Lab 1: RF Spectrum

Today

- Frequency, wavelength
- Antennas
- RF exposure

Frequency and Wavelength

Wavelength and Frequency

- wavelength = (speed of light)X(period)

- wavelength = (speed of light)/(frequency)

- If we measure speed in 10^6 m/s, and frequency in MHz, then

wavelength (in m) = 300 / frequency (in MHz)

Finding Wavelengths

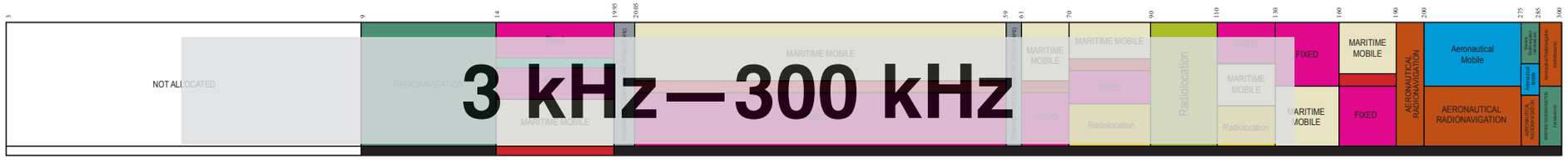
- What are the wavelengths for
  - Citizens band ~30 MHz
  - FM radio ~100 MHz
  - Cell phone ~900 MHz
  - WiFi ~ 2.4 GHz and 5.5 GHz

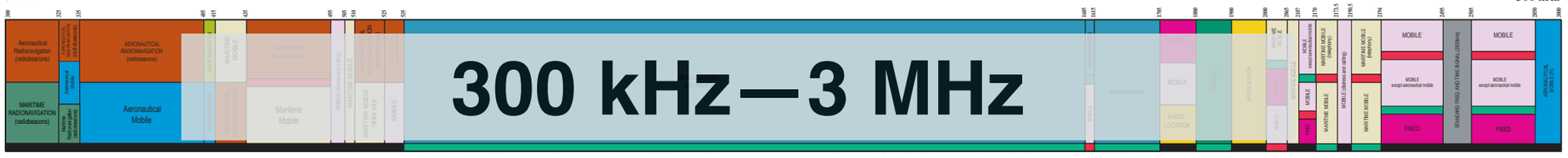
Finding Frequencies

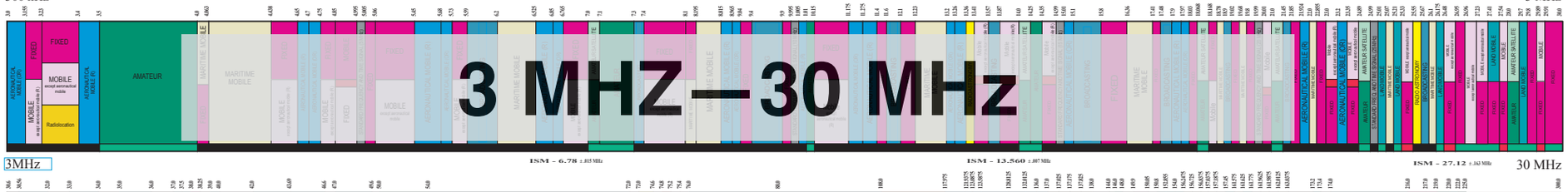
- What are the frequencies for
  - 33 cm ISM band
  - 2 m Amateur band
  - 60 m shortwave band
  - 200 m AM band

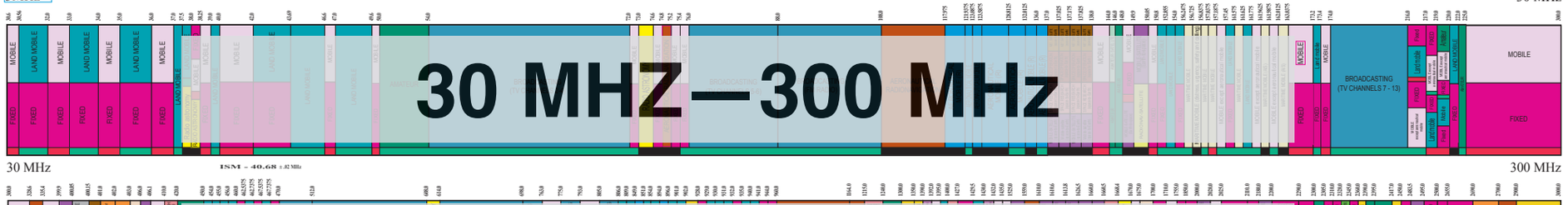
UNITED STATES FREQUENCY ALLOCATIONS

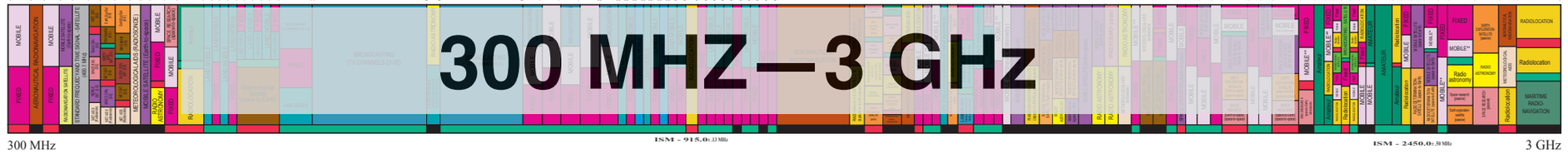
THE RADIO SPECTRUM

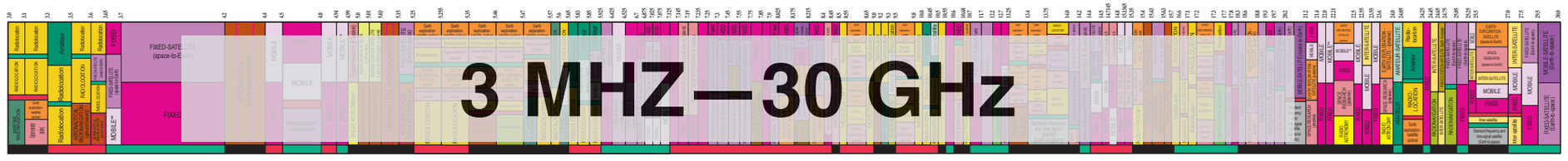


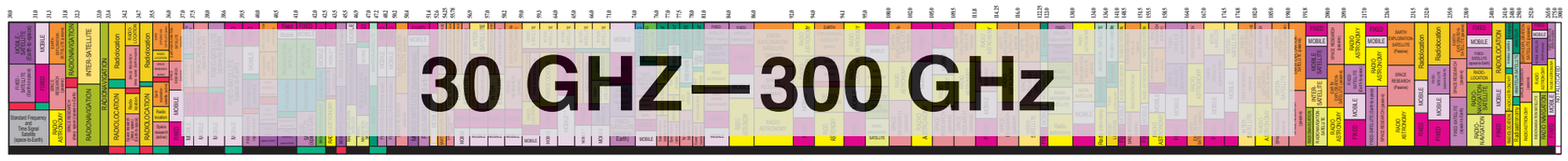












RADIO SERVICES COLOR LEGEND

- 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
- 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

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it does not completely reflect all aspects, i.e. footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

August 2011

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* EXCEPT AERONAUTICAL MOBILE (R)

** EXCEPT AERONAUTICAL MOBILE

PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

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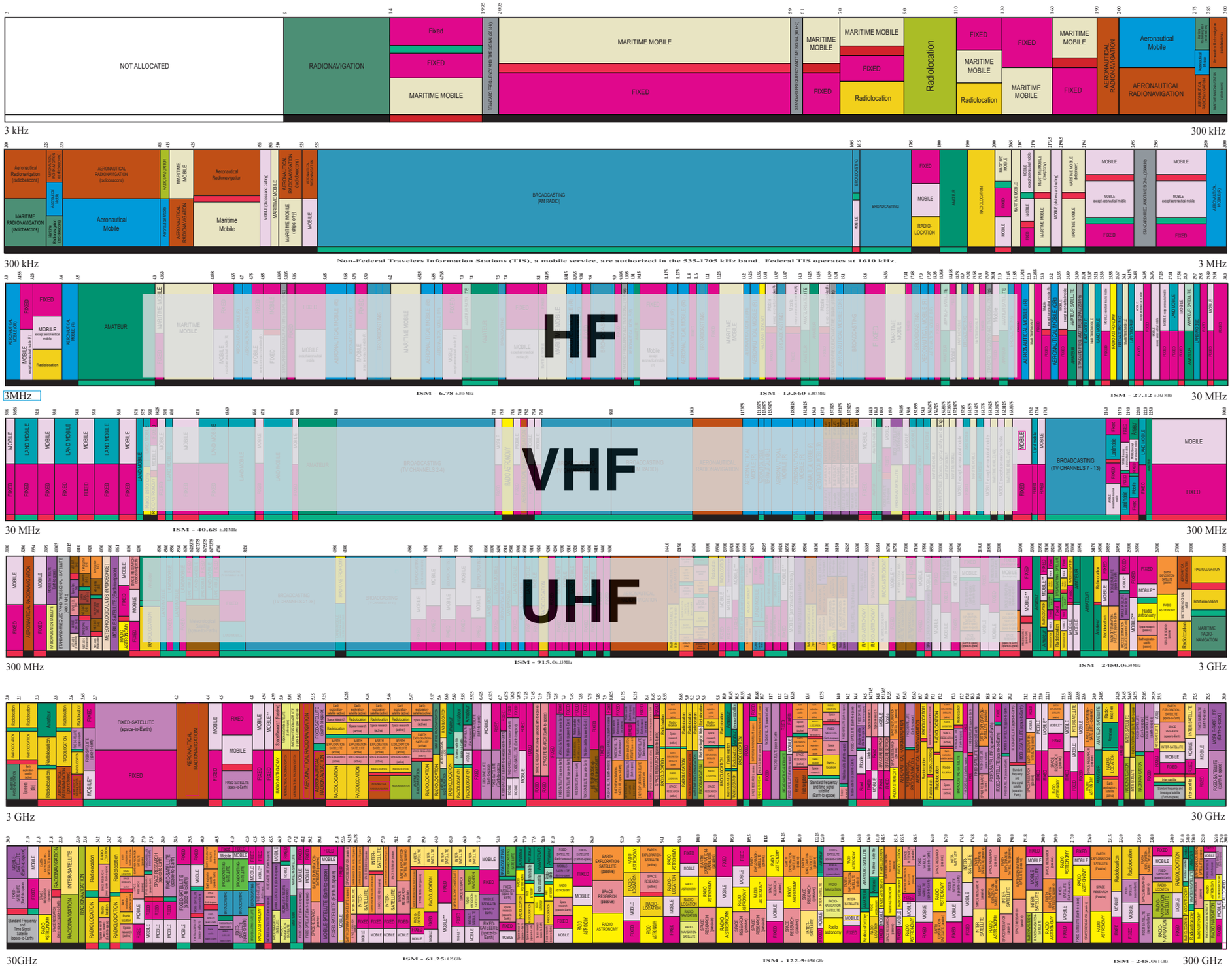

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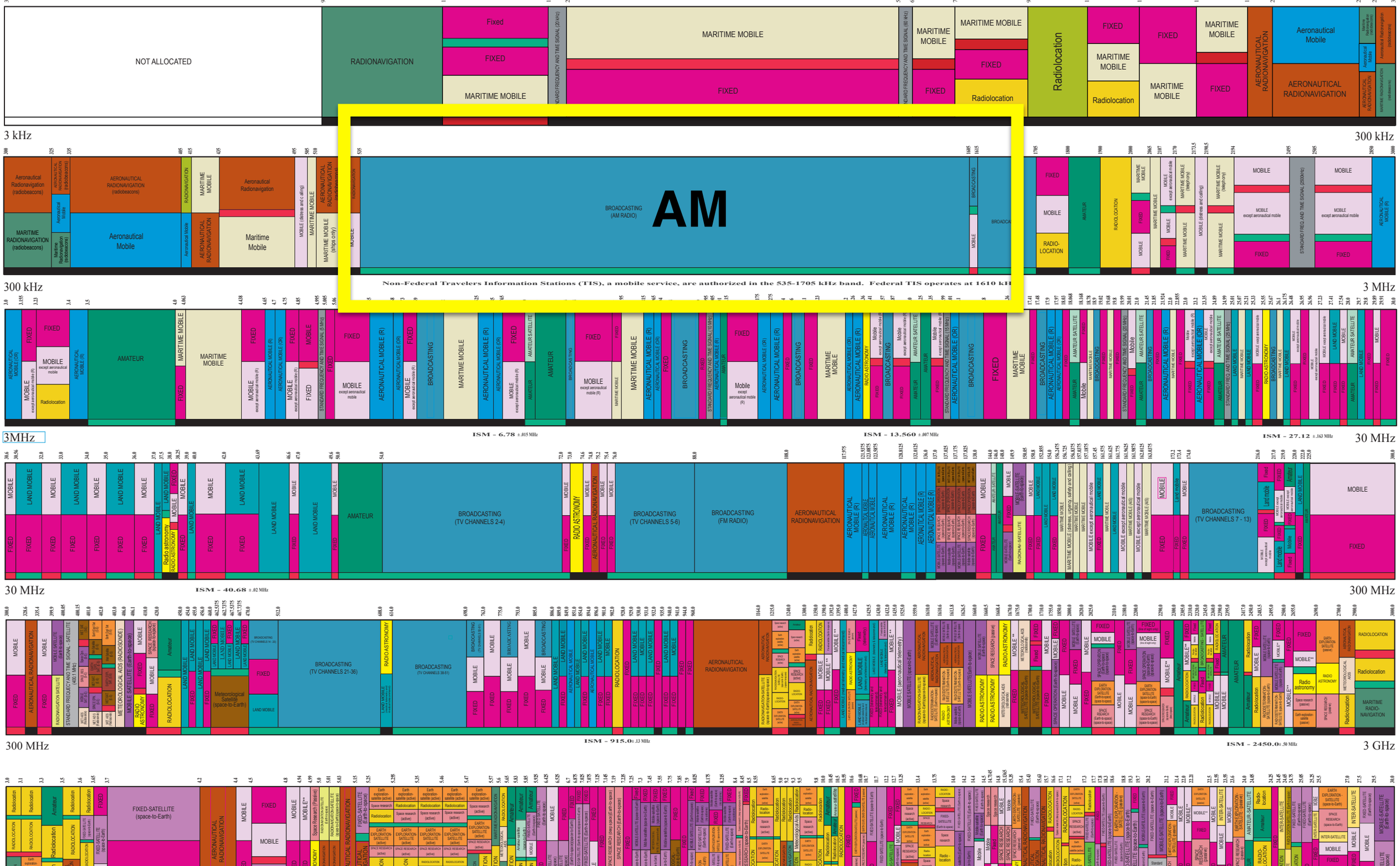
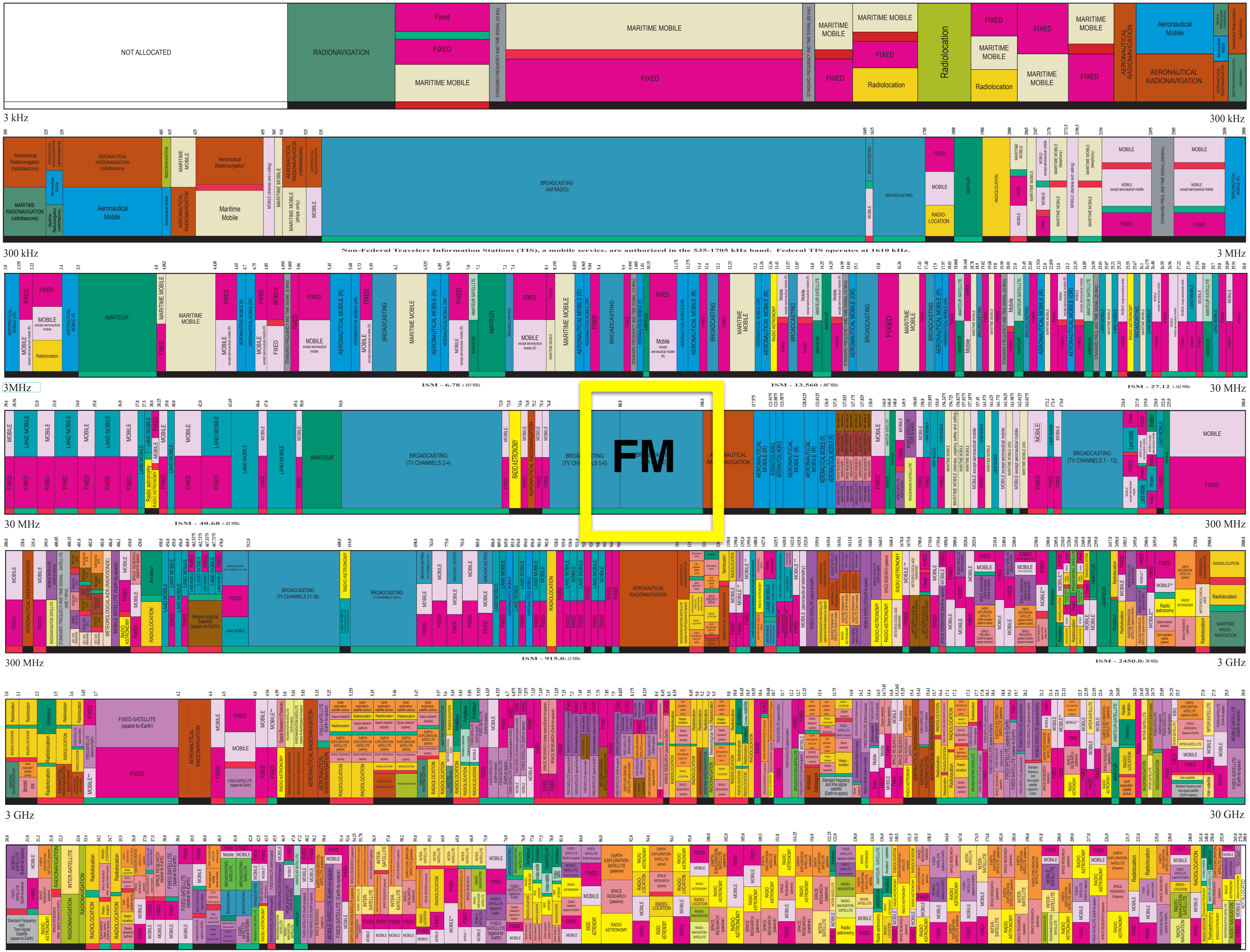
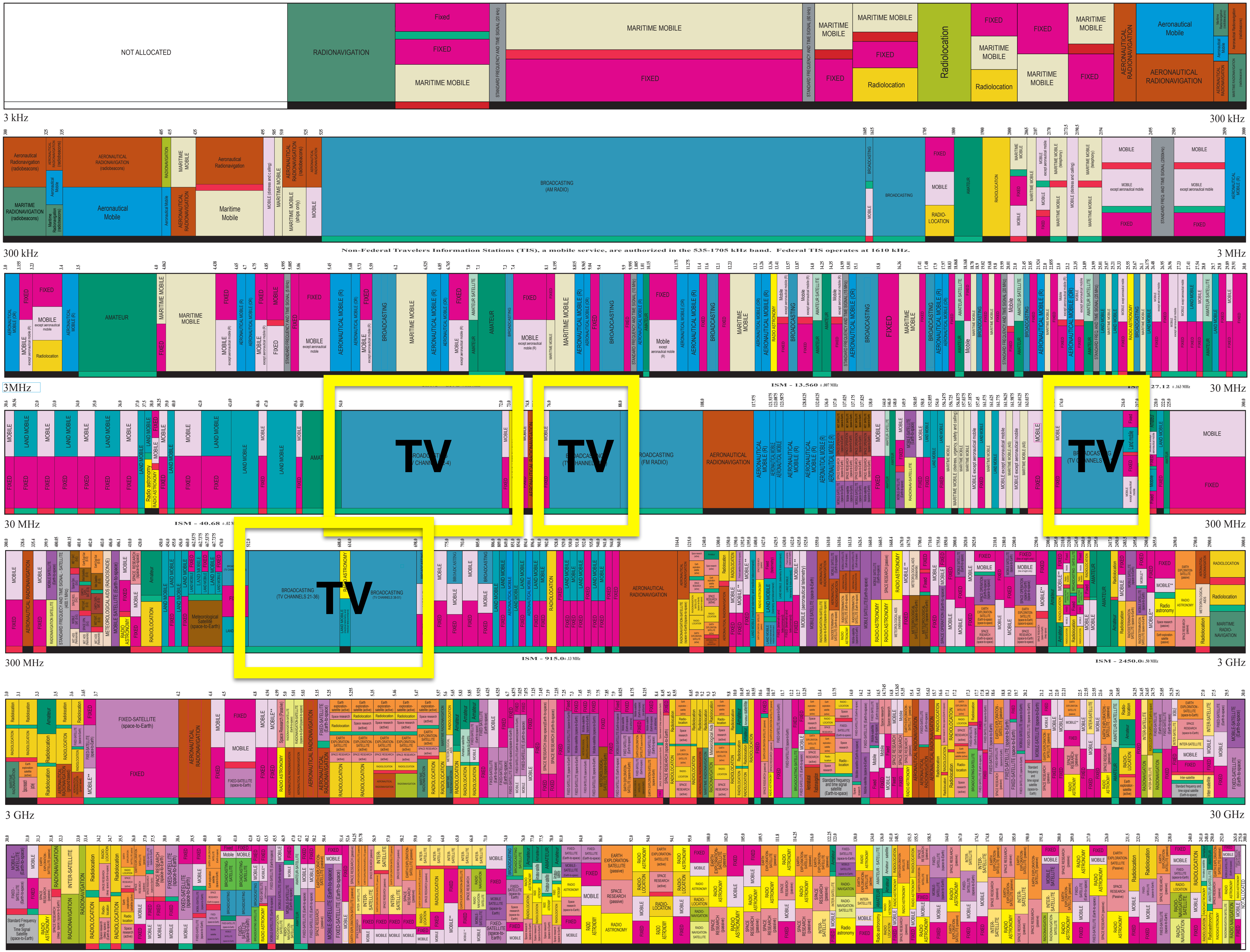
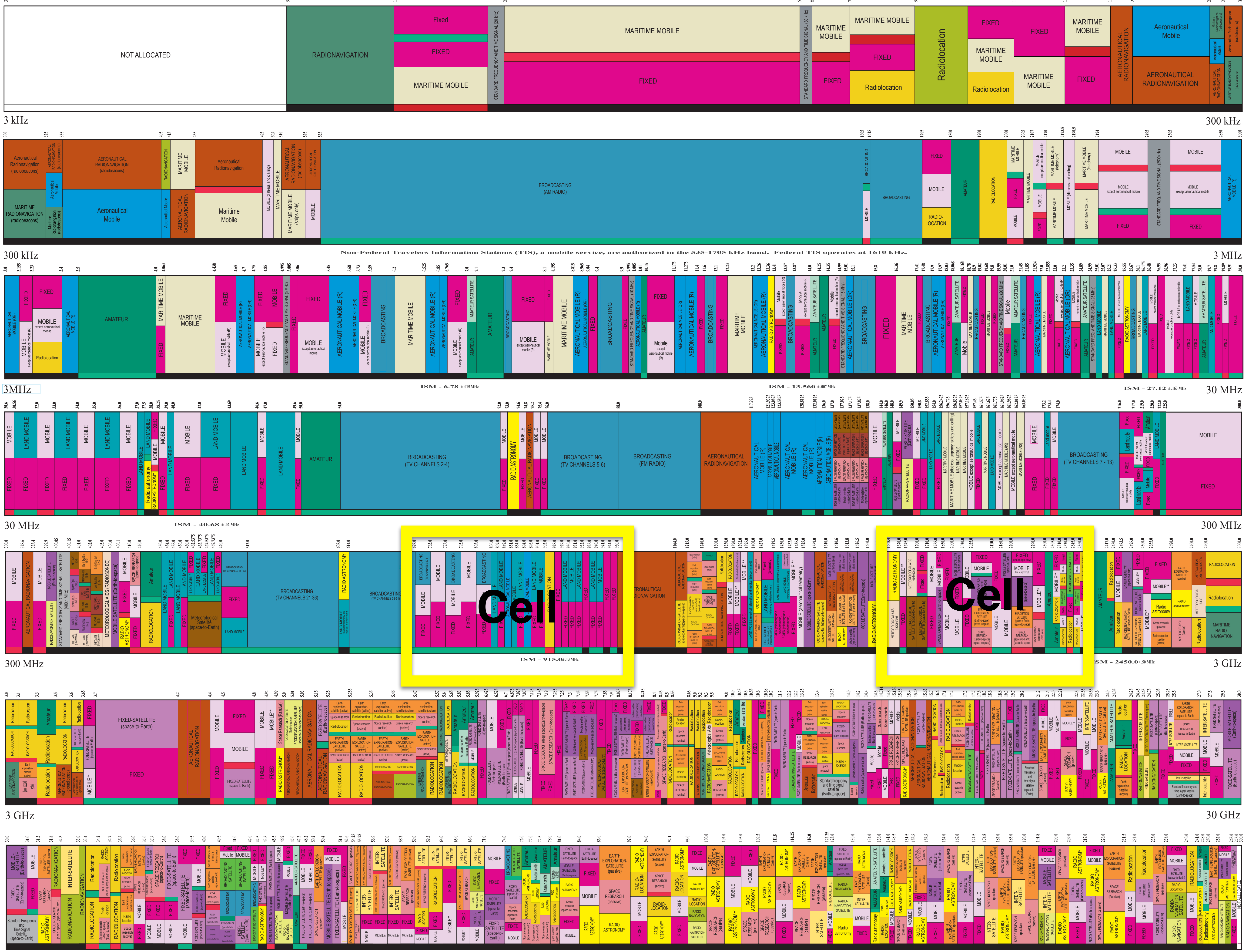

3 kHz
300 kHz
AM
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535–1705 kHz band. Federal TIS operates at 1610 kHz
300 kHz
3 MHz
3MHz
30 MHz
30 MHz
300 MHz
300 MHz
3 GHz
3 GHz
30 GHz

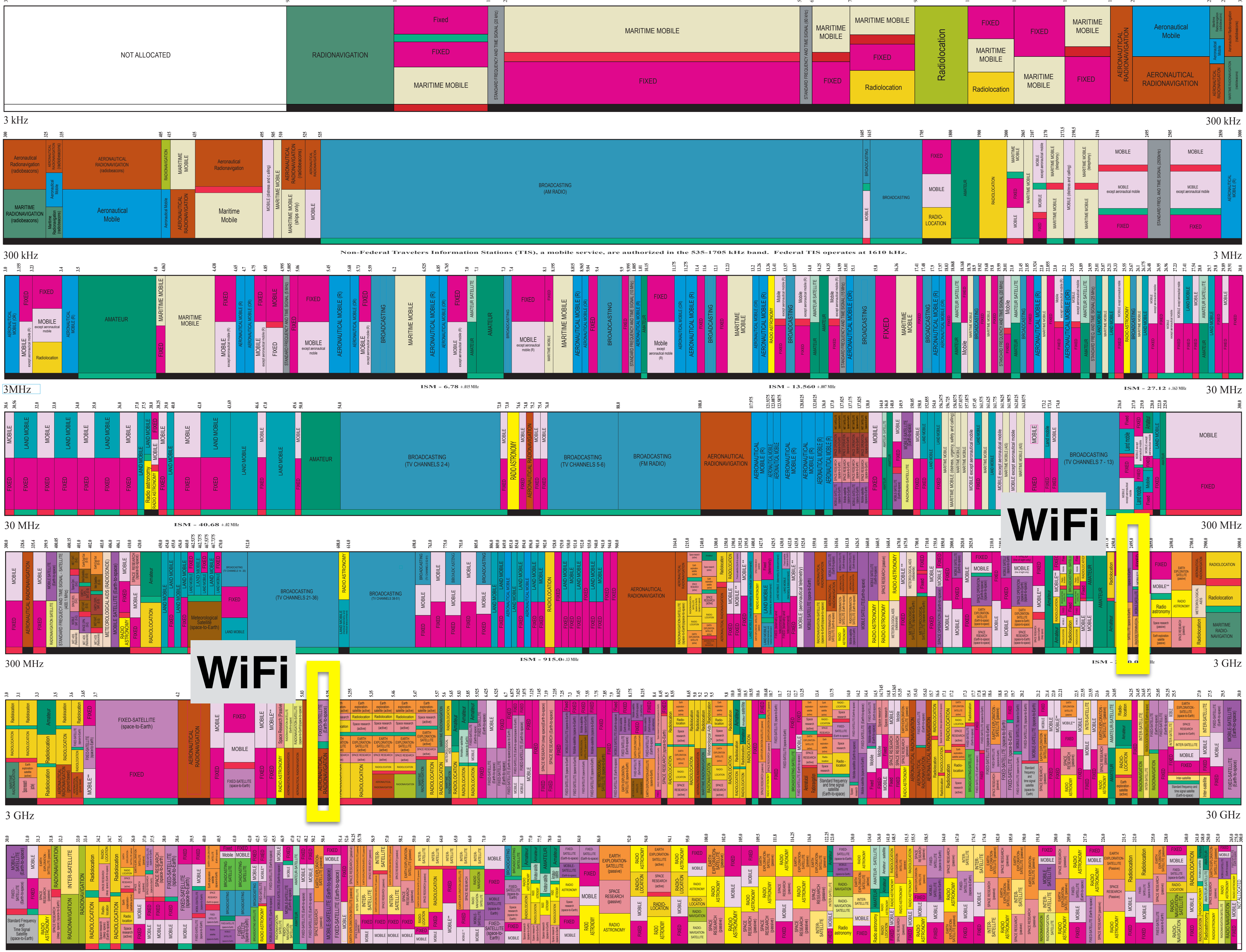


NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
Radiolocation
AERONAUTICAL RADIONAVIGATION
Aeronautical Mobile
3 kHz
300 kHz
BROADCASTING (AM RADIO)
300 kHz
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535-1705 kHz band. Federal TIS operates at 1610 kHz.
3 MHz
AMATEUR
3MHz
ISM – 6.78 ±.015 MHz
ISM – 13.560 ±.007 MHz
ISM – 27.12 ±.163 MHz
30 MHz
BROADCASTING (TV CHANNELS 2-4)
FM
AERONAUTICAL RADIONAVIGATION
BROADCASTING (TV CHANNELS 7 - 13)
30 MHz
ISM – 40.68 ±.02 MHz
300 MHz
BROADCASTING (TV CHANNELS 21-36)
AERONAUTICAL RADIONAVIGATION
300 MHz
ISM – 915.0 ±.13 MHz
ISM – 2450.0 ±.50 MHz
3 GHz
FIXED-SATELLITE (space-to-Earth)
3 GHz
30 GHz


NOT ALLOCATED
RADIONAVIGATION
FIXED
MARITIME MOBILE
Radiolocation
AERONAUTICAL RADIONAVIGATION
Aeronautical Mobile
3 kHz
300 kHz
BROADCASTING (AM RADIO)
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535-1705 kHz band. Federal TIS operates at 1610 kHz.
3 MHz
AMATEUR
BROADCASTING
ISM – 13.560 ± .007 MHz
ISM – 27.12 ± .163 MHz
30 MHz
TV
BROADCASTING (FM RADIO)
ISM – 40.68 ± .02 MHz
300 MHz
BROADCASTING (TV CHANNELS 21-36)
BROADCASTING (TV CHANNELS 38-51)
ISM – 915.0 ± .13 MHz
ISM – 2450.0 ± .50 MHz
3 GHz
FIXED-SATELLITE (space-to-Earth)
30 GHz

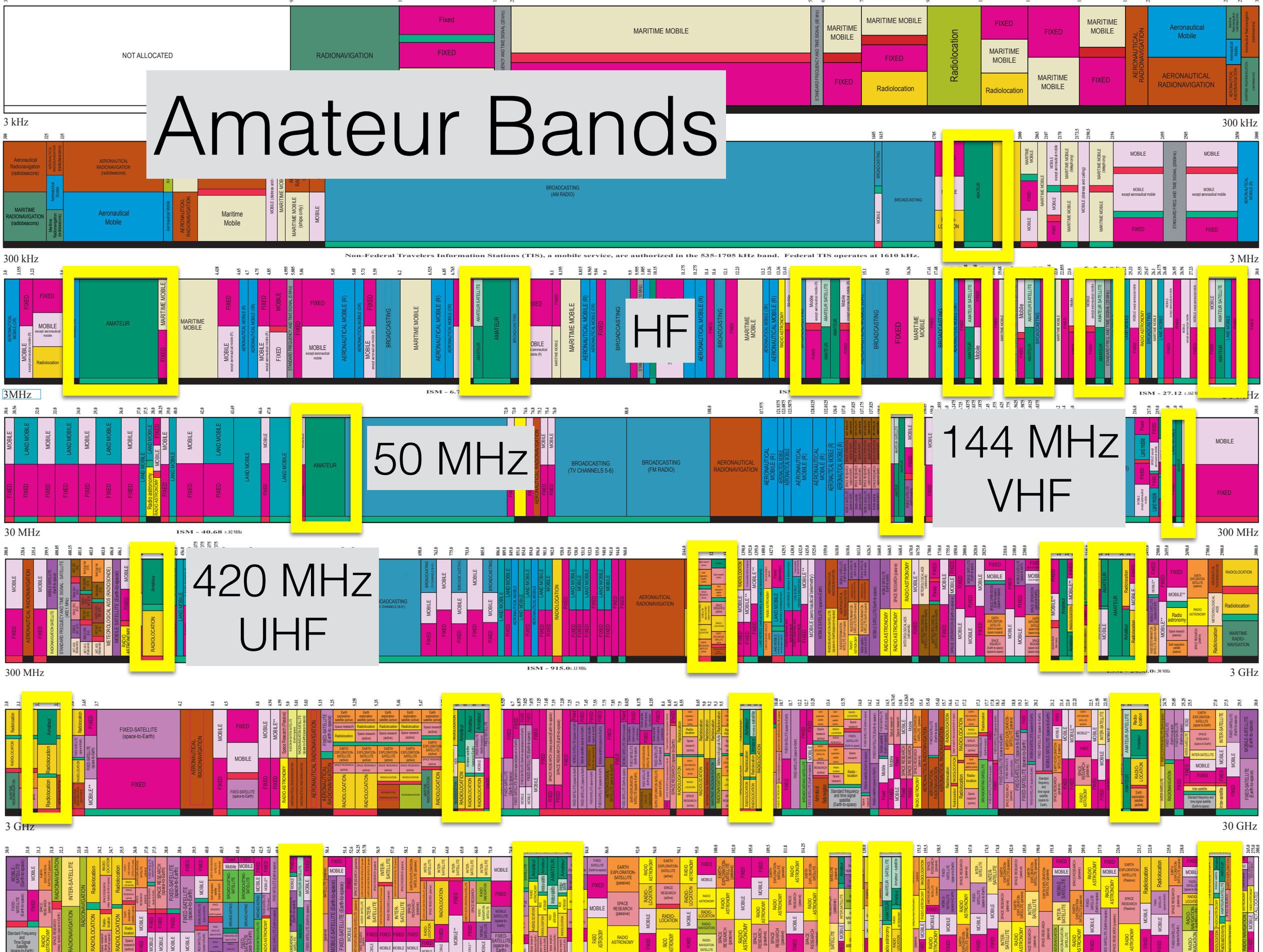


NOT ALLOCATED
RADIONAVIGATION
FIXED
MARITIME MOBILE
Radiolocation
AERONAUTICAL RADIONAVIGATION
Aeronautical Mobile
3 kHz
300 kHz
BROADCASTING (AM RADIO)
Aeronautical Radionavigation (radiobeacons)
MARITIME RADIONAVIGATION (radiobeacons)
Aeronautical Mobile
Maritime Mobile
300 kHz
3 MHz
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535-1705 kHz band. Federal TIS operates at 1610 kHz.
AMATEUR
BROADCASTING
3MHz
30 MHz
ISM - 6.78 ±.015 MHz
ISM - 13.560 ±.007 MHz
ISM - 27.12 ±.163 MHz
BROADCASTING (TV CHANNELS 2-4)
BROADCASTING (TV CHANNELS 5-6)
BROADCASTING (FM RADIO)
BROADCASTING (TV CHANNELS 7 - 13)
AERONAUTICAL RADIONAVIGATION
30 MHz
300 MHz
ISM - 40.68 ±.02 MHz
BROADCASTING (TV CHANNELS 21-36)
Meteorological Satellite (space-to-Earth)
Cell
Cell
ISM - 915.0 ±.13 MHz
SM - 2450.0 ±.50 MHz
300 MHz
3 GHz
FIXED-SATELLITE (space-to-Earth)
3 GHz
30 GHz



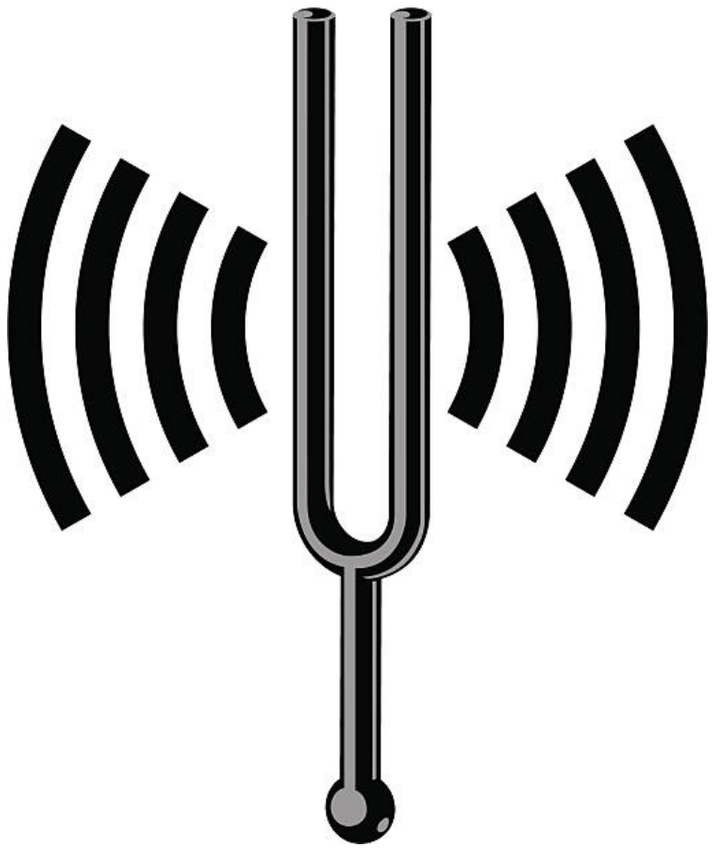
NOT ALLOCATED
RADIONAVIGATION
Fixed
FIXED
MARITIME MOBILE
FIXED
MARITIME MOBILE
Radiolocation
AERONAUTICAL RADIONAVIGATION
Aeronautical Mobile
3 kHz
300 kHz
Aeronautical Mobile
Maritime Mobile
BROADCASTING (AM RADIO)
300 kHz
Non-Federal Travelers Information Stations (TIS), a mobile service, are authorized in the 535-1705 kHz band. Federal TIS operates at 1610 kHz.
3 MHz
AMATEUR
MARITIME MOBILE
3MHz
ISM - 6.78 ±.015 MHz
ISM - 13.560 ±.007 MHz
ISM - 27.12 ±.163 MHz
30 MHz
AMATEUR
BROADCASTING (TV CHANNELS 2-4)
BROADCASTING (TV CHANNELS 5-6)
BROADCASTING (FM RADIO)
AERONAUTICAL RADIONAVIGATION
BROADCASTING (TV CHANNELS 7 - 13)
MOBILE
FIXED
WiFi
30 MHz
ISM - 40.68 ±.02 MHz
300 MHz
BROADCASTING (TV CHANNELS 21-36)
BROADCASTING (TV CHANNELS 38-51)
AERONAUTICAL RADIONAVIGATION
RADIOLOCATION
MARITIME RADIONAVIGATION
WiFi
300 MHz
ISM - 915.0±.13 MHz
3 GHz
FIXED-SATELLITE (space-to-Earth)
FIXED
MOBILE
3 GHz
30 GHz

Amateur Bands

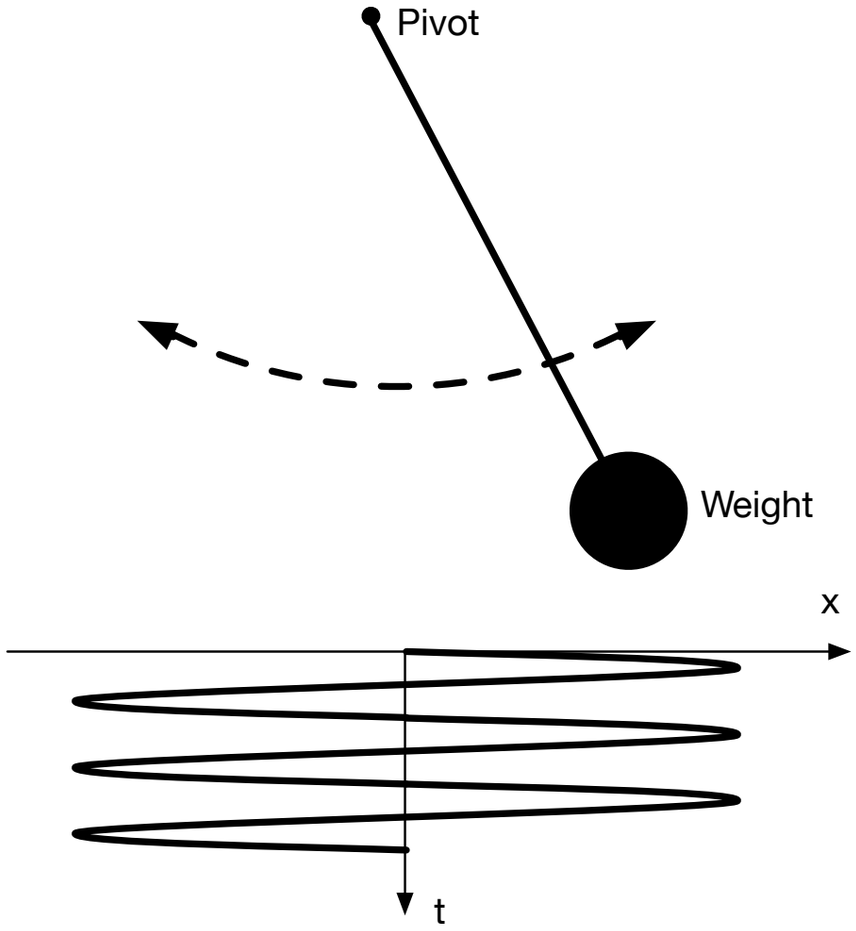


Antennas

Resonance

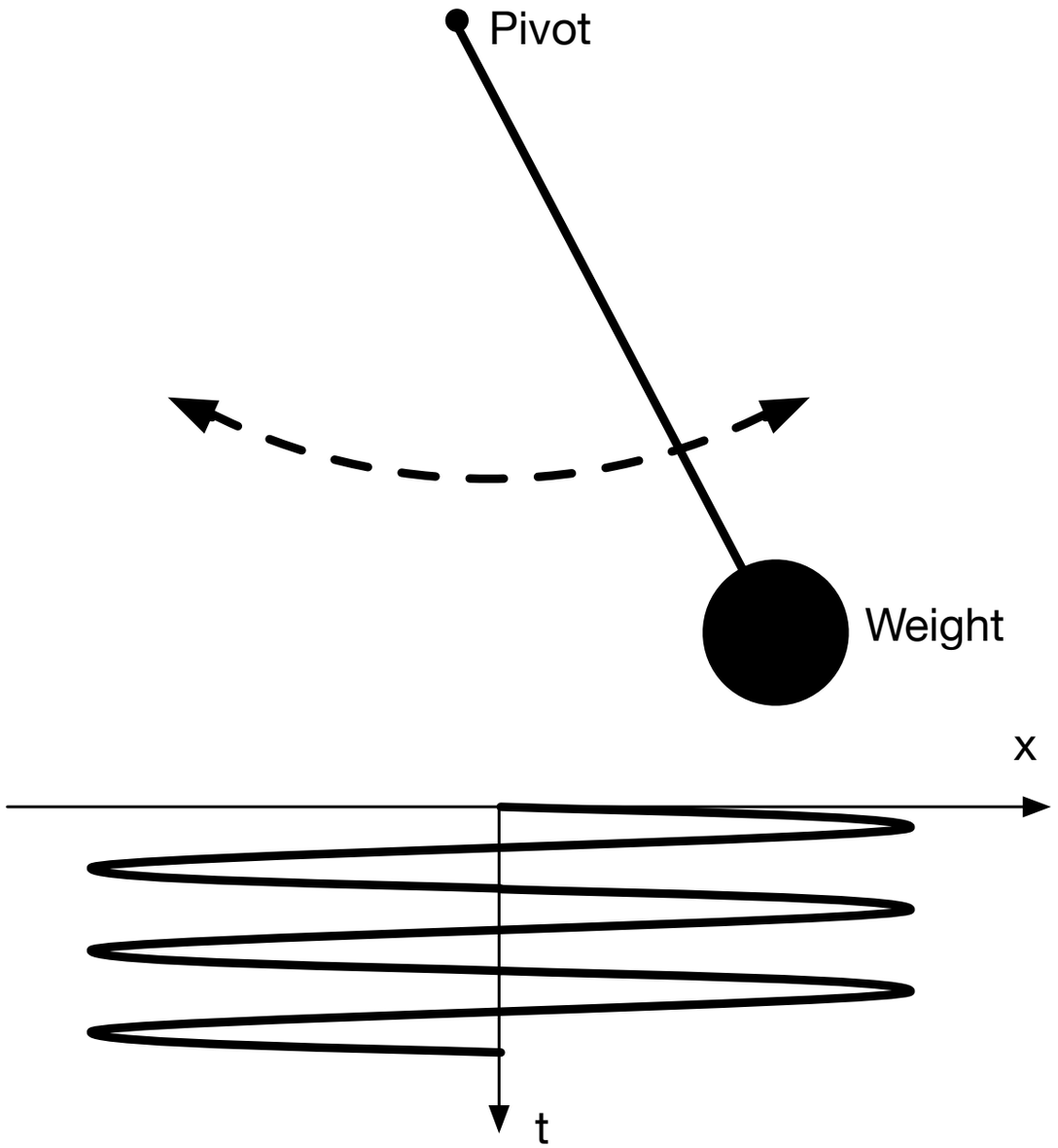


Tuning Fork



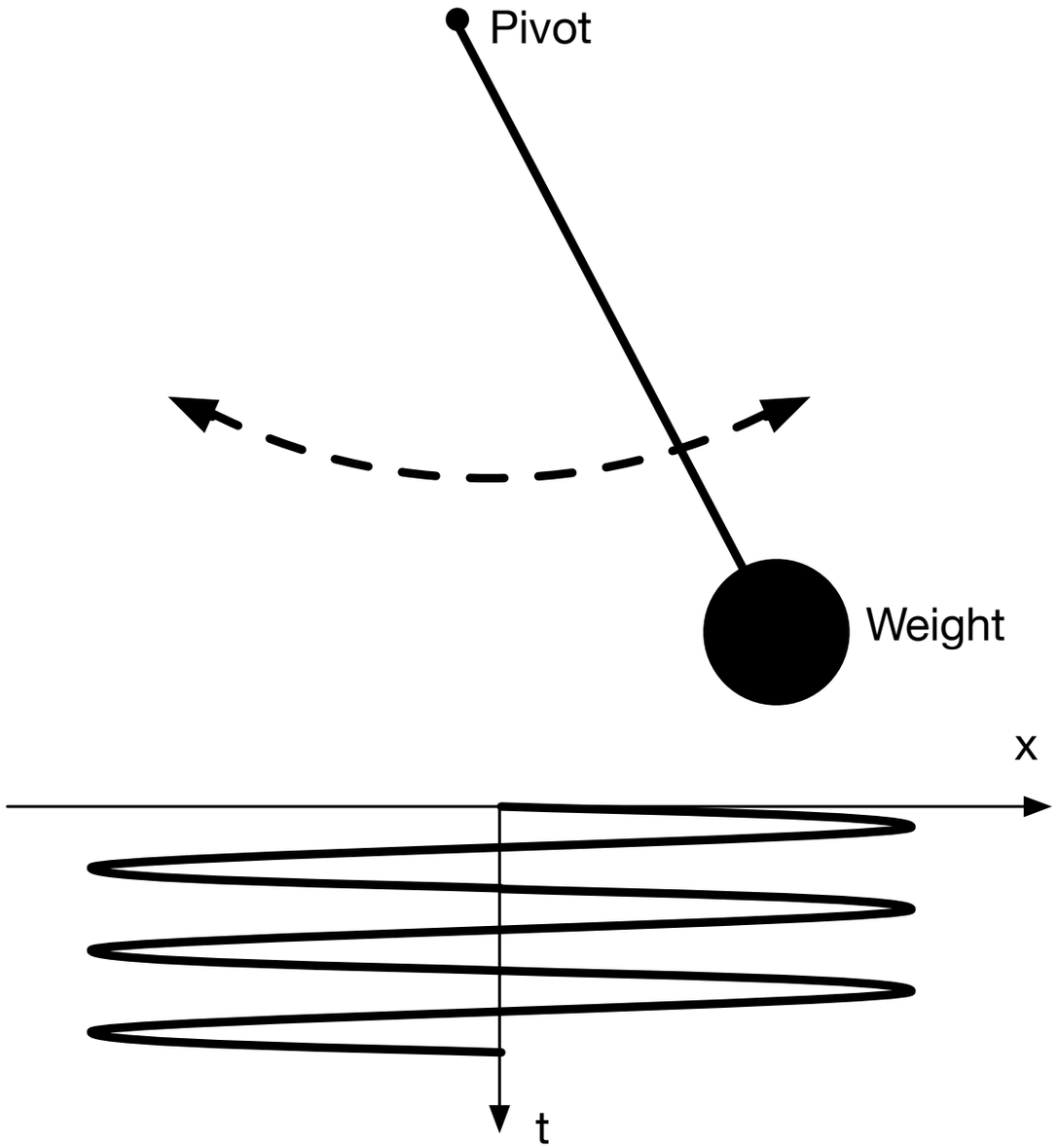
Pendulum

Pendulum



- Think of it as a swing
- How often should you push?
- When should you push?
- How hard/long should you push?

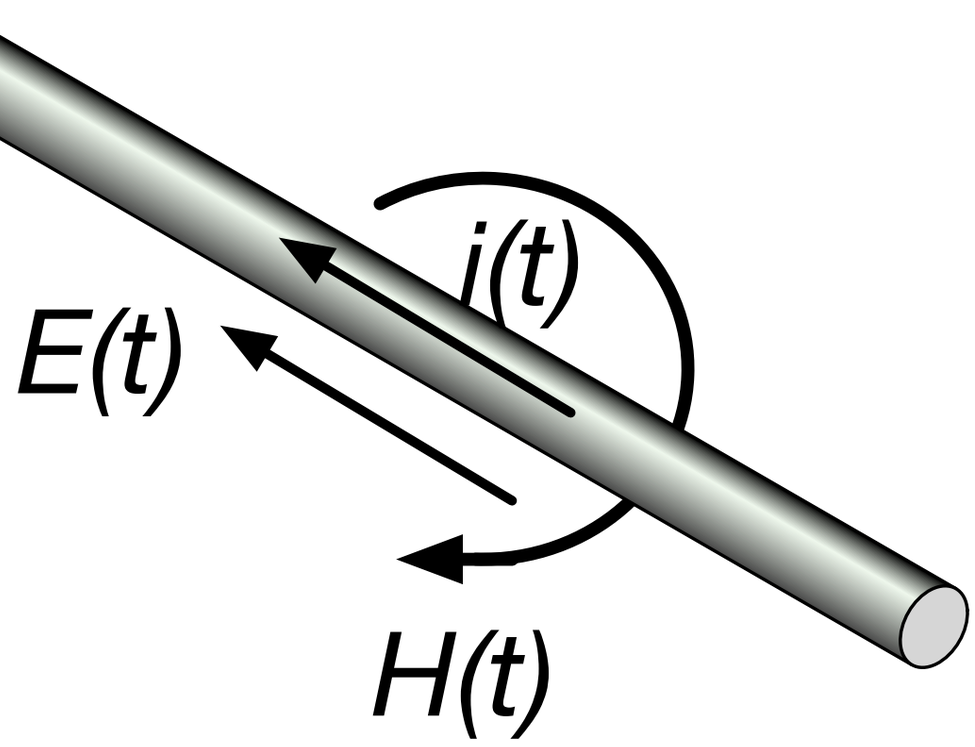
Pendulum, Input



- Push once per cycle works well
- How about twice per cycle?
- Once every two cycles?
- Only certain frequencies couple energy into the system

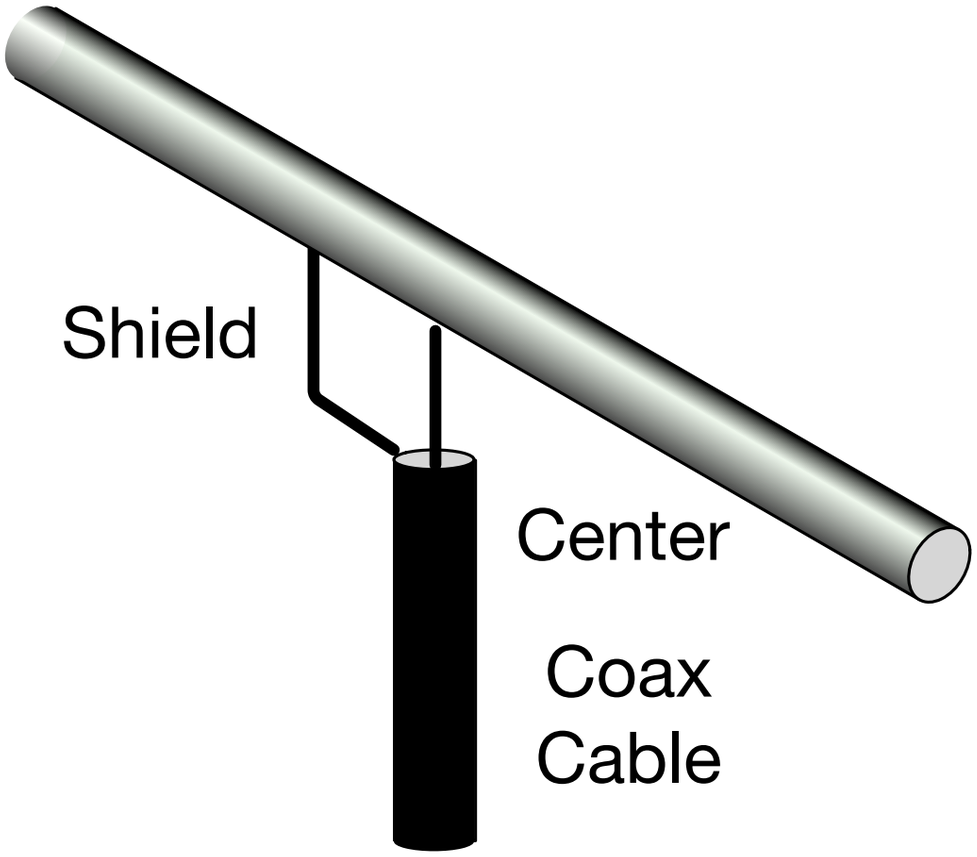
Resonant Antennas

- Current flows along conductor
- Electric and magnetic fields propagate at the speed of light
- We'd like the antenna round trip to match the transmit frequency



Dipole Antenna

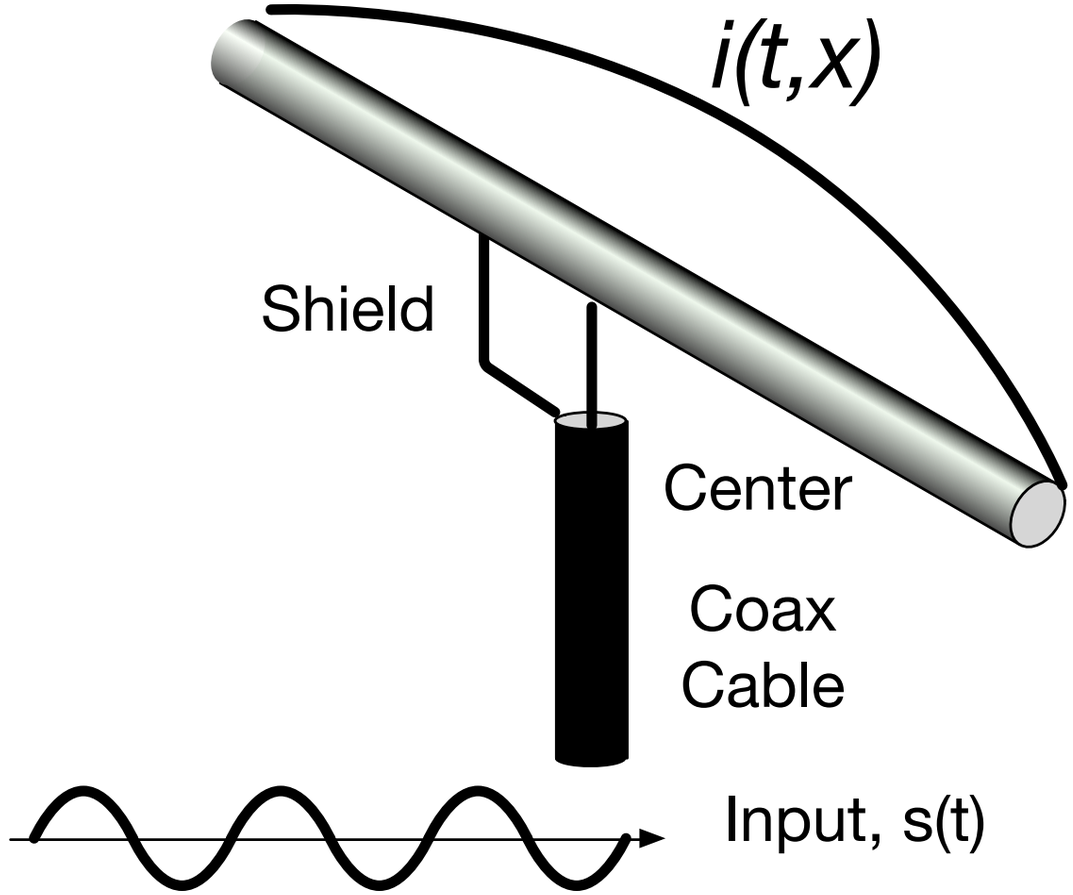
- Drive the antenna at center, offset
- Sets the input impedance



Dipole Antenna

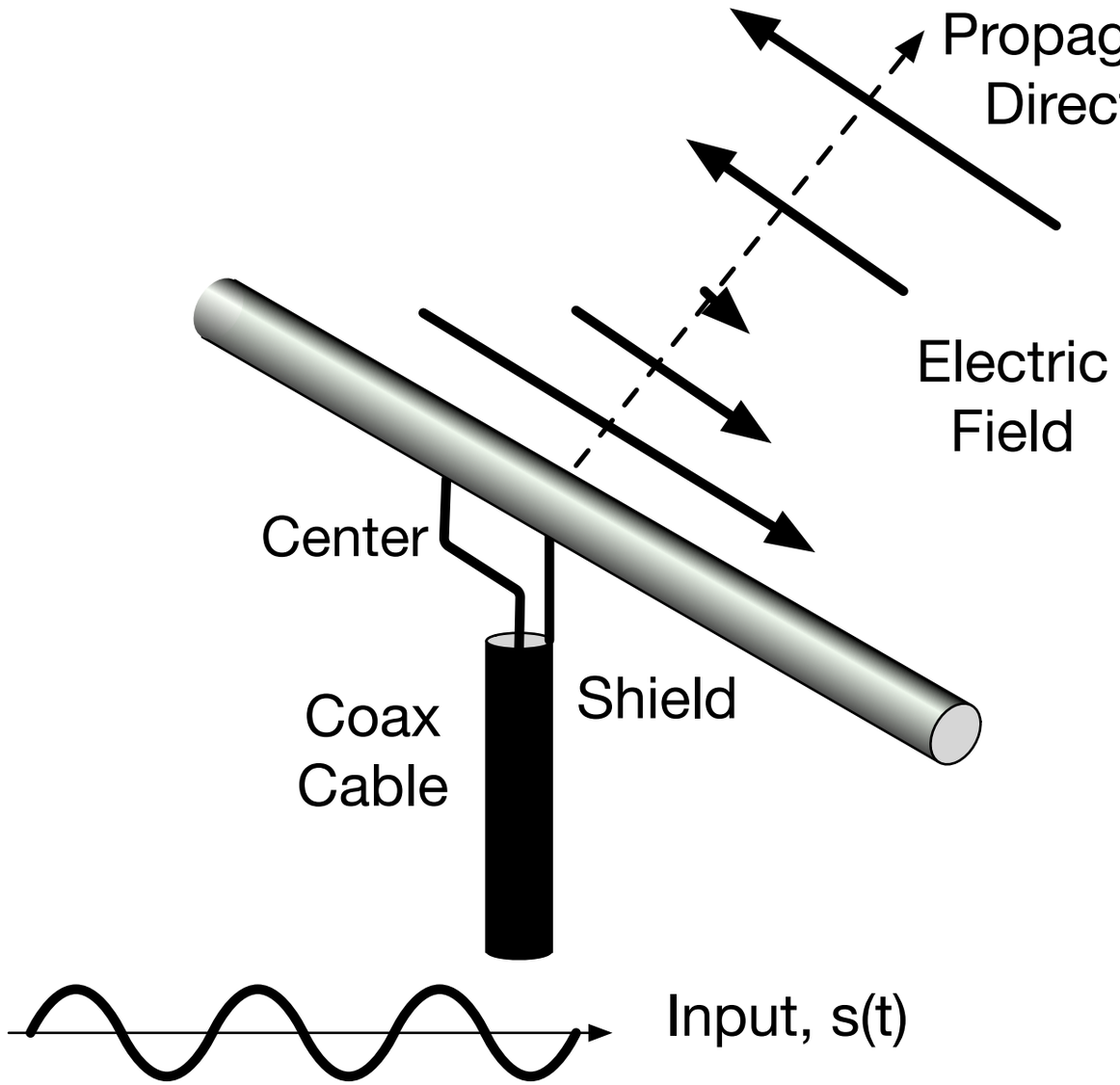
- Sinusoidal input sets up half cycle of current along antenna

- Length should be 1/2 wavelength for the frequency



Dipole Antenna

- Oscillating electric field propagates away from antenna



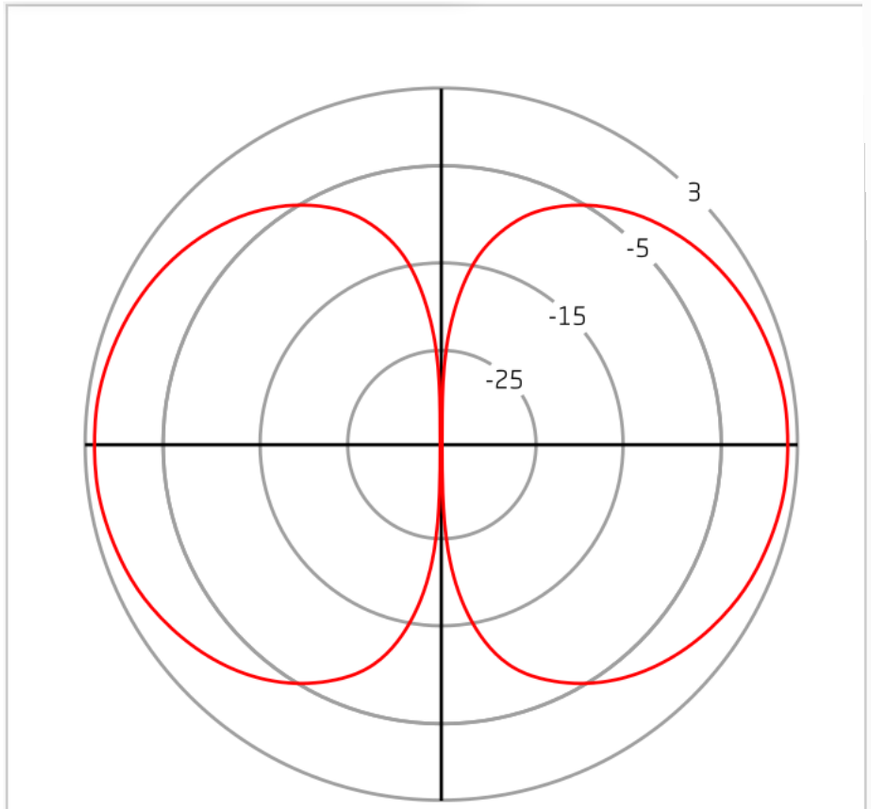
Dipole Antenna

- Length is 1/2 wavelength of the transmit carrier frequency

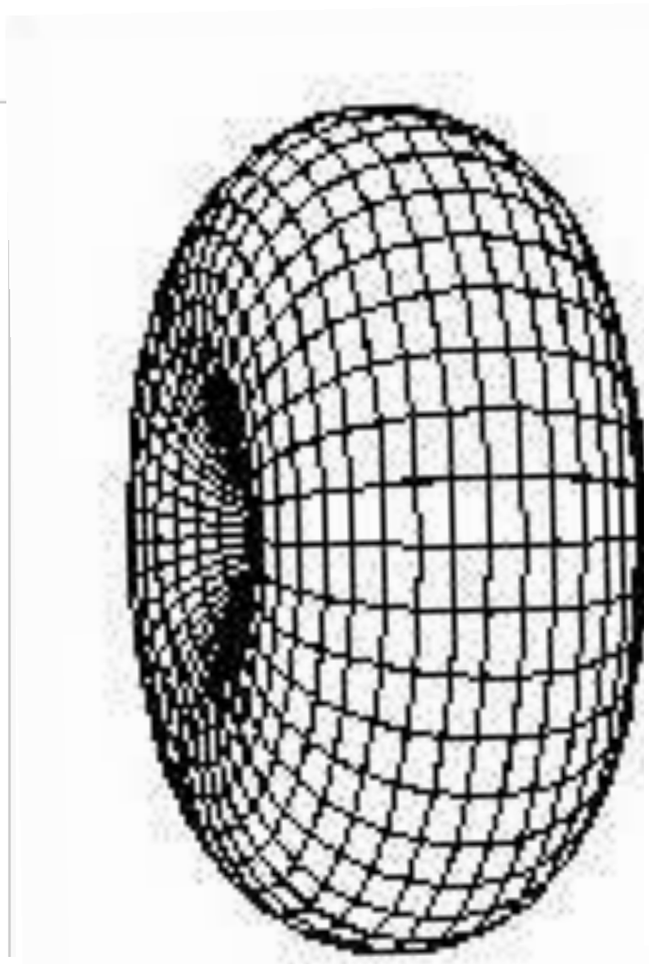
- For 150 MHz one wavelength is 2 m, and the antenna should be 1 m long

- For 450 MHz, one wavelength is 67 cm, and the antenna should be 33 cm long

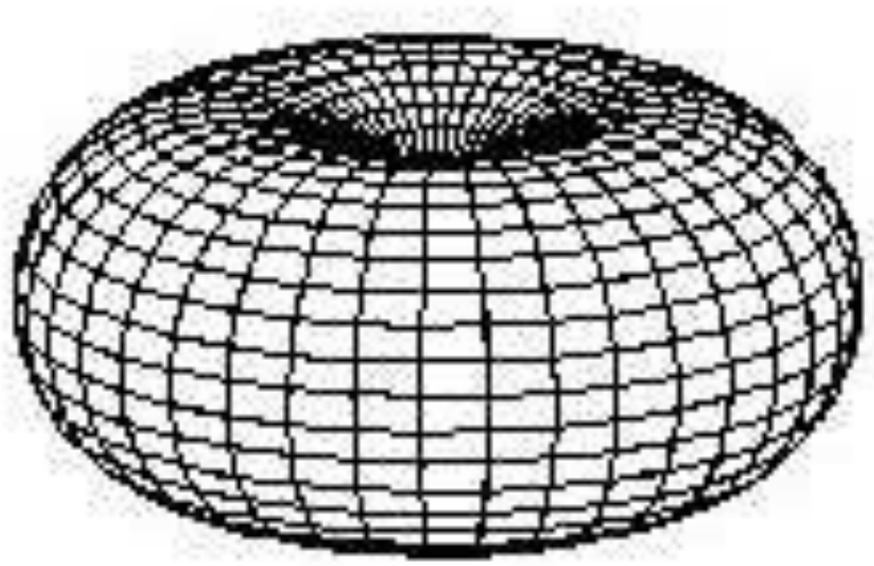
Dipole Radiation Pattern



Horizontal



Horizontal



Vertical

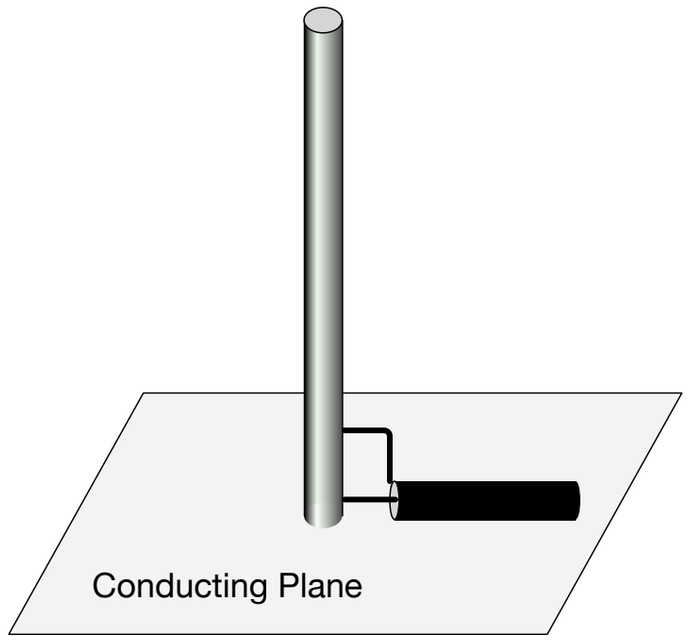
Polarization

- Polarization is the direction of the electric field (horizontal, vertical, circular)
- A horizontal dipole has a horizontal polarization
- A vertical dipole has a vertical polarization
- If the transmitting and receiving antennas have different polarizations, there can be a very large signal loss

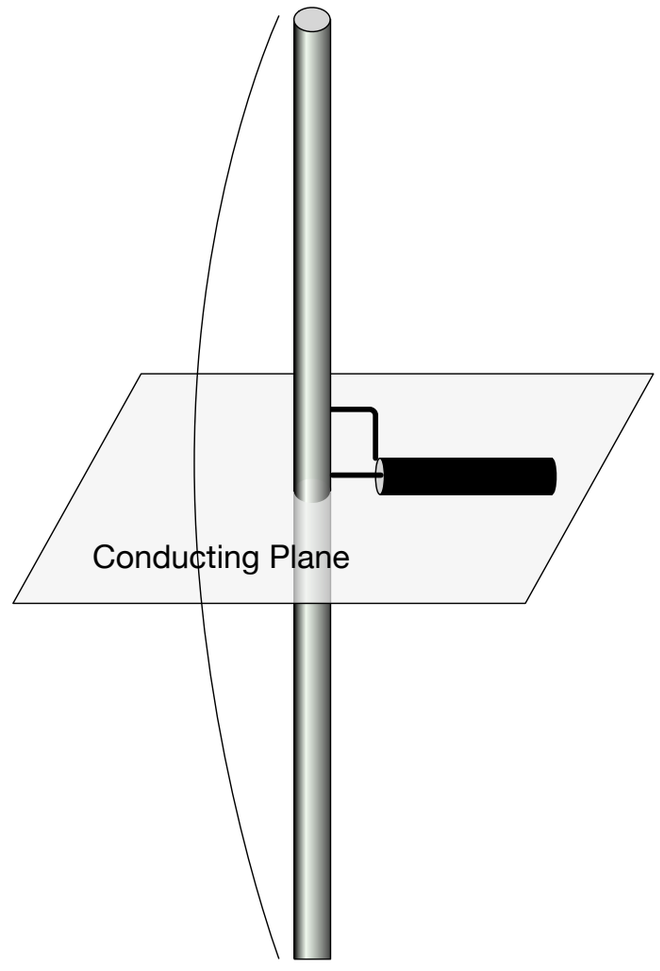
1/4 Wave Vertical Antennas

- Conducting surfaces (the earth, your car roof) act as current mirrors

- You get the second half of the antenna for free!



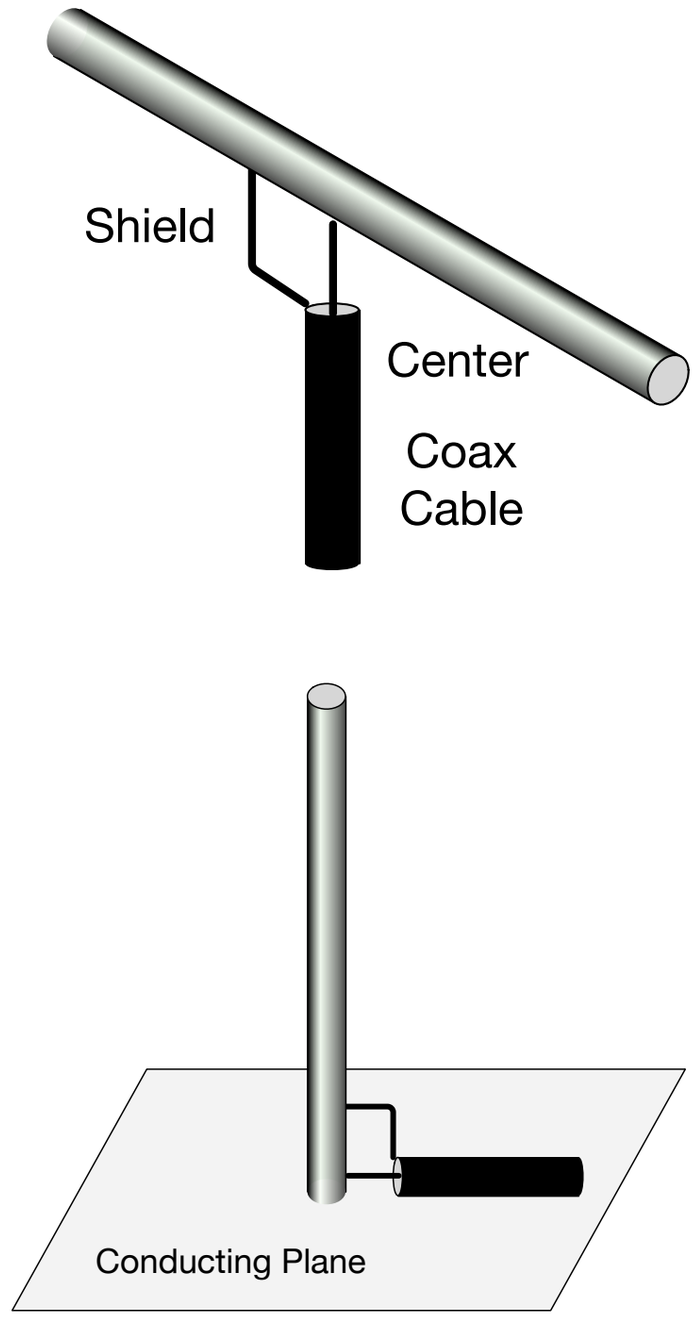
Antenna above Conducting Plane



Effective Antenna

Key Points

- Half-Wave Dipole
  - Usually horizontal
  - Driven at middle
  - Half wavelength
- Quarter Wave
  - Usually vertical
  - Driven at end
  - Quarter wavelength



How Long are These?

- 1/4 wave FM antenna (100 MHz)
- 1/2 wave TV antenna (300 MHz)
- 1/4 wave WiFi antenna (6 GHz)
- 1/4 wave cell phone antenna (600 MHz)
- 1/4 wave shortwave antenna (3 MHz)

RF Exposure

RF Exposure

- Exposure to high levels of RF can cause problems.
- If precautions are taken, RF exposure is minimal and not dangerous.
- Problem is RF energy can heat body tissues.
- Heating depends on the RF intensity and frequency.

RF Power Density

- Actual transmitter power.
- Antenna gain and proximity.
- Transmission duty cycle.

Antenna Proximity

- Controlled Environment:
  - People know what they are doing, and that the RF is there
  - Higher power allowed
- Uncontrolled Environment:
  - You have no idea, or have no control of people near your antenna.
  - Less power is allowed because you have to assume the worse case scenario.

RF Exposure and Frequency

- When body parts act like antennas, those parts absorb RF energy at certain frequencies (wavelengths) more efficiently and increase risk.

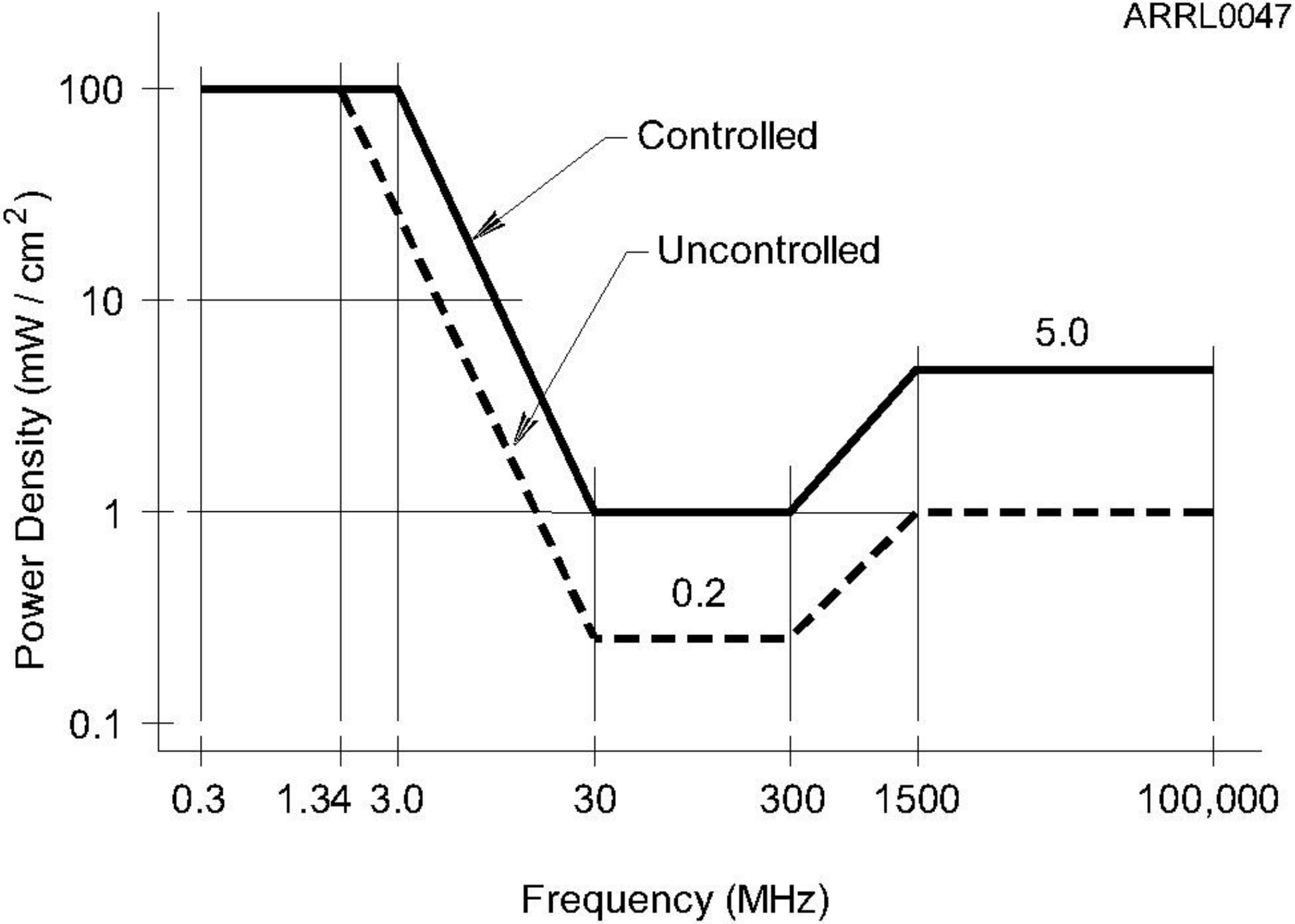
- RF exposure risk varies with frequency.

- More caution is dictated at some frequencies more than other frequencies.

- At what frequencies are you a 1/2 or 1/4 wave dipole? Assume you are 2 m tall, for simplicity.

RF Exposure and Frequency

ARRL0047



RF Exposure and Frequency

- You will see this plot in almost every FCC filing.
- Does the specific device in question produce heating above the standard spec?
- This doesn't address other ways that RF might interact with tissue. These are still research topics, and under very active research.
- However, we've done a very large population study, and any negative effects are exceedingly difficult to find.