Public Safety Radio Bands

- **VHF-Low Band**: 25 MHz to 50 MHz
- **VHF-High**: 138 MHz to 174 MHz
- **UHF**: 408 MHz to 512 MHz
- **700 MHz (new)**
- **800 MHz**
- **4.9 GHz (new)**
Why is this a problem?

- Radios only operate in one band!
  - Multi-band radios are rare and expensive
- If Agency A uses VHF and Agency B uses UHF, they can’t talk to each other UNLESS...
- ...They have planned ahead!
  - Two radios in a rig, etc.
Propagation Basics- Free Space Path Loss

• Path Loss (in dB) = 36.6+20xLog[D]+20xLog[F]
  – Where:  D is distance in miles
            F is frequency in MHz

• So: as frequency increases, path loss increases

• This means that if everything else were equal, a system at a lower frequency would reach farther than a system at a higher frequency

• But...other factors are at play as well
Propagation & Band Characteristics

- **VHF Low Band (30-50 MHz)**
  - Best propagation in undeveloped and hilly terrain–Poor building penetration
- **VHF High Band (150-174 MHz)**
  - Very good propagation in undeveloped and hilly terrain–Moderate building penetration
- **UHF (450-512 MHz)**
  - Good propagation in undeveloped and hilly terrain–Good building penetration
- **700/800 MHz**
  - Poor propagation in undeveloped and hilly terrain–Very good building penetration–
    - 700 currently subject to incumbent television stations in some areas
    - 800 currently subject to interference from commercial carriers
- **4.9 GHz**
  - Microwave propagation used for short range (Wi-Fi type) or point-to-point links
Frequencies vs. Channels

- A frequency is a point in the radio spectrum – part of what describes a channel
- A channel is a set of parameters that can include one or more frequencies, CTCSS tones, name, etc.
- Example: VCALL is a channel with transmit and receive frequency 155.7525 MHz, CTCSS tone of 156.7 Hz
CTCSS (PL) Tones

- PL stands for Private Line, a Motorola trademark
- Other names include Code Guard, Tone Squelch, Call Guard, Channel Guard, Quiet Channel, Privacy Code, Sub-audible Tone, etc.
- “Generic” term is CTCSS – Continuous Tone Coded Squelch System
What Are These Tones?

- A PL tone is a sub-audible (barely audible) tone that is sent along with the transmitted audio.
- A receiver that has CTCSS decode (a.k.a. a receive PL tone) activated will only open its speaker if the correct tone is received.
- PL tones are different than tones used to set off pagers (two-tone sequential paging).
- Remember...PL tones are sub-audible and continuous...they are being sent the entire time a radio is transmitting.
Standard CTCSS Tone Table

<table>
<thead>
<tr>
<th>CTCSS/CDCSS Tone Frequencies (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CTCSS</strong></td>
</tr>
<tr>
<td>67.0</td>
</tr>
<tr>
<td>97.4</td>
</tr>
<tr>
<td>136.5</td>
</tr>
<tr>
<td>192.8</td>
</tr>
</tbody>
</table>
What Are They Used For

- PL Tones are used to **MASK** interference
- They **DO NOT REMOVE** INTERFERENCE
- Useful for masking interference from computers, electronics, etc.
- Useful for masking interference from “skip”
- Should **NOT** be used to block out traffic from neighboring (nearby) departments
  - This is OK for taxis, etc., but not for public safety
  - Creates “Hidden Interference” problem – missed calls possible
What Are They Used For (cont.)

- Used to activate remote links
- Used to access repeaters
DCS – Digital Coded Squelch

- A.k.a. Digital Private Line (DPL)
- Similar to CTCSS, but uses a digital code instead of an audio tone
- Used on analog radio systems, even though it is a digital code
Encode vs. Decode

- PL (or DPL, et.c) *Encode* means to transmit the tone
- *Decode* means that the receiver will listen for the tone and not let anything through unless the correct tone is received
- TX and RX tone can be different
- Radio can be set to TX tone but have no RX tone (all traffic is received)
- If in doubt, don’t program RX tone
- “Monitor” function bypasses RX tone
Results of Improper Programming

- If Radio 1 is set for TX tone only and Radio 2 is set for TX/RX, both radios will hear each other. Radio 1 will hear any interference on the channel.
- If Radio 1 is set for TX tone only and Radio 2 is set for no tone, both radios will hear each other. Both radios will hear any interference on the channel.
- If Radio 1 is set for TX/RX tone and Radio 2 is set for TX/RX tone, both radios will hear each other.
- If Radio 1 is set for TX/RX tone and Radio 2 is set for no tone, *Radio 1 will not hear Radio 2.* Radio 2 will hear Radio 1.
- ANY radio programmed with an incorrect TX tone will not be heard by radios using a RX tone, even though it can hear traffic from other radios.
Simplex

- Very Reliable
- Limited Range
- Radio Channel uses 1 frequency
Duplex

- Radio Channel using 2 frequencies, Freq 1 to talk from radio A to radio B, and Freq 2 to talk from radio B to radio A
- Each user must be line of sight with each other
- Examples: Cordless Telephone systems, which both parties can talk at the same time and listen at the same time.
Base Station – Height Improves Range

Some units don’t hear transmission because of obstructions.
Base Station – Height Improves Range

Dispatcher relays message – heard by all units
Remote Base Operation

Remote Link
Microwave, Phone Line, etc.

Dispatch Center

Unit 1
Unit 2
Unit 3
Unit 4
Conventional Repeater

- Receives a signal on one frequency and retransmits (repeats) it on another frequency
- Placed at a high location
- Increases range of portable and mobile radio communications
- Allows communication around obstructions (hills, valleys, etc.)
- User radios receive on the repeaters transmit frequency and transmit on the repeater’s receive frequency (semi-duplex)
Conventional Repeater

All units within range of repeater hear all transmissions through the repeater
Conventional Systems

When one user is talking, other users on that channel are cannot talk, even though other repeaters in the area may be idle.

Public works repeater may be idle 90% of the time, which means that frequency is largely wasted.

PD 1

PD 2

PD 3

PD 4

PD 3 cannot talk to PD 4 because PD 1 is using the repeater

PW 1

PW 2

PW 3

FD 1

FD 2

FD 3

Idle

Communicating
Trunking

- Trunking is a method of combining repeaters at the same site to “share” frequencies among users
- Spectrally efficient
- Allows many more “virtual” channels (called talkgroups) than there actually are frequencies
- Computer controlled
• Frequencies are dynamically assigned by system controller
• User radio may be on a different frequency every time it transmits
• Talkgroups are “virtual” channels
• Possible to have many more talkgroups than actual frequencies
• Statistically, not all talkgroups will be active at the same time
Trunked System Operation

- User radios continuously monitor a dedicated “control channel”
- When a user wants to transmit, the user’s radio makes a request to the system controller
- If a repeater is available, the system controller temporarily assigns that repeater channel to the talkgroup making the request
- Transmitting user’s radio will give a “talk beep”, indicating that a repeater has successfully been assigned...user can talk
- All user radios monitoring that talkgroup automatically switch to the frequency of the assigned repeater and hear the transmission
- When the transmission is complete, all radios return to monitoring the control channel
Multi-Site Systems

- Conventional
  - Repeaters on same output, different input
  - Linked repeaters on different frequencies
  - Remote Receive Sites
    - Voting
    - Simulcasting

- Trunking
  - Roaming
  - Simulcasting
Repeaters on same output frequency, different input frequency (or PL tone)

Only one repeater active at a time

Users must manually change channel to different repeater depending on their physical location
Repeaters on same output frequency, different input frequency (or PL tone)

Only one repeater active at a time

Users must manually change channel to different repeater depending on their physical location
Linked repeaters on different frequencies

Both repeaters active at the same time with same traffic, but on different frequencies

Link (microwave, phone line, etc.)

Users must manually change channel to different repeater depending on their physical location
Voter (comparator) chooses best received signal and sends that signal to the transmitter.

Users do not need to change channel depending on location. System (voter) automatically picks best receive tower site.
Simulcasting

Both repeaters transmit at the same frequency at the same time

Transmitters must be carefully synchronized to prevent interference in overlap areas

Link (microwave, phone line, etc.)
Antenna Polarization & Gain
Radio Wave Polarization

- Two-way radio systems use vertical polarization (antenna elements are oriented vertically)
- Cross-polarization results in signal loss (can be very dramatic)
- What does this mean? Hold portable radio so that antenna is oriented vertically...don’t hold it sideways!!
Antenna Gain

• Gain refers to how power is transmitted in different directions from an antenna.
• An antenna with no gain (0 dBi, or dB relative to an isotropic radiator) radiates an equal amount of power in all directions.
• An antenna with some gain (say 3 dBi) radiates 3 dB more power in one direction than the 0 dBi antenna, but this means that less power is radiated in another direction.
• The amount of power transmitted doesn’t change due to antenna gain...*where* the power is transmitted changes (think of squeezing a balloon).
• Gain is only useful if the antenna is pointed at the target (Think TV antenna).
Isotropic & Dipole Radiation Patterns
Dipole Antenna Radiation Pattern

Source: http://www.tpub.com/content/neets/14182/css/14182_186.htm
¼ Wave vs “Gain” Antenna Radiation Patterns
Omnidirectional “gain” antenna radiation patterns over ground
Highly Directional Antenna Radiation Pattern

Relative to a Dipole

Relative to Isotropic
Why does gain matter?

- Antenna orientation matters
- “High gain” antennas send more energy towards horizon, less into the air (good for ground comms, bad for air-ground)
- Radiation patterns are greatly affected by the antenna ground plane and nearby metal
- For best performance, mobile antennas should be mounted in the center of the roof
Analog vs. Digital Modulation
Common Analog Modulation Schemes

- FM – Frequency Modulation
- AM – Amplitude Modulation
- SSB – Single Sideband AM
- Almost all analog public safety communications use FM
- AM is used for CB radio, aircraft communication
Frequency Modulation (FM)

- To modulate means “to change” or “to vary”
- Frequency Modulation means changing the frequency of the transmitter in proportion to the audio being picked up by the microphone
- The receiver detects the change in transmitter frequency and uses it to reproduce the audio signal at the speaker
Frequency Modulation – An Illustration

Microphone Output:

-1
0
1
Volts

Time (milliseconds)

Transmitter Output:

154.215
154.205
154.195
Frequency (MHz)

Time (milliseconds)
FM Radio Block Diagrams
(simplified)

**Transmitter**

- Sound Waves
- Mic
- Audio Signal
- RF Signal
- Modulator
- RF Amplifier
- Amplified RF Signal
- Antenna

**Receiver**

- Antenna
- RF Signal
- Demodulator
- Audio Signal
- Audio Amplifier
- Amplified Audio Signal
- Spkr
Digital Modulation

• Signal from microphone is converted from a voltage into numbers through a process called sampling
• Those numbers are processed by a computer
• Binary information (ones and zeros) is sent over the air instead of analog (continuous voltage) information
Sampling

Time (milliseconds)

<table>
<thead>
<tr>
<th>115</th>
<th>203</th>
<th>12</th>
<th>73</th>
<th>200</th>
<th>52</th>
<th>215</th>
<th>208</th>
</tr>
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<tbody>
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<td>0111011</td>
<td>11001011</td>
<td>00001000</td>
<td>01001001</td>
<td>01001000</td>
<td>00110100</td>
<td>11010111</td>
<td>11010000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10</th>
<th>199</th>
<th>222</th>
<th>73</th>
<th>169</th>
<th>218</th>
<th>84</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001010</td>
<td>11000111</td>
<td>11011110</td>
<td>01001001</td>
<td>10101001</td>
<td>11011010</td>
<td>01010100</td>
</tr>
</tbody>
</table>
Frequency Shift Keying – An Illustration

Digital Bitstream:

Transmitter Output:

Time (milliseconds)

Frequency (MHz)

Volts
Vocoding

- Vocoding is used to reduce the amount of data that needs to be sent over the air
- Used to reduce necessary bandwidth – conserves spectrum
- “Compresses” digital audio – analogous to .mp3 versus .wav audio files
- Uses known human speech characteristics to “fill in gaps” of data that is removed
Digital Radio Block Diagrams
(simplified)

Transmitter

Receiver
The Digital Radio “Problem”

- Parametric vocoder uses known human voice characteristics to encode and decode data.
- When background noise (non-human noise) is present, vocoder doesn’t always know how to respond.
- Unpredictable results (garble, loss of communication, etc.)
- In a similar situation, an analog radio would transmit the background noise right along with the intended audio (background noise might overpower voice, but some audio is still received).
Possible Permutations

- VHF Analog Conventional Simplex
- UHF Analog Conventional Simplex
- 800 MHz Analog Conventional Simplex
- VHF Analog Conventional Repeater
- UHF Analog Conventional Repeater
- 800 MHz Analog Conventional Repeater
- VHF Digital Conventional Simplex
- UHF Digital Conventional Simplex
- 800 MHz Digital Conventional Simplex
- VHF Digital Conventional Repeater
- UHF Digital Conventional Repeater
- VHF Analog Trunking Repeater (very rare)
- UHF Analog Trunking Repeater (rare for public safety)
- 800 MHz Analog Trunking Repeater
- VHF Digital Trunking Repeater
- UHF Digital Trunking Repeater
- 800 MHz Digital Trunking Repeater
What is Narrowbanding?

- Effort by FCC to increase the number of useable radio channels below 512 MHz
- Advances in technology allow signals to take up less bandwidth than in the past
- Regulations are changing to take advantage of new technologies
- Starting 2013, all radio systems must be narrowband compliant
What is Narrowbanding? (cont.)

- Splits 25 kHz wide channel into two 12.5 kHz wide channels
- When technology permits, there will be another migration to 6.25 kHz technology
- For FM (analog) systems, narrowbanding is accomplished by reducing the transmitter’s FM deviation – receiver must compensate on the other end
Existing VHF Systems: Already a problem. Not able to use adjacent channels at close distances.

- 155.745
- 155.760
- 155.775

20KHz Bandwidth

WideBand

Overlap

Adjacent channels

15KHz Channel Spacing

Joe Kuran Oregon SIEC
After Narrowband:

Still a problem

Narrowband channels not usable until wideband users vacate.
After all convert to Narrowband
Still some overlay with analog modulation

This represents analog voice with a 11KHz necessary bandwidth

11KHz Bandwidth

7.5KHz Channel Spacing
Still a very minor overlay in the VHF band. UHF band will have no overlay because of 12.5KHz Channel Spacing.

P25 with C4FM Modulation only requires 8.1KHz Necessary Bandwidth
What Do I Need to Do?

- Update FCC License
- Obtain narrowband-capable radios
- Program all radios for narrowband operation (at the same time)
- DOES NOT require moving to 800 MHz or digital (although those are options)
Why New Radios?

- Narrowbanding halved a frequency’s bandwidth and deviation.
  - Many older wideband radios will not operate on frequencies set 12.5kHz apart (154.XXXX instead of 154.XXX)
  - An older wideband radio’s bandwidth is 25kHz. This would interfere with both new 12.5kHz narrowband frequencies on either side of the old 25kHz frequency.
  - An older wideband radio’s deviation is 5kHz. New narrowband radios will respond to this signal by either:
    - Not process the wideband deviation into a received audio signal.
    - Process it into a bad received audio signal (garbled, distorted, etc.).
Migration Problems

• Problems can occur when both wideband and narrowband are used to communicate on the same channel.
  – Channels are programmed for either wide or narrowband.
  – Channels must be programmed consistently for all radios in use.

• Narrowband Radio Transmitting to Wideband Radio:
  – Received audio may be very soft and quiet.
  – Caution, wideband radios must turn up volume to hear. However, once a second wideband radio transmits, the original wideband radio’s received audio will become very loud.

• Wideband Radio Transmitting to Narrowband Radio:
  – Received audio may be loud, distorted, or inaudible.
  – Caution, if you turn down the volume, narrowband communications may not be heard.

• Migration to Narrowband must be planned for all users of the channel!!
Rebanding

800 MHz Only
What is Rebanding?

- Nextel (and smaller, similar systems) caused interference to some public safety 800 MHz radio systems
- To solve this problem, Sprint-Nextel is paying to change the frequencies of every public safety 800 MHz radio system in the country that could potentially be affected
- Depending on the system, this may only require reprogramming all radios, or it could mean replacing all radios
- See [www.800ta.org](http://www.800ta.org) for more info
System Failure, Reliability, Backup Plans
Possible Points of Failure

• User Radio
  – Vocoder
  – Loss of Power (dead battery)

• Repeater
  – Loss of Power (downed power line)
  – Antenna Failure (windstorm)
  – Catastrophic Site Loss (Tornado)

• Link (T1 line, microwave link, etc.)
  – Loss of Power
  – Antenna Failure
  – Utility Outage (phone line)
Key – Choose the most reliable communication path possible for the job at hand

Patrol Officer to Dispatch
- Most reliable path is a repeater because many times the officer will be out of range of the dispatch center

Firefighter to IC
- Most reliable path is simplex because of the short range involved. Repeater failure is no longer an issue, nor is being out of range of the repeater.
Mitigation Techniques

- Hardened Sites
- Backup Power
- Redundant/Backup Sites
- Overlapping Coverage
- Preplanning (i.e. radio programming)
- Portable/Transportable Systems
- User Training
Interoperability & Mutual Aid
Nationwide Mutual Aid Channels

- VCALL & VTAC (VHF Narrowband)
- UCALL & UTAC (UHF Narrowband)
- ICALL & ITAC (800 MHz)

These channels can be used by ANY agency for inter-agency communications (police to fire, state to federal, etc.)
Preplanning is Key to Interoperability

- Radios must be programmed with mutual aid & interop channels beforehand
- When the “big one” hits, it’s too late
- Program as many mutual aid channels into radios as you have capacity for
- Establish communications (make sure they work) before going into the field
- Common naming convention is important
Practical Tips

- Hold radio in hand for maximum range (radio on belt with speaker mic greatly reduces range unless remote antenna is used)
- Don’t swallow the mic – 2 inches away
- PTT – Push button, Take a Breath, Talk – allow time for repeater to activate, links to establish, etc.
- Hold radio so that antenna is vertical
- Don’t yell – causes overdeviation, distorts audio, unreadable
- Know how the radio works – scan, priority scan, scan resume, talkaround, monitor, etc.
- Ensure the channel is correctly programmed for narrowband or wideband operation (if this isn’t an option in the radio, it’s probably not narrowband capable)
- Use consistent channel names when programming