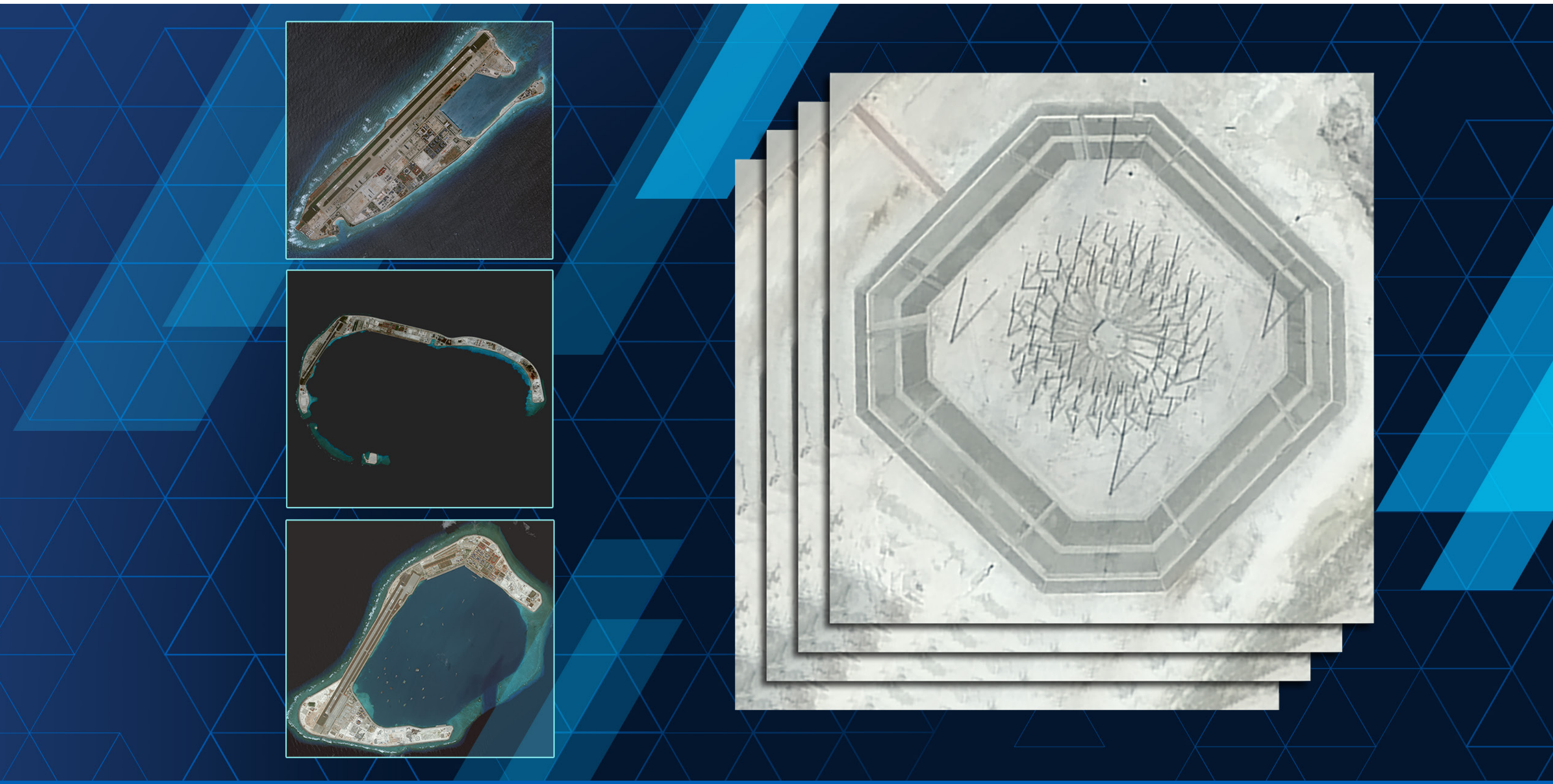
SOUTH CHINA SEA MILITARY CAPABILITY SERIES

A Survey of Technologies and Capabilities on China's Military Outposts in the South China Sea



IN-DEPTH: SUBI REEF COUNTER-STEALTH RADAR

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Introduction

This military capability (MILCAP) study focuses on a unique very-high-frequency (VHF) radar array located on Chinese-held Subi Reef in the South China Sea (SCS). Chinese sources describe this radar as a "counter-stealth radar."[1]

SCS MILCAP studies provide a survey of military technologies and systems on seven Chinese-claimed island-reefs in the SCS, approximately 1,300 kilometers (700 nautical miles) south of Hong Kong (see Figure 1). The Chinese outposts in the Spratly Islands have become significant People's Liberation Army (PLA) bases that will enhance future Chinese military operations in the SCS, an area where Beijing has disputed territorial claims (see Appendix B). The SCS MILCAP series highlights PLA informationized warfare strategy to gain and maintain information control in a military conflict. Overview graphics of all capabilities noted on major outposts in SCS MILCAP studies appear in Appendix C.

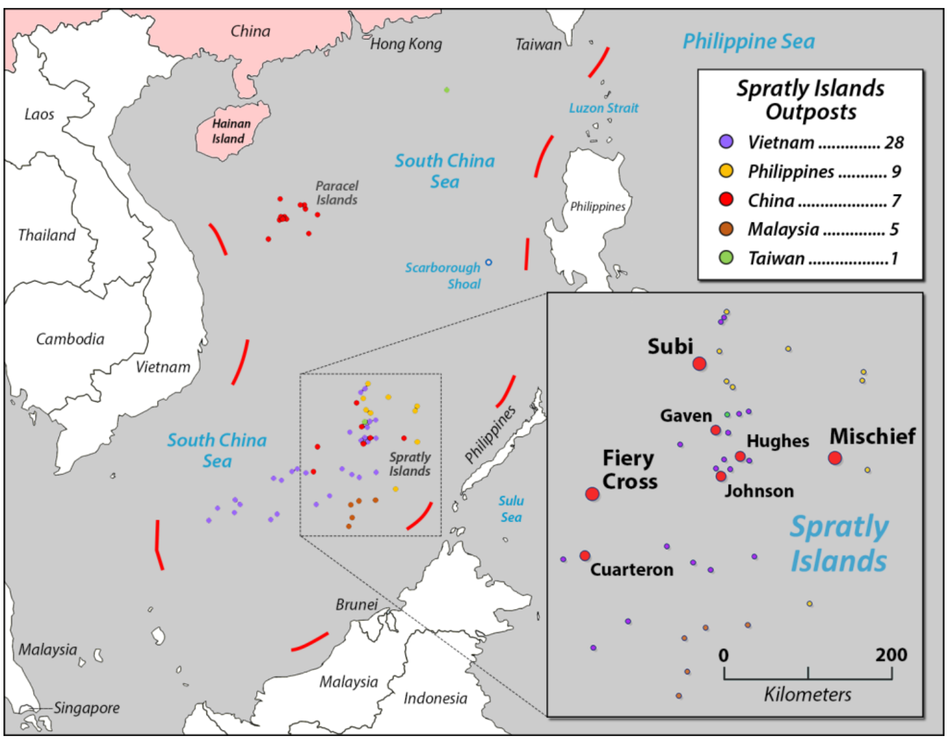

Figure 1. SCS Occupied Features

[1] Liu Xuanzun, "China's Meter Wave Anti-Stealth Radar Capable of Guiding Missiles to Destroy Stealth Aircraft: Senior Designer," *Global Times*, May 23, 2019, https://www.globaltimes.cn/content/1151216.shtml.

The PLA installed an antenna array on Subi Reef that Chinese researchers claim has significant capabilities to detect and track low-observable, stealth aircraft. In Chinese, this radar is known as "综合脉冲与孔径雷达." In English, the Chinese refer to this system as a synthetic impulse and aperture radar (SIAR). The Subi Reef SIAR, which reportedly operates in the VHF band (30–300 megahertz), is located on the southern end of the outpost and consists of three concentric rings of antenna elements (see Figure 2). As of mid-2020, the Subi Reef SIAR was the only radar of its type noted on the island-reefs.

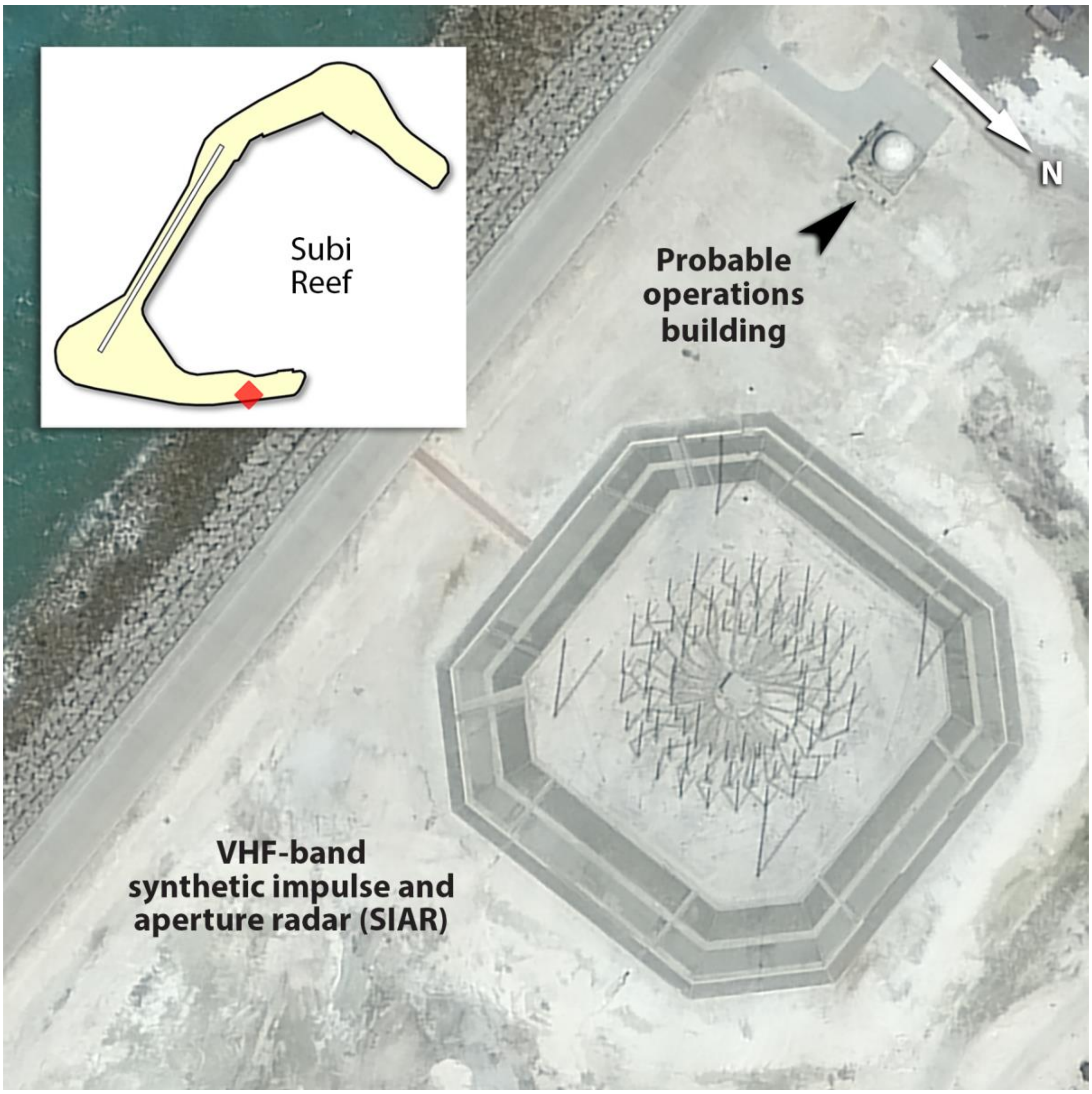

Figure 2. Subi Reef Synthetic Impulse and Aperture Radar

Chinese sources revealed, and, in fact, publicly promoted, a great deal of information about this novel counter-stealth radar design. Since the mid-1990s, Chinese researchers affiliated with state-owned enterprises authored dozens of scientific journal articles on the development and application of SIAR technology. In 2011, China's National Defense Industry Press published a 400-page book on the fundamentals of SIAR that was translated and published in English in 2014.[2] In 2018, one of the authors of the SIAR book appeared on Chinese state television to promote the radar he developed for the military. Later that year, a SIAR presentation at China's Anhui University indicated that one of these VHF-band radars was deployed to the SCS.[3] A May 2019 article published in both Chinese and English by the state-run *Global Times* newspaper claimed that Chinese SIAR technology is "capable of guiding missiles to destroy stealth aircraft."[4]

SIAR Development

The type of radar the Chinese dub SIAR was pioneered in the 1970s by French researchers as RIAS (*Radar á Impulsion et Antenne Synthétique*). The French firm Thompson built an operational circular RIAS array in northern France that operated in the low end of the VHF-band at 50 megahertz. Beyond the impracticality of its size—over 500 meters (1/3 of a mile) in diameter—the RIAS techniques demanded significant signal processing that presented challenges for computers of the day.[5] German researchers also experimented with VHF-band circular arrays in the 1980s and 1990s with an array nick-named LARISSA.[6] Citations in SIAR books and articles indicate Chinese researchers capitalized on this early European work.

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[2] Chen Baixiao and Wu Jianqi, *综合脉冲孔径雷达 [Synthetic Impulse Aperture Radar],* (Beijing: National Defense University Press, 2011); Chen Baixiao and Wu Jianqi, *Synthetic Impulse and Aperture Radar (SIAR): A Novel Multi-Frequency MIMO Radar* (Singapore: John Wiley & Sons, 2014).

[3] Wu Jianqi, Chief Scientist at the CETC 38th Research Institute presented at Anhui University on December 24, 2018. See SIAR photos and map on slides 39 and 42 in, "中国米波雷达能探测 F22 [China Meter-Wave Radar can Detect the F22], 新浪军事 [Sina Military (reposted on huaibeitechan.net], December 26, 2018, http://www.huaibeitechan.net/mil/283888.html.

[4] Liu Xuanzun, "China's Meter Wave Anti-Stealth Radar Capable of Guiding Missiles to Destroy Stealth Aircraft: Senior Designer."

[5] P. van Genderen, "State-of-the-Art Trends in Phased Array Radar," in *Proceedings of Perspectives on Radio Astronomy: Technologies for Large Array Antennas*, ed. A. B. Smolders and M. P. van Haarlem (Dwingeloo, The Netherlands: ASTRON Institute, 2000), 2; Jean-Marie Colin, "Phased Array Radars in France: Present and Future," *Proceedings of International Symposium on Phased Array Systems and Technology* (Boston: IEEE, 1996), 461–462.

[6] Heiner Kuschel, "VHF/UHF Radar, Part 2: Operational Aspects and Applications," *Electronics & Communication Engineering Journal* 14, no. 3 (June 2002): 101.

Two engineers appear to lead SIAR research in China: Chen Baixiao (陈伯孝) of the National Laboratory of Radar Signal Processing at Xidian University and Wu Jianqi (吴剑旗), currently the deputy director and chief scientist at the China Electronics Technology Group (CETC), 38th Research Institute (38th RI). Chen and Wu probably met when Wu Jianqi was dispatched from the 38th RI to Xidian University to conduct radar research in the 1990s.[7] The profile of their work significantly increased following the erroneous US B-2 stealth bomber strike on the Chinese embassy in Belgrade, Yugoslavia in 1999. Attacking stealth aircraft became one of the requisite capabilities in the PLA's "three attacks, three defenses" (三打三防) concept.[8] Since then, the two scientists and their protégés have written dozens of scientific journal articles on SIAR.[9] In 2011, Chen and Wu coauthored a book that was translated and published in English in 2014, *Synthetic Impulse and Aperture Radar (SIAR): A Novel Multi-Frequency MIMO Radar*.[10]

In early 2018, Wu Jianqi was a featured guest on a Chinese state-television program, 对话 [Dialogue]. Wu displayed a model of a circular radar array on the nationally televised CCTV-2 talk show. The model array consisted of antennae of different heights in three concentric rings with a box located in the center. It appears to be identical to the Subi Reef array. At the time, Wu did not specifically refer to the system as a "synthetic impulse and aperture radar" but described the radar's operating principles in nontechnical terms for the television audience. Wu said that it was a "meter-wave radar" (米波雷达), referring to the wavelength in the VHF-band between 1 and 10 meters (30 to 300 MHz).[11]

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[7] Cai Meng and Sun Qiuxia, " '信念笃定, 坚守使命': 记中国电子科技集团公司第三十八研究所副所长吴剑旗" ["Certain Faith, Stick to the Mission": Wu Jianqi, Deputy Director of the 38th Research Institute of China Electronics Technology Group Corporation], 中国科技奖励 [China Awards for Science and Technology] 196 (October 2015): 29.

[8] The "three attacks" are against ballistic and cruise missiles, stealth aircraft, and helicopters. The "three defenses" are against precision strike, electronic jamming, and intelligence, surveillance, and reconnaissance (ISR).

[9] Among their first published articles are Wu Jianqi and Ruan Xinchang, "稀布阵综合脉冲孔径雷达主要性能分析" [Performance Analysis of Sparse Array Synthetic Impulse and Aperture Radar], 现代电子 [*Modern Electronics*], no. 3 (1994); and Chen Baixiao and Zhang Shouhong, "阵元幅相误差对综合脉冲孔径雷达测角精度的影响" [Influence of Amplitude and Phase Error of Array Elements on Angular Accuracy of Synthetic Impulse and Aperture Radar], 现代电子 [*Modern Electronics*], no. 3 (1996).

[10] Chen and Wu, 综合脉冲孔径雷达 [Synthetic Impulse Aperture Radar]; Chen and Wu, *Synthetic Impulse and Aperture Radar (SIAR): A Novel Multi-Frequency MIMO Radar*.

[11] "《对话》20180318 我是总师—反隐身雷达总师" ["Dialogue"20180218 I Am the Master—Anti-Stealth Radar Chief], CCTV-2 video, 53:26, March 18, 2018, http://tv.cntv.cn/video/C10316/98558ad0b9454e2da81f01438c49f8dc (SIAR model at 16:47 and 31.33).

Citing the 1999 shoot-down of a US F-117 stealth fighter, with subsequent video of B-2 stealth bombers and F-22 fighters playing in the background for effect, the 38th RI chief scientist openly claimed that the radar on display is a "反隐身雷达"—a "counter-stealth radar." [12] He observed that stealth aircraft are designed to be "invisible" to higher frequency radars like those typically used in surface-to-air missile (SAM) fire control. Wu claimed that the relatively low VHF-band operating frequency of his radar readily reflects off of these otherwise stealthy aircraft.

Chinese researchers claim to have solved many of the problems associated with conventional VHF radar using SIAR and its inherent multiple-input, multiple-output (MIMO) techniques. VHF-band radar typically suffer from ground clutter, multipath interference, poor angular resolution, and an inability to reliably determine target elevation.[13] While a VHF radar may detect the presence of low-observable aircraft in a general direction, the nature of VHF propagation means that conventional radars operating at these lower frequencies cannot accurately track stealth aircraft, let alone target them with a weapon such as a SAM.

SIAR Operating Principle

Chinese articles, as well as Chen and Wu's book on SIAR, explain operating principles and model the radar's performance in some detail. In a SIAR system, each transmission element simultaneously transmits a unique pulse—orthogonally phased, frequency modulated, and coded. Each receiver in the array collects reflections of each unique transmitted pulse. Individual signals are synthesized at the receiver into beams in a technique called impulse synthesis. This information is then combined with data generated through aperture synthesis. Aperture synthesis analyzes pulse returns using inverse synthetic-aperture radar (ISAR) techniques to exploit the Doppler shift created by the motion of a tracked object relative to the array.[14] The fusion of impulse synthesis and aperture synthesis in the SIAR system yields a three-dimensional track—range, bearing, and elevation, as well as a target's speed.

SIAR Design

Chinese-developed SIAR includes a number of independent transmitting and receiving elements arranged in a large, circular array purportedly to improve angular

[12] Ibid. (Wu's comments at 14:00).

[13] Wu Jianqi, "反隐身与发展先进米波雷达" [Anti-Stealth Development of Advanced Metric-Wave Radar], 雷达科学与技术 [*Radar Science and Technology*] 13, no. 1 (February 2015): 1–2.

[14] Chen and Wu, *Synthetic Impulse and Aperture Radar* (2014), 106–107.

resolution. In a 2008 Chinese *Radar Science and Technology* article, researchers from CETC's 38th RI presented their findings on experiments involving a three-ring circular SIAR array consisting of twenty-five transmitting elements located within inner and outer rings with twenty-five receiving elements each.[15]

Setting antenna elements at different heights prevents mutual coupling, which is interference that distorts the radiation patterns of individual elements in a multi-element array. The 38th RI engineers explain that an optimized random-height array can solve the coupling interference problem that might otherwise significantly degrade the radar's elevation resolution.[16] Therefore, the different heights observed in imagery do not represent the length of the antenna elements; each element of similar length is simply positioned at different heights in the array.

Figure 3 highlights the Subi Reef SIAR antennae, showing that this array also has twenty-five elements of varying heights arranged in three concentric rings. This commercial satellite image clearly shows similarities to the model presented by the 38th RI chief scientist on Chinese television. The middle ring is likely the transmitting array, while the inner and outer rings are likely the receiving arrays. This structure is consistent with the multi-element circular array described in the 2008 38th RI research paper. The diameter of the rings are approximately 21, 32, and 41 meters, which is also consistent with the paper's findings on the optimal circular array distribution. This distribution, according to Chinese claims, reduces large sidelobes that might otherwise hamper the radar's operation at low VHF-band frequencies.[17]

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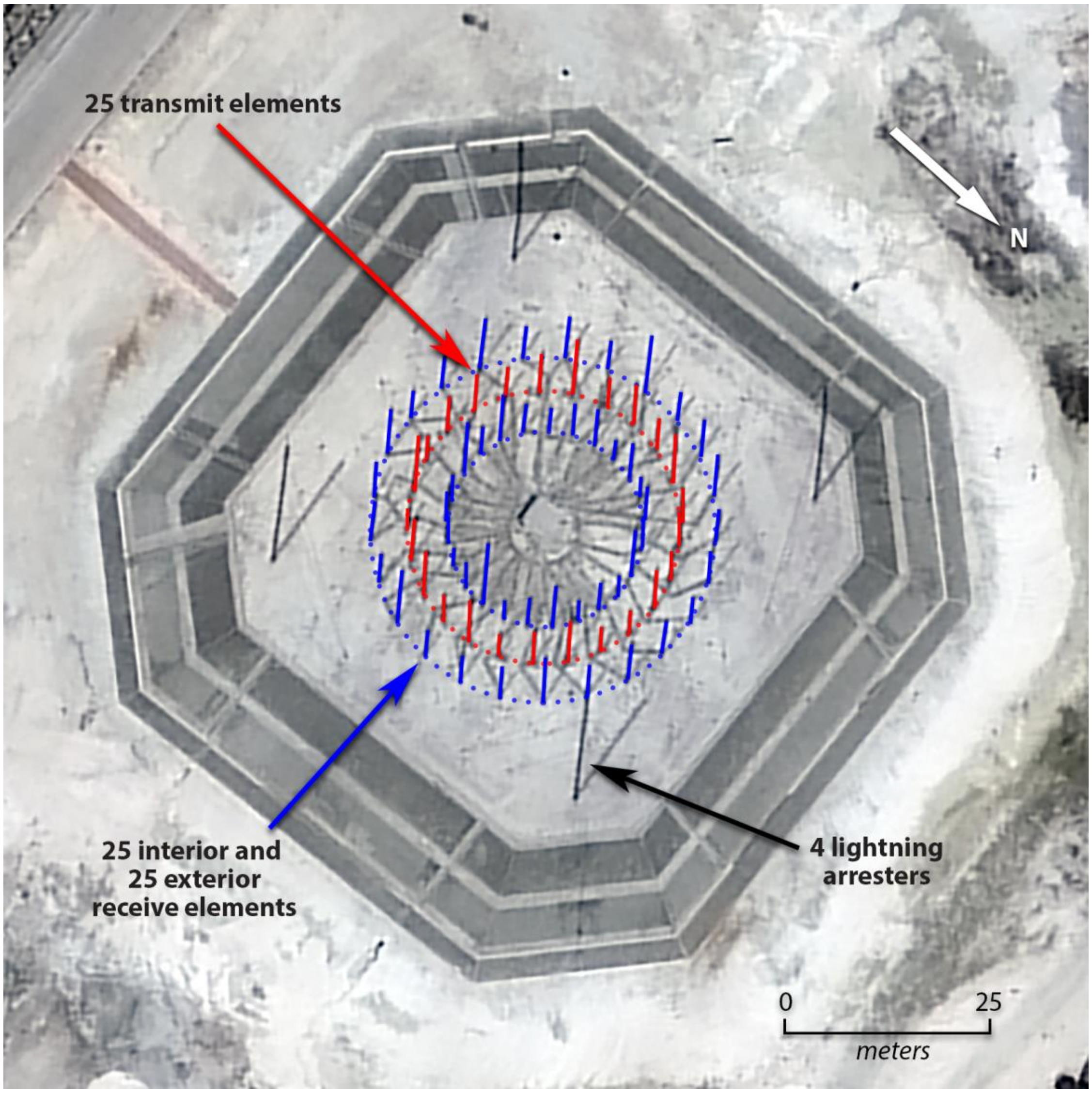
[15] Lu Pengcheng, Xu Haizhou, Xu Jin, Fu Qizhong, and Hu Kunjiao, "稀布阵综合脉冲孔径雷达阵列优化设计" [Optimization Design of Array Distribution of SIAR"], 雷达科学与技术 [*Radar Science and Technology*] 6, no. 4 (August 2008): 244–246.

[16] Ibid., 244–245.

[17] Ibid., 246.



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 3. Subi Reef SIAR Transmit and Receive Elements

Operating Frequency

The specific operating frequencies of the SIAR array deployed on Subi Reef could not be determined from available sources. The 38th RI constructed an experimental SIAR circular array consisting of twenty-five transmit elements and twenty-five receive elements arranged in only two rings. This experimental array was larger than the Subi array (90 meters in diameter) and operated in the 100-megahertz range. Chen and Wu claim that because a SIAR array has multiple independent elements, it can operate in a large absolute bandwidth. The authors state that if the array's central frequency can hop from 100 to 200 megahertz, SIAR can achieve the same absolute bandwidth and range resolution of much higher frequency radars.[18] The Subi Reef radar probably creates pulses across a similar frequency range in the mid-VHF band.

Power Output

The Subi Reef SIAR probably radiates a significant amount of power. Each of the twenty-five solid-state transmitters fed 1 kilowatt of power to each antenna in the 38th RI experimental twenty-five element array.[19] The SIAR array on Subi Reef may have been moved 500 meters west from its original location in late 2017 or early 2018 because of the radar's significant electromagnetic emissions (see Figure 4).

Figure 4. Subi Reef SIAR Moved 500 Meters West between Late 2017 to Early 2018

An October 2017 photograph, taken from an aircraft and obtained by the *Philippine Daily Inquirer* newspaper, shows that the SIAR array was previously located adjacent to Subi Reef's SAM facility. Note that the *Inquirer*'s photo, shown in Figure 5, mistakenly labeled the SIAR array as "Commo Facilities."[20] Interference in electronic equipment commonly caused by strong VHF emissions may have forced the SIAR's move to the west, where it is now relatively isolated from buildings or equipment.

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[18] *Synthetic Impulse and Aperture Radar* (2014), 9, 30.

[19] Ibid, 135.

[20] Frances Mangosing, "Exclusive: New Photos Show China Is Nearly Done with Its Militarization of South China Sea," *INQUIRER.net (Philippine Daily Inquirer)*, February 5, 2018, http://www.inquirer.net/specials/exclusive-china-militarization-south-china-sea.

(Philippine Daily Inquirer)

Figure 5. Subi Reef SIAR, Photo from Aircraft, October 2017

Signal Processing

Chinese researchers assert that by using the circular, random-height antenna configuration and SIAR signal-processing techniques, this "advanced meter-wave radar" (先进米波雷达) is able to overcome the conventionally accepted limitations of VHF-band radar and operate as a true four-dimensional radar, determining range, azimuth, elevation, and velocity of airborne targets. There are claims that this Chinese SIAR also has a "low-altitude capability." If true, an ability to overcome ground clutter to track low-flying targets would certainly make it unique among VHF-band radars.[21]

According to Xidian University researchers, the most significant technical feature of Chinese SIAR is that the radar array's omnidirectional emissions, when combined with signal processing at the receiver, form multiple "stacked" beams simultaneously. Therefore, all twenty-five transmission elements in the Subi Reef SIAR could generate unique pulses that would radiate 360 degrees, all of which might reflect off of a target. All twenty-five reflections would then be collected by fifty receive elements distributed in the array. Chinese researchers claim that the coherent integration of all

[21] Wu, "反隐身与发展先进米波雷达" [Anti-Stealth Development of Advanced Metric-Wave Radar], 3–4.

of these beams improves the SIAR's ability to detect weak target returns, such as those from low radar-cross-section targets like missiles or low-observable aircraft.[22]

Potential for Disinformation

Whether Chinese claims about the counter-stealth capabilities of their SIAR array are fact or hype, the warnings emanating from Chinese state media are fairly transparent. Those who might threaten China's interests should know—or at least believe—that the PLA has a radar capable of detecting and tracking low-observable military aircraft operating near China or in the SCS.

It is possible, but very unlikely, that the information available on Chinese SIAR capabilities is part of an intricate PLA deception campaign. The SIAR clearly on display on Subi Reef in commercial satellite imagery is apparently not the only SIAR in the PLA inventory. A May 2020 image, published on a Chinese Ministry of National Defense website, shows a SIAR in the background of a photograph of a live-fire exercise.[23] The location of this SIAR could not be determined from the image, but the significant vegetation in the photo indicates this radar was not on Subi Reef. A number of Chinese military enthusiasts commented that this photograph is the first image of China's purported counter-stealth radar.[24]

Suspicions that China's SIAR may be an elaborate fake are further discredited by the fact that China's basic scientific research on SIAR evolved methodically over more than two decades. Chinese papers on the radar theory and the physics behind SIAR, many presented at international radar conferences, seek to advance Chinese scientists' own research in collaboration with their peers in the international scientific community. Considering the volume of SIAR work published in Chinese- and English-language engineering journals for over twenty years, colleagues would have certainly highlighted "fake math" or outrageous claims.

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[22] Chen Baixiao, Yang Minglei, Wang Yi, Dang Xiaofang, and Wu Bo, "The Applications and Future of Synthetic Impulse and Aperture Radar," in *Proceedings of 2016 CIE International Conference on Radar* (Hoboken, NJ: IEEE), 1–2.

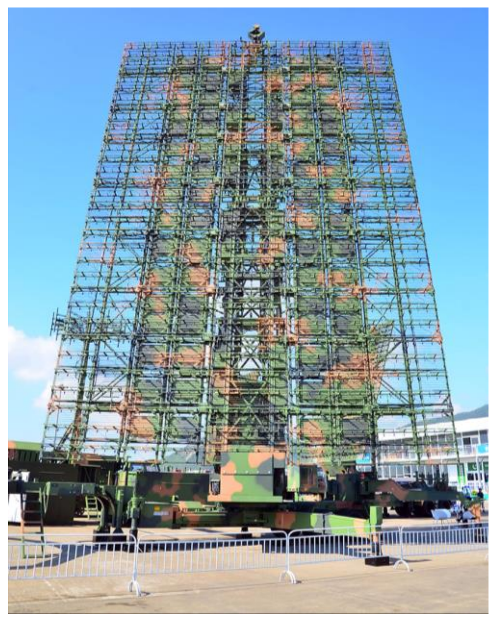
[23] See the image of the "Live-fire test of an HQ-6A" and the dozens of SIAR antenna elements to the right in "Hainan Island Shelters PLA Chinese Navy Only Air Defense Brigade," *Army Recognition*, May 26, 2020, https://www.armyrecognition.com/may_2020_news_defense_global_security_army_industry/hainan_island_shelters_pla_chinese_navy_only_air_defense_brigade.html.

[24] See, for example, 撒手锏 ["Assassin's Mace"], "南海舰队防空旅发射 HQ6A 首次曝光米波稀布阵雷达 [South Sea Fleet Air Defense Brigade Launches HQ6A Exposing for the First Time a Meter-Wave Sparse Array Radar], 超级军事区 [*Super Military Zone*] (blog), May 24, 2020, https://lt.cjdby.net/forum.php?mod=viewthread&tid=2623988.

Internal and external factors may have motivated public acknowledgment of China's counter-stealth radar. Domestic competition may have contributed to SIAR's exposure. CETC's 38th RI, even though it is state owned, is nevertheless in competition with other research institutes to raise its profile while developing radars for military and civil use, some of which are exported internationally. It is certainly possible that a higher level information campaign is also underway. If the PLA deployed a capable counter-stealth radar to Subi Reef, where it is difficult to conceal from even commercial satellite imagery, the Chinese military may wish to promote the radar's capabilities—real or inflated—against low-observable aircraft in the SCS. Creating a perception of stealth aircraft vulnerability may deter against militaries operating such aircraft in East Asia. Such perceptions could also deter those militaries that may not possess stealth aircraft but are allied with nations that do.

Other VHF-Band Counter-Stealth Radars

SIAR developer Wu Jianqi and CETC's 38th RI are also responsible for development and production of the massive JY-27A VHF-band radar (see Figure 6). Export marketing materials describe the JY-27A as a digital AESA (active electronically scanned array) radar.[25] The 38th RI received an award for the engineering design that overcame the challenges of erecting and precisely spinning this massive four-story tall radar, especially in windy conditions. Wu offers additional insights into VHF-band radar theory and detailed descriptions of JY-27A development and design in his 2015 book, *先进米波雷达 (Advanced Metric Wave Radar)*.[26] JY-27A radars were not noted on the SCS outposts as of mid-2020.



(JHU/APL Photo)

Figure 6. JY-27A Radar

[25] "JY-27A," trade brochure, East China Research Institute of Electronic Engineering (aka 38th RI), 2018.

[26] Wu Jianqi, *先进米波雷达 [Advanced Metric Wave Radar]*, (Beijing: National Defense University Press, 2015). English translation: Wu Jianqi, *Advanced Metric Wave Radar* (Singapore: Springer, 2020).

Conclusions

The scope of this study does not allow for a detailed assessment of Chinese claims about SIAR capabilities, nor is any attempt made to qualify Chinese SIAR capabilities against Western stealth technologies. Specific details of Chinese SIAR design, electronic signal parameters, and signal processing software have not been published by Chinese sources and would be necessary to evaluate actual capabilities. Regardless, images of the Subi Reef array taken with the body of available research on SIAR technology confirms that this VHF-band radar has been fielded with the PLA.

Chinese researchers, for their part, highlight the inherent susceptibility of low-observable aircraft to detection by VHF-band radars.[27] This is not a new observation. Stealth designs and radar absorbing materials have typically been optimized to defeat higher frequency band radars. VHF radars generally perform poorly against airborne targets and are not considered much of a threat, especially as they relate to directing missiles toward stealth targets. However, if the CETC 38th RI perfected the three-dimensional resolution and tracking abilities of SIAR VHF radar, the Subi Reef array might aid and enable missile engagements against low radar cross section targets.

The Subi SIAR array, even if only marginally effective against low-observable targets, will work in conjunction with other Chinese ISR systems, both on and off the island-reefs, to build a comprehensive surveillance picture based on multiple detection phenomenologies across a wide range of frequencies. The Subi Reef SIAR counter-stealth capabilities may be complemented by a radar housed in a very large radome on Mischief Reef that likely operates in the ultra high frequency (UHF) or VHF bands. External observations of other radar infrastructure on China's SCS island-reefs show that the PLA likely has a number of different types of radar operating across a broad swath of the frequency spectrum. For more information on these capabilities, see the SCS MILCAP study, "Air and Surface Radar."

The Chinese commitment to diverse and redundant radar systems demonstrates a PLA informationized warfare strategy that emphasizes information control. The detection threat to foreign militaries operating in the SCS is not from a single, invulnerable radar but from the sum total of different radars operating in conjunction with other reconnaissance systems. Island-reef-based capabilities will be further networked with space-, air-, surface-, and underwater-based systems to create a diverse, distributed PLA sensor network. Countering complex Chinese sensor networks will require an integrated system-of-systems approach to deny PLA designs to gain and maintain battlespace information advantage.

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[27] Chen and Wu, *Synthetic Impulse and Aperture Radar* (2014), 2.

Appendix A. Sources and Methods

Observations and analysis of the Chinese SCS outposts in these MILCAP studies rely on commercial satellite imagery licensed to JHU/APL and collected by the Maxar/DigitalGlobe Inc. WorldView-3 satellite (see Table 1). WorldView-3 can collect images up to 30-centimeters resolution, which translates to image quality between 5.0 and 6.0 on the National Imagery Interpretation Rating Scale (NIIRS).[28] For these studies, software like Google Earth Pro and Adobe Photoshop were used to interpret imagery, measure features, and adjust image color and balance. These images were not subject to any special processing or proprietary enhancements.

Table 1. DigitalGlobe Inc. WorldView-3 Satellite Imagery Details

Island-Reef	Location	Date	DigitalGlobe Image ID
Fiery Cross Reef	09°33′00″ N, 112°53′25″ E	June 14, 2018	104001003C49BB00
Subi Reef	10°55′22″ N, 114°05′04″ E	June 19, 2018	104001003E841300
Mischief Reef	09°54′10″ N, 115°32′13″ E	June 19, 2018	104001003D964F00

Reference images published in these studies cover hundreds of square meters, which necessarily obscures many specific features used in making assessments. Zoomed-in examples of details available in these satellite images are shown in Figure 7. The dots made up of only a few pixels in Figure 7(A) cannot be readily identified. However, their location on the basketball court leads to a conclusion that these may be personnel. As shown in Figure 7(B), observing shadows and other features may reveal structures such as a common HF dipole antennae, even if the fine-gauge wires cannot be seen in the image. Shadow length may be translated into object height using satellite image metadata and simple trigonometry. Figure 7(C) is an example that indicates the likely connection between two widely separated troposcatter terminals based on antenna pointing angles. Figure 7(D) demonstrates that positive identification of detailed features may be possible with a much higher quality reference image. The PLA Navy Type 056 corvette in the satellite image may be an anti-submarine warfare variant (Type 056A) based on the light colored feature seen where the door for a towed sonar array should be located.[29]

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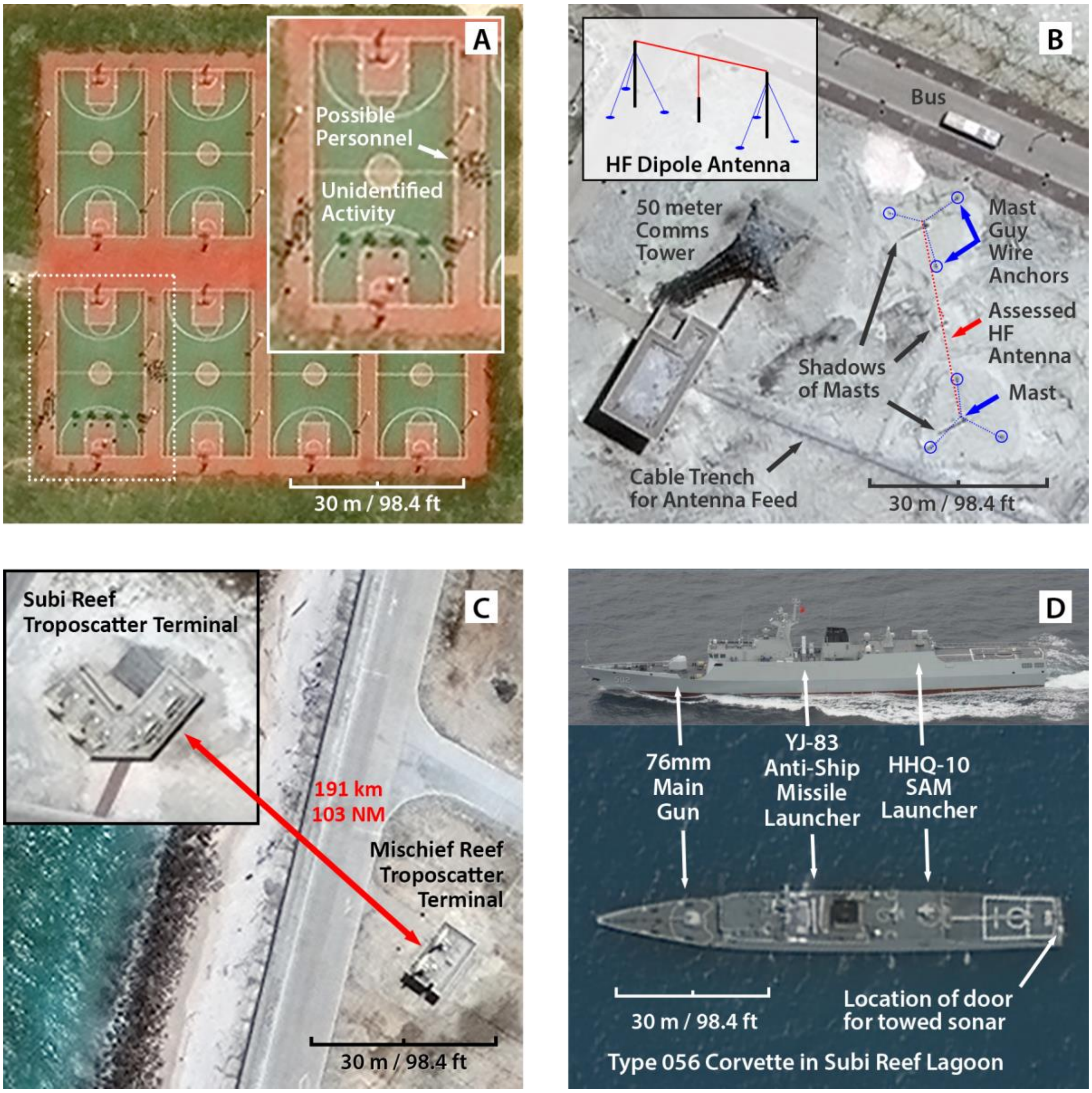
[28] Leigh Harrington, David Blanchard, James Salacain, Stephen Smith, and Philip Amanik, *General Image Quality Equation; GIQE version 5*, (Washington, DC: National Geospatial-Intelligence Agency (NGA), 2015), https://gwg.nga.mil/ntb/baseline/docs/GIQE-5_for_Public_Release.pdf.

[29] See close-up images of the towed array door at, "'Sanmenxia,' First Type 056A ASW Corvette (Jiangdao Class), Commissioned in Chinese Navy (PLAN)," *Navy Recognition*, November 19, 2014, accessed July 1, 2020, http://navyrecognition.com/index.php?option=com_content&view= article&id=2189.



(Images © 2020 Maxar/DigitalGlobe, Inc. Photograph of ship courtesy of Japan Self Defense Force)

Figure 7. Detailed Image Examples. (A) Mischief Reef Basketball Courts, (B) Mischief Reef HF Antenna, (C) Troposcatter Terminals, (D) Type 056 Frigate

Publicly accessible satellite imagery, available on Google Earth or from organizations like the Asia Maritime Transparency Initiative, provides historical images that may show changes to island-reef features over time. Official or semi-official Chinese sources discussing military capabilities on the SCS outposts complement imagery analysis and help qualify imagery observations. Where appropriate, these studies also reference secondary sources such as credible media reporting on China's SCS island-reefs or public U.S. government statements about PLA capabilities in the SCS.

Appendix B. South China Sea Maritime Territorial Claims

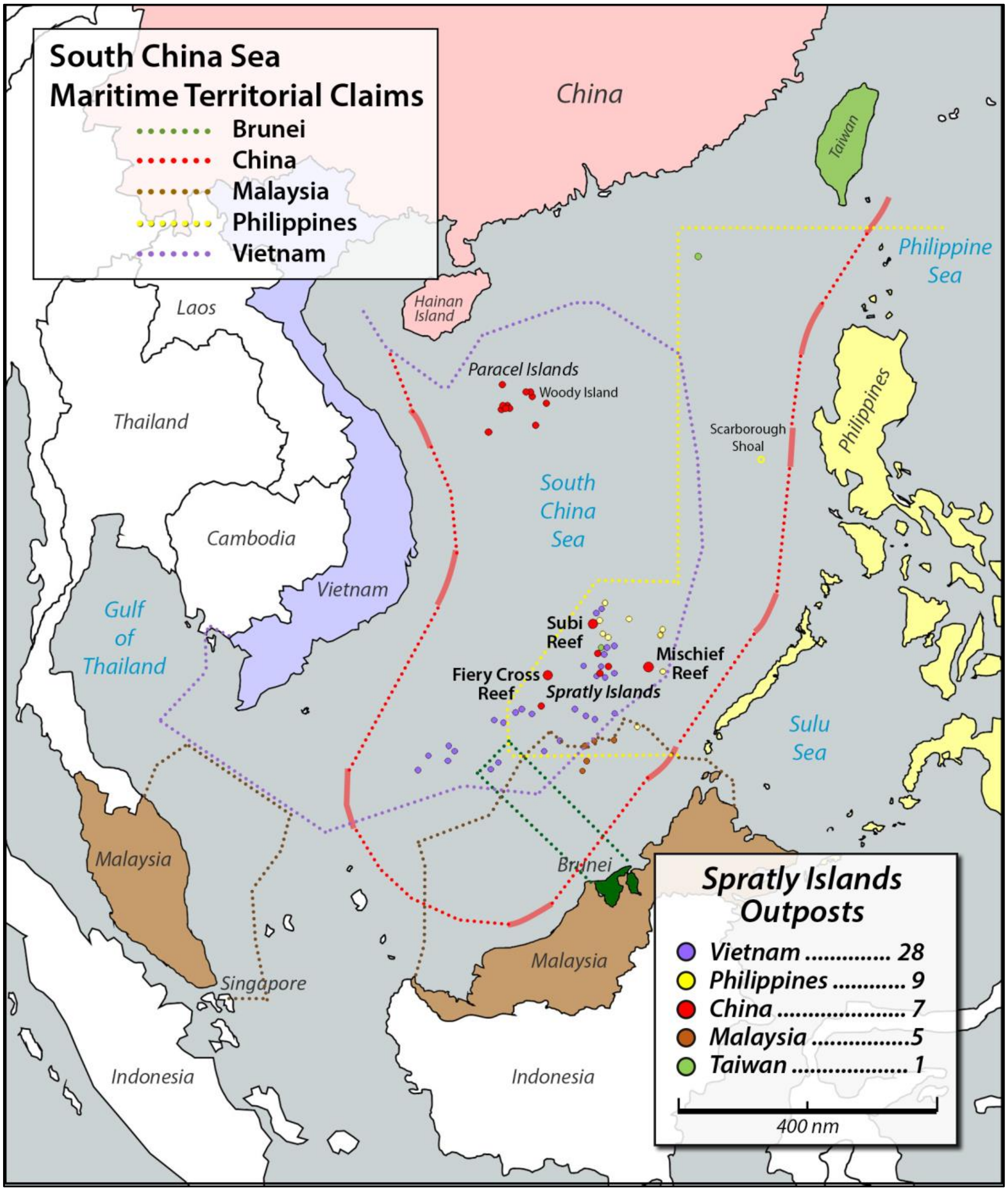
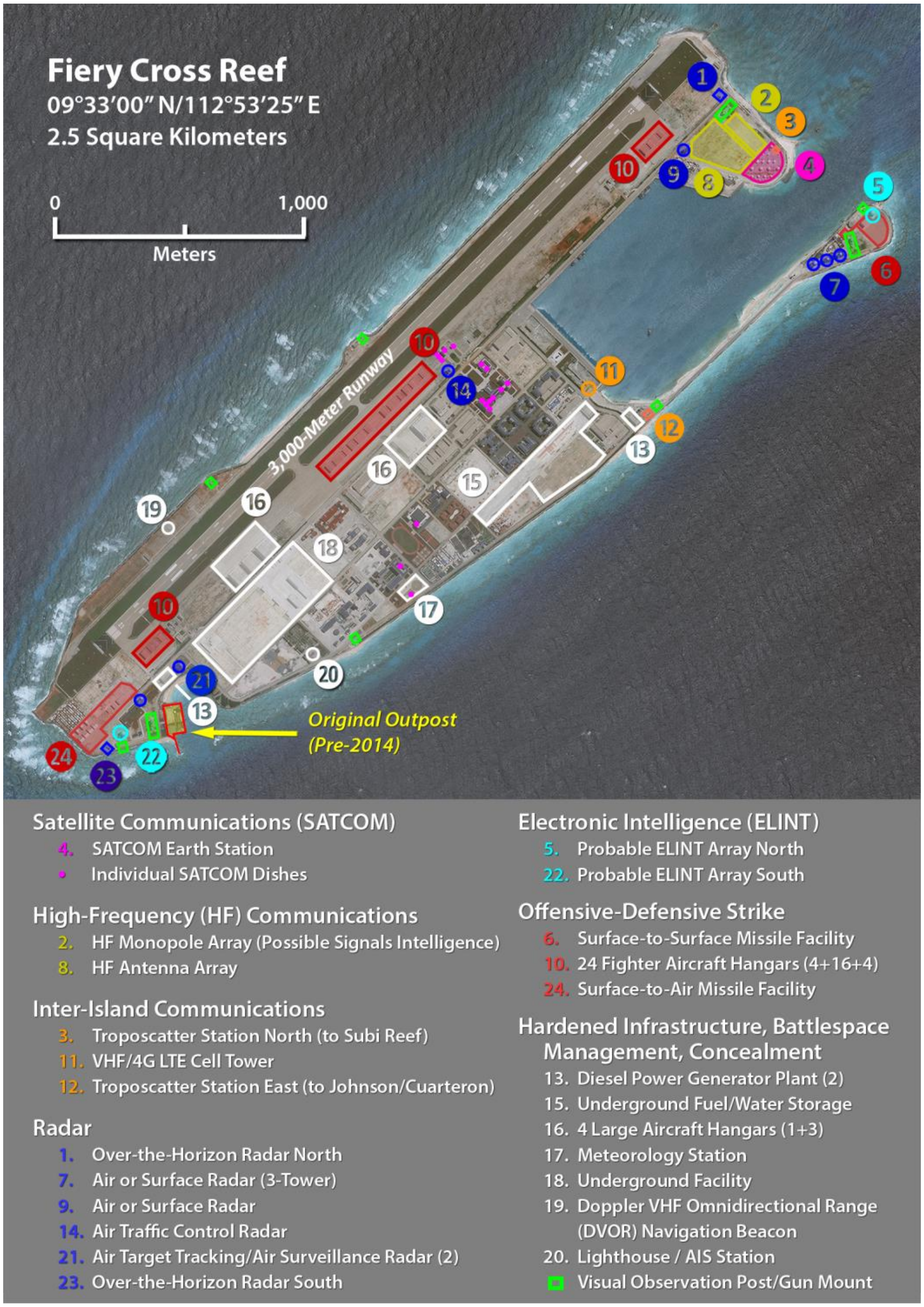


Figure 8. South China Sea Maritime Territorial Claims

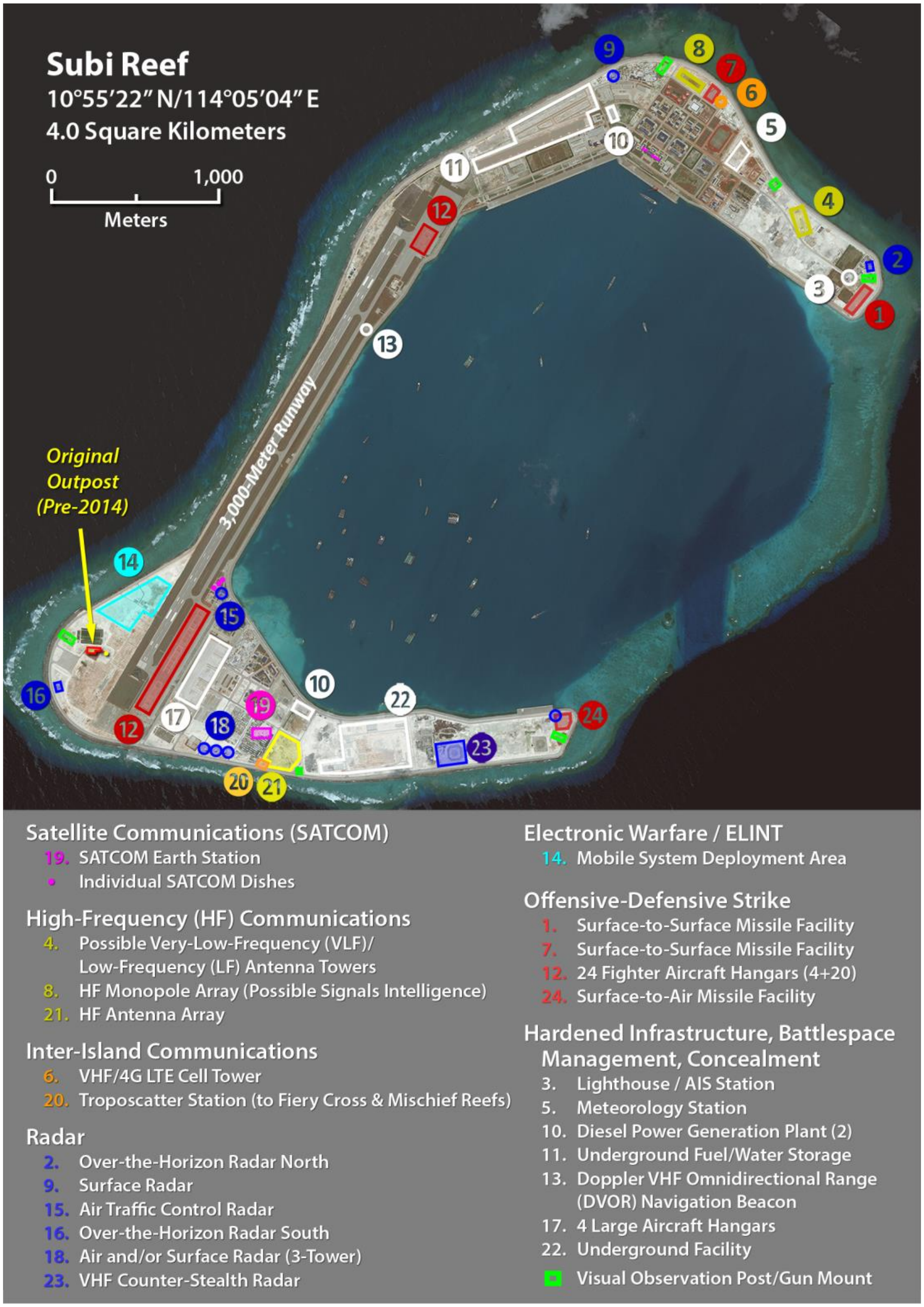
Appendix C. Island-Reef Capabilities Overview Graphics



(Image © 2020 DigitalGlobe, Inc.)

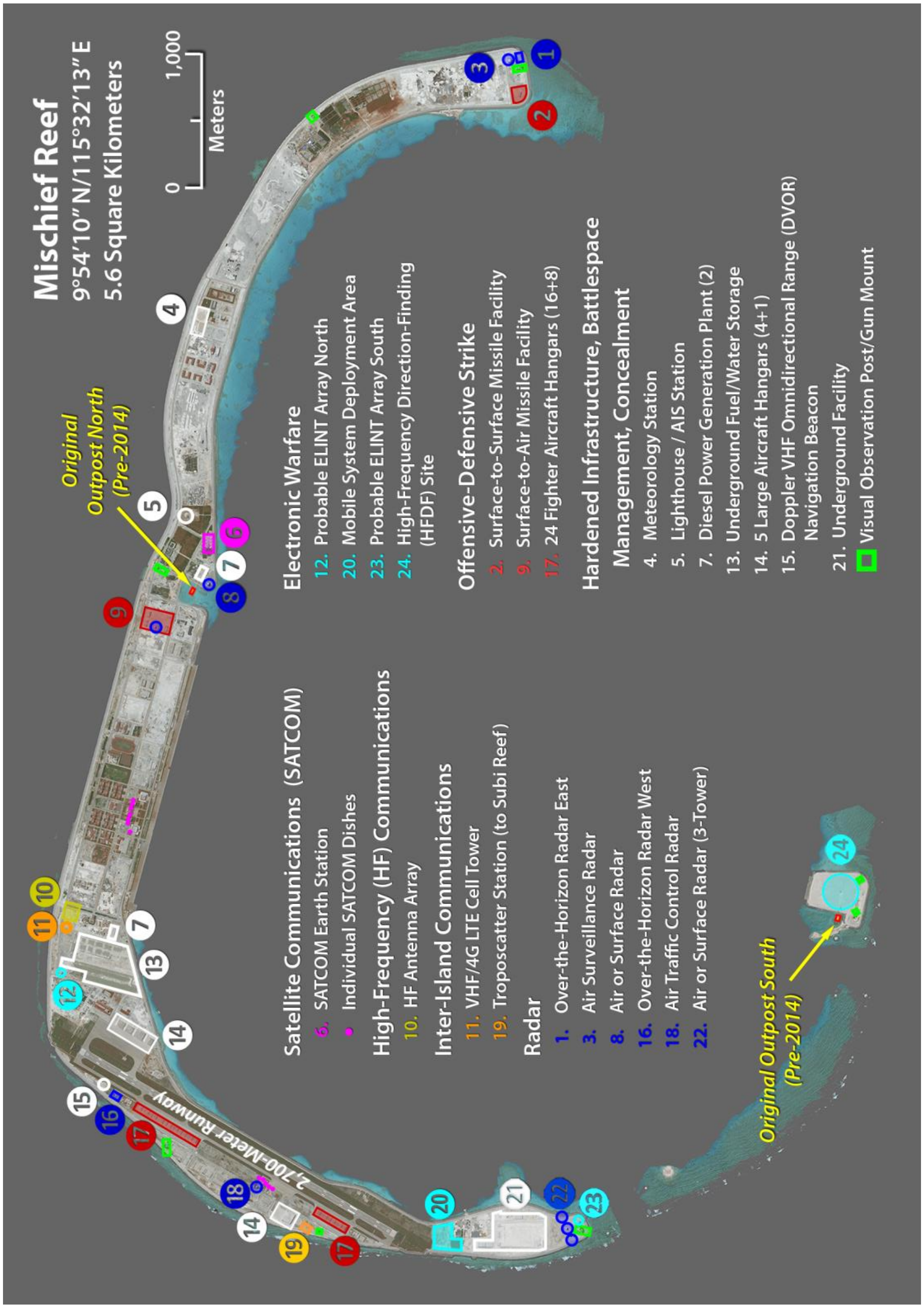
Figure 9. Fiery Cross Reef Overview

In Depth: Subi Reef Counter-Stealth Radar



(Image © 2020 DigitalGlobe, Inc.)

Figure 10. Subi Reef Overview



(Image © 2020 DigitalGlobe, Inc.)

Figure 11. Mischief Reef Overview

Appendix D. Definitions and Abbreviations

AIS—Automatic identification system; tracking system used by large ships

4G LTE—Fourth-generation long-term evolution; cellular communications

ASCM—Anti-ship cruise missile

C4—Command, control, communications, and computers. Sometimes rendered C3, dropping “computers” or C2, “command and control”

C4ISR—Command, control, communications, computers, intelligence, surveillance, and reconnaissance. Sometimes C5ISR or C5ISRT, including “cyber” and “targeting”

CCD—Camouflage, concealment, and deception

ELINT—Electronic intelligence

EMS—Electromagnetic spectrum; common frequency bands are shown in Table 2

Table 2. Radio and Radar Frequency Bands

<table>
<tr><th>ITU Radio Bands</th><th>Band Name</th><th>Frequency Range</th><th>IEEE Radar Bands</th><th>Frequency Range</th></tr>
<tr><td>VLF</td><td>Very-low frequency</td><td>3-30 kHz</td><td></td><td></td></tr>
<tr><td>LF</td><td>Low frequency</td><td>30-300 kHz</td><td></td><td></td></tr>
<tr><td>MF</td><td>Medium frequency</td><td>300-3000 kHz</td><td></td><td></td></tr>
<tr><td>HF</td><td>High frequency</td><td>3-30 MHz</td><td></td><td></td></tr>
<tr><td>VHF</td><td>Very-high frequency</td><td>30-300 MHz</td><td>VHF</td><td>30-300 MHz</td></tr>
<tr><td rowspan="2">UHF</td><td rowspan="2">Ultra-high frequency</td><td rowspan="2">300-3000 MHz</td><td>UHF</td><td>300-1000 MHz</td></tr>
<tr><td>L</td><td>1-2 GHz</td></tr>
<tr><td rowspan="6">SHF</td><td rowspan="6">Super-high frequency</td><td rowspan="6">3-30 GHz</td><td>S</td><td>2-4 GHz</td></tr>
<tr><td>C</td><td>4-8 GHz</td></tr>
<tr><td>X</td><td>8-12 GHz</td></tr>
<tr><td>Ku</td><td>12-18 GHz</td></tr>
<tr><td>K</td><td>18-27 GHz</td></tr>
<tr><td>Ka</td><td>27-40 GHz</td></tr>
<tr><td>EHF</td><td>Extremely-high frequency</td><td>30-300 GHz</td><td></td><td></td></tr>
</table>

EW—Electronic warfare

HFDF—High-frequency direction finding

Information power—信息力 (*xìnxī lì*)—A Chinese term referring to the capability of a military force to achieve information superiority, ensuring the use of information for friendly operational forces while simultaneously denying adversary operational forces the use of information

Informationized warfare—信息化作战 (*xìnxī huà zuòzhàn*)—The prevailing "form of war" (战争形态, *zhànzhēng xíngtài*) in Chinese military theory.

Island-reef—岛礁 (*dǎo jiāo*)—A Chinese term for an islet or an island of sand that has built up on a reef. China's military outposts in the Spratly Island group were formerly rocks or high-tide features that do not have the international legal status of island that might otherwise define territorial waters or an exclusive economic zone

ISR—Intelligence, surveillance, and reconnaissance

PLA—People's Liberation Army; Refers to the entire Chinese military

PLAN—People's Liberation Army Navy

PNT—Positioning, navigation, and timing

SATCOM—Satellite communications

SAM—Surface-to-air missile

SCS—South China Sea

SoS—System-of-systems.

Southern Theater—One of five PLA theater commands created in 2016 Chinese military reorganization. Area of responsibility includes southern China, Hainan Island, the SCS, and Paracel and Spratly island-reef bases

SSF—PLA Strategic Support Force

SSM—Surface-to-surface missile

Troposcatter— Troposcatter or tropospheric communications are microwave signals, generally above five hundred megahertz, scattered by dust and water vapor in the atmosphere, allowing for over-the-horizon communication links

UAV—Unmanned aerial vehicle

USV—Unmanned surface vehicle

UUV—Unmanned underwater vehicle

About the Author

J. Michael Dahm is a senior national security researcher at the Johns Hopkins University Applied Physics Laboratory where he focuses on foreign military capabilities, operational concepts, and technologies. Before joining JHU/APL, he served as a US naval intelligence officer for over 25 years. His most recent assignments included senior analyst in the USPACOM China Strategic Focus Group, assistant naval attaché at the US embassy in Beijing, China, and senior naval intelligence officer for China at the Office of Naval Intelligence.

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