National Defence Défense nationale

Canadian Forces College

Collège des Forces Canadiennes

Information Warfare in the 21st Century: Achieving Assured Command and Control in Modern Naval Warfare

Lieutenant-Commander Christopher Jawornicki

JCSP 50

Exercise Solo Flight

Disclaimer

Opinions expressed remain those of the author and do not represent Department of National Defence or Canadian Forces policy. This paper may not be used without written permission.

PCEMI n° 50

Exercice Solo Flight

Avertissement

Les opinons exprimées n'engagent que leurs auteurs et ne reflètent aucunement des politiques du Ministère de la Défense nationale ou des Forces canadiennes. Ce papier ne peut être reproduit sans autorisation écrite.

Canada

CANADIAN FORCES COLLEGE - COLLÈGE DES FORCES CANADIENNES

JCSP 50 - PCEMI n° 50
2023 - 2024

Exercise Solo Flight – Exercice Solo Flight

Information Warfare in the 21st Century:
Achieving Assured Command and Control in Modern Naval Warfare

Lieutenant-Commander Christopher Jawornicki

Information Warfare in the 21st Century:
Achieving Assured Command and Control in Modern Naval Warfare

INTRODUCTION

From smoke signals to telegraphy, to the present age of 5G cellular networks and satellite communications (SATCOM), how we transmit data to communicate has continuously evolved, enabling us to convey information at faster speeds and with greater throughput than ever before. These technological advancements have not only changed how we communicate but have also had a significant impact on our society. Today, we find ourselves immersed in a digital landscape where data flows seamlessly across the globe, powering everything from real-time financial transactions to instantaneous communication and collaboration.

Naturally, there was a military use case for each new communication technology to enable faster communication over greater distances for Commanders and fighting units. At first, semaphore, flags and other visual signals were used by navies to communicate with ships, but they required a clear line-of-sight (LOS) between the sender and receiver, and thus limited their utility due to range[1]. Then on December 12th, 1901, Guglielmo Marconi revolutionized communication technology when he successfully transmitted the first transatlantic wireless signal[2]. In the wake of Marconi's groundbreaking invention, the maritime industry and naval forces quickly recognized its transformative potential[3], and by the early 20th century, wireless communications systems were being integrated into their operations[4].

As the telecommunications evolution continued so did the adaptation of said technologies by naval forces, whereas a modern warship can now communicate over various electromagnetic (EM) frequency bandwidths to meet the numerous information exchange requirements (IER) that are required for a warship to function as a military unit at sea. Enhancements in SATCOM technology have allowed warships to seamlessly link their onboard computer networks with those ashore. Warships can now exchange data for logistics support, maintenance reporting, quality of life, intelligence, enterprise applications, battlespace awareness (BSA), and command and control (C2), all in near real-time. Western nations have enjoyed undisputed access to the EM spectrum (EMS),[5] such that they have become reliant on the unfettered access and connectivity that SATCOM allows. The prevalence of connectivity at sea has reached a point where it is expected that every deployed Royal Canadian Navy (RCN) warship will not only maintain uninterrupted SATCOM access but will also be assigned a larger "pipeline" allocation (relative to ships conducting force generation (FG)) to accommodate the various operational IERs. Whether through email, electronic chats, orders via voice over

---

[1] Rens, Invisible Empire: A History of the Telecommunications Industry in Canada, 1846-1956, 6.
[2] Rens, Invisible Empire: A History of the Telecommunications Industry in Canada, 1846-1956, 184.
[3] Marconi and Jackson, "History of Naval Ships Wireless Systems I 1890's to the 1920's."
[4] Bigelow, "Wireless in Warfare, 1885-1914 | Proceedings - February 1951 Vol. 77/2/576."
[5] U.S. Department of Defense, "New Spectrum Strategy Reveals DOD's Plan to Master Airwaves," n.d., https://www.defense.gov/News/News-Stories/Article/Article/2404027/new-spectrum-strategy-reveals-dods-plan-to-master-airwaves/.

internet-protocol (VoIP), or conventional formatted military messages, the speed and ease of SATCOM have rendered it the preferred medium, and thus relegated other methods to relay orders and directives. Despite its advantages, it is necessary to acknowledge the inherent limitations and vulnerabilities associated with SATCOM. In a high-end war fight (HEW) with near-peer adversaries, interruptions to SATCOM and other EM communications methods are a very real possibility. Despite these interruptions, a warship still needs to conduct missions and tasks, and respond to higher command directives. The concept of assured C2 (AC2) is the ability to maintain C2 in a denied, degraded, intermittent or limited (DDIL) environment. A warship in a DDIL environment has three primary warfighting functions that must be maintained: command forces in any environment (C2), coordinate fires in all domains (integrated fires), and assess fires and own force status (battlespace awareness (BSA) and maritime domain awareness (MDA)).[6]

For the RCN to achieve AC2, it must be able to recognize when it is in or about to enter a DDIL environment, revitalize legacy communication methods, invest in new technologies, and adopt new warfare methodologies to be a proficient, capable, and reliable ally. To develop this thesis, this essay will be structured around four main parts. The first will examine how Navies may find themselves in a DDIL environment. The second will demonstrate how revitalizing legacy systems can help achieve AC2 in DDIL scenario, while the third will look at emerging communications technologies that the RCN's allies are investing in, which specifically have AC2 in mind. Finally, the last section will analyze how the RCN's allies have restructured their composite warfare command (CWC) structure to utilize an information warfare commander (IWC) as part of their warfare staff to oversee and be responsible for AC2.

DENIED, DEGRADED, INTERMITTENT AND LIMITED ENVIRONMENTS

In modern warfare, the EMS has become an indispensable part of the battlefield, facilitating communication, real-time data exchange, navigation, precision targeting, and surveillance capabilities critical to military operations. The uncontested use of the EMS has traditionally been taken for granted, but with the rise of advanced technologies and the growing sophistication of adversaries, Western militaries now face significant challenges in protecting their access to it.[7] There are many ways both internal and external to a warship in which communications and information exchange can be interrupted, and thus putting a warship into a DDIL environment.

Internal to the ship, interruptions could be from the technical degradation of communications equipment, be that from a physical or electronic malfunction, or even due to battle damage. Even self-imposed emissions control (EMCON) restrictions can impact the ability to exchange information over the EMS. An EMCON state is akin to an order for "radio silence". The objective of which is to limit the amount (power output) or type (radios, radars, SATCOM, etc.) of EM emissions that are transmitted, with the goal

---

[6] William E. Leigher, "U.S. Navy Information Dominance Roadmap, 2013–2028," 2013, https://defenseinnovationmarketplace.dtic.mil/wp-content/uploads/2018/02/Information_Dominance_Roadmap_March_2013.pdf.
[7] Department of Defense, "Electromagnetic Spectrum Superiority Strategy."

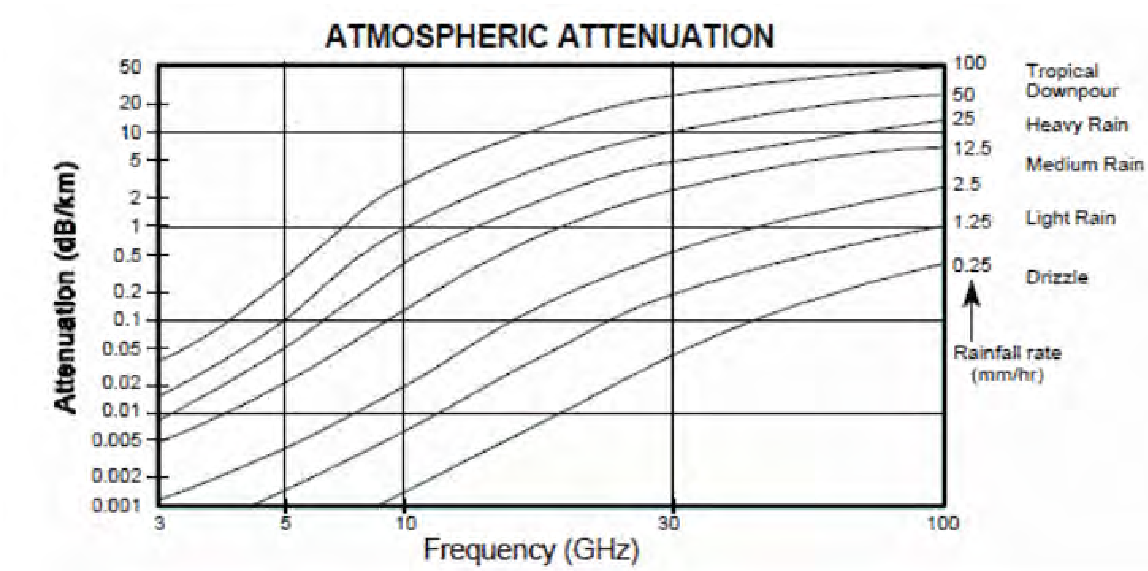
of reducing the adversary's ability to intercept the communication or detect the ship through direction finding and triangulation. EMCON states may be ordered by a single warship or for a task group (TG) by the Officer in Tactical Command (OTC). EMCON states range from completely restrictive where all outgoing transmissions are ceased, to less restrictive where transmitting on specific frequencies, or for certain operational reasons is allowed.[8] Other factors such as the inherent finite throughout of a SATCOM channel, and the overall distance that a SATCOM signal must travel (and that associated latency) are also considered internal DDIL contributors.

Additionally, a myriad of external environmental factors exist that can put a warship into a DDIL state. Environmental factors such as the weather, atmospheric conditions, and solar phenomena can interfere with radio frequency (RF) signals.[9] Precipitation can cause interference known as "rain fade", which is more pronounced at higher frequencies, and it occurs primarily in the microwave frequency bands which are used for SATCOM (see Figure 1).[10] This is because higher frequencies have shorter wavelengths, such that they can penetrate a rain drop causing them to scatter or be absorbed, thereby deviating EM signals from their original path and attenuating them as they traverse the atmosphere. Rain fade can be caused by precipitation at either the uplink or downlink location, meaning that a warship may find itself in a DDIL environment even if it is sailing in clear conditions, but the receiving downlink satellite ground terminal is being affected by rain or snow. [11] Thunderstorms cause additional interference to the EMS. As lightning strikes, it causes an electrical discharge that propagates RF

[8] North Atlantic Treaty Organization, "ALLIED TACTICAL PUBLICATION - 01, VOLUME II,: ALLIED MARITIME TACTICAL SIGNAL AND MANEUVERING BOOK Edition (G) Version (1)."
[9] "Solar Flares (Radio Blackouts) | NOAA / NWS Space Weather Prediction Center."
[10] Lim et al., "Review of Temperature and Humidity Impacts on RF Signals."
[11] Al-Saegh et al., "Rainfall Effect on Satellite Communications in Mosul at Frequencies above 10 GHz."

radiation and radio bursts into the atmosphere. Although, not as impactful as rain fade, thunderstorms nonetheless create EM interference that affects wireless communication.[12]

Figure 1 - Rain Attenuation[13]



In addition to environmental factors on earth, space weather can also affect RF signals. Solar phenomena such as solar flares and coronal mass ejections also affect RF signals. While most solar flares are not strong enough to have a noticeable impact on terrestrial RF signals, some solar storms can be strong enough that they can affect satellites, telecommunications systems, and even power grids.[14] On September 6, 2017, during the Atlantic hurricane season, a large solar flare erupted while several powerful storms were active in the Atlantic Ocean, including Hurricane Irma, Tropical Storm Jose and Tropical Storm Katia. This combination of hurricane activity and the solar flare disrupted radio communications for many Caribbean islands and portions of the southern United States.[15,16]

While internal and environmental factors can cause DDIL situations, they are generally well understood and can be planned and accounted for. External factors that are caused by adversaries, however, are the most challenging impacts to account for. The ongoing power competition between Western nations, and Russia and China, is characterized by a multifaceted interplay of economic influence, technological advancement, and strategic maneuvering. With tensions simmering on multiple fronts, from trade disputes to maritime territorial claims, Western powers are bracing for a future HEW that will test the latest in maritime tactics and technologies.[17] These global

[12] Liu and Dwyer, "Thunderstorm High-Frequency Radio Bursts With Weak Low-Frequency Radiation."
[13] Everything RF, "What Is the Impact of Rain on RF Signal Propagation? - Everything RF."
[14] Encyclopedia Britannica, "Learn How Solar Flares Can Affect Satellites, Rockets, Telecommunications Systems and Activity on the Surface of the Earth."

[15] Redmon et al., "September 2017's Geoeffective Space Weather and Impacts to Caribbean Radio Communications During Hurricane Response."
[16] Berg, "Understanding How Solar Flares Affect Radio Communications."
[17] Royal Canadian Navy, "The Oceans and Great Power Competition in Our Era."

competitors also acknowledge the importance of the EMS as a complex domain that affects a nation's economic prosperity and relative military advantage. Recognizing this reliance on the EMS, these adversaries "have spent 30 years studying, investing, and implementing policies, capabilities, and procedures with the single focus of gaining military advantage over [Western] forces . . . across the [EMS]."[18] China and Russia possess the ability to engage in electronic warfare (EW) capabilities that can jam or intercept RF signals, as they have been developing and fielding new technologies aimed at Western EMS capabilities.[19] Russia has shown its ability to jam global positioning system (GPS) signals, whether around key cities such as Moscow to prevent precision strikes as a defensive measure,[20] or to disrupt local maritime and air traffic.[21] China has also demonstrated that it will protect its maritime assets and territorial claims by leveraging the EMS. In 2023, multiple civilian aircraft reported communication and GPS jamming while flying over Chinese warships in and around the "South China Sea, Philippine Sea, [and] East of Indian Ocean. In some cases, the flights were [contacted by warships and] provided vectors to avoid the airspace over the warship."[22] Communications and GPS jamming affect both civilian and military activities, and while they can be disruptive, by their nature they are temporary and can be planned, adjusted, and accounted for.

"One of the biggest risks to the *military* is the growing possibility-indeed the likelihood-that an enemy will destroy our satellites or otherwise neutralize their effectiveness."[23] It is indeed worrisome that both China and Russia have demonstrated credible anti-satellite (ASAT) capabilities. There are kinetic ASAT methods such as an interceptor ASAT where a highly precise missile is aimed at a specific satellite, or the less discriminate non-directed nuclear ASAT where a nuclear missile is sent into space, and upon detonation it destroys all satellites within its blast radius.[24] The biggest consequence of kinetic ASAT attacks is that they leave a field of debris that can damage or destroy other satellites that are still in orbit for years, and even decades, to come. In January 2007, China conducted an ASAT test in which it destroyed one of its own non-operational weather satellites with a ballistic missile. According to the Secure World Foundation, this created a cloud of more than 3,000 pieces of space debris, and it is estimated that this debris will further dissipate into over 30 000 smaller pieces that are

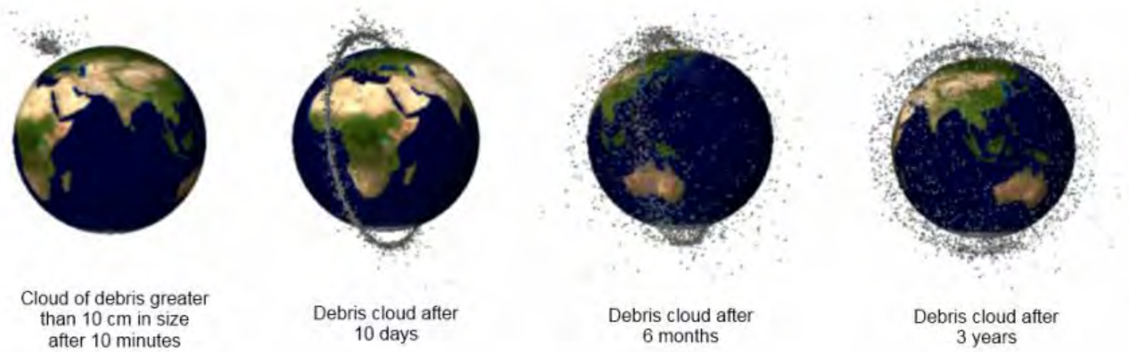
---

[18] Department of Defense, "Electromagnetic Spectrum Superiority Strategy."
[19] Ibid.
[20] Moscow Times, "Russia Expands GPS Signal Jamming to 15 Regions."
[21] Hsu, "Unprecedented GPS Jamming Attack Affects 1600 Aircraft Over Europe."
[22] Saines and Saines, "Australian Aircraft's GPS Receiver Jammed Allegedly by Chinese Warships - GPS World."
[23] Wayne P. Hughes and Robert Girrier, Fleet Tactics and Naval Operations, 3rd ed. (US Naval Institute Press, 2018). Pg 256
[24] Wilson and Commission to Assess United States National Security Space Management and Organization, "Threats to United States Space Capabilities."

unable to be tracked (see figure 2).[25] In November 2021, the International Space Station was forced to make an avoidance maneuver to dodge debris created by this test.[26]

Figure 2 - Evolution of the debris cloud from a kinetic kill ASAT attack[27]

In addition to kinetic ASAT capabilities, both Russia and China possess non-kinetic ASAT capabilities. There exists a variety of directed energy weapons that can be used against satellites. A laser ASAT weapon uses either a low-power laser to spoof or jam satellite electro-optical sensors using laser radiation, thus temporarily blinding the



satellite, or a high-power laser that can permanently damage or destroy a satellite by radiating enough energy to overheat its electronics and sensors.[28] RF ASAT weapons emit intense radio bursts, while particle-beam ASAT weapons emit charged ions, both with the intended purpose to interfere or damage onboard satellite sensors and electronics.[29]

According to the Annual Threat Assessment (ATA) of the US Intelligence Community, dated February 5, 2024, "China remains committed to becoming a world-class space leader and continues to demonstrate its growing prowess by deploying increasingly capable space systems."[30] China has counterspace-weapons capabilities intended to target U.S. and allied satellites as "counterspace operations will be integral to potential [People's Liberation Army] military campaigns."[31] The ATA states that Russia "will continue to employ all applicable sources of national power to advance its interests and try to undermine the United States and its allies"[32] and despite facing setbacks in Ukraine and the difficulties associated with international sanctions and export controls, Russia will remain a key space competitor as it is "prioritizing assets critical to its national security and integrating space services",[33] and it continues to invest in directed

[25] Weeden and Secure World Foundation, "2007 Chinese Anti-Satellite Test."
[26] Luckenbaugh, "Space Force Still Dodging Chinese Satellite Debris."
[27] Wright, "Space Debris."
[28] Wilson and Commission to Assess United States National Security Space Management and Organization, "Threats to United States Space Capabilities."
[29] Ibid.
[30] Office of the Director of National Intelligence, "Annual Threat Assessment of the US Intelligence Community.", 11.
[31] Ibid. 11.
[32] Ibid, 14.
[33] Ibid, 14.

energy weapons to counter Western space assets and continues to develop ground-based ASAT missiles.[34]

While internal and environmental factors pose challenges and cause DDIL scenarios, it is the external threats posed by adversaries like China and Russia that present the greatest concern. These nations have demonstrated not only the ability to disrupt the EMS through EW tactics but also possess kinetic and non-kinetic ASAT capabilities, which could have far-reaching consequences for global communication and navigation systems.

REVITALIZING LEGACY SYSTEMS

At the core of AC2 is the ability to transition to communication methods resistant to denial or degradation, that are still capable of bridging vast distances between Commanders and deployed forces. High frequency (HF) communications emerge as a robust solution due to their innate characteristics. HF signals enable true beyond LOS (BLOS) communication by leveraging multipath propagation, bouncing off the ionosphere to cover vast distances. Because HF propagates via surface waves, direct waves, and skywaves, it is less susceptible to adversary denial, as jamming one path may not stop the signal from arriving via the other paths (Figure 3). Adversaries face additional challenges in disrupting HF communications, because HF signals utilize a wider frequency bandwidth (compared to other bands higher in frequency in the EMS), and an adversary would thus have to target a wider bandwidth to jam. For an HF signal to be used to transmit over large distances, it must be sent from a high-powered transmitter to ensure that it arrives with sufficient signal strength, and as such an adversary would need to send an even stronger signal to overpower and jam an HF signal, which requires substantial resources.[35]

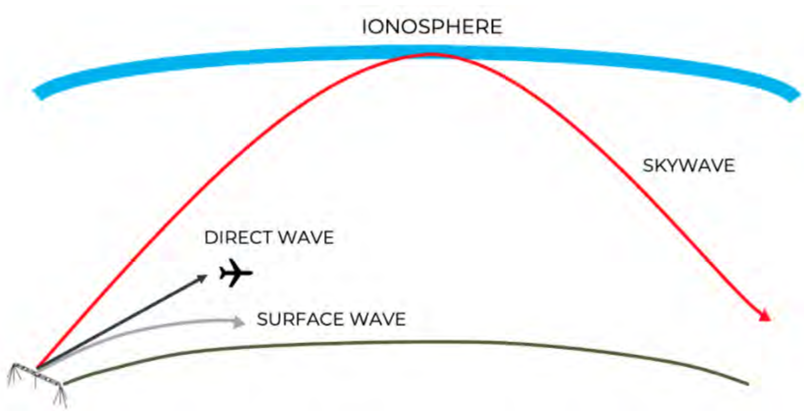
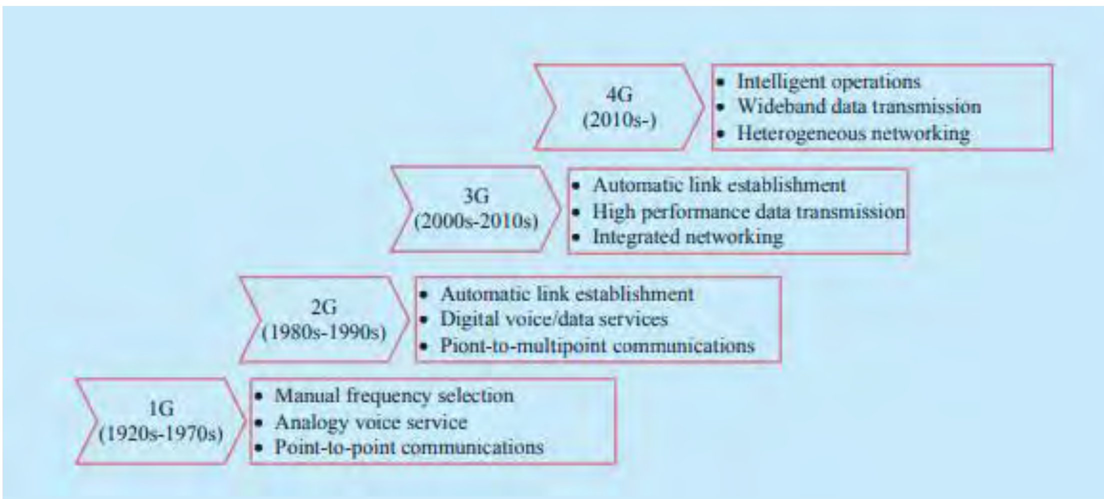


Figure 3 – HF radio wave propagation paths[36]

[34] Ibid, 14.
[35] Thomas Withington, "HF Radio: Still Valid After 100 Years - Asian Military Review," Asian Military Review, June 10, 2020, https://www.asianmilitaryreview.com/2020/06/hf-radio-still-valid-after-100-years/.
[36] Lespretentieux, "HF Communications Are Making a Comeback, and Here's Why You Need to Get in on It! - Base Camp Connect," Base Camp Connect, February 10, 2022, https://www.basecampconnect.com/hf-communications-making-a-comeback.

While HF offers resilience, its usage within the RCN has diminished primarily due to operational challenges. The ionosphere is directly affected by solar radiation, and as such it changes from day to night. When night falls, the ionosphere thins out as previously ionized particles relax back into neutral particles. It is also affected by large thunderstorms and even space weather.[37] These diurnal variations and environmental effects pose constraints on over-the-horizon ranges, demanding continual frequency and power adjustments for optimal link quality. The legacy HF equipment onboard RCN vessels requires manual tuning by skilled operators, relying on experience rather than automation for effective transmission, a skill that is fading as more reliance is put on other systems such as SATCOM. Moreover, until recent advancements, HF's data throughput was limited to 9.6kbps, lagging far behind higher frequency alternatives. Similar to how successive generations of cell phone technology have allowed for faster transmission speeds while being able to accommodate a growing number of users,



advancements in HF technology coupled with updates to standardization protocols such as the US Department of Defence's Military Standard 188-110B (MIL-STD-188-110B) and the North Atlantic Treaty Organization's Standardization Agreement 4539 (STANAG 4539), have likewise expanded bandwidth, throughput and added automation and other capabilities (as represented in Figure 4). The progress through these four generations has enabled throughput of up to 240kbps under favorable conditions.[38] This improved throughput allows for real-time IP traffic transmission and is even capable of file and low-resolution video transfers.

Figure 4 – The evolution of HF communications[39]

Key to HF's resurgence is not only the advancements in the waveforms, but also the advent of software defined radios (SDRs). SDRs offer adaptability and automation, employing software processing for modulation, demodulation, and signal processing tasks. Automatic link establishment (ALE) streamlines the setup of communication links,

---

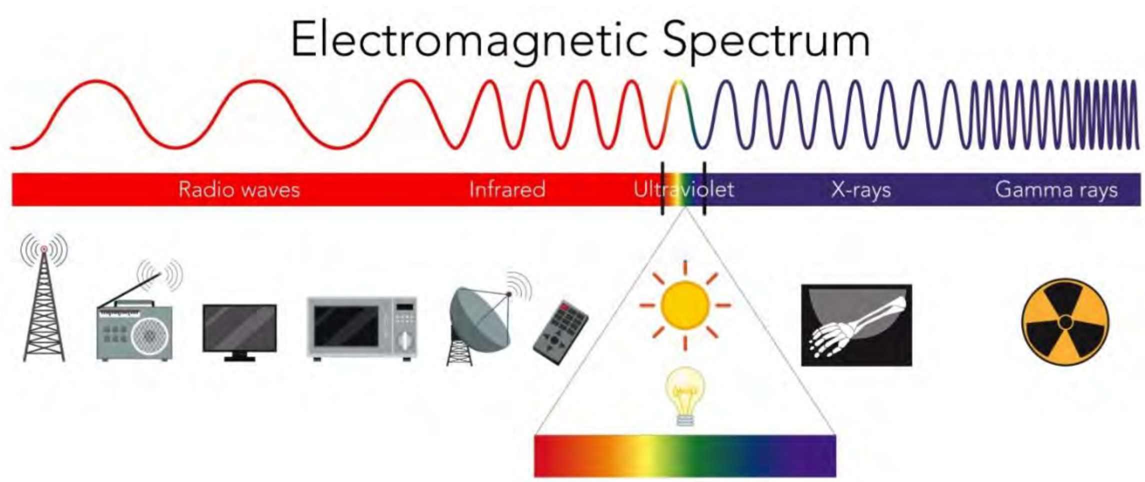
[37] NASA, "10 Things to Know About the Ionosphere," January 24, 2024, https://science.nasa.gov/earth/10-things-to-know-about-the-ionosphere/.
[38] Withington, "HF Radio: Still Valid After 100 Years - Asian Military Review."
[39] Jinlong Wang, Guoru Ding, and Haichao Wang, "HF Communications: Past, Present, and Future," China Communications 15, no. 9 (September 1, 2018): 1–9, https://doi.org/10.1109/cc.2018.8456447.

and automatically adjusts frequencies, gain and power based on atmospheric and ionospheric conditions to maintain the link, thus easing the burden and skillset required for operators. SDRs allow for frequency agility, adaptive modulation, and error correction which enhance communication quality and efficiency. Furthermore, SDRs employ techniques like frequency hopping spread spectrum (FHSS) that spreads the signal energy across multiple frequencies making interference and jamming even harder, ensuring reliable connectivity even in the presence of an adversary.[40]

HF communications offer a resilient solution for AC2 in DDIL environments, while offering global reach. To fully maximize these effects, the RCN must leverage advancements in HF technology and SDR capabilities, which lessens the skill and experience required for operators and technicians, while adding more functionality thus ensuring continuity of mission-critical communications amidst evolving threats.

INVESTING IN FUTURE TECHNOLOGIES

Besides renewing older systems, to successfully realize AC2 in warfare, it is crucial to invest in new communication technologies designed for use in environments where adversaries can deny or degrade communications. The development of resilient and adaptive communication solutions, which are designed for low-probability-of-intercept (LPI), low-probability-of-detection (LPD) with anti-jamming capabilities, is crucial in a DDIL environment. The key is to leverage parts of the EMS (as seen in Figure 5) that are even harder to deny or degrade by utilizing light and laser-based technologies to achieve AC2. By harnessing the potential of emerging light-based communication tools, navies can effectively adapt to the complexities of modern warfare, ensuring strategic superiority and mission success in future confrontations.



[40] L3Harris Technologies, Inc., "Staying Connected Through the Power of Modern HF," L3Harris® Fast. Forward., October 31, 2023, https://www.l3harris.com/newsroom/editorial/2023/10/staying-connected-through-power-modern-hf.

Figure 5 – Electromagnetic Spectrum[41]

As discussed earlier, ships enter EMCON states for various reasons, but mainly to avoid detection and interception by adversaries. Furthermore, communications on a specific frequency can be jammed by sending a stronger signal across said frequency. The fleet is thus left vulnerable when conducting operations near an adversary with such EW capabilities, while relying solely on RF communications. Hence, a need for reliable alternative means of communications becomes apparent.

While RF communications have their stated limitations, their major advantage is that they can be used to communicate BLOS and reach vast distances. The first major impediment to using light-based LOS methods is the need to be close enough to see the source of the transmission. Thus, LOS communications will largely be relegated to tactical communications within a fleet where a TG commander will still be able to exercise C2 over their fleet, but may have little to no value as a strategic long range communication method. The second disadvantage of LOS communications is that traditionally they have been slow, with a very small data throughput as they are mostly done manually. While LOS methods such as morse code flashing light, semaphore and flag hoists are still used today,[42] they are mainly used for training purposes and to maintain traditions but are rarely used to pass on any vital tactical information due to the speed and ease of other RF methods. Free space optics (FSO) is a communication technology that enables the transmission of data using modulated light through the air, typically over short to medium distances. FSO utilizes laser beams or infrared light to establish a direct LOS connection between two points, a transmitter and a receiver, each equipped with optical components such as lasers, lenses, and photodetectors.[43] While commercial FSO systems are slowly being introduced between fixed sites such as metro network extensions, last-mile access, enterprise connectivity, and disaster recovery; military and specifically naval applications of FSO technologies are not yet widely available due to the more challenging mobile nature of military vessels, and specifically the motion of ships caused by sea conditions.[44] Automated acquisition, tracking and pointing (ATP) systems are required for FSO implementation on mobile platforms. These ATP systems must account for each ships' speed, movement (roll, pitch and yaw) and sea conditions (as seen in Figure 6), as well as the relative speed between two moving ships to keep a constant communications link between the two platforms.

---

[41] Alexis Martin, "The Electromagnetic Spectrum," Online Learning College, August 17, 2022, https://online-learning-college.com/knowledge-hub/gcses/gcse-physics-help/electromagnetic-spectrum/.
[42] Jerry Proc, "Visual Signalling," n.d., http://www.jproc.ca/rrp/rrp2/visual.html.
[43] Fibre Systems, "US Navy Experiments With Free-space Optics System for Ships | Fibre Systems," n.d., https://www.fibre-systems.com/news/us-navy-experiments-free-space-optics-system-ships.
[44] Oguzhan Timus, "FREE SPACE OPTIC COMMUNICATION FOR NAVY SURFACE SHIP PLATFORMS," Defense Technical Information Center, March 2004, https://apps.dtic.mil/sti/citations/ADA422340.

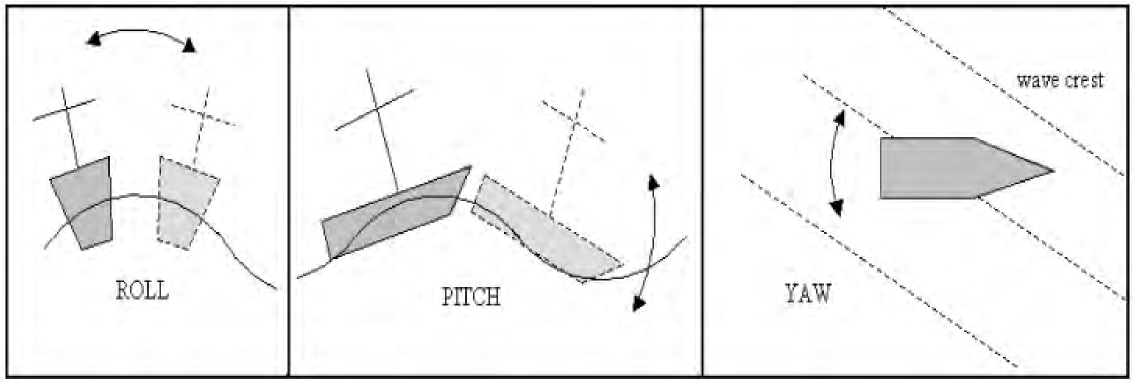


Figure 6 – Ships movements[45]

While these technical limitations can be solved, they require some hardening and ingenuity to ensure that the ATP systems can operate in adverse environmental conditions at sea. There may also be requirements for more than one ATP system per ship (so that they can ensure that the LOS isn't obstructed by items such as radars and masts on the upper decks, or to be able to communicate with more than one other ship at a time). Commercial shipping will continue to rely on RF communication as they have no viable use case for an FSO system, making the development of mobile ATP maritime systems a military only endeavor to meet their specific needs such as "system mobility, link range, and data rate all while operating in the highly scintillated terrestrial environment, especially close to the water."[46]

One of the key advantages of FSO is its high data transmission rates, which can rival or even exceed those of traditional wired connections like fiber optics. In a 2017 trial, the United States Navy (USN) was able to achieve data rates as high as 7.5Gb/s between two vessels during a 2017 test.[47] "Error free data transport at 1–2Gb/s was achieved at ranges greater than 25km; voice communications was possible over more than 35km; and chat messaging out to 45km."[48] FSO systems designed for naval use continue to be tested and upgraded, with improvements planned to integrate RF and FSO technologies into a mesh airborne network.[49]

Another advantage of FSO technology is the fact that the signal is highly concentrated in a laser-beam and aimed directly at the receiver. This means that FSO are highly resistant to adversary jamming, disruption, or intercept, as the adversary would need to physically be between the sender and receiver to affect the communications. This also means that FSO communications within a TG would allow for a LPD, allowing the exact geolocation of the TG to remain unknown to an adversary, and would also be LPI thus ensuring the confidentiality and availability of the communications.

---

[45] Timus, "FREE SPACE OPTIC COMMUNICATION FOR NAVY SURFACE SHIP PLATFORMS."
[46] Fibre Systems, "US Navy Experiments With Free-Space Optics System for Ships | Fibre Systems."
[47] Fibre Systems, "US Navy Experiments With Free-Space Optics System for Ships | Fibre Systems."
[48] Ibid.
[49] Ibid.

While FSO systems are not yet ready for widespread adoption, Canada's Five Eyes partners such as the USN and the Royal Navy (RN) continue to test and trial the technology to implement it as a means of AC2.[50] Naval platforms increasingly need to operate effectively in reduced-RF or EMCON conditions while maintaining their tactical advantage and situational awareness, and FSO emerges as a viable and robust solution. By proactively investing in this next-generation technologies and partnering with Five Eyes partners, the RCN can mitigate the risks posed by adversarial interference, thereby safeguarding C2 functions critical to mission success in future conflicts.

EMPLOYING AN INFORMATION WARFARE COMMANDER

Renewed HF and future FSO systems bring new capabilities that enable AC2 in a DDIL environment, but relying solely on new technologies for future conflicts may still prove insufficient. While advancements in communication technologies are crucial, their effectiveness hinges on skilled tactical adaptations, procedural adjustments, and the expertise of personnel. To ensure resilient communication in a HEW, naval forces must prioritize the integration of strategic planning, training, and skilled personnel capable of swiftly recognizing situations and adapting tactics and procedures to dynamic conditions. Five Eyes partners are committed to having a team of experts integrated within a TG that will oversee all information related capabilities (IRC) and activities. Five Eyes partners have been developing the concept of an Information Warfare Commander (IWC) that will have the situational awareness and expertise to prioritize all IRCs based on the tactical situation. The RN and USN have already deployed this nascent capability within some of their carrier TGs,[51] and continue to develop the tactics, techniques, and procedures (TTP) to exercise AC2 in a DDIL scenario.

Modern naval warfare has been effectively divided into well-established sub-domains for the better portion of the last century.[52] The CWC structure assigns principal warfare commanders (PWC) to specific sub-domains such as anti-submarine warfare (ASW), anti-air warfare (AAW) and anti-surface warfare (ASuW), to name a few.[53] Each PWC is responsible for their specific area of warfare and reports to an OTC that coordinates and prioritizes the entire modern naval battle. The OTC normally assigns EMCON conditions and gives overall direction to ensure communication stability and availability. As discussed throughout, Commanders now face ever escalating complexity in the information environment (IE), necessitating comprehensive consideration of Information Warfare (IW) tactics across all operational domains. Safeguarding the IE becomes imperative to enable freedom of action to conduct operations effectively as technological advancements have heightened the complexity of the IE, making it a

---

[50] "Global Underwater Hub," Global Underwater Hub, n.d., https://www.globalunderwaterhub.com/media-centre/news-feed/article/?title=US%20Navy%20RFI%20for%20free%20space%20optics%20communications.

[51] United States Navy, "Information Warfare Commander Holds Change of Command Ceremony at Hist," n.d., https://www.navy.mil/Press-Office/News-Stories/Article/2603280/information-warfare-commander-holds-change-of-command-ceremony-at-historic-penn/.

[52] Wayne P. Hughes and Robert Girrier, Fleet Tactics and Naval Operations, 3rd ed. (US Naval Institute Press, 2018).

[53] North Atlantic Treaty Organization. Allied Maritime Tactical Instructions and Procedures. ATP-01. Newport: NATO Standardization Agency, 2002.

contested territory for adversaries and friendly forces alike.[54] This has necessitated the need to establish a new PWC, known as the IW Commander (IWC), whose role is to know the complexities and vulnerabilities of the other areas of warfare, but also has expertise in the IE (consisting of the EMS, space, cyber, and information domains) and knows best how to accomplish a mission while maintaining the three aspects of AC2 (C2, MDA/BSA, and Integrated Fires) (as seen in Figure 7). The Canadian Armed Force's (CAF) own Pan-Domain Force Employment Concept (PFEC) states that "the CAF must develop deep expertise across all domains, particularly in the newer and less understood space and cyber domains, as well as in the [IE], and incorporate that expertise into operations."[55]

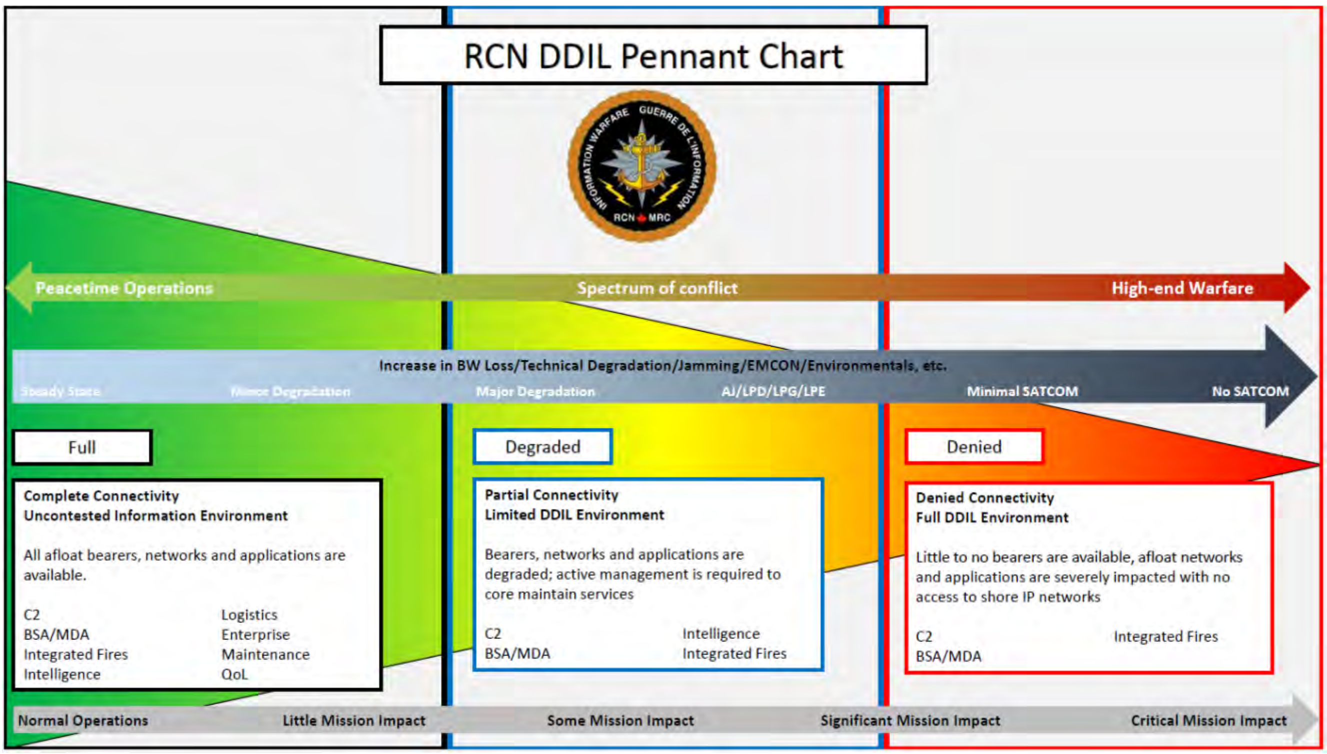


Figure 7 – RCN DDIL Pennant Chart[56]

"Pan-domain integration will require the CAF to view the connections and relationships between domains, capabilities, and forces as equally important or even more important than these components themselves."[57] The IWC will assume this critical role of integrating operations within the TG to ensure AC2 across all warfighting domains at sea. "[IWCs] need a proficient understanding of weapon systems, emitters, and the threat and must understand where these systems overlap and where they conflict with other warfare

---

[54] Dale Armstrong, "Principal Maritime Information Warfare Commander" (Service Paper, Canadian Forces College, 2021), https://www.cfc.forces.gc.ca/259/290/23/192/Armstrong.pdf.
[55] Canadian Armed Forces, "Pan-Domain Force Employment Concept" (National Defence, 2023).
[56] Directorate of Naval Information Warfare, "RCN DDIL Pennant Chart."
[57] Canadian Armed Forces, "Pan-Domain Force Employment Concept."

commander's objectives."[58] The IWC will then be able to refine the OTC's priorities and preplanned responses to ensure mutual understanding across warfare areas, enable mission command, and meet the commander's intent. The IWC thus advises the OTC and other PWCs on maneuver schemes essential for executing operations while considering all aspects of the IE, such as LPI/LPD when making EMCON recommendations, and will prioritize and shift communication methods to ensure that all aspects of AC2 are maintained. The IWC's specialized understanding of all threat dynamics and vulnerabilities and specifically the IE, uniquely positions them to assess risks to friendly forces, particularly concerning changes in posture resulting from the execution of various EMCON plans. According to Capt Wayne Hughes Jr., USN (Ret.), to know tactics, you must know technology,[59] and the IWC has a unique expertise where they understand the impact of all technologies and how they inter-relate through their tactical use in modern warfare. Ultimately, the establishment of an IWC fosters better collaboration with joint and combined operational partners and allies, while facilitating a more focused campaign to achieve strategic objectives at sea. The integration of the IWC will allow the OTC to "possess a sufficient combination of integral capabilities and external support to maintain pan-domain situational awareness, integrate pan-domain effects, and defend across domains"[60] as envisioned by the PFEC.

The role of the IWC is pivotal when executing operations and missions, by ensuring that relevant information is received, processed, and passed on to the appropriate PWC so that the OTC's command intent is met. They will have the expertise to know when to switch technologies to ensure AC2, such as utilizing updated HF communications, or entering EMCON and using FSO, all based on the tactical situation and the adversarial threat. The IW staff under the IWC will ensure that training IW evolutions is routinely conducted during workups, exercises, and other FG serials so that the entire warfare team works cohesively across all domains. The current reliance on SATCOM and other RF bearers means that rarely do ships train to be in a highly disruptive DDIL environment.[61] The RCN must train like it will fight, and that includes not deliberately separating IW training from other warfare training. These events must overlap not only for the IWC, but for all PWCs, to gain proficiency in meeting all commanders' requirements in the most adverse IE and DDIL conditions.

The RCN recognizes the importance of the IWC construct, as they took a leading role in developing the North Atlantic Treaty Organization's (NATO) Allied Tactical Publication (ATP) that established the IWC as a new PWC within the CWC construct.[62] ATP-113, Maritime Information Warfare, describes the role of the IWC and the IW staff, their functions and responsibilities, and how they work and relate to the other warfare

---

[58] "Make Information Warfare the Supported Warfare Commander | Proceedings - September 2023 Vol. 149/9/1,447," U.S. Naval Institute, August 31, 2023, https://www.usni.org/magazines/proceedings/2023/september/make-information-warfare-supported-warfare-commander.
[59] Hughes and Girrier, Fleet Tactics and Naval Operations. Pg 7
[60] Canadian Armed Forces, "Pan-Domain Force Employment Concept."
[61] "No-Space Days: Conducting Sustained Operations in a Denied Environment" (Service Paper, Canadian Forces College, 2023), https://www.cfc.forces.gc.ca/259/290/49/192/Anon269.pdf.
[62] Armstrong, "Principal Maritime Information Warfare Commander."

domains.[63] As the RCN has yet to establish its own IWC training, it must rely on its Five Eyes partners like the USN and RN, to train the initial cadre of IW professionals that will fill this vital role within a TG. The IWC's role will continue to grow in importance as the adversary's capabilities improve, and this is not an area the RCN can afford to be left behind on.

Effective C2 in warfare demands not just technological advancements but also thorough adaptations to TTPs, and expert training for personnel. To navigate the complexities of the IE, naval forces must prioritize strategic planning, training, and the integration of personnel capable of swift recognition and adaptation to dynamic conditions. The establishment of an IWC within TGs, as envisioned by Five Eyes and NATO partners, represents a critical step in ensuring AC2 across all warfighting domains at sea. By leveraging their specialized understanding of threat dynamics and vulnerabilities, the IWC facilitates better collaboration with joint and combined operational partners, fostering a more focused campaign to achieve strategic objectives. The integration of the IWC not only enhances operational effectiveness but also ensures that relevant information is processed and disseminated effectively to meet command intent, with training across all warfare domains crucial for proficiency in adverse IE conditions. As the RCN recognizes the significance of the IWC construct and its evolving role, collaboration with allies and investment in training will be vital to staying ahead in an increasingly complex and contested maritime landscape.

CONCLUSION

"Today, there does not seem to be a speedup in the advent of new and revolutionary weapons that matches the accelerating pace of technology itself."[64] This evolution of communication technologies, from the ancient methods of smoke signals to the modern era of 5G cellular networks and SATCOM, has profoundly impacted both societal and military landscapes, propelling us into an era of unprecedented connectivity and information exchange. However, as we enter the complexities of future HEW scenarios, the imperative to achieve AC2 in DDIL environments becomes increasingly critical. Amidst this technological evolution, adversaries such as Russia and China have rapidly developed and deployed sophisticated capabilities aimed at disrupting Western militaries' access to the EMS. These nations possess the ability through EW tactics, to easily jam or intercept RF signals, compromising communication channels vital for C2 functions. China's demonstrated ability to disrupt GPS and communication signals, and Russia's utilization of GPS jamming technology in both defensive and offensive capacities underscore the growing sophistication and overt intent of these adversary's capabilities. Moreover, their advancements in ASAT capabilities, including kinetic and non-kinetic methods, pose significant threats to satellite-based global communication and navigation systems, further exacerbating the challenge of maintaining C2 abroad.

---

[63] North Atlantic Treaty Organization. Maritime Information Warfare. ATP-113. Halifax: NATO Standardization Agency, 2020.
[64] Hughes and Girrier, Fleet Tactics and Naval Operations. Pg 226

To counter these threats and ensure AC2 in future conflicts, the RCN must not only improve existing communication systems but also invest in innovative technologies resilient to adversary interference. Revitalizing legacy systems, such as HF communications, presents a resilient solution for bridging vast distances amidst DDIL environments. Developments in HF waveform technology and the integration of SDRs offer technological advancements and capabilities that ensure the continuity of mission-critical communications. Investment in future technologies is equally crucial. Emerging light-based communication, such as FSO, offer potential solutions resistant to adversary jamming and disruption. Offering LPI/LPD and high data transmission rates, FSO systems promise robust communication channels for naval operations.

Furthermore, the integration of an IWC within TGs represents a critical step in enhancing naval operations' resilience and effectiveness. The IWC's role in prioritizing IW tactics across all maritime operational domains ensures strategic superiority amidst evolving threats. Collaboration with the RCN's allies and investment in training are paramount to effectively implementing the IWC construct and staying ahead in the dynamic maritime landscape.

As we confront the realities and challenges of modern warfare, the path to achieving AC2 lies in a comprehensive approach that combines technological innovation, strategic planning, and personnel training. By remaining vigilant to emerging threats and collaborating with allies, naval forces can navigate the IE and maintain operational effectiveness in the face of evolving challenges posed by adversarial actors.

BIBLIOGRAPHY

Al-Saegh, Ali M., Taha A. Elwi, Osama A. Abdullah, Aduwati Sali, and Abdulmajeed Al-Jumaily. "Rainfall Effect on Satellite Communications in Mosul at Frequencies above 10 GHz." 2021 7th International Conference on Space Science and Communication (IconSpace), November 23, 2021. https://doi.org/10.1109/iconspace53224.2021.9768738.

Armstrong, Dale. "Principal Maritime Information Warfare Commander." Service Paper, Canadian Forces College, 2021. https://www.cfc.forces.gc.ca/259/290/23/192/Armstrong.pdf.

Berg, Cameron. "Understanding How Solar Flares Affect Radio Communications." Barrett Communications, July 20, 2022. https://www.barrettcommunications.com.au/news/understanding-how-solar-flares-affect-radio-communications/.

Bigelow, Robert P. "Wireless in Warfare, 1885-1914 | Proceedings - February 1951 Vol. 77/2/576." U.S. Naval Institute, July 7, 2023. Accessed March 22, 2024. https://www.usni.org/magazines/proceedings/1951/february/wireless-warfare-1885-1914

Canadian Armed Forces. "Pan-Domain Force Employment Concept." National Defence, 2023.

Canadian Global Affairs Institute. "The Rise and Fall of Military Strategic Communications at National Defence 2015-2021: A Cautionary Tale for Canada and NATO, and a Roadmap for Reform," n.d. https://www.cgai.ca/the_rise_and_fall_of_military_strategic_communications_at_national_defence_2015_2021.

Department of Defense, "2020 Department of Defense Electromagnetic Spectrum Superiority Strategy" (Department of Defense, October 2020), https://media.defense.gov/2020/Oct/29/2002525927/-1/-1/0/ELECTROMAGNETIC_SPECTRUM_SUPERIORITY_STRATEGY.PDF.

Desmarais, Anna. "GPS Jamming by Russia Was Already a Concern. For the Nordic NATO Countries, It May Only Get Worse." Euronews, March 14, 2024. https://www.euronews.com/next/2024/03/13/gps-jamming-by-russia-was-already-a-concern-for-the-nordic-nato-countries-it-may-only-get-.

Directorate of Naval Information Warfare, "RCN DDIL Pennant Chart" (Royal Canadian Navy, March 2023).

Encyclopedia Britannica, "Learn How Solar Flares Can Affect Satellites, Rockets, Telecommunications Systems and Activity on the Surface of the Earth," in

Encyclopedia Britannica, n.d., https://www.britannica.com/video/183276/overview-solar-flares.

Everything RF, "What Is the Impact of Rain on RF Signal Propagation? - Everything RF," n.d., https://www.everythingrf.com/community/what-is-the-impact-of-rain-on-rf-signal-propagation.

Fibre Systems. "US Navy Experiments With Free-space Optics System for Ships | Fibre Systems," n.d. https://www.fibre-systems.com/news/us-navy-experiments-free-space-optics-system-ships.

Global Underwater Hub. "Global Underwater Hub," n.d. https://www.globalunderwaterhub.com/media-centre/news-feed/article/?title=US%20Navy%20RFI%20for%20free%20space%20optics%20communications.

Hines, Aaron. (United States Space Force Major), in discussion with the author. March 2024.

Hughes, Wayne P., and Robert Girrier. Fleet Tactics and Naval Operations. 3rd ed. US Naval Institute Press, 2018.

Hsu, Jeremy. "Unprecedented GPS Jamming Attack Affects 1600 Aircraft Over Europe." New Scientist, April 2, 2024. https://www.newscientist.com/article/2424678-unprecedented-gps-jamming-attack-affects-1600-aircraft-over-europe/.

L3Harris Technologies, Inc. "Staying Connected Through the Power of Modern HF." L3Harris® Fast. Forward., October 31, 2023. https://www.l3harris.com/newsroom/editorial/2023/10/staying-connected-through-power-modern-hf.

Leigher, William E. "U.S. Navy Information Dominance Roadmap, 2013–2028," 2013. https://defenseinnovationmarketplace.dtic.mil/wp-content/uploads/2018/02/Information_Dominance_Roadmap_March_2013.pdf.

Lespretentieux. "HF Communications Are Making a Comeback, and Here's Why You Need to Get in on It! - Base Camp Connect." Base Camp Connect, February 10, 2022. https://www.basecampconnect.com/hf-communications-making-a-comeback.

Lim, Natalie Chen Yi, Lisa Yong, Hieng Tiong Su, Abel Yu Hao Chai, Chamath Kalanaka Vithanawasam, Yi Lung Then, and Fei Siang Tay. "Review of Temperature and Humidity Impacts on RF Signals." 2020 13th International UNIMAS Engineering Conference (EnCon), October 27, 2020. https://doi.org/10.1109/encon51501.2020.9299327.

Liu, Ningyu, and J. R. Dwyer. "Thunderstorm High-Frequency Radio Bursts With Weak Low-Frequency Radiation." Geophysical Research Letters 47, no. 23 (December 1, 2020). https://doi.org/10.1029/2020gl090325.

Luckenbaugh, Josh. "Space Force Still Dodging Chinese Satellite Debris." National Defense Magazine, December 15, 2023. Accessed April 16, 2024. https://www.nationaldefensemagazine.org/articles/2023/12/15/space-force-still-dodging--chinese-satellite-debris.

Marconi, Guglielmo, Sr., and HB Jackson. "History of Naval Ships Wireless Systems I 1890's to the 1920's." History of Naval Ships Wireless Systems, 1897. https://rnzncomms.files.wordpress.com/2011/01/history-of-naval-ships-wireless-systems.pdf.

Martin, Alexis. "The Electromagnetic Spectrum." Online Learning College, August 17, 2022. https://online-learning-college.com/knowledge-hub/gcses/gcse-physics-help/electromagnetic-spectrum/.

Military+Aerospace Electronics. "Navy eyes free-space laser communications to transmit wireless data to users more than six miles away." Military+Aerospace Electronics, June 24, 2021. https://www.militaryaerospace.com/communications/article/14205806/laser-communications-wireless.

NASA. "10 Things to Know About the Ionosphere," January 24, 2024. https://science.nasa.gov/earth/10-things-to-know-about-the-ionosphere/.

"No-Space Days: Conducting Sustained Operations in a Denied Environment." Service Paper, Canadian Forces College, 2023. https://www.cfc.forces.gc.ca/259/290/49/192/Anon269.pdf.

North Atlantic Treaty Organization, "ALLIED TACTICAL PUBLICATION - 01, VOLUME I,: ALLIED MARITIME TACTICAL INSTRUCTIONS AND PROCEDURES Edition (D)" (North Atlantic Treaty Organization, January 2002).

North Atlantic Treaty Organization, "ALLIED TACTICAL PUBLICATION - 01, VOLUME II,: ALLIED MARITIME TACTICAL SIGNAL AND MANEUVERING BOOK Edition (G) Version (1)" (North Atlantic Treaty Organization, January 2016).

North Atlantic Treaty Organization. Maritime Information Warfare. ATP-113. Halifax: NATO Standardization Agency, 2020.

Proc, Jerry. "Visual Signalling," n.d. http://www.jproc.ca/rrp/rrp2/visual.html.

Redmon, R. J., Daniel B. Seaton, R. A. Steenburgh, Jing He, and J. V. Rodriguez. "September 2017's Geoeffective Space Weather and Impacts to Caribbean Radio Communications During Hurricane Response." Space Weather 16, no. 9 (September 1, 2018): 1190–1201. https://doi.org/10.1029/2018sw001897.

Rens, Jean-Guy. Invisible Empire: A History of the Telecommunications Industry in Canada, 1846-1956. McGill-Queen's Press - MQUP, 2001.

Richter, Stephen P. "Digital Semaphore: Tactical Implications of QR Code Optical Signaling for Fleet Communications." Master's Thesis, NAVAL POSTGRADUATE SCHOOL MONTEREY CA, 2013. https://apps.dtic.mil/sti/citations/ADA582902.

Royal Canadian Navy, "The Oceans and Great Power Competition in Our Era" (Canadian Armed Forces, March 2023).

Saines, Maddie, and Maddie Saines. "Australian Aircraft's GPS Receiver Jammed Allegedly by Chinese Warships - GPS World." GPS World - The Business and Technology of Global Navigation and Positioning (blog), April 12, 2023. https://www.gpsworld.com/australian-aircrafts-gps-receiver-jammed-by-alleged-chinese-warships/.

"SMOS and Swarm Team up to Spot Huge Solar Storm," n.d., https://www.esa.int/Applications/Observing_the_Earth/FutureEO/SMOS_and_Swarm_team_up_to_spot_huge_solar_storm#:~:text=Space%20weather%20%E2%80%93%20electromagnetic%20radiation%20and,communications%20and%20even%20power%20grids.

"Solar Flares (Radio Blackouts) | NOAA / NWS Space Weather Prediction Center," n.d., https://www.swpc.noaa.gov/phenomena/solar-flares-radio-blackouts#:~:text=When%20a%20strong%20enough%20solar,environment%20of%20the%20D%2Dlayer.

Stein, Aaron. "Is Military Space-Based Jamming Normal? Some Worry It Is - War on the Rocks." War on the Rocks, February 15, 2024. https://warontherocks.com/2023/11/is-military-space-based-jamming-normal-some-worry-it-is/.

Times, Moscow. "Russia Expands GPS Signal Jamming to 15 Regions." The Moscow Times, April 16, 2024. https://www.themoscowtimes.com/2023/05/05/russia-expands-gps-signal-jamming-to-15-regions-a81049.

Timus, Oguzhan. "FREE SPACE OPTIC COMMUNICATION FOR NAVY SURFACE SHIP PLATFORMS." Defense Technical Information Center, March 2004. https://apps.dtic.mil/sti/citations/ADA422340.

U.S. Department of Defense. "New Spectrum Strategy Reveals DOD's Plan to Master Airwaves," n.d. https://www.defense.gov/News/News-

Stories/Article/Article/2404027/new-spectrum-strategy-reveals-dods-plan-to-master-airwaves/.

U.S. Naval Institute. “Make Information Warfare the Supported Warfare Commander | Proceedings - September 2023 Vol. 149/9/1,447,” August 31, 2023. https://www.usni.org/magazines/proceedings/2023/september/make-information-warfare-supported-warfare-commander.

United States Navy. “Information Warfare Commander Holds Change of Command Ceremony at Hist,” n.d. https://www.navy.mil/Press-Office/News-Stories/Article/2603280/information-warfare-commander-holds-change-of-command-ceremony-at-historic-penn/.

Wang, Jinlong, Guoru Ding, and Haichao Wang. “HF Communications: Past, Present, and Future.” China Communications 15, no. 9 (September 1, 2018): 1–9. https://doi.org/10.1109/cc.2018.8456447.

Weeden, Brian and Secure World Foundation. “2007 Chinese Anti-Satellite Test,” 2007. https://swfound.org/media/9550/chinese_asat_fact_sheet_updated_2012.pdf.

Wilson, Tom and Commission to Assess United States National Security Space Management and Organization. “Threats to United States Space Capabilities,” 2001. https://spp.fas.org/eprint/article05.html.

Withington, Thomas. “HF Radio: Still Valid After 100 Years - Asian Military Review.” Asian Military Review, June 10, 2020. https://www.asianmilitaryreview.com/2020/06/hf-radio-still-valid-after-100-years/.

Wright, David. “Space Debris.” Physics Today 60, no. 10 (October 1, 2007): 35–40. https://doi.org/10.1063/1.2800252.