Receiver (Wireless) Basics

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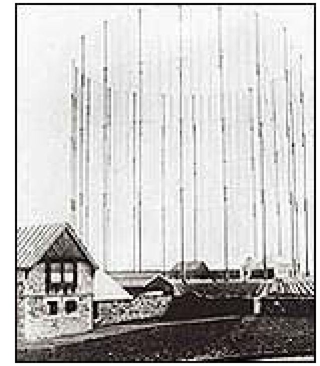
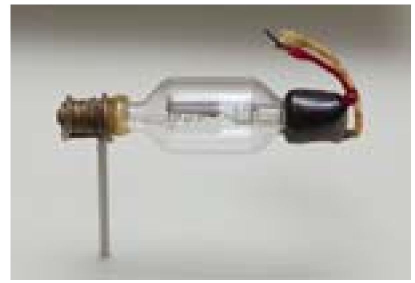
A Few Highlights of Wireless History

1901 Guglielmo Marconi: transatlantic radio transmission → "S"



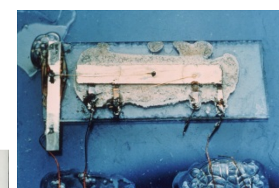
1905 Ambose Fleming:
vacuum tube
→ detection of radio waves

1906 Lee De Forest:
triode vacuum tube
→ amplify radio waves

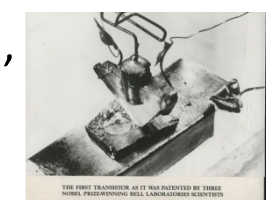


1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

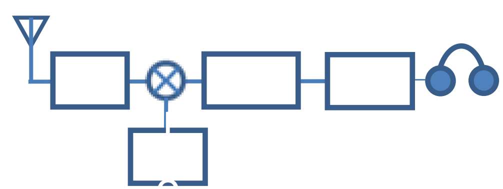
1959: Noyce, Kirby:
integrated circuit



1948: Bardeen, Brattain,
Shockley: transistor

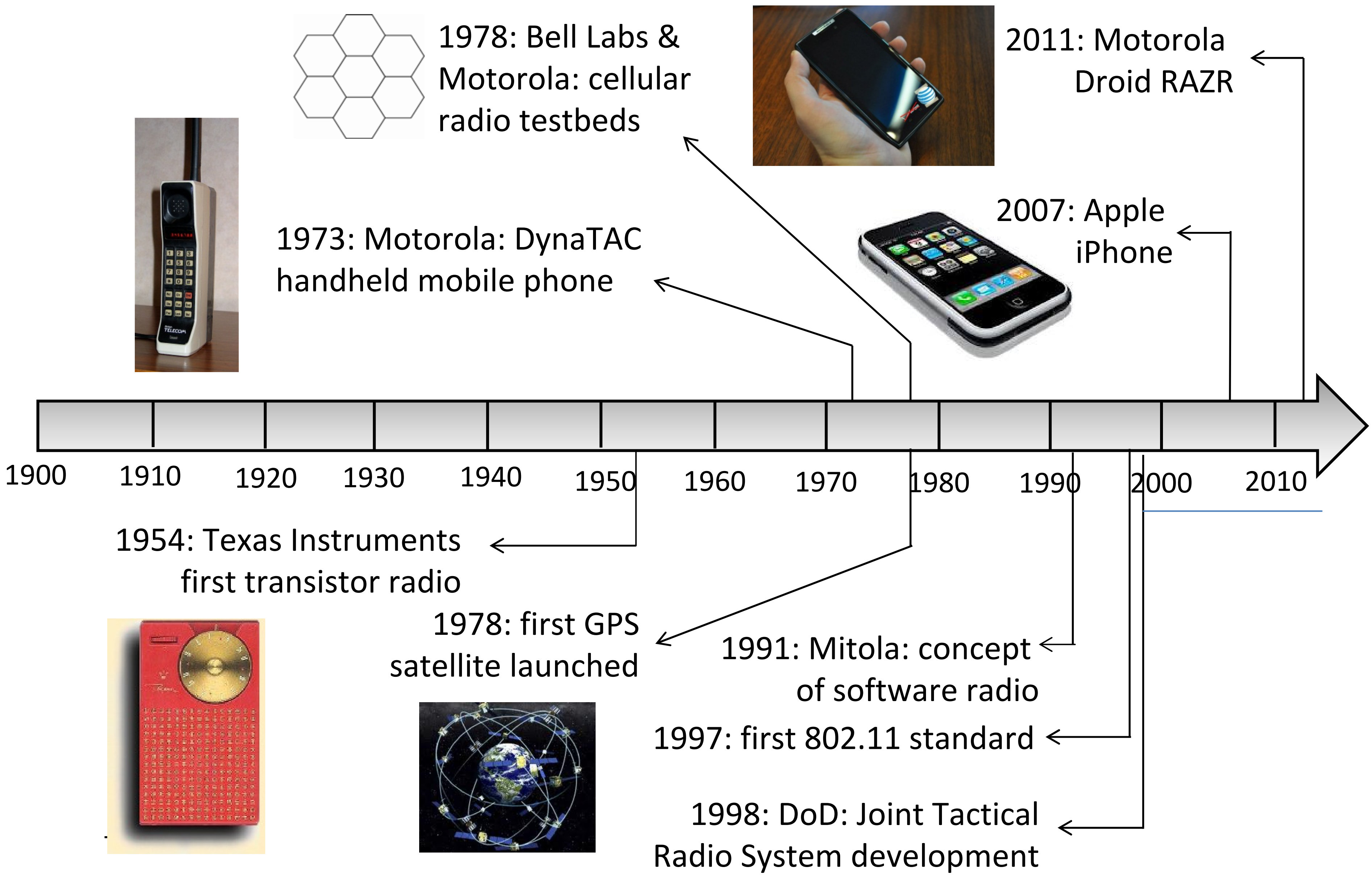


1918 Edwin Armstrong: superhet receiver



1906 Bose & Packard:
cat's wisker detector
(used until 1945)

A Few Highlights of Radio History



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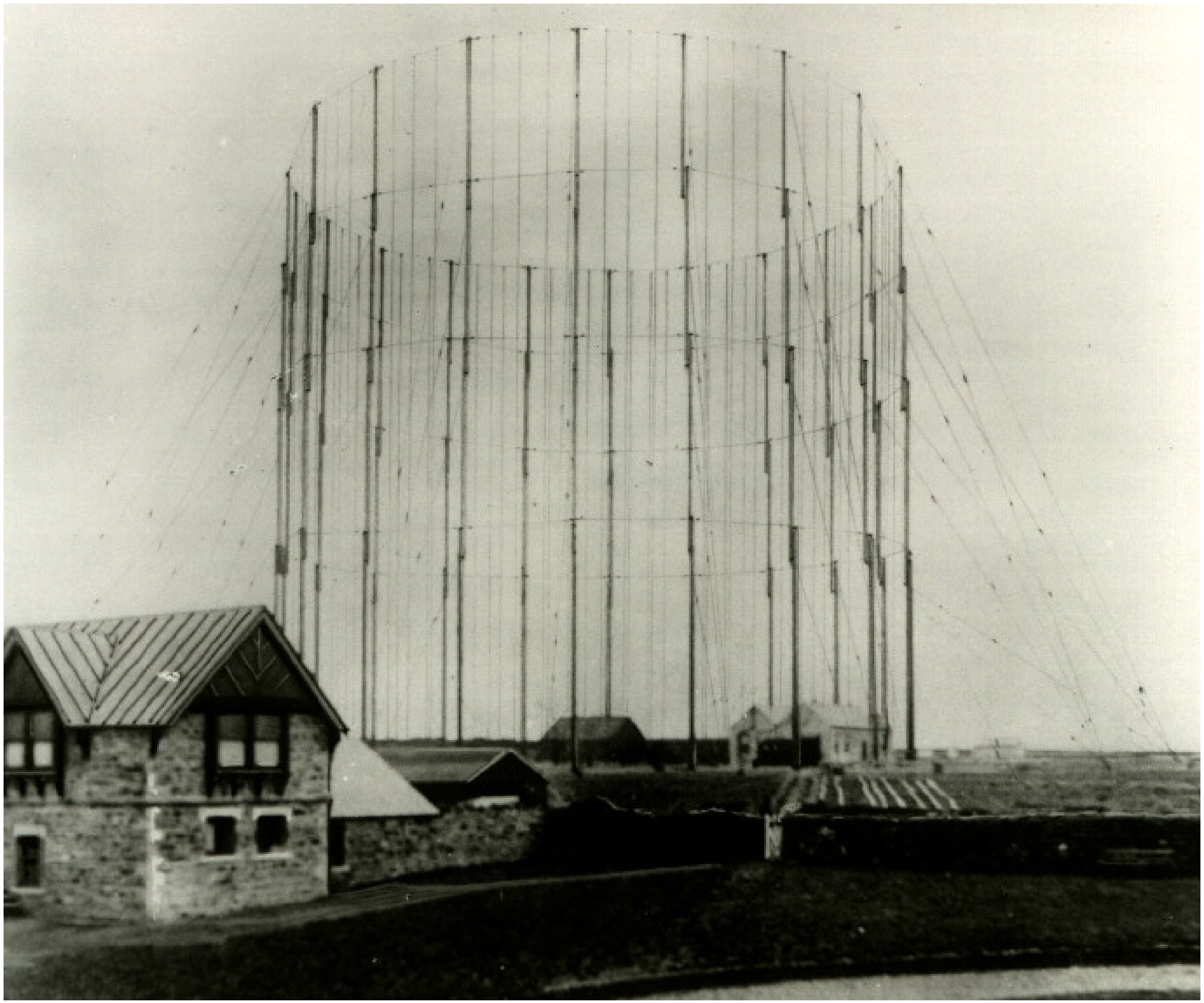
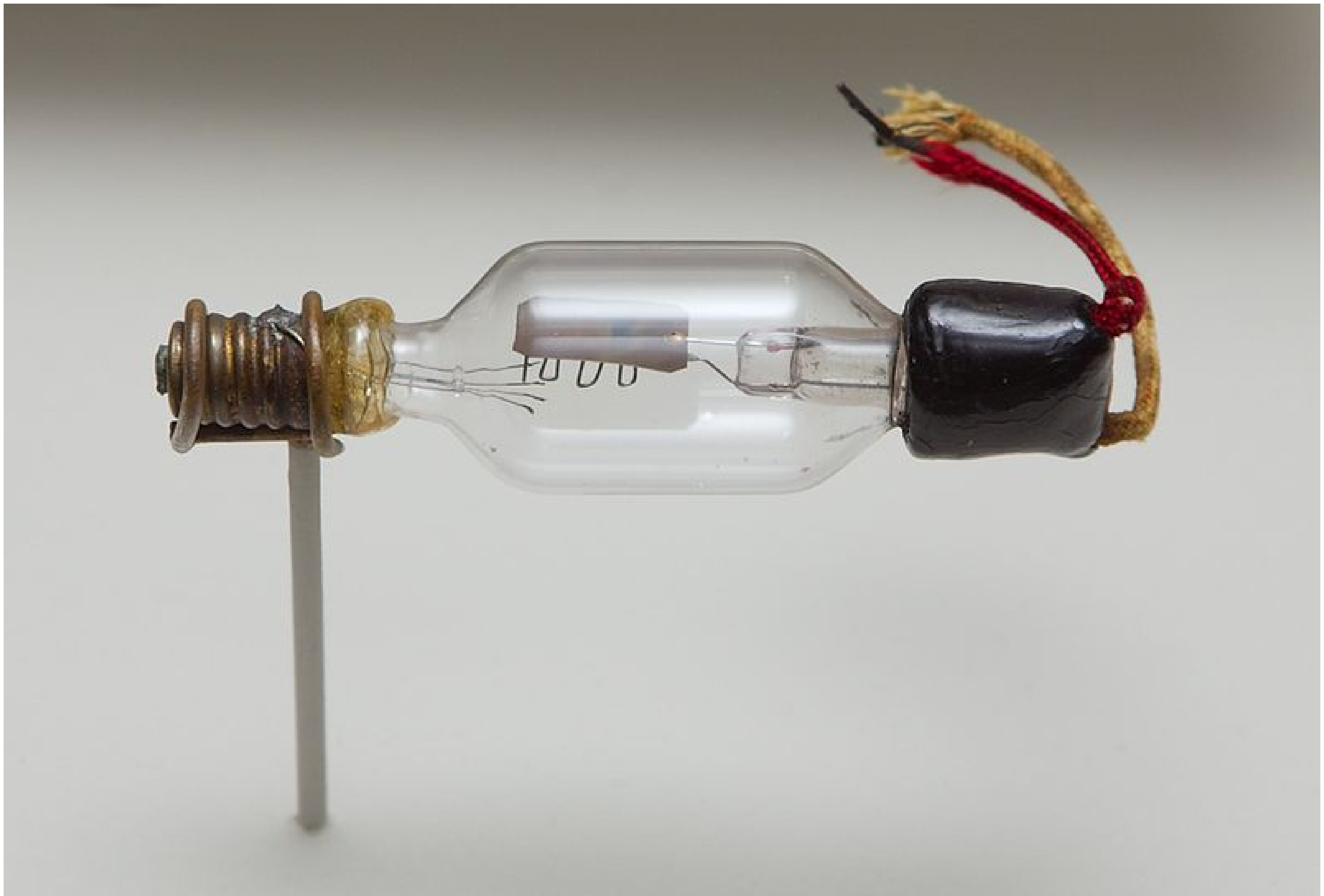


1906 Lee De Forest: triode vacuum tube



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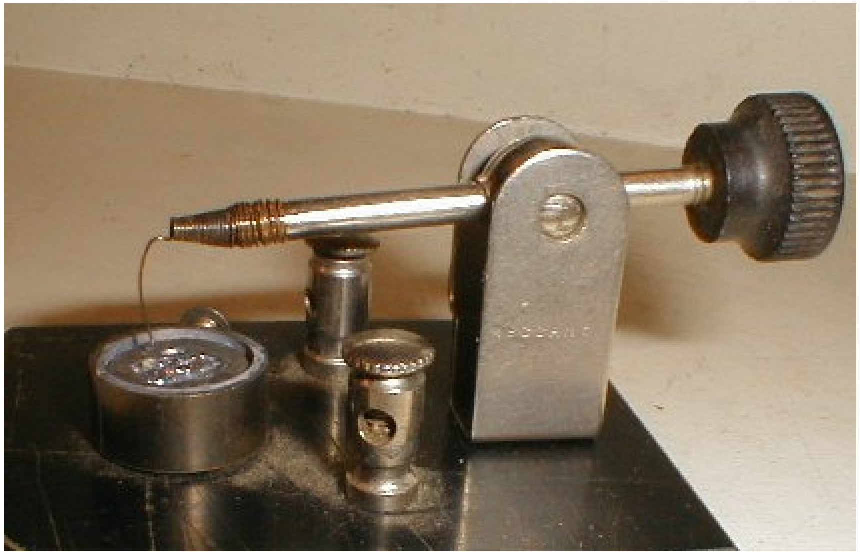
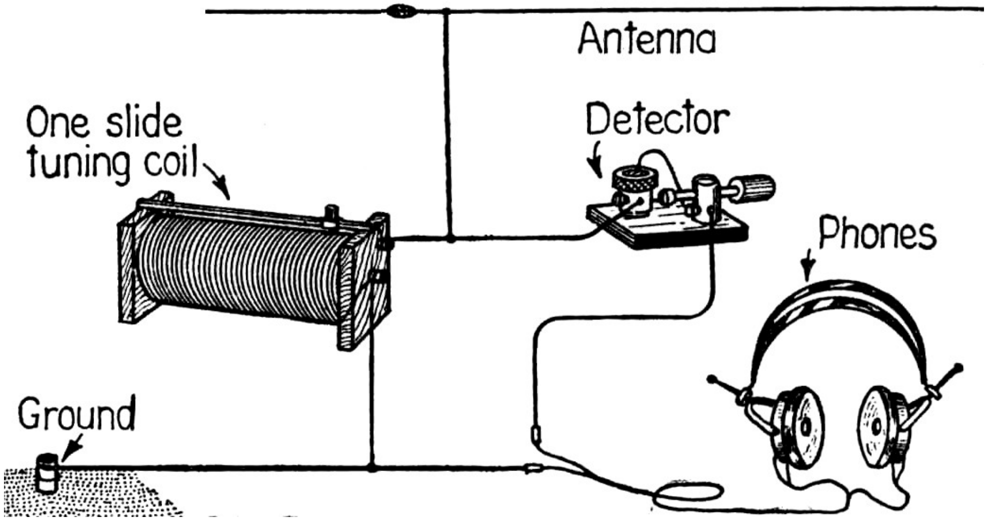
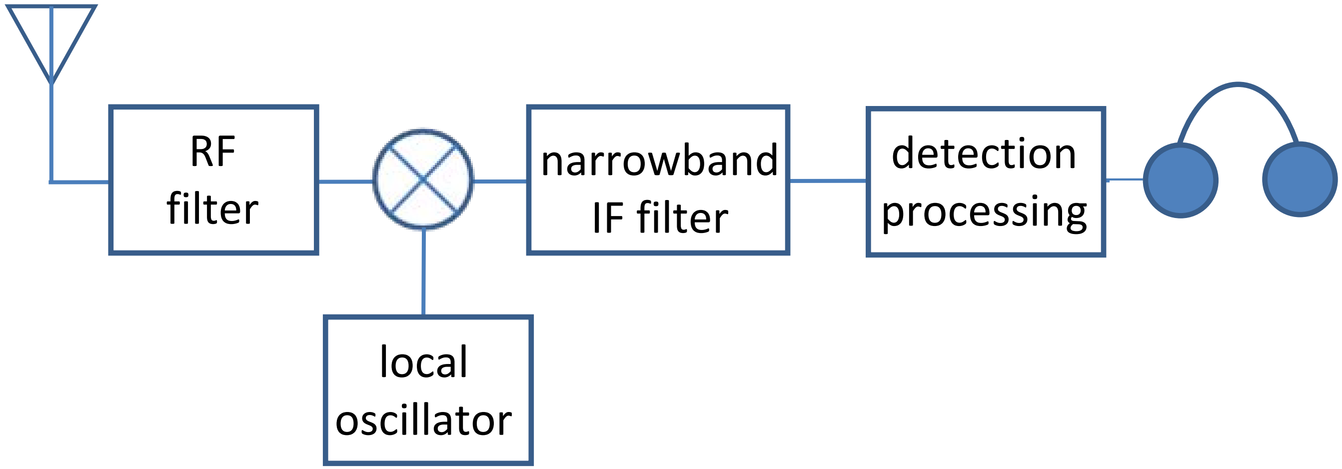
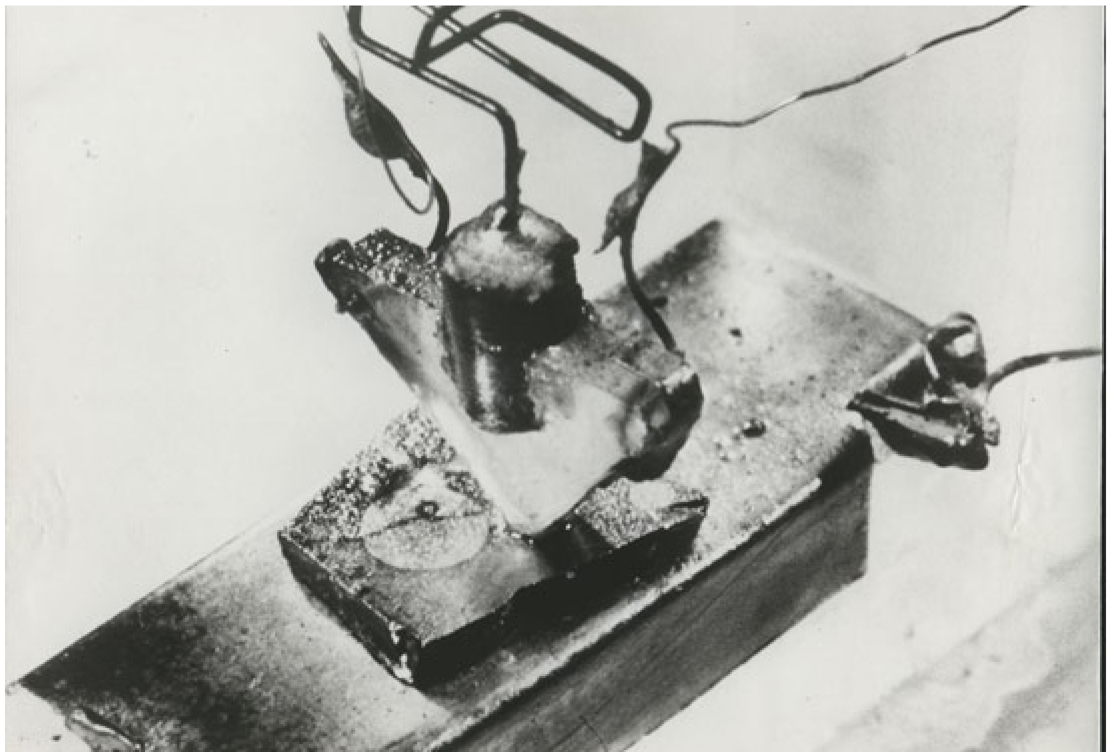




1918 Edwin Armstrong: superhetrodyne receiver



1948: Bardeen, Brattain, Shockley: transistor



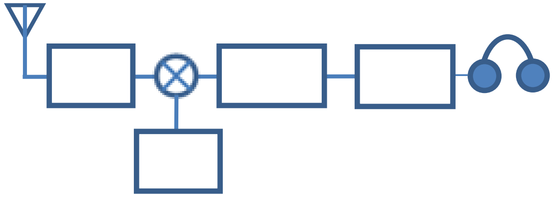
THE FIRST TRANSISTOR AS IT WAS PATENTED BY THREE
NOBEL PRIZE-WINNING BELL LABORATORIES SCIENTISTS

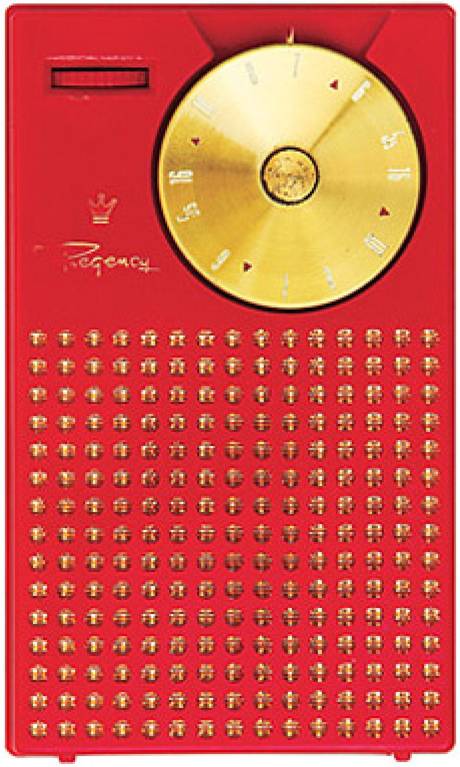
1954: First Commercial Transistor Radio

Regency TR-1

Jointly developed by Industrial Development Engineering and Texas Instruments.

In TIME Magazine's "Top 100 Gadgets" list.





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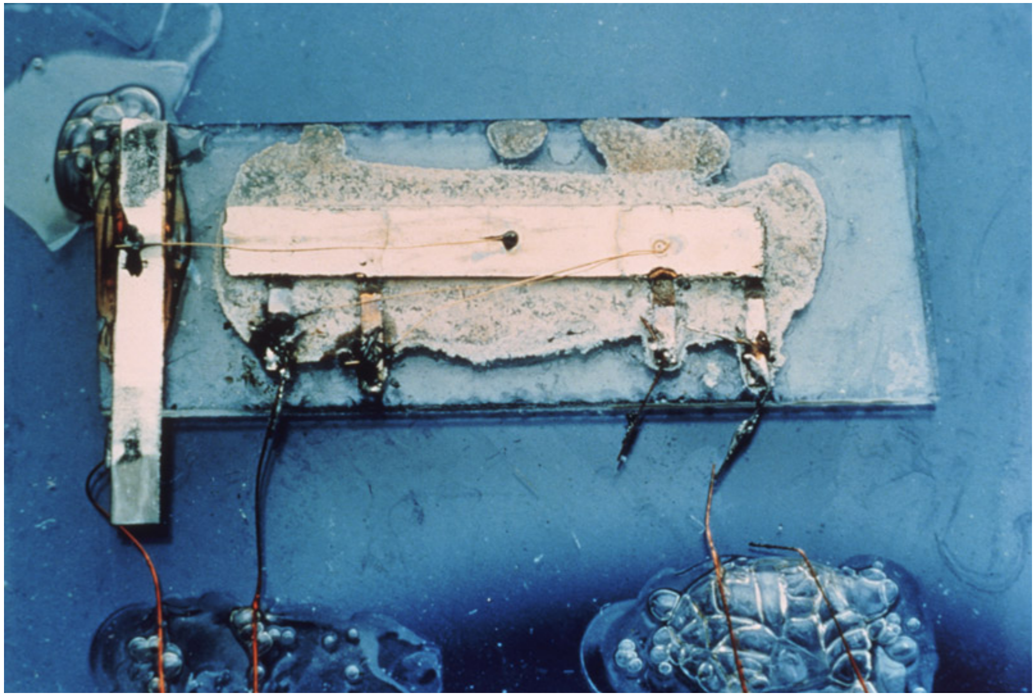
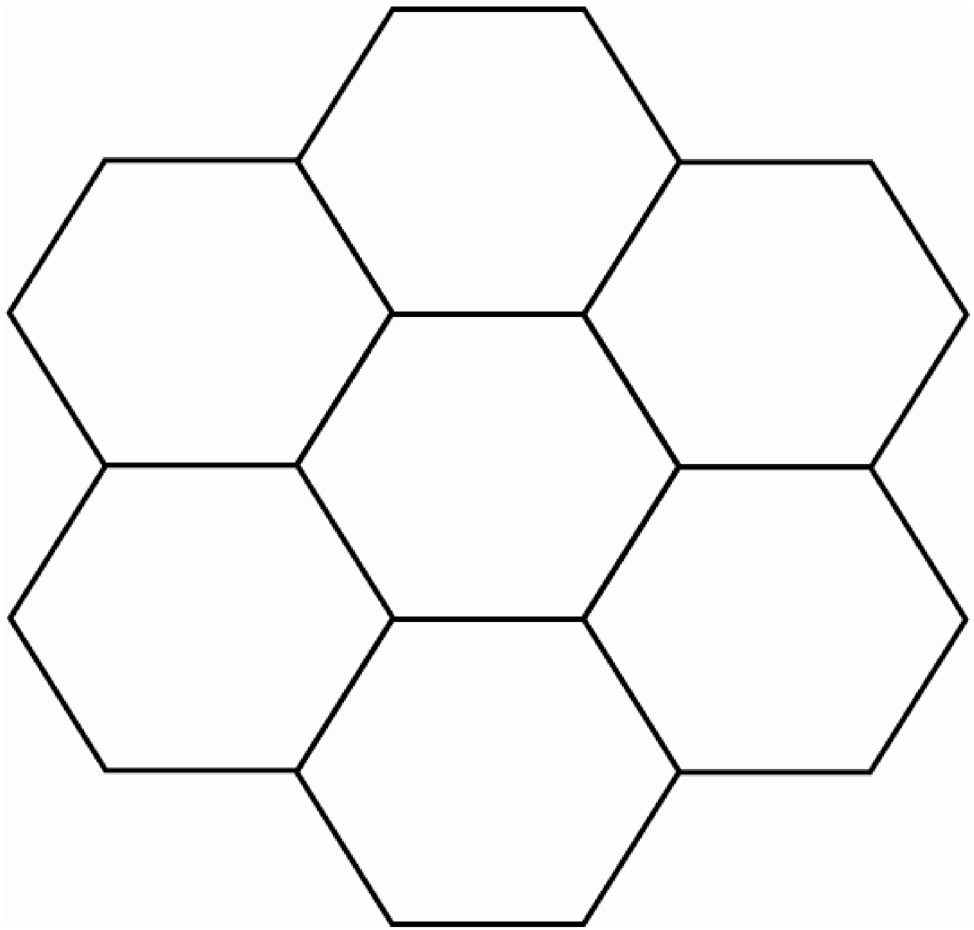


1978: Bell Labs & Motorola: cellular test beds



Brief History of Radio

1978: first GPS satellite launched

1991: early GSM transceiver

GSM Phone (Siemens) from 1991

Joint Tactical Radio System

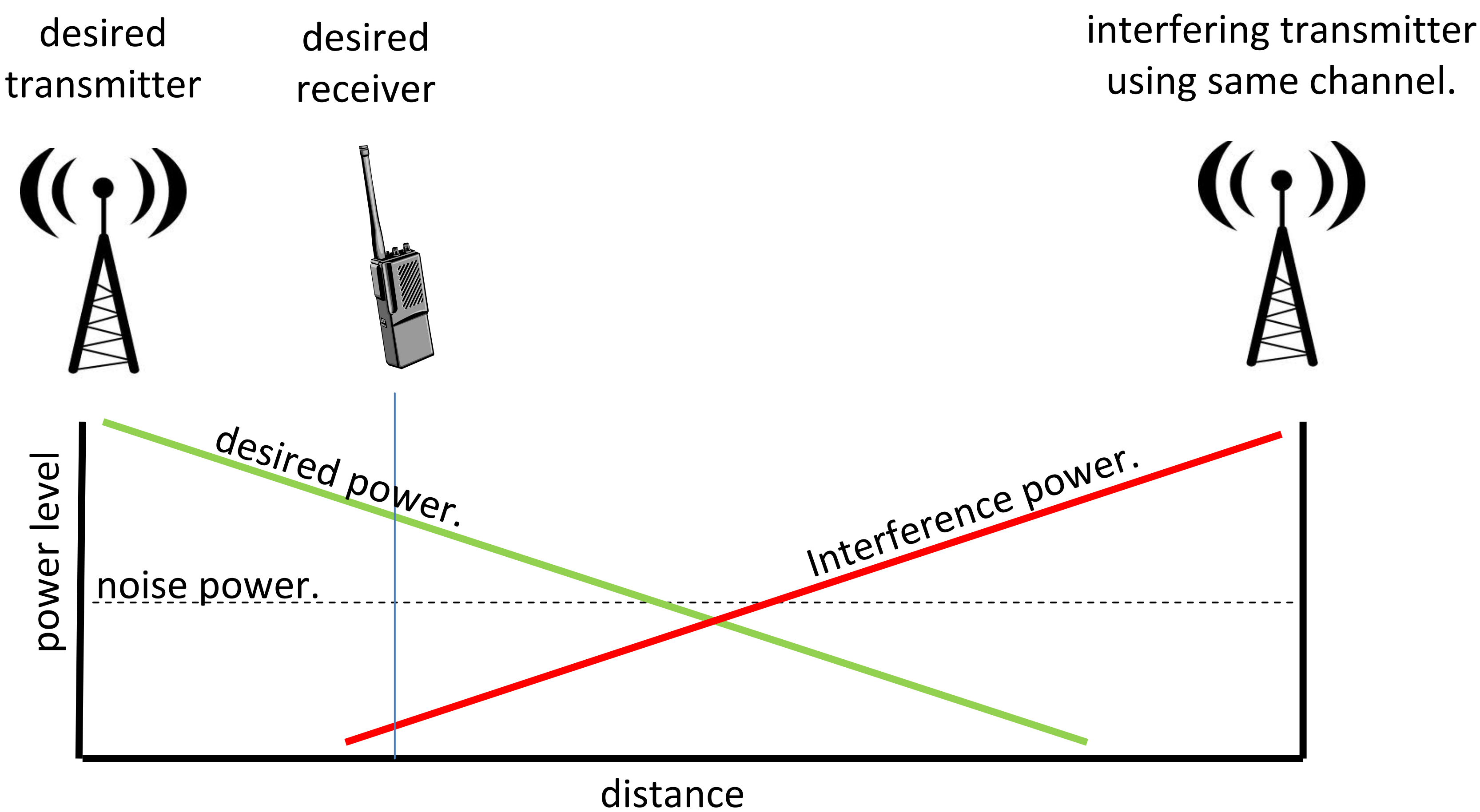
Multifunctional
Information
Distribution
System

General
Dynamics
Handheld
AN/PRC-154

Wideband
Networking
Radio

Radio Coexistence Concepts 1/5

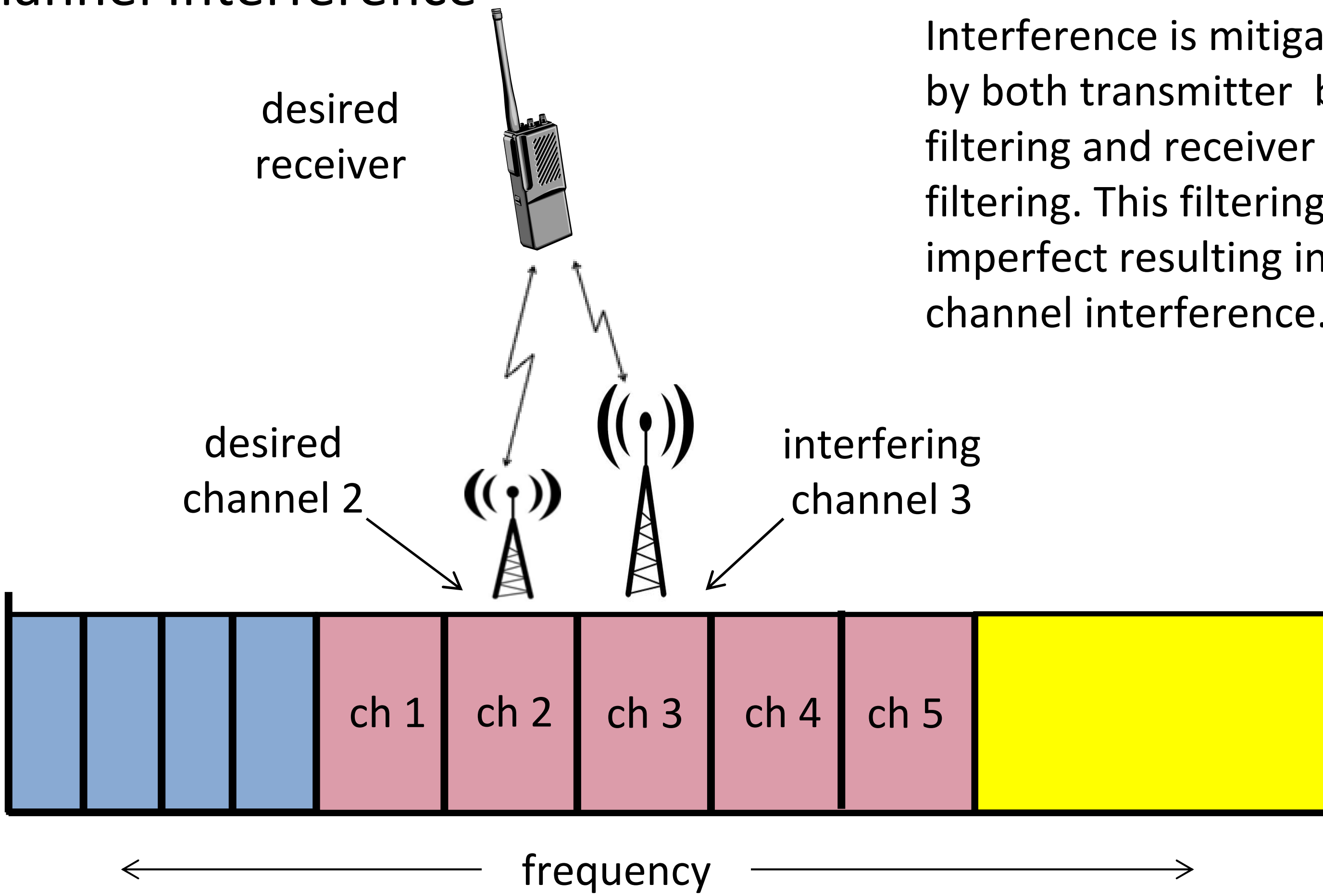
- Geographic separation of systems –> Issue: Co-Channel Interference Coexistence



Radio Coexistence Concepts 2/5

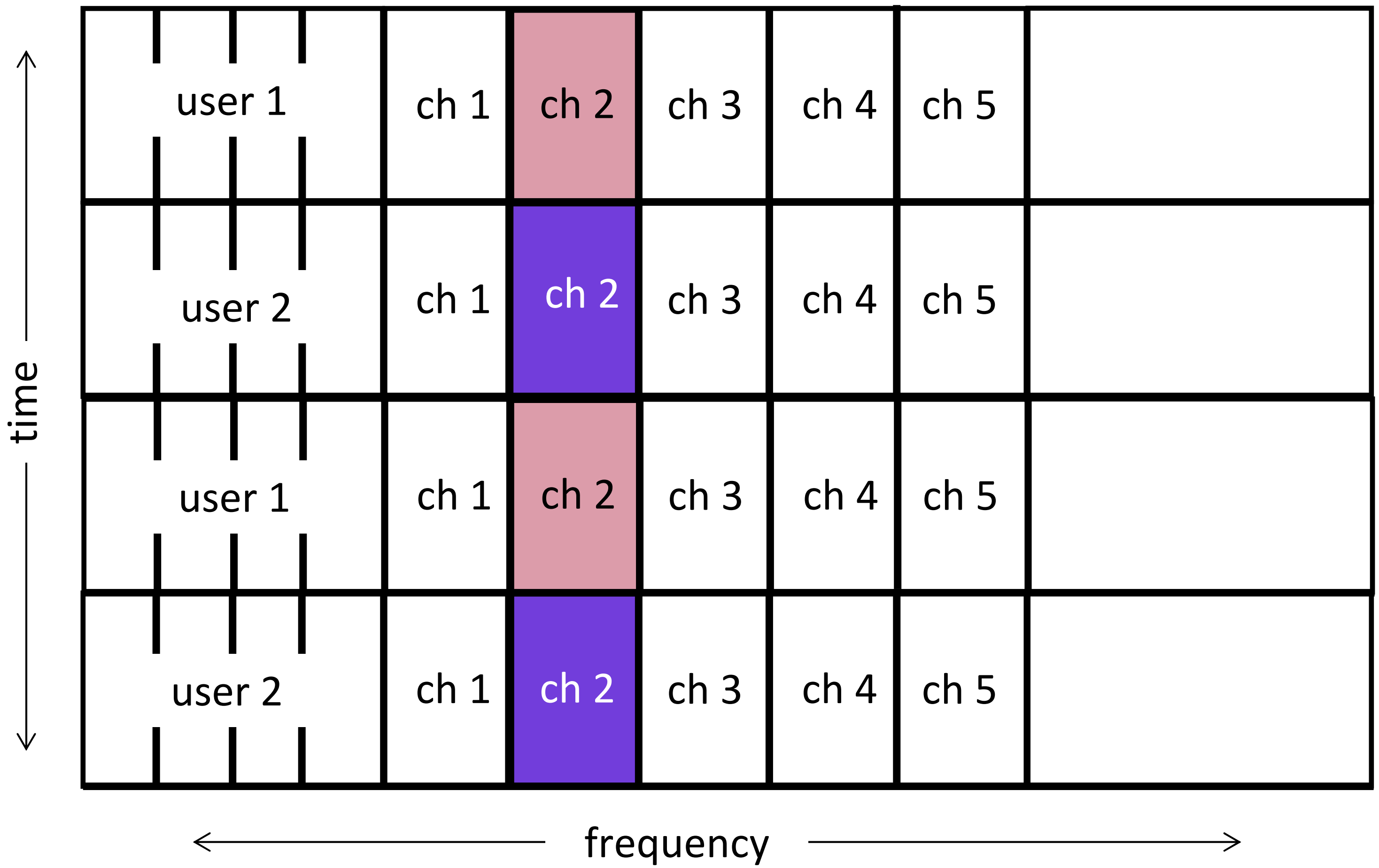
- Frequency separation of systems -> Issue: Adjacent Channel Interference

Interference is mitigated by both transmitter bandpass filtering and receiver bandpass filtering. This filtering may be imperfect resulting in adjacent channel interference.



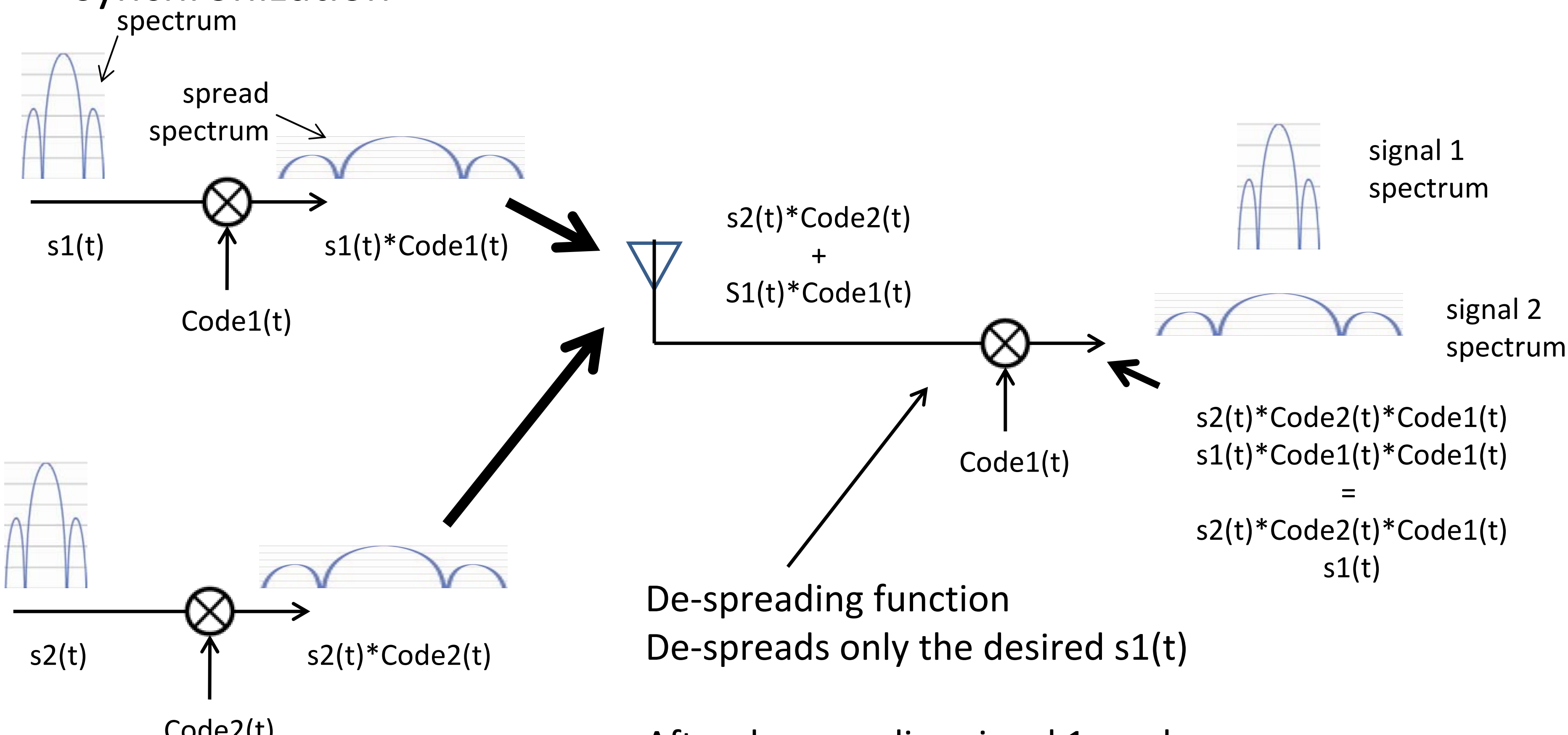
Radio Coexistence Concepts 3/5

- Time separation of systems -> Issue: impacted by multipath delays



Radio Coexistence Concepts 4/5

- Separation of systems using spread-spectrum coding -> Issue: synchronization



De-spreading function
De-spreads only the desired s1(t)

After de-spreading signal 1 can be
Isolated via band pass filtering.

Radio Coexistence Concepts 5/5

- The transmitter for a desired signal is completely unaffected by the existence of an interfering transmitter.

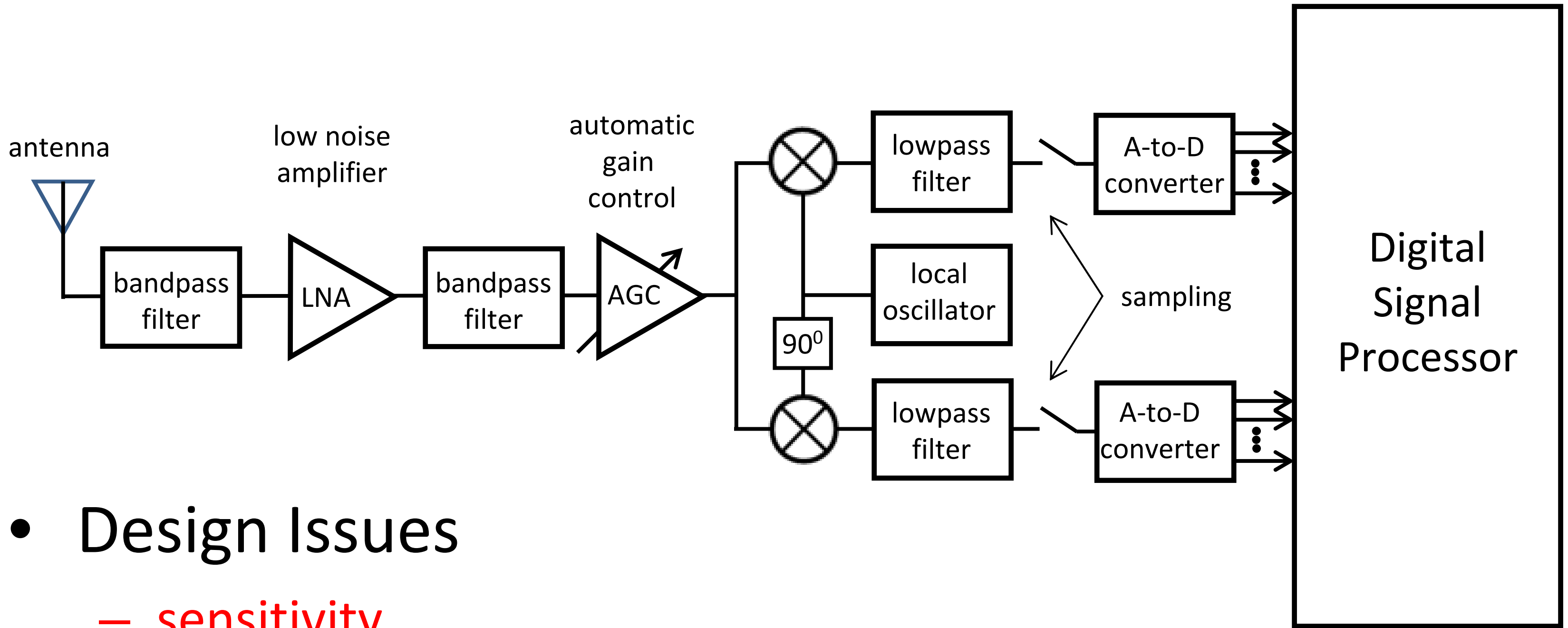
- The receiver for a desired signal is highly affected by the existence of an interfering signal.

→ interference only exists at the receiver!

However….

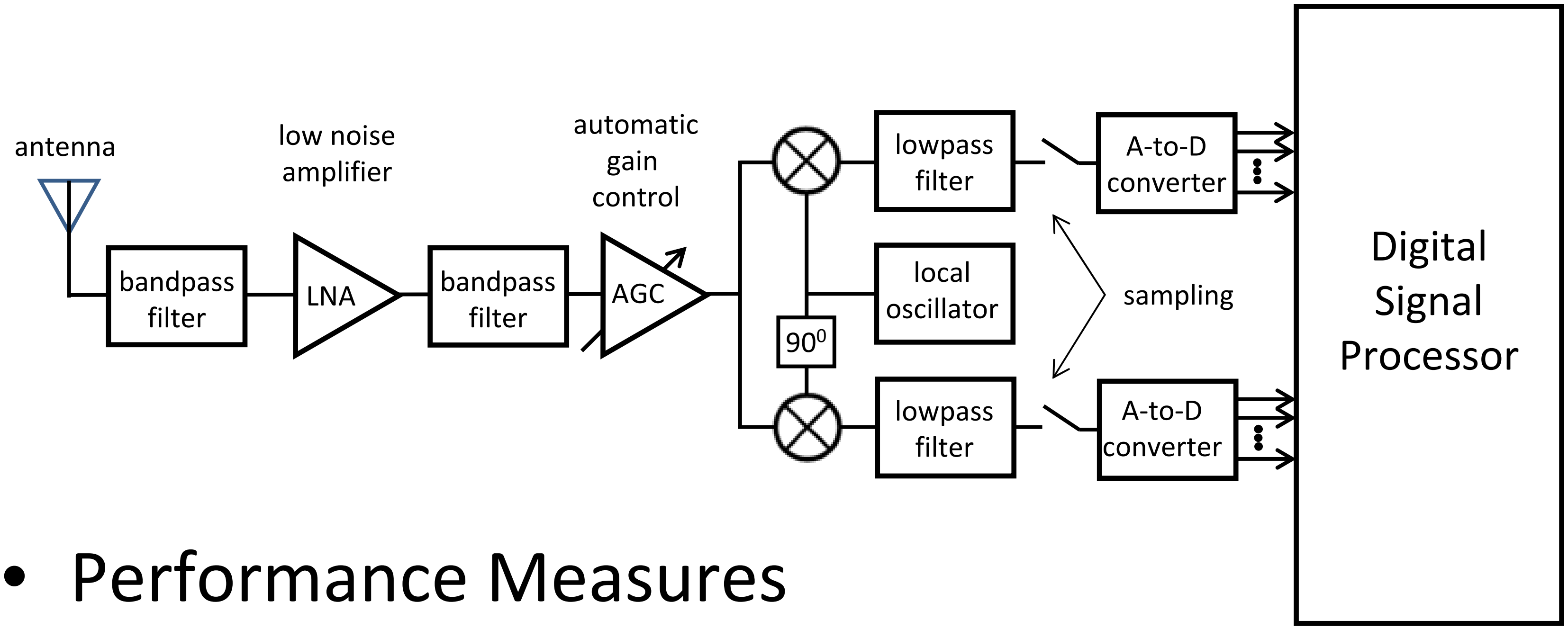
- Interference mitigation and spectrum sharing techniques affect the receiver AND the transmitter and can involve spatial, spectral, temporal and coding techniques to achieve the desired result .

Communications Receiver Fundamentals



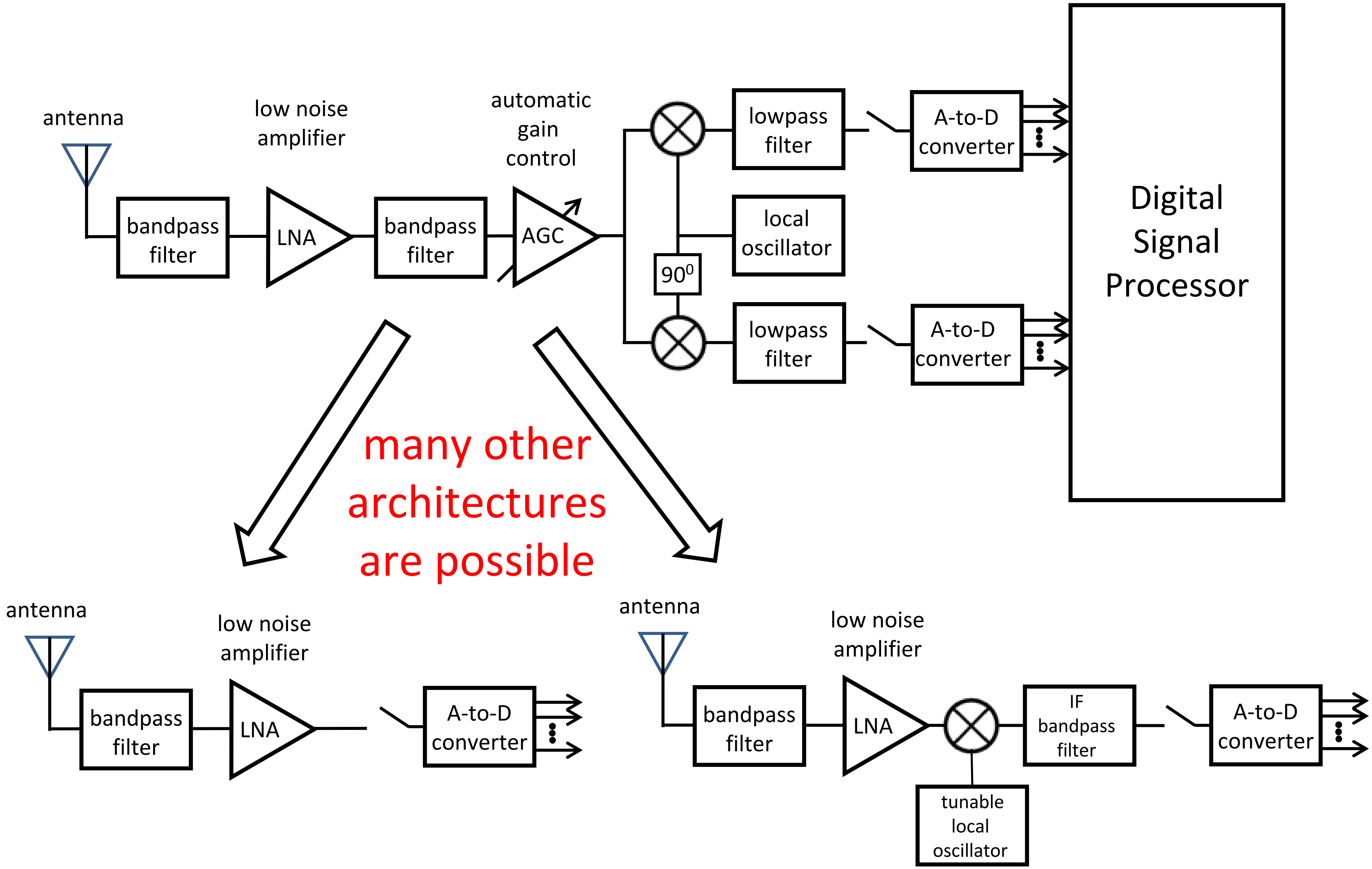
- Design Issues
  - sensitivity
    - noise figure
  - selectivity
    - bandwidth of desired signal
    - out-of-band rejection
  - dynamic range
    - A-to-D converter rate and resolution
  - local oscillator phase noise
  - linearity
  - antenna directivity
  - DSP processing speed

Communications Receiver Fundamentals

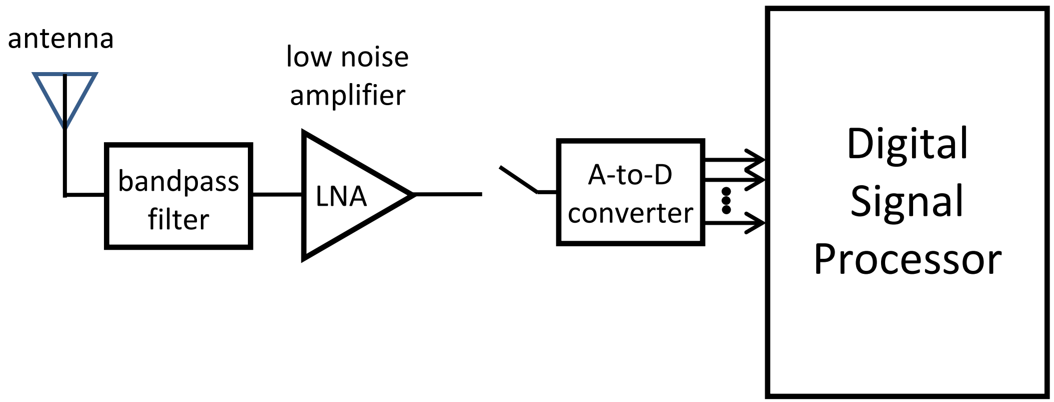


- Performance Measures
  - demodulated/decoded bit error rate (BER) (for digitally modulated signals)
  - demodulated signal-to-noise ratio (SNR) (for analog modulated signals)
  - coexistence characteristics (function of receiver design and waveform design and system design)

Communications Receiver Fundamentals

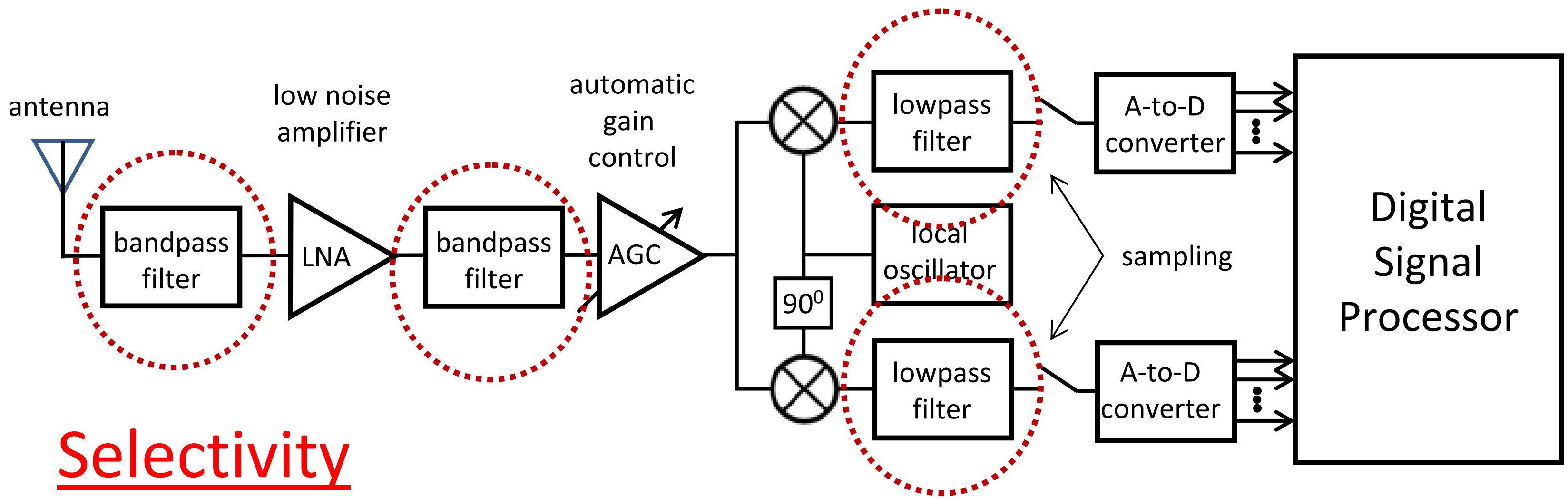


Communications Receiver Fundamentals

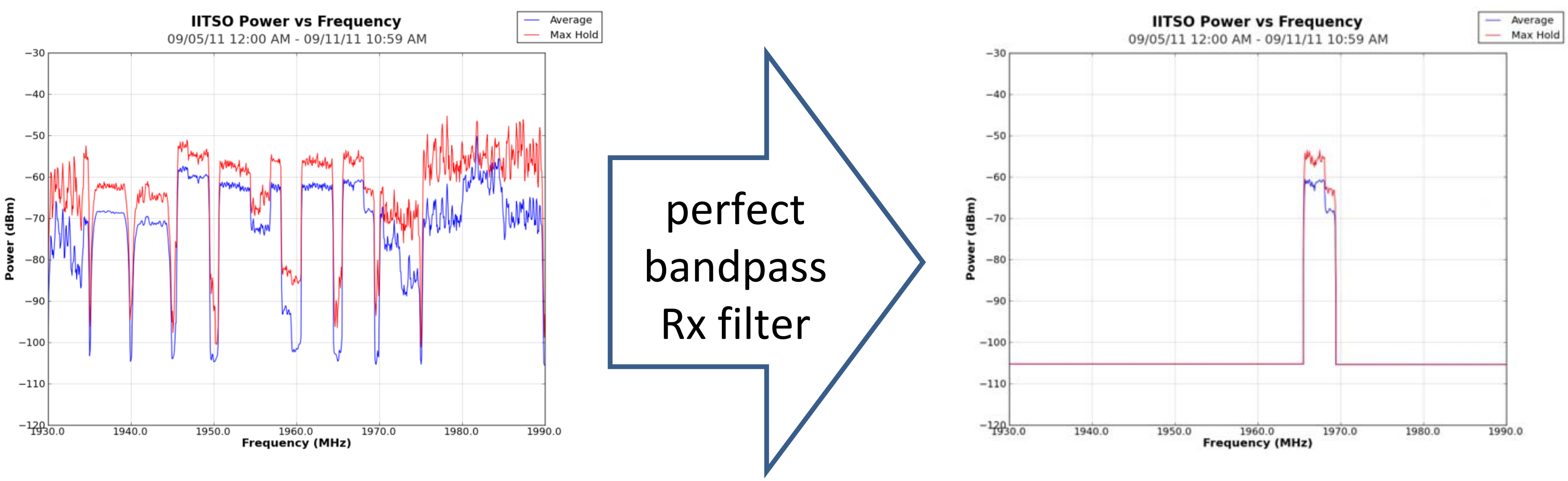


- "someday challenge"
  - ultra-high-speed ultra-high-resolution sampler and converter digitizes the received RF at (or near) the antenna
  - ultra-high-speed DSP is able to process all possible received waveforms

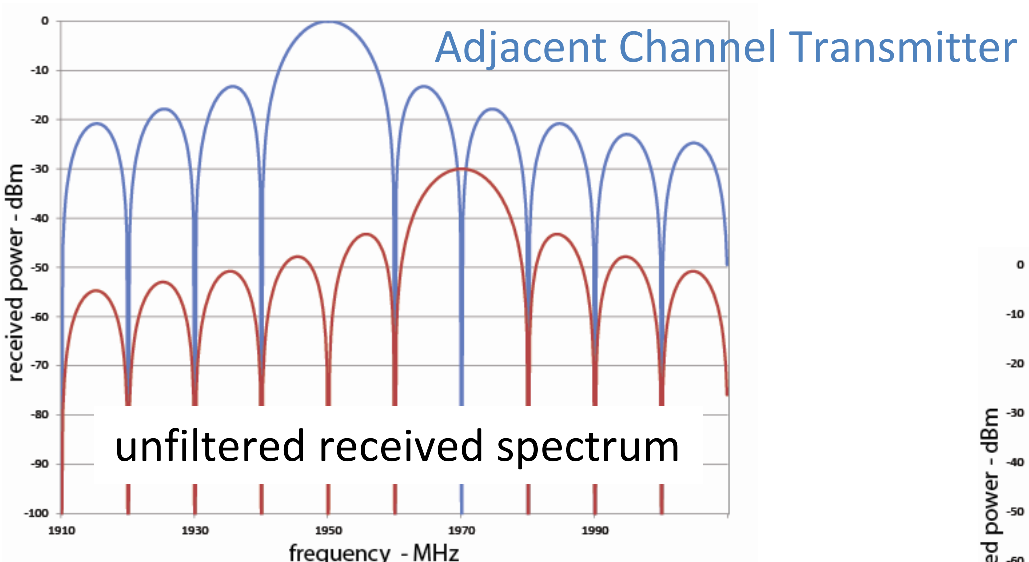
Communications Receiver Fundamentals

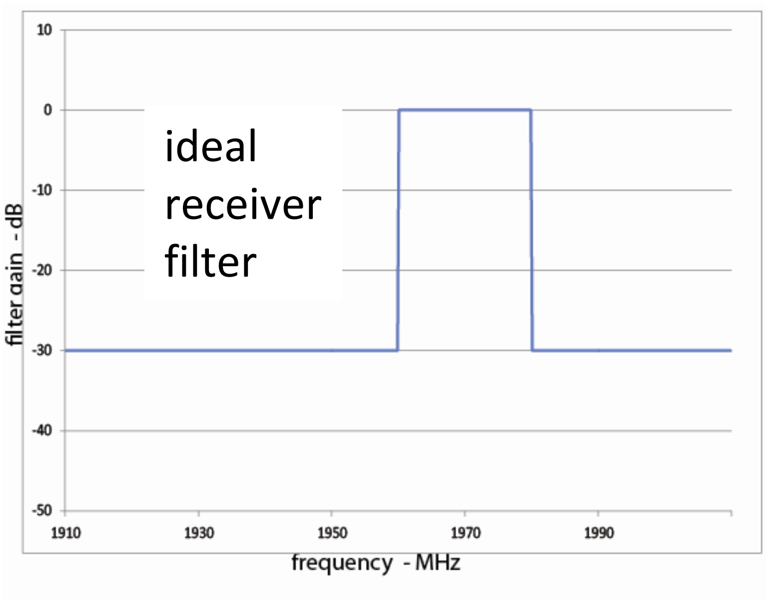


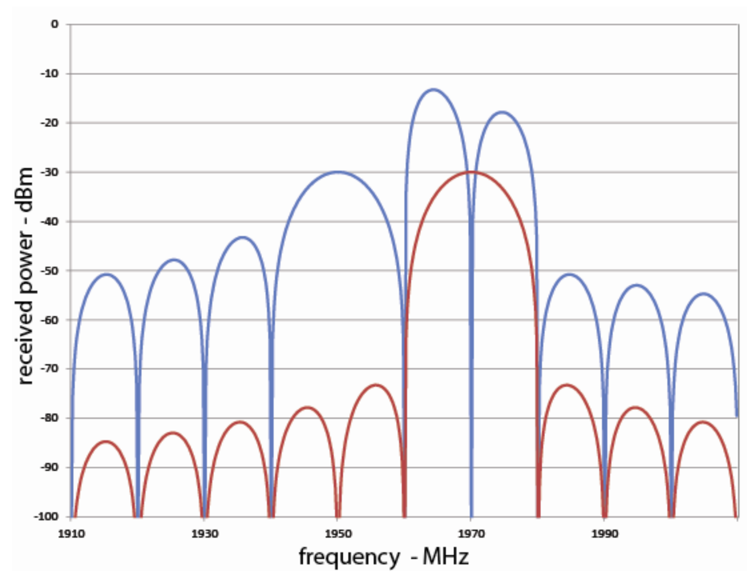
Selectivity



Strong Interferer on Adjacent Channel



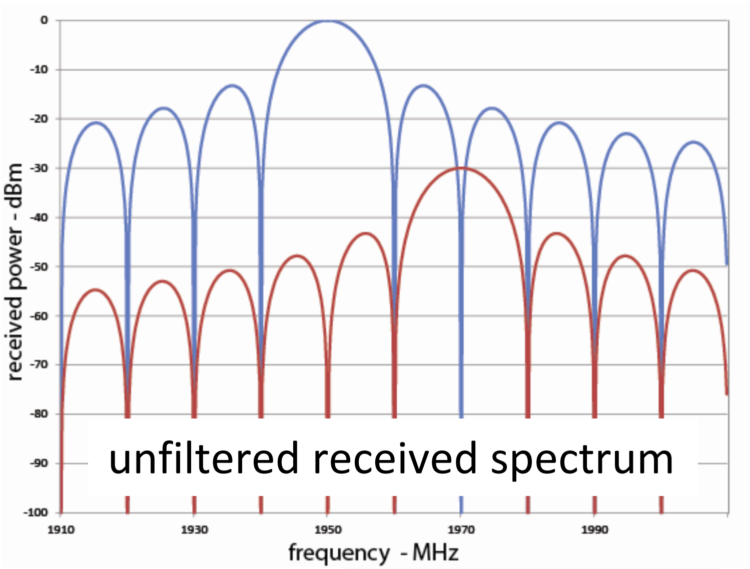


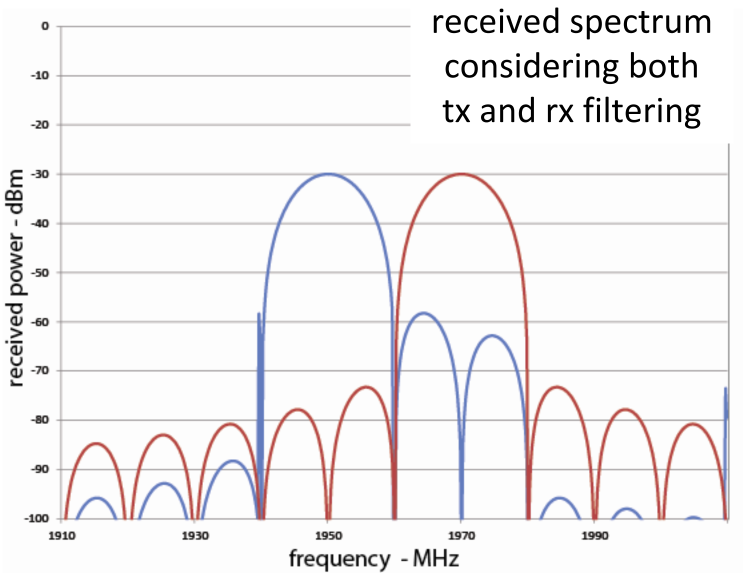


received spectrum after receive filtering only

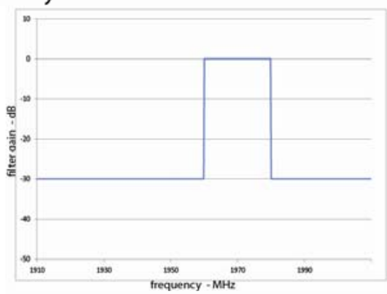
<u>Selectivity</u>

Strong Interferer on Adjacent Channel

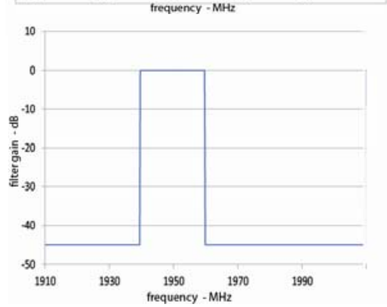




receiver filter



transmitter filter

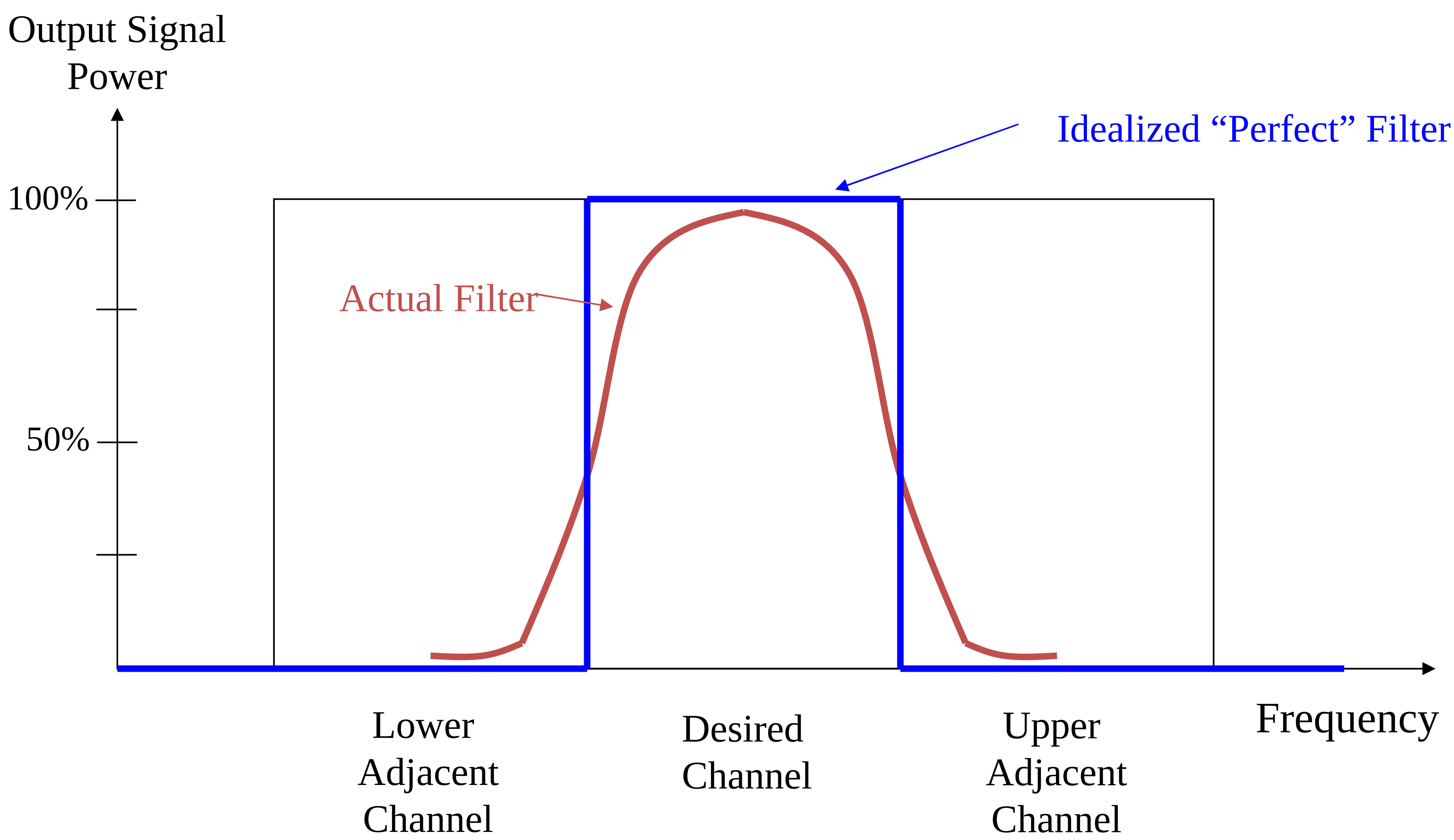


In this example, receiver out-of-band attenuation appears insufficient with respect to the very strong interferer.

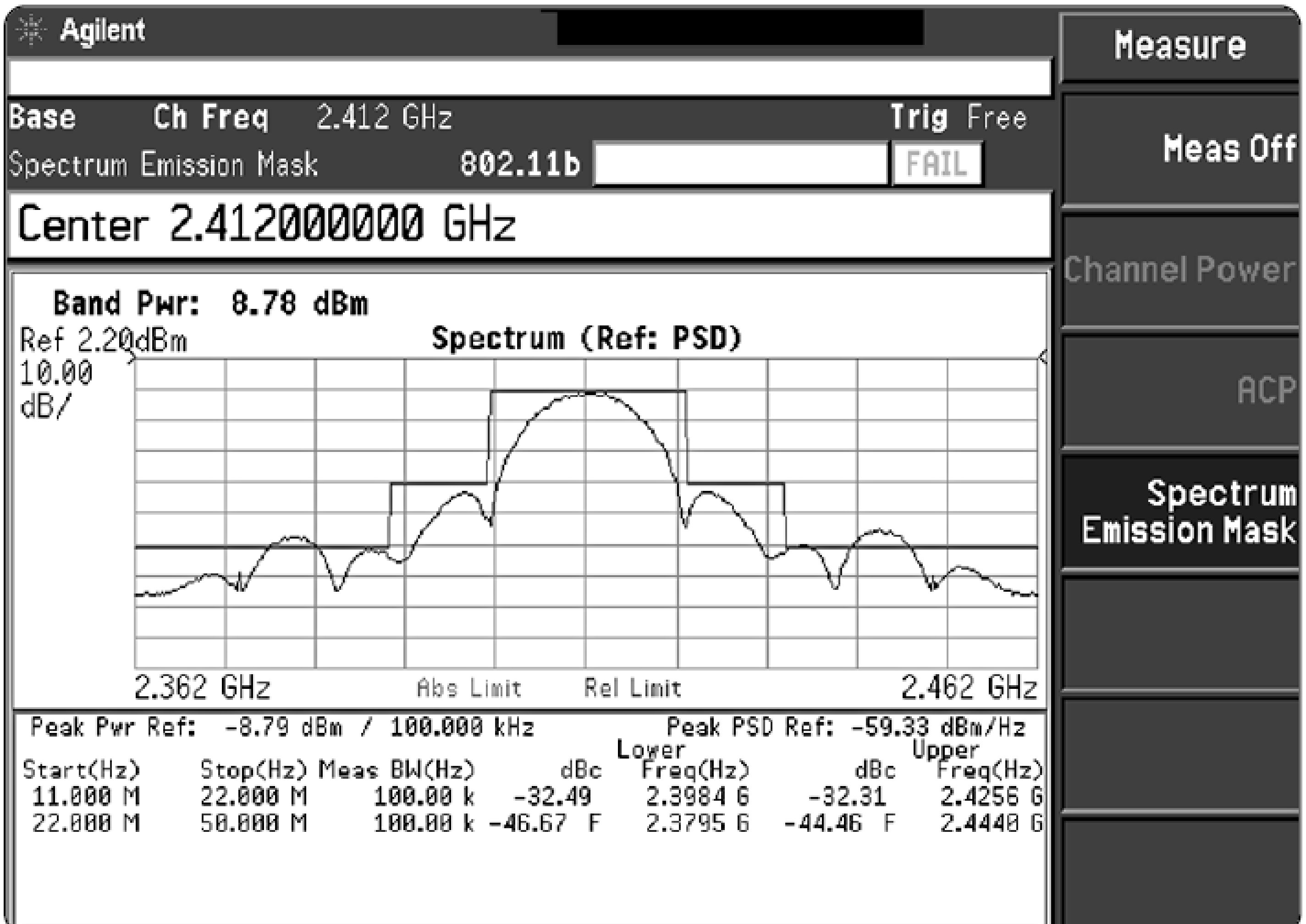
Receiver performance degradation due to very strong adjacent channel interference must be mitigated by BOTH transmitter AND receiver design!

But….filters, nor any of the other components are not "ideal"

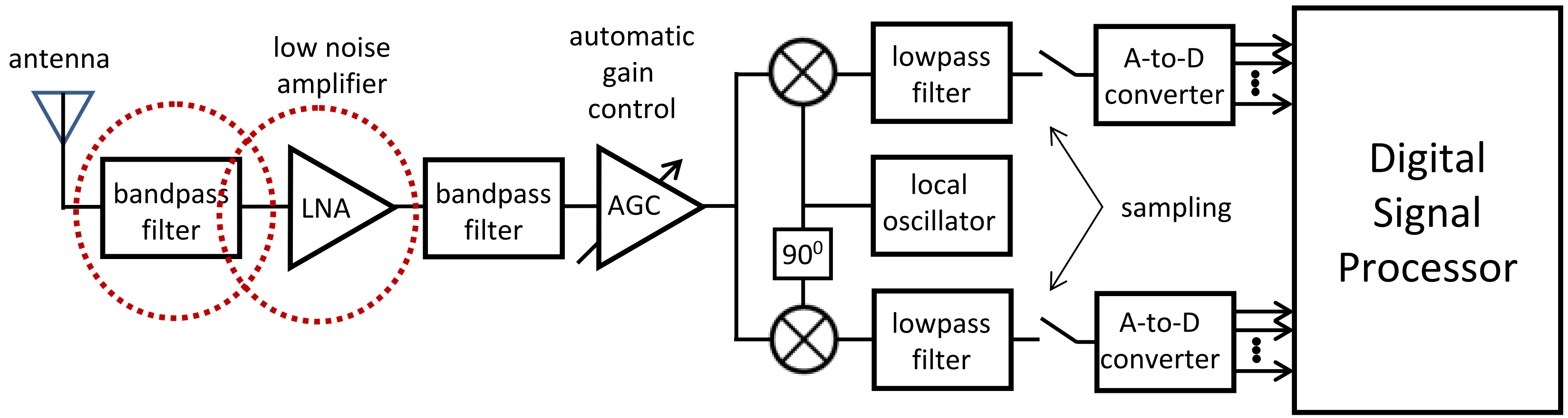
Slide courtesy: Dale Hatfield



Example Spectrum Mask and Measured WiFi Transmit Spectrum



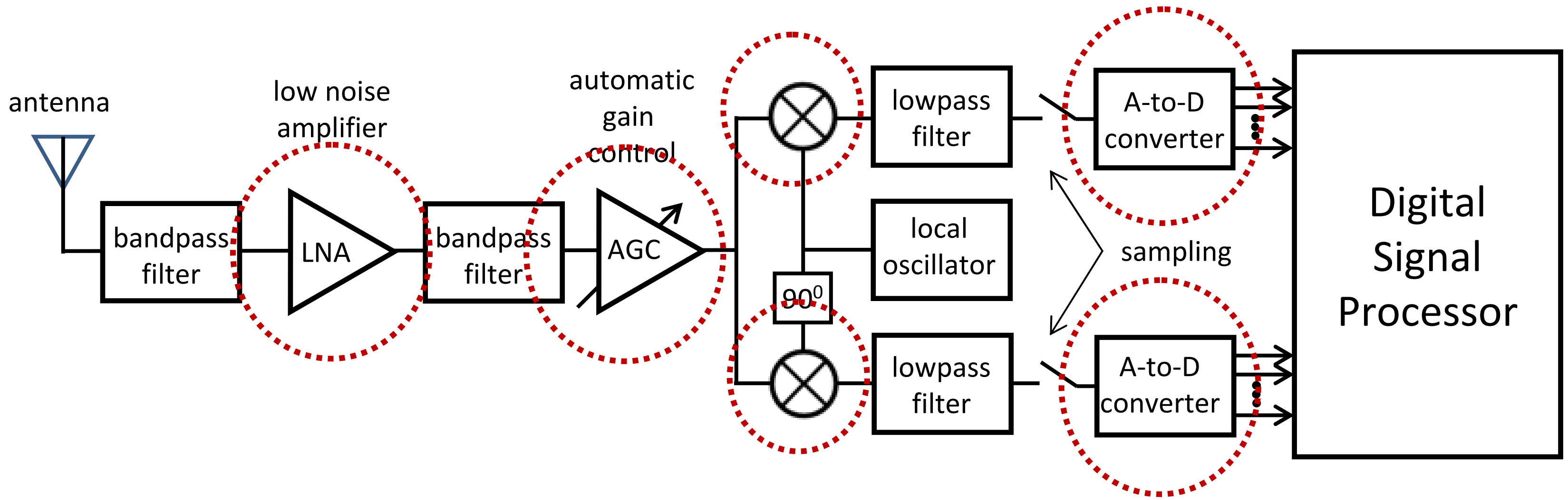
Communications Receiver Fundamentals



Receiver Sensitivity

- Noise is added to received signal at the receiver front end (filters and amplifiers) → bounds the smallest signal that may be received
- "Noise Figure" is a measure of how much the receiver front end degrades received signal-to-noise ratio.
- "Receiver sensitivity" is the minimum received signal power (milliwatts) at which the receiver can perform to specification
- Receivers with better sensitivity improve system coverage.
- Improving sensitivity normally increases receiver cost.

Communications Receiver Fundamentals



Dynamic Range = signal power range over which the receiver operates properly

Minimum power is the receiver sensitivity.

Maximum power limited by

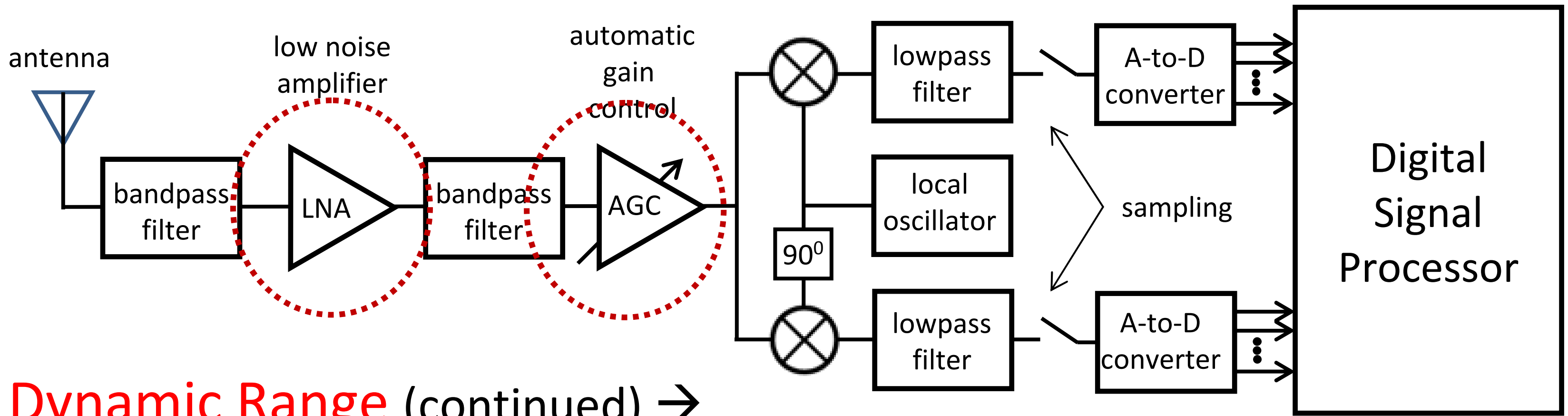
•component (amplifiers, mixers, other) nonlinearities that create undesired signals in the processing bandwidth

•automatic gain control limitations

•resolution (i.e. number of bits) in the A-to-D converters

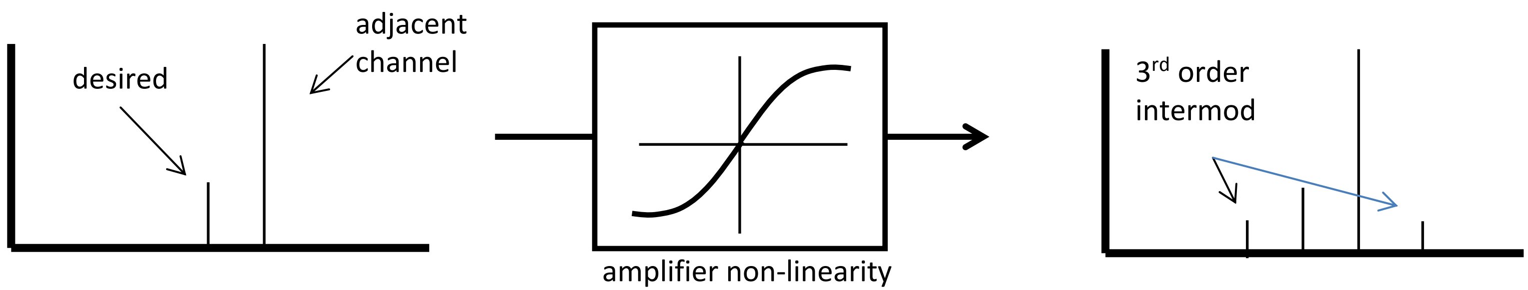
Dynamic range is an issue when a large interferer is processed in the same analysis bandwidth as a small desired signal.

Communications Receiver Fundamentals

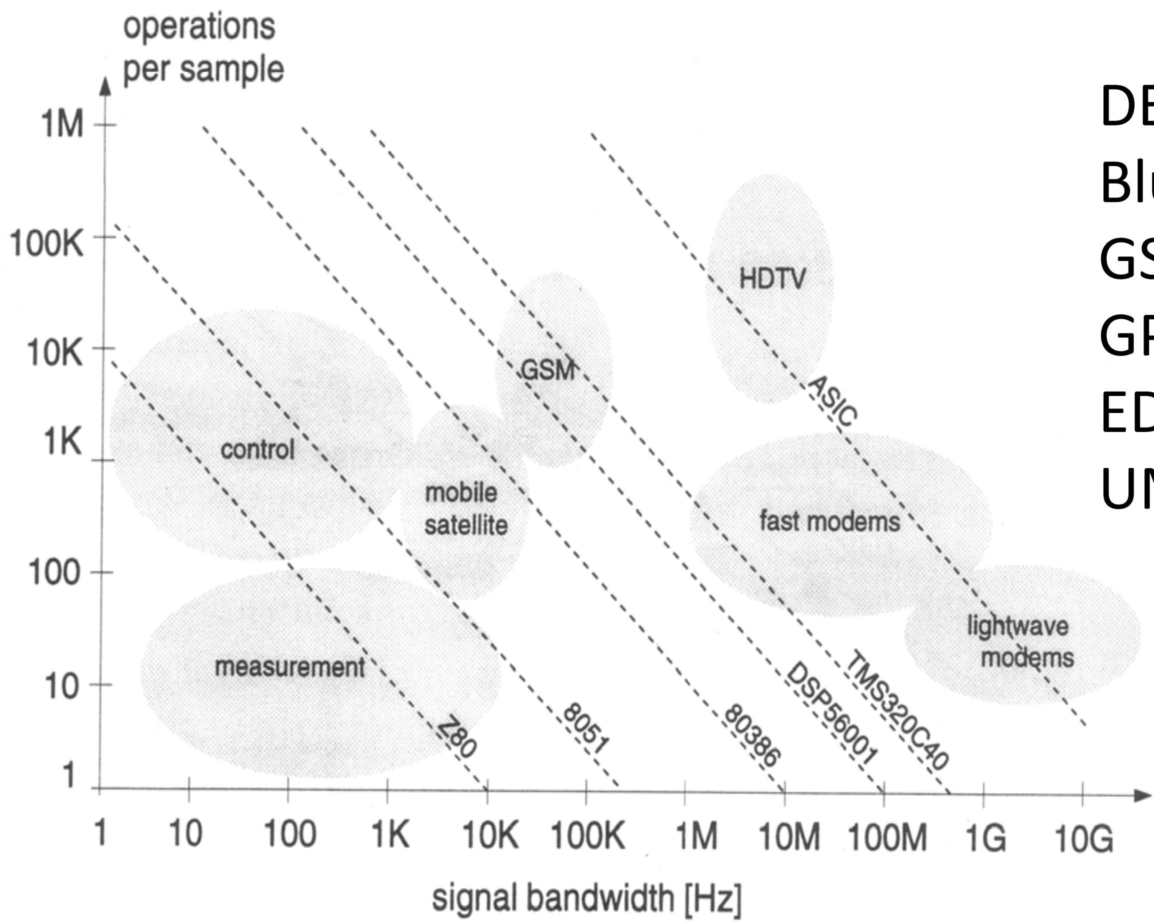


Dynamic Range (continued) →

- nonlinearities in the receiver input stages can create intermodulation components within the processing bandwidth
- receiver input stages usually have a processing bandwidth larger than the Intermediate Frequency (IF or signal of interest) bandwidth → a large adjacent channel interferer can create intermodulation components affecting performance



DSP Processing Requirement



] Complexity versus Signal Bandwidth Plot

DECT	10 MIPS
Bluetooth	20 MIPS
GSM	100 MIPS
GPRS	350 MIPS
EDGE	1200 MIPS
UMTS	5800 MIPS*

*Can be drastically reduced with hardware assists

Conclusions

- Wireless operation is a systems game with transmitters and receivers cooperating to coexist while meeting user requirements. Ideally, all transmitters AND receivers across the spectrum, i.e. all wireless systems would similarly cooperate to enable the optimal use of the scarce spectrum resource.
- Hopefully this Workshop will enable us to make progress toward the achievement of this lofty goal.