

# **ISART** *2011*

## Inventory Briefings

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*Moderator:*

Matthew Hussey (Legislative Assistant,  
Senator Olympia J. Snowe)

*Presenters:*

David DeBoer (UC Berkeley)

Frank Sanders (NTIA/ITS)

Bob Sole (NTIA/OSM)

Chris Tourigny (FAA)



# Session Outline

- Goals: To describe the current and projected use radar systems in and around the U.S. and to provide background on these systems to support discussions for the remainder of the ISART conference.
- Presentations:
  - Congressional Perspective  
Matthew Hussey
  - Technical Overview  
Frank Sanders
  - HF  
Frank Sanders
  - VHF/UHF  
Frank Sanders
  - L Band  
Robert Sole
  - Lower S Band (2700 – 2900 MHz)  
Robert Sole
  - Upper S Band (2900 – 3650 MHz)  
Frank Sanders
  - Maritime S Band (near 3050 MHz)  
Joe Hersey
  - C Band (5250 – 5925 MHz)  
Frank Sanders
  - TDWR C Band (5600 – 5650 MHz)  
Chris Tourigny
  - X Band (8500 – 10, 500 MHz)  
Robert Sole
  - Ku/Ka/mm  
David DeBoer

# Congressional Perspective

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Presenter: Matthew Hussey



# Wireless Spectrum Initiative

The White House

Office of the Press Secretary

For Immediate Release

June 28, 2010

## Presidential Memorandum: Unleashing the Wireless Broadband Revolution

MEMORANDUM FOR THE HEADS OF EXECUTIVE DEPARTMENTS AND AGENCIES

SUBJECT: Unleashing the Wireless Broadband Revolution

America's future competitiveness and global technology leadership depend, in part, upon the availability of additional spectrum. The world is going wireless, and we must not fall behind. The success of American productivity growth

make available **a total of 500 MHz** of Federal and nonfederal spectrum over the **next 10 years**, suitable for both mobile and fixed wireless broadband use.

technologies hold the promise for a virtuous cycle – millions of consumers gain faster access to more services at less cost, spurring innovation, and then a new round of consumers benefit from new services. The wireless revolution has already begun with millions of Americans taking advantage of wireless access to the Internet.

Expanded wireless broadband access will trigger the creation of innovative new businesses, provide cost-effective connections in rural areas, increase productivity, improve public safety, and allow for the development of mobile telemedicine, telework, distance learning, and other new applications that will transform Americans' lives.





# Growing demand for spectrum

## – Consumers

### • WIRELESS BROADBAND!!!



## – Federal Users & Military

- Defense, surveillance, imaging radar, eGov 2.0, etc.



## – Others

- Public Safety & D-Block
- Utilities/smart grids
- Railroads









# Why a spectrum inventory?

“In order to free up additional spectrum, decision makers at the FCC, NTIA, and Congress must have a clear, detailed, up-to-date understanding of how spectrum is currently being used and by whom—such data is essential to sound policy decisions.”

—Senator Olympia Snowe





# Disparate databases

- Bifurcated model creates challenges

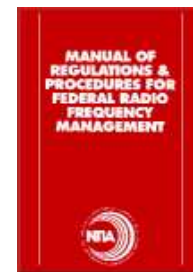
- FCC's Multiple Databases

- Spectrum Dashboard & LicenseView
- Universal Licensing System (ULS)
- Broadcast Radio and Television Electronic Filing system (CDBS)
- International Bureau Electronic Filing system (MyIBFS)



- NTIA's Government Master File (GMF)

- Contains records of frequency assignments to all US Federal Government agencies







# Current inventory efforts

## FCC Baseline Inventory

- Creation of Spectrum Dashboard and LicenseView
- Helps “unleash significant additional spectrum”
- Provides “more complete picture”
- Confirms Congress should “swiftly take” action to authorize voluntary incentive auctions

**Over 2 million active licenses**

## NTIA Evaluation

- Fast Track
  - 5 initial bands examined\*
  - 115 MHz found for reallocation
  - Further review of 1755-1780 by Sept 30<sup>th</sup>
- Ten-Year Plan
  - Evaluating 2,200 MHz of spectrum
  - Greater incentives and assistance for repurposing

**69 agencies use spectrum**

\*1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, 4200-4220 MHz, & 4380-4400 MHz



# ***Snowe-Kerry RADIOS Act (S.455)***

## **Sec. 3 – Spectrum Inventory Provision**

- **Inventory from 300 MHz to 6.5 GHz**
  - Authorized licensees or government users
  - Total spectrum per user in band (% and sum)
  - Number and type of devices
  - Contour maps & geo-locations of base stations
  - Extent of use
  - Activities, capabilities, functions, or missions supported
  - Unlicensed authorization/activity
- **Centralized portal where most data publicly accessible**
- **Congressional Report**



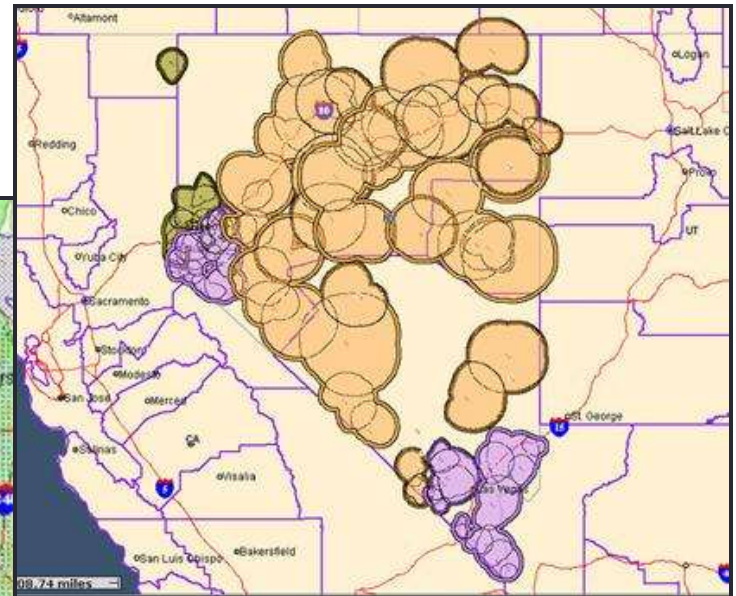


# Inventory provides more detail

Deriving information from the data...



← Licenses



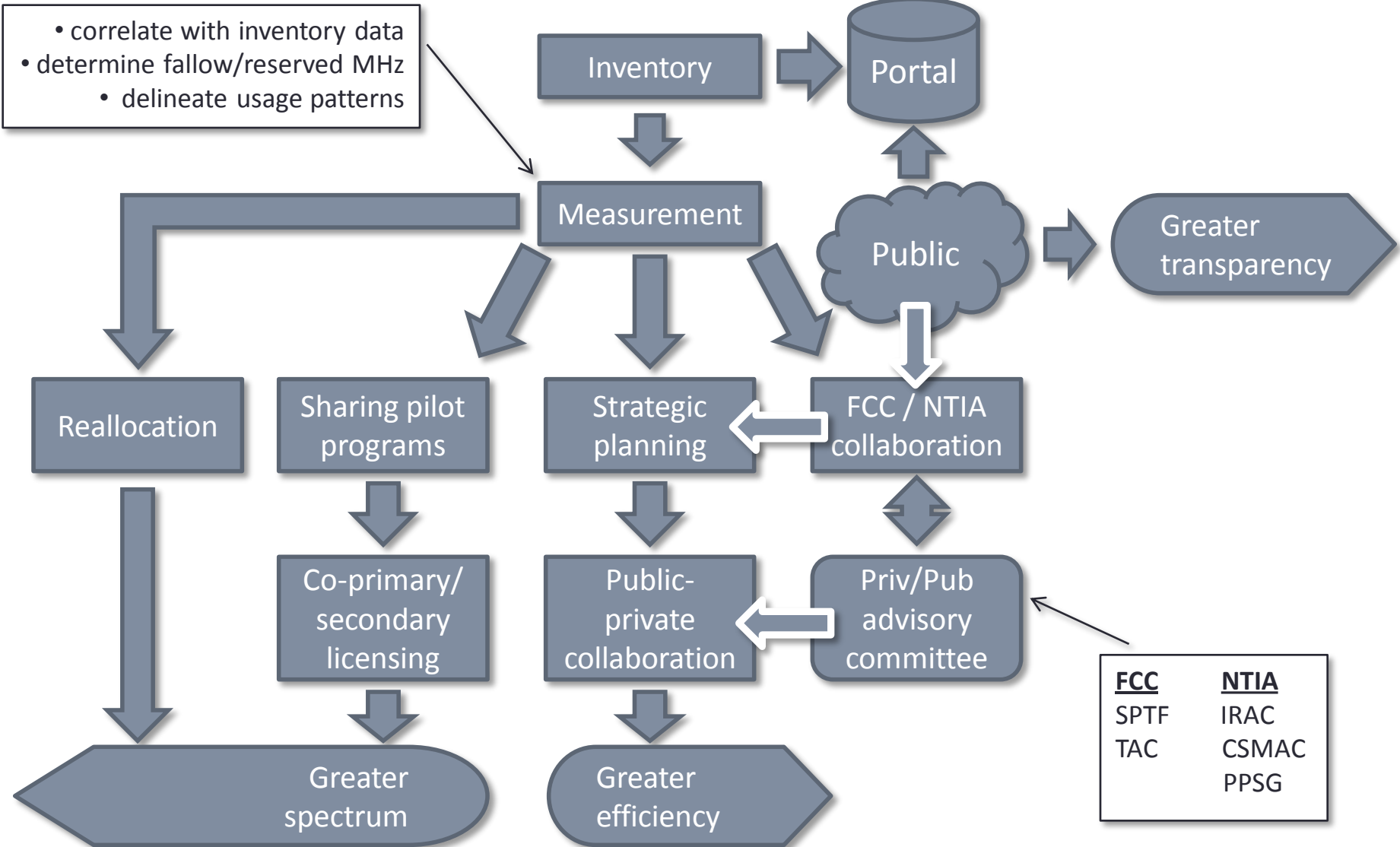
↑ Deployment

Contour Maps →





# Foundation for next steps





# How an inventory will help

- Proper starting point to ensure long-term health of the spectrum ecosystem
- Provide greater clarity for reallocation, more sharing, and more efficiency
- Essential to proper planning and will be a necessary component to greater collaboration (planning, design, co-existence)



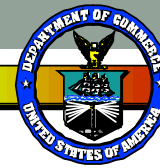
# Technical Overview

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Presenter: Frank Sanders

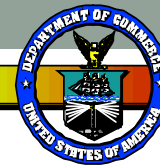






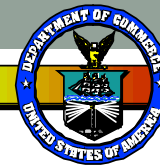
## Technical Overview: Useful Radar Facts

- As we review band-specific radar characteristics in this session, it may be useful to keep the following information in mind:
  - Radar transmitters typically produce effective isotropic radiated power levels between hundreds of kilowatts to as much as 40 gigawatts
  - During the “listen” part of their cycles, radars need to detect echoes on the order of 1/100 picowatt
  - No two models of radar are alike; each model has been designed to accomplish a specific mission
  - New radar designs continue to be evolved; dual-band radars are currently a hot topic



# Compatibility Sketch: Radar Receiver

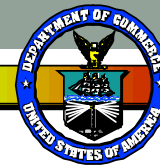
- Radar receiver sensitivity is driven by the problem of detecting target pulse echoes at long ranges. What's this number?
- Do the math. Build a typical air traffic control radar:
  - 1 MW transmitted pulse power ( $p_t = 10^6 \text{ W}$ )
  - 30 dBi transmitter antenna gain ( $g_t = 1000$ )
  - $1/10 \text{ m}^2$  reflective target cross section ( $\sigma = 0.1$ )
  - 150 km (80 nm) range ( $r = 1.5 \cdot 10^5 \text{ m}$ )
  - $10 \text{ m}^2$  receive antenna effective aperture ( $a_e = 10 \text{ m}^2$ )
- Received power is the effective radiated power (transmit power multiplied by antenna gain) divided by the surface area of the expanding spherical wavefront (going out to the target and then back again), multiplied by the target cross section and the effective aperture of the receiving antenna:
  - $p_r = p_t \cdot g_t \cdot 1/(4\pi r^2)^2 \cdot \sigma \cdot a_e$



# Radar Receiver Sensitivity

$$\begin{aligned} p_r &= p_t \cdot g_t \cdot 1/(16 \pi^2 r^4) \cdot \sigma \cdot a_e \\ &= 10^6 \text{ W} \cdot 10^3 \cdot 0.1 \cdot 10 \text{ W m}^4 / (16 \pi^2 (1.5 \cdot 10^5)^4) \text{ m}^4 \\ &= 10^9 \text{ W m}^4 / (800 \cdot 10^{20} \text{ m}^4) \\ &= 1.25 \cdot 10^{-14} \text{ W (about 1/100 of a picowatt)} \end{aligned}$$

- This received echo power in the radar receiver is  $1.25 \cdot 10^{-11} \text{ mW} = -109 \text{ dBm}$
- If that's the received power, what's the inherent noise level in the receiver, against which these -109 dBm echoes must be detected?



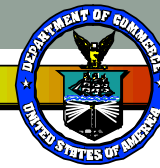
# Radar Receiver Sensitivity, continued

- If the pulses are  $1 \mu\text{s}$  long (so that targets can be resolved to 500 ft in space), then the receiver bandwidth needs to be about  $1/(1 \mu\text{s}) = 1 \text{ MHz}$
- The inherent **thermal electron noise** (kTB) in 1 MHz is -114 dBm
- If receiver **noise figure** is 5 dB, receiver's noise level is **-109 dBm**
- This noise has the **same power** as the level of the pulse echoes from the target (!)
- Radars overcome this problem by *integrating* multiple echoes (say, 20) from each target to “grow” the echo energy in the receiver up to a more detectable level
- Therefore, radar receivers cannot afford to lose even **1 dB** in performance. This is the increase in noise produced by interference at  $\frac{1}{4}$  (**-6 dB**) of the receiver noise power relative to receiver noise.  
(i.e., -6 dB + 0 dB = +1 dB)

# Coastal Crowding and Radar Operations

- According to NOAA analysis of Census data, **55% of US population** lives within **50 miles** of US coasts (east, west, Gulf, and Great Lakes—the green zone in the figure).
- As will be seen in this session, this 50-mile zone sees heavy use by radars: marine (littoral), airborne, and terrestrial/fixed installations.

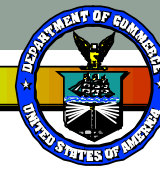




# A Brief Note on U.S. Radar Bands

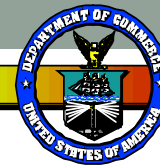
- Radar band designations developed during WW II — a legacy
- Designators originally designed to confuse the enemy, but now just confuse everyone except radar engineers
- **Radar band** designators are **not** the same as **NATO band** designators (e.g., the radar “C” band is not the same as NATO “C” band)
  - **HF**: 5-28 MHz
  - **P** (VHF): 420-450 MHz
  - **Lower L** (UHF): 902-928 MHz
  - **L**: 1215-1390 MHz  
(formerly 1215-1400 MHz)
  - **Lower S**: 2700-2900 MHz
  - **Upper S**: 2900-3100, 3100-3650 MHz  
(upper edge formerly 3700 MHz)
  - **C**: 5250-5925 MHz
  - **X**: 8.5-10.5 GHz
  - **Ku** (“under K”) 13.4-14.0, 15.7-17.7, 24.05-24.5 GHz
  - **Ka** (“above K”) 33.4-36.0 GHz





# A Brief Note on Radar Nomenclatures

- Old-style (WW II) **A/N** radar designators = part of a broader system for generally categorizing DoD radio systems (“A/N” = Army-Navy, pre 1947 USAF spin-off)
- A/N-*iPj(k)* designations:
  - “*i*” is radar basing mode: *S* = shipborne, *A* = airborne, *T* = transportable, etc.
  - “*P*” stands for radar, “*R*” having originally been taken for “radio”.
  - “*j*” is radar’s primary function: *N* = navigation, *S* = search, etc.
  - “*k*” is an optional trailing letter that designates a variation within a radar model. These go alphabetically: A, B, C, etc. (but a trailing “(V)” in parentheses means “variant” or “version”, or even “production units vary from one to the next”)
- Not all radars use A/N designators. Examples include:
  - ASR = airport surveillance radar
  - ARSR = air route surveillance radar
  - TDWR = Terminal Doppler weather radar
  - NEXRAD = next-generation weather radar (also called WSR-88D, for weather surveillance radar, Doppler capable, type-accepted in 1988)



# Band-by-Band Parameters for Radars

## *5 MHz to 40 GHz*

- Application/function
- System designation(s)
- Mission(s)
- Tuning range/emission bandwidth/frequency requirements
- Geographic and mobility analysis
- Operation schedules
- Antenna gain/beam direction/revisit time
- Range/propagation effects
- Life cycle
- Procurement/Replacement Cost
- Nominal noise figure

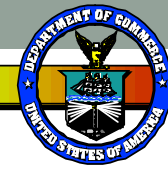
# HF

(3 – 30 MHz  $\rightarrow$   $\lambda = 10 - 100$  m)

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Presenter: Frank Sanders



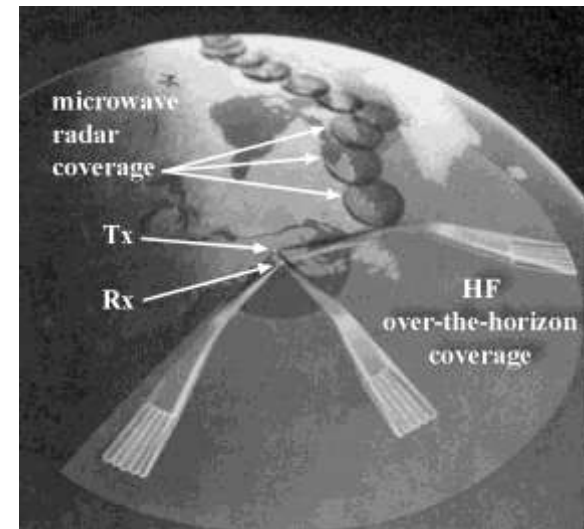


## HF (5 – 28 MHz $\rightarrow$ $\lambda$ = 10 – 60 m)

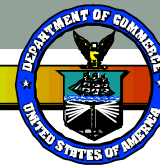
- Application/function for systems in this band:
  - Over-the-horizon radar coverage using semi-permanent terrestrial installations
  - Propagation research studies
  - Ionospheric physics studies
- Radar designation: Relocatable Over-the-Horizon Radar (ROTHR, aka TPS-71)
- Mission: Wide-area ocean surveillance



ROTHR transmitter station Courtesy: USN

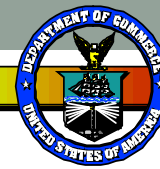


Notional diagram of OTH coverage



# HF (5-28 MHz), continued

- Radar spectrum needed to accommodate:
  - Time-varying frequency-dependent propagation across this HF band
  - Spectrum sharing with many other HF systems in the 5-28 MHz band
- Radar geographic and mobility analysis:
  - Ocean coverage from coastal locations
  - Installations are semi-permanent
  - Other geographic zones could be covered in the future
- Radar operations occur: 24 / 7 / 365
- Radar antenna gain/beam direction/revisit time:
  - Long wavelengths compared to antenna size
  - Antenna backlobes could be appreciable
  - Multiple beam directions with varying revisit intervals



## HF (5-28 MHz), continued

- Radar range/propagation:
  - 1,000s of km with ionospheric bending of radio wave propagation
  - Frequencies move as HF propagation varies
- Radar life cycle: Multiple decades
- Radar procurement / replacement cost:
  - Existing systems are relatively low-cost to operate
  - Replacement costs would be substantial
  - Alternatives (space-based surveillance?) could be much more costly
- Nominal noise figure: HF atmospheric noise can be a limiting factor
- Narrow bandwidths and high duty cycles



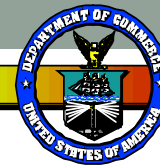
VHF (30 – 300 MHz →  $\lambda = 1 - 10$  m)

UHF (300 – 1000 MHz →  $\lambda = 0.3 - 1$  m)

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Presenter: Frank Sanders





## VHF (P) (420-450 MHz $\rightarrow$ $\lambda = 0.7$ m)

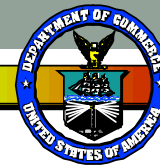
- Applications/functions for systems in this band:
  - Radiolocation (radar) coverage at very long ranges
  - Radar air surveillance and warning
  - Radar space surveillance and warning
  - Radar vertical atmospheric wind profiling
    - Improves efficiency and safety of long-range aerial routing
    - Needed to support space launches
    - Atmospheric research studies
  - Radar foliage penetration
  - Operations at test ranges
  - Operations at space launch facilities
  - Development of new defense systems

## VHF (P) (420 – 450 MHz), cont.

- Radar system platforms:
  - Fixed ground-based radars
  - Shipborne radars
  - Airborne radars
- Radar missions:
  - Space surveillance
  - Long-range surveillance
  - Wind profiling
  - Foliage penetration
- Band also used for range ops & launch ops

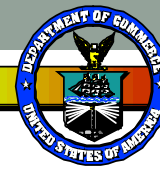


FPS-123(V) PAVE PAWS (see Skolnik)  
Courtesy: USAF.



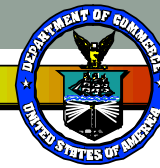
## VHF (P) (420 – 450 MHz), cont.

- Radar spectrum need: Multiple frequencies across entire VHF band
  - Use of multiple frequencies improves probability of target detection
  - Frequency selection allows compensation for time-varying propagation factors
  - Frequency selection improves operations between multiple radar systems
  - Frequency diversity helps electronic counter-countermeasures (ECCM)
  - **New systems** may be designed and introduced in the future
  - **Parameters of existing systems may evolve over time**
- Radar geographic and mobility analysis:
  - Terrestrial (fixed) installations across CONUS
  - Shipborne (mobile)
  - Airborne (mobile)
- Radar operations occur:
  - 24/7/365 at fixed terrestrial sites
  - Time-varying around & above CONUS and USP for ships and aircraft



# VHF (P) (420 – 450 MHz), cont.

- Radar antenna gain/beam direction/revisit time:
  - In this band a 30 dBi gain antenna is 9.8 m (30 feet) across
  - Repetitive rotational scanning with vertical fan beams for some radars in this band
  - Electronic pencil-beam scanning for some radars in this band
  - Nearly constant beam directions (usually within 15 deg. of vertical) for wind profilers
  - No overall regularity or predictability for beam scanning in this band
- Radar range/propagation:
  - Thousands of miles (space) to hundreds of miles (other platforms)
  - VHF propagation is ideal for long-range radar applications, foliage penetration, & wind profiling
- Radar life cycle: Multiple decades; some systems have operated for over 30 years
- Radar procurement/replacement cost:
  - Replacement costs would be substantial
  - No readily available alternative technologies are available
  - Futuristic alternatives such as space-based surveillance could be much more costly
  - Higher frequency bands would offer worse propagation characteristics for these missions
- Nominal noise figure: Internal electron noise in receivers; 3-5 dB might be typical



## UHF (Lower L: 902-928 MHz $\rightarrow$ $\lambda = 0.3$ m)

- Applications/functions for systems in this band:
  - Radiolocation (radar) coverage at long ranges
  - Radar air surveillance and warning
  - Radar vertical atmospheric wind profiling
    - Improves efficiency and safety of long-range aerial routing
    - Needed to support space launches
    - Atmospheric research studies
  - Antenna testing
  - Operations at test ranges
  - Operations at space launch facilities
  - Non-government vehicle control system testing

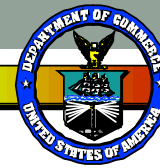
## UHF (Lower L: 902 – 928 MHz), cont.

- Radar designations:
  - shipborne radars
  - WPR radars
- Radar missions:
  - long-range surveillance
  - wind profiling
- Band also used for range ops & launch ops



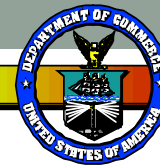
900 MHz wind profiler radar. Courtesy: Vaisala Corp.





## UHF (Lower L: 902 – 928 MHz), cont.

- Radar spectrum need: Multiple frequencies across entire UHF L band:
  - Use of multiple frequencies improves probability of target detection
  - Frequency selection allows compensation for time-varying propagation factors
  - Frequency selection improves operations between multiple radar systems
  - Frequency selection improves EMC with other radio systems
  - Frequency diversity helps electronic counter-countermeasures (ECCM)
  - **New systems** may be designed and introduced in the future
  - **Parameters of existing systems may evolve over time**
- Radar geographic and mobility analysis:
  - Terrestrial fixed installations across CONUS
  - Shipborne (mobile) throughout US littoral waters
- Radar operations occur:
  - 24/7/365 at fixed terrestrial sites
  - Time-varying around CONUS and USP for ships in littoral areas



## UHF (Lower L: 902 – 928 MHz), cont.

- Radar antenna gain/beam direction/revisit time:
  - In this band a 30 dBi gain antenna is 4 m (14 feet) across
  - Rotational scanning by some radars in this band
  - Nearly constant beam directions (usually within 15 deg. of vertical) for wind profilers
  - Some regularity for beam scanning by some systems in this band
- Radar range/propagation:
  - More than many tens of miles
  - UHF propagation is ideal for long-range radar applications and atmospheric profiling
- Radar life cycle: Multiple decades
- Radar procurement/replacement cost:
  - Replacement costs would be substantial
  - No readily available alternative technologies for air search and profiling missions
  - Futuristic alternatives such as space-based surveillance could be much more costly
  - Other frequency bands might offer worse propagation characteristics for these missions
- Nominal noise figure: Internal electron noise in receivers; several dB might be typical

# L Band (1 – 2 GHz → $\lambda=15 – 30$ cm)

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- Radar applications

- Long-range air defense detection and tracking
- En-route air traffic control (ATC)
- Airborne surveillance and collision avoidance

- Radar allocations

- 1030/1090 MHz: Aeronautical radionavigation
- 1215-1240 MHz: Radiolocation
- 1240-1300 MHz: Aeronautical radionavigation / radiolocation
- 1300-1350 MHz: Aeronautical radionavigation
- 1350-1370 MHz: Aeronautical radionavigation (US & Canada)
- 1350-1390 MHz: Radiolocation



# 1215-1390 MHz Band: Allocations, Systems, Technical and Operational Characteristics

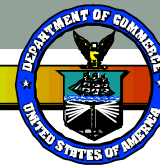
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Robert Sole

[rsole@ntia.doc.gov](mailto:rsole@ntia.doc.gov)

(202) 482-1245



 NTIA

## **Allocations in the Band 1215-1390 MHz**

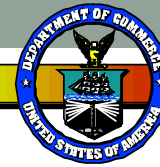
Radiolocation, Aeronautical Radionavigation, RNSS, Fixed, Mobile  
(1215-1240, 1240-1300, 1300-1370, 1350-1390 MHz)  
(see footnotes in NTIA Redbook for more details)

## **NTIA Regulations**

Radar Spectrum Engineering Criteria (RSEC)

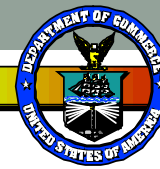
### **Most radars are Criteria C**

Places limits on bandwidth, OOB and spurious emissions, interference rejection, antenna sidelobes



## Major Systems operating in 1215-1390 MHz

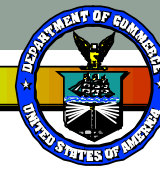
- GPS L2 (1227.6 MHz)  
Civilian and Defense usage
- Long Range Air Route Surveillance Radars (FAA/DoD/DHS)  
FAA: ARSR-1, -2, -3, -4, CARSR, and FPS series.
- Tactical, Defense, and Security Radars  
DoD/DHS: AN/TPS, TPQ, and others
- Tactical land and sea data/communication systems  
DoD: Used for battlefield and ship/shore/ship communications
- Telemetry  
DoD: Used for flight instrumentation and timing



# GPS General Information

- The Federal Radionavigation Plan provides a detailed description of how the federal agencies use the GPS service for aviation, maritime, space and land navigation. Non-navigation applications such as geodesy and surveying, mapping and charting, agriculture and natural resources, Geographic Information Systems, meteorological and timing are also described. The requirements of civil and military users for radionavigation services based upon the technical and operational performance needed for military missions, transportation safety, and economic efficiency are also described
- The GPS L2 radionavigation signal is transmitted in the  $1227.6 \pm 15.345$  MHz segment of the 1215-1240 MHz RNSS band. On the L2 carrier frequency two radionavigation signals are currently transmitted: the L1 Coarse/Acquisition (C/A) code signal and the L1 Precision (P(Y)) code signal.

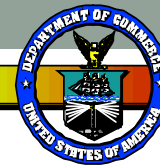




## General information:

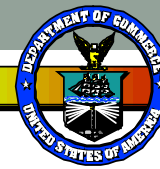
# Long Range Radar Systems 1215-1390 MHz

- The Federal Aviation Administration (FAA), Department of Defense (DoD), and the Department of Homeland Security (DHS) benefit from long-range aeronautical radionavigation and radiolocation radar systems in the 1215-1390 MHz band.
- Used to detect aircraft (range and azimuth) and for the separation and control of air traffic in the En Route (high altitude) phase of flight within the national airspace system, along the border areas, and around military bases and airfields. Also provides weather data to ATC that is combined with other weather data sources.
- The data collected by the FAA/ DoD/ DHS systems are displayed on a plan position indicator scope at the radar site and also transmitted to air traffic control centers, air defense sectors, and homeland security centers for further processing. The information is used for the safety and regularity of flight operations, national defense, and the security of the homeland.
- Most assignments are between 1240 and 1370 MHz.



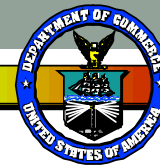
## Bandwidth and frequency requirements for ARSR systems

Radar System Designator	Radar Type	Function	Tuning Range (MHz)	Emission Bandwidth (MHz)	Frequency Requirements
ARSR-1	Ground-Based Fixed	ATC Defense/Security	1240-1350	10	One operational frequency, with one hot stand-by frequency
ARSR-2	Ground-Based Fixed	ATC Defense/Security	1240-1350	10	One operational frequency, with one hot stand-by frequency
ARSR-3	Ground-Based Fixed	ATC Defense/Security	1250 -1350	8	Two frequencies separated by a minimum of 25 MHz
ARSR-4	Ground-Based Fixed	ATC Defense/Security	1215-1370	2.8	Two frequencies separated by a fixed 83 MHz
CARSR	Ground-Based Fixed	ATC Defense/Security	1240 - 1350	2.9 2.4	Two frequency pairs separated by a minimum of 26 MHz, with a 5.2 MHz fixed separation between frequencies within a pair. One pair must be assigned below 1300 MHz and one pair must be assigned above 1300 MHz.
AN/FPS-20	Ground-Based Fixed	ATC Defense/Security	1250 -1350	6	Two frequencies separated by at least 18 MHz
AN/FPS-64	Ground-Based Fixed	ATC Defense/Security	1250 -1350	6	Two frequencies separated by at least 18 MHz
AN/FPS-66	Ground-Based Fixed	ATC Defense/Security	1250 -1350	5	Two frequencies separated by at least 18 MHz
AN/FPS-67	Ground-Based Fixed	ATC Defense/Security	1250 -1350	6	Two frequencies separated by at least 18 MHz
AN/FPS-117	Ground-Based Fixed	Defense/Security	1215-1400	1.8 0.80	Frequency hopping on multiple channels
Various	Ground-Based Transportable	Defense/Security	1215-1390	Various	Frequency hopping on multiple channels/Fixed Channels



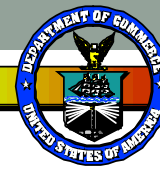
## Power and duty cycle for ARSR and other systems

Radar System Designation	Peak Power (Watts)	Duty Cycle (Percent)	Mainbeam Antenna Gain (dBi)	Maximum EIRP (Watts)
ARSR-1	$4 \times 10^6$	0.072	34	$10 \times 10^9$
ARSR-2	$4 \times 10^6$	0.072	34	$10 \times 10^9$
ARSR-3	$6.5 \times 10^6$	0.062 – 0.076	35	$13 \times 10^9$
ARSR-4	$80 \times 10^3$	2.5 and 1.8	39	$3.5 \times 10^9$
CARSR	$60 \times 10^3$	3.82 and 7.0	34	$1.3 \times 10^9$
AN/FPS-20	$2.5 \times 10^6$	0.16	34	$8.2 \times 10^9$
AN/FPS-64	$2.5 \times 10^6$	0.2	34	$8.2 \times 10^9$
AN/FPS-66	$2.5 \times 10^6$	0.2	34	$8.2 \times 10^9$
AN/FPS-67	$5 \times 10^6$	0.2	34	$11 \times 10^9$
AN/FPS-117	$25 \times 10^3$	1.7 - 30	39	$1.5 \times 10^9$
Various Defense and Security Radars	Various	Most older models are Low DC, most newer are High DC	Up To 32	Various
Kilowatt is $1 \times 10^3$ Watts Megawatt is $1 \times 10^6$ Watts Gigawatt is $1 \times 10^9$ Watts				



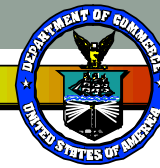
## Antenna Characteristics: Radar systems 1215-1390 MHz

- ASR and FPS series radar systems use antennas with narrow horizontal and wide vertical beamwidth with mostly mechanical scanning. CARSR will use existing antenna of ARSR-1,-2, and -3 and FPS systems. Typical horizontal rotation rate is 5 rpm with gain of 33 dBi. Operated from fixed locations.
- Tactical radar systems use antennas with narrow horizontal and narrow vertical beamwidth, with electrical and mechanical scanning. Variable rotating speeds and typical gain of 24 dBi. Many are transportable.



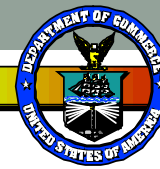
# Number of sites and hours of operation for ARSR and other systems

Radar System Designation	Number of Sites	Operating Time	Geographic Distribution
ARSR-1	24	Continuous	At fixed locations along the interior of the United States
ARSR-2	19	Continuous	At fixed locations along the interior of the United States
ARSR-3	14	Continuous	At fixed locations along the interior of the United States
ARSR-4	21	Continuous	At fixed locations along the perimeter of the United States
CARSR	77	Continuous	At fixed locations along the interior of the United States
AN/FPS-20	2	Continuous	At fixed locations along the interior of the United States
AN/FPS-64	1	Continuous	At fixed location in the interior of the United States
AN/FPS-66	6	Continuous	At fixed locations along the interior of the United States
AN/FPS-67	11	Continuous	At fixed locations along the interior of the United States
AN/FPS-117	18	Continuous	Puerto Rico/ Alaska/ Hawaii/ UT (testing)
Various Defense and Security Long Range Radar Systems	Up to 100 Not all at the same time and some are used only for testing/training.	Intermittent – Short Duration as necessary	Anywhere in the US&P



## Defense and Security Radars 1215-1390 MHz

- The DoD and DHS operate tactical radar systems in the 1215-1390 MHz band
- Many are more easily tuned than fixed radars, since they are transportable and have to adapt to the environment
- Many use frequency hopping or agility and solid state transmitters
- Generally located on border areas, near/on military bases or training areas with intermittent usage, however these can be located anywhere in the US&P as required for a particular defense or security mission
- Tethered Aerostat Radar (TAR) systems also operate in this band, they consist of balloon mounted radars used for monitoring the borders and Caribbean airspace for boarder protection and drug interdiction
- Operates as weather permits

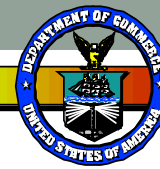


# Radar Coordination 1215-1390 MHz

- Hundreds of high-power long-range radar systems operate across the United States and Possessions in this band.
- Compatible operation between different types of radar systems is accomplished through careful design of the radar systems, frequency selection, and NTIA spectrum standards. FAA is the national coordinator for the band.
- The radars use various types of circuitry and signal processing in their receiver to reduce or eliminate the effects of pulsed low duty cycle interference from other radars.
- Generally not given assignments on or near the GPS frequency at 1227 MHz and most are between 1240 and 1370 MHz.
- This limits interference to GPS and assists in coordination with the tactical point-to-point and telemetry systems in the band 1350-1390 MHz.

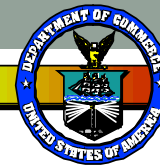






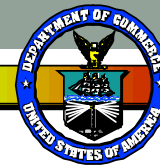
# Tactical communication systems

- The DoD operates tactical radios that are used for point-to-point communication systems to support battlefield command and control operations in the fixed service. Most of these systems are assigned frequencies above 1370 MHz. They also operate ship-to-ship communication systems that have assignments above 1350 MHz and mobile telemetry systems as well. Operated intermittently at military facilities and test/training ranges with small radius of operations.
- There are also operations allocated by footnote for a nuclear burst detection system, remote sensing, and radio astronomy observations above 1350 MHz.



## Technical Characteristics of Tactical Communication Systems

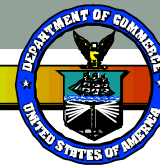
Parameter	MSE	HCLOS	DWTS	
			Shore-to-Ship	Ship-to-Shore and Ship-to-Ship
<b>Frequency Range</b>	1350-1850 MHz	1350-2690 MHz	1350-1850 MHz or 1350- 2690 MHz	1350-1850 MHz
<b>Number of Channels</b>	4000	10,720	4000 Or 10,720	4000
<b>Channel Spacing</b>	125 kHz	125 kHz	125 kHz	125 kHz
<b>Channel Bandwidth</b>	1.20 MHz	2.40 MHz	610 kHz	2.85 MHz 610 kHz
<b>Number of Frequencies</b>	Two frequencies per link for full duplex communication	Two frequencies per link for full duplex communication	Two frequencies per link for full duplex communication	Two frequencies per link for full duplex communication
<b>Tuning Capability</b>	Tunable across frequency range	Tunable across frequency range	Tunable across frequency range	Tunable across frequency range
<b>Power</b>	0.5 to 5 watts	31 mW to 1.6 watts	3 watts	5 to 250 watts
<b>Antenna Gain</b>	20	23	20	1.5 dBi



# Planned Use for 1215-1390 MHz

## Aeronautical Radionavigation/Radiolocation

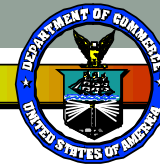
- The government use for the band 1215 to 1390 MHz for the Radiodetermination service will remain the same for the foreseeable future.
- Although many of the fixed-based programs are “built out” and no new installations are planned in the immediate future, new radar sites could be added if the need arises to monitor additional airspace or other vital assets.
- Flexibility in frequency assignment will remain necessary to mitigate interference due to new or unexpected sources to better manage the exiting fleet’s spectrum requirements as systems are upgraded, and to provide spectrum for transportable systems.
- Some of the newer radar transmitters and receivers are replacing older equipment, therefore, long-term spectrum requirements for long-range radars in this band can be expected for at least twenty years.



# Planned Use for 1350-1390 MHz

## Fixed Service

- DoD transportable stations like those operated in the band 1350 to 1390 MHz are used to extend wideband communications to any part of the globe rapidly.
- Military operations and training make extensive use of transportable microwave terminals that are designed to be transported to an overseas combat or support area, set up rapidly, configured into a communications network, and used for critical operational command and control communications for the duration of the mission.
- These capabilities are also used domestically to support training and to provide support of disaster relief and similar missions.
- Therefore the Fixed systems that operate in this band are expected to still be used in the foreseeable future.



# Planned Use for 1215-1390 MHz

## Mobile Service

- The government use for the band 1350 to 1390 MHz for the mobile service will remain the same for the foreseeable future. The aeronautical telemetry, air-ground-air, and ship-shore-ship operations are vital to test range/aircraft instrumentation operations and reliable command and control communication links between shore and ship stations, respectively.

# S Band (2 – 4 GHz → $\lambda=7.5 - 15$ cm):

---

- Presenters

- Lower S Band – Robert Sole
- Upper S Band – Frank Sanders
- Maritime S Band – Joe Hersey

- Applications

- Medium-Range Surveillance
- Maritime Surveillance
- Airport Surveillance Radar (ATC)
- Long-Range Weather (200 nmi)

- Allocations

- 2300-2500 MHz
- 2700-2900 MHz: ATC, Weather (NEXRAD)
- 2900-3100 MHz: Weather (NEXRAD), Maritime Navigation
- 3100-3700 MHz



# Lower S Band: 2700-2900 MHz Band Allocations, Systems, Technical and Operational Characteristics

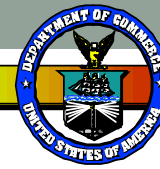
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Robert Sole

[rsole@ntia.doc.gov](mailto:rsole@ntia.doc.gov)

(202) 482-1245





## **Allocations in the Band 2700-2900 MHz**

Aeronautical Radionavigation

Meteorological aids

Radiolocation (secondary)

(see footnotes in NTIA Redbook for more details)

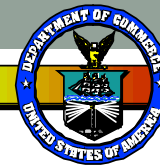
### **NTIA Regulations**

Radar Spectrum Engineering Criteria (RSEC)

#### **Criteria D**

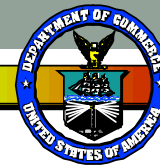
Places limits on bandwidth, OOB and spurious emissions, interference rejection, antenna sidelobes.

Is most stringent of RSEC criteria



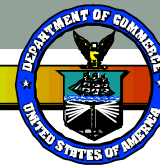
## Major Systems Operating in 2700-2900 MHz

- NEXRAD WSR-88D (NWS, Air Force, and FAA)
  - Used for detecting precipitation and atmospheric movement (winds) from a nationwide network of fixed doppler radars. (fielded late 80's – 90's)
- Airport Surveillance Radars (FAA and DoD)
  - FAA: ASR-7 (oldest), ASR-8 (80's), ASR-9 (90's), ASR-11 (fielding)
- DoD: Variants of these systems, use GPN nomenclature.
  - Used for surveillance of the air space in and around airports/airfields, departure and arrival traffic control, and weather detection at fixed locations.



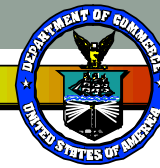
# General Information: ASR/GPN Systems 2700-2900 MHz

- ASR/GPN systems are used for:
  - Flight Safety: air traffic separation and control along approach and departure routes
  - Defense and Security: the detection, tracking, and display of airborne objects
- ASRs are also capable of detecting precipitation and this data product is combined with other weather data (like NEXRAD) to produce a composite weather product.
- FAA ASR systems located at over 250 airports for management and control of aircraft in terminal airspace. The DoD operates approximately 150 ASR systems.
- ASR systems have a range of 60 nautical miles and operate continuously.



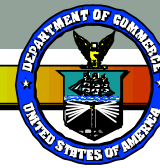
## Bandwidth and frequency requirements for ASR systems

System Designator	Emission Bandwidth (MHz)	Frequency Usage
ASR-7 and AN/GPN-12	10	Two operational frequencies separated by a fixed frequency plan
ASR-8 and AN/GPN-20/27	10	Two operational frequencies with a minimum separation of 60 MHz.
ASR-9	4	One operational frequency and one hot stand-by frequency with a preferred separation of at least 50 MHz
ASR-11 and AN/GPN-30	2.8 (Long Pulse Mode) 5.1 (Short Pulse Mode)	Two pairs of operational frequencies with a minimum separation of 30 MHz. Each pair is separated by 1 MHz. A short pulse is transmitted on one frequency followed by a long pulse transmitted on a second frequency, then the sequence reverses.
AN/TPN-31	3.2 (Short Pulse Mode) 1.6 (Long Pulse Mode)	Two pairs of operational frequencies with a minimum separation of 30 MHz. Each pair is separated by 1 MHz. A short pulse is transmitted on one frequency followed by a long pulse transmitted on a second frequency, then the sequence reverses.
AN/TPN-24	7.5	Two operational frequencies with a minimum separation of 80 MHz.
AN/TPN-73	2	Frequency hops across the entire band
AN/TPN-14K	3.5	One operational frequency.



# Power and duty cycle for ASR systems

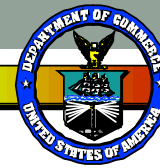
System Designation	Peak Power (Watts)	Duty Cycle (Percent)	Mainbeam Antenna Gain (dBi)	EIRP (Watts)
ASR-7 and AN/GPN-12	$425 \times 10^3$	0.06 (min) 0.1 (max)	34	$1.1 \times 10^9$
ASR-8 and AN/GPN-20	$1.4 \times 10^6$	0.07 (min) 0.1 (max)	33	$2.5 \times 10^9$
ASR-9 and AN/GPN-27	$1.4 \times 10^6$	0.13	33	$2.5 \times 10^9$
ASR-11 and AN/GPN-30	$25 \times 10^3$	0.1 (min) 9 (max)	34	$63 \times 10^6$
AN/TPN-31	650	0.14 (min) 8 (max)	31	$746 \times 10^3$
AN/TPN-24	$450 \times 10^3$	0.12	33	$857 \times 10^6$
AN/TPS-73	$14.5 \times 10^3$	0.92 (min) 11 (max)	34	$36 \times 10^6$
AN/MPN-14K	$1 \times 10^6$	0.11	32	$1.6 \times 10^9$
Kilowatt is $1 \times 10^3$ Watts Megawatt is $1 \times 10^6$ Watts Gigawatt is $1 \times 10^9$ Watts				



## General Information: NEXRAD Systems

- Joint program funded by the NWS, FAA, and DoD consisting of 159 operational sites within the contiguous United States with radars that provide weather monitoring capabilities.
- NEXRAD data is converted into visual images and used by the NWS forecasters, the FAA, and the military to provide weather information to the nation, also made available on the internet and shown on television weather broadcasts.
- Local and national television meteorologists use NEXRAD data to keep their viewers informed of real-time weather conditions, including storms, tornados, flash floods and other severe events.
- The NEXRAD operates continuously, and provides severe weather coverage out to 125 statute miles and storm tracking out to 250 statute miles.

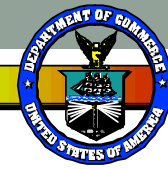




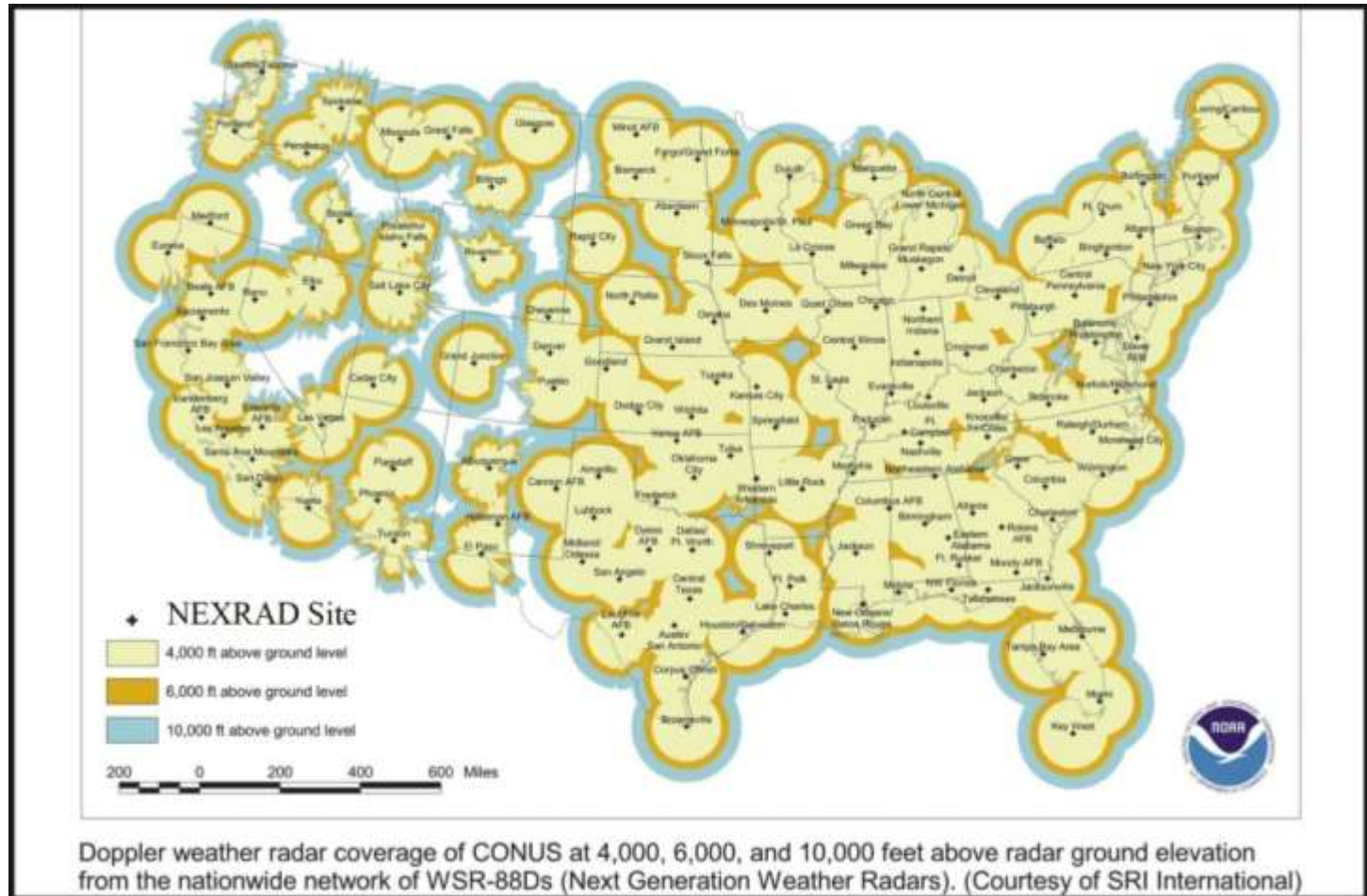
# NEXRAD Technical Information

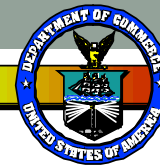
- More information on Nexrad at <http://www.roc.noaa.gov/WSR88D/>

Characteristic	Value
Power Output	1 Megawatt ( $1 \times 10^6$ Watts)
Antenna Gain	45 dBi
Duty Cycle	maximum 0.21 percent, minimum 0.05 percent
Frequency Requirements	1 frequency per site
Antenna Height	90 feet AGL

# NEXRAD Coverage Map

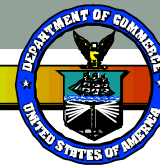




# Frequency Coordination: ASR/GPN and NEXRAD

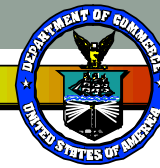
- The FAA is responsible for managing the 2700 – 2900 MHz band, including frequency assignment. FAA spectrum engineering criteria for the various systems are used to safely and efficiently provide spectrum to users and participates in mitigation of interference when hazardous interference is experienced and reported.





## Planned Use 2700 – 2900 MHz

- There are no plans to replace the radar systems operating in the band 2700-2900 MHz with a technology that could meet the safety-of-life and other requirements for air traffic control, weather surveillance, and national security-related missions.
- The FAA and DoD use of the ASR systems in the band 2700-2900 MHz will remain the same for the foreseeable future.
- The existing NEXRAD systems in the band 2700-3000 MHz will continue to operate for the foreseeable future. There are no new NEXRAD installations planned at this time.
- A Multi Function Phased Array Radar (MPAR) has been proposed to replace all ASR and weather radars with one platform that provides both functions, however no plans to implement this technology exist.



## Upper S (2900 – 3650 MHz $\rightarrow$ $\lambda = 10$ cm)

- Applications/functions for systems in this band:
  - Radiolocation (radar) surveillance at short, medium & long ranges
  - Maritime radionavigation (surface search) throughout navigable waters
  - Weather surveillance (below 3000 MHz)
  - Short-range artillery/projectile search, track, and warning
  - Terrestrial, naval and ground-based search, surveillance, and navigation
  - Multi-capability tactical operational support
  - Operations at space launch facilities
  - Ongoing development of new defense systems
  - Bird tracking
  - Antenna-range testing
  - Operations at test ranges
  - Geostationary satellite links



# Upper S (2900 – 3650 MHz), cont.

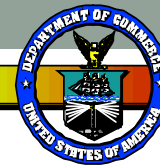
- Radar system designations:
  - Shipborne (mobile) air search radars
  - Airborne (mobile) radars
  - Terrestrial transportable radars
  - (Mostly) fixed weather radars
- Radar missions:
  - Short to long range air surveillance
  - Weather surveillance (up to 3 ghz)
  - Maritime surface navigation
  - Aerial navigation
  - Ground-based navigation
  - Naval air traffic control (ATC)
  - Warn & track for artillery/projectiles
  - Test range ops
  - Bird tracking
- Band also used for range ops, launch ops, and geostationary satellite communications



SPN-43C  
naval ATC  
(navigation)  
radar  
Courtesy:  
Defense  
Video and  
Imagery



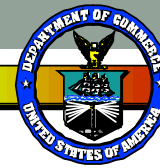
TPS-43E  
transportable  
air surveillance  
radar  
Courtesy: USAF



## Upper S (2900 – 3650 MHz), cont.

- Radar spectrum need: Multiple frequencies across entire band
  - Use of multiple frequencies improves probability of target detection
    - Frequency selection allows compensation for time-varying propagation factors
    - Frequency selection de-conflicts ops between multiple radar systems
    - Frequency diversity helps electronic counter-countermeasures (ECCM)
    - **New radar systems are being designed and are planned for future introduction**
    - **Parameters of existing systems are evolving over time**
- Radar geographic and mobility analysis:
  - Terrestrial fixed weather radars installations across CONUS
  - Shipborne (mobile) throughout US littoral waters & navigable rivers
  - Airborne (mobile) across CONUS
- Radar operations occur:
  - 24 / 7 / 365 at weather radar sites
  - Time-varying around & above CONUS and USP for ships and aircraft





## Upper S (2900 – 3650 MHz), cont.

- Radar antenna gain/beam direction/revisit time:
  - In this band a 30 dBi gain antenna is 1.4 m (4.7 feet) across
  - Repetitive rotational scanning with vertical fan beams for some radars in this band
  - Electronic pencil-beam scanning with mechanical scanning for some radars in this band
  - No overall regularity or predictability for beam scanning in this band
- Radar range/propagation:
  - A few thousand feet to a few miles for some nav. & warning systems; over 100 miles for others
  - Propagation is ideal for short to medium range applications and some weather surveillance
- Radar life cycle: Multiple decades; some systems have operated for over 30 years
- Radar procurement/replacement cost:
  - Replacement costs would be enormous
  - No clearly identifiable technically feasible alternatives proposed for radar missions in this band
  - Other frequency bands would offer worse propagation characteristics for some missions
  - This band offers many advantages for **new dual-band radars** currently in development
- Nominal noise figure: Internal electron noise in receivers; 3-5 dB might be typical

# Maritime S Band

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Joe Hersey  
U.S. Coast Guard



# S-band Maritime Radar 2900-3100 MHz

- S-band marine radar use is widespread
  - Used universally by shipping and government vessels
  - Superior performance in poor weather
  - Mandated by Safety of Life at Sea (SOLAS) Convention on ships >3000 t
  - S-band shipboard radars also used in western rivers
- Numbers of users are large
  - ~70,000 SOLAS vessels
  - Thousands of non-SOLAS vessels

# Superior performance in poor weather (> X10)

Figure 1.

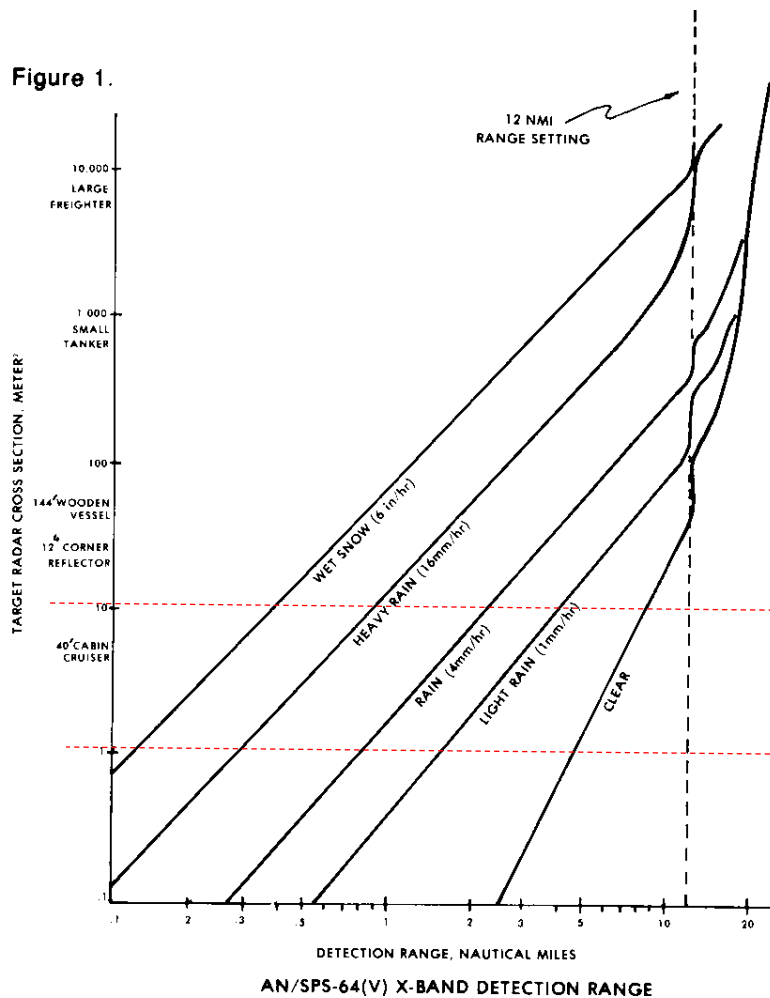
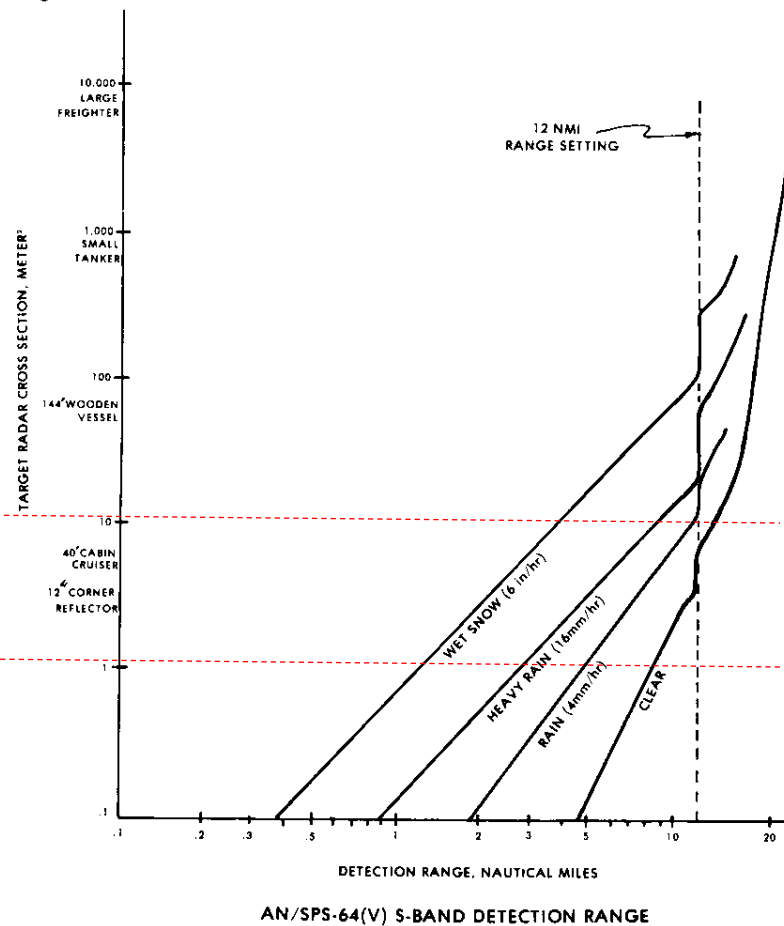


Figure 2.



# Magnetron radars well studied; Solid State radars not so well studied

**Table 1. Characteristics of Shipborne Radionavigation Radars**

<b>Characteristic</b>	<b>System Designation in ITU-R M.1460-1 IMO and Fishing</b>
<b>Frequency (MHz)</b>	3020-3080
<b>Peak Power(Watts)</b>	$30 \times 10^3$ - $75 \times 10^3$
<b>Mainbeam Antenna Gain (dBi)</b>	26-28
<b>Maximum EIRP (Watts)</b>	$11.9 \times 10^6$ – $47.3 \times 10^6$
<b>Duty Cycle (percent)</b>	0.0018-0.48

Radar duty cycle, peak power and frequency values do not apply to solid state radars

# Commercial magnetron frequencies standardized

Magnetrons		
<b>S-Band Magnetron</b>		
Type	Power	Frequency
MG5223	30 kW	3040-3080 Mhz
MG5223F	30 kW	3040-3080 Mhz
MG5240	60 kW	3040-3080 Mhz
MG5240F	62 kW	3040-3080 Mhz
MG5500	30 kW	3010-3030 Mhz
MG5501	30 kW	3070-3090 Mhz
		
<b>S-Band magnetron</b>		
MG5287	60 kW	3025-3075 Mhz
		
<b>S-Band Magnetron</b>		
MG5315	10 kW	3040-3080 Mhz
		

## Expected Lifetime

X-Band 12kW

4000h - 12000h

X-Band 25kW

4000h - 7000h

S-Band 30kW

7000h - 15000h

# Market driving solid state



# Solid State/Magnetron Interference

- A new emerging problem in the maritime service, not yet well studied
- One major marine radar manufacturer privately admits to interference
  - Magnetron to solid state
  - Solid State to magnetron
  - Bundesamt für Seeschifffahrt und Hydrographie (BSH, Federal Maritime and Hydrographic Agency in Germany) studying the problem



# C Band (4 – 8 GHz → $\lambda=3.75 - 7.5$ cm)

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- Presenters:

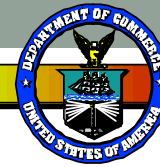
- C Band (general) – Frank Sanders
- TDWR – Chris Tourigny

- Primary Applications

- Long-Range Tracking
- Airborne Radio Altimeter (avoiding terrain)
- Airborne Doppler Weather Radar (avoiding storms)
- Terminal Doppler Weather Radar

- Primary Radar Allocations

- 4200-4400 MHz: Aeronautical Radionavigation (Radio Altimeter)
- 5350-5460 MHz: Aeronautical Radionavigation/Radiolocation
- 5460-5470 MHz: Radionavigation
- 5600-5650 MHz: Meteorological Aids/ Radiolocation

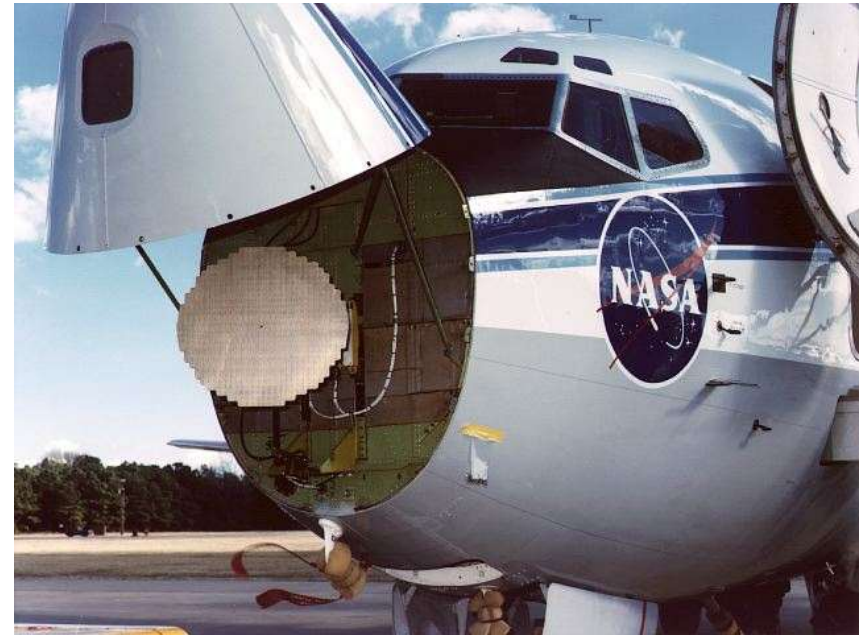


## Radar C Band (5250 – 5925 MHz → $\lambda = 5$ cm)

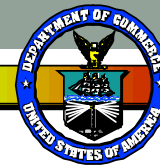
- Applications/functions for systems in this band:
  - Radiolocation (incl. test-range tracking) at medium ranges
  - Radionavigation, including:
    - Aeronautical radionavigation
    - Maritime radionavigation.
    - Meteorological aids (weather radars)
    - Airborne surveillance incl. weather for flight safety
  - Operations at test ranges
  - Operations at space launch facilities
  - Antenna testing
  - Development of new defense systems

## Radar C Band (5250 – 5925 MHz), cont.

- Radar system designations:
  - Airborne (mobile) radars
  - Shipborne (mobile) radars
  - Ground-based fixed radars
  - Transportable radars
- Radar missions:
  - Maritime navigation
  - Aeronautical navigation
  - Weather surveillance
  - Tracking
  - Border security
- Band also used for some communication systems, test-range ops & launch ops

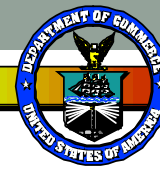


Example: 5-GHz airborne weather radar used on airliners



## Radar C Band (5250 – 5925 MHz), cont.

- Radar spectrum need: Multiple frequencies across entire band
  - Use of multiple frequencies improves probability of target detection.
    - Frequency selection allows compensation for time-varying propagation factors
    - Frequency selection improves operations between multiple radar systems
    - Frequency diversity helps electronic counter-countermeasures (ECCM)
    - New systems may be introduced in the future
    - Parameters of existing systems may evolve over time
- Radar geographic and mobility analysis:
  - Terrestrial fixed installations across CONUS
  - Shipborne (mobile)
  - Airborne (mobile)
  - Ground-based transportable (irregular)
- Radar operations occur:
  - 24/7/365 at fixed terrestrial sites
  - Time-varying around & across CONUS and USP ships, aircraft, & transportables



## Radar C Band (5250 – 5925 MHz), cont.

- Radar antenna gain/beam direction/revisit time:
  - In this band a 30 dBi gain antenna is 0.7 m (2.3 feet) across
  - Repetitive rotational scanning w. fan beams for some radars (e.g., maritime nav.) in this band
  - Electronic pencil-beam scanning for some radars in this band
  - Sector scanning for many airborne radars
  - No overall regularity or predictability for beam scanning in this band
- Radar range/propagation:
  - 1,000s of feet to a few miles to over 100 miles depending on radar type & operational mode
  - Propagation is ideal medium-range operations
- Radar life cycle: Multiple decades
- Radar procurement/replacement cost:
  - Replacement costs would be enormous
  - No clearly identified technical alternatives to radars have been proposed for missions in this band
- Nominal noise figure: Internal electron noise in receivers; 3-5 dB might be typical

# Aeronautical Surveillance Spectrum Management

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TDWR

Chris Tourigny

Federal Aviation Administration



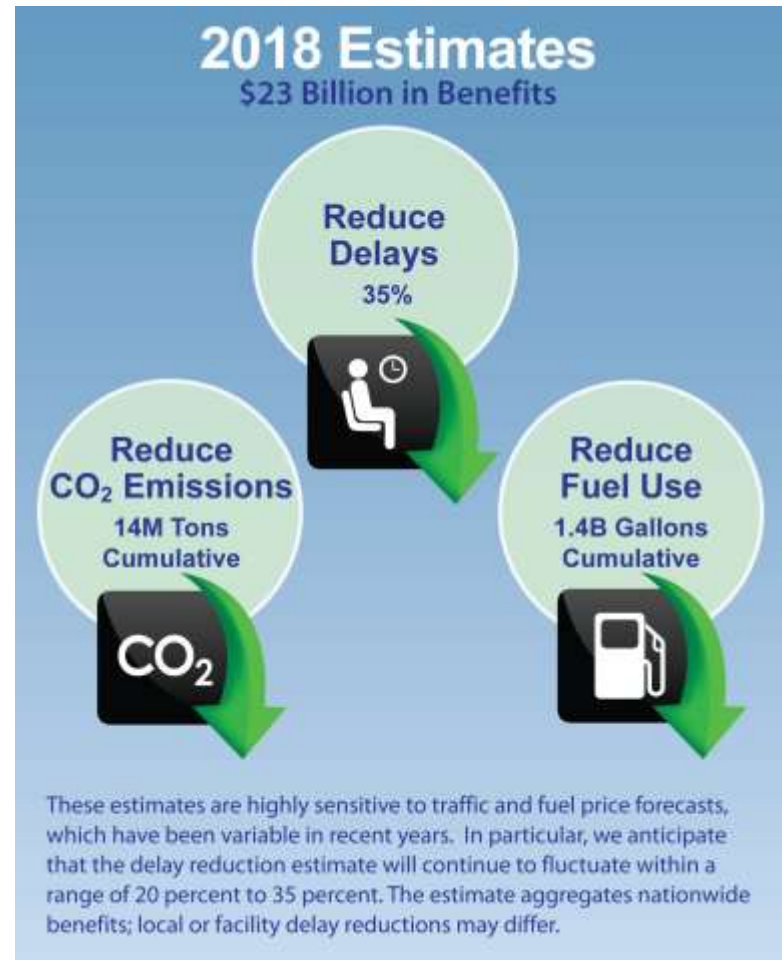
# Outline

- NextGen
- Delta Flight 191
- Terminal Doppler Weather Radar (TDWR)



# NextGen

- The Next Generation Air Transportation system (NextGen) is transforming the National Airspace System (NAS) from a ground-based system of Air Traffic Control to a satellite-based system of Air Traffic Management
- NextGen is opening the skies to continued growth and increased safety while reducing aviation's environmental impact
- The integrated approach includes new solutions such as: Automatic Dependent Surveillance – Broadcast, Data Communications, System Wide Information Management, NAS Voice System, Collaborative Air Traffic Management, and NextGen Network Enabled Weather
- This transformation depends on adequate interference-free availability of aeronautical communications, navigation, and surveillance spectrum





# Transformation of Weather Detection Systems

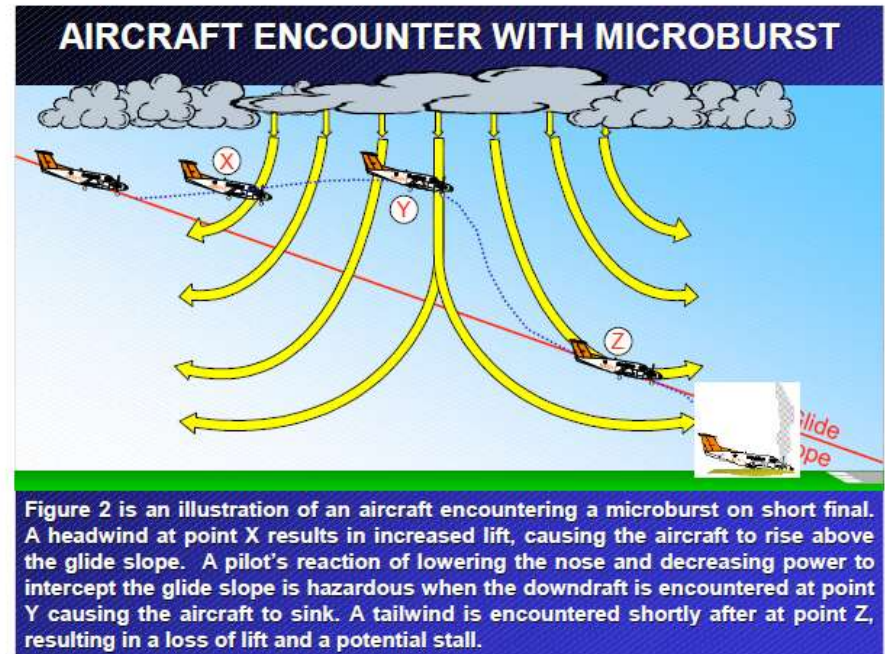
- Tragedy struck on AUG 2, 1985 at about 6 pm when Delta 191 crashed into the ground on approach into DFW killing 134 people on board and 1 highway motorist
- Investigation Revealed (NTSB AAR-86/05)
  - No evidence of aircraft malfunction
  - Flightcrew were certified and trained
  - ATC were certified and trained
  - NWS meteorologists and DFW weather observers were qualified and certified
  - Airport Low Level Wind shear Alert System (LLWAS) had not triggered an alert
  - No evidence to indicate the aviation weather specialists were negligent in their duties
  - Learjet landed safely 1 minute ahead of Delta 191
  - So what happened?



# Most Probable Cause

- The crew voice recordings and flight data indicate a classic example of the aircraft entering a microburst:

- Increasing headwind, Downdraft, Decreasing headwind (tailwind)
- After recovery from the first sequence and attempting to recover the glide slope, the aircraft experienced a rapid vertical change from downdraft to an updraft, rapidly increasing the angle of attack along with rapidly changing winds in the horizontal axis, indicative of vortices
- At higher altitudes, the pilot can trade altitude for airspeed



- Aircrew had sufficient information that they were entering weather, but the severity just before the crash was unknown
- In about 8 minutes, weather changed from level 1 (light) rain to level 4 (very strong) thunderstorm, centered 12,000 feet from the end of the runway and about 11,000 feet in diameter



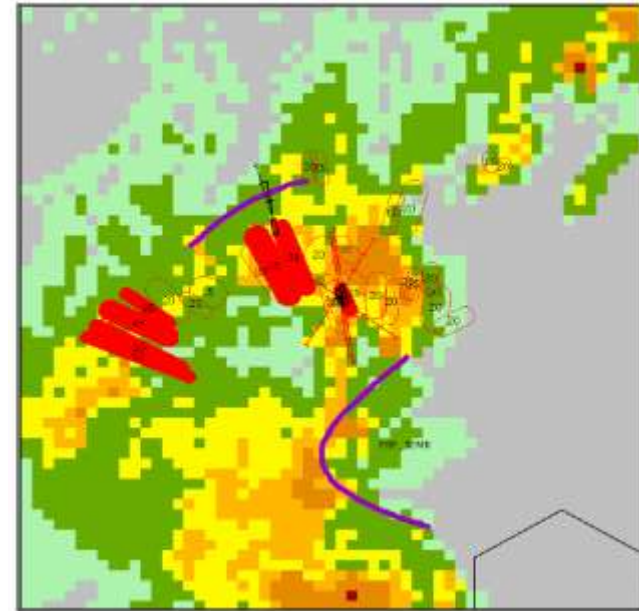
# Conclusions, Recommendations, and Mitigations

- NTSB Report: “The storm cell’s rapid development made it virtually impossible for routine weather observation and reporting procedures to transmit an accurate and timely description of the cell to the air traffic controllers and, in turn, to flight 191.”
- Existing weather sensors and other radars were not able to describe the severity of the weather associated with the cell.
- Pilot had sufficient information to determine a thunderstorm had developed, but avoidance procedures were not clear for the low-altitude - approach phase of flight.
- NTSB recommended FAA expedite the development of better wind shear detection systems
- April 1986, FAA produced a draft of the Integrated Wind Shear Program Plan:
  - Better crew training
  - Enhanced LLWAS
  - Airport Terminal Doppler Weather Radar (TDWR)
  - Develop sensors for airborne wind shear detection (airborne Doppler weather radar)



# TDWR

- Wind shear detection system used to increase the safety of the National Airspace System
  - 45 commissioned at the largest airports vulnerable to wind shear
  - Uses a 360-degree scan strategy to build a series of circular scans at various elevations
  - Operates in one of two modes
    - Monitoring (used to search all directions for microburst activity)
    - Hazardous (1-minute near surface scan update to capture rapid evolution of wind shear)
- Displays precipitation reflectivity
- Capable of microburst detection up to 16nmi
  - Uses the doppler shift and other requirements to set an alarm for ATC
  - ATC then relays info to pilots
  - Pilots determine to proceed or not
- Capable of gust front detection up to 32.4 nmi
  - Used to alert ATC, then pilots
  - Used for AT planning, including runway configuration changes or AT spacing
- Specifications: 5600 – 5650 MHz tuning range, Resolution (0.55 degree angular, 150 meter range), Power 250 kW, Pulse Length 1.1 us, 460 km reflectivity range, 89 km Doppler range



# Federal Aviation Administration

For more information:

[WWW.FAA.GOV](http://WWW.FAA.GOV)

[WWW.FAA.GOV/NextGen](http://WWW.FAA.GOV/NextGen)

[WWW.ATO.FAA.GOV](http://WWW.ATO.FAA.GOV)



Federal Aviation  
Administration

# X Band (8 – 12 GHz → $\lambda=2.5 - 3.8$ cm)

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- Primary Applications
  - Airborne Doppler Radar (avoiding storms)
  - Airport Surface Detection Equipment (collision avoidance)
- Primary Radar Allocations
  - 8750-8850 MHz: Aeronautical Radionavigation/Radiolocation
  - 9000-9200 MHz: Aeronautical Radionavigation

# 8.5-10 GHz Band: Allocations, Systems, Technical and Operational Characteristics

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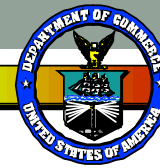
Robert Sole

[rsole@ntia.doc.gov](mailto:rsole@ntia.doc.gov)

(202) 482-1245







## **Allocations in the Band 8.5 -10 GHz**

Radiolocation, EESS (active), Space Research, Aeronautical Radionavigation, Maritime Radionavigation, Mobile

(8-8.550, 8.8550-8.650, 8.650-9.0, 9.0-9.2,  
9.2-9.3 9.3-9.5, 9.5-9.8, 9.8 -10 GHz)

(see footnotes in NTIA Redbook for more details)

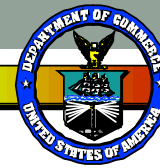
## **NTIA Regulations**

Radar Spectrum Engineering Criteria (RSEC)

### **Most radars are Criteria B**

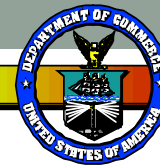
Places limits on bandwidth, OOB and Spurious emissions, interference rejection





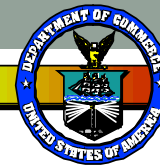
# General Information: 8.0-10 GHz

- Various types of land, air, and sea based systems are operated in the band for radiolocation, radionavigation, mobile telecommand and other functions.
- There are also assignments for research, development, testing and evaluation of new and modified radars.
- Some systems with assignments may have multiple stations for each assignment. This is the case for many airborne and ship based systems.
- Many of the radars that have the ability to operate across many of the bands in 8.5 to 10 GHz are not permitted to operate in the 9000 to 9200 MHz band.
- This is done to protect the operations of the Precision Approach Radars (PAR) and Airport Surface Detection Equipment (ASDE) radars that operate in the 9000 to 9200 MHz band.
- Some systems have geographical limits of operations (i.e., within some distance of the shorelines).



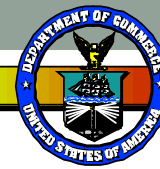
# Sample Systems 8.0-8.550 GHz

- AN/SPQ-9B
  - Primarily a shipboard system but has a land based assignment that is used for target tracking in gunnery training. The AN/SPQ-9B is a high-resolution narrow beam (1 degree beamwidth) radar that provides for air and surface target detection and tracking and can detect aircraft or missiles approaching just above the sea surface. It can be in use anytime the missions require its services. The peak power is 50 kW with an antenna gain of 42 dBi.
- Vitro Radars
  - The Vitro RIR 778 and MR 710 are transportable radars used by test ranges to support various missions for tracking and monitoring aircraft. They can be moved around within the with the test range, and can be in use anytime the missions require their services. They operate in the band 8500 to 8975 MHz with a power up to 300 kW and an antenna gain of 27 dBi.



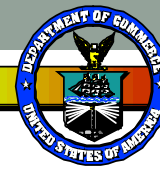
# Sample Systems 8.550-8.650 GHz

- AN/SPG-53
  - The AN/SPG-53A is a ship based radar that is used for tracking air and surface targets, that has a land based assignment in Dam Neck, Virginia. It has a band assignment to operate in the 8500 to 9600 MHz band, but it is not permitted to operate in the 9000 to 9200 MHz band. It can be in use anytime the missions require its services. Transmits a peak power is 250 kW with an antenna gain of 42 dBi.
- AN/APS-80
  - The AN/APS-80 is an airborne search radar that is used for surveillance and reconnaissance on multiple aircraft and has a frequency band area assignment for the Atlantic Ocean in the band 8500 to 9600 MHz. It can operate on fifteen or more frequencies across the 8500 to 9600 MHz band, but it is not permitted to operate within the 9000 to 9200 MHz band. Transmits a peak power of 50 kW with an antenna again of 34 dBi.



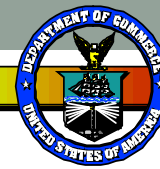
# Sample Systems 8.650-9.0 GHz

- ARRS
  - The Advanced Radar Surveillance System (ARSS) is transportable surveillance radar used by the US Air Force and the Department of Homeland Security (DHS) for detecting and tracking vehicle and man-sized targets. This radar has assignments in both the mobile and land radiolocation classes. Transmits 5 watts of peak power with a phased array antenna that has a gain of 31 dBi.
- ELM-2022
  - The Coast Guard has a US&P frequency assignment for the ELM-2022, a multi mode airborne Doppler radar mounted on HC-130J aircraft. The assignment authorizes its operations at 8550 MHz for ten aircraft with nineteen unique waveforms. The system is used for surface search and reconnaissance for anti-smuggling and search & rescue missions and other functions. Transmits a peak power of 3.5 Kw with an antenna gain of 33 dBi.



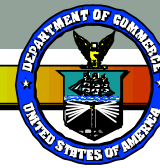
# Systems and Operations 9.0-9.2 GHz

- The 9000-9200 MHz band is dedicated for precision approach radar systems (PARS) and Airport Surface Detection Equipment (ASDE). Fixed and transportable land and ship based systems.
- With a few notable exceptions, nearly all systems located within this band are PARS and ASDEs. Other types of systems are generally not permitted in the band.
- The PARS and ASDE systems operating in this band (reserved for air traffic control systems) are essential for transportation safety of life and national defense.
- Some assignments for research, development, testing and evaluation of new and modified radars for this band that serve the primary purpose.
- Systems with assignments in the band may have multiple stations for each assignment.



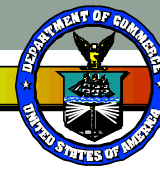
# Sample Systems 9.0-9.2 GHz

- ASDE-X SMRi
  - The ASDE-X improved surface movement radar (SMRi) is an upgraded version of the Raytheon ASDE-X and is incrementally replacing the ASDE-X. It is fixed radar system which provides a comprehensive view of the airport's air traffic, surface movement, and approach corridors for advance air traffic control purposes. ASDE-X systems are located at 35 major airports across the continental US plus Hawaii. Peak power of 155 W with an antenna gain of 35 dBi.
- AN/MPN-14K
  - The AN/MPN-14K Landing Control Central radar set is a transportable integrated all-weather air traffic control (ATC) and PARS system which can be configured as a complete Radar Approach Control (RAPCON) or Ground Controlled Approach (GCA) facility. The ATC radar has primary radar coverage up to 60 nautical miles with secondary radar coverage up to 200 nautical miles. Peak power of 120 kW with an antenna gain of 38 dBi.
- AN/SPN-35
  - The AN/SPN-35 radar set is a secondary PARS system used on US Navy vessels to direct landing operations. They are used on aircraft carriers to provide azimuth and elevation data for precision approaches of aircraft during adverse weather conditions. There are also some land-based AN/SPN-35 systems located at navy installations, primarily for training purposes. Ship-based systems typically do not radiate within 100 miles of shore and are usually aimed away from shore to limit the potential for interference. Peak power of 200 kW with an antenna gain of 34 dBi.



# Sample Systems 9.2-9.3 GHz

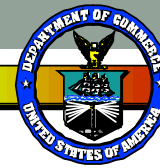
- AN/TPN-18
  - The AN/TPN-18 is a lightweight, helicopter-transportable radar set designed for use during all weather conditions. It provides information used for air traffic control, radar surveillance, and ground controlled approach of aircraft. The AN/TPN-18 is a component of Landing Control Centrals AN/TSQ-71A and AN/TSQ-72. Peak power of 200 kW with an antenna gain of 38 dBi.
- AN/MPA-4
  - The AN/MPA-4 is a general purpose instrumentation radar that is to support research testing and development. The radar has an assignment at the Barking Sands, Hawaii test range. It is authorized for occasional, but not limited to workweek hours of operations. Peak power of 225 kW with an antenna gain of 39 dBi
- AN/APS-135
  - The AN/APS-135 is a SLAR sea surveillance radar installed on C-130 aircraft operated by the Coast Guard with a US&P assignment. Its mission is to detect surface ships, sea ice and oil slicks due to pollution spills. The AN/APS-135 is a variant of the AN/APS-131. Peak power of 250 kW with an antenna gain of 34 dBi.



# Sample Systems 9.3-9.5 GHz

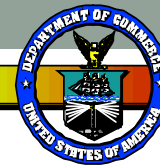
- COTS Radar systems
  - Several commercial-off-the-shelf (COTS) radar systems are used at various fixed land locations, typically for bird detection at airports (anti-birdstrike safety of life issue) or surface detection, security/traffic monitoring, and harbor control at ports and other waterfront locations. The systems typically use narrow pulse widths (a few nanoseconds to about a microsecond) and a low duty cycle.
- AN/SPS-73
  - A two-dimensional surface-search and navigation radar system used by the Navy and Coast Guard which provides contact range and bearing information. It has automatic target detection capability and the surface-search function provides short-range detection and surveillance of surface units and low-flying air units while the navigation function provides position relative to nearby vessels and navigational hazards. The radar has a peak power of 25 kW with an antenna gain of 31 dBi.
- RACONS
  - The US Coast Guard operates RACONS, also called radar responders, or radar transponder beacons in the band 9300 to 9500 MHz. They are receiver/transmitter transponder devices that are used as a navigation aid, identifying landmarks or buoys on a shipboard marine radar display. The Coast Guard buys the devices from commercial vendors and installs them where ships need enhanced navigation such as harbor or port inlets, piers, bridges, or other possible hazardous locations





# Sample Systems 9.5-9.8 GHz

- AN/SPN-35(B)
  - The AN/SPN-35 is a short range three-dimensional radar installed on Tarawa-class amphibious assault ships and provides precise control of aircraft during their final approach and landing. The equipment can automatically acquire, control, and land aircraft in all weather conditions. It transmits 200 watts of power into an antenna with a gain of 38 dBi.
- AN/APD-14
  - The AN/APD-14 radar was developed as part of the Open Skies Treaty, which was established to allow a regime of unarmed aerial observation flights over the entire territory of its participants. There are 34 countries included in the treaty. The radar is a synthetic aperture (SAR) that was developed for overland flights to obtain images of selected areas. The radar has a US&P assignment to operate in the band. The radar has a peak power of 50 kW with an antenna gain of 29 dBi.
- AN/APS-137
  - The AN/APS-137 is an airborne radar that provides long-range surface search and target tracking, periscope detection in high sea states, ship imaging and classification using Inverse Synthetic Aperture Radar (ISAR), and Synthetic Aperture Radar (SAR) for overland surveillance, ground mapping, and targeting. The radar has a peak power of 500 kW with an antenna gain of 35 dBi. The radar has a frequency band assignment for the US&P in the band 9500 to 10000 MHz for operations on C-130 aircraft.



# Sample Systems 9.8-10.0 GHz

- AN/UPQ-3(A)
  - The AN/UPQ-3(A) is data link used for air-ground-air communications. It has the ability to operate from 9.5 to 10.5 GHz. The airborne transmitter has a power level of 70 watts into a 24dBi antenna and the ground transmitter has a power level of 200 watts into an antenna with a gain of 43 dBi. Since this is a duplex link, the uplink and downlink must be separated by 500 MHz.
- AN/TPQ-36 (V)8
  - The AN/TPQ-36(V)8 Firefinder mobile ground based radar provides automatic, fast and accurate locations of artillery, mortars and rocket launchers. It is an upgraded version of the AN/TPQ-36. Transmits with 31 kW of power with an antenna gain of 42 dBi.

# Ku / Ka / mm Bands

---

David DeBoer  
UC Berkeley  
NAS/CORF



## Ku Band (12 – 18 GHz → $\lambda=1.7 - 2.5$ cm)

- Radar Applications
  - High-Resolution Mapping
  - Satellite Altimetry
  - Airborne Doppler Weather Radar
  - Airport Surface Detection Equipment
- Primary Radar Allocations
  - 13.25-13.40 GHz: Aeronautical Radionavigation
  - 13.4-14.0 GHz: EESS (active), Radiolocation
  - 15.7-16.2 GHz: Radiolocation (Aeronautical application co-equal)
  - 15.7-17.7 GHz: EESS (active), Radiolocation

## Ka Band (27 – 40 GHz $\rightarrow$ $\lambda=0.75 - 1.1$ cm)

- Applications
  - Very-High-Resolution Mapping
  - Short-Range Tracking
- Allocations
  - 33.4-36.0 GHz: Radiolocation, EESS (active)

mm (40 – 300 GHz  $\rightarrow$   $\lambda=0.1$  – 0.75 cm)

- Applications

- Smart Munitions
- Experimental
- Remote Sensing

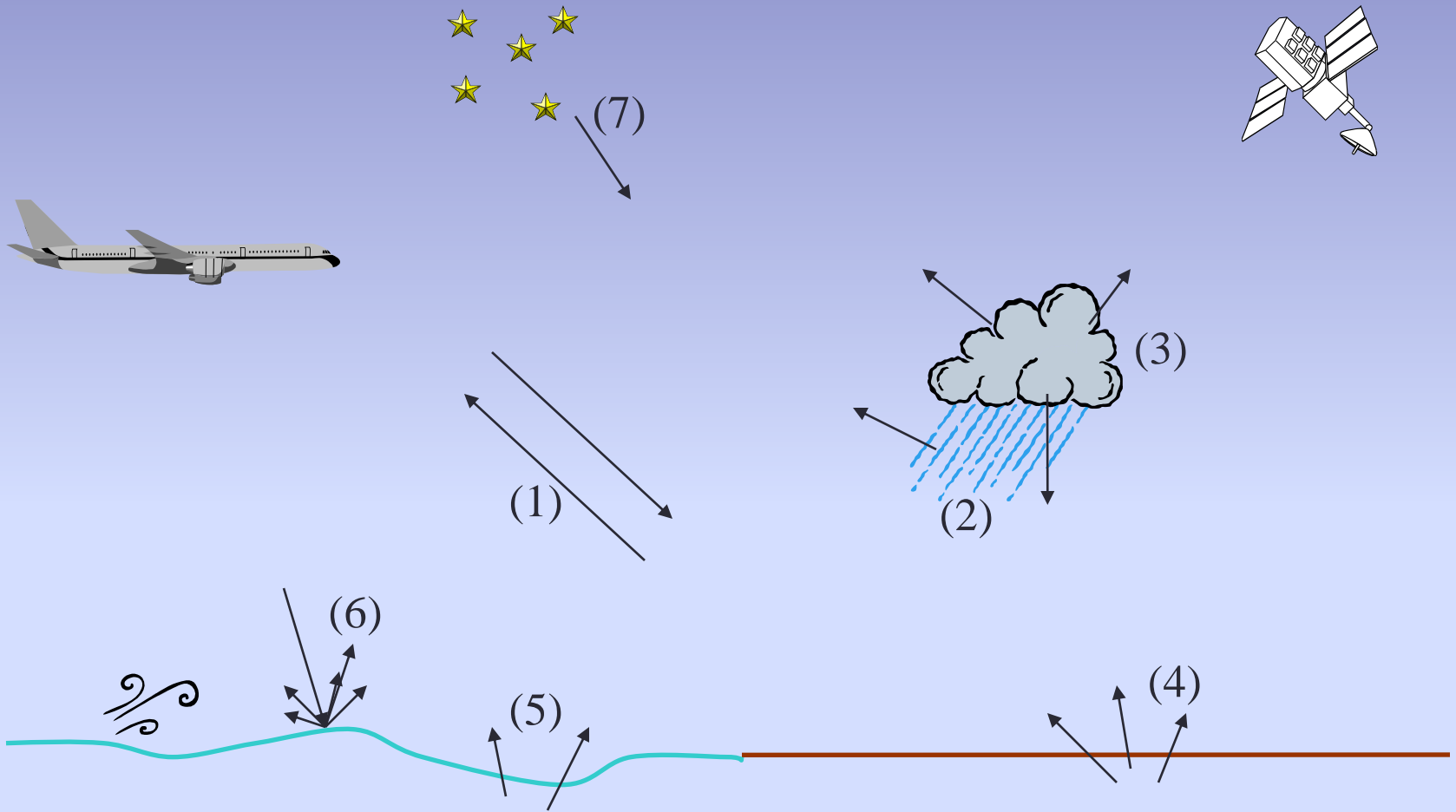
- Allocations

- 59-64 GHz: Radiolocation
- 76-81 GHz: Radiolocation
- 92-100 GHz: Radiolocation, EESS (active)
- 126-142 GHz: Radiolocation, EESS (active)
- 144-149 GHz: Radiolocation
- 231-235 GHz: Radiolocation
- 238-248 GHz: Radiolocation

# Uses of “Small” Wavelengths

- Wavelengths 0.1 – 1.7 cm
  - Physical size of raindrops, roses, whiskers on kittens
  - Can resolve small things and measure bulk properties of big things
- Higher gain for given antenna size
- Smaller field-of-view for given antenna size
  - ➔ Localized and point-to-point applications
- Ku and Ka bands generally good transmission
- mm many spectral features and overall more absorption
- Primarily scientific uses

# Natural Sources of Microwave Radiation



(1) Atmosphere

(2) Rain

(3) Clouds

(4) Land

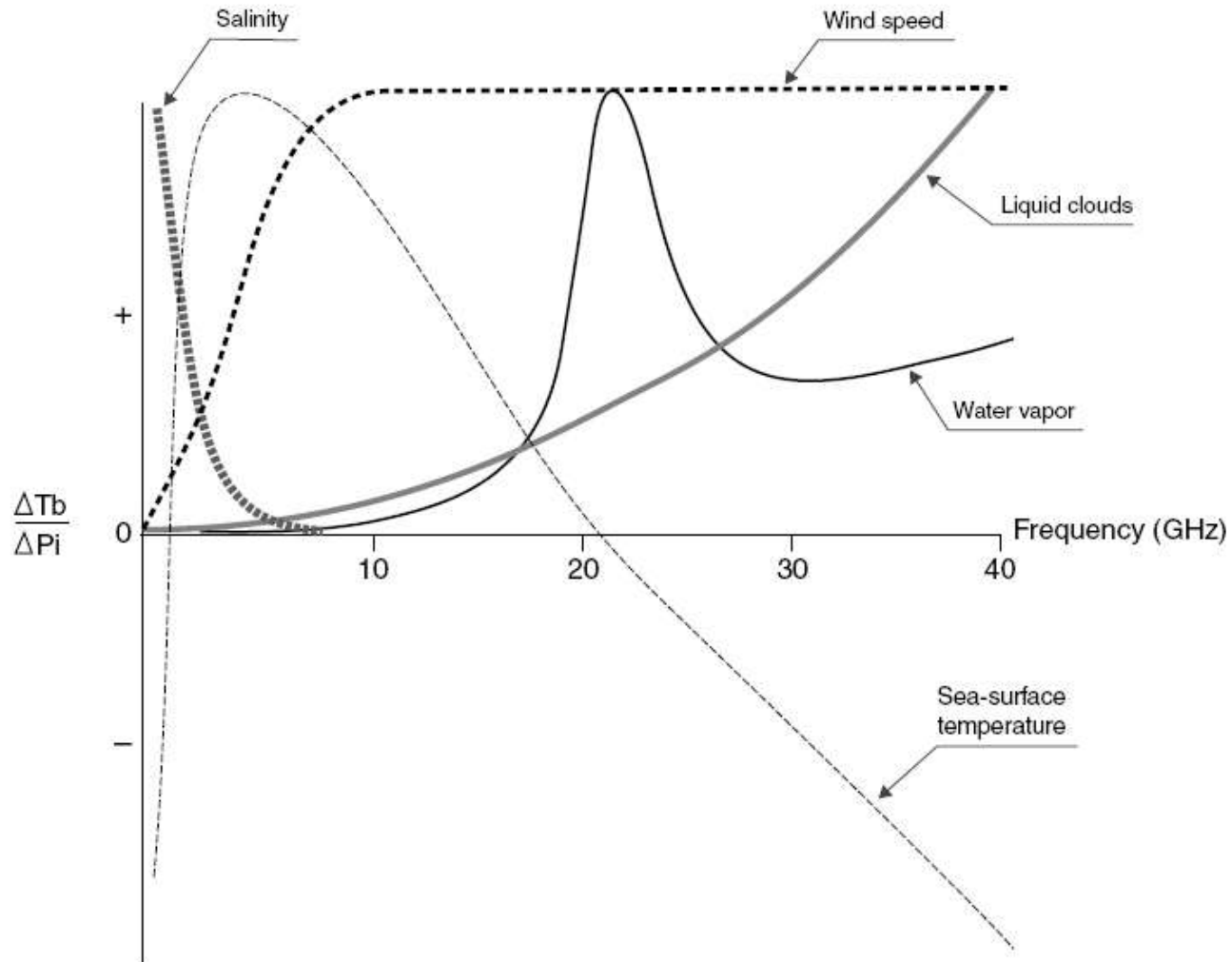
(5) Oceans

(6) Scattering

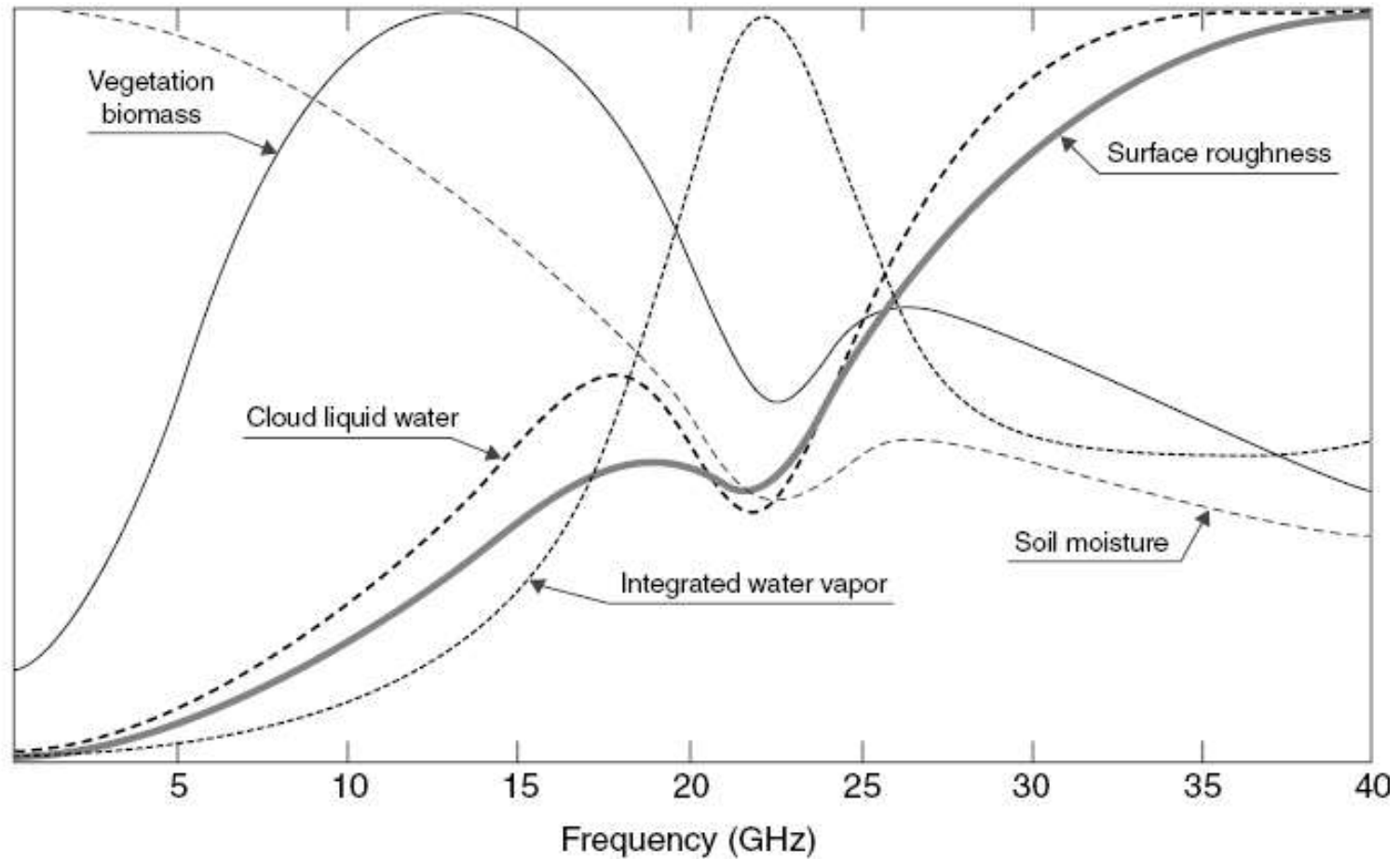
(7) 2.7 K Cosmic Background



# Frequencies for Observing Over Ocean



# Frequencies for Observing Over Land



# Spectrum Usage Recommendations for EESS

Table 1. Frequency bands for passive microwave remote sensing. (From ITU-R SA.515-4.)

Frequency band	Nominal Channel Bandwidth (MHz)	Band Center (GHz)	Measurement
L Band	100	1.4	Soil moisture, ocean salinity, sea surface temperature, vegetation index
S Band	45	2.7	Ocean salinity, soil moisture, vegetation index
C Band	200	4.3	Sea surface temperature, soil moisture
C Band	200	6.85	Sea surface temperature, soil moisture
X Band	100	10.65	Rain rate, snow water equivalent, ice morphology, sea state, ocean surface wind speed and direction
Ku Band	200	15.3	Water vapor, rain rate
K Band	200	18.7	Rain rates, sea state, sea ice, water vapor, ocean surface wind speed and direction, soil emissivity and humidity
K Band	200	21.3	Water vapor, liquid water
K Band	300	22.235	H <sub>2</sub> O Absorption Line Water vapor, liquid water
K Band	400	23.8	Water vapor, liquid water, associated channel for atmospheric sounding

## Committee on Radio Frequencies

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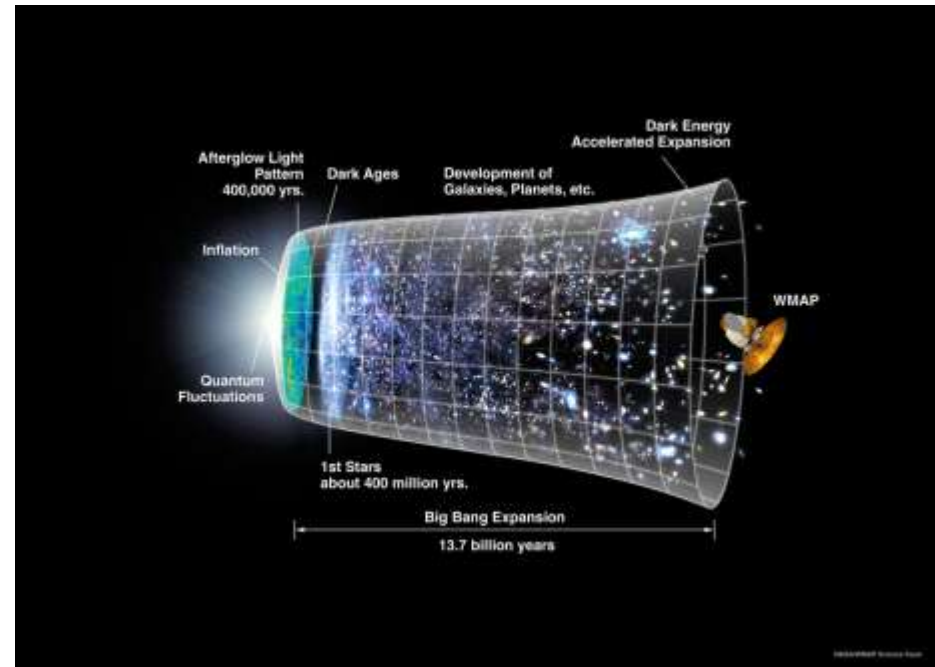
## Committee on Radio Frequencies (CORF)

- Deals with radio-frequency requirements and interference protection primarily through filing comments under the aegis of the National Academy of Sciences in public proceedings of the FCC and NTIA
  - Comments are drafted and developed by CORF and its legal counsel. Comments go through a detailed review process per NRC protocol, and are finally approved and signed by the NAS President's Office
- Coordinates the views of the U.S. scientists, and acts as a channel for representing the interests of U.S. scientists
- Conducts spectrum studies and maintains Handbook
- Operates under the Board on Physics and Astronomy
- Is supported by NASA and NSF

# Radio Astronomy (RAS)

- Radio astronomy has great potential for further fundamental discoveries, including the origins and evolution of the universe, the nature of matter, and life in other solar systems, which will have an enormous impact on our understanding of fundamental physics and the place of humanity in the Universe.

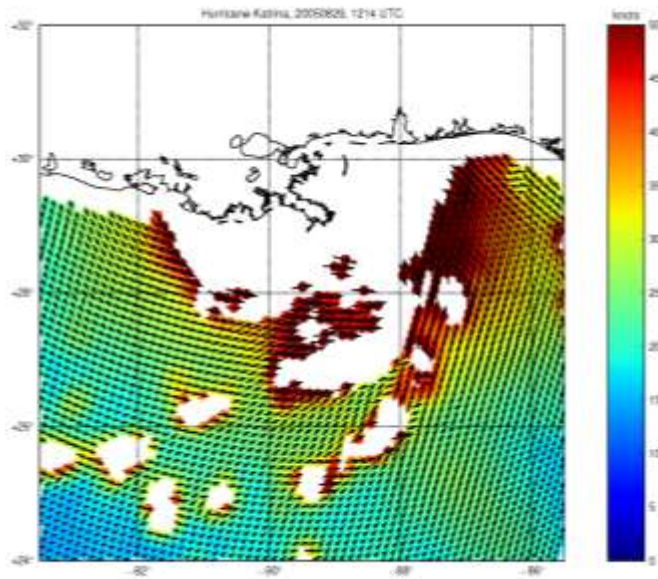
Artist's conception of the history of the Universe. Time runs from left to right. The Universe was born in an explosion popularly called the "Big Bang." After a period of inflation the Universe settled to a nearly steady expansion rate. As the afterglow died out the Universe became dark. After hundreds of millions of years gravitational contraction of the material in the original density fluctuations produced the first stars, which gave off light, and so the "Dark Ages" ended. The Universe became more complex, and now is evolving rapidly, with many varieties of stars and galaxies and exotic objects. Results from the WMAP satellite were used to make the afterglow pattern.





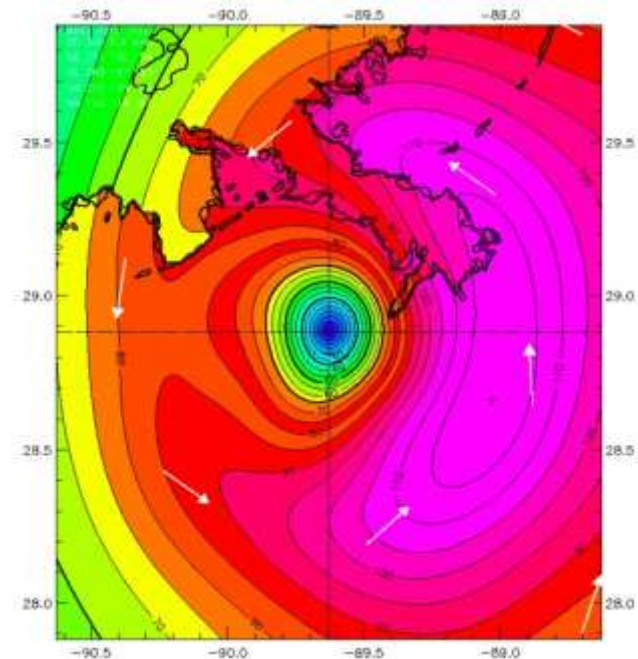
# The Importance of Earth Exploration Satellite Services

- Microwave measurements from satellites are vital for weather forecasting (e.g. Hurricane Katrina) and long-range climate studies (e.g. ice cover)



(Left) Image of the wind speed of Hurricane Katrina (in knots), observed by passive microwave radiometers on WindSat, a Naval Research Laboratory satellite, as the hurricane makes landfall near New Orleans on August 28, 2005.

(Right) Output from a model that combines data from WindSat and other remote sensing instruments. The model provides information on the hurricane's wind speed. The values over land are extrapolations.



# Allocations

United States		
Federal Allocation	Non-Federal Allocation	Federal Usage
<p>13.25-13.4 GHz EARTH EXPLORATION-SATELLITE (active) AERONAUTICAL RADIONAVIGATION 5.497 SPACE RESEARCH (active) 5.498A</p>	<p>13.25-13.4 GHz AERONAUTICAL RADIONAVIGATION 5.497 Earth exploration-satellite (active) Space research (active)</p>	<p>The military agencies operate airborne Doppler navigation radars in this band.</p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars.</p> <p>The National Aeronautics and Space Administration uses this band for active remote sensing of the Earth from space using altimeters, scatterometers and precipitation radars.</p>
<p>13.4-13.75 GHz EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION G59 SPACE RESEARCH 5.501A Standard frequency and time signal-satellite (Earth-to-space)</p> <p>5.501B</p>	<p>13.4-13.75 GHz Earth exploration-satellite (active) Radiolocation Space research Standard frequency and time signal-satellite (Earth-to-space)</p>	<p>The military agencies military services operate shipborne radiolocation point defense weapon systems, including search radars, tracking radars, and missile and gun fire-control radars.</p> <p>The National Aeronautics and Space Administration (NASA) uses this band for active sensor systems used in joint programs with the Centre National d'Etudes Spatiales (CNES) for space-based observations and measurements of surface topography, ocean winds and precipitation.</p> <p>NASA uses this band for space-based precipitation radars in the Tropical Rainfall Measurement Mission (TRMM), Global Precipitation Mission (GPM), and terrestrial precipitation radars.</p> <p>NASA uses this band for spacecraft communications downlinks involving space research. NASA uses the band for its tracking and data relay satellite system (TDRSS) to provide communications to the space shuttle and other spacecraft.</p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars.</p>
<p>13.75-14 GHz RADIOLOCATION G59 Standard frequency and time signal-satellite (Earth-to-space) Space research US337</p> <p>US356 US357</p>	<p>13.75-14 GHz FIXED-SATELLITE (Earth-to-space) US337 Standard frequency and time signal-satellite (Earth-to-space) Space research Radiolocation</p> <p>US356 US357</p>	<p>The military agencies operate shipborne defense weapon systems, including search radars, tracking radars, and missile and gun fire-control radars.</p> <p>The National Aeronautics and Space Administration (NASA) operates the Tropical Rainfall Measurement Mission precipitation radar in this band on an NIB basis as well as other terrestrial based precipitation radars.</p> <p>NASA uses this band for spacecraft communications downlinks involving space research.</p> <p>NASA uses this band for its tracking and data relay satellite system (TDRSS) to provide communications to the space shuttle and other spacecraft.</p> <p>NASA uses this band for deep-space communications to and from planetary spacecraft conducting radio science experiments as well as exchanging some command and ranging data.</p> <p>NASA uses this band for rendezvous radar on the Space Shuttle.</p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars.</p>



# Allocations

		United States	
Federal Allocation	Non-Federal Allocation	Federal Usage	
15.7-16.6 GHz RADIOLOCATION G59	15.7-17.2 GHz Radiolocation	<p>The Federal Aviation Administration operates airport surface detection equipment (ASDE) radars in this band to monitor aircraft and vehicles on the ground near airports.</p> <p>The military agencies use this band for radars for guided weapons systems, combat surveillance, mortar locating, airborne weapons control radars, and radars on Unmanned Aerial Vehicles (UAVs). The Army uses the 15.7-17.3 GHz band for: UAVs tactical endurance radars (TESAR); the UAV small tactical synthetic aperture radars (STACSAR); terrain following radars; forward looking multimode radars on helicopters; and the LANTRIN terrain following radars.</p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including the research of the formaldehyde line and quasars.</p> <p>Federal agencies use this band for security perimeter surveillance radar systems.</p>	
16.6-17.1 GHz RADIOLOCATION G59 Space research (deep space) (Earth-to-space)		<p>The military agencies use this band for radars for guided weapons systems, combat surveillance, mortar locating, airborne weapons control, and on Unmanned Aerial Vehicles (UAVs). The Army uses the 15.7-17.3 GHz band for: UAVs tactical endurance radars (TESAR); the UAV small tactical synthetic aperture radars (STACSAR); terrain following radars; forward looking multimode radars on helicopters; and the LANTRIN terrain following radars.</p>	
17.1-17.2 GHz RADIOLOCATION G59		<p>The military agencies use this band include radars employed for guided weapons systems, combat surveillance, mortar locating, airborne weapons control, and on Unmanned Aerial Vehicles (UAVs). The Army uses the 15.7-17.3 GHz band for: UAV tactical endurance radars (TESAR); the UAV small tactical synthetic aperture radars (STACSAR); terrain following radars; forward looking multimode radars on helicopters; and the LANTRIN terrain following radars.</p>	
17.2-17.3 GHz EARTH EXPLORATION-SATELLITE (active) RADIOLOCATION G59 SPACE RESEARCH (active)	17.2-17.3 GHz Earth exploration-satellite (active) Radiolocation Space research (active)	<p>The military agencies use this band for radars for guided weapons systems, combat surveillance, mortar locating, airborne weapons control, and on Unmanned Aerial Vehicles (UAVs). The Army uses this band for: Unmanned Aero Vehicle (UAV) tactical endurance radars (TESAR); the UAV small tactical synthetic aperture radars (STACSAR); terrain following radars; forward looking multimode radars on helicopters; and the LANTRIN terrain following radars. The National Aeronautics and Space Administration uses this band for active sensing of the Earth using scatterometers and precipitation radars.</p>	
17.3-17.7 GHz Radiolocation US259 G59	17.3-17.7 GHz FIXED-SATELLITE (Earth-to-space) US271 BROADCASTING-SATELLITE US402 NG163	<p>The military agencies use this band for radars on a secondary basis.</p>	
US402 G117	US259		
24.05-24.25 GHz RADIOLOCATION G59 Earth exploration-satellite (active)	24.05-24.25 GHz Amateur Earth exploration-satellite (active) Radiolocation	<p>Federal agencies operate radar speed guns in this band for vehicular speed control.</p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines and continuum measurements. Observations of three major ammonia lines are performed in this band that help deduce the temperature of interstellar mediums.</p> <p>The National Aeronautics and Space Administration (NASA) uses this band for active sensing of the Earth using precipitation radars.</p>	
5.150	5.150		

# Allocations

United States		
Federal Allocation	Non-Federal Allocation	Federal Usage
<p>31.8-32.3 GHz  <b>RADIONAVIGATION</b> US69            SPACE RESEARCH            (deep space)            (space-to-Earth) US262</p>	<p>31.8-32.3 GHz            SPACE RESEARCH            (deep space)            (space-to-Earth) US262</p>	<p><b>The military agencies use this band for airborne precision mapping radars.</b></p> <p>The National Aeronautics and Space Administration uses this band for deep space (space-to-Earth) communications links, including the Mars Global Surveyor (Mars), Mars Reconnaissance Orbiter (Mars), Cassini (Saturn) and Kepler (astronomy) spacecraft conducting radio science experiments and exchanging command and ranging data as well as SurfSat which performs experiments using the Deep Space Network.</p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including continuum observations. Observations are made in this band because this is the first radio window (31.2- 37.5 GHz) in the millimeter wave region, and it also provides for research studies of continuum spectrum of galactic and extragalactic objects. Radio astronomy observations are also made in the 25-35 GHz band for continuum measurements and spectral-line studies.</p>
<p>5.548 US211</p>	<p>5.548 US211</p>	<p>The Navy operates an automatic aircraft carrier landing system in this band.</p>
<p>33.4 -34.2 GHz  <b>RADIOLOCATION</b></p>	<p>33.4-34.2 GHz  <b>Radiolocation</b></p>	<p><b>The National Aeronautics and Space Administration operates a Doppler radar tracking system in this band.</b></p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including continuum observations. Observations are made in this band because this is the first radio window (31.2- 37.5 GHz) in the millimeter wave region, and it also provides for research studies of continuum spectrum of galactic and extragalactic objects. Radio astronomy observations are also made in the 25-35 GHz band for continuum measurements and spectral-line studies.</p>
<p>US360 G117</p>	<p>US360</p>	

# Allocations

United States		
Federal Allocation	Non-Federal Allocation	Federal Usage
<b>34.2-34.7 GHz</b> <b>RADIOLOCATION</b> SPACE RESEARCH (deep space) (Earth-to-space) US262	<b>34.2-34.7 GHz</b> <b>Radiolocation</b> Space research (deep space) (Earth-to-space) US262	<p>The National Aeronautics and Space Administration (NASA) uses this band for communications links with spacecraft in deep space such as the Cassini spacecraft that is conducting radio science experiments as well as exchanging some command and ranging data. The mission is to investigate the planet Saturn and its moons.</p> <p><b>NASA operates a Doppler radar tracking system in this band.</b></p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including continuum observations. Observations are made in this band because this is the first radio window (31.2- 37.5 GHz) in the millimeter wave region, and it also provides for research studies of continuum spectrum of galactic and extragalactic objects. Radio astronomy observations are also made in the 25-35 GHz band for continuum measurements and spectral-line studies.</p> <p><b>The military agencies are operating vehicle speed measurement radar guns and cloud height measuring radars in this band, and conducting research into radars.</b></p>
US360 G34 G117	US360	
<b>34.7-35.5 GHz</b> <b>RADIOLOCATION</b>	<b>34.7-35.5 GHz</b> <b>Radiolocation</b>	<p>The military agencies use this band for fixed and mobile radars supporting operational and research and experimentation. The military uses include airborne side-looking radars, the experimental research of radars and radar techniques, and improving on the accuracy of sensor and navigational systems.</p> <p><b>The National Aeronautics and Space Administration (NASA) uses this band for the scientific investigation of clouds using radars.</b></p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including continuum observations. Observations are made in this band because this is the first radio window (31.2- 37.5 GHz) in the millimeter wave region, and it also provides for research studies of continuum spectrum of galactic and extragalactic objects. Radio astronomy observations are also made in the 25-35 GHz band for continuum measurements and spectral-line studies.</p> <p><b>Federal agencies use this band for security perimeter surveillance radar systems.</b></p>
US360 G117	US360	
<b>35.5-36 GHz</b> <b>EARTH EXPLORATION- SATELLITE (active)</b> <b>RADIOLOCATION</b> SPACE RESEARCH (active)	<b>35.5-36 GHz</b> <b>Earth exploration-satellite (active)</b> <b>Radiolocation</b> Space research (active)	<p><b>The National Aeronautics and Space Administration (NASA) uses this band for active sensing of the Earth from space and aircraft using precipitation radars.</b></p> <p><b>NASA conducts scientific investigations using radars of clouds in this band. NASA operates a Doppler radar tracking system in this band.</b></p> <p>The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including continuum observations. Observations are made in this band because this is the first radio window (31.2- 37.5 GHz) in the millimeter wave region, and it also provides for research studies of continuum spectrum of galactic and extragalactic objects. Radio astronomy observations are also made in the 25-35 GHz band for continuum measurements and spectral-line studies.</p> <p><b>Federal agencies use this band for security perimeter surveillance radar systems.</b></p>
US360 G117	US360	



# Allocations

United States		Federal Usage
Federal Allocation	Non-Federal Allocation	
<b>36-37 GHz</b> EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE SPACE RESEARCH (passive)		The National Aeronautics and Space Administration (NASA) and the National Oceanographic and Atmospheric Administration use this band for passive sensing of the Earth from space using microwave radiometers to obtain data on rain rates, snow, ocean ice, oil spills and clouds. This band is used in conjunction with passive sensing bands around 6.7, 10.6, 18.7 and 23.6 GHz to obtain several important climatological parameters.  <b>NASA uses this band for airborne radars performing topographic mapping.</b>
<b>59-59.3 GHz</b> EARTH EXPLORATION-SATELLITE (passive) FIXED INTER-SATELLITE 5.556A MOBILE 5.558 <b>RADIOLOCATION 5.559</b> SPACE RESEARCH (passive)  US353	<b>59-59.3 GHz</b> EARTH EXPLORATION-SATELLITE (passive) FIXED MOBILE 5.558 <b>RADIOLOCATION 5.559</b> SPACE RESEARCH (passive)  US353	The military agencies use this band for fixed microwave radio relay communications links on various military test ranges.  The National Aeronautics and Space Administration (NASA) and the National Oceanographic and Atmospheric Administration (NOAA) use this band for passive sensing of the Earth from space using microwave radiometers. Remote sensing is used to measure atmospheric temperature profiles at various atmospheric heights via oxygen absorption lines in this band.  The military agencies are conducting research in this band to determine the proof of concept of millimeter wave radiocommunication links.
<b>59.3-64 GHz</b> FIXED INTER-SATELLITE MOBILE 5.558 <b>RADIOLOCATION 5.559</b>  5.138 US353	59.3-64 GHz FIXED MOBILE 5.558 RADIOLOCATION 5.559  5.138 US353	The military agencies use this band for fixed microwave radio relay communications links on various military test ranges.  This military agencies use this band for inter-satellite crosslink communications, specifically for the MILTSTAR, Advanced EFF, and other satellite systems.  The 61-61.5 GHz band with a center frequency of 61.25 GHz is used for industrial, scientific and medical (ISM) applications.
<b>76-77.5 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b> Space research (space-to-Earth)	<b>76-77 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b> Amateur Space research (space-to-Earth)  US342	None
	<b>77-77.5 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b> Amateur Amateur-satellite Space research (space-to-Earth)  US342	None
<b>78-79 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b> Space research	<b>78-79 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b> Amateur	<b>The National Aeronautics and Space Administration (NASA) uses this band for active sensing of the Earth using spaceborne radar measurements for cloud monitoring.</b>

# Allocations

United States		
Federal Allocation	Non-Federal Allocation	Federal Usage
<b>130-134 GHz</b> EARTH EXPLORATION-SATELLITE (active) 5.562E FIXED INTER-SATELLITE MOBILE 5.558 RADIO ASTRONOMY  5.562A US342		The National Science Foundation uses this band for the radio astronomy research observations of spectral-lines including various formaldehyde lines and continuum observations.  The National Aeronautics and Space Administration uses the 133.5-134 GHz band for cloud profiling radar applications.
<b>136-141 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b>  US342	136-141 GHz RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite  US342	The National Science Foundation uses this band for the radio astronomy research observations of spectral-lines including various formaldehyde lines and continuum observations.
<b>141-148.5 GHz</b> FIXED MOBILE RADIO ASTRONOMY <b>RADIOLOCATION</b>  US342		The National Science Foundation uses this band for the radio astronomy research observations of spectral-lines including various formaldehyde lines and continuum observations.
<b>141-148.5 GHz</b> FIXED MOBILE RADIO ASTRONOMY <b>RADIOLOCATION</b>  US342		The National Science Foundation uses this band for the radio astronomy research observations of spectral-lines including various formaldehyde lines and continuum observations.
<b>235-238 GHz</b> EARTH EXPLORATION-SATELLITE (passive) FIXED-SATELLITE (space-to-Earth) SPACE RESEARCH (passive)  5.563A 5.563B		The National Aeronautics and Space Administration uses this band for passive sensing of the Earth from space using microwave limb sounding radiometers. Ozone measurements and other types of research are conducted in this band. <b>The 237.9-238 GHz band is also used for spaceborne cloud radars.</b>  The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including various carbon lines and its isotopes as well as hydrogen lines and its associated compound lines, and for observing continuum observations.
<b>241-248 GHz</b> RADIO ASTRONOMY <b>RADIOLOCATION</b>  5.138 US342	241-248 GHz RADIO ASTRONOMY RADIOLOCATION Amateur Amateur-satellite  5.138 US342	The National Science Foundation uses this band for the radio astronomy research of various spectral-lines, including various carbon lines and its isotopes as well as hydrogen lines and its associated compound lines, and for observing continuum observations.  The 244-246 GHz band with a center frequency of 245 GHz is used for industrial, scientific and medical (ISM) applications.

# Active Spaceborne Systems

Currently Operational Spaceborne Active Sensor Missions (Updated: June 2011)

Mission	Agency	ITU Name	Frequency (MHz)	Radiated Power (W)
Aquarius Scatterometer	NASA	AQUARIUS	1260	200
ERS-2 SAR/WS/RA	ESA	ERS-1	5300/5300/ <u>13800</u>	4800/4000/134
RADARSAT-1/2 SAR	CSA	RADARSAT-1A RADARSAT-2C RADARSAT-2D RADARSAT-2E RADARSAT-2F	5300	5000
ENVISAT ASAR/RA-2	ESA	ENVISAT	5300/ <u>13575</u> , 3200	4800/114, 65
COSMO-SkyMed	ASI	COSMO SKYMED	9600	2800
TerraSAR-X SAR	DLR	TERRASAR	9650	2260
JASON-1 (OSTM) SSALT	CNES	PROTEUS-TPFO	5300, <u>13575</u>	25, 7
JASON-2 (OSTM) SSALT	CNES	JASON2	5300, <u>13575</u>	25, 8
MetOp ASCAT	ESA/EUMETSAT	METOP	5300	120
QUIKSCAT SEAWINDS	NASA	QUIKSCAT	<u>13400</u>	110
TRMM PR	NASA/JAXA	TRMM	<u>13800</u>	518
CLOUDSAT CPR	NASA	USCLOUDSAT	<u>94050</u>	1500

<sup>[1]</sup> The ERS-2 satellite operations will be stopped in July this year.

<sup>[2]</sup> QUIKSCAT experienced antenna spinning problems (since Nov 23, 2009).

# Active Spaceborne Systems

Some upcoming missions

Mission	Agency	ITU Name	Frequency (MHz)	Radiated Power (W)
Global Precipitation Monitor Dual-Frequency Precipitation Radar (GPM/DPR)	NASA/JAXA		<u>13597,13603,</u> <u>35547,35553</u>	
SARAL/ALTIKA Ka-band altimeter	CNES/ISRO		<u>35,750 GHz</u>	2

<sup>[1]</sup> The ERS-2 satellite operations will be stopped in July this year.

<sup>[2]</sup> QUIKSCAT experienced antenna spinning problems (since Nov 23, 2009).

# JAXA GPM/DPR Project Status

Masahiro Kojima  
GPM/DPR Project manager  
JAXA

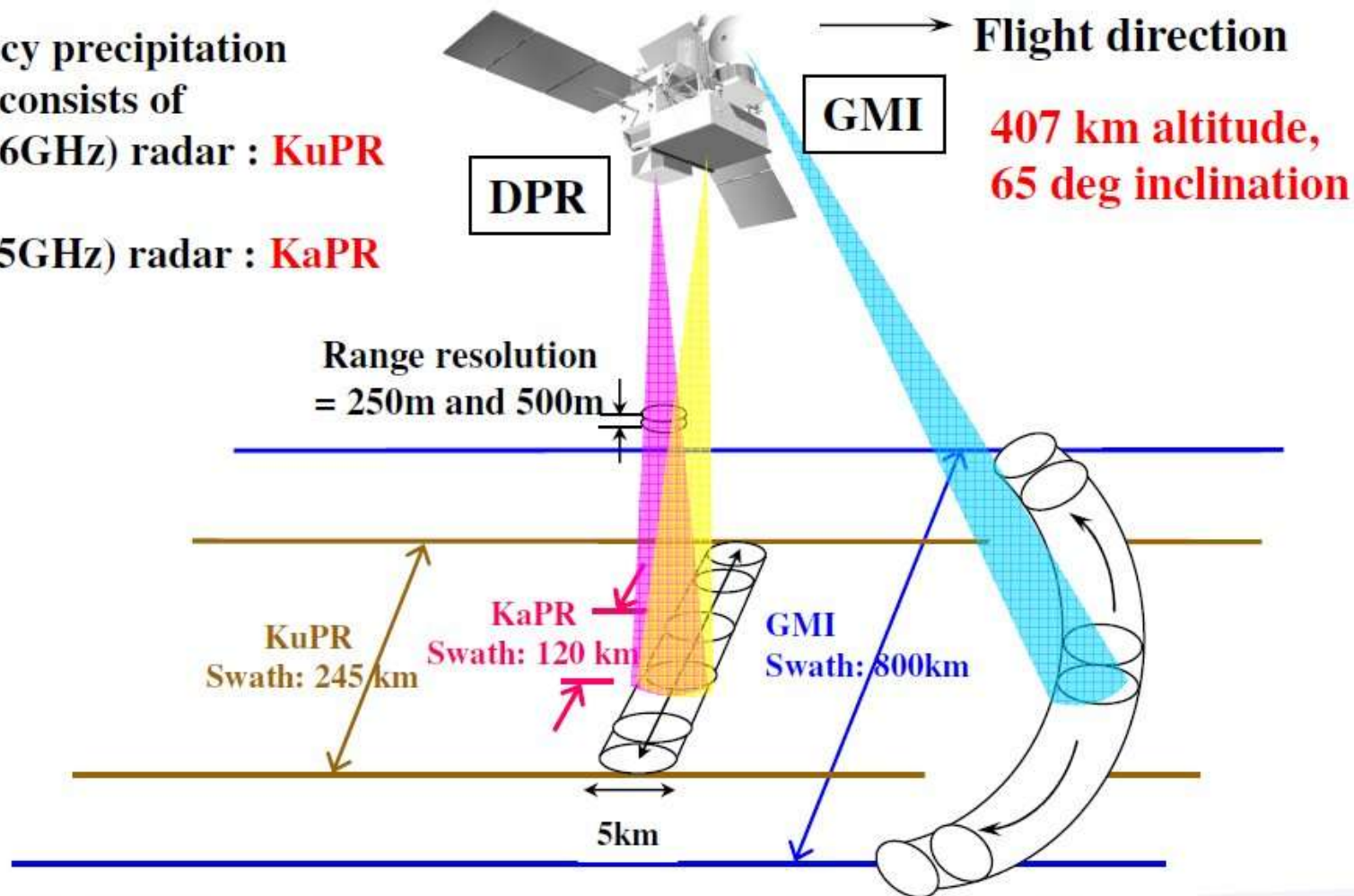


## Main Characteristics of DPR

	<b>KuPR</b>	<b>KaPR</b>
<b>Frequency</b>	13.597 , 13.603 GHz	35.547 , 35.553 GHz
<b>Horizontal Resolution</b>	5.2 km (at nadir)	5.2 km (at nadir)
<b>Swath Width</b>	245 km	120 km
<b>Scan period</b>	0.7 sec	0.7 sec
<b>Range Resolution</b>	250 m	250 m / 500 m
<b>Observation altitude</b>	Up to 19 km	Up to 19 km
<b>Minimum Detectable Rainfall Rate</b>	0.5 mm/hr	0.2 mm/hr
<b>Measurement Accuracy</b>	within $\pm 1$ dB	within $\pm 1$ dB
<b>Beam-matching Accuracy</b>	< 1000 m	
<b>Data Rate</b>	< 108.5 kbps	< 81.5 kbps
<b>Mass</b>	< 472 kg	< 336kg
<b>Power Consumption</b>	< 446 W	< 344 W
<b>Size</b>	2.5 × 2.4 × 0.6 m	1.2 × 1.4 × 0.7 m

# Concept of precipitation measurement by GPM core satellite

Dual-frequency precipitation radar (DPR) consists of  
 Ku-band (13.6GHz) radar : **KuPR**  
 and  
 Ka-band (35.5GHz) radar : **KaPR**



# Automotive Radar

- Automotive radar works to assist the driver.
- Very fluid state: 17 automotive radar vendors deploying 80 different radar platforms<sup>[1]</sup>
- Bands at 24-26, 77-81 GHz
- Power levels 77-81 GHz +55 dBm (peak)<sup>[2]</sup>
- Plans for no provisions for off switch or geographical awareness

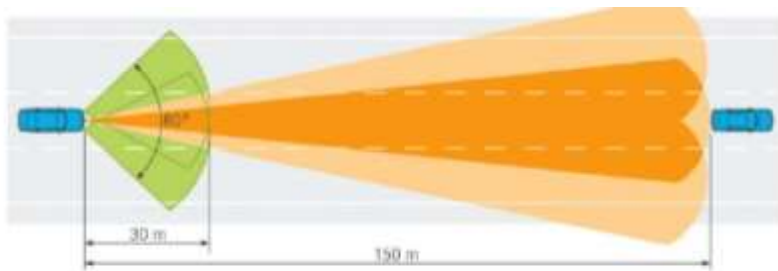


Figure 3. Combination of LRR and SRR for advanced safety features.

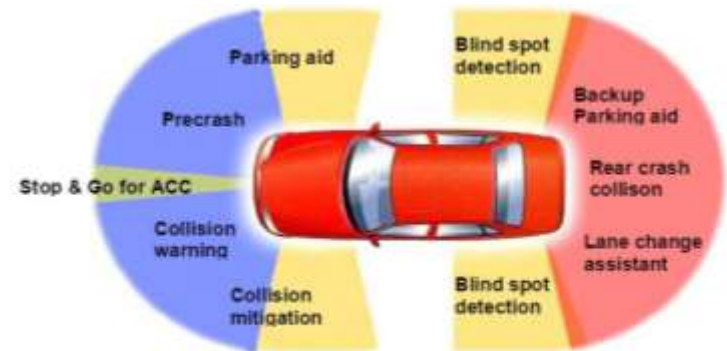


Figure 2. Possible applications using SRR.

[1] Wihi, IWPC 2011

[2] Wenger IEEE CSIC 2005