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Quantum Radar Is Stealth Radar: Examining the Potential Impact on the Defence Team

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QUANTUM RADAR IS STEALTH RADAR: EXAMINING THE POTENTIAL IMPACT ON THE DEFENCE TEAM

AIM

1. In February 2021, the Department of National Defence (DND) and the Canadian Armed Forces (CAF) released its Quantum Science and Technology (S&T) Strategy.[1] The strategy acknowledges that quantum technologies will be disruptive to the future operating environment. The strategy does not substantively explore which technologies are preeminent, and which ones could be the most disruptive to the modern battlefield. The following paper will explore the current status of *quantum radar* (QuDAR), its potential applications in the defence establishment, current progress by near-peer adversaries, and provide recommendations on how DND/CAF proceeds over the next five years.

BACKGROUND

2. The Battle of Midway was fought in 1942. It saw the United States Navy (USN) Pacific Fleet inflict heavy losses on the Imperial Japanese Navy. Going into the battle, the US had two major advantages. The first advantage was intelligence regarding Japan's scheme of manoeuvres, gathered through the earlier breaking of its communication codes. The USN knew when and where a strike would happen. The second advantage was a technological one in terms of radar and sonar. Radar and sonar provided the USN with the ability to detect enemy aircraft and ships at longer ranges, and better prepare for attacks. Quantum technologies, in particular QuDAR, could represent the next major step in advanced sensors currently dominated by active electronically scanned array (AESA) systems such as the SPY-6.[2]

3. The most basic theoretical principle behind QuDAR involves the generation of an entangled photon pair, also called quantum entanglement. These two entangled particles are more strongly connected than non-entangled particles used in current radars, and their quantum states remain more strongly linked across any distance than classical counterparts. In theory, when one particle is affected, it can be compared or correlated with its pair, and measurable properties such as position, spin momentum and polarization determined.[3]

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[1]Department of National Defence, *DND/CAF Quantum S&T Strategy: Preparing for disruptions in the future operating environments* (Ottawa: Defence Research and Development Canada, 2021), 6.

[2]Raytheon Missiles and Defence, "U.S. Navy's SPY-6 Family of Radars," last accessed 9 January 2022, https://www.raytheonmissilesanddefense.com/capabilities/products/spy6-radars.

[3]D. Luong et al, "Receiver Operating Characteristics for a Prototype Quantum Two-Mode Squeezing Radar," *IEEE Transactions on Aerospace and Electronic Systems* 56, no. 3 (June 2020), 1.

4. At its core, radar measures correlation between a transmitted signal and a replica of the transmitted signal. From a QuDAR perspective, an entangled signal provides a pair of photons, termed signal and idler, where the correlation between the signal and idler is much stronger than is possible using radar transmitters built with current technologies. QuDAR in development today (referred to as class 1), involve sending one of the paired photons towards a target, and retaining the second photon.[4] The first photon, down converted from the visible light spectrum to microwave frequency, would then work in conjunction with a classical radar transceiver setup. The downrange photon would hit a target and be reflected back, indicating the presence of a target. A high-level diagram of a QuDAR can be found at Annex A. According to a joint paper between the University of Waterloo's Institute for Quantum Computing (IQC), and Defence Research and Development Canada (DRDC) Radar Sensing and Exploitation group, a class 1 QuDAR can see detection improvements by a factor of 10, i.e. the required time on target to detect is one-tenth that of the best possible classical radar.[5] This improvement factor can not only overcome interference such as clutter, jammers, and noise, but potentially even defeat stealth technology of modern military aircraft.

5. Despite the promise of QuDAR and its potential for military applications, technological challenges and debate within the scientific community exist. A study done by Lincoln Laboratory / Massachusetts Institute of Technology (MIT) for the Under Secretary of Defense Research and Engineering, concluded the feasibility of Quantum Illumination Radar (QIR) as having low potential.[6] Specifically, they stated in their executive summary that "Quantum radar does not have the potential for long range standoff sensing (>10 km) at radio frequencies (<100 GHz)."[7] Supporting their conclusions are key findings that system requirements (namely superconductivity) needed to realize quantum enhancements are a limiting factor, and that the integration time for a returning pulse could require up to three years of processing time. The Defence Science Board, an independent Department of Defence board of advisors, has also concluded that quantum radar "will not provide upgraded capability to the DOD."[8] Despite these concerns, the US National Quantum Initiative Act was signed into law on 22 December 2018, providing $1.2 billion to fund activities that promote and develop quantum information science.[9]

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[4]John Haystead, "Quantum Radar Sees the Light," *The Journal of Electronic Defense* (July 2019): 25.

[5]C.W. Sandbo Chang et al, "Quantum-enhanced noise radar," Applied Physics Letters 114, no. 112601 (2019): 4, https://doi.org/10.1063/1.5085002.

[6]Lincoln Laboratory Massachusetts Institute of Technology, "Quantum Illumination Radar Feasibility," last accessed 9 January 2022, https://apps.dtic.mil/sti/pdfs/AD1132052.pdf.

[7]*Ibid.*

[8]Congressional Research Service, *Defense Primer: Quantum Technology* (Washington, DC: United States Congress, 2021), 1.

[9]MIT Technology Review, "President Trump has signed a $1.2 billion law to boost US quantum tech," last accessed 9 January 2022, https://www.technologyreview.com/2018/12/22/138149/president-trump-has-signed-a-12-billon-law-to-boost-us-quantum-tech/.

6. Other organizations and emerging scientific literature seem to disagree with these conclusions. In a 2019 study for the Swedish Ministry of Defence, the Swedish Defence Research Agency concluded that QuDAR is based on solid and well-accepted physics,[10] and has the potential to surpass its classical counterparts, if a sufficient amount of research and engineering is put into the endeavour. Dr. Bhashyam Balaji from DRDC Ottawa comes to similar conclusions.[11] While acknowledging that the cryogenic / superconductivity infrastructure needed to generate an entangled photon pair in the microwave frequency is currently a challenge for future real-world applications, he also concludes that "QIR can definitely be built … however, building a QIR will require a concerted and proper investment, which could result in some demanding and very important defence applications."[12] In fact, several lab based prototypes, with verifiable results have already been developed in both Canada and Austria.[13] China also claims to have deployed a system capable of operating up to 62 miles; claims which have not been independently verified.[14]

7. There are many technological routes to building a QuDAR, just as there are many ways to build a quantum computer. The most popular route today is based on working directly in the microwave regime. However, this approach requires demanding cryogenics in the form of dilution refrigeration allowing you to operate in the milli-kelvin temperature range. Cryogenics is clearly unsuitable for materiel fielding by armed forces in the short term. Another more promising approach would be to carry out optical-to-microwave photon conversion. Although this is currently at a lower technological readiness level, it would lead to considerably more compact QuDARs. As a point of comparison, the first mobile phones were roughly the size of a briefcase, and are now only limited in size by the anatomy of the human hand. Miniaturization will undoubtably solve these infrastructure issues, as long as the theoretical application of the technology in warfare is built upon strong scientific concepts.

DISCUSSION

8. In a comprehensive article for the *Journal of Electronic Defense,* senior editor John Haystead concludes that QuDAR "…is one of the most significant technologies

[10]Swedish Defence Research Agency, *Quantum Radar: A survey of the science, technology and literature* (Stockholm: Ministry of Defence, 2019), 4.

[11]Bhashyam Balaji, *Quantum Radar: Snake Oil or Good Idea?,* 2018 International Carnahan Conference on Security Technology (Montreal: IEEE, 2018), 6.

[12]*Ibid.*

[13]D. Luong et al, "A Quantum-Enhanced Radar Prototype," *2019 IEEE Radar Conference* (2019), 1, https://doi.org/10.1109/RADAR.2019.8835632.

[14]Popular Mechanics, "China Claims It Developed "Quantum" Radar to See Stealth Planes," last accessed 9 January 2022, https://www.popularmechanics.com/military/research/a22996/china-quantum-stealth-radar/.

being pursued for military application, with the potential to supersede stealth in terms of its impact on the battlespace."[15] To come to this conclusion, he interviewed scientists closest to the technology from both IQC, Lockheed Martin, and DRDC. They conclude that QuDAR would be uniquely effective for detecting low reflectivity targets against a high noise background. For stealth objects like aircraft, which strive to reduce their radar cross section with curved surfaces and radar absorbing materials, quantum enhancements of traditional radar systems could make them more easily detectable. This includes correlating transmitted photons against those which were retained after the quantum entanglement process; resulting in reflected energy being better distinguished from background noise and interference. This improvement in signal to noise ratio (SNR) for returns would also by extension increase a radar's maximum detection range. Improving SNR by a factor of four or six-dB, which is a conservative estimate for QIR, would mean an increase in range of approximately 40%.[16]

9. The advantage of stealth in the aerospace domain, which extends to both the maritime and land environments, has been significant to western militaries. F-117 Nighthawk aircraft were the first to bomb Baghdad during Desert Storm, eluding enemy radars and delivering laser guided bombs with precision. The F-15, one of the most dominant fighters in history, has a radar cross section several orders of magnitude greater that of a F-35.[17] The F-15 as a result can be detected more than 200 miles out with modern radars. The F-35 on the other hand, can get within 21 miles before it is detected. This advantage enjoyed by the US and its allies for the last 30 years will not last. The Russians and Chinese have both fielded stealth aircraft over the last decade. The Russians have the Su-57 which entered service in December 2020. The Chinese are even further ahead with their now operational J-20. The Chinese J-31 aircraft, which has a similar profile to the F-35, could also soon be ready for mass production.[18] QuDAR therefore represents a burgeoning technology, that could provide a means of detecting these newly developed stealth fighters and bombers of our adversaries. With North American Aerospace Defense Command (NORAD) modernization now a priority for both Canada and the US, investing in a QuDAR capability also represents an opportunity to limit or outright defeat potential future intrusions by new Russian and Chinese stealth aircraft.[19]

10. Another area of warfare which will be affected by QuDAR is electronic warfare. As the transmitted energy of a QuDAR could be noise like, traditional electronic support

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[15]Haystead, *Quantum Radar Sees the Light,* 23.

[16]Edward Parker, *Commercial and Military Applications and Timelines for Quantum Technology* (Santa Monica, Calif: RAND, 2021), 7.

[17]Air Force Magazine, "History of Stealth: From Out of the Shadows," last accessed 9 January 2022, https://www.airforcemag.com/article/history-of-stealth-from-out-of-the-shadows/.

[18]*Ibid.*

[19]Government of Canada, "Joint Statement on Norad Modernization," last accessed 9 January 2022, https://www.canada.ca/en/department-national-defence/news/2021/08/joint-statement-on-norad-modernization.html.

measures and electronic intelligence (ELINT) collection systems will be hard pressed to detect their signals. Put in another way, the low probability of intercept (LPI) capability of a QuDAR is orders of magnitude better than existing radar. Additionally, lacking any processed ELINT, jamming any such quantum radar signal would be next to impossible, as the emitted entangled photons would exhibit a noise signal that will be exactly the same as background, thermal noise.[20] Currently, the vast majority of ELINT collection systems are found in both the maritime, and space environments. In addition, unmanned aerial systems, which are continuing to gain in prominence as more conventional threat scenarios develop, will feature ELINT systems.[21] Ignoring and not investing in quantum radar prototypes to better understand the technology and how to defeat it, could put at risk Canadian investments and projects, such as the Remotely Piloted Aircraft System, or the Canadian Surface Combatant. As famously stated by Sun Tzu, "victorious warriors win first and then go to war, while defeated warriors go to war first and then seek to win."

11. In the 2021 US Annual Threat Assessment, China's push for global power is listed as the leading threat to US national security.[22] In line with this report, its past and current substantial investments in quantum technologies should also serve as a wake-up call to not just the US, but to Canada as well. In 2017, China announced an investment of $10 billion to develop and build the National Laboratory for Quantum Information Sciences (NLQIS). This announcement, builds upon the launch of the first quantum communication satellite by China in 2016 just a year earlier. A Chinese defense contractor has also claimed to have successfully developed the world's first quantum radar system, unveiling it at the Zhuhai Airshow in China in November 2018.[23] Despite the inability to verify the claim regarding the development of a functional QuDAR, it is clear that China is leading the way in quantum technology breakthroughs, under the leadership of Jian-Wei Pan, referred to as "the father of quantum."[24]

12. Jian-Wei Pan has deep political, academic, and even military connections. While his scientific achievements and academic partnerships are well known in western circles, his links to the Chinese Communist Party and Chinese defence companies are less

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[20]Swedish Defence Research Agency, *Quantum Radar: A survey …,* 36.

[21]Journal of Electronic Dominance, "An Approach to UAV-Based ELINT," last accessed 10 January 2022, https://www.jedonline.com/2020/05/20/an-approach-to-uav-based-elint-jed-december-2017/.

[22]Office of the Director of National Intelligence, *2021 Annual Threat Assessment of the US Intelligence Community*, (Washington, DC: Congressional Intelligence Committees, 2021), 6.

[23]Spacewatch Asia Pacific, "China's CETC Claims Breakthrough in Quantum Radar Development," last accessed 10 January 2022, https://spacewatch.global/2018/11/chinas-cetc-claims-breakthrough-in-quantum-radar-development/.

[24]MIT Technology Review, "The Man Turning China into a Quantum Superpower," last accessed 10 January 2022, https://www.technologyreview.com/2018/12/19/1571/the-man-turning-china-into-a-quantum-superpower.

publicized.[25] An intelligence dossier produced by Strider Technologies, a Washington based security company, detailed the extent of the collaboration through publicly available Chinese language documents.[26] One of the most interesting connections was that Pan signed a 2018 cooperation agreement between his university, the University of Science and Technology of China, which houses the NLQIS, and China Electronics Technology Group Corporation (CETC). CETC is a large state-owned defense contractor, and coincidentally, the firm which unveiled China's first QuDAR in 2018. Due to China's National Security laws, it should come as no surprise that any academic progress with quantum technologies, will be passed over to the defense and military establishments. Western collaboration with Chinese scientists must therefore be heavily scrutinized, especially if the research could lead to military applications. A 2019 United States Senate report to the Committee on Homeland Security, explored this very threat and describes how American taxpayers have funded research that has contributed to China's global rise.[27] Most disturbingly, it concluded that "China unfairly uses the American research and expertise it obtains for its own economic, and military gain" through its national strategy known as Military-Civilian Fusion.

CONCLUSION

13. While QuDAR remains a new subject of research, experimentation in the microwave domain is accelerating and at least two verified laboratory prototypes have been developed to date. By utilizing the principle of quantum entanglement, the potential military applications of QuDAR are difficult to ignore. These potential advantages include the defeat of stealth, and the development of LPI radars which could usher in a new era of detection supremacy amongst western nations. The augmentation of traditional radar systems, would also not negate their original capabilities. This differs from both quantum computing and communication, where the entire technology stream is built upon the entanglement principle.

14. The development of countermeasures against QuDAR would also prove difficult, if not impossible without our own continued investment in the technology. The very low transmitted power from a QuDAR, means that traditional jamming methods such as barrage jamming or home-on-jam would be relatively ineffective as the transmitted signal could operate at, or below the noise threshold.

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[25]Washington Post, "China's top quantum scientist has ties to the country's defense companies," last accessed 10 January 2022, https://www.washingtonpost.com/technology/2019/12/26/chinas-top-quantum-scientist-has-ties-countrys-defense-companies/.

[26]Strider Intelligence, "Quantum Dragon Report," last accessed 10 January 2022, https://www.striderintel.com/resources/quantum-dragon-report/.

[27]United States Senate Permanent Subcommittee on Investigations, *Threats to the U.S. Research Enterprise: China's Talent Recruitment Plans* (Washington, DC: Committee on Homeland Security and Governmental Affairs, 2019), 5.

15. Canada is currently a world leader in quantum initiatives, centered around the IQC, Institut quantique de l'Université de Sherbrooke, DRDC Ottawa, the National Research Council, and internationally renowned quantum computing companies such as D-Wave, 1Qbit, and Xanadu. It is also home to Qubic, the world's first microwave QuDAR company that spun out of research carried out at the ICQ on the world's first microwave QuDAR experiment that attracted international attention.[28] If we are to continue to hold this advantage and keep pace with our adversaries, a deepening of ties between industry, academia, and defence must be seriously pursued. While the DND/CAF Quantum S&T strategy is a positive first step, sustainable and long-term funding, as well as robust security measures must be enacted. Funding by government will allow clients, such as the CAF to shape and advise the R&D program, including the building and testing of QuDAR prototypes which will be relevant in future conflicts. Security protocols, along with the screening of those participating in projects, will ensure the protection of Canadian intellectual property (IP), and foster the talent and creation of new industries in this niche field of study.

RECOMMENDATION

16. The following specific recommendations for DND/CAF would lead to progress in the fielding of QuDAR over the next five years, and better support a Canadian national strategy regarding Quantum technologies:

a. Normalize CAF engagement with DRDC Ottawa, in particular the Radar Sensing and Exploitation group which has scientists involved in cutting edge radar research. This engagement should include both warfighters from the four commands involved in force generation (Royal Canadian Navy, Royal Canadian Air Force, Canadian Army, and Canadian Special Operations Forces Command), Intelligence experts from Canadian Forces Intelligence Command, and supporting engineers from Assistant Deputy Minister (ADM) (Information Management), and ADM (Materiel);

b. Fund the ADM(DRDC) Quantum S&T strategy with sustainable and long-term financial commitments. This funding can come from S&T programmes found within Level One organizations, or current / future major projects such as the Canadian Surface Combatant, or NORAD modernization. Supporting and developing quantum startups, and other technological routes to build QuDARs (and countermeasures) from established companies should be prioritized under the strategy; and

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[28] C.W. Sandbo Chang et al, "Quantum-enhanced noise radar," 1.

c. Develop new robust security protocols, and apply those to future collaborative agreements between DND/CAF and any academic organizations. This will prevent the loss of any IP, and dissuade adversaries from attempting to steal research which could give them a tactical advantage in future conflicts.

Annex: A. Quantum Radar Block Diagram

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Annex A Quantum Radar Block Diagram