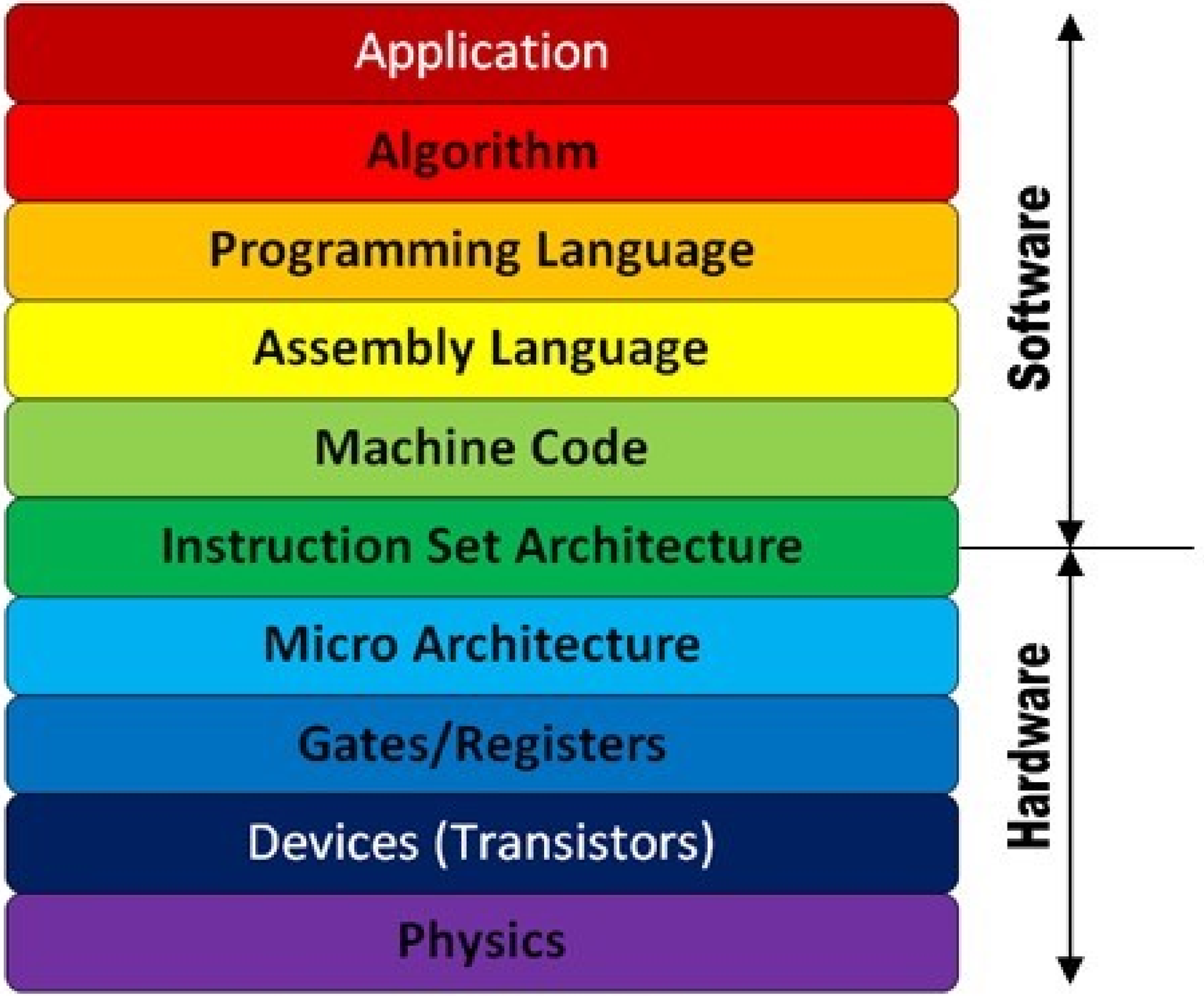
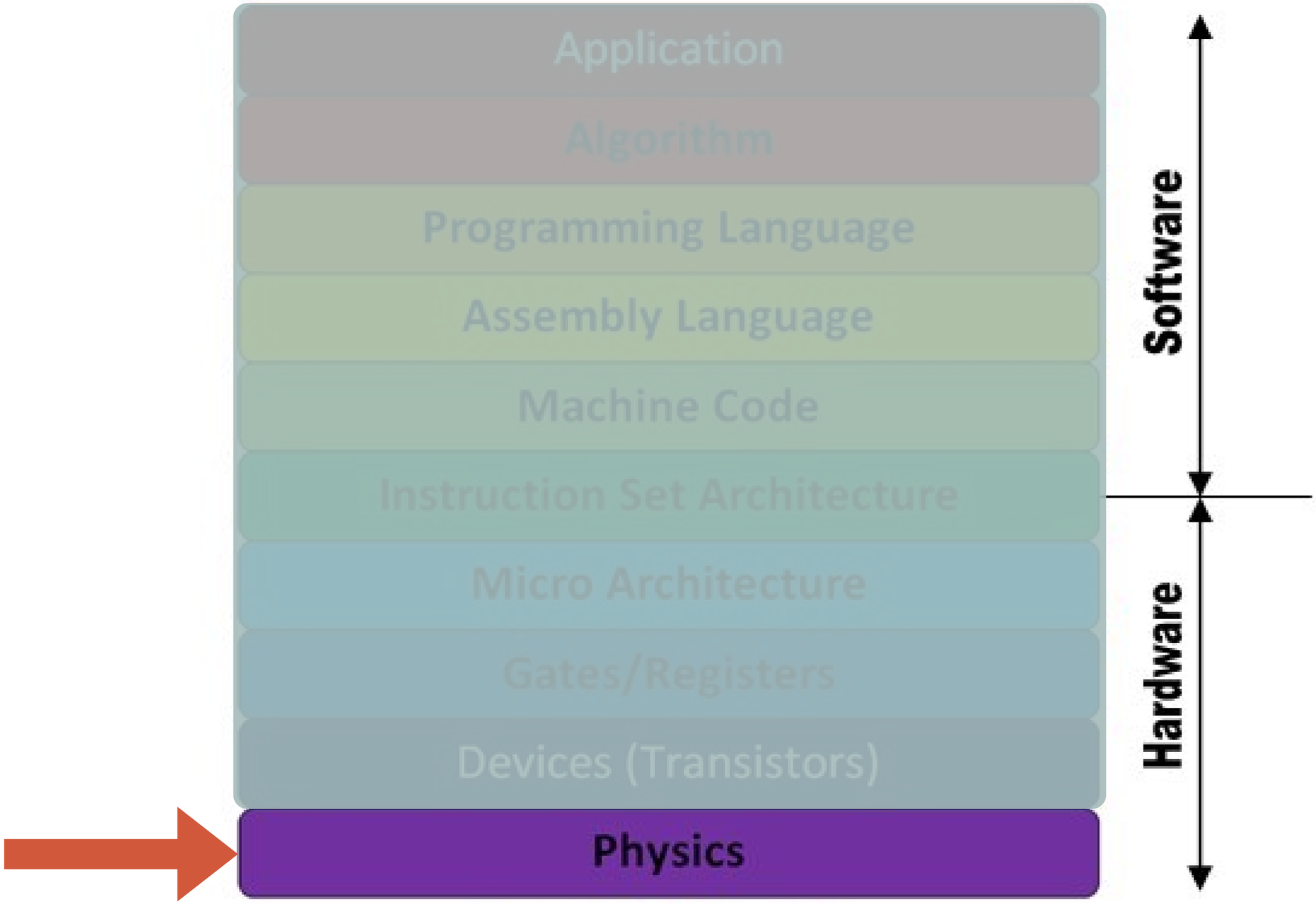
WIRELESS COMMUNICATION

ECE3400, Fall 2017

ABSTRACTION HIERARCHY

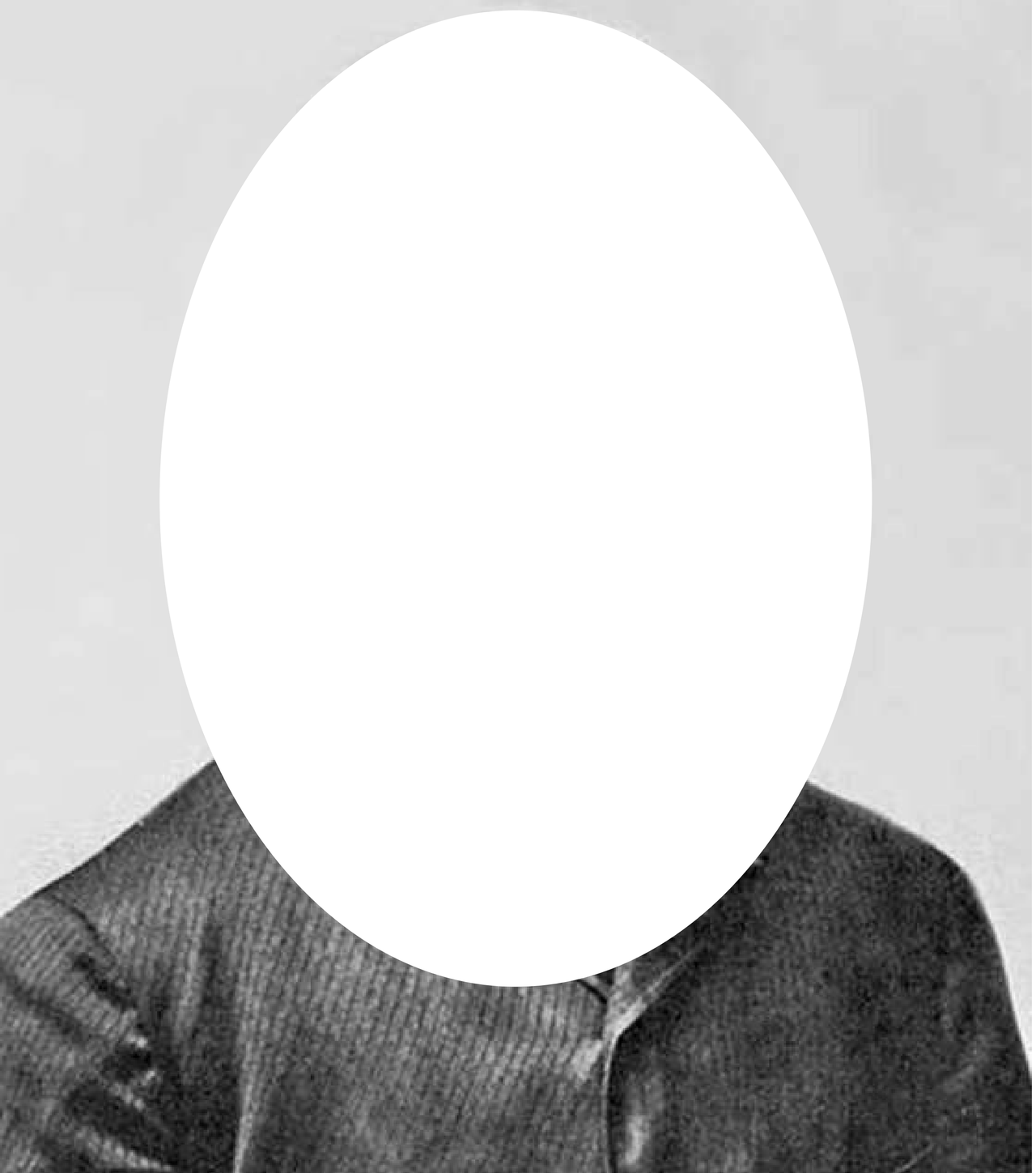


Layers of Abstraction



Layers of Abstraction

RADIO



1950S VOCABULARY

- “intelligence” == “information”
- “cycles” == “hertz”*

*(adopted by the General Conference on Weights and Measures in 1960)

HEINRICH HERTZ

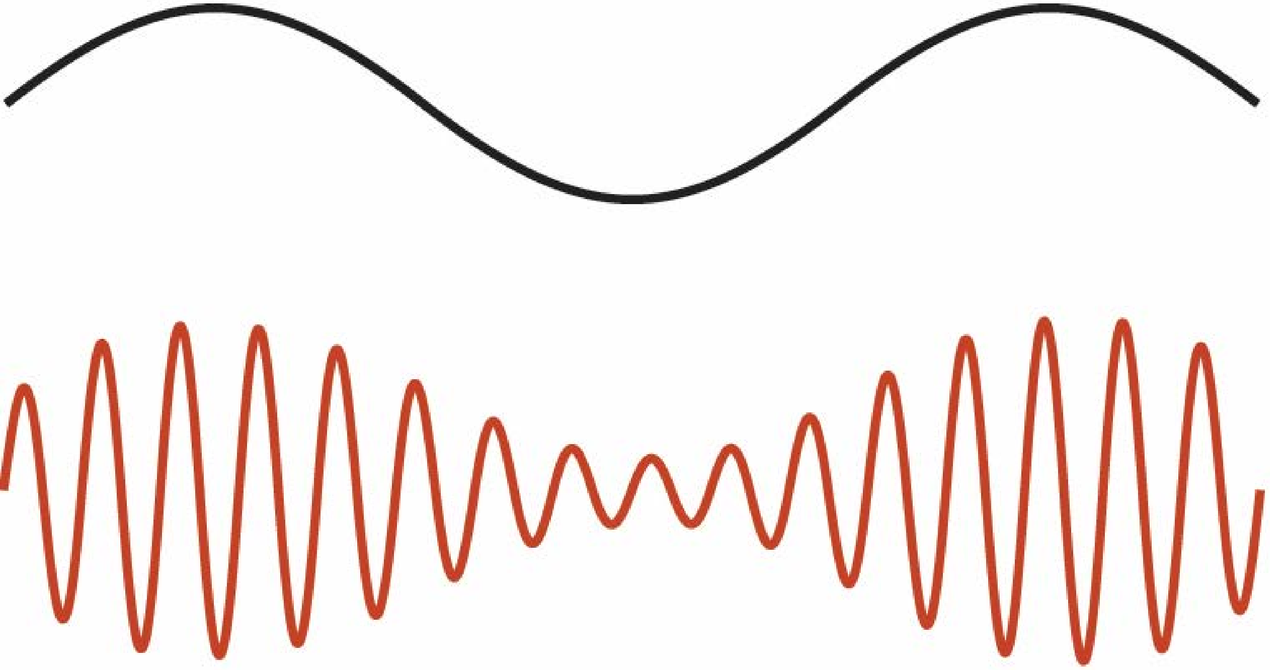
1950S VOCABULARY

- “intelligence” == “information”
- “cycles” == “hertz”*

*(adopted by the General Conference on Weights and Measures (CGPM) in 1960)

AMPLITUDE MODULATION (AM)

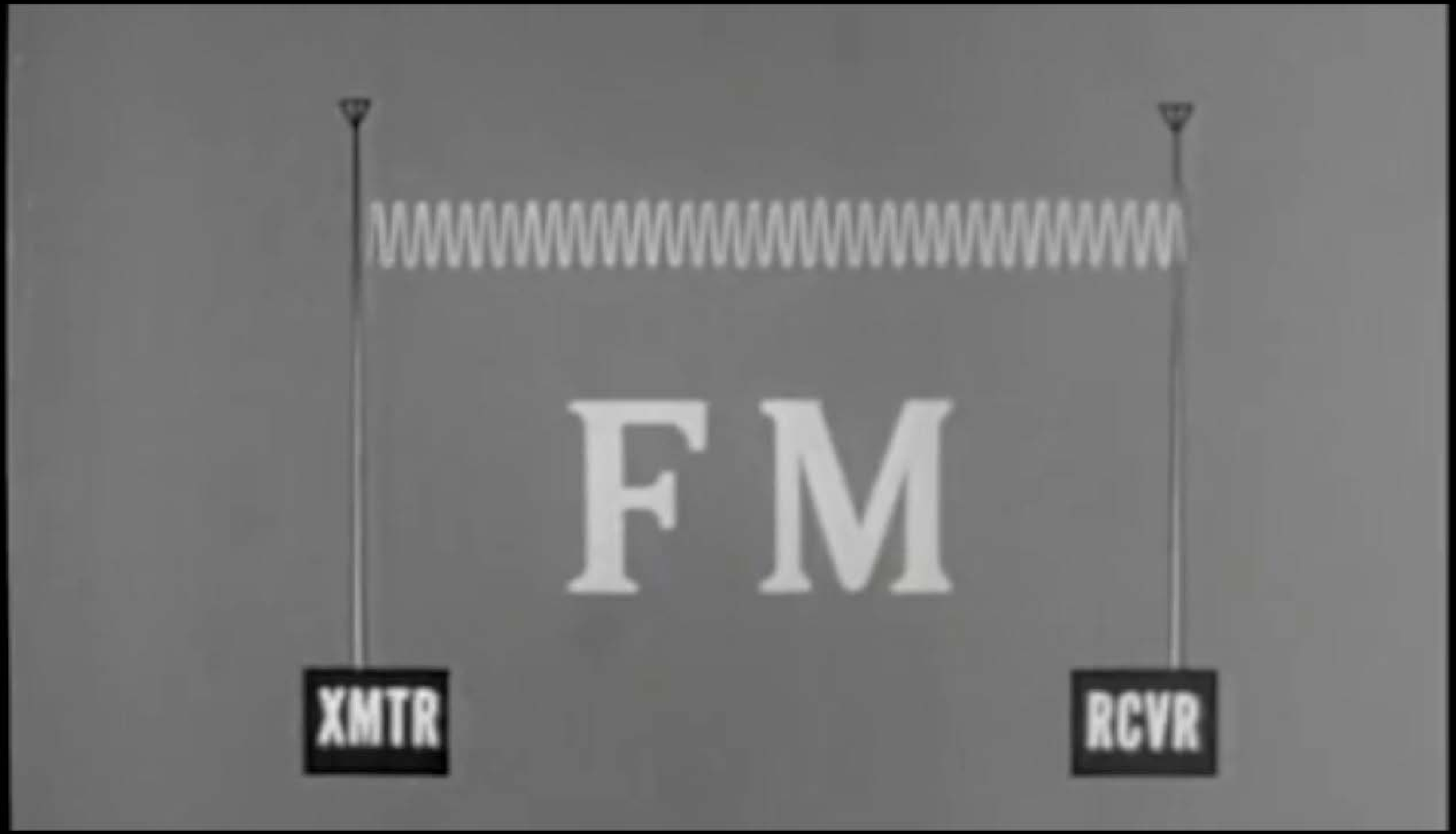
FM

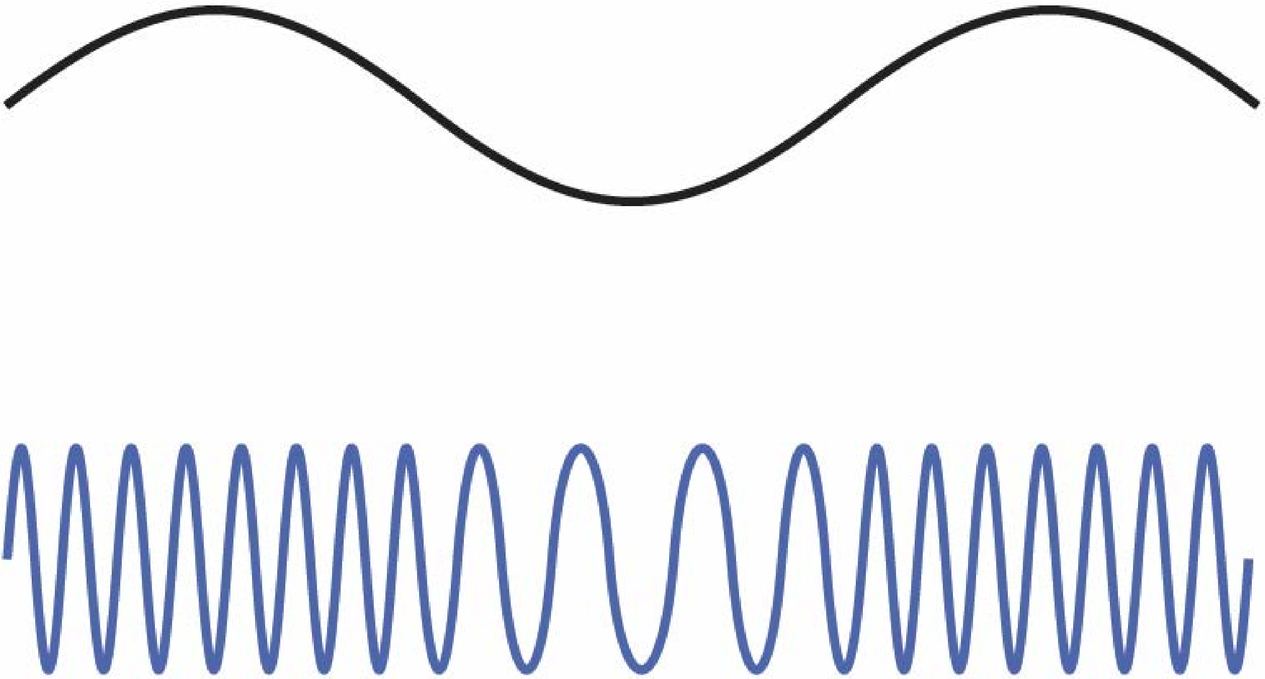


AMPLITUDE MODULATION (AM)

- Advantages?
- Disadvantages?
- How do we fix it?

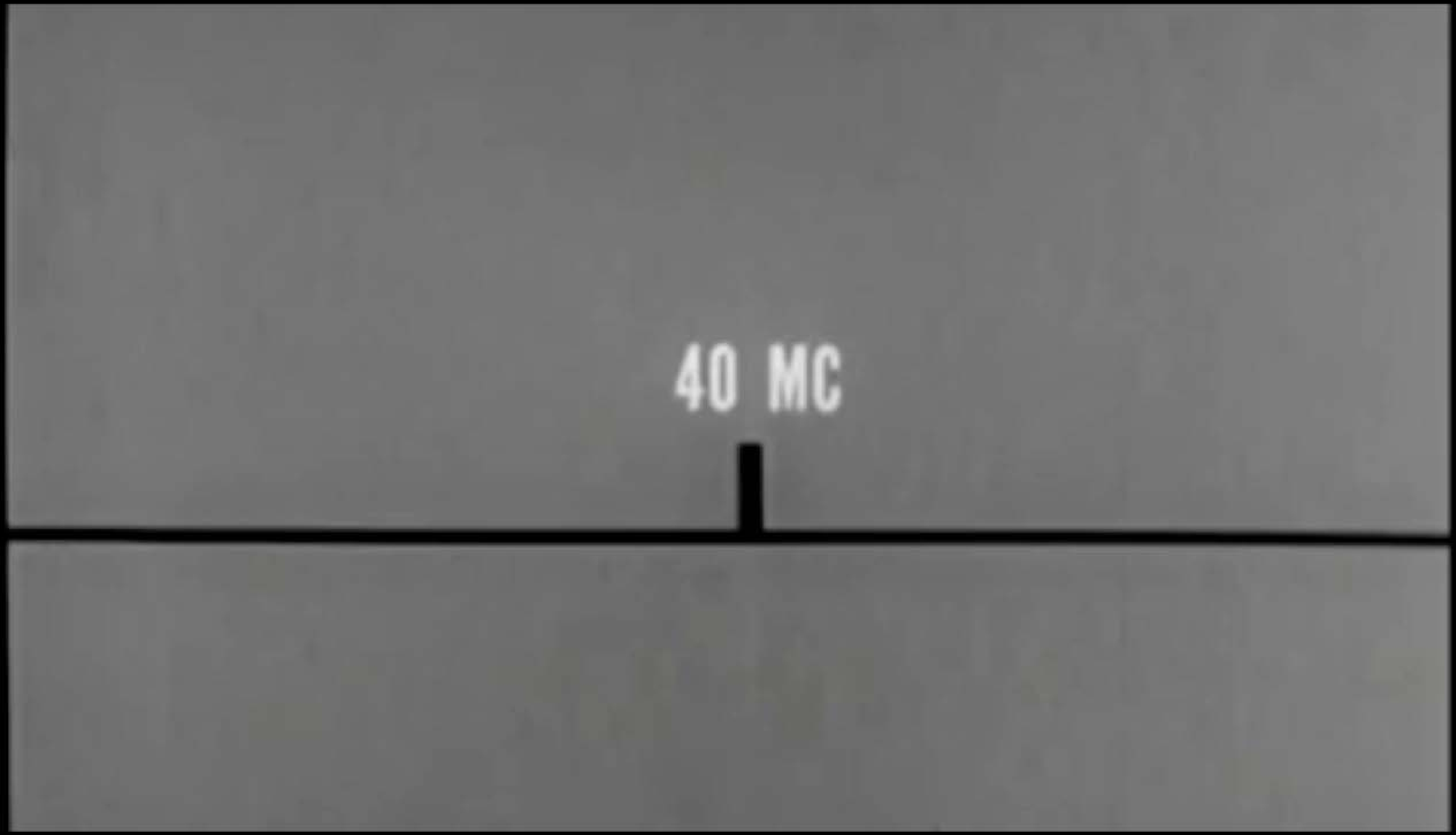
FREQUENCY MODULATION (FM)


FM
XMTR
RCVR



FREQUENCY MODULATION (FM)

- Advantages?
- Disadvantages?


40 MC

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

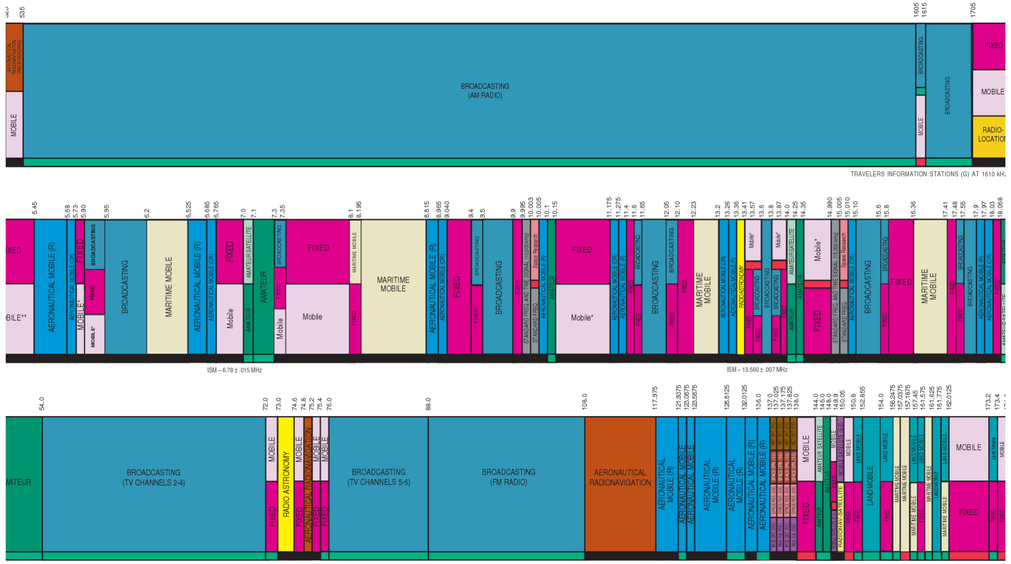
- AERONAUTICAL MOBILE
- AERONAUTICAL MOBILE SATELLITE
- AERONAUTICAL RADIONAVIGATION
- AMATEUR
- AMATEUR SATELLITE
- BROADCASTING
- BROADCASTING SATELLITE
- EARTH EXPLORATION SATELLITE
- FIXED
- FIXED SATELLITE
- INTER-SATELLITE
- LAND MOBILE
- LAND MOBILE SATELLITE
- MARITIME MOBILE
- MARITIME MOBILE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

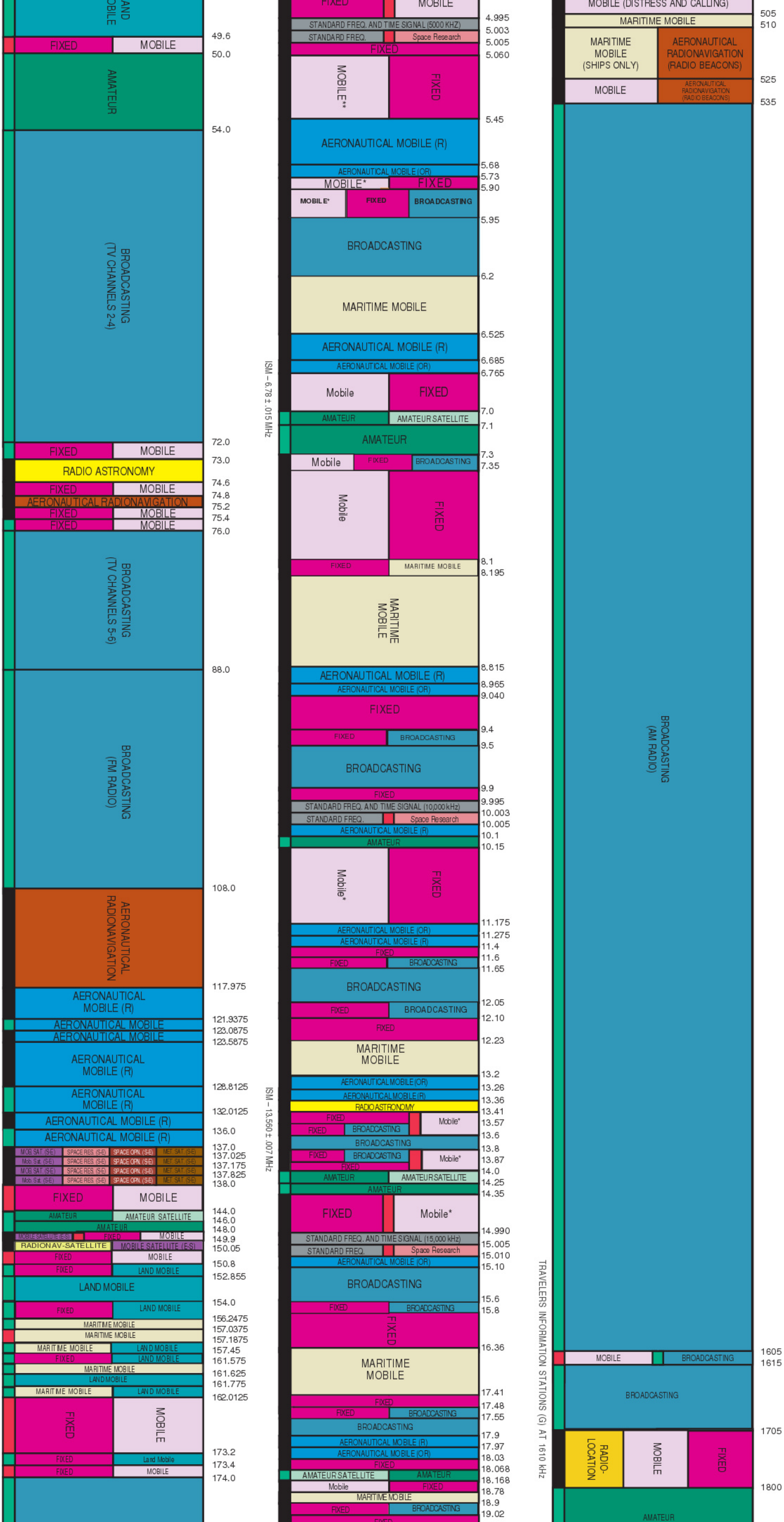
ACTIVITY CODE

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

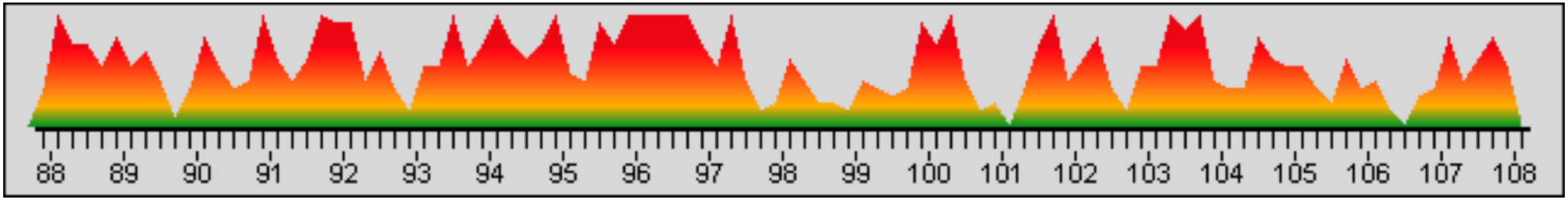
ALLOCATION USAGE DESIGNATION

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


BROADCASTING (AM RADIO)
MOBILE
FIXED
MOBILE
RADIO-LOCATION
TRAVELERS INFORMATION STATIONS (G) AT 1610 kHz
ISM – 6.78 ± .015 MHz
ISM – 13.560 ± .007 MHz
AMATEUR
BROADCASTING (TV CHANNELS 2-4)
RADIO ASTRONOMY
BROADCASTING (TV CHANNELS 5-6)
BROADCASTING (FM RADIO)
AERONAUTICAL RADIONAVIGATION
MARITIME MOBILE
LAND MOBILE


FIXED
MOBILE
49.6
50.0
AMATEUR
54.0
BROADCASTING (TV CHANNELS 2-4)
72.0
73.0
RADIO ASTRONOMY
74.6
74.8
AERONAUTICAL RADIONAVIGATION
75.2
75.4
76.0
BROADCASTING (TV CHANNELS 5-6)
88.0
BROADCASTING (FM RADIO)
108.0
AERONAUTICAL RADIONAVIGATION
117.975
AERONAUTICAL MOBILE (R)
121.9375
123.0875
AERONAUTICAL MOBILE
123.5875
128.8125
132.0125
136.0
137.0
137.025
137.175
137.825
138.0
144.0
146.0
148.0
149.9
150.05
150.8
152.855
154.0
156.2475
157.0375
157.1875
157.45
161.575
161.625
161.775
162.0125
173.2
173.4
174.0
ISM – 6.78 ± .015 MHz
ISM – 13.560 ± .007 MHz
4.995
5.003
5.005
5.060
5.45
5.68
5.73
5.90
5.95
6.2
6.525
6.685
6.765
7.0
7.1
7.3
7.35
8.1
8.195
8.815
8.965
9.040
9.4
9.5
9.9
9.995
10.003
10.005
10.1
10.15
11.175
11.275
11.4
11.6
11.65
12.05
12.10
12.23
13.2
13.26
13.36
13.41
13.57
13.6
13.8
13.87
14.0
14.25
14.35
14.990
15.005
15.010
15.10
15.6
15.8
16.36
17.41
17.48
17.55
17.9
17.97
18.03
18.068
18.168
18.78
18.9
19.02
STANDARD FREQ. AND TIME SIGNAL (5000 KHZ)
STANDARD FREQ.
Space Research
MOBILE**
AERONAUTICAL MOBILE (R)
AERONAUTICAL MOBILE (OR)
MOBILE*
MOBILE*
FIXED
BROADCASTING
MARITIME MOBILE
Mobile
AMATEUR
AMATEUR SATELLITE
Mobile
FIXED
BROADCASTING
MARITIME MOBILE
AERONAUTICAL MOBILE (R)
AERONAUTICAL MOBILE (OR)
STANDARD FREQ. AND TIME SIGNAL (10,000 kHz)
STANDARD FREQ.
Space Research
Mobile*
AERONAUTICAL MOBILE (OR)
AERONAUTICAL MOBILE (R)
RADIO ASTRONOMY
Mobile*
AMATEUR
AMATEUR SATELLITE
AMATEUR
Mobile*
STANDARD FREQ. AND TIME SIGNAL (15,000 kHz)
STANDARD FREQ.
Space Research
AERONAUTICAL MOBILE (OR)
MOBILE (DISTRESS AND CALLING)
505
510
MARITIME MOBILE
MARITIME MOBILE (SHIPS ONLY)
AERONAUTICAL RADIONAVIGATION (RADIO BEACONS)
525
MOBILE
AERONAUTICAL RADIONAVIGATION (RADIO BEACONS)
535
BROADCASTING (AM RADIO)
1605
1615
MOBILE
BROADCASTING
BROADCASTING
1705
RADIO-LOCATION
MOBILE
FIXED
1800
AMATEUR
TRAVELERS INFORMATION STATIONS (G) AT 1610 kHz

⚡	ⓘ	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



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**

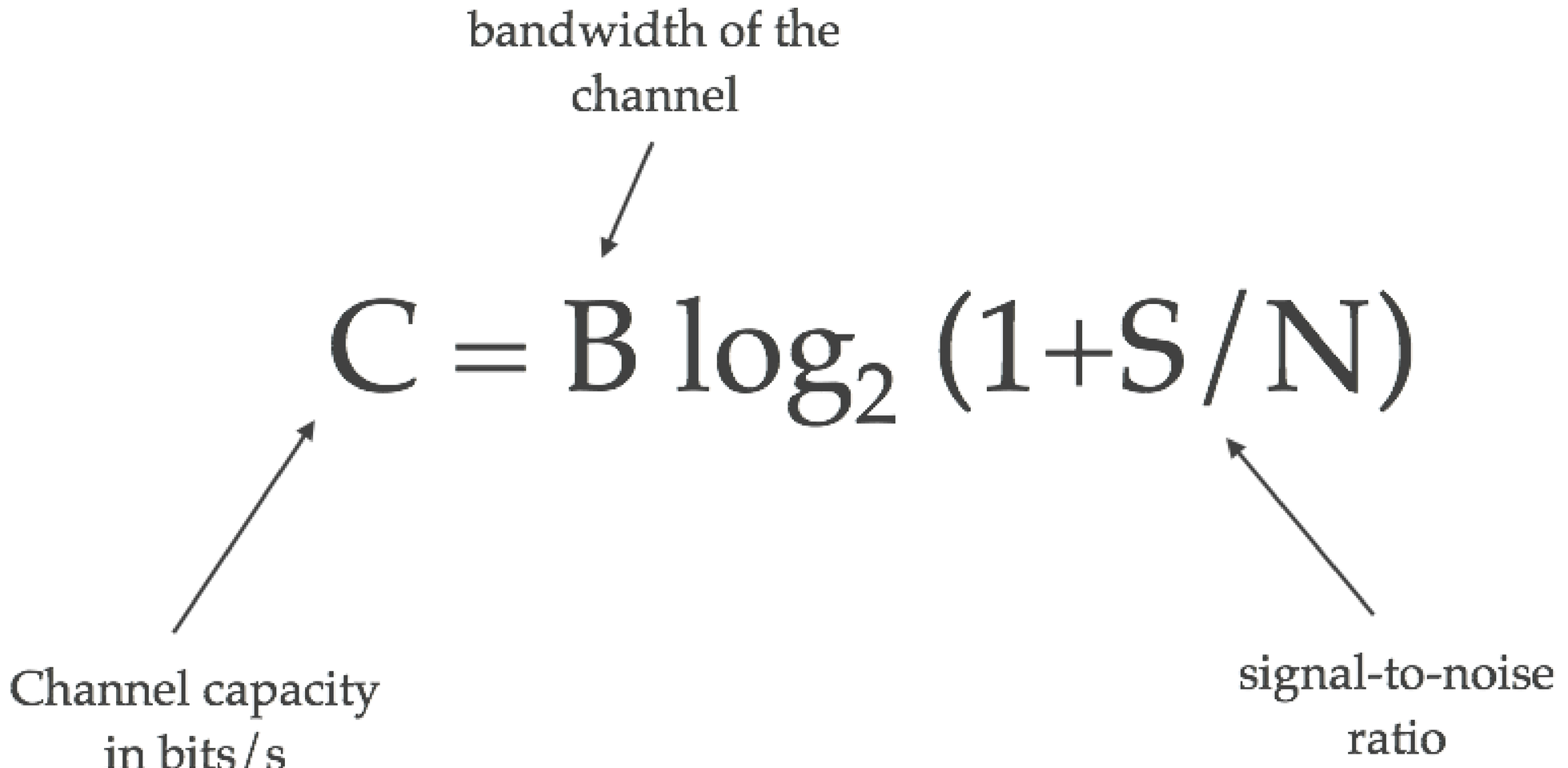
Attention: Before transmitting on an FM frequency, always check to see if the channel is truly vacant by listening with an FM radio. Your audio device will work best on an empty channel and you will be less likely to cause interference with other people's radio reception.

BANDWIDTH
REST FREQ
DEVIATION
BELOW REST
DEVIATION
ABOVE REST

SHANNON-HARTLEY THEOREM

$$C = B \log_2 (1+S/N)$$

SHANNON-HARTLEY THEOREM



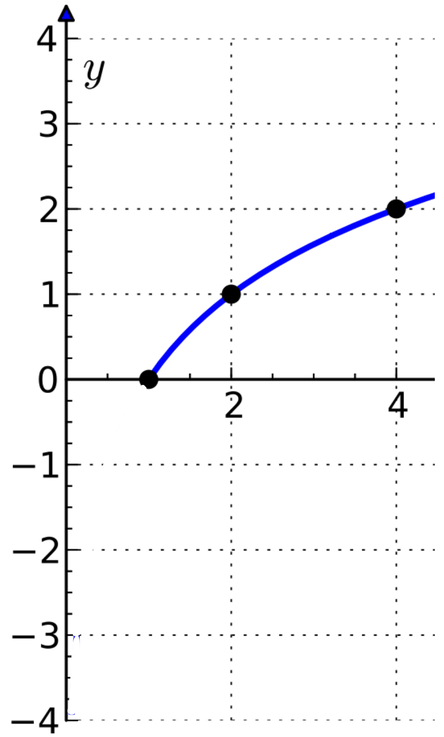
SHANNON-HARTLEY THEOREM

bandwidth of the channel

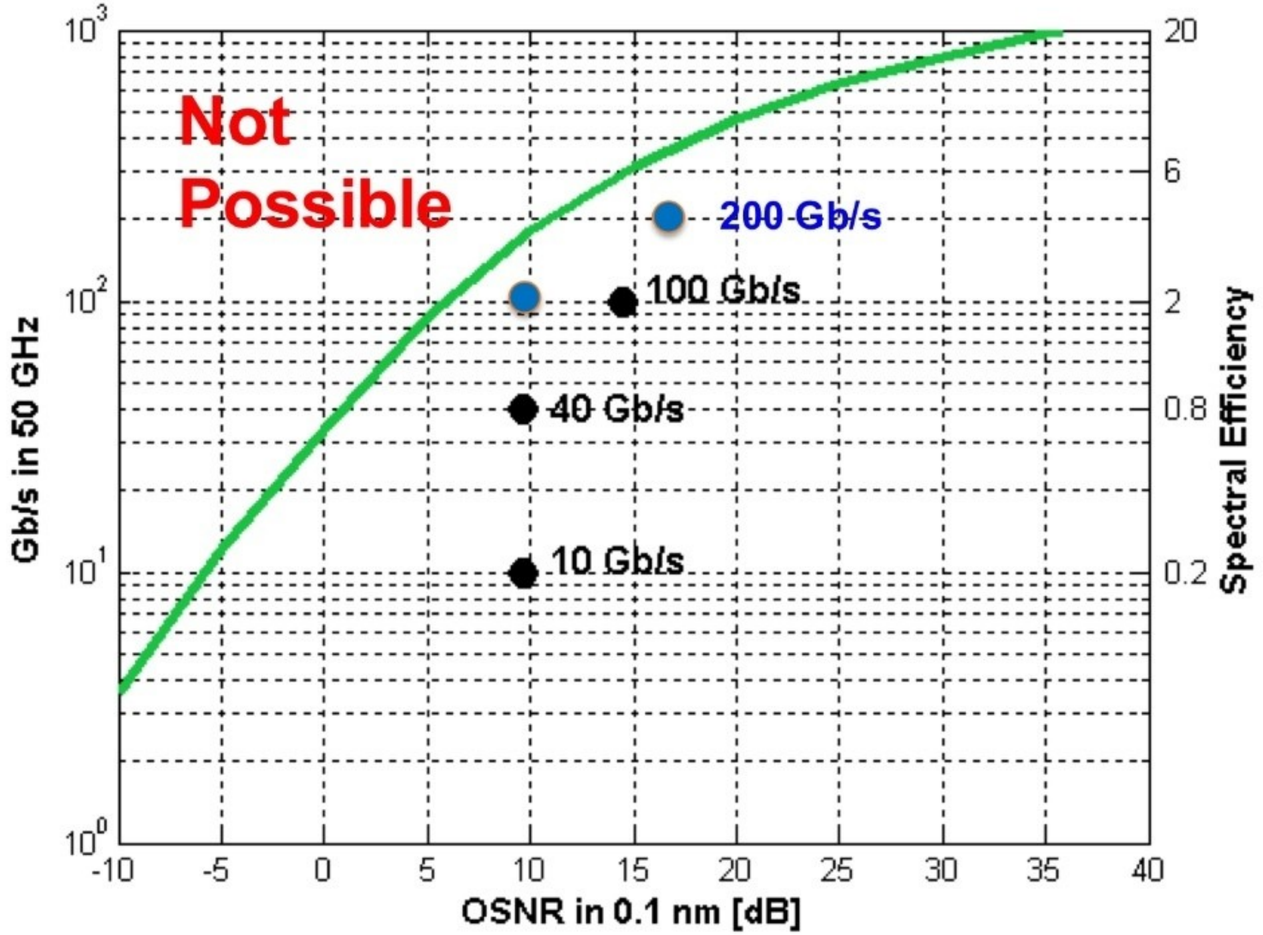
$$C = B \log_2 (1+S/N)$$

Channel capacity in bits/s

signal-to-noise ratio



SHANNON LIMIT

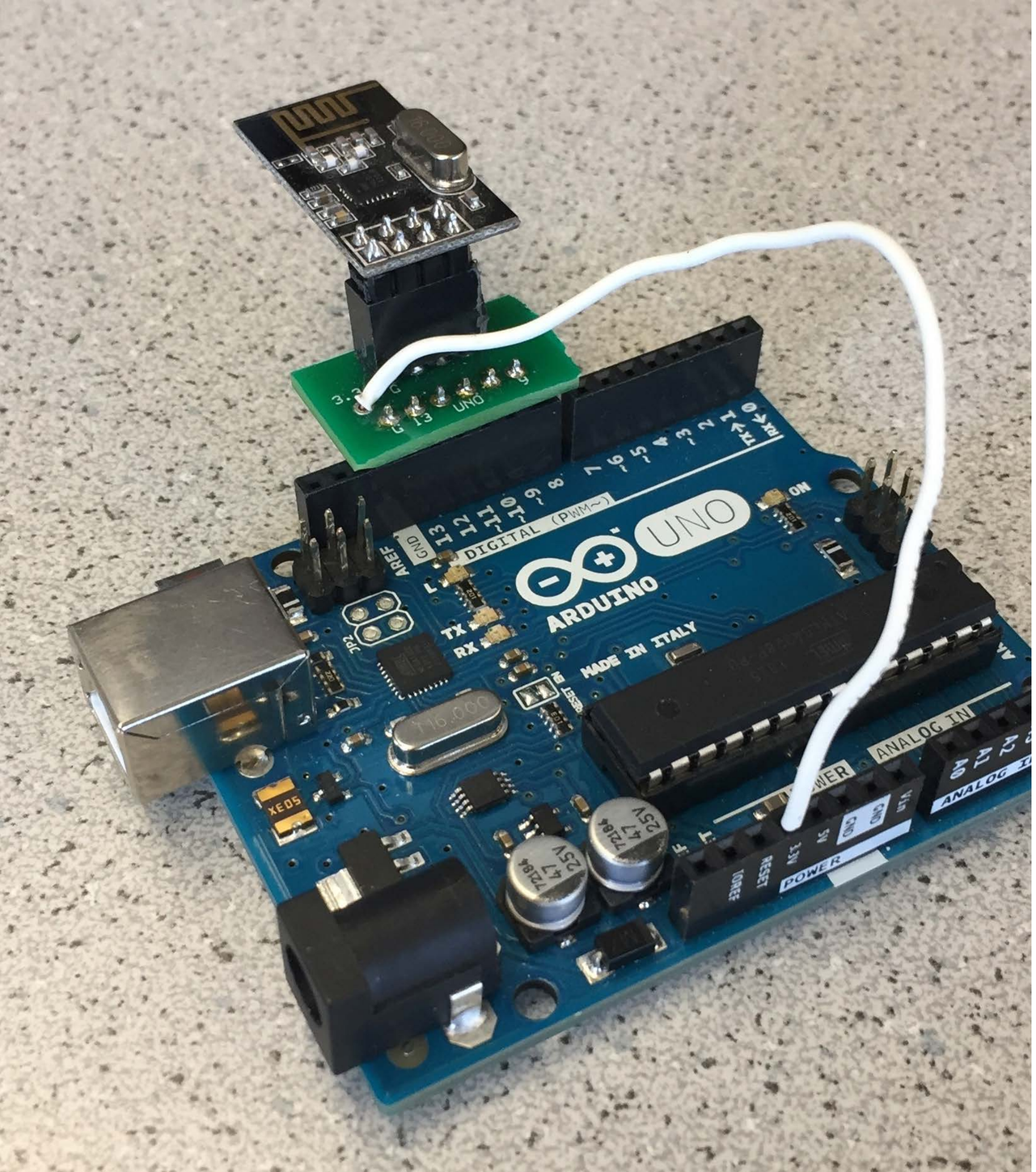


Example: Optical fiber channel linking US and China

RADIO SUMMARY

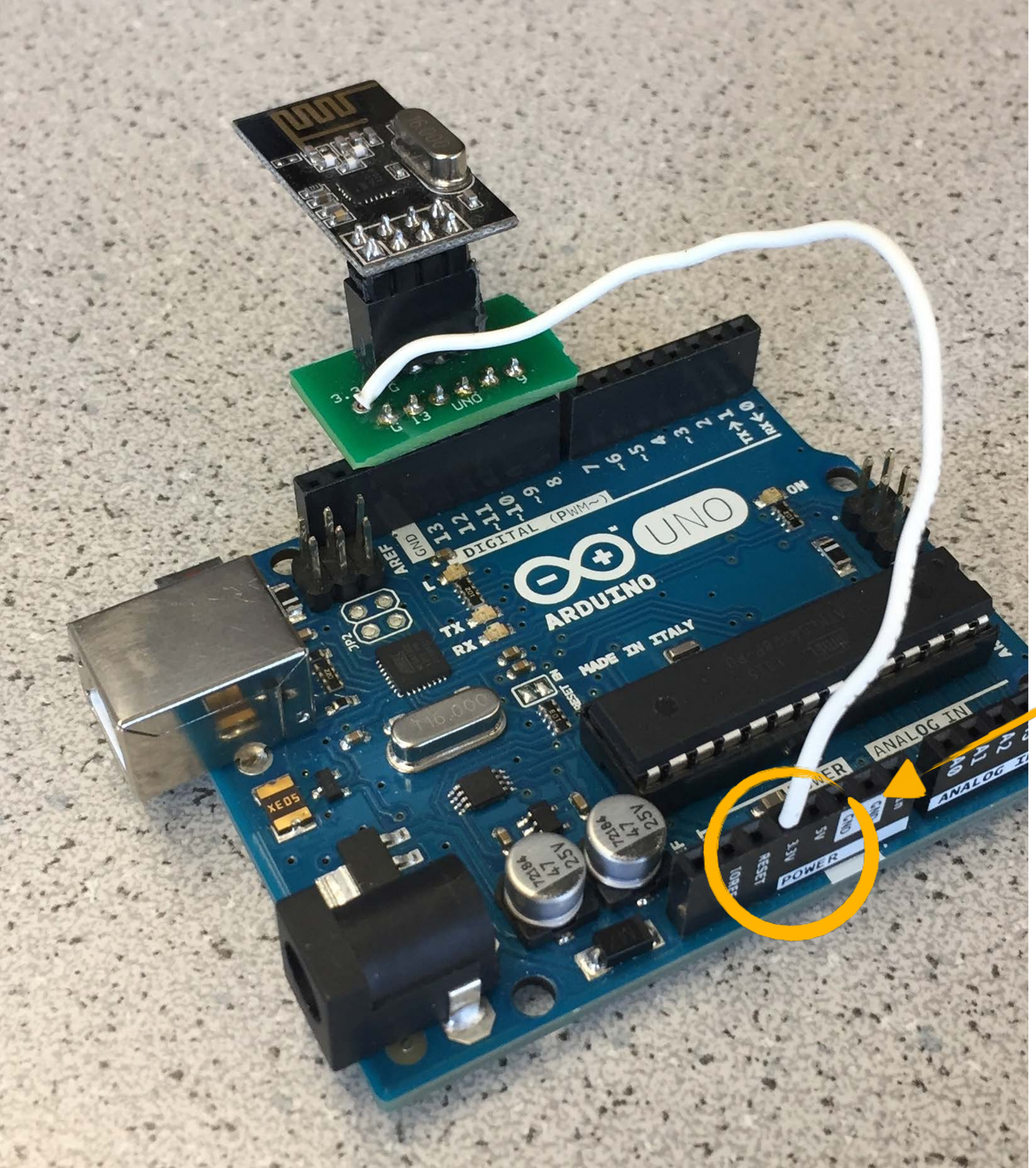
- Analog radio
- Your radios use a digital protocol!
- Abstraction…

LAB 4



NORDIC NRF24L01+

- Packet-based communication
- Enhanced ShockBurst™
- **Radio runs on 3.3V!**



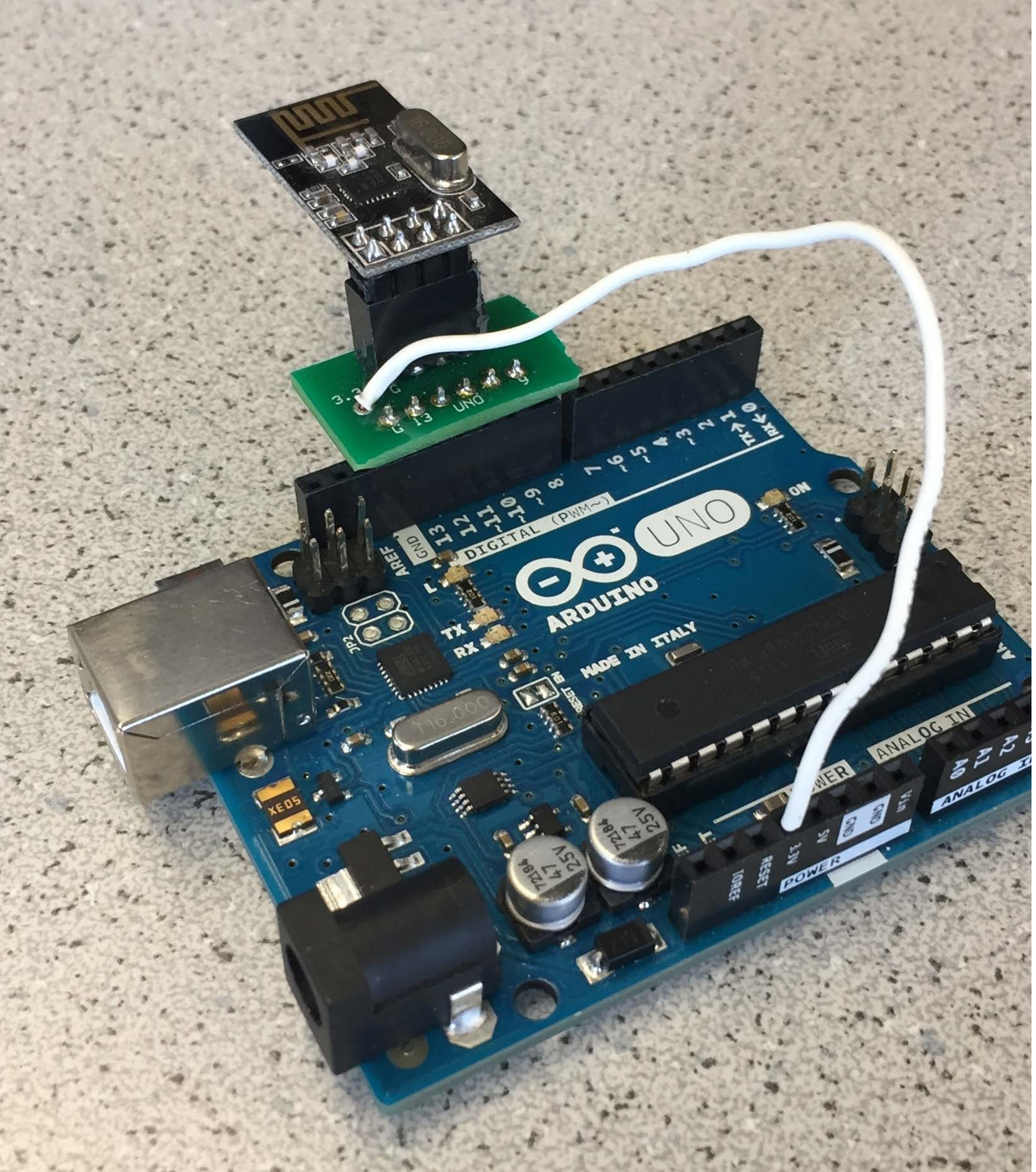
NORDIC NRF24L01+

- Packet-based communication
- Enhanced ShockBurst™
- **Radio runs on <u>3.3V</u>!**

3.3 VOLTS

VOLT

S

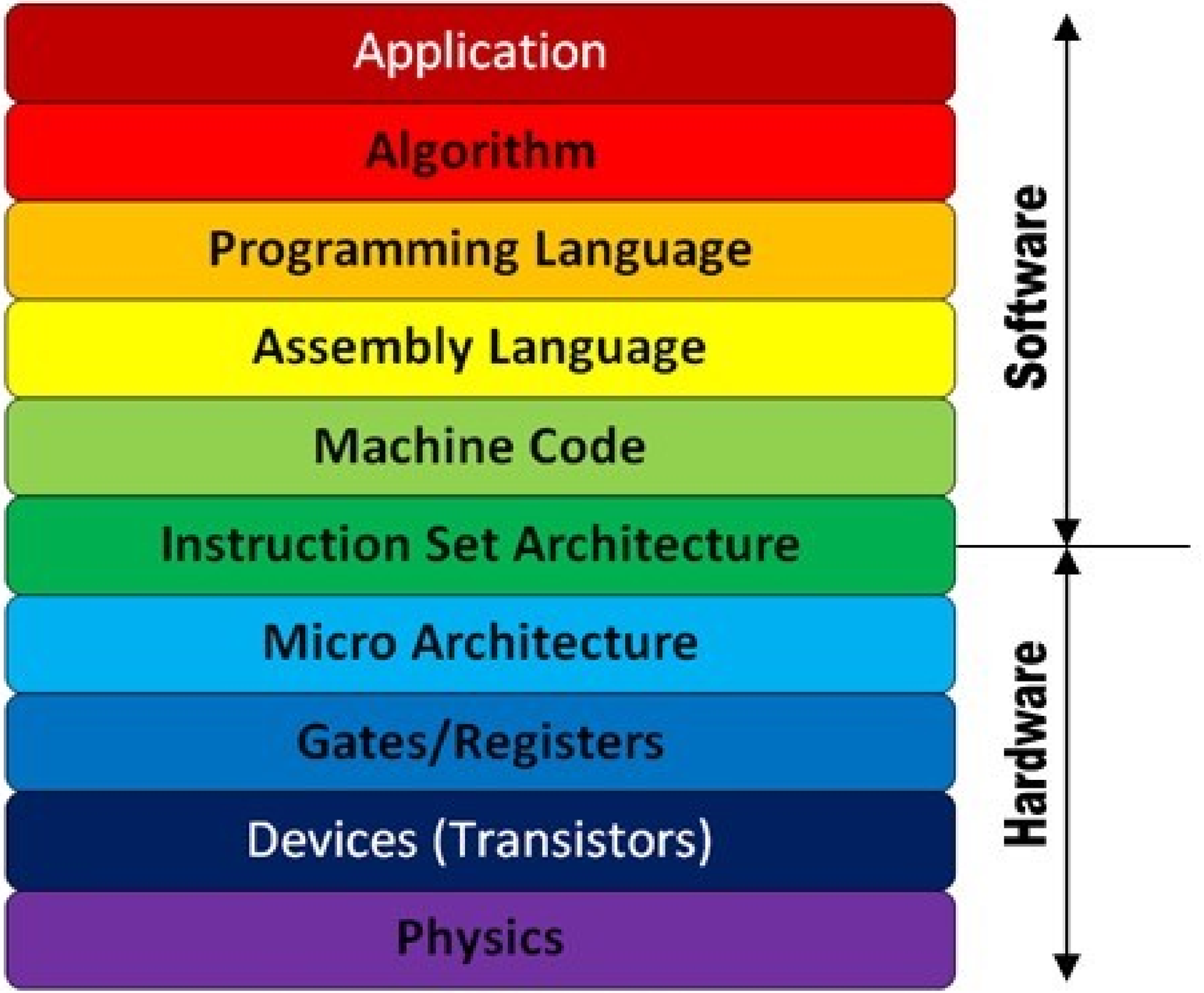


NORDIC NRF24L01+

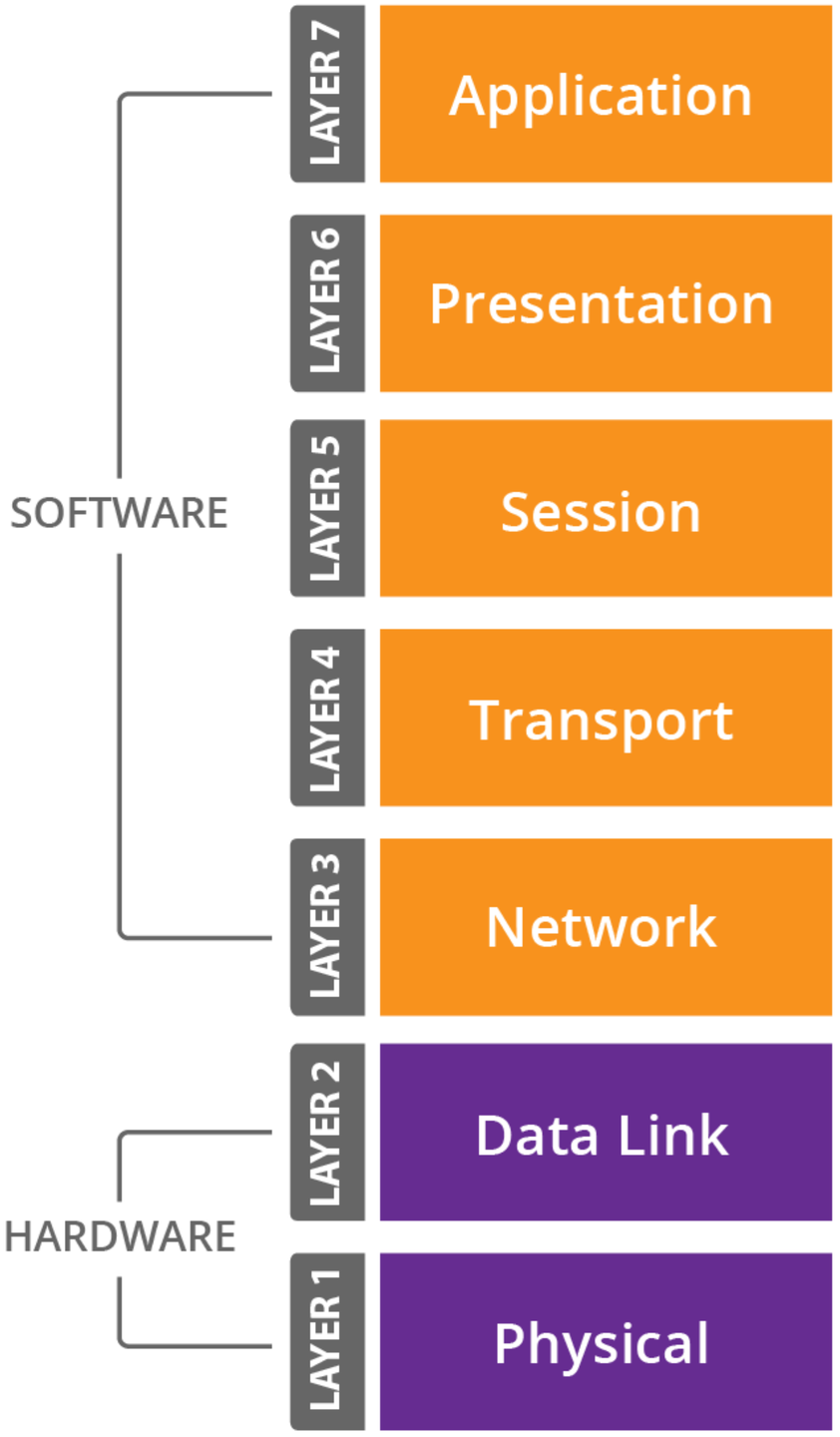
- Packet-based communication
- Enhanced ShockBurst™
- **Radio runs on 3.3V!**

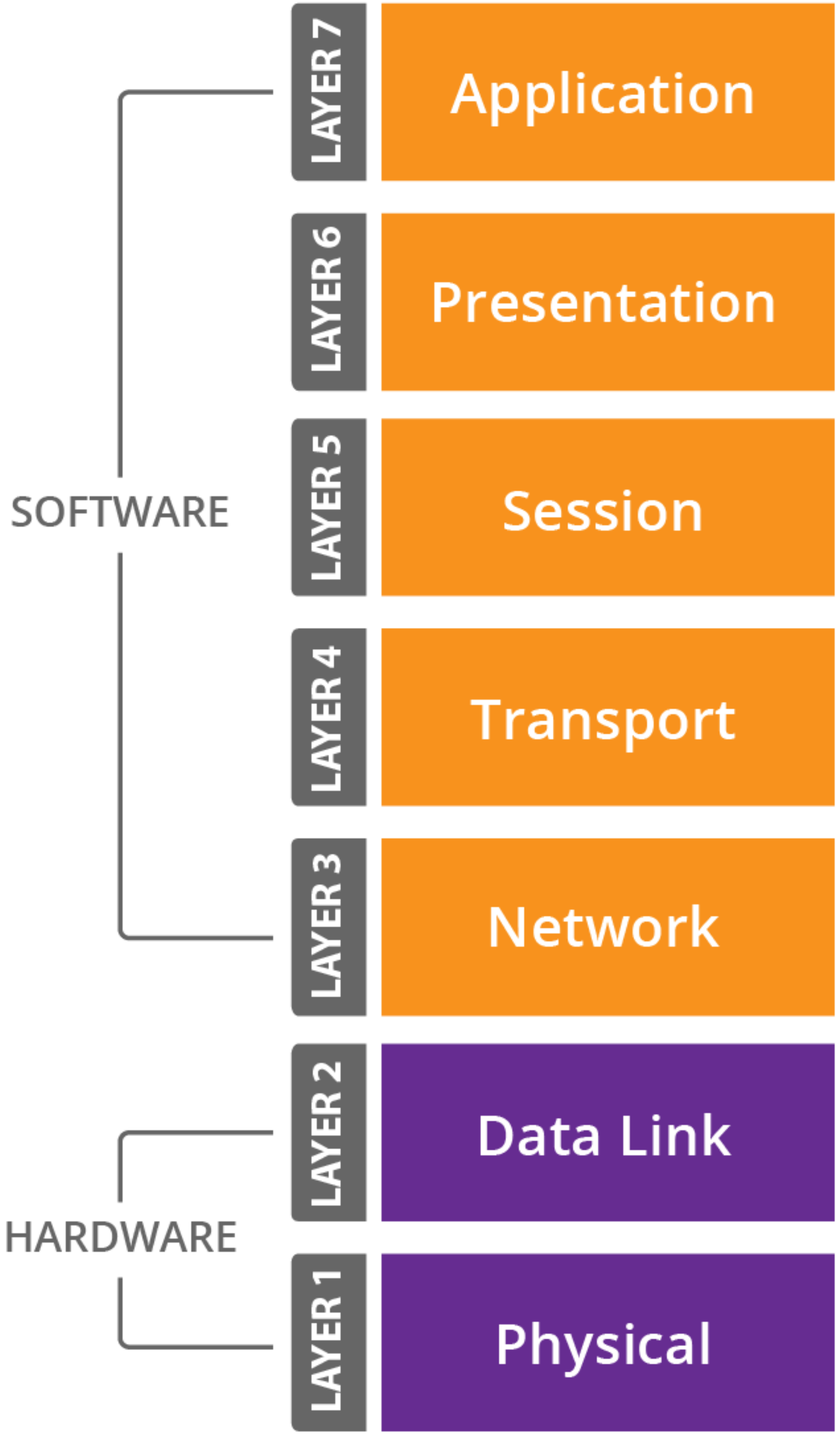
7 Enhanced ShockBurst™

Enhanced ShockBurst™ is a packet based data link layer. It features automatic packet assembly and timing, automatic acknowledgement and re-transmissions of packets. Enhanced ShockBurst™ enables the implementation of ultra low power, high performance communication with low cost host microcontrollers. The features enable significant improvements of power efficiency for bi-directional and uni-directional systems, without adding complexity on the host controller side.



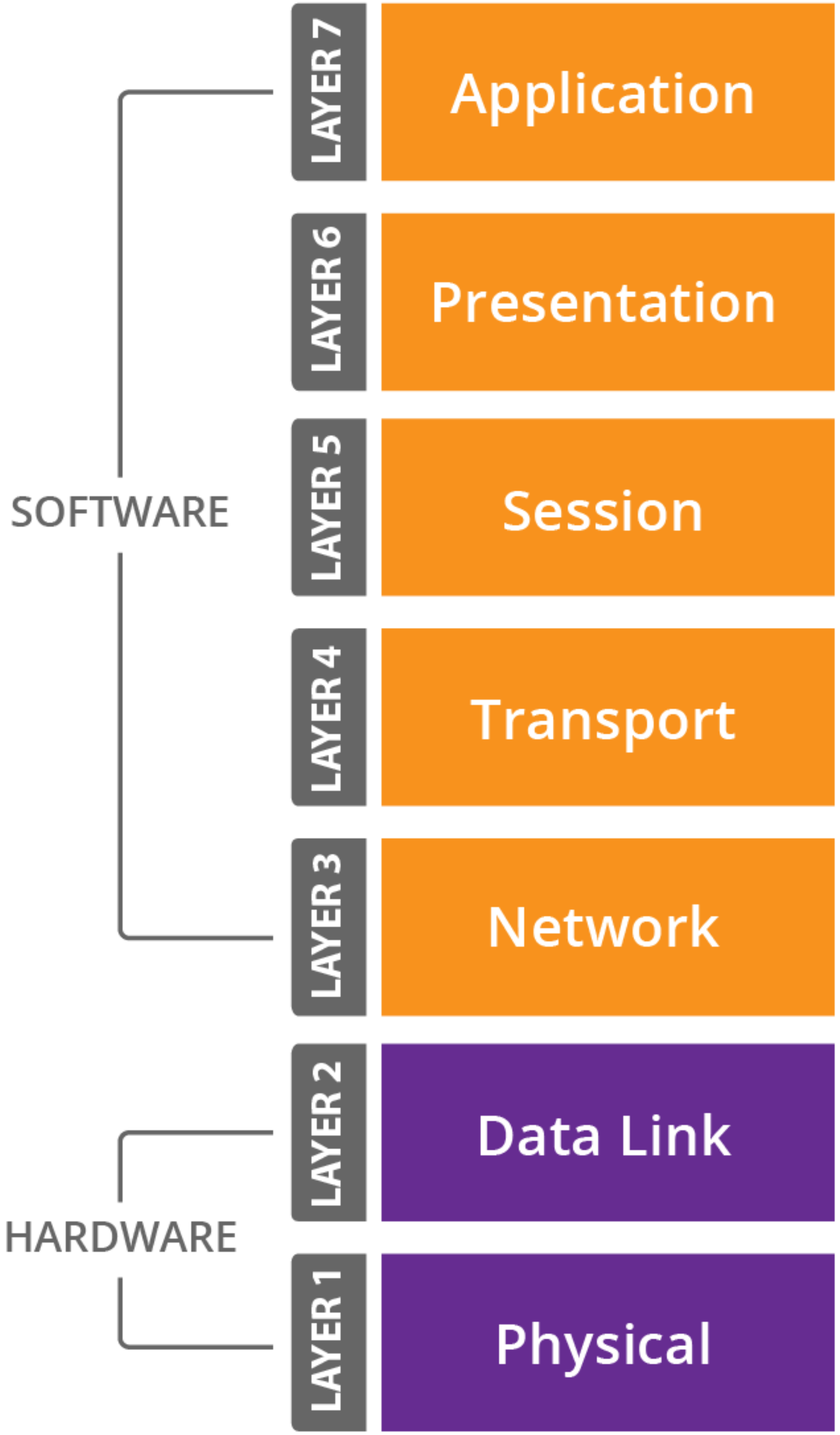
Layers of Abstraction


LAYER 7
Application
LAYER 6
Presentation
LAYER 5
Session
LAYER 4
Transport
LAYER 3
Network
LAYER 2
Data Link
LAYER 1
Physical
SOFTWARE
HARDWARE



OSI MODEL

- Open Systems Interconnection model
- Abstraction hierarchy for networks



OSI MODEL

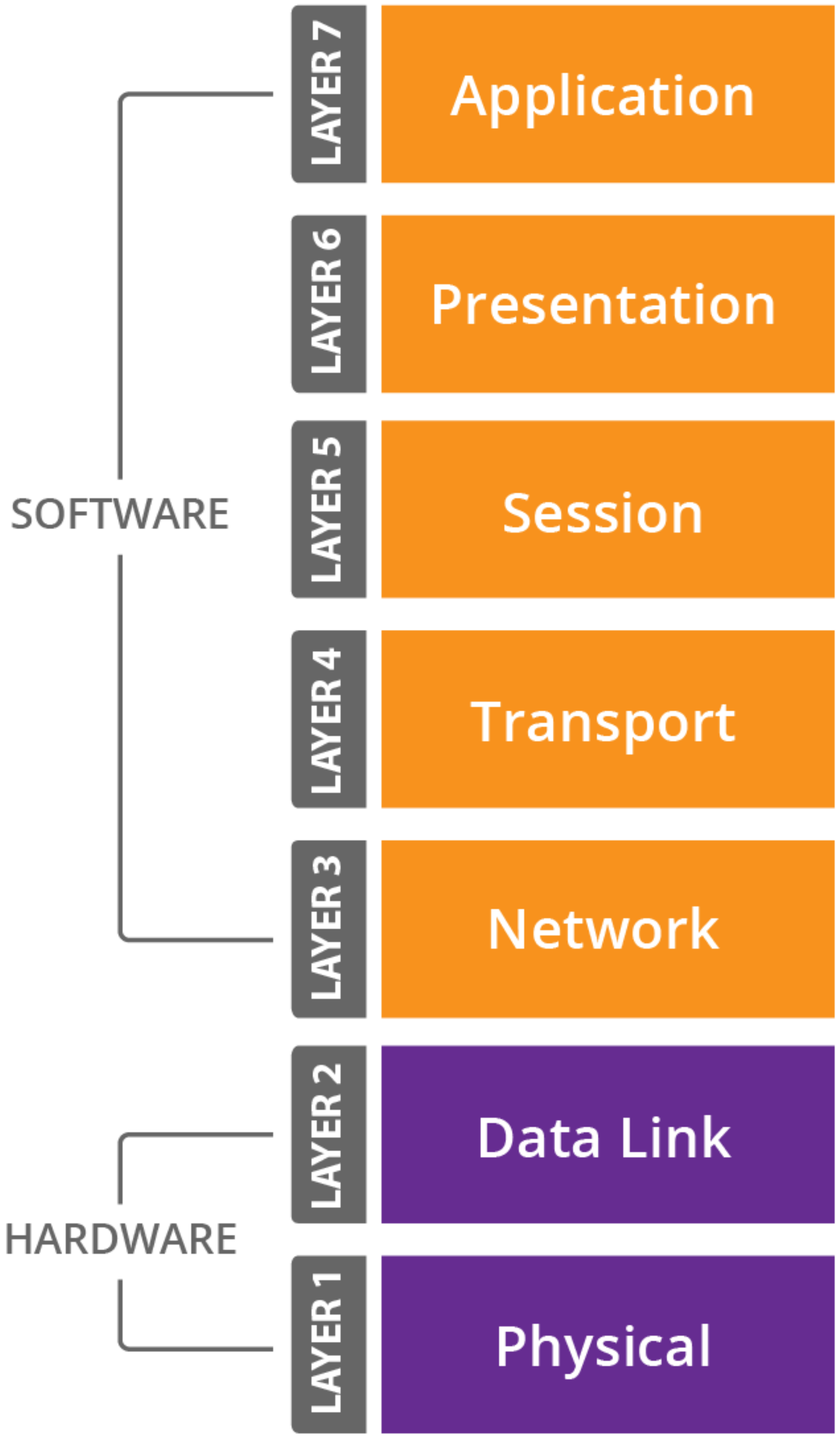
- Open Systems Interconnection model
- Abstraction hierarchy for networks

Protocol (Enhanced ShockBurst™)

Radio

ENHANCED SHOCKBURST™

- Packet-based
- Handles **retries**
- Handles **ACKs**

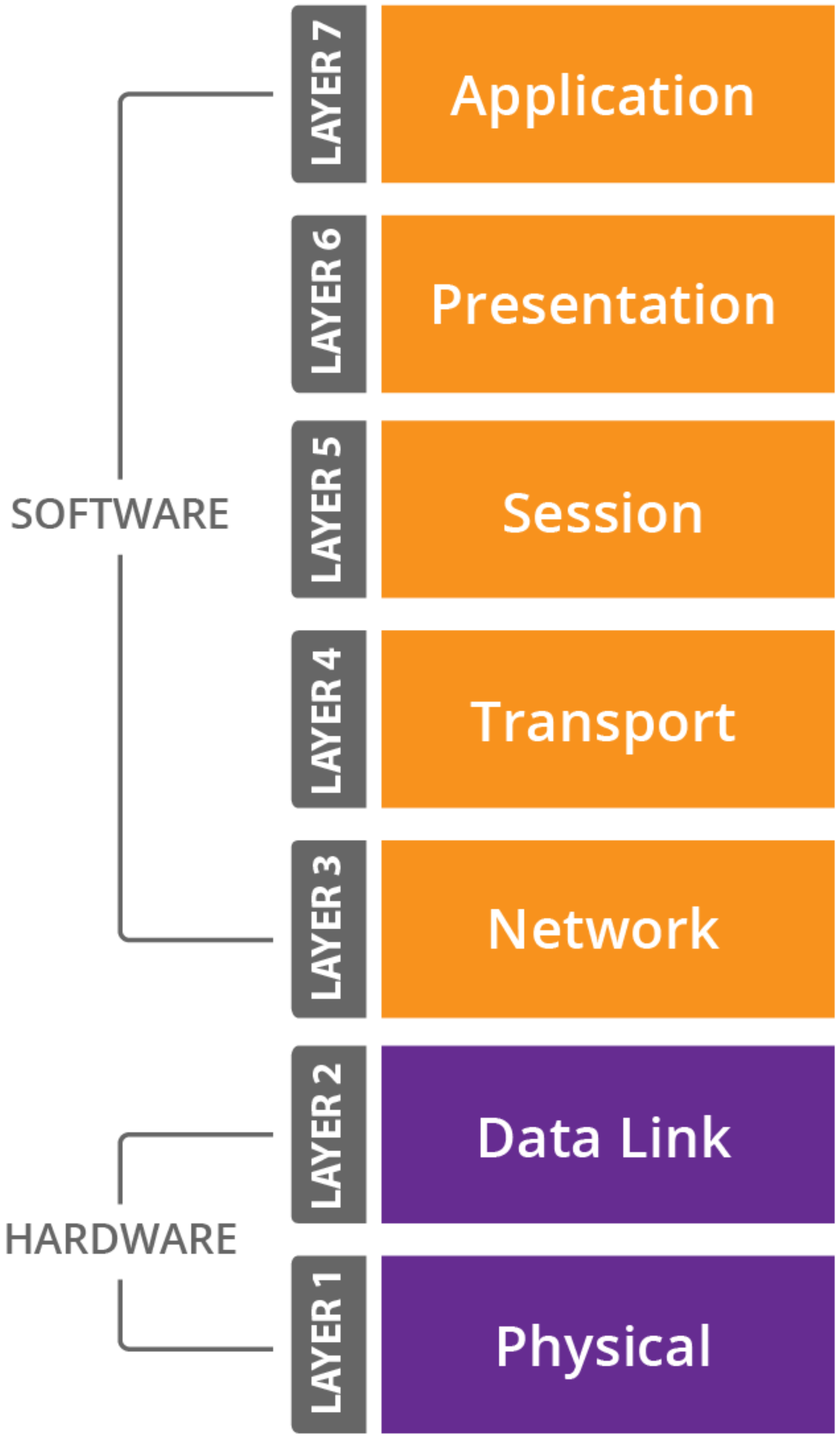


OSI MODEL

- Open Systems Interconnection model
- Abstraction hierarchy for networks

Protocol (Enhanced ShockBurst™)

Radio



OSI MODEL

- Open Systems Interconnection model
- Abstraction hierarchy for networks

TCP/IP

Protocol (Enhanced ShockBurst™)

Radio

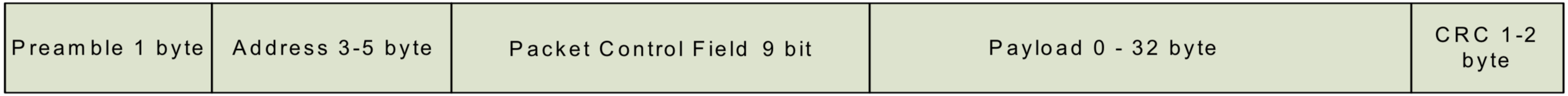


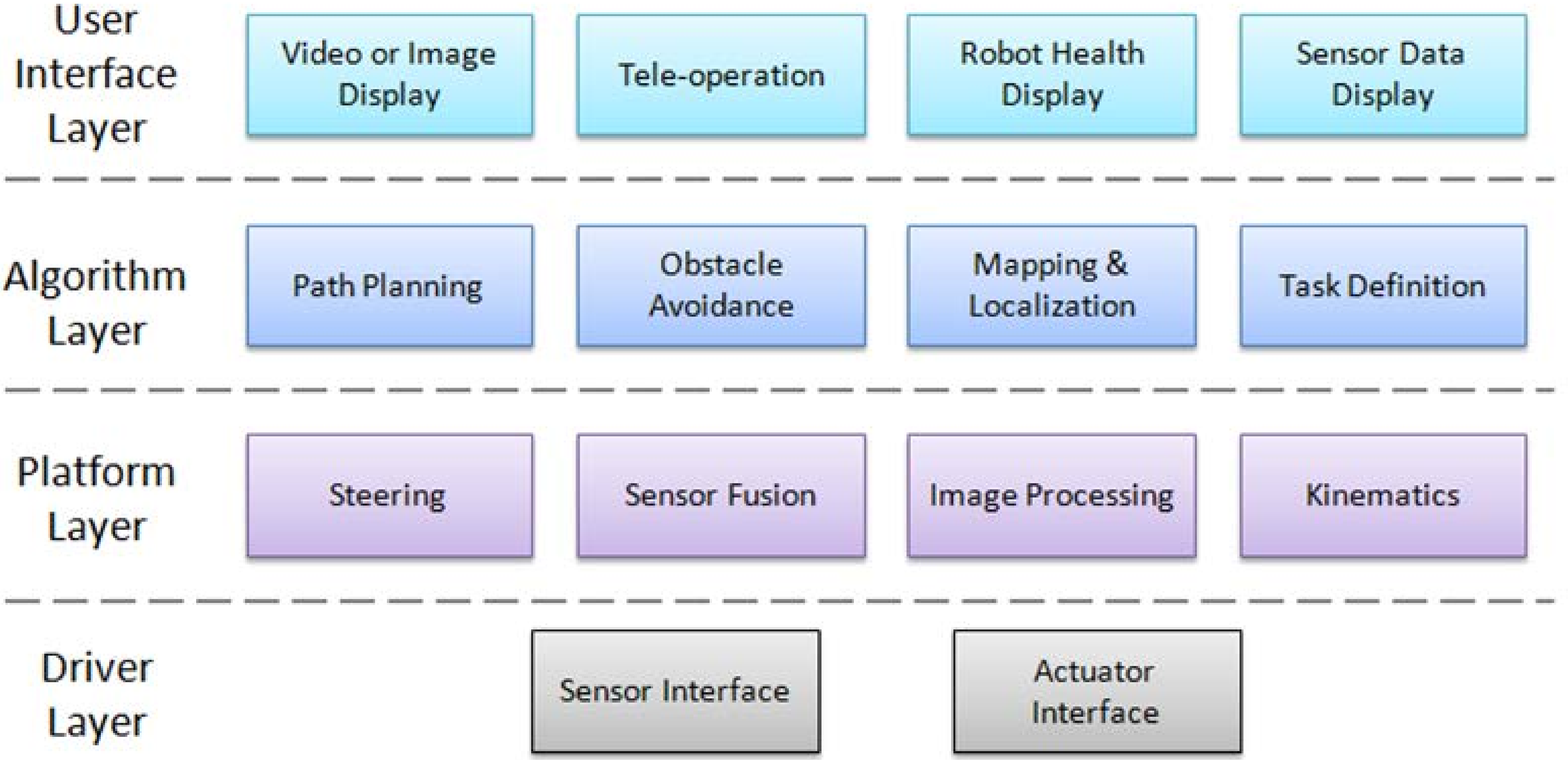
Figure 4. An Enhanced ShockBurst™ packet with payload (0-32 bytes)

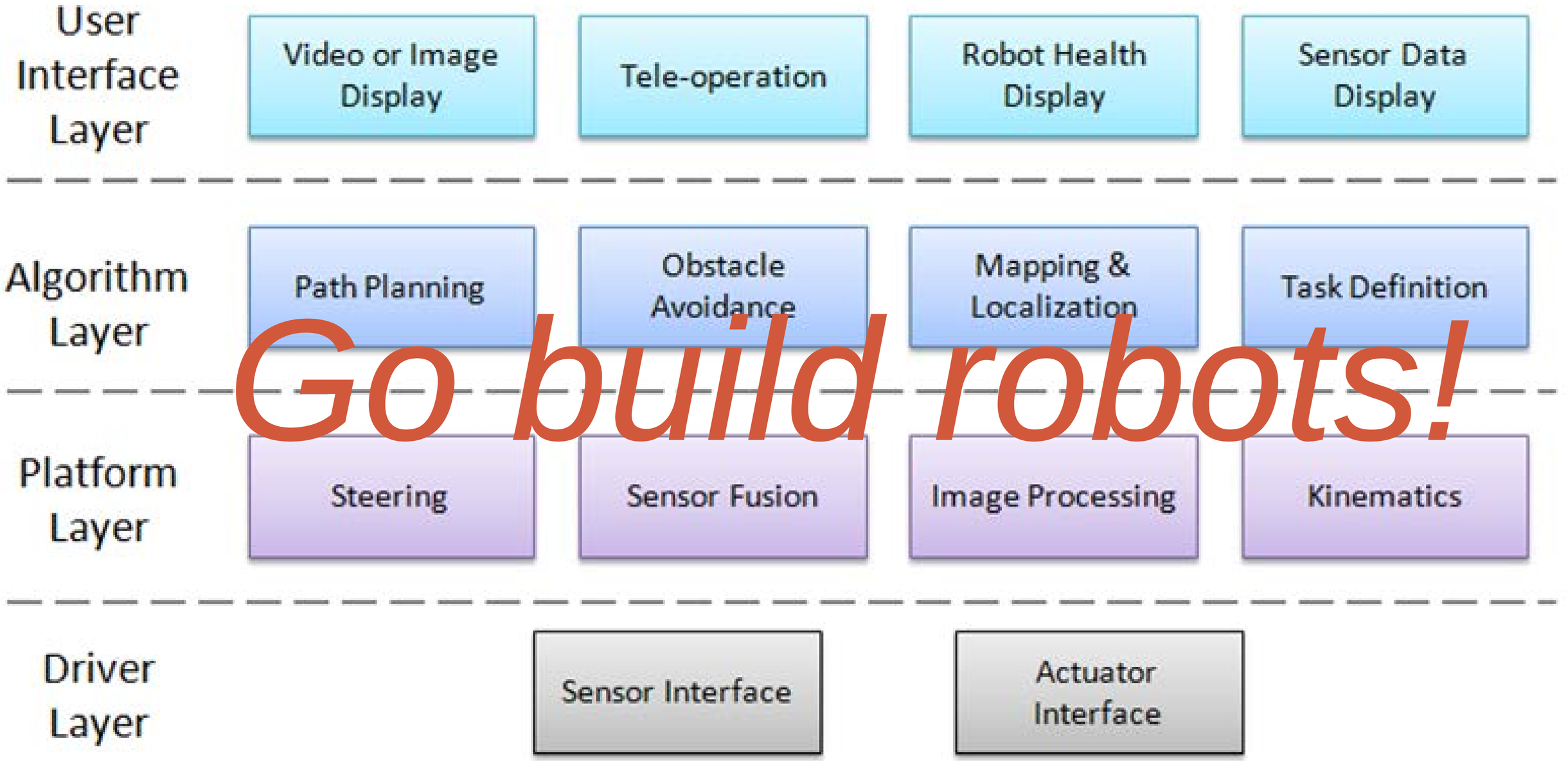
Figure 4. An Enhanced ShockBurst™ packet with payload (0-32 bytes)

Figure 5. Packet control field

ALL OF THIS IS DONE FOR YOU!

YOUR LIFE MADE EASY
(BY ABSTRACTION)


User Interface Layer
Video or Image Display
Tele-operation
Robot Health Display
Sensor Data Display
Algorithm Layer
Path Planning
Obstacle Avoidance
Mapping & Localization
Task Definition
Platform Layer
Steering
Sensor Fusion
Image Processing
Kinematics
Driver Layer
Sensor Interface
Actuator Interface



Go build robots!

- **Abstraction image:** http://theembeddedguy.com/wp-content/uploads/2016/05/Layers-of-Abstraction.jpg
- **Claude Shannon video:** https://www.youtube.com/watch?v=vPKkXibQXGA
- **Frequency Modulation video:** https://www.youtube.com/watch?v=gfz1FbIOMbs
- **Radio stations in Ithaca**: https://radio-locator.com/cgi-bin/locate?select=city&city=Ithaca&state=NY&band=Both&dx=0&sort=freq
- **Shannon-Hartley Figure:** https://electronics.stackexchange.com/questions/234735/maximum-bit-rate-of-a-noise-less-channel
- **Shannon Limit Figure**: **http://www.gazettabyte.com/home/2012/5/15/the-capacity-limits-facing-optical-networking.html**
- **OSI Model: https://maidsafeplatform.files.wordpress.com/2015/02/maid-osi.png**