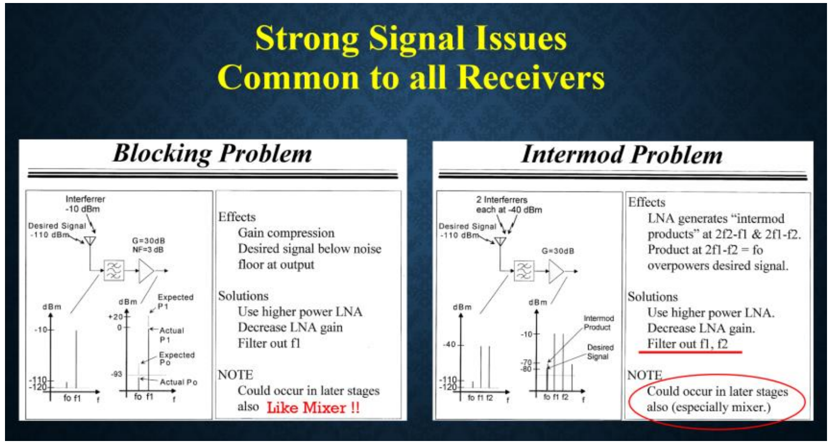
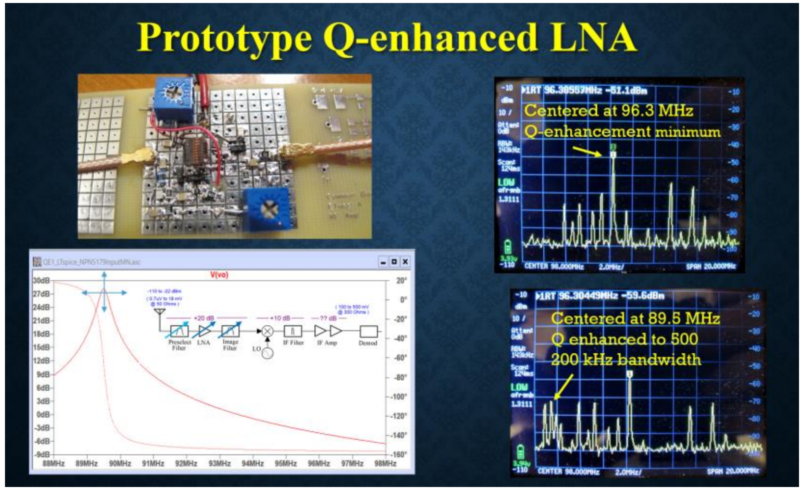
Radio Design 101   Epilogue 3 – Receiver Architectures

Slides downloaded from: https://ecefiles.org/rf-design/
Companion video at: https://www.youtube.com/watch?v=XW3TYQstiuk

In this final epilogue, we complete our study of receiver receiver hardware design by looking at block diagrams and schematics of various receiver architectures developed over the years. The main problems and solutions for dealing with strong signals in crowded frequency spectrums are discussed, and illustrated with real-world commercial products, including an ATS25 DSP Software Defined Radio (SDR). The epilogue concludes by looking at a research-level Q-enhanced filter which allows our radio to exceed the performance of all the commercial designs tested.



Station	dBm	ATS 25	VR-120	SW-60	RD-101
88.1	-96				
88.9	-58				
89.5	-75				
89.9	-61				
90.3	-77				
90.5	-85				
90.7	-71				
91.3	-80				
91.9	-55				
92.5	-82				TBD
92.7	-70				|
93.3	-41				|
94.5	-63				V
95.3	-60				
96.3	-24				
97.5	-80				
97.9	-66				

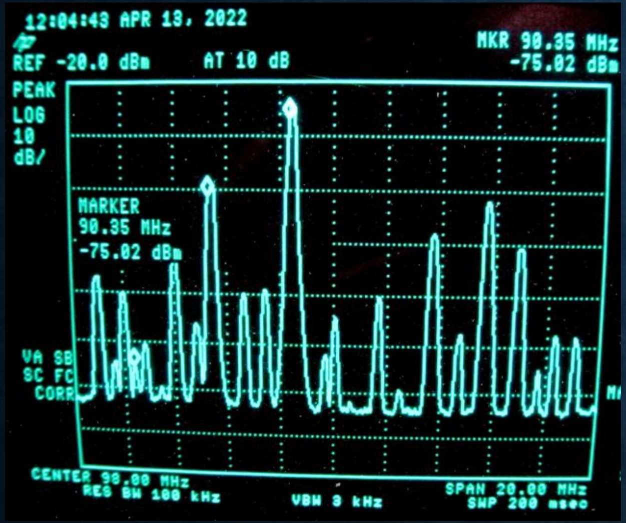


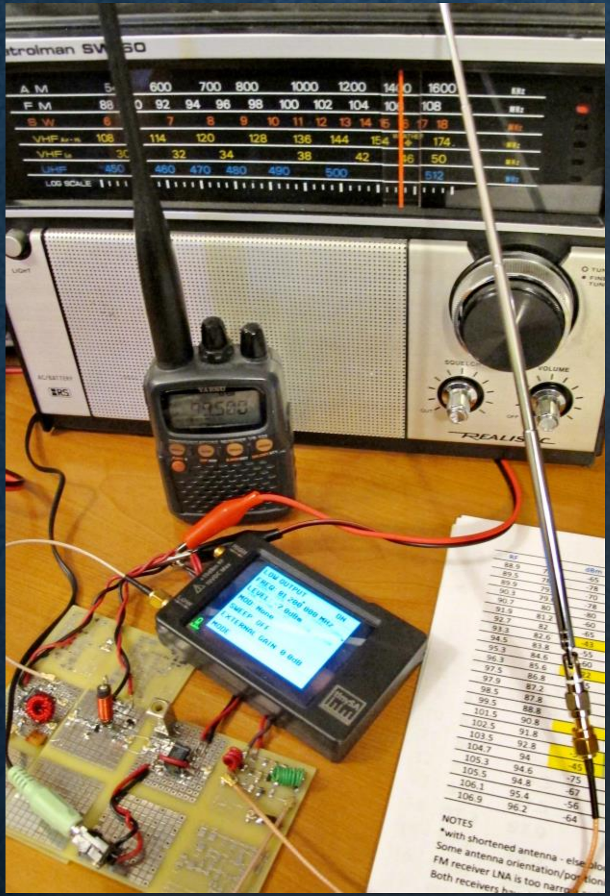
Radio Design 101

Epilogue 3

Receiver Architectures

A Tale of Four Radios





1990 Portable multi-band (Patrolman SW-60)

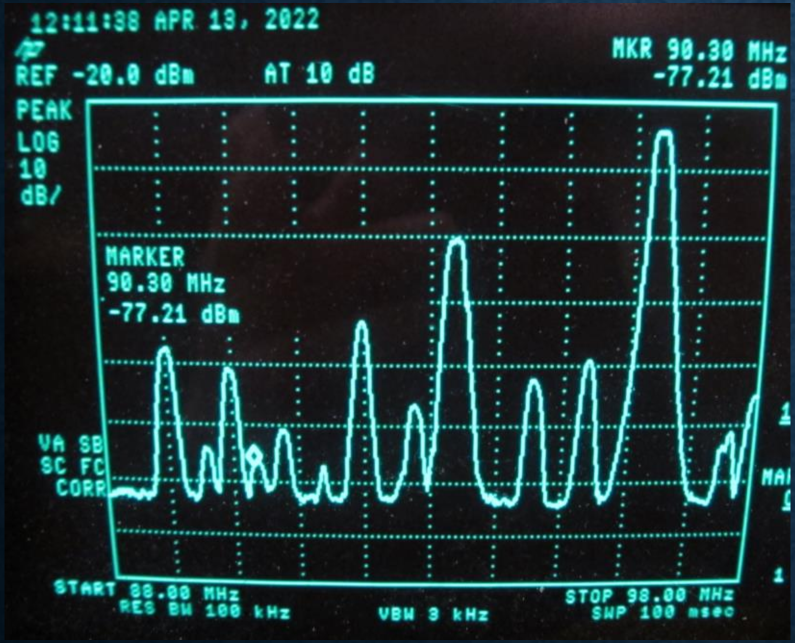
2003 Commercial wideband handheld (VR-120)

2021 Software-Defined Radio (ATS-25)

2022 Homebrew FM classic superhet (RD-101)

Lower Half of Band

88 to 98 MHz



Station	dBm	ATS 25	VR-120	SW-60	RD-101*
88.1	-96				
88.9	-58				
89.5	-75				
89.9	-61				
90.3	-77				
90.5	-85				
90.7	-71				
91.3	-80				
91.9	-55				
92.5	-82				TBD
92.7	-70				|
93.3	-41				|
94.5	-63				V
95.3	-60				
96.3	-24				
97.5	-80				
97.9	-66				

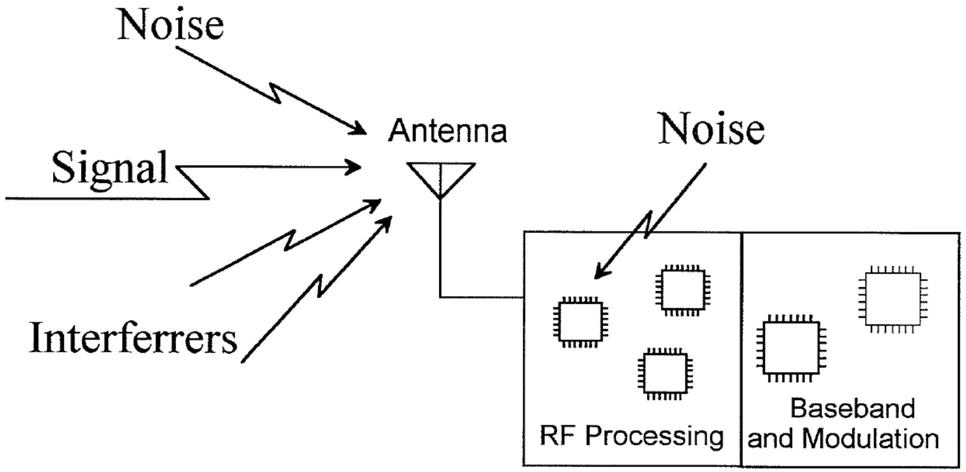
Outline of Today's Episode

- *Challenges in Receiver Design*
- *Receiver Architecture Alternatives*
- *Key Points for Achieving Good Performance*
- *Ideal Low Power Receiver Design*

Main Design Goals

88 to 108 MHz

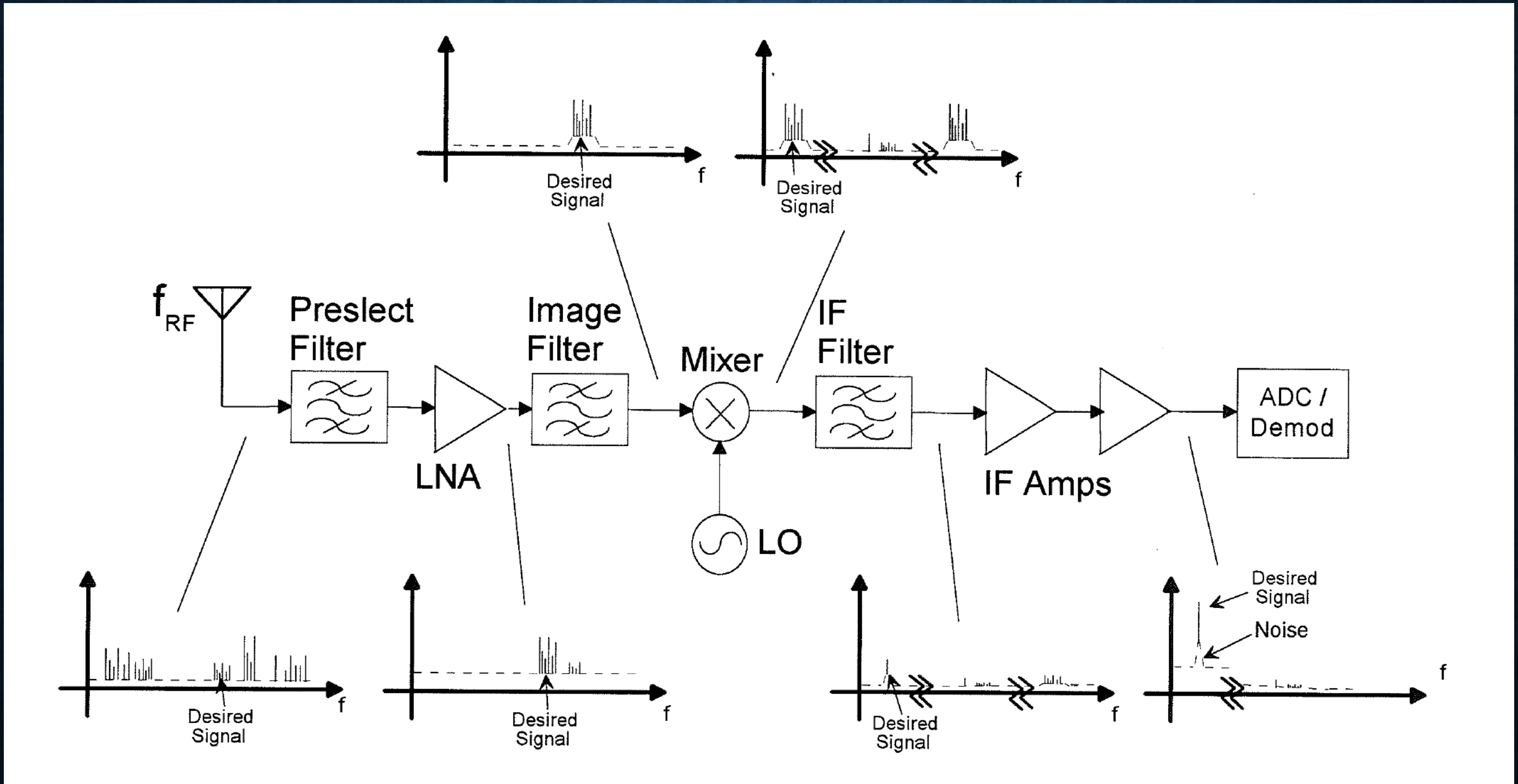
95 to 100 MHz



Design Requirements:

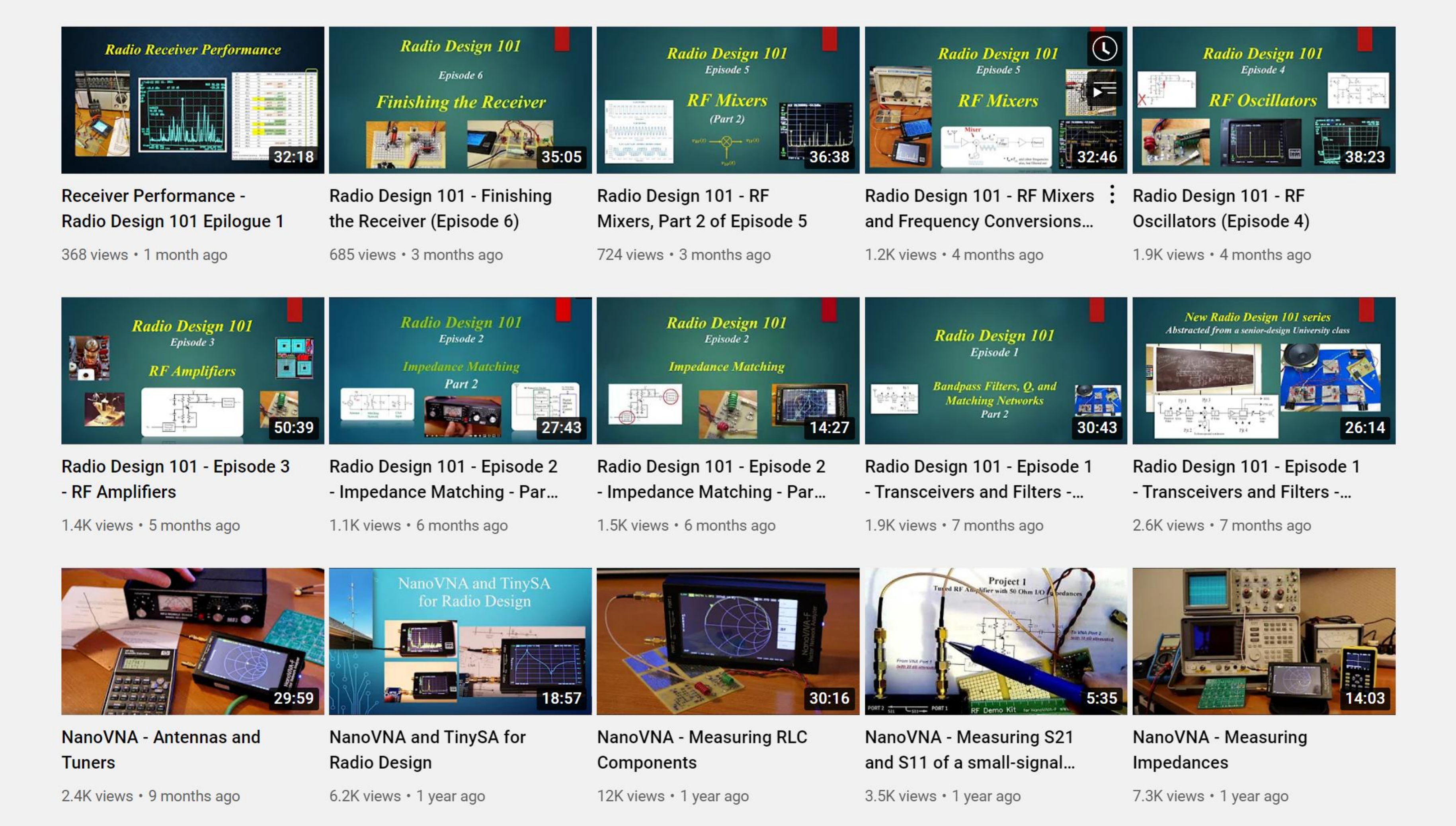
Amplify (weak) desired signal
Filter out interferrers
Minimize internally generated noise
Limit bandwidth to maximize S/N and sensitivity
Select desired signal and demodulate

Classic Superhet Solution

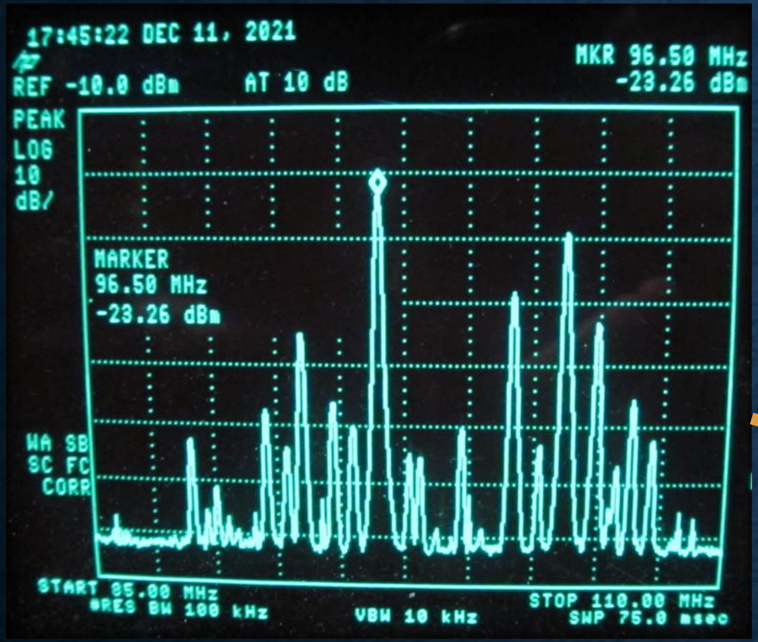


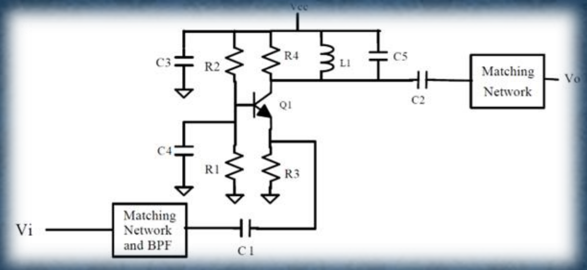
Circuit Issues Discussed in "Radio Design 101"

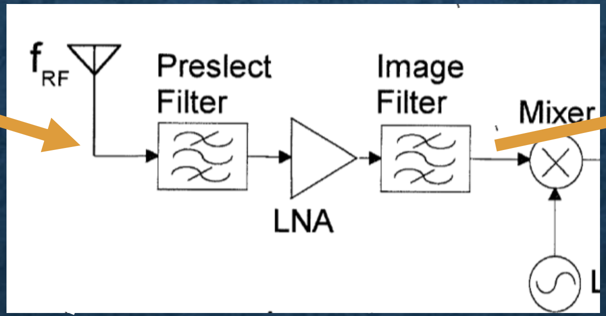
20+ videos based on and supporting a university senior-design class in RF/wireless circuits

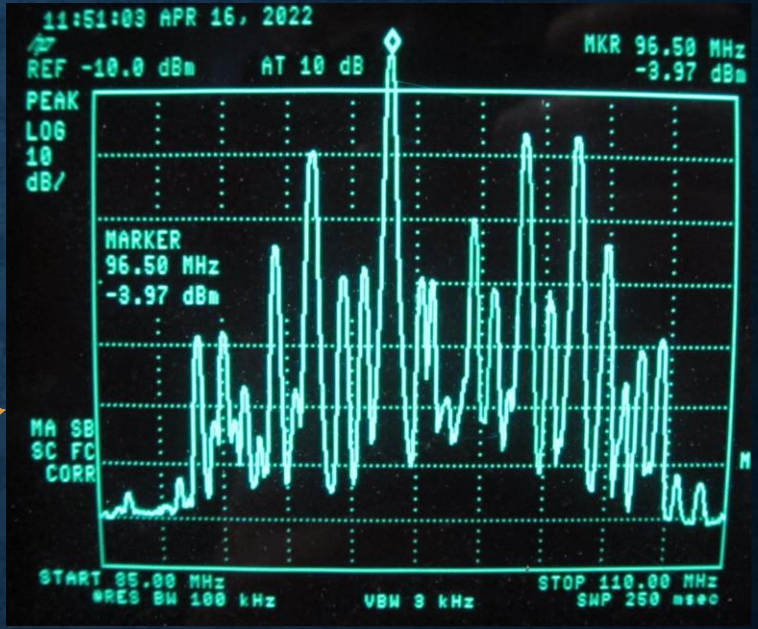


Recall RD-101 Receiver Problems





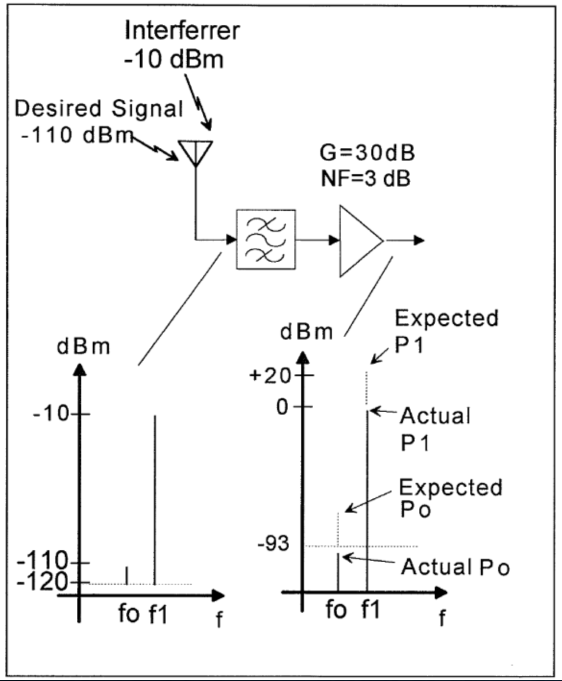




- Signal environment was harsh !
- Front-end had fixed 20 dB gain, and filtering was fixed-tuned
- So mixer was overdriven due to strong 96.3 MHz station, reducing overall gain and creating “intermod products”
- IF filter had limited off-channel rejection causing some additional “signal blocking”

Strong Signal Issues Common to all Receivers

Blocking Problem

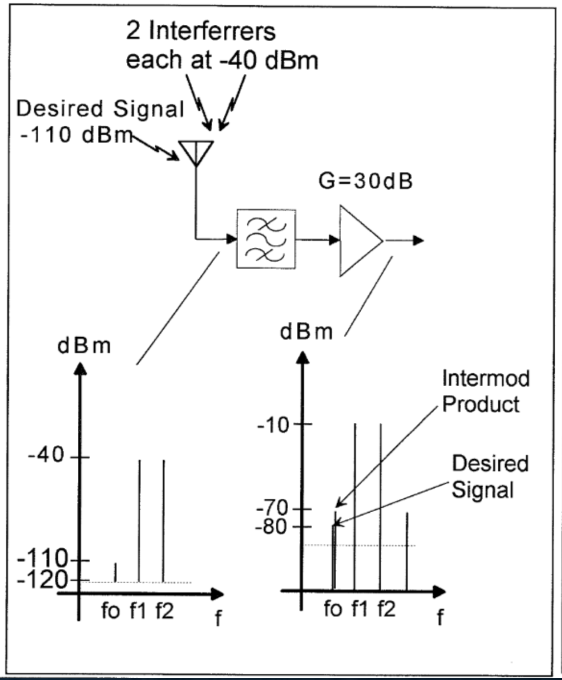


Effects
- Gain compression
- Desired signal below noise floor at output

Solutions
- Use higher power LNA
- Decrease LNA gain
- Filter out f1

NOTE
- Could occur in later stages also **Like Mixer !!**

Intermod Problem



Effects
- LNA generates "intermod products" at 2f2-f1 & 2f1-f2. Product at 2f1-f2 = fo overpowers desired signal.

Solutions
- Use higher power LNA.
- Decrease LNA gain.
- Filter out f1, f2

NOTE
- Could occur in later stages also (especially mixer.)

Outline of Today's Episode

- *Challenges in Receiver Design*
- ***Receiver Architecture Alternatives***
- *Key Points for Achieving Good Performance*
- *Ideal Low Power Receiver Design*

Architectures Through the Years

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

4.1 Early Tuned-RF Architectures

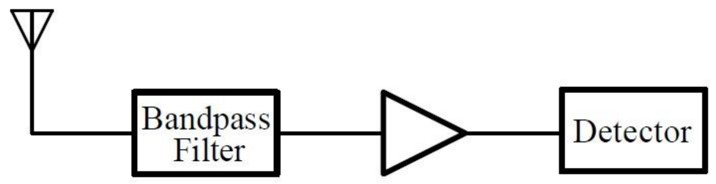


Figure 4.1: Tuned RF receiver architecture.

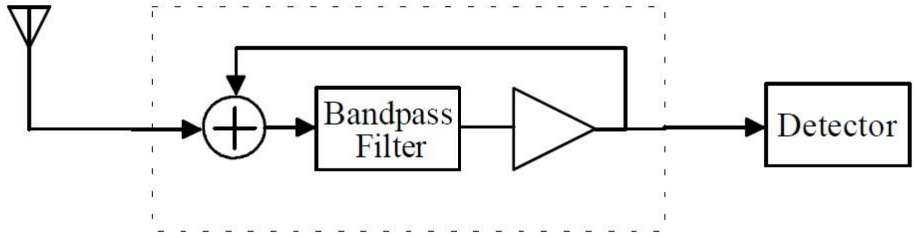


Figure 4.3: Regenerative receiver architecture.

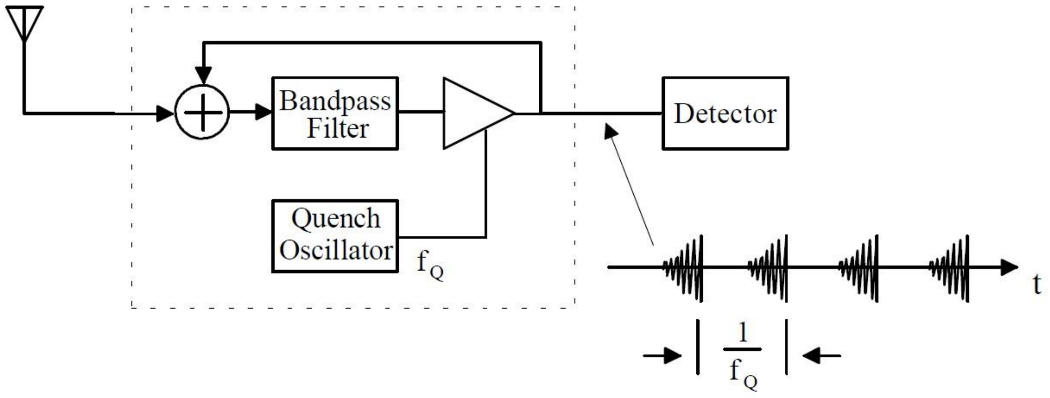
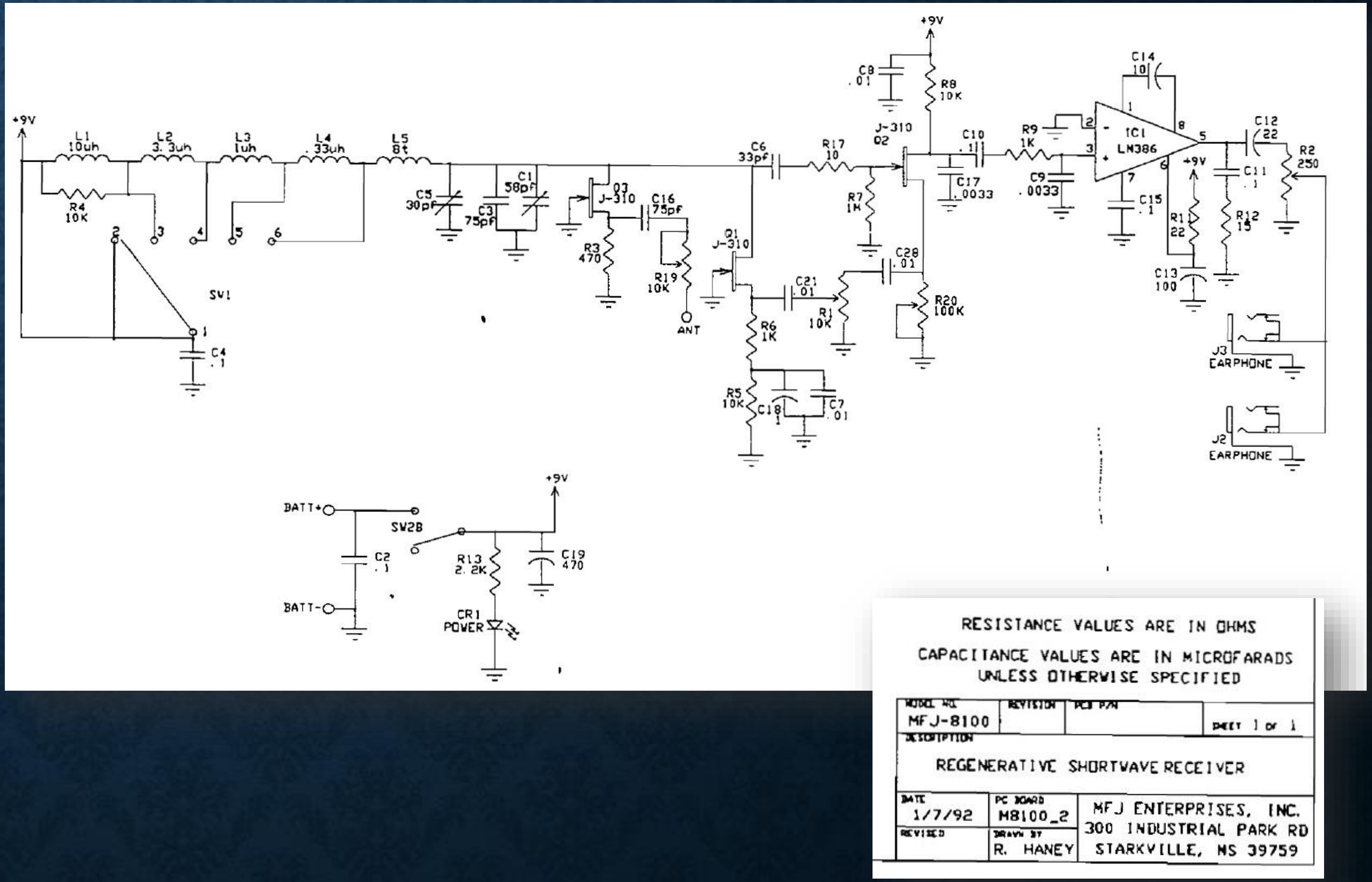


Figure 4.4: Super-regenerative receiver architecture.

Example Regenerative Receiver



4.2 Superheterodyne Receivers

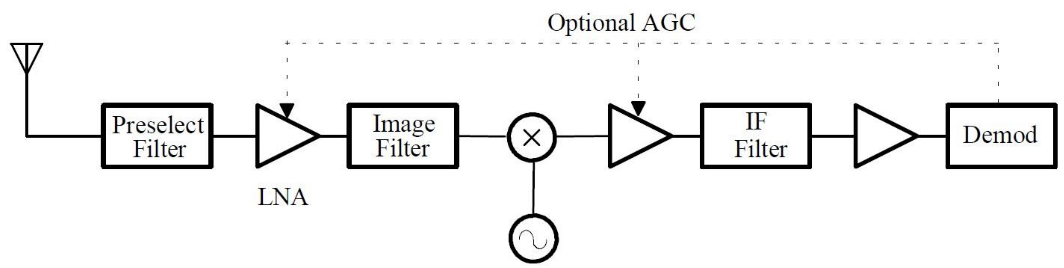


Figure 4.6: Modern superheterodyne receiver.

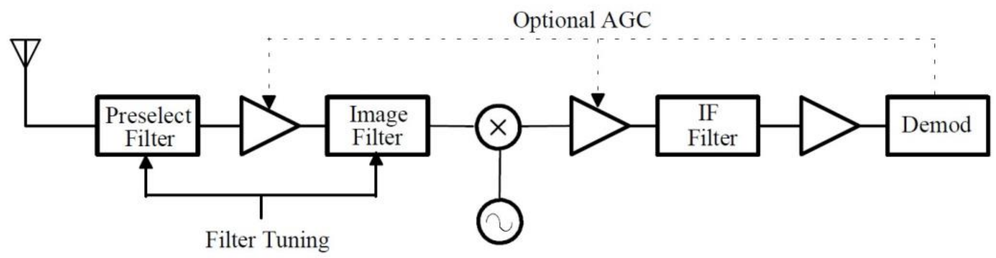


Figure 4.7: Single conversion superheterodyne with tracking preselect.

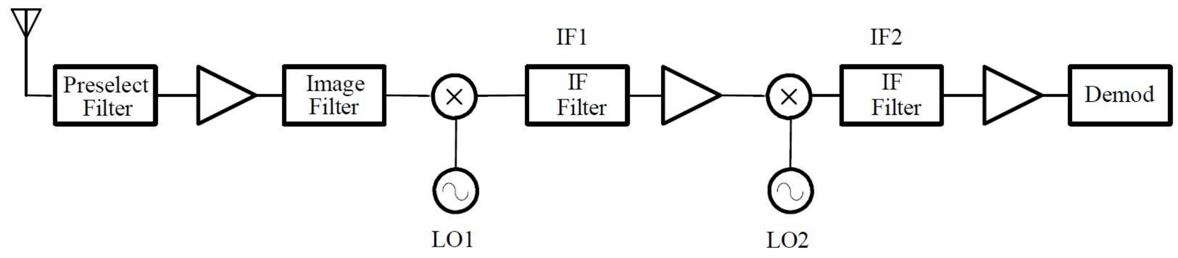


Figure 4.8: Multiple conversion superheterodyne.

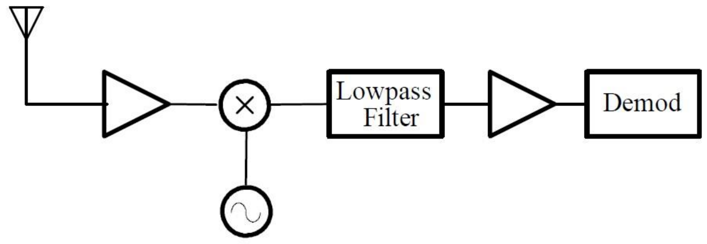
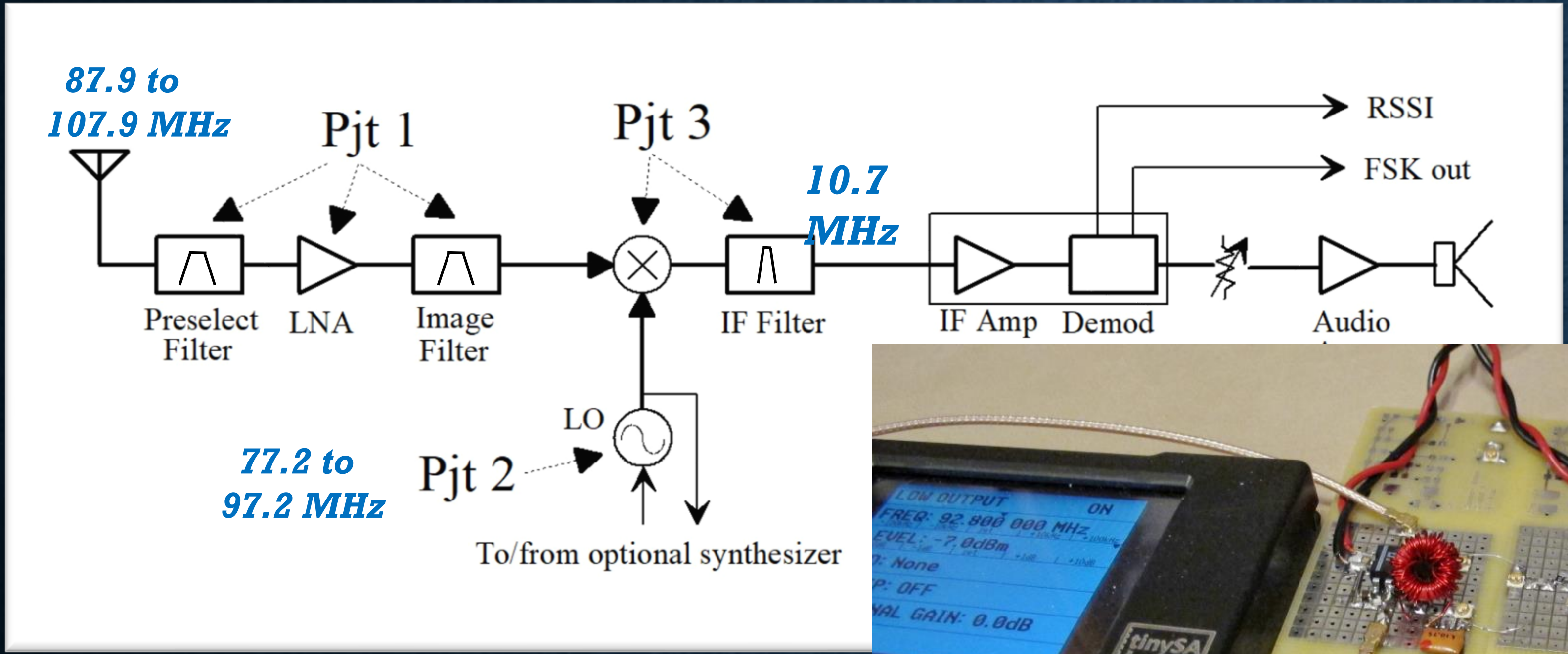
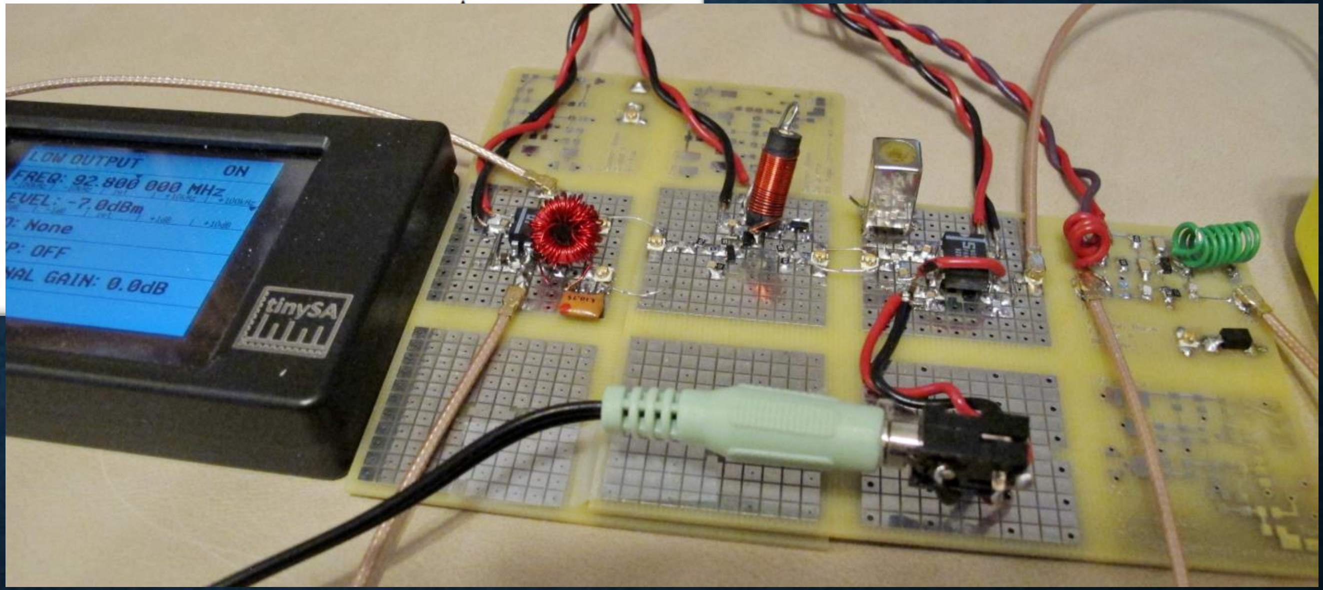


Figure 4.10: Ultra-low IF superheterodyne.

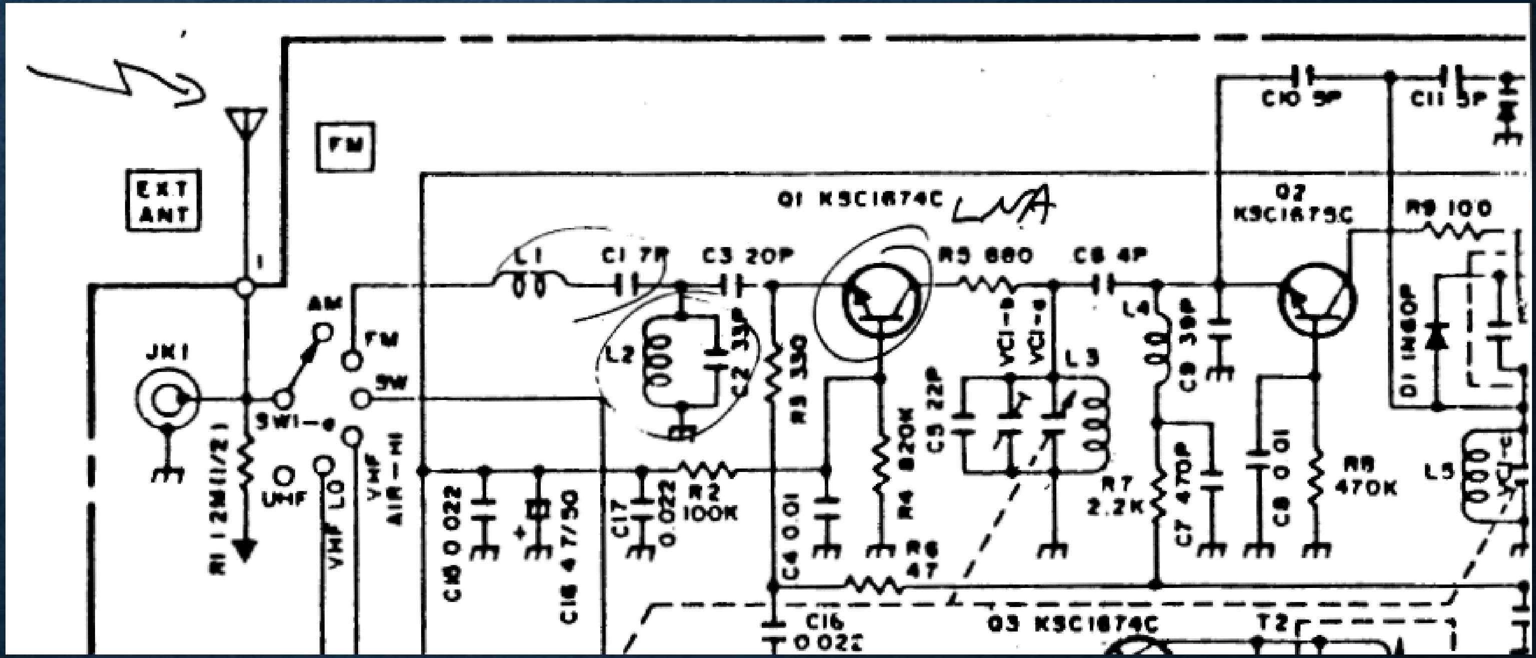
Example Superhet Receiver 1





Fixed-tuned Preselect/Image Filters Lead to Problems …

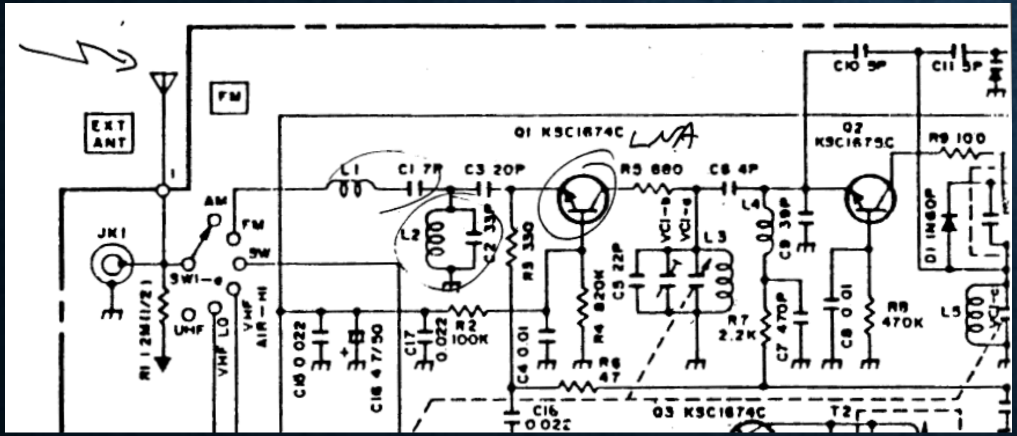
Example Superhet Receiver 2

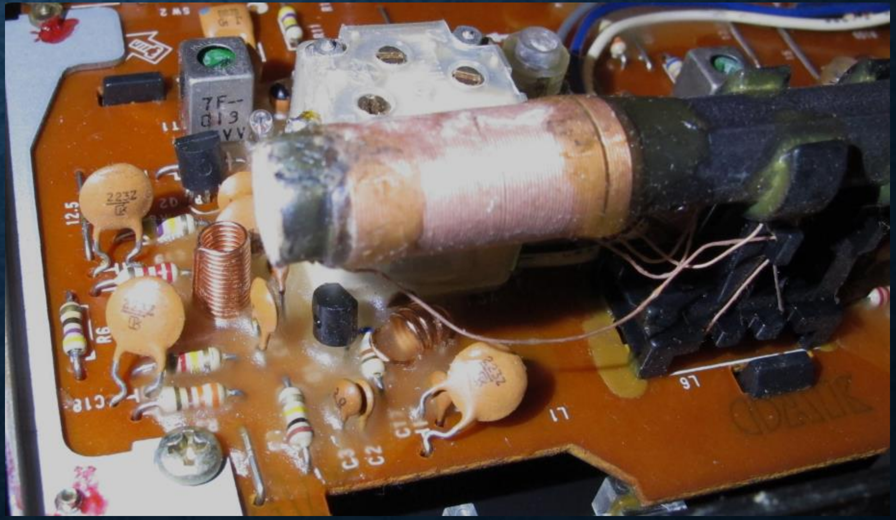


Two-Pole Preselect + Tracking Image Filter
Solves Problems ☺

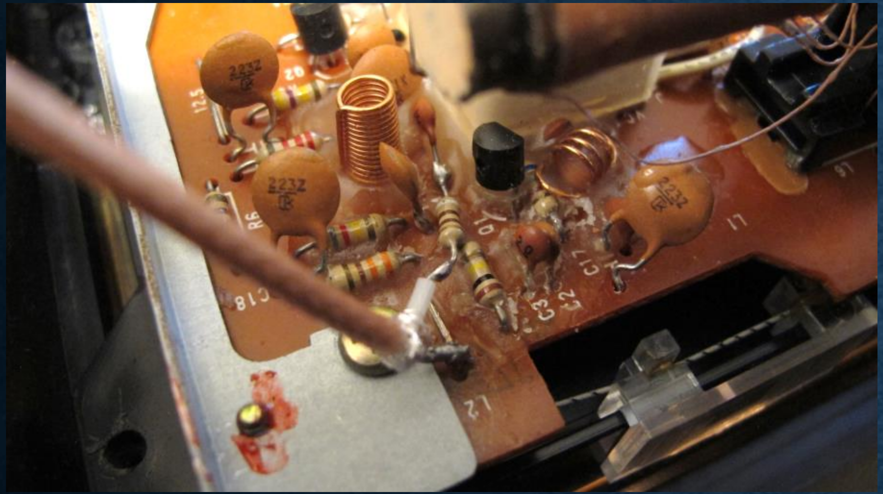
Example Superhet Receiver 2

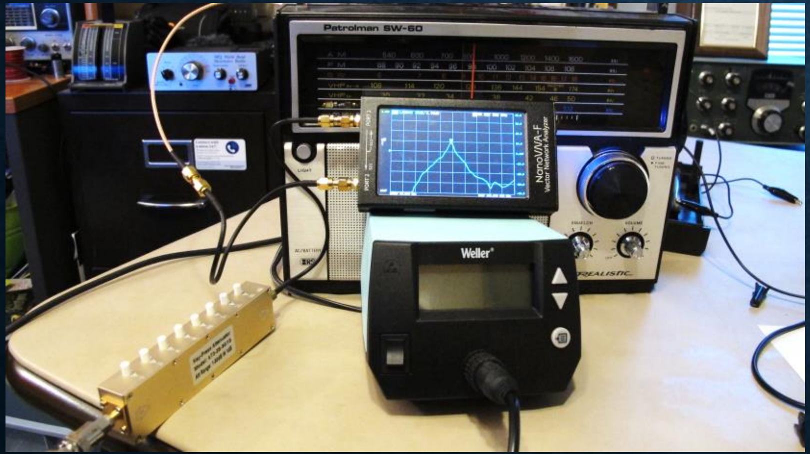
CAUTION – TO PREVENT ELECTRIC SHOCK, DO NOT REMOVE COVER
NO USER-SERVICEABLE PARTS INSIDE. REFER SERVICING
TO QUALIFIED SERVICE PERSONNEL





Example Superhet Receiver 2

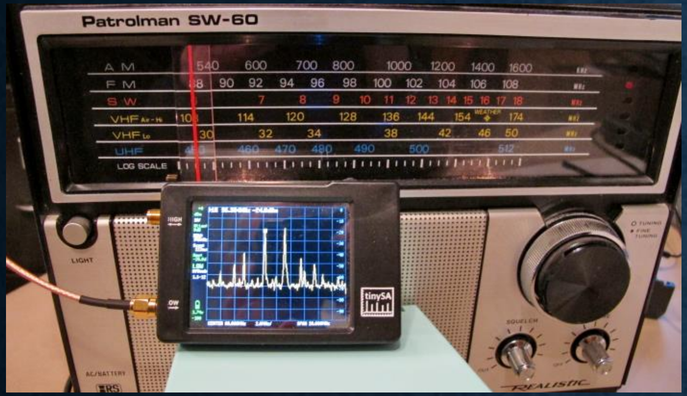


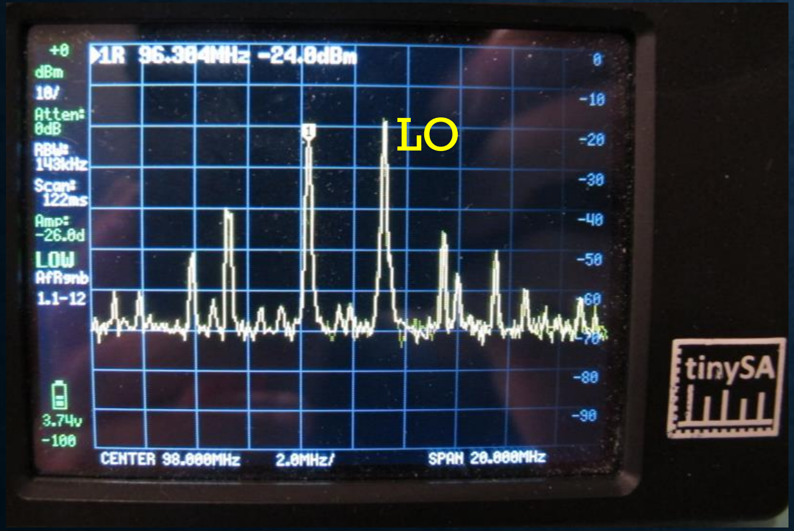


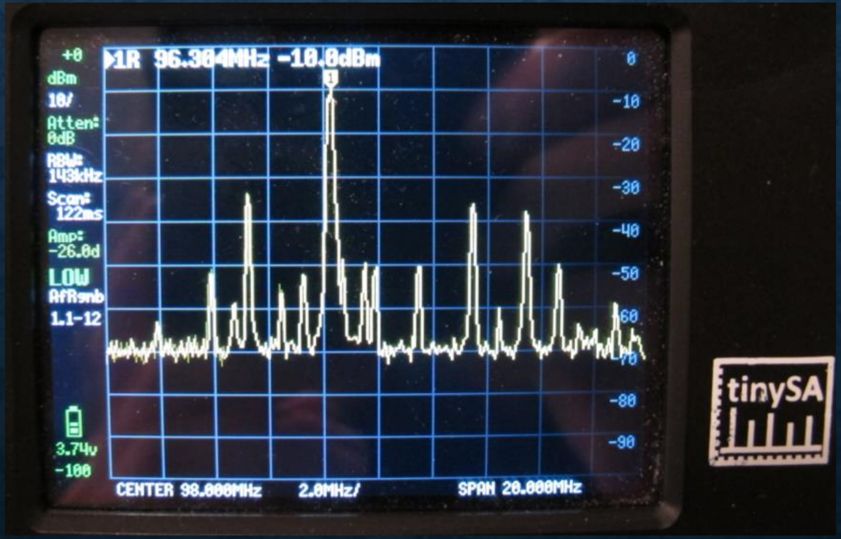
Measured 3 dB Bandwidth = 4 MHz
(Selectivity Q of 25)

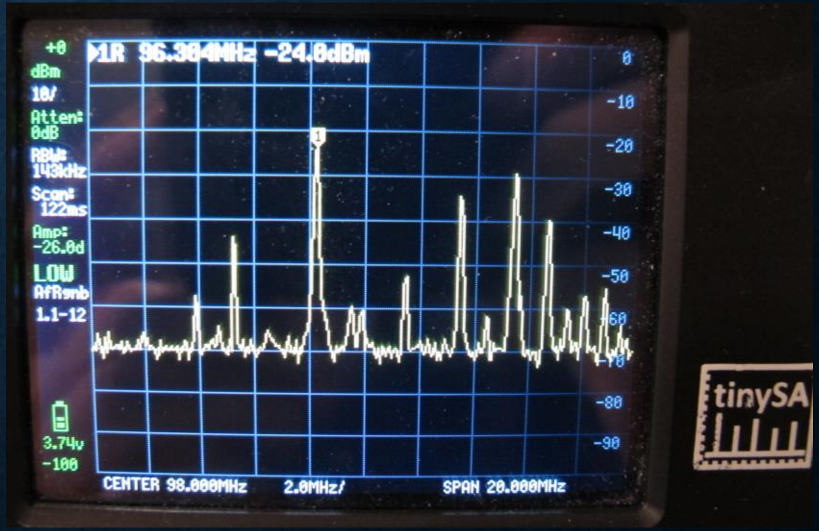
0 to 200 MHz span. With 20 dB attenuation to prevent compression. Actual gain is 20 dB higher.

Example Superhet Receiver 2

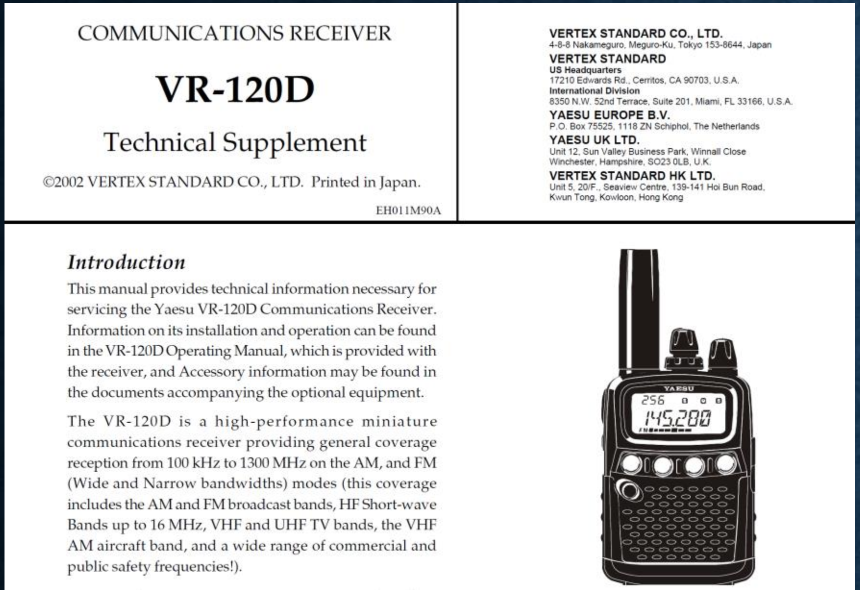








Example Superhet Receiver 3


COMMUNICATIONS RECEIVER

VR-120D

Technical Supplement

EH011M90A

VERTEX STANDARD CO., LTD.
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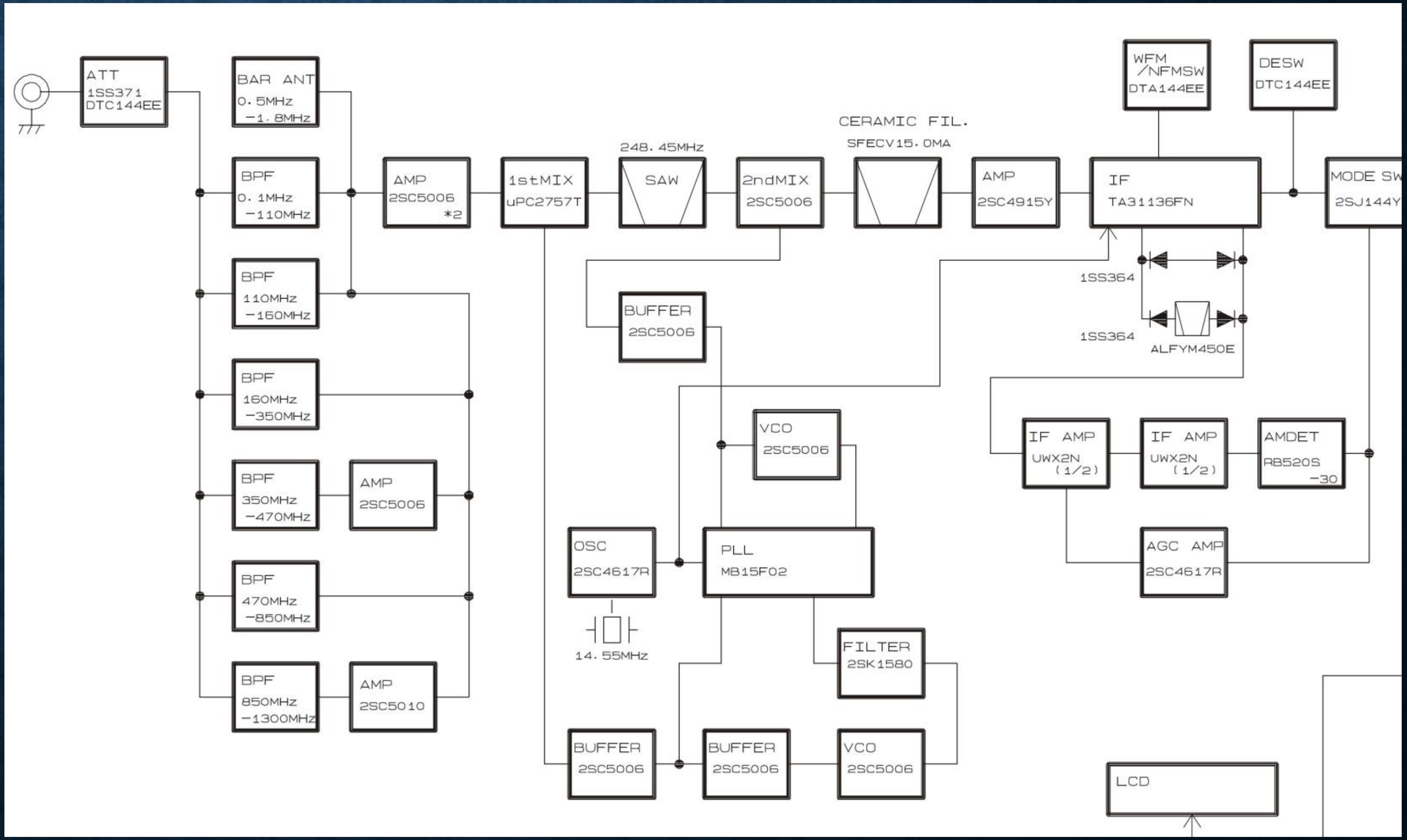
YAESU UK LTD.
Unit 12, Sun Valley Business Park, Winnall Close
Winchester, Hampshire, SO23 0LB, U.K.
VERTEX STANDARD HK LTD.
Unit 5, 20/F., Seaview Centre, 139-141 Hoi Bun Road,
Kwun Tong, Kowloon, Hong Kong

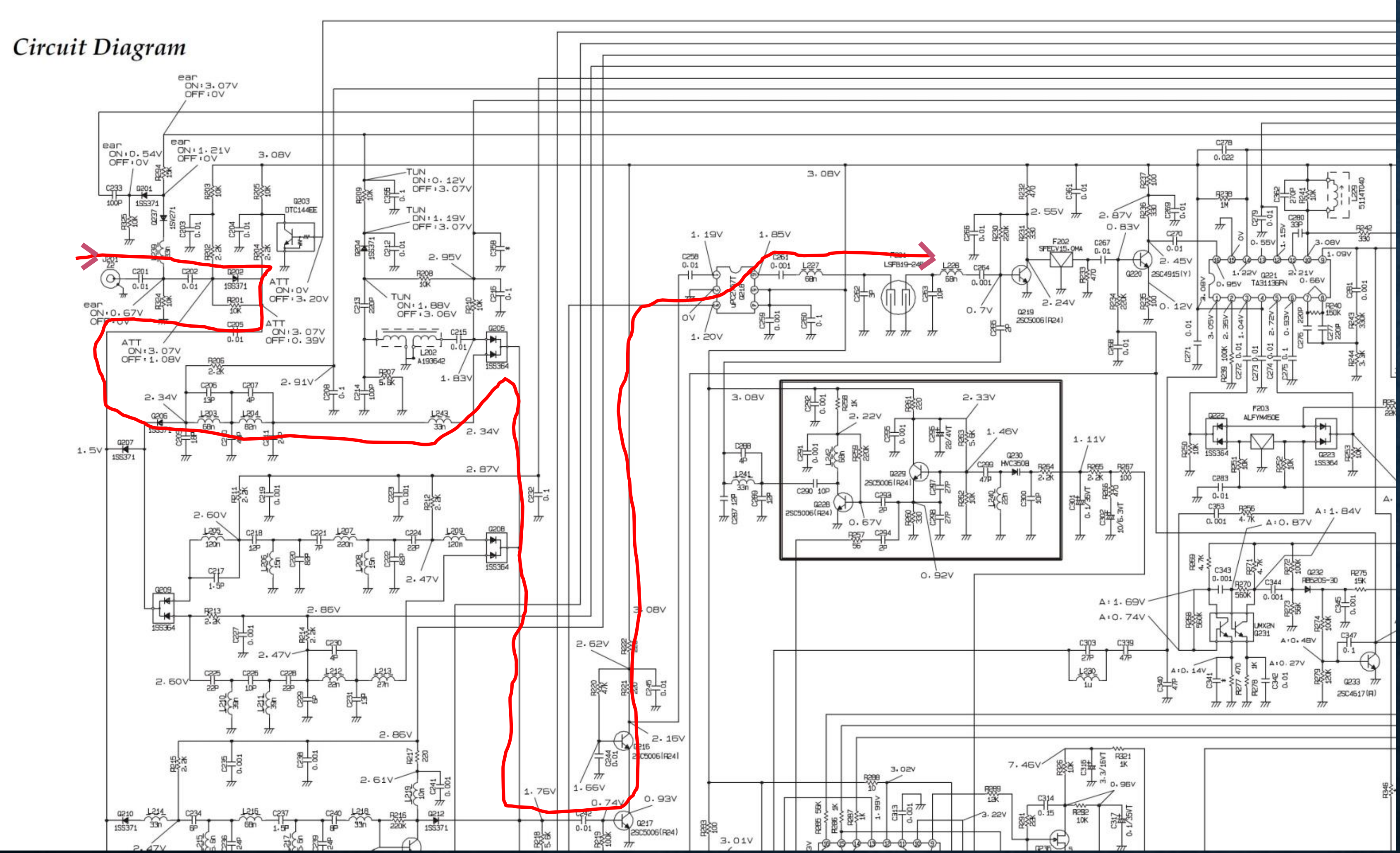
Introduction

This manual provides technical information necessary for servicing the Yaesu VR-120D Communications Receiver. Information on its installation and operation can be found in the VR-120D Operating Manual, which is provided with the receiver, and Accessory information may be found in the documents accompanying the optional equipment.

The VR-120D is a high-performance miniature communications receiver providing general coverage reception from 100 kHz to 1300 MHz on the AM, and FM (Wide and Narrow bandwidths) modes (this coverage includes the AM and FM broadcast bands, HF Short-wave Bands up to 16 MHz, VHF and UHF TV bands, the VHF AM aircraft band, and a wide range of commercial and public safety frequencies!).



Example Superhet Receiver 3

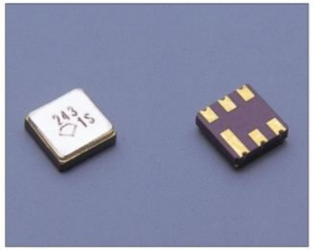


LSFB25-243-220K0
LSFB19-248-220K0

200MHz Band SAW Filter of PHS

■Features

- SAW filter for PHS.
- Miniature size and light weight.
- Because it is leadless type, automatic mounting is possible.



■Standard Frequencies

- 243.95MHz.
- 248.45MHz.

■Specifications

Item	Unit	Conditions	LSFB25-243-220K0 Specifications	LSFB19-248-220K0 Specifications
Nominal Frequency	MHz	———	243.95	248.45
Operating Temperature Range	℃	−10~+60	———	———
Storage Temperature Range	℃	−35~+85	———	———
Insertion Loss	dB	Minimum Loss	5.0 MAX.	5.0 MAX.
Guaranteed Attenuation	dB	Fo±0.6MHz	25 MIN.	25 MIN.
		Fo±1.2MHz	40 MIN.	40 MIN.
Group Delay Deviation	μsec	Fo±110kHz	1.2 MAX.	1.2 MAX.

4.3 Direct Conversion Receivers

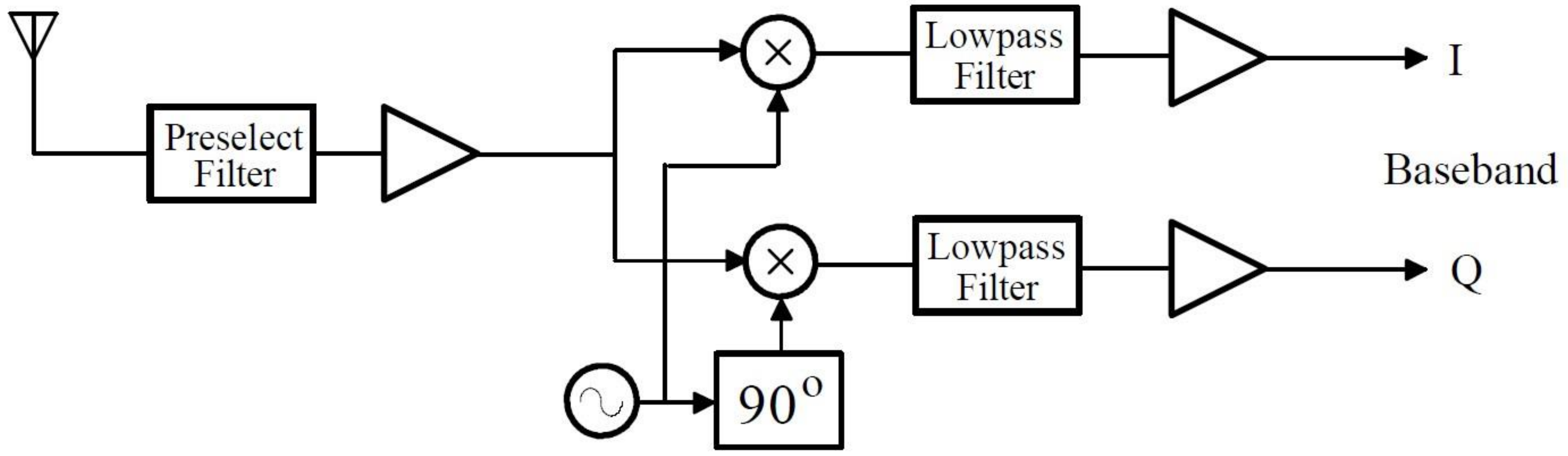


Figure 4.13: Direct conversion receiver architecture.

4.4 Digital Receivers

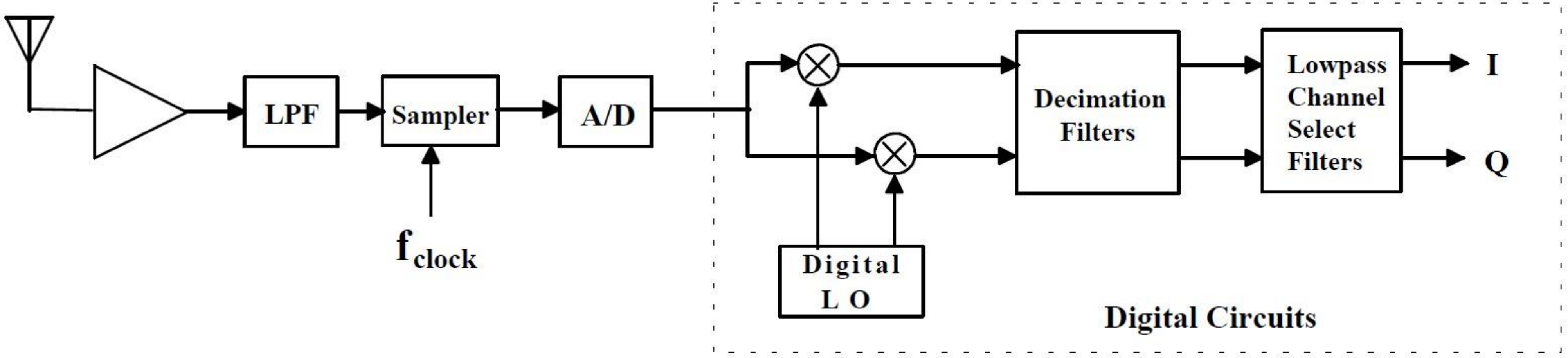
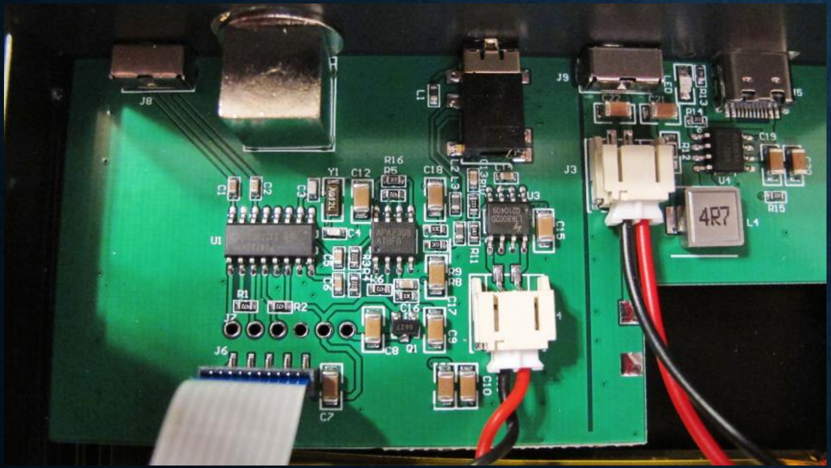


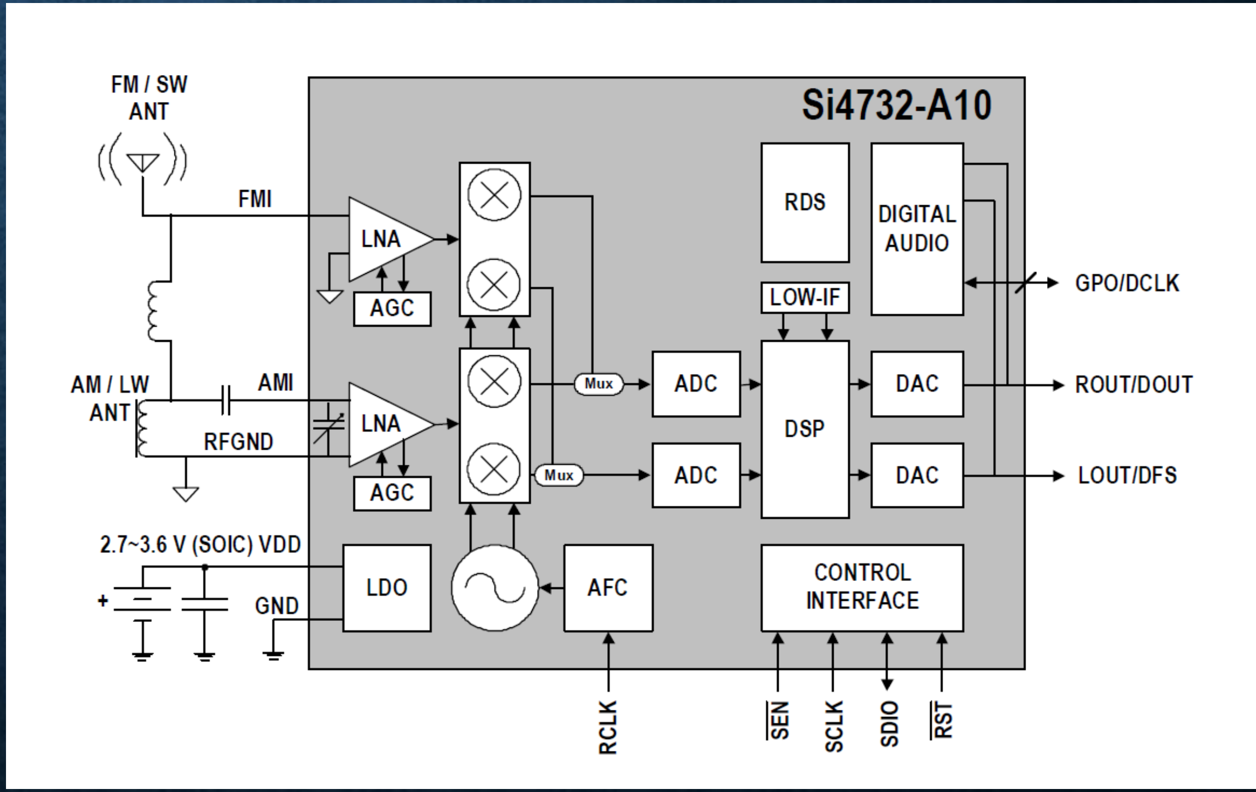
Figure 4.14: Simplified digital receiver architecture.

Example Low-IF / Direct Conversion Receiver

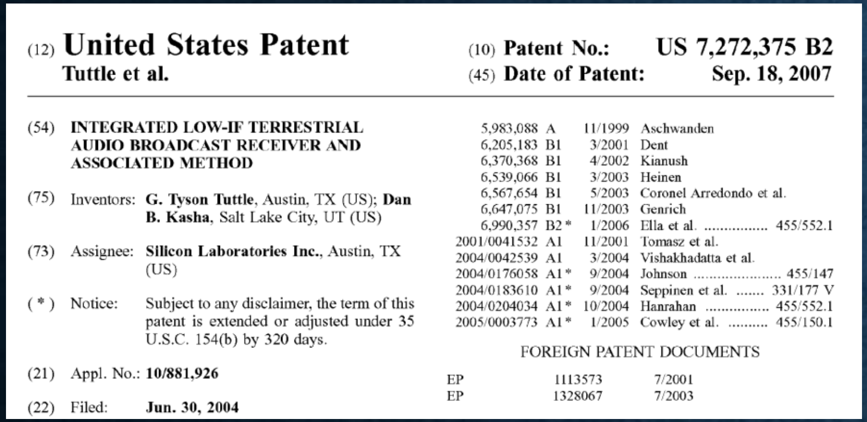


Si4732-A10

Broadcast AM/FM/SW/LW/RDS Radio Receiver



Example Zero/Low-IF Receiver with DSP
(SDR)



(12) **United States Patent**
Tuttle et al.

(10) **Patent No.:** **US 7,272,375 B2**
(45) **Date of Patent:** **Sep. 18, 2007**

(54) **INTEGRATED LOW-IF TERRESTRIAL AUDIO BROADCAST RECEIVER AND ASSOCIATED METHOD**

(75) Inventors: **G. Tyson Tuttle**, Austin, TX (US); **Dan B. Kasha**, Salt Lake City, UT (US)

(73) Assignee: **Silicon Laboratories Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 320 days.

(21) Appl. No.: **10/881,926**

(22) Filed: **Jun. 30, 2004**

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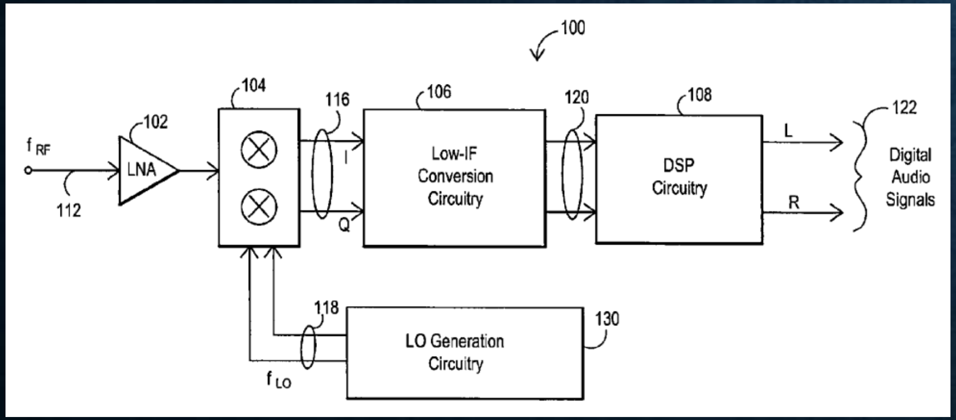

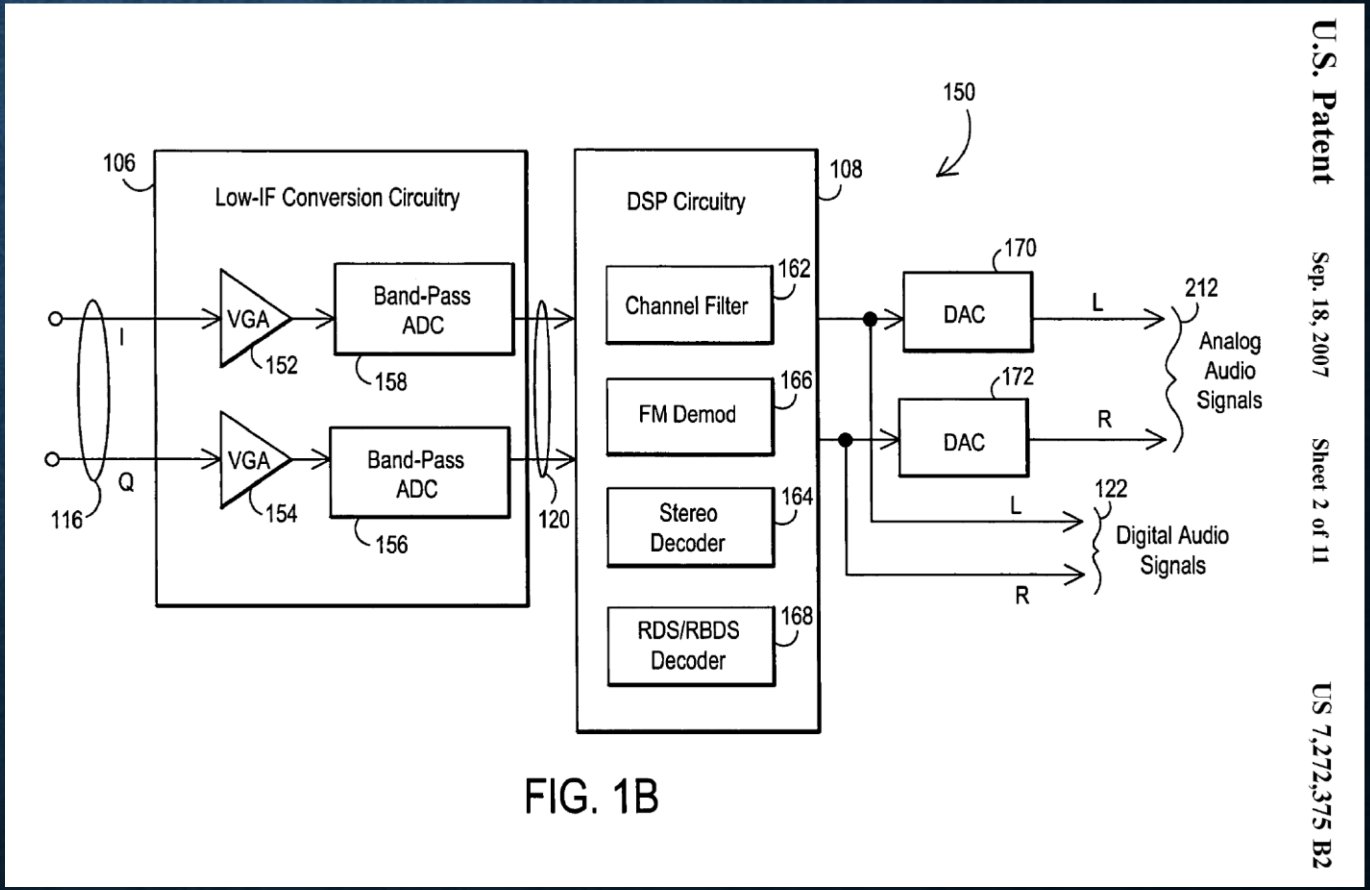

FIG. 1B

Example Zero/Low-IF Receiver with AGC

(12) **United States Patent**
Srinivasan et al.

(10) **Patent No.:** **US 7,426,376 B2**
(45) **Date of Patent:** **Sep. 16, 2008**

(54) **RECEIVER HAVING DIGITAL AUTOMATIC GAIN CONTROL**

(75) Inventors: **Vishnu S. Srinivasan**, Austin, TX (US); **G. Tyson Tuttle**, Austin, TX (US); **Dan B. Kasha**, Seattle, WA (US); **Alessandro Piovaccari**, Austin, TX (US)

(73) Assignee: **Silicon Laboratories Inc.**, Austin, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 443 days.

(58) **Field of Classification Search** 455/136, 455/138, 232.1, 239.1, 240.1, 250.1, 252.1, 455/234.1, 333
See application file for complete search history.

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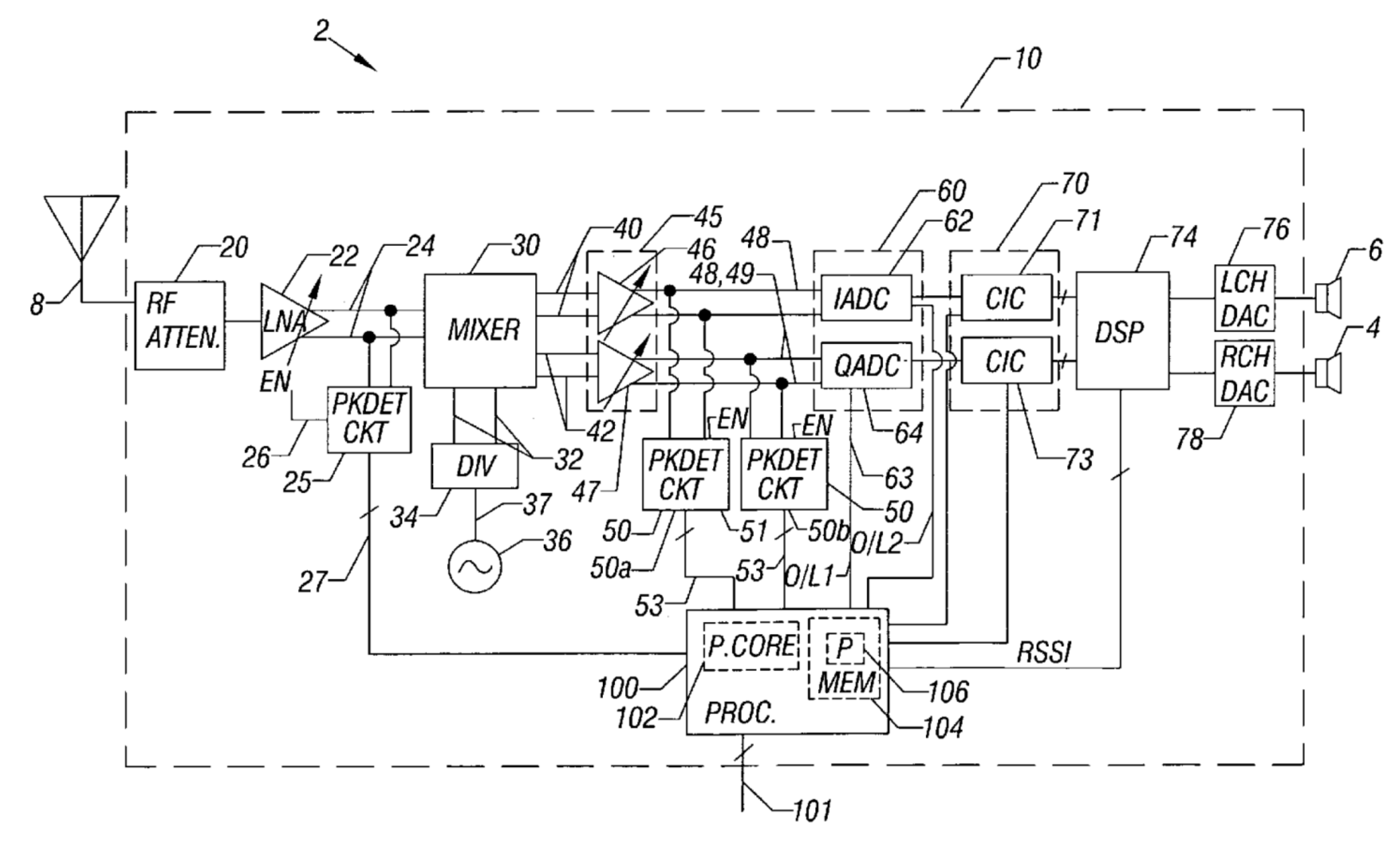


Outline of Today's Episode

- *Challenges in Receiver Design*
- *Receiver Architecture Alternatives*
- ***Key Points for Achieving Good Performance***
- *Ideal Low Power Receiver Design*

Key Takeaways

- Strong-signal interferers create blocking and intermod problems in receivers ! (can be out-of-band or in-band)
- Traditional solutions
  - Preselect (and image) filtering
  - RF (and IF) gain control using attenuators/AGC
  - Selective antennas (Resonant and/or directive)
  - Higher power consumption in circuits to improve compression and intermodulation performance
- Tracking front-end filters generally provide best performance if low power is needed (but are difficult to integrate on-chip)
- Leveraging classic technique of regeneration can provide additional solutions (Q-enhanced filtering)
- Offers possibility of good performance without high power consumption

Outline of Today's Episode

- *Challenges in Receiver Design*
- *Receiver Architecture Alternatives*
- *Key Points for Achieving Good Performance*
- *Ideal Low Power Receiver Design*

Ideal <u>Low Power</u> Receiver

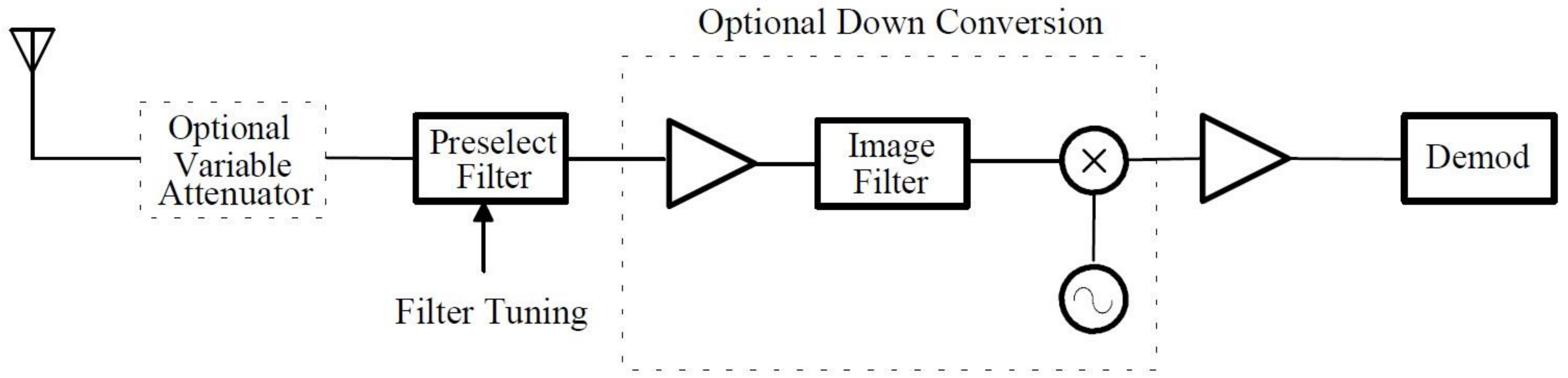
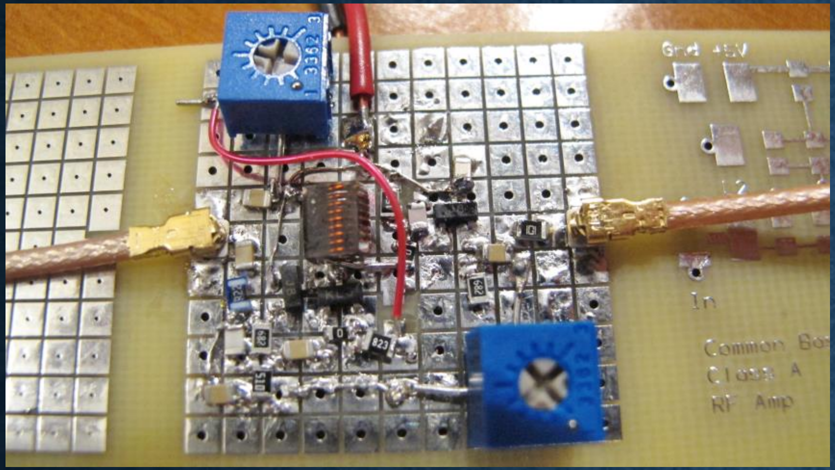
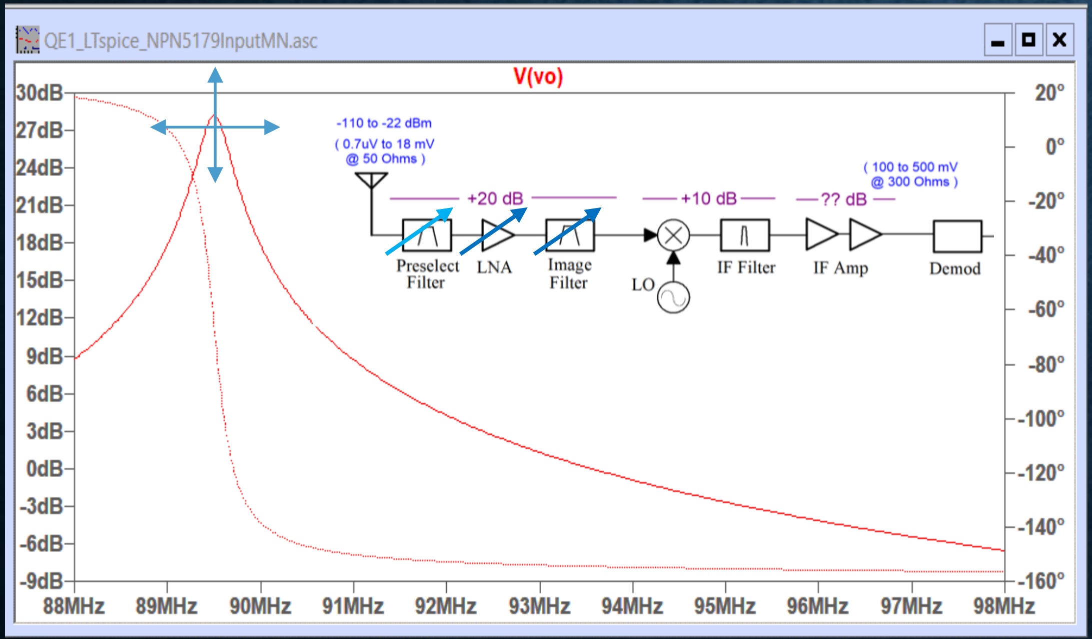


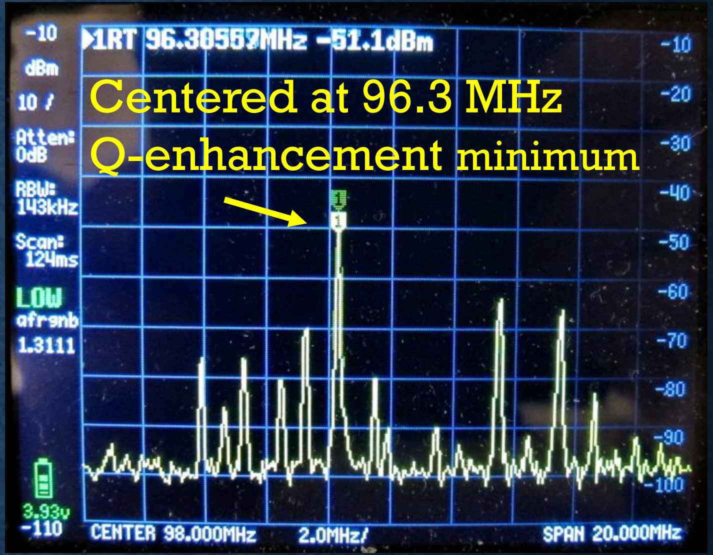
Figure 4.16: Ideal receiver architecture.

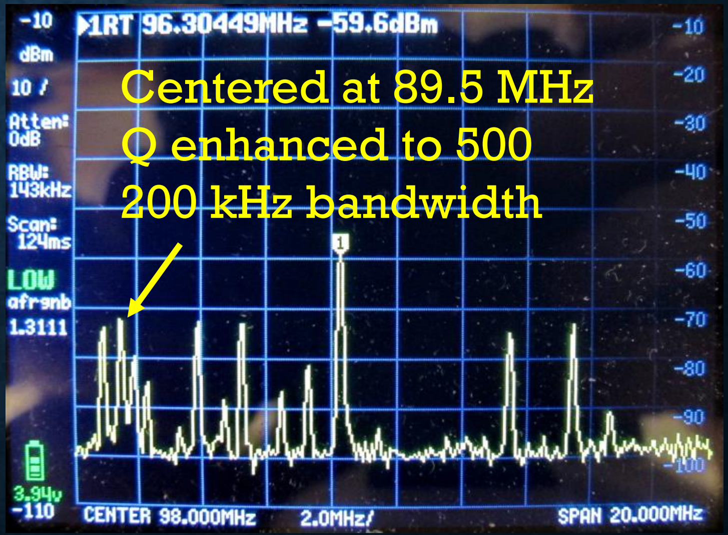
From: Design of Integrated, Low Power, Radio Receivers in BiCMOS Technologies, PhD dissertation, Virginia Tech, 1995.

Prototype Q-enhanced LNA



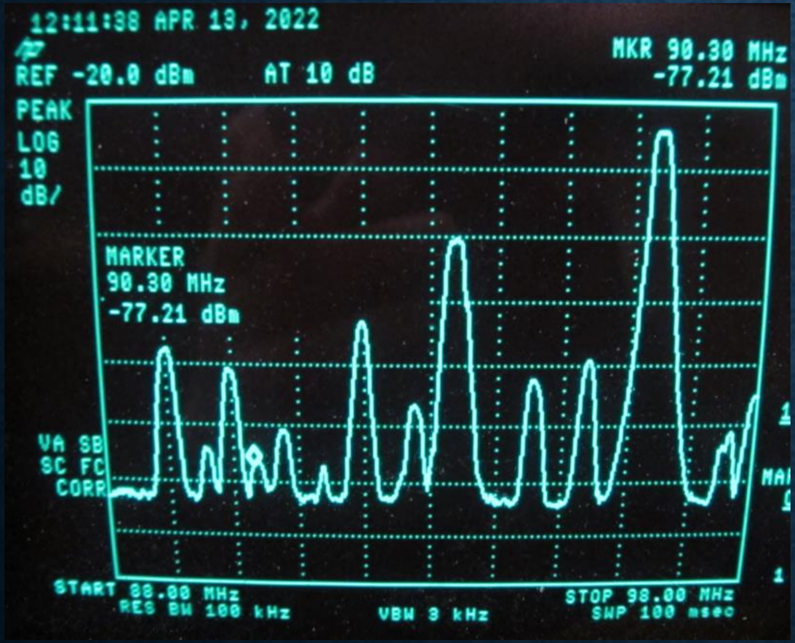






Lower Half of Band

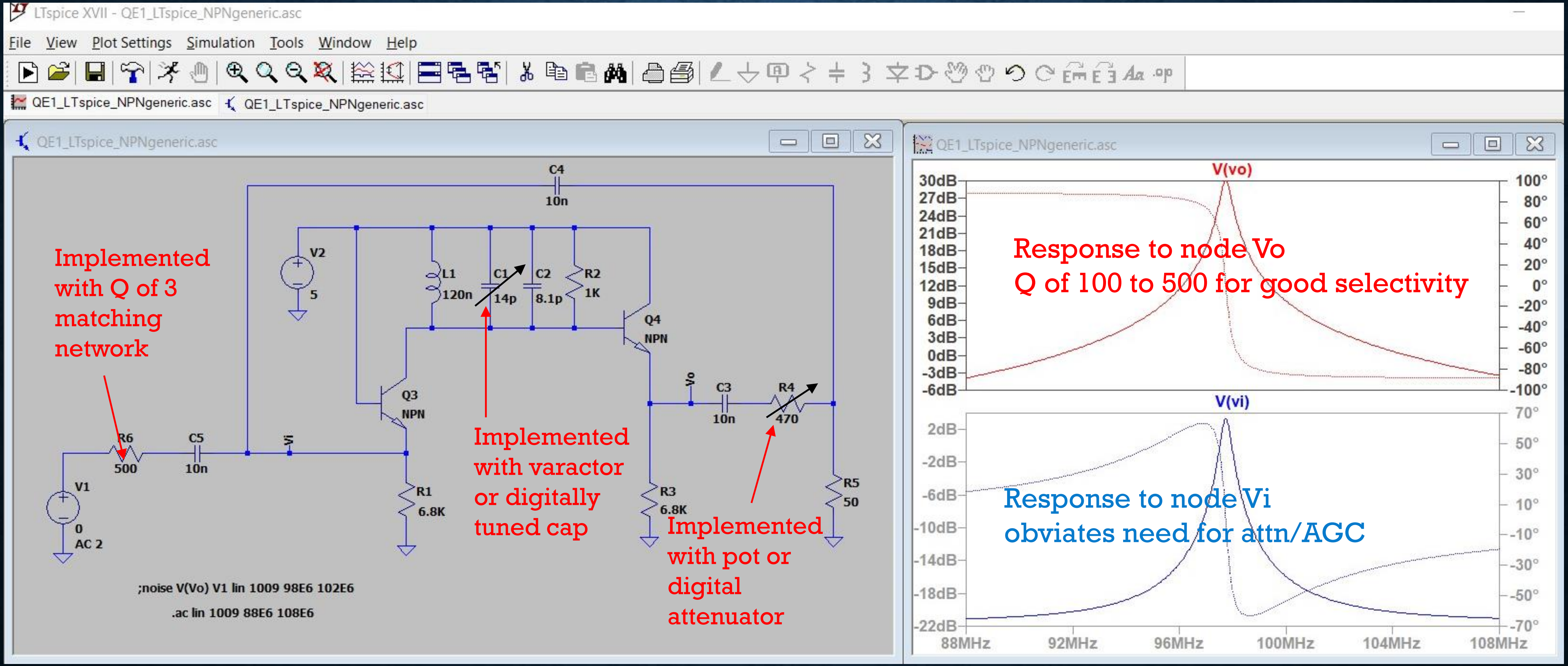
88 to 98 MHz



Station	dBm	ATS 25	VR-120	SW-60	RD-101*
88.1	-96				
88.9	-58				
89.5	-75				
89.9	-61				
90.3	-77				
90.5	-85				
90.7	-71				
91.3	-80				
91.9	-55				
92.5	-82				TBD
92.7	-70				|
93.3	-41				|
94.5	-63				V
95.3	-60				
96.3	-24				
97.5	-80				
97.9	-66				

Prototype Q-enhanced LNA

1.2 mA at 5 V ☺



Future Video Series Topics ?

- Further Q-Enhanced Front-End Development (Including Linearization and Tuning Control Algorithms)
- Performance measures (compression points, intermodulation, power consumption)
- Spurious frequency products from mixers
- Receiver ideal sensitivity (MDS, Noise Figure, etc.)
- Elevated Noise Floors (RFI caused by modern switch-mode power supplies and lighting)

Thanks For Watching !