ECS 455 Chapter 1

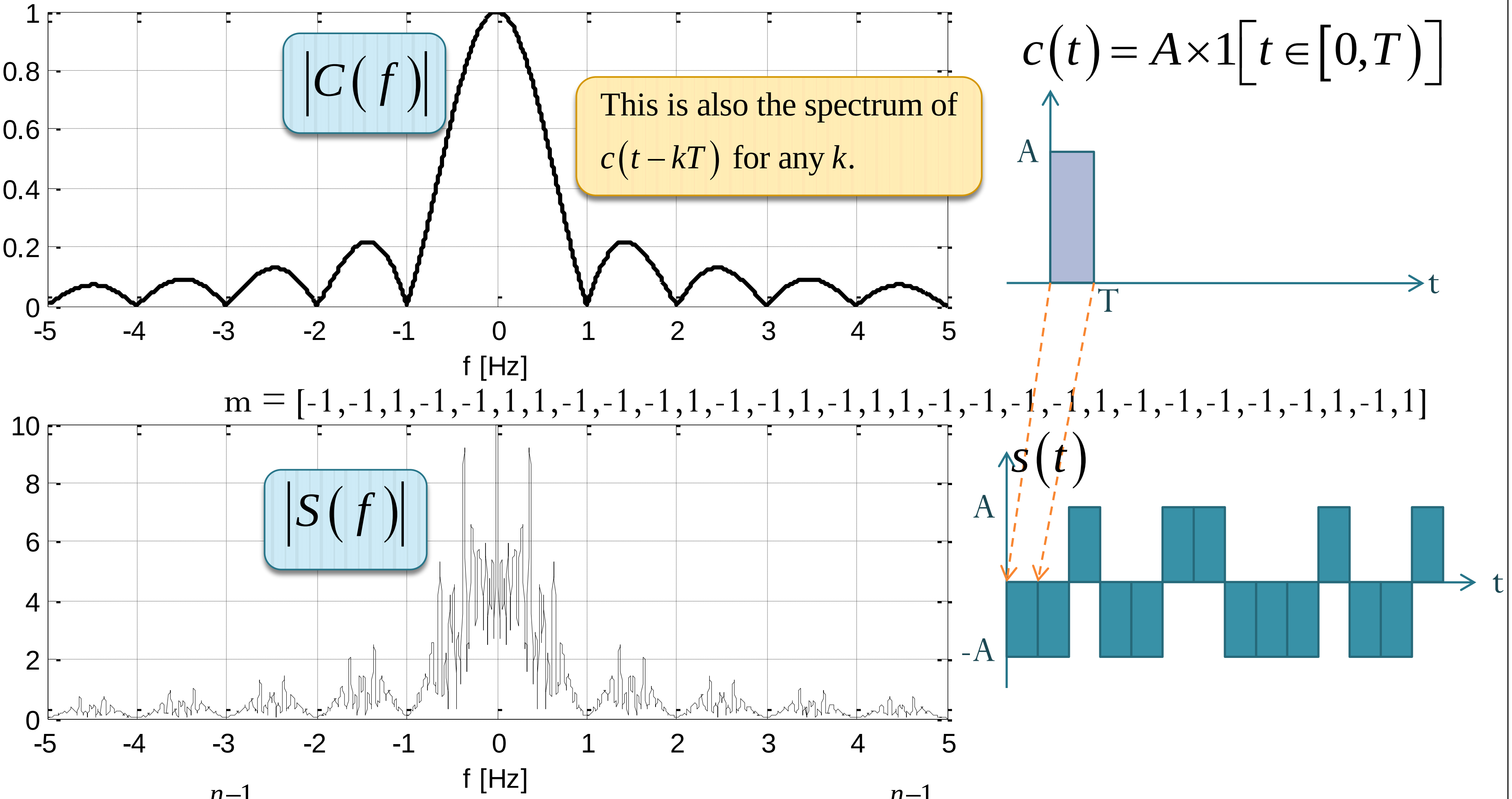
Introduction & Review

1.2 Fourier Transform and Communication System

Office Hours:
BKD 3601-7
Wednesday 15:30-16:30
Friday 9:30-10:30

Spectrum of Digital Data (4/4)

$(A=1, T=1)$



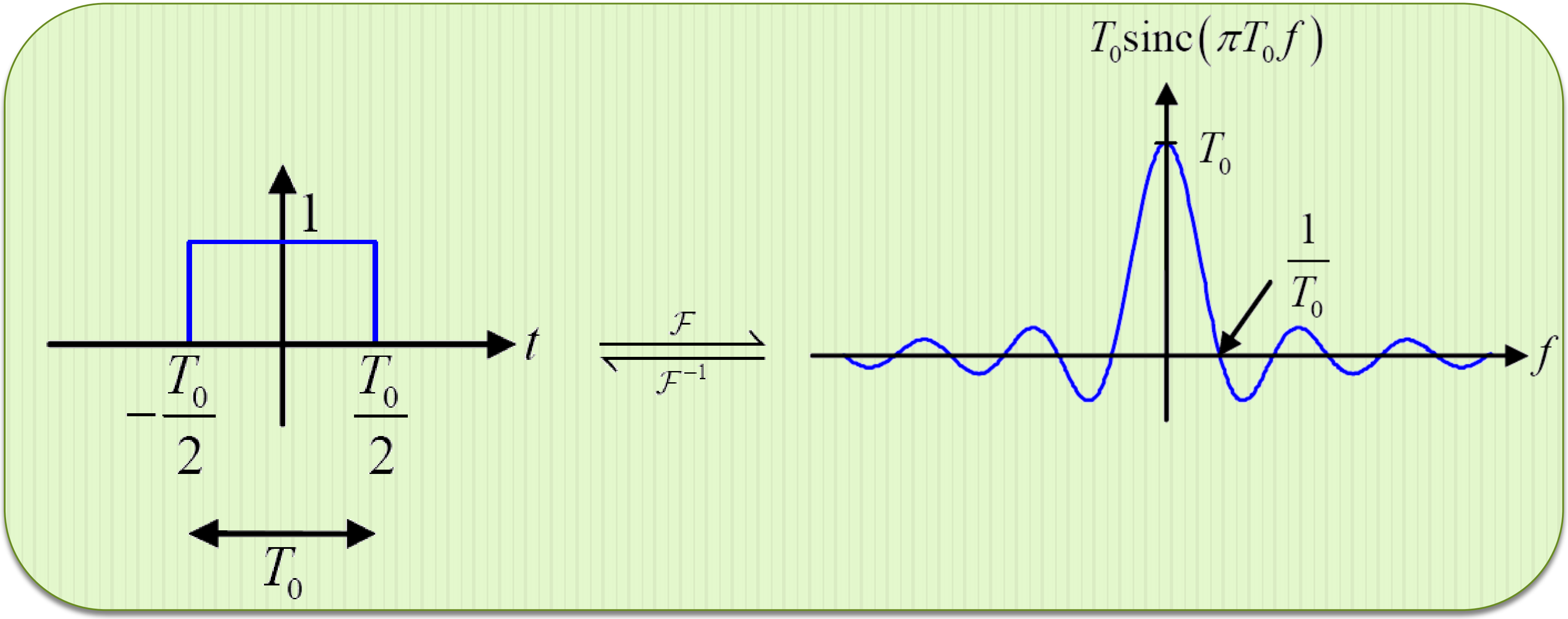
This is also the spectrum of $c(t-kT)$ for any k.

$$c(t) = A\times 1\left[t\in[0,T)\right]$$

m = [-1,-1,1,-1,-1,1,1,-1,-1,-1,1,-1,-1,1,-1,1,1,-1,-1,-1,-1,1,-1,-1,-1,-1,-1,1,-1,1]

$$s(t)=\sum_{k=0}^{n-1} m_k c(t-kT) \xrightarrow{\mathcal{F}} S(f)=C(f)\sum_{k=0}^{n-1} m_k e^{-j2\pi fkT}$$

Frequency-Domain Analysis



Shifting Properties: $\boxed{g(t-t_0) \overset{\mathcal{F}}{\rightleftharpoons} e^{-j2\pi f t_0} G(f)}$ $\boxed{e^{j2\pi f_0 t} g(t) \overset{\mathcal{F}}{\rightleftharpoons} G(f-f_0)}$

Modulation: $m(t)\cos(2\pi f_c t) \overset{\mathcal{F}}{\rightleftharpoons} \frac{1}{2} M(f-f_c) + \frac{1}{2} M(f+f_c)$

Important Formula

$$e^{j\theta} = \cos\theta + j\sin\theta$$

$$2\cos^2 x = 1 + \cos(2x)$$

$$2\sin^2 x = 1 - \cos(2x)$$

$$G(f) = \int_{-\infty}^{\infty} g(t) e^{-j2\pi ft} dt$$

$$\cos(2\pi f_c t + \theta) \overset{\mathcal{F}}{\rightleftharpoons} \frac{1}{2}\delta(f - f_c)e^{j\theta} + \frac{1}{2}\delta(f + f_c)e^{-j\theta}$$

$$g(t - t_0) \overset{\mathcal{F}}{\rightleftharpoons} e^{-j2\pi ft_0} G(f)$$

$$e^{j2\pi f_0 t} g(t) \overset{\mathcal{F}}{\rightleftharpoons} G(f - f_0)$$

$$m(t)\cos(2\pi f_c t) \overset{\mathcal{F}}{\rightleftharpoons} \frac{1}{2}M(f - f_c) + \frac{1}{2}M(f + f_c)$$

Instantaneous Frequency (Ex 1/6)

- Suppose you want the frequency of

$$\cos\left(2\pi ft\right)$$

  to change as a function of time $f\left(t\right)=t^2$

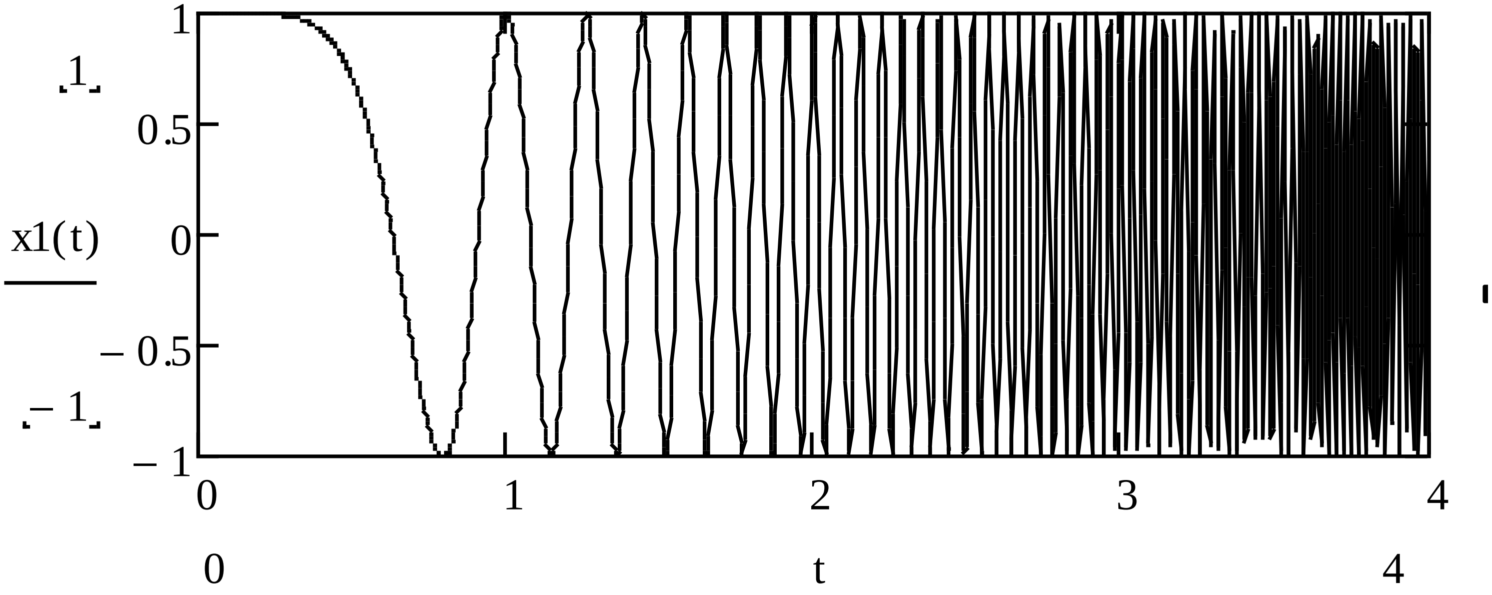
- Intuitively, the following substitution makes sense:

$$\cos\left(2\pi\left(t^2\right)t\right)$$

- But will it work?

Instantaneous Frequency (Ex 2/6)

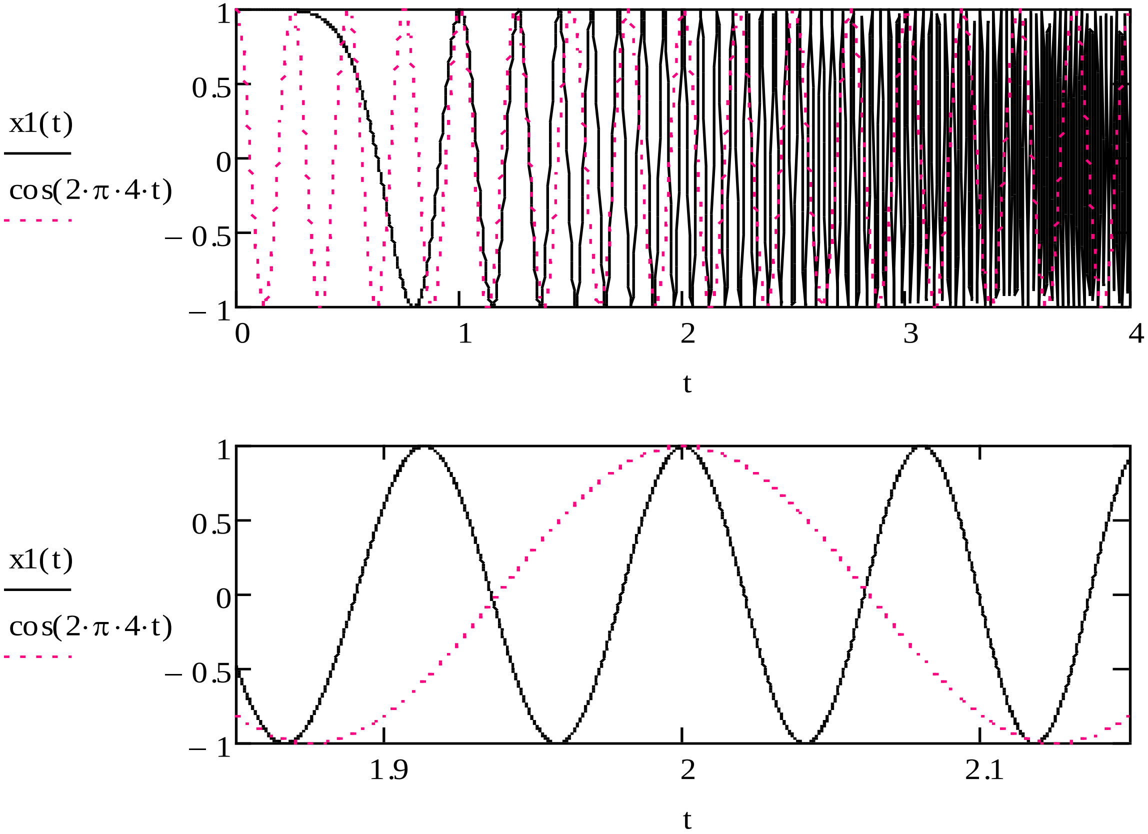
$$x_1(t) = \cos\left(2\pi t^2 t\right)$$



At t = 2, frequency = ?

Instantaneous Frequency (Ex 5/6)

$$x_1(t) = \cos\left(2\pi t^2 t\right)$$



At t = 2, $\cos\left(2\pi\left(t^2\right)t\right)$ oscillates much faster than 4Hz.

Instantaneous Frequency

of Generalized Sinusoids $x(t) = A\cos\left(\theta(t)\right)$

$$f(t) = \frac{1}{2\pi}\theta'(t)$$

QAM

$$s(t) = \overbrace{m_I(t)}^{\text{In-phase component}}\cos(\omega_c t) - \overbrace{m_Q(t)}^{\text{Quadrature component}}\sin(\omega_c t)$$

$$= \mathrm{Re}\left\{\underbrace{\left(m_I(t) + jm_Q(t)\right)}_{m(t)} e^{j\omega_c t}\right\}$$

- Complex baseband signal
- Complex envelope of $s(t)$
- Compex lowpass equivalent signal of $s(t)$

ECS 455 Chapter 1

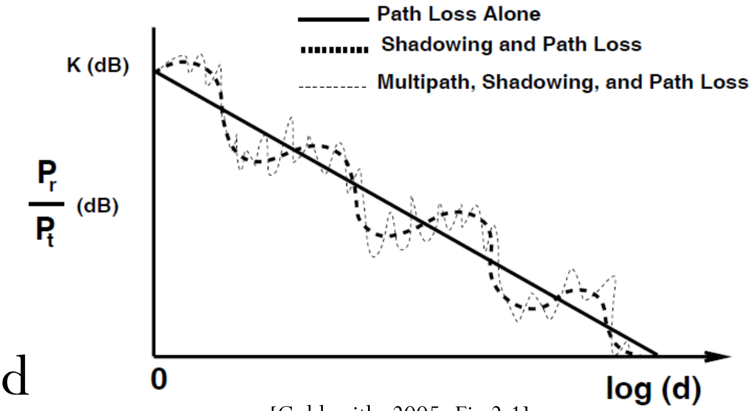
Introduction & Review

1.3 Wireless Channel (Part 1)

Office Hours:
BKD 3601-7
Wednesday 15:30-16:30
Friday 9:30-10:30

Wireless Channel

- **Large-scale** propagation effects
  1. Path loss
  2. Shadowing
  - Typically frequency independent
- **Small-scale** propagation effects
  - Variation due to the constructive and destructive addition of **multipath** signal components.
  - Occur over very short distances, on the order of the signal wavelength.



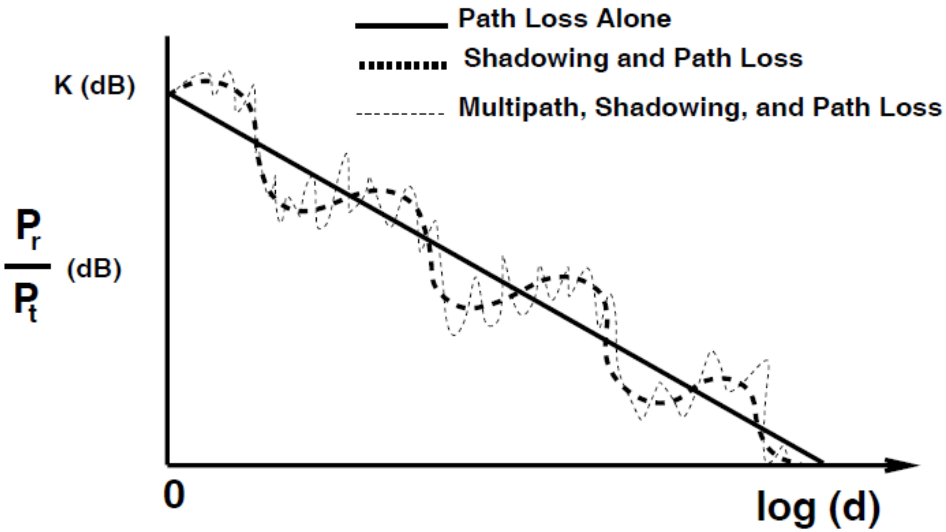
[Goldsmith, 2005, Fig 2.1]

$$\boxed{\lambda = \frac{c}{f}} \qquad c \approx 3\times10^8 \text{ [m/s]}$$

$f = 3$ GHz → $\lambda = 0.1$ m

Path loss

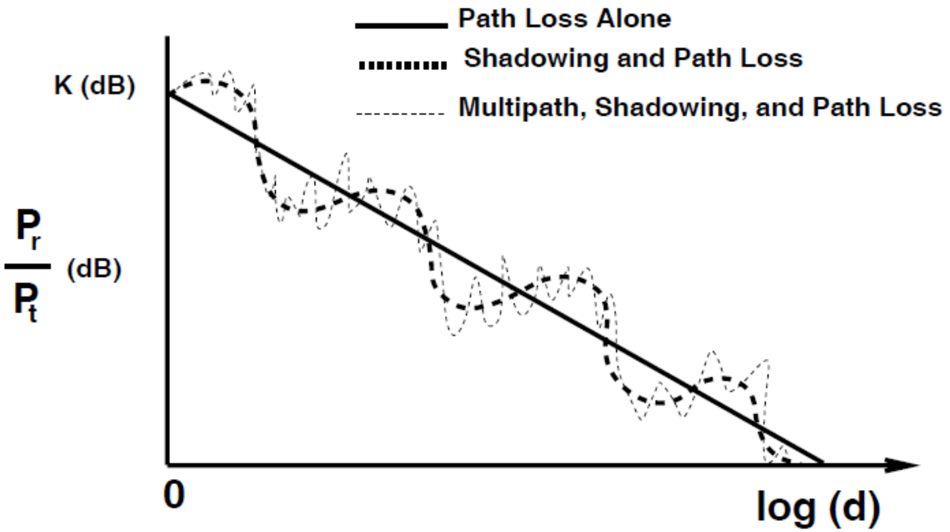
- Caused by
  - dissipation of the power radiated by the transmitter
  - effects of the propagation channel
- Models generally assume that it is the same at a given transmit-receive distance.
- Variation occurs over **large distances** (100-1000 m)



[Goldsmith, 2005, Fig 2.1]

Shadowing

- Caused by **obstacles** (**large objects** such as buildings and hills) between the transmitter and receiver.
  - Think: cloud blocking sunlight
- Attenuate signal power through absorption, reflection, scattering, and diffraction.
- Variation occurs over distances proportional to the length of the obstructing object (10-100 m in outdoor environments and less in indoor environments).



[Goldsmith, 2005, Fig 2.1]

Path Loss

$$P_L = \frac{\text{Transmitted power}}{\text{Average received power}} = \frac{P_t}{P_r}$$

Averaged over any random variations due to shadowing

- **Free-Space Path Loss**:

$$\frac{P_r}{P_t} \propto \frac{1}{d^2}$$

  - P_r falls off inversely proportional to the square of the distance d between the Tx and Rx antennas.
  - For other signal propagation models, P_r falls off more quickly relative to d.
- **Simplified** Path Loss Model:

$$\frac{P_r}{P_t} = K\left(\frac{d_0}{d}\right)^{\gamma}$$

Friss Equation

- One of the most fundamental equations in antenna theory

$$\frac{P_r}{P_t} = \left(\frac{\sqrt{G_{Tx}G_{Rx}}\,\lambda}{4\pi d}\right)^2 = \left(\frac{\sqrt{G_{Tx}G_{Rx}}\,c}{4\pi df}\right)^2$$

- More power is lost at higher frequencies.

$$2.4\text{ GH} \longrightarrow 5\text{ GHz} \longrightarrow 60\text{ GHz}$$

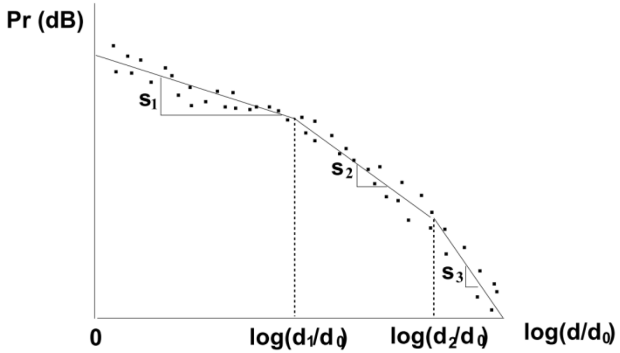
6.4 dB loss $20\log_{10}\frac{5}{2.4}$

21.6 dB loss $20\log_{10}\frac{60}{5}$

- Some of these losses can be offset by reducing the maximum operating range. The remaining loss must be compensated for by increasing the antenna gain.

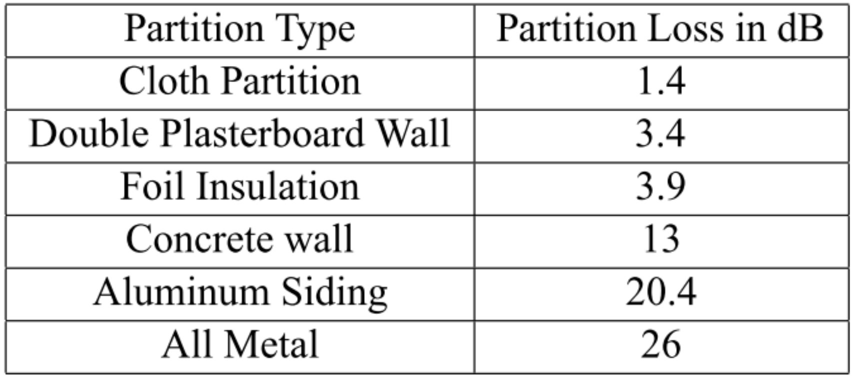
Path Loss Models

- Analytical models
  - Maxwell's equations
  - Ray tracing
- Empirical models
  - Okumura
  - Hata
  - COST 231
    - by EURO-COST (EUROpean Cooperative for Scientific and Technical research)
  - Piecewise Linear (Multi-Slope) Model
- Tradeoff: Simplified Path Loss Model



Indoor Attenuation Factors

- Building penetration loss: 8-20 dB (better if behind windows)
- Attenuation between floors
  - @ 900 MHz
    - 10-20 dB when the Tx and Rx are separated by a single floor
    - 6-10 dB per floor for the next three subsequent floors
    - A few dB per floor for more than four floors
  - Typically worse at higher frequency.
- Attenuation across floors



Partition Type	Partition Loss in dB
Cloth Partition	1.4
Double Plasterboard Wall	3.4
Foil Insulation	3.9
Concrete wall	13
Aluminum Siding	20.4
All Metal	26

[Goldsmith, 2005, Sec. 2.5.5]

Simplified Path Loss Model

$$\boxed{\frac{P_r}{P_t} = K\left(\frac{d_0}{d}\right)^{\gamma}}$$

Captures the essence of signal propagation without resorting to complicated path loss models, which are only approximations to the real channel anyway!

- K is a unitless constant which depends on the antenna characteristics and the average channel attenuation
  - $\left(\frac{\lambda}{4\pi d_0}\right)^2$ for free-space path gain at distance d_0 assuming omnidirectional antennas

(Near-field has scattering phenomena.)

- d_0 is a reference distance for the antenna far-field
  - Typically 1-10 m indoors and 10-100 m outdoors.
- γ is the **path loss exponent**.

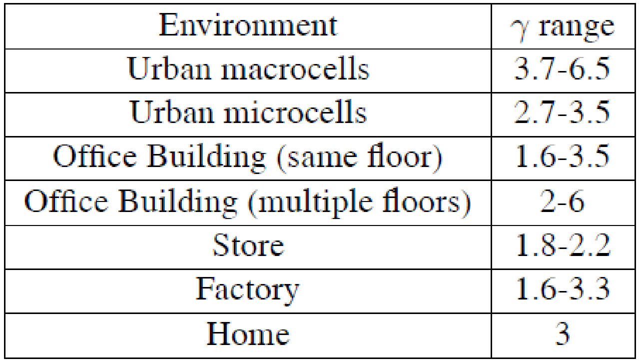
[Goldsmith, 2005, Table 2.2]

Path Loss Exponent

- 2 in free-space model
- 4 in two-ray model

  [Goldsmith, 2005, eq. 2.17]
- Cellular: 3.5 – 4.5

  [Myung and Goodman, 2008 , p 17]
- Larger @ higher freq.
- Lower @ higher antenna heights



Environment	γ range
Urban macrocells	3.7-6.5
Urban microcells	2.7-3.5
Office Building (same floor)	1.6-3.5
Office Building (multiple floors)	2-6
Store	1.8-2.2
Factory	1.6-3.3
Home	3

Log-normal shadowing

- Random variation due to blockage from objects in the signal path and changes in reflecting surfaces and scattering objects → random variations of the received power at a given distance

4 – 13 dB

$$10\log_{10}\frac{P_t}{P_r} \sim \mathcal{N}\left(\mu,\sigma^2\right)$$

in dB

- This model has been confirmed empirically to accurately model the variation in received power in both outdoor and indoor radio propagation environments.

Doppler Shift: 1D Move

- At distance $d = 0$, suppose we have

$$A_0 \cos(2\pi f t + \phi)$$

- At distance r, we have

Time to travel a distance of *r*

$$A_r \cos\left(2\pi f\left(t - \boxed{\frac{r}{c}}\right) + \phi\right)$$

- If moving, r becomes $r(t)$.
- If moving ***away*** at a constant velocity v, then $r(t) = r_0 + vt$.

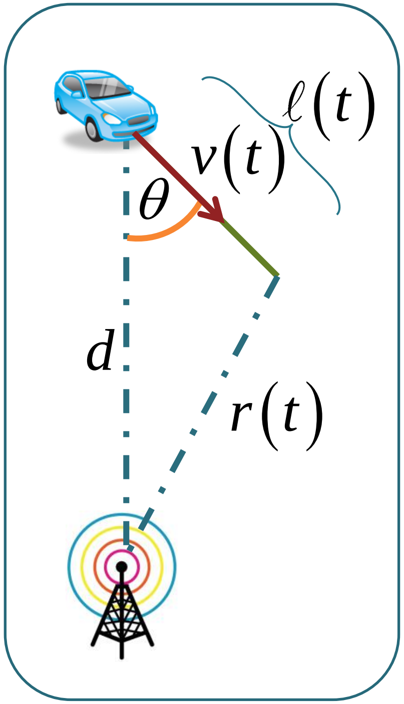
$$A_{r(t)} \cos\left(2\pi f\left(t - \frac{r_0 + vt}{c}\right) + \phi\right) = A_{r(t)} \cos\left(2\pi\left(f - \boxed{f\frac{v}{c}}\right)t - 2\pi f\frac{r_0}{c} + \phi\right)$$

Frequency shift

$$= \frac{v}{\lambda}$$

Doppler Shift: With angle

Rx speed = $v(t)$. At time t, cover distance $\ell(t)=\int_0^t v(\tau)d\tau$



$$r(t)=\sqrt{d^2+\ell^2(t)-2d\ell(t)\cos\theta}$$

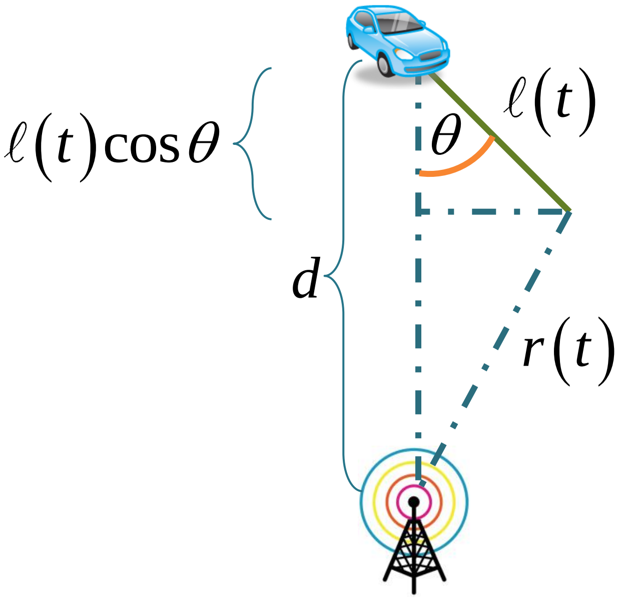
$$\frac{d}{dt}r(t)=\frac{2\ell(t)-2d\cos\theta}{2\sqrt{d^2+\ell^2(t)-2d\ell(t)\cos\theta}}v(t)$$

$$\left.\frac{d}{dt}r(t)\right|_{t=0}=-\cos\theta v(0)$$

$$f_{\text{new}}(t)=f-\frac{1}{\lambda}\frac{d}{dt}r(t)$$

$$f_{\text{new}}(0)=f+\underbrace{\frac{1}{\lambda}\cos\theta v(0)}_{\textbf{Frequency shift}}$$

Doppler Shift: Approximation



$$r(t) \approx d - \ell(t)\cos\theta$$

$$\frac{d}{dt} r(t) \approx -v(t)\cos\theta$$

$$f_{\text{new}}(t) \approx f + \frac{v(t)\cos\theta}{\lambda}$$

$$\Delta f = \frac{v\cos\theta}{\lambda}$$

For typical vehicle speeds (75 Km/hr) and frequencies (around 1 GHz), it is on the order of 100 Hz

[Goldsmith, 2005, Fig 2.2]

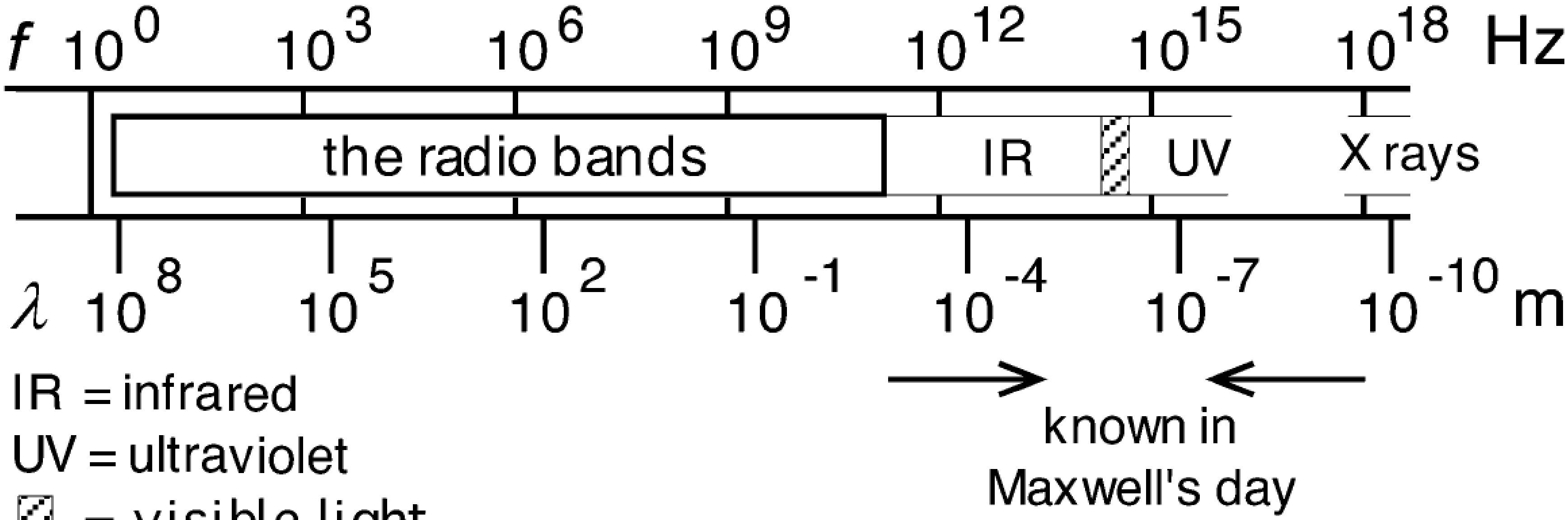
ECS 455 Chapter 1

Introduction & Review

1.4 Spectrum Allocation

Office Hours:
BKD 3601-7
Wednesday 15:30-16:30
Friday 9:30-10:30

Electromagnetic Spectrum



IR = infrared

UV = ultraviolet

▨ = visible light

[Gosling , 1999, Fig 1.1]

$$c = f\,\lambda$$

3×10^{8} m/s

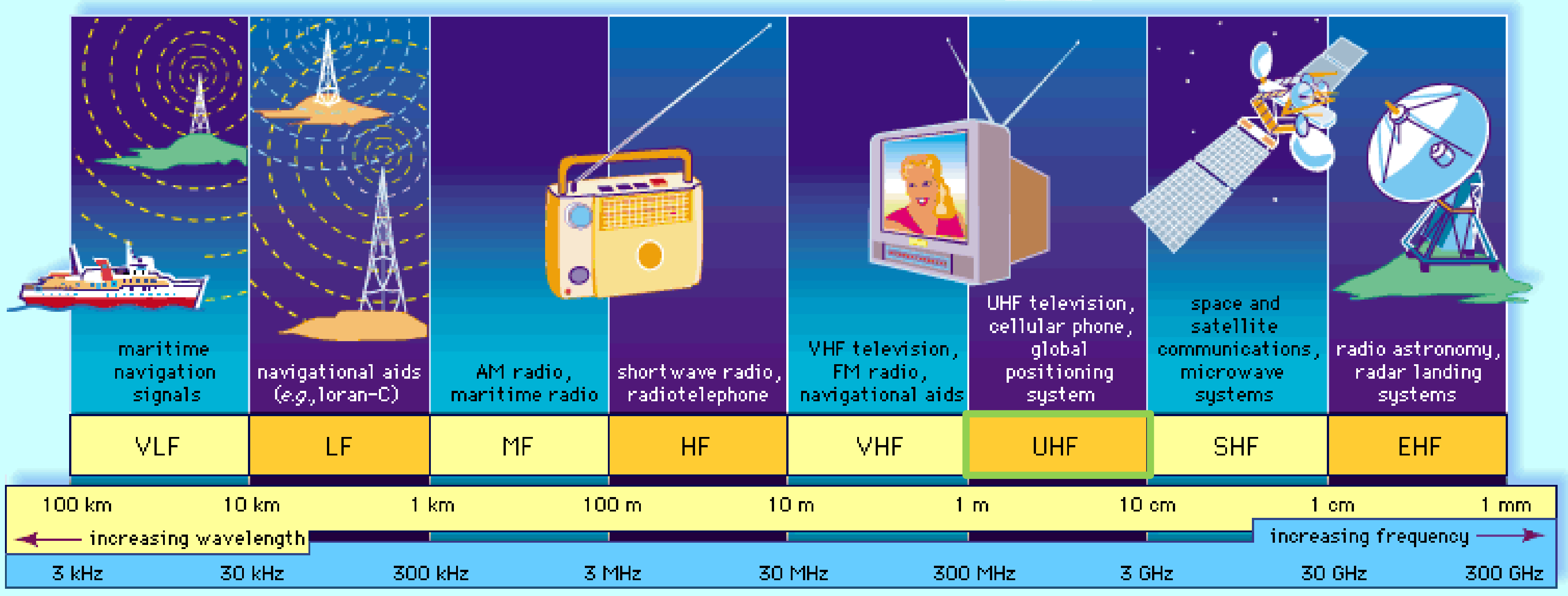
Wavelength

Frequency

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

Radio-frequency spectrum

- Commercially exploited bands



© 1999 Encyclopædia Britannica, Inc.

$$c = f\lambda$$

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.

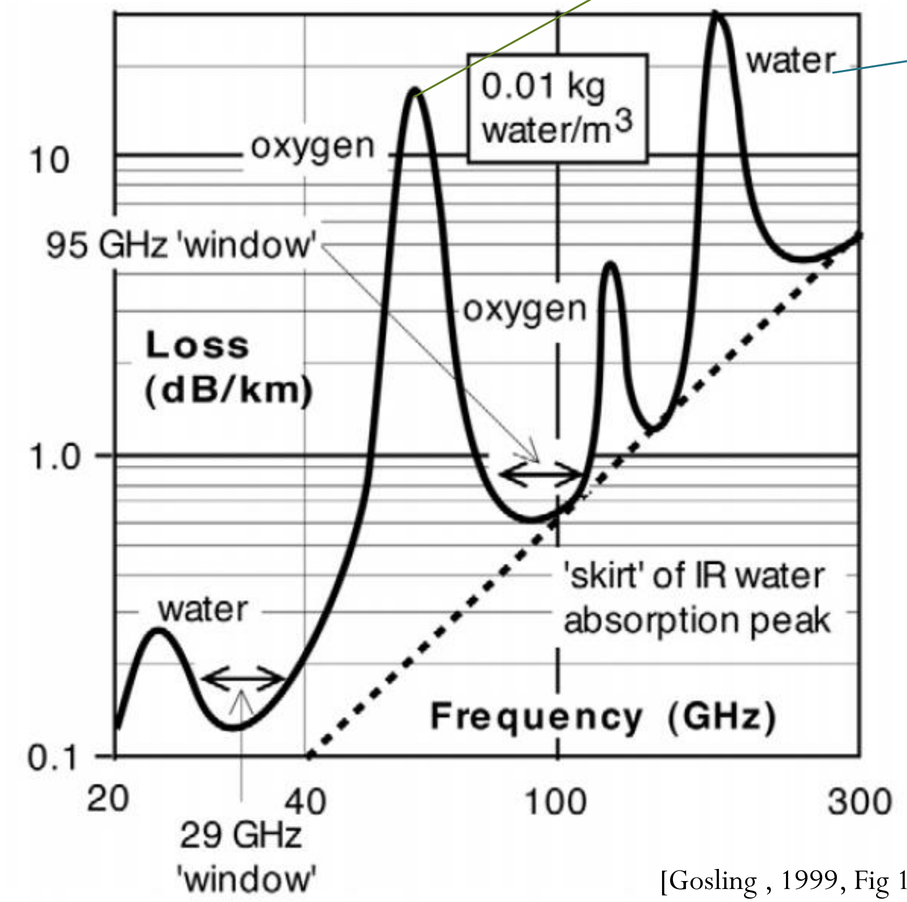
Cellular Bands

- 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 147W
    - All the remainder of the power dissipates as heat.

Upper limits on radio use



14 dB/km @ 60 GHz

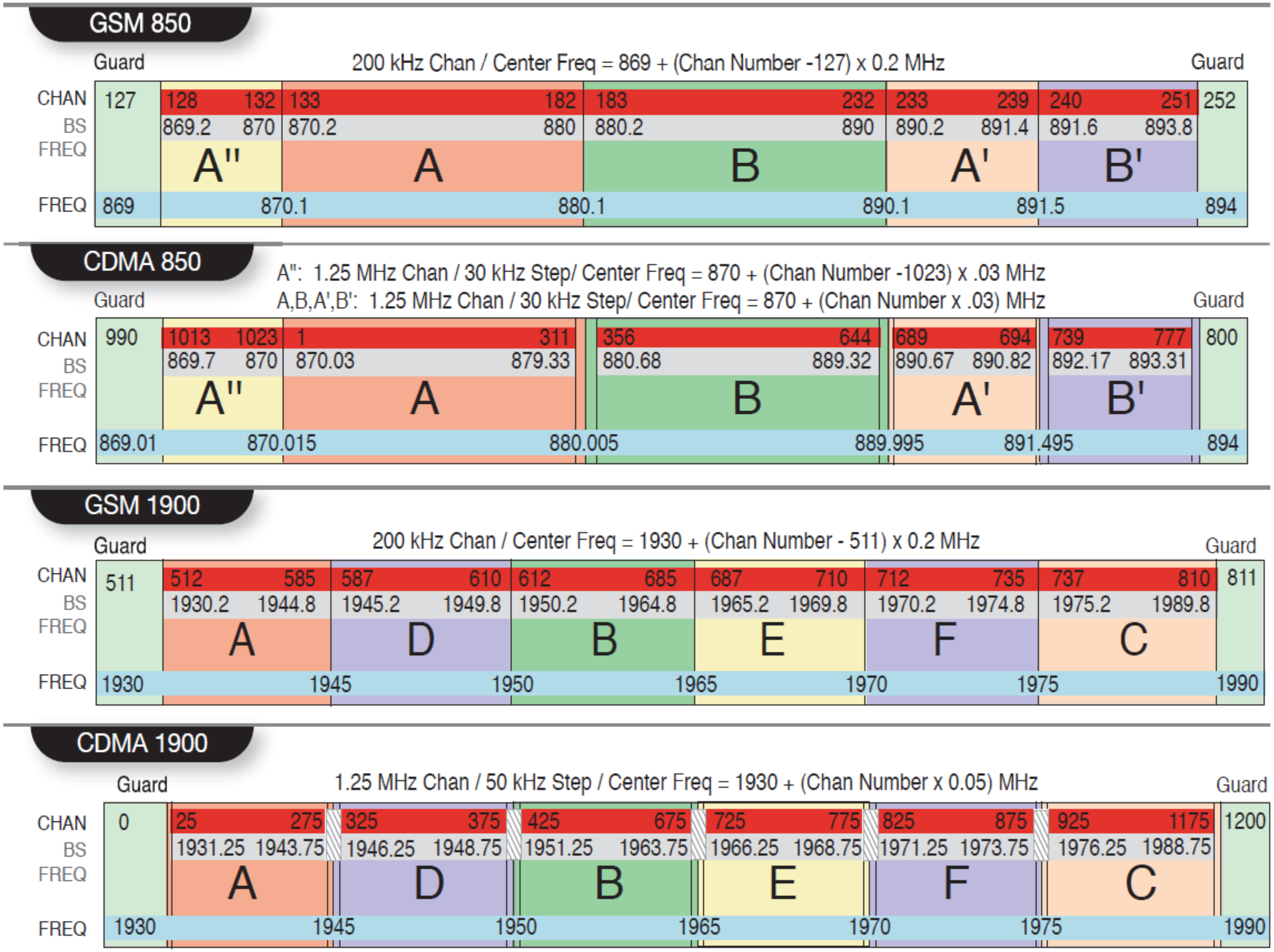
Make commu. very dependent on weather conditions

[Gosling , 1999, Fig 1.1]

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

Forward link (BS to MS) Frequencies and Channelization (1)

[http://www.qrctech.com/freq_chart_24x36.pdf]



GSM 850

200 kHz Chan / Center Freq = 869 + (Chan Number -127) x 0.2 MHz

	Guard						Guard
CHAN	127	128 132	133 182	183 232	233 239	240 251	252
BS FREQ		869.2 870	870.2 880	880.2 890	890.2 891.4	891.6 893.8	
		A''	A	B	A'	B'	

FREQ 869 870.1 880.1 890.1 891.5 894

CDMA 850

A'': 1.25 MHz Chan / 30 kHz Step/ Center Freq = 870 + (Chan Number -1023) x .03 MHz

A,B,A',B': 1.25 MHz Chan / 30 kHz Step/ Center Freq = 870 + (Chan Number x .03) MHz

	Guard						Guard
CHAN	990	1013 1023	1 311	356 644	689 694	739 777	800
BS FREQ		869.7 870	870.03 879.33	880.68 889.32	890.67 890.82	892.17 893.31	
		A''	A	B	A'	B'	

FREQ 869.01 870.015 880.005 889.995 891.495 894

GSM 1900

200 kHz Chan / Center Freq = 1930 + (Chan Number - 511) x 0.2 MHz

	Guard							Guard
CHAN	511	512 585	587 610	612 685	687 710	712 735	737 810	811
BS FREQ		1930.2 1944.8	1945.2 1949.8	1950.2 1964.8	1965.2 1969.8	1970.2 1974.8	1975.2 1989.8	
		A	D	B	E	F	C	

FREQ 1930 1945 1950 1965 1970 1975 1990

CDMA 1900

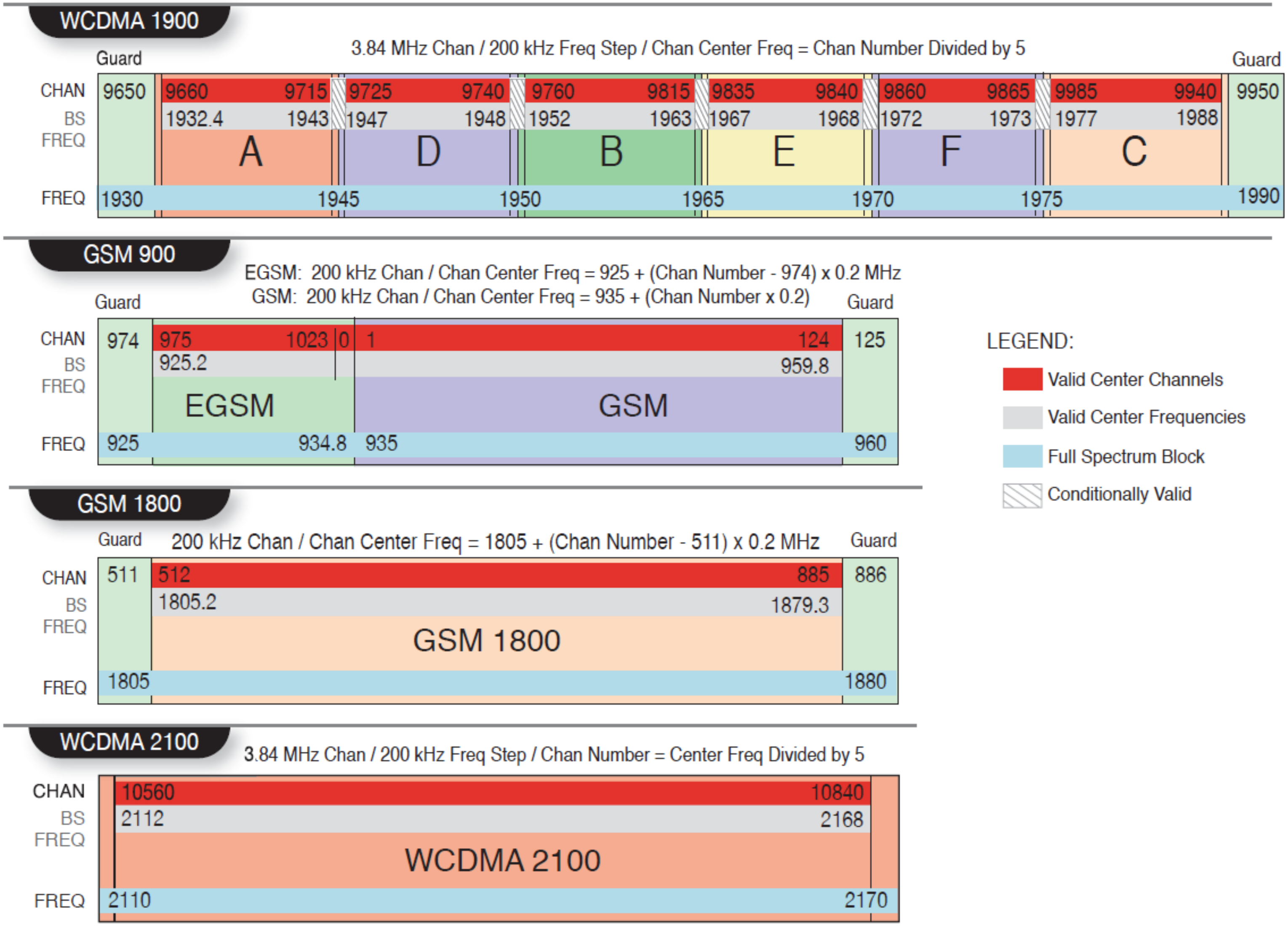
1.25 MHz Chan / 50 kHz Step / Center Freq = 1930 + (Chan Number x 0.05) MHz

	Guard							Guard
CHAN	0	25 275	325 375	425 675	725 775	825 875	925 1175	1200
BS FREQ		1931.25 1943.75	1946.25 1948.75	1951.25 1963.75	1966.25 1968.75	1971.25 1973.75	1976.25 1988.75	
		A	D	B	E	F	C	

FREQ 1930 1945 1950 1965 1970 1975 1990

[http://www.qrctech.com/freq_chart_24x36.pdf]

Forward link (BS to MS) Frequencies and Channelization (2)



WCDMA 1900

3.84 MHz Chan / 200 kHz Freq Step / Chan Center Freq = Chan Number Divided by 5

	Guard							Guard
CHAN	9650	9660 9715	9725 9740	9760 9815	9835 9840	9860 9865	9985 9940	9950
BS FREQ		1932.4 1943	1947 1948	1952 1963	1967 1968	1972 1973	1977 1988	
		A	D	B	E	F	C	
FREQ	1930	1945	1950	1965	1970	1975		1990

GSM 900

EGSM: 200 kHz Chan / Chan Center Freq = 925 + (Chan Number - 974) x 0.2 MHz
GSM: 200 kHz Chan / Chan Center Freq = 935 + (Chan Number x 0.2)

	Guard			Guard
CHAN	974	975 1023 | 0	1 124	125
BS FREQ		925.2	959.8	
		EGSM	GSM	
FREQ	925	934.8	935	960

GSM 1800

200 kHz Chan / Chan Center Freq = 1805 + (Chan Number - 511) x 0.2 MHz

	Guard		Guard
CHAN	511	512 885	886
BS FREQ		1805.2 1879.3	
		GSM 1800	
FREQ	1805		1880

WCDMA 2100

3.84 MHz Chan / 200 kHz Freq Step / Chan Number = Center Freq Divided by 5

CHAN	10560 10840
BS FREQ	2112 2168
	WCDMA 2100
FREQ	2110 2170

LEGEND:

- 🟥 Valid Center Channels
- ⬜ Valid Center Frequencies
- 🟦 Full Spectrum Block
- ▨ Conditionally Valid

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

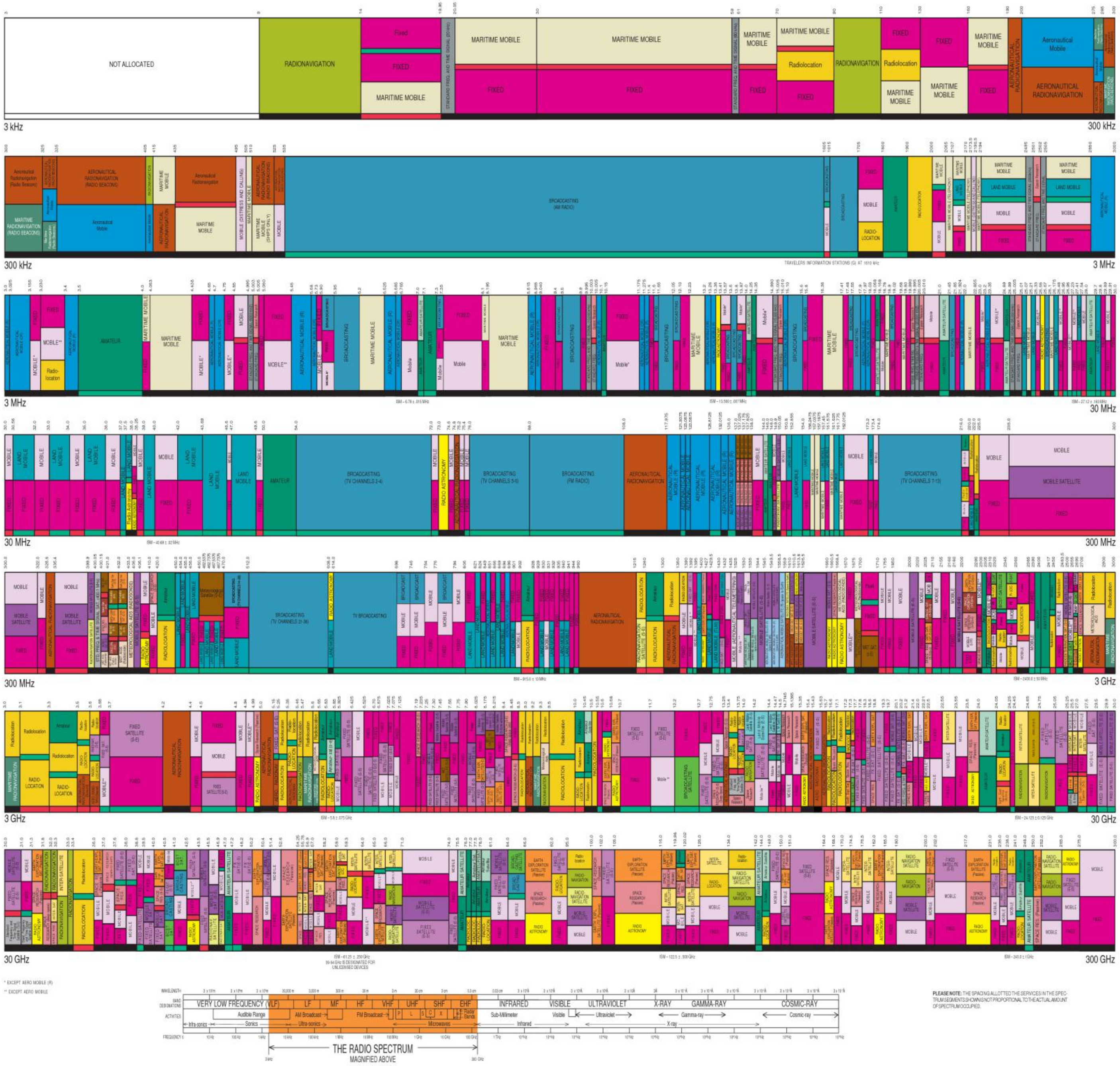
ALLOCATION USAGE DESIGNATION

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

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

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

October 2003



* EXCEPT AERO MOBILE (R)

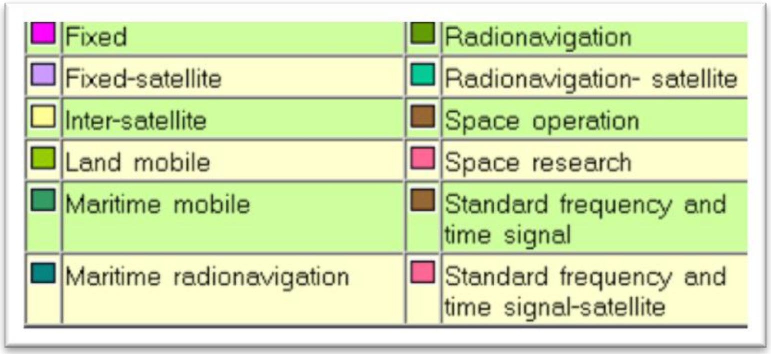
** EXCEPT AERO MOBILE

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

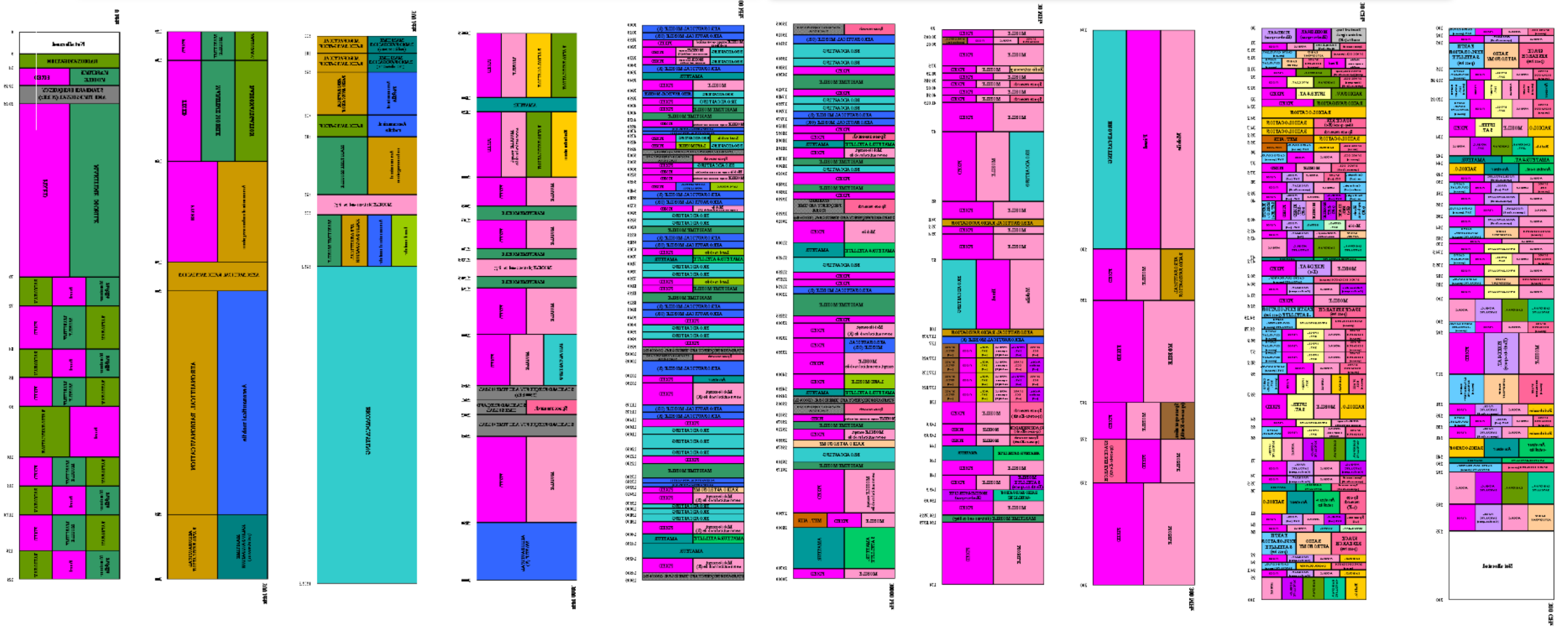
Thailand Freq. Allocations Chart

RADIO SERVICES COLOR LEGEND

■	Aeronautical mobile	■	Meteorological aids
■	Aeronautical radionavigation	■	Meteorological-satellite
■	Amateur	■	Mobile
■	Amateur-satellite	■	Mobile-satellite
■	Broadcasting	■	Radio astronomy
■	Broadcasting-satellite	■	Radiodetermination-satellite
■	Earth exploration- satellite	■	Radiolocation



■	Fixed	■	Radionavigation
■	Fixed-satellite	■	Radionavigation- satellite
■	Inter-satellite	■	Space operation
■	Land mobile	■	Space research
■	Maritime mobile	■	Standard frequency and time signal
■	Maritime radionavigation	■	Standard frequency and time signal-satellite



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

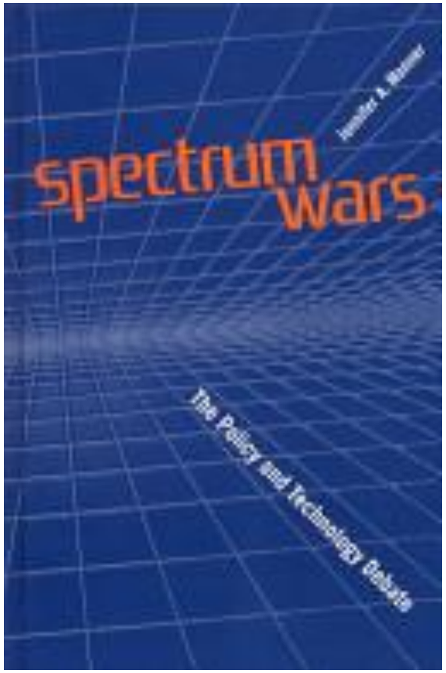
Spectrum Allocation

- 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**; สำนักงานคณะกรรมการกิจการโทรคมนาคมแห่งชาติ; กทช.)
- 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."



US licensed spectrum

AM Radio	535-1605 KHz
FM Radio	88-108 MHz
Broadcast TV (Channels 2-6)	54-88 MHz
Broadcast TV (Channels 7-13)	174-216 MHz
Broadcast TV (UHF)	470-806 MHz
3G Broadband Wireless	746-764 MHz, 776-794 MHz
3G Broadband Wireless	1.7-1.85 MHz, 2.5-2.69 MHz
1G and 2G Digital Cellular Phones	806-902 MHz
Personal Communications Service (2G Cell Phones)	1.85-1.99 GHz
Wireless Communications Service	2.305-2.32 GHz, 2.345-2.36 GHz
Satellite Digital Radio	2.32-2.325 GHz
Multichannel Multipoint Distribution Service (MMDS)	2.15-2.68 GHz
Digital Broadcast Satellite (Satellite TV)	12.2-12.7 GHz
Local Multipoint Distribution Service (LMDS)	27.5-29.5 GHz, 31-31.3 GHz
Fixed Wireless Services	38.6-40 GHz

Unlicensed bands

- In addition to spectral auctions, spectrum can be set aside in specific frequency bands that are **free to use** with a license according to a specific set of **etiquette rules**.
- The purpose of these unlicensed bands is to encourage innovation and low-cost implementation.
- Many extremely successful wireless systems operate in unlicensed bands, including **wireless LANs, Bluetooth, and cordless phones**.
- Major difficulty: Interference
  - If many unlicensed devices in the same band are used in close proximity, they generate much **interference** to each other, which can make the band unusable.

Unlicensed bands (2)

- Unlicensed spectrum is allocated by the governing body within a given country.
- Often countries try to match their frequency allocation for unlicensed use so that technology developed for that spectrum is compatible worldwide.
- The following table shows the unlicensed spectrum allocations in the U.S.

(ISM = Industrial, Scientific, and Medical)

900 MHz	ISM Band I (Cordless phones, 1G WLANs)	902-928 MHz
2.4 GHz	ISM Band II (Bluetooth, 802.11b WLANs)	2.4-2.4835 GHz
	U-NII / ISM Band III (Wireless PBX)	5.725-5.85 GHz
	NII Band I (Indoor systems, 802.11a WLANs)	5.15-5.25 GHz
	NII Band II (short outdoor and campus applications)	5.25-5.35 GHz
	NII Band III (long outdoor and point-to-point links)	5.725-5.825 GHz

U-NII = Unlicensed National Information Infrastructure

[Tse Viswanath, 2005, Section 4.1]

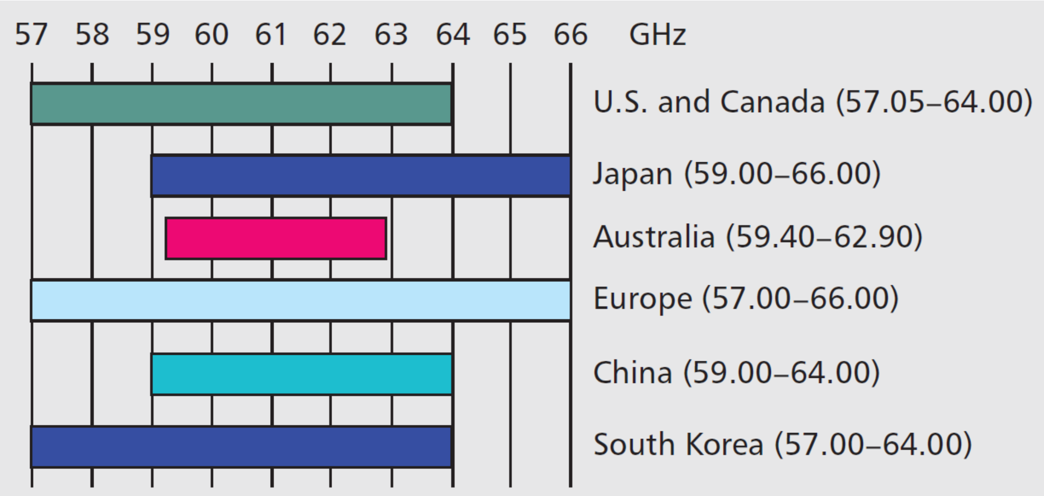
Licensed vs. Unlicensed Spectra

Licensed	Unlicensed
Typically nationwide. Over a period of a few years. From the spectrum regulatory agency.	For experimental systems and to aid development of new wireless technologies.
Bandwidth is very expensive.	Very cheap to transmit on.
No hard constraints on the power transmitted within the licensed spectrum but the power is expected to decay rapidly outside.	There is a maximum power constraint over the entire spectrum.
Provide immunity from any kind of interference outside of the system itself.	Have to deal with interference.

Unlicensed 60 GHz Frequency Band

- A lot of bandwidth available

Worldwide spectrum availability

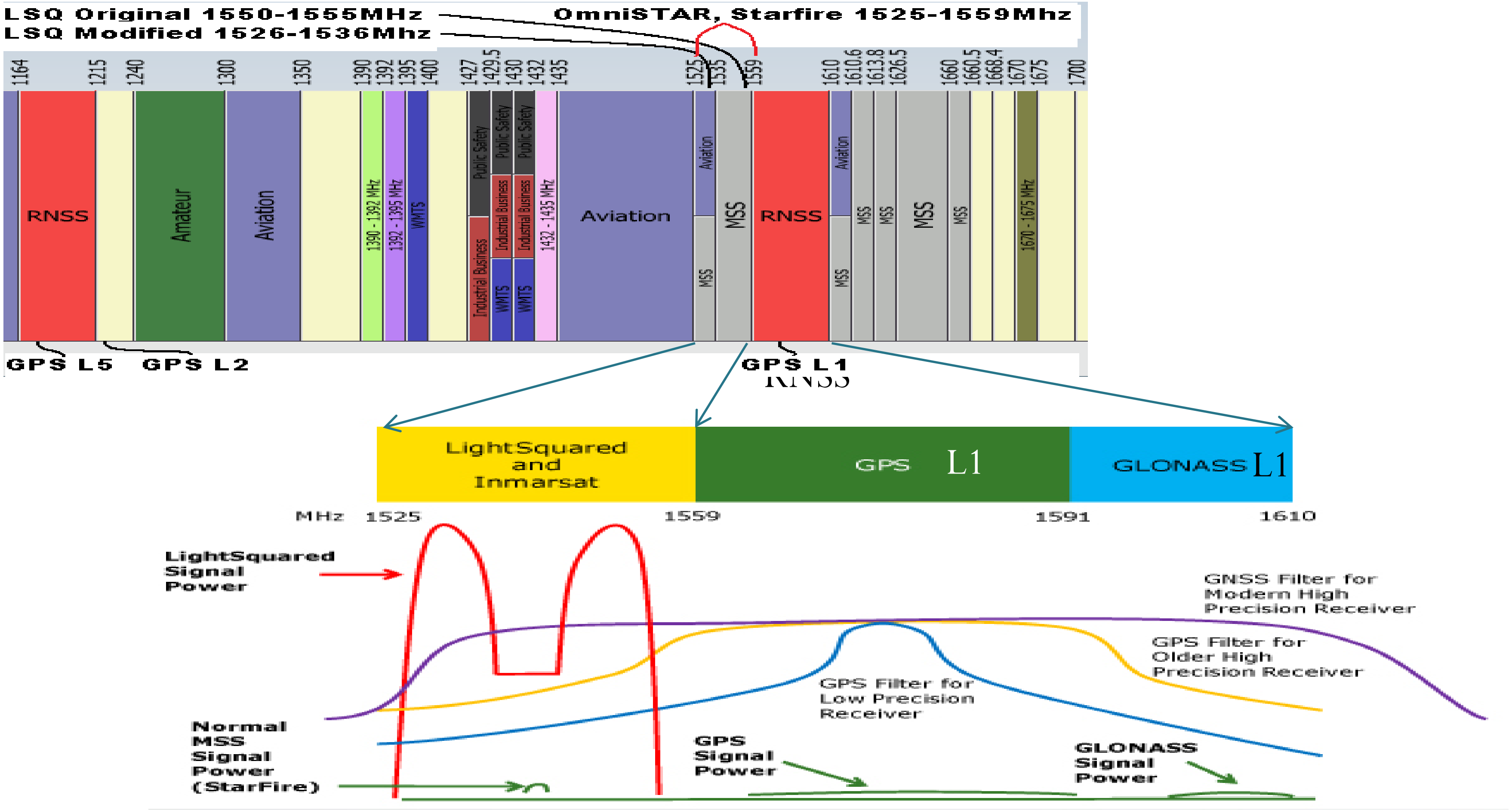


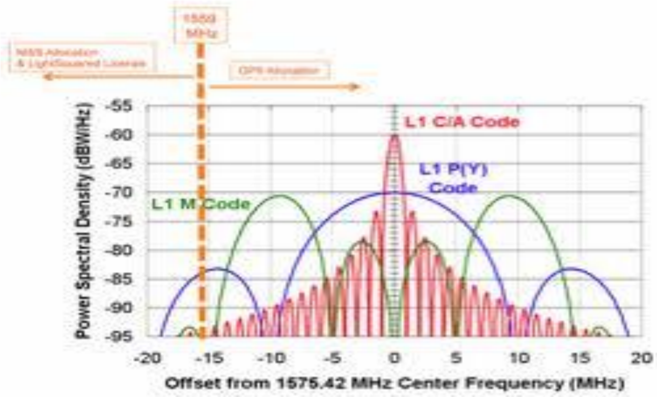
- Even for the smallest allocation, there is more than 3 GHz of bandwidth available, and most regions allow use of at least **7 GHz**.
  - In comparison, the 5 GHz unlicensed band has about 500 MHz of total usable bandwidth.
  - The 2.4 GHz band has less than 85 MHz of bandwidth in most regions.

News: LightSquared vs. GPS industry

- The FCC recently (Jan 2011) 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.

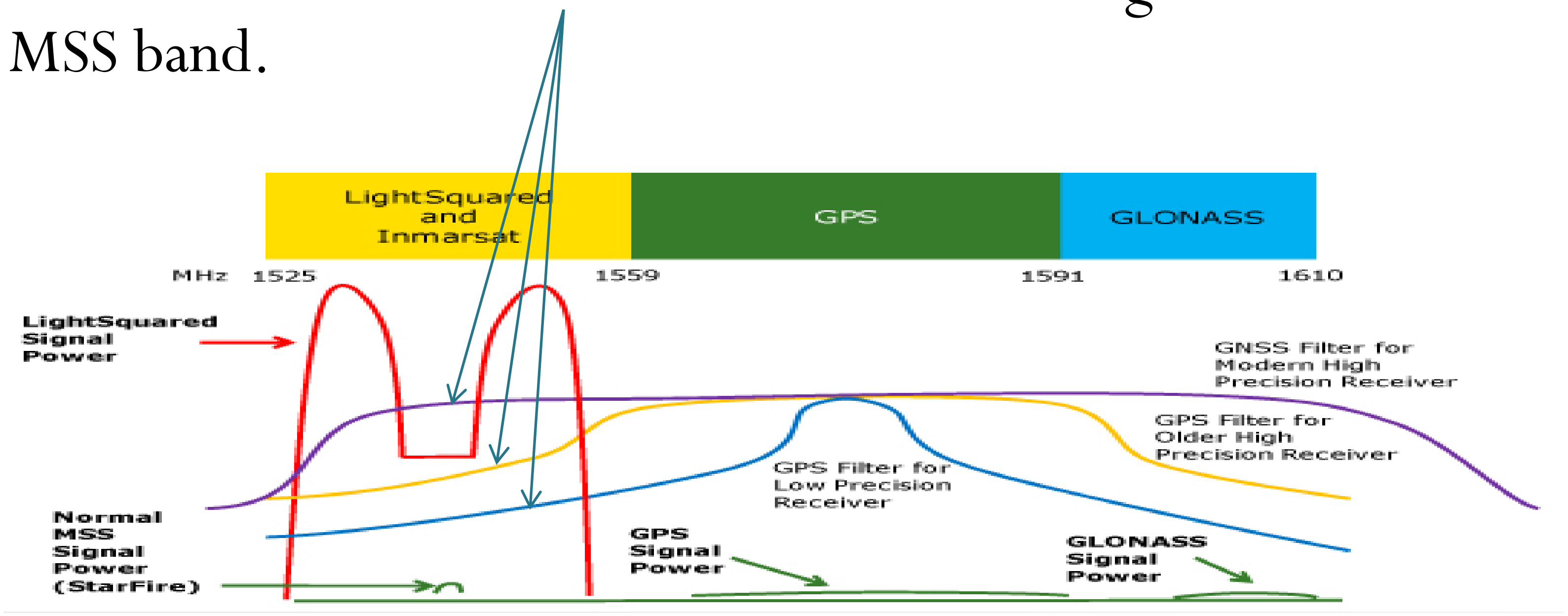
[GPS World, December 2011]


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
Public Safety
Industrial Business
WMTS
Public Safety
Industrial Business
WMTS
1432 - 1435 MHz
Aviation
Aviation
MSS
MSS
RNSS
Aviation
MSS
MSS
MSS
MSS
MSS
1670 - 1675 MHz
GPS L5
GPS L2
GPS L1
RNSS
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
MSS Allocation & LightSquared License
GPS Allocation
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.
- Mobile networks based on different standards may use the same "frequency chunk".
  - For example, AMPS, D-AMPS, N-AMPS and IS-95 all use the 800 MHz "frequency chunk".
  - This is achieved by the use of **different channels**.