Overview. The proposed new antenna is expected to meet various requirements:

1. Incorporate electronic beam steering in elevation $\pm 25^{o}$ providing more than two elevation beams, incorporate cosec2 coverage, handle peak power up to 300 kW at 4% duty cycle, sidelobe reductions and beamwidth, the gain not less than 28 dBi
2. Incorporate the electronic steering and stabilization of beams in the elevation plane (“row-board”) to lower overall and maintenance cost, extend the radar operational life and improve its reliability
3. **No radome design** to meet antenna assembly weight constraint
4. The mechanical structure should be capable of withstanding **without radome lightning strikes**, high winds (90 knots operational and 120 knots without damage), an ice load of 7 pounds per square foot of antenna surface. It shall maintain the specified performance over the temperature range -54^{o}C to +65^{o}C when exposed to a relative humidity of 95 percent, sold fog, and other conditions in accordance with MIL-E-16400

Parabolic Cylinder Reflectarray. The central element of the proposed solution is to replace the current massive and oversized parabolic reflector with an affordable, lightweight, and efficient spatially-fed parabolic cylinder shape reflectarray of *L*=17.17’ x *H*=6.24’ x *W*=2.26’ (TBD). The front flat-panel schematic and patch element incorporated on the parabolic cylinder surface as Fig. 1 and 2 demonstrate (not in scale), respectively. 8 rows of horizontal patches corporate connected in each row form the collimated azimuth beam that is steered using the rotary joint. The feed network with “row-boards” phase shifters (TBD) connected to each element (assumed behind the reflectarray but not shown in the drawing) ensures the required elevation scan, multibeam operation up to 3 beams, cosec2 pattern, and over horizon electronic beam stabilization.

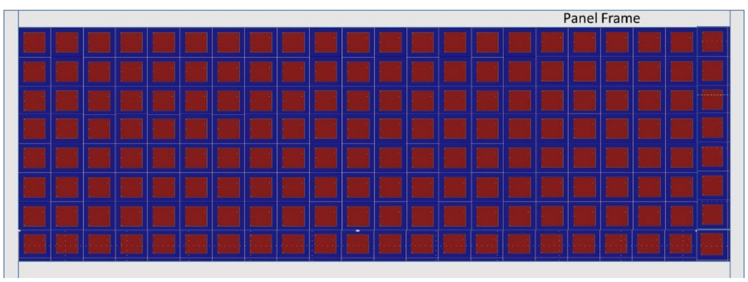

Fig. 1 The front view of antenna aperture

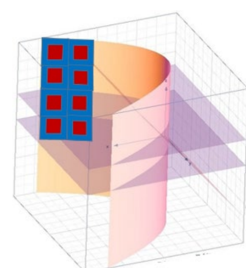

Fig. 2 Parabolic cylinder reflectorarray

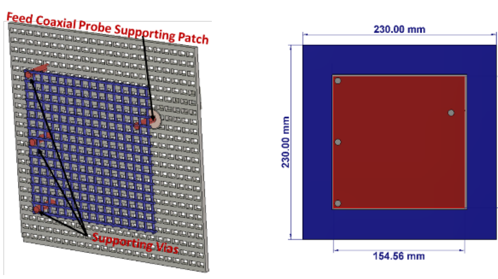

Fig. 3 The patch element image

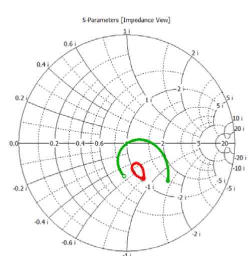

Fig. 4 Smith chart showing input impedance

Patch Element. Fig. 3 depicts the broadband patch element. According to Fig. 4, the input impedance in array environment is practically independent on the elevation scan angle (boresight is the red line while elevation angle 25^{o} is the green line) that guarantees the proper intercommunication with the feed network or loading each patch element varactor diode/ferroelectric thin film/MEMS. The feasibility computer analysis demonstrates that the proposed reflectarray boresight directivity varies from 30 dBi at 850 MHz to 31 dBi at 950 MHz for a uniformly driven reflectarray. The expected 2 – 3 dBi margin will mitigate the gain decline due to spill-over, phase shifter module loss, tapering, sidelobe reduction in azimuth & elevation, cross-pol loss, etc.

Weight, Size, and Cost Reduction. According to preliminary numerical simulation, such a patch array should have almost 100% aperture efficiency in comparison to 32% for the current parabolic reflector. As a result, the expected total antenna weight will be around 1,500 lbs. (TBD). The set of 176 = 22 x 8 (TBD) is executed as an organic whole with the parabolic screen due to the rigid 4-points via connection. Both are fabricated from a metal grid the same way as the current parabolic reflector or thin perforated sheet of aluminum or conductive, lightweight composite material like carbon fiber. The 3 edge vias play the dual role being the patch **lightning grounding** and matching elements for broadband performance. Since in the proposed design the parabolic mirror width (W) decreases from current 3.16' to 2.26', the feedhorn support boom and high power waveguide connected to a rotary joint became shorter. As a result, the antenna dimension aligned horizontally shrinks (~1.5 times, TDB) thereby reducing the overall inertia moment and extending thus the rotary joint life-cycle. The modular/Lego structure (patch + phase shifter = one integrated element) allows cost-effective periodic preventive and corrective maintenance. The replacement of out of service or damaged antenna elements becomes straightforward, shrinks to minutes efforts, does not require re-seal, and minimizes re-paint. **<u>It is worth mentioning that the proposed concept does not require redevelopment of any of the radar high power feed elements thereby lowing the project cost substantially</u>.**

Over horizon electronic beam stabilization. To lighten the load on the antenna rotary joint further and lower thereby its overall and maintenance cost, the electronic stabilization of beams in the elevation plane ("row-board") will be proposed. If required, the electronic stabilization in azimuth could be added. The final recommendations will be formulated during Phase I technical efforts and based on cost, weight, and performance comparison.

Commercialization. The modular/Lego structure (patch + phase shifter = one integrated element) of the proposed parabolic cylinder schematic or transition to flat-panel makes the suggested design to be highly flexible and suitable to upgrade not only antenna of the existing shipboard but land-based military radars, weather, air traffic control systems, etc.

Further Development. The simplified drawing (not in scale) of the proposed reflectantenna on the support boom is shown in Fig. 5, i.e., it can be readily incorporated into the existing antenna structure. Two additional variants of spatially-fed reflectarray implementation will be considered during Phase I. The first one is the Cassegrain dual-reflectarray antenna, as shown in Fig. 6 (copy from https://www.nature.com/articles/s41598-017-13125-5.pdf), and the second is a spatially-fed lens- through array depicted in Fig. 7. Both structures allow getting rid of all variable phase shifters inside of the large main panel and making multibeaming and scan performance more flexible. Both variants will be analyzed and compared through their power handling, electrical and mechanical performance, complexity, and implementation cost.

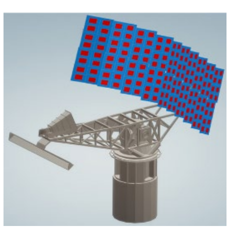

Fig. 5 Cylindrical reflectarray

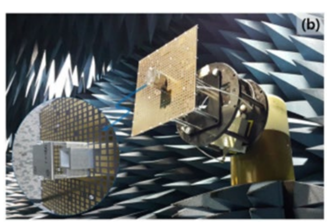

Fig. 6 Cassegrain reflectarray

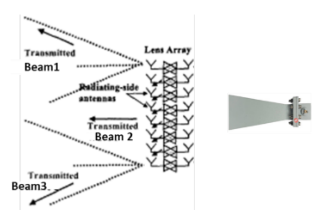

Fig. 7 Schematic of lens-through array

Preliminary Analysis. The extensive computer simulation was carried out to prove the technical feasibility of the proposed concept. All data are preliminary and correspond to the array without beam sidelobe reduction. The patterns and gain of the proposed flat-panel of 22 x 8 elements in azimuth and elevation cross-section are pictured in Fig. 4. The 3-dB beamwidth in azimuth is equal to 3.4° at 850 MHz, 3.2° at

900 MHz, and 3.0º at 950 MHz while in elevation 9.4º at 850 MHz, 8.9º at 900 MHz, and 8.4º at 950 MHz. These beamwidths will slightly increase as the sidelobe reduction will be implemented.

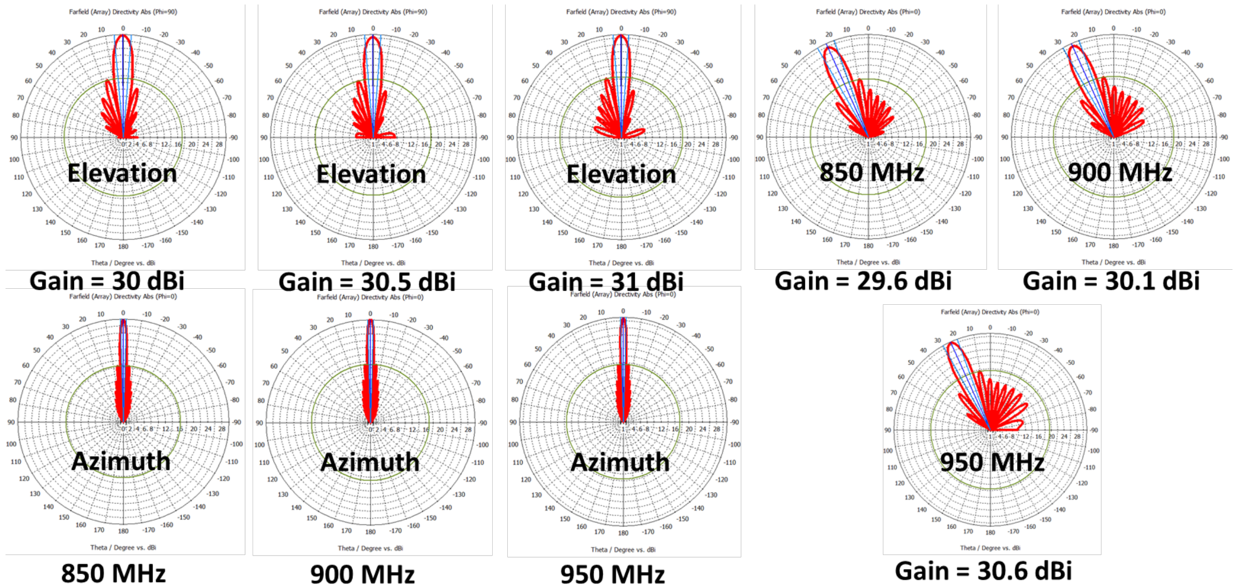

Fig. 4 Radiation characteristics of the antenna panel

The Power Handling is not an issue because each of the array patch elements with phase shifters should hold just 300 kW/176 = 1.7 kW of peak or 68 W average power. If so, the active liquid cooling is not required.