ECS 455 Chapter 1

Introduction & Review

1.4 Spectrum Allocation

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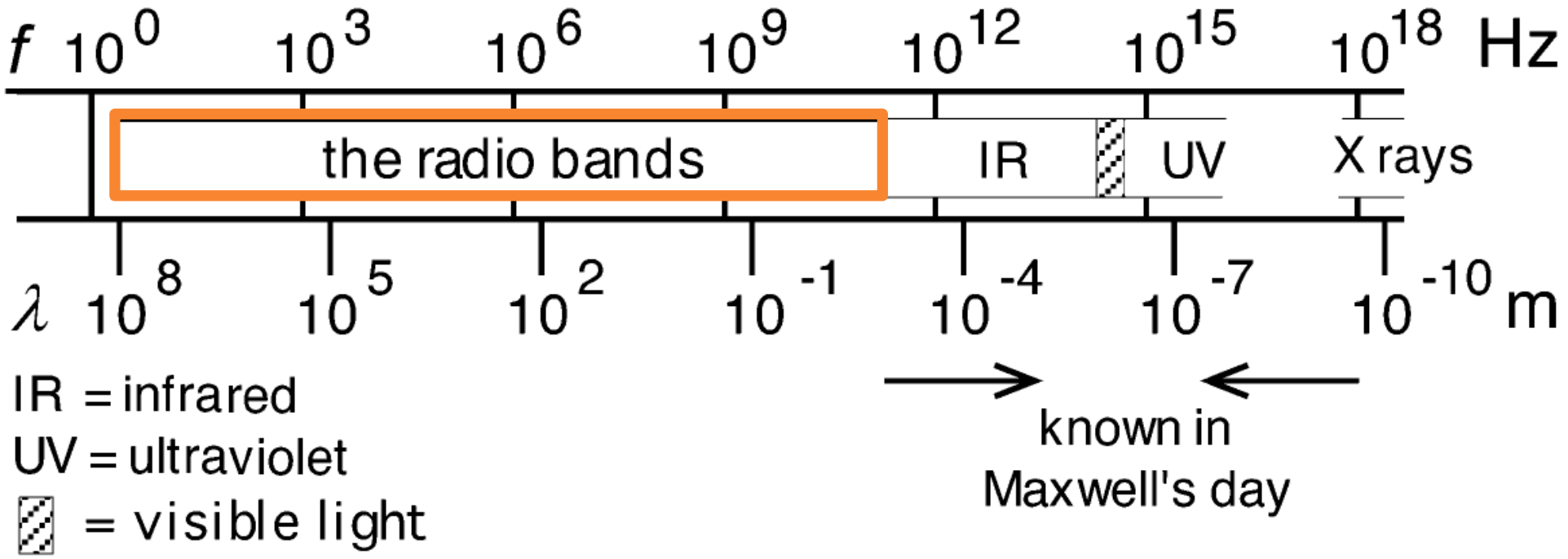
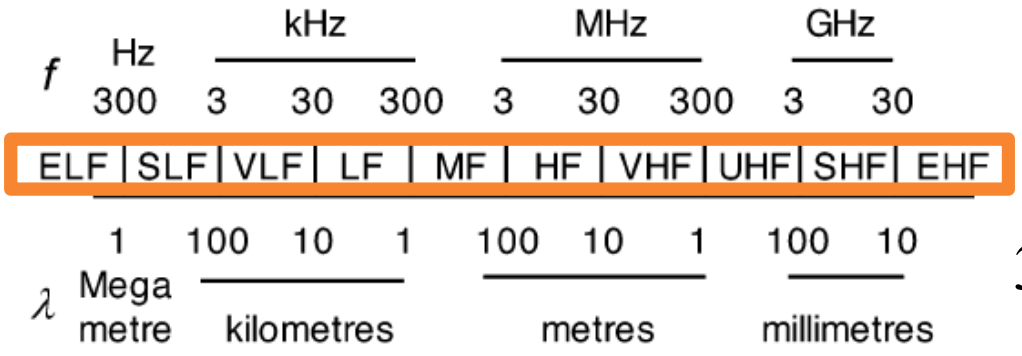
Office Hours:
BKD 3601-7

Tuesday	**9:30-10:30**
Tuesday	**13:30-14:30**
Thursday	**13:30-14:30**

Electromagnetic Spectrum



[Gosling , 1999, Fig 1.1 and 1.2]



$c = f\lambda$

3×10^8 m/s

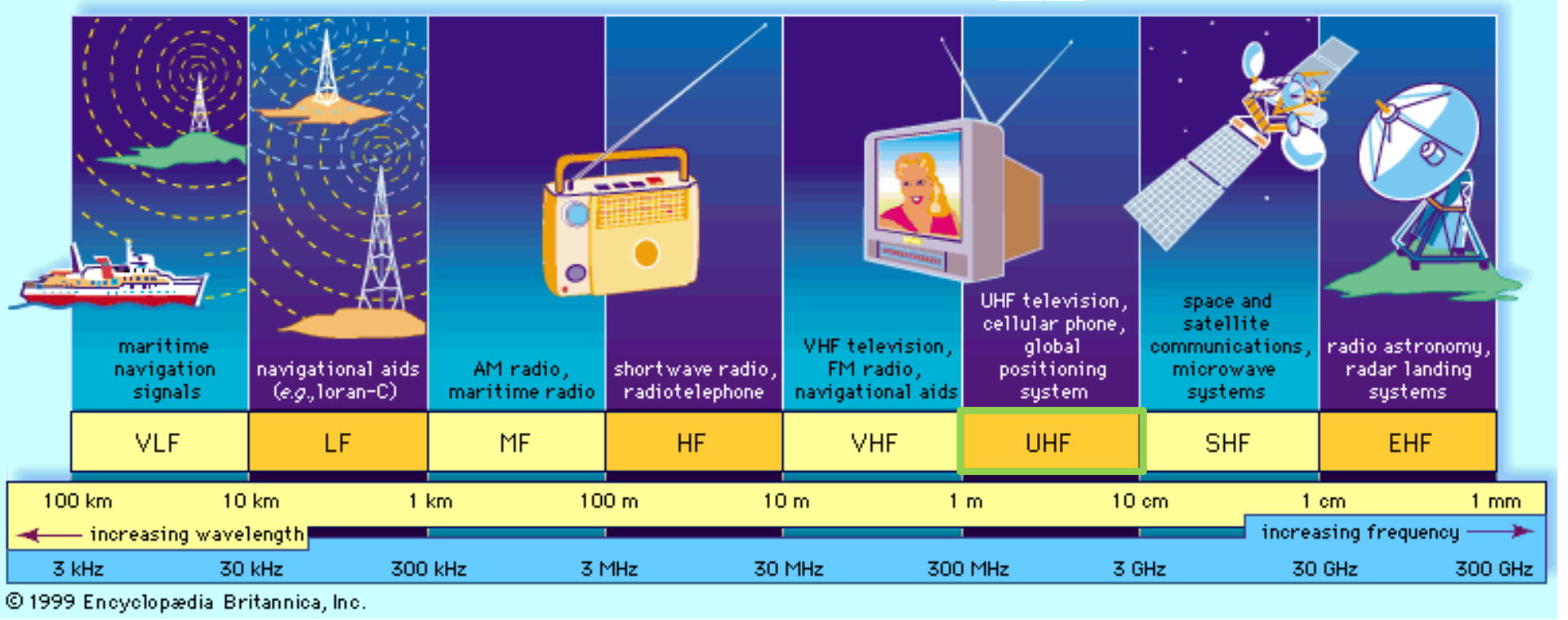
Wavelength

Frequency

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

Radio-frequency spectrum

- Commercially exploited bands



$$c = f\lambda$$

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, GPS, 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

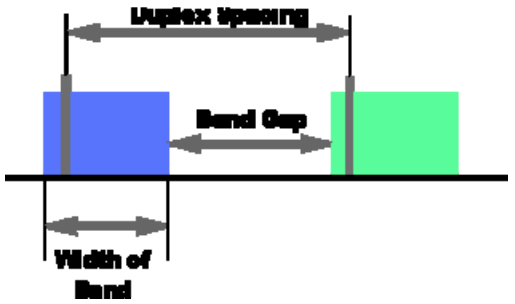
FDD and TDD LTE frequency bands

FDD LTE frequency band allocations

LTE BAND NUMBER	UPLINK (MHZ)	DOWNLINK (MHZ)	WIDTH OF BAND (MHZ)	DUPLEX SPACING (MHZ)	BAND GAP (MHZ)
1	1920 - 1980	2110 - 2170	60	190	130
2	1850 - 1910	1930 - 1990	60	80	20
3	1710 - 1785	1805 -1880	75	95	20
4	1710 - 1755	2110 - 2155	45	400	355
5	824 - 849	869 - 894	25	45	20
6	830 - 840	875 - 885	10	35	25
7	2500 - 2570	2620 - 2690	70	120	50
8	880 - 915	925 - 960	35	45	10
9	1749.9 - 1784.9	1844.9 - 1879.9	35	95	60
10	1710 - 1770	2110 - 2170	60	400	340
11	1427.9 - 1452.9	1475.9 - 1500.9	20	48	28
12	698 - 716	728 - 746	18	30	12
13	777 - 787	746 - 756	10	-31	41
14	788 - 798	758 - 768	10	-30	40
15	1900 - 1920	2600 - 2620	20	700	680
16	2010 - 2025	2585 - 2600	15	575	560
17	704 - 716	734 - 746	12	30	18
18	815 - 830	860 - 875	15	45	30
19	830 - 845	875 - 890	15	45	30
20	832 - 862	791 - 821	30	-41	71
21	1447.9 - 1462.9	1495.5 - 1510.9	15	48	33
22	3410 - 3500	3510 - 3600	90	100	10
23	2000 - 2020	2180 - 2200	20	180	160
24	1625.5 - 1660.5	1525 - 1559	34	-101.5	135.5
25	1850 - 1915	1930 - 1995	65	80	15

TDD LTE frequency band allocations

LTE BAND NUMBER	ALLOCATION (MHZ)	WIDTH OF BAND (MHZ)
33	1900 - 1920	20
34	2010 - 2025	15
35	1850 - 1910	60
36	1930 - 1990	60
37	1910 - 1930	20
38	2570 - 2620	50
39	1880 - 1920	40
40	2300 - 2400	100
41	2496 - 2690	194
42	3400 - 3600	200
43	3600 - 3800	200



[http://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/lte-frequency-spectrum.php]

(โทรทัศน์ภาคพื้นดิน)

Analog (Old) terrestrial TV in BKK

ความถี่สัญญาณโทรทัศน์ VHF.(Low Band)			
Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
2	47 - 54	48.25	53.75
3	54 - 61	55.25	60.75
4	61 - 68	62.25	67.75
ความถี่สัญญาณโทรทัศน์ VHF.(Hight Band)			
Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
5	174 - 181	175.25	180.75
6	181 - 188	182.25	187.75
7	188 - 195	189.25	194.75
8	195 - 202	196.25	201.75
9	202 - 209	203.25	208.75
10	209 - 216	210.25	215.75
11	216 - 223	217.25	222.75
12	223 - 230	224.25	229.75
ความถี่สัญญาณโทรทัศน์ UHF.(Band 4)			
Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
26	510 - 518	511.25	516.75
27	518 - 526	519.25	524.75
28	526 - 534	527.25	532.75
29	534 - 542	535.25	540.75
30	542 - 550	543.25	548.75
31	550 - 558	551.25	556.75
32	558 - 566	559.25	564.75
33	566 - 574	567.25	562.75
34	574 - 582	575.25	580.75

ความถี่สัญญาณโทรทัศน์ UHF.(Band 5)			
Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
35	582 - 590	583.25	588.75
36	590 - 598	591.25	596.75
37	598 - 606	599.25	604.75
38	606 - 614	607.25	612.75
39	614 - 622	615.25	620.75
40	622 - 630	623.25	628.75
41	630 - 638	631.25	636.75
42	638 - 646	639.25	644.75
43	646 - 654	647.25	652.75
44	654 - 662	655.25	660.75
45	662 - 670	663.25	668.75
46	670 - 678	671.25	676.75
47	678 - 686	679.25	684.75
48	686 - 694	687.25	692.75
49	694 - 702	695.25	700.75
50	702 - 710	703.25	708.75
51	710 - 718	711.25	716.75
52	718 - 726	719.25	724.75
53	726 - 734	727.25	732.75
54	734 - 742	735.25	740.75
55	742 - 750	743.25	748.75
56	750 - 758	751.25	756.75
57	758 - 766	759.25	764.75
58	766 - 774	767.25	772.75
59	774 - 782	775.25	780.75
60	782 - 790	783.25	788.75

(โทรทัศน์ภาคพื้นดิน)

Terrestrial TV in BKK

ความถี่สัญญาณโทรทัศน์ VHF.(Low Band)			
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Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
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12	223 - 230	224.25	229.75
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Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
26	510 - 518	511.25	516.75
27	518 - 526	519.25	524.75
28	526 - 534	527.25	532.75
29	534 - 542	535.25	540.75
30	542 - 550	543.25	548.75
31	550 - 558	551.25	556.75
32	558 - 566	559.25	564.75
33	566 - 574	567.25	562.75
34	574 - 582	575.25	580.75

MUX 1

MUX 2

MUX 3

MUX 4

MUX 5

ความถี่สัญญาณโทรทัศน์ UHF.(Band 5)			
Channel.	Bandwidth.	Picture Carrier.	Audio Carrier.
35	582 - 590	583.25	588.75
36	590 - 598	591.25	596.75
37	598 - 606	599.25	604.75
38	606 - 614	607.25	612.75
39	614 - 622	615.25	620.75
40	622 - 630	623.25	628.75
41	630 - 638	631.25	636.75
42	638 - 646	639.25	644.75
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52	718 - 726	719.25	724.75
53	726 - 734	727.25	732.75
54	734 - 742	735.25	740.75
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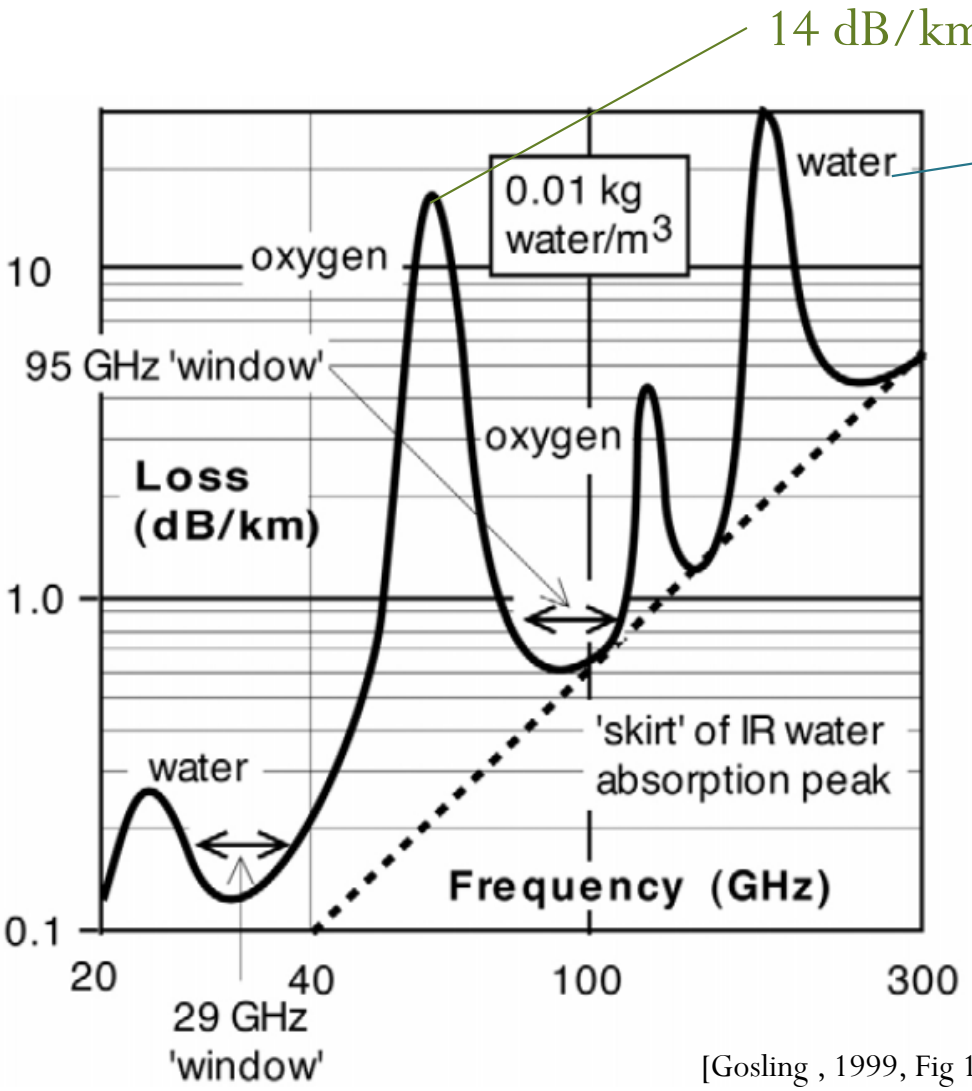
57	758 - 766	759.25	764.75
58	766 - 774	767.25	772.75
59	774 - 782	775.25	780.75
60	782 - 790	783.25	788.75

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]

Upper limits on radio use



[Gosling , 1999, Fig 1.3]

Make commu. very dependent on weather conditions

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

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 Broadcasting and Telecommunications Commission (**NBTC**; คณะกรรมการกิจการกระจายเสียง กิจการโทรทัศน์และกิจการโทรคมนาคมแห่งชาติ ; กสทช.)

- Blocks of spectrum are now commonly assigned through **spectral auctions** to the highest bidder.

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

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

OCTOBER 2011

NOT ALLOCATED
RADIONAVIGATION
FIXED
MARITIME MOBILE
RADIOLOCATION
AERONAUTICAL MOBILE
AERONAUTICAL RADIONAVIGATION
AMATEUR
BROADCASTING
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz

Crowded!!!

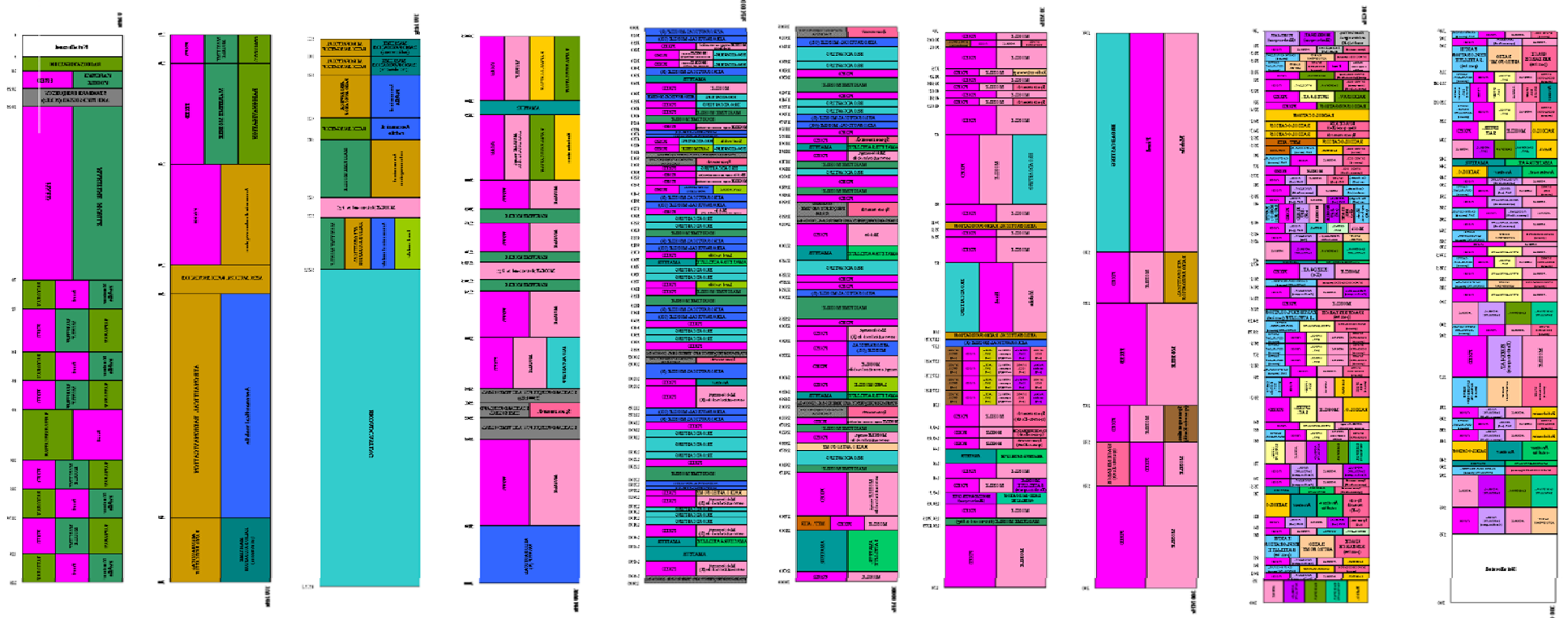
2011

[http://www.ntia.doc.gov/page/2011/united-states-frequency-allocation-chart]

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



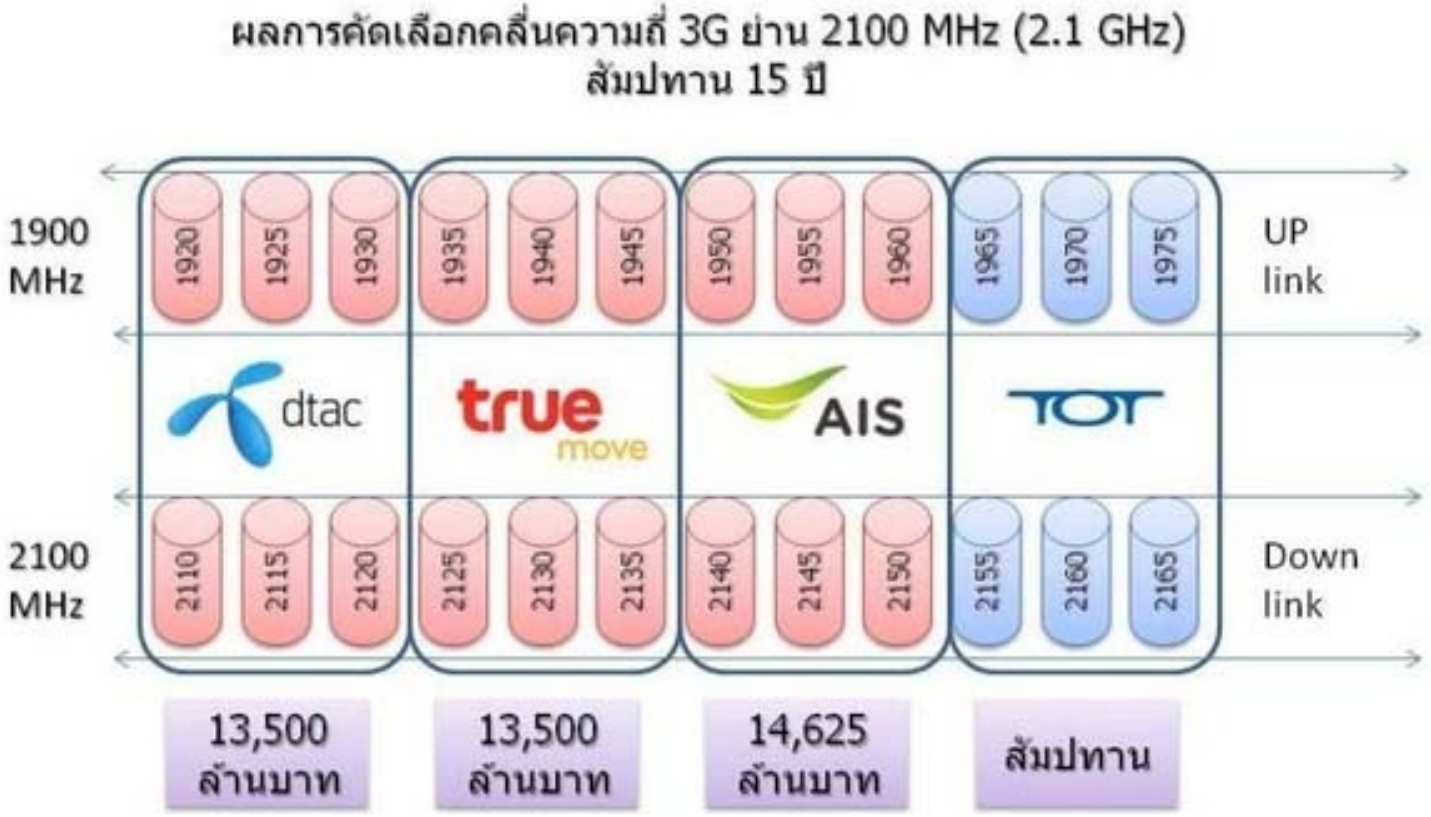
http://www.ntc.or.th/uploadfiles/freq_chart_thai.htm

Spectrum Allocation (Final Words)

- Spectrum is a **scarce** resource.
  - "Radio spectrum will be the first of our finite resources to run out, long before oil, gas or mineral deposits."
- 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**.

Oct 2012: Thailand 2.1GHz Auction

- ≈ 4.5bn baht per license (freq chunk)
  - 1 license (chunk) = 5 MHz (UL) + 5 MHz (DL)
  - ≈ 450 million baht per MHz
  - ≈ 30 million baht per MHz per year

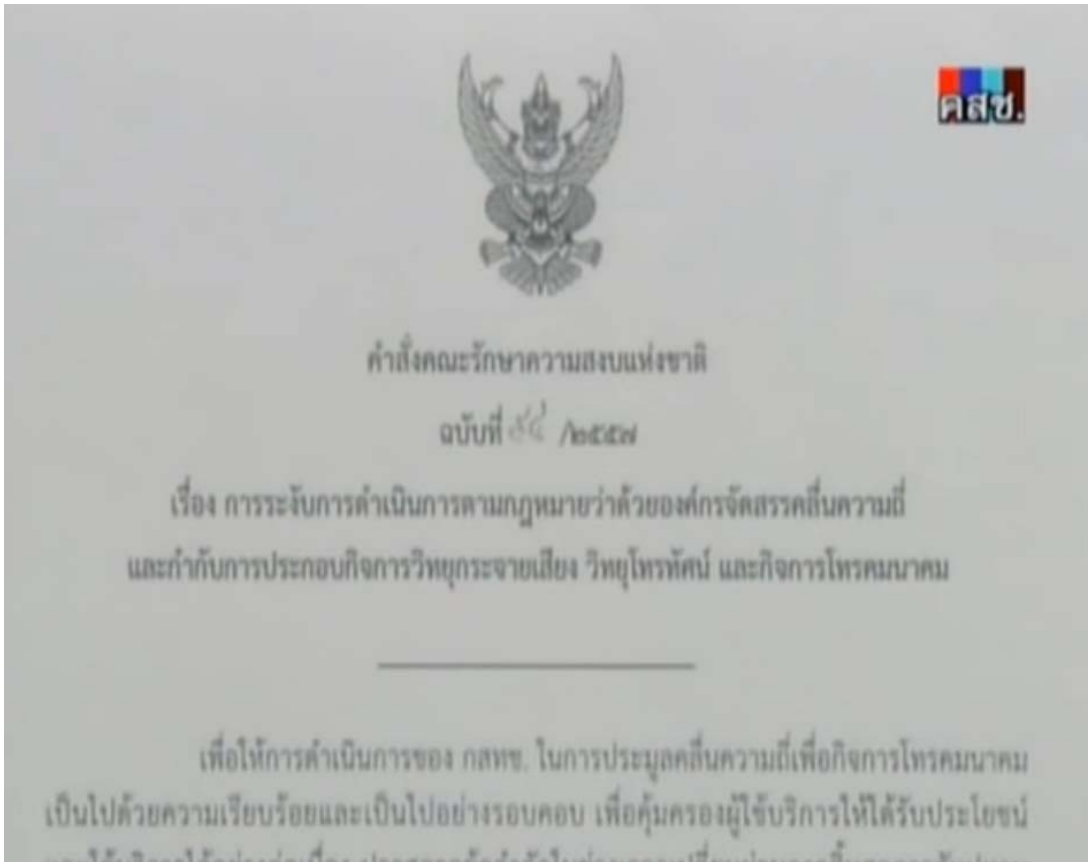


2015 Auction(s) (in August?)

- 42.5 MHz of (currently 2G) spectrum
  - 25 MHz of the 1800-MHz spectrum
  - 17.5 MHz of the 900-MHz spectrum
- Previously leased to AIS, TrueMove, and Digital Phone Co (DPC)
  - TrueMove and DPC's 1800 MHz band concession (สัมปทาน) expired since September 2013.
    - Extended for one year by the NBTC's customer protection measures
  - AIS's concession (from TOT) in the 900 MHz band will expire in September 2015.
  - Auctions (planned to be in Aug 2014 and Nov 2014, respectively) were postponed (at least) until July 2015 by an order from the National Council for Peace and Order (NCPO)

คำสั่งฉบับที่ 94/2557(คสช.)

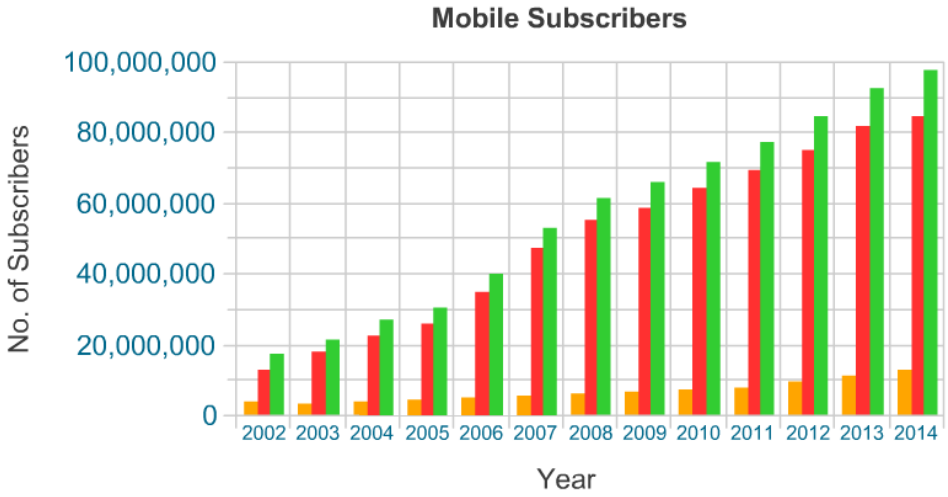
ข้อ 1 ให้ กสทช.ชะลอการดำเนินการเกี่ยวกับการประมูลคลื่นความถี่ เพื่อกิจการโทรคมนาคมออกไปเป็นระยะเวลาหนึ่งปี

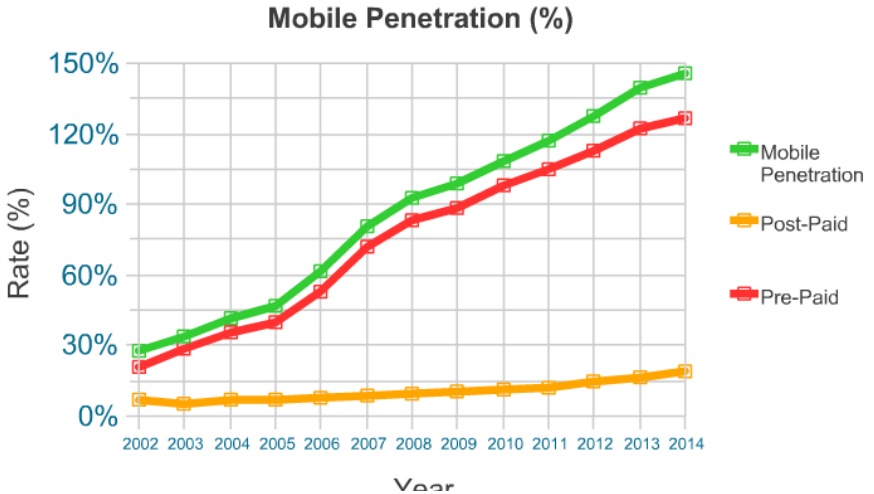


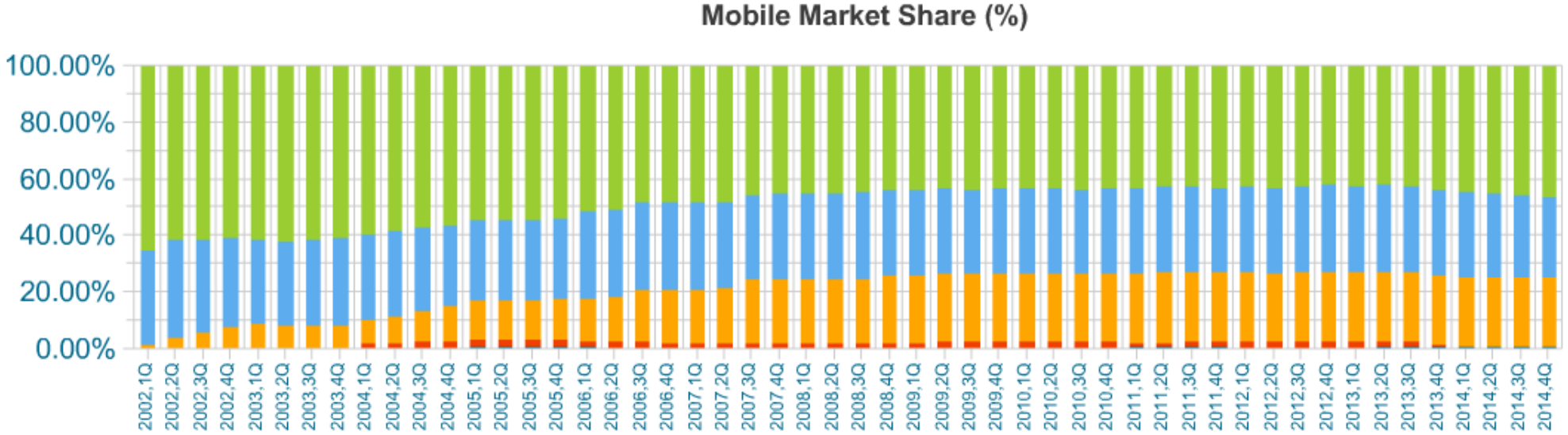
https://www.youtube.com/watch?v=HipFi2PDxG8
https://www.youtube.com/watch?v=w1baTZKu1T8

Thailand Status in 2014

$100/70 \approx 140\%$







http://www2.nbtc.go.th/TTID/

Last updated: 8 January 2015
*** Estimated information for Q4 Year 2014.*
Source: Operators

Digital TV License Auction in 2012

Channels for variety TV in high definition (HD) and standard definition (SD)

[http://hilight.kapook.com/view/95367]

Digital TV License Auction in 2012

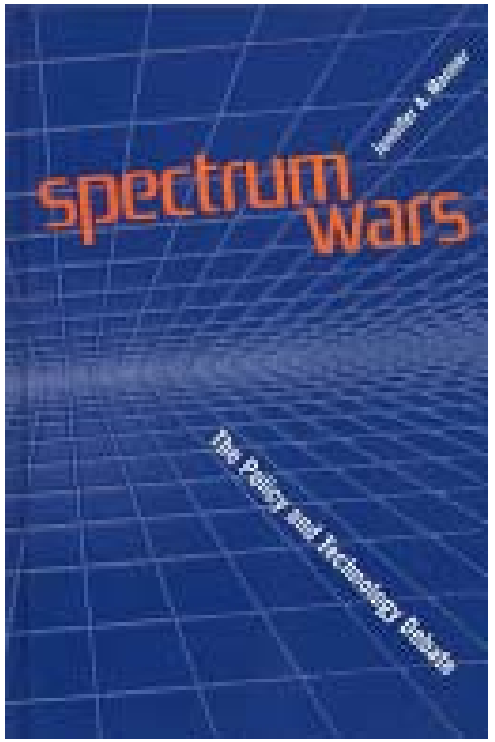
News and children's/family channels

[http://hilight.kapook.com/view/95408]

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."

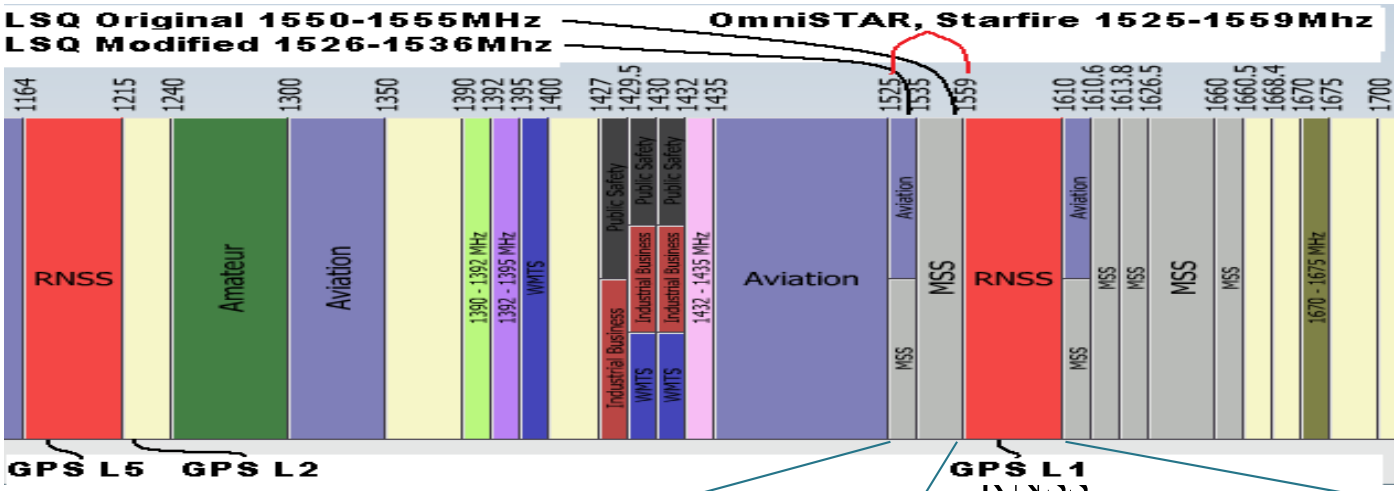


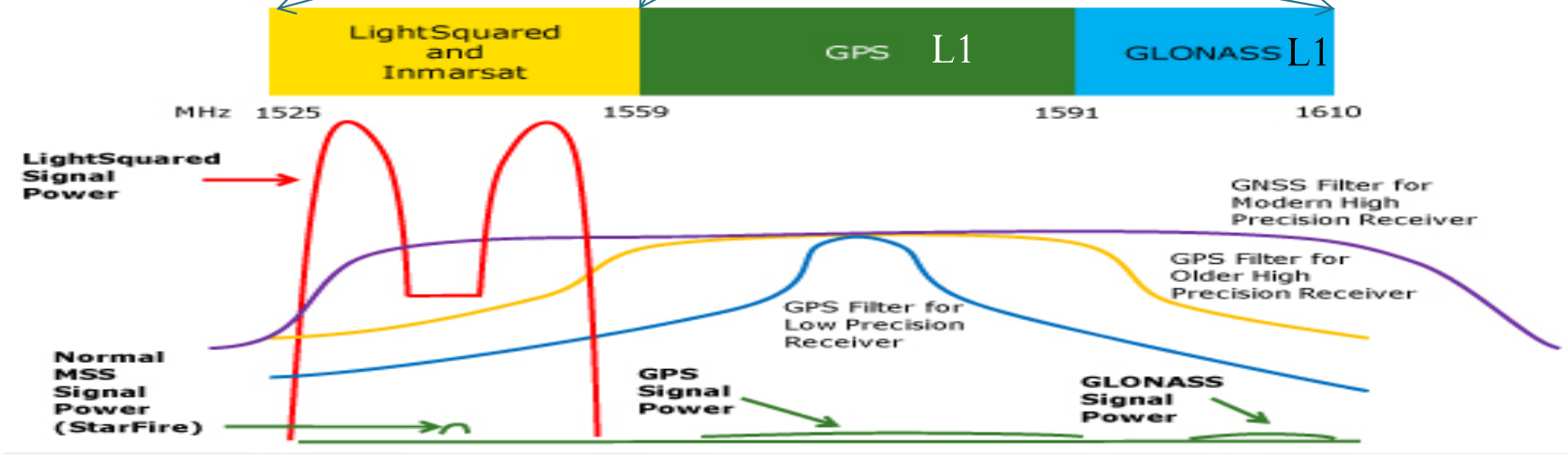
[Manner, 2003]

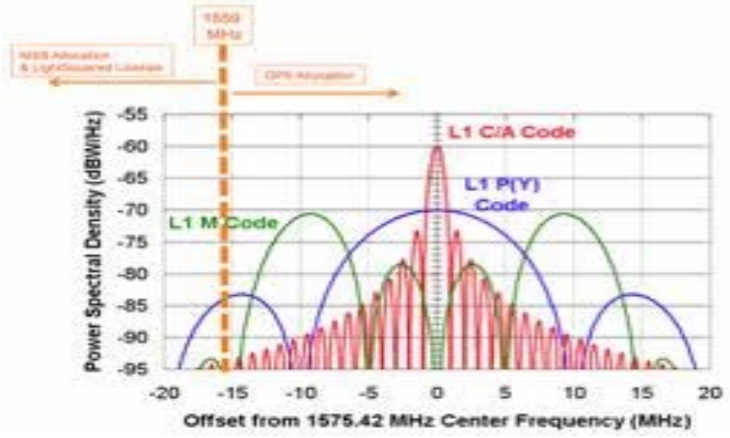
News: LightSquared vs. GPS industry

- In Jan 2011, the FCC 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 (L1)**
  - 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 (the relatively faint) GPS receivers.

[GPS World, December 2011]

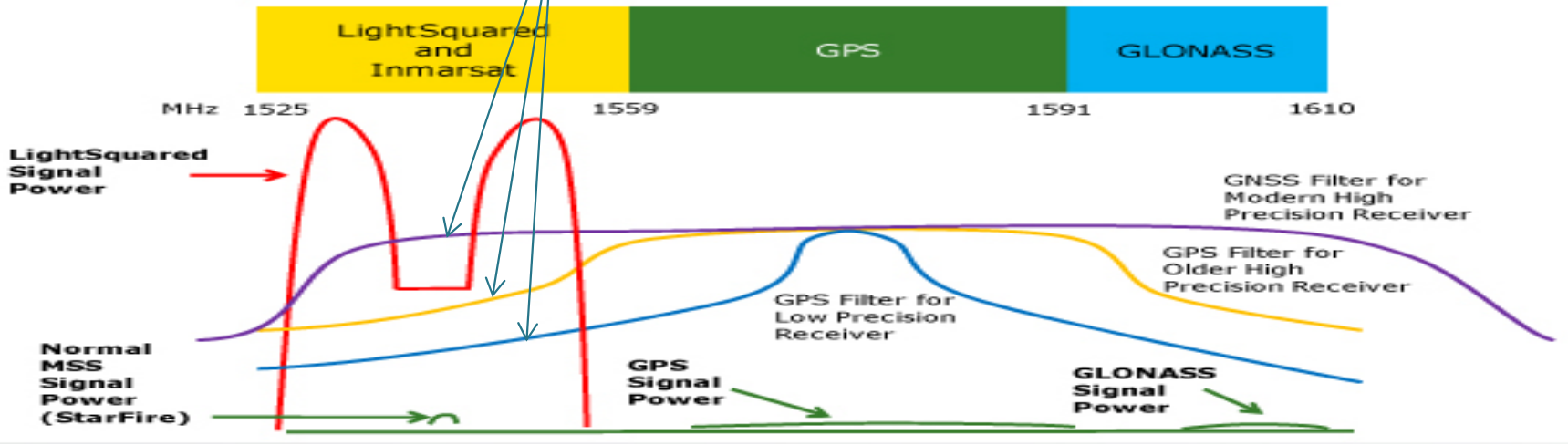

LSQ Original 1550-1555MHz
LSQ Modified 1526-1536Mhz
OmniSTAR, Starfire 1525-1559Mhz
1164
1215
1240
1300
1350
1390
1392
1395
1400
1427
1429.5
1430
1432
1435
1525
1535
1559
1610
1610.6
1613.8
1626.5
1660
1660.5
1668.4
1670
1675
1700
RNSS
Amateur
Aviation
1390 - 1392 MHz
1392 - 1395 MHz
WMTS
Public Safety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

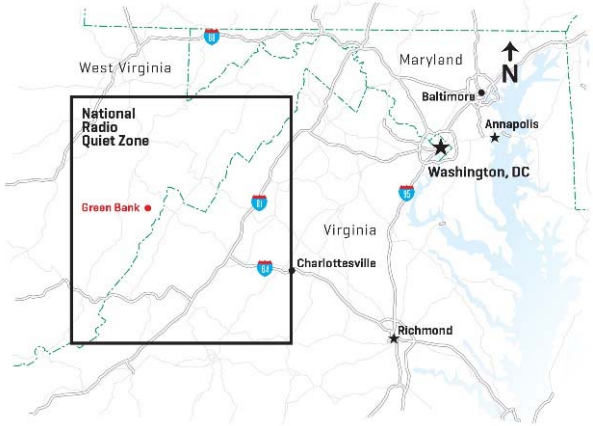
- GPS receivers have filters that do not block signals from the MSS band.



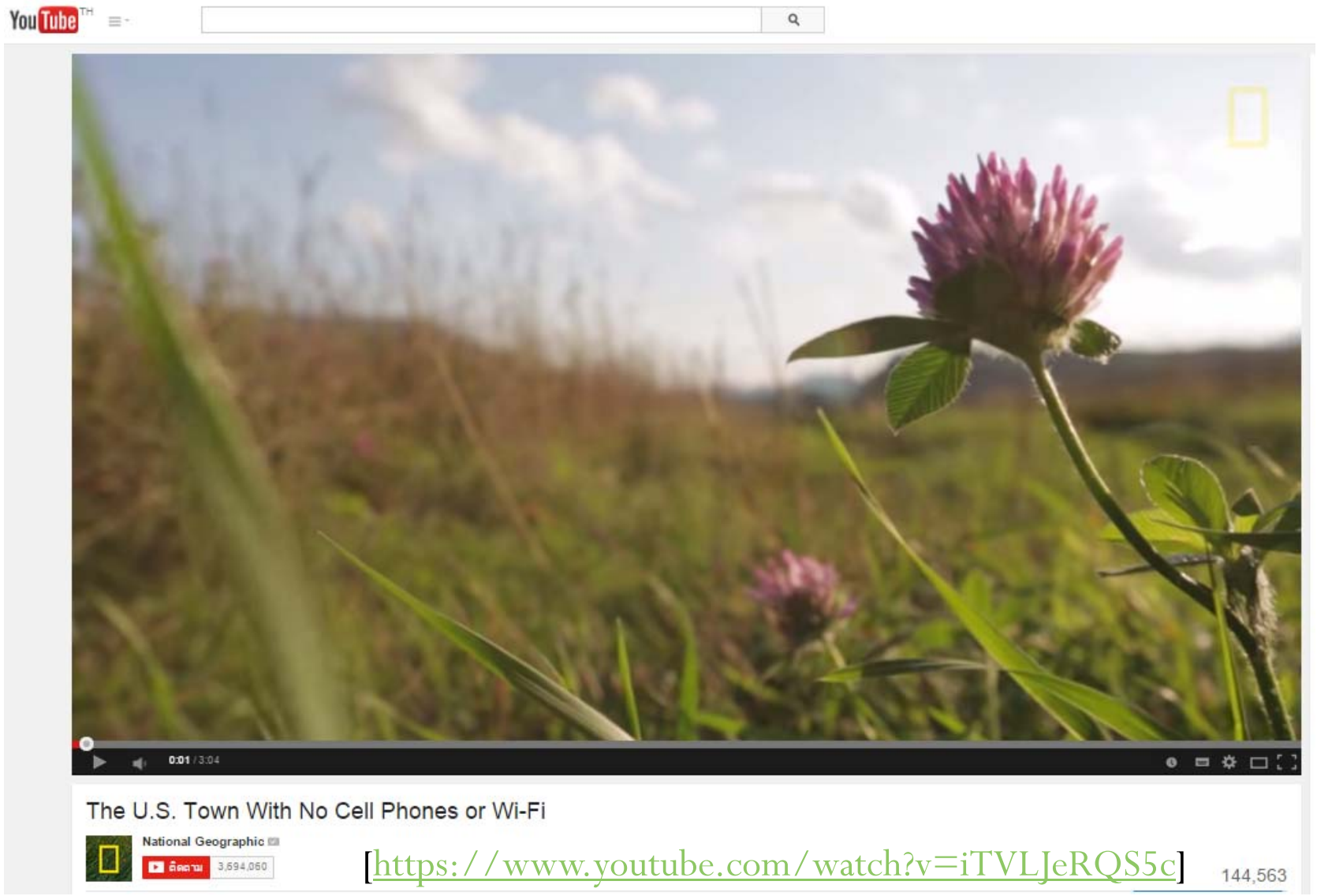
- These filters has enabled both low-cost and high-precision GPS receivers.
- Assumption: Signals in MSS band were low-power.
- Latest updates: See www.gps.gov/spectrum/lightsquared/

Electromagnetic silence in a town where wireless signals are forbidden

- 13,000 sq miles (33,000 sq km) **National Radio Quiet Zone**
- Green Bank, West Virginia
- Wi-Fi, cellphones, Bluetooth, AM radio are banned under state law.
  - Residents are allowed to use land-line phones and wired internet
  - The only way anyone just passing through can reach the rest of the world is by using the pay phone on the side of a road in town
- Only diesel vehicles are allowed on-site, because a gasoline-powered engine's spark plugs give off interfering radiation.
- The cafeteria's microwave is kept in a shielded cage.
- The Interference Protection Group was formed to hunt down rogue signals.



National Radio Quiet Zone: Video



[https://www.youtube.com/watch?v=iTVLJeRQS5c]

Robert C. Byrd radio telescope

- Green Bank is the site of the gigantic Robert C. Byrd radio telescope.
  - In recent years, the telescopes have been used to track NASA's Cassini probe to Saturn's moon and to examine Mercury's molten core.
  - So sensitive that it can pick up the energy equivalent of a single snowflake hitting the ground.
- Even a basic AM radio transmission is enough to overpower faint readings from outer space.

Unforeseen newcomers

- Diane Schou
- She believed the cell-phone tower near her home in Iowa is the source of her illness.
  - Symptoms range from acute headaches, skin burning, muscle twitching and chronic pain.
- She spent months living in a Faraday cage (shielded cage), a wood-framed box with metal meshing that blocked out cell signals.

EM Radiation Refugees

[https://www.youtube.com/watch?v=N8SelMsICrE]

Unforeseen newcomers

- **Electrosensitivity**
  - Formally, **Electromagnetic Hypersensitivity** (**EHS**)
    - Or Idiopathic environmental intolerance attributed to electromagnetic fields (IEI-EMF)
  - 5%? of Americans. (Estimates vary widely.)
  - Claim that exposure to electromagnetic fields (EMF) (typically created by mobile phones, wi-fi and other electronic equipment) makes them physically ill.
  - Whether EHS is real is still debatable.
    - Not medically recognized in the US.
    - Sweden is the first country to recognize EHS as a disability.
- Since 2007, electrosensitives started to move into Green Bank.
- Electrosensitives' demands clash with locals.
  - They demand that local businesses uninstall fluorescent lights, and want a church to stop using wireless microphones.

[http://www.washingtonian.com/articles/people/the-town-without-wi-fi/index.php]
[http://boingboing.net/2015/01/05/in-west-virginia-theres-a-t.html]
[http://boingboing.net/2011/09/13/in-west-virginia-wi-fi-refugees-seek-shelter-from-electromagnetic-oppression.html]
[http://www.bbc.co.uk/news/world-us-canada-14887428]

Unforeseen newcomers

Unlicensed bands

- Frequency bands that are **free to use**
  - 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:
  - 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
5.8 GHz	ISM Band III (Wireless PBX)	5.725-5.85 GHz
5 GHz	NII Band I (Indoor systems, 802.11a WLANs)	5.15-5.25 GHz
5 GHz	NII Band II (short outdoor and campus applications)	5.25-5.35 GHz
5.8 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]

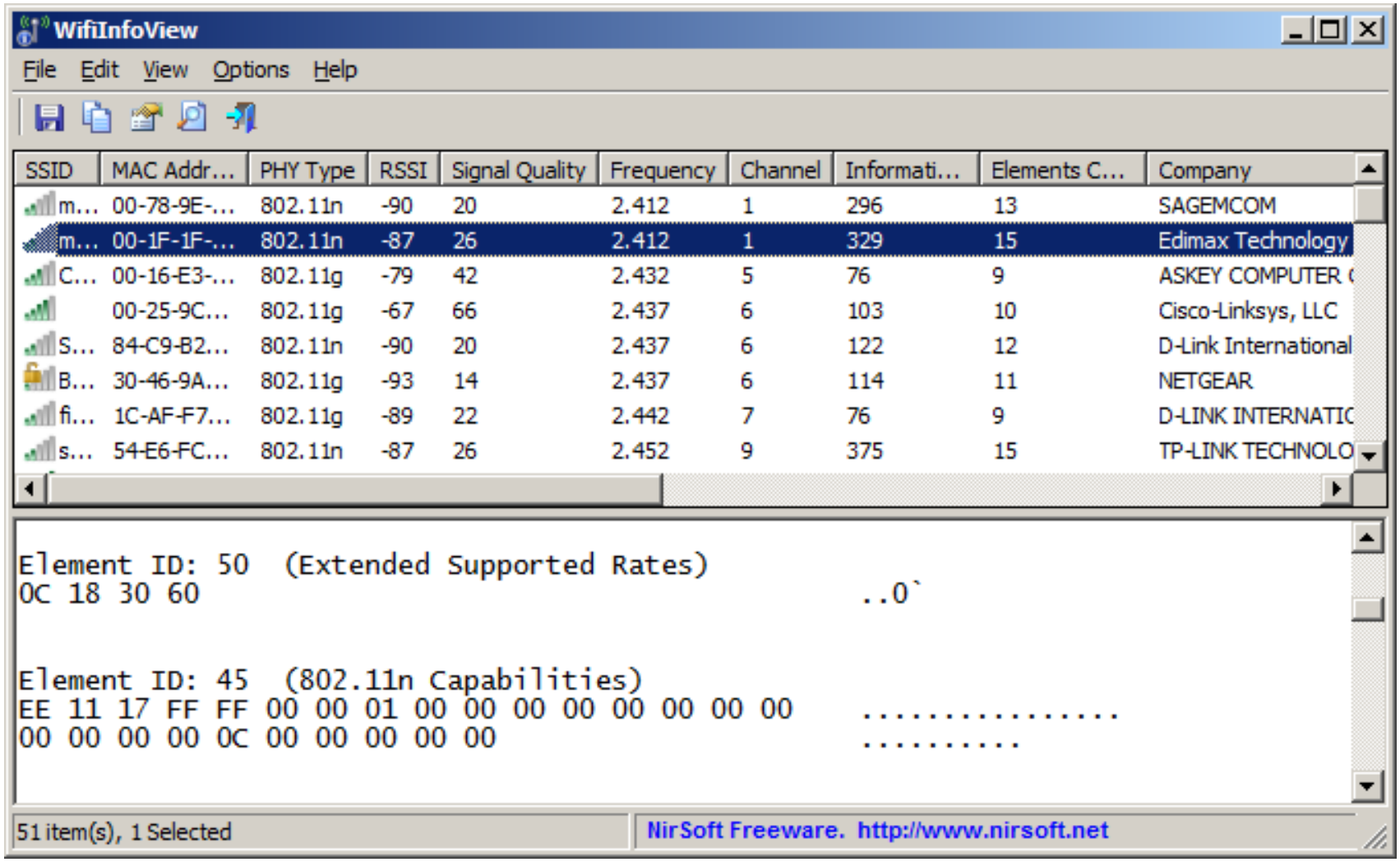
Licensed vs. Unlicensed Spectra

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.

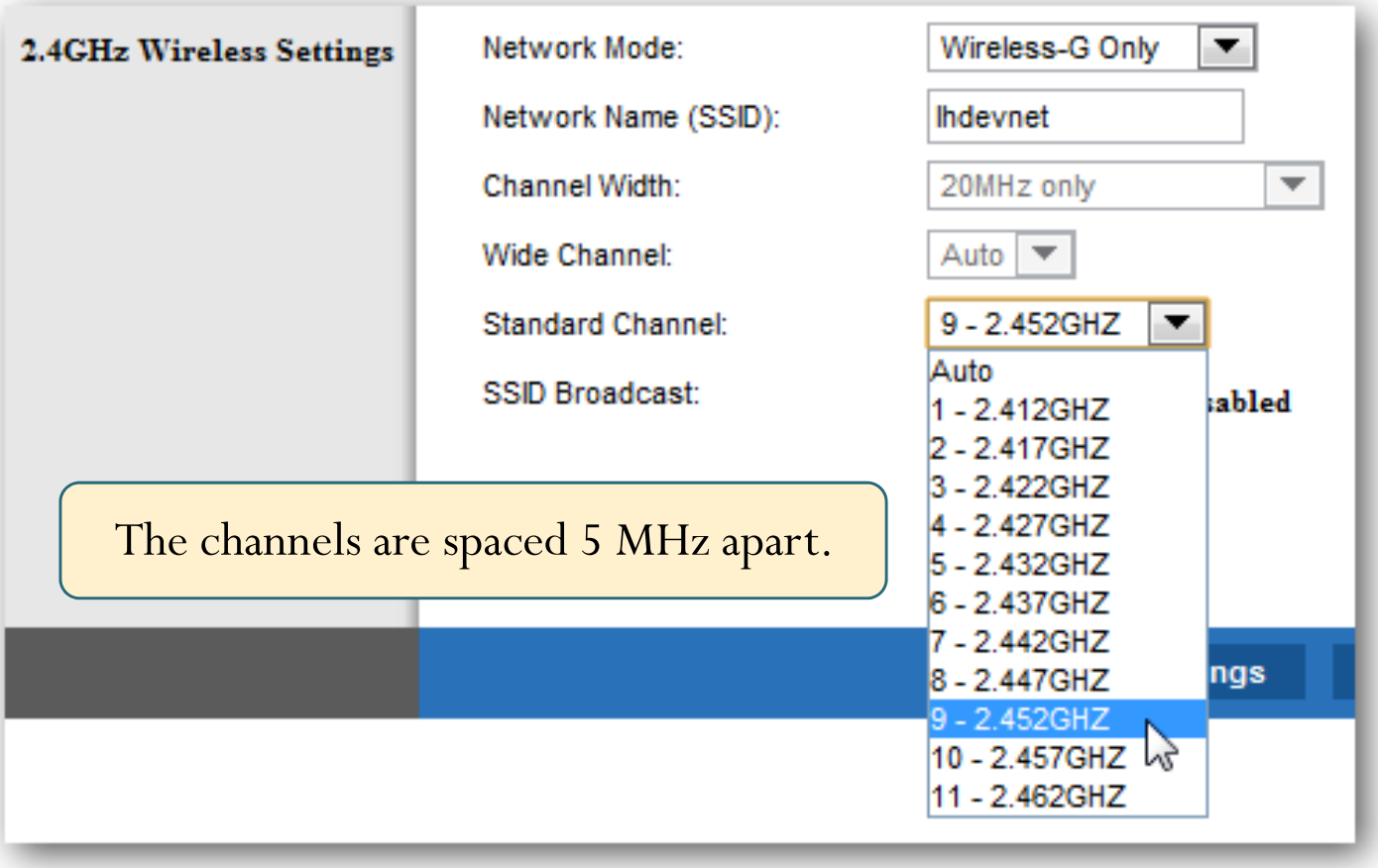
Ex. Wi-Fi Standards

- 802.11a/b/g/n operate in the 2.4 GHz band.
- 802.11n optionally supporting the 5 GHz band.
- The new 802.11ac standard mandates operation only in the 5 GHz band.
  - 2.4 GHz band is susceptible to greater interference from crowded legacy Wi-Fi devices as well as many household devices.
  - The 5 GHz band has relatively reduced interference and there are a greater number of nonoverlapping channels available (**25** non-overlapping channels in US) compared to the 2.4 GHz band (**3** non-overlapping channels in the US).

2.4 GHz has > 10 Channels?



2.4 GHz has > 10 Channels?



- In the US, FCC regulations permit channels 1 to 11 to be used.
- Channels 10 and 11 are the only channels which are common throughout the world.
- Channel 14, where available, is restricted to 802.11b operation only.

[http://www.ieeeghn.org/wiki/index.php/Wireless_LAN_802.11_Wi-Fi]

Can many networks generally operate in close proximity without interfering with each other?

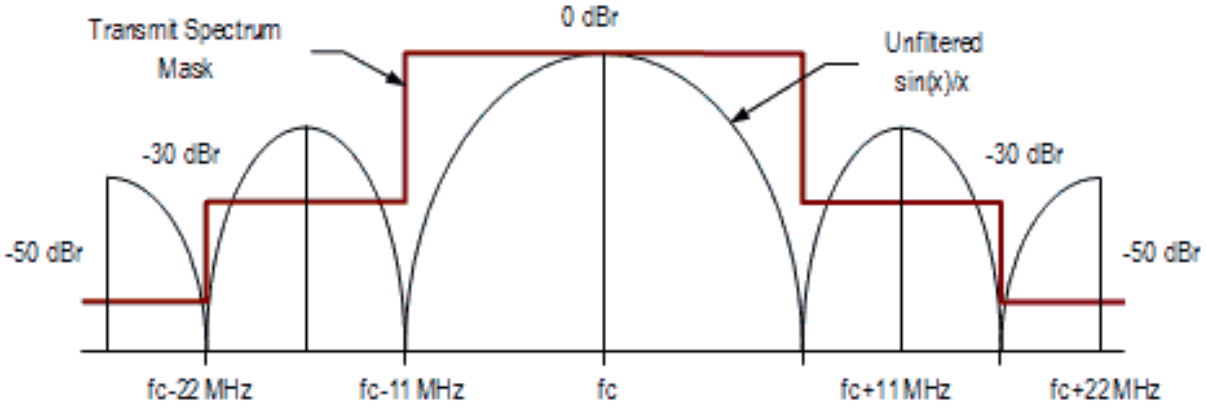
2.4 GHz Channels in Various Parts of the World

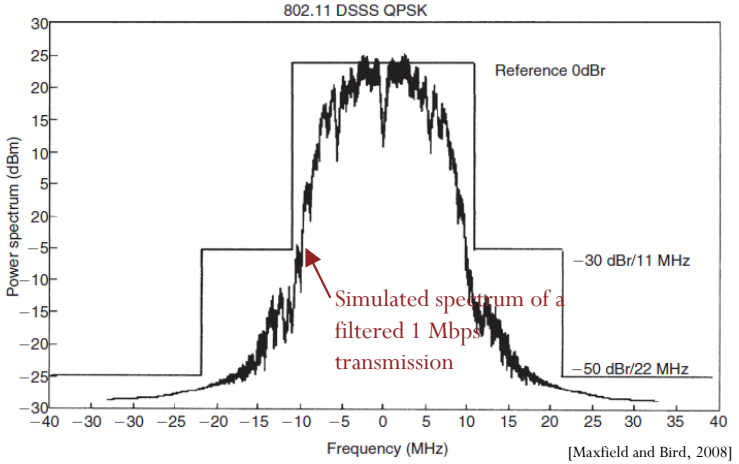
Channel	MHz	U.S.	Canada	Europe (ETSI)	Spain	France	Japan
1	2412	×	×	×		×	×
2	2417	×	×	×		×	×
3	2422	×	×	×		×	×
4	2427	×	×	×		×	×
5	2432	×	×	×		×	×
6	2437	×	×	×		×	×
7	2442	×	×	×		×	×
8	2447	×	×	×		×	×
9	2452	×	×	×		×	×
10	2457	×	×	×	×	×	×
11	2462	×	×	×	×	×	×
12	2467			×		×	×
13	2472			×		×	×
14[a]	2484						

[a]Channel 14, where available, is restricted to 802.11b operation.

[Sohraby, Minoli, and Znati, 2007]

The 802.11b Spectral Mask



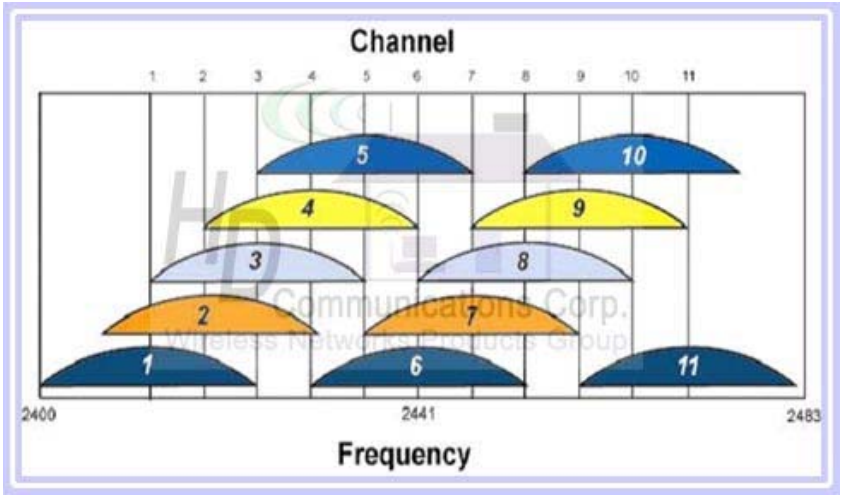


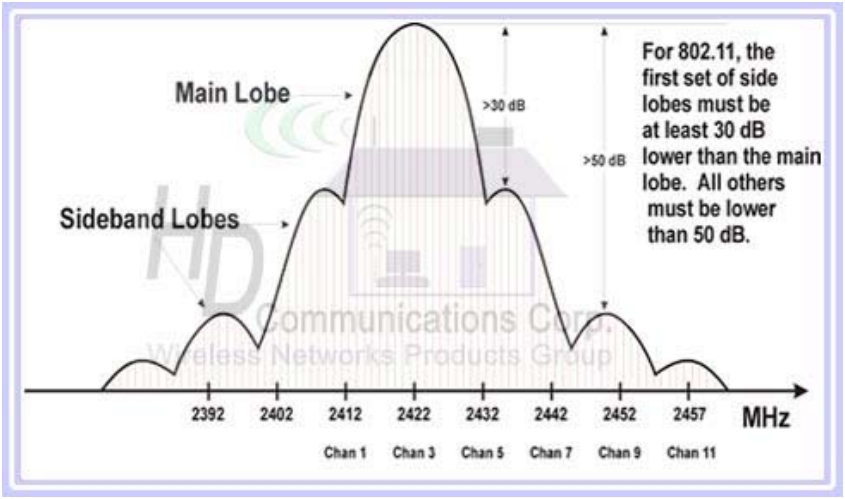
[Maxfield and Bird, 2008]

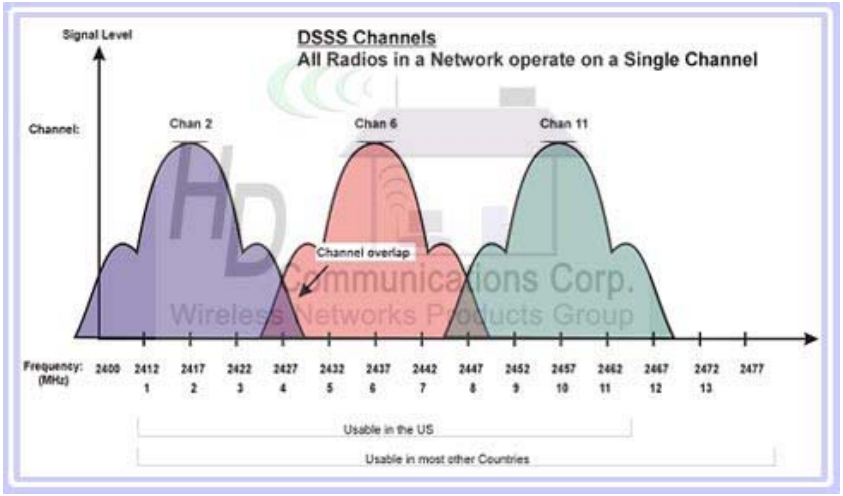
- The 802.11b (and 802.11g) standards do not specify the width of a channel.
  - Rather, they specify the center frequency of the channel and a spectral mask for that channel.
- The energy radiated by the transmitter extends well beyond the 22-MHz bandwidth of the channel (±11 MHz from f_c).
  - At 11 MHz from the center of the channel, the energy must be 30 dB lower than the maximum signal level.
  - At 22 MHz away, the energy must be 50 dB below the maximum level.

WiFi in the 2.4 GHz bands

- It is common to hear that channels 1, 6 and 11 do not overlap.
- It is more correct to say that, given the separation between channels 1, 6, and 11, the signal on any channel should be sufficiently attenuated to minimally interfere with a transmitter on any other channel.
- Same for any two channels that are 5 or more ch. numbers away.
- Tools such as Vistumbler or inSSIDer can help you visualize the WiFi landscape.

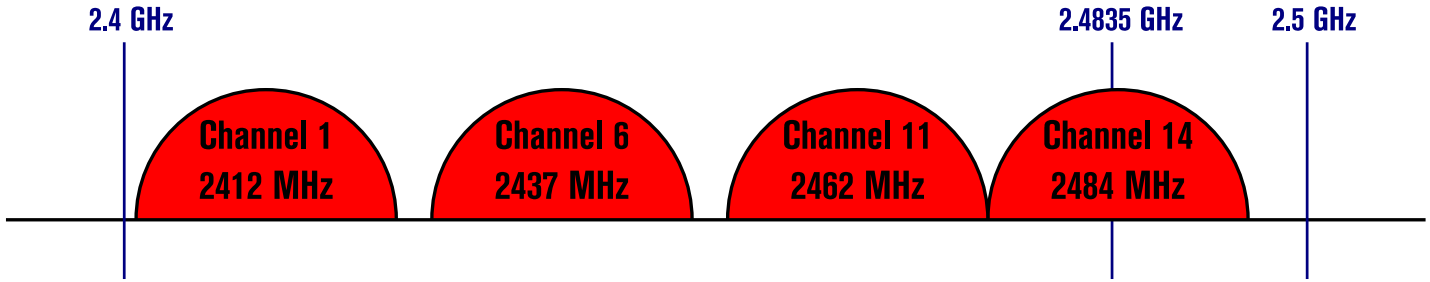




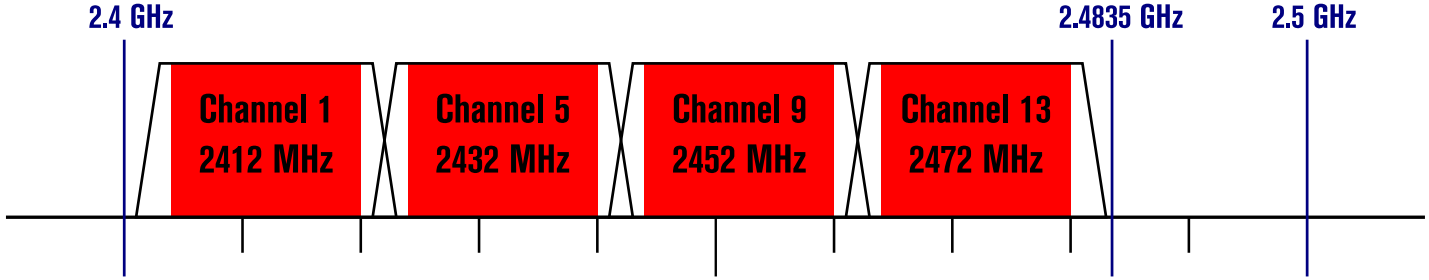


"Non-Overlapping" Channels for 2.4 GHz WLAN

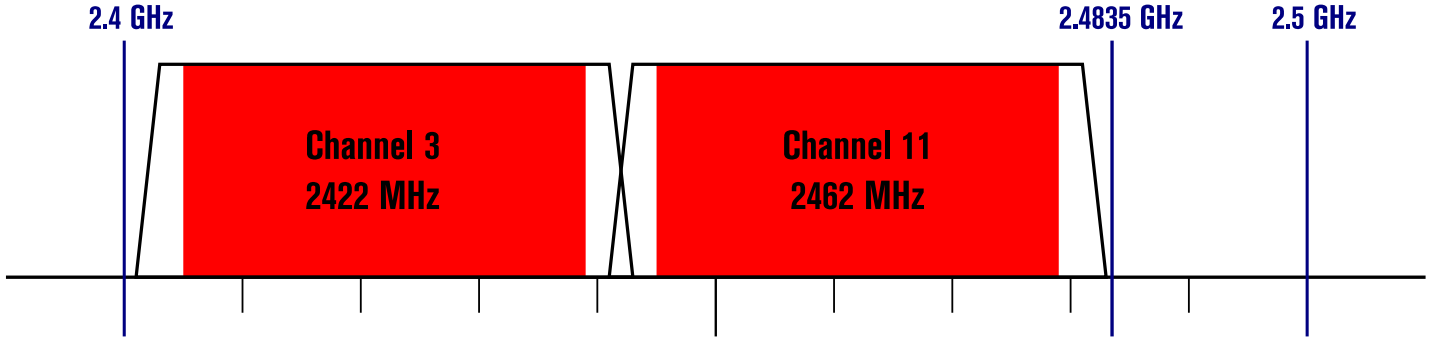
802.11b (DSSS) channel width 22 MHz



802.11g/n (OFDM) 20 MHz ch. width – 16.25 MHz used by sub-carriers



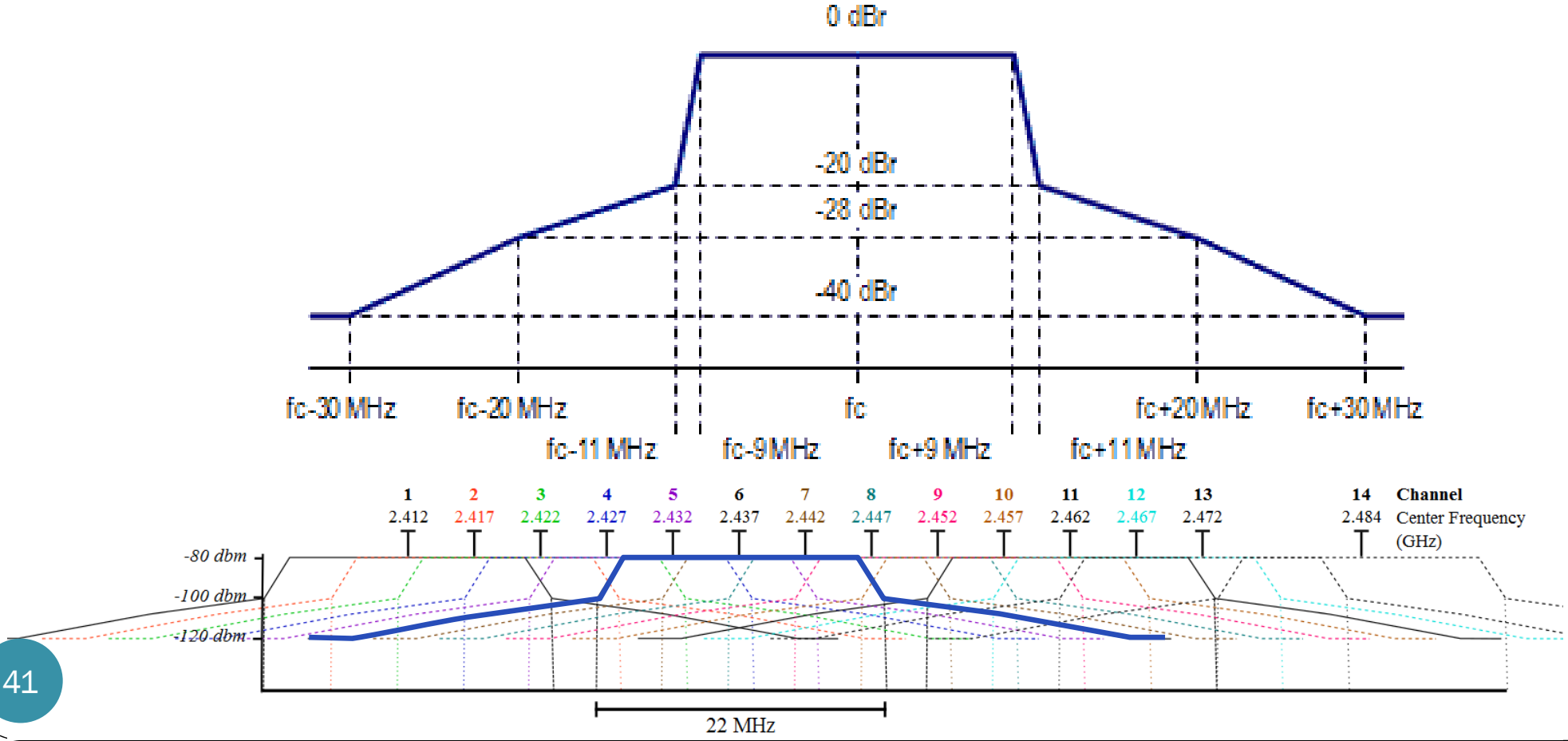
802.11n (OFDM) 40 MHz ch. width – 33.75 MHz used by sub-carriers



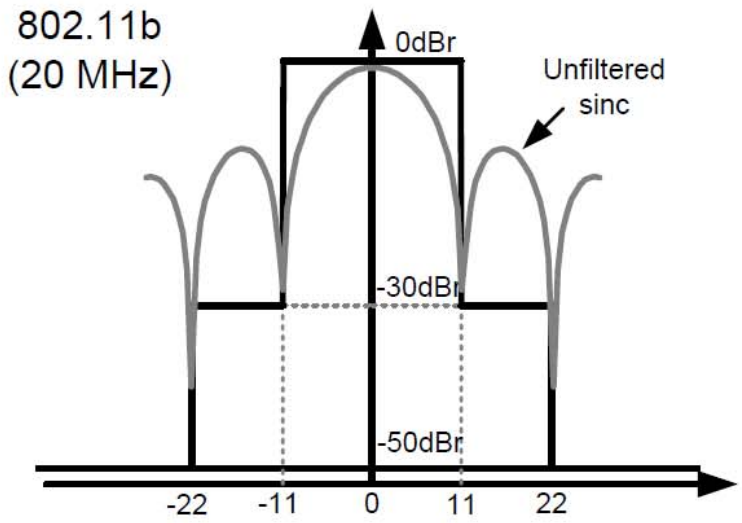
[http://en.wikipedia.org/wiki/IEEE_802.11]

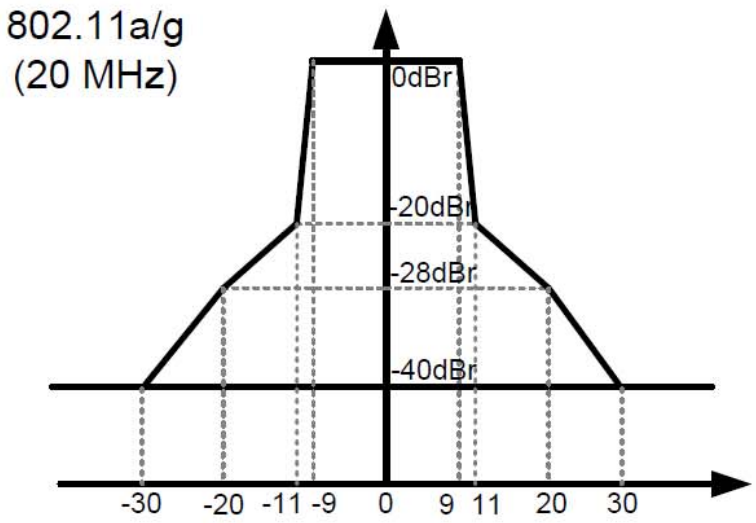
802.11g Spectral Mask

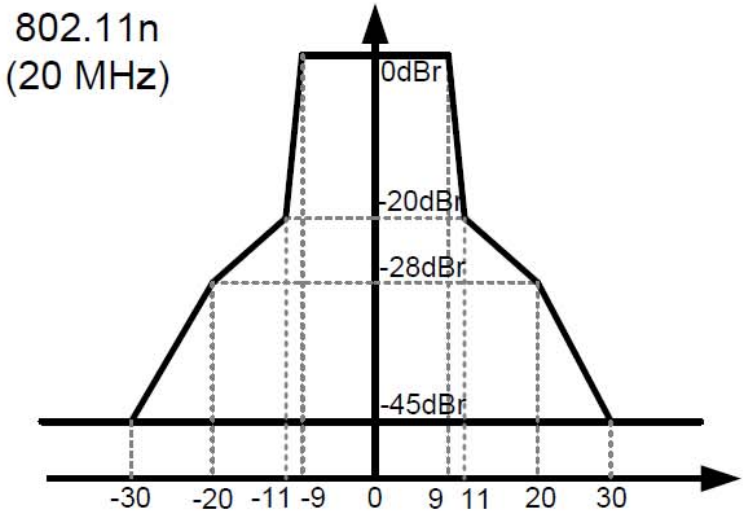
- At 11 MHz from the center, the transmitter energy level is only 20 dB below the maximum (as opposed to 35 dB for 802.11b)
- At 22 MHz away, the energy is only about 30 dB below (as opposed to 50 db for 802.11b). Even as far out as 40 MHz, the energy is still only 40 dB below the maximum.

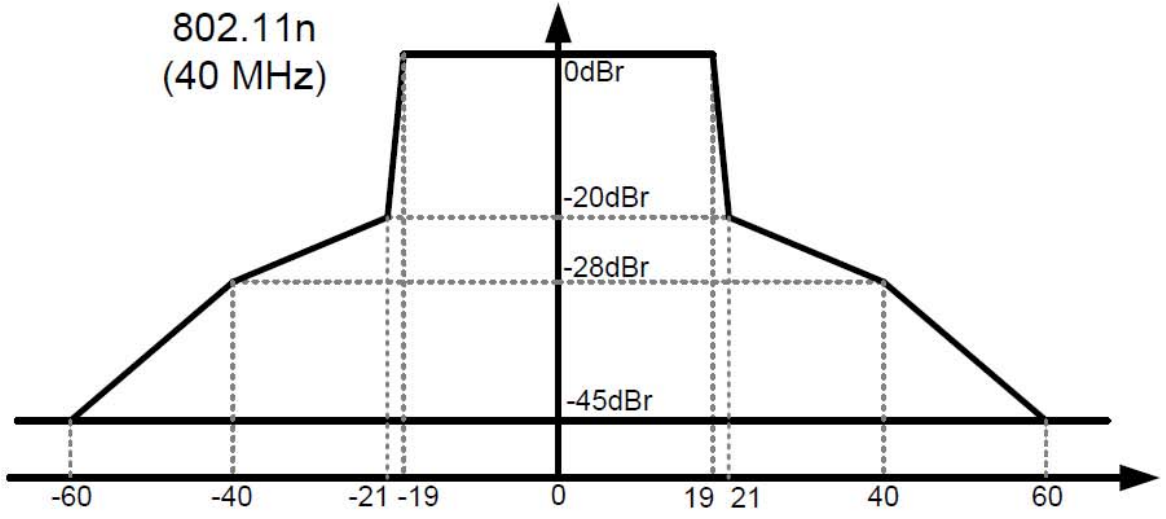


Spectral Mask Comparison









5 GHz Band Channels

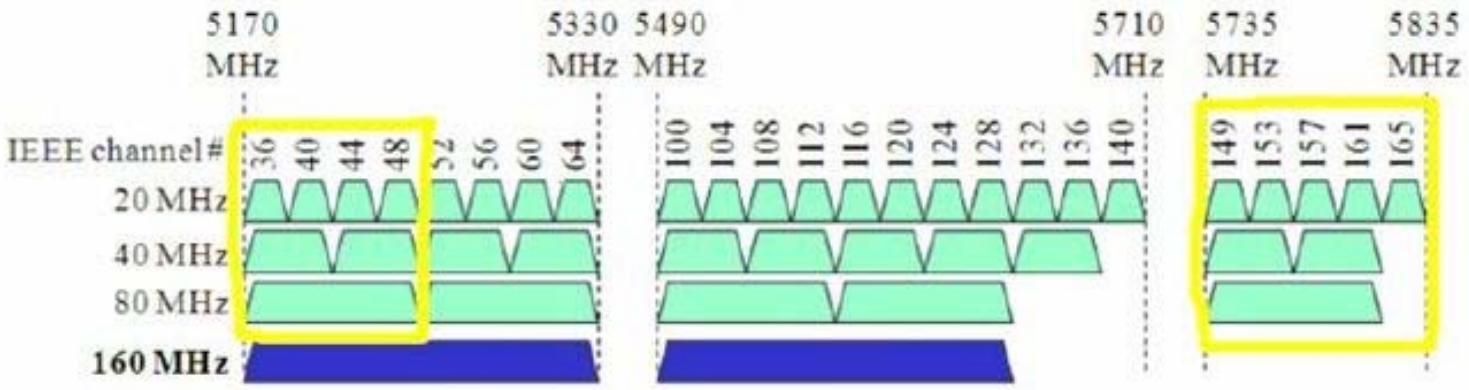


Figure 1: US Channel Allocation

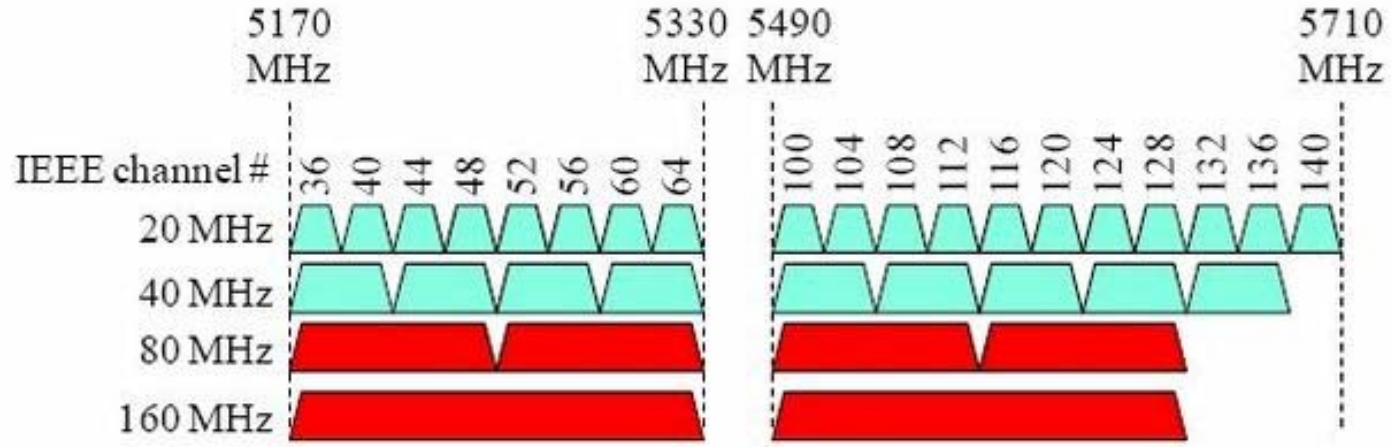
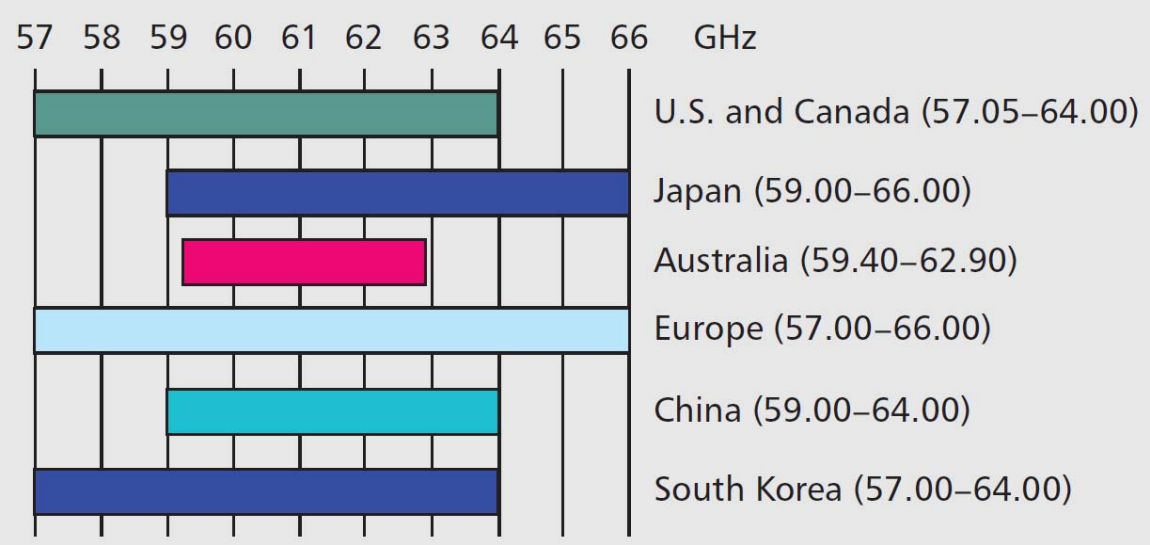


Figure 2: Europe, Japan and Global Operating Class Channel Allocation

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.