

P-band Antenna Array for NASA's Space Exploration Synthetic Aperture Radar (SESAR) Instrument

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Abstract— A dual-polarized, wideband, lightweight P-band (435 MHz) antenna element and array for spaceborne radar applications has been developed for NASA's SESAR (Space Exploration Synthetic Aperture Radar) instrument for planetary synthetic aperture radar (SAR) applications. The antenna array is based on lightweight, low-profile antenna elements that form the building blocks of configurable "array panels" that can in turn be used to build larger arrays consisting of multiple panels. The element design combines a novel, mostly planar conductor antenna element geometry with a robust lightweight composite material construction.

Keywords— SAR; phased array, antennas, digital beamforming; polarimetry; scatterometry, P-band; wideband.

I. INTRODUCTION

NASA's Space Exploration Synthetic Aperture Radar (SESAR) instrument [1], [2] is designed for planetary and lunar surface and sub-surface exploration, whereby the long wavelength (~ 70 cm) is suitable for deep surface penetration of several meters, allowing fine spatial resolution imaging of the surface with full polarimetry. A 40-element SAR instrument panel was successfully designed, built and tested under relevant Moon and Mars environmental conditions with the goal of maturing the technology to a Technical Readiness Level (TRL) 6. More recently, a lighter version of this radar that is compatible with small satellite platforms was formulated in the form of SESAR-Lunar Investigations Targeted Experiment (-LITE) [3], with the aim of addressing some of the scientific goals of NASA's Artemis program for exploration of the moon's surface.

The SESAR architecture enables beam agile and high-resolution polarimetric imaging and sounding, or scatterometry, using transmit and receive digital beamforming in the cross-track direction and SAR (doppler) processing in the along-track direction. The beams are synthesized with programmable incident angle, side-lobe structure, and polarimetric mode: single (HH or VV), dual (HH, HV; or VH, VV), hybrid (CH, CV), or full polarization (HH, VV, VH, HV). Measurements of the radar backscattering cross-sections (RCS) in hybrid and full polarimetric modes permits the derivation of the Stokes parameters, which are used in the analysis of the different scattering mechanisms associated with a variety of geological textures and geometries.

The SESAR instruments are the latest development from NASA's SAR instrument research work [4], with previous projects that include EcoSAR [5], [6], [7] an airborne P-band SAR developed at GSFC for the polarimetric and interferometric measurements of ecosystem structure and biomass; and the L-band DBSAR-1 and DBSAR-2 instruments [8], [9].

One of the key components of the SESAR instrument is the antenna array, which will be described here. Due to the low P-band frequencies, the electrically large antenna array required for a synthetic aperture radar (SAR) implies a physically large antenna that needs to be robust enough to withstand the harsh outer space environment and stresses during launch, but at the same time needs to have minimal mass to reduce the launch costs and spacecraft infrastructure to support it.

II. ANTENNA DESIGN

A. Physical size considerations

The SESAR antenna array, patent pending [10], targets the frequency band 385MHz – 485MHz. For digital beam-forming, the upper frequency limit places a constraint on the physical element spacing in the scan plane or cross-track direction, while the goal of stowability – i.e. folding the array into panels and stacking them – places practical constraints on the array element height. An element height limit of ~ 100 mm (about $1/6$ of a wavelength) before the addition of structural support was determined early on via evaluation of the element bandwidth as a function of the height, while an arbitrary element spacing of 355mm (about 0.6 wavelengths) was chosen for the along-track direction.

B. Array configuration

The antenna array is built up in rows and columns of a light weight antenna "element", designed specifically for the purpose of allowing beam steering up to the maximum desirable angle without incurring grating lobes in the radiation patterns. For flexible mission planning, a large array can be built from a number of small "panels" deployable from a folded/stacked stowed configuration during launch to be arranged side by side during operation, where each panel is by itself a fully functional small antenna array, or at least of a manageable stowable size.

Fig. 1 shows a prototype panel array of 5 subarrays $\times$ 8 elements built for a planetary SESAR application, and Fig. 2 shows a schematic of an array of 12 subarrays $\times$ 3 elements proposed for SESAR-LITE, that can be subdivided into four stowable 3 $\times$ 3 element panels. Each subarray has its own “fixed” excitation feed network, which defines the beam shape in the along-track plane, while cross-track beam forming is done by excitation at the sub-array level. A spacing of $d_x = 301$ mm between subarrays was chosen to allow up to 40° cross-track beam scanning for 5 subarrays, or 45° for 12 subarrays. The predicted cross-track radiation pattern performance of the panel array in Fig. 1 is shown in Fig. 3, for the maximum 40° scan angle in the xz-plane and at the upper end of the frequency range. The element spacing d_x in the x-direction is chosen to sufficiently suppress the grating lobe that occurs at -80° . The number of panels can, of course, be chosen as dictated by the particular mission objectives and mission budget.

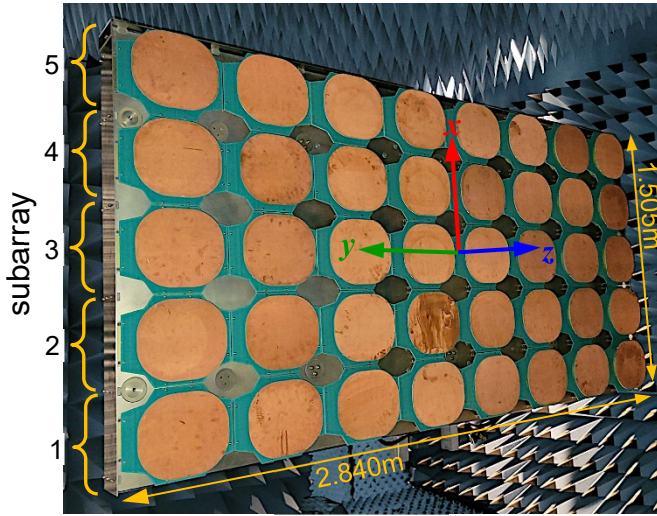


Fig. 1 A single 2.84m $\times$ 1.505m SESAR panel array of 40 elements, which consists of 5 subarray's of 8 elements each.

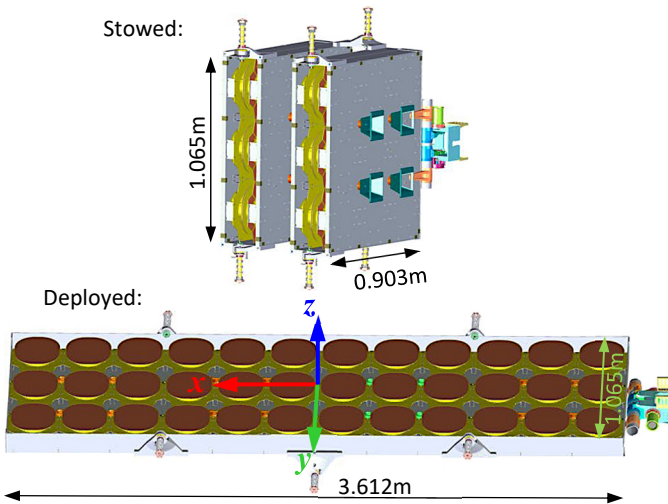


Fig. 2 The 36 element SESAR-LITE array configuration, which consists of 12 subarray's of 3 elements each. The array is subdivided into four 3 $\times$ 3 stowable panels.

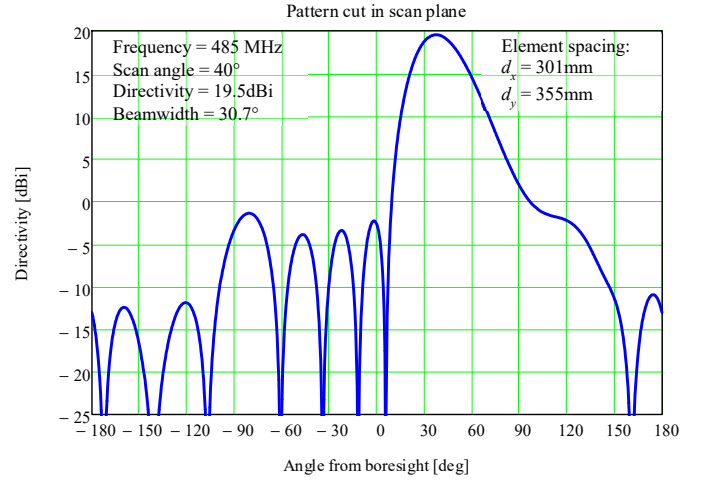


Fig. 3 The predicted cross-track antenna pattern of the panel array in Fig. 1 is shown for the beam scanned to 40° at 485GHz. A cosine excitation taper is used across 5 subarrays ports to suppress the sidelobes. The beam is scanned in the xz-plane defined in Fig. 1.

C. Antenna element design

The antenna element design evolved from an original concept of a cavity-backed slot-coupled patch antenna, a well know antenna geometry developed a few decades ago [11]. The final topology described here is perhaps more akin to a crossed-dipole coupled patch geometry. The general cavity backed slot coupled patch antenna operation mechanism can be summarized as follows: A short slot (typically up to about half a wavelength in length) in a ground plane, is excited by a voltage source across the gap near the center of the slot (typically using a transmission line strip bridging the gap), thereby creating a standing wave of electromagnetic fields in the slot. The slot couples electromagnetically to a thin metal patch parallel to the ground plane, setting up an resonance in the patch. The energy stored in the resonance finally bleeds away in the form of electromagnetic radiation. If the slot is also resonant, a second order coupled slot-patch resonance is created, which can be exploited to achieve a wider frequency band of operation compared to a single resonator.

To prevent the slot from radiating into the hemisphere on the side of the ground plane opposite to the patch, a cavity can be constructed to block the slot off from that hemisphere. For dual polarization, a crossed slot is used to excite the patch in two orthogonal modes.

Patch antennas were developed for ease of fabrication by exploiting printed circuit technology, whereby thin metal features can be printed or etched on supporting dielectric substrates. For wide band operation at P-band frequencies, such a substrate will be prohibitively thick and massive, thus alternative ways of supporting the patch and slotted ground plane is required. The thin metal patch and ground plane geometries are however attractive from a lightweight design perspective, as it requires a minimal amount of metal. The SESAR element design strives to enhance the structural performance enough to allow for minimal support structures, thereby minimizing the total mass.

For the SESAR element, the slotted ground plane and patch conductors are supported with lightweight planar sandwiches consisting of two thin composite material face sheets bonded to an internal foam core layer. Copper clad face sheets are etched to form the path and ground conductors. Starting with the basic cavity backed slot coupled patch topology, the “cavity” is opened up, with large parts of the cavity walls removed near the four corners of the element cell as shown in Fig. 4, leaving only minimal sections of the walls. These act as support structures for partial support of the roof of the cavity (which is also the ground plane of the patch), in the form of C-section brackets.

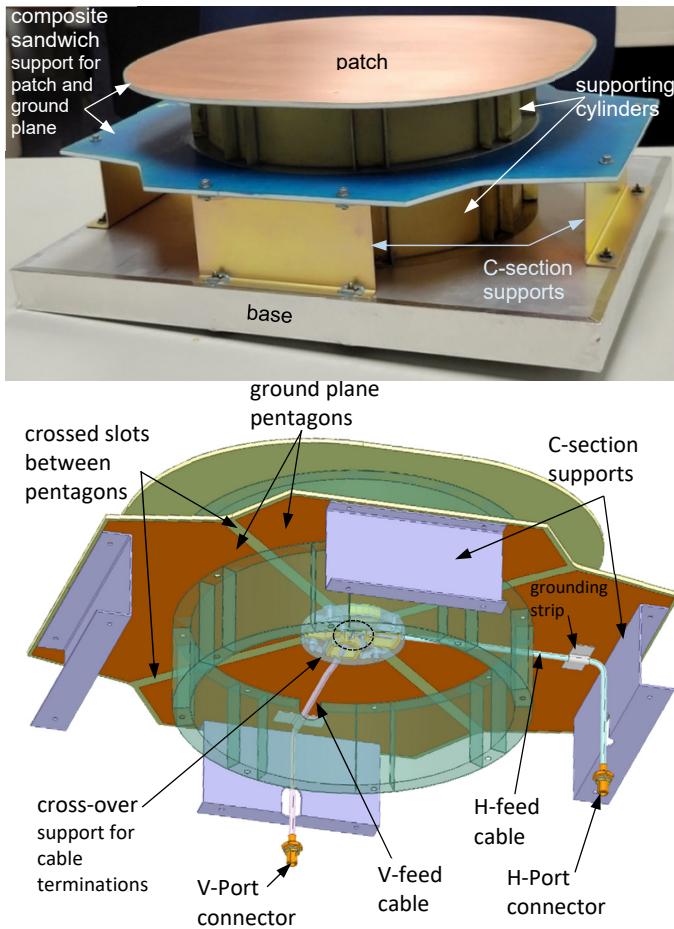


Fig. 4 A photograph of the SESAR element is shown with a CAD picture without the base structure, depicting the different major parts.

The slots are widened at their ends and opened up to connect with adjacent element’s slots, thereby breaking the ground conductor into four separate, roughly pentagonal sections. The slots’ widths vary along their lengths to help provide optimal impedance matching at the central feed points. Large circular cylindrical pillars made of non-conducting composite dielectric material sheets with stiffening fins provide additional support for the sandwiches. All these element structures are supported by the array base, which itself consists of a top and bottom aluminum face sheet separated by a core of aluminum honeycomb.

The open-ended slots and open “cavity” alter the electromagnetic behavior somewhat, but operation can still be explained in terms of a basic slot-coupled-patch mechanism. Alternatively, the changed geometry can also be viewed as a dipole-coupled-patch arrangement: The open cavity and open slotted ground arrangement can be viewed as a dual-polarized end-grounded dipole pair. Each dipole is formed by two diagonally opposite pentagonal sections (which are the monopole arms), and the ends of the monopoles which are normally free, are grounded to the base plate by the C-sections. The dipole pair is closely nestled, forming the crossed slots between the pentagons.

A dipole is normally fed by a balun that resides in a central stem near the feed points at the center. In the SESAR element however, balanced excitation is achieved simply by the coaxial cables’ outer conductors hugging the pentagon/monopole conductors and the inner conductors bridging the crossed slot gap at the center, forming an “infinite” bandwidth balun. In practice the final bandwidth is ultimately limited by the dipole response and parasitic capacitances between parts. Two of the C-sections brackets provide a path for two coaxial cables to approach the central cross-over feed region of the two nestled dipoles. The cables are fed through two holes in the base to provide connectorized ports at the back of the base. A central cross-over bracket supports the cable and slot cross-over region to ensure connection integrity. The H-port refers to the antenna element port that receives/transmits horizontal E-field polarization at cross-track positions on the ground, which is also orthogonal to the cross-track scan plane. The V-port receives/transmits the orthogonal polarization.

The element was tuned to minimize the array’s central elements’ active S-parameters over the beam scan angle range. The predicted active S-parameters for the optimized element is shown in Fig. 5.

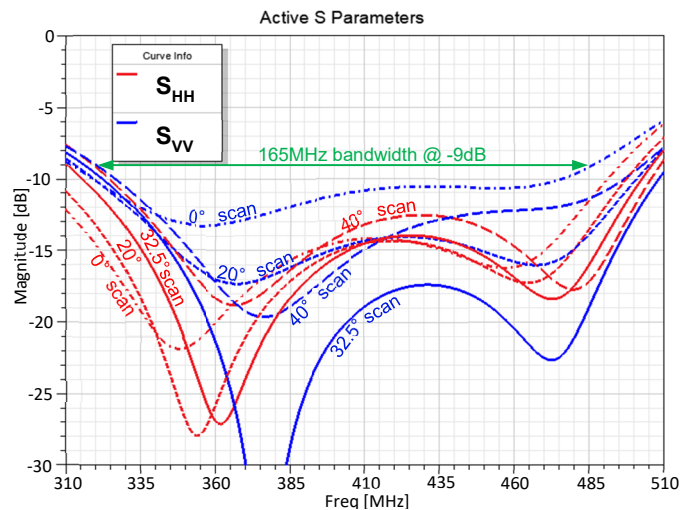


Fig. 5 Active S-parameters of an element in a large array, for different beam scan angles. “V” refers to the V-port, and “H” to the H-port.

The final antenna element mass without the base was less than 0.5 kg. For the array structural support, an aluminum honeycomb base of about 25 mm thick added a mass of about

0.5 kg per element, resulting in about 1 kg total mass per element; a volumetric density of about 70 kg/m³.

III. MEASURED PERFORMANCE RESULTS

The panel array shown in Fig. 1 was set up for radiation pattern measurements at the NASA GSFC GEMAC anechoic chamber. The array was fed using two 8-way power splitters/combiners per subarray, one for the V-ports and one for the H-ports, to create combined V- and H-ports for each subarray. These ports were then in turn actively excited using a cosine square amplitude taper to suppress sidelobes in the scan-plane (xy-plane in Fig. 1). The results for the H-port and V-port patterns are shown in Fig. 6 and Fig. 7 respectively, for several beam scan angles.

The large size of the array stretched the capacity of the measurement chamber somewhat beyond its recommended “quiet zone”, and the P-band frequencies were slightly below the low end of the chambers’ recommended frequency range. As a result, the uncertainty in the gain measurements were about ± 1 dB. The measured gain also included feed cable losses of about 1 dB, and mismatch losses of about 1 dB, hence the gain shown is about 2 to 3 dB lower than the expected directivity.

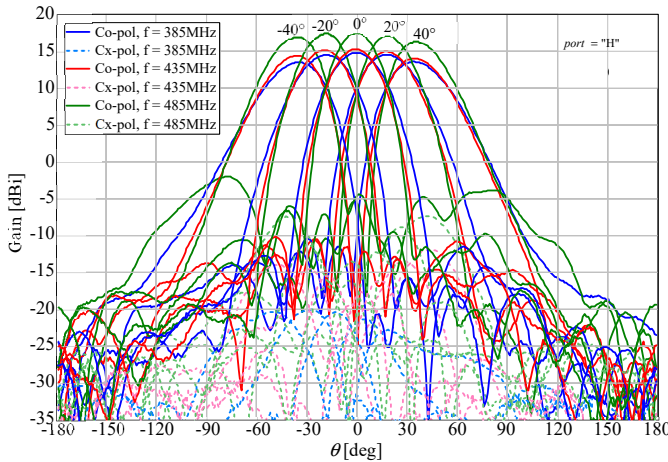


Fig. 6 The H-port measured radiation patterns of the panel array in Fig. 1 are shown for several scan angles: -40° , -20° , 0° , 20° , and 40° .

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The H-port and V-port cross-polarization patterns are more than 25 dB and 35 dB below the beam peak respectively, with the worst cases occurring for the $\pm 40^\circ$ scan angles at 485 MHz. Similarly, the sidelobe performance is worst under the latter conditions, up to -17 dB with respect to the beam peak.

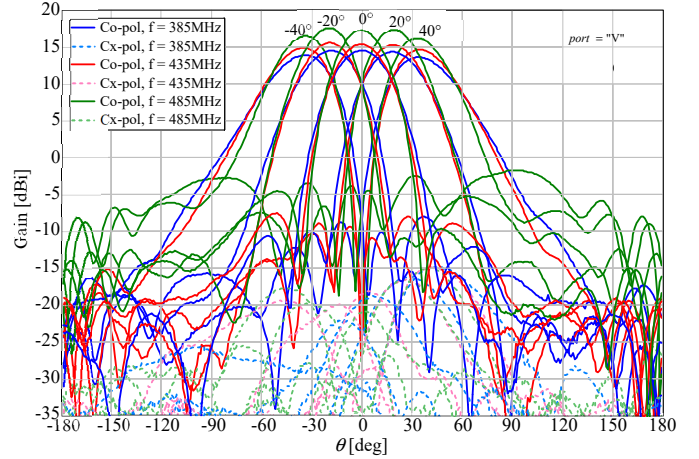


Fig. 7 The H-port measured radiation patterns of the panel array in Fig. 1 are shown for several scan angles: -40° , -20° , 0° , 20° , and 40° .

IV. CONCLUSIONS

The successful design and construction of an antenna suitable for NASA’s SESAR instrument was described. An array configuration design targeting cross-track beam steering up to $\pm 40^\circ$, coupled with an extremely light weight low profile element design suitable for space applications were presented. Measurement results showed that a prototype panel of 5×8 elements were capable of the expected beam steering range while maintaining low sidelobe and cross-polarization levels.

ACKNOWLEDGMENT

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