History and Principles of RF Spectrum Management

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NSF ERC Program Director

5th IUCAF Spectrum School
Stellenbosch, South Africa, March 1-7, 2020

Objectives

1. Brief history of Radio-Frequency (RF) Spectrum Management (SM)
2. Basic Concepts of RFSM
3. Acronyms & Definitions used in RFSM
4. Brief into to Antenna Theory concepts

RFSM

BRIEF HISTORY

Brief History

- 1865 - ITU founded by 20 countries in Paris as the International Telegraph Union
  - 1st international body in record history
- 1932, merge of ITU and the International Radiotelegraph Union (IRU founded in 1908)
  - adopted its current name, International Telecommunication Union.
- 1947- became a specialized agency of the UN. The United Nations had just been formed 2 years earlier at the end of World War II.

Brief History

- In 1888 Hertz demonstrated EM waves resulting from Maxwell's eqs.,
  - but said that there was "not much use for electromagnetic waves"
- In 1891, Heaviside stated "they are everywhere"!

Brief History

- 1906, IRU Conference in Berlin, 2 of the proposed changes in regulations included:
  - to receive and process emergency radio messages, no matter what their origin was.
  - to continuously watch for distress signals, 24/7.
- Marconi succeeded in ensuring that the governments of Great Britain and Italy opposed these 2 proposals, in order to defend his company's interests.
- Private interest was put above public interest.

Brief History

- When Titanic hit an iceberg near Greenland, they sent emergency signals which were received in Canada.
- But there were too many ham radio operators using the airwaves that night along the coast of the U.S. which prevented the distress signals from being relayed promptly to operators.
- Also, in spite there being a ship less than 10-miles away from the Titanic, it did not receive the distress calls because its radio operator had just turn off its radio only 25 minutes before the accident!

***'CQD CQD SOS Titanic Position 41.44 N 50.24 W.
Require immediate assistance.
Come at once. We struck an iceberg.
Sinking'
(12.17am 15.April.1912)***

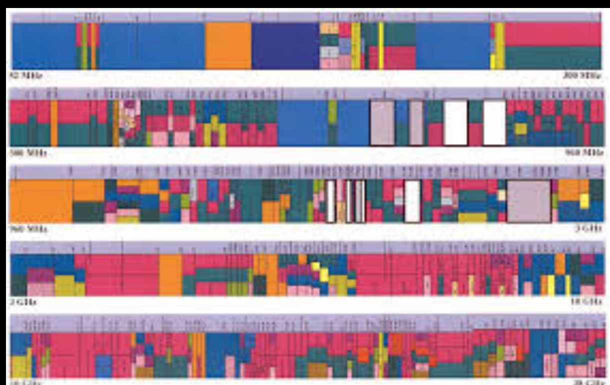
The Titanic departing Southampton on April 10, 1912.

Brief History

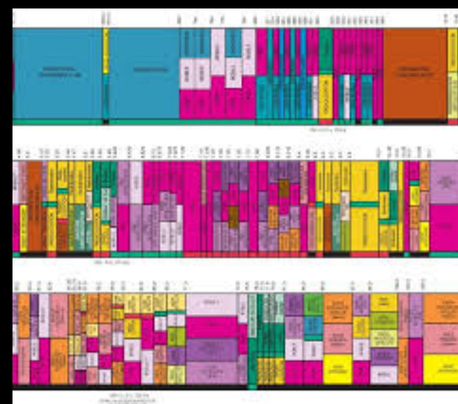
- The 2 new radio regulations would have most certainly prevented the Titanic ship disaster.
- 1912-next IRU Conference, 3 months after the Titanic sank, these 2 radio regulations were finally approved, and
- the Table of Allocations was born.

Engraving by Willy Stöwer: Der Untergang der Titanic (color added later) CC0

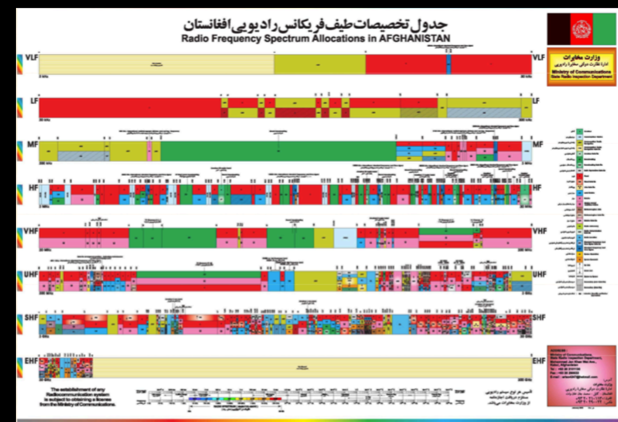
Frequency Allocation Table (FAT) examples



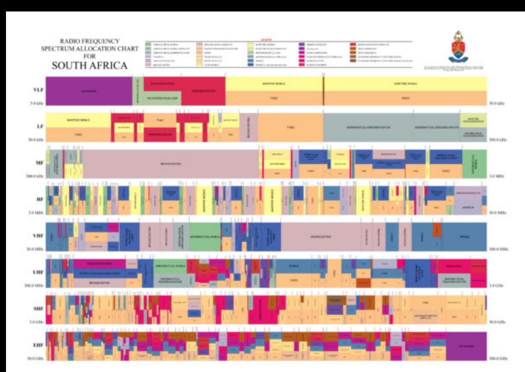
Canada



Australia

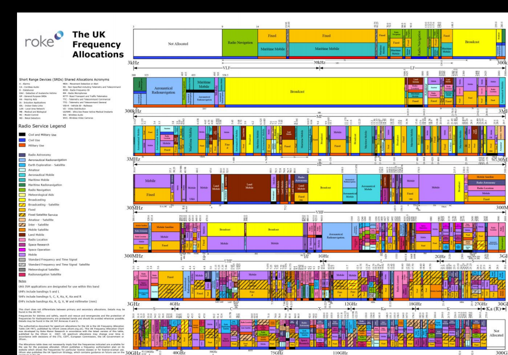


Afghanistan



South Africa

EU



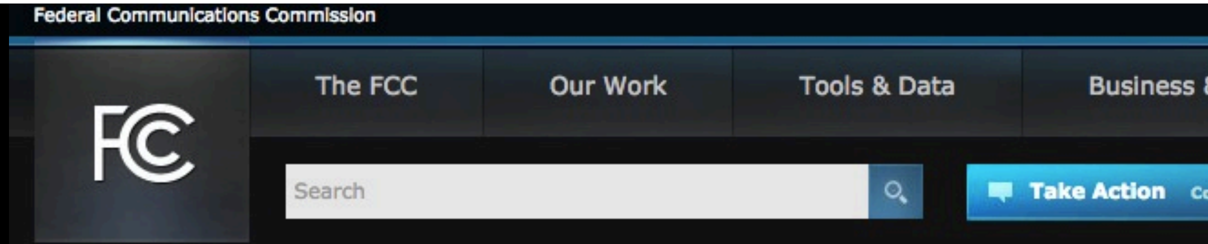
UK

RFSM

BASIC CONCEPTS

Did you know that…?

- It's illegal to design a device to work at certain frequencies?
- Your Wi-Fi home modem could interfere with an airport Weather Radar (TDWR)?
- Cellphone satellites could interfere with solar storms forecast and Earth remote sensing?
- The UN has a body to regulate *RF* signals used all over the World?



You could get a fine from FCC if you are using an illegal frequency.

FCC Fines Hinson for Dangerous Misuse of Public Safety Radio System

Full Title: C[redacted], Surry County, North Carolina
Document Type(s): Forfeiture Order
Bureau(s): Enforcement

Description:
This Forfeiture Order imposes a $39,278 penalty against [redacted]n for operating a radio on frequencies licensed for public safety uses to Surry County, North Carolina

DA/FCC #: FCC-19-82
FCC Record Citation: 34 FCC Rcd 7619 (9)

FCC Record: FCC-19-82A1_Rcd.pdf

Related Document(s):
News Release - FCC Fines Hinson for Dangerous Misuse of Public Safety Radio System

Document Dates

Released On: Aug 7, 2019
Adopted On: Aug 6, 2019
Issued On: Aug 7, 2019

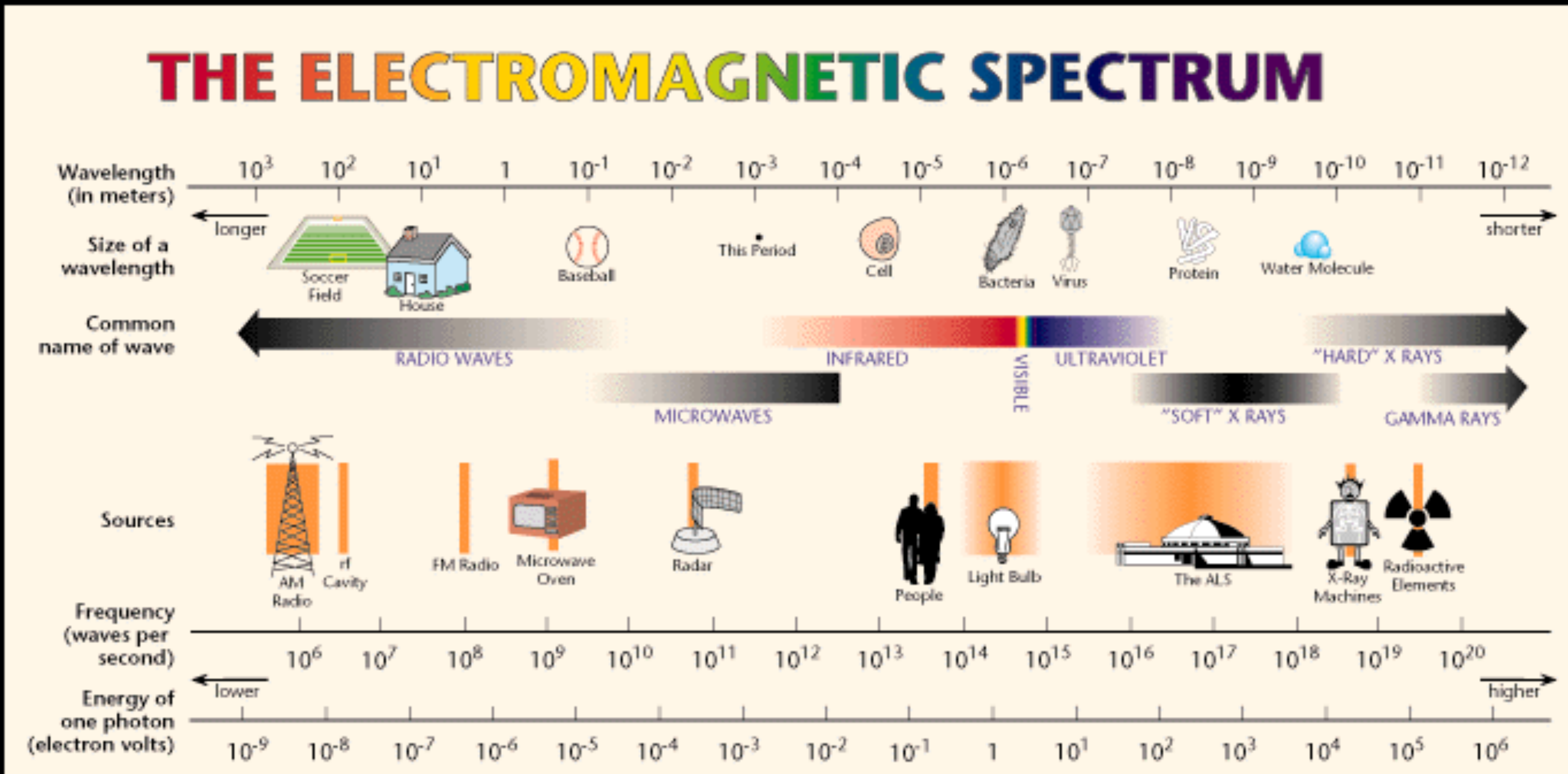
Tags:
Emergency Communications - Enforcement - Interference - Public Safety - Radio - Spectrum - Unauthorized Operation

http://www.fcc.gov/encyclopedia/weather-radar-interference-enforcement

RF Spectrum Definition

- UN ITU → 3kHz to 3THz
- Electromagnetic Spectrum:
  - RF (this talk)
  - Far IR
  - Near IR
  - Visible
  - UV
  - X-Rays
  - Gamma

RF Spectrum is a LIMITED resource - SM ensures Access


THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
10^3 10^2 10^1 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12}
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
10^6 10^7 10^8 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}
lower
higher
Energy of one photon (electron volts)
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10^1 10^2 10^3 10^4 10^5 10^6

Credit: NASA

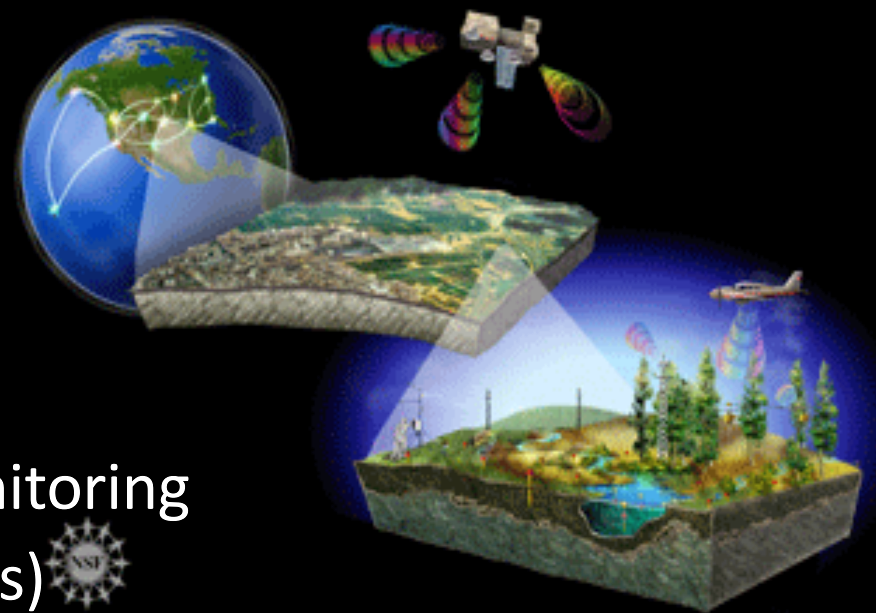
Imagine a World w/o RF

- No data on hurricane monitoring
- No Postal packages tracking
- No 5 days Weather forecasting
- No GPS navigation system
- Airport implications in navigation

- Solar storms not predicted
  - (Energy grid disruption)
- No cellphones! No text, calls…
- Satellite TV, Wi-Fi internet, AM and FM radio, broadcast TV ,…

Some science Applications used in the public sector

- Agriculture
- Fire-prone mapping
- Iceberg navigation maps
- Oil spill monitoring
- Renewable energy management
- El Niño Southern Oscillation monitoring
- Solar storms forecasting (1-3 days)
  - GPS, energy grid disruption



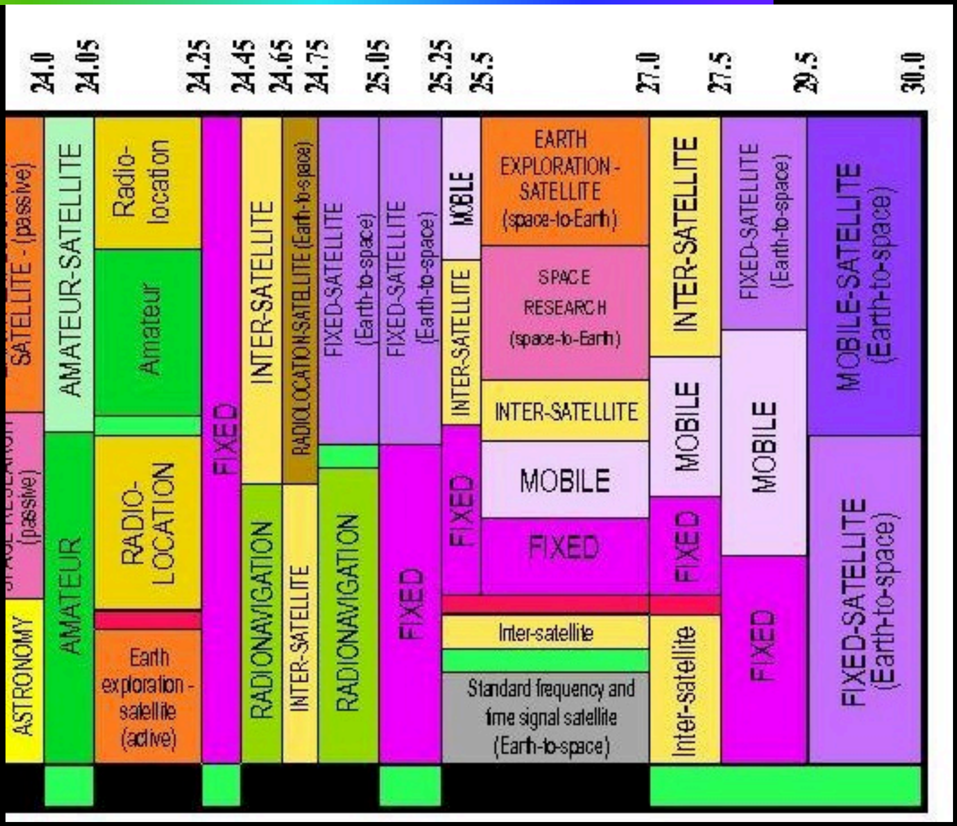
Globalization Problems:

Ex. GPS & cellphone Jammer

- Use to block signals, but also RFI to airport weather radars
- Easy to buy online
- Fines of up to over $100,000 per violation and could lead to criminal prosecution (including imprisonment) or seizure of the illegal device.

What is Spectrum Management?

Spectrum management is the process of regulating the use of RF to promote efficient use and gain a net social benefit.



Example of RF Spectrum section for the US Table of Frequency Allocations

FAT Closer look, 1 pg example

Table of Frequency Allocations — 2655-4990 MHz (UHF/SHF)

International Table			United States Table		FCC Rule Part(s)
Region 1 Table	Region 2 Table	Region 3 Table	Federal Table	Non-Federal Table	
2655-2670 FIXED 5.410 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.208B 5.413 5.416 Earth exploration-satellite (passive) Radio astronomy Space research (passive) 5.149 5.412	2655-2670 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) (space-to-Earth) 5.415 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416 Earth exploration-satellite (passive) Radio astronomy Space research (passive) 5.149 5.208B	2655-2670 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) 5.415 MOBILE except aeronautical mobile 5.384A BROADCASTING-SATELLITE 5.413 5.416 Earth exploration-satellite (passive) Radio astronomy Space research (passive) 5.149 5.208B 5.420	2655-2690 Earth exploration-satellite (passive) Radio astronomy US385 Space research (passive)	2655-2690 FIXED US205 MOBILE except aeronautical mobile Earth exploration-satellite (passive) Radio astronomy Space research (passive)	Wireless Communications (27)
2670-2690 FIXED 5.410 MOBILE except aeronautical mobile 5.384A Earth exploration-satellite (passive) Radio astronomy Space research (passive) 5.149 5.412	2670-2690 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) (space-to-Earth) 5.208B 5.415 MOBILE except aeronautical mobile 5.384A Earth exploration-satellite (passive) Radio astronomy Space research (passive) 5.149	2670-2690 FIXED 5.410 FIXED-SATELLITE (Earth-to-space) 5.415 MOBILE except aeronautical mobile 5.384A MOBILE-SATELLITE (Earth-to-space) 5.351A 5.419 Earth exploration-satellite (passive) Radio astronomy Space research (passive) 5.149	US205	US385	
2690-2700 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY SPACE RESEARCH (passive) 5.340 5.422			2690-2700 EARTH EXPLORATION-SATELLITE (passive) RADIO ASTRONOMY US74 SPACE RESEARCH (passive) US246		
2700-2900 AERONAUTICAL RADIONAVIGATION 5.337 Radiolocation 5.423 5.424			2700-2900 METEOROLOGICAL AIDS AERONAUTICAL RADIONAVIGATION 5.337 US18 Radiolocation G2 5.423 G15	2700-2900 5.423 US18	Aviation (87)
2900-3100 RADIOLOCATION 5.424A RADIONAVIGATION 5.426 5.425 5.427			2900-3100 RADIOLOCATION 5.424A G56 MARITIME RADIONAVIGATION 5.427 US44 US316	2900-3100 MARITIME RADIONAVIGATION Radiolocation US44 5.427 US316	Maritime (80) Private Land Mobile (90)

Note:
Capital letters → Primary
Lowercase → Secondary

Footnotes

Economic Gain

- The use of the RF spectrum for many applications such as communications yields a huge amount of economic gain.
  - FCC bidding
- Growing tension between public and commercial sector.

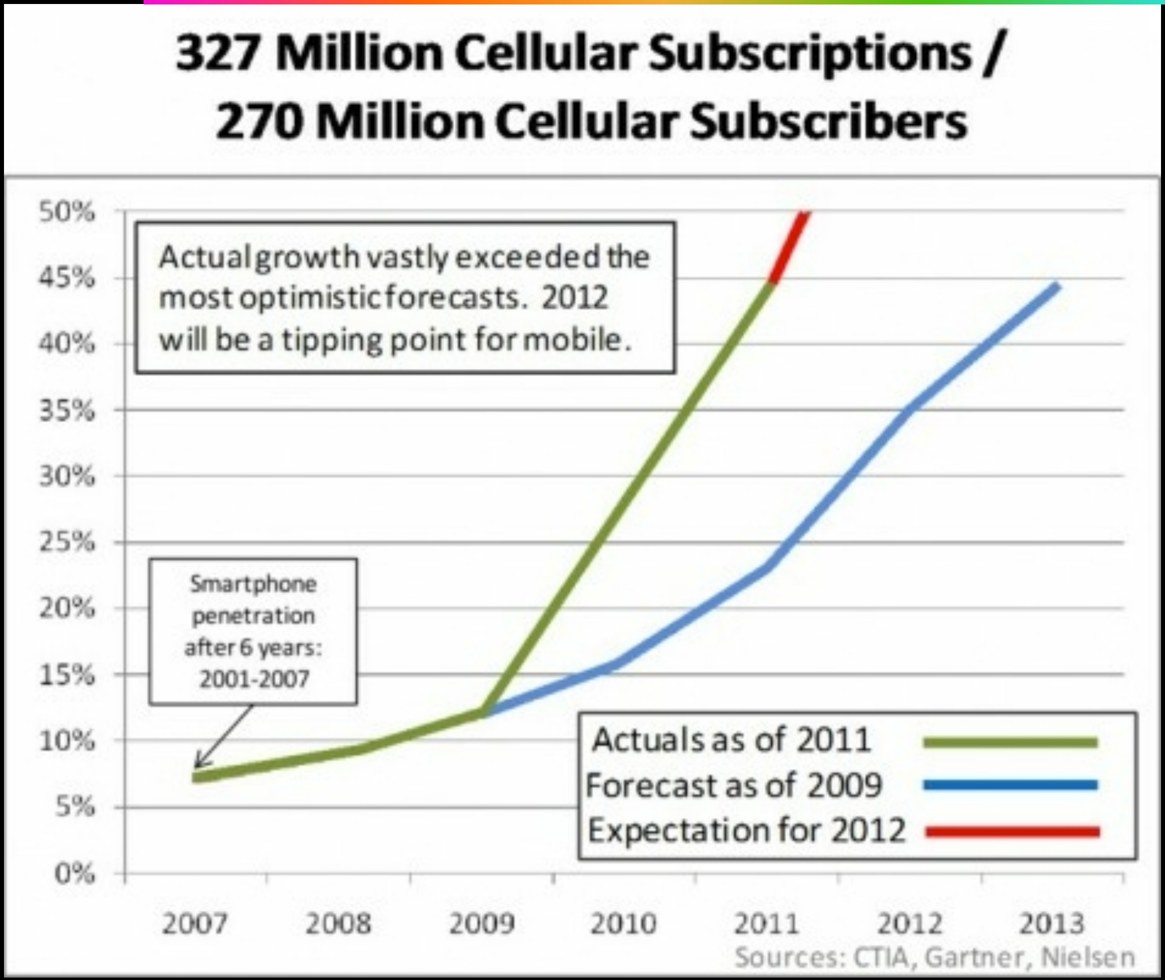
U.S. Presidential MEMOs

- *2010: All agencies must make 500 MHz of Federal and nonfederal spectrum available for wireless broadband use by 2020*
- *2013 Presidential Memorandum -- Expanding America's Leadership in Wireless Innovation.*
- *2018 Presidential Memorandum- Developing a Sustainable Spectrum Strategy for America's Future*

Response examples:

- NSTC's Wireless Spectrum Research & Development Interagency Working Group (WSRD), Research and Development Priorities for American Leadership in Wireless Communications and
- NTIA National Spectrum Strategy

Multimillion $ Industry



The # of Wi-Fi devices is twice the population in the U.S.!
Many people have iPads, work/personal cellphones , laptop.

Key drivers of the explosive growth in mobile broadband include:

- the development of smartphones and other mobile computing devices,
- the emergence of broad new classes of connected devices (the IoT or Internet of Things,)
- and the rollout of Fifth-Generation (abbreviated 5G) wireless technologies beyond LTE (Long Term Evolution)
- a growing commercial space sector

International Trends in Commercial Use of the Radio Spectrum

Trends in international spectrum usage and policies (ITU and others)

Licensed Spectrum Summary – USA and Selected Countries

Country	Current	Pipeline	Current + Pipeline
USA	608	55+	663+
Australia	478	230	708
Brazil	554	0	554
China	227	360	587
France	555	50	605
Germany	615	0	615
Italy	540	20	560
Japan	500	10	510
Spain	540	60	600
U.K.	353	265	618

Note: US pipeline numbers do not include the significant amount of spectrum that will be made available for mobile broadband from incentive auctions and federal repurposing.

Unlicensed Spectrum Summary – USA and Europe

Band	Current (USA)	Pipeline (USA)	Current (Europe)	Pipeline (Unknown) (Europe)
TV White Spaces [Unl1]	0 - 150	+	-	
863-870 MHz	-	-	7 [Unl2]	
902-928 MHz	26 [Unl3]	-	-	
1880-1930 MHz	10 [Unl4]	-	20 [Unl5]	
2400-2483.5 MHz [Unl6]	83.5	-	83.5	
3550-3700 MHz	50 [Unl7]	100 [Unl8]	-	
5150-5350 & 5470-5825 MHz [Unl9]	555	-	555	
5350-5470 & 5850-5925 MHz	-	195 [Unl10]	-	
	724.5 - 874.5	295+	665.5	

Note: Includes "licensed-light" spectrum.

NRC Study

Trends in Commercial Use of the Radio Spectrum

Source: Bazelon & Kolosky

Spectrum Auction News from 2017

"Zombies" Among Us – FCC Approves Sale of Station Sold in Auction, Not Yet Sharing

BY ARI MELTZER, JOHN BURGETT AND JESSICA ROSENTHAL ON OCTOBER 20, 2017
POSTED IN BROADCAST REGULATION, TRANSACTIONS

The Deal ROOM

The FCC has, for the first time, approved an application for the assignment of the license of a television station that agreed to relinquish its spectrum in the Broadcast Television Incentive Auction but has not yet commenced channel sharing.

These so-called "zombie" or "nomad" licenses have perplexed broadcasters and the FCC staff for months. In April, shortly after the Commission announced the results of the Incentive Auction, Hero LicenseCo LLC filed an application to assign KBEH to KWHY-22 Broadcasting, LLC. The rub, however, was that Hero submitted a successful bid in the Incentive Auction to relinquish its spectrum usage rights (in exchange for nearly $150 million). Although KWHY-22 apparently planned to implement a channel sharing arrangement between KBEH and KWHY-TV (which itself received $123 million to move to a low-VHF channel), the parties sought consent to assign KBEH before KWHY-22 filed its application to channel share (much less implemented sharing).

NEWS FOR PEOPLE IN PUBLIC MEDIA
Current

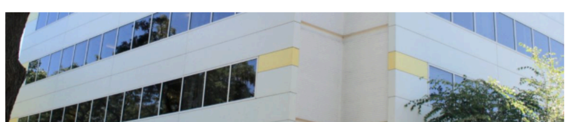
Programs/Content Development System/Policy People Tech "The Pub" Podcast Jobs

Don't Miss Federal Funding Spectrum Auction I Am Public Media Currently Curious Rewind: The Roots of Public Media

Channel-share agreements bring Connecticut station $32.6M in spectrum auction

By Jill Goldsmith | April 26, 2017

SHARE TWEET EMAIL PRINT MORE



HOME › MEDIA › INCENTIVE AUCTION SECOND PRIORITY FILING WINDOW OPENS: WHAT TO KNOW

Incentive Auction Second Priority Filing Window Opens: What to Know

BY DAN KIRKPATRICK ON SEPTEMBER 21, 2017
POSTED IN CABLE, ENFORCEMENT, MEDIA, TELECOMMUNICATIONS

On Sept. 20, the FCC announced the second filing window for all full power and Class A television stations receiving new channel assignment as part of the post-incentive auction repack. The filing window will open Oct. 3 and close at 11:59 p.m. EDT on Nov. 2. During this "second priority" filing window, all eligible stations may file applications requesting authority to operate on a new channel or with expanded facilities.

Stations eligible to file during the second priority filing window include all Class A and full power stations that were assigned new channels by the Commission during the repack, including those who were involuntarily assigned new channels, and those who elected to move from a UHF to VHF channel (or from high VHF to low VHF) as part of the auction. If an eligible station's initial post-auction construction permit application remains pending, it can submit its second priority filing window application as an

End of Local TV?

Former NJ governor asks state to support public TV after spectrum auction win

By April Simpson, Associate Editor | April 25, 2017

SHARE TWEET EMAIL PRINT MORE

A former New Jersey governor is urging the state to invest some of its $332 million in spectrum auction revenues in public broadcasting.

New Jersey Public Broadcasting Authority sold spectrum assigned to two stations in its NJTV network, WNJN in Montclair and WNJT in Trenton. The state holds the broadcast licenses for NJTV stations, although a nonprofit subsidiary of WNET in New York City has been operating them under a local management agreement since 2011. It's unclear how the state will use the funds, and how much will be reinvested in the stations.

FCC bids of RF waves

- *In 2006, the FCC auctioned 90MHz of the spectrum for 3G cellular communications with a gain for the US Treasury of $13.7B.*
- *In Jan 2016, 65MHz were auctioned for close to $45B.*

The gain obtained from better weather prediction, and Earth remote-sensing studies is harder to quantify, nevertheless provides great benefit to society. It is documented on a 2010 Report by the ITU, named the ITU-R RS.2178 Report, which highlights the economic impact on the order of over $240B in disaster management alone.


Radio Frequency Spectrum*
Increase demand for the RF spectrum requires more ways to efficiently share this limited resource specially f<6GHz
*"Companies bid $45 billion .. 65 MHz of the electromagnetic spectrum"- Jan 2015

Spectrum Managers

No university offers degree as of 2020

Spectrum Managers

- At: NOAA, Google, NASA, DoI, DoD, FAA, Navy, Boeing, Nokia…

Useful knowledge

- **RF Radio Regulations**
- **RF systems; mixers, oscillators, transmission line propagation, etc.**
- **Filter design and Harmonics**
- **Fourier, time-domain, frequency-domain**
- **Microwave and millimeter remote sensors: both passive and active**
- **Research using these bands: C-band, S-band, X-band, Ku-band, K-band, Ka-band, W-band**
- **Microwave Remote Sensing: Atmospheric Attenuation and Propagation, Mie Scattering, Bragg scattering, Rayleigh Scattering**
- **Rain, hail and other hydrometeor effect in atmospheric path delay**

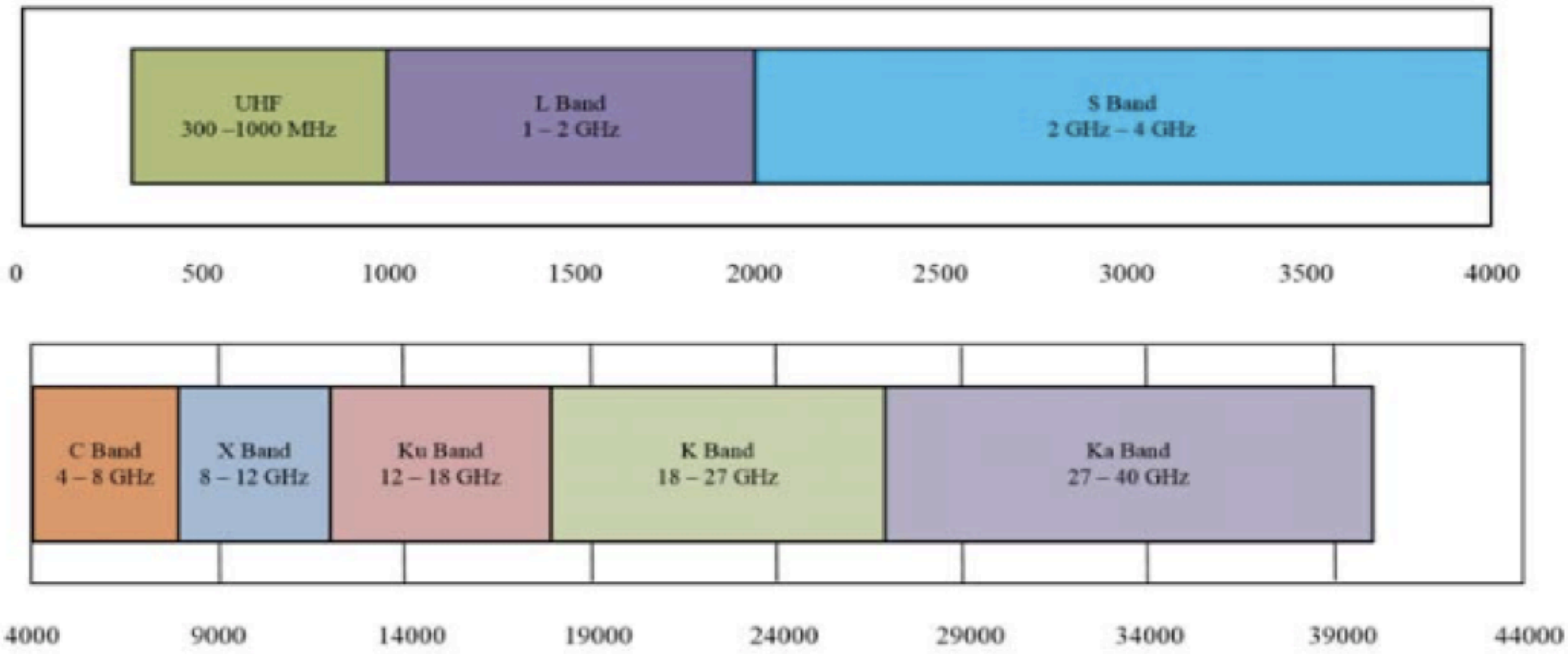
- Radiometer design
- Power flux density, dB/m^2/Hz, Jy
- dBW, dBm, …
- Radar Equation
- Radar range resolution
- Bandwidth – and relation to pulse width, integration time
- Received power Budget (a.k.a. Friis equation)
- Sensitivity equation S/N
- Noise/Interference
- Antenna theory and design; Sidelobes, radiation patterns, beamwidth, Gregorian dish,
- Antenna arrays (interferometry)

RFSM

ACRONYMS & DEFINITIONS

RF Bands

IEEE Standard



Letter Designation of RF Bands (Source: NASA)

GSM
Global System for Mobile *frequencies*
(UHF to L-band)

- GSM was originally developed at 900 MHz (UHF) in Europe and is the global standard for mobile communications
- Currently there are several GSM bands from 380-1900 MHz (UHF/L-band). Some examples:

GSM band	*f* (MHz)	Uplink (MHz) (Mobile to Base)	Downlink (MHz) (Base to Mobile)	Equivalent LTE band
GSM-850	850	824.2 – 848.8	869.2 – 893.8	5
P-GSM-900	900	890.0 – 915.0	935.0 – 960.0	
E-GSM-900	900	880.0 – 915.0	925.0 – 960.0	8
R-GSM-900	900	876.0 – 915.0	921.0 – 960.0	
T-GSM-900	900	870.4 – 876.0	915.4 – 921.0	
DCS-1800	1800	1710.2 – 1784.8	1805.2 – 1879.8	3
PCS-1900	1900	1850.2 – 1909.8	1930.2 – 1989.8	2

Table from Wikipedia

UNII

Unlicensed National Information Infrastructure

(C-band)

Unlicensed means that gadgets can use this band to transmit and/or receive without a license

* Each country defines the ‘fine print’.

Example: Wi-Fi is a UNII device that operates at 5 GHz

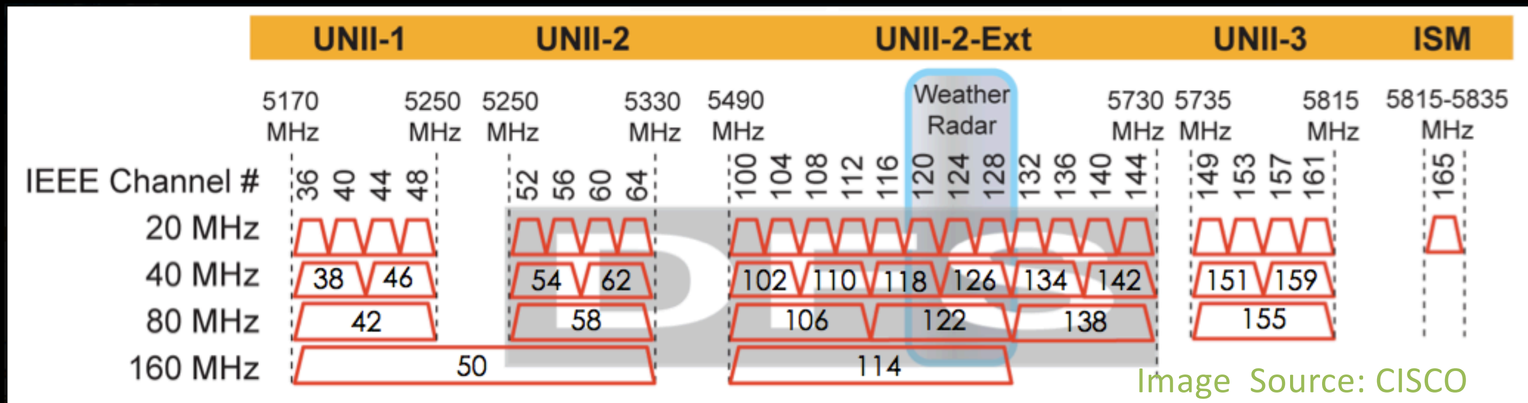


Image Source: CISCO

The UNII bands In the U.S.:

Name(s)	Frequency range
U-NII-1 or UNII Low	5.150-5.250 GHz
U-NII-2A	5.250-5.350 GHz
U-NII-2C / U-NII-2e or U-NII Worldwide* *not used in China or Israel	5.470-5.725 GHz -subject to Dynamic Frequency Selection (DFS) for radar avoidance.
U-NII -3 or U-NII Upper	5.725 to 5.850 GHz, overlaps with ISM

“Not unlicensed” UNII

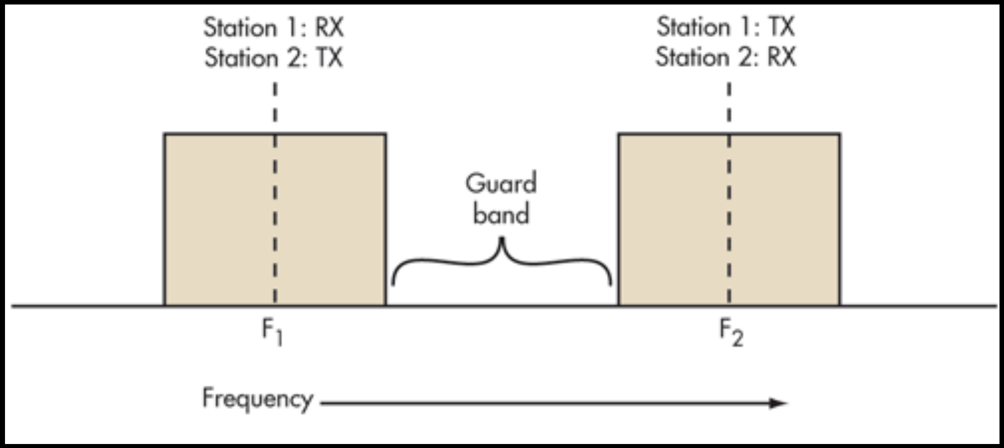
- U-NII-2B: 5.350-5.470 GHz (not unlicensed)
  - This band is allocated on a Primary basis to the Earth Exploration Space Service (EESS) Research, and Radiolocation Services for federal operations and on a secondary basis for non-federal operations.
- U-NII-4: 5.850 to 5.925 GHz – For licensed Amateur Radio Operators and for Dedicated Short Range Communications Service (DSRC) Being considered by FCC for unlicensed.

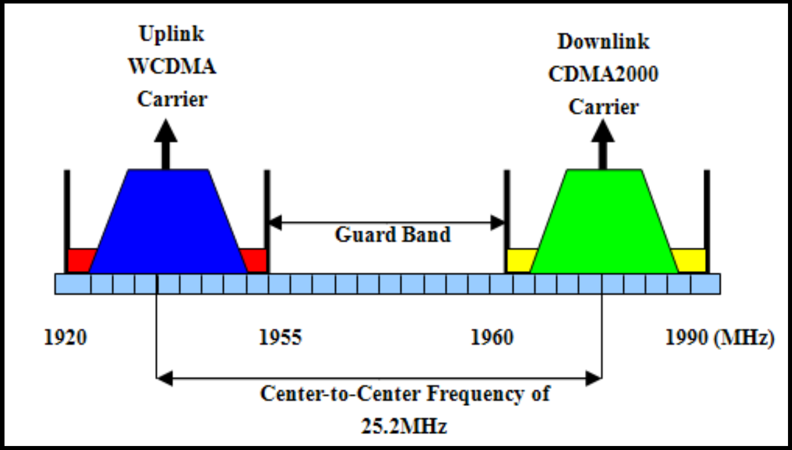
Microwave ovens
(S-band)

- Unlicensed Operation at 2.45 GHz
- High-power emissions could produce RFI
- Glass door is designed to block some of the radiation
  - holes are much smaller than the wavelength
- They were given a few MHz space in both directions. (guard band) to reduce RFI with adjacent bands
  - And so the 2.4-to-2.4835-GHz ISM band was born.

Guard band

- When a frequency gap is left between to designated bands to prevent interference, this is known as a guard band That way they can both transmit/receive simultaneously without interfering with each other.
- Used in FDM (Frequency Division Multiplexing)





ISM (unlicensed)
Industrial, Scientific and Medical

Examples: Microwave ovens at 2.45Ghz

- Cancer Treatment -Radiation at several ISM frequencies for medical diathermy
- Cordless phones
- Industrial heaters
- Bluetooth devices (2.4GHz)
- Wi-Fi on 2.4-GHz and 5GHz
- Walkie-talkies at 900-Mhz
- Cellphones (GSM) operating at some ISM bands

They all share several ISM bands without any regulatory protection from RFI from each other. That’s why sometimes your Wi-Fi router or your oven can interfere with your Bluetooth mouse!

IEEE 802.11

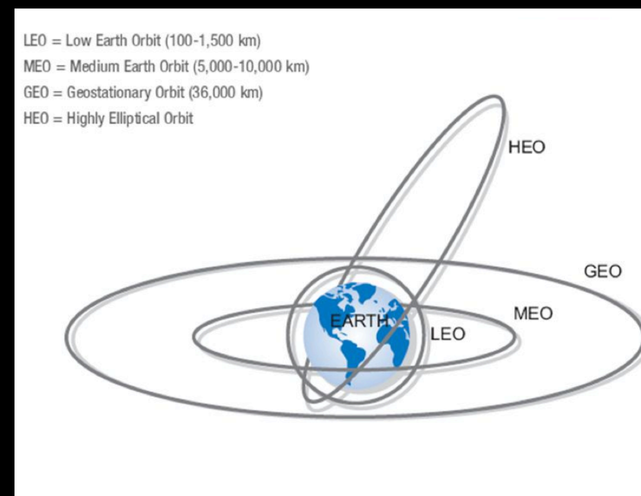
Specifications for WLAN communications.

Frequencies:

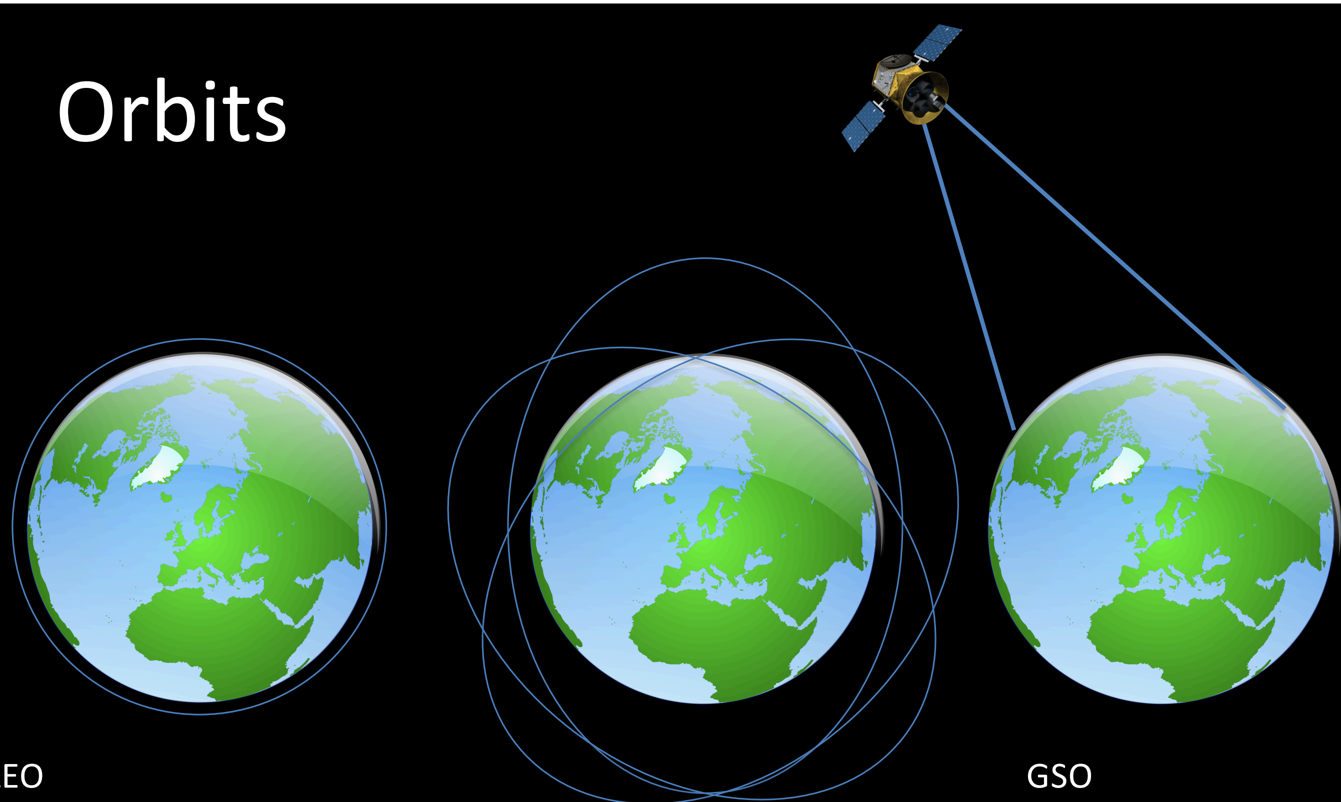
- 900 MHz (802.11ah)
- 2.4 GHz (802.11b/g/n)
- 3.65 GHz (802.11y)
- 4.9 GHz (802.11j) public safety WLAN
- 5 GHz (802.11a/h/j/n/ac)
- 5.9 GHz (802.11p) for vehicular communication systems.
- 60 GHz (802.11ad)

RFSM Definitions

- s-E = space to Earth (downlink)
- E-s = Earth to space (uplink)
- LEO = Low Earth Orbit
- MEO = Mid Earth Orbit
- HEO = Highly Elliptical Orbit
- GSO- Geo-stationary orbit
- NGSO = Non-GSO



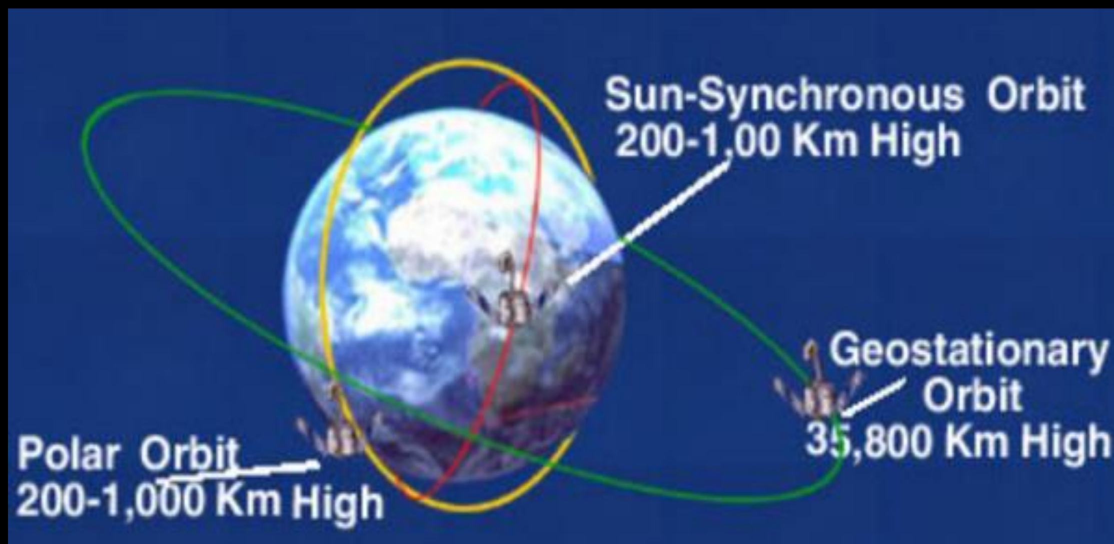
Orbits



LEO
H= 160- 2000 km
Rotation 90 min
LOS time with
Earth station   15 min
Ex. Polar orbits (200 to 1000 km),Sun synchronous for remote Sensing, military

MEO
H= 8000 – 20,000 km
Rotation 5-12 hrs
LOS time with
Earth station   2-4 hrs
Ex. GPS satellites, telecommunications

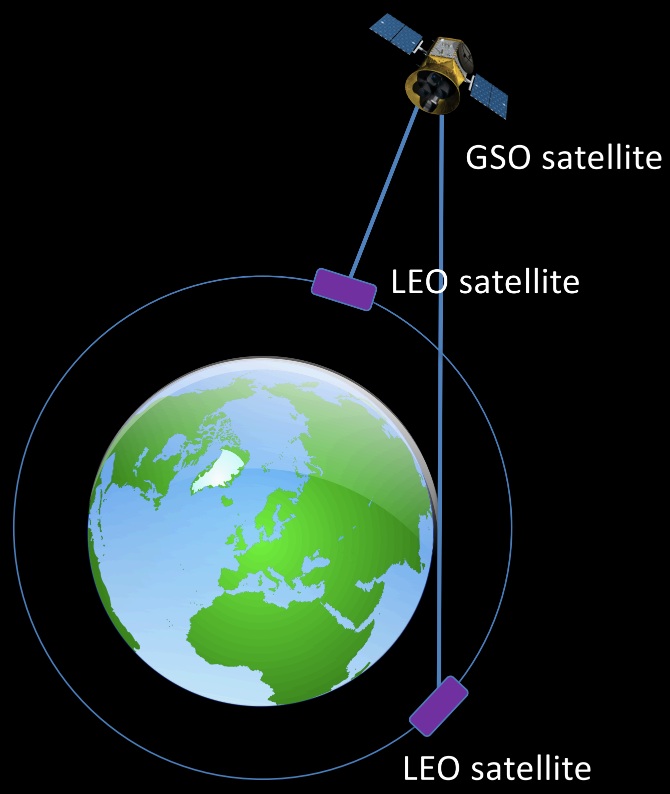
GSO
H= 35 786 km
Rotation 24 hrs
LOS time with
Earth station   24 hrs
Ex. Weather / Communications like ImarSat C, Ku, Ka



The orbit altitude affects the distance travelled, the Power attenuation, and the atmospheric attenuation.

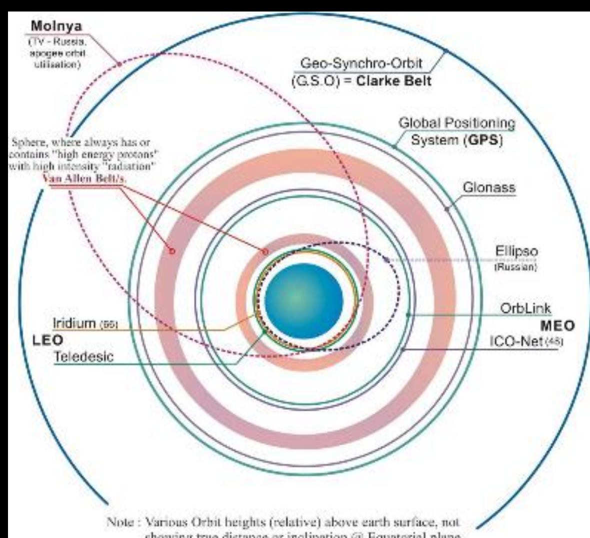
Equivalent power flux density (EPFD)

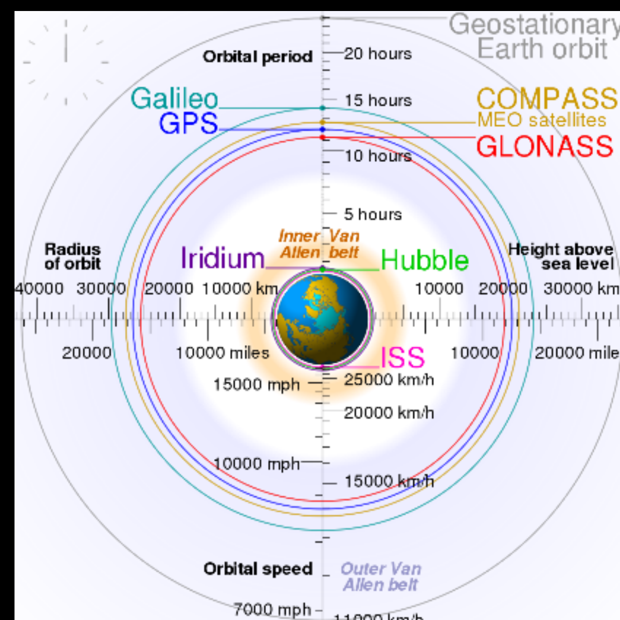
- (EPFD) is the total power where if received from a single transmitter, it would be the same is actually received from the aggregate of the various transmitters.
- Figure shows 2 geometry examples of potential RFI



Examples

- Communications, military, civic and science satellites share some of the same orbits. (they avoid the Van Allen belt)
- This has to be taken into consideration to minimize RFI

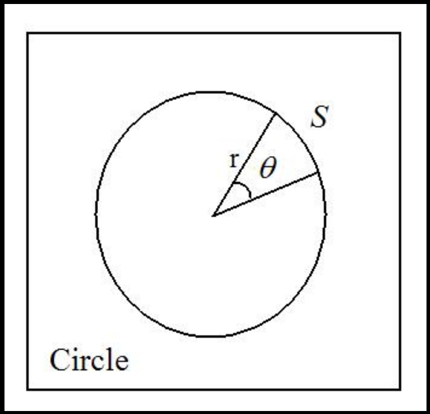


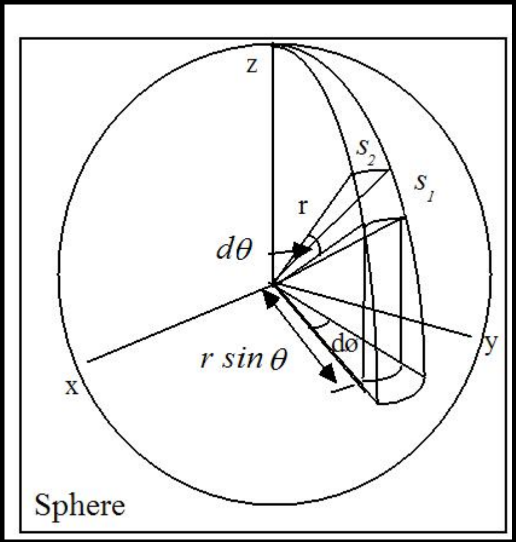


Basic Parameters of

ANTENNAS

Solid Angle





$s = \theta r$ = arch

θ = plane angle

- *the total arch is a Circle:*
  $= 2\pi r$
- *total angle:* $= 2\pi$ [radians]

$s_1 = r\, d\theta \quad s_2 = r \sin\theta\, d\phi$

$dA = s_1\, s_2$

$dA = r^2 \sin\theta\, d\phi\, d\theta$

$= r^2\, d\Omega$

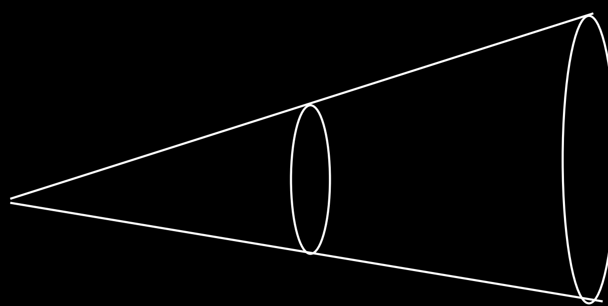
$d\Omega$ = elements of solid angle

- *the total area is a sphere:*
  $= 4\pi r^2$
- *total angle:* $= 4\pi$ [rad^2]
  $= 4\pi$ [sr]

1 steradian (sr) = (1 radian)^2

Power density

- Given in solid angles – doesn't change with range



$$\boxed{S = U / r^2}$$

Spectral Power flux density

Jansky is a non-SI unit of spectral flux density

$$1\ \mathrm{Jy} = 10^{-26}\ \mathrm{W/(m^2\,Hz)}$$

Decibels

Decibel is used to **compare** one variable with a another

- It changes a linear scale to a **logarithm** scale which allows to see a wide range of values in a single graph
- It's defined as:

$$1dB = 10\log\frac{P_2}{P_1}$$

- So for P_2 that is 1000 times larger than P_1, we get 30 dB

*Note that dB is not a unit

$\frac{P_2}{P_1}$	10^{x}	dB
1	10^{0}	0
2	$10^{0.3}$	3
10	10^{1}	10
100	10^{2}	20
10000	10^{4}	40
.5	$10^{-0.3}$	-3
.1	10^{-1}	-10
.01	10^{-2}	-20
.001	10^{-3}	-30

Power: dBm or dBW

To cover large range of power amplitudes, we use a logarithmic scale

dBm= If we use P_1=1mWatt as reference, then
P_2 is expressed in dBm

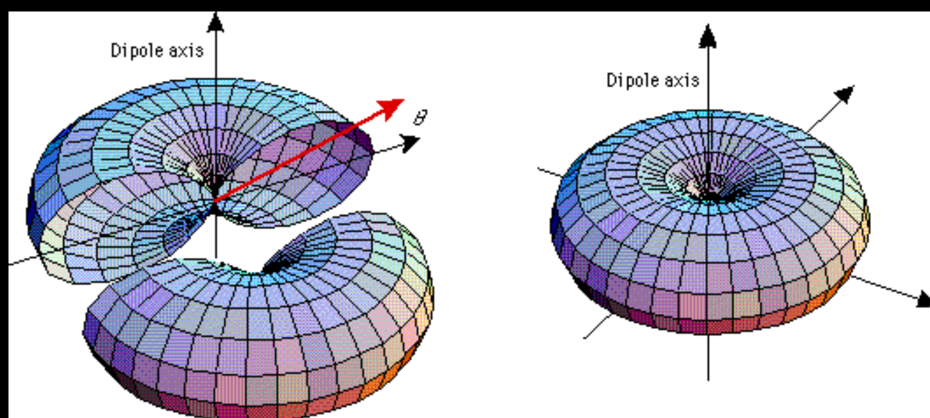
30 dBm= 1dBW

dBW= If we use P_1=1Watt as reference, then
P_2 is expressed in dBW

Radiation Pattern

- Is the relative amplitude of the radiated power as a function of direction. It's given by:

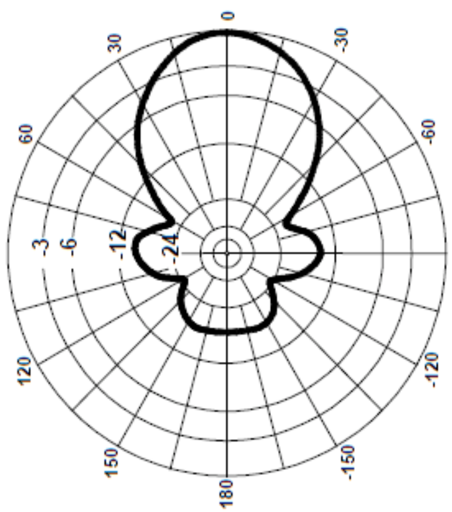
$$f_n(\theta,\varphi) = \frac{P(\theta,\varphi)}{P_{max}}$$



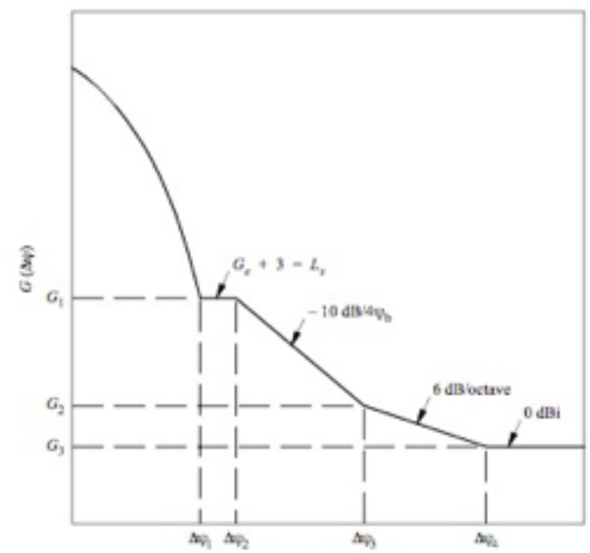
- It is defined at a region far enough from the antenna know as the 'Far field".

http://www.antenna-theory.com/

2D plots

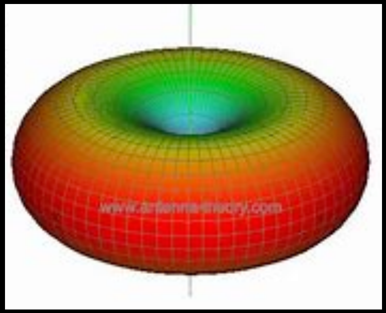


Polar

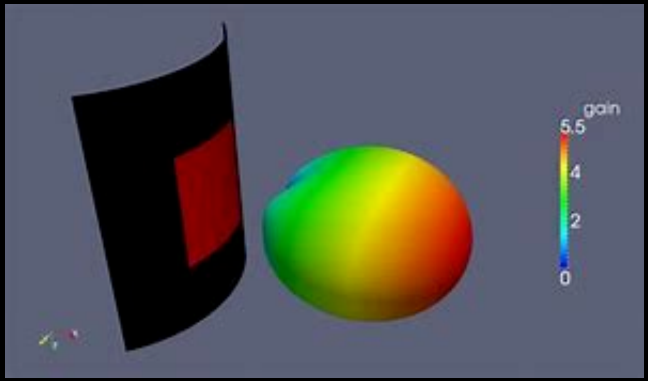


Rectangular

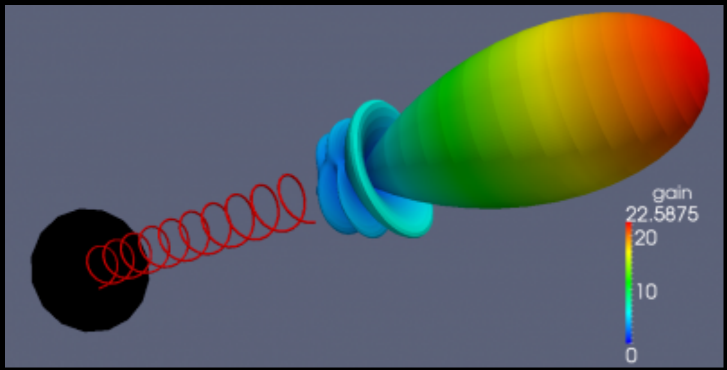
Examples of Antenna Patterns



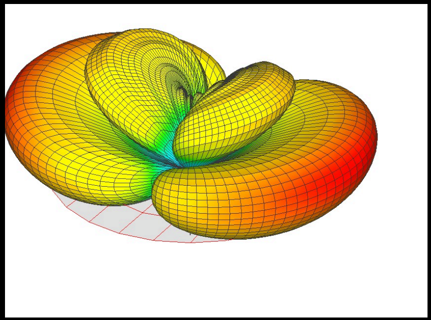
Dipole antenna



Microstrip antenna



helix antenna



Dual band blade antenna

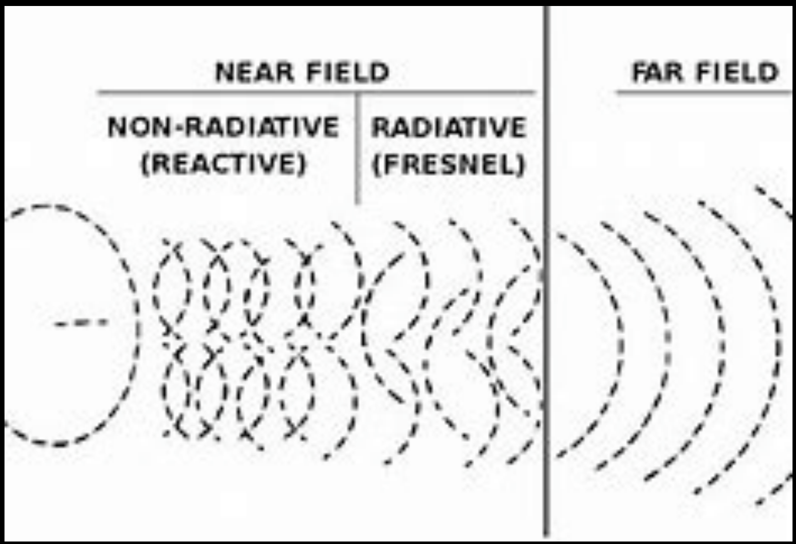
Images courtesy of Mathworks Matlab

Far Field

- The 'Far field" is defined as

$$r_{ff} \geq \frac{2D^2}{\lambda}$$

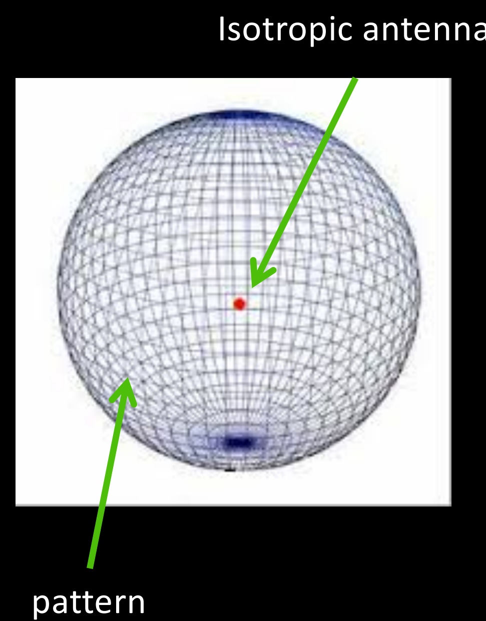
where *D* is the largest dimension of the antenna and λ is the wavelength



Isotropic antenna

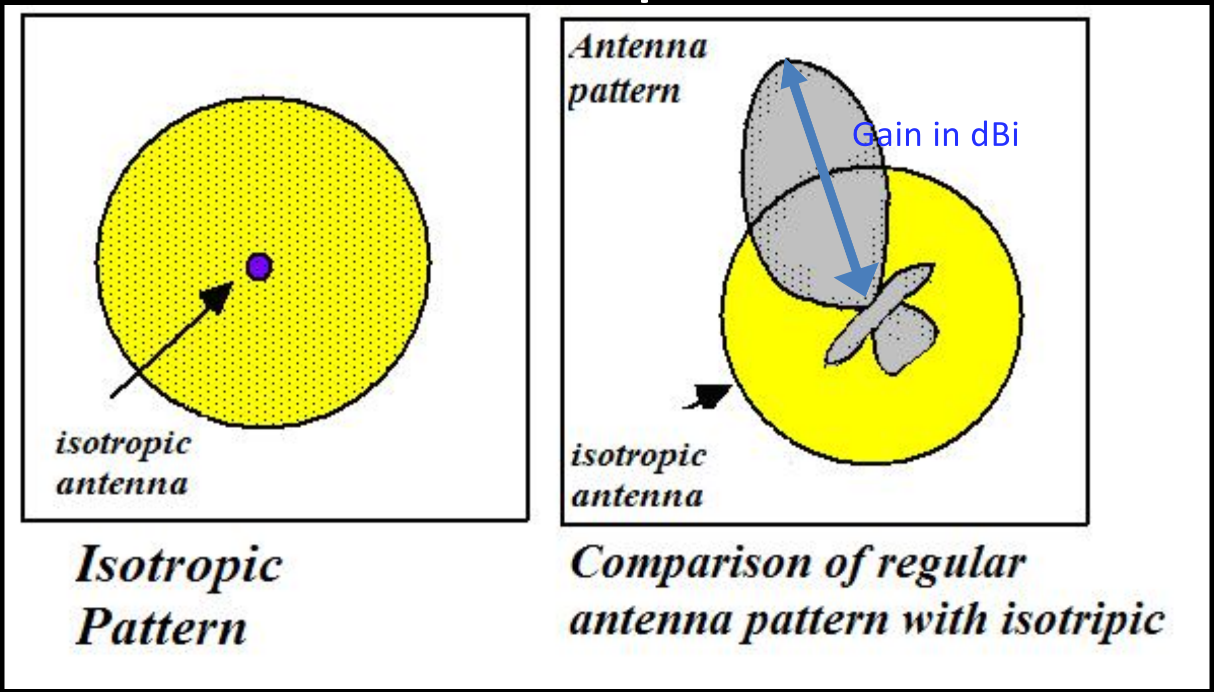
- It's a hypothetic antenna, i.e., it does not exist in real life, yet it is used as a measuring bar for real antenna characteristics.

- It's a point source that occupies a negligible space. Has no directional preference, therefore its radiation pattern has the shape of a sphere.



Gain or Directivity

An isotropic antenna and a real antenna fed with the same power.



Their patterns would compare as in the figure on the right.

Gain

- In general , the gain is a function of direction.

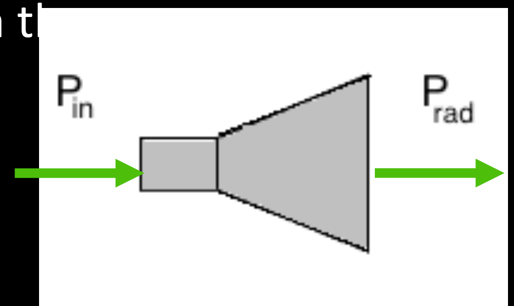
$$G(\theta) = \frac{P(\theta)}{P_{max}/_{4\pi}}$$

- But sometimes when people talk about the gain of an antenna, they usually mean the maximum gain. Note that the gain toward the sidelobes, is much smaller than they gain toward the mainlobe.

Antenna efficiency, η

The directivity of antenna measures the capacity it has to concentrate power in some direction.

The Gain, G, takes into account the losses. For an ideal antenna t gain is equal to the directivity.



$$P_{rad} = \eta \mathrm{P}_{in}$$

- D = Directivity in $dBi = 10 \log \left(\frac{P}{P_{isotropic}} \right)$

$$G = \eta D$$

where η is the efficiency of the antenna

$$\eta = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

dBi or dBd

Antenna patterns are typically expressed in **dBi** (Decibels relative to an isotropic antenna).

$$\text{Gain or Directivity } dBi = 10\log\left(\frac{P}{P_{isotropic}}\right)$$

- dBi is the amount of decibels above the gain for the isotropic antenna

But in occasions it is expressed wrt the half-dipole antenna

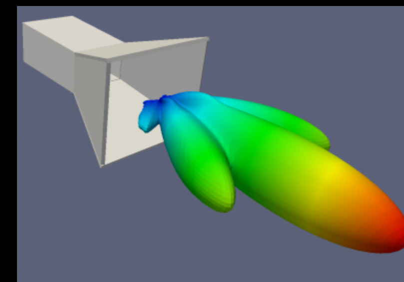
$$\text{Gain or Directivity } dBd = 10\log\left(\frac{P}{P_{dipole}}\right)$$

- dBd is the amount of decibels above the gain for the half-dipole antenna, which is 1.64 [10log(1.64) =2.15]

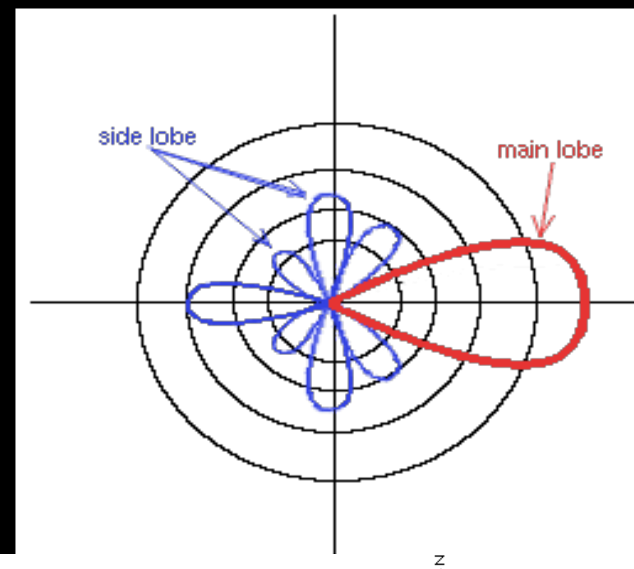
$$G_{dBi} = G_{dBd} + 2.15$$

Sometimes the pattern is given in ***Normalized*** form. In that case the maximum gain is 0dB. The distance between HPBW is found as the radial distance between the two -3dB point around the main lobe.

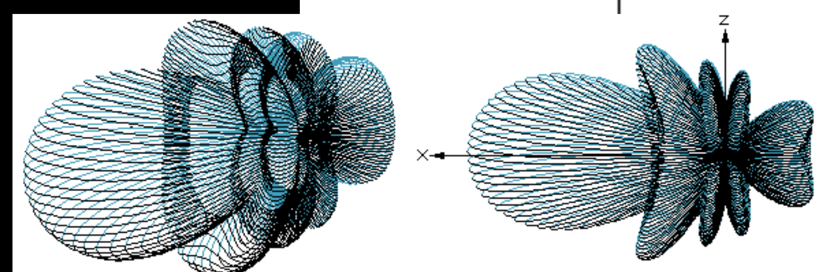
Sidelobes and Backlobes



- Sidelobes are peaks in gain other than the main lobe (the "beam") on the sides of the antenna pattern.
- Backlobes are opposite to the main lobe



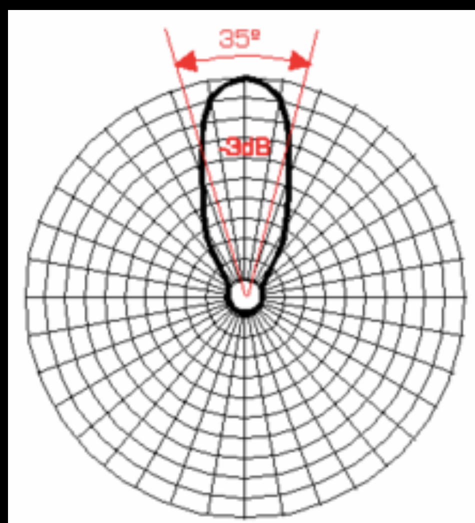
Both can potentially cause interference and lost of power in case of transmitting antennas.

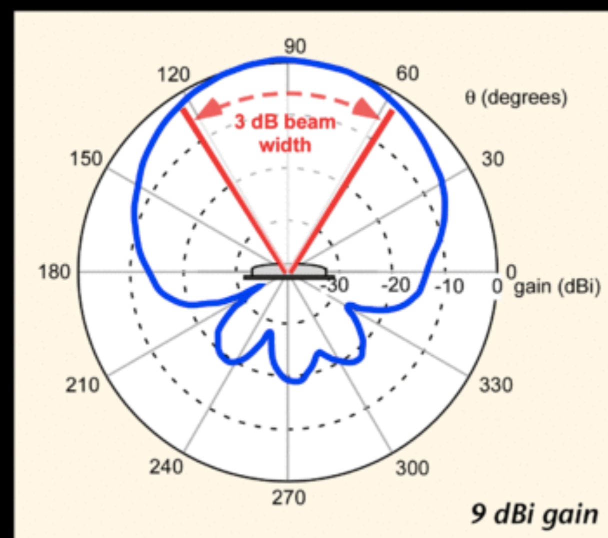


Beamwidth, *HPBW*

Is the angular distance in radians o degrees between two points on opposite sides of the pattern mainlobe where the radiated power is half of the maximum.

- Can be found by solving $f_n(\theta,\phi)=.5$



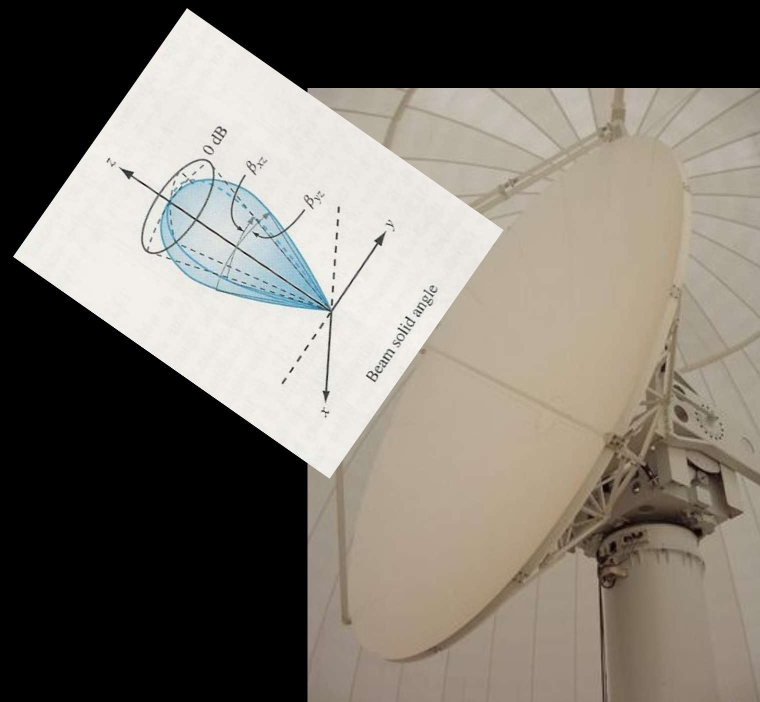


$$G_{max} \approx \frac{4\pi}{HPBW_E HPBW_H}$$

Typical **Pencil Beam pattern**

For a typical pencil beam pattern

HPBW= $70^{o}\frac{\lambda}{d}$ [degrees]



- Pattern for an GSO earth stations antenna

With D/λ=45 as given below in dBi by ITU-R-REC-S.1428:

$$G(\varphi) = \begin{cases} G_{max} - 2.5\times10^{-3}\left(\frac{D}{\lambda}\varphi\right) & for\ 0 < \varphi < \varphi_m \\ G_1 & for\ \ \varphi_m < \varphi < \left(95\,\frac{\lambda}{D}\right) \\ 29 - 25\log\varphi & for\left(95\,\frac{\lambda}{D}\right) < \varphi < 33.1^o \\ -9 & for\ \ 33.1^o < \varphi < 80^o \\ -4 & for\ \ \ 80^o < \varphi < 120^o \\ -9 & for\ \ \ 120^o < \varphi < 180^o \end{cases}$$

where: D= antenna diameter

λ=wavelength

φ :off-axis angle of the antenna in degrees

$$G_{max} = 20\log\left(\frac{D}{\lambda}\right) + 7.7$$

$$G_1 = 29 - 25\log\left(95\,\frac{\lambda}{D}\right)$$

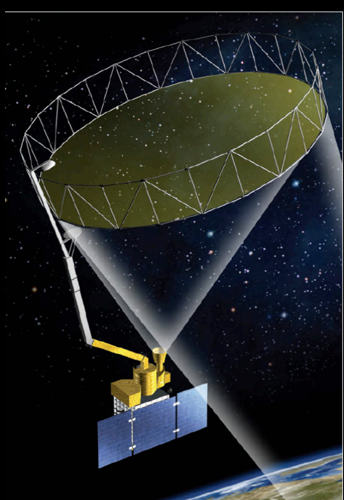
$$\varphi_m = \frac{20\lambda}{D}\sqrt{G_{max} - G_1}\ \text{[degrees]}$$

Using ITU-R RS.1813,plot the pattern if D= 4 λ

$$G(\varphi) = G_{max} - 1.8 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2 \qquad \text{for} \quad 0° \le \varphi \le \varphi_m$$

$$G(\varphi) = \max\left(G_{max} - 1.8 \times 10^{-3}\left(\frac{D}{\lambda}\varphi\right)^2, 33 - 5\log\left(\frac{D}{\lambda}\right) - 25\log(\varphi)\right) \qquad \text{for} \quad \varphi_m < \varphi \le 69°$$

$$G(\varphi) = -13 - 5\log\left(\frac{D}{\lambda}\right) \qquad \text{for} \quad 69° < \varphi \le 180°$$



In the case of $G(\varphi) < -23$ dBi, the value -23 dBi is to be used, where:

$$G_{max} = 10\log\left(\eta\pi^2\frac{D^2}{\lambda^2}\right)$$

$$\varphi_m = \frac{22\lambda}{D}\sqrt{5.5 + 5\log(\frac{D}{\lambda}\eta^2)}$$

G_{max}: maximum antenna gain (dBi)

$G(\varphi)$: gain (dBi) relative to an isotropic antenna

φ: off-axis angle (degrees)

D: antenna diameter (m)

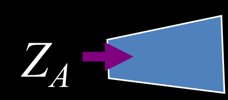
λ: wavelength (m)

η: antenna efficiency (if η is unknown, 60% can be assumed as a representative value);

Antenna Impedance

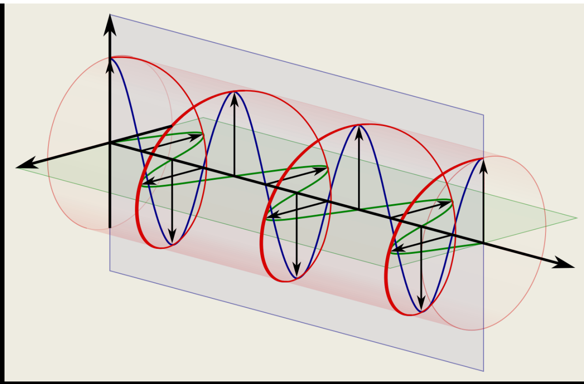
- An antenna is “seen" by the generator as a load with impedance Z_A, connected to the line.

$$Z_A = (R_{rad} + R_L) + jX_A$$



- The real part is the radiation resistance plus the ohmic resistance.
  - Minimizing impedance differences at each interface will reduce SWR and maximize power transfer through each part of the antenna system.
  - Complex impedance, Z_A, of an antenna is related to the electrical length of the antenna at the wavelength in use.

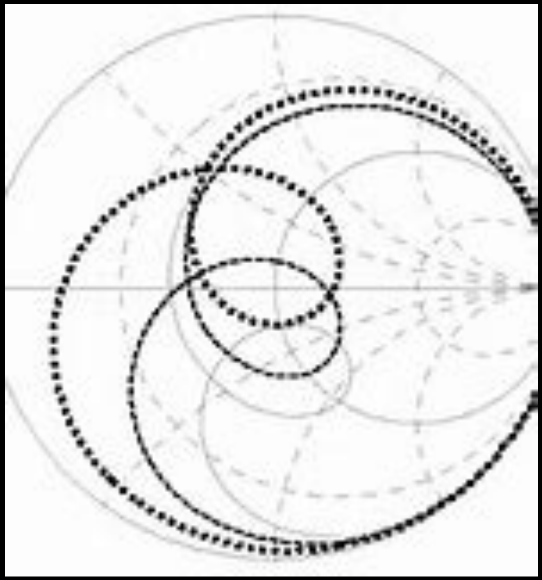
Antenna
Polarisation



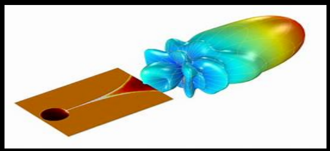
- The polarisation of an antenna is the polarization of the signals it emits.
  - The ionosphere changes the polarization of signals unpredictably, so for signals which will be reflected by the ionosphere, polarization is not crucial.
  - However, for line-of-sight communications, it can make a tremendous difference in signal quality to have the transmitter and receiver using the same polarization.
  - Polarizations commonly considered are *vertical*, *horizontal*, and *circular*.

Antenna Bandwidth

- The bandwidth of an antenna is the range of frequencies over which it is effective, usually centered around the operating frequency.



Effective Area



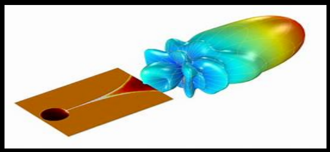
- How a receiver antenna extracts energy from incident wave and delivers it to a load?

$$A_e = \frac{P_{received}}{P_{incident}} = \frac{\lambda^2 G}{4\pi}$$

If you need a G=40dB or 100, compute:
The effective areas for a radar that operates at
S-band (2.5GHz) ,
X-band (10GHz), and
W-band (95GHz

ANSWER:
The effective areas would be: 12 m^2, 0.7 m^2 and 0.08 m^2 , respectively.
Showing that, the higher the frequency , the smaller the antenna size to attain the same Gain.

Effective Area



For an antenna with circular cross section, of diameter d,

- We can solve the last equation for gain, to obtain:

$$G = \eta\pi^2\left(\frac{df}{c}\right)^2$$

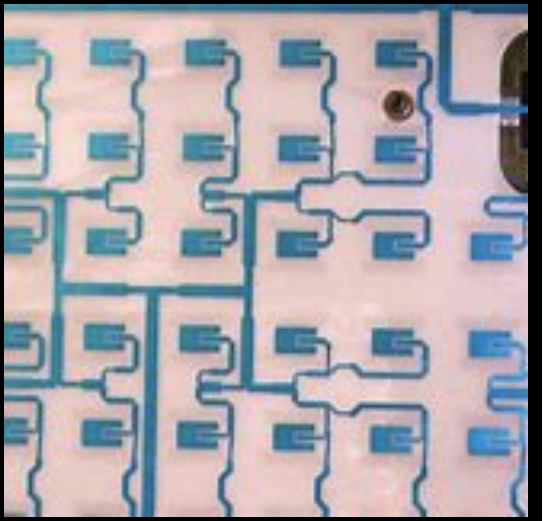
- Where we are taking into account the antenna efficiency, etha.

Antenna Arrays

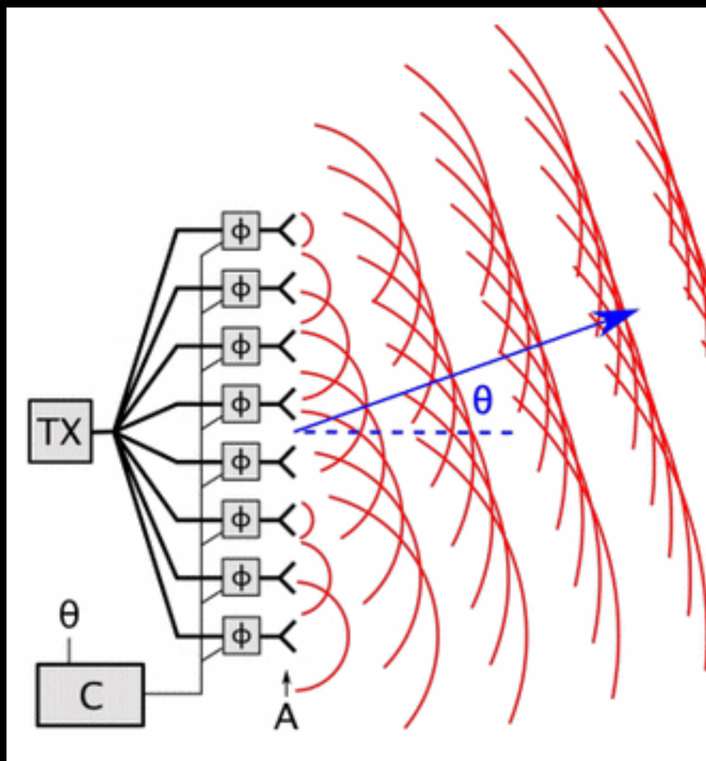
Use many antennas synchronized with each other to improve their performance.

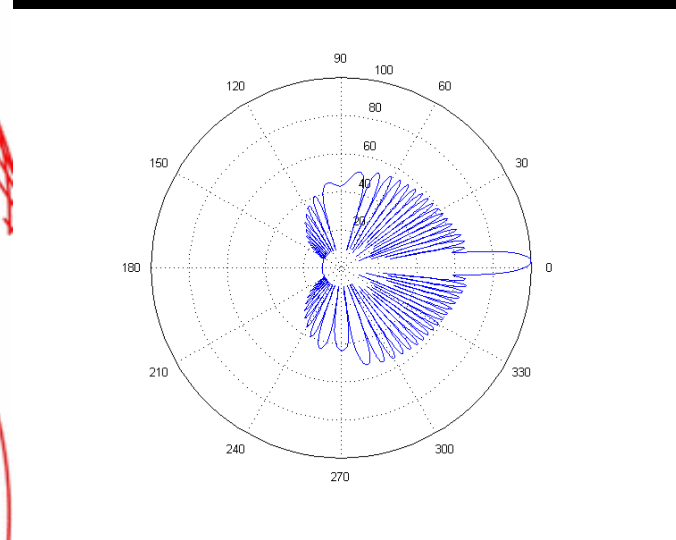
They can:

- increase the gain or directivity
- to minimize the sidelobes
- Scan the mainlobe without moving the antenna
- Reduce RF interference



Electronically scanned arrays





More

ACRONYMS

RFSM Acronyms

- ITU= International Telecommunications Union
  - WRC= World Radiocommunications Conference
  - CPM - Conference Preparatory Meeting for WRC
- U.S. RF Regulations Agencies:
  - FCC = Federal Communications Commission
  - NTIA = National Telecommunications & Information Administration
    - IRAC =Interdepartment Radio Advisory Committee
- NAS- National Academies of Sciences
  - CORF – Committee of Radio Frequencies
- IEEE FARS – Frequency Allocations in Remote Sensing

RFSM Definitions

- ITU-R- Radiocommunication Sector of the ITU
- ITU RA- Radiocommunication Assembly
- Rec. ITU = Recommendation ITU
- RR = Radio Regulation

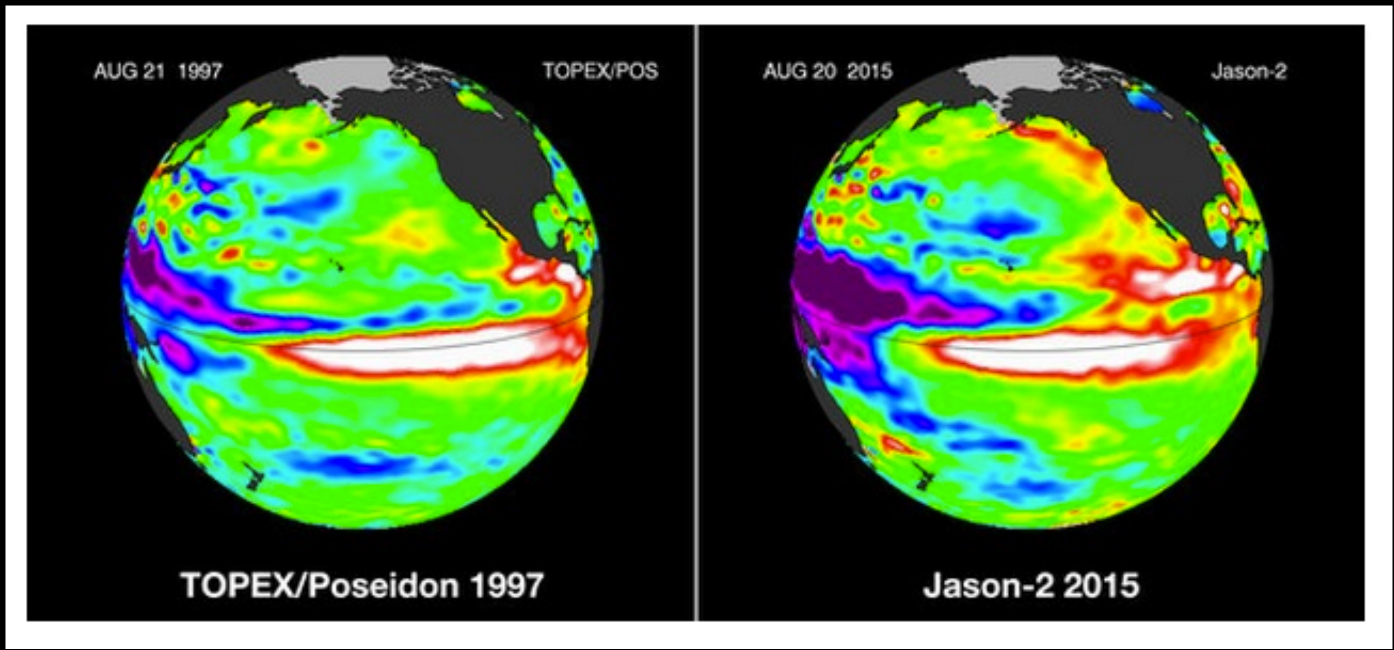
RFSM Definitions

- NOI -Notice of Inquiry
- NPRM - Notice of Proposed Rule Making
- FNPRM -Further Notice of Proposed Rulemaking
- FN&O -Further Notice of Proposed Rulemaking and Order
- FR = Federal Register is the official journal of the federal government of the USA. Ex. 47 CFR 15.205 - Restricted bands of operation

RFSM Definitions

- PFD - Power flux density
- EPFD- Equivalent PFD
- U-NII - Unlicensed National Information Infrastructure
- LAN = local area network
- WLAN = wireless LAN

ENSO
El Niño Southern Oscillation

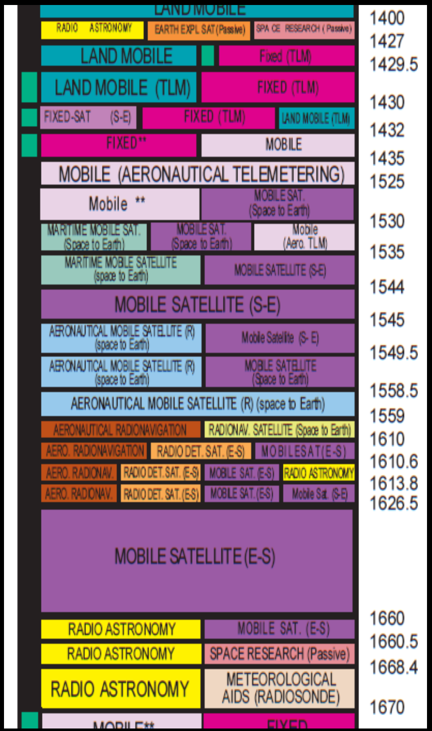


License vs. Assignment

- In the U.S. , licenses to use the spectrum are given by the FCC
- The federal agencies equivalent is an assignment.

Allocation vs. Assignment

Analogous to zones in a city:



Allocation types

- Primary allocations grant specific services priority in using a particular swathe of allocated spectrum. In cases where there are multiple primary services within a band, they have equal rights. A station has the right to be protected from any others that start operation at a later date.
- Secondary allocations involve services that must protect all primary allocations in a particular band. Services operating in secondary allocations must not cause harmful interference to, and must accept interference from, primary users. All secondary service stations have equal rights among themselves in the same band.

RFSM Definitions

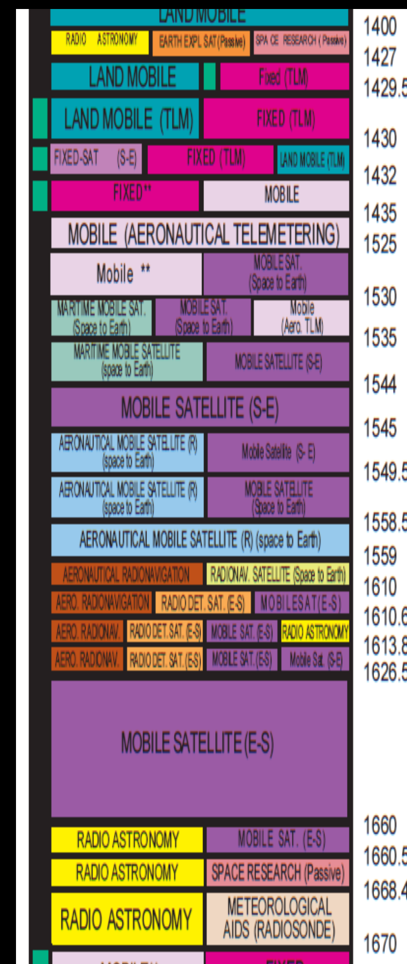
- RFI – Radio-frequency interference
- Spurious emission: non- intentional emission frequency outside the necessary BW and the level of which may be reduced without affecting TX.
  - Ex. include harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products, but exclude out-of-band emissions OOBE. [NTIA] [RR] (188)
- OOBE =out of band emissions immediately outside the necessary BW which results from the modulation process, but excluding spurious emissions.
- Harmful interference = endangers the functioning of another service

Services: users or applications

- **EESS** = Earth Exploration Satellite Service
- **RAS** = Radio Astronomy Service

List of some RF Services abbreviations

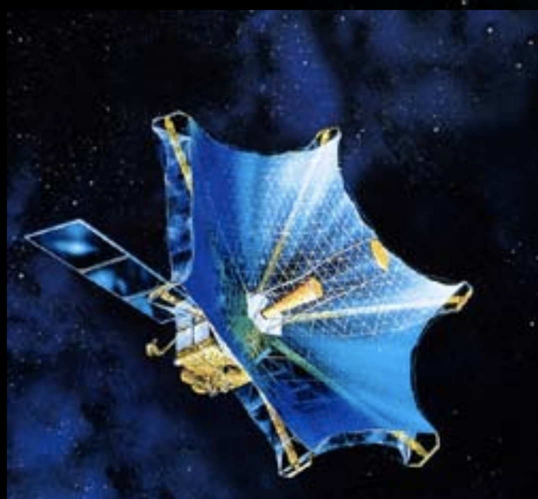
Abbreviations	Radio services
AMS	aeronautical mobile service
AM(R)S	aeronautical mobile (route) service
AMSS	aeronautical mobile-satellite service
AMS(R)S	aeronautical mobile-satellite (route) service
ARNS	aeronautical radionavigation service
ARNSS	aeronautical radionavigation-satellite service
AS	amateur service
ASS	amateur-satellite service
BS	broadcasting service
BSS	broadcasting-satellite service
EESS	Earth exploration-satellite service
FS	fixed service
FSS	fixed-satellite service
ISS	inter-satellite service
LMS	land mobile service
LMSS	land mobile-satellite service
MetAids	meteorological aids service



RAS

- Radio astronomy service

Radio astronomy service- uses mostly passive ground-based observations for the reception of radio waves of cosmic origin but also uses satellites to study objects far away in space. Such is the case of the Japanese VSOP - the VLBI (Very Long Baseline Interferometry) Space Observatory Programme

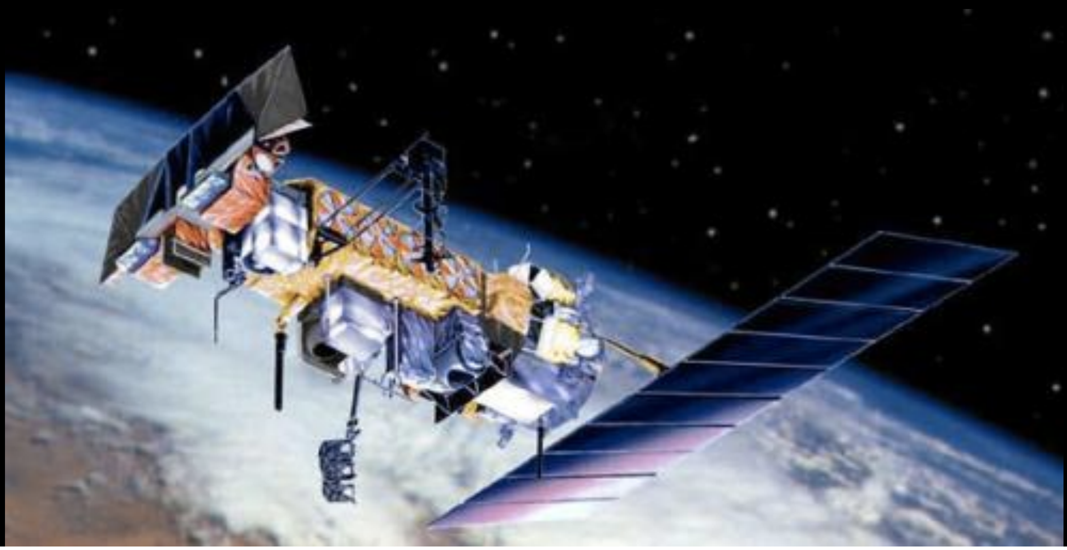


RAS satellites study objects far away in space.

RAS ground-based systems.

SRS

- Space Research Satellite Service –they operate on or around planets and includes telemetry and data downlinks for space RAS and other science satellites.

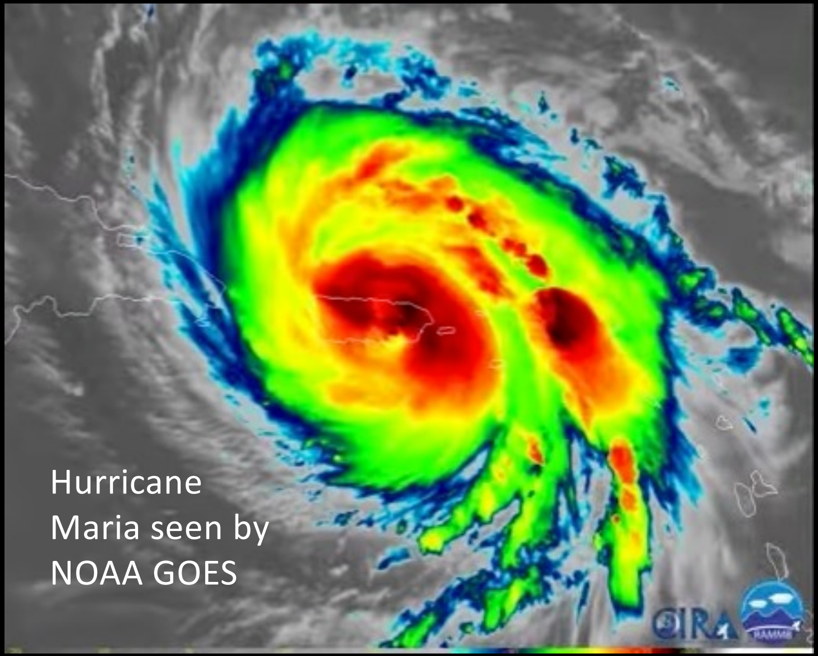


List of some RF Services abbreviations

Abbreviations	Radio services	RR definition
MetSat	meteorological-satellite service	No. **1.52**
MMS	maritime mobile service	No. **1.28**
MMSS	maritime mobile-satellite service	No. **1.29**
MRNS	maritime radionavigation service	No. **1.44**
MRNSS	maritime radionavigation-satellite service	No. **1.45**
MS	mobile service	No. **1.24**
MSS	mobile-satellite service	No. **1.25**
RAS	radio astronomy service	No. **1.58**
RDS	radiodetermination service	No. **1.40**
RDSS	radiodetermination-satellite service	No. **1.41**
RLS	radiolocation service	No. **1.48**
RLSS	radiolocation-satellite service	No. **1.49**
RNS	radionavigation service	No. **1.42**
RNSS	radionavigation-satellite service	No. **1.43**
SOS	space operation service	No. **1.23**
SRS	space research service	No. **1.55**

MetSat

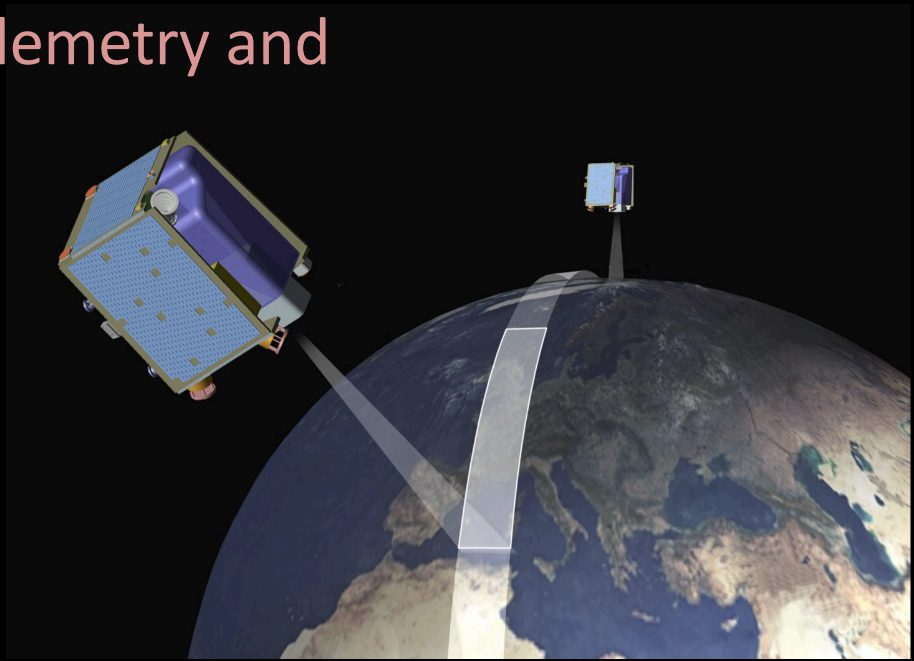
- Meteorological satellite service- refers to weather satellites, ex. Tracking hurricanes



r Puerto Rico on Sept 17, 2018.

SOS

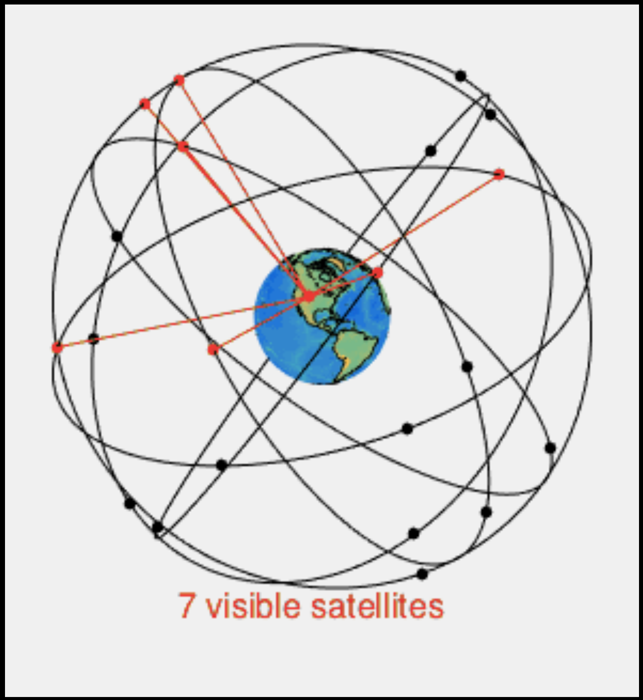
- Space Operation Service – deals with radio communications concerned exclusively with the operation of spacecraft, such as space tracking, telemetry and telecommand



RNSS

RadioNavigation Satellite service

- The global navigation satellite system (GNSS) Service, provide accurate position and timing data –Ex. GPS



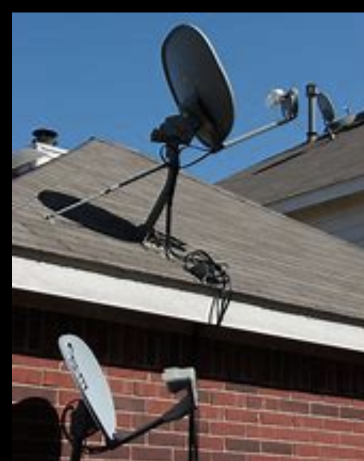
EESS

- The Earth Exploration Satellite Service – performs remote sensing from orbit both active and passive and the data downlinks for their satellites

FSS, BSS and MSS examples

- Fixed Satellite Service (FSS) – mobile phones, Internet on airplanes, TV, more

- **Broadcasting-satellite services (BSS)- satellite TV**

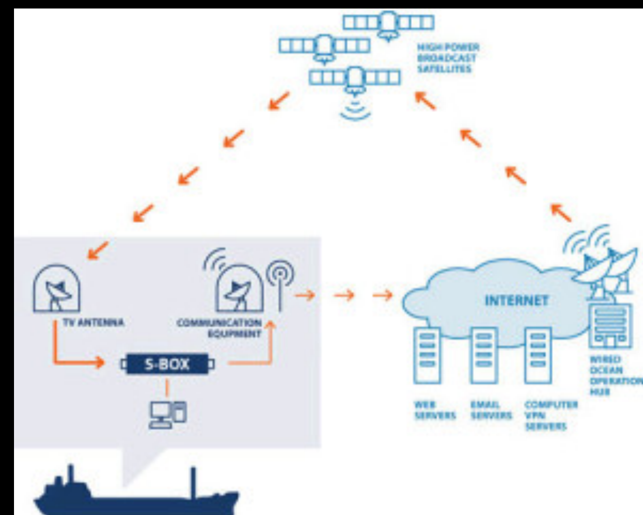


- **Mobile-satellite services (MSS): satellite phones**

For example:

MSS

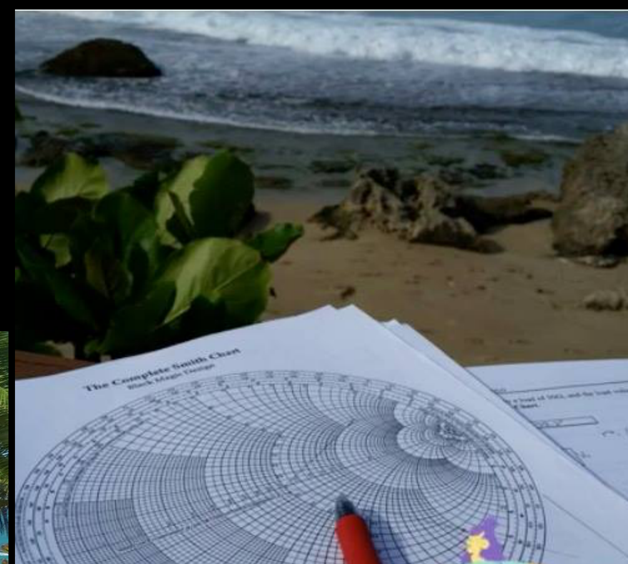
MMSS



Source: www.efxkits.us

Low *f* = *“beach front”*

- Offer low atmospheric attenuation in general, and LOS links.
  - Receiver front-end noise figure and antenna gain are the defining factors in line-of-sight signal propagation in the local area.



Spectrum Engineering
(Technical Standards)

describes procedures for:

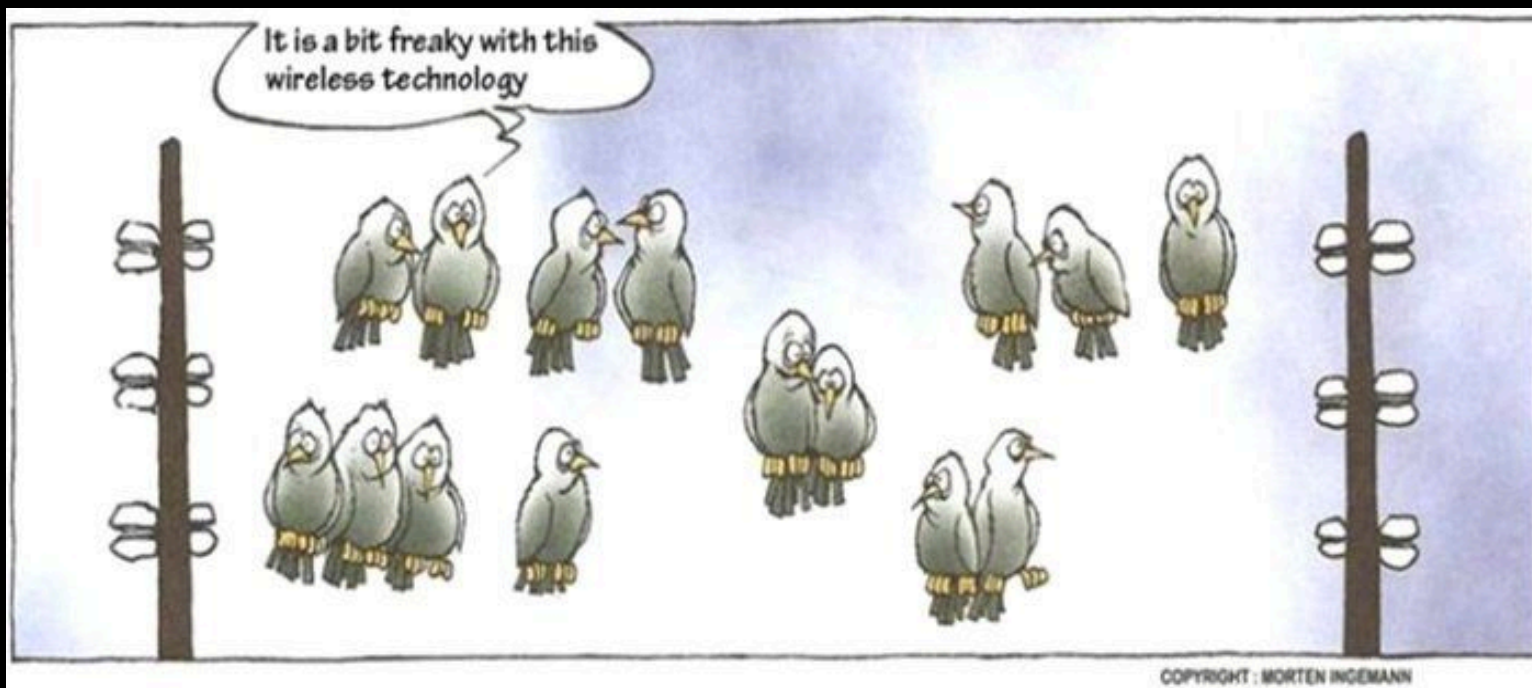
- Spectrum operating standards state the minimal technical requirements for the efficient use of a specified frequency band or bands.
- Equipment standards involve certification of radio equipment such as transmitters, receivers and antennas in order to determine compliance with radio operating standards.

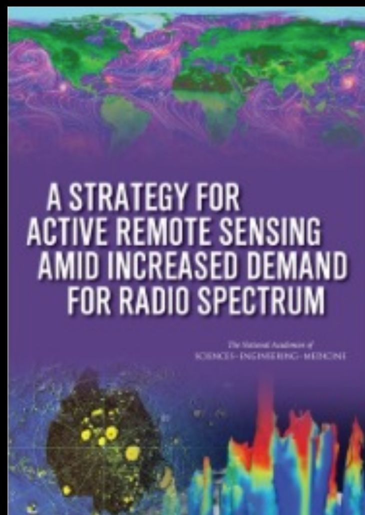
Ex: description of equipment and the application; an indication of licensing; spectrum channel plan arrangements; modulation techniques; transmitter power; and transmission limits for unwanted emissions.

The mutual interaction of electronic equipment is known as "Electromagnetic Compatibility" (EMC).

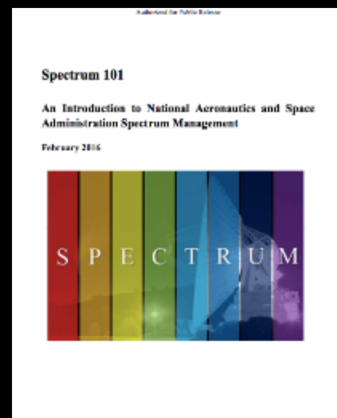
Spectrum monitoring and compliance activities are needed to ensure user compliance with frequency allocations, terms of assignments and technical standards. These activities help users to avoid incompatible frequency usage through the identification of sources of harmful interference, and to resolve interference problems for existing and potential users. Ensuring compliance with national spectrum management regulations maximizes the benefit of the spectrum resource to society

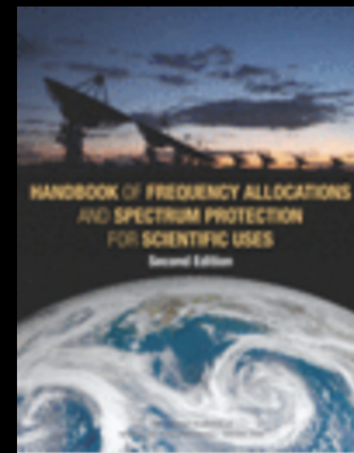
Questions?


It is a bit freaky with this wireless technology
COPYRIGHT : MORTEN INGEMANN



Free in PDF





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