Army Spectrum Management

Frequency & Band Selection Guidance

For

Objective Force (OF)

Managers And Developers

SPECTRUM MANAGEMENT OVERVIEW FOR OBJECTIVE FORCE (OF) MANAGERS AND DEVELOPERS.

<u>Frequency Assignment Guidance For Objective Force Managers And Developers</u>

A Message from the Director

The Objective Force (OF) is the Army's program to modernize and lighten its combat forces while providing the same lethality. Meeting this objective will require an increased dependence upon the radio frequency (RF) spectrum. In partnership with DARPA the Army has initiated a program, as part of the OF, entitled Future Combat Systems (FCS) to meet this challenge.

The purpose of this document is to provide preliminary information to help a vendor or material developer attain a Certification of spectrum (radio frequency) supportability. The law requires that all spectrum dependent devices to be produced or procured on behalf of the Army receive a certification of spectrum supportability or a "Spectrum Certification". Although achieving spectrum supportability for a system can be an involved process, my organization is dedicated to providing you the assistance needed to meet this requirement.

For those of you who do not work in the spectrum management area we understand there may be some apprehension about dealing with its intricacies. Vice Admiral Jon L. Boyes, USN, former Director of Naval C3 once characterized this feeling as follows:

> "Radio frequency management is done by experts who meld years of experience with a curious blend of regulations, electronics, politics and not a little bit of larceny. They justify requirements, horse-trade, coerce, bluff and gamble with an intuition that cannot be taught other than by long experience".

While somewhat tongue in cheek, this quote does reflect the experience of some newcomers to this area especially if they go it alone. The good news is that the staff of the Army Spectrum Management Office is committed to providing you with the support you need to turn the above statement into nothing more than an entertaining anecdote.

It is our desire to roll up the sleeves and work with you. We want to partner with you early in the process of developing spectrum dependent systems. This will allow us to guide you smoothly and efficiently thought what can be an arduous, bureaucratic process – that of achieving spectrum certification for your systems.

Document Summary

This pamphlet contains five specific areas. Following the introductory commentary above is a short description of spectrum certification – your goal if you are developing or buying spectrum dependent systems. This is followed by an introduction to the electromagnetic spectrum and a discussion on how spectrum is managed in the United States for Federal organizations. This is important to understand because it has a direct effect on the design and implementation of technologies. Note that the Federal Communications Commission (FCC) is the spectrum management entity for the commercial sector. Following a paragraph on legacy interoperability, you will find several appendices that provide insight into frequency selection; common terminology and a summary of some of the more interesting technologies found in the commercial sector that are under consideration for adaptation to military use. This last section is included to familiarize the non-technical reader with a specific technology. Appendix A addresses frequency allocation. Frequencies are grouped into bands and each band is allocated to a specific service, which has specialized functions and restrictions. For example, you would not want anyone to transmit and interfere with air traffic control frequencies therefore there are initiations to the kind of things one can do in bands specified for this function. Appendix A lists the frequencies and associated functions that may be used in a given band.

As you read through this document, keep in mind that each frequency band has specialized restrictions both within and outside CONUS, therefore final band selection must be done in concert with my staff. At the earliest possible opportunity, you should contact my office so that we may begin to work together to help you work thorough the process of attaining spectrum supportability for your system.

Joe C. Capps
Director, Army Spectrum Management

Spectrum Certification Defined

Spectrum Certification is the process validating spectrum supportability. In English, this means determining whether or not a piece of equipment conforms to applicable statutes, regulations, directives, standards and specifications. Most importantly, it is a process that determines whether or not a spectrum dependent device will operate in its intended environment without causing harmful interference to other devices operating in the same environment.

Regulatory Controls

Spectrum Certification is required by law. The National Telecommunications and Information Agency (regulators of Federal Spectrum users) Manual, DoD 5000.1, DoD 5000.2-R, AR 5-12 and finally the Defense Federal Acquisition Regulations Supplement (DFARS) 235.071 and 235.235-7003 all speak to the requirement to achieve spectrum supportability (aka certification).

The DFARS specifically defines spectrum dependent equipment requiring certification as "all systems and equipment that emit or receive hertzian waves". In simplest form, if it intentionally emits energy into the environment, you must go through the certification process.

Without certification, frequency assignments will not be issued and the equipment may not be legally operated. Certification is also the path to achieve "Host Nation Coordination" or the authorization granted by a foreign government to operate within its territory.

Introduction To the Electromagnetic Spectrum

To better understand spectrum management, several fundamental concepts must first be understood. Electromagnetic (EM) radiation is the creation of energy and the propagation of that energy through space in the form of a wavefront. The most familiar propagating energy is light, called the visible portion of the EM spectrum. The non-visible or radio frequency wave bands are our immediate area of concern in this document.

A specific point on the radio frequency spectrum can be stated as a certain frequency or wavelength. Wavelength is the distance a wavefront of radio frequency (RF) energy travels in free space while completing one cycle (360 degrees). For example, when this distance is stated in meters, a frequency of 30MHz is in the 10-meter band; 150MHz is in the 2-meter band and 300MHz is in the 1-meter band. Frequencies in the ultra high frequency (UHF) band and above are categorized as being in the centimeter or millimeter bands. Throughout this document frequency will be expressed in Hertz (abbreviated Hz), Kilohertz (kHz), Megahertz (MHz) or Gigahertz (GHz).

The radio spectrum is used for all forms of wireless communications including cellular telephony, paging, personal communications service, radio and television broadcast, telephone radio relay, aeronautical and maritime radio navigation, and satellite command and control and military tactical operations.

Unlike other national resources (water, timber, coal etc.), most which are not reusable in their original form, radio frequencies are. However, multiple users and reuse of this limited and valuable resource do invite conflict in the form of interfering transmissions. To ensure that all users of the radio spectrum operate harmoniously, careful policy, band allocation and frequency scheduling methodologies are employed. This is the essence of Spectrum Management.

Table 1 shows how, by international agreement, the electromagnetic spectrum is divided into band groupings to facilitate unambiguous reference. The groups or bands as they are normally referred, are logically ordered such that frequencies that fall within a particular band share similar propagation characteristics.

Electromagnetic Band Groupings

Frequency range	Band designation	
30-300 Hz	ELF (extremely low frequencies)	
0.3-3 kHz	VF (voice frequencies)	
3-30 kHz	VLF (very low frequencies)	Radio Bands
30-300 kHz	LF (low frequencies)	
0.3-3 MHz	MF (medium frequencies)	
3-30 MHz	HF (high frequencies)	
30-300MHz	VHF (very high frequencies)	
0.3-3 GHz	UHF (ultra high frequencies)	
3-30 GHz	SHF (super high frequencies)	
30-300 GHz	EHF (extremely high frequencies)	
0.3-3 THz	Infrared light	
3-30 THz	Unassigned	
30-300 THz	Visible-light spectrum	
0.3-3 PHz	Ultraviolet light	
3-30 PHz	X-ray	
30-300 PHz	Unassigned	
0.3-3 EHz	Gamma rays	
3-30 EHz	Cosmic rays	

10^0, hertz (Hz); 10^3, kilohertz (kHz); 10^6, megahertz (MHz); 10^9, gigahertz (GHz); 10^{12}, terahertz (THz); 10^{15}, petahertz (PHz); 10^{18}, exahertz (EHz).

Table 1

In the United States and worldwide the electromagnetic spectrum is treated as a sovereign resource. The electromagnetic spectrum is also grouped or allocated by each nation into bands and services. Equipment that radiates electromagnetic energy must conform to the allocation scheme of the nation in which it is used. It is the Army Spectrum Manager who ensures that there are sufficient resources for the Army to conduct operations. The Army Spectrum Manager also works with international counterparts to make sure that Army spectrum dependent equipment is granted the authority to operate overseas by a host nation.

Every transmitted signal requires some spectrum bandwidth. Throughout most discussions related to electromagnetic communications, a quantitative valuation is made regarding bandwidth – of being either narrowband or wideband. The distinction in spectrum technology between narrowband and wideband is that *narrowband* signals have a smaller bandwidth (on the order of kilohertz - kHz) and are used for transmission of the spoken voice, beacons, paging and low-speed data. Whereas, *wideband* signals are measured in the order of many MHz in bandwidth and can support advanced telecommunications services like high-speed data and video transmission. Wideband waveforms will play a major part in the operation of the Objective Force radio network. Just where the transition occurs between what constitutes wideband and narrowband RF emissions is not always clear, and is more a function of technological evolution.

Ultimately, frequency allocation by the Government regulates the use of radio and wire communications subject to its control so as to meet the needs of national security, safety of life and property, international relations, and the business, social, educational, and political life of the Nation.

Spectrum Management in the United States.

Within the U.S. Department of Commerce, the National Telecommunications and Information Administration (NTIA), Office of Spectrum Management is charged with the responsibility for administering the rules drawn from NTIA documents, Regulations and Procedures for Federal Radio Frequency Management[1]. Frequency management within NTIA is under the direction of its Associate Administrator, Office of Spectrum Management, which among other things provides the staff for the Interdepartmental Radio Advisory Committee (IRAC). The IRAC consists of 20 member departments and agencies that include separate representatives from the Army, Air Force, Coast Guard and Navy.

The following graphic (Figure 1) shows the authoritative structure and responsible links necessary to perform national spectrum management and international frequency assignment.

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[1] NTIA Manual of Regulations and Procedures For Federal Radio Frequency Management most recent volume January 2000 edition, January/May/September 2001 Revisions.

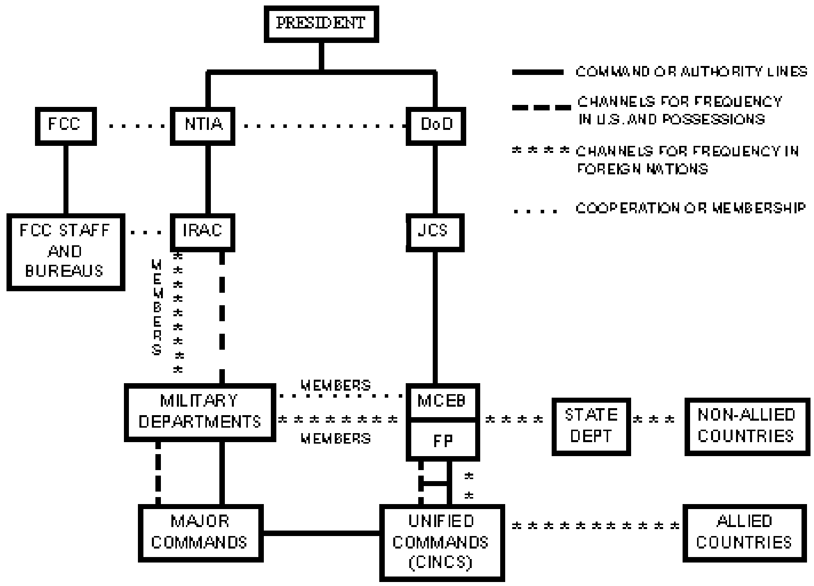

Figure 1

Two thoughts to take away from this discussion are as follows: First – the Army does not use the electromagnetic spectrum as it sees fit. Radio frequency resources are allocated to the Army and all federal users for that matter by the NTIA. There are many portions of the spectrum that we may not use. Second, is that most of the spectrum that the Army uses, is not exclusively under Army control. The Army Spectrum Manager often has to negotiate with other Federal users and in many cases the FCC.

To illustrate the extent to which we must "borrow spectrum" to operate and train in the US, consider the SINCGARS radio. The radio itself is capable of operating on 2320 discrete frequencies. Of those 2320 frequencies, the maximum number of frequencies that can be used ***anywhere*** in CONUS is 1600 (at the Ft. Hood training facility). At all US locations, close coordination with the FCC is required to avoid interference with television channels 2, 3, 4, 5, or 6 – all of which fall within the 30MHz to 88MHz operating range of the SINCGARS radio. This example illustrates the challenge faced today for those building the Objective Force network where there exists an environment of ever increasing demands for RF spectrum and bandwidth.

Spectrum Management Outside of the United States.

Operations overseas are further complicated by the fact the other Nations do not necessarily allocate their bands and services as we do in the US. A common myth is that the US Army may enter and operate in another nation and operate with impunity. The reality is quite different. Even during conflict we cannot expect to have free reign over the electromagnetic environment.

The challenge to the developer is to make sure that a system is built to be tunable or adaptable such that changes or nuances in the operating environment may be accommodated.

Outside the Untied States and its Possessions, a Host Nation on a case-by-case basis approves certification and frequency assignments. As with the US, Host Nations have sovereign rights over the spectrum within their borders and its use is stringently regulated. Employment of US spectrum dependent commercial and military devices in another nation must be preceded by detailed coordination and negotiation. There have been cases where the proper coordination was not accomplished and host nations are not hesitant to deny the use of a device that does not conform to their spectrum allocation plan.

Requirements For Legacy Communications Within The Objective Force

The FCS based component of the Objective Force must reliably interface with legacy, Joint, allied and coalition force radio systems to maintain real-time information transfer. The FCS-to-legacy radio linkage has to provide secure, reliable, timely, survivable, command and control across the battlefield. The requirement for Objective Force developers to create technologies to interface with existing battlefield radio systems extends beyond the battlefield but also must serve as an affective conduit to the Global Information Grid. The technological scope of these newly developed devices will be complex; nonetheless, their application must achieve connectivity that is seamless assured, user-transparent and facilitate total connectivity from the foot-soldier or from each ground or air vehicle into the Global Information Grid. The external connectivity requirement of OF/FCS designed equipment must also extend to other non-military U.S. Government agencies, foreign governments, NGO's and PVO's, commercial infrastructures and space-based radio networks.

The task is complex and the interface technology will have to accommodate a range of frequencies, bandwidths, national and international specifications and standards and signaling protocols. These variable interface criteria must be automated and handled entirely by the Objective Force network. The disparate type of data the FCS must accommodate (voice, text, graphics, imager, video, analog, digital) should be converted into uniform structures that are moved across a common transport infrastructure. These interface technologies must not be restrictive but continue to provide commanders with a flexible tactical communications system of high capacity, low latency and the ability to serve all categories of fixed and mobile users to accommodate all phases of military activity.

Listed below are some of the types of equipment, waveforms and systems that the FCS will encounter.

- Integrated, low-rate voice, data, and video
- Independent wideband voice and data services
- Low-rate interactive applications over tactical internet, extensive TCP/IP
- Collaborative, wideband multimedia applications over tactical communications, megabits of data transfer with some ATM Utilization
- Separate circuit-packet-message-switched networks
- Integrated message and data networks; commercial wireless networks
- Tactical narrowband and broadband Integrated Services Digital Network
- Analog LOS trunk radios
- High speed digital LOS trunk radios
- Analog FM repeater networks
- 2.4 kbps UHF SATCOM, 16 kbps SHF DSCS
- Single-channel radios with limited programmability
- Software programmable, multi-band RF interoperability, multi-waveforms
- Smart radio networks that include jam resistance, LPI, EMI/RFI management
- Single user radios with limited network management capability
- Semi-autonomous networks with commercial interfaces
- Interface with SME battlefield phone networks
- Waveforms to be implemented include SINCGARS SIP, EPLRS VHSIC, UHF SATCOM DAMA, Rocket Data Waveform, HaveQuick I/II, LPI, T1, GPS, cellular phone, and HF SSB, AME, ALE, serial modem, and hopping-AJ.

Technological Advances

In 1969, ARPA in collaboration with BBN (Bolt, Beranek & Neumann) and several universities developed what we now call the Internet. The remarkable impact of the Internet on all of humanity is the result of applied innovation and the genius to extrapolate the solution of a problem beyond the known. The resources that are being made available for the development of the OF/FCS, will enable us to accomplish immediate goals. In addition, we fully expect to see wholly new forms of communications and computing methods emerge. Some early or examples include:

Enhanced Frequency Re-Use. The Objective Force network will place extensive demands on the radio frequency spectrum. This is already driving government and commercial efforts that will push the envelope, producing advanced spectrum management techniques. Additionally, anticipated Objective Force data throughput requirements already demand that we develop innovative waveforms that are capable of operating *interference free* within the same bands with existing legacy waveforms.

Frequency re-use continues to be a high agenda item for commercial cellular providers worldwide. But, that effort has primarily concerned itself with the short-term capture of temporarily (e.g., less than several seconds) vacant frequencies using the following methods:

- Split the number of channels into groups
- Assign frequencies in each group to a cell
- Group cells into cluster-groups containing all frequencies
- Repeat cluster-groups across the area to be covered
- Same frequencies are not used in adjacent cells
- Separation by distance for frequency reuse

One company has developed a method to modify existing GSM networks to achieve up to 70% channel reuse. While these and other commercial methods of achieving higher frequency usage efficiencies may be applicable without modification to battlefield clusters (cells), these technologies may be modified and included as part of implementing the FCS broadband backbone waveform. An interesting and closely related commercial experimental application is one where an in-building, stand-alone, parasitic cellular network system uses the concept of simultaneously reusing the frequencies of cellular systems in-use, outside the building for wireless communications operating *inside* the building.

To accomplish the FCS communication requirements, given the extremely crowded bands, FCS innovation should strive toward developing a wideband waveform capable of reusing (*re-farming*) portions of the DoD allocated spectrum. This OF/FCS waveform has to be capable of operating on a non-interference basis with all legacy waveforms now in use.

Low Probability of Intercept/Low Probability of Detection (LPI/LPD) Waveform Development. LPI/LPD Waveform development will include adapting commercial cellular PCS (CDMA and W-CDMA) technologies to the needs of the dismounted soldier. Application of these technologies offers significant advantages in multipath performance (MOUT operations) and Anti-Jam/Low Probability of Detection protection for the soldier. A developmental objective is to eliminate the fixed cell infrastructure upon which commercial PCS commercial networks are based and to implement true Mobile Ad hoc Networking (MANET). Developers might want to consider building upon the technical advances of CDMA technologies achieved in DARPA's Commercial Communications Technology Test bed (C2T2) and CECOM's C2TL programs.

Another objective within this area of innovation is to develop peer-to-peer and multihop packet relaying RF protocols implemented on handheld or body-worn computers, functioning as a non-cellular PCS handset. Some of the ancillary products and applications that might evolve from a wide band LPI/LPD project are:

- Tactical Handheld & Network LPI/D Radios
- Non-LOS LPI/D Groundwave Communications
- LPI/D Altimeter/Obstacle Avoidance Radar
- Tags (Facility and personnel security, logistics)
- Intrusion Detection Radars
- Precision Geolocation Systems
- Unmanned Aerial Vehicle (UAV) and Unmanned Ground Vehicle (UGV) Datalinks
- Proximity Fuses
- LPI/D Wireless Intercom Systems
- High Speed (20+ Mb/s) LAN/WANs
- RF Tags and Sensors

Conclusion

The U.S. Army Spectrum Management Office is here to help Program Managers and Systems developers field spectrum dependent systems that will be able to operate worldwide, as intended, without causing harmful interference to other US or host nation systems. To that end, it is essential that we establish and then maintain a regular dialogue early in your development cycle.

Reference Documents:

1. NTIA Manual of Regulations and Procedures For Federal Radio Frequency Management most recent volume January 2000 edition, January/May/September 2001 Revisions.
2. DoD 5000.1
3. DoD 5000.2-R
4. AR 5-12
5. Defense Federal Acquisition Regulations Supplement (DFARS) 235.071 and 235.235-7003

Appendix A:

Frequency/Band & Service Allocations

What follows are listings of specific communications functions and their corresponding radio frequency bands. When designing equipment or developing concepts of operation, maximum effort should be made to ensure the device under development conforms to the allocation scheme in the following pages.

Each radio function is normally assigned to operate within a specific band(s). The exact frequency bands are listed in tabular format following a brief discussion of the function. The reader should be aware that even though a frequency band may be listed it does not necessarily mean that it is available nationally or internationally. The ultimate decision for frequency availability and assignment will be made after processing a DD Form 1494 (certification process).

Air Communication - Air To Ground

Requirements for radio communication between aeronautical mobile entities and fixed or mobile ground stations or mobiles. Types of information conveyed may be voice, data or telemetry and may be of analog or in digital form. Narrowband modulations methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS). The following is a sample list of frequency bands that are allocated to aeronautical mobile functions. Additionally, one band not listed here is the 225-400 band which the military typically uses for mobile communications of all sorts. This emphasizes the need to confer with your spectrum manager prior to final band selection.

Operating frequencies
(air to ground)
200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
10005-10100 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *
* = secondary user

Air Communication - Air To Air

Radio communication requirements between aeronautical mobile entities. Types of information conveyed may be voice, data or telemetry and may be of analog or in digital form. Narrowband modulations methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS). Additionally, one band not listed here is the 225-400 band, which the military typically uses for mobile communications of all sorts. This emphasizes the need to confer with your spectrum manager prior to final band selection.

Operating frequencies
(air to air)
200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *
* = secondary user

Air Communication - Air To Satellite

Radio communication requirements between aeronautical mobile entities and satellites. For example, as part of the FCS Reachback network. Types of information conveyed may be voice, video, data or telemetry and may be analog but is usually in digital format. Narrowband modulations methods include frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS).

Operating frequencies
(air to satellite)
1545.0-1559.0 MHz
1646.5-1660.5 MHz

Air Communication -UAV (air-to-air, air-to-ground)

Unmanned aeronautical vehicles (UAV) may have bi-directional radio links with aeronautical, fixed ground or mobile ground entities with multiple channels of multiplexed data that may include information conveyed as voice, data or telemetry and may be of analog or in digital form. Narrowband modulation methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS).

Operating frequencies
Air to Ground

200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *

Aeronautical Navigation
190-200 kHz
200-275 kHz
275-285 kHz
325-405 kHz
415-435 kHz
435-495 kHz *
510-535 kHz
74.8-75.2 MHz
108-117.975 MHz
328.6-335.4 MHz
960-1215 MHz
1559-1610 MHz
1610-1626.5 MHz
3500-3700 MHz
4200-4400 MHz
5000-5250 MHz
5350-5460 MHz
9000-9200 MHz
13.25-13.4 GHz
15.4-15.7 GHz

* = secondary user

Air Communication - UGV (ground-to-air)

Unmanned ground vehicle (UGV—robots) have bi-directional radio links with aeronautical vehicles with multiple channels of multiplexed data that may include information conveyed as voice, data, telemetry or navigation beacons and may be of analog or in digital form. Narrowband modulations methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS).

Operating frequencies (ground to air mode)	Aeronautical Radio navigation
200-275 kHz *	190-200 kHz
275-285 kHz *	200-275 kHz
325-405 kHz *	275-285 kHz
2850-3155 kHz	325-405 kHz
3400-3500 kHz	415-435 kHz
4650-4750 kHz	435-495 kHz *
5450-5730 kHz	510-535 kHz
6525-6765 kHz	74.8-75.2 MHz
8815-9040 kHz	108-117.975 MHz
11175-11400 kHz	328.6-335.4 MHz
13200-13360 kHz	960-1215 MHz
15010-15100 kHz	1559-1610 MHz
17900-18030 kHz	1610-1626.5 MHz
21924-22000 kHz	3500-3700 MHz
23200-23350 kHz	4200-4400 MHz
117.975-121.9375 MHz	5000-5250 MHz
123.0875-136.000 MHz	5350-5460 MHz
216-220 MHz *	9000-9200 MHz
* = secondary user	13.25-13.4 GHz
	15.4-15.7 GHz
	* = secondary user

Air Communication - Air Traffic Control (ATC)

Radio communication requirements between air craft and fixed air traffic control ground stations. Types of information conveyed may be voice, data or telemetry and may be of analog or in digital form. Narrowband modulations methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS). Radio navigation is included in this function.

Operating frequencies
(air traffic control)
200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *
225-399.95 MHz
* = secondary user

Radio Navigation

190-200 kHz
200-275 kHz
275-285 kHz
325-405 kHz
415-435 kHz
435-495 kHz *
510-535 kHz
74.8-75.2 MHz
108-117.975 MHz
328.6-335.4 MHz
960-1215 MHz
1559-1610 MHz
1610-1626.5 MHz
3500-3700 MHz
4200-4400 MHz
5000-5250 MHz
5350-5460 MHz
9000-9200 MHz
13.25-13.4 GHz
15.4-15.7 GHz
* = secondary user

Air Communication - High data rate RF applications

Generally considered as digital data transmissions within the range from 56 Kbps to 4 Mbps and covering most all the common requirements including T1, 1/2T1, T1C and E1. These ultra high-speed links require exceptionally wide bandwidths on the order of 1.0 GHz and greater. Typically, these types of data channels are developed for use as the backbone of the entire system. The FCS system-of-systems will depend heavily upon an ultra high-speed RF backbone network.

Other applications of high-speed data links are:

- Telemetry
- Guidance
- LAN Interconnect
- Remote Bridging
- Satellite Extensions

Operating frequencies
Within authorized bands >1.0 GHz

Air Communication - Medium data rate RF applications

Generally considered as digital data transmissions between 2400 and 1,000,000 bits per second. These medium speed links require moderate to wide bandwidths from 12 kHz to 1.0 GHz. Typically, these types of data channels provide command and control throughout the FCS.

A good example of a medium data rate family of radios is the Harris Corporations RF-5800M group of multiband tactical radio systems. This multi-mode, multi-mission manpack radio supports continuous operation across the 30 MHz to 512 MHz frequency range using voice and data modes using an embedded high-speed modem. These higher speed modems supports rates up to 64 kbps reducing on-air time for transmissions and enabling higher data rate applications such as image transmissions. This particular radio meets legacy mission needs for ground-to-ground, ground-to-air and ship-to-shore communications links.

Operating frequencies

Within authorized bands >30MHz

Air Communication - Low data rate RF applications

Generally considered as digital data transmissions between 0 and 2400 bits per second. These low speed links require the least amount of bandwidth from a few dozen hertz to 10 kHz. Typically, these types of data channels provide low speed status messaging, IP based textual email, telemetry and low volume reporting.

Operating frequencies

Any authorized band from VLF through SHF (1 kHz – 300 GHz).

Ground Communication - Soldier-to-Soldier.

Lightweight, battery operated transceivers that will operate in either voice or data modes across the HF, VHF, UHF or SATCOM frequency ranges. Modulation techniques include narrowband AM or FM, frequency hopping or spread spectrum methods.

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1429-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz (distress)
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-235 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Satellite bands
(ground to satellite)

137-137.025 MHz
137.025-137.175 MHz *
137.175-137.825 MHz
137.825-138 MHz *
148-150.05 MHz
399.9-400.05 MHz
400.15-401 MHz
1525-1545 MHz
1545-1549.5 MHz *
1549.5-1558.5 MHz
1610-1646.5 MHz
1646.5-1651 MHz *
1651-1660 MHz
2483.5-2500 MHz
7250-7300 MHz
7300-7750 MHz *
7900-8025 MHz
8025-8400 MHz *
20.2-21.2 GHz
30-31 GHz
39.5-40.5 GHz
43.5-47 GHz
50.4-51.4 GHz
66-74 GHz
81-84 GHz
95-100 GHz
134-142 GHz
190-200 GHz
252-265 GHz

* = secondary user

Ground Communication - Soldier to Soldier via repeater(s) and trunked radio systems.

The military uses trunking systems to help alleviate the congestion in the VHF/UHF FM tactical spectrum, and allow more users to share the same frequencies by way of dynamic re-use. Trunking is a method of using relatively few communication paths to accommodate large number potential users.

Same as Ground group
frequencies above 30 MHz.
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz

14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user.

Ground Communication - Soldier to ground vehicle, aeronautical or satellite vehicle.

Operating frequencies
Ground to air

200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *

Satellite bands
(ground to satellite)

137-137.025 MHz
137.025-137.175 MHz *
137.175-137.825 MHz
137.825-138 MHz *
148-150.05 MHz
399.9-400.05 MHz
400.15-401 MHz
1525-1545 MHz
1545-1549.5 MHz *
1549.5-1558.5 MHz
1610-1646.5 MHz
1646.5-1651 MHz *
1651-1660 MHz
2483.5-2500 MHz
7250-7300 MHz
7300-7750 MHz *
7900-8025 MHz
8025-8400 MHz *
20.2-21.2 GHz
30-31 GHz
39.5-40.5 GHz
43.5-47 GHz
50.4-51.4 GHz
66-74 GHz
81-84 GHz
95-100 GHz
134-142 GHz
190-200 GHz
252-265 GHz

* = secondary user

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Ground Communication - Vehicle to vehicle (direct or via fixed repeaters, UAVs or satellite)

Operating frequencies
Ground to air

200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *

Satellite bands

137-137.025 MHz
137.025-137.175 MHz *
137.175-137.825 MHz
137.825-138 MHz *
148-150.05 MHz
399.9-400.05 MHz
400.15-401 MHz
1525-1545 MHz
1545-1549.5 MHz *
1549.5-1558.5 MHz
1610-1646.5 MHz
1646.5-1651 MHz *
1651-1660 MHz
2483.5-2500 MHz
7250-7300 MHz
7300-7750 MHz *
7900-8025 MHz
8025-8400 MHz *
20.2-21.2 GHz
30-31 GHz
39.5-40.5 GHz
43.5-47 GHz
50.4-51.4 GHz
66-74 GHz
81-84 GHz
95-100 GHz
134-142 GHz
190-200 GHz
252-265 GHz

* = secondary user
Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Ground Communication - UAV

The Unmanned Aerial Vehicle (UAV) will perform intelligence, surveillance, and reconnaissance (ISR) missions.

Operating frequencies	11175-11400 kHz
200-275 kHz *	13200-13360 kHz
275-285 kHz *	15010-15100 kHz
325-405 kHz *	17900-18030 kHz
2850-3155 kHz	21924-22000 kHz
3400-3500 kHz	23200-23350 kHz
4650-4750 kHz	117.975-121.9375 MHz
5450-5730 kHz	123.0875-136.000 MHz
6525-6765 kHz	216-220 MHz *
8815-9040 kHz	* = secondary user

Ground Communication - UGV

Unmanned ground vehicle (UGV) may have bi-directional radio links with fixed and mobile ground entities consisting of multiple channels of multiplexed data that may include information conveyed as voice, data or telemetry and may be of analog or in digital form. Narrowband modulations methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS).

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Ground Communication - Air Traffic Control (ATC)

Radio communication requirements between air craft and fixed traffic control ground stations. Types of information conveyed may be voice, data or telemetry and may be of analog or in digital form. Narrowband modulations methods include amplitude modulation (AM), single side band (SSB), frequency modulation (FM), frequency shift keying (FSK), phase shift keying (PSK) and phase modulation (PM). Wideband modulation techniques include frequency hopping (FH) and spread spectrum (SS).

Operating frequencies	11175-11400 kHz
200-275 kHz *	13200-13360 kHz
275-285 kHz *	15010-15100 kHz
325-405 kHz *	17900-18030 kHz
2850-3155 kHz	21924-22000 kHz
3400-3500 kHz	23200-23350 kHz
4650-4750 kHz	138-150 MHz
5450-5730 kHz	216-220 MHz *
6525-6765 kHz	225-400 MHz
8815-9040 kHz	117.975-121.9375 MHz
	123.0875-136.000 MHz
	* = secondary user

Ground Communication - High data rate RF applications

Generally considered as digital data transmissions that exceed 1.0 gigabytes per second. These ultra high-speed links require exceptionally wide bandwidths on the order of 1.0 GHz and greater. Typically, these types of data channels are developed for use as the backbone of the entire system. The FCS system-of-systems will depend heavily upon an ultra high-speed RF backbone network.

Operating frequencies

Authorized bands >1.0 GHz

1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz

15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz

92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Ground Communication - Function: Medium data rate RF applications

Generally considered as digital data transmissions between 2400 and 1,000,000 bits per second. These higher speed links require moderate to wide bandwidths from 12 kHz to 1.0 GHz. Typically, these types of data channels provide command and control throughout the FCS.

Operating frequencies

Authorized bands >30MHz

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Ground Communication - Low data rate RF applications

Generally considered as digital data transmissions between 0 and 2400 bits per second. These low speed links require the least amount of bandwidth from a few dozen hertz to 10 kHz. Typically, these types of data channels provide low speed status messaging, telemetry and low volume reporting.

Operating frequencies

Any authorized band from VLF through SHF (1 kHz – 300 GHz).

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Backbone Communications

- Function: Soldier to soldier
- Function: Between vehicles
- Function: Between echelons (command levels)
- Function: UAV
- Function: UGV
- Function: ATC
- Function: High data rate applications
- Function: Medium data rate applications
- Function: Low data rate applications

The most advanced project within the RF portion of the FCS will be the development of the ultra wideband *backbone* communications network that will carry all of above listed functions simultaneously and with low latency. The Backbone network is analogous to a computer system's backplane in that its purpose is to carry and convey all the individual functionalities at a high speed. Without the Backbone, the FCS system-of-systems concept does not work. The RF backbone network does not yet exist; although the current technical thinking concludes that the operational frequency should be at 38 GHz or above.

36-38.6 GHz	66-75.5 GHz	168-182 GHz
42.5-43.5 GHz	81-86 GHz	185-217 GHz
45.5-47 GHz	92-95 GHz	231-241 GHz
50.2-51.4 GHz	95-100 GHz	252-300 GHz
54.25-58.2 GHz	116-142 GHz	
59-64 GHz	149-151 GHz	

Sensors including links to vehicles, soldiers and commands - Tethered data links

By their very nature, the methods by which a tethered sensor is held in place also serves to convey the sensed data either by conductive wires or fiber optics. In either case, no RF radiation is involved and frequency management is not an issue. If RF signals are broadcast from a tethered sensor then normal UAV frequency bands are to be utilized.

Operating frequencies	5450-5730 kHz	117.975-121.9375 MHz
Air to Ground	6525-6765 kHz	123.0875-136.000 MHz
	8815-9040 kHz	216-220 MHz *
200-275 kHz *	11175-11400 kHz	* = secondary user
275-285 kHz *	13200-13360 kHz	
325-405 kHz *	15010-15100 kHz	
2850-3155 kHz	17900-18030 kHz	
3400-3500 kHz	21924-22000 kHz	
4650-4750 kHz	23200-23350 kHz	

Sensors including links to vehicles, soldiers and commands - Balloon

Balloon sensors that are tethered (physically held in place) will convey the sensed data either by conductive wires or fiber optics. In either case, no RF radiation is involved and frequency management is not an issue. If RF broadcast from the tethered sensor does occur then normal UAV frequency bands are to be utilized.

Operating frequencies
Air to Ground

200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *
* = secondary user

Sensors including links to vehicles, soldiers and commands - Powered devices - UGV (Unmanned ground vehicles.)

UGVs range from lightweight, man-portable mobile robots for operation in urban environments (indoor, outdoor and underground) to full-sized vehicles that provide surveillance operations at slow to moderate speed over up to 10 kilometers. The UGVs complement of reconnaissance, surveillance, and target acquisition sensors (RSTA) may be remotely controlled by a tethered fiber optics (up to 10 km.) or by a short range RF link. The data channel includes 9600-baud full-duplex FM transceivers for slow to medium baud rates and wide bandwidth transmitters for video.

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Sensors including links to vehicles, soldiers and commands - Fixed ground sensors

A combination of small, unattended ground sensor systems gather information about what's going on in a battlefield using magnetic, chemical, seismic, acoustic, or any of a number of other type sensors, including visible or infrared imagers. The main components of this kind of system are low-power, miniature devices with a sensor, battery, and radio. The demand for bandwidth increases as the amount of data increases for robots with multiple sensors and, for most applications. Transmission latency must be quite low because data processing needs to occur in near real time.

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
7300-8100 kHz *
10150-11175 kHz *
13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
18168-18780 kHz
20010-21000 kHz
23000-23200 kHz
23000-23200 kHz *
23350-24890 kHz
25330-25550 kHz
26480-26950 kHz
27540-28000 kHz
29.89-29.91 kHz
32-33 MHz
34-35 MHz
36-37 MHz
38-39 MHz
40-42 MHz
46.6-47 MHz
49.6-50 MHz
74.6-74.8 MHz
75.2-75.4 MHz
148-149.9 MHz
150.05-150.8 MHz
162.0125-173.2 MHz
173.4-174 MHz
220-222 MHz
225-234 MHz
235-328.6 MHz
335.4-339.9 MHz
406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
2200-2300 MHz
2310-2360 MHz *
2360-2390 MHz
4400-4990 MHz
14.4-14.47 GHz *
14.47-14.5 GHz
14.5-14.7145 GHz *
14.7145-15.1365 GHz
15.1365-1535 GHz
21.2-21.4 GHz
21.4-23.6 GHz
25.25-27.5 GHz
36-38.6 GHz
42.5-43.5 GHz
45.5-47 GHz
50.2-51.4 GHz
54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Sensors including links to vehicles, soldiers and commands - Unmanned aeronautical sensors – UAV

UAVs provide real-time and near real-time data required to support intelligence surveillance and reconnaissance with high-resolution, near-real-time imagery of large geographic areas. A combination of sensors allows a UAV to collect intelligence day or night, in clear or cloudy weather. Communication links may include a wide band satellite link and line-of-sight digital and analog downlinks.

Operating frequencies	5450-5730 kHz	117.975-121.9375 MHz
Air to Ground	6525-6765 kHz	123.0875-136.000 MHz
	8815-9040 kHz	216-220 MHz *
200-275 kHz *	11175-11400 kHz	* = secondary user
275-285 kHz *	13200-13360 kHz	
325-405 kHz *	15010-15100 kHz	
2850-3155 kHz	17900-18030 kHz	
3400-3500 kHz	21924-22000 kHz	
4650-4750 kHz	23200-23350 kHz	

Satellite Communication

- Function: Satellite to satellite
- Function: Vehicle to satellite
- Function: Soldier to satellite
- Function: UAV, UGV, ATC
- Function: High data rate applications
- Function: Medium data rate applications
- Function: Low data rate applications

Satellite bands
(ground to satellite)

137-137.025 MHz
137.025-137.175 MHz *
137.175-137.825 MHz
137.825-138 MHz *
148-150.05 MHz
399.9-400.05 MHz
400.15-401 MHz
1525-1545 MHz
1545-1549.5 MHz *
1549.5-1558.5 MHz
1610-1646.5 MHz
1646.5-1651 MHz *
1651-1660 MHz
2483.5-2500 MHz
7250-7300 MHz
7300-7750 MHz *
7900-8025 MHz
8025-8400 MHz *
20.2-21.2 GHz
30-31 GHz
39.5-40.5 GHz
43.5-47 GHz
50.4-51.4 GHz
66-74 GHz
81-84 GHz
95-100 GHz
134-142 GHz
190-200 GHz
252-265 GHz

* = secondary user
Operating frequencies
(air to satellite)
1545.0-1559.0 MHz
1646.5-1660.5 MHz

Naval Communication

- Function: UAV, UGV, ATC
- Function: High data rate applications
- Function: Medium data rate applications
- Function: Low data rate applications

Operating frequencies
Ground to air

200-275 kHz *
275-285 kHz *
325-405 kHz *
2850-3155 kHz
3400-3500 kHz
4650-4750 kHz
5450-5730 kHz
6525-6765 kHz
8815-9040 kHz
11175-11400 kHz
13200-13360 kHz
15010-15100 kHz
17900-18030 kHz
21924-22000 kHz
23200-23350 kHz
117.975-121.9375 MHz
123.0875-136.000 MHz
216-220 MHz *

Satellite bands
(ground to satellite)

137-137.025 MHz
137.025-137.175 MHz *
137.175-137.825 MHz
137.825-138 MHz *
148-150.05 MHz
399.9-400.05 MHz
400.15-401 MHz
1525-1545 MHz
1545-1549.5 MHz *
1549.5-1558.5 MHz
1610-1646.5 MHz
1646.5-1651 MHz *
1651-1660 MHz
2483.5-2500 MHz
7250-7300 MHz
7300-7750 MHz *
7900-8025 MHz
8025-8400 MHz *
20.2-21.2 GHz
30-31 GHz
39.5-40.5 GHz
43.5-47 GHz
50.4-51.4 GHz
66-74 GHz
81-84 GHz
95-100 GHz
134-142 GHz
190-200 GHz
252-265 GHz

* = secondary user
Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
2505-2850 kHz
3155-3400 kHz
4438-4650 kHz
4750-4995 kHz
5060-5450 kHz *
5730-5950 kHz
6765-7000 kHz *
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13410-13600 kHz *
13800-14000 kHz *
14350-14990 kHz
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20010-21000 kHz
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23000-23200 kHz *
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54.25-58.2 GHz
59-64 GHz
66-75.5 GHz
81-86 GHz
92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Missile Control Links

- Function: High data rate applications
  Wide bandwidth waveforms will operate above 1.0 GHz.
- Function: Medium data rate applications
  Medium bandwidth waveforms will operate above 30 MHz.
- Function: Low data rate applications
  Narrow bandwidth waveforms can use the full Ground group.

Operating Frequencies
(ground to ground mode)
LAND MOBILE Group
216-220 MHz *
220-222 MHz
1395-1400 MHz
1492-1432 MHz

(ground to ground mode)
MOBILE Group
495-505 kHz – distress
525-535 kHz
1605-1615 kHz
1705-1800 kHz
2000-2065 kHz
2107-2170 kHz
2173.5-2190.5 kHz
2194-2495 kHz
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406.1-420 MHz
1350-1390 MHz
1427-1429 MHz
1432-1435 MHz
1710-1850 MHz
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14.5-14.7145 GHz *
14.7145-15.1365 GHz
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92-95 GHz
95-100 GHz
116-142 GHz
149-151 GHz
168-182 GHz
185-217 GHz
231-241 GHz
252-300 GHz

* = secondary user

Appendix B:

Glossary of Terms

2.5G	Will gradually evolve into a more sophisticated "3G," or third generation wireless technology.
3G	3G Third Generation wireless (3G) - where high-speed, broadband mobility meets the Internet. 160 MHz of additional spectrum would be required for 3G systems. NTIA and the FCC have released interim and final reports on the 1710-1850 MHz band.
802.11	Wireless LAN
802.11a	802.11a uses an encoding scheme, called OFDM (orthogonal frequency division multiplexing). Designed to operate in the more recently allocated 5-GHz UNII (Unlicensed National Information Infrastructure) band. The 802.11a standard, which supports data rates of up to 54 Mbps, is the Fast Ethernet analog to 802.11b, which supports data rates of up to 11 Mbps.
802.11b	Operates in the 2.4 to 2.4835Ghz band and supports operational data rates of 1 and 2 Mbps (theoretical maximums up to 10 Mbps).
ACE	Analysis Control Elements
ACN	Adaptive C4I Node (ACN)
ACUS	Army Common User System (ACUS): ACUS is a secure, multi-user, high volume command and control, operations/intelligence, and administration/logistics voice and data traffic system. It is an integrated switching system.
AJ/LPI/LPD	Anti-Jam/Low Probability of Intercept/Low Probability of Detection
ALE	Automatic Link Establishment (ALE) is the principle where a specialized radio modem, known as an ALE adaptive controller, is assigned the task of automatically controlling an HF receiver and transmitter in order to establish the highest quality communication link with 1 or multiple HF radio stations.
AM	Amplitude Modulation
AN/PSC-2	Small computer used to transmit data over FM radio.
AN/VRC	Army-Navy/Vehicular Radio Communications
AN/VSC-2	Radio-teletype set mounted on HMMWV
ATM	Asynchronous Transfer Mode. A very high-speed data transmission method.
ATT	Advanced Theater Transport (ATT)
AUTODIN	Automatic Digital Network
AUTOVON	Automatic Voice Network
BFA	Battlefield Functional Area
Bluetooth	Short range (10 meter) frequency-hopping radio link between devices.
C2OTM	Command and Control On-the-Move (C2OTM)
CDMA	Code Division Multiple Access. CDMA is a digital cellular communications technology. Each call has an individual code to identify the call. Multiple calls can be grouped together on a single frequency. CDMA uses spread-spectrum techniques.

Appendix B Glossary of Terms

CDMA	CDMA is a spread-spectrum technology that allows multiple frequencies to be used simultaneously. CDMA codes every digital packet it sends with a unique key. A CDMA receiver responds only to that key and can pick out and demodulate the associated signals.
CDMA	Code Division Multiple Access
CFF	Call For Fire -or- Contained Firing Facility
COMINT	Communications Intelligence.
COP	Share integrated Common Operating Picture (COP) to enable early understanding of threat actions & intentions. COP is defined as critical combat information.
CROP	Common Relevant Operational Picture CROP. Provides situational understanding to each platform.
CSMA	Carrier Sense Multiple Access
DAMA	Demand Assigned Multiple Access. Takes Advantage of SATCOM Higher Data Rate to allow Multiple Channels to Share the Link (4 to 1)
DCD	DIRECTORATE OF COMBAT DEVELOPMENTS. Develop activities and actions to support operational concepts, organization and force design, and materiel system requirements, which as applied to the total force.
DSSS	Direct Sequence Spread Spectrum. A communication technique that spreads a signal bandwidth over a wide range of frequencies for transmission and then de-spreads it to the original data bandwidth at the receiver.
EAB	Echelons Above Brigade (EAB)
EEC	Error Correcting Codes -- Convolution, Viterbi, Huffman, Golay etc.
ELINT	Electronic Intelligence.
EMC	Electromagnetic Compatibility.
EMI	Electromagnetic Interference.
EMPRS	Enroute Mission Planning and Rehearsal System (EMPRS) functionality
EPLRS	Enhanced Position Location Reporting System (EPLRS): Optimized for data distribution to support battlefield automated weapons systems. Uses time-division multiple access (TDMA) technology to provide secure, jam-resistant, near-real-time data communications. EPLRS is a Time Division Multiple Access System using a frequency hopping; spread spectrum waveform in the UHF band.
FARP	Forward Area Rearm/refuel Points
FCS	Future Combat Systems
FDMA	Frequency Division Multiple Access. A method of modulation a radio frequency carrier.
FH	Frequency Hopping. The transmitter hops to one of many channels, The receiver knows the sequence of the frequency hopper and follows each hop. See SINCGARS.
FM	Frequency Modulation
FSK	Frequency Shift Keying

GFSK	Gaussian Frequency Shift Keying -- with channel bandwidths of 1Mhz with the first center frequency starting at 2.402 GHz.
GIG	Global Information Grid (GIG). To provide one single communications architecture that can support all the needs of the Army and in fact can be integrated into an overall global capability.
GMF	NTIA Government Master File (GMF) of Frequency Assignments
GMSK	A modulation technique known as Gaussian minimum-shift keying (used in GPRS networks).
GPRS	General Packet Radio Service technology. A commercial non-voice RF data network created through FCC authorization.
GPS	Global Positioning System
GSM	Global System for Mobiles (900 MHz). European Posts and Telegraphs group called the Groupe Spécial Mobile (GSM) to study and develop a pan-European public land mobile system.
GUARDRAIL	A COMINT/ELINT configuration of vans that receives data from ground and air sensors. The total system provides signal intelligence (Near real-time information) to tactical commanders to include the locations of deployed hostile forces. AN/USD-9A IMPROVED GUARDRAIL V (IGRV) PROCESSING COMPLEX (AN/TSQ-105(V)4).
IMINT	Imagery Intelligence
IMT-2000	An international implementation of what is called 3G in the United States.
IPng	Internet Protocol next generation (IPng) candidates with respect to their application to military tactical radio frequency (RF) communication networks.
ISDN	Integrated Services Digital Network. , ISDN delivers a five-fold speed improvement (up to 128 Kbps) and provides essentially perfect transmission reliability.
ISM Bands	Industrial, Scientific & Medical bands. Three bands where unlicensed wireless devices may operate: 915MHz/26MHz bandwidth, 2.4GHz/83.5MHz bandwidth, and 5.8GHz/125MHz bandwidth. Other unlicensed bands fall with the 900MHz, 5.2GHz and 23GHz bands. Under discussion for unlicensed commercial use are the 60GHz, 90GHz and 120GHz bands.
ISR	Intelligence, Surveillance, Reconnaissance
JNMS	Software and database to provide an automated planning, control and management capability to assist [commanders] in communications planning and execution.
JTR	Joint Tactical Rotorcraft (JTR)
JTRS	JTRS is specified to operate over the frequency bands from 20MHz to 2GHz. It will support data rates up to about 10 MBPS.
LAM	Loitering Attack Munitions

Longley-Rice Longley-Rice Model. One method for predicting digital television signal coverage. The Longley-Rice Model provides a mathematical method for predicting the geographic coverage area surrounding a broadcast tower.

LMDS Local Multipoint Distribution Service. 27.5 to 28.35 GHz; 29.1 to 29.25 GHz. Internet access and telco services. A line-of-sight technology using microwave technology in the 28 and 38 GHz range.

LOS Line of Sight radio communications.

LWIR Long Wavelength (8-13um) Infrared

MAC Media Access Control

MANET Mobile Ad hoc Network (MANET) technologies.

MMDS Multichannel Multipoint Distribution Service

MOUT Military Operations on Urbanized Terrain (MOUT).

MSE Mobile Subscriber Equipment (MSE): Is the ACUS for all US Army corps and divisions. MSE integrates the functions of transmission, switching, control and terminal equipment into one system, and provides the user with a switched telecommunications system.

MUOS The Mobile User Objective System is being developed as a replacement to the UFO (UHF Follow On) constellation for IOC in 2007. It will provide global SATCOM narrowband (64kpbs and below) connectivity for voice, video and data for US and Allied services.

NLOS Non-Line Of Sight communications

OFDM Orthogonal Frequency Division Multiplexing

OFTF Objective Force Task Force

OPNET Optimized Network Engineering Tools. A technology development environment, allowing the design and study of communication networks, devices, protocols, and applications. An object-oriented modeling approach with graphical editors that mirror the structure of actual networks and network components, to support all network types and technologies, allowing the most difficult electronic communication questions.

PKI Public Key Infrastructure

PM Phase Modulation

PMCS Programmable, Modular Communications System.

PSK Phase Shift Keying

QoS Quality of Service. A technology that guarantees bandwidth and prioritizes network packets. QoS makes sure that the important data gets across the network before less important packets.

QUICKLOOK Quicklook intercepts, locates, identifies, and reports non-communications emitters. Consists of airborne equipment installed in RV-1D aircraft. To be replaced by the Advanced Quicklook (AQL) airborne equipment to be installed in RC-12K aircraft and ground equipment to be installed in the Guardrail/Common Sensor Integrated Processing Facility.

RDEC Research, Development and Engineering Center at CECOM, Ft. Monmouth NJ

Reachback	Communications links that link the theater of military operations to CONUS control and command centers.
RSTA	Reconnaissance, Surveillance, and Target Acquisition Sensors
SAS	Situation Awareness Systems (SAS)
SATCOM	Satellite Communications
SBU	Sensitive But Unclassified (SBU)
SDR	Software Defined Radios
SINCGARS	Single Channel Ground and Airborne Radio System. SINCGARS provides vhf-fm (30-88 megahertz) combat net radio communication with Eccm capability (frequency hopping) and digital data capability (data rate adapter).
SS	Spread Spectrum
SSB	Single Side Band amplitude modulation
SUO	Small Unit Operation (SUO)
SUO SAS	The Small Unit Operations Situational Awareness System (SUO SAS).
TAMD	Theater Air and Missile Defense (TAMD)
TCP/IP	The most widely used set of standardized, vendor-independent communications protocols today is the Transmission Control Protocol/Internet Protocol suite (TCP/IP). Versions of TCP/IP are also available for use on packet radio networks.
TDMA	Time division multiple access (TDMA) is digital transmission technology that allows a number of users to access a single radio-frequency (RF) channel without interference by allocating unique time slots to each user within each channel.
TDMA	Time Division Multiple Access
TOC	Tactical Operations Center (TOC)
Trunking	Dynamic frequency re-use of repeater links to accommodate a large number of users.
TSV	Theater Support Vessel (TSV)
UHF	Ultra High Frequency - 300MHz to 3 GHz
UMTS	Universal Mobile Telephone Service is a Third Generation (3G) mobile system being developed within the ITU's IMT-2000 framework. WRC'92 identified the frequency bands 1885-2025 MHz and 2110-2200 MHz for future IMT-2000 systems, with the bands 1980-2010 MHz and 2170-2200 MHz intended for the satellite part of these future systems.
UWB	Ultra-Wide Band (UWB) communications
WEBS	Warrior Extended Battle Space Sensors
WIN-T	War fighter information network-tactical, or WIN-T. This program will replace mobile subscriber equipment (MSE) and the tri-service tactical communications (TRI-TAC).

WLAN — Wireless local area networks. Some of the applications that use WLAN technologies are: security systems, computer accessories such as the untethered mouse, home automation, emergency call buttons for the sick and elderly, wireless local area networks, and radio frequency identification. WLAN applications differ from the longer-distance telecommunication services by their short range, typically only up to several hundred meters.

WNW — Wideband Network Waveform

WPAN — Commercial wireless personal area network (WPAN) technologies (e.g., Bluetooth™).

Appendix C:

Synopsis of Communications Technologies

As we continue to exploit the use of commercial off the shelf technologies to meet emerging Army requirements we are exposed to a variety of new technologies (new to the tactical Army). The following pages consist of a series of short articles on some of the more prevalent technologies along with a non technical explanation. This part is meant only as familuarization.

Bluetooth - A Short-Range RF data link

***<u>Bluetooth</u>*: A Danish king of ancient folklore.**

Bluetooth is the name given to a new technology using short-range radio links, intended to replace the cable(s) connecting portable and/or fixed electronic devices. It is envisaged that it will allow for the replacement of the many propriety cables that connect one device to another with one universal radio link. Its key features are robustness, low complexity, low power and low cost. Designed to operate in noisy frequency environments.

The Short Range nature of this RF product will use one of three power levels:

- Power Class 1: is designed for long range (~100m) devices, with a max output power of 20 dBm
- Power Class 2: for ordinary range devices (~10m) devices, with a max output power of 4 dBm
- Power Class 3: for short-range devices (~10cm) devices, with a max output power of 0 dBm.

FHSS in the ISM band from 2.402GHz to 2.480GHz in 79 hops.

Bluetooth protocol can support a single asynchronous data link of 723.2Kb/s or up to three simultaneous synchronous connections links for voice. Each voice channel can support a 64 Kb/s synchronous channel in each direction.

The Bluetooth modulation method and associated protocol is finding wide commercial use in industrial, office and home applications. Bluetooth is <u>not</u> yet part of the FCS communications systems; but, short-range control links to robotics where low-power and long battery life are a requirement will probably draw on these type of RF innovations.

A severe limitation: The Bluetooth protocol can only provide direct communications between devices: thus the quality of service does not include relay nodes or translation from gated networks.

For commercial applications the Bluetooth specifications details three levels of security and while adequate for that environment it does not meet military NSA standards. Generally the three level of data protection are:

Security Mode 1: non-secure
Security Mode 2: service level enforced security
Security Mode 3: link level enforced security

CDMA - Code Division Multiple Access

d

Code Division Multiple Access is a way to increase channel capacity.

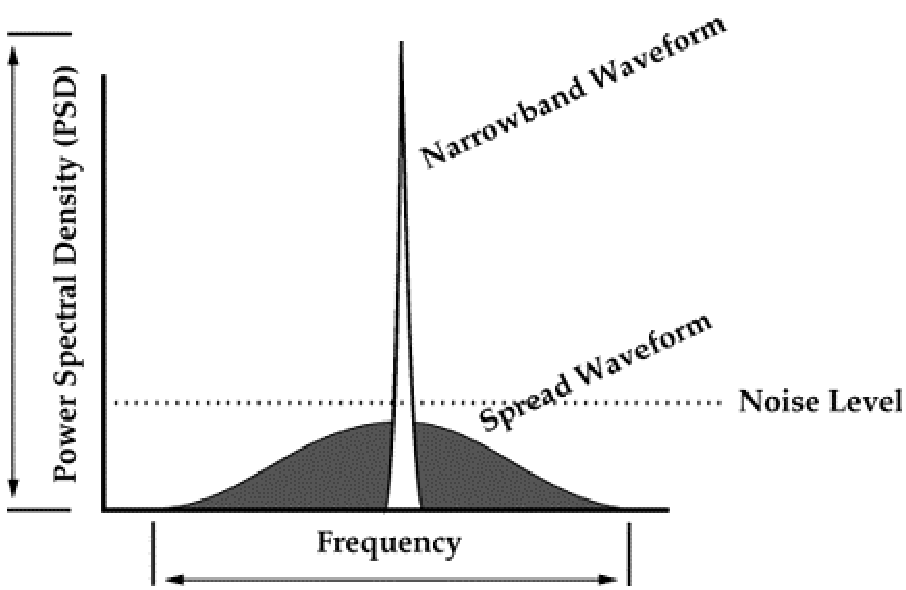
Commercial Applications for spread spectrum range from wireless products for home and office wireless LAN's (Local Area Network) to warehouse bar code scanning, palmtop computers, radio modems for remote sensing, digital dispatch, cellular telephone communications, computer data links, email, and multi media data; all of which has a military function corollary.

Spread Spectrum is recognized by three key properties:

- ***signal occupies a wide bandwidth***
- ***spreading uses a pseudo-random code***
- ***independent codes allows multiple users to access the same frequency***

CDMA is a "spread spectrum" technology. This type of technology spreads the information contained in a particular signal of interest over a much greater bandwidth than the original signal. The CDMA system works directly on 64 kbit/sec digital signals, that might contain digitized voice, ISDN channels, modem data, etc.

This method of wireless communication works by adding redundant data (called 'chips'), to the signal. At least 10 chips per bit are added to the signal, the code used to modulate the transmitted data is called the spreading code and only receivers, which know the spreading code, can decipher the signal. This unique spreading code is what allows multiple direct sequence transmitters to operate in the same area.



Low power allows it to be used in the ISM bands

Because the transmission is spread across a wide frequency band (as a result of the spreading process), transmission power is lower than that of narrowband transmissions. Redundant data contained within the SS format helps to recover the original signal in cases of signal corruption; the number of chips is directly proportional to the immunity from interference.

DSSS - Direct Sequence Spread Spectrum

<u>Shannon:</u>
Information theorem

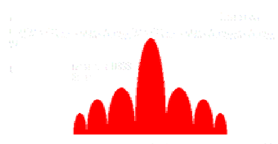
C=W log2 (1+ S/N)

C = Channel capacity in bits
W = Bandwidth in Hertz
S = Signal Power
N = Noise Power

Spread Spectrum technology is a system in which an otherwise narrow band signal is spread over a frequency much wider than the minimum bandwidth required to transmit the signal. The basic idea of applying this 'spreading' technique is to overcome narrow band noise by increasing the transmitted signal bandwidth: this results in an increased probability that the received information will be correct. Claude Shannon's famous information equation provides the mathematical basis for this technology.

The result of signal spreading increases channel capacity (C), the system processing gain and actually provides increased system performance without requiring a high signal-to-noise ratio.

Direct Sequence Spread Spectrum (DSSS) is the most widely used form of spread spectrum. A DSSS signal is created by multiplying an RF carrier with a very high bit-rate pseudo-noise (PN) digital signal. This modulation scheme causes the otherwise narrow band RF signal to be replaced with a very wide bandwidth signal with the spectral equivalent of a noise signal.



The DSSS signals generated with this technique appear as noise in the frequency domain. The wide bandwidth provided by the PN code allows the signal power to drop below the noise threshold without loss of information. The spectral content of an SS signal takes on the familiar mathematical sequence; (sin x / x)2 as the spectrum form.

Spread Spectrum systems transmit an RF signal bandwidth that may be as wide as 20 to 254 times the bandwidth of the information being sent. Some special application spread spectrum systems that are designed to exhibit strong LPI and anti-jam characteristics employ RF bandwidths 1000 times their information bandwidth.

GPS…
Wireless LAN
Remote Robotics

The Global Positioning System (GPS) represents what is the first widespread use of spread spectrum technology in a high volume product that many levels of civil and military groups had need and access to.

Other applications the use DSSS technology are: home and office wireless LANs, wide area (regional) LANs, PCN and PCS voice and data communications, enhance 911 and emergency notification, remote robotics and instrumentation, barcode readers & industrial management and RF identification detection.

FH - Frequency Hopping

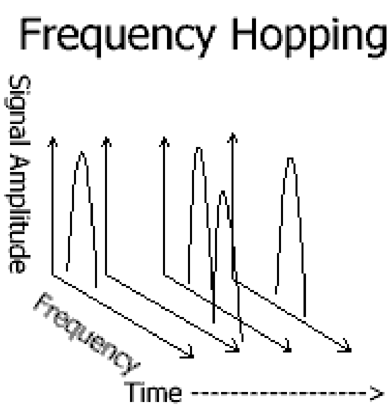
Frequency Hopping is a type of radio communications that has the transmitter and receiver hop in synchronization from one frequency to another according to a prearranged pattern. It is a form of Spread Spectrum technology.

Frequency Hopping is characterized by the short burst of data that is transmitted on a narrowband after which the transmitter quickly retunes to another frequency and transmits the next group of data. The sequence of hops (frequency changes) the transmitter makes is pseudorandom but, of course, is known by the receiver enabling it to receive each short burst of data, reconstruct the sequence such that the stream of data appears to be constant at the receiver output.

Even though FH is sometimes considered to be another spread spectrum technology, it isn't! Actually the frequency hopping technique does not spread the signal but instead, chops the data into small pieces and narrowband transmits them across the frequency domain, in hops across the time domain. One negative result of this technique is that there is no immediate processing gain. Some processing gain is appreciated due to the increase in power density when the signal is synchronized at the receive end; this gives improvement in the received signal's S/N ratio. Note that a frequency hopping radio needs to put out more power in order to achieve the same S/N as a direct sequence spread spectrum radio.

Considerations:

- ***High Multipath immunity***
- ***Voice commo impervious to noise***
- ***Good for multi-channel data***
- ***Good LPI***
- ***Can jam 'friendly' comms***
- ***Requires higher power***
- ***Highly complex architecture***
- ***Long sync time***



Direct Sequence	vs.	**Freq Hopper**
Easy and Simple	vs.	Complicated
Use lower power	vs.	Use higher power
Short Latency Time	vs.	Long Latency Time
Quick Lock In	vs.	Slow Lock In
Short Indoor Range	vs.	Long Indoor Range
Low Data Rate	vs.	High Data Rate

The SINCGARS family of radios uses frequency-hopping technology.

JNMS -Joint Network Management System

Enhanced SA

Enhanced Commander Control

Enhanced Control of Network Resources

Increased Network Security

The Joint Network Management System (JNMS) is an automated software system that will provide communications planners with a common set of tools to conduct high-level planning, detailed planning and engineering, monitoring, control and reconfiguration, spectrum planning and management, and security of systems. It will promote force-level situational awareness, provide enhanced flexibility to support the commander's intent, improve the management of scarce spectrum resources, and provide increased security of critical systems and networks.

The JNMS is conceptually an automated system that will serve as a "brain center" for networks supporting forces in the field and is intended to provide commanders with a commercial-off-the-shelf solution that will give them control over the multiple communications networks used in joint-forces combat missions.

FOREIGN COUNTERPART

No known foreign counterpart

FOREIGN MILITARY SALES

None. The objective JNMS will include a releasable version for Combined/ Allied/Coalition use.

PROGRAM STATUS

- 3QFY00 Operational requirements document approved (Rev 2).
- 4QFY00 Milestone I/II approval.
- 1QFY01 Solicitation issued.

PROJECTED ACTIVITIES

- 2QFY01 Contract award.
- 3QFY01 System requirements review.
- 4QFY01 Architecture demonstration.
- 1QFY02 Critical design review.

PRIME CONTRACTORS

Science Applications International Corporation (SAIC) MCLEAN, VA

The Program Executive Office, Command, Control and Communications Systems (PEO C3S) located at Ft. Monmouth, N.J., is the joint services executive agent for JNMS, and the U.S. Army Communication-Electronics Command (CECOM), also located at Ft. Monmouth, N. J., is the acquisition activity.

MANET - Mobile Ad hoc Networking

Ad hoc Node:
a router with multiple hosts, and wireless connectivity

As a definition, Ad Hoc can narrowly be defined as 'to a specific end' or 'purposefully built'. A wireless ad-hoc network is the cooperative engagement of a collection of mobile nodes without the required intervention of a centralized access point or existing infrastructure where the nodes within an ad hoc network are able to organize a network structure all on their own. Conceptually, the ad hoc network is pragmatic, dynamically constructed and transient.

The purpose of ad hoc networking within the FCS is to create the ability for a flexible method for establishing communications for fire, safety, rescue and other military operations that require rapidly deployable communications with survivable, efficient dynamic IP-based networking. This group of technologies will include wide bandwidth, multi-media "wearable" computing and communications devices fully integrated into the IP-compliant mobile network.

Issues:
Service discovery
Service portability
Resource allocation

Principal characteristics of the MANET are:
1) Dynamic topologies: Nodes are free to move arbitrarily
2) Bandwidth-constrained, variable capacity links
3) Energy-constrained operation
4) Able to accommodate tens or hundreds of nodes per routing area

Developmental challenges surrounding the creation of a suite of protocols imposed by the demands of ad hoc node networking includes taking into account unpredictable and continuous change in the network topology, radio propagation range, and multihop routing. These characteristics in combination with bandwidth, energy and memory constraints will drive ad hoc networking research and development challenges. Other areas to be addressed are:

For F_o = millimeter bands, Antennas are:
omnidirectional, directional, electronically steerable

- Routing, multicasting and broadcasting protocols
- New paradigm antennas
- TCP and reliable multicast
- Assured communications
- Energy efficient protocols
- Distributed database research
- Adaptation of commercial protocols
- Spectrum management
- Quality of service (QoS) criteria
- Sensor fusion
- Interoperation with legacy/joint systems
- Congestion, self-forming, self-healing

OFDM - Orthogonal Frequency Division Multiplexing

***A highly robust multi-user system*.**

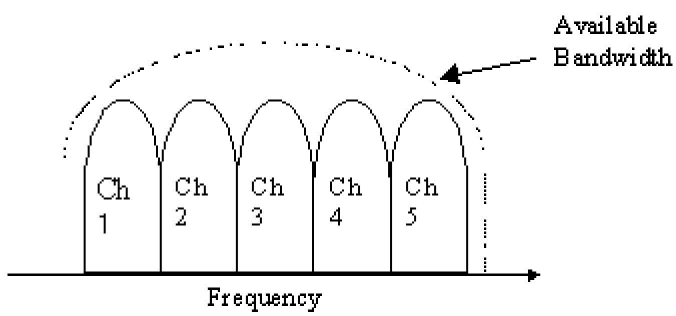
Orthogonal Frequency Division Multiplexing (OFDM) is a method to transmit high data rates in a hostile radio frequency. Empirical testing has shown that OFDM performs well, providing a high tolerance to multipath delay spread, peak power clipping, and channel noise.

OFDM allows many users (7-16 for CDMA, up to 128 for OFDM) to transmit in an allocated band, by subdividing the available bandwidth into many narrow bandwidth carriers. OFDM signals are generated such that the carriers are orthogonal to one another (very closely spaced, but not overlapping), thus allowing them to achieve a high spectral efficiency.

FEC enhances error correction.

Coded Orthogonal Frequency Division Multiplexing (COFDM) is the same as OFDM except that forward error correction (FEC) is applied to the signal before transmission. This is to overcome errors in the transmission due to lost carriers from frequency selective fading, channel noise and other propagation effects.

OFDM carriers are very closely spaced and achieve high spectral efficiency.



An OFDM system is a highly robust, spectrally efficient communication system suitable for high performance digital video broadcasting and short-range wide bandwidth wireless LANs.

OSI - Open Standards Interface

The ISO (International Organization for Standardization) has defined an abstract standard (ISO 7498) for network interconnections, where different layers of networking operations are described - the Open Systems Interconnection Reference Model.

International Standards Organization (ISO) 7-level model

Layer	Function	Definition
7	Application	Application layer is responsible for managing the communication between the applications.
6	Presentation	Presentation layer provides common operations on the structure of data being exchanged
5	Session	Session layer provides the control structure for managing communications; for example establishing, managing, and terminating sessions (connections).
4	Transport	Transport layer provides reliable transparent data transfer between end points (there may be more than two end points); provide error recovery and flow control.
3	Network	Network layer makes the upper layers independent of the data transmission, switching technologies, and topology of the network; determine which path (or paths) in the network that a given unit of data will take (routing).
2	Link	Link layer provides reliable transfer across the physical links; establishes the beginning and end of blocks of data (with synchronization when necessary) [framing]; error detection and possibly correction; (link) flow control.
1	Physical	Physical layer provides transmission of unstructured bits across the physical medium (be it electrical, optical, mechanical, ...).

The OSI model does not provide the specifications for the different layers, but rather their functional description. Some implementations of the ISO model modify the seven-layer structure. For example most TCP/IP networks implement only four-layers as:

Modified TCP/IP 4-Layer Model

4	Application	Applications include NFS, DNS, arp, rlogin, talk, ftp, ntp and traceroute.
3	Transport	Handles communication among programs on a network. (TCP and UDP)
2	Network	This layer is used for basic communication, addressing and routing
1	Link	This layer defines the network hardware and device drivers.

WBW - Wide Band Wireless

Methods Include:

AMPS
CDMA
CDPD
GSM
Microwave
PCS
Satellite
TDMA
WAP
UWB
WCDMA
Wireless ATM
WLAN
WLL
3G Wireless
4G Wireless
Packet (GPRS)

Wide**B**and **W**ireless is a generic term used to wrap many unique radio transmission technologies into a category of emitters that all share one characteristic: broad bandwidth signals having low power/Hz spectrum signatures that operate at, or below, the ambient noise level.

Emerging WBW applications include:

- hand-held devices that support personal videoconferencing
- self-configuring desktop networks without the mess of cables
- high-speed wireless local area networks
- wall penetrating short-range radar detection
- ultra high-speed multi-channel multi-media wireless networks
- short-range data collection and robotics control

Two of the more esoteric but important WBW technologies are:

UWB – Ultra-Wideband (UWB) technology is a non-sinusoidal communication technology with extremely short pulses. The Federal Communications Commission (FCC) defines Ultra-Wideband (UWB) technology as any wireless transmission scheme that occupies a bandwidth of more than 25% of a center frequency, or more than 1.5GHz.

One area of concern regarding UWB is that this technology derives this broadband capability by spreading its signals over a wide swath of frequencies, including those used by aircraft Global Positioning System (GPS) navigation systems and radar systems operated by the Federal Aviation Administration (FAA). The FCC has decided that Life and Safety interference issues are minimal and allowed continued UWB operation.

WBW technology provides LPI, LPD, anti-Jam, ultra high speed, multi-media, low power devices.

WCDMA – Wide Code Division Multiple Access is a leading 3rd generation technology that provides users with high speed, high bandwidth multimedia access; accomplishing efficient use of radio spectrum. This technology provides mobile users with data rates up to 2Mbit/s.