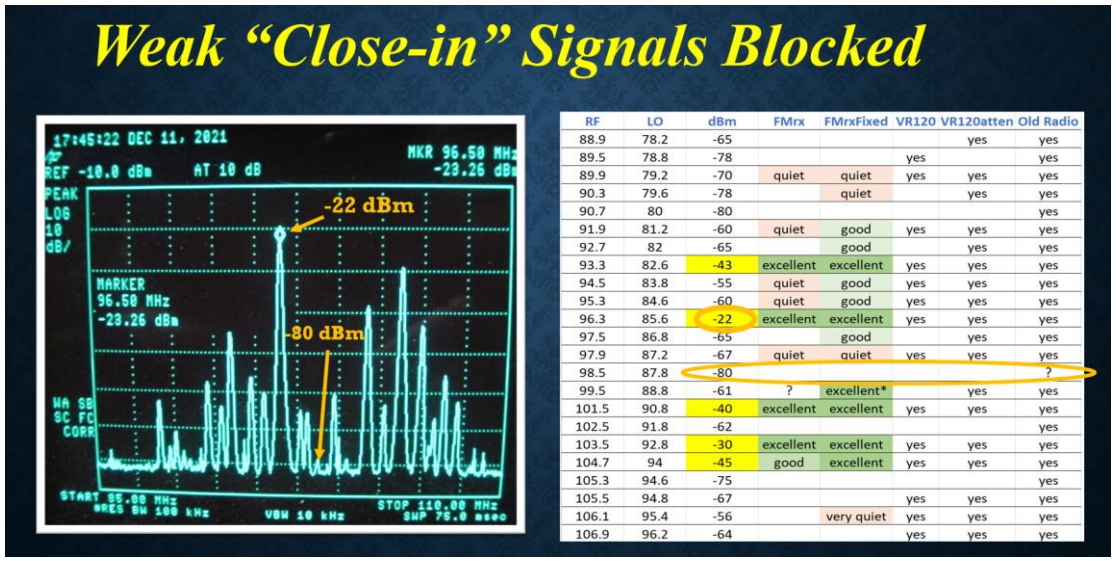
Radio Design 101 Epilogue 1 - Receiver Performance

Slides downloaded from: https://ecefiles.org/rf-design/
Companion video at: https://www.youtube.com/watch?v=pRsXqeU9Vtw

In this Epilogue to the Radio Design 101 series, we look at receiver performance - using our own design as well as commercial radios to demonstrate design challenges. Strong interfering signals are shown to be a large problem and various techniques for dealing with them are illustrated.





RF	LO	dBm	FMrx	FMrxFixed	VR120	VR120atten	Old Radio
88.9	78.2	-65				yes	yes
89.5	78.8	-78			yes		yes
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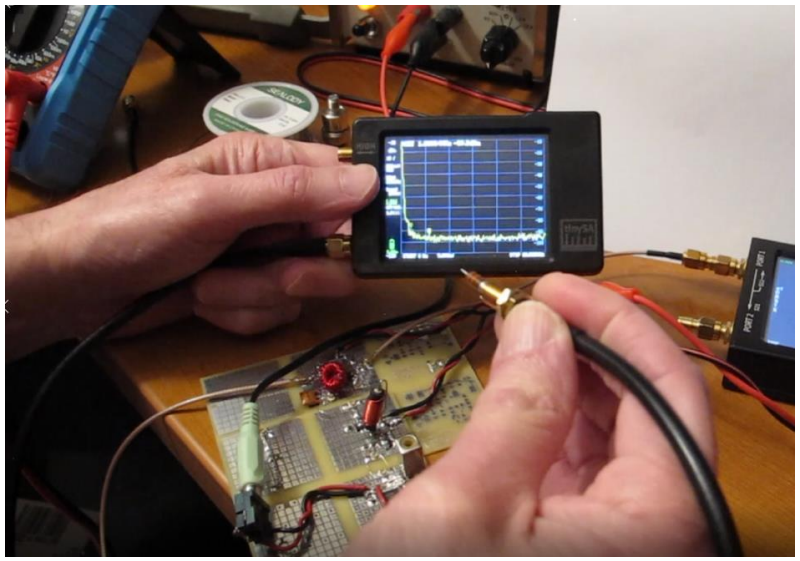
90.3	79.6	-78		quiet		yes	yes
90.7	80	-80					yes
91.9	81.2	-60	quiet	good	yes	yes	yes
92.7	82	-65		good		yes	yes
93.3	82.6	-43	excellent	excellent	yes	yes	yes
94.5	83.8	-55	quiet	good	yes	yes	yes
95.3	84.6	-60	quiet	good	yes	yes	yes
96.3	85.6	-22	excellent	excellent	yes	yes	yes
97.5	86.8	-65		good		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

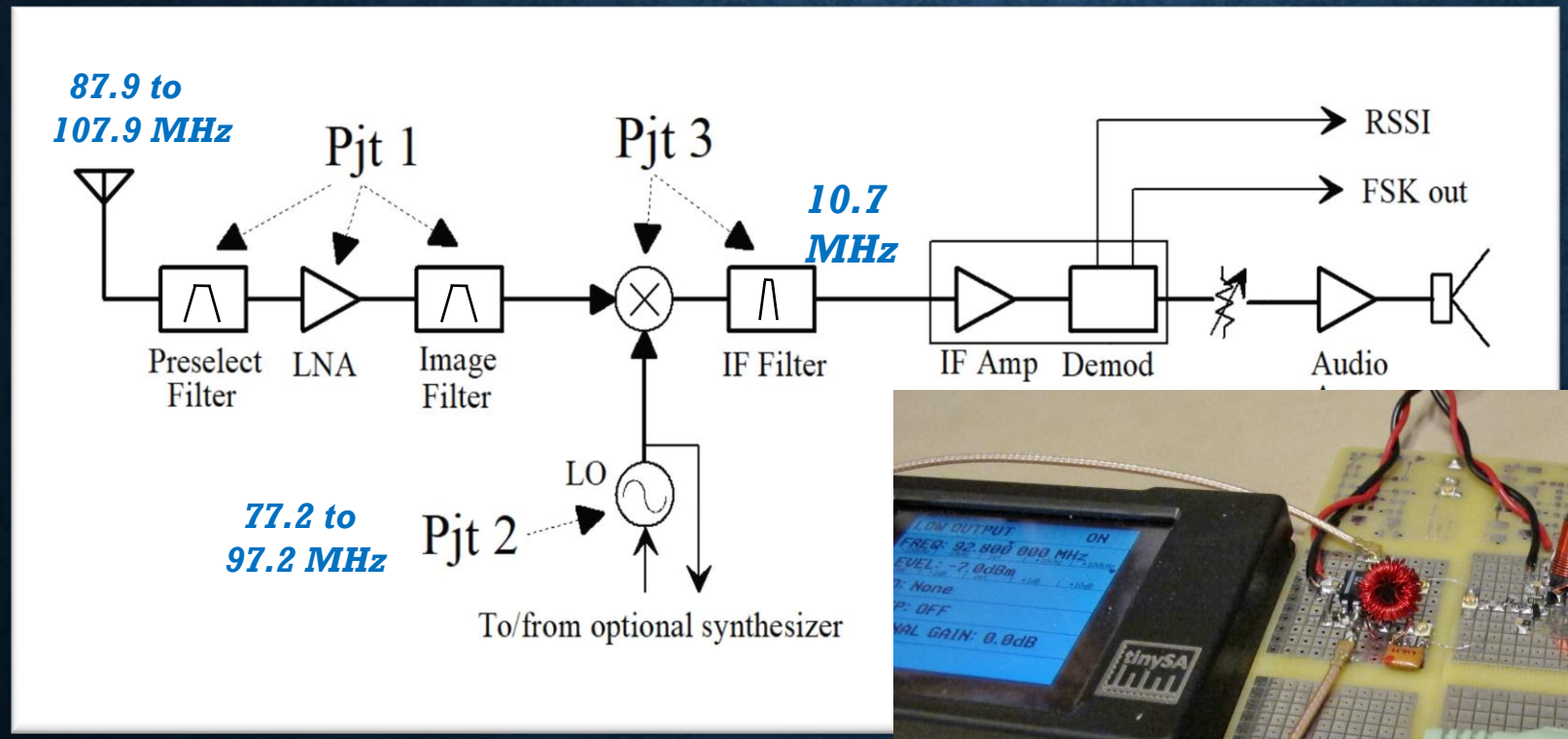


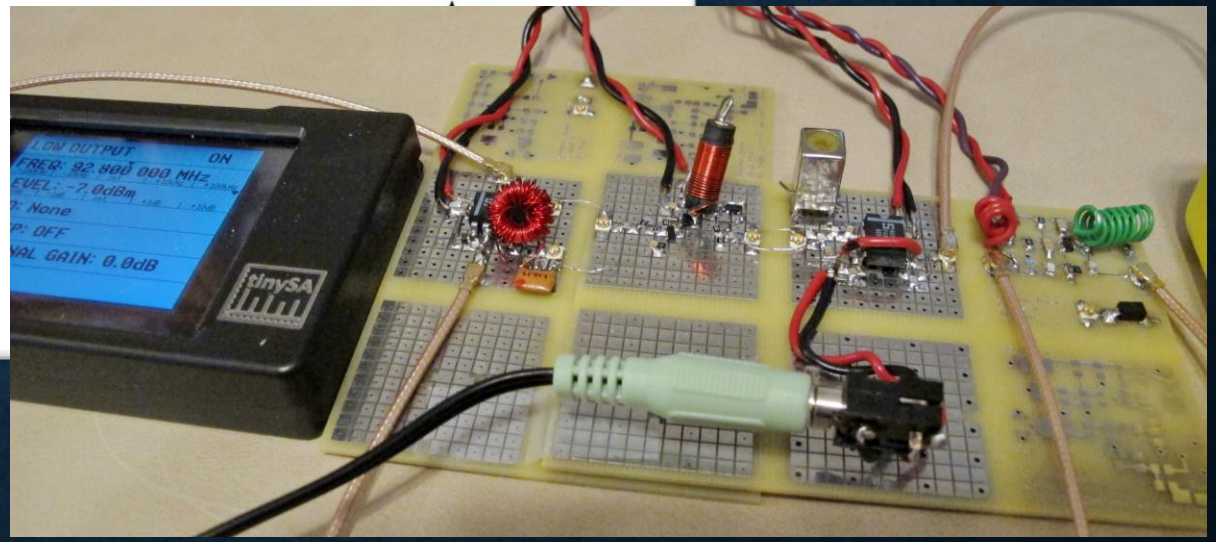
Radio Design 101

Epilogue 1

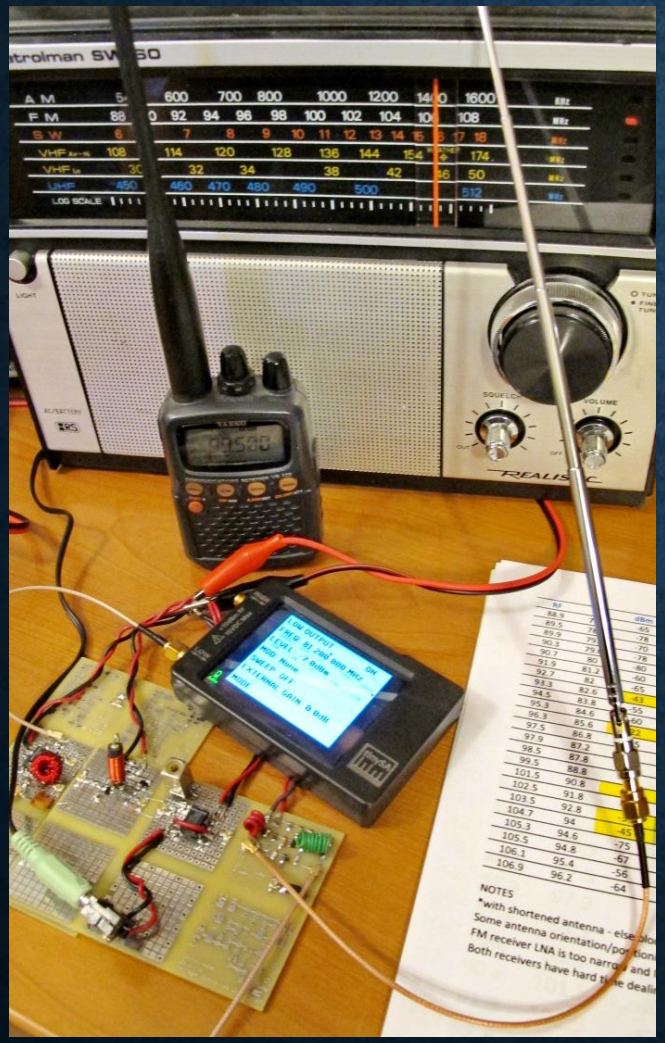
Receiver Performance

FM Receiver from Radio Design 101





Verses Commercial Radios …



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105.3	94.6	-75					yes
105.5	94.8	-67			yes	yes	yes
106.1	95.4	-56		very quiet	yes	yes	yes
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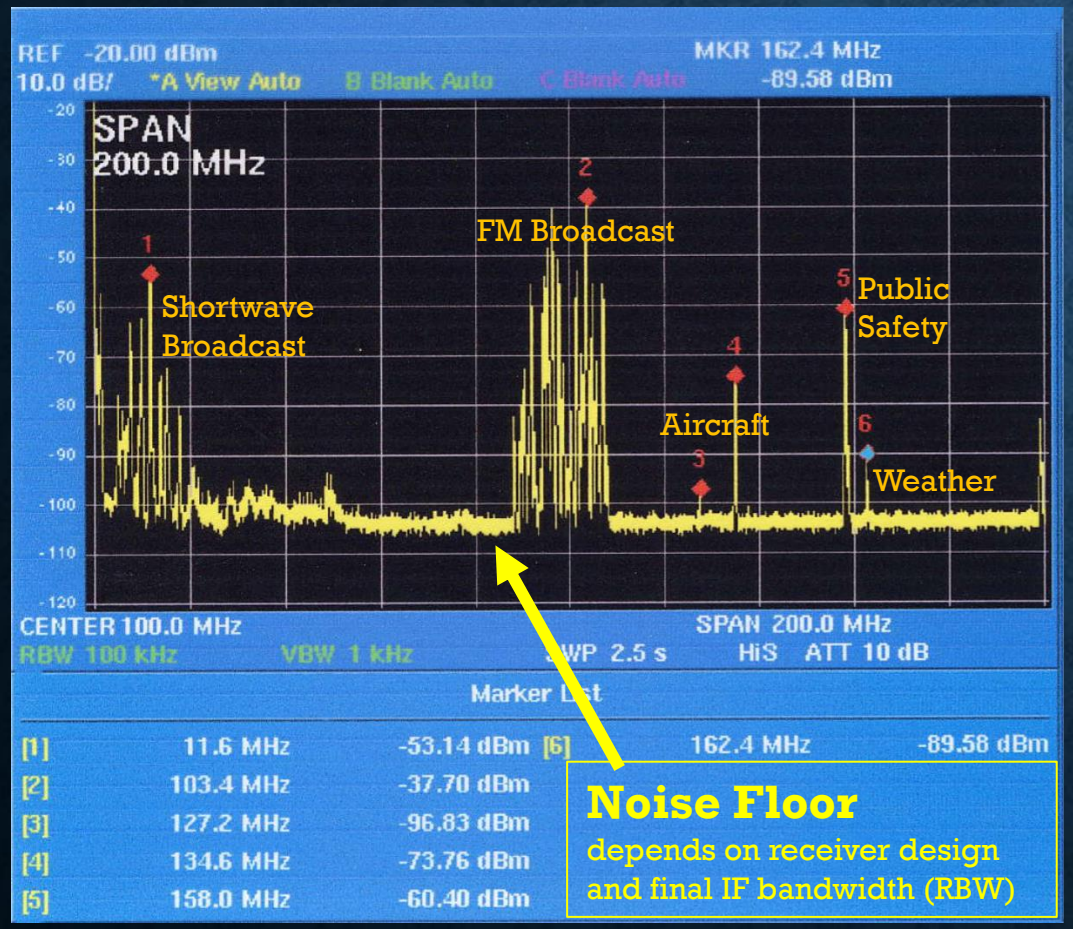
Outline of Today's Episode

- *Basic receiver design and testing*
- *Circuits from Radio Design 101*
- *Improving the receiver*
- *Future topics in Radio Design 101*
- *Epilogues*

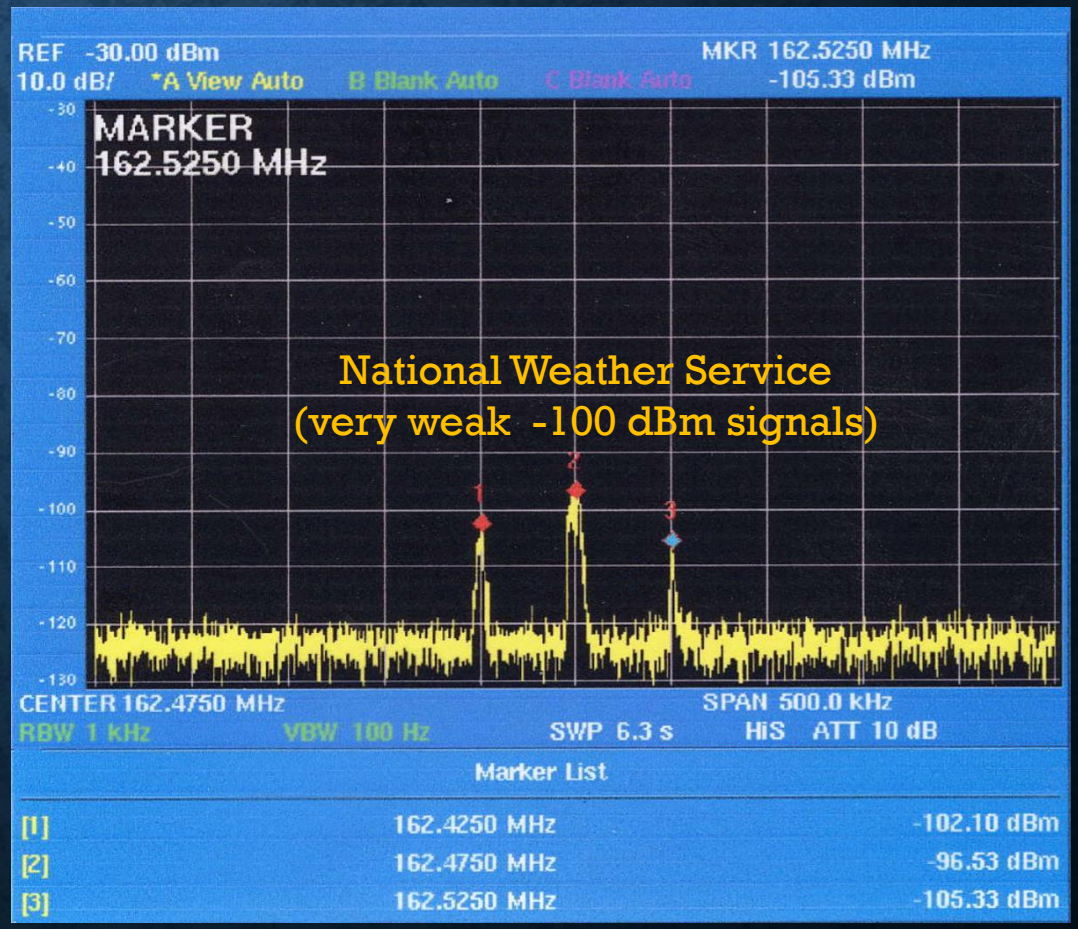
The Spectrum Environment

0 to 200 MHz, 100 kHz RBW

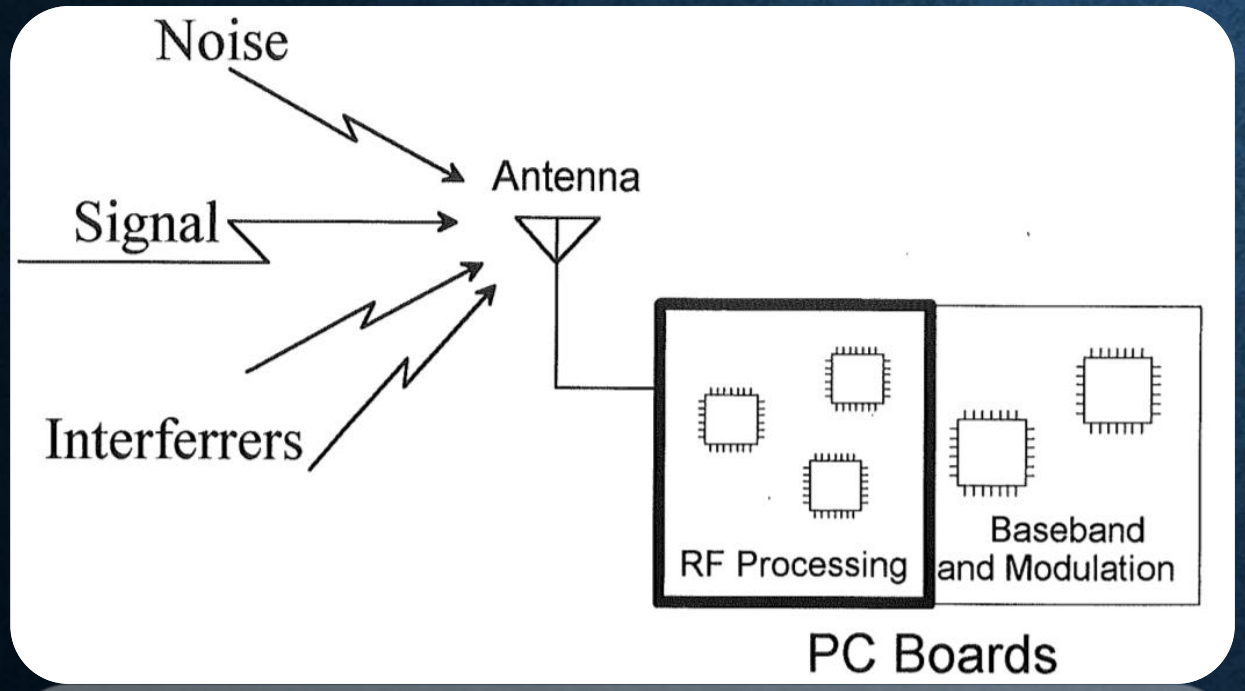


Noise Floor
depends on receiver design and final IF bandwidth (RBW)

162.5 MHz, 500 kHz Span, 1 kHz RBW



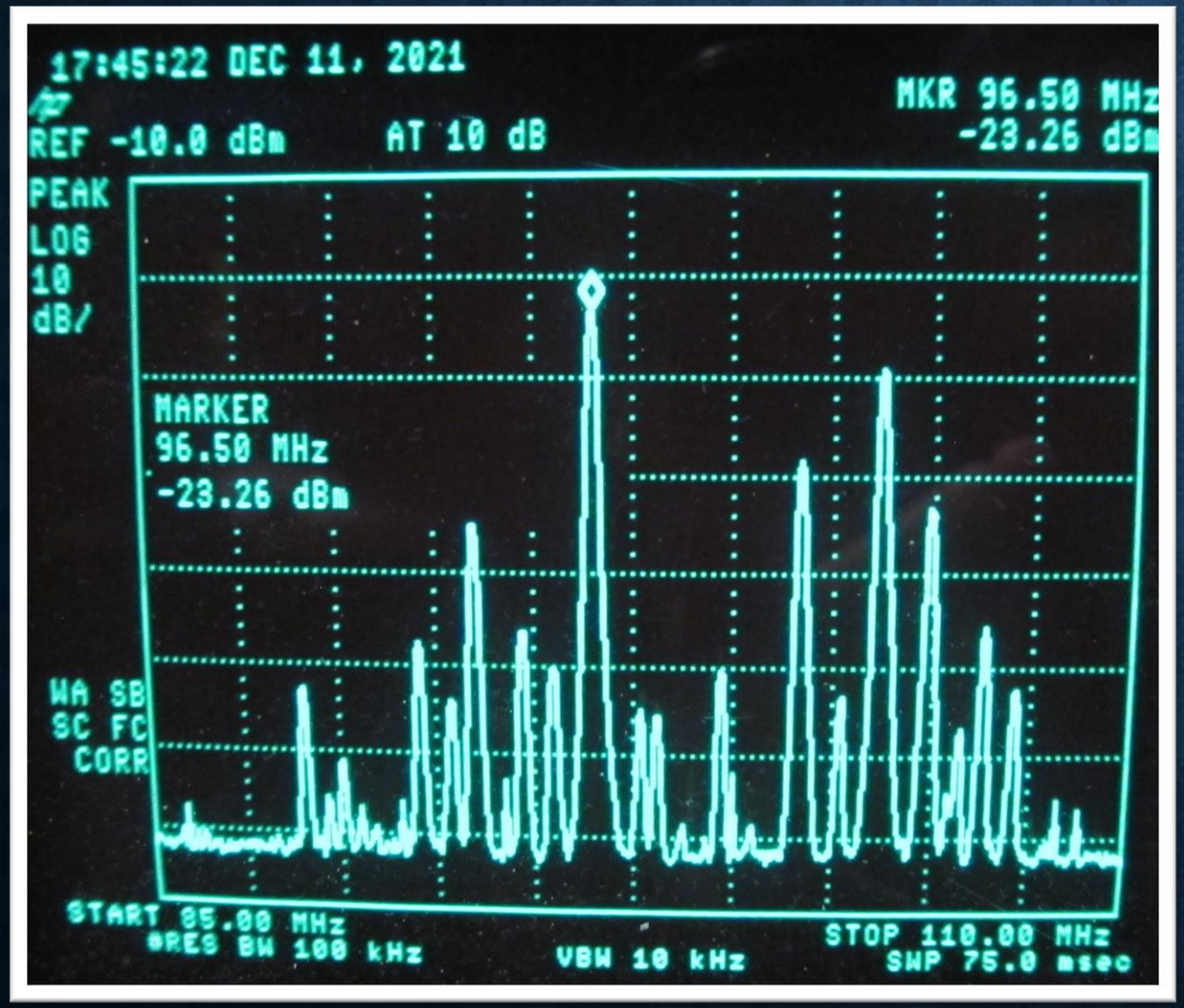
Receiver Design



- Amplify signals
- Filter out interferers
- Limit bandwidth to select single channel (and optimize S/N ratio into demod)
- Demodulate to recover voice/data

Test Results

(Needs more gain/sensitivity !)



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105.3	94.6	-75		
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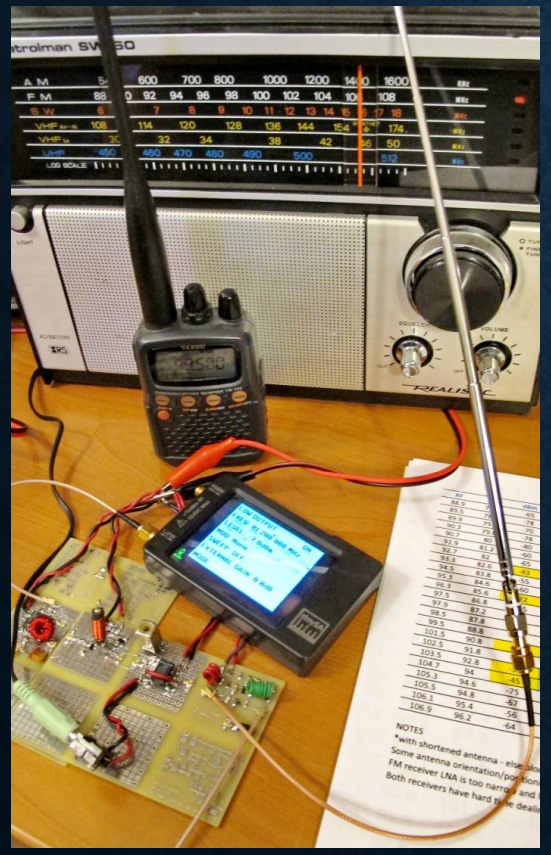
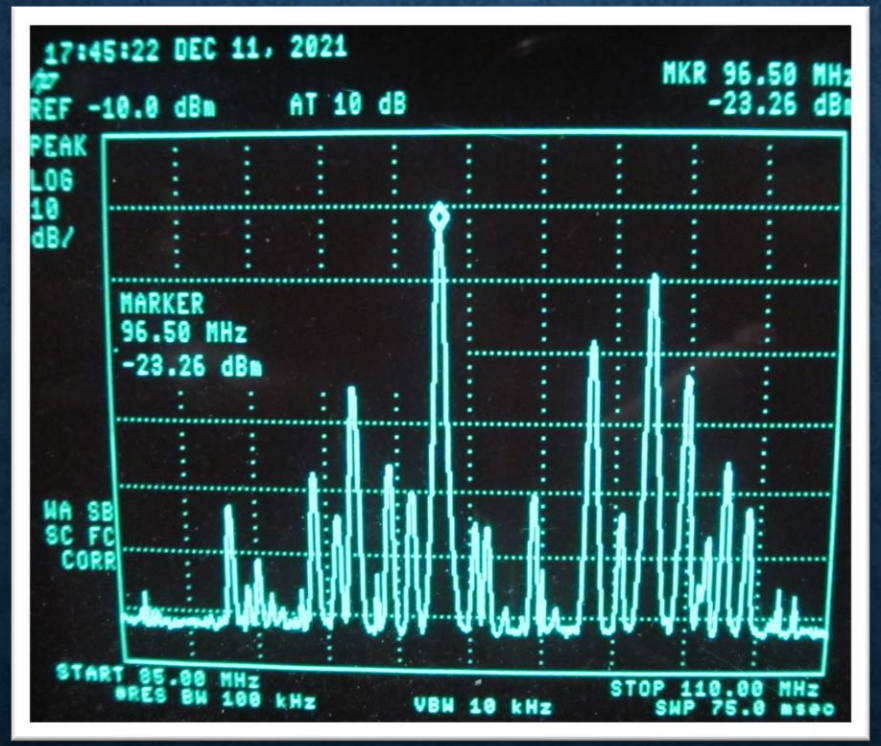
106.1	95.4	-56		very quiet
106.9	96.2	-64		

But … Too Much Sensitivity can be Bad !

(Unless the receiver is designed right …)





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106.9	96.2	-64			yes	yes	yes

NOTES

*with shortened antenna - else blocked by 96.3

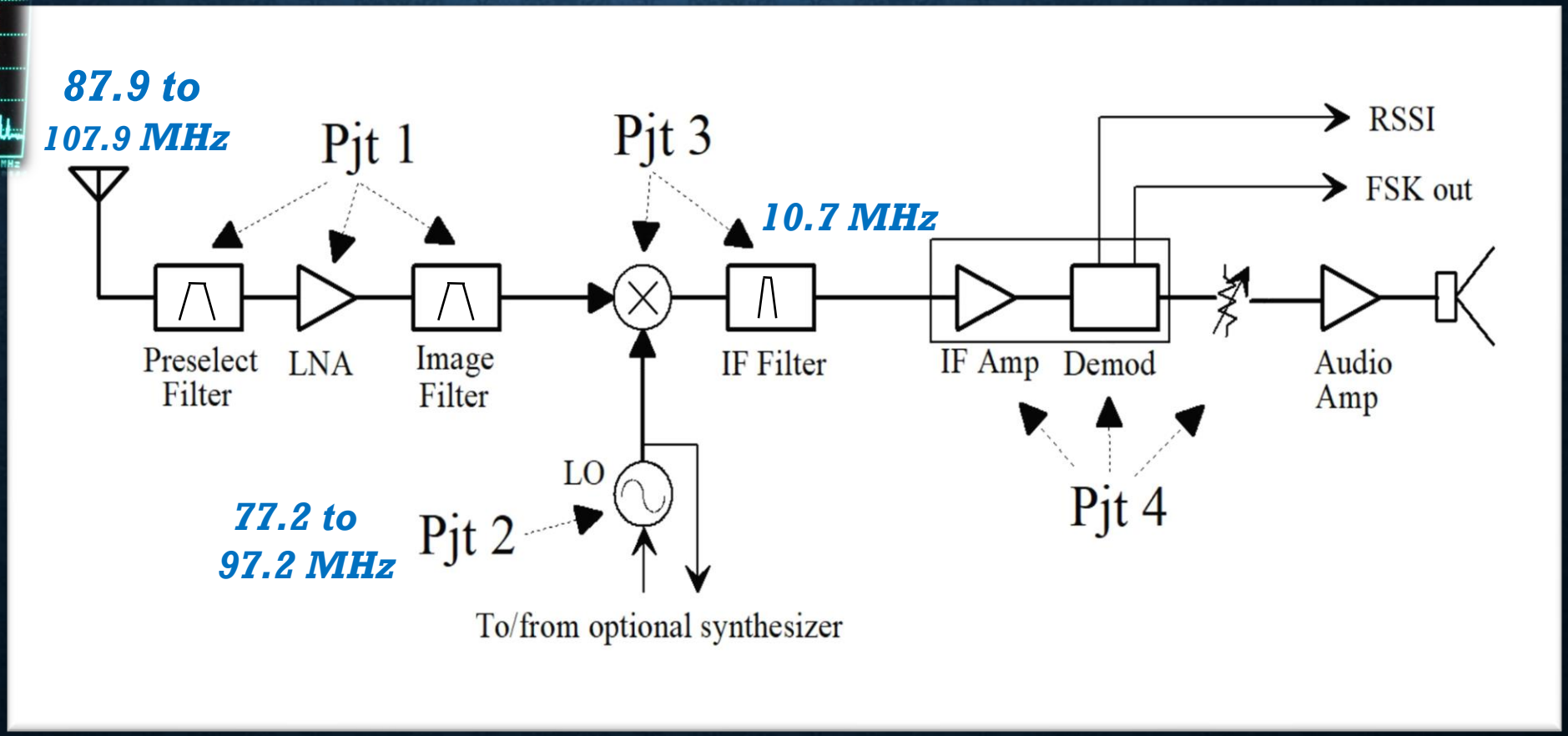
Some antenna optimization done to get best signal for all cases

What Makes Some Signals So Strong ?

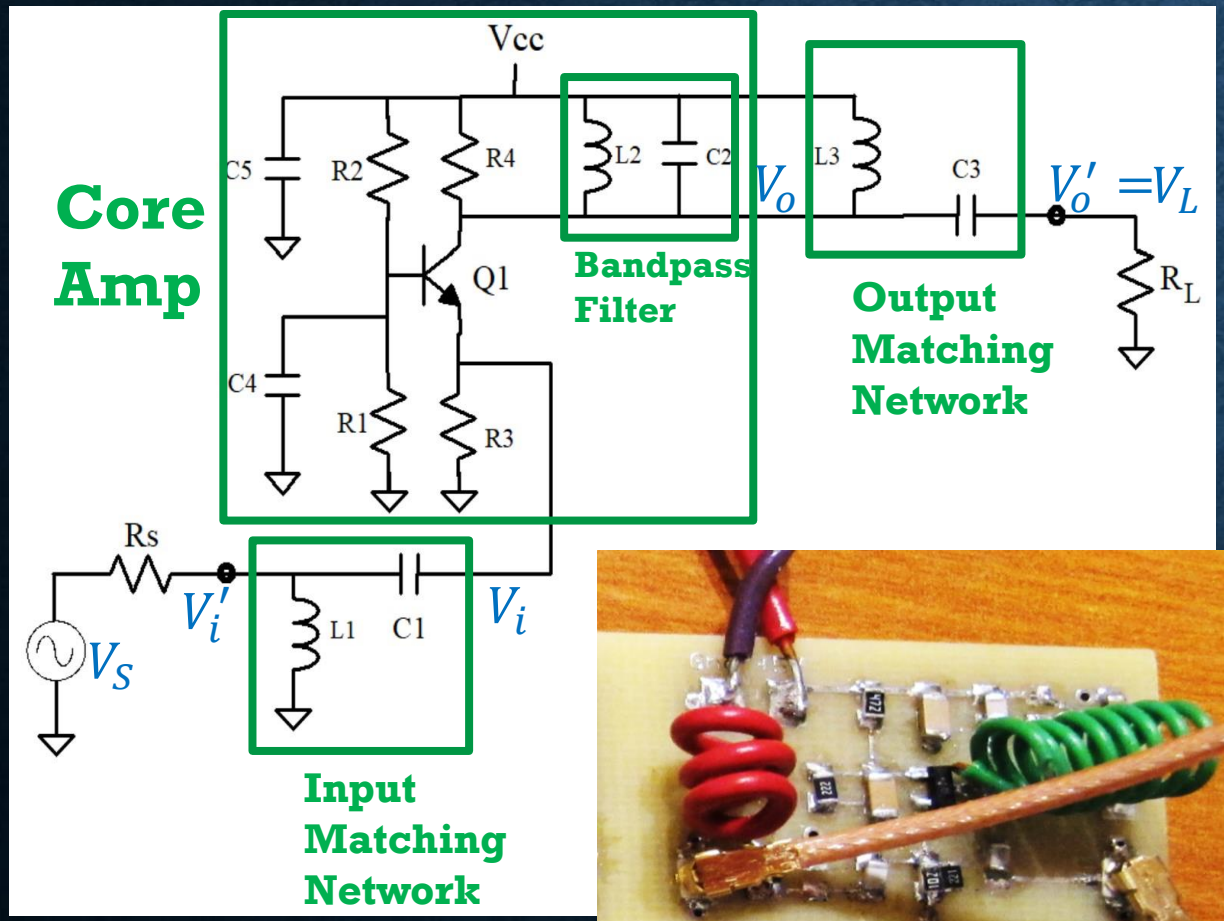
Outline of Today's Episode

- *Basic receiver design and testing*
- ***Circuits from Radio Design 101***
- *Improving the receiver*
- *Future topics in Radio Design 101*
- *Epilogues*

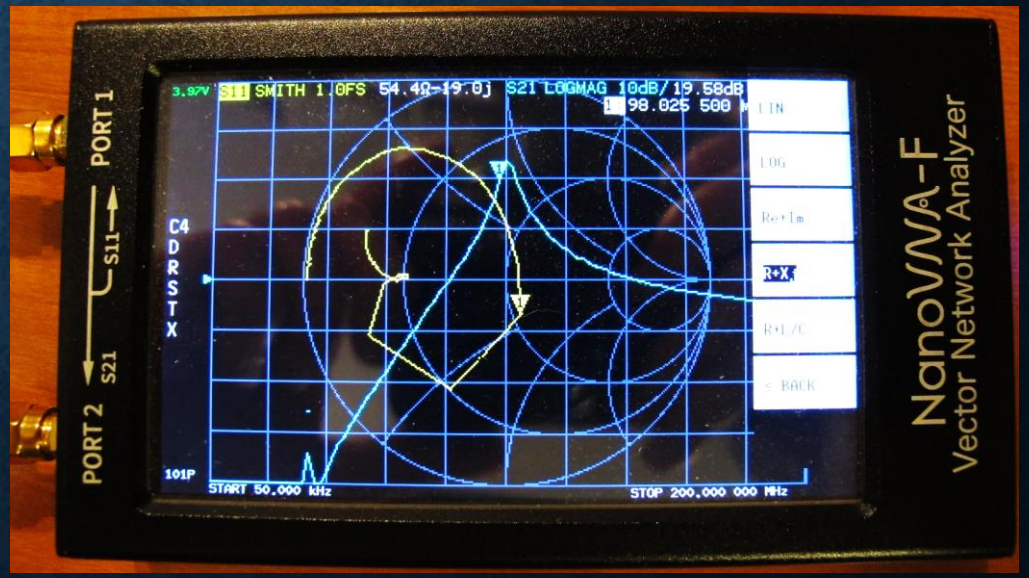
Classic Superhet Receiver Architecture



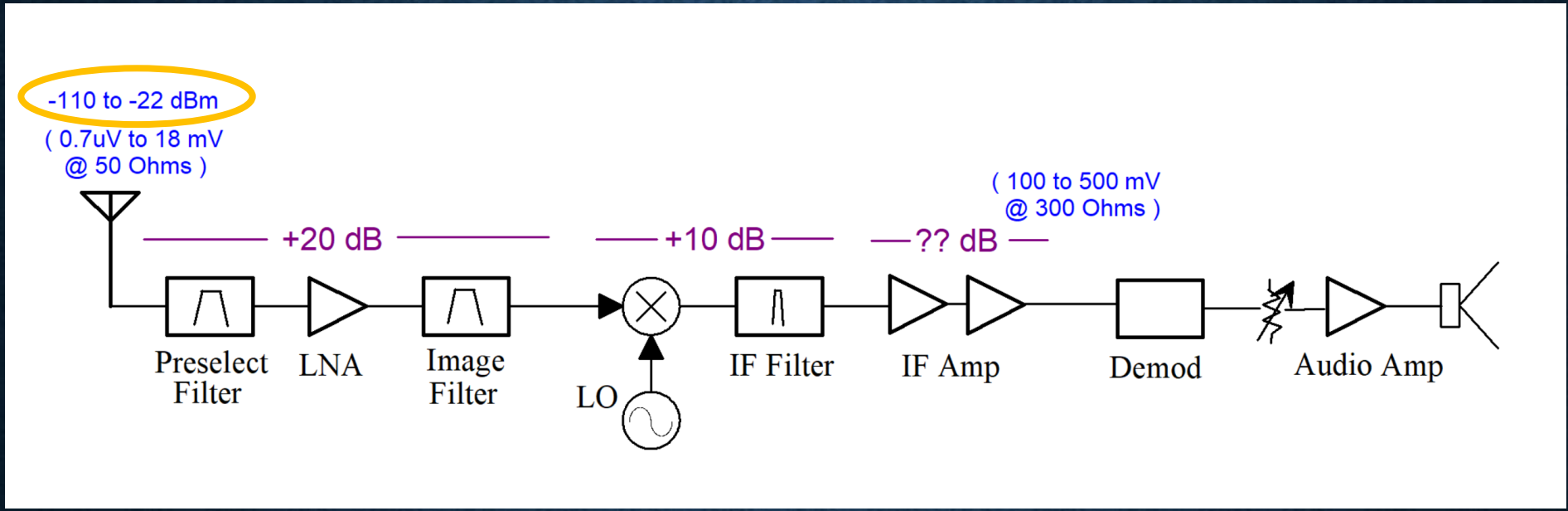
LNA Gain and Frequency Response



- LNA has 20 dB gain and is well centered near 98 MHz
- But bandwidth is a bit narrow (unless tuned together with the LO)

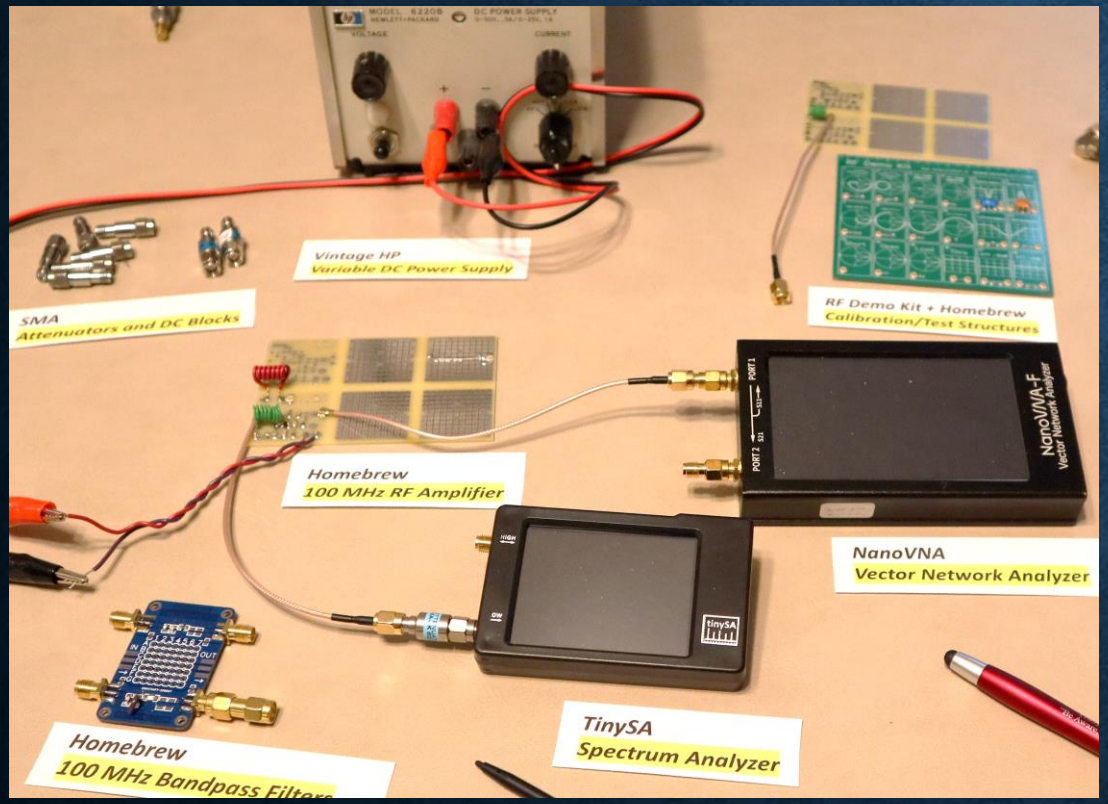


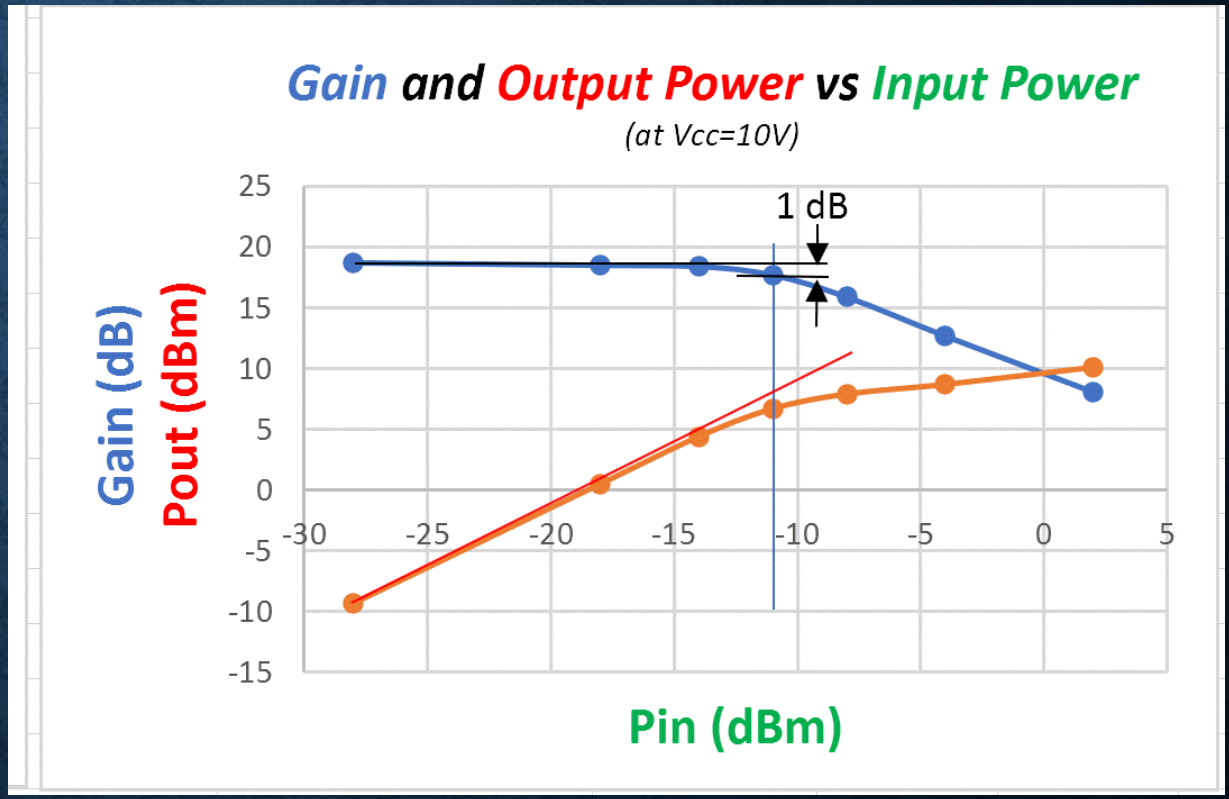
Gain distribution in existing design



- Ideally, IF Amp should have 65 dB of small-signal gain to achieve -110 dBm sensitivity
- Current design only implemented one stage and provides 40 dB.
- Still, receiver sensitivity should be a reasonable -85 dBm. However, …
- ***Gain compression*** **from large -22 dBm signal can cause issues if it happens before the IF channel-select filter …**

Is LNA in Compression ?

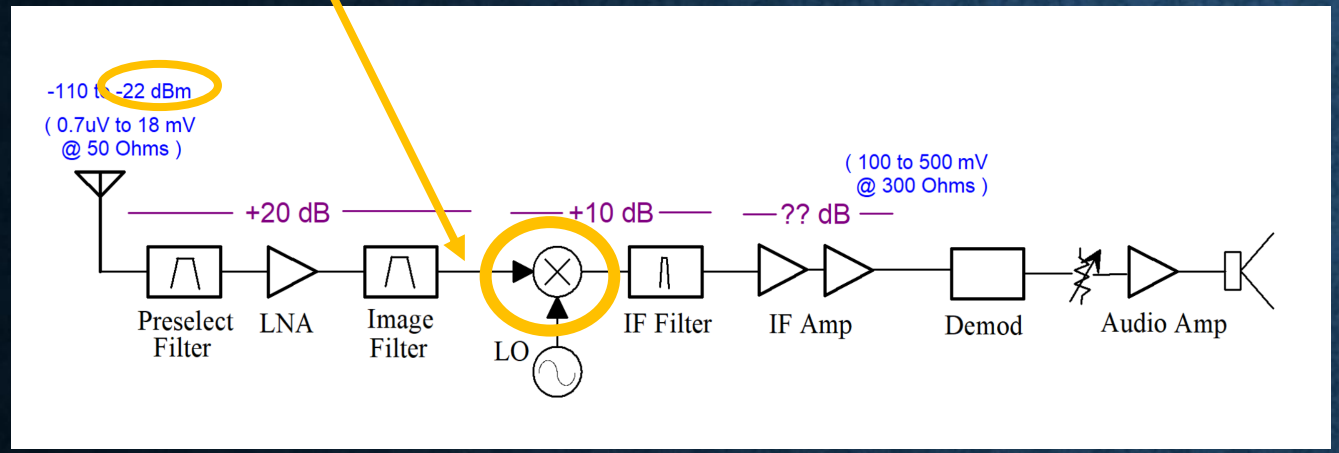


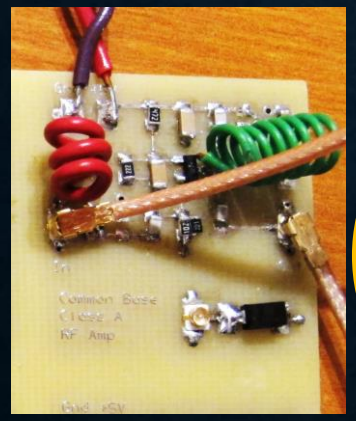


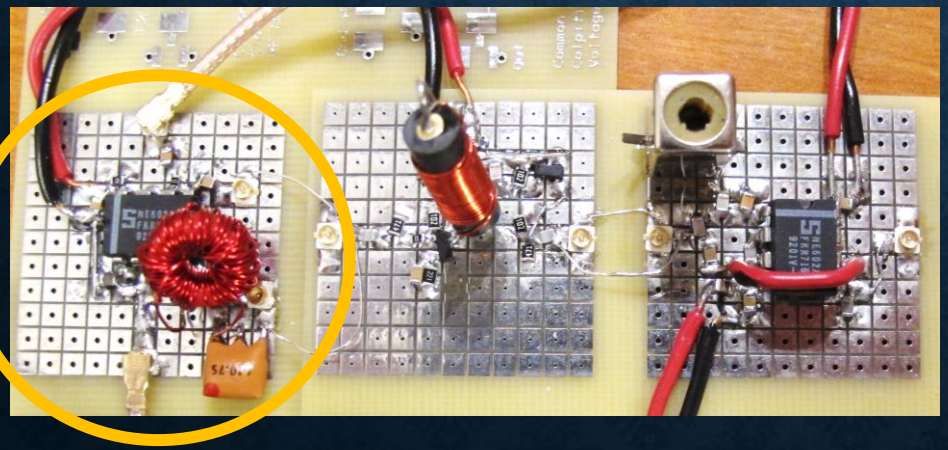
NO ☺ (Recall largest signal is about -22 dBm in our situation)

Is Mixer in Compression ?

YES ☹ **Amplified -22 dBm signal is close to 0 dBm here !**







Result is approx 20 dB gain reduction

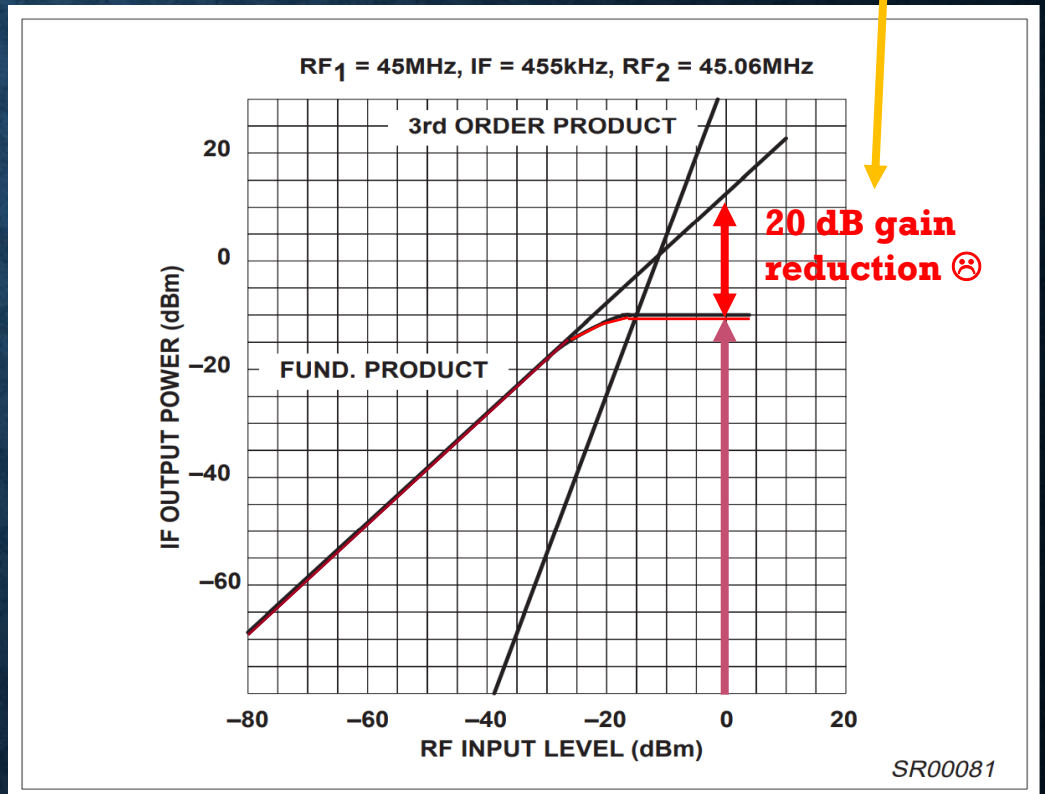
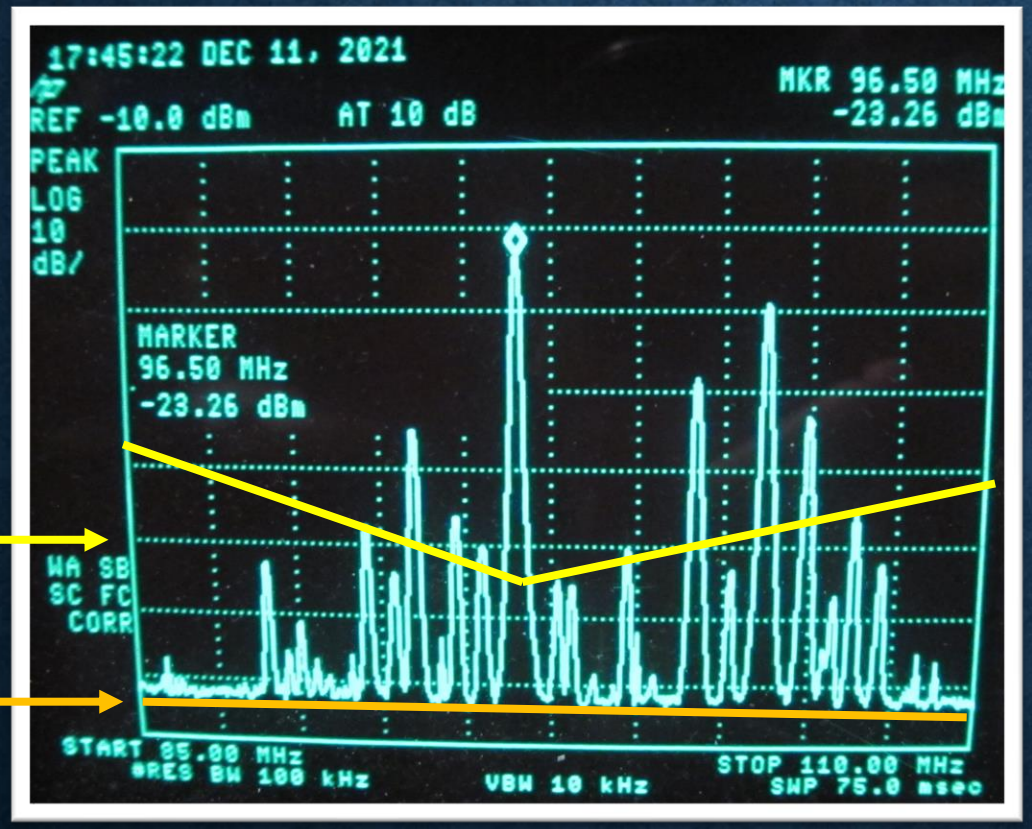


Figure 14. Third-Order Intercept and Compression

Philips Semiconductors — Product specification

Double-balanced mixer and oscillator — SA602A

Gain Reduction Effects



Actual sensitivity worse than -65 dBm

Expected sensitivity -85 dBm

Sloped lines show approximate net sensitivity assuming loss of 20 dB gain from compression (slopes are due to LNA frequency response)

RF	LO	dBm	FMrx
88.9	78.2	-65	
89.5	78.8	-78	
89.9	79.2	-70	quiet
90.3	79.6	-78	
90.7	80	-80	
91.9	81.2	-60	quiet
92.7	82	-65	
93.3	82.6	-43	excellent
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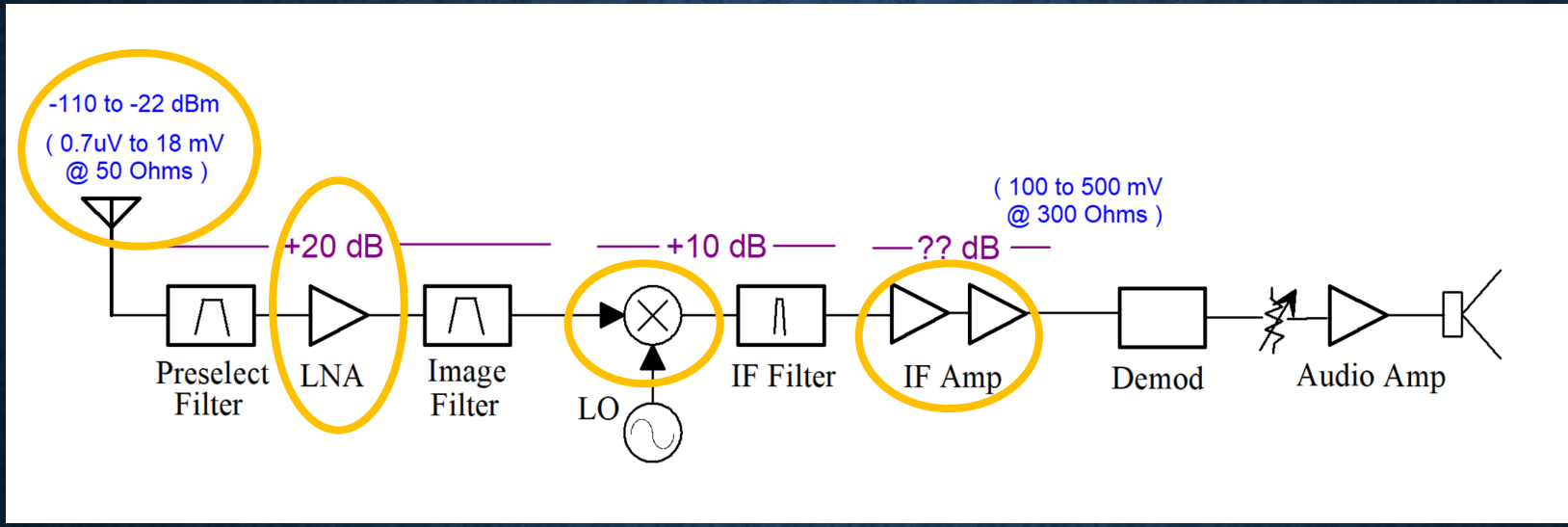
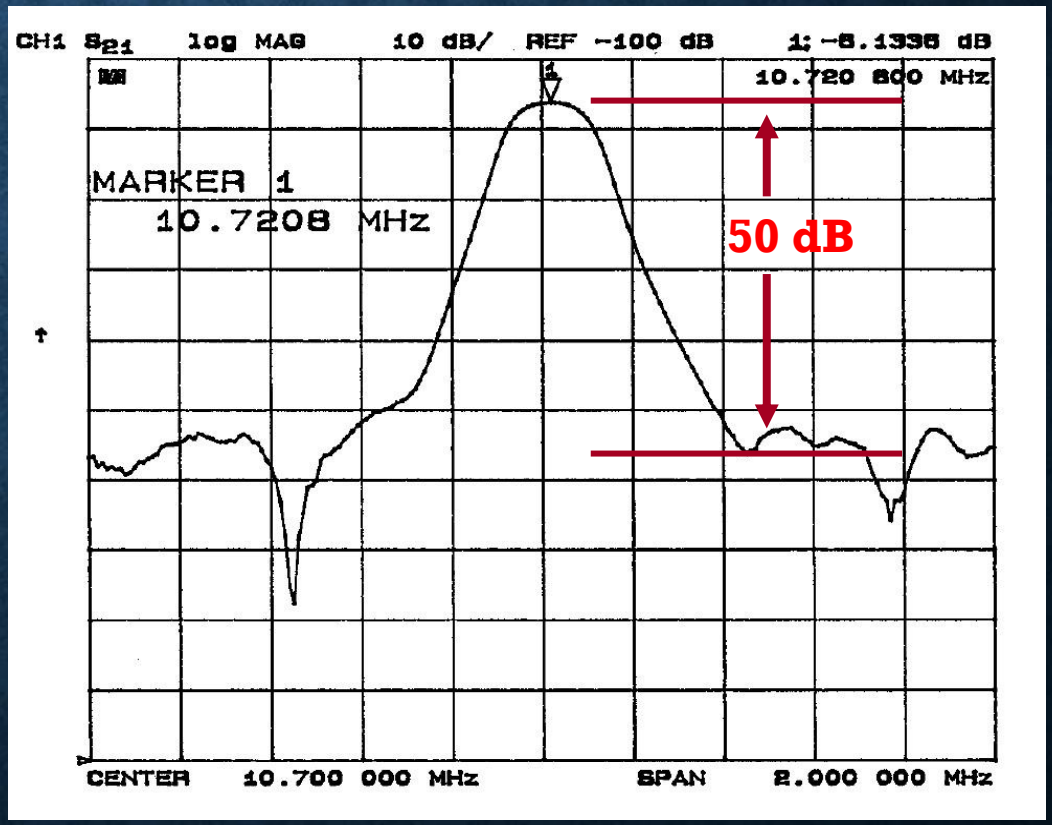
Possible Solutions



- Attenuate input signals or decrease LNA gain. Raises "noise-figure", decreasing sensitivity ☹
- Replace mixer with higher compression-point device (e.g. diode ring mixer or high-power FET design) *But burns more power* ☹
- Add more gain in IF section to make up the deficit ?

Another Problem

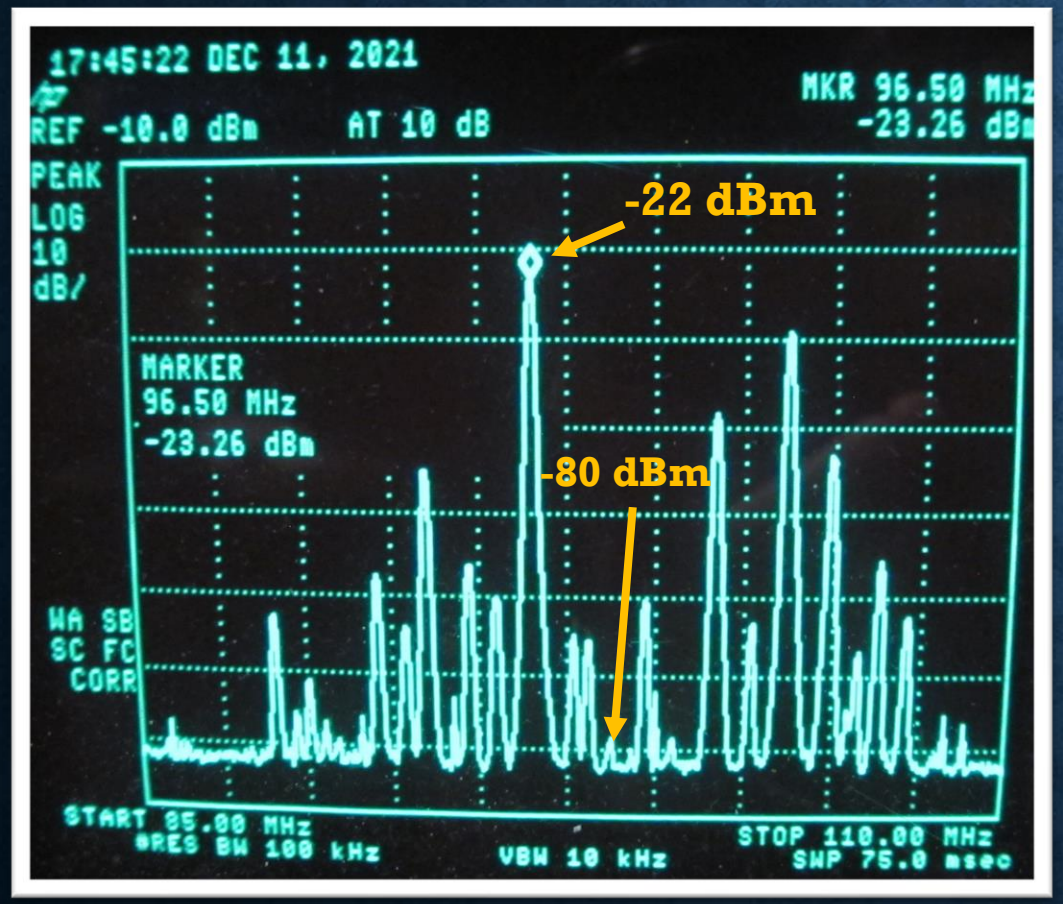
IF Filter has limited off-channel rejection



10.7 MHz Center, 2 MHz span, 10dB/div vertical

(Measurement made with 4:1 Z transformers in custom test-jig)

Weak "Close-in" Signals Blocked



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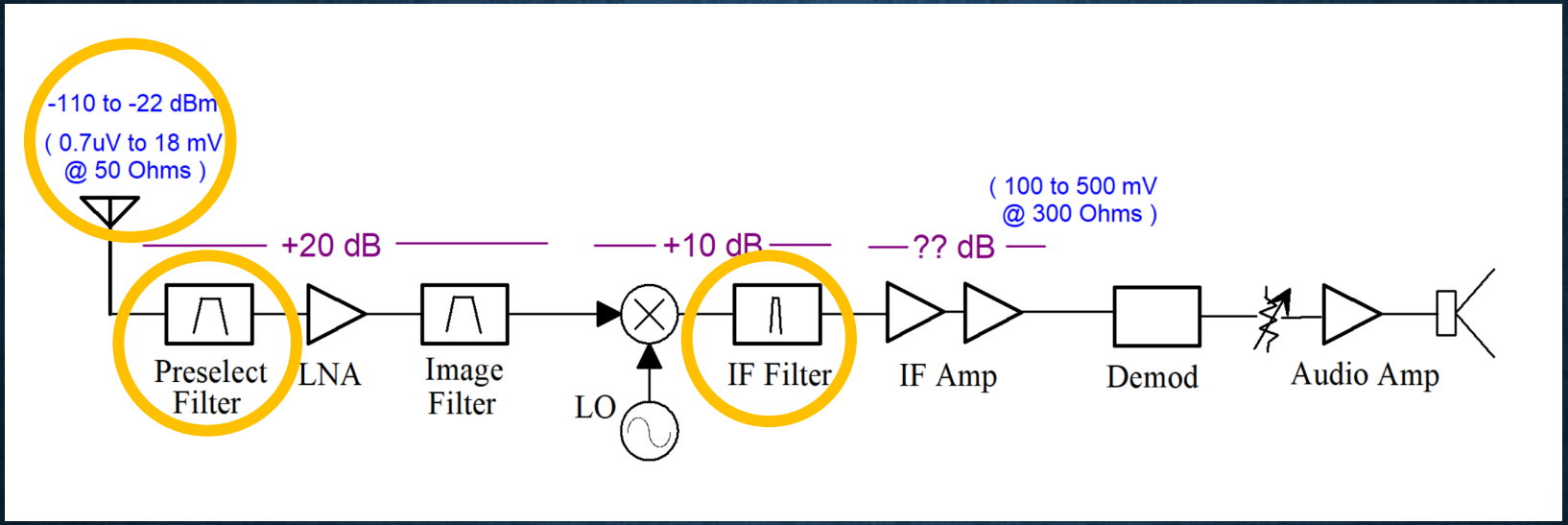
106.1	95.4	-56		very quiet	yes	yes	yes
106.9	96.2	-64			yes	yes	yes

NOTE: There are other issues too: (e.g. mixer spurious products)

Possible Solutions



- Reposition radio/antenna ☺
- Add a second IF filter (and be careful with PCB coupling)
- Implement better pre-select filtering !

(but 200 kHz bandwidth at 100 MHz is not feasible without regen …)

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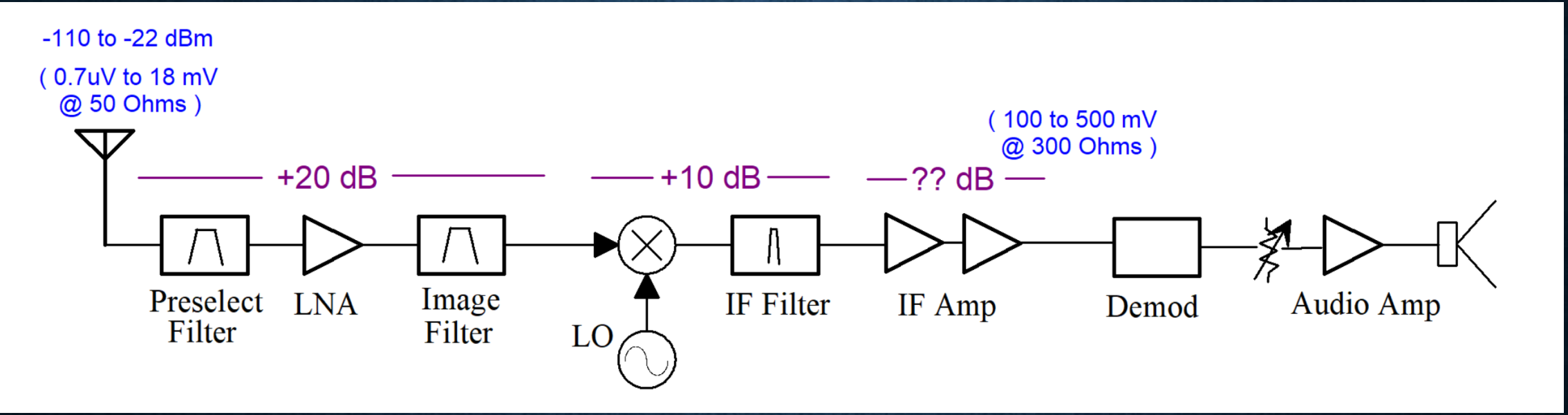
Summary of Bugs in Current Design

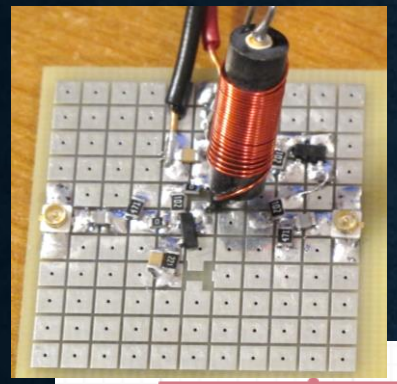


LNA has narrow bandwidth, but is not tunable (no tracking preselection)

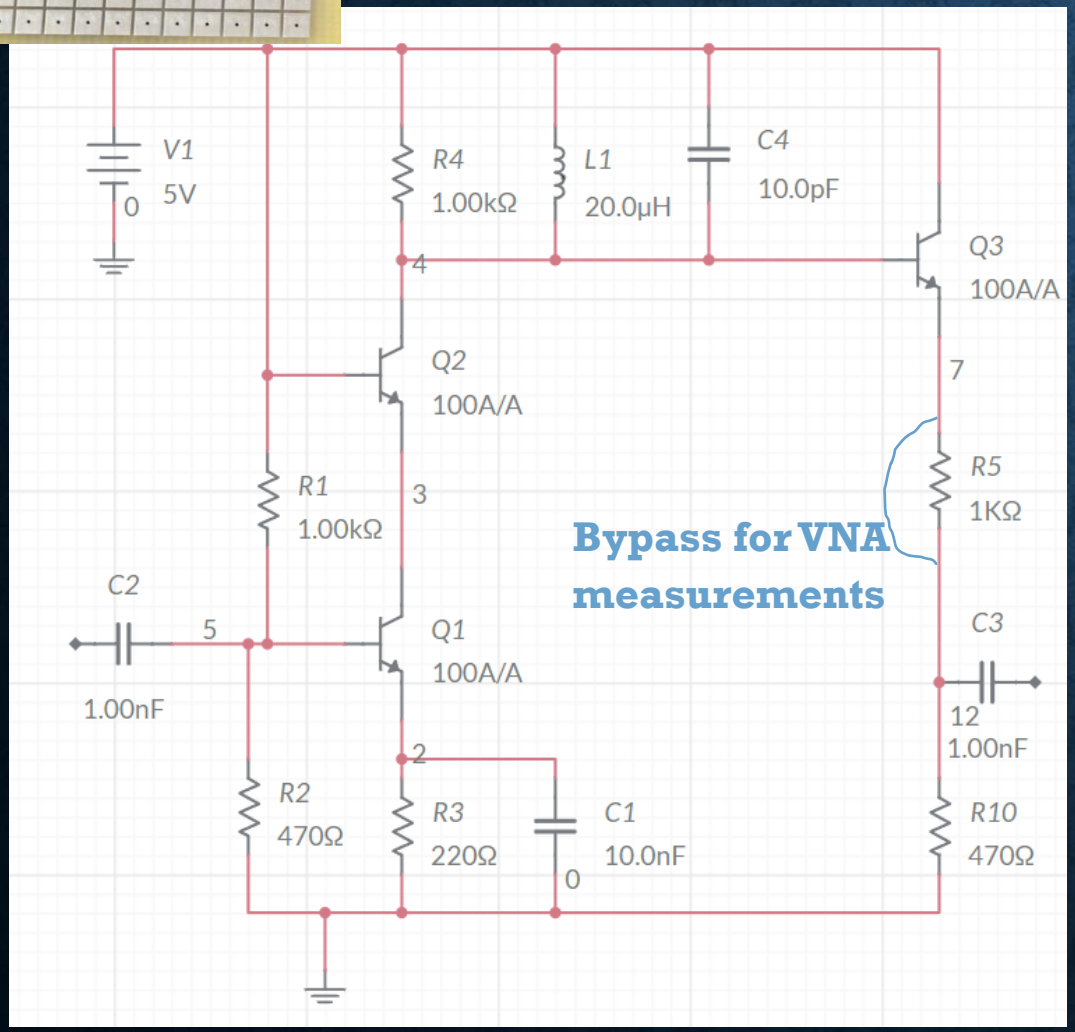
Mixer is overdriven in this service area due to strong 96.3 MHz station, reducing gain

IF filter has limited off-channel rejection which could create "signal blocking"

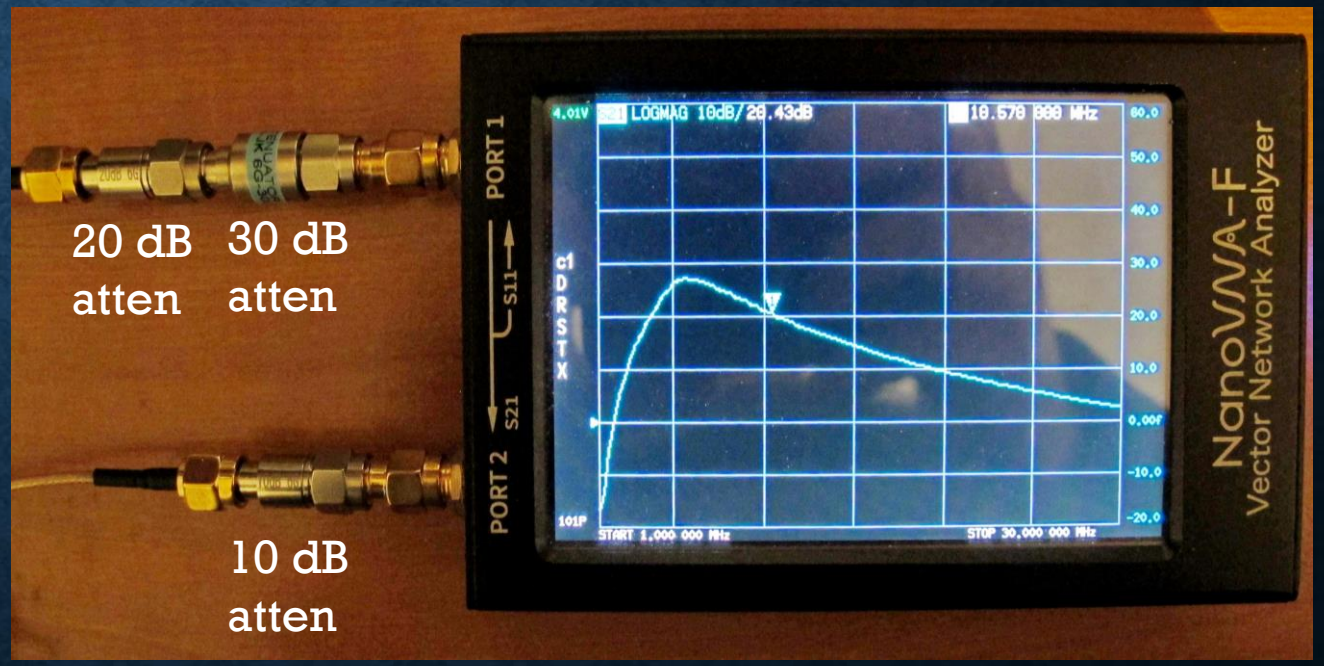
IF amp gain is low (maybe we can improve this first with a simple mod ?)



Existing IF Amp Design

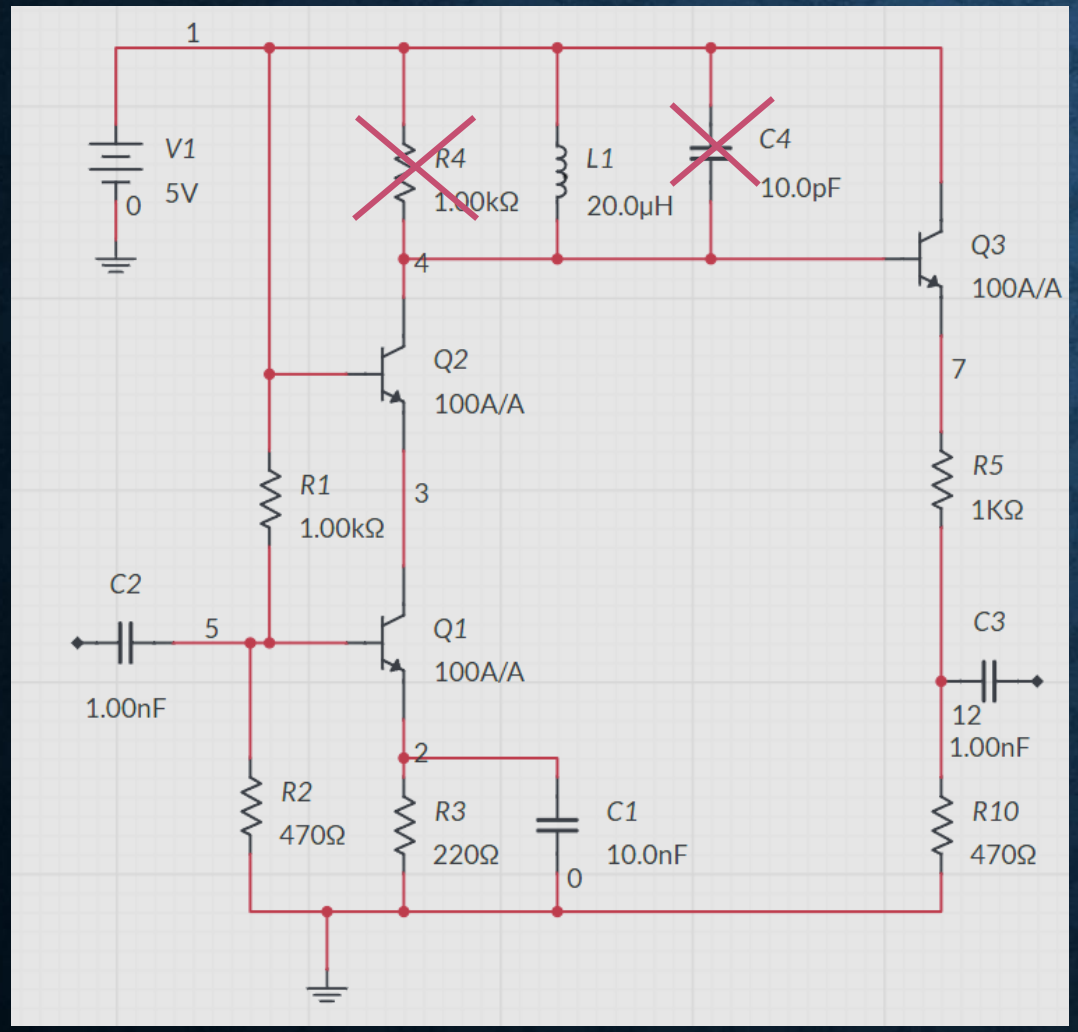


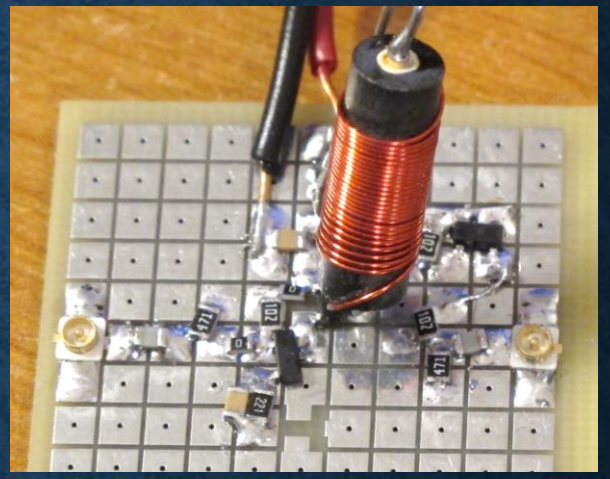
- **40 dB gain at 10.7 MHz.**
- **Needs some tweaking, and additional gain …**



- NOTE: Extra 20 dB attenuator on port 1 added after cal, but did NOT recalibrate, so displayed gain is 20 dB lower than actual

IF Amp Modifications



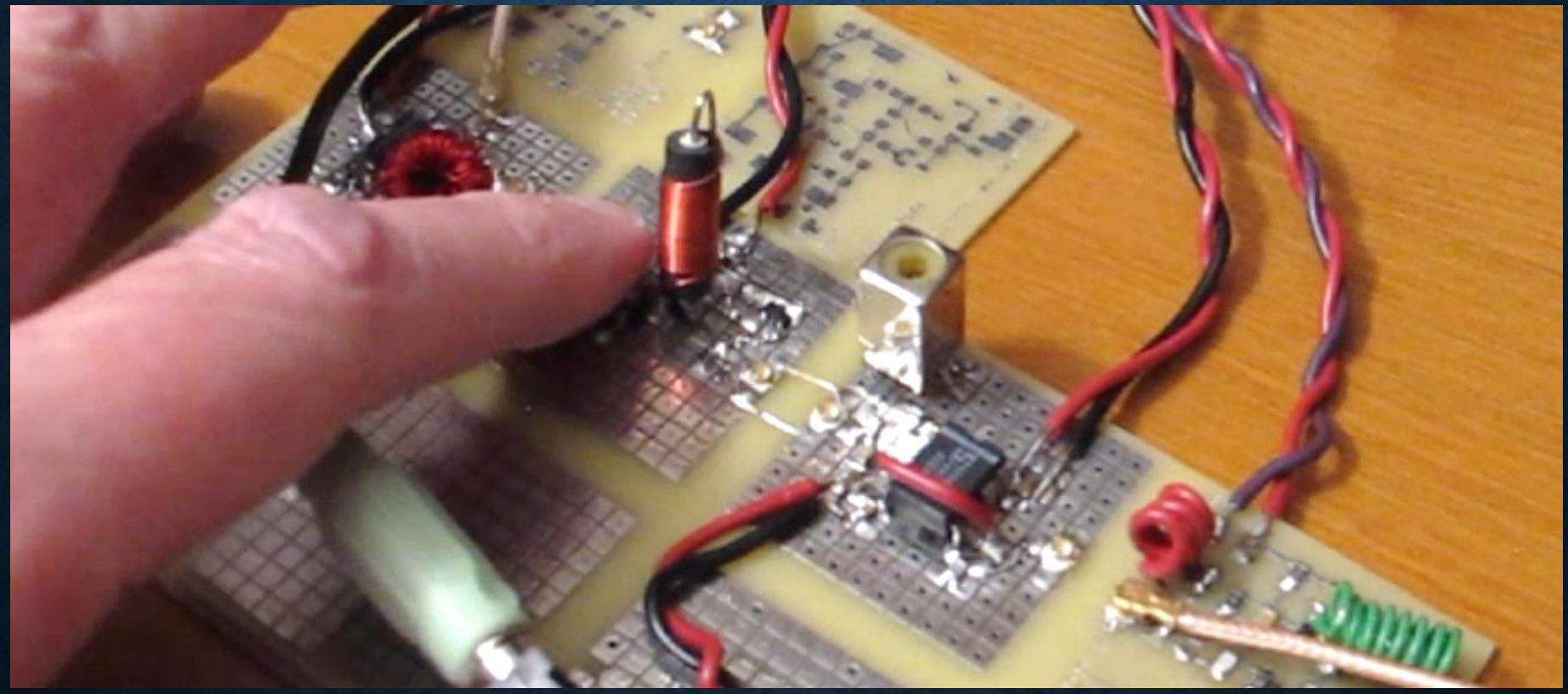


- Removed R4 and C4 to increase gain and raise resonant frequency.

$$A_v = -g_m R \qquad f_o = \frac{1}{2\pi\sqrt{LC}}$$

- Receiver lost virtually all sensitivity ! ☹

The Problem and Symptoms



Outline of Today's Episode

- *Basic receiver design and testing*
- *Circuits from Radio Design 101*
- *Modifying and breaking the receiver*
- ***Future topics in Radio Design epilogues***

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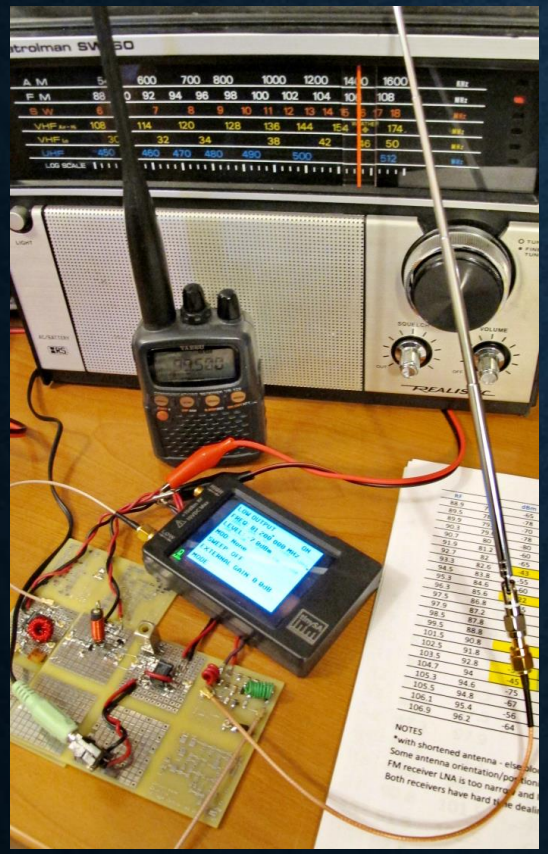
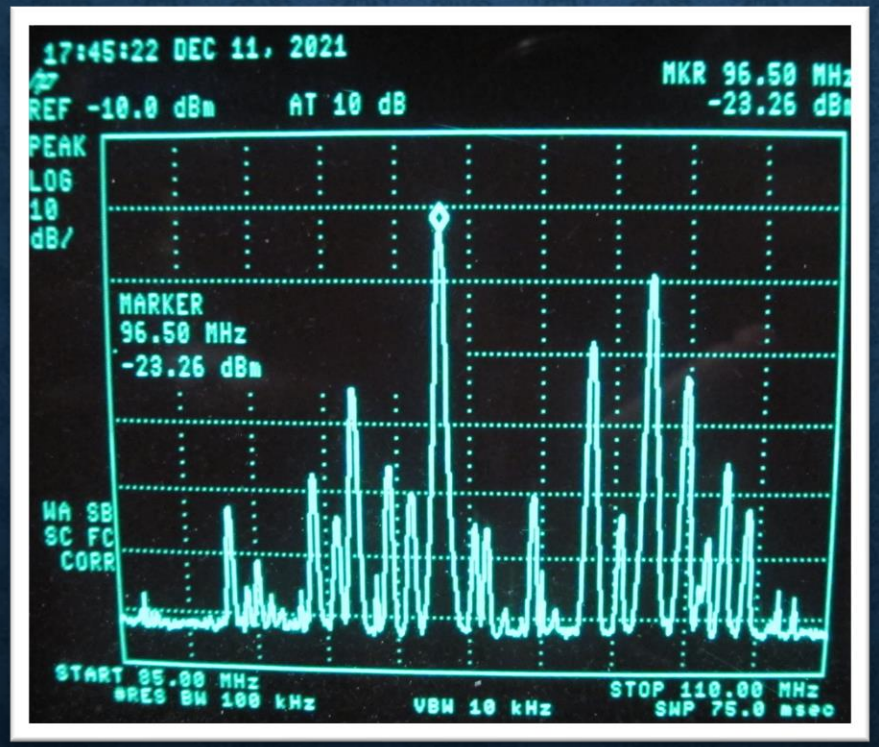
Older Radio is the Best -- Why?





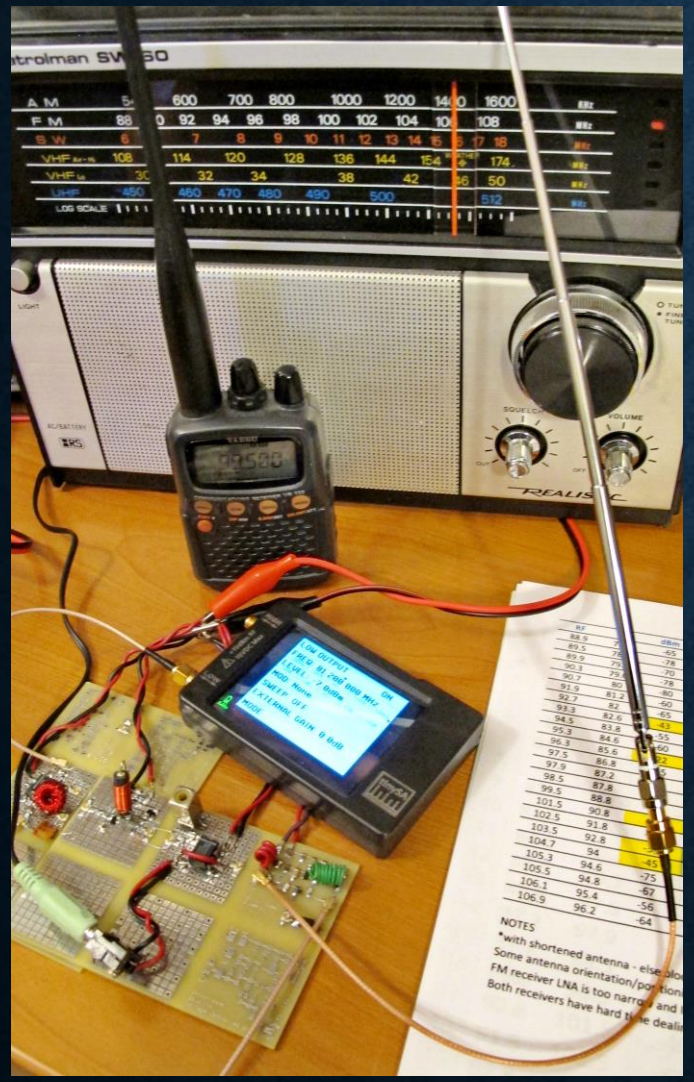
RF	LO	dBm	FMrx	FMrxFixed	VR120	VR120atten	Old Radio
88.9	78.2	-65				yes	yes
89.5	78.8	-78			yes		yes
89.9	79.2	-70	quiet	quiet	yes	yes	yes
90.3	79.6	-78		quiet		yes	yes
90.7	80	-80					yes
91.9	81.2	-60	quiet	good	yes	yes	yes
92.7	82	-65		good		yes	yes
93.3	82.6	-43	excellent	excellent	yes	yes	yes
94.5	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

Possible Future Topics



- Next Episode -- **Troubleshooting !**
- Study of commercial radio designs
- Classic performance measures (P1dB, IIP3, OIP3, …)
- Spurious products from mixers
- Receiver ideal sensitivity (MDS, Noise Figure, and required S/N ratio for given modulation)
- RFI from modern switch-mode power supplies, amplifiers, and lighting
- Possible Projects ☺
  - Tracking preselect filters using digitally tuned capacitors
  - Q-enhanced bandpass filter front-end circuits

Thanks For Watching !