

Wireless!

The forces and strategies that shaped a revolution



Lecture 13

**Frequency, Wavelength and Coverage-
Real world**

Lecture 13- Classwork

1. Please summarize in 3-4 sentences the Pre-Lecture reading for Lecture 13 including some important takeaways from your reading.
2. Why do sound waves and radio waves of similar wavelength behave in similar ways in many real-world environments?
3. Why is 100MHz good for police but not as good for cellular?
4. What environmental factors can cause problems for satellite TV at 12 GHz but not for lower frequencies like cellular systems?
5. We have seen that the newer cellular frequencies at 2 GHz had less range than 900 MHz because of smaller antennas. What environmental impairments would also be a bit worse at 2 GHz than at 900 MHz?
6. What are the advantages and disadvantages of 30 GHz “millimeter wave” frequencies for 5G cellular?
7. What was the advantage of 5 GHz for WiFi?

Sound, light and radio waves are also
affected by objects in the “Real World”

a wave can

penetrate

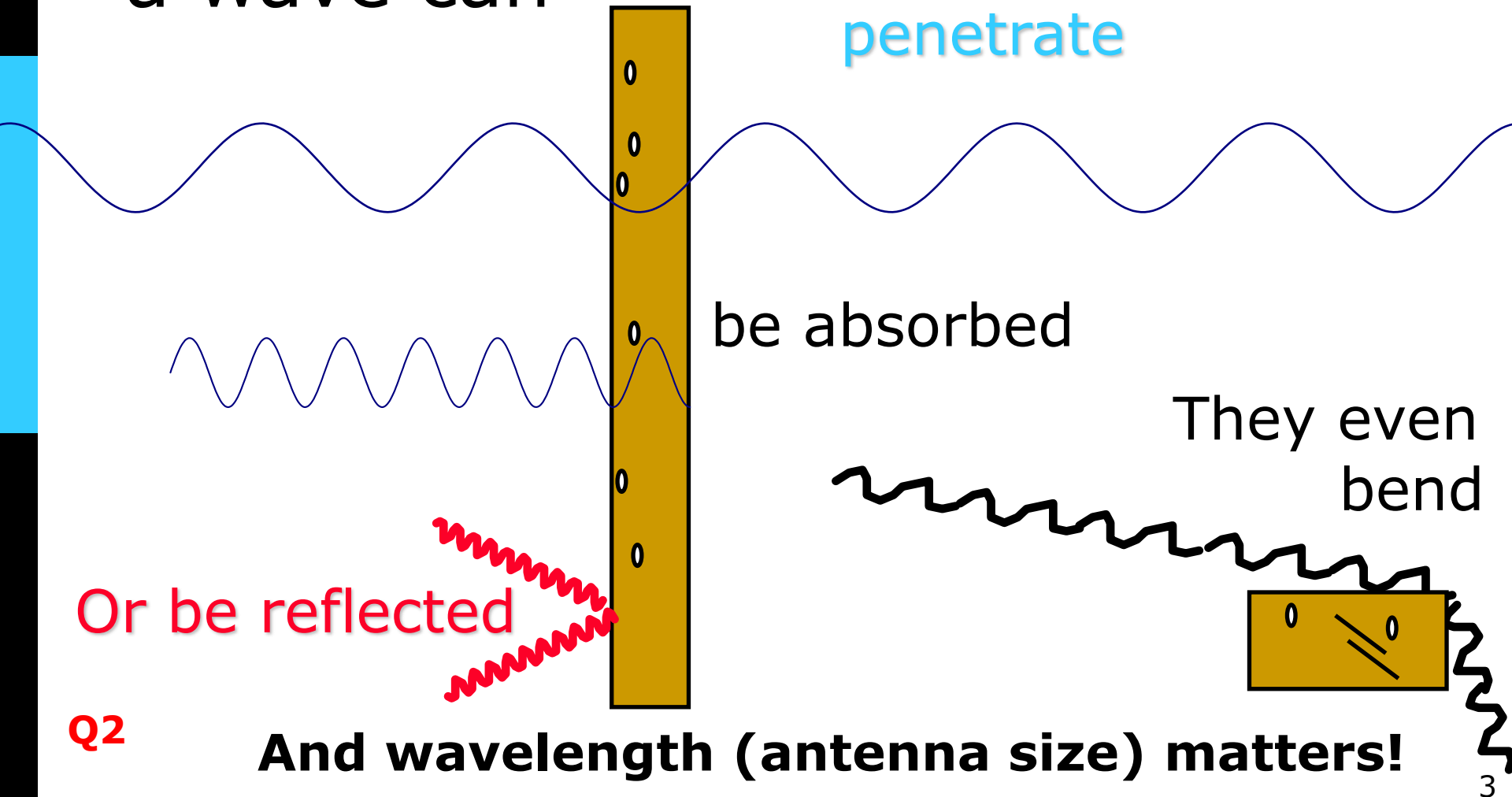
be absorbed

They even
bend

Or be reflected

Q2

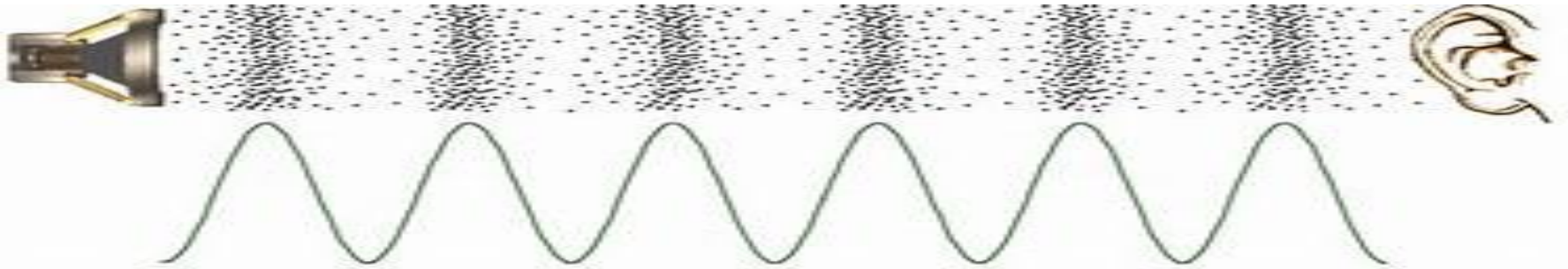
And wavelength (antenna size) matters!



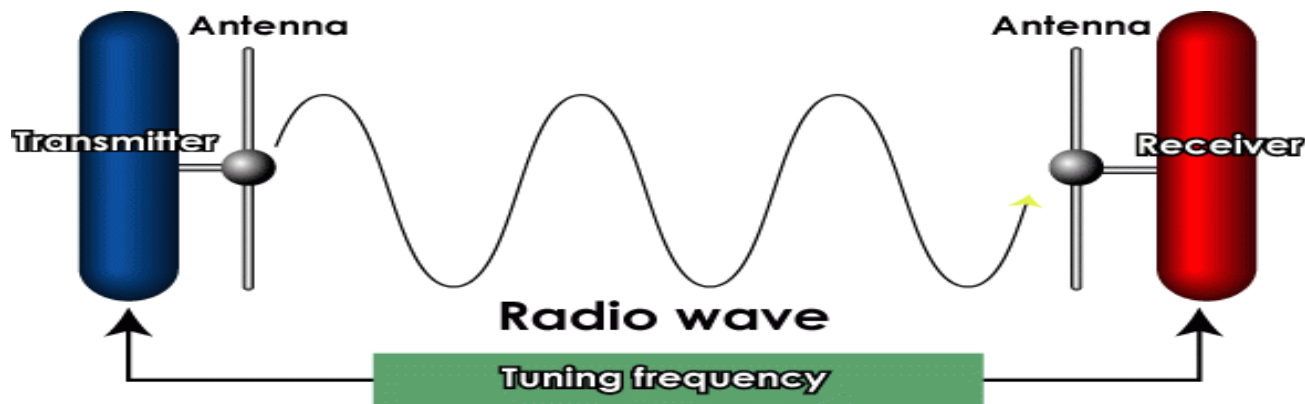
Sound and radio waves at the same wavelength

Wavelength = velocity / frequency

1 KHZ sound travelling at ~1 thousand feet/second →

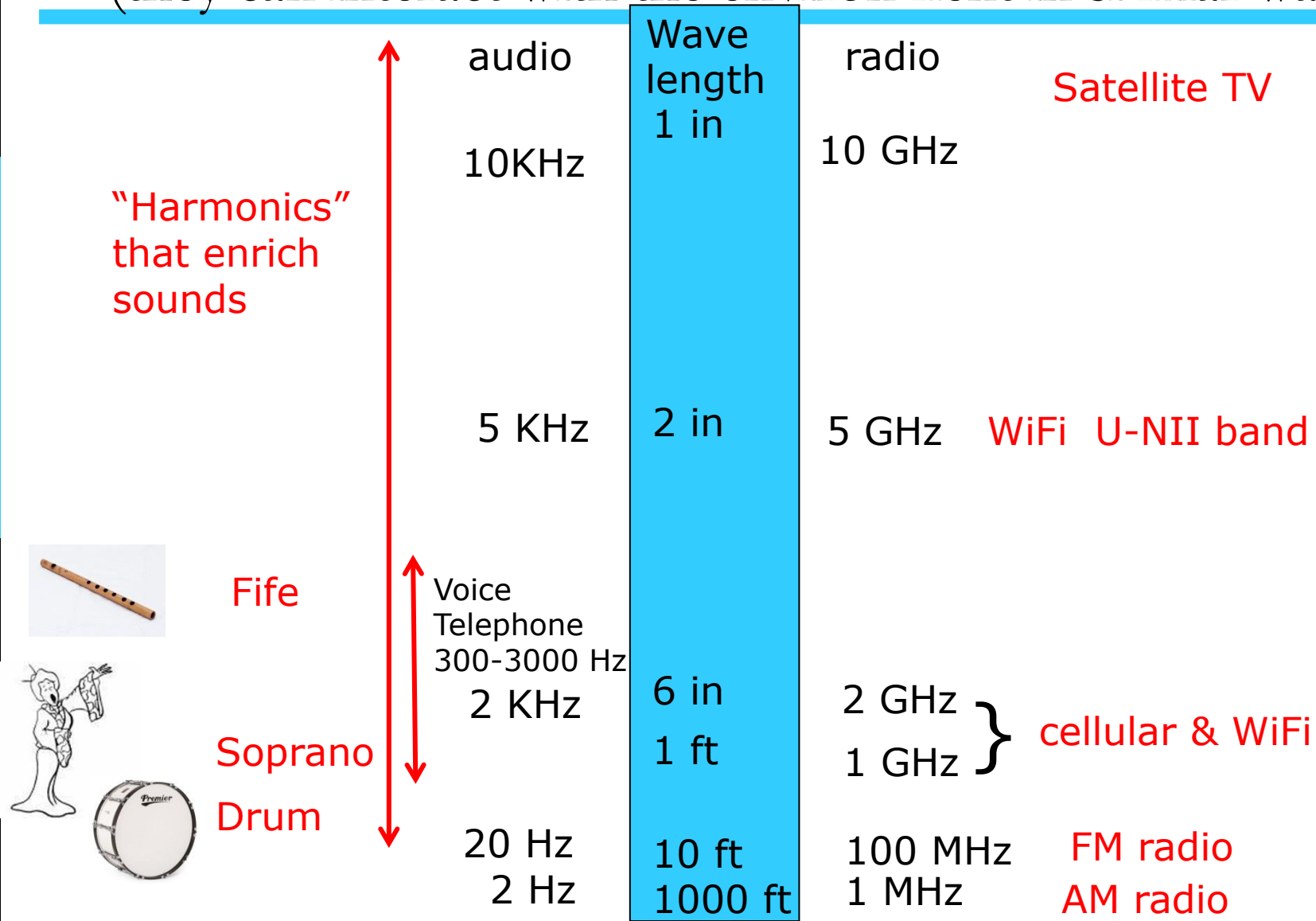


1 GHz radio travelling at ~1 billion feet/second →



Both have wavelengths of 1 foot and interact with some objects in similar ways

The sounds we hear have wavelengths similar to the
radio channels we are interested in
(they can interact with the environment in similar ways)

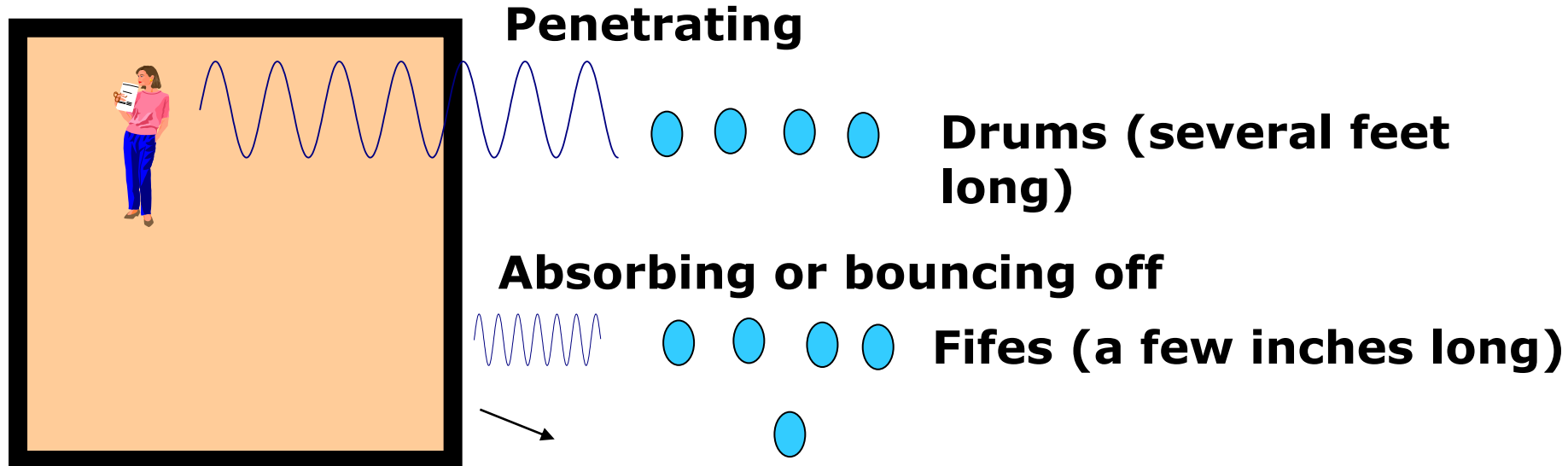


Fifes and drums: very different wavelengths (inches and feet)



Passing through and bouncing off walls

Long waves from the drums pass through walls
Short waves bounce off (or are absorbed)

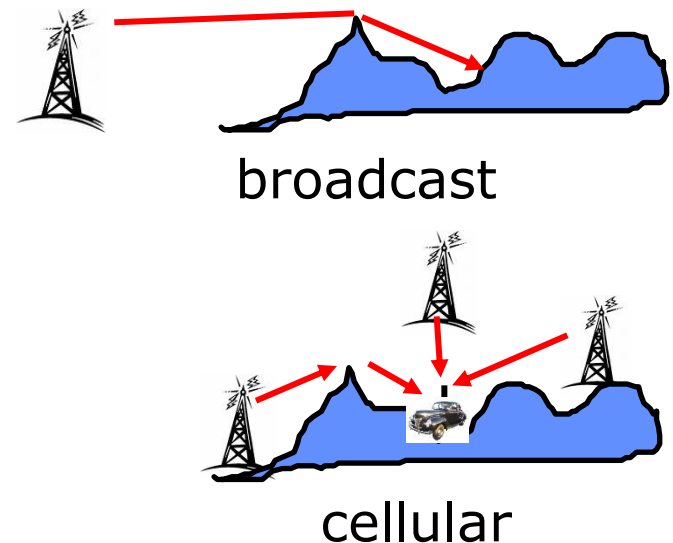
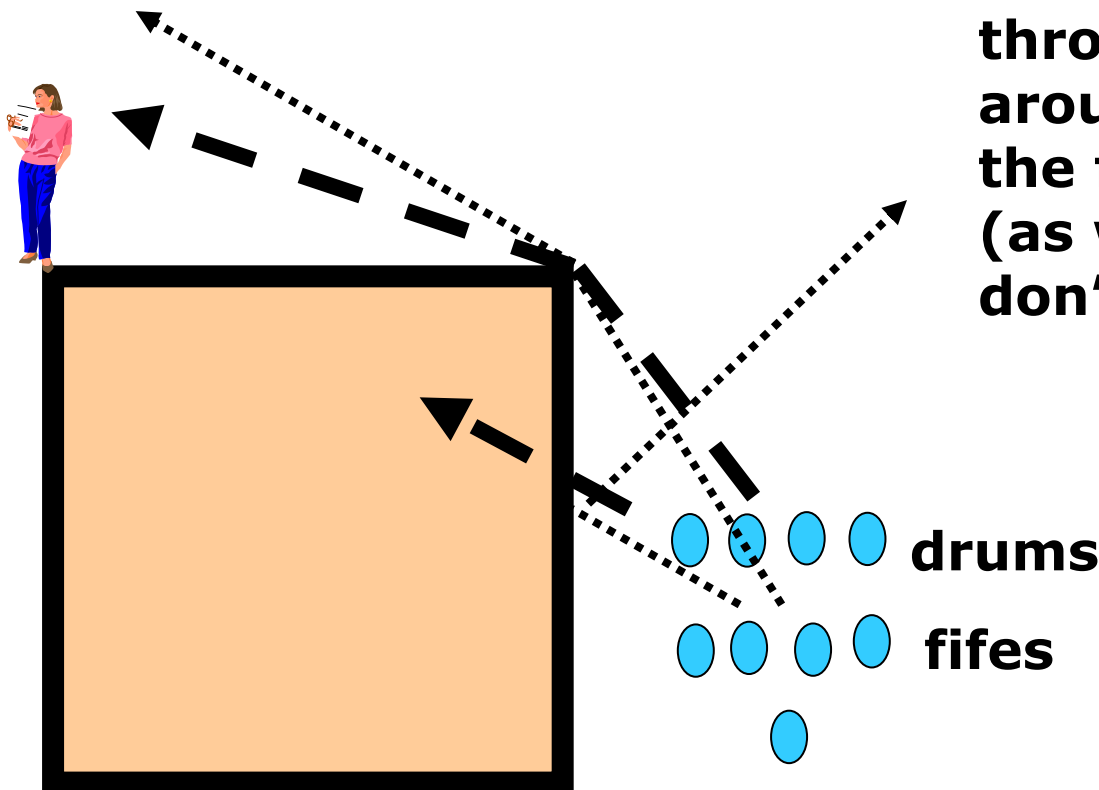


Is the wave much longer than the thickness of the wall? What about "5G" millimeter waves?

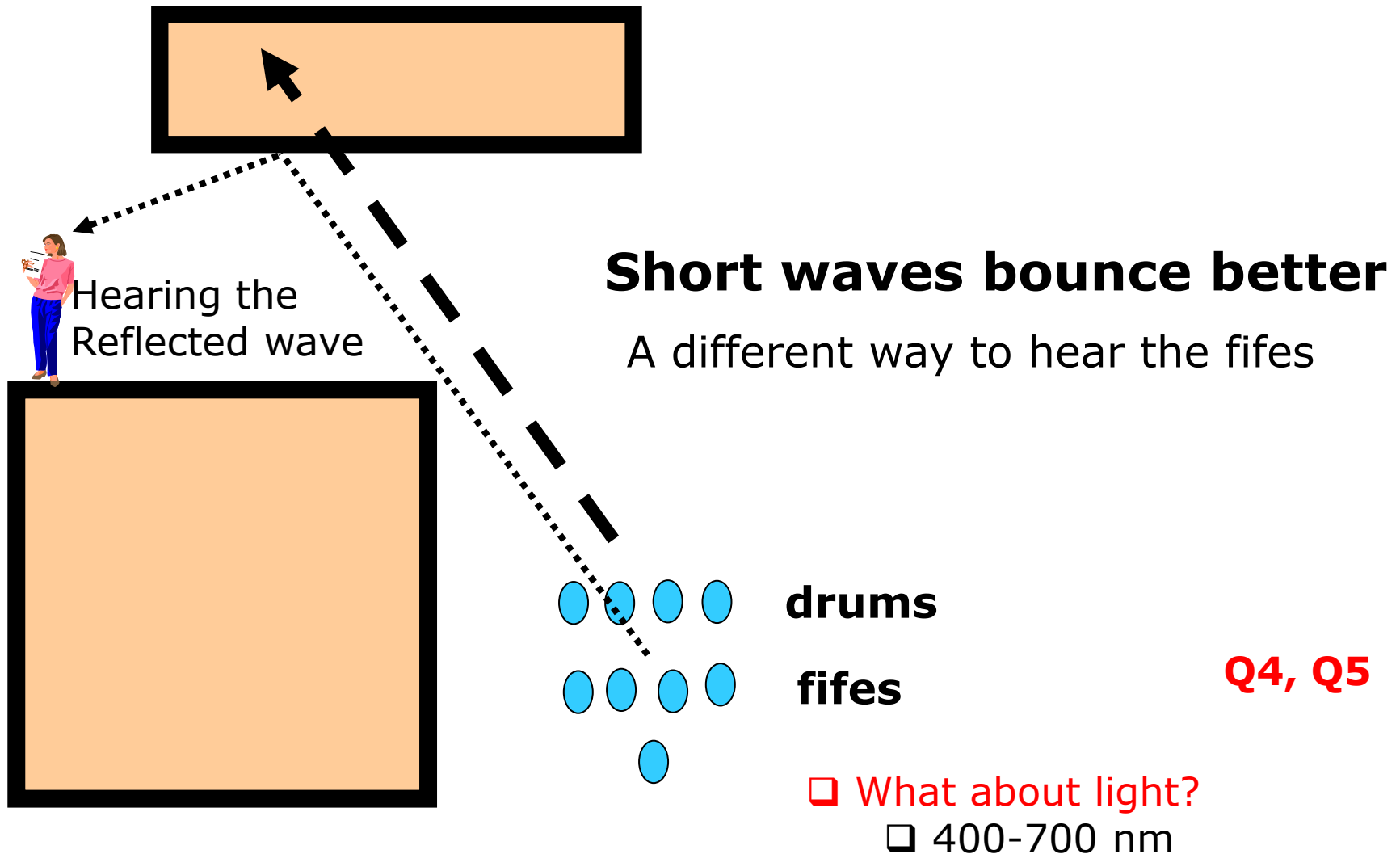
Bending around corners (diffraction)

Long waves bend more easily

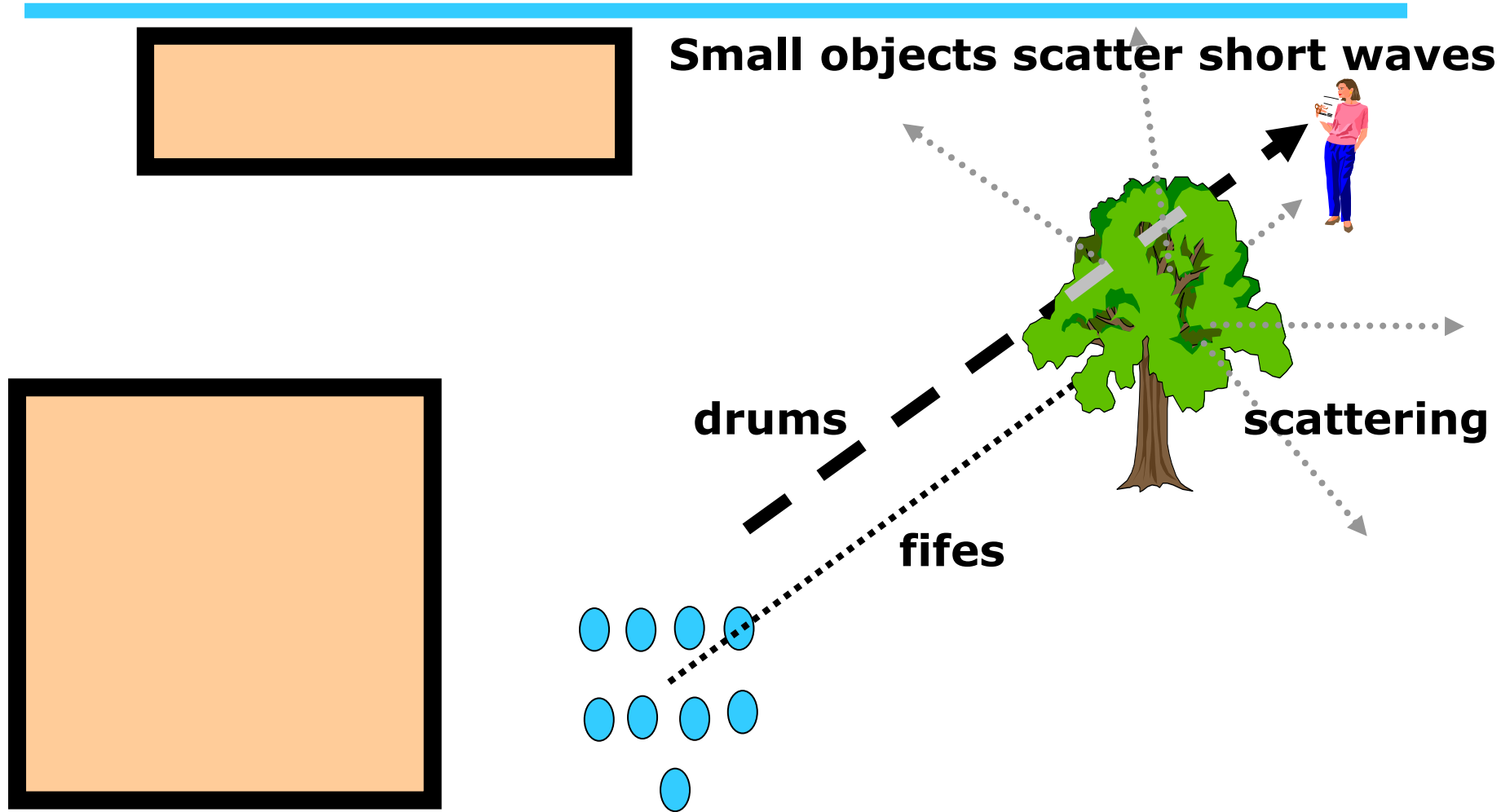
We can hear the drums through the building or around the corner), but the fifes bounce off (as we have seen) and don't bend as well either



Bouncing off objects is actually a good thing
It fills the world with light and offers useful paths for radio



Many small objects like leaves (especially wet leaves) can absorb and scatter small waves like 5 GHz (2.5 inch waves)
(long waves are less affected)

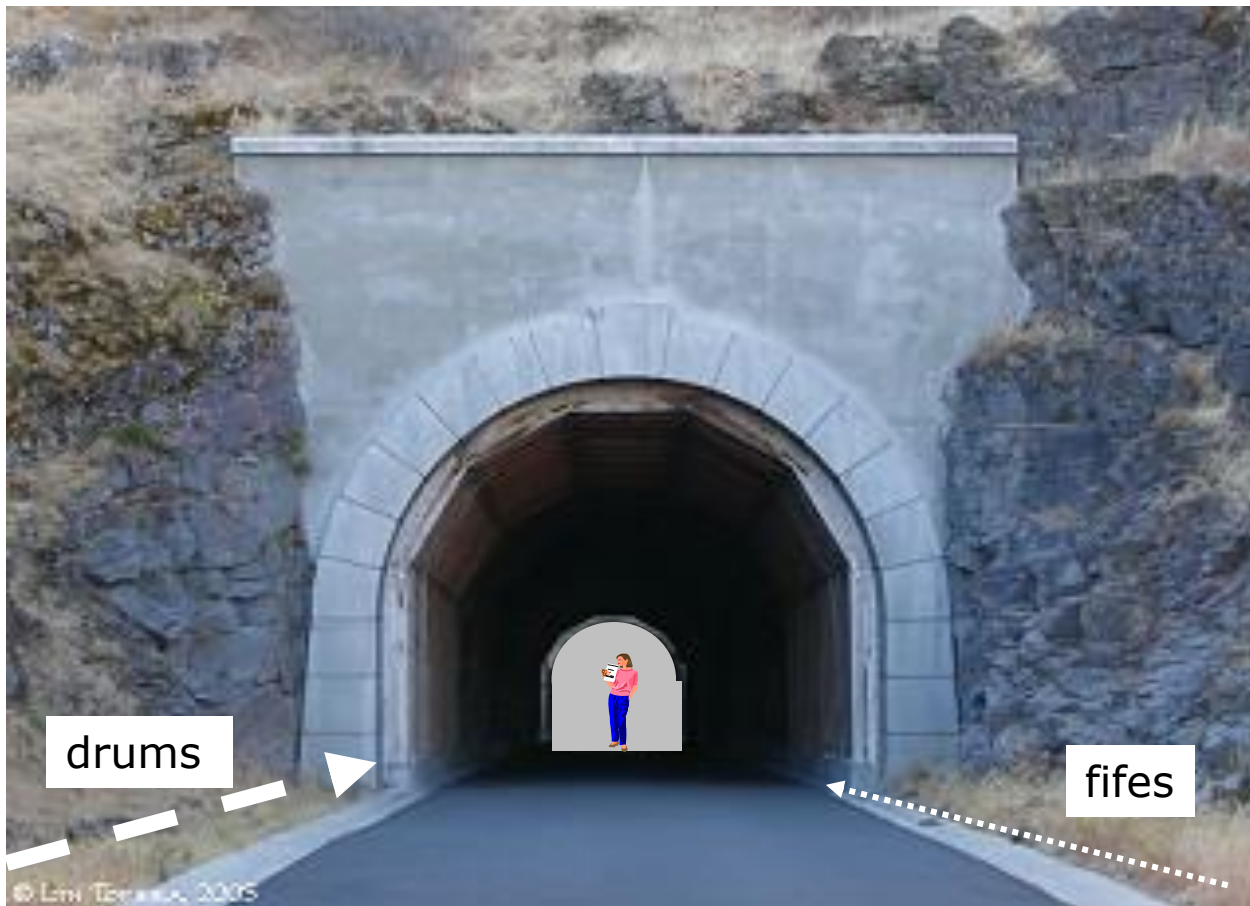


Raindrops can scatter satellite radio (12-18 GHz) (1 inch waves)
and more so for "5G" millimeter waves

Some structures can actually favor
higher frequencies (most don't)



Through a Tunnel: Drums vs Fifes?

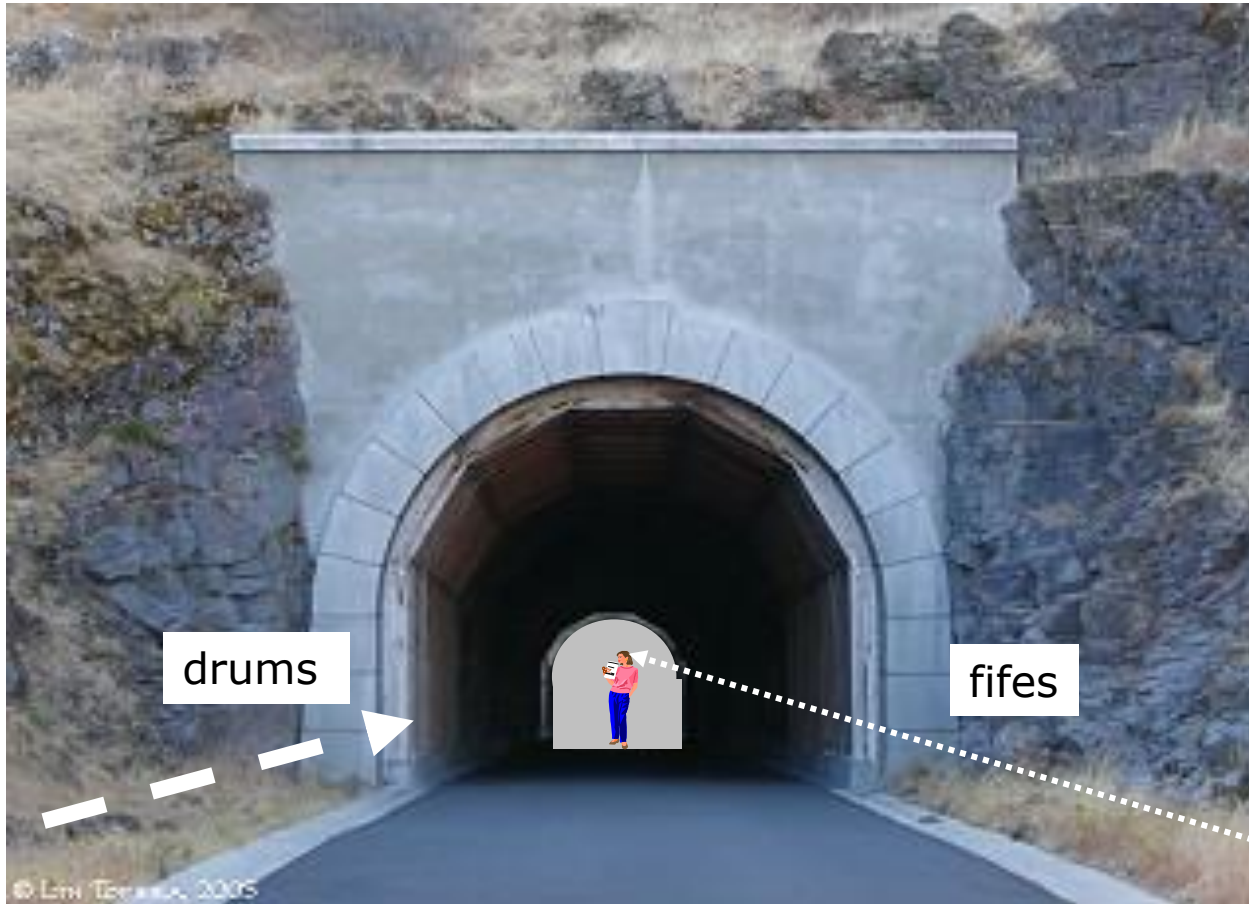


AM Broadcast
vs.
FM Broadcast?

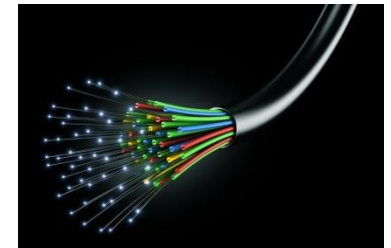
drums

fifes

In tunnels there is a low frequency “cutoff” below which sounds disappear in a few feet. Higher frequency waves can pass, and there is a “waveguide” effect that favors a specific frequency.

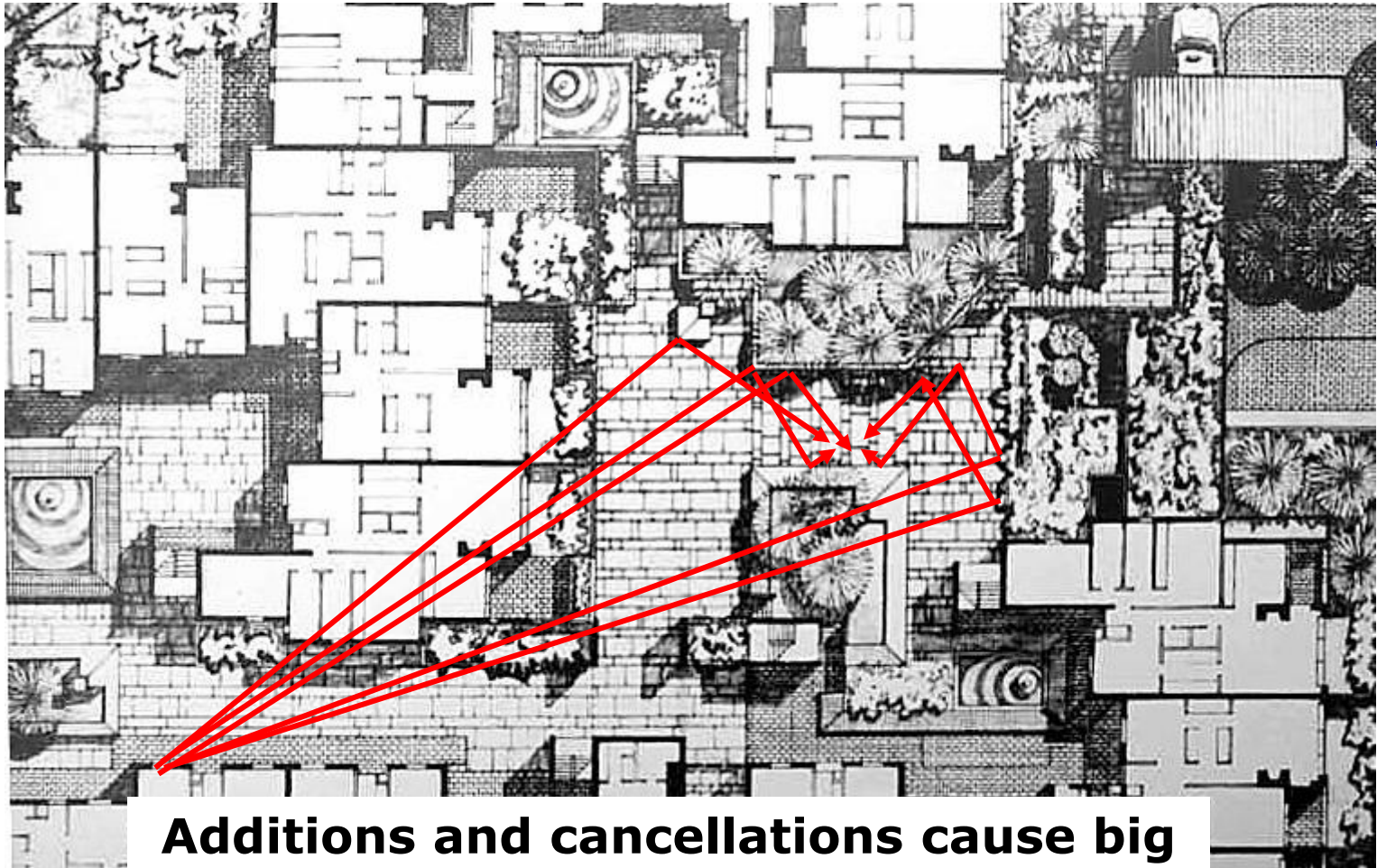


This leads to low-loss radio waveguides,



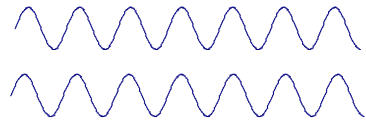
And to low-loss optical fiber waveguides

And another “real world” problem for designers
The signal arrives as “rays” by many paths with
different lengths

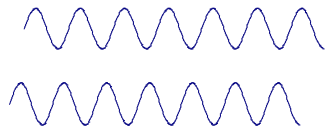
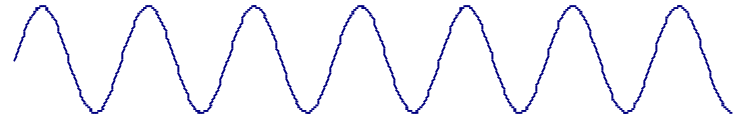
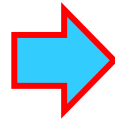


**Additions and cancellations cause big
power swings in a few inches!**

Adding many waves that have traveled different distances causes “Rayleigh fading”
(sharp variations in power on a few inches)



In “phase”
addition



Out of “phase”
cancellation

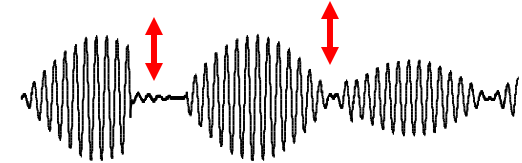


The phase changes in inches because the cell phone is moving, so the signal has sharp and frequent “fades” that we Hear as “clicks”

Signal below interference causes “click”



Interference



Signal

~ 1/2 wavelength

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

	AERONAUTICAL MOBILE		INTER-SATELLITE		RADIO ASTRONOMY
	AERONAUTICAL MOBILE SATELLITE		LAND MOBILE		RADIODETERMINATION SATELLITE
	AERONAUTICAL RADIONAVIGATION		LAND MOBILE SATELLITE		RADIOLOCATION
	AMATEUR		MARITIME MOBILE		RADIOLOCATION SATELLITE
	AMATEUR SATELLITE		MARITIME MOBILE SATELLITE		RADIONAVIGATION
	BROADCASTING		MARITIME RADIONAVIGATION		RADIONAVIGATION SATELLITE
	BROADCASTING SATELLITE		METEOROLOGICAL		SPACE OPERATION
	EARTH EXPLORATION SATELLITE		METEOROLOGICAL SATELLITE		SPACE RESEARCH
	FIXED		MOBILE		STANDARD FREQUENCY AND TIME SIGNAL
	FIXED SATELLITE		MOBILE SATELLITE		STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

	FEDERAL EXCLUSIVE		FEDERAL/NON-FEDERAL SHARED
	NON-FEDERAL EXCLUSIVE		

Land Mobile Service

- The land mobile service is defined as
 - A mobile service between base stations and land mobile services, or between land mobile stations
 - Various categories of land mobile include commercial mobile radio services, cellular telephony, personal communications services (PCS), industrial and business mobile services, Federal agencies' mobile units, State and local public safety services, and Federal law enforcement mobile units.

[illegible]

300 kHz



3 MHz

Non-Federal Trainers Information Stations (TIS), a mobile service, are authorized in the 535-4705 kHz band. Federal TIS operates at 1610 kHz.



表 6-7-8 续

地址: 上海南京路 100 号

30 MHz



1531 - 1538 - 1539

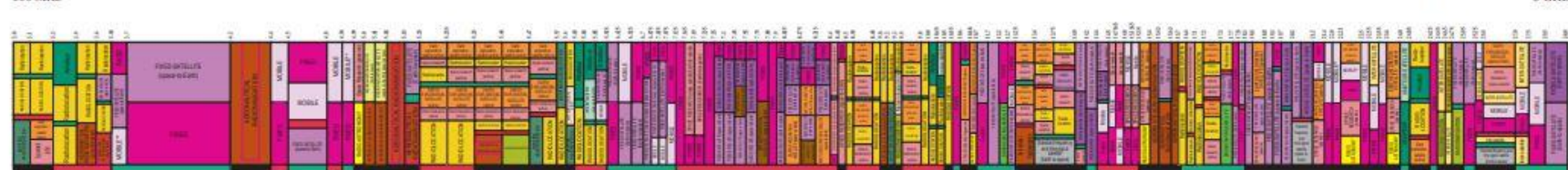
300 MHz



1995年 1月 1日

1000

3 GHz



100

30 GHz



1997年12月10日

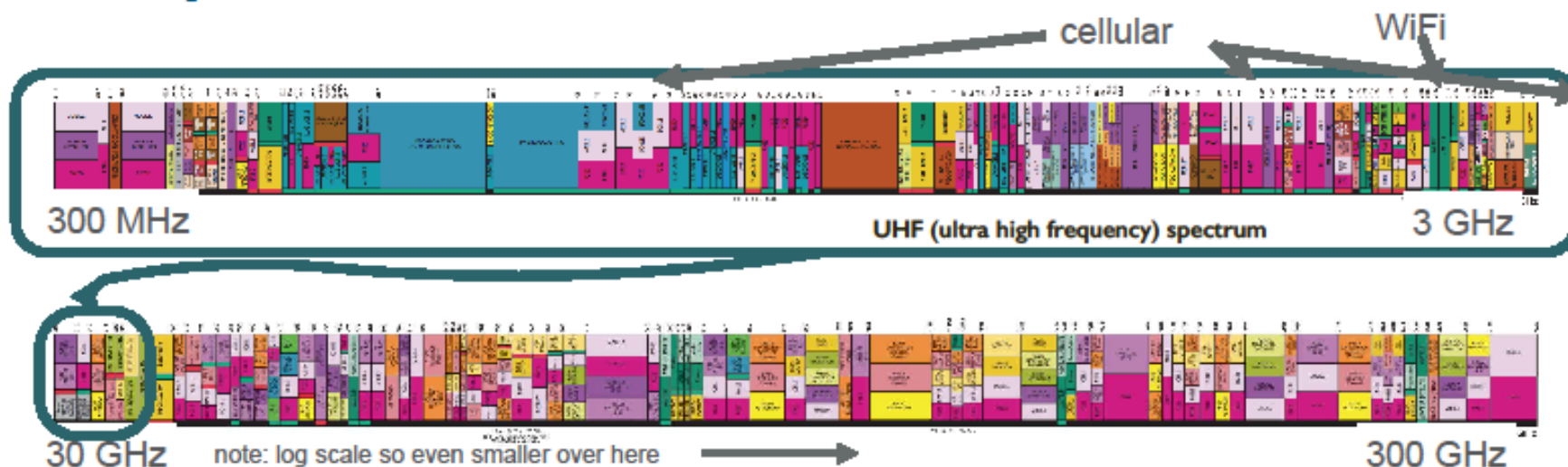
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5400-10-0101

300 GHz

Millimeter waves (30, 40 or 60 GHz) for “5G” cellular

Why millimeter wave for 5G?



- ◆ Huge amount of spectrum possibly available in mmWave bands
- ◆ Technology advances make mmWave possible for cheap consumer devices
- ◆ mmWave research is as old as wireless, e.g. Bose 1895 and Lebedew 1895

mmWave spectrum auctions resulted in cheap spectrum:
less than \$0.01/MHz/POP

The “real world” delivers much less radio energy than “free space”

- ❑ The “expanding sphere” in free space led to a “square law” for path loss
 - Our antenna captured $\frac{1}{4}$ the power when we doubled the distance ($p \sim 1/d^2$)
- ❑ The additional effects of the “real world” cause much larger losses
 - Cellular systems generally assume a “fourth power” loss ($p \sim 1/d^4$)
 - Higher frequencies are usually more affected by real world losses (e.g., leaf scatter)
 - Additional impairments like Rayleigh fading must be considered