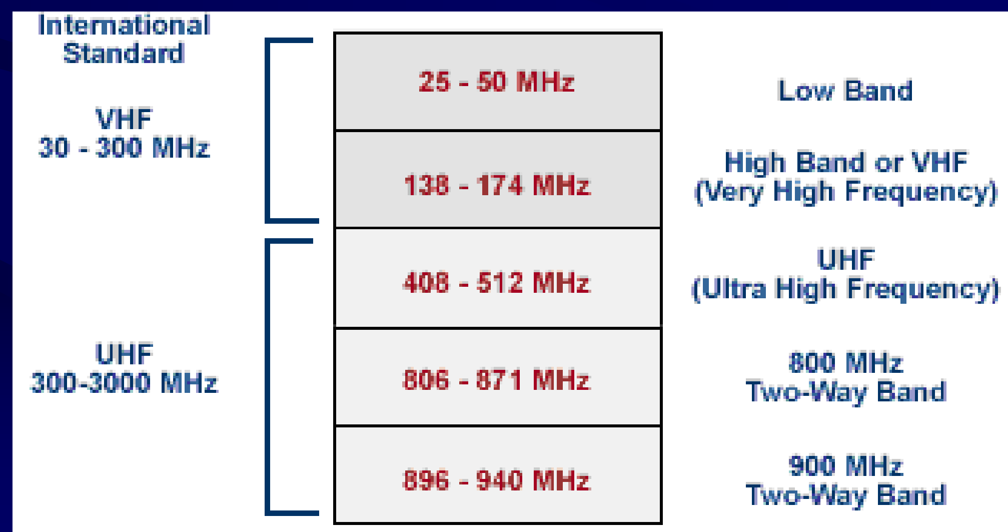
Public Safety Radio Bands

- 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

CTCSS/CDCSS Tone Frequencies (Hz)

CTCSS

67.0	71.9	74.4	77.0	79.7	82.5	85.4	88.5	91.5	94.8
97.4	100.0	103.5	107.2	110.9	114.8	118.8	123.0	127.3	131.8
136.5	141.3	146.2	151.4	156.7	162.2	167.9	173.8	179.9	186.2
192.8	203.5	210.7	218.1	225.7	233.6	241.8	250.3		

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

CDCSS

023	025	026	031	032	036	043	047	051	053
054	065	071	072	073	074	114	115	116	122
125	131	132	134	143	145	152	155	156	162
165	172	174	205	212	223	225	226	243	244
245	246	251	252	255	261	263	265	266	271
274	306	311	315	325	331	332	343	346	351
356	364	365	371	411	412	413	423	431	432
445	446	452	454	455	462	464	465	466	503
506	516	523	526	532	546	565	606	612	624
627	631	632	654	662	664	703	712	723	731
732	734	743	754						

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

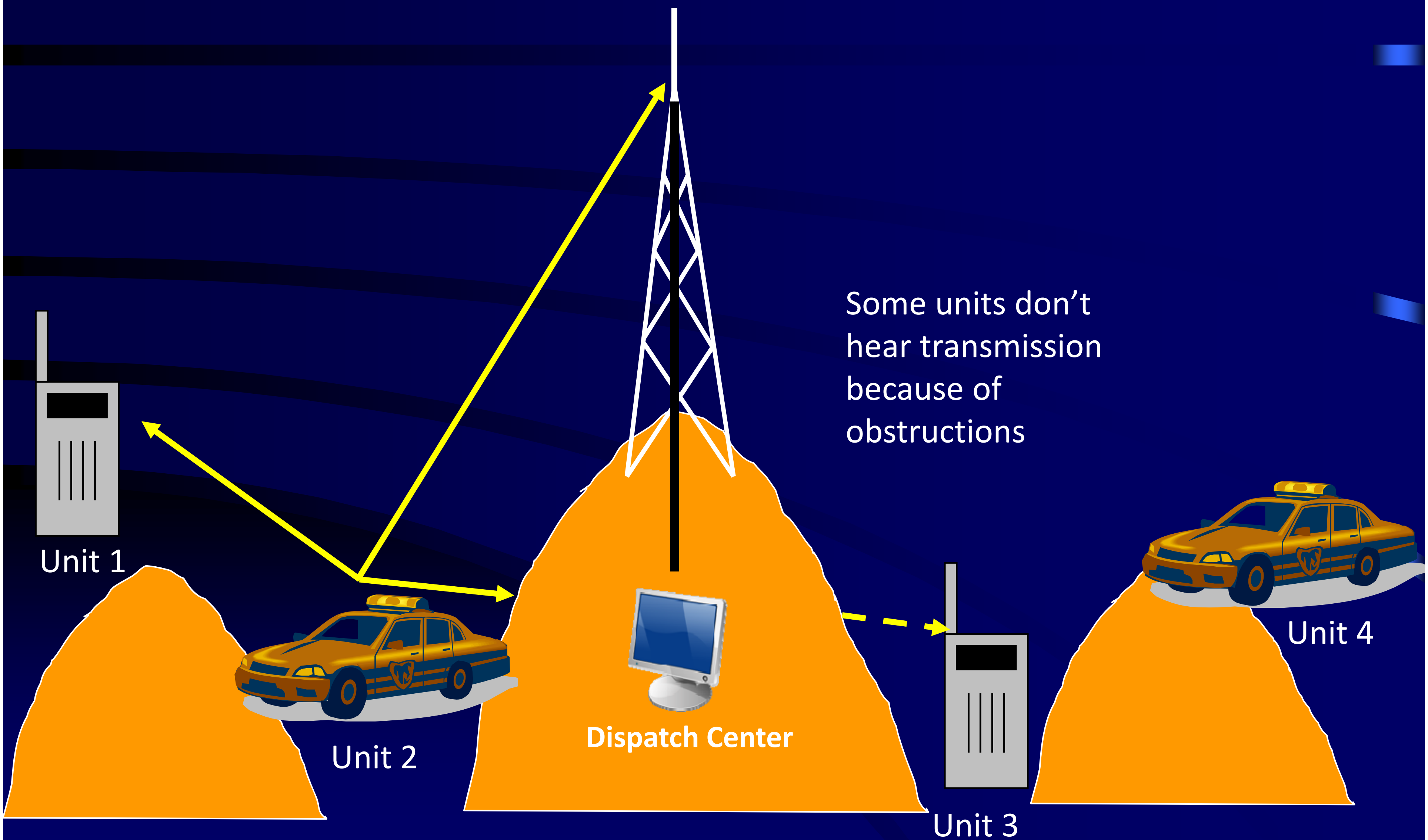
Simplex

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

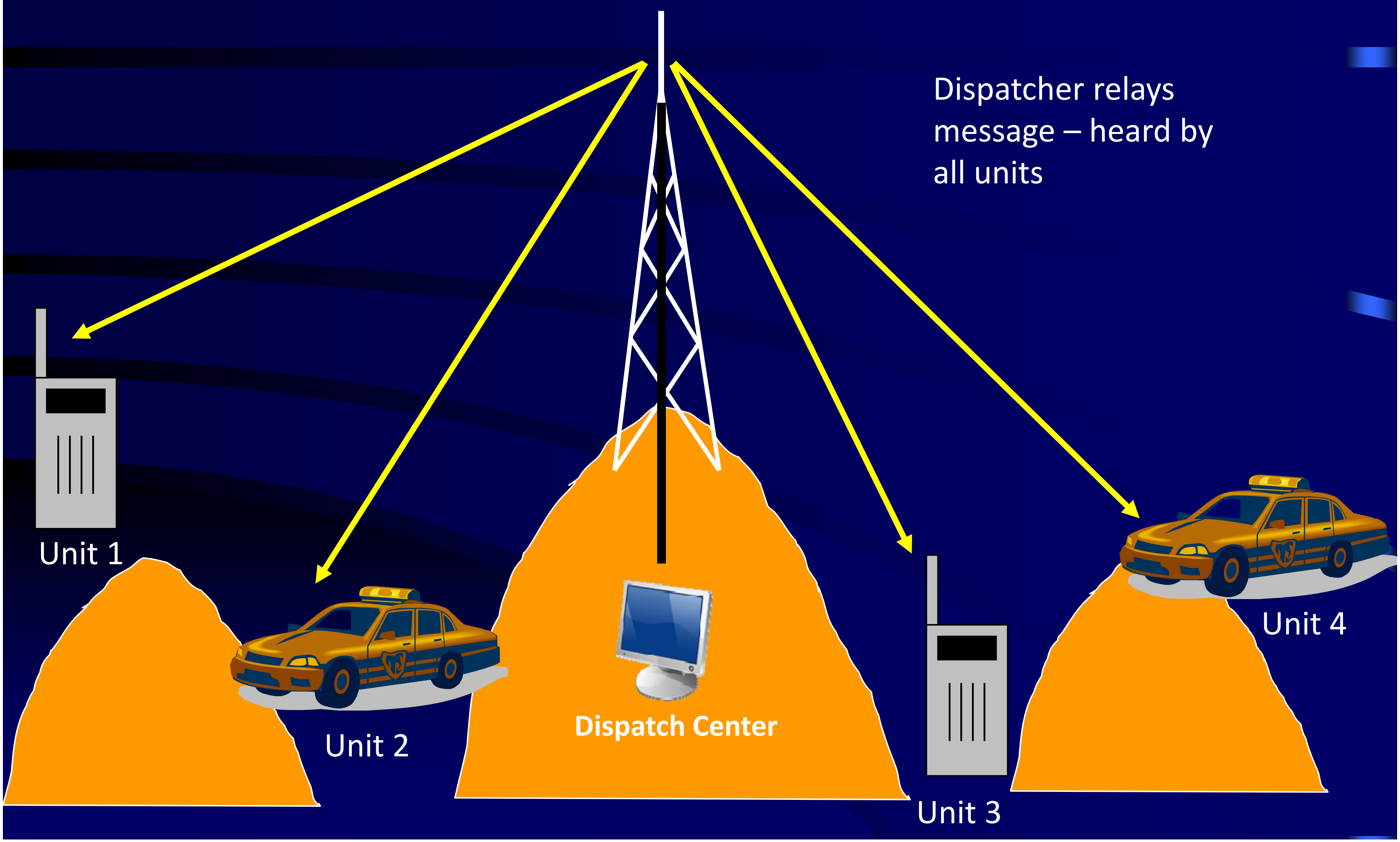
Duplex

- 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.

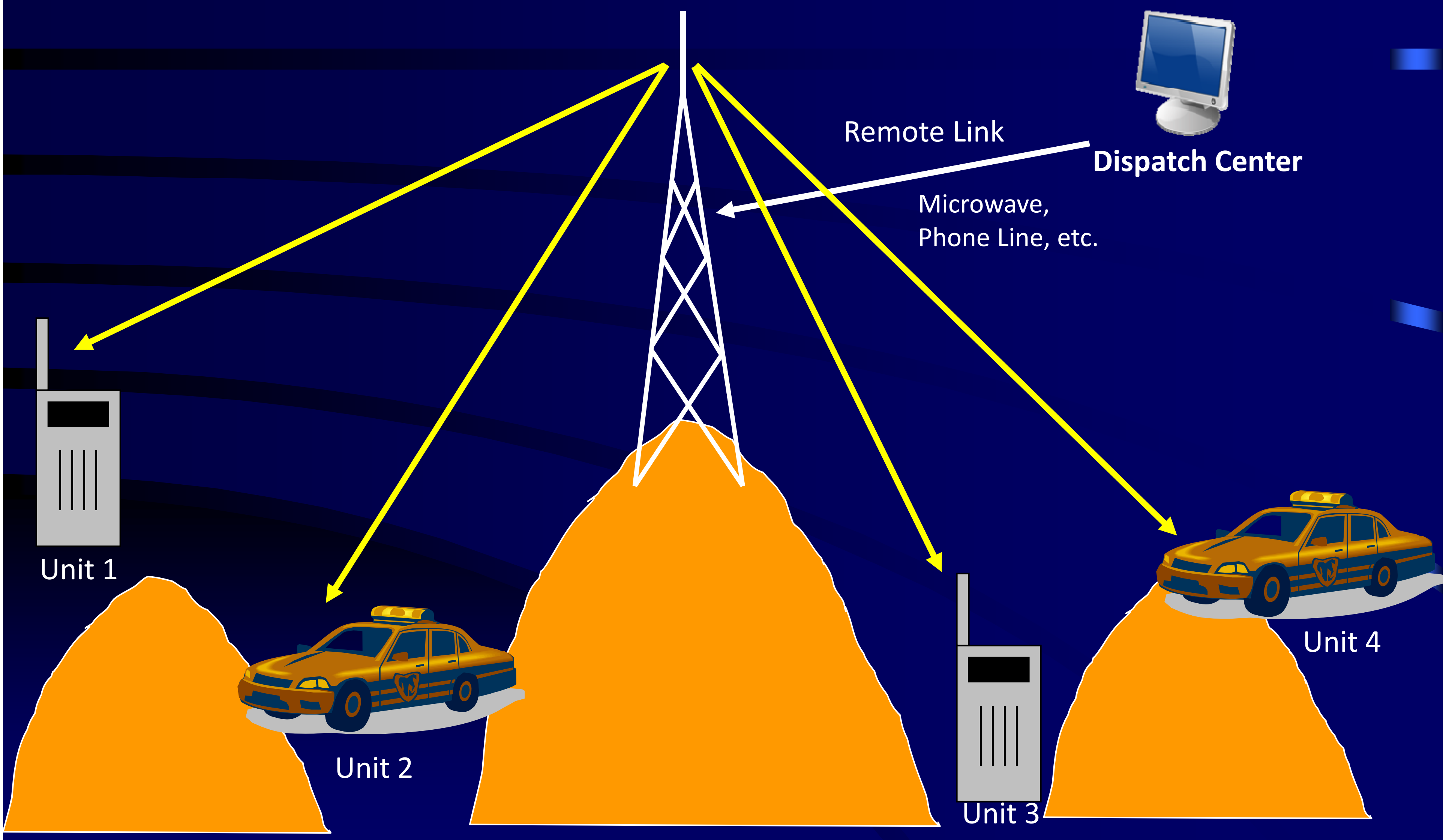
Base Station – Height Improves Range



Base Station – Height Improves Range



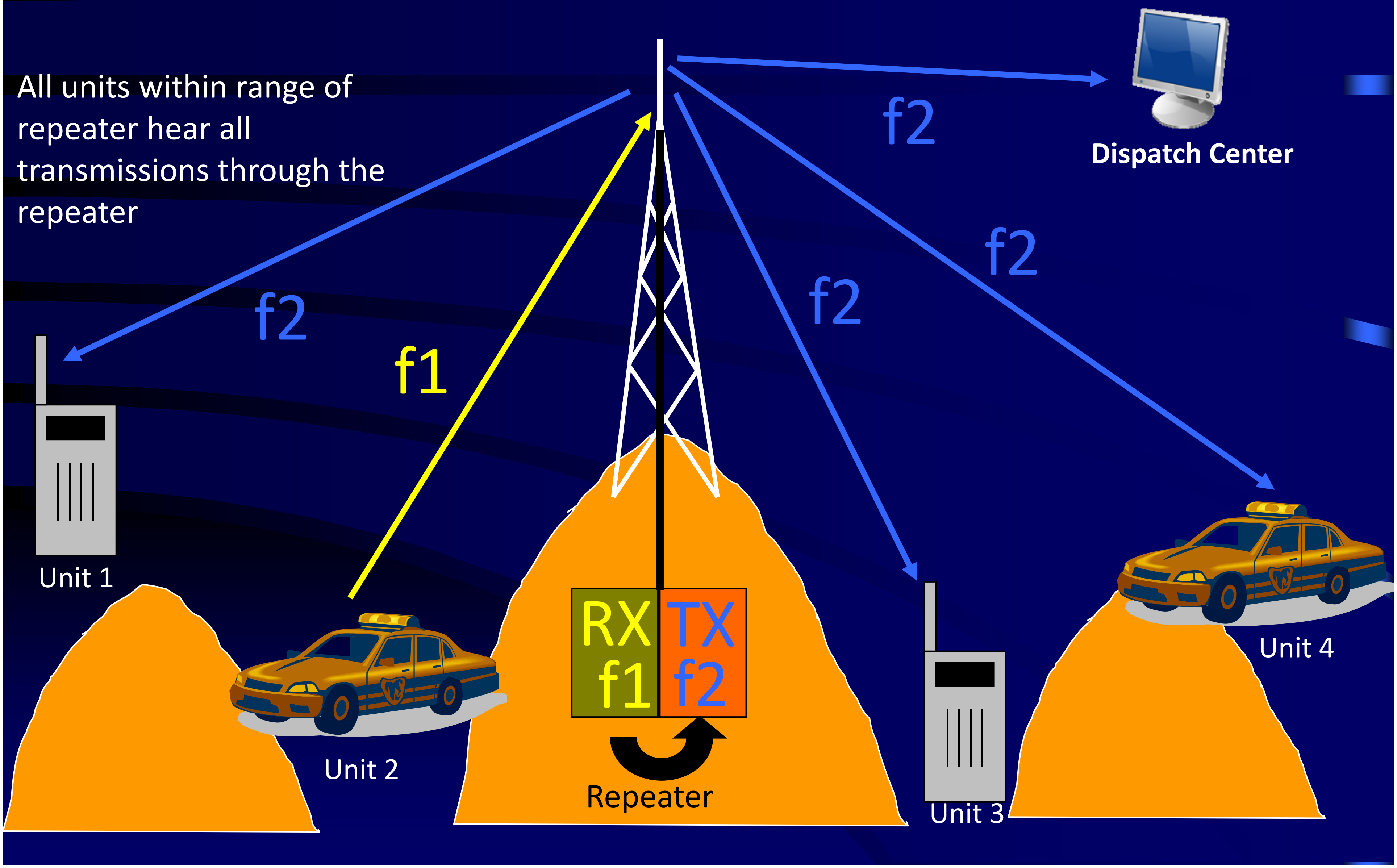
Remote Base Operation



Conventional Repeater

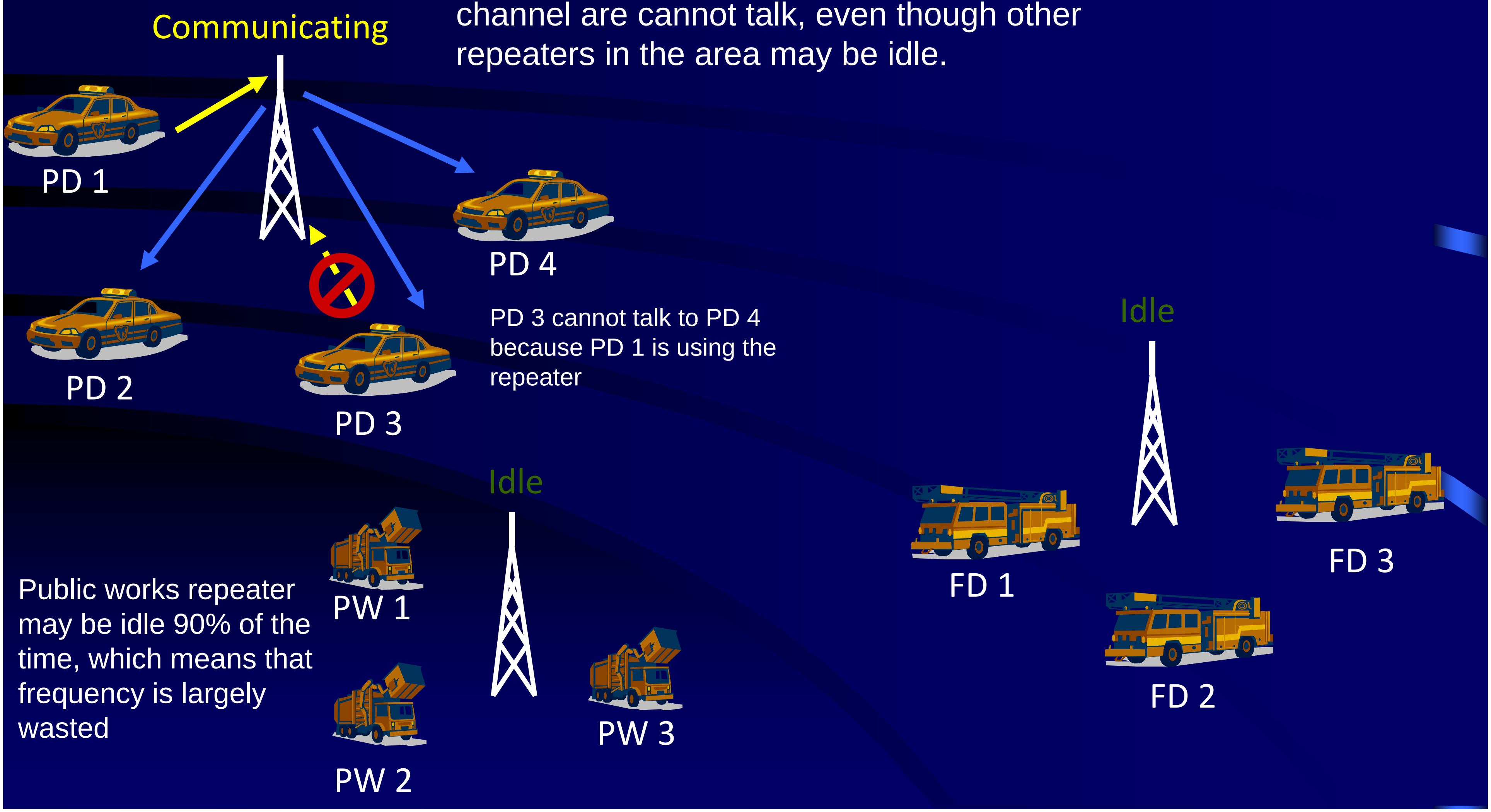
- Receives a signal on one frequency and retransmits (repeats) it on another frequency
- Placed at a high location
- Increases range of portable and mobile radio communications
- Allows communication around obstructions (hills, valleys, etc.)
- User radios receive on the repeaters transmit frequency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

Conventional Repeater



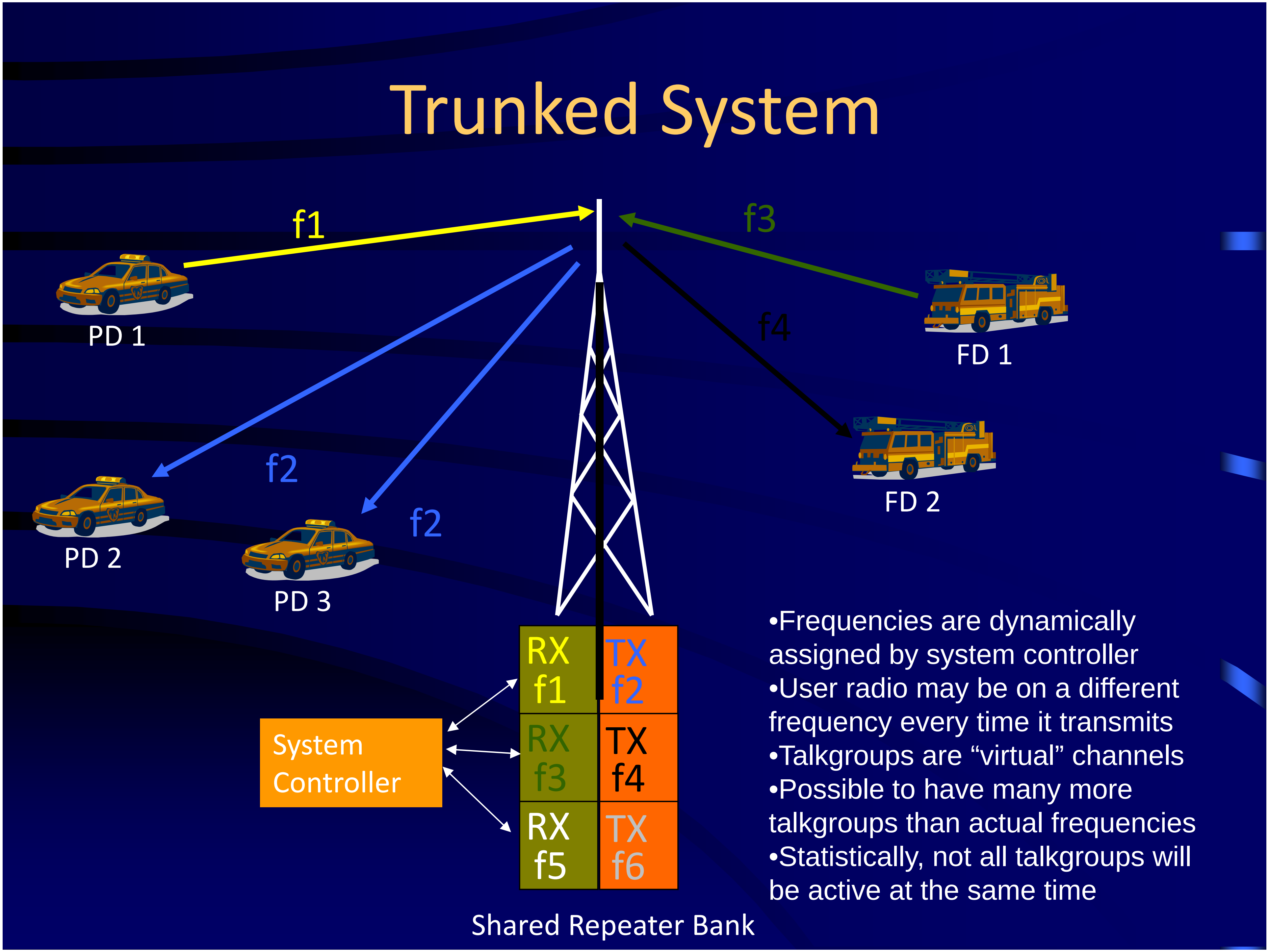
Conventional Systems

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



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

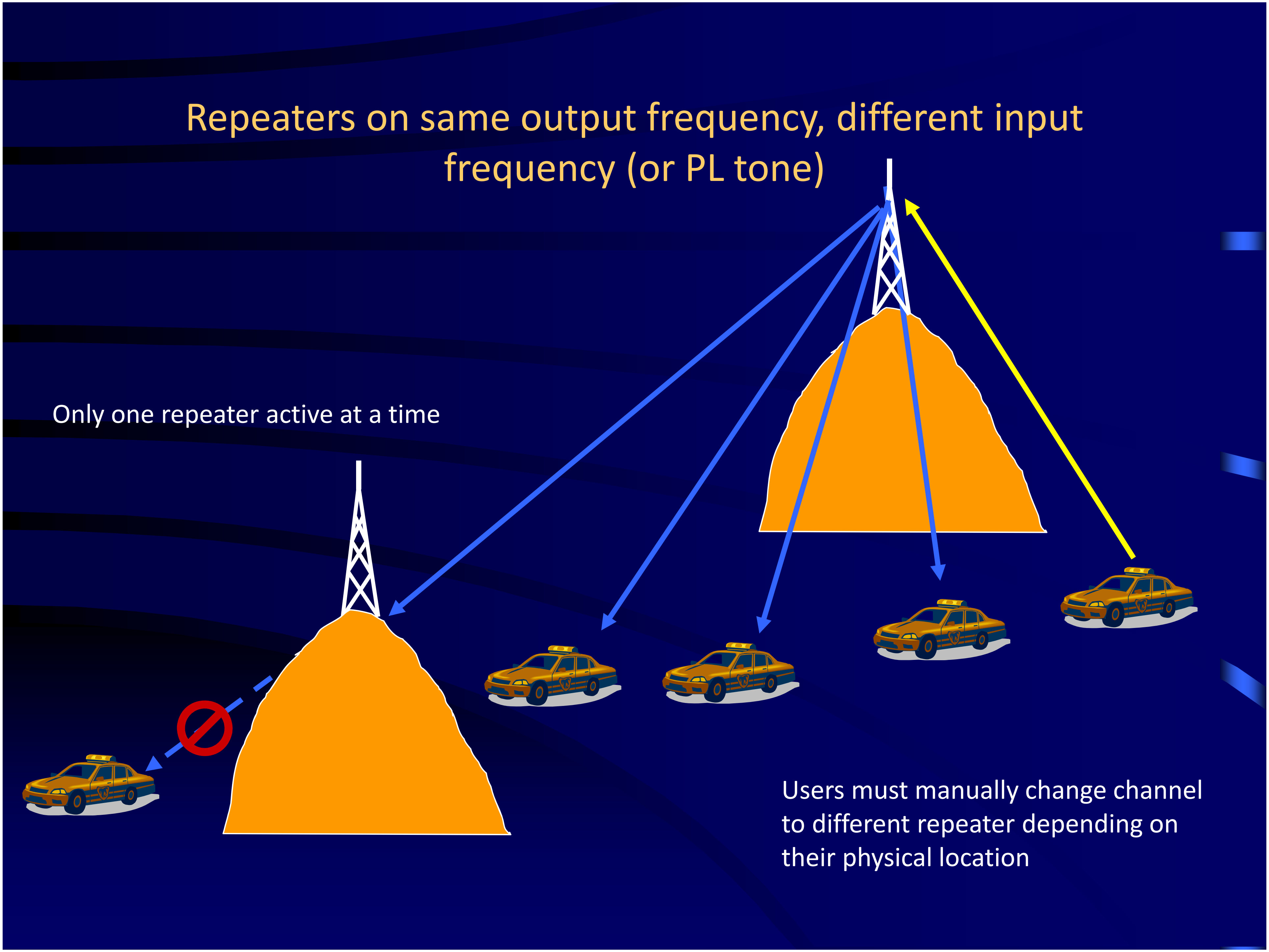

Trunked System
f1
f3
PD 1
f4
FD 1
f2
FD 2
f2
PD 2
PD 3
RX
f1
TX
f2
System
Controller
RX
f3
TX
f4
RX
f5
TX
f6
Shared Repeater Bank
•Frequencies are dynamically assigned by system controller
•User radio may be on a different frequency every time it transmits
•Talkgroups are “virtual” channels
•Possible 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

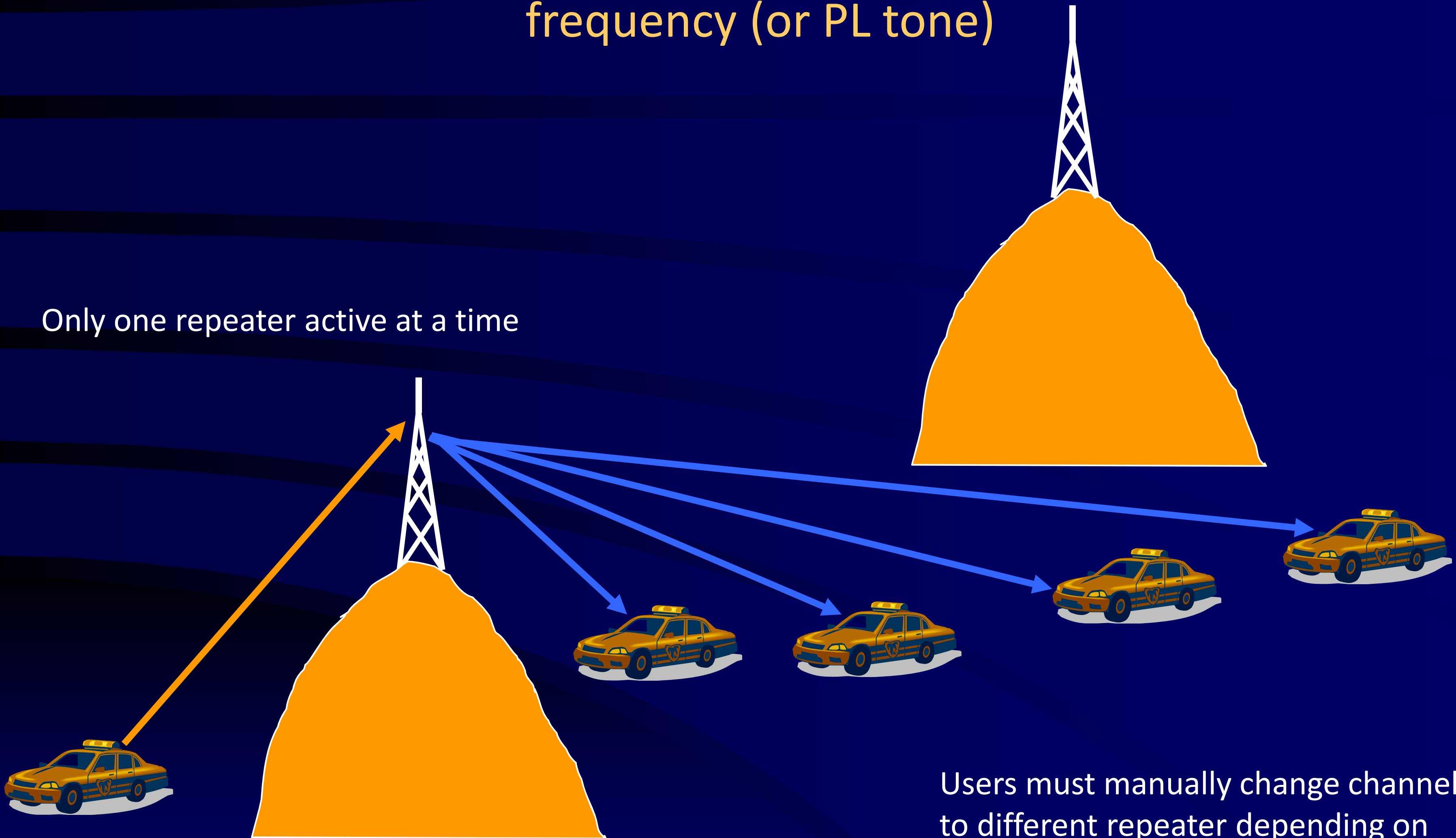
Multi-Site Systems

- 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)

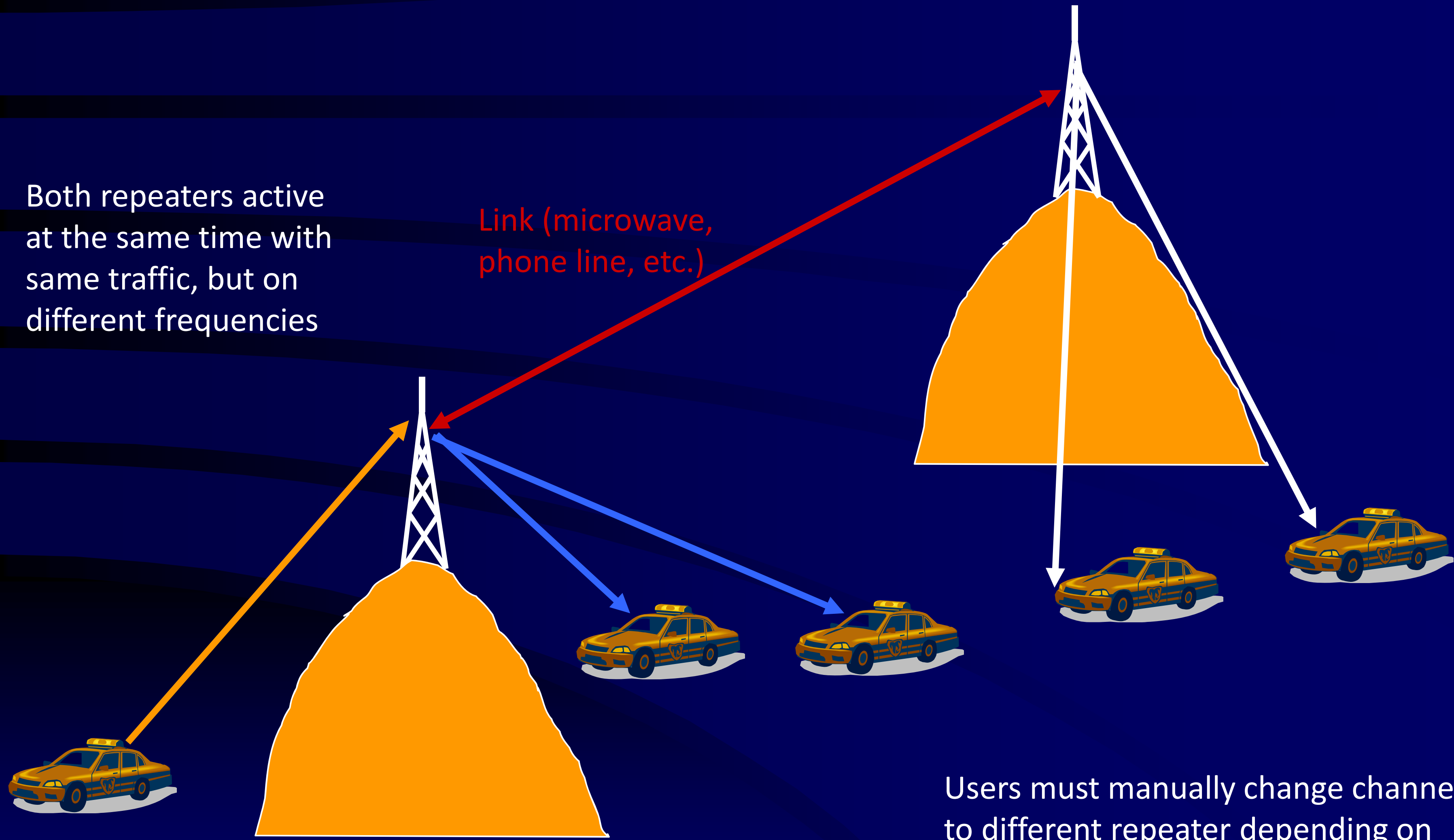
Only one repeater active at a time



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

Linked repeaters on different frequencies

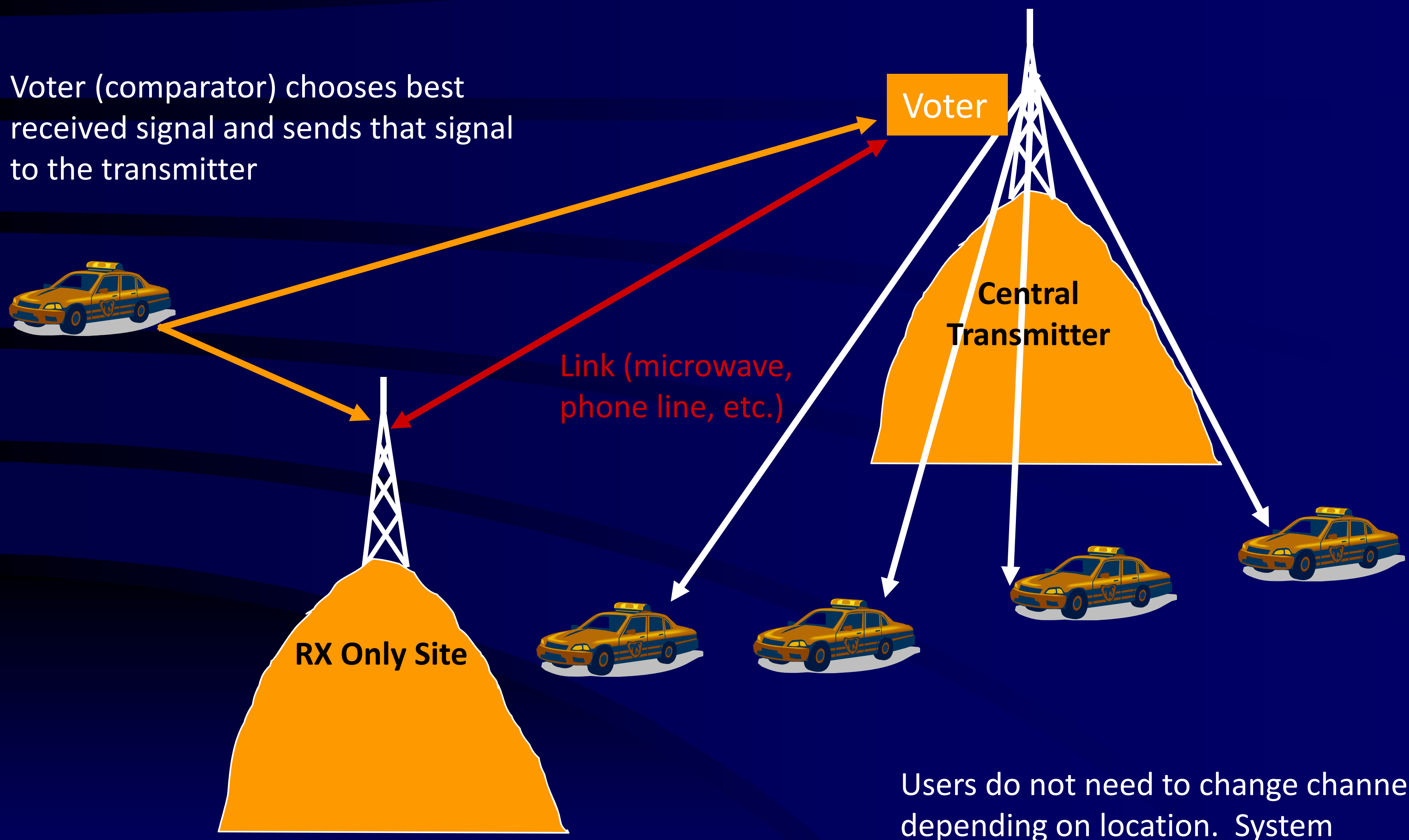
Both repeaters active at the same time with same traffic, but on different frequencies



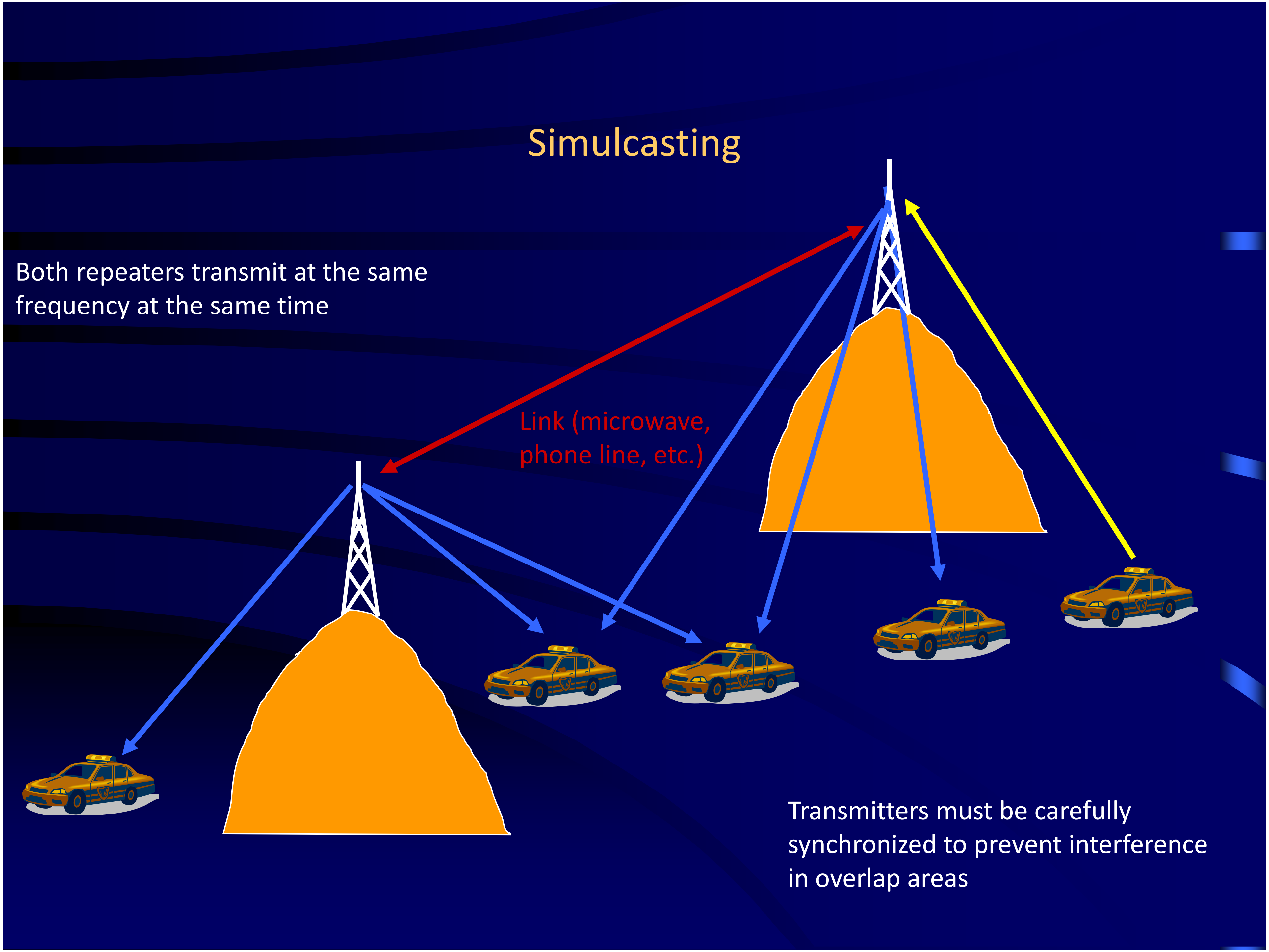
Users must manually change channel to different repeater depending on their physical location

Voting Receivers

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
Link (microwave, phone line, etc.)
Transmitters must be carefully synchronized to prevent interference in overlap areas

Antenna Polarization & Gain

Radio Wave Polarization

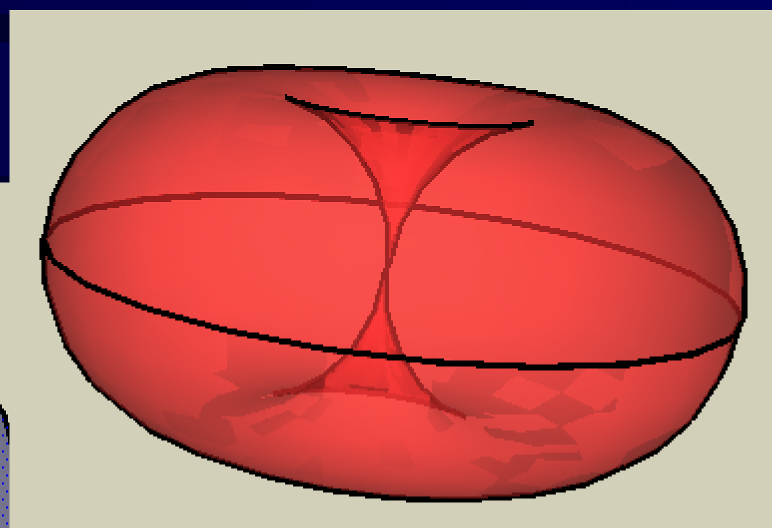
- Two-way radio systems use vertical polarization (antenna elements are oriented vertically)
- Cross-polarization results in signal loss (can be very dramatic)
- What does this mean? Hold portable radio so that antenna is oriented vertically…don't hold it sideways!!

Antenna Gain

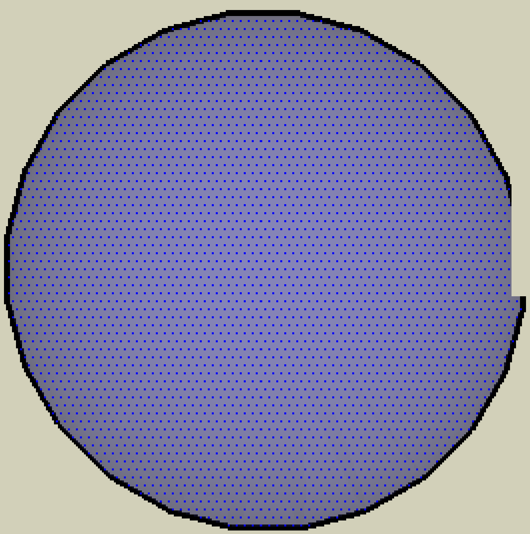
- Gain refers to how power is transmitted in different directions from an antenna
- An antenna with no gain (0 dBi, or dB relative to an isotropic radiator) radiates an equal amount of power in all directions
- An antenna with some gain (say 3 dBi) radiates 3 dB more power *in one direction* than the o 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

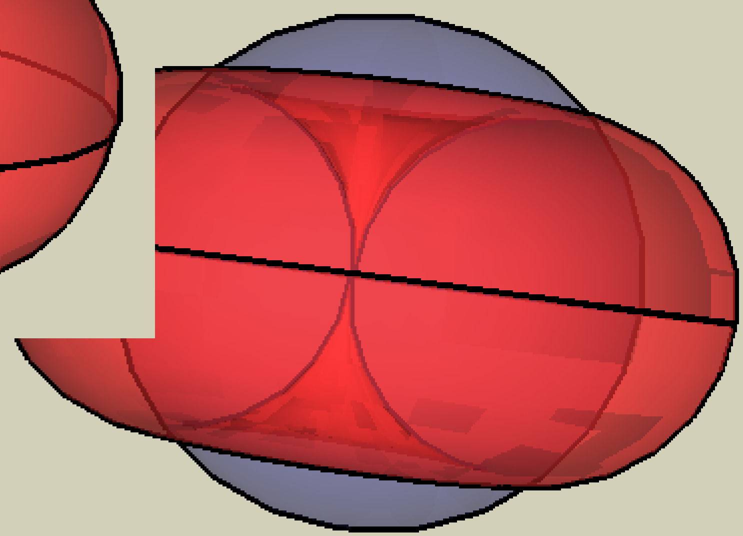
Dipole



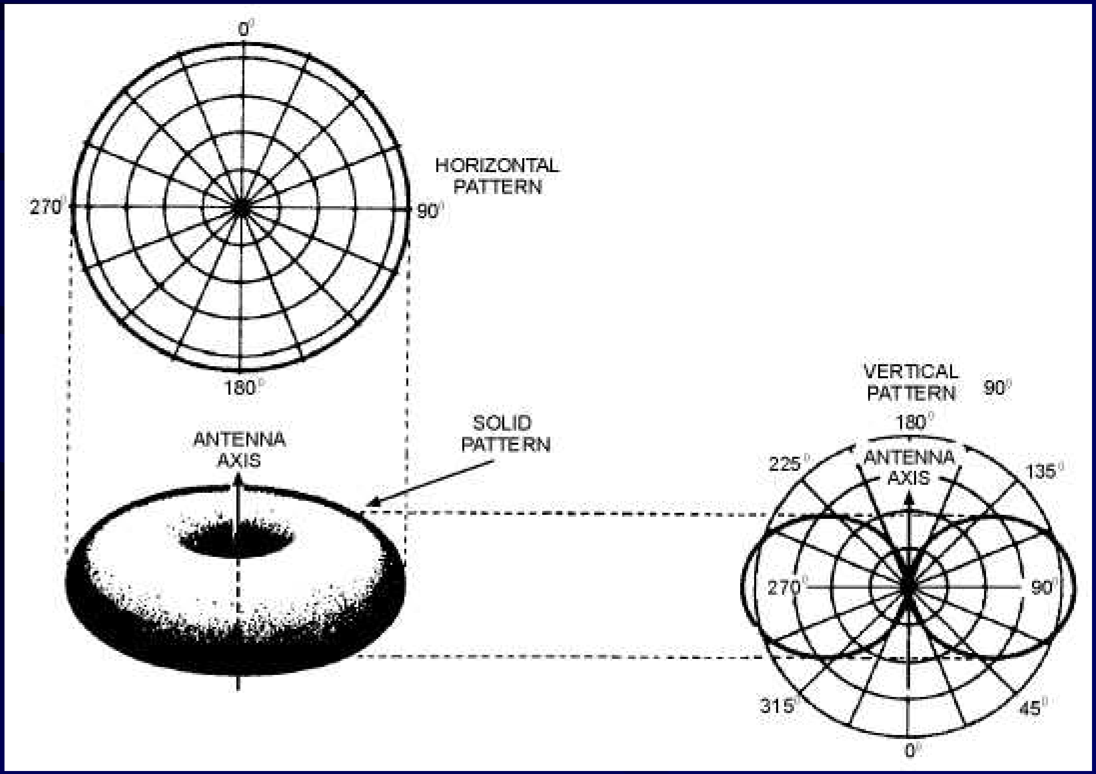
Isotropic



Together

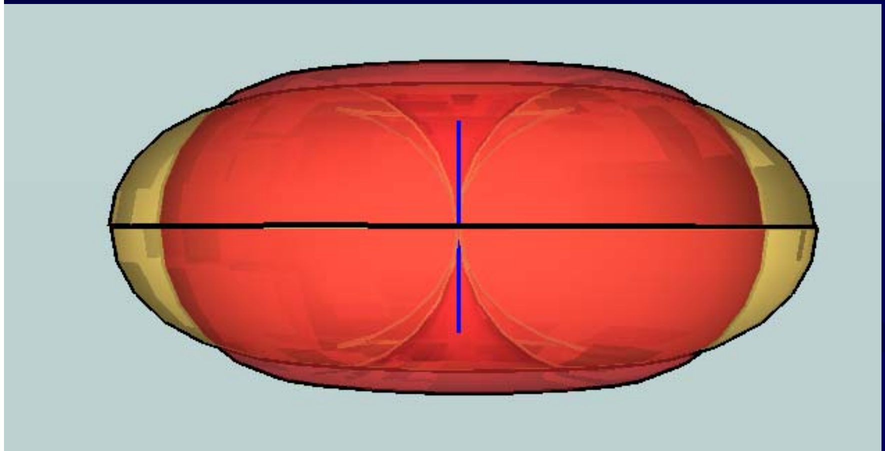


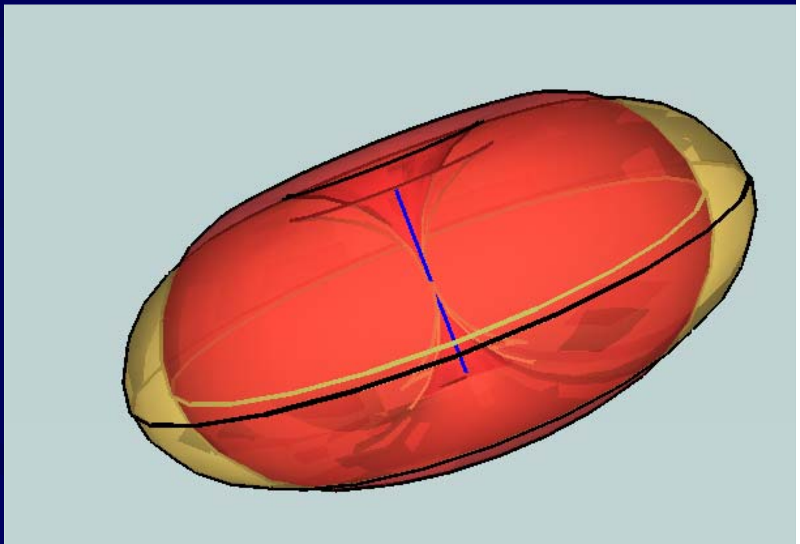
Dipole Antenna Radiation Pattern



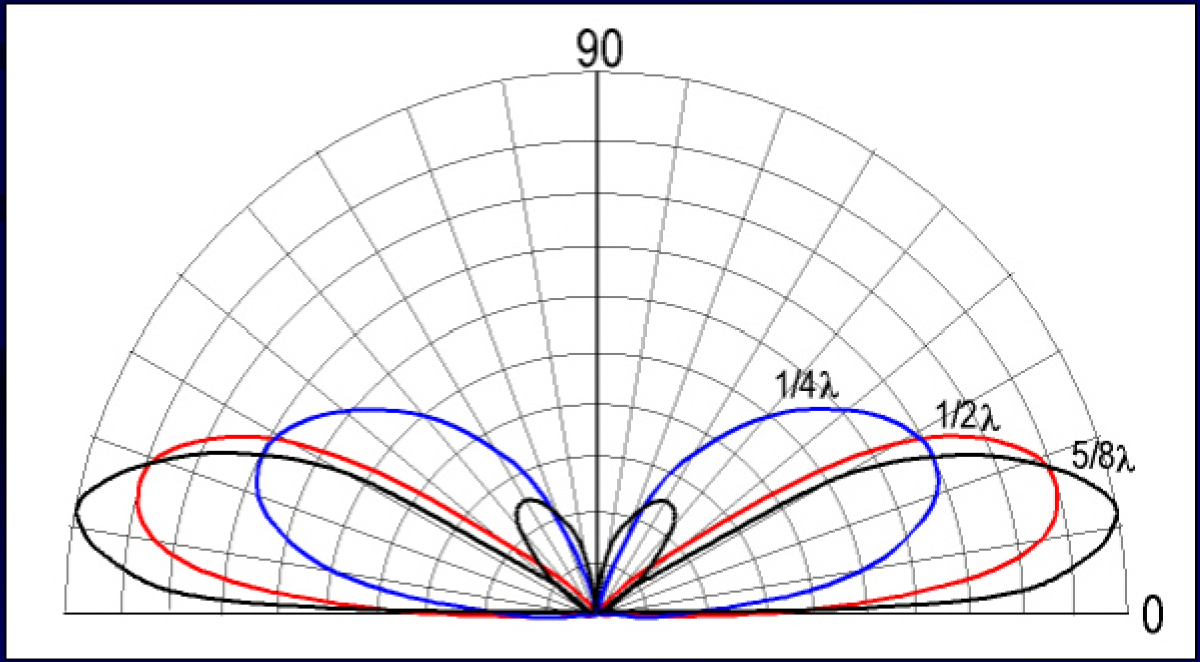
Source: http://www.tpub.com/content/neets/14182/css/14182_186.htm

¼ Wave vs "Gain" Antenna Radiation Patterns



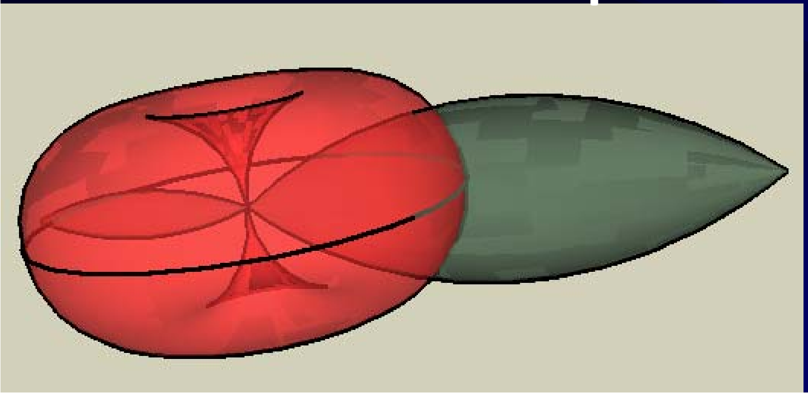


Omnidirectional “gain” antenna radiation patterns over ground

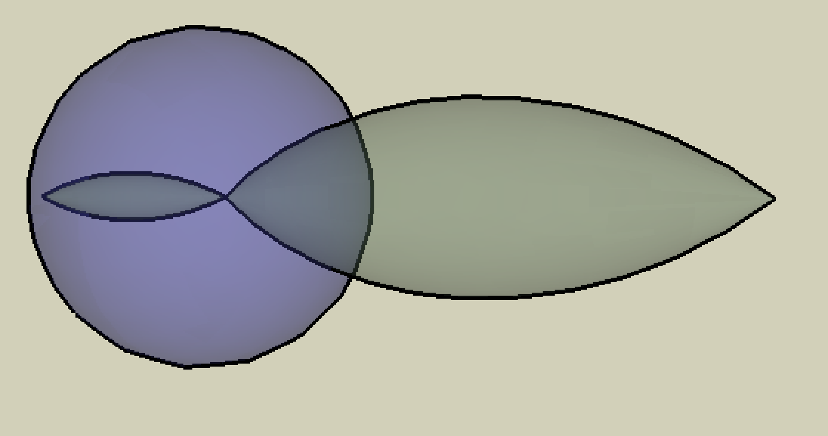


Highly Directional Antenna Radiation Pattern

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

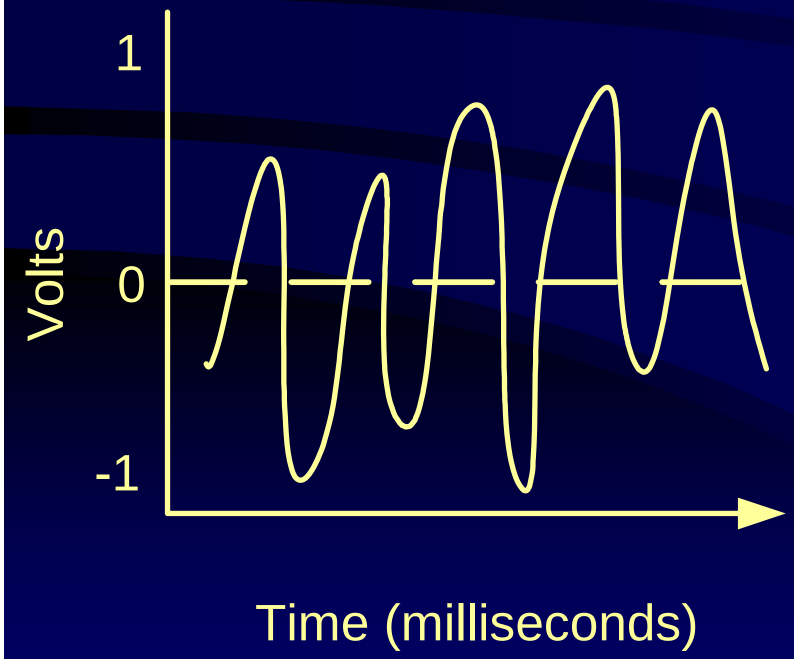
- FM – Frequency Modulation
- AM – Amplitude Modulation
- SSB – Single Sideband AM
- Almost all analog public safety communications use FM
- AM is used for CB radio, aircraft communication

Frequency Modulation (FM)

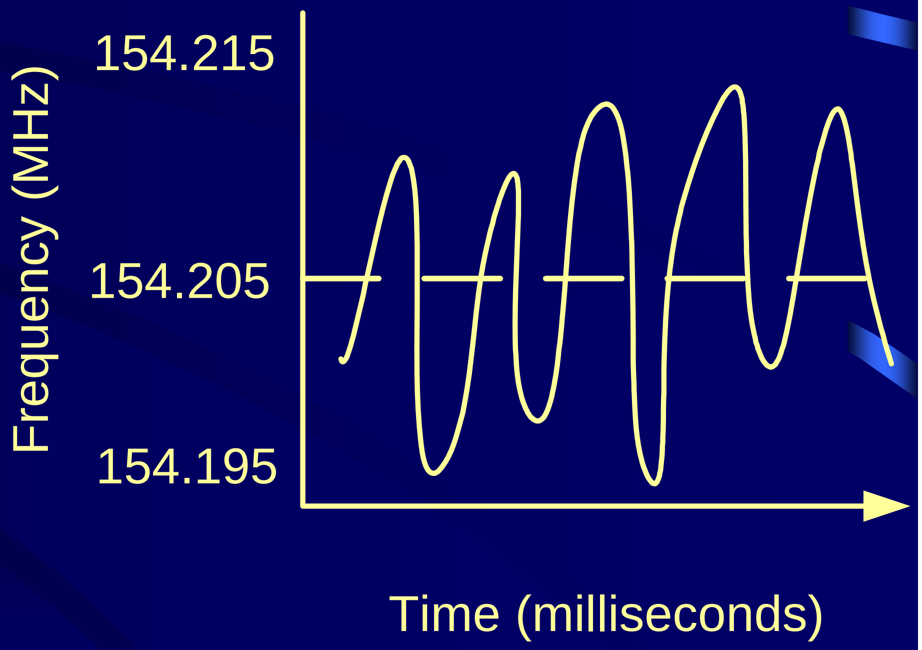
- To modulate means “to change” or “to vary”
- Frequency Modulation means changing the frequency of the transmitter in proportion to the audio being picked up by the microphone
- The receiver detects the change in transmitter frequency and uses it to reproduce the audio signal at the speaker

Frequency Modulation – An Illustration

Microphone Output:



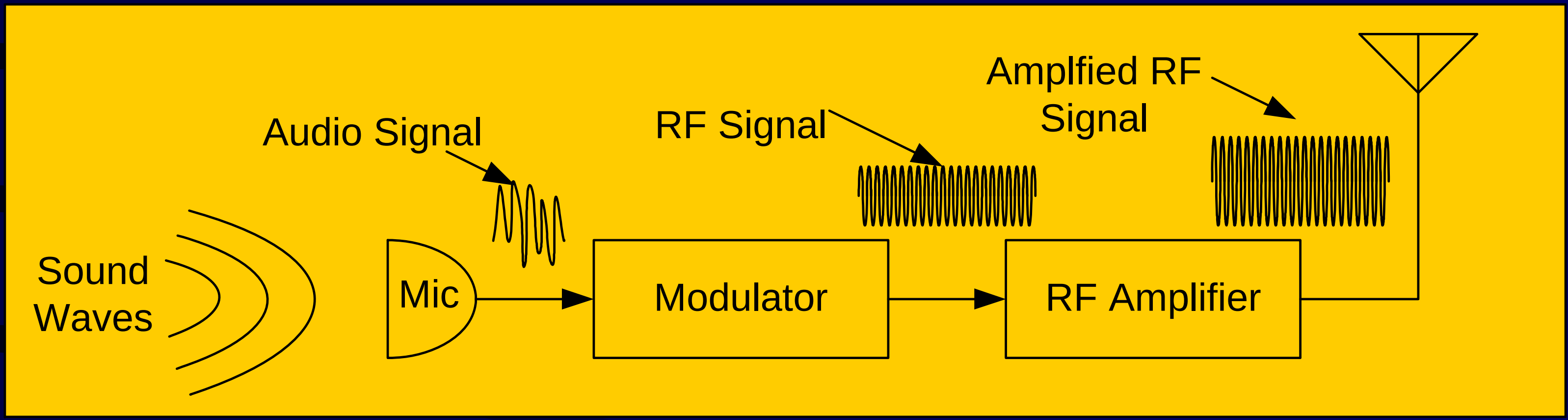
Transmitter Output:



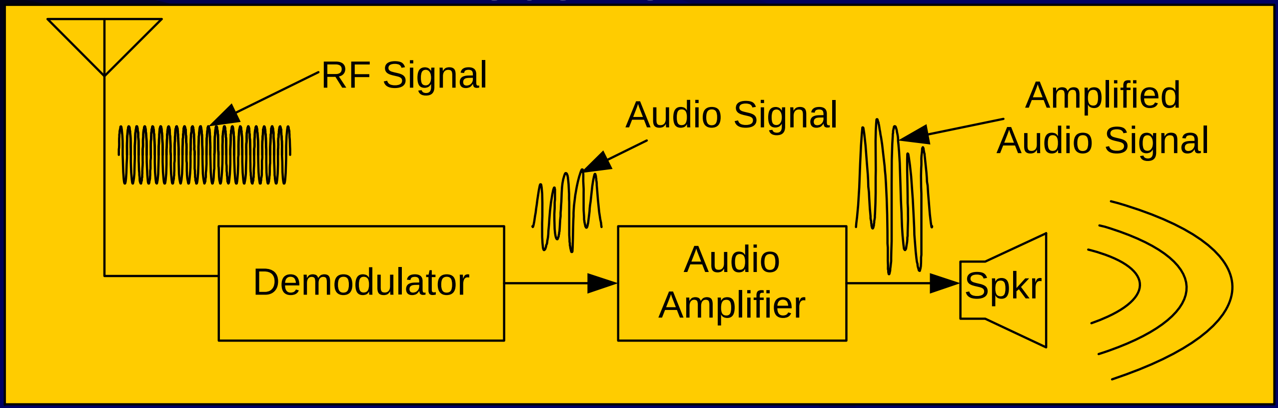
FM Radio Block Diagrams

(simplified)

Transmitter



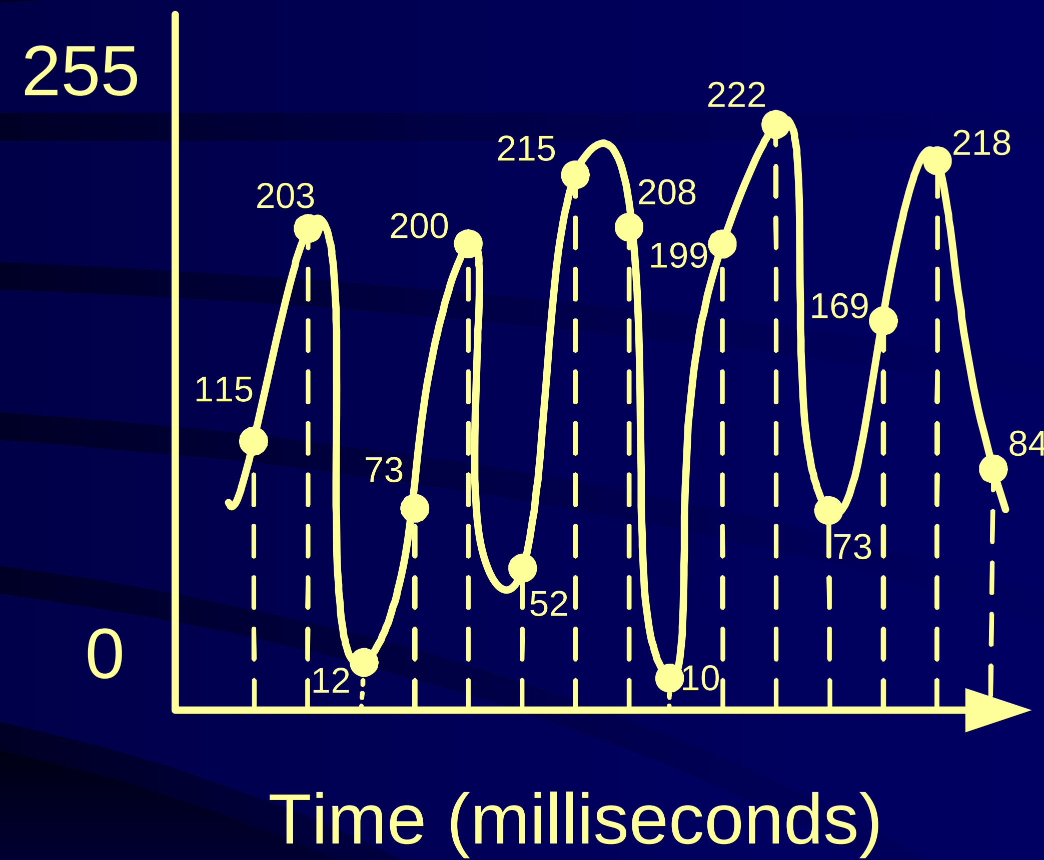
Receiver



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

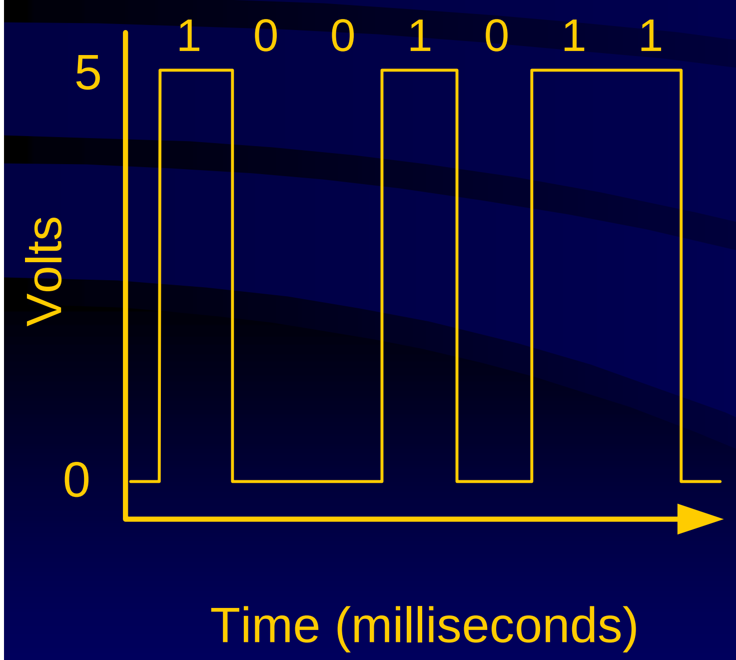


115	203	12	73	200	52	215	208
0111011	11001011	00001000	01001001	01001000	00110100	11010111	11010000

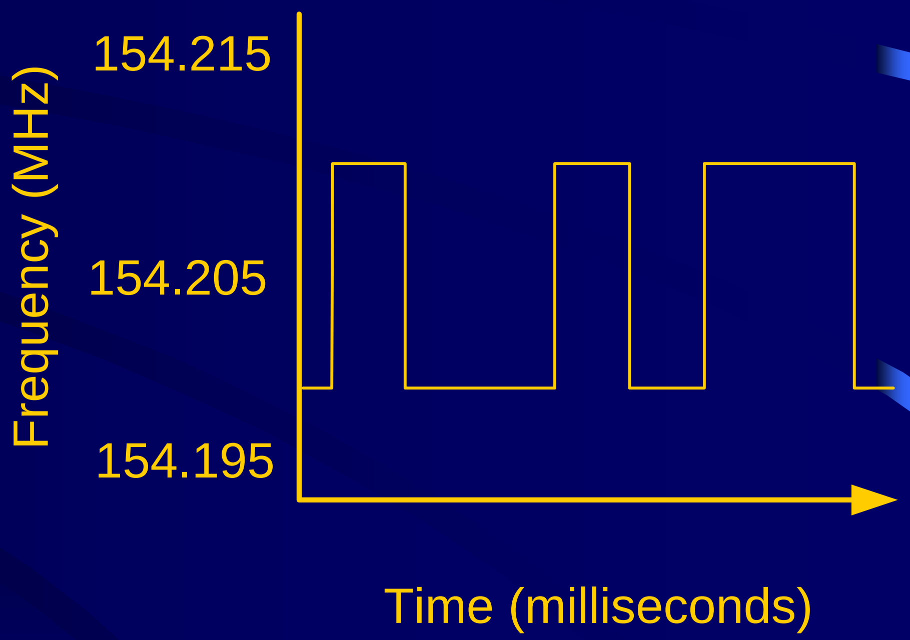
10	199	222	73	169	218	84
00001010	11000111	1101110	01001001	10101001	11011010	01010100

Frequency Shift Keying – An Illustration

Digital Bitstream:



Transmitter Output:



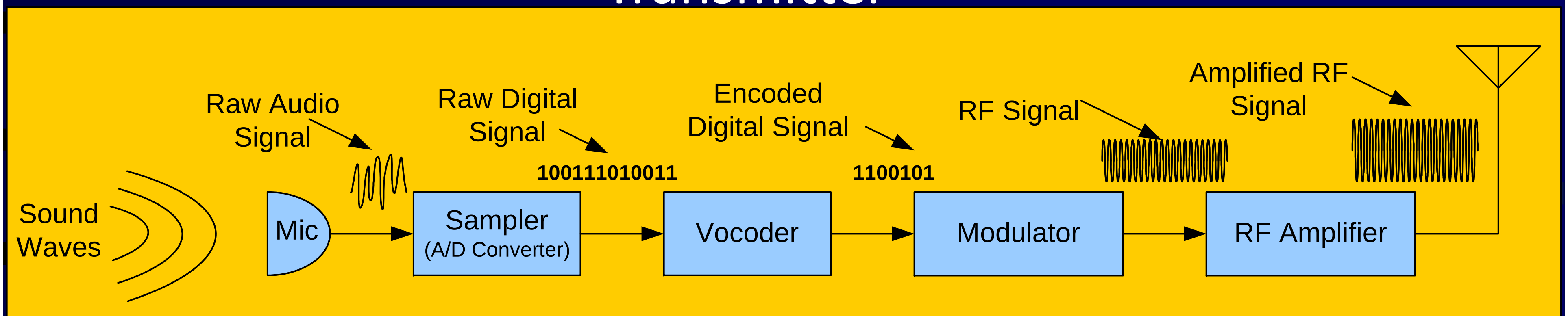
Vocoding

- 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

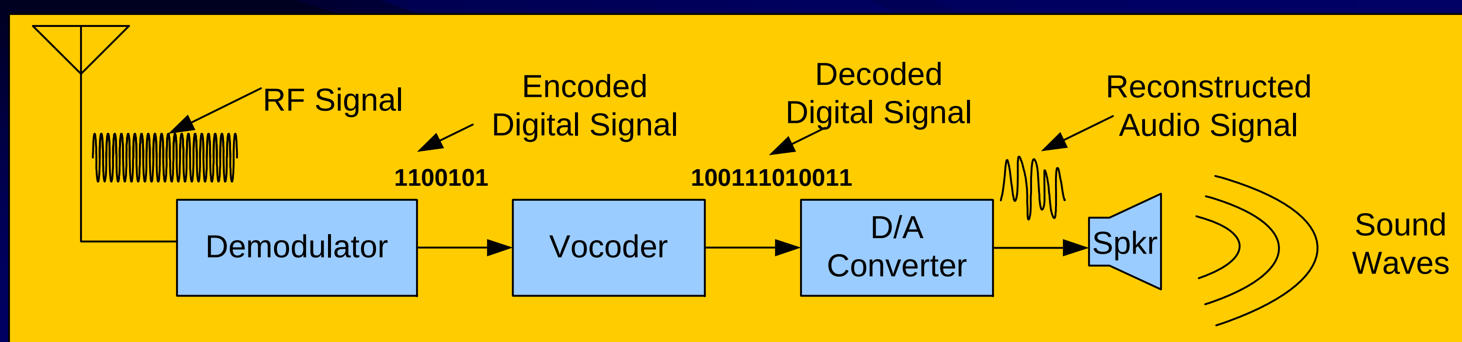
Digital Radio Block Diagrams

(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

Narrowbanding

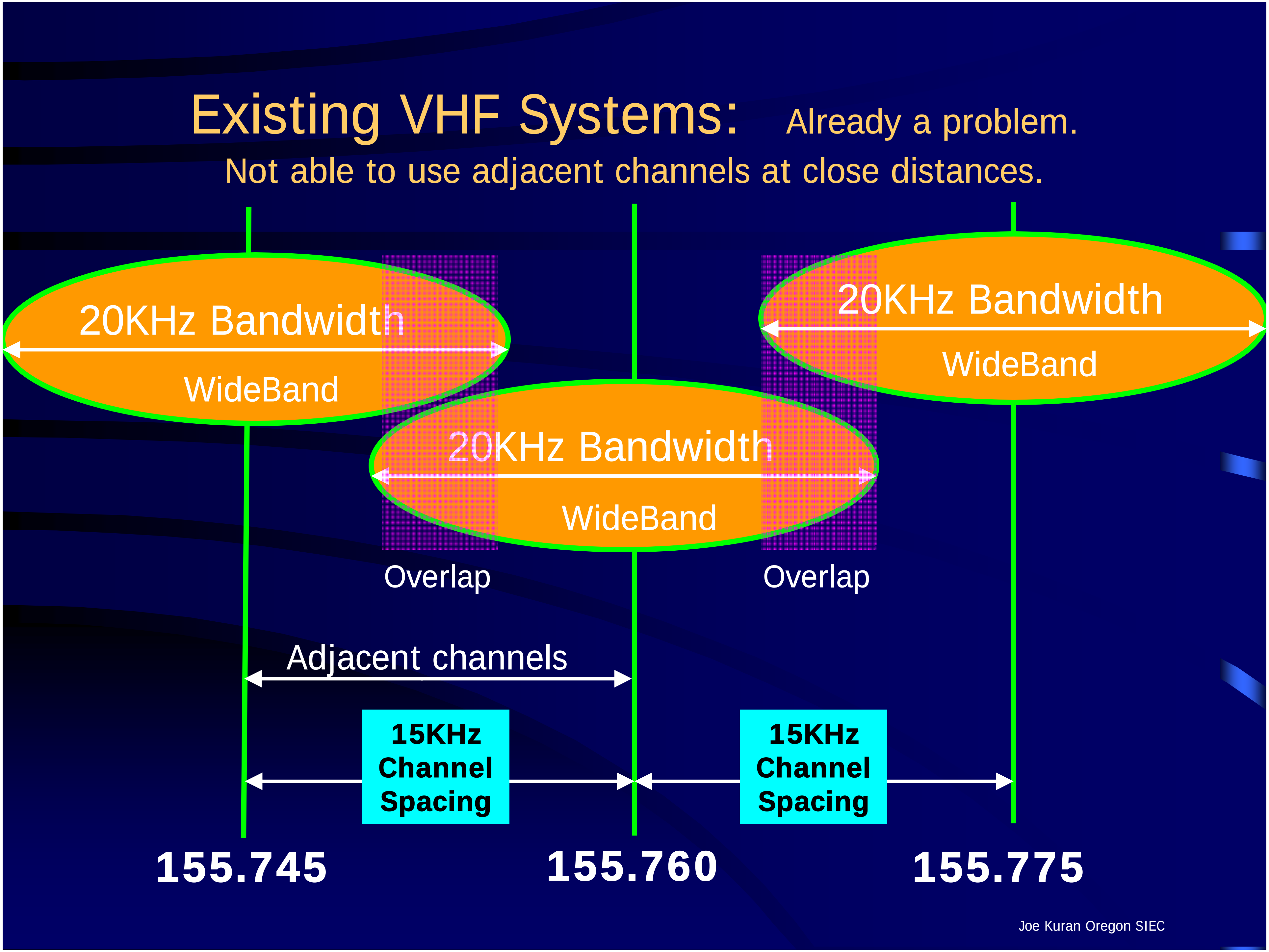
Deadline: 2013

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.)

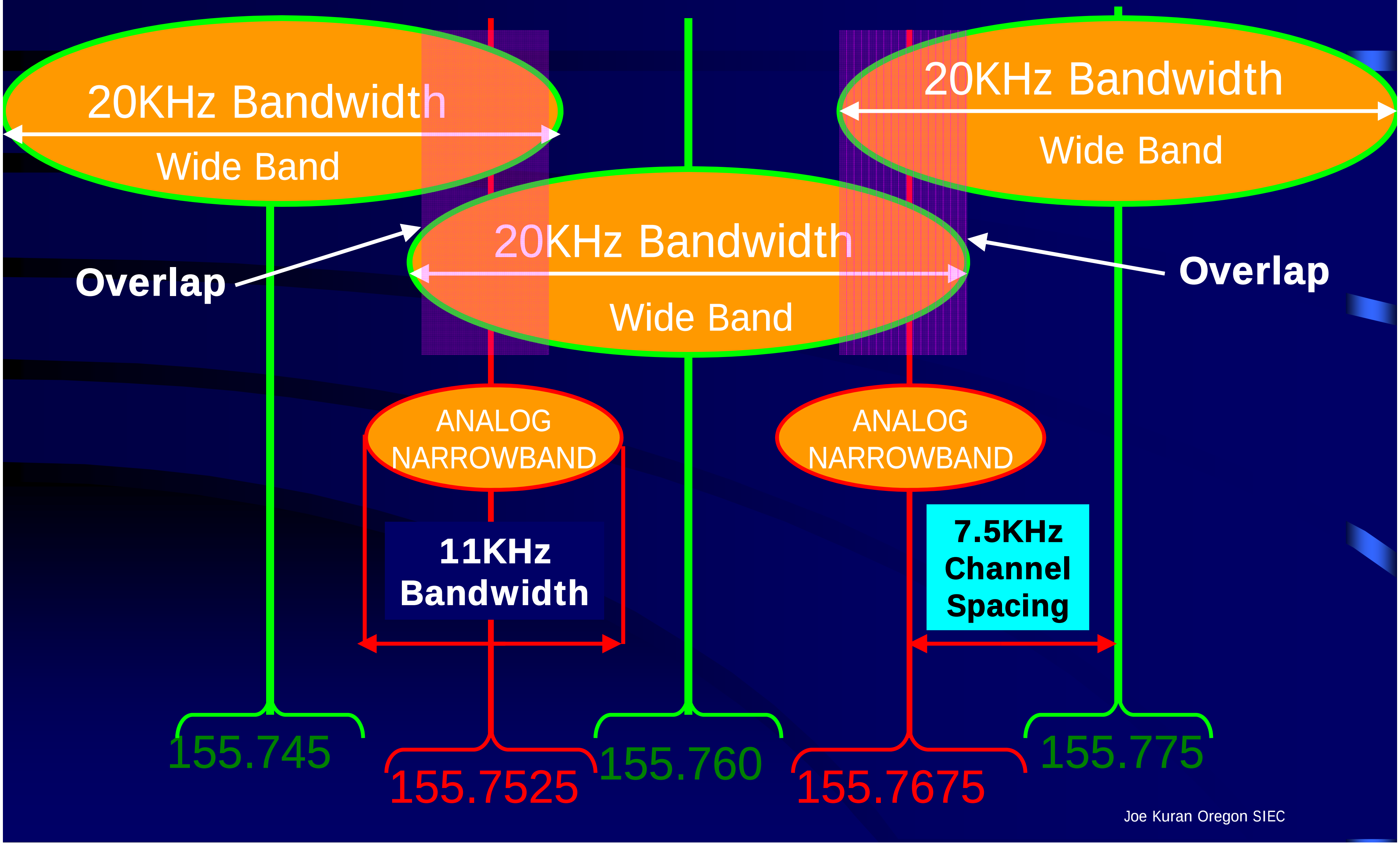
- Splits 25 kHz wide channel into two 12.5 kHz wide channels
- When technology permits, there will be another migration to 6.25 kHz technology
- For FM (analog) systems, narrowbanding is accomplished by reducing the transmitter’s FM deviation – receiver must compensate on the other end


Existing VHF Systems: Already a problem.
Not able to use adjacent channels at close distances.
20KHz Bandwidth
WideBand
20KHz Bandwidth
WideBand
20KHz Bandwidth
WideBand
Overlap
Overlap
Adjacent channels
15KHz Channel Spacing
15KHz Channel Spacing
155.745
155.760
155.775
Joe Kuran Oregon SIEC

After Narrowband:

Still a problem

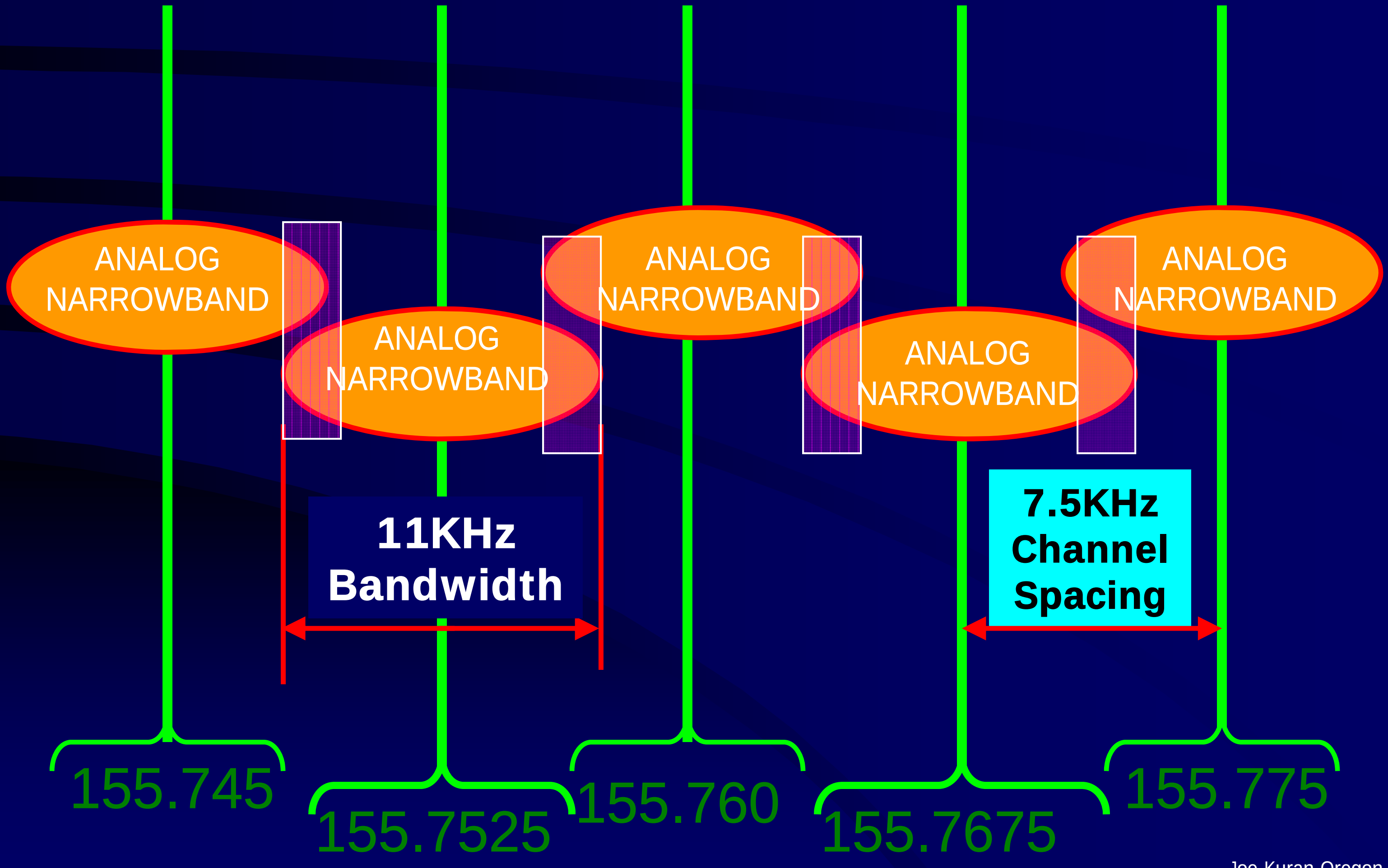
Narrowband channels not usable until wideband users vacate.



After all convert to Narrowband

Still some overlay with analog modulation

This represents analog voice with a 11KHz necessary bandwidth



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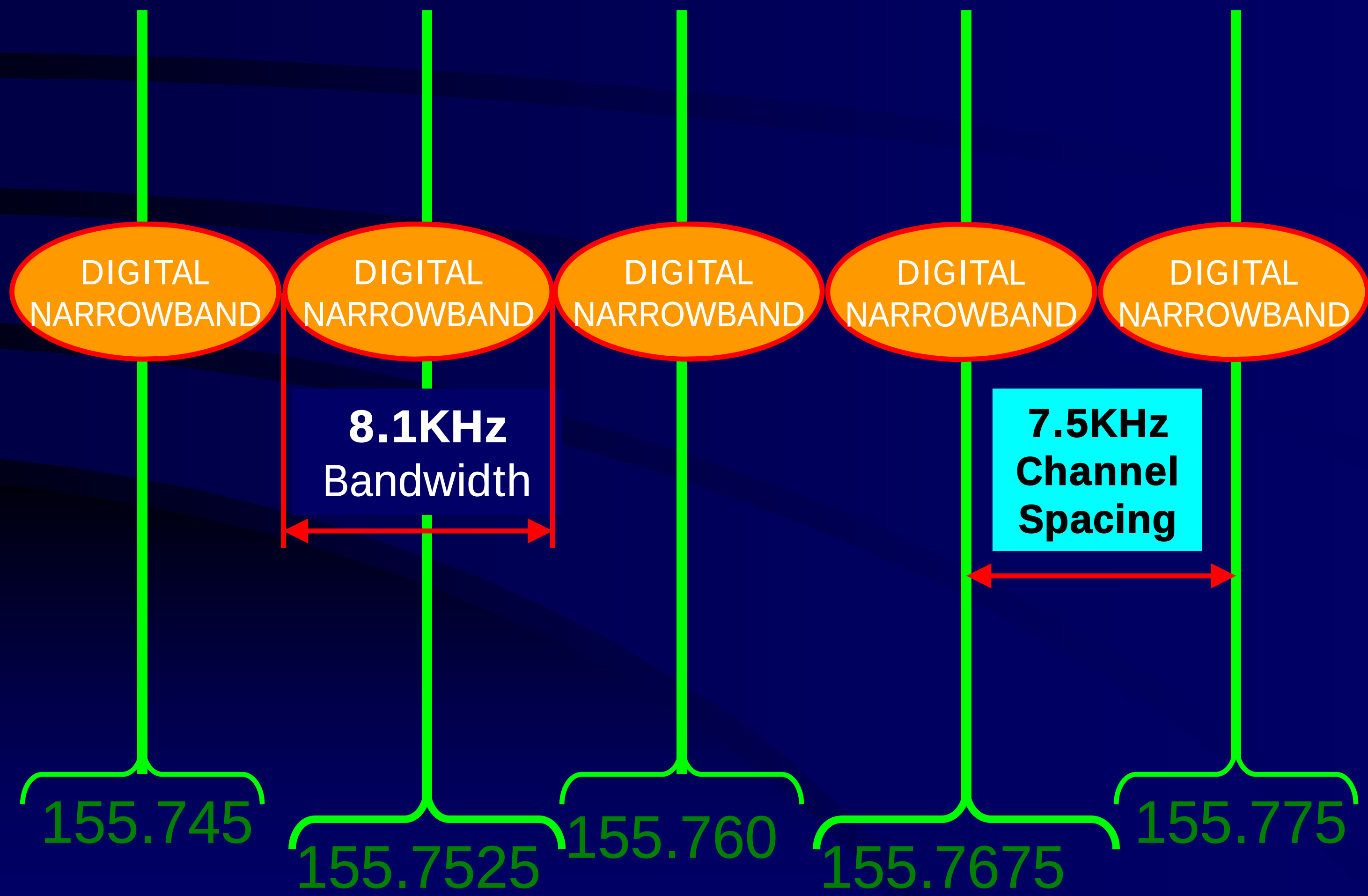
Convert to Project 25 Digital

Phase I Digital Modulation allows tighter packing of channels

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



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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 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