Receiver (Wireless) Basics

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A Few Highlights of Wireless History

1901 Guglielmo Marconi: transatlantic radio transmission → “S”

1905 Ambrose Fleming: vacuum tube → detection of radio waves

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

1906 Bose & Packard: cat’s whisker detector (used until 1945)

1918 Edwin Armstrong: superhet receiver

1948: Bardeen, Brattain, Shockley: transistor

1959: Noyce, Kirby: integrated circuit
A Few Highlights of Radio History

1954: Texas Instruments first transistor radio

1973: Motorola: DynaTAC handheld mobile phone

1978: Bell Labs & Motorola: cellular radio testbeds

1978: first GPS satellite launched

1991: Mitola: concept of software radio

1997: first 802.11 standard

1998: DoD: Joint Tactical Radio System development

2007: Apple iPhone

2011: Motorola Droid RAZR
1901 Guglielmo Marconi:
transatlantic radio transmission → “S”
1906 Lee De Forest: triode vacuum tube
1906 Bose & Packard: cat’s wisker detector
1918 Edwin Armstrong: superheterodyne receiver
1948: Bardeen, Brattain, Shockley: transistor
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.
1959: Noyce, Kirby: integrated circuit
1978: Bell Labs & Motorola: cellular test beds
Brief History of Radio
1978: first GPS satellite launched
1991: early GSM transceiver

Size: 210 x 168 x 80 mm
Weight: 2500 g
Transmit Power: 5 W

GSM Phone (Siemens) from 1991
Joint Tactical Radio System

Multifunctional Information Distribution System

Wideband Networking Radio

General Dynamics Handheld AN/PRC-154
Radio Coexistence Concepts 1/5

- **Geographic separation** of systems → Issue: Co-Channel Interference Coexistence

![Diagram showing desired transmitter and receiver vs. interfering transmitter using same channel, with power levels and distance on axes.](image-url)
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

```
  | ch 1 | ch 2 | ch 3 | ch 4 | ch 5 |
---|------|------|------|------|------|
user 1 |      |      |      |      |      |
user 2 | ch 1 |      |      |      |      |
user 1 |      | ch 2 |      |      |      |
user 2 | ch 1 | ch 2 |      |      |      |
```

- Time separation of systems means that different systems use different time slots. This issue can be impacted by multipath delays, which affect the synchronization of transmissions across different channels.
Radio Coexistence Concepts 4/5

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

De-spreading function
De-spreads only the desired $s_1(t)$

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
• **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

- antenna
- low noise amplifier
- bandpass filter
- LNA
- bandpass filter
- AGC
- automatic gain control
- lowpass filter
- local oscillator
- A-to-D converter
- Digital Signal Processor
- many other architectures are possible
- antenna
- low noise amplifier
- bandpass filter
- LNA
- A-to-D converter
- tunable local oscillator
- IF bandpass filter
- A-to-D converter
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

perfect bandpass Rx filter
Strong Interferer on Adjacent Channel

Adjacent Channel Transmitter

unfiltered received spectrum

ideal receiver filter

received spectrum after receive filtering only

Selectivity
Strong Interferer on Adjacent Channel

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”
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.
**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

- 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.