INNOVATING ULTRA-WIDEBAND HF-VHF-UHF BEAMFORMING ANTENNAS FOR STEALTH NAVAL USE

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NAVAL HF-VHF-UHF ANTENNAS

Modern naval vessel can employ as many as 100 antennas, each tailored for a specific shipboard communication or sensing system [1]. The desire to support new and legacy systems has caused the quantity and size of these antennas to explode, demanding more real estate on the ship's platform (Fig. 1a) [1]. Therefore, it is highly desirable to consolidate these antennas.

(a)

(b)

Fig. 1 (a) Naval antennas [1] (b) discone VHF antenna [2]

Furthermore the physical implementation of conventional antennas lies contrary to the design trend of modern naval ships as they can obfuscate visibility and enhance adversarial detectability (Fig. 1b) [2]. Traditionally, the radar cross section (RCS) of naval ships was not a critical ship design parameter. However, growing overseas threats have fueled the need for stealthy ship designs which minimize RCS, such as the Independence- (Fig. 1a) and Zumwalt-class vessels (Fig. 1b) [3][4]. These RCS-reducing design elements may include the size, shape and contour of the vessel, as well as the materials used for the ship's hull. Too many antennas will impact these parameters. While some effort has been made to integrate antennas into the ship's structure [5], a better approach is to design ships with a low RCS and then employ conformal antennas which do not violate original intent of the ship design. It is also highly desirable to utilize the ship's hull or platform for electromagnetic propagation.

(a)

(b)

Fig. 2 (a) Independence-class vessel [3] (b) Zumwalt class vessel [4]

DEMAND FOR IMPROVED ANTENNAS FOR STRATEGIC DOMINANCE

HF (2 MHz to 30 MHz), VHF (30 to 88 MHz), and UHF (225 MHz to 3 GHz) continue to serve as a robust communications systems and we endeavor to develop an antenna system which can replace low-gain discone, dipoles and monopoles. Such an antenna system would (1) cover multi-octave bandwidths; (2) conform to the surface of the ship; (3) possess beam-forming capabilities (MIMO); (4) include the ships structure as part of the conducting medium, while (5) maintaining comparable performance to existing design. Satisfying all five requirements in a single design is extremely challenging due to fundamental limitations in conventional antenna topologies which express contradictory characteristics.

Spiral antennas serves as the ideal candidate for HF to UHF ultra-wide band (UWB) MIMO conformal antennas [6][7]. Modeling and simulations performed at UCD have produced a hexagonal Archimedean spiral antenna for UHF (Fig. 2a) and a log spiral antenna for VHF (Fig. 2b). The gain of a VHF log spiral are simulated at 500MHz and 3GHz (Figs. 2c and 2d, respectively), demonstrating 3.75-10 dBi gain across band which is better than shipboard discones or dipoles which typically have around 2dBi gain [8]. Inclusion of a ground plane will further increase the gain [9].

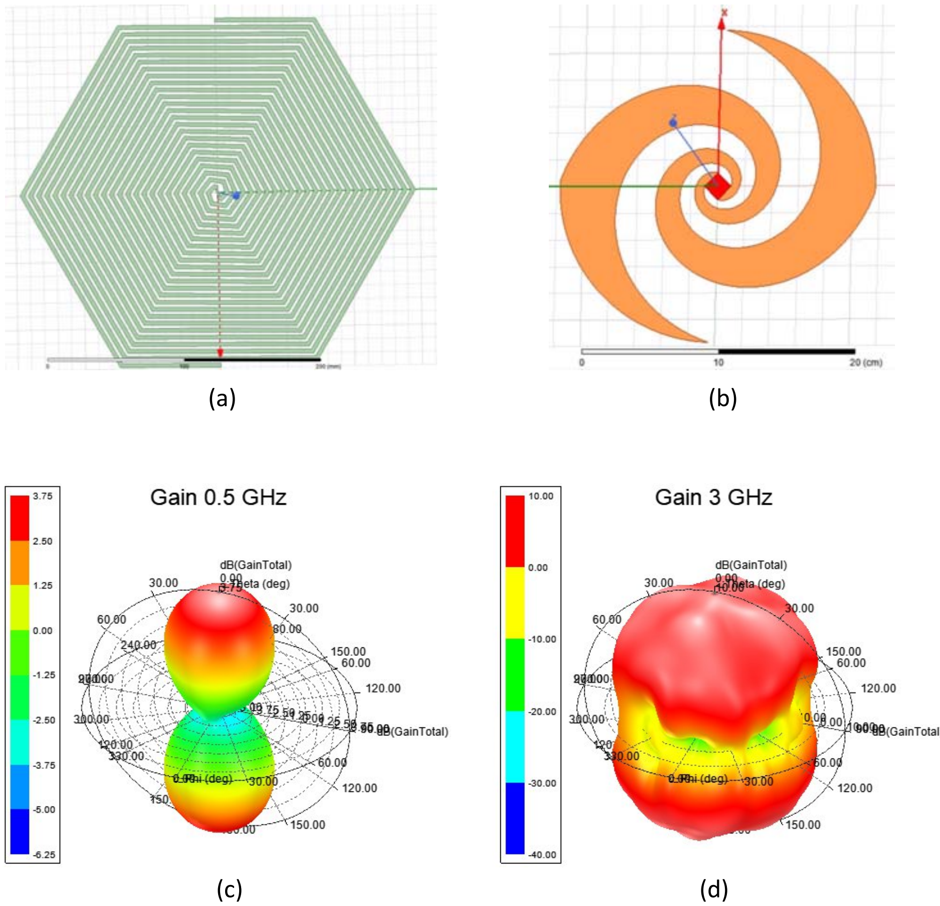


Fig. 2 (a) Hexagonal Archimedean spiral (b) Log spiral (c) Log spiral gain at 0.5GHz (d) Log spiral gain at 3GHz

Like patch antennas, spiral antennas have a broadside radiation pattern and can be fabricated to affix to the side of a ship. As such, the ship's hull can perform as a conducting ground plane or cavity, thereby enhancing antenna gain and rendering the antenna pattern unidirectional [7][9]. The low-profile or planar manufacturability lends itself to good conformability either as a flexible substrate antenna or as a tiled antenna system or both (Fig. 3a) [10][11]. This feature allows UWB spiral antennas be easily fabricate into phased-array antenna systems (Fig. 3b). Their use in MIMO systems is an active area of research [7]. The hexagonal structure simulated by UCD allows for compact implementation of antenna array elements on ships such as the Arleigh Burke-class destroyer (Fig. 3c).

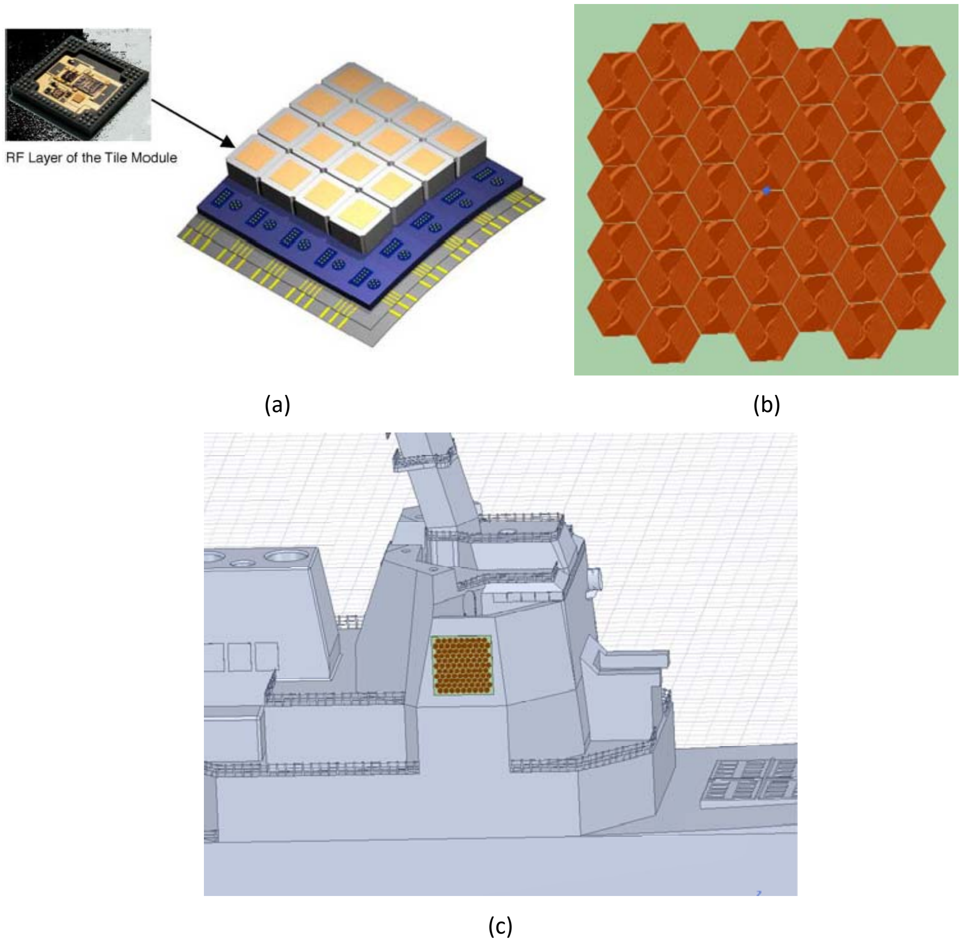


Fig. 3 (a)Tiled concept phased array with underlying T/R modules [10] (b) UCD 38 element UHF Archimedean hexagonal spiral phased array antenna, 1.6m x 1.5m (c) UCD Phased array concept affixed to the port superstructure of an Arleigh Burke-class ship (to scale)

ADVANCES IN ANTENNAS USING ADDITIVE MANUFACTURING

Although the spiral architecture has been used for many decades, new techniques in additive manufacturing have enabled performance improvement, miniaturization and novel/flexible form factors suitable for a shipboard conformal antenna application. Aspects of antenna design which benefit from advancements in 3D printing include the conductive layer of the antenna, multi-layer/multi-material substrates and the fabrication of guide structures (lenses, polarizers).

Deficiencies in metallization layer quality increases the antenna loss at RF (UHF) due to skin depth effects. Therefore, antennas can benefit from the improvements in direct metal printing which enhance the conductivity, uniformity and surface smoothness of the metal ink layers. Already, advanced omnidirectional metal nanoparticle printing on arbitrary geometries has enabled the integration of RF antennas conforming to any surface or structure (Fig. 4a) [12]. Furthermore, 3D printing of fiber-reinforced composite substrates has enabled the development of load-bearing panels which can directly replace a ships panel while serving as a platform for integrated, conformal antennas [13].

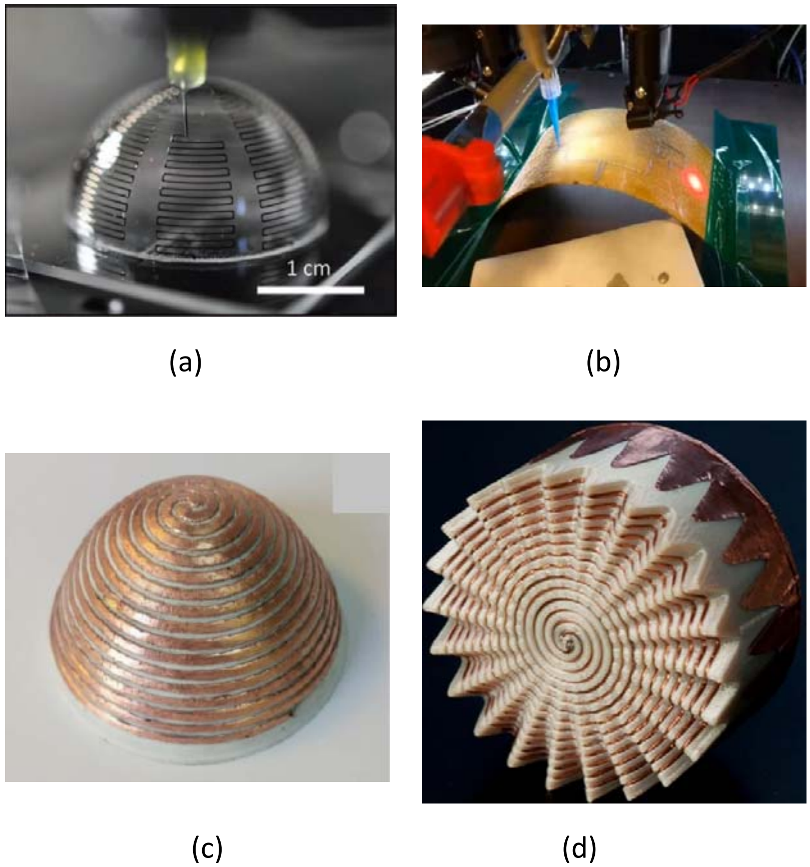
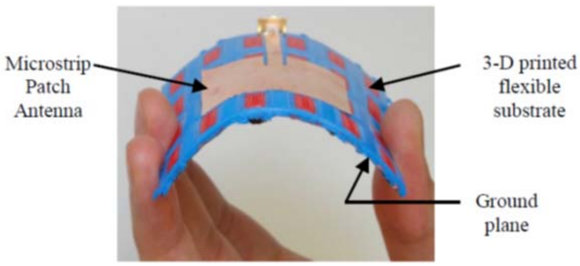


Fig. 4. (a) conformal printing of metal lines [12] (b) printing of a conformal load bearing antenna panel [13] (c) volumetric spiral antenna [14] (d) cavity backed periodic spiral antenna [15]

In UWB spiral antennas, the upper RF cutoff frequency depends on the resolution and metallization quality of the inner turns while the lower cutoff frequency is dictated by the overall conductor length. Therefore, it is desirable retain high manufacturing precision while pursuing miniaturization. Fortunately, 3D printing has also enabled a number of miniaturization techniques by the use of complex substrate geometries. Specialized structures such as volumetric spirals (Fig. 4c) and periodic spiral antenna (Fig. 4d) can only be investigated using additive manufacturing techniques [14][15]. These structures work by increasing the length but reducing the radius of the spiral. Such structures, although they are higher profile, can be manufactured in a tiled format and mounted on the side of ship with minimal impact on the ship's RCS (Fig.3a).

Additive manufacturing has also allowed for the experimentation with flexible substrates which can further enhance comformability. Substrates ranging from low cost PLA [14] and ABS [11] to exotic Ninjaflex [16] and ceramic-doped silicone-based compounds [17] have been studied with respect to bendability, versatility, loss and dielectric performance. The flexibility of these materials can give rise to low-profile, applique antenna or antenna "skin".



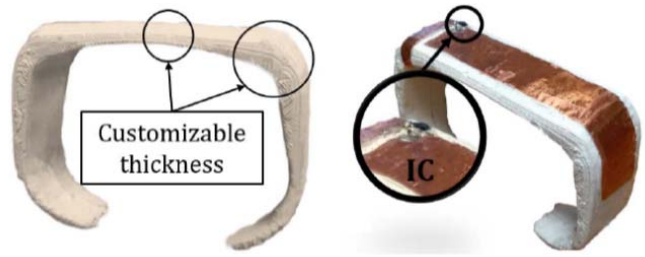


Fig. 5. (a) Patch antenna on Ninjaflex substrate [16] (b) Antenna on ceramic-doped silicone bracelet made from 3D printed mold [17]

RESEARCH POTENTIAL AND FURTHER INQUIRIES

The wide-ranging implications of conformal and applique antennas for UWB HF-VHF-UHF beamforming are tremendous. Not only do these technologies carry a great potential for the Navy, they can also be applied in the automotive, aerospace, construction and infrastructure industries. Additive manufacturing is rapidly evolving and the unique structures which it enables can pioneer new directions for low-obstruction, conformal UWB communications across all bands.

Echoic Engineering is actively seeking collaboration in the areas of UWB HF-VHF-UHF conformal beamforming antennas. Please contact us at www.echoicrf.com or by email at ksyuk@echoicrf.com.

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