Go Big with High Frequency (HF)

Title	Go Big with High Frequency (HF)
Item Type	Technical Report
Authors	Garren, David A.;Wood, Brian;Ramos, Reiner O.
URI	https://hdl.handle.net/10945/75109
Publisher	Monterey, CA; Naval Postgraduate School
Date Issued	2026-03-27
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Download date	2026-06-30 02:01:28
Link to Item	https://hdl.handle.net/10945/75109

NPS-ECE-26-003

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

GO BIG WITH HIGH FREQUENCY (HF)

by

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27 March 2026

Distribution Statement A. Approved for public release: Distribution is unlimited.

Prepared for: Naval Information Warfighting Development Center (NIWDC).
This research is supported by funding from the Naval Postgraduate School, Naval Research Program (PE 0605853N/2098). NRP Project ID: NPS-25-N101-A

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REPORT DOCUMENTATION PAGE

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED	
March 2026	Technical Report	START DATE 20 OCT 2024	END DATE 31 MAR 2026

4. TITLE AND SUBTITLE
Go Big with High Frequency (HF)

5a. CONTRACT NUMBER	5b. GRANT NUMBER	5c. PROGRAM ELEMENT NUMBER
		0605853N/2098
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**
NPS-25-N101-A		

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
Naval Postgraduate School 1 University Circle Monterey, CA 93943-5000	NPS-ECE-26-003

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)	11. SPONSOR/MONITOR'S REPORT NUMBER(S)
Naval Research Program Naval Information Warfighting Development Center	NRP NIWDC	NPS-ECE-26-003 NPS-25-N101-A

12. DISTRIBUTION/AVAILABILITY STATEMENT

Distribution Statement A. Approved for public release: Distribution is unlimited.

13. SUPPLEMENTARY NOTES

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15. SUBJECT TERMS
high-frequency communications, long-range communications

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
a. REPORT	b. ABSTRACT	C. THIS PAGE	UU	43
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19a. NAME OF RESPONSIBLE PERSON	19b. PHONE NUMBER *(Include area code)*
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The report entitled "Go Big with High Frequency (HF)" was prepared for Naval Information Warfighting Development Center (NIWDC) and funded by the Naval Postgraduate School Naval Research Program (PE 0605853N/2098).

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ABSTRACT

High-frequency (HF) radio capabilities do not have the capacity to meet signal demand for all combat operations. The purpose of this proposed research is to determine the amount of HF infrastructure that is needed to support combat operations adequately in a satellite-degraded environment. In particular, it is necessary to assess the HF infrastructure that would be required to overcome a fully denied satellite state. Specifically, if the required warfighting capabilities are assumed to be (a) battle space awareness, (b) assured command and control (C2), and (c) integrated fires, then it is necessary to determine the HF infrastructure that is needed for combat operations across HF beyond line of sight (BLOS) networks. This study is looking beyond the tactical level of war to develop solutions for the operational and strategic levels. The objective of this research is to create a clearer vision into the types of BLOS HF networks that would be required to support prolonged combat operations with a peer adversary.

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I. INTRODUCTION

A. ANALYSIS OVERVIEW

High frequency (HF) radio capabilities do not have the capacity to meet signal demand for all combat operations. The purpose of this proposed research is to determine the amount of HF infrastructure that is needed to support combat operations adequately in a satellite degraded environment. In particular, it is necessary to assess the HF infrastructure that would be required to overcome a fully denied satellite state. Specifically, if the required warfighting capabilities are assumed to be: (a) battle space awareness, (b) assured command and control (C2), and (c) integrated fires, then it is necessary to determine the HF infrastructure that is needed for combat operations across HF beyond line of sight (BLOS) networks.

HF communications paths involve traversal through the ionosphere, which is relatively straightforward to utilize. In addition, the ionosphere provides a reasonably robust communications channel since it is a target area that is difficult to disrupt for long periods of time. However, the application of a single narrow HF band link provides only limited data speed, so that the specific information that is transmitted over the communications channel must be selected judiciously.

This analysis is looking beyond the tactical level of war to develop solutions for the operational and strategic levels. The objective of this research is to create a clearer vision into the types of BLOS HF networks that would be required to support prolonged combat operations with a peer adversary.

B. BACKGROUND OF HF COMMUNICATIONS

High frequency radiation lies within the span of 3 MHz to 30 MHz and has been utilized for long range communications (comms) for decades. Some unique propagation mechanisms that occur at these frequencies enable such long-range communications, especially ionospheric reflections and ground waves. However, the perceived utility of HF has decreased in recent decades due to development of satellite communication (SATCOM) systems. Nevertheless, there has been renewed interest in the use of HF to provide backup communications networks for scenarios involving SATCOM performance failure or degradation, there have been recent concerns regarding the vulnerability security of satellite systems.

The primary elements of 2-way communications include antenna transmitters, receivers, and the propagation channel, which includes the physical environment in the intervening path between the two communication nodes. There exist three primary categories of HF propagation mechanisms, as shown in Figure 1. A number of these different mechanisms can exist at any time, and the relative importance of the different contributions can change in time.

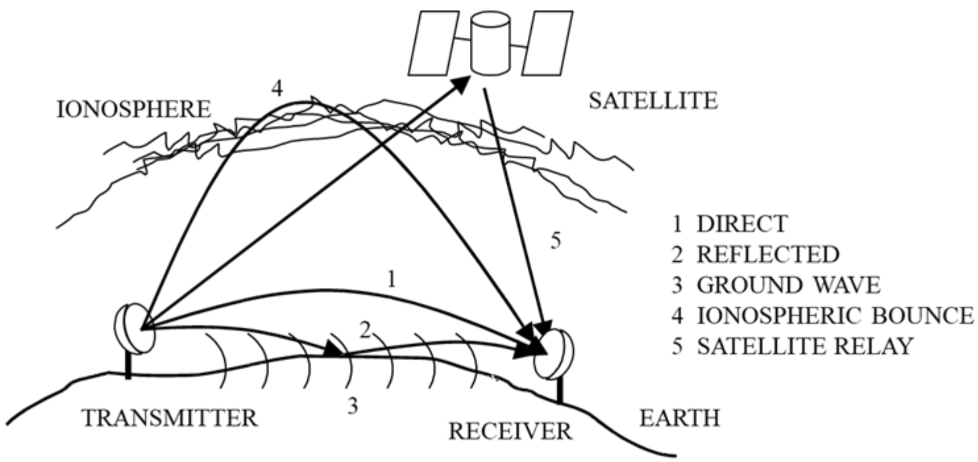

Figure 1. Illustration of HF propagation mechanisms.

The skywave paths shown in Figure 1 constitute some of the dominant communication links over longer distances (up to thousands of km) which are relevant for this study. One primary subset includes communication over long distances by using ground-based antennas and vertical polarization, wherein the antenna beam launch angle is close to the horizon. For many systems, high transmitter power transmitters are required, as well as sensitive receivers with a strong ability to detect weak signals.

II. HF FOR MILITARY OPERATIONS

A. STRATEGIES OF USING HF COMMUNICATIONS

HF propagation is highly dependent on atmospheric conditions, frequency, time of day, and solar activity. HF ionospheric paths are variable, and the specific frequencies that will propagate over long distances change with the time of day, season, latitude, and sunspot cycle (Hortaleza, 2021). Optimal HF frequencies drift from higher bands in daylight to lower bands after dark. Solar flares or geomagnetic storms can disrupt the ionosphere and cause HF blackouts or unpredictable behavior (Naval Network Warfare Command, 2008). These factors make HF less straightforward to use than fixed-frequency line-of-sight (VHF/UHF) or satellite links, and effective HF operation often requires frequent retuning, or agile frequency management, to find a usable channel as conditions change (Hortaleza, 2021). Modern techniques, like automatic link establishment (ALE), help automate the process of finding a usable channel (Gallup, 2015).

There exist some important limitations of using HF. In particular, HF has a narrow available bandwidth and variable reliability. Traditional HF channels are only 3 kHz wide, limiting data rates to around 300–2400 baud for teleprinter and a few kilobits per second for data in most legacy systems. Even using techniques like independent sideband (i.e., pairing two 3 kHz channels for 9.6–19.2 kbps data), HF cannot approach the high throughput of modern satellite communications (Hortaleza, 2021). In terms of signal quality, HF channels are noisy and susceptible to interference. Additionally, HF communication often has notable latency due to long propagation paths and the need for automatic repeat request (ARQ) and error-correction in data modes. Furthermore, HF can suffer from phenomena like multi-path interference and skip zones, which are regions where no usable signal is received due to propagation geometry (Naval Network Warfare Command, 2008).

The long-range propagation of HF is omni-directional, with its transmissions intercepted far from the source. Thus, low probability of interception (LPI) can be a challenge for HF. The presence of the HF signal is difficult to hide despite having the ability to encrypt transmissions (Naval Network Warfare Command, 2008).

HF offers unique advantages, particularly as a backup when SATCOM is unavailable. HF provides long-range BLOS connectivity without any intermediate infrastructure as enabled by using the natural ionospheric layers (Naval Network Warfare Command, 2008). HF is inexpensive compared to SATCOM and is field expedient, requiring only transceivers and antennas (Hortaleza, 2021).

Another advantage is that HF signals can reach into high-latitude regions where geostationary satellites have poor coverage (due to low look-angles). Moreover, certain HF frequencies can penetrate ionospheric disturbances that block SATCOM (e.g., during scintillation events near the equator) (Naval Network Warfare Command, 2008). These characteristics give HF a resilience and geographic reach that complement other communication methods (Hortaleza, 2021).

HF communications trade high data throughput to instead have global reach and independence from infrastructure. HF provides a vital lifeline for C2 in a SATCOM denied environment (SDE). The following sections discuss the methods by which the Navy uses HF today and the various systems and training which underpin the Navy's HF capability.

B. HF IN FLEET OPERATIONS AND DENIED ENVIRONMENTS

SATCOM offers higher bandwidth, global coverage, and user-friendly operation (e.g., automated network management, stable circuits, etc.), whereas HF is seen as slow, labor-intensive, and less dependable. According to one analysis, after Operation Desert Storm (1991), the rapid expansion of satellite bandwidth (e.g., INMARSAT, Commercial Wideband SATCOM, and later the DoD's own constellations) demoted HF into a second-class citizen status in the realm of communications. Not surprisingly, HF expertise within the fleet has atrophied (Hortaleza, 2021).

However, the strategic environment of the 21st century shifted, leading to a renewed appreciation for the value of HF. The threat of a satellite denied environment during a conflict with near-peer competitor through anti-satellite (ASAT) weapons and electronic warfare has driven the U.S. military to re-examine legacy communication pathways (Maldonadodelrio, 2021). In the past five years, there has been a resurgence of interest in HF as a survivable communications path for denied and degraded environments (Paulaitis, 2020). Commanders are asking: *If our SATCOM went dark, could we still coordinate the fight over HF?*—and are working to ensure the answer is yes.

In a notional example, consider a Carrier Strike Group operating in the Western Pacific. In peacetime or permissive conditions, this strike group can rely on SATCOM (e.g., SHF and EHF satellites) and line-of-sight networks (e.g., UHF/VHF radio, tactical data links) for most communications. But if those links were unavailable, the strike group could fall back on HF to maintain at least a baseline of connectivity. HF circuits could pass essential command orders, share sensor information, and coordinate with theater commanders or other task forces when no other BLOS method is available. The data rates would be far lower (perhaps a few kbps instead of Mbps) for chat, email, or contact reports, but these low values are better than a data rate of zero (Hortaleza, 2021).

An enemy can jam specific HF frequencies locally but cannot stop HF propagation everywhere without enormous transmitting power or a continental-scale disruption of the ionosphere (Naval Network Warfare Command, 2008). E. Jonhson (2020) noted that HF is experiencing a *resurgence of interest* precisely because it offers a way to communicate mission-critical information when SATCOM is denied or unavailable (Johnson, 2020). Fourth-generation wideband HF technologies and modern software-defined radio (SDR) implementations are emerging to make HF more capable and user-friendly in this role (Hortaleza, 2021). In exercises, the Navy and Marine Corps have begun practicing communications-degraded scenarios where units must rely on HF and other low-tech methods. Long-haul communications cannot be taken for granted and warfighters must be ready to *go old school* with HF radio if needed (Johnson, 2020; Maldonadodelrio, 2021).

Importantly, the role of HF today is envisioned as augmenting SATCOM in safeguarding C2 through diversity. HF provides an alternate path for Command and Control in a Denied/Degraded Environment (C2D2E) to maintain C2 under adversity. During fleet exercises, HF radio integrated into the Navy Tactical Grid when primary networks are contested. In July 2017, Naval Mobile Communication Battalion One (NMCB ONE) successfully transmitted voice and data via HF from Naval Base Guam to Port Hueneme, California—a path of over 6,000 miles—as a test of long-range backup communications. This demonstration used high-power HF transmitters and novel configurations to achieve communications from the Western Pacific to the Continental USA without satellites. It underscores that HF radio can span the globe to connect widely dispersed naval forces (Hortaleza, 2021).

The Navy of the 21st century views HF as a critical fallback and a complementary medium. For day-to-day operations, SATCOM is the favored means for convenience and throughput. But worst-case scenarios now weave HF into operational plans. In an SDE, HF can keep the Navy's lines of communication alive. However, ships must maintain HF systems in working order and sailors must remain proficient in using them. As one thesis succinctly put it, interest in HF has "resurged as a resilient alternative" for critical operations in an SDE. The challenge is to ensure that this alternative is truly ready and effective when called into action.

C. CURRENT HF SYSTEMS AND INITIATIVES IN THE FLEET

1. Legacy and Core Shipboard HF Radio Systems

Most U.S. Navy surface combatants have AN/URC-131 High Frequency Radio Group (HFRG), introduced under the "HF 2000" modernization program in the 1990s. Before HFRG, ships had a collection of individual HF transmitters, receivers, and antennas such as AN/URT-23 transmitters/R-2368 receivers, manually configured for each circuit. HFRG integrated these into a more automated, broadband system. A reduced number of broadband antennas (e.g., whip or fanwire) support dozens of simultaneous channels using multicouplers and broadband amplifiers and allow up to 46 HF receivers using only two passive antennas, and up to 26 transmit circuits through two transmit antennas. HFRG can operate 28 wideband voice and data transmission channels and 3 narrowband channels concurrently, a remarkable increase in capacity and flexibility (Ogden Gov't Services-SEMCOR, 1995; Harris Corporation, 2005).

HFRG has eliminated the need for numerous single-frequency antenna rigs and frequent manual retuning by covering the 2–30 MHz range with broadband antennas and power amplifiers. This strategy has reduced topside antenna clutter and freed deck space while decreasing maintenance workloads for technicians, i.e., there are fewer antennas and couplers equal fewer points of failure. A computer interface controls the system which automates tasks previously done by hand. HFRG represented the Navy's shift to fully integrated HF suites, one system with many channels. As of 2020, the Navy installed HFRG on 85 active ships in the surface fleet (Hortaleza, 2021).

HFRG itself is an aging system with many of its components dating to the 1990s. In a joint U.S. Fleet Forces/USPACFLT assessment (2017), commanders noted that the "HF Radio Group hardware is obsolete" and that parts availability and maintenance costs are not sustainable going forward (Stephenson, 2017). New construction ships have not been receiving HFRG but are slated to receive a Digital Modular Radio (DMR)-based HF solution with digital exciter and amplifier components. A replacement is a combination of the AN/USC-61(D) DMR and an HF Distribution Amplifier Group (HFDAG). The DMR is a multi-band (including HF) SDR offering a more compact and easily upgradable architecture. However, delays and funding issues have plagued its rollout; thus, many ships still rely on legacy HFRG equipment (Defense Advancement, 2022). In addition, URT-23 transmitters/R-2368 receivers (pre-HFRG) are in use as backups or in submarines and smaller vessels (Williams, 2023; Hortaleza, 2021).

The Navy's core HF hardware, as exemplified by HFRG, provides the basic radio frequency (RF) plumbing needed to employ HF communications: high-power transmitters, sensitive receivers, broadband antennas, and control systems to tie them together. The Battle Force Tactical Network (BFTN) represents the Navy's effort to leverage HF for robust data connectivity in denied environments.

D. BATTLE FORCE TACTICAL NETWORK (BFTN) AND IP-OVER-HF

BFTN is an HF (and low-band UHF) system for transmitting Internet-Protocol (IP) data ship-to-ship and ship-to-shore intended to provide assured connectivity in an SDE. BFTN forms a network that can carry secure data traffic (e.g., email, chat, and common operational picture updates). It acts as a backup Secret Internet Protocol Router Network (SIPRNET) path, keeping units connected to the tactical IP network over HF channels (Hortaleza, 2021).

BFTN leverages existing infrastructure (e.g., antennas, cabling) by adding HF data modems and controllers that interface with the ship's routers. In practice, a BFTN installation includes rack-mounted HF data modems (typically MIL-STD-188-110A/B waveform modems and ALE controllers), networking gear, and sometimes an HFIP (High Frequency Internet Protocol) router. If two destroyers at long range need to communicate in an SDE, BFTN can automatically schedule an HF data link between them and route the IP data accordingly. By 2016, the Navy completed BFTN installations on 84 ships with shore sites also planned to tie floating networks to land-based headquarters (Maldonadodelrio, 2021).

However, BFTN encountered challenges in implementation and utilization. One issue was performance: while BFTN provided nominal data rates of 9.6–19.2 kbps per channel, this is still a small fraction of typical SATCOM bandwidth (25+ Mbps) (Hortaleza, 2021). It is adequate for text-based communication and low-volume track data but cannot support large data flows. Another challenge was reliability and user confidence: operators reported difficulty maintaining stable HF network links, and a lack of training or perceived complexity caused BFTN to be under-utilized (Maldonadodelrio, 2021). Indeed, the "main operational and strategic issue with BFTN" noted by Paulaitis (2020) was that the system's performance and user proficiency were not always up to the task (Paulaitis, 2020). There were cases during fleet exercises where BFTN either was not activated in time or could not carry the needed traffic, limiting its effectiveness as a backup network (Hortaleza, 2021).

In FY18–19, the program faced budgetary hurdles with a 500% cost overrun, primarily through technical and integration challenges. Some upgrades were deferred or scaled back. The Navy had envisioned an enhanced version called BFTN-E (or BFTN 2.0), which would incorporate new waveforms and Wideband HF capabilities. The full leap to wideband did not occur under the original BFTN program due to these constraints (Hortaleza, 2021; Maldonadodelrio, 2021).

The Navy then initiated the BFTN Resilient Command, Control, and Communications (RC3) System Enhancement (BRSE), a more robust and user-friendly BFTN. According to official statements, BRSE includes "modern High Frequency radios, modems, network controllers, and network management systems." BRSE upgrades include bug fixes to existing BFTN software (to improve stability), increased system reliability, better integration with other communication systems, and revisions to support operations at extremely low data rates. The latter suggests an emphasis on ensuring that even if only a trickle of HF bandwidth is available, the network can still pass critical traffic by prioritizing and adapting to those conditions (May, 2024).

BRSE development has been ongoing since 2020, including software development and testing. The plan extended the BFTN upgrade effort to address requirements identified by a Fleet working group on resilient comms. The Navy is doubling down on HFIP networking as a viable backup through BRSE. Upgrades include new wideband modems, 4th-generation ALE, and more intuitive network management interfaces (Hortaleza, 2021). This is a clear indication that HF is expected to remain a key piece of the Navy's comms architecture in contested environments (Hortaleza, 2021).

E. WIDEBAND HF TECHNOLOGY AND URG-IV

A major development boosting the potential of HF communications is the advent of Wideband HF (WBHF) technology. The paradigm of traditional HF systems (3 kHz channels) is broken by WBHF by using much wider channels on the order of 24 kHz, 48 kHz, and beyond to carry high-speed data through improved modulation techniques and new standards (MIL-STD-188-110C/D and NATO STANAG 5069) that define wideband HF waveforms. WBHF modems can achieve data rates up to 240 kbps in a 48 kHz channel under ideal conditions, orders of magnitude higher than legacy HF data rates. Even at more modest channel widths (e.g., 24 kHz), speeds of 120 kbps can be possible, and at 12 kHz, 40–80 kbps can be achieved, all far beyond the earlier 9.6 kbps limit (Collins Aerospace, n.d.; Hortaleza, 2021).

During Trident Warrior 2011, multiple sites formed a WBHF network. In that event, four ground stations spread across North America successfully linked via HF, using a single-frequency network and achieving reliable data transfer among nodes up to 600 miles apart. Another trial involved a Canadian patrol frigate and a U.S. site establishing robust HF connectivity with data rates from 76.8-96 kbps on several 24 kHz channels. In 2014, an experiment treated an HF link as a "surrogate satellite," managing to transmit full-motion video over an 800-mile HF path (72 kbps, 100W power amps). These tests showed that applications like streaming low-rate video or large file transfer once unthinkable over HF could be achieved with wideband techniques (Hortaleza, 2021).

One enabling advancement for WBHF is 4th-Generation Automatic Link Establishment (4G ALE) and adaptive protocols. It can scan a broad swath of spectrum and identify a contiguous stretch of clear frequencies to use, coordinating the transmitter and receiver to hop onto the best 24 or 48 kHz slice available. It also quickly reforms links after breaks. The U.S. approach (per MIL-STD-188-110D) is to use a single-carrier wideband waveform that dynamically adapts its bandwidth based on channel conditions. This was chosen over multi-carrier approaches to avoid intermodulation interference issues on ships with multiple transmitters. In practice, if a full 48 kHz is not clear, the radios might negotiate a narrower band within that range that is free of interference at both ends and use that for the link, even if one end (e.g., an aircraft) is limited to 3 kHz transmission. This occurs rapidly and automatically making WBHF more user-friendly than old manual HF networking (Hortaleza, 2021).

The Department of the Navy (DON) has been actively pushing to implement WBHF channels for operational use. The DON's spectrum authorities have worked on allocating global WBHF channels (e.g., assigning certain 24 kHz channel sets to military use worldwide). This would eliminate ad-hoc channel bonding and give a structured way to use WBHF in exercises and operations. However, not all countries or regions allow 24–48 kHz HF emissions in all bands, and some platforms (like aircraft under aeronautical rules) are still restricted to narrow channels. Efforts are underway to update these rules and obtain the necessary permissions for military WBHF operation on a global scale (Johnson, 2020; Hortaleza, 2021).

Legacy HF sets like HFRG were not initially designed for very wide bandwidths (i.e., they focused on 3–6 kHz channels and independent sideband). To utilize WBHF, the Navy has been exploring new wideband-capable HF radios and modems. One notable example is the Collins Aerospace URG-IV HF Communication System. The URG-IV (Universal Radio Group IV) is a state-of-the-art HF radio suite unveiled in 2019, featuring digital architecture with 4G ALE. It boasts data throughput up to 20 times faster than legacy HF (Collins Aerospace, n.d.) (consistent with achieving 100+ kbps in good conditions) and is explicitly marketed for BLOS comms in contested environments as an alternative to SATCOM. The URG-IV includes components like the RT-2200A wideband HF transceiver and high-power amplifiers that cover 1.5–30 MHz with continuous tuning. It supports 48 kHz channels, ALE, and standard voice modes. Systems like URG-IV are attractive HFRG replacements. A modern wideband HF set can seamlessly switch between narrowband legacy waveforms and wideband modes, providing high reliability (with digital signal processing and self-calibration) and reducing operator workload (Collins Aerospace, n.d.).

WBHF blurs the line between HF and other data networks by enabling applications that previously were impractical over HF. For example, a 100 kbps HF link could carry imagery or augment tactical chat with file transfer, enabling richer information exchange in an SDE. It also means multiple nodes (dozens of ships or shore units) could share an HF network with time-division multiple access (TDMA) and still each get a slice of usable bandwidth. To be clear, HF will never rival SATCOM or line-of-sight microwave in capacity, but WBHF significantly narrows the gap (DMello, 2024; Johnson, 2020).

That said, WBHF adoption comes with constraints. Wideband signals require more careful frequency management. Finding 24–48 kHz of clean spectrum can be difficult in crowded bands (especially in Europe or coastal areas with many users). High data rates also often demand higher power and excellent antennas to maintain the required signal-to-noise ratio; otherwise, the throughput will scale down, or the link will drop in noise. Innovations like adaptive bandwidth and power control (power up only as needed) are thus important. Additionally, not all units need WBHF, and smaller ships or older platforms might stick with narrowband HF due to hardware limitations, meaning the fleet will operate a mix of HF capabilities. However, backward compatibility is maintained—WBHF systems can fall back to narrowband modes (Johnson, 2020; Hortaleza, 2021).

Core HF radio hardware is being updated (HFRG to DMR/URG-IV), and BFTN is being enhanced (via BRSE) to exploit those updates. The result should be a far more potent HF toolkit for commanders: one in which a ship can automatically establish an HF Internet link and send large data chunks with minimal operator intervention.

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III. TRAINING PIPELINE FOR HF COMMUNICATIONS

A. HF COMMUNICATIONS TRAINING—IP OFFICERS AND IT ENLISTED

Capable HF equipment is only half the battle; the Navy must effectively train its people in HF systems. Assessments have identified a training and proficiency gap in HF communications across the fleet. Younger generations of Information Systems Technicians (ITs) and officers in the Information Professional (IP) community have not had extensive hands-on experience with HF radio operations. This chapter outlines the training pipeline for both IP officers and enlisted ITs, from instruction to on-board qualifications, and highlights gaps that exist in preparing personnel for HF employment in high-end operations (Naval Network Warfare Command, 2008; Villa, 2021).

1. Information Professional Officers

Navy IP officers (1820 designators) are responsible for managing communications and networks for naval units. Their training pipeline includes foundational schooling in communications and information warfare. Typically, new IP officers attend the Information Warfare Basic Course (IWBC) at an Information Warfare Training Command (IWTC) where they receive academic instruction on Navy communications systems (including HF theory, spectrum fundamentals, and an overview of systems like HFRG and BFTN). Much of an IP officer's HF education historically has been theoretical unless they get hands-on exposure during a tour (Naval Network Warfare Command, 2008).

After IWBC, IP officers may serve as Communications Officers (COMMOs) or Cyber Officers, where they oversee the Radio Division and comms equipment. On the job, they rely on senior enlisted ITs and Electronics Technicians (ETs) to operate the HF radios, but the officer must understand capabilities and limitations to plan communications (e.g., crafting the COMMPLAN with HF in mind for certain circuits). There is also an IP-specific pipeline for advanced qualifications, e.g., the IP Intermediate Course comes later in their careers, and some attend the Naval Postgraduate School (NPS) for specialized communications or networks degrees. Those curricula at NPS cover communications in denied environments, which include HF resurgence discussions. Furthermore, IP officers can receive training through fleet-wide forums and working groups like the DoD HF Working Group, which Navy personnel participate in, to stay current on HF initiatives (Maldonadodelrio, 2021).

Despite this, gaps exist. A common observation is that many IP officers have not physically set up or troubleshot an HF circuit since their IWBC labs. If a strike group suddenly had to go *HF-only*, some IP leadership might struggle to effectively direct their teams. This is an area flagged for improvement, ensuring IP officers get more practical HF knowledge either through simulations or cross-training with their enlisted operators. Other recommendations include incorporating more HF scenarios into officer training and even offering short refresher courses on HF systems for officers en route to key fleet billets (Naval Network Warfare Command, 2008; Villa, 2021).

2. Enlisted ITs (Information Systems Technicians)

Sailors in the IT rating are the backbone of day-to-day naval communications. The training pipeline for an IT in HF comms begins at "A" School and provides basic training in networking, radio fundamentals, messaging, and communications security (Villa, 2021). Students learn about HF theory, frequency ranges, propagation basics, and standard Navy comms equipment. However, due to the breadth of topics ITs cover. A school offers only a cursory overview of HF systems (Naval Network Warfare Command, 2008; Maldonadodelrio, 2021).

Advanced, system-specific training occurs in "C" schools, often tied to Navy Enlisted Classification (NEC) codes. For HF, there have been specific C schools such as the HFRG Maintenance Technician course, HFRG Operator course, and BFTN Specialist course. These courses delve into the specifics of equipment: an HFRG maintenance course would train a Sailor in troubleshooting the URC-131 system, perform alignments, and operate its control interfaces; a BFTN course would teach setting up HFIP networks, modem configurations, and use of system management software. Typically, a ship will send a few (but not all) technicians to get the HF-related NECs who then serve as shipboard experts (Naval Information Warfare Training Group, 2024).

Once aboard a ship, an IT will go through Personnel Qualification Standards (PQS) certification for various watch stations and responsibilities including HF theory, operations, and the capabilities of systems. These PQS standards ensure that by the time an IT stands duty, every Communications Watch Officer or Tech Control Supervisor has a baseline familiarity with HF operations (Naval Information Warfare Training Group, 2024).

Despite formal training pipelines, the proficiency gap often cited is that sailors do not get enough practice with HF outside of infrequent drills, so that skills atrophy. A 2017 fleet assessment bluntly stated that the Navy "does not have adequate classroom training to support the currently fielded HF systems," pointing to outdated curricula and insufficient time dedicated to HF in schools. Moreover, Navy training does not cover newer systems well, leaving sailors unaware of assets they could be using. Recognizing these issues, current initiatives aim to beef up HF training: e.g., adding modules on wideband HF and HF global networks to school courses, and increasing the frequency of shipboard HF drills (Stephenson, 2017).

A positive development in training is the use of fleet exercises and labs to provide real-world HF experience. Navy Reserve units and technical training groups have run intensive HF training events in recent years. In 2024, Naval Information Warfare Center-Atlantic's (NIWC-Lant's) Radio Communications team integrated Navy reservists into a two-week training program that included working on live HF radios, setting up BFTN circuits, and troubleshooting under realistic conditions. An IT3 quoted in a NIWC news story, noted that such training strengthened their foundational knowledge and skills on HF systems, far beyond what classroom instruction alone provided. The program even culminated in a Mobilization Exercise (MOBEX) with these trainees experiencing a simulated wartime scenario requiring them to activate and use HF alongside NIWC engineers. This kind of immersive training is invaluable for building confidence and competence with HF. The Navy is also leveraging the Communications Simulator to practice HF operations without actual long-haul transmissions, which helps in high-demand environments where airwaves are busy (Sekerak, 2025).

The training pipeline for HF has historically been under-emphasized. IP officers get academic grounding but need more practical exposure; enlisted ITs get equipment training and PQS but need continual practice to remain sharp. The Navy's renewed focus on HF has highlighted the urgent need to address training shortfalls. Villa (2021) specifically examined this issue, finding that junior sailors often lacked HF proficiency due to outdated training materials and limited hands-on opportunities, and advocated for updated, standardized instruction to revitalize HF skills across the force. The Navy seems to be heeding that advice, as evidenced by evolving curricula and the integration of HF scenarios into Fleet Training (Villa, 2021).

B. ROLE OF TRAINING INSTITUTIONS AND CERTIFICATION

The Navy employs a layered training approach to ensure units and personnel are prepared for operations. Key organizations include the Information Warfare Training Commands, which manage individual training (schools and courses), and the Naval Information Warfare Training Group (NIWTG), which is responsible for unit-level and integrated training of shipboard Information Warfare (IW) teams. These organizations, working within the framework of the Optimized Fleet Response Plan (OFRP), orchestrate the progression of a ship from basic training to deployment certification (Office of the Chief of Naval Operations, 2014). In the realm of HF communications, both IWTC and NIWTG have important roles: IWTCs develop and deliver curricula to build foundational HF knowledge, while NIWTG provides underway training, assessment, and certification events that validate a crew's ability to operate HF under operational conditions (Naval Information Warfare Training Group, 2024).

Information Warfare Training Command: The IWTC organization (under Naval Information Forces, (NAVIFOR)) runs the IT A and C schools and IP pipeline courses for officers. In addition, they host specialized courses for fleet personnel, such as the HFRG operator course or BFTN system administrator course. These commands update the curriculum to reflect new systems. One challenge IWTCs face is keeping pace with technological changes, e.g., NTP-4(E) (Naval Telecommunications Publication 4(E)), the Navy's comms manual, last updated in 2008, and it had scant mention of emerging HF systems like BFTN or the HF Global Communications System until fleet feedback suggested adding them. Ensuring training commands have the latest information is a continuous effort, often requiring close coordination with program offices and fleet subject matter experts (Naval Network Warfare Command, 2008).

Naval Information Warfare Training Group: NIWTG is the organization that executes the training and assessment of shipboard IW teams during the Basic Phase of OFRP. NIWTG trainers embark on ships or work with crews on the pierside to conduct drills and scenarios. NIWTG will run the ship's Radio Center through a series of training exercises starting with classroom training and basic drills (e.g., Command, Control, Communications, Computers, and Intelligence—(C4I)—Team Training), moving to integrated scenarios where communications must be established and maintained in a tactical simulation (Naval Information Warfare Training Group, 2024).

NIWTG might conduct the following events: setting up an HF voice circuit (e.g., a ship-to-ship HF net using plain or secure voice), setting up HF data circuits (BFTN testing), and participation in fleet-wide HF exercises. In fact, one of the communications training requirements in the NIWTG User Guide is for ships to "Participate in HF relay or HF Mobile Communications Network Fleet Exercise" as part of their Basic Phase training, e.g., HF readiness tests where multiple ships and shore stations practice making contact on HF and passing traffic (Naval Information Warfare Training Group (NIWTG), 2024). NIWTG assesses the crew's ability to properly tune transmitters, coordinate frequency use, and exchange messages over HF. Additionally, the trainers evaluate procedural compliance, such as, are sailors following comms check-in procedures, using proper radiotelephone phraseology, maintaining logs, etc., during these HF drills (Naval Information Warfare Training Group, 2024).

The culmination of the involvement of NIWTG is usually a Communications Certification Event. During the Basic Phase of OFRP, ships undergo a final Certification Exercise to evaluate all warfare areas. NIWTG provides a recommendation to the Type Commander (TYCOM) on whether the ship's IW team is proficient and ready. The ship must demonstrate it can execute required comms tasks under time constraints and stress. According to one NIWTG instruction, a ship might need to demonstrate HF radio operations which could involve establishing an HF link (i.e., voice or data) with a fleet asset and maintaining it. Another graded item might be participating in an HF fleet broadcast or relay, ensuring the ship can receive or relay an HF message as part of the broader Navy circuit. NIWTG trainers would check that at least 50% of all HF equipment is operational for the drills. They also verify the crew's knowledge asking watchstanders HF related questions to gauge depth of understanding (Naval Information Warfare Training Group (NIWTG), 2024).

NIWTG will require corrective action for any shortfalls. For example, if sailors are unfamiliar with establishing an HF data link, trainers will provide additional instruction and require more practice until the crew becomes self-sufficient. They might recommend additional exercises (short-notice HF drills) during the ship's remaining in-port time or tailored mentoring for the Communications Officer and Chief. Only when NIWTG is confident in a ship's ability to perform will they endorse the ship for communications certification, after which the ship transitions to the Integrated Phase (Naval Information Warfare Training Group, 2024).

Optimized Fleet Response Plan (OFRP) Integrated Phase: After Basic Phase certification, ships join multi-unit training (like Composite Training Unit Exercise, COMPTUEX), where HF usage is further assessed in a strike group context. During COMPTUEX, scenarios may simulate SATCOM outages forcing operators to use alternatives. For example, a Large-Scale Exercise might impose a communications-denial vignette for 48 hours during which the strike group staff will rely on HF to communicate from the flagship to other ships. Such scenarios validate that all the training from Basic Phase holds up under more complex conditions. By the end of Integrated Phase, the strike group, now certified for deployment, can communicate in degraded environments (Office of the Chief of Naval Operations (OPNAV), 2014).

The OFRP construct ensures repeating of this training cycle repeats and the sustainment of knowledge. However, one issue identified is that while a ship might pass its HF checks in Basic Phase, if it then deploys and never uses HF for months, the skills can atrophy. Thus, even the Sustainment Phase (the period after deployment while the ship is still in readiness) emphasizes continuous training. Fleet commanders sometimes schedule periodic HF communication exercises (e.g., quarterly fleet-wide HF days). The Navy's worldwide HF station network also schedules drills where ships can check in and practice using those global circuits. The Naval Information Warfighting Development Center (NIWDC) and Navy Warfare Development Command (NWDC) develop tactics and doctrine, including communications in denied environments. They may publish tactical memoranda on how to integrate HF into distributed operations, and they coordinate HF lessons learned from exercises. Those lessons flow back into training syllabi and doctrine updates (for example, refining how to employ HF in conjunction with other modes for hybrid communications networks) (Office of the Chief of Naval Operations, 2014).

Overall, the training ecosystem (IWTC for individual training, NIWTG for unit training, OFRP to sequence it) is adapting to treat HF with renewed importance. NIWTG's user guide (2024) explicitly lists HF-related training requirements and indicates that ships must be able to operate HF systems and networks as a condition of deployment certification. The presence of dedicated HF training events and the requirement to complete HF exercises during workups demonstrate that HF readiness is now a formal part of fleet readiness generation (Naval Information Warfare Training Group, 2024).

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IV. ANALYSIS OF HF CHALLENGES AND STRATEGIES

A. CURRENT TRENDS

Current Trends: The Navy's effort to revitalize HF communications comes at a time when defense circles acknowledge a *high-frequency renaissance*. HF, once nearly written off and now a hot topic, ensures resilient communications (Johnson, 2020). Senior leaders have publicly stressed the need for multi-path communications. For example, U.S. Fleet Forces Command and U.S. Pacific Fleet in have directed units to incorporate alternate comms, including HF, into their training and operations plans (sometimes phrased as "practice fighting disconnected or degraded"). Large exercises include SATCOM-denial injects—in Large Scale Exercise 2023, for example, one of the objectives was to evaluate the fleets' ability of command and control across 22 time zones without full satellite availability. Such exercises inevitably highlight any gaps that exist in HF proficiency and system performance (U.S. Fleet Forces Command Public Affairs, 2023).

B. OPERATIONAL CHALLENGES

Using HF in the fleet today still faces challenges beyond training. One is integration with modern networks. HF circuits are slower and often require protocol adaptations to carry modern data. While BFTN provides an IP interface, applications running over it (email, chat, common operational picture software) may need tuning (e.g., lower refresh rates, smaller data packages) to work well (Maldonadodelrio, 2021). There have been reports from exercises that when forced to use HF, certain data links simply time out or overwhelm the link. Doctrinally, this means units must know what HF can and cannot realistically transmit. For example, streaming video or large imagery may be off the table; but compressed text and small situational reports are feasible. Developing Tactics, Techniques, and Procedures (TTPs) for a "thin C2" environment is an ongoing operational task. The Navy is drafting comms plans that specify what the minimum essential data to exchange is if utilizing HF only, for example, maybe a daily brief via formatted message, position location info via an HF Link-11/Link-22 data link in very condensed form, and reliance on pre-planned responses for much else. The training community must incorporate these TTPs so that crews can execute them. Part of Paulaitis' recommendation was to update or create TTPs for use of assets like the HF Global Communications System (HFGCS) by surface ships. HFGCS is a worldwide network of HF stations (primarily Air Force-run) that provides coverage for aircraft and can support ships. Navy surface communicators were not familiar with how to utilize HFGCS (which frequencies, how to request a broadcast, etc.), representing a missed opportunity for a reliable long-range path. Addressing this by adding to doctrine and training ensures the fleet can tap into that resource (Paulaitis, 2020).

Another operational challenge is electromagnetic interference (EMI) and antenna constraints on ships. The HF antenna farm on a ship must coexist with other emitters (UHF/VHF radios, radars, SATCOM terminals). Issues like antenna coupler problems, interference from another onboard system, or improper configuration can lead to poor HF performance (Hortaleza, 2021). This is partly a materiel/training crossover issue—leading to a requirement of sailor training in RF deconfliction and basic spectrum management on their platform. For example, knowing not to place an HF receiver online on a frequency that is harmonically related to a ship's radar pulse repetition frequency, or understanding how to configure an HF transmitter to avoid intermodulation with another transmitter. During COMPTUEX, spectrum managers often inject such issues to see if the ship can figure out why their HF link is getting blocked. It remains an area requiring careful attention, as the complexity of shipboard RF only grows with new systems (Villa, 2021).

C. TRENDS IN MITIGATION

One trend to overcome these challenges is increased HF automation and planning tools, such as fielding automated HF network planning software that can recommend frequencies and schedules (taking into account ionospheric forecasts) (Naval Information Warfare Systems Command, 2021). Another trend is multi-path integration—using HF in parallel with other means in an automated way. For example, systems that can send a message simultaneously via SATCOM and HF (so-called *dual net* or redundant routing) would invisibly utilize HF if SATCOM fails. This kind of integration would hide complexity from the end-user and ensure that HF remains in the forefront (Hortaleza, 2021).

D. RECENT EXERCISES AND REPORTS

At times, results from recent fleet exercises have been encouraging with units successfully passing critical data over HF when required. In others, they exposed gaps—for example, an after-action report from a 7th Fleet exercise noted that "initial attempts to shift a strike group to HF-only comms were slow, as ships had to locate the correct crypto fills and configurations, indicating a need for more regular practice" (Stephenson, 2017). NAVIFOR and NWDC capture these lessons to update training. Additionally, allied navies have been actively sharing tactics on HF resurgence. This multinational aspect appears in events like RIMPAC exercises, where combined forces establish HF nets for coalition coordination when simulating SATCOM loss (U.S. Fleet Forces Command Public Affairs, 2023).

E. PERSISTENT TRAINING GAPS

Villa's 2021 study specifically pointed out the *lack of standardized HF training* across the fleet and suggested targeted solutions. For example, junior ITs often learn HF informally on the job, leading to uneven knowledge—some become very proficient if they have a mentor or a lot of drills, others might barely grasp it if their ship rarely touches HF. Standardizing a Fleet-wide HF training syllabus or periodic HF readiness tests can ensure everyone meets a baseline. Villa also highlighted outdated training materials (echoing others) and limited hands-on training devices. Implementing his recommendations, the Navy could introduce things like HF trainers or simulators at waterfront training facilities, so sailors can practice tuning and troubleshooting without needing to be at sea with a live circuit (Villa, 2021).

Recent anecdotal evidence suggests improvement: Navy units have shown better results in HF communications over the past five years. More units are keeping their HF equipment operational (reducing the tendency to cannibalize HF gear for other uses, which sometimes happened during HF's era of less importance). There is also a cultural shift—senior leadership discusses HF. A telling sign: Fleet Commanders are asking during briefings, *What is our HF plan?* This top-down interest drives ships to pay attention (U.S. Fleet Forces Command Public Affairs, 2023).

Yet, challenges remain, such as ensuring sustainment of expertise. Navy HF subject matter experts are mid-to-senior career individuals who grew up when HF was more common or have specialized in it. As they retire, that knowledge could disappear unless institutionalized in training. Therefore, capturing expert knowledge into updated manuals, and leveraging civilian certifications or training could help. Exploring civilian Ham radio certifications might be a future area, as they encapsulate practical HF knowledge that could benefit Navy operators (Paulaitis, 2020).

The current trend is that the Navy is closing the gap on HF communications capability, but it is an ongoing process. Revised curricula, more rigorous unit-level training, and incorporation of HF into high-end exercises identify and address training gaps. The recognition of operational challenges like limited bandwidth, Electromagnetic Interference (EMI), and network integration leading to the development of solutions (technical and procedural). The fleet's mindset is evolving to treat HF not as antiquated backup, but as a *must-know skill* and a key component of warfighting resilience. As one recent NIWC-Lant training report put it, these efforts are strengthening *"the resilience of our fleet communications"* by ensuring even the Reserve force is well-versed in HF and related radio skills (Sekerak, 2025).

V. SUMMARY

Collectively, these case studies and research efforts paint a picture of a Navy that is actively learning and adapting its HF communications practice. They highlight that success in HF employment is a multi-faceted challenge: it requires modern equipment (as shown by WBHF tests and BRSE efforts), robust training and doctrinal emphasis (Paulaitis, 2020; Villa, 2021), and innovative operational concepts (as explored by Maldonadodelrio with unmanned integration (Maldonadodelrio, 2021)). A common thread is the need for better training and awareness—every study calls for improved education on HF, from basic operator skills to high-level planning.

Encouragingly, we see the application of these insights. The Navy is updating school curricula and PQS, increasing HF training events, investing in new HF technologies, and revising doctrine (for example, drafting comms annexes that detail actions in comms-denied scenarios, including HF use). There is also more cross-pollination with allies and other services—the Air Force's shares its expertise in HF (through experience with HFGCS and nuclear C2 via HF) with Navy, and vice versa. The DoD HF Working Group mentioned by Paulaitis is one venue where such knowledge transfer happens (Paulaitis, 2020).

In summary, the deep research and case studies reinforce the chapter's narrative: HF communications, once a fading art, now acts as a critical enabler in the U.S. Navy's operational toolkit. The fleet is re-learning and innovating in this domain. Yet challenges remain in fully institutionalizing HF proficiency.

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ACRONYMS

4G	Fourth Generation
ALE	Automatic Link Establishment
AN/URC	Army/Navy General Utility Radio Transceiver
AN/URT	Army/Navy General Utility Radio Transmitter
AN/USC	Army/Navy General Utility Special Types Communication
ARQ	Automatic Repeat Request
ASAT	Anti-Satellite
BFTN	Battle Force Tactical Network
BFTN-E	Battle Force Tactical Network-Enhanced
BLOS	Beyond Line of Sight
BRSE	BFTN RC3 System Enhancement
C2	Command and Control
C2D2E	Command and Control in a Denied/Degraded Environment
COMMO	Communications Officer
COMMPLAN	Communications Plan
COMPTUEX	Composite Training Unite Exercise
CSP	Communication Strategy Phase
CTF	Commander, Task Force
DMR	Digital Modular Radio
DoD	Department of Defense
DON	Department of the Navy
EHF	Extremely High Frequency
EMCON	Emissions Control
EMI	Electromagnetic Interference
ET	Electronics Technician
FY	Fiscal Year
HF	High Frequency
HFDAG	High Frequency Distribution Amplifier Group
HFGCS	High Frequency Global Communications System
HFIP	High Frequency Internet Protocol
HFRG	High Frequency Radio Group
INMARSAT	International Maritime Satellite
IP	Information Professional
IP	Internet Protocol
IT	Information Systems Technician
IWBC	Information Warfare Basic Course
IWTC	Information Warfare Training Command
kbps	Kilobit(s) per Second

kHz	Kilohertz
Lant	Atlantic
LMACC	Lightly Manned Automated Combat Capability
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
Mbps	Megabit(s) per Second
MHz	Megahertz
MIL	Military
MOBEX	Mobilization Exercise
MOC	Maritime Operations Center
NATO	North Atlantic Treaty Organization
NAVIFOR	Naval Information Forces
NAVWAR	Naval Information Warfare Systems Command
NEC	Navy Enlisted Classification
NIWC	Naval Information Warfare Center
NIWDC	Naval Information Warfighting Development Center
NIWTG	Naval Information Warfare Training Group
NMCB	Navy Mobile Communications Battalion
NPS	Naval Postgraduate School
NTP	Naval Telecommunications Publication
NWDC	Navy Warfare Development Command
OFRP	Optimized Fleet Response Plan
PMW	Project Manager, Warfare
PQS	Personnel Qualifications Standards
RC3	Resilient Command, Control, and Communications
RF	Radio Frequency
SATCOM	Satellite Communications
SDE	SATCOM Denied Environment
SDR	Software Defined Radio
SHF	Super High Frequency
SIPRNET	Secret Internet Protocol Router Network
STANAG	Standardized Agreement
STD	Standard
TDMA	Time-Division Multiple Access
TTP	Tactics, Techniques, and Procedures
TYCOM	Type Commander
U.S.	United States
UHF	Ultra-High Frequency
URC	Universal Radio Communications
URG	Universal Radio Group
USPACFLT	United States Pacific Fleet

USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle
VHF	Very High Frequency
WBHF	Wideband High Frequency

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