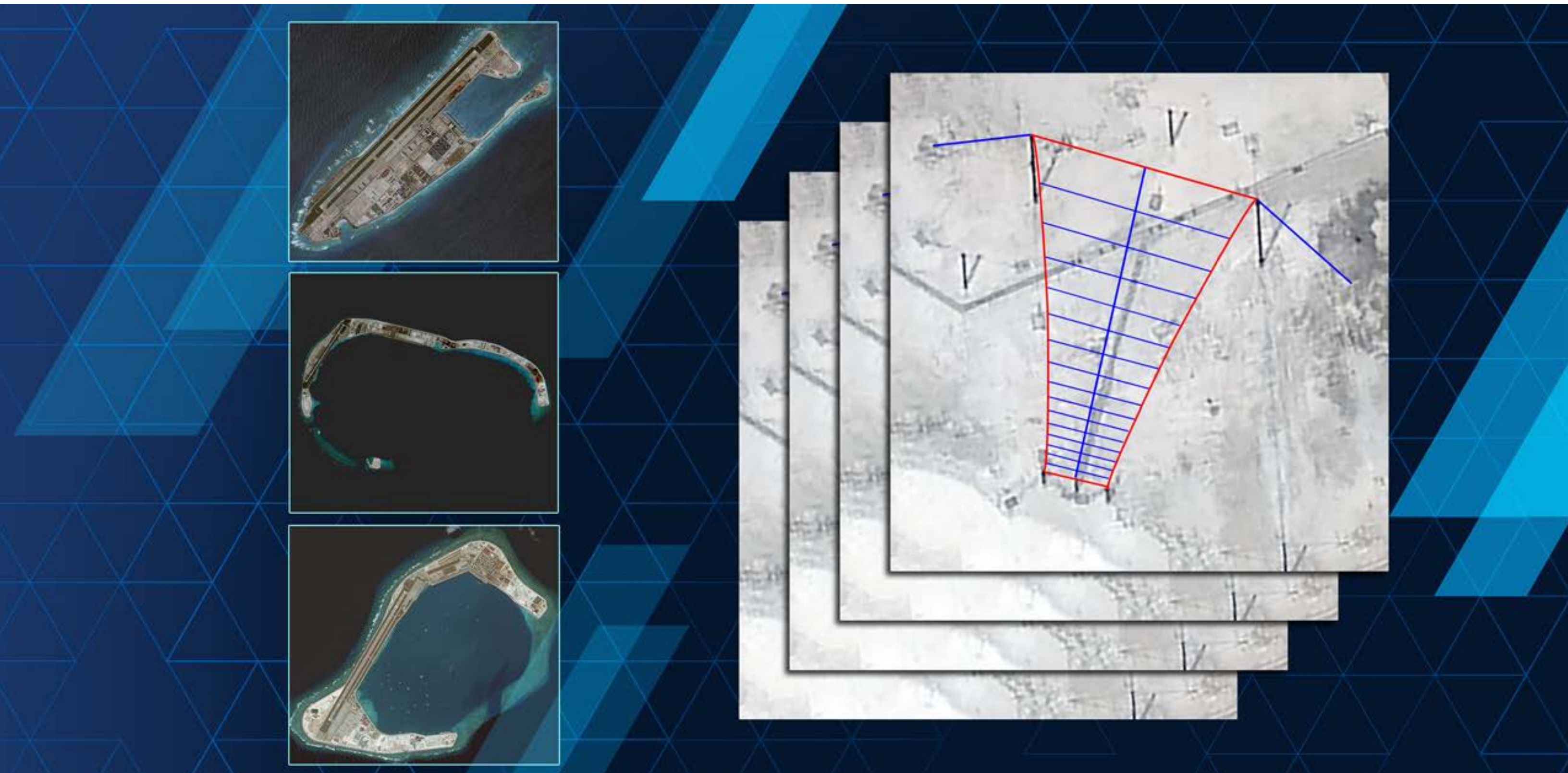
SOUTH CHINA SEA MILITARY CAPABILITY SERIES

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



HIGH-FREQUENCY COMMUNICATIONS

J. Michael Dahm

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

HIGH-FREQUENCY COMMUNICATIONS

J. Michael Dahm

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

This study contains the best opinion of the author based on publicly available, open-source information at time of issue. It does not necessarily represent the assessments or opinions of APL sponsors.

The author is responsible for all analysis and annotations of satellite images contained in this report. Satellite images are published under license from Maxar Technologies/DigitalGlobe, Inc., which retains copyrights to the original images. Satellite images in this report may not be reproduced without the express permission of JHU/APL and Maxar Technologies/DigitalGlobe, Inc. See Appendix A for notes on sources and analytic methods.

NSAD-R-20-045
July 2020

Contents

This page intentionally left blank.

Figures

Tables

Introduction

This military capability (MILCAP) study focuses on high-frequency (HF) communications capabilities on seven Chinese island-reef outposts in the South China Sea (SCS). These SCS MILCAP studies provide a survey of military technologies and systems on Chinese-claimed island-reefs in the Spratly Islands approximately 1,300 kilometers (700 nautical miles) south of Hong Kong (Figure 1). The Chinese outposts 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 a PLA informationized warfare strategy to gain and maintain information control in a military conflict.

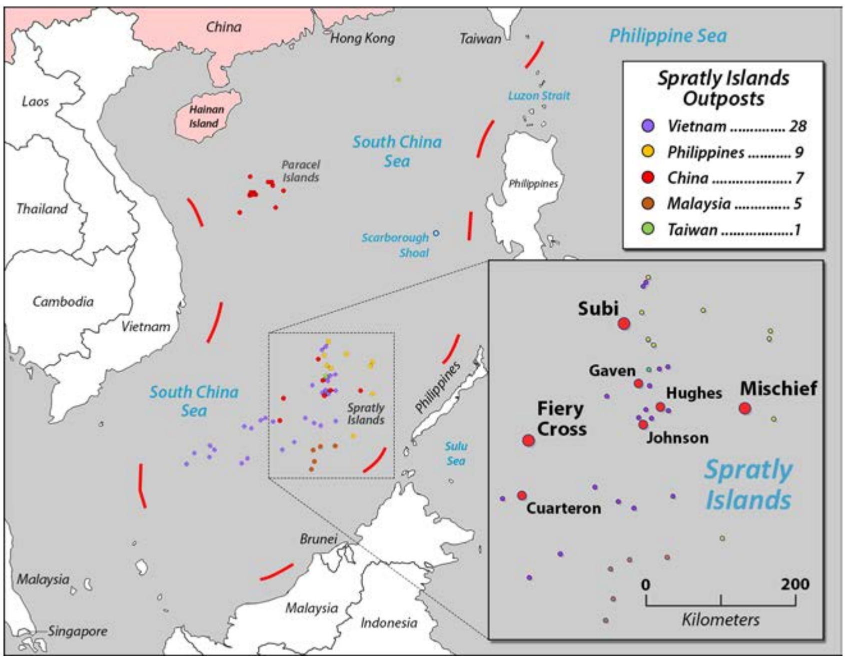


Figure 1. SCS Occupied Features

Large, complex HF antenna arrays were noted on each of the major outposts—Fiery Cross Reef, Subi Reef and Mischief Reef—as well as on the southern-most outpost, Cuarteron Reef. These arrays feature a variety of large HF antenna types, some with masts as tall as 26 meters (85 feet). HF communications provide the PLA with over-the-horizon links to ships or aircraft, the Chinese mainland, or other island-reefs. These communications are complementary to other outpost long-range communications such as undersea fiber-optic cable and satellite communications

(SATCOM). Overview graphics of all capabilities noted on major outposts appear in Appendix C.

HF Communications, 短波通信

An extensive PLA HF communications network complements Chinese SATCOM and fiber-optic cable communications on island-reefs in the SCS. HF capabilities provide the PLA with communications in the 3 to 30 megahertz range. While the technology is seemingly dated and limited in bandwidth, the Chinese military continues to integrate modernized HF-band communications into PLA military networks. The Chinese term for HF communications is "短波通信" (shortwave communications). Large, complex antenna arrays that allow the PLA to exploit the entire HF spectrum are located on each of the major island-reefs, as well as on Cuarteron Reef (see Figure 2).

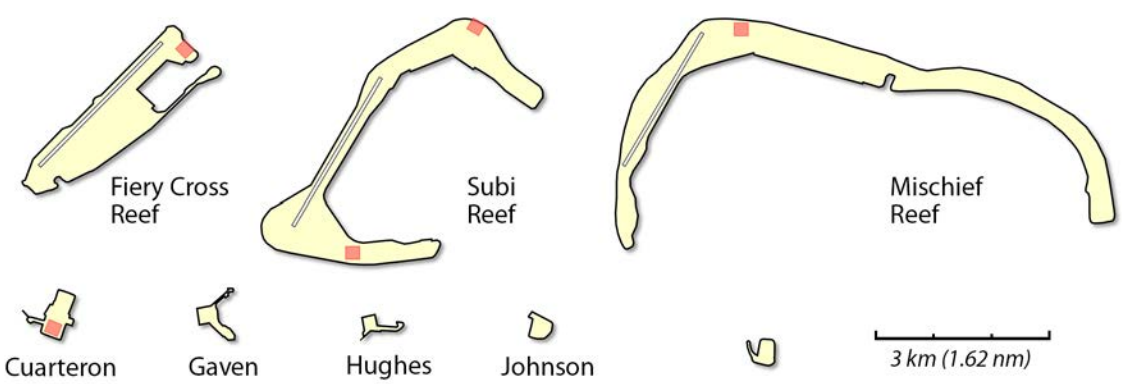


Figure 2. Observed SCS HF Antenna Array Locations, June 2018

Types of HF Antennae

Understanding the configuration of different types of HF antennae and their function is instructive in determining which antennae are likely present on the SCS outposts. Identifying HF arrays using satellite imagery or even handheld imagery from an aircraft can be challenging because HF antenna wiring has such a small diameter that it is only visible at close range. In most cases, masts and towers that support the wire elements are visible at longer ranges. While there are an endless variety of HF antenna configurations employed for civilian and military use, the following common antenna types appear to be present on the SCS outposts. In each example shown in Figure 3 through Figure 10, masts that might be visible in imagery are highlighted in green.

Half-wave dipole antenna. A half-wave dipole antenna consists of two quarter-wavelength dipole antennae extending parallel to the ground from a vertical feed. Two tall masts support the ends of the horizontally polarized antenna elements. The shorter mast, halfway between the taller masts, supports the vertical feed element. A simple half-wave dipole antenna contains radiating elements along a single axis (see Figure 3). These "two-tall, one-short" mast configurations could support any number of dipole variations, including the folded dipole antenna (Figure 4), the cage dipole antenna (Figure 5), a bow tie dipole (not shown), or even a complex biconical antenna (Figure 6). Each of these more complex examples serves to increase the bandwidth of the dipole antenna.

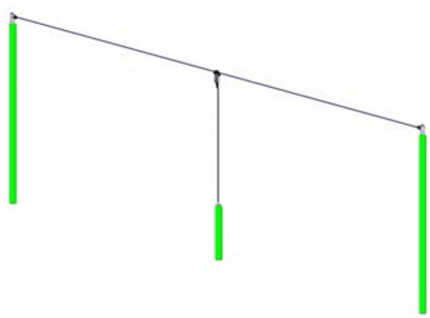


Figure 3. Simple Half-Wave Dipole Antenna

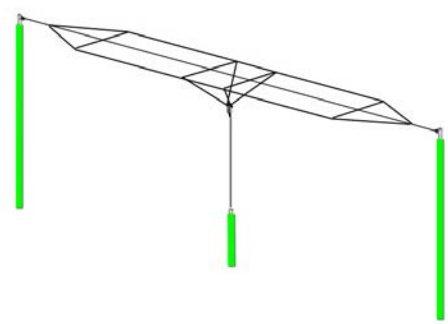


Figure 4. Folded Dipole Antenna

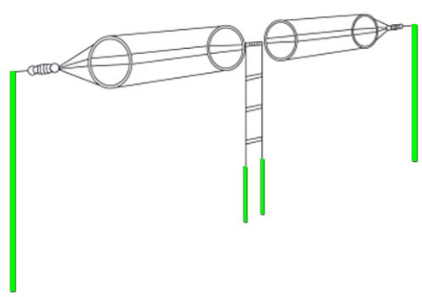


Figure 5. Cage Dipole Antenna

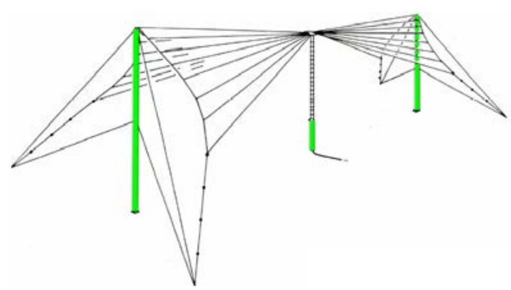


Figure 6. Biconical Dipole Antenna

Horizontal log-periodic antenna. A more complex antenna that is used extensively on the SCS outposts is the horizontally polarized log-periodic antenna. The supports for this type of antenna consist of two tall masts and three much shorter masts (see Figure 7). Based on the dimensions of these trapezoid-shaped antennae, they provide tunable, broadband HF communications between 4 and 30 megahertz. This configuration provides directional transmission away from the slope of the antenna, yielding an elevation pattern between 30 and 40 degrees above the horizon, which makes them ideal for airborne communications and "sky waves" that reflect off the ionosphere. The Guangdong-based Zhongyunhai Technology Company is one Chinese producer of these HF antennae that supplies communication equipment to the PLA.[1]

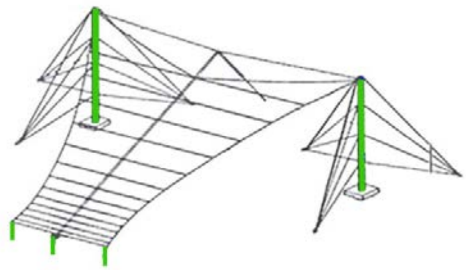


Figure 7. Horizontal Log-Periodic Antenna

Vertical log-periodic antenna or sloping antenna. There appear to be a number of antennae that share a relatively tall single mast with a shorter single mast. This configuration indicates at least two possibilities: a vertically polarized log-periodic antenna (see Figure 8) or a simpler sloping antenna that might be used to orient the polarization and takeoff angle of an antenna like a folded or cage dipole (Figure 9).

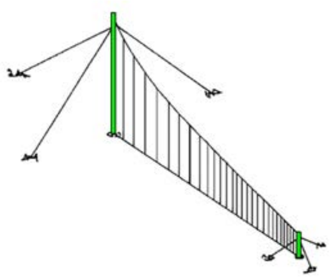


Figure 8. Vertical Log-Periodic Antenna

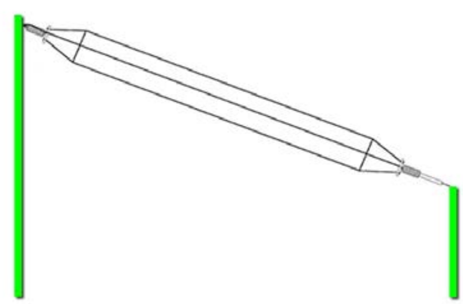


Figure 9. Sloping Antenna

This “tall–short” configuration is most likely for a vertical log-periodic antenna that, like its horizontal counterpart, provides broadband HF communications between 5 and 30 megahertz. The vertical polarization of the log-periodic antenna also creates “surface waves” that follow the curve of the Earth, providing efficient over-the-horizon communications.

[1] “Company Profile,” 中云海科技有限公司 (Zhongyunhai Technology Co., Ltd.), accessed November 18, 2018, http://www.cscxd.cn/article.php?id=38.SeeZhonguynhai’shorizontallog-periodicantennaat“5–30MHz 短波☒数周期天☒” (“5–30 MHz Short Wave Logarithmic Periodic Antenna”), 中云海科技有限公司 (Zhongyunhai Technology Co., Ltd.), accessed November 18, 2018, http://www.cscxd.cn/goods.php?id=104.

Monopole antenna. A monopole antenna (see Figure 10) is another vertically polarized antenna. A monopole antenna, even a quarter-wavelength antenna, must be necessarily tall to reach the lowest frequencies in the HF-band (3 megahertz). Normally more than 18 meters (59 feet) tall, these antennae could be used for either HF transmission or reception as well as surveillance. Imagery of the SCS outposts indicates that monopole antennae are normally secured by three guy-wires for support. The visible portion of the antenna may include only the base or a portion of the antenna element and the three support anchors, as depicted in Figure 10.

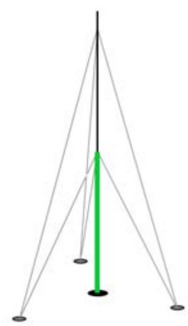


Figure 10. Monopole Antenna

HF Array on Fiery Cross Reef

The HF antenna array on Fiery Cross Reef is just to the east of the island-reef's SATCOM station. The tallest masts in the array extend as high as 26 meters (85 feet). The array includes **six broadband horizontal log-periodic antennae**, outlined as red trapezoids in Figure 11 through Figure 13. The wire elements that would be necessary on a single horizontal log-periodic antenna are drawn in blue for illustration. Given their dimensions, they likely operate between 4 and 30 megahertz. (Note that each horizontal log-periodic antenna is actually the same size; the skewed perspective is created by the antenna sloping away from the satellite look angle.) The array also includes **four half-wave dipole antennae** that could operate as low as 4 to 5 megahertz. **One "tall–short" mast configuration may be a vertical log-periodic antenna or sloping antenna**. Three tall masts in the center of the image likely indicate a large antenna of undetermined design, possibly some type of curtain array (see Figure 11). At the north end of the antenna field are **seven monopole antennae** of undetermined function that are discussed in greater detail in a subsequent section.

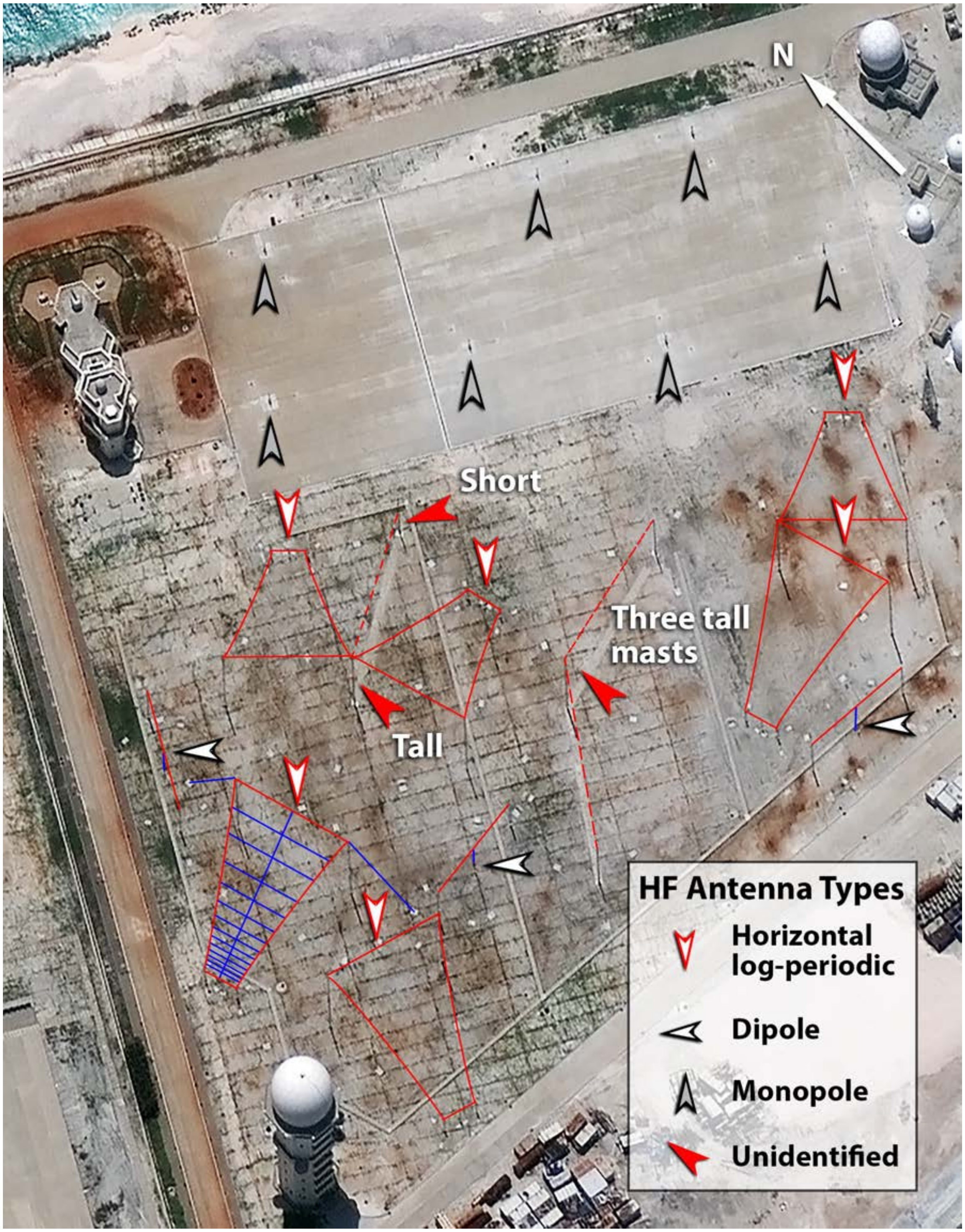


Figure 11. HF Communications Array, Fiery Cross Reef

HF Array on Subi Reef

The HF array on Subi Reef is directly southeast of the outpost's SATCOM station. This array is almost identical to the Fiery Cross HF array. It consists of **six horizontal log-periodic antennae** likely operating between 4 and 30 megahertz. There are also **four half-wave dipole** antennae operating as low as 4 to 5 megahertz. The Subi Reef array has **two "tall–short" mast configurations that may indicate vertical log-periodic antennae or sloping antennae** (see Figure 12).

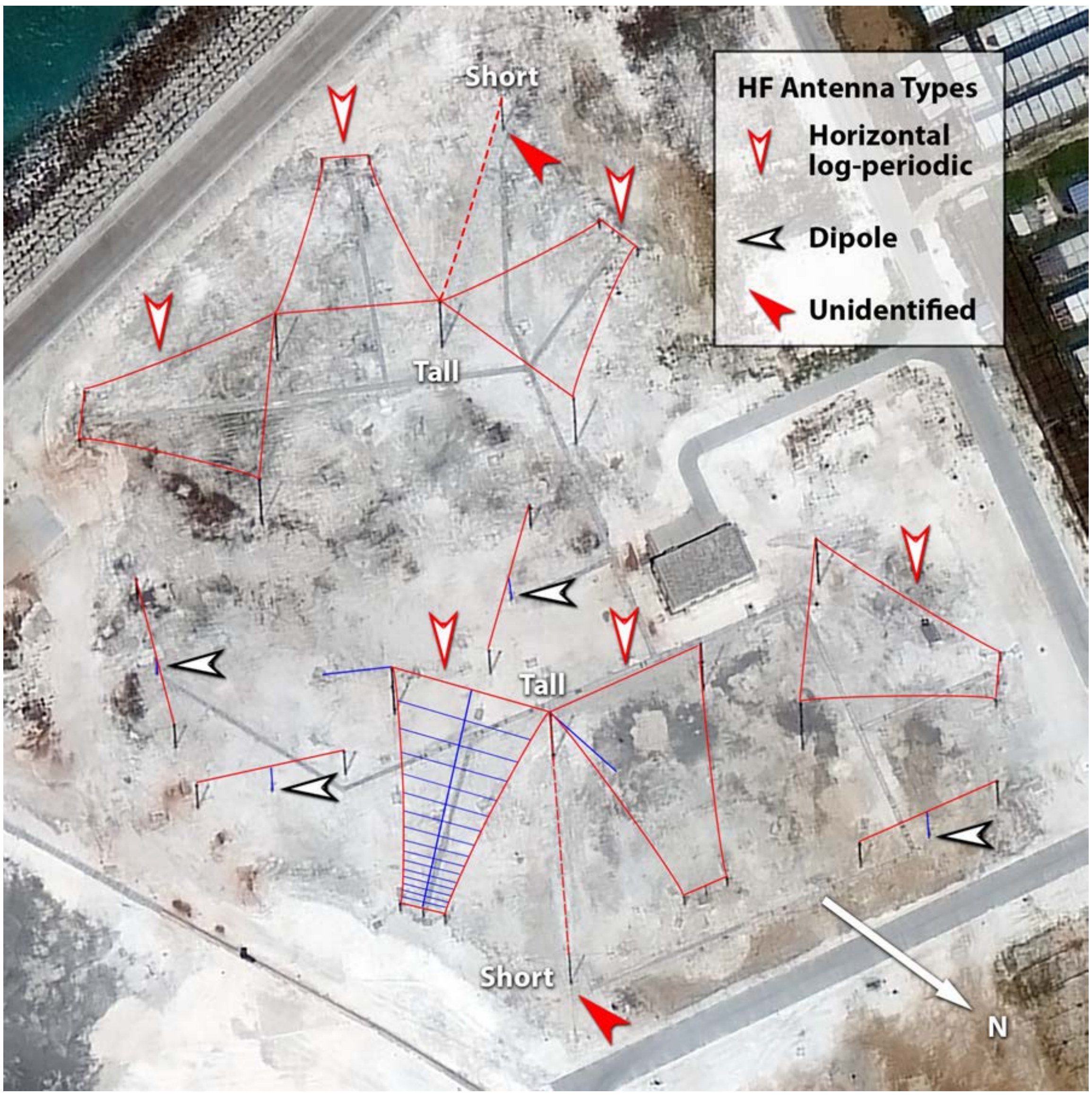
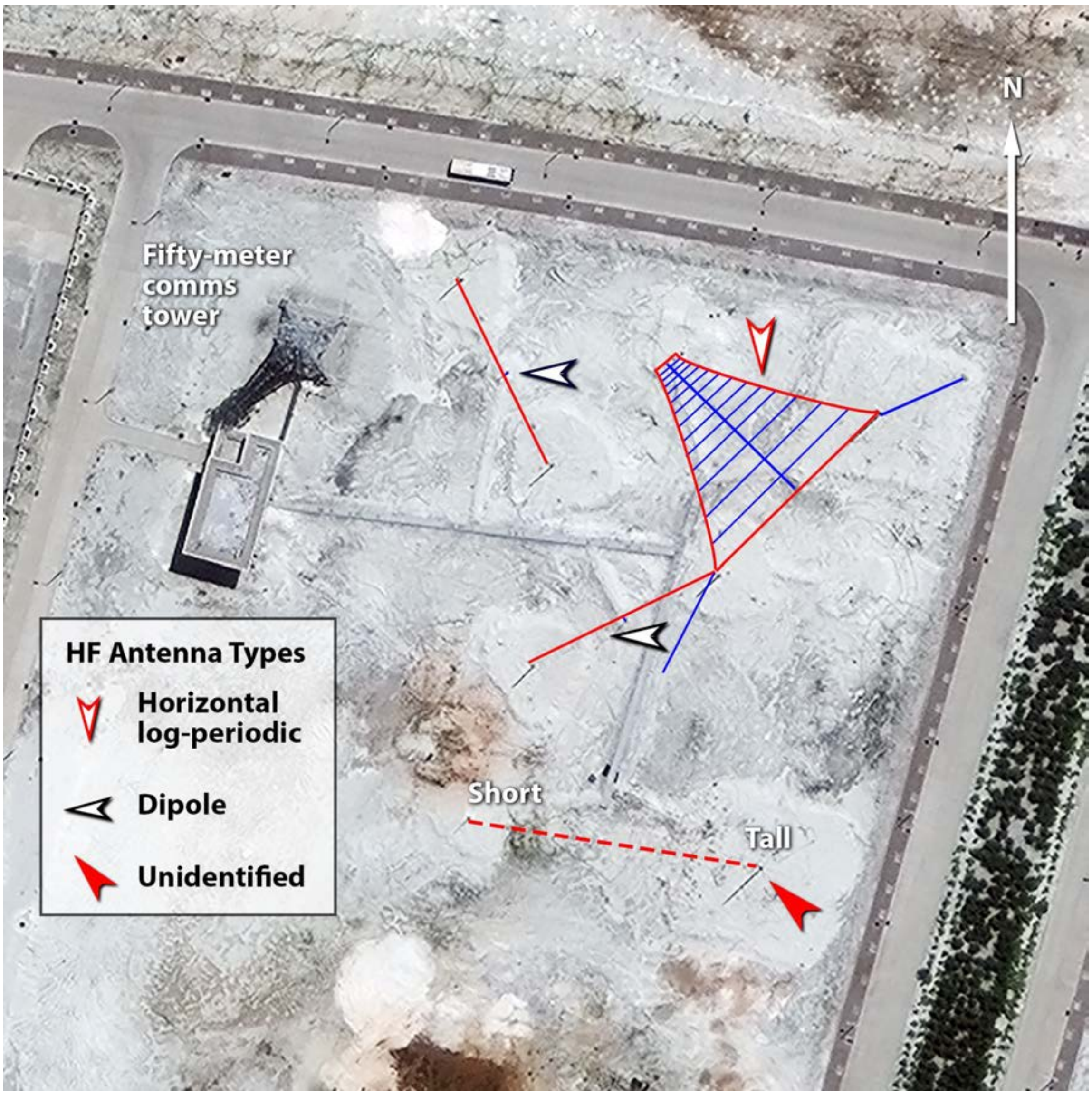


Figure 12. HF Communications Array, Subi Reef

HF Array on Mischief Reef

The HF array on Mischief Reef is colocated with the island-reef's 55-meter communications tower and is considerably smaller than the arrays on Subi and Fiery Cross Reefs. It consists of a **single horizontal log-periodic antenna, two half-wave dipole antennae,** and a **single "tall–short" mast configuration that may be a vertical log-periodic antenna or sloping antenna** (see Figure 13).

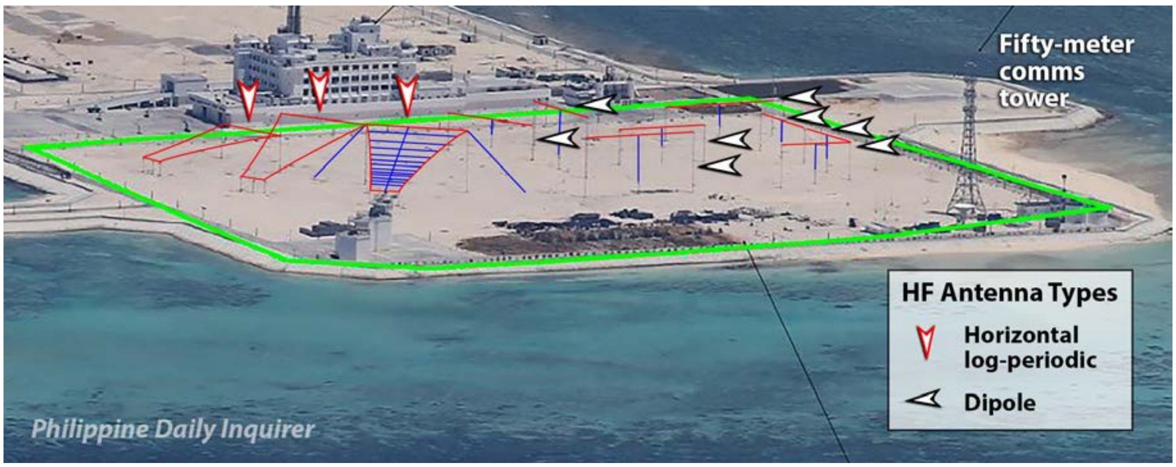


(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 13. HF Communications Array, Mischief Reef

HF Array on Cuarteron Reef

A photograph taken from an aircraft in June 2016, obtained by the *Philippine Daily Inquirer*, reveals the size and scale of the outpost HF arrays juxtaposed against the four-story operations building on Cuarteron Reef (see Figure 14).[2] Again, the tallest masts in this array are approximately 26 meters (85 feet) high. The Cuarteron Reef HF array consists of **three horizontal log-periodic antennae**. One appears to be oriented at a lower angle than the other two. There also appear to be as many as **eight half-wave dipole antennae**. Other antenna types may be present but could not be identified because of the quality of the image.



(Philippine Daily Inquirer)

Figure 14. HF Communications Array, Cuarteron Reef, June 2016

HF Monopole Antenna Arrays

As previously mentioned, there is a field of seven monopole antennae just to the north of the Fiery Cross Reef HF antenna field (see Figure 15). The array consists of seven monopoles approximately 18 meters (59 feet) tall. Three are set in a line to the north, and four are in a line to the south with one set 12 meters back from that line. The perpendicular orientation of the array is 45 degrees (northeast). This array rests at the northernmost point of Fiery Cross Reef, with no obstructions to the sea.

---

[2] 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.

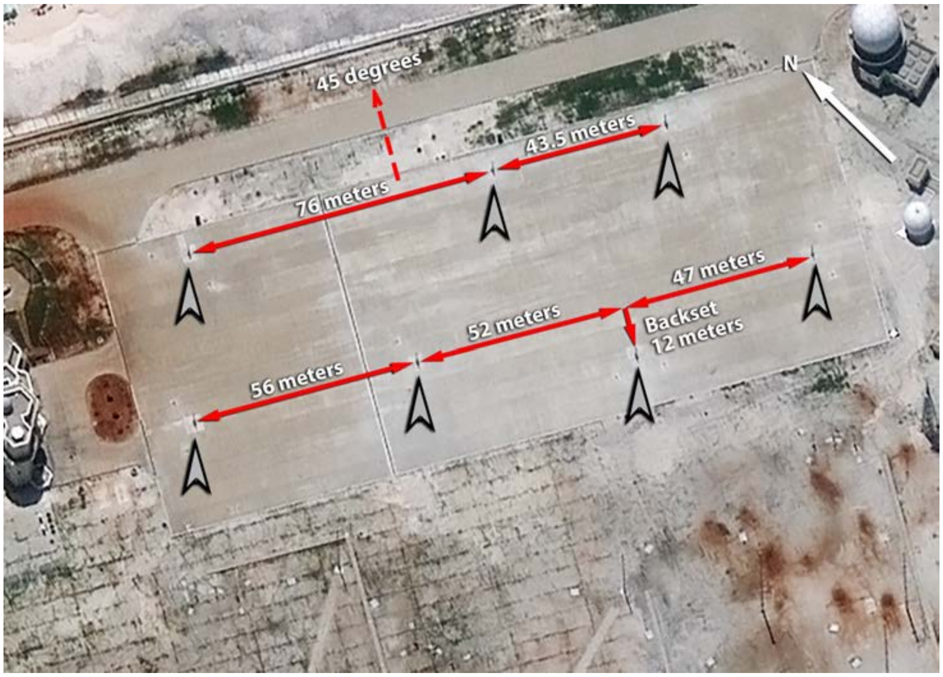


Figure 15. Seven HF Monopole Antenna Array, Fiery Cross Reef

There is another seven-monopole array on Subi Reef with a visually similar arrangement of antennae (see Figure 16). As on Fiery Cross, the array is at the northernmost point of Subi Reef, and there are no obstructions between it and the water. Unlike on Fiery Cross, this array is far from the HF communications array at the opposite end of the island-reef. The perpendicular orientation of the array is 35 degrees (northeast).

An extensive search of Chinese sources and other texts on HF array design did not reveal the specific function of these arrays. The two arrays are strikingly similar and likely serve the same function, but the antennae are set at different distances and in dissimilar proportions. The arrays could function as listening posts; the parallel lines and backset antennae may be used for time difference of arrival geolocation of signals. They may also serve as receive sites for some type of HF over-the-horizon radar. However, an over-the-horizon-radar transmitter was not identified.

The 45- and 35-degree lines of bearing that extend perpendicular from the arrays bracket Scarborough Shoal (600 kilometers northeast) and then pass through the Luzon Strait (1,500 kilometers northeast) north of the Philippines and south to the Strait of Malacca (see Figure 17). This geometry suggests that the arrays may work collaboratively to monitor the northern and southern approaches to the SCS and Spratly Islands. Imagery analysis alone could not determine the function of these HF arrays.

(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 16. Seven HF Monopole Antenna Array, Subi Reef

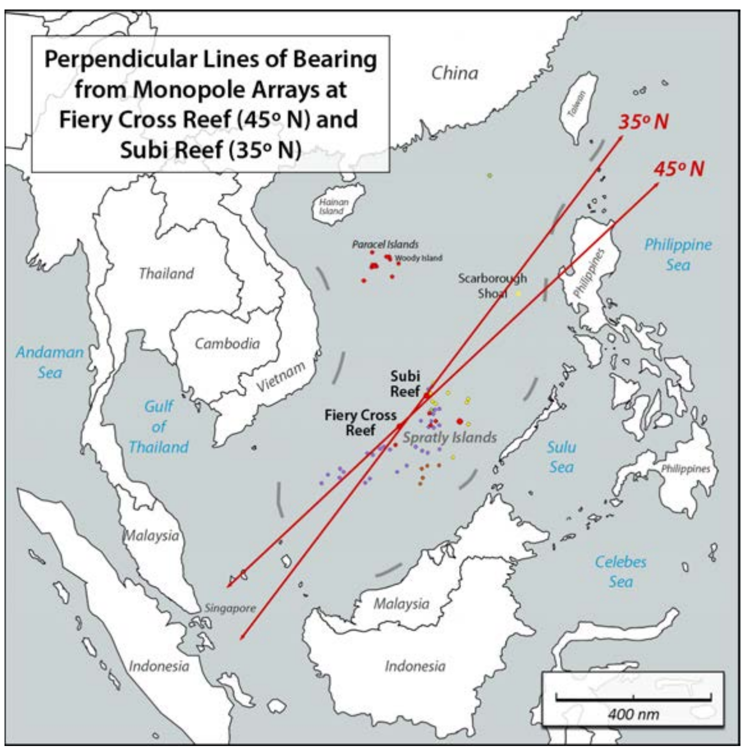


Figure 17. Lines of Bearing from Fiery Cross and Subi Reefs

Possible Very Low-Frequency/Low-Frequency Communications

There is a probable transmitter on the northeast end of Subi Reef that may provide communications in the very low-frequency (VLF) band (3 to 30 kilohertz) or the low-frequency (LF) band (30 to 300 kilohertz) (see Figure 18). Commercial satellite imagery provides compelling evidence of such an antenna on Subi Reef, the only one of its kind on China's SCS outposts. Unlike higher-frequency radio waves, VLF signals are capable of penetrating deep underwater. This antenna, even at relatively low power, may allow the PLA to communicate over long distances with submarines or unmanned underwater vehicles (UUVs) that might deploy VLF or LF antennae just below the surface of the water in the SCS.

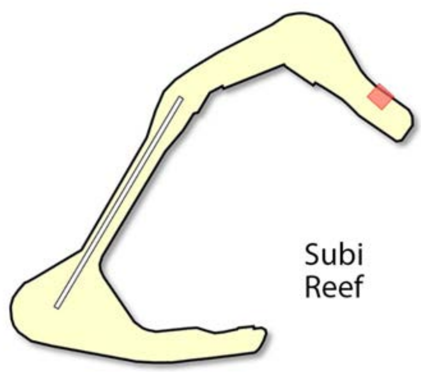
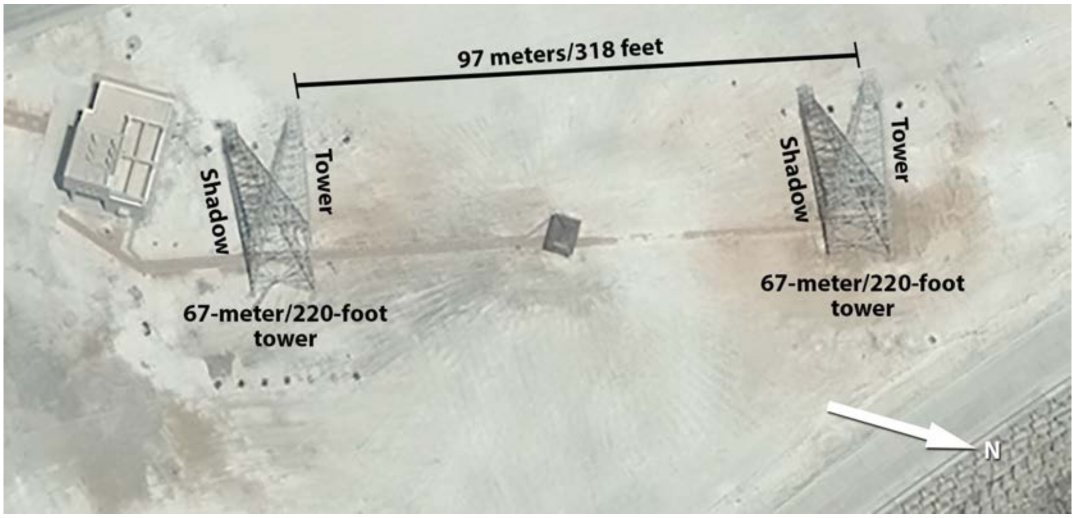


Figure 18. Location of Possible VLF/LF Transmitter

The suspect antenna consists of two 67-meter (220-foot) lattice towers set 97 meters (318 feet) apart. As with HF antennae, the relatively small gauge wires of the antenna are not visible in imagery, so an assessment must be based on the configuration of the masts and other infrastructure. The towers each appear to be topped with a structure that forms a T parallel to the other tower that might be used to support a number of wires strung between the two towers. There is a small structure located midway between the two towers and a possible operations building located directly to the south. The towers are located approximately 100 meters from the water on the northern edge of Subi Reef (see Figure 19).



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 19. Possible VLF/LF Antenna, Subi Reef

The configuration of the antenna suggests a relatively simple VLF/LF transmitter design dating back to the early days of AM radio (Figure 20). Such a "T-antenna" consists of an electrically short monopole radiator element that is a small fraction of the kilometers-long VLF/LF wavelengths. The structure in the middle of the Subi Reef antenna may house a loading coil used to achieve the resonant VLF/LF frequency. The "flat top" or "top hat" wires, strung between the two towers, are for capacitive top loading to counter the electrical ground, which significantly increases the radiating efficiency of the transmission element.

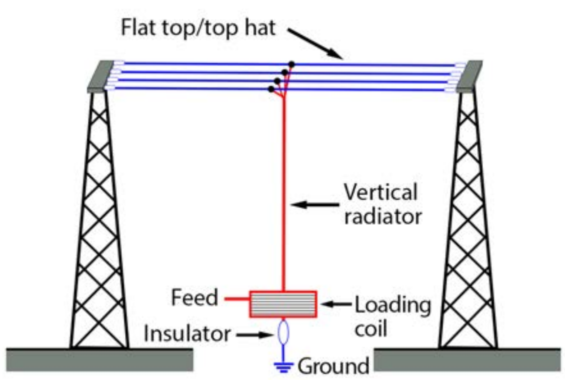
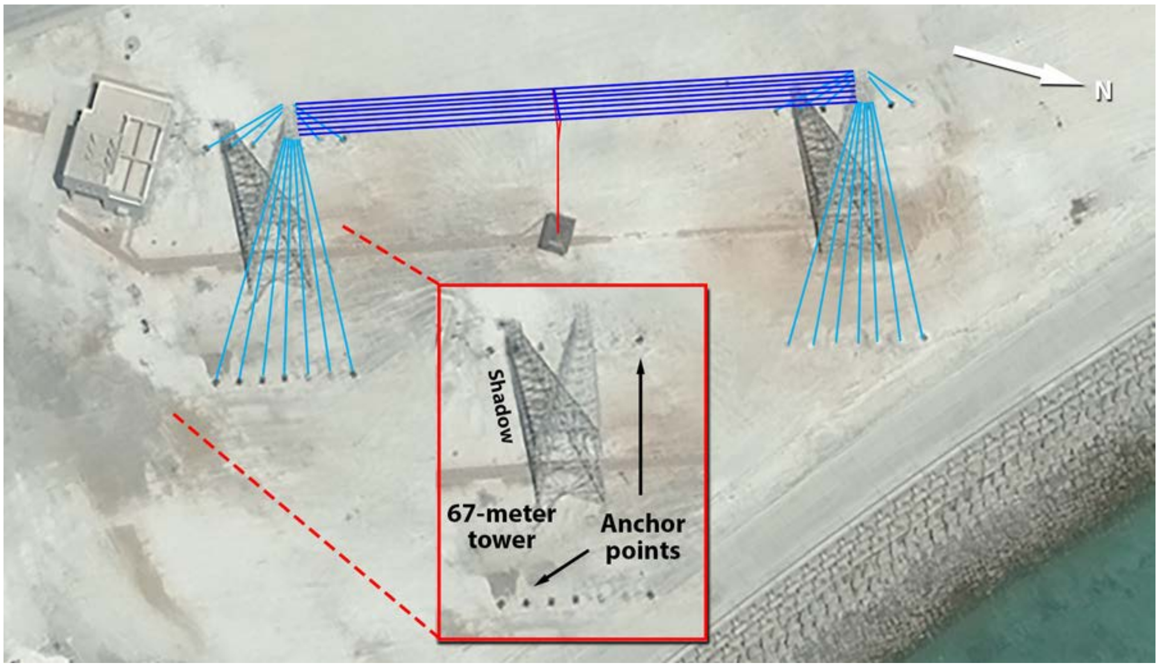


Figure 20. Simple VLF/LF Transmitter

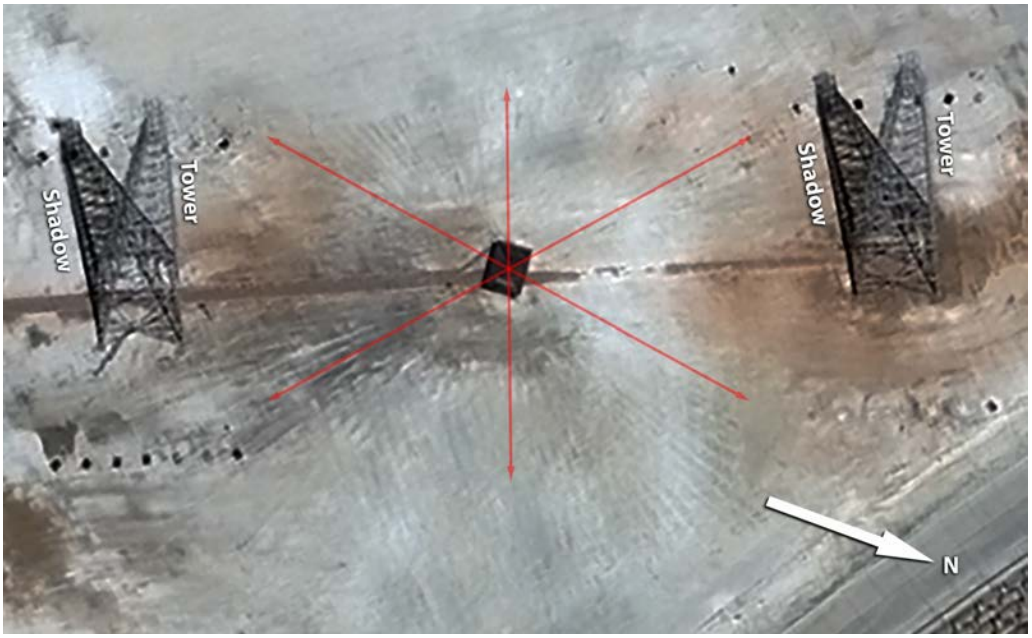
Assuming such a VLF/LF design, the antenna elements might be arranged as shown in Figure 21. There appear to be seven anchor points located east and west of each tower. It is unlikely that these are for support because the towers have substantial bases. If they are structural guy-wires, they appear to extend in only two directions, east and west. Wires between the anchor points and the towers may be an extension of the "top hat" to further increase antenna efficiency. This is speculation, however, because such a configuration has not been observed in other common VLF/LF antennae. The definitive function of the anchor points is unknown.



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 21. Possible Antenna Element Configuration for VLF/LF Transmitter, Subi Reef

Adjusting the tone of the image highlights spokes extending from where a VLF/LF vertical monopole antenna may be (see Figure 22). This is likely a "counterpoise," an artificial Earth connection, or "ground," created by wires that compensate for the low conduction properties and high electrical resistance of dry sand. By extending the counterpoise to the water, a VLF/LF antenna would achieve great efficiency as the LF surface waves then travel out over seawater that has extremely high conductivity and very low resistance.



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 22. Probable VLF/LF Antenna Counterpoise

Conclusions

This study noted over fifty large HF antennae on the three major Chinese outposts and Cuarteron Reef. Several additional HF antennae are likely located atop buildings and on Gaven, Hughes, and Johnson Reefs. HF communications arrays on the island-reefs allow for long-range, over-the-horizon communications among China's SCS outposts, with the Paracel Islands and the Chinese mainland as well as with ships and aircraft that may be operating thousands of miles from the island-reefs. The possible VLF/LF antenna on Subi Reef may allow for communications with submerged submarines or UUVs operating in the SCS. The large HF arrays may allow the PLA to monitor communications in the HF spectrum from foreign ships and aircraft as well as HF communications from other Southeast Asian nations.

The PLA's HF communications capability is complementary to other long-range Chinese SCS communications, such as undersea fiber-optic cable and SATCOM. This HF capability also serves as a back-up to inter-island communications such as troposcatter communications or line-of-sight communications and data links. The redundancy and structure of the PLA's SCS communications offers dozens of different combinations to support a self-healing network. In a conflict, as different communications are jammed or physically damaged, battlespace information as well as command and control may be rerouted from one link to the next through ships, aircraft, and the island-reefs until communications reach their intended destination (see Figure 23).

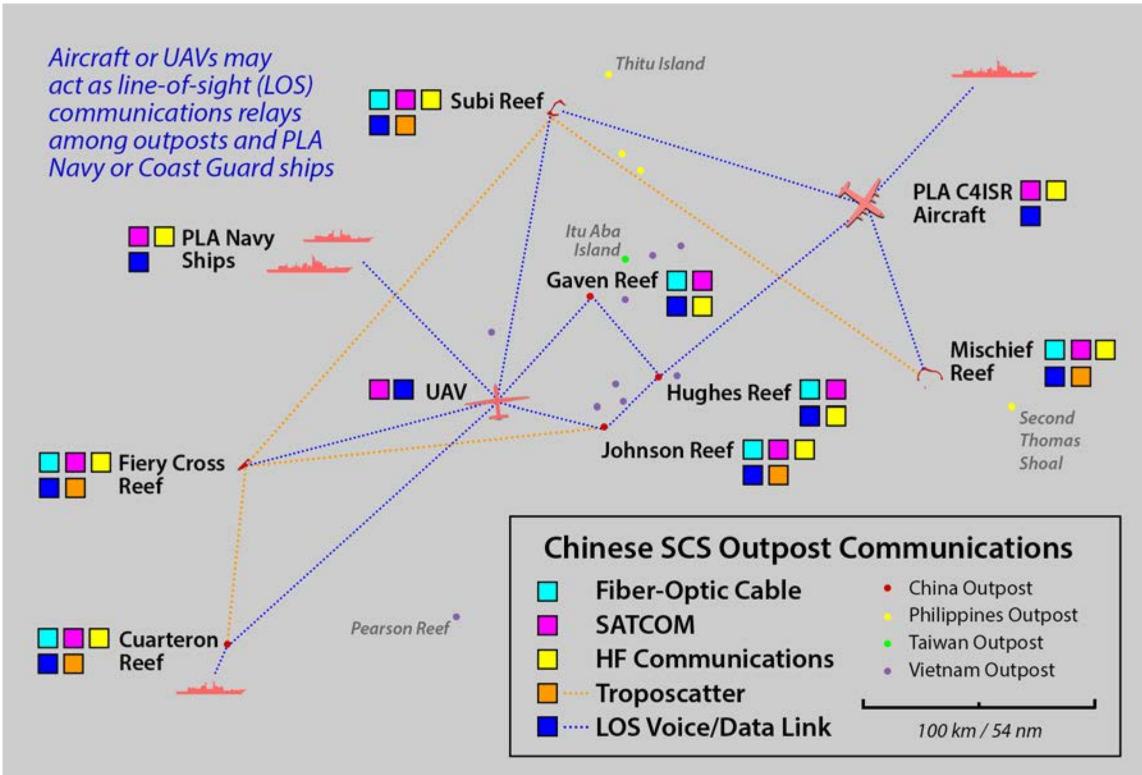


Figure 23. Chinese SCS Outpost Communications

The Chinese investment in HF communications on their island-reefs demonstrates a PLA informationized warfare strategy that emphasizes information control. Taken with other communications and reconnaissance capabilities, these HF arrays contribute to robust and redundant capabilities that cover a broad swath of the electromagnetic spectrum. Countering the PLA's ability to communicate in a conflict will involve simultaneously interfering with or destroying a number of Chinese communication means to deny PLA designs to gain and maintain battlespace information advantage.

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).[3] 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 24. The dots made up of only a few pixels in Figure 24(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 24(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 24(C) is an example that indicates the likely connection between two widely separated troposcatter terminals based on antenna pointing angles. Figure 24(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.[4]

[3] 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.

[4] See close-up images of the towed array door in "'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.

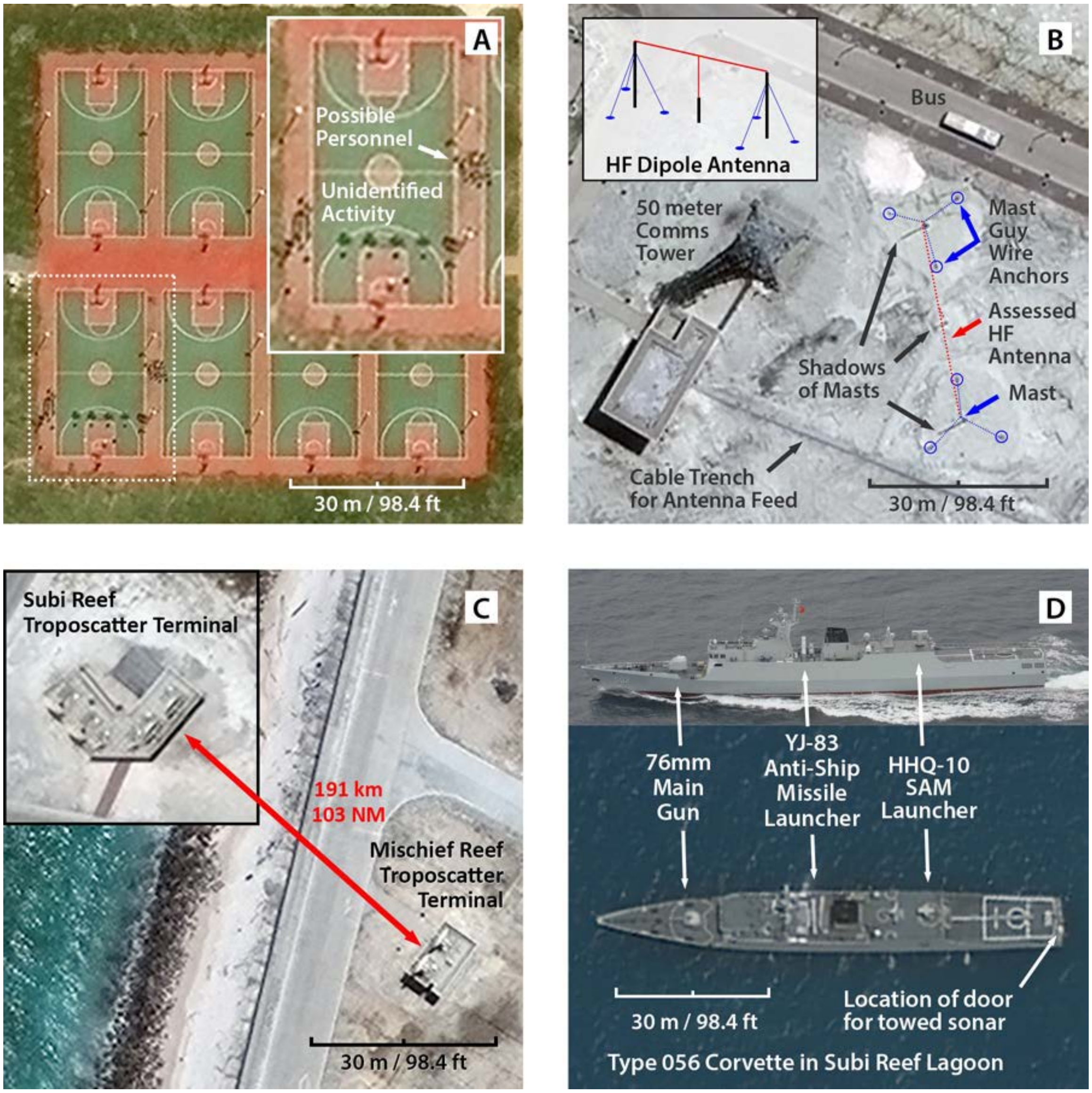


Figure 24. Detailed Image Examples. (A) Mischief Reef Basketball Courts, (B) Mischief Reef HF Antenna, (C) Troposcatter Terminals, (D) Type 056 Frigate

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

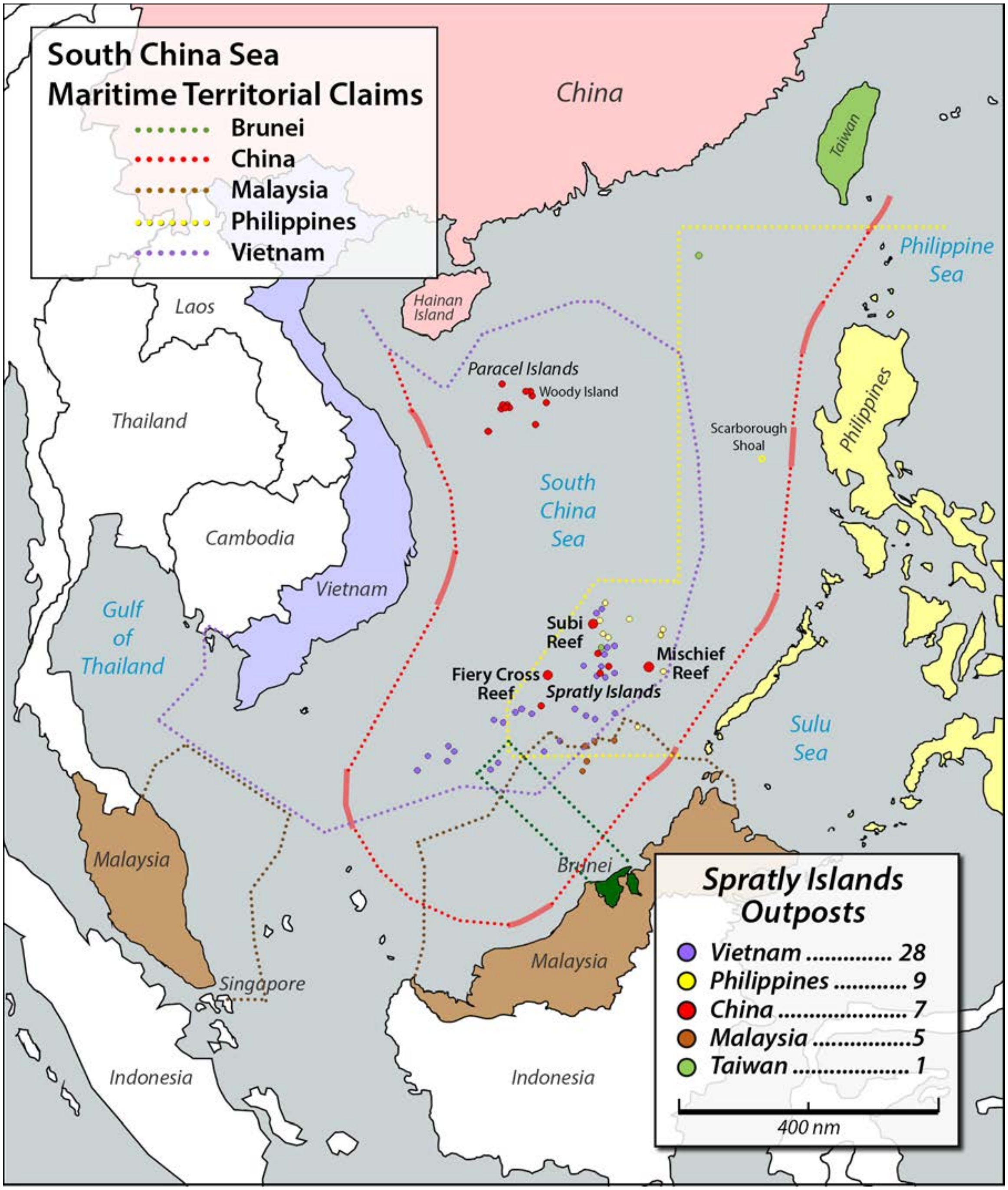
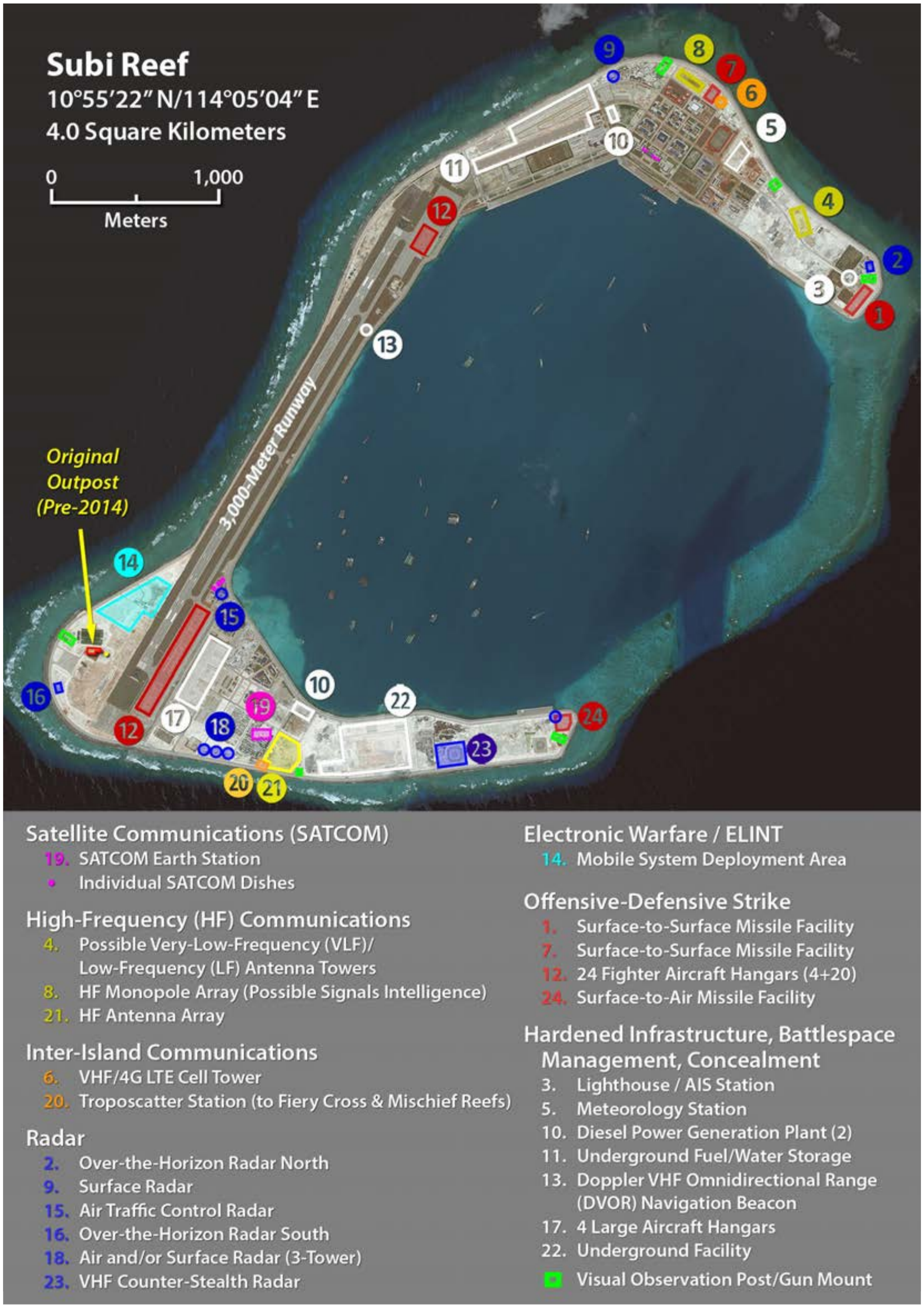


Figure 25. South China Sea Maritime Territorial Claims

Appendix C. Island-Reef Capabilities Overview Graphics

(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 26. Fiery Cross Reef Overview



(Image © 2020 Maxar/DigitalGlobe, Inc.)

Figure 27. Subi Reef Overview

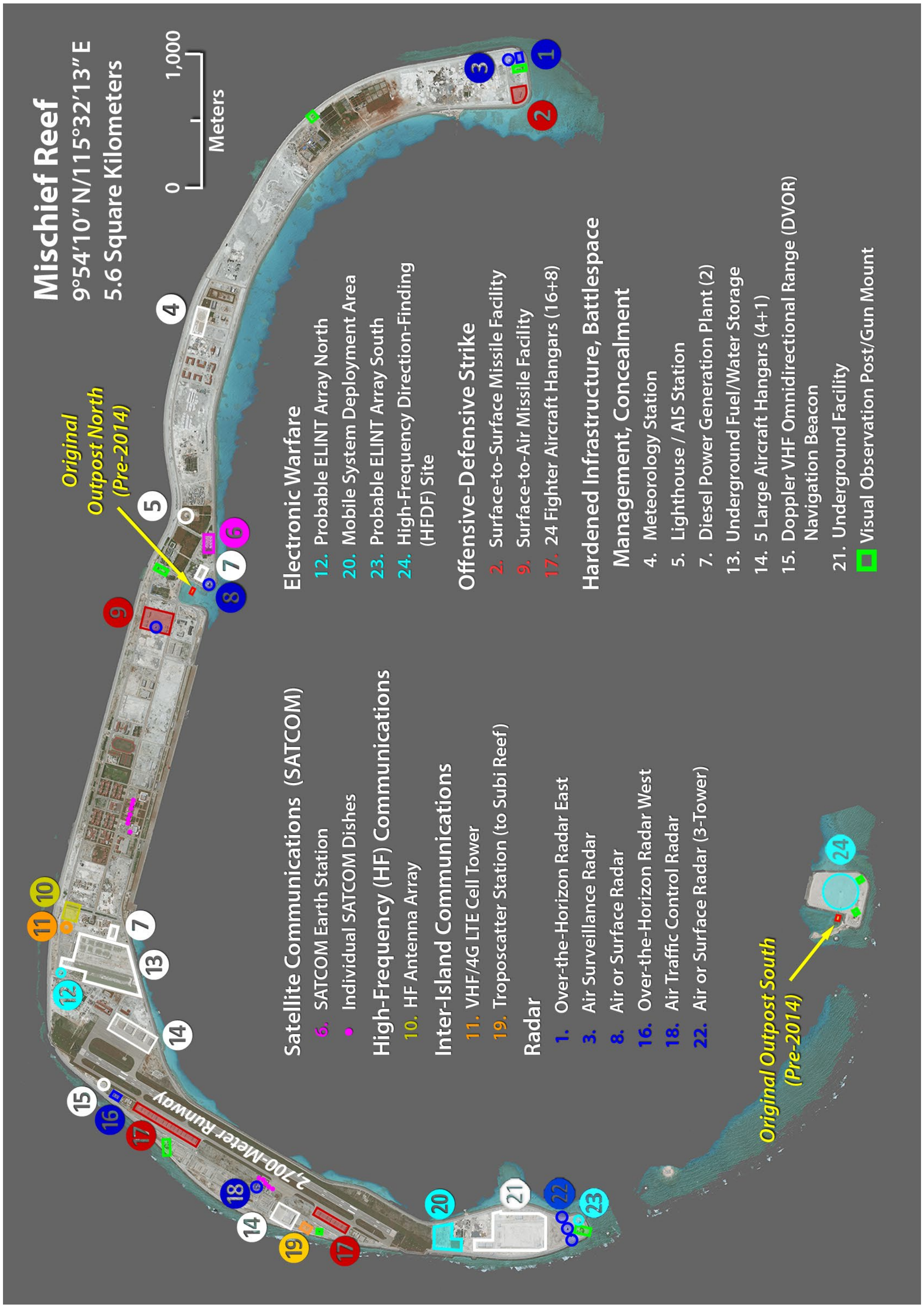


Figure 28. Mischief Reef Overview

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.

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY