CSBA also conducted a study on EMS spectrum dominance that proposed over the years electromagnetic warfare has shifted in phases, and the current one is "low-to-no power" EMS warfare.[48] IPCs and photonic phased arrays are capable of providing these "low-to-no-power" sensors that enable new operational concepts. The study also pushes investment in networked, agile, multifunctional, small and affordable, and adaptive or cognitive technologies.[49] All of these features can be enabled by IPCs alone or paired with a photonic phased array as the underlying technology. Subsequently shown in Figure 3, emerging technologies will drive new operational concepts that potentially require significant changes in force structure by more integration of currently separate but parallel organizations that will resist. There is no room for resistance to adapt or lack of preparedness; the future undoubtedly holds multiple revolutionary changes. Focusing on technologies with the potential to produce a paradigm shift and also have strategic value can accelerate disruptive effects on the character of war. Integrating and removing duplicate efforts provides the efficacy to find these technologies.

The path towards securing EMS superiority for the US requires significant investment in linking experts across academia, government, and industry. Holley suggests that transformative military technological advancement relies heavily on knowing and partnering with industry.[50] Take it one step further and add academia. While there are already numerous methods the AF and DoD are linked to industry and academia, it seems overly complicated and duplicative.[51] Similarly, removing duplicative efforts between the services is also necessary. Not only would it reduce cost, but it also provides a more holistic approach to field more networked, agile, multifunction capabilities essential to future EMS warfare operations. RF Photonics is on a path to disrupt future EMS operations and enable JADO and underlying ABMS inter-service MDO; the sooner *action* is taken to collaborate, increase awareness, invest, define new operational

concepts, and employ them, the more significant edge the AF and DoD will have in the EMS. "What is revolutionary is not the *speed* with which the change takes place, but rather the *magnitude* of the change itself" (emphasis added).[52] The preparedness of a nation's ability to maintain a competitive advantage and assert itself rests in its technological base and the understanding of the strategic value it brings.

Notes

[1] I give appreciation to my family and Dr. Paul Hoffman for their humble review and input. All errors within are my own., May 6, 2020.
[2] Giulio Douhet, *The Command of the Air*, trans. Dino Ferrari (Washington, D.C.: Air Force History and Museums Program, 1998), 30.
[3] Douhet, 30.
[4] Bryan Clark and Mark Gunzinger, "Winning The Airwaves Regaining America's Dominance In The Electromagnetic Spectrum" (Center for Strategic and Budgetary Assessments., 2017), i.
[5] Michael Kratsios, "Emerging Technologies and Their Expected Impact on Non-Federal Spectrum Demand" (Office of Science and Technology Policy, May 2019), https://www.whitehouse.gov/wp-content/uploads/2019/05/Emerging-Technologies-and-Impact-on-Non-Federal-Spectrum-Demand-Report-May-2019.pdf.
[6] Department of Defense, "Electromagnetic Spectrum Strategy" (Department of Defense Chief Information Officer, September 2013), 2, https://dodcio.defense.gov/Portals/0/Documents/Spectrum/ESS.pdf.
[7] AFWIC, "AFWIC 101."
[8] AFWIC.
[9] Maj David Stuckenberg, Amb. R. James Woolsey, and Col Douglas DeMaio, "Electromagnetic Defense Task Force 2.0" (Air University Press, August 2019), 3.
[10] Secretary of the Air Force Public Affairs, "Air Force Announces Electronic Warfare, Electromagnetic Spectrum Superiority Enterprise Capability Collaboration Team Results," U.S. Air Force, April 16, 2019, https://www.af.mil/News/Article-Display/article/1816024/.
[11] Preetpaul Singh Devgan, *Applications of Modern RF Photonics* (Artech House, 2018), 18.
[12] Devgan, 17.
[13] Stavros Iezekiel, ed., *Microwave Photonics: Devices and Applications* (John Wiley & Sons, Ltd, 2009), 6.
[14] Iezekiel, 7.
[15] Devgan, *Applications of Modern RF Photonics*, 19–22.
[16] Xiang Liu et al., "Joint Transmit Beamforming for Multiuser MIMO Communication and MIMO Radar," *ArXiv:1912.03420 [Eess]*, February 1, 2020, http://arxiv.org/abs/1912.03420; Xiangrong Wang, Aboulnasr Hassanien, and Moeness Amin, "Dual-Function MIMO Radar Communications System Design Via Sparse Array Optimization," *ArXiv:1808.04940 [Eess]*, August 14, 2018, http://arxiv.org/abs/1808.04940; Xiangrong Wang, Aboulnasr Hassanien, and Moeness Amin, "Sparse Transmit Array Design for Dual-Function Radar Communications by Antenna Selection," *ArXiv:1808.04938 [Eess]*, August 14, 2018, http://arxiv.org/abs/1808.04938.
[17] *Russia Military Power: Building a Military to Support Great Power Aspirations* (Washington, D.C.: Defense Intelligence Agency, 2017); *China Military Power: Modernizing a Force to Fight and Win* (Washington, D.C: Defense Intelligence Agency, 2019); Kratsios, "Emerging Technologies and Their Expected Impact on Non-Federal Spectrum Demand."
[18] Sophia Chen, "Photonic Chips for Neuromorphic Computing" (The International Society for Optics and Photonics, February 7, 2020), https://spie.org/news/photonic-chips-for-neuromorphic-computing.

[19] Dr. Benjamin Griffin, "RF Photonics Characterization Laboratory" (Air Force Research Laboratory, September 13, 2019), sec. 17.
[20] "Central PIC Ecosystem," AIM Photonics, accessed April 1, 2020, http://www.aimphotonics.com/central-pic-ecosystem.
[21] Xu Wang et al., "Wideband Adaptive Microwave Frequency Identification Using an Integrated Silicon Photonic Scanning Filter," *Photonics Research* 7, no. 2 (February 2019): 172, https://doi.org/10.1364/PRJ.7.000172.
[22] Dr. Benjamin Griffin, "RF Photonics Characterization Laboratory."
[23] Dr. Benjamin Griffin, sec. 15.
[24] AFRL, "Photonic-Enabled HVAA Protection System," sec. 1.
[25] AFRL, sec. 8.
[26] Dr. Benjamin Griffin, "RF Photonics Characterization Laboratory," sec. 15.
[27] Dr. Benjamin Griffin, "RF Photonics Characterization Laboratory."
[28] Office of the Chairman of the Joint Chiefs, "Joint Doctrine Note 3-16: Joint Electromagnetic Spectrum Operations," October 20, 2016, I–1, https://www.jcs.mil/Portals/36/Documents/Doctrine/jdn_jg/jdn3_16.pdf.
[29] James Mattis, "Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge" (The United States Department of Defense, 2018), 6, https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.
[30] Brig Gen Hinote, "Designing the Air Force We Need to Be" (AFWIC, July 2019).
[31] Jianping Yao, "Microwave Photonics for 5G," in *Broadband Access Communication Technologies XIII*, vol. 10945 (Broadband Access Communication Technologies XIII, International Society for Optics and Photonics, 2019), 1094504, https://doi.org/10.1117/12.2512117.
[32] Ben Griffin, "RE: Breifing the ACTS 2.0 Research Task Force (RTF) from Air University - RF Photonics," December 18, 2019.
[33] "RF Beamforming" (Morton Photonics, n.d.), https://mortonphotonics.com/rf-beamforming; Paul Morton, "Simultaneous RF Beamforming Phased Array Sensors Through Wafer Scale Photonic Integration" (DTIC R&E Gateway, March 2015), https://www.dtic.mil.
[34] "Simultaneous RF Beamforming Phased Array Sensors through Wafer Scale Photonic Integration | SBIR.Gov," n.d., https://www.sbir.gov/sbirsearch/detail/817243.
[35] I.B. Holley, Jr., *Ideas and Weapons*, Office of Air Force History, 1997 (New Haven: Yale University Press, 1953), 10, https://media.defense.gov/2016/Nov/07/2001664470/-1/-1/0/IDEAS_&_WEAPONS.PDF.
[36] "U.S. Air Force Doctrine," accessed April 6, 2020, https://www.doctrine.af.mil/.
[37] USAF, "Air Force Doctrine Annex 3-51 Electromagnetic Warfare and Electromagnetic Spectrum Operations" (LeMay Center, July 2019), https://www.doctrine.af.mil/Portals/61/documents/Annex_3-51/3-51-Annex-EW-EMSO.pdf.
[38] Alan Dayton, "Winning the Invisible Fight: The Need for Spectrum Superiority" (Center for Strategic and International Studies, December 21, 2016), https://defense360.csis.org/winning-the-invisible-fight-the-need-for-spectrum-superiority/.
[39] Adam Harrison, Bharat Rao, and Bala Mulloth, "Developing an Innovation-Based Ecosystem at the U.S. Department of Defense" (National Defense University, May 15, 2017), https://ndupress.ndu.edu/Portals/68/Documents/defensehorizon/DH-81.pdf; Jeffrey P Bialos, Christine E Fisher, and Stuart L Koehl, *Against the Odds: Driving Defense Innovation in a*

Change-Resistant Ecosystem, 2017, http://transatlanticrelations.org/wp-content/uploads/2017/05/Against-The-Odds-Driving-Defense-Innovation-in-a-Change-Resistant-Ecosystem-Final.pdf; Clarence Henderson, "The Defense Innovation Ecosystem" (National Defense Battlelab LLC, June 26, 2019), https://acquisitiontalk.com/wp-content/uploads/2019/06/DOD-innovation-bureaucracy.pdf.

[40] General Stanley McChrystal et al., *Team of Teams: New Rules of Engagement for a Complex World* (New York, New York: Portfolio, 2015).

[41] "Joint Doctrine Library," Joint Electronic Library Plus Database Search, accessed April 6, 2020, https://jdeis.js.mil.

[42] I. B. Holley, *Technology and Military Doctrine: Essays on a Challenging Relationship* (Maxwell Air Force Base, Ala: Air University Press, 2004), 20.

[43] Holley, 128.

[44] Holley, 142.

[45] Holley, 154.

[46] Harrison Schramm, Daniel Patt, and Bryan Clark, "Mosaic Warfare: Exploiting Artificial Intelligence and Autonomous Systems to Implement Decision-Centric Operations" (Center for Strategic and Budgetary Assessments., February 2020), 18.

[47] Harrison Schramm, Daniel Patt, and Bryan Clark, 19.

[48] Bryan Clark and Mark Gunzinger, "Winning The Airwaves Regaining America's Dominance In The Electromagnetic Spectrum," ii.

[49] Bryan Clark and Mark Gunzinger, iii.

[50] I.B. Holley, Jr., *Ideas and Weapons*, 32–33.

[51] Henderson, "The Defense Innovation Ecosystem."

[52] Andrew F. Krepinevich et al., *The Military-Technical Revolution: A Preliminary Assessment* (Washington, DC: Center for Strategic and Budgetary Assessments, 2002), 3.