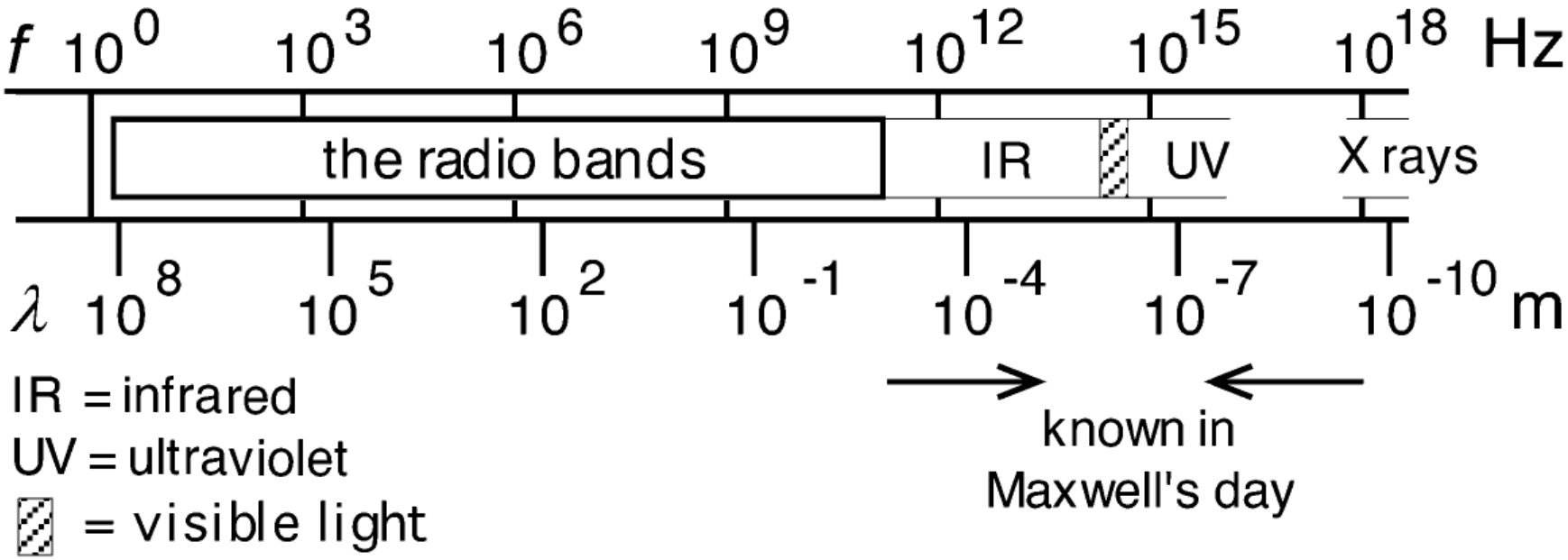
Electromagnetic Spectrum



[Gosling , 1999, Fig 1.1]

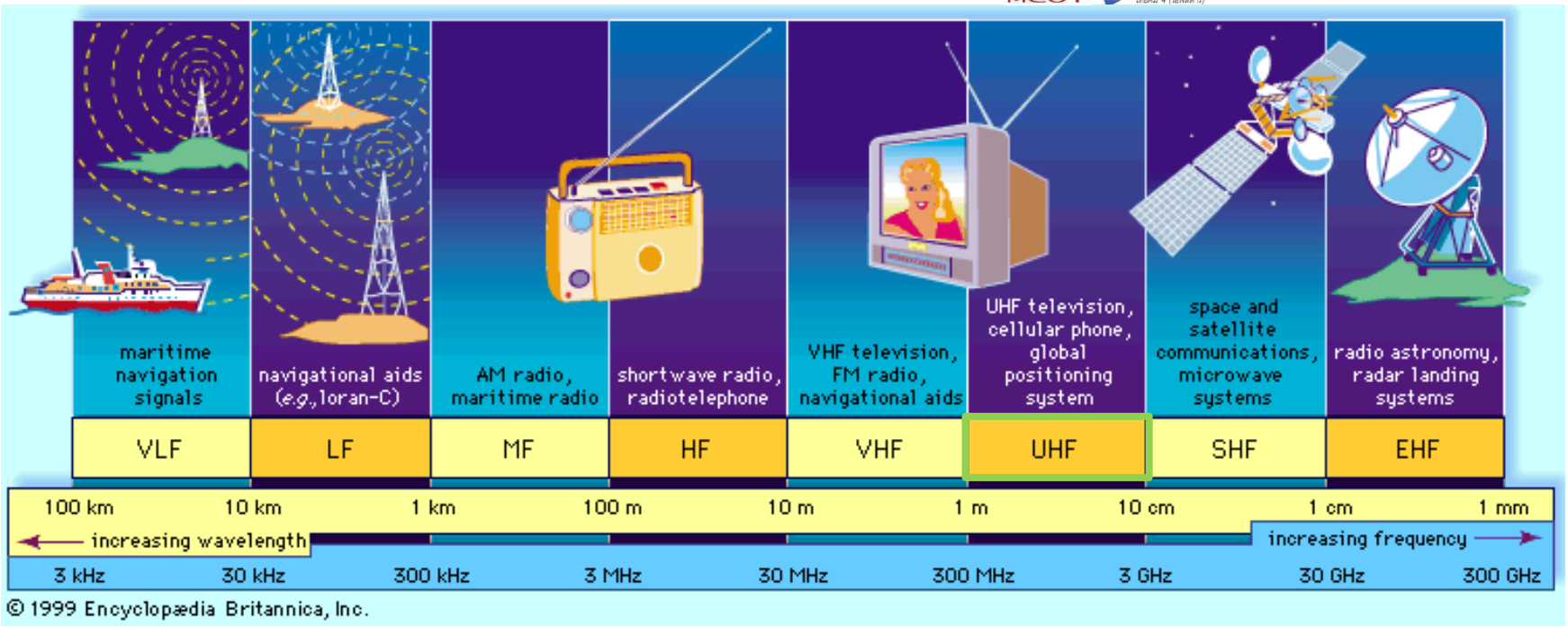
$$c = f\lambda$$

3×10^8 m/s — Frequency — Wavelength

[http://www.britannica.com/EBchecked/topic-art/585825/3697/Commercially-exploited-bands-of-the-radio-frequency-spectrum]

Radio-frequency spectrum

- Commercially exploited bands



$$c = f\lambda$$

3×10^{8} m/s

Wavelength

Frequency

Note that the freq. bands are given in decades; the VHF band has 10 times as much frequency space as the HF band.

Cellular Bands

- All cellular phone networks worldwide use a portion of the radio frequency spectrum designated as **ultra high frequency (UHF)** (300 MHz to 3 GHz)
  - The UHF band is also used for television, Wi-Fi and Bluetooth transmission.
  - Due to historical reasons, radio frequencies used for cellular networks differ in the Americas, Europe, and Asia.
- Frequency bands recommended by ITU-R (in June 2003) for terrestrial Mobile telecommunication IMT-2000:
  - 806-960 MHz
  - 1710-2025 MHz
  - 2110-2200 MHz
  - 2500-2690 MHz

Lower limits on radio use

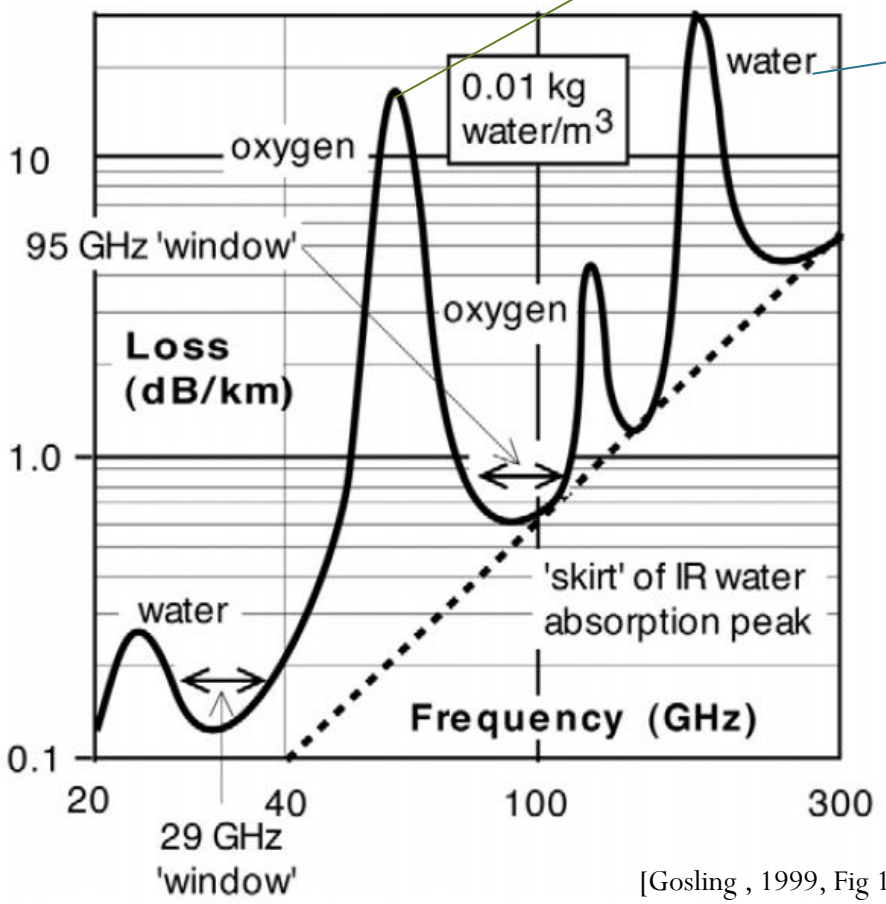
- **Efficiency** of an antenna in radiating radio energy is dependent on its length expressed as a fraction of **wavelength**.
  - Too low frequency = too large antenna
- Ex. The "Sanguine" submarine communication system
  - 30 Hz (10,000 km wavelength)
  - Designed (but never built) for the US Navy
  - Base antenna: 24 km square mesh of wires.
  - 10MW RF input
    - Radiate only 147 W
    - All the remainder of the power dissipates as heat.

[Gosling, 1999, p 11]

(terrestrial propagation)

Upper limits on radio use

14 dB/km @ 60 GHz



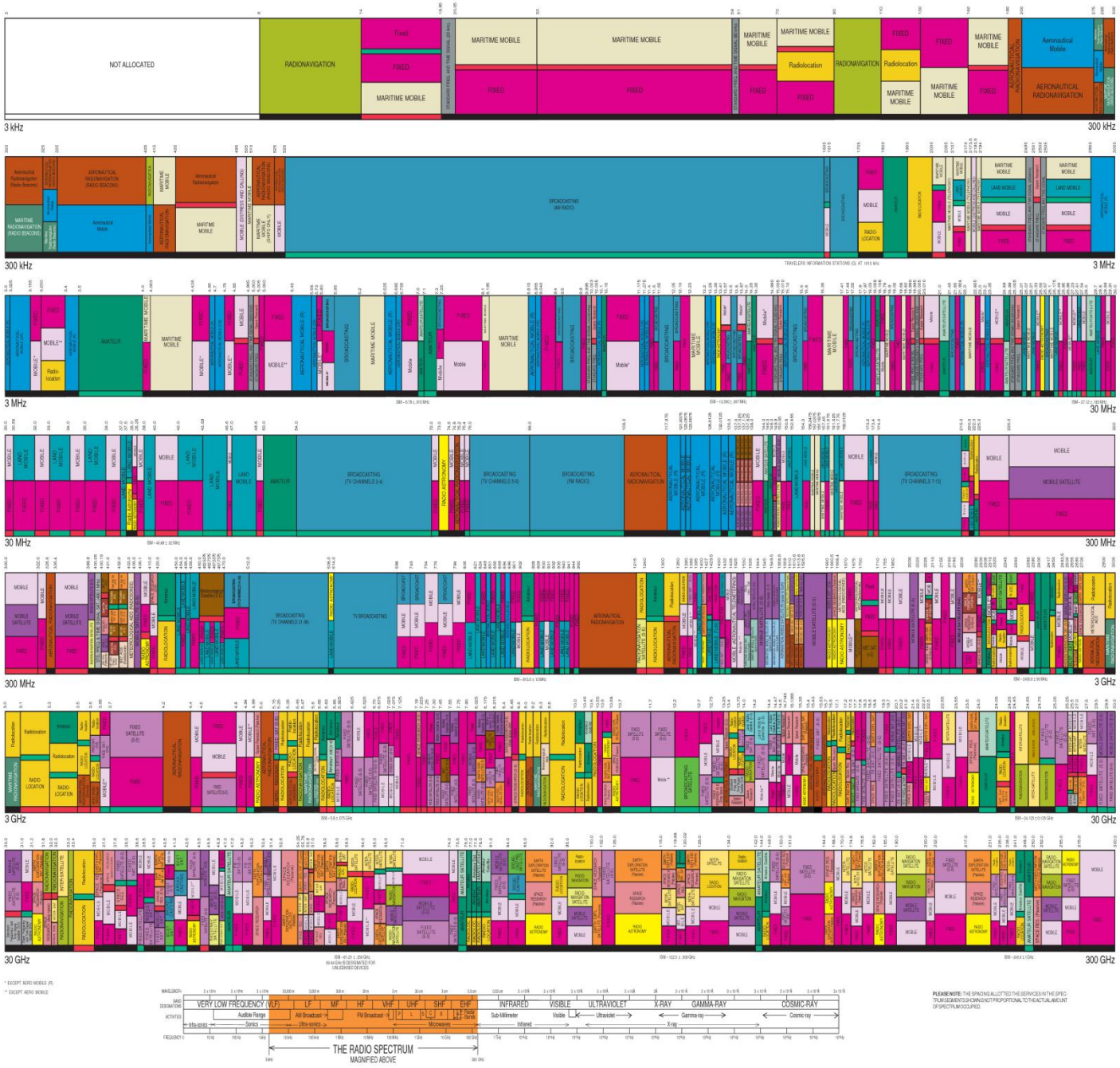
[Gosling , 1999, Fig 1.1]

Make commu. very dependent on weather conditions

- Atmospheric absorption
- Quasi-optical propagation
  - Short wavelength = Deep shadows behind obscuring objects = Unreliable coverage.
- Increased absorption by building and structural materials

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
- METEOROLOGICAL 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 [illegible] NTIA. As such, it does not completely reflect all aspects, i.e., footnotes and recent changes to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table of Frequency Allocations. Therefore, for complete information, users should consult the most recent the current status of U.S. allocations.

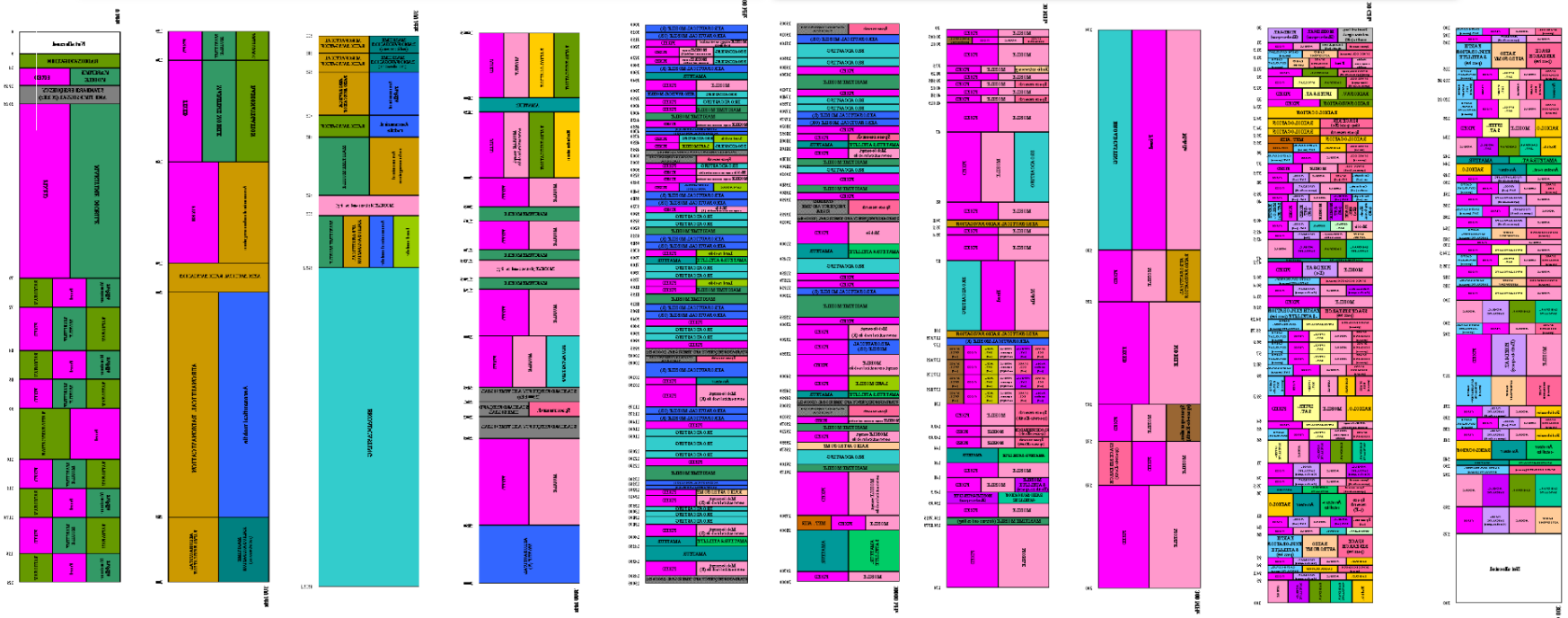
PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

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

October 2003

Thailand Freq. Allocations Chart

RADIO SERVICES COLOR LEGEND			
Aeronautical mobile	Meteorological aids	Fixed	Radionavigation
Aeronautical radionavigation	Meteorological-satellite	Fixed-satellite	Radionavigation- satellite
Amateur	Mobile	Inter-satellite	Space operation
Amateur-satellite	Mobile-satellite	Land mobile	Space research
Broadcasting	Radio astronomy	Maritime mobile	Standard frequency and time signal
Broadcasting-satellite	Radiodetermination-satellite	Maritime radionavigation	Standard frequency and time signal-satellite
Earth exploration- satellite	Radiolocation		



http://www.ntc.or.th/uploadfiles/freq_chart_thai.htm

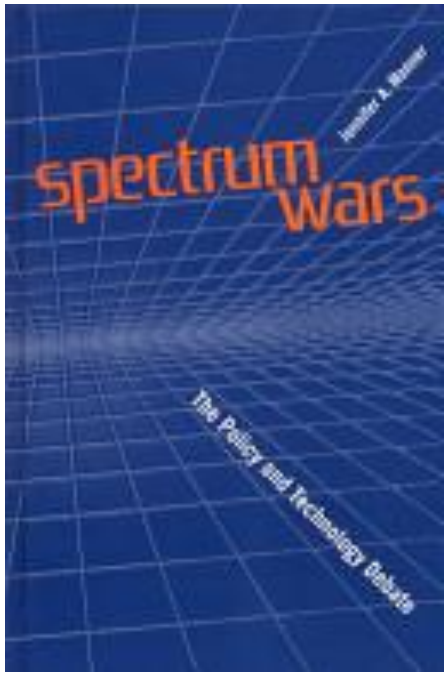
Spectrum Allocation

- Spectral resource is limited.
- Most countries have government agencies responsible for allocating and controlling the use of the radio spectrum.
- Commercial spectral allocation is governed
  - **globally** by the International Telecommunications Union (**ITU**)
    - ITU Radiocommunication Sector (**ITU-R**) is responsible for radio communication.
  - in the U.S. by the Federal Communications Commission (**FCC**)
  - in Europe by the European Telecommunications Standards Institute (ETSI)
  - in **Thailand** by the National Telecommunications Commission (**NTC**; คณะกรรมการกิจการโทรคมนาคมแห่งชาติ; กทช.)
    - replaced by the National Broadcasting and Telecommunications Commission (**NBTC**; คณะกรรมการกิจการกระจายเสียง กิจการโทรทัศน์และกิจการโทรคมนาคมแห่งชาติ ; กสทช.)
- Blocks of spectrum are now commonly assigned through **spectral auctions** to the highest bidder.

Interesting Book

- Spectrum Wars: The Policy and Technology Debate

"Designed to help you ensure that your company **wins the battle for the spectrum**, this text maps out the strategies required for structuring entry and operations in the spectrum. It offers advice on how to master the lobbying, technical, regulatory, legal and political tools needed for success."

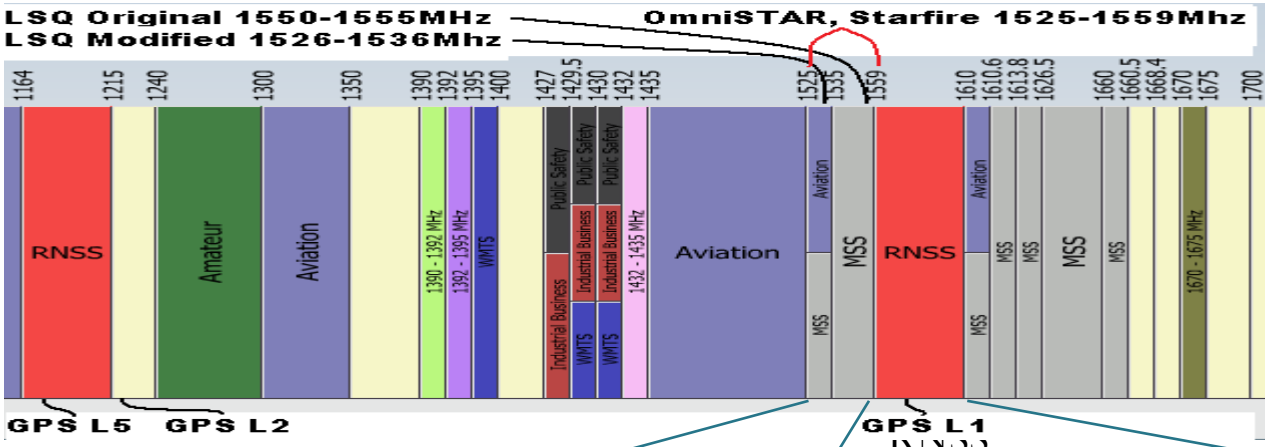


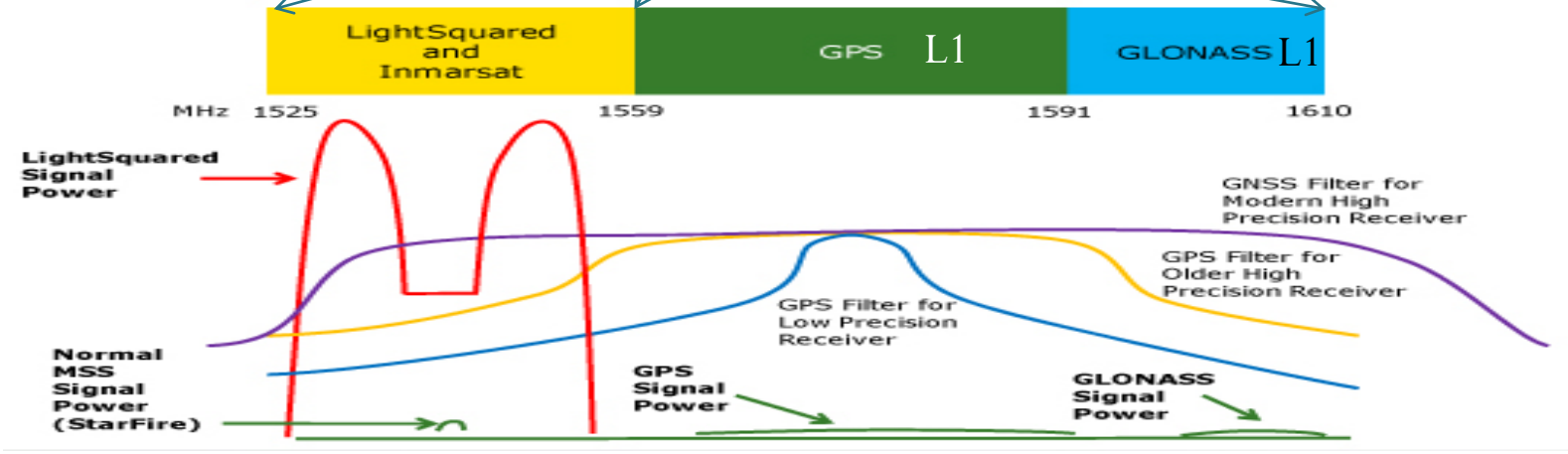
[Manner, 2003]

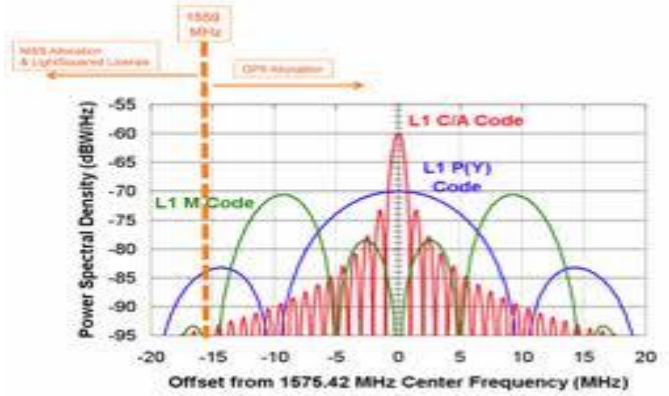
News: LightSquared vs. GPS industry

- In Jan 2011, the FCC recently granted a conditional waiver to **LightSquared** allowing the expansion of terrestrial use (for launching a new **LTE** network) of the **mobile satellite spectrum (MSS)** immediately neighboring that of the **GPS**
  - As its name suggested, MSS has been reserved for satellite services
  - Earlier, FCC permitted "ancillary" terrestrial uses intended to "fill in" locations where satellite coverage was problematic.
  - The new order allows a high powered nationwide terrestrial broadband network.
- Extremely high-powered ground-based transmissions could potentially cause severe interference to GPS receivers.
- LightSquared bought the spectrum right next door to GPS cheaply, hoping to change the rules and make the spectrum more valuable.

[GPS World, December 2011]

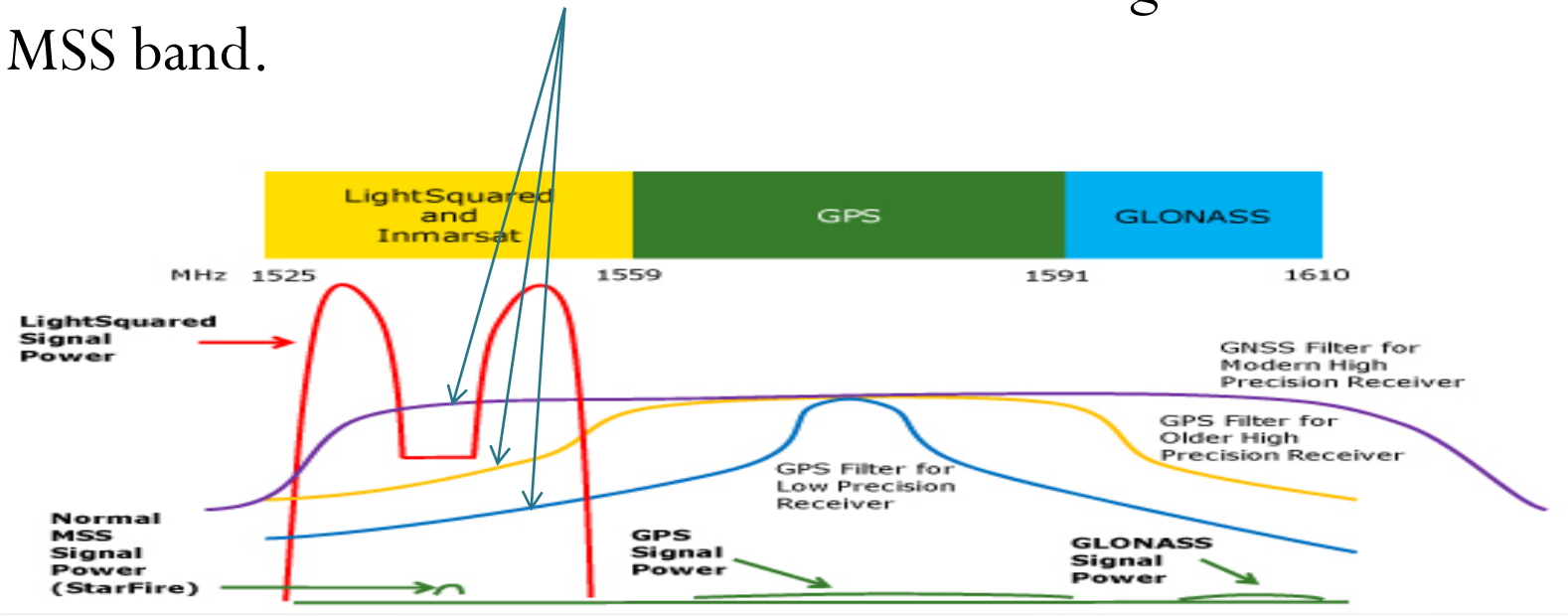

LSQ Original 1550-1555MHz
LSQ Modified 1526-1536Mhz
OmniSTAR, Starfire 1525-1559Mhz
1164
1215
1240
1300
1350
1390
1392
1395
1400
1427
1429.5
1430
1432
1435
1525
1535
1559
1610
1610.6
1613.8
1626.5
1660
1660.5
1668.4
1670
1675
1700
RNSS
Amateur
Aviation
1390 - 1392 MHz
1392 - 1395 MHz
WMTS
Public Safety
Industrial Business
WMTS
Public Safety
Industrial Business
WMTS
1432 - 1435 MHz
Aviation
Aviation
MSS
MSS
RNSS
Aviation
MSS
MSS
MSS
MSS
1670 - 1675 MHz
GPS L5
GPS L2
GPS L1


LightSquared and Inmarsat
GPS L1
GLONASS L1
MHz
1525
1559
1591
1610
LightSquared Signal Power
GNSS Filter for Modern High Precision Receiver
GPS Filter for Older High Precision Receiver
GPS Filter for Low Precision Receiver
Normal MSS Signal Power (StarFire)
GPS Signal Power
GLONASS Signal Power


1559 MHz
L1 C/A Code
L1 P(Y) Code
L1 M Code
Power Spectral Density (dBW/Hz)
-55
-60
-65
-70
-75
-80
-85
-90
-95
-20
-15
-10
-5
0
5
10
15
20
Offset from 1575.42 MHz Center Frequency (MHz)

Completely Separated?

- GPS receivers have filters that do not block signals from the MSS band.



- These filters has enabled both low-cost and high-precision GPS receivers.
- Assumption: Signals in MSS band were low-power.

Spectrum Allocation (Final Words)

- Spectrum is a scarce resource.
- Spectrum is allocated in "chunks" in **frequency** domain.
  - "Chunks" are licensed to (cellular/wireless) operators.
- Within a single cellular operator, the chunk is further divided into many **channels**.
  - Each channel has its own band of frequency.