3500-3650 MHz

1. Band Introduction

The Department of Defense (DoD) operates high-powered shipborne, airborne, and ground-based radar systems in this band. These radar systems are used in conjunction with weapons control systems for the detection and tracking of airborne targets. The DoD operates radar systems used for fleet air defense, missile and gunfire control, bomb scoring, battlefield weapon locations, air traffic control, and range safety. This band is critical to military radar operations supporting national defense.

2. Allocations

2a. Allocation Table

The frequency allocation table shown below is extracted from the NTIA Manual of Regulations and Procedures for Federal Radio Frequency Management, Chapter 4 – Allocations, Allotments and Plans.

Table of Frequency Allocations

United States Table

Federal Table	Non-Federal Table	FCC Rule Part(s)
3500-3650 RADIOLOCATION G59 AERONAUTICAL – RADIONAVIGATION (ground-based) G110 US245	3500-3600 Radiolocation	Private Land Mobile (90)
	3600-3650 FIXED-SATELLITE – (space-to-Earth) US245 Radiolocation	Satellite – Communications (25) Private Land Mobile (90)

2b. Additional Allocation Table Information

G59 In the bands 902-928 MHz, 3100-3300 MHz, 3500-3650 MHz, 5250-5350 MHz, 8500-9000 MHz, 9200-9300 MHz, 13.4-14.0 GHz, 15.7-17.7 GHz and 24.05-24.25 GHz, all Federal non-military radiolocation shall be secondary to military radiolocation, except in the sub-band 15.7-16.2 GHz airport surface detection equipment (ASDE) is permitted on a co-equal basis subject to coordination with the military departments.

G110 Federal ground-based stations in the aeronautical radionavigation service may be authorized between 3500-3650 MHz when accommodation in the band 2700-2900 MHz is not technically and/or economically feasible.

US245 In the bands 3600-3650 MHz (space-to-Earth), 4500-4800 MHz (space-to-Earth), and 5850-5925 MHz (Earth-to-space), the use of the non-Federal fixed-satellite service is limited to international inter-continental systems and is subject to case-by-case electromagnetic compatibility analysis. The FCC's policy for these bands is codified at 47 CFR 2.108.

3. Federal Agency Use

3a. Federal Agency Frequency Assignments Table

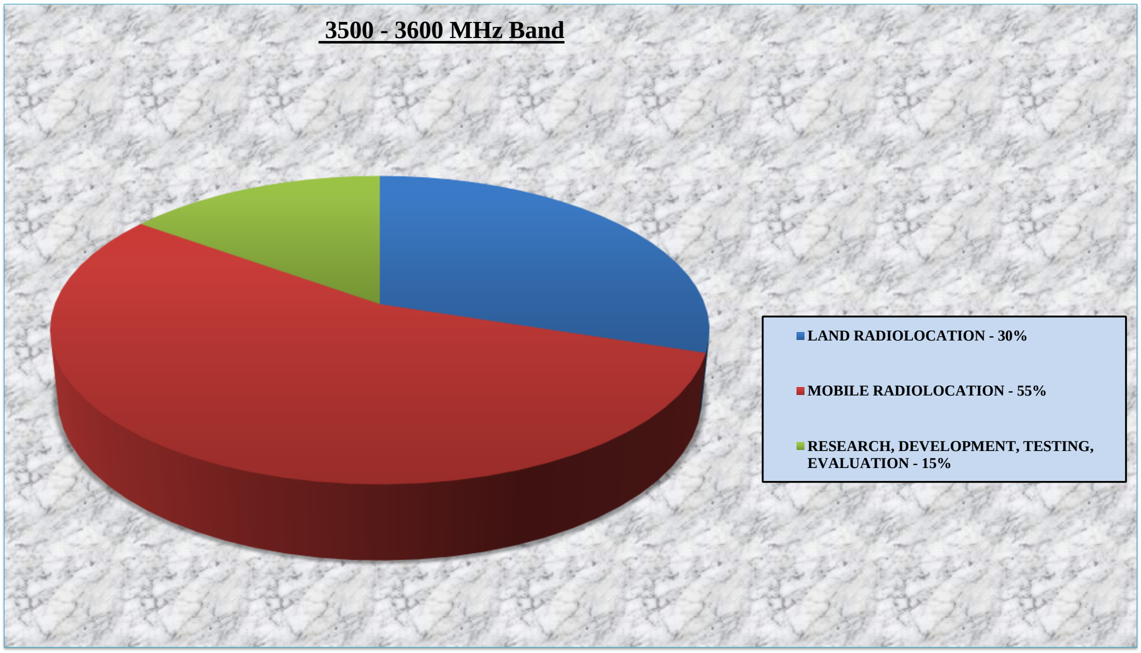
The following table identifies the frequency band, type(s) of allocation(s), types of application, and the number of frequency assignments by agency.

Federal Frequency Assignment Table

3500-3650 MHz Band						
SHARED BAND						
	AERONAUTICAL RADIONAVIGATION (ground based) FIXED SATELLITE (space-to-Earth) RADIOLOCATION					
	TYPE OF APPLICATION					
AGENCY	LAND RADIOLOCATION	MOBILE RADIOLOCATION			RESEARCH, DEVELOPMENT, TESTING, EVALUATION	TOTAL
AF		2			1	3
N	5	7				12
TOTAL	5	9			1	15
The number of actual systems, or number of equipments, may exceed and sometimes far exceed, the number of frequency assignments in a band. Also, a frequency assignment may represent, a local, state, regional or nationwide authorization. Therefore, care must be taken in evaluating bands strictly on the basis of assignment counts or percentages of assignments.						

3b. Percentage of Frequency Assignments Chart

The following chart displays the percentage of frequency assignments in the Government Master File for the different systems operating in the frequency band 3500-3650 MHz.



4. Frequency Band Analysis By Radio Service

The 3500-3650 MHz band includes allocations to the radiolocation and aeronautical radionavigation services. DoD uses this band for airborne, land-based, and shipborne radar systems. The radar systems operating in this band represent significant investment on the part of DoD.

The NTIA report, An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands, contains more detailed information on the systems in this band.[1]

4a. Shipborne Radiolocation

The Navy operates an air traffic control (ATC) radar system that is used on aircraft carriers and large amphibious assault ships (CV and LH class ships). The Navy ATC radar system is a two-dimensional, air traffic control, air-surveillance radar system that provides for simultaneous control and identification of aircraft within the ship area of

[1] An Assessment of the Near-Term Viability of Accommodating Wireless Broadband Systems in the 1675-1710 MHz, 1755-1780 MHz, 3500-3650 MHz, and 4200-4220 MHz, 4380-4400 MHz Bands, (hereinafter NTIA Assessment Report), can be found at the following url: http://www.ntia.doc.gov/reports/2010/FastTrackEvaluation_11152010.pdf.

responsibility and in the terminal area (vectoring aircraft into final approach). This radar system has two sets of transmitters (modulators), receivers, and their associated power supplies; the second set provides an immediate on-line backup capability in case of either a transmitter or receiver equipment failure. The system is used in conjunction with the carrier-controlled-approach radar for aircraft landing operations. This radar system also serves as a backup short-range, air-search radar system.

This system is comprised of numerous preset crystals operating on 15 or more frequencies throughout the entire band. This allows operator flexibility to select the most optimal frequency taking into account wave guide reflection due to weather conditions, system design, ducting, and other operating units.

The Navy ATC radar system provides azimuth and range information. Special indicators in the Carrier ATC Center enable operators to direct aircraft along a predetermined azimuth to touchdown. At this point, the aircraft is “handed-off” to the final approach controller .This ATC system is a coherent receive radar system with a pulsed magnetron transmitter. The radar antenna is mounted at a high point on the ship platform to provide the greatest signal detection range.

The Navy ATC radar routinely operates in and around ports and in close proximity to United States and possessions coastlines to support all aspects of Naval aviation. In addition, three systems are operated on land to support testing and training operations; 1) In Service Engineering Agent, Naval Air Warfare Center Aircraft Division St. Inigoes, Maryland; 2) In Service Engineering Agent Pascagoula, Mississippi; and 3) Naval Air Technical Training Command in Pensacola, Florida.[2]

The Navy operates a shipborne and ground-based radar system in the 3600-3650 MHz band in Hawaii. This radar system is part of the Fleet Operational Readiness Checksite and provides measurement of a ships’ sensor and navigational accuracy.

4b. Airborne Radiolocation

The Air Force operates Station Keeping Equipment (SKE) airborne and ground-based components up to 3510 MHz. This system is used to enhance flight safety as well as facilitate the management of cargo multi-aircraft formations. SKE formations can range in size from a single two-aircraft element to multi-element formations. The operator selects the desired formation position prior to takeoff and the SKE system uses pulsed radio frequency signals to maintain that position.

The Zone Marker and the Miniaturized Zone Marker are operated in conjunction with SKE equipment. The Zone Marker is a ground-based beacon used to provide a ground reference point to enhance aircraft navigation.

[2] In accordance with US footnote 348, the FCC shall coordinate all non-Federal operations in the 3650-3700 MHz band within 80 km of these sites with NTIA on a case-by-case basis due to the reallocation of 3650-3700 MHz under the Omnibus Reconciliation Act of 1993.

4c. Ground-Based Radiolocation

The Air Force operates Station Keeping Equipment (SKE) airborne and ground-based components up to 3510 MHz. This system is used to enhance flight safety as well as facilitate the management of cargo multi-aircraft formations. SKE formations can range in size from a single two-aircraft element to multi-element formations. The operator selects the desired formation position prior to takeoff and the SKE system uses pulsed radio frequency signals to maintain that position.

The Zone Marker and the Miniaturized Zone Marker are operated in conjunction with SKE equipment. The Zone Marker is a ground-based beacon used to provide a ground reference point to enhance aircraft navigation.

The Military is in the process of fielding a new radar system. This radar includes a number of improvements. This radar system will replace the aging medium-range radars now in the DoD's inventory. The Marine Corps also operates a multi-function radar system -that provides surveillance, air traffic control and fire quality data.

4d. Radar Characteristics

ITU-R Recommendation M.1465-1 provides technical characteristics for radiolocation radars in this frequency range.[3] The example system data provided in this recommendation is typical for radar systems deployed in the United States . Table 1 summarizes the tuning range, transmitter power level, emission 3 dB bandwidth, duty cycle, mainbeam antenna gain and equivalent isotropically radiated power (EIRP), for the radar systems operating in the band 3500-3650 MHz.[4] Though Recommendation M.1465-1 indicates the tuning range for these systems is up to 3700 MHz, radiolocation and radionavigation systems only operate up to 3650 MHz in the United States.

Table 1. Characteristics of Radiolocation Radars

Parameter	Land-based systems		Ship systems	Airborne system
	A	B	A	A
Use	Surface and air search	Surface search	Surface and air search	Surface and air search

[3] *See*, Recommendation ITU-R M.1465-1, "Characteristics of and protection criteria for radars operating in the radiodetermination service in the frequency band 3 100-3 700 MHz" (Geneva, 2007).

[4] Duty cycle is a measure of the fraction of the time that a radar is transmitting in relation to the overall time between pulses. The maximum duty cycle occurs with the longest pulse width and the maximum number of pulses per second.

Modulation	P0N/Q3N	P0N	P0N	Q7N
Tuning range (GHz)	3.1-3.7		3.5-3.7	3.1-3.7
Tx power into antenna (kW) (Peak)	640	1 000	1 000	1 000
Pulse width (µs)	160-1 000	1.0-15	0.25, 0.6	1.25[(1)]
Repetition rate (kHz)	0.020-2	0.536	1.125	2
Compression ratio	48 000	Not applicable	Not applicable	250
Type of compression	Not available	Not applicable	Not applicable	Not available
Duty cycle (%)	2-32	0.005-0.8	0.28, 0.67	5
Tx bandwidth (MHz) (–3 dB)	25/300	2	4, 16.6	> 30
Antenna gain (dBi)	39	40	32	40
Antenna type	Parabolic		Parabolic	SWA
Beamwidth (H,V) (degrees)	1.72	1.05, 2.2	1.75, 4.4, csc^2 to 30	1.2, 6.0
Vertical scan type	Not available	Not applicable	Not applicable	Not available
Maximum vertical scan (degrees)	93.5	Not applicable	Not applicable	±60
Vertical scan rate (degrees/s)	15	Not applicable	Not applicable	Not available
Horizontal scan type	Not applicable	Rotating	Rotating	Rotating
Maximum horizontal scan (degrees)	360		360	360
Horizontal scan rate (degrees/s)	15	25.7	24	36
Polarization	RHCP	V	H	Not available
Rx sensitivity (dBm)	Not available	–112	–112	Not available
S/*N* criteria (dB)	Not applicable	0	14	Not available
Rx noise figure (dB)	3.1	4.0	4.8	3
Rx RF bandwidth (MHz) (–3 dB)	Not available	2.0	Not available	Not available
Rx IF bandwidth (MHz) (–3 dB)	380	0.67	8	1
Deployment area	Worldwide	Worldwide	Worldwide	Worldwide

(1) 100 ns compressed.

SWA: Slotted waveguide array

A more detailed description of the technical characteristics of radar systems that operate in the band 3500-3650 MHz can be found in ITU-R Recommendation M.1465-1.[5]

4e. Frequency Use

Radar systems are designed to operate in this band due to propagation characteristics unique to this frequency range.[6] In order to provide maximum flexibility the radar systems operating in this band are capable of tuning over frequency ranges of several hundred megahertz.

Radiolocation and radionavigation radars operate with a high degree of mutual compatibility within this band. This is due to the capability of radar systems to preferentially detect the echoes of their own transmitters and to reject the low duty cycle pulse echoes of other radars.[7] This immunity to low duty cycle pulsed emissions allows radar systems to operate compatibly in the band, whereas other non-pulsed signals would cause interference.

Many older radar systems use high power tube output devices to generate short duration pulses transmitted at a low duty cycle.[8] Newer radar systems use solid state output devices to generate pulses. Radars using solid state devices must transmit longer duration pulses as compared to radars using high power tube output devices. The longer duration pulses, increase the transmit duty cycle of the radar system. As the duty cycle for a radar signal increases, the distance and frequency separation requirements for compatible operation among radar system will also tend to increase. To overcome possible interference from other radars, frequency hopping and frequency agility features can be employed. Radars using klystrons or magnetrons tube based output devices are fixed tuned at the factory and cannot be easily re-tuned to other operating frequencies. There are also other components associated with the tube-based systems such as the output filters or diplexers that must also be re-tuned when the operating frequency is changed. Radars using solid state output devices have the capability to be re-tuned are more easily and quickly.

4f. Exclusion Zones

As part of the NTIA study examining the viability of accommodating wireless broadband systems in the 3500-3650 MHz band, exclusion zones were developed to protect base stations from potential interference caused by ground-based and shipborne radar

[5] *See supra,* n. 3.

[6] In this region of the spectrum multipath propagation problems decrease which is critical for the detection of targets at low elevation angles.

[7] *See*, "Effects of RF interference on radar receivers", NTIA Technical Report TR-06-444, Sep. 2006. URL: http://www.its.bldrdoc.gov/pub/ntia-rpt/06-444/ .

[8] Magnetrons and klystrons are examples of tube-type output devices used in older radar systems.

systems.[9] Figure 1 shows the exclusion zones for the ground-based radar systems where commercial service cannot operate.

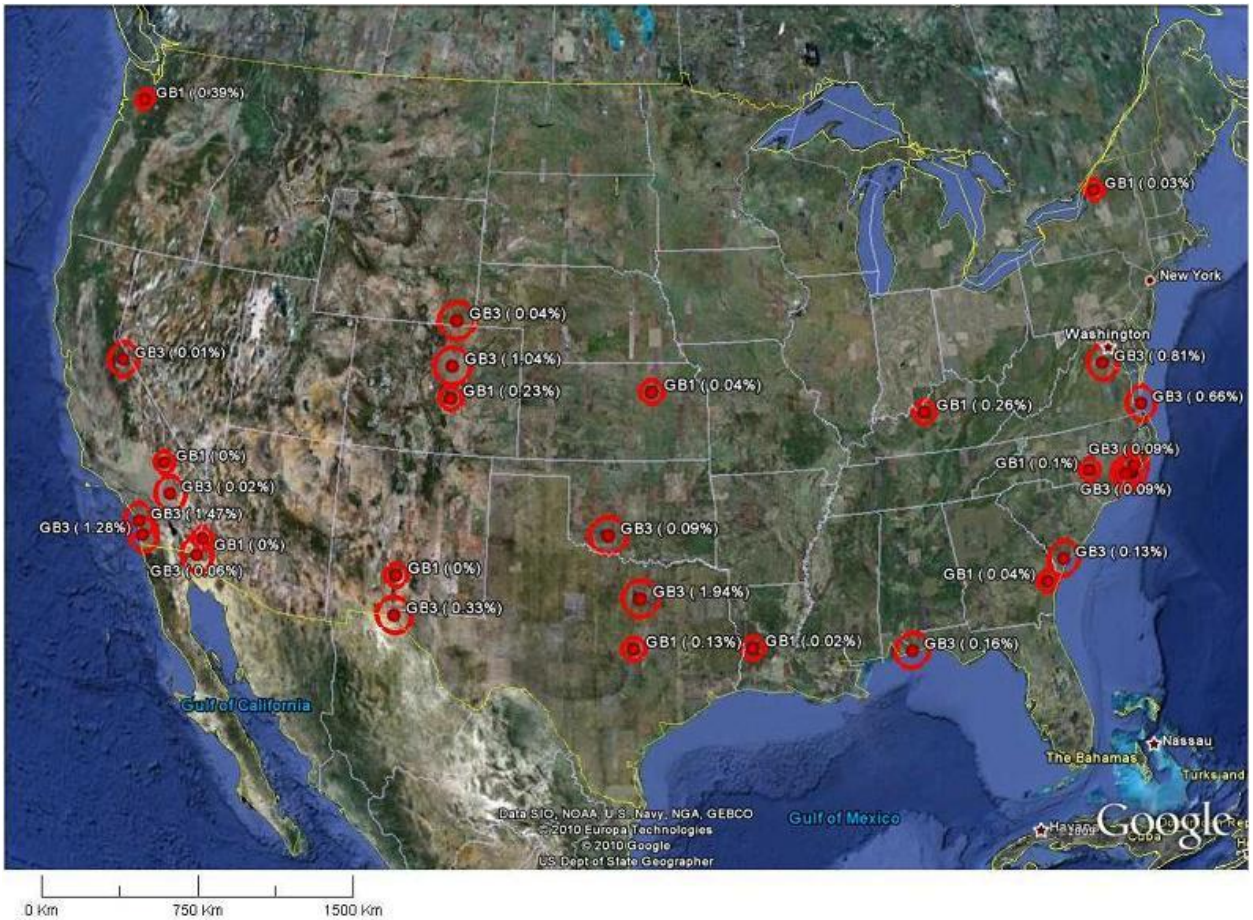


Figure 1. Ground-Based Radar Exclusion Zones, Lower 48 States

The exclusion zones for the shipborne radar systems are shown in Figure 2.

[9] The methodology used for developing the exclusion zones is contained in the NTIA Assessment Report.

Figure 2. Composite Depiction of Exclusion Zone Distances, Shipborne Radar Systems

5. Planned Use

The DoD is expected to continue its use of the 3500-3650 MHz band for critical national security applications such as long-range air search and surveillance radars, missile and aircraft surveillance radars, and associated radar target tracking applications.

The DoD will continue to need access to the 3500-3650 MHz band to develop and deploy the Navy's new volume search radar system on the next generation destroyers.

The DoD also expects to increase use of the 3500-3650 MHz band in the future.