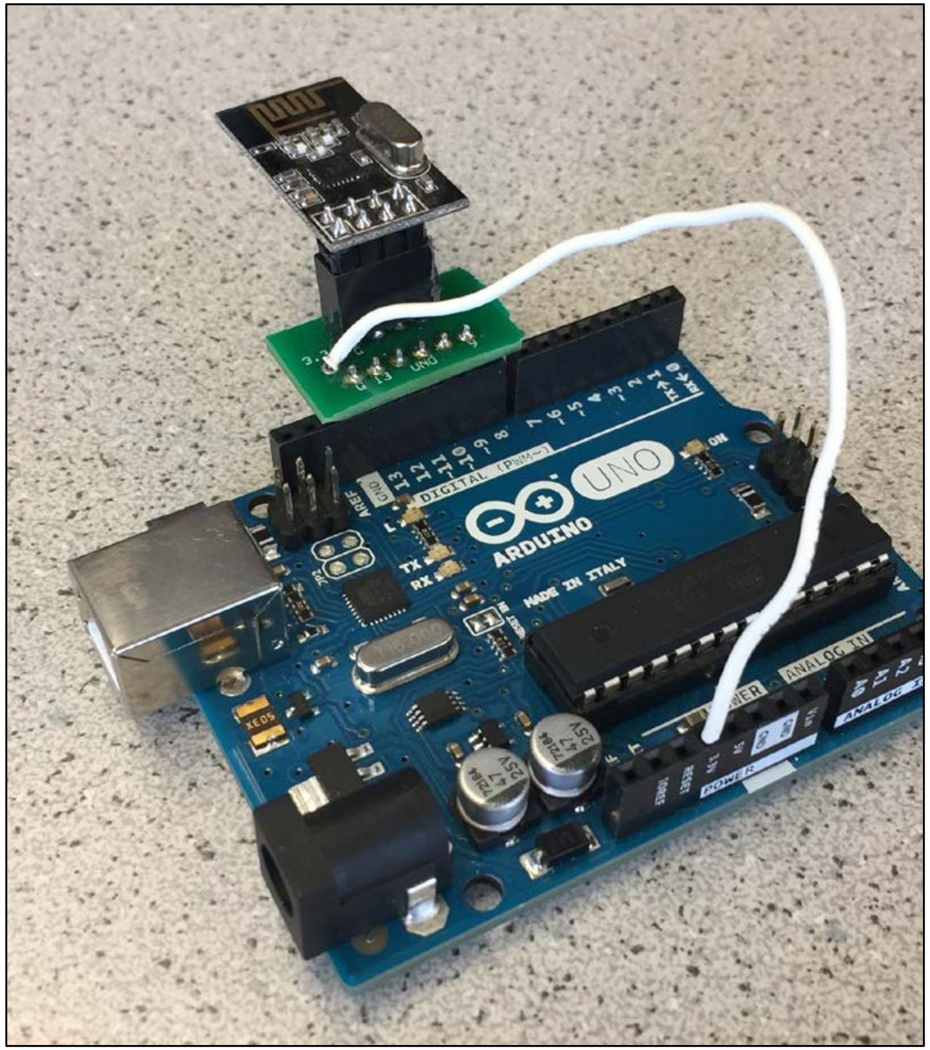
Wireless Communication

- **ECE 3250** Mathematics of Signal and System Analysis
- **ECE 4670** Digital Communication System Design
- **ECE 3030** Electromagnetic Fields and Waves

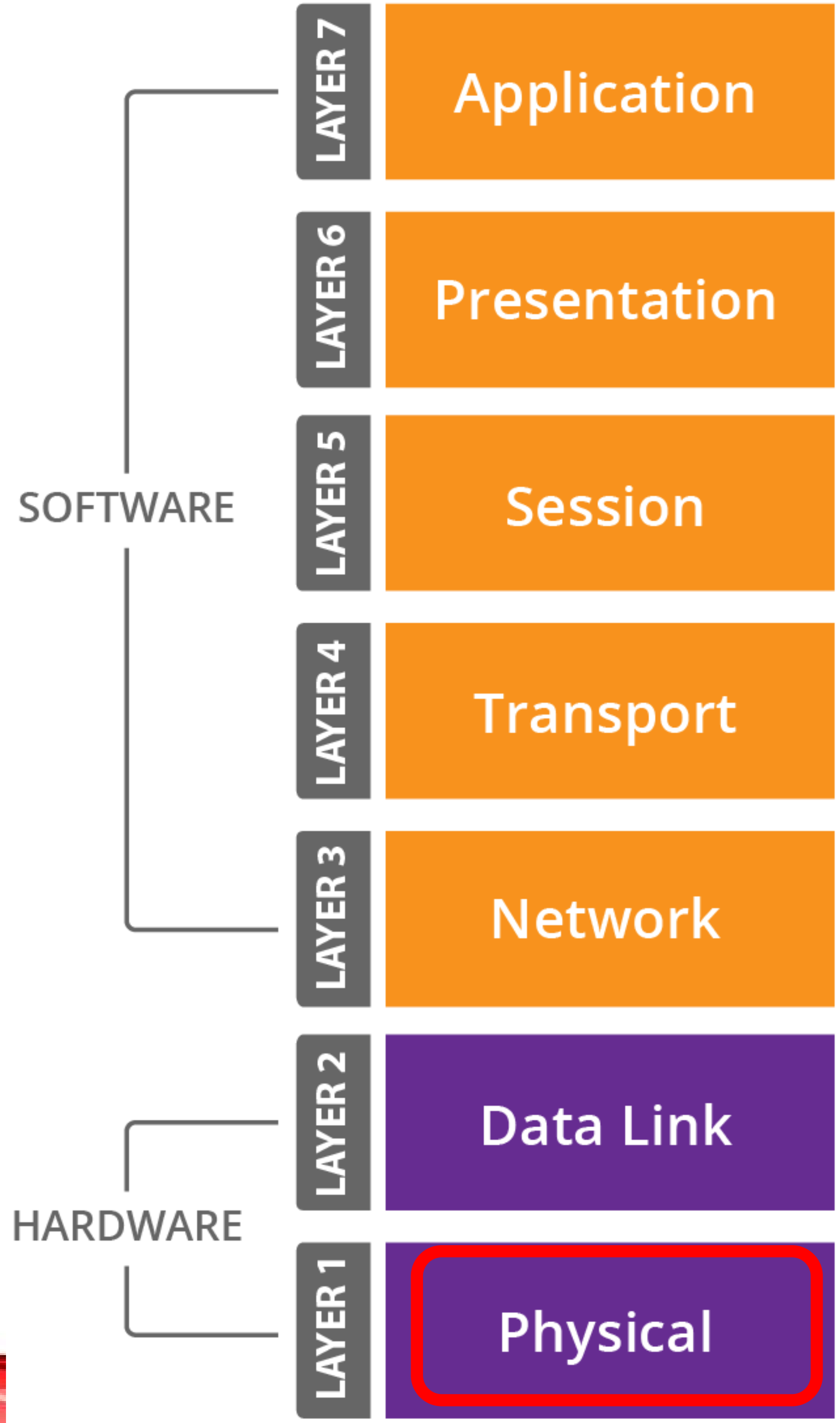
- Radio spectrum
- AM/FM
- R24 Nordic module
- Maze representation
- EMI

ECE 3400: Intelligent Physical Systems

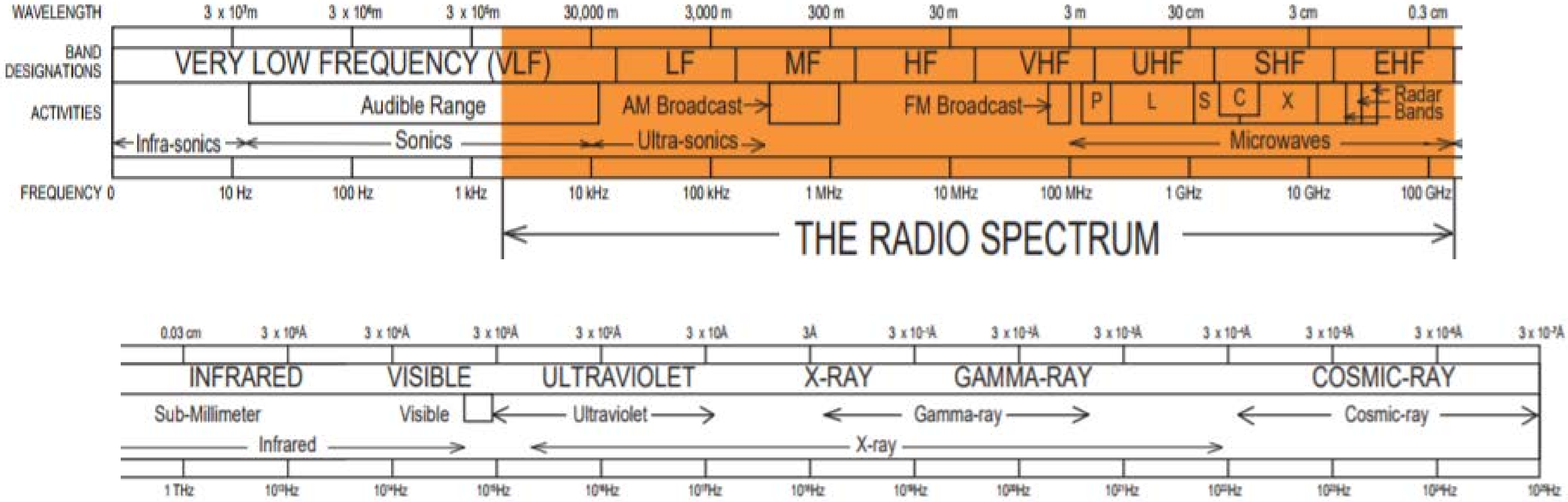
Wireless Communication

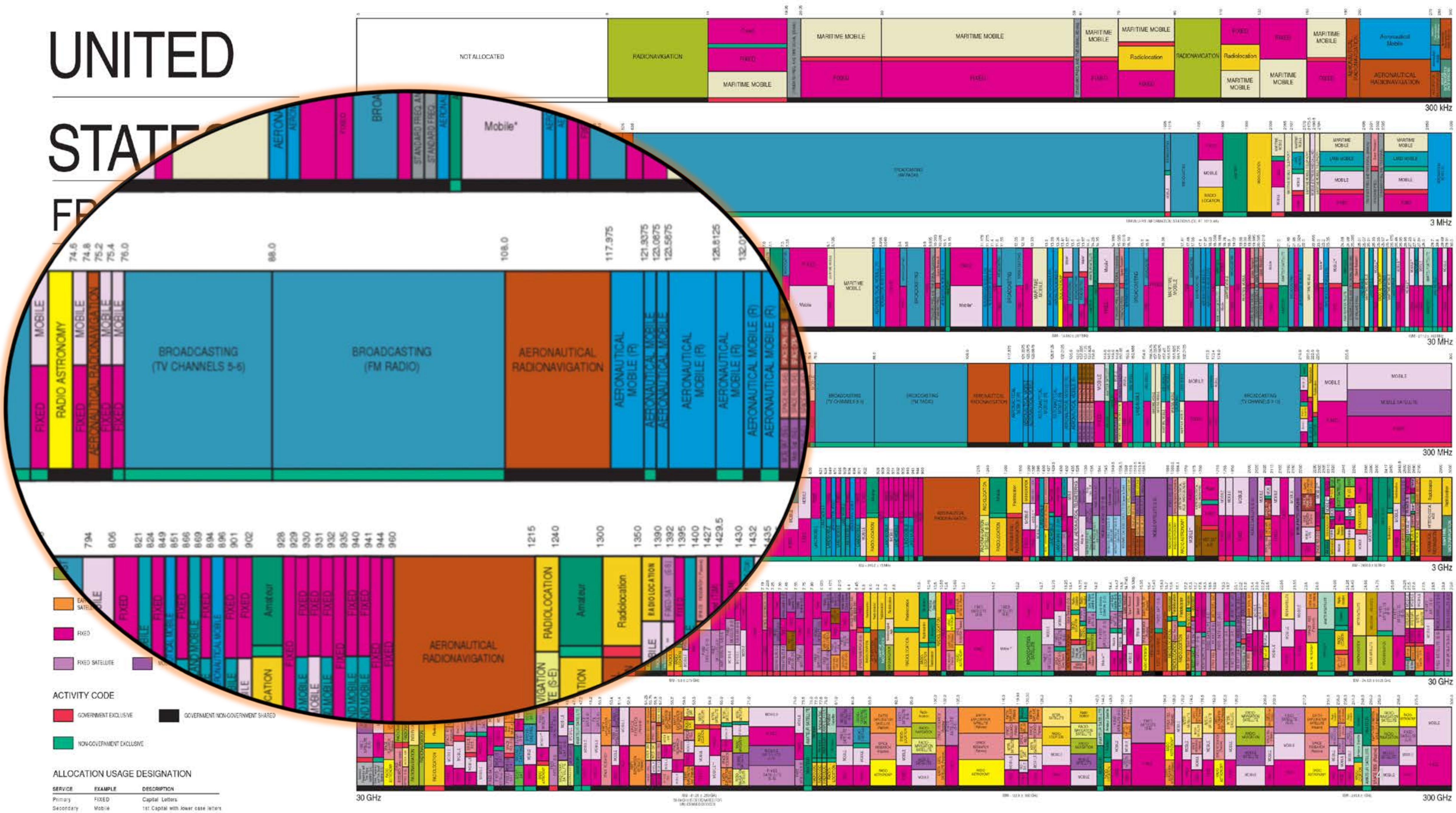


- Nordic nRF24L01+ transceivers
- *datasheet*



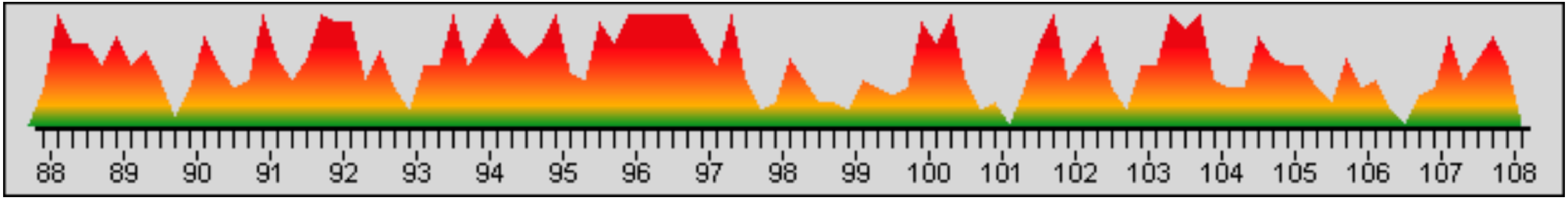
Radio Spectrum




UNITED
STATES
FR
NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
FIXED
Radiolocation
AERONAUTICAL RADIONAVIGATION
Aeronautical Mobile
300 kHz
3 MHz
30 MHz
BROADCASTING (TV CHANNELS 5-6)
BROADCASTING (FM RADIO)
AERONAUTICAL RADIONAVIGATION
AERONAUTICAL MOBILE (R)
RADIO ASTRONOMY
MOBILE
Mobile*
MOBILE SATELLITE
300 MHz
RADIOLOCATION
Amateur
3 GHz
30 GHz
300 GHz
FIXED
FIXED SATELLITE
ACTIVITY CODE
GOVERNMENT EXCLUSIVE
GOVERNMENT/NON-GOVERNMENT SHARED
NON-GOVERNMENT EXCLUSIVE
ALLOCATION USAGE DESIGNATION
SERVICE
EXAMPLE
DESCRIPTION
Primary
FIXED
Capital Letters
Secondary
Mobile
1st Capital with lower case letters

WITH	90.1 FM	10.0 mi.	Ithaca, NY		Public Radio
WSQG	90.9 FM	10.0 mi.	Ithaca, NY		Public Radio
WICB	91.7 FM	1.8 mi.	Ithaca, NY	Ithaca College	College
W221CW (WSQG)	92.1 FM	10.0 mi.	Ithaca, NY		Public Radio
WVBR	93.5 FM	2.7 mi.	Ithaca, NY		Rock
W231DK (WNYY-AM)	94.1 FM	3.8 mi.	Ithaca, NY		Oldies
W235BR (WQNY)	94.9 FM	3.8 mi.	Ithaca, NY		Country
WFIZ	95.5 FM	9.5 mi.	Odessa, NY		Top-40
W240CB (WQNY)	95.9 FM	3.8 mi.	Ithaca, NY		Country
W242AB (WYXL)	96.3 FM	3.8 mi.	Ithaca, NY		Adult Contemporary
W244CZ (WYXL)	96.7 FM	3.8 mi.	Ithaca, NY		Adult Contemporary
WYXL	97.3 FM	6.6 mi.	Ithaca, NY		Adult Contemporary
WIII	99.9 FM	19.2 mi.	Cortland, NY		Classic Rock
W262AD (WIII)	100.3 FM	3.8 mi.	Ithaca, NY		Classic Rock
W269AW (WMHR)	101.7 FM	2.1 mi.	Ithaca, NY		Religious
W272DY (WZXV)	102.3 FM	2.7 mi.	East Ithaca, NY		Religious
W277BS (WQNY)	103.3 FM	3.8 mi.	Ithaca, NY		Country
WQNY	103.7 FM	9.5 mi.	Ithaca, NY		Country
W283BQ (WRVO)	104.5 FM	4.1 mi.	Ithaca, NY	State University of New York Oswego	Public Radio

Interference



We found 2 vacant channels on the FM dial in Ithaca, New York.

The graph above shows the predicted interference from other stations at each frequency on the FM dial. Red indicates strong interference, green indicates a weak interference.

Vacant Channels	Next Best Channels	Third Best Channels
101.1 FM **BEST!** 106.5 FM **BEST!**	89.7 FM **GREAT**	92.9 FM **GOOD** 97.7 FM **GOOD** 98.9 FM **GOOD** 100.7 FM **GOOD** 102.7 FM **GOOD** 106.3 FM **GOOD**

Attention: Before transmitting on an FM frequency, always check to see if the channel is truly vacant by listening with an FM radio. Your audio device will work best on an empty channel and you will be less likely to cause interference with other people's radio reception.

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRU

RADIO SERVICES COLOR LEGEND

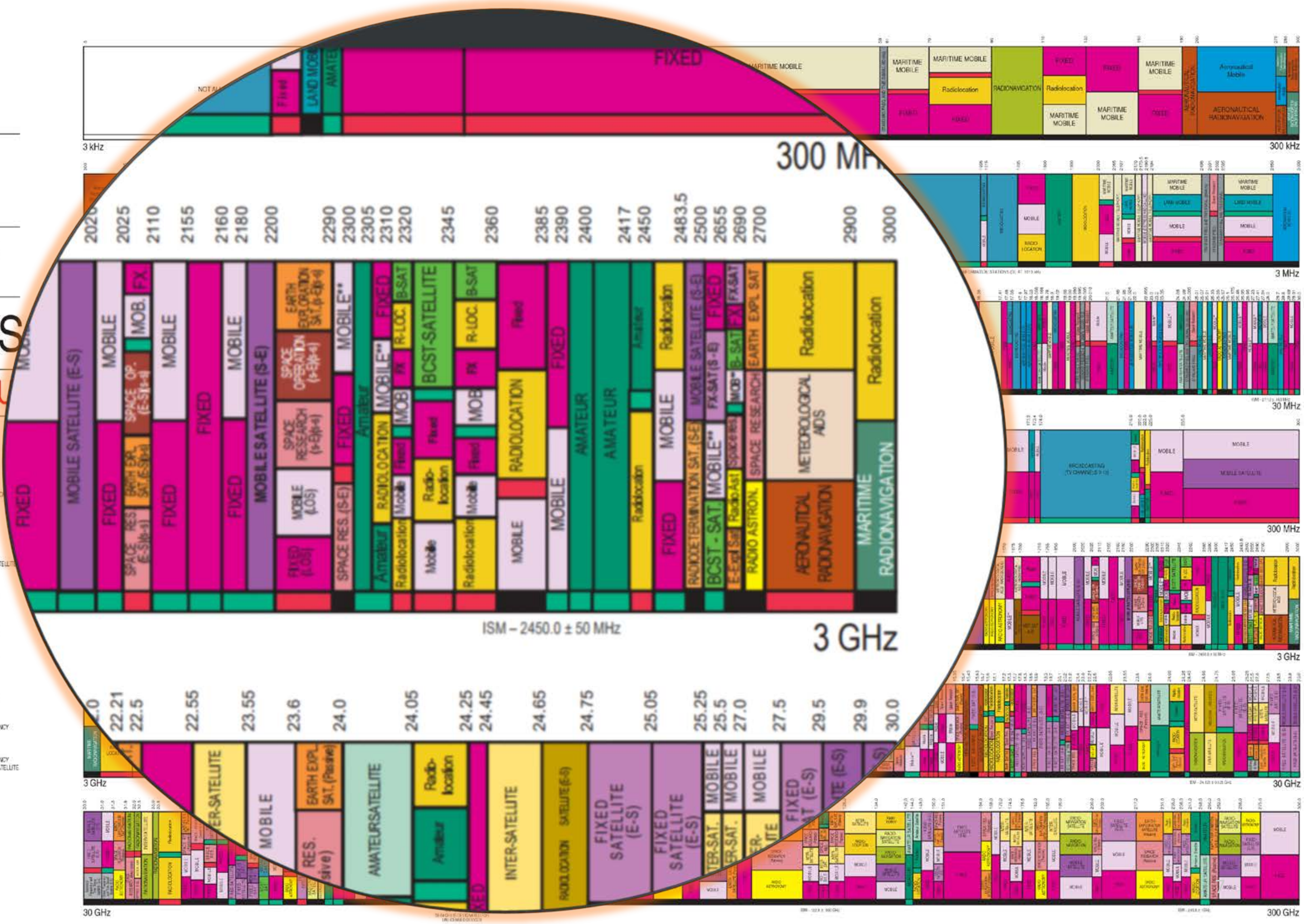
AERONAUTICAL MOBILE	INTER-SATELLITE	RADIO ASTRONOMY
AERONAUTICAL MOBILE SATELLITE	LAND MOBILE	RADIODETERMINATION SATELLITE
AERONAUTICAL RADIONAVIGATION	LAND MOBILE SATELLITE	RADIOLOCATION
AMATEUR	MARITIME MOBILE	RADIOLOCATION SATELLITE
AMATEUR SATELLITE	MARITIME MOBILE SATELLITE	RADIONAVIGATION
BROADCASTING	MARITIME RADIONAVIGATION	RADIONAVIGATION SATELLITE
BROADCASTING SATELLITE	METEOROLOGICAL AIDS	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

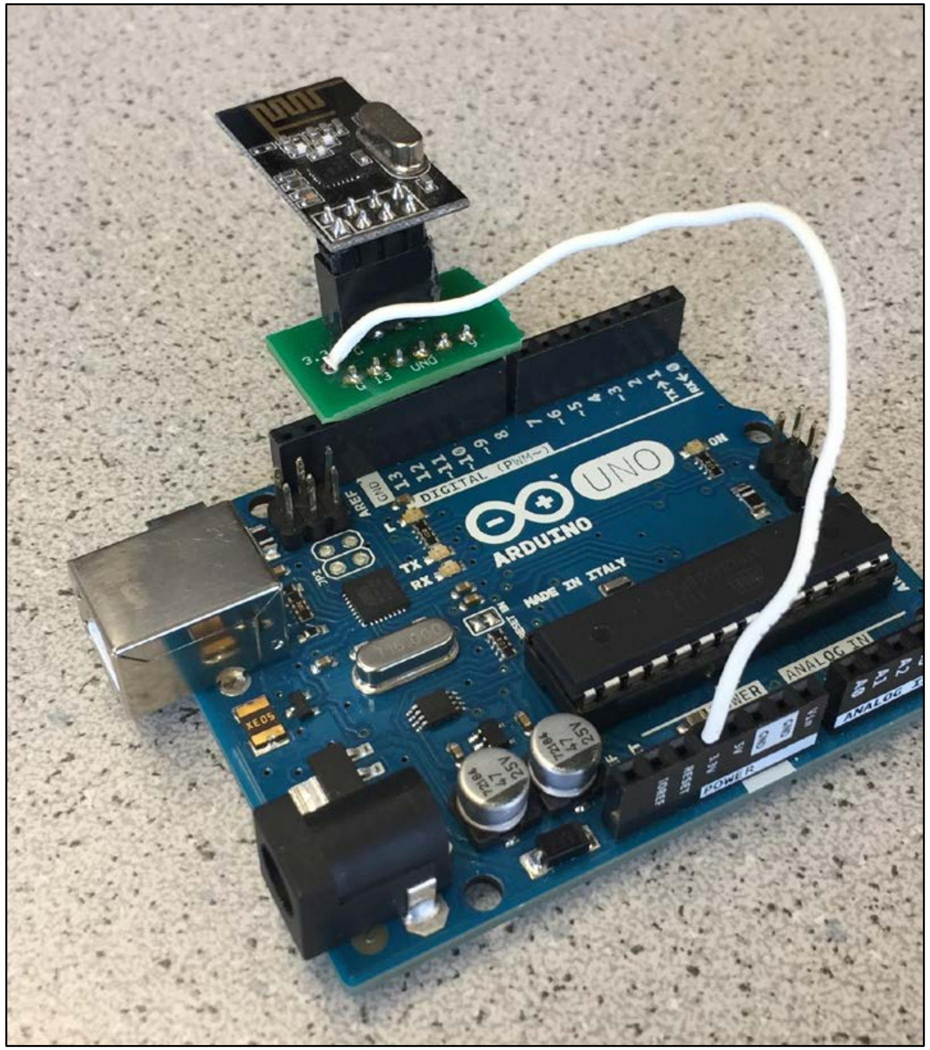
- GOVERNMENT EXCLUSIVE
- GOVERNMENT/NON-GOVERNMENT SHARED
- NON-GOVERNMENT EXCLUSIVE

ALLOCATION USAGE DESIGNATION

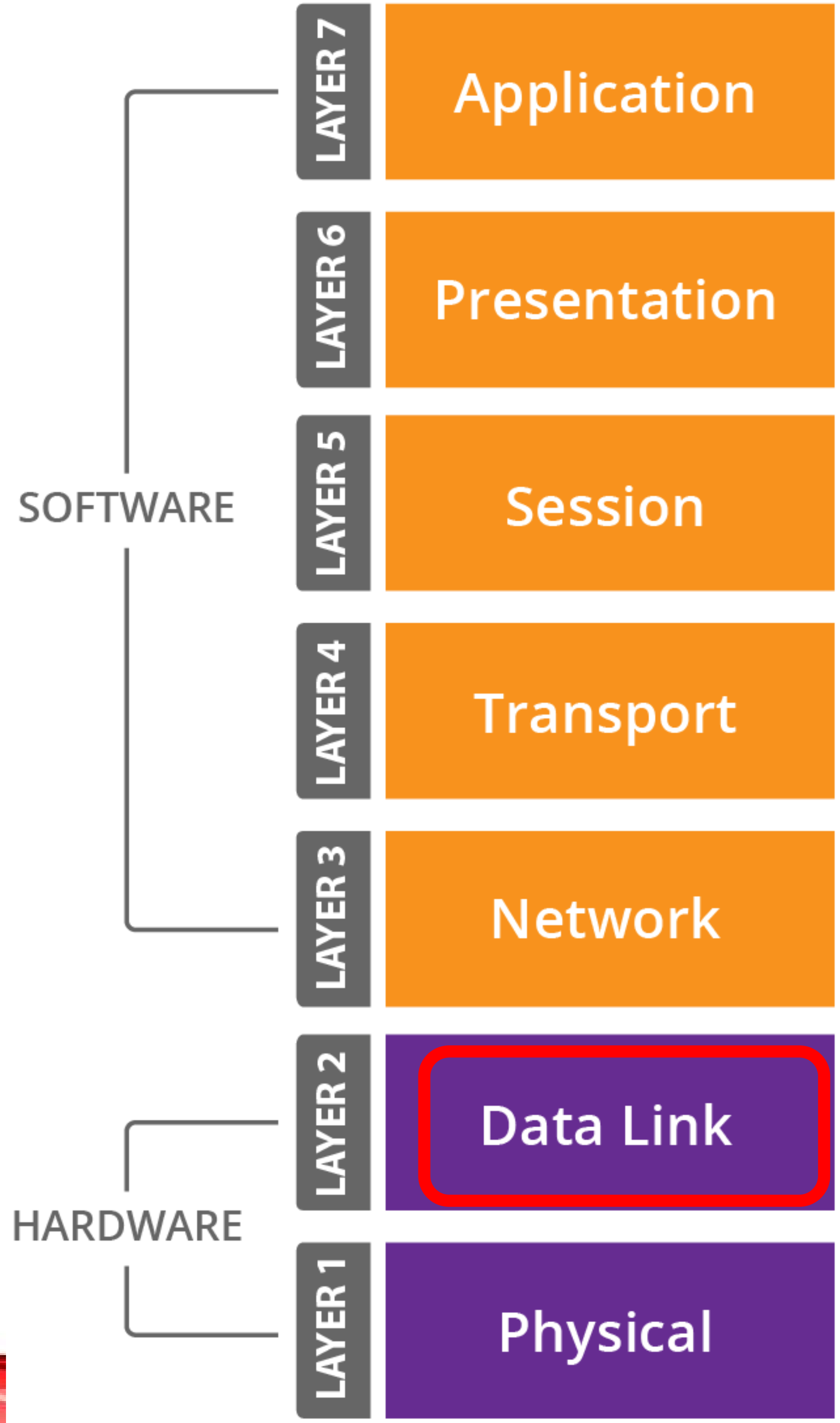
SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters



Wireless Communication

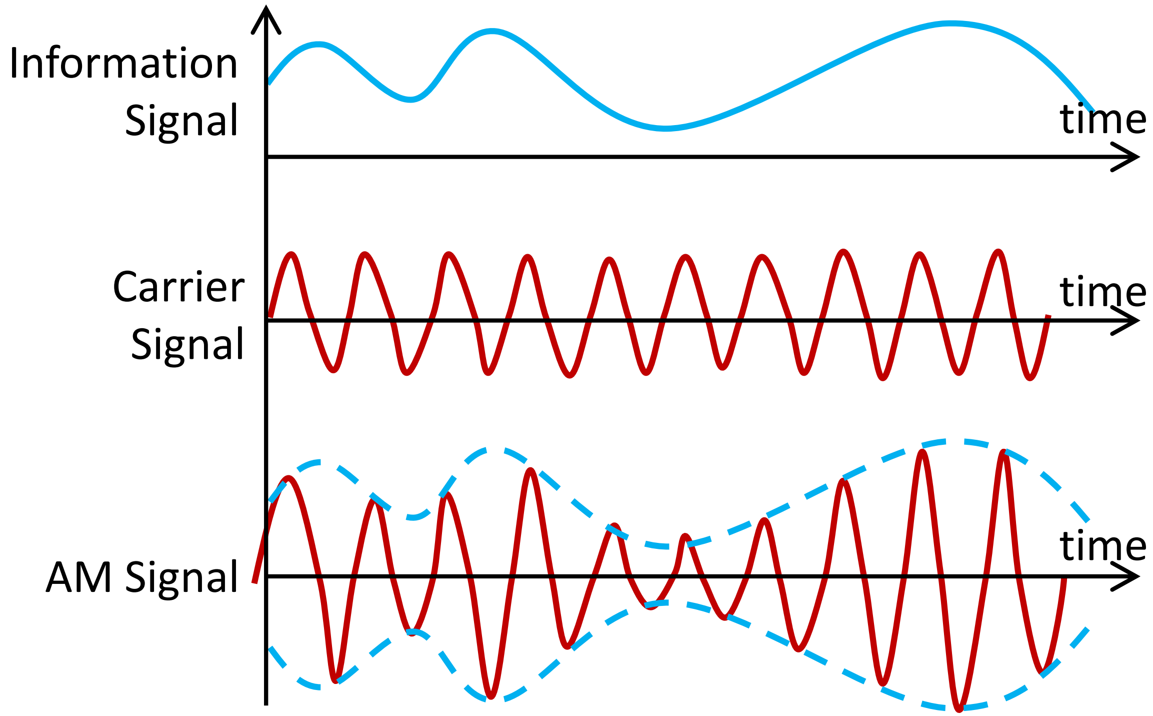


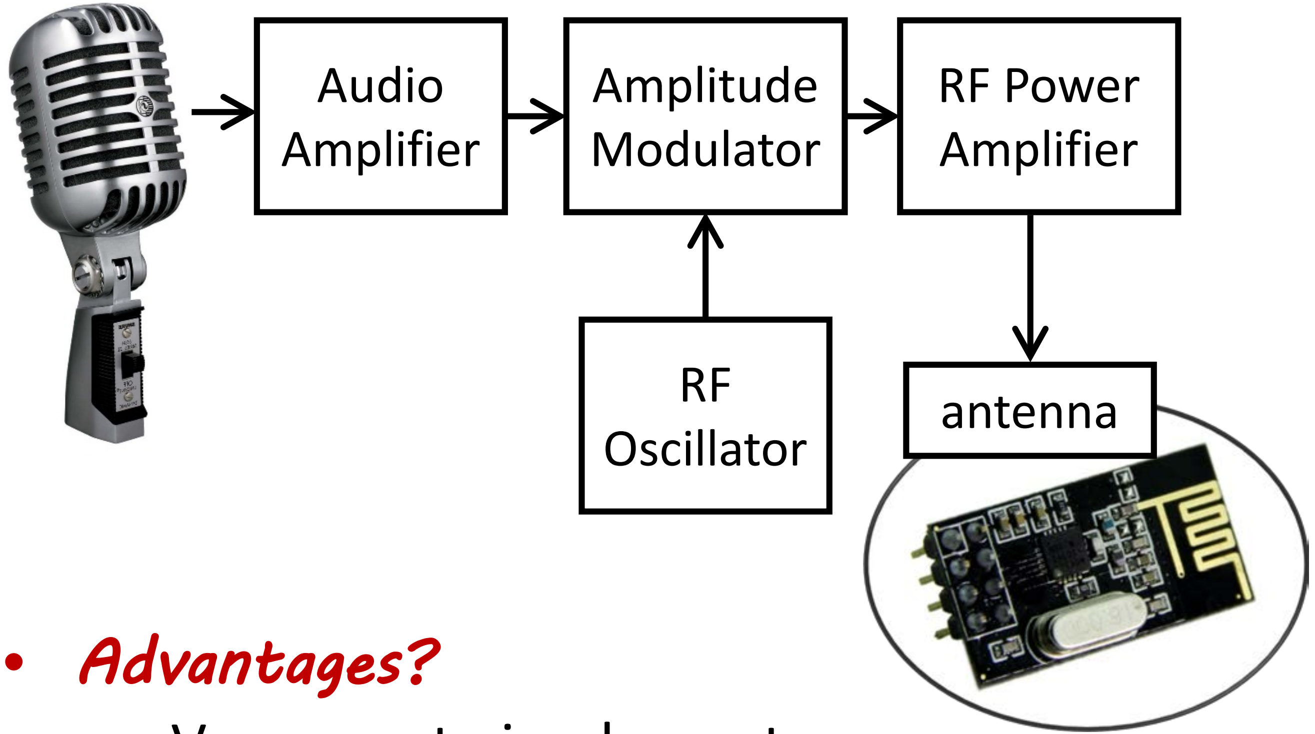
- Nordic nRF24L01+ transceivers
- *datasheet*



Amplitude Modulation (AM)

- Earliest modulation method used to transmit voice by radio (1900)



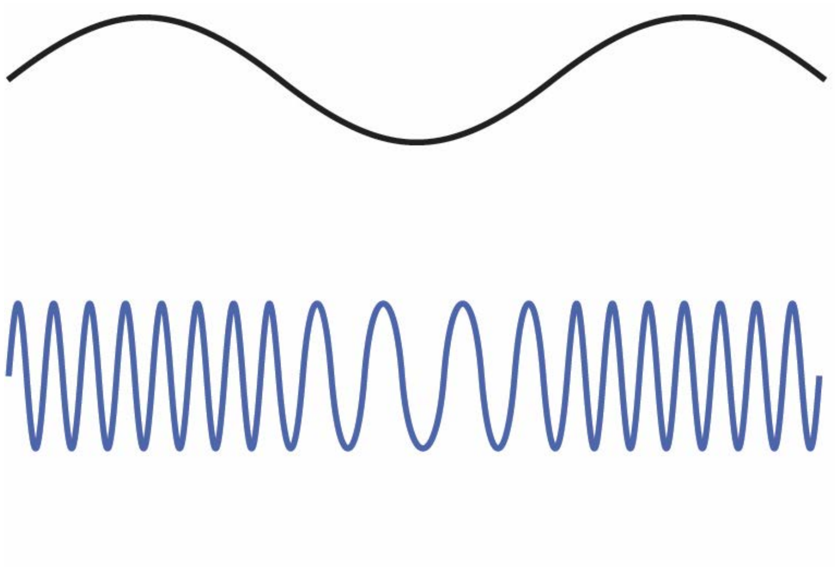


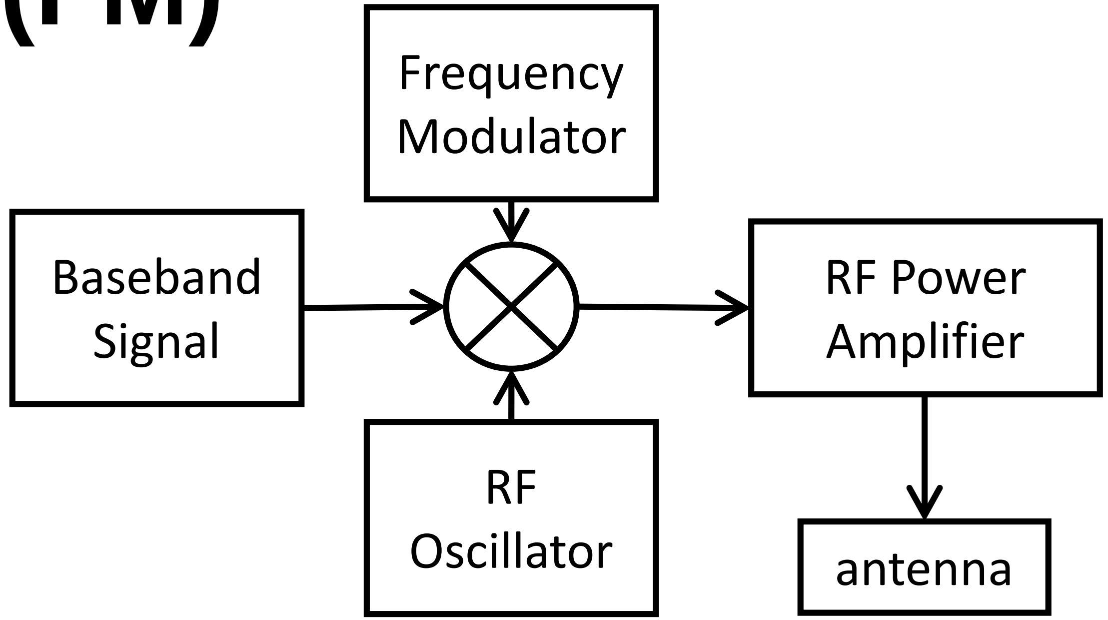
Why bother with a carrier wave?

- *Advantages?*
  - Very easy to implement
- *Disadvantages?*
  - Inefficient
  - Susceptible to noise

Frequency Modulation (FM)

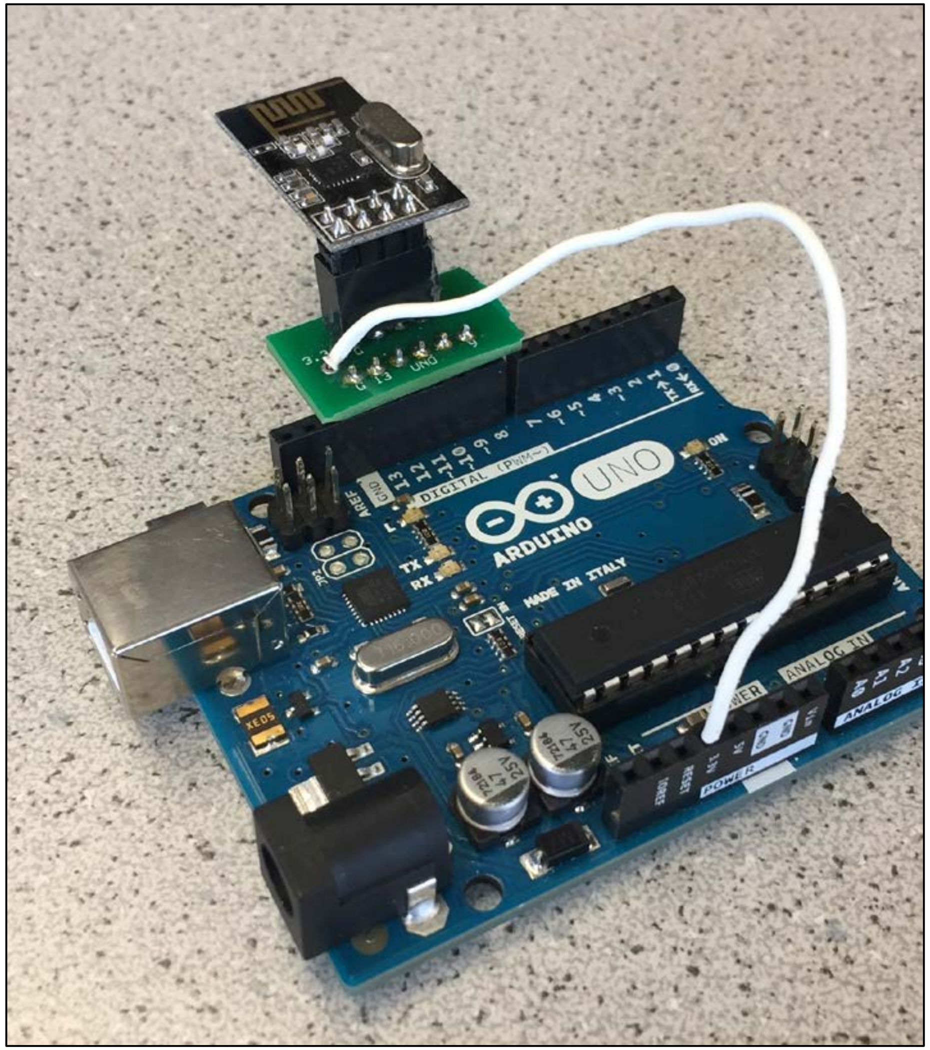
datasheet





- *Advantages?*
  - Less susceptible to noise
  - More power efficient
- *Disadvantages?*
  - Harder to demodulate

Wireless Communication



- Nordic nRF24L01+ transceivers
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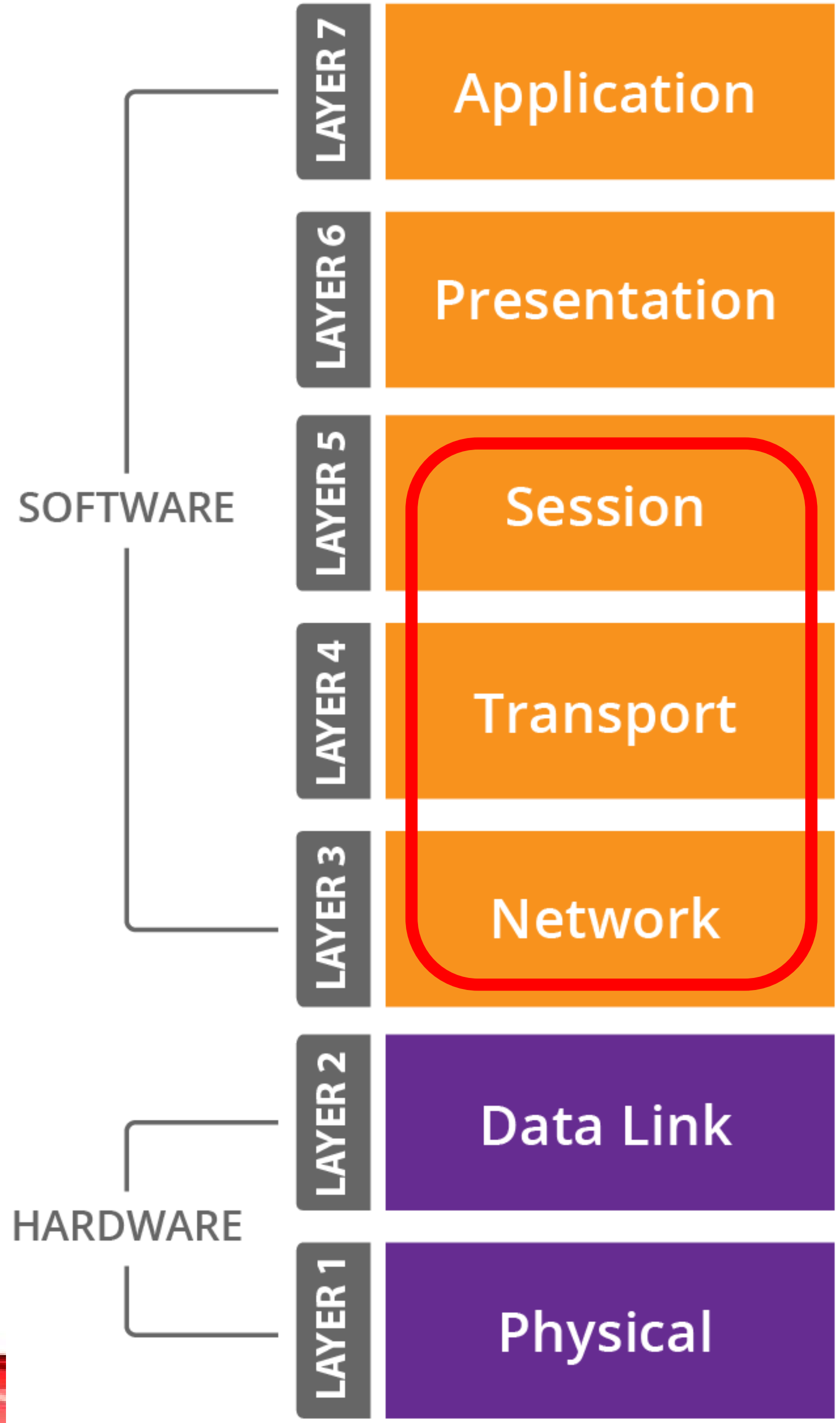
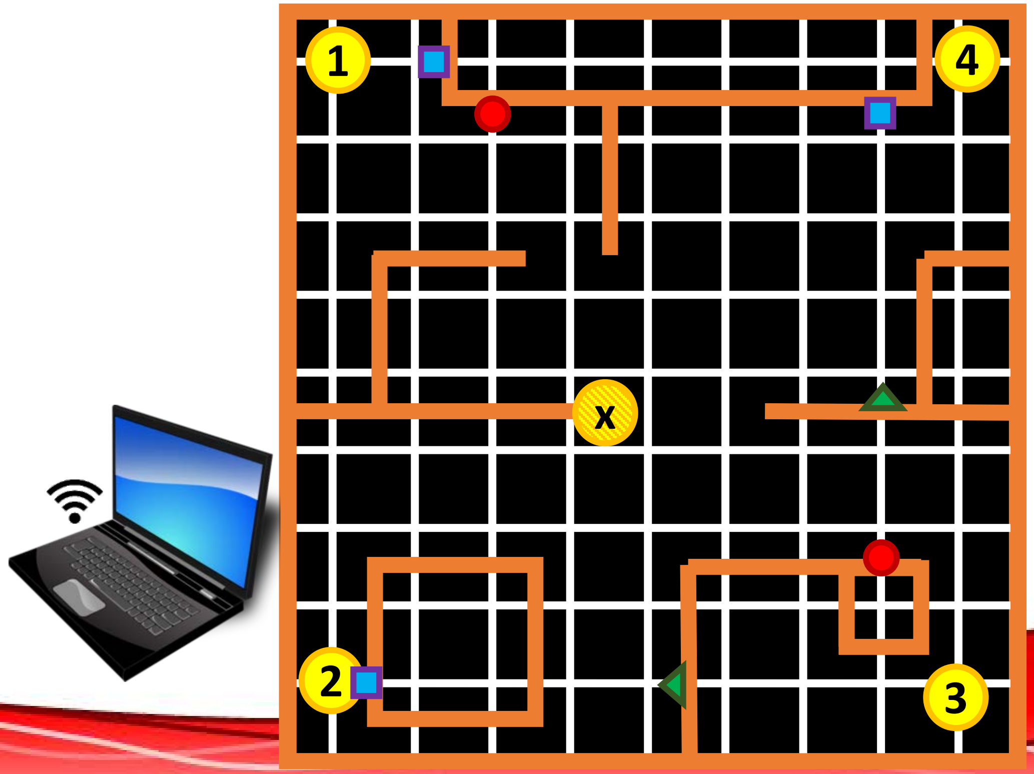
- "Enhanced Shockburst"
  - Packet-based
    - (p. 25)
  - Handles **retries**
  - Handles **ACKs**



What will you be sending?

- 9x9 squares
  - Each square can be either explored or un-explored
  - Each square can have 0-4 walls (N, E, S, W, NE, NES, etc.)
  - Each square can have 0-1 treasure
    - Each treasure can have one of 3 colors, and one of 3 shapes
  - (a square can also have a robot in it)



What will you be sending too? (GUI Protocol)

- The GUI will run for 5min, then stop capturing data. You'll be scored for what's on the screen!

How many bytes will this message require?

- Example: `Serial.println("0,0,west=true,north=true,tshape=circle");`

Parameter	Allowed Values	Default Value	Description
west	True, False	False	Is a wall to the west?
north	True, False	False	Is a wall to the north?
east	True, False	False	Is a wall to the east?
south	True, False	False	Is a wall to the south?
robot	True, False	False	Is another robot present?
tshape	Circle, Triangle, Square, None	None	What shape treasure is present?
tcolor	Red, Green, Blue, None	None	What color treasure is present?

Storage (Maze Information)

- 9x9 squares
  - Each square can be either explored or un-explored
  - Each square can have 0-4 walls (N, E, S, W, NE, NES, etc.)
  - Each square can have 0-1 treasure
    - Each treasure can have one of 3 colors, and one of 3 shapes
  - (a square can also have a robot in it)

- *How to represent the maze to minimize processing?*
  - Assign a Boolean to each possible state of a square
  - Explored?, North?, East?, South?, West?, treasure?, red?, blue?, green?, square?, diamond?, triangle?, robot?
  - 13 B/square * 81 squares = 1,053kB

8 bit system

Storage (SRAM)

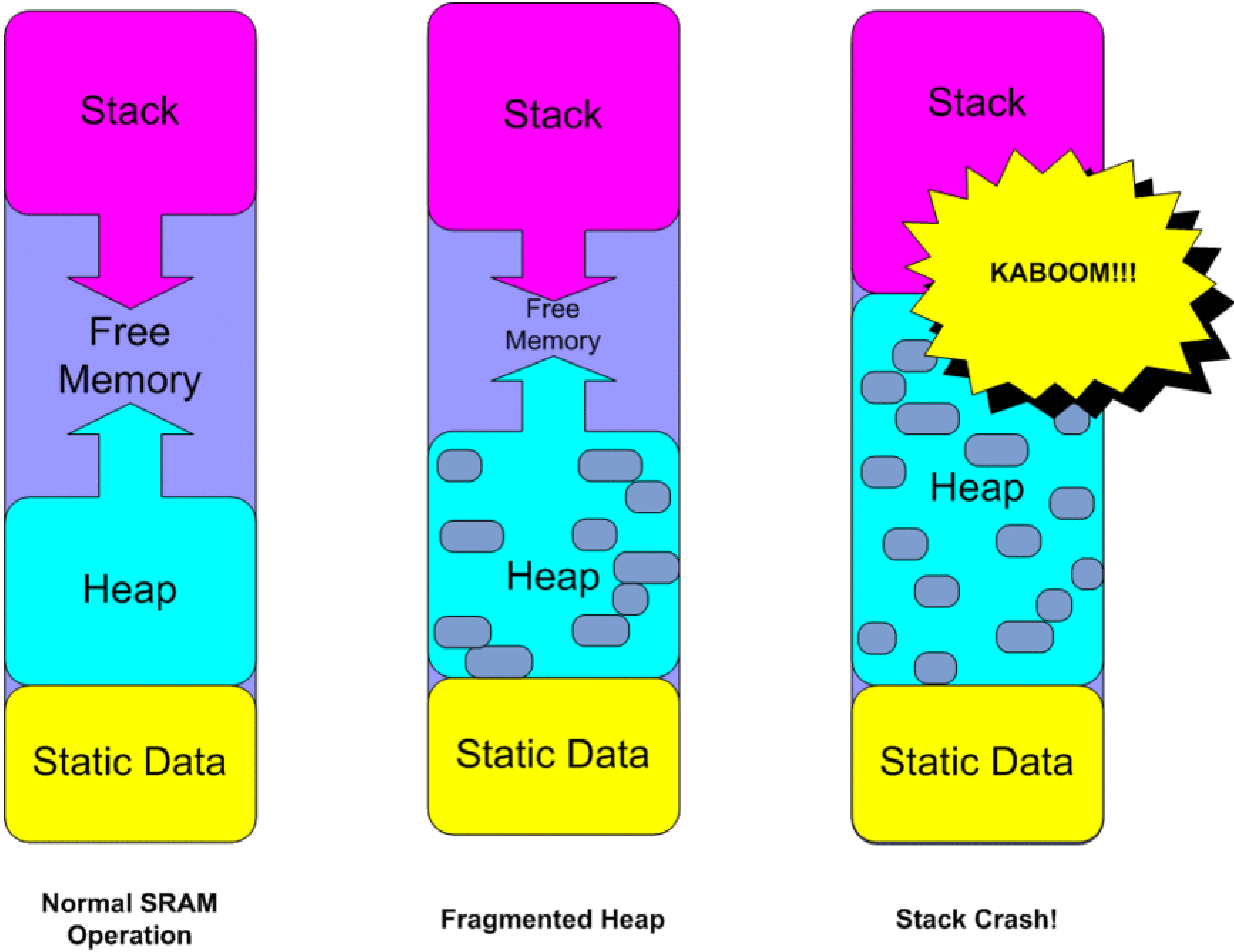
- ATmega328 datasheet
- 2,048 B RAM

Function calls
- *reclaimable!*
- *recursive fcts*

Whenever possible, pick local variables!

Dynamically allocated objects

Global/static variables



Storage

- Datasheet: SRAM = 2,048 B
- *How much space does the basic code require?*
  - 9 B
- *How much space does the Serial library require?*
  - 175 B
- *How much space will your debugging require?*
  - Use the F macro for long strings
- *…and all the other variables…*
- *How much space does the FFT library require?*
  - 128 samples (real and imaginary), doubles (1,024B)

- *You need to compress the maze information!!!*

Storage (Maze Information)

- 9x9 squares
  - Each square can be either explored or un-explored
  - Each square can have 0-4 walls (N, E, S, W, NE, NES, etc.)
  - Each square can have 0-1 treasure
    - Each treasure can have one of 3 colors, and one of 3 shapes
  - (a square can also have a robot in it)

- ***How to represent the maze to minimize processing?***
- ***How to represent the maze to minimize storage?***
  - Encode treasure values, 3 bytes per square

(3B/square → 243 B)

Storage (Maze Information)

- 9x9 squares
  - Each square can be either explored or un-explored
  - Each square can have 0-4 walls (N, E, S, W, NE, NES, etc.)
  - Each square can have 0-1 treasure
    - Each treasure can have one of 3 colors, and one of 3 shapes
  - (a square can also have a robot in it)

- *How to represent the maze to minimize processing?*
- *How to represent the maze to minimize storage?*
  - *What is the smallest number of bits you can store "explored" in?* 1 bit
  - *How about walls?* 4 bits
  - *How about treasures?* 4 bits

(still 2B/square → 162B)

(or 9bits*81squares → 729 bits = 92B)

Bit Masking

- Handy tricks
  - Bitwise NOT operator:
    - `Cell = ~0b11000000 //negate`
    - `Cell = 0b00111111`
  - Bitwise AND operator:
    - `Cell = 0b11000000 & 0b01111110 = 0b01000000`
    - `Cell &= 0b00000001; //clear everything except whatever is already in bit 0!`
  - Bitwise OR operator:
    - `Cell = 0b11000000 | 0b01111110 = 0b11111110`
    - `Cell |= 0b00000001; //make sure bit 0 is on!`
  - Bitwise XOR operator
    - `Cell = 0b11000000 ^ 0b01111110 = 0b10111110`
    - `LED ^= LED;`

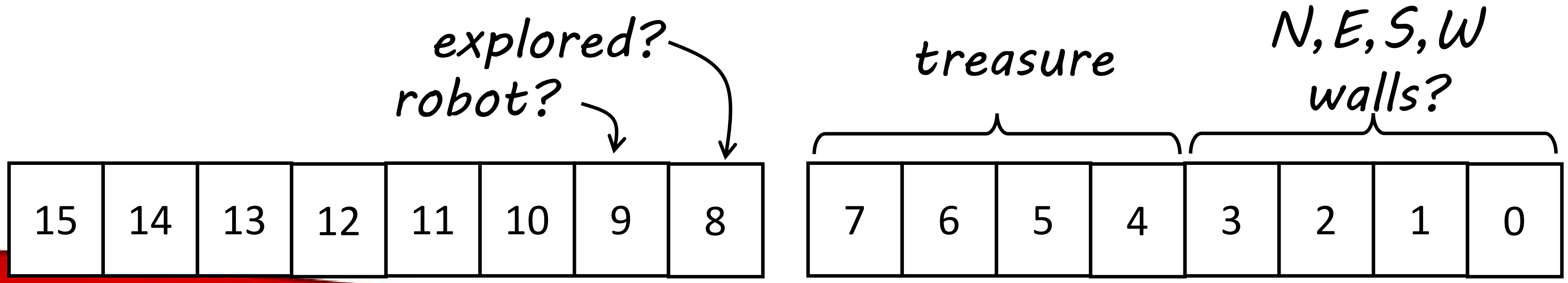
Bit Masking

- Handy tricks
  - Bit-shift
    - `127 >> 1 = 0b01111111 >> 1 = 0b00111111 = 63`
    - `127 << 1 = 0b01111111 << 1 = 0b11111110 = 254`
    - `TCCR0 |= (1 << CS00);`
  - NB: behavior depends on the datatype!
    - `unsigned char A = 0b11111000;`
    - `A>>2 = 0b00111110;`
    - `signed char A = 0b11111000;`
    - `A>>2 = 0b11111110; //sign extension`
    - `signed char A = 0b11111000;`
    - `(unsigned char)A>>2 = 0b00111110;`

Computation time (ATmega328, 16MHz):
- Subtraction/Addition: 3896 us
- Multiplication: 3896 us
- Division: 153236 us

Bit Masking – handy tricks

- Priority?
  - `A &= ~(1 << 6);`
  - `A = A & ~0b01000000;`
  - `A = A & 0b10111111;`
  - `Clear bit 6!`
- *What if you wanted to assign a treasure value of 5 to a 2D matrix with this data structure?*
  - `treasure = 5;`
  - `maze(x,y,0) = maze(x,y,0)|(treasure<<4); //(if unassigned)`



Consequences!

High-power, high-frequency signals don't play nice with small signals and excessive wiring…