# The DESDynI Synthetic Aperture Radar Array-Fed Reflector Antenna

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**Abstract**—*DESDynI is a mission being developed by NASA with radar and lidar instruments for Earth-orbit remote sensing. This paper focuses on the design of a large-aperture antenna for the radar instrument. The antenna comprises a deployable reflector antenna and an active switched array of patch elements fed by transmit / receive modules. The antenna and radar architecture facilitates a new mode of synthetic aperture radar imaging called 'SweepSAR'. A system-level description of the antenna is provided, along with predictions of antenna performance.*

## 1. Introduction

DESDynI (Deformation, Ecosystem Structure, and Dynamics of Ice) is a NASA mission currently in pre-formulation for studying hazards and global environmental change [1]. This mission combines two sensors that, taken together, provide observations important for solid-Earth (surface deformation), ecosystems (terrestrial biomass structure) and climate (ice dynamics). The sensors are: 1) an L-band Interferometric Synthetic Aperture Radar (InSAR) system with multiple polarization, and 2) a multiple beam lidar operating in the infrared. This paper focuses on the antenna system for the L-band InSAR instrument. The frequency and size of the antenna are driven by the need to balance temporal decorrelation of InSAR data with required coverage, as well the as the accuracy of height measurements. Polarimetry allows estimation of three-dimensional biomass structure.

These requirements result in the need for a physically large, spaceborne antenna with polarization agility and beam-scanning. Traditionally, planar active electronically-scanned arrays (AESAs) have been used for such purposes. At L-band, the antenna typically comprises an array of microstrip patch elements fed by transmit / receive modules (TRMs) [2,3,4,5]. To meet DESDynI science requirements, the EIRP of the antenna system must be on the order of 65 dBW.

This poses a challenge for a conventional planar AESA, because it results in a large antenna containing many T/R modules and a multi-panel deployment system. This in turn poses issues in terms of cost and technology readiness. DESDynI is being developed as a low-cost, high-TRL alternative to large-aperture spaceborne radar instruments.
This paper provides a summary of the overall design considerations for the antenna system of the DESDynI InSAR instrument. The specific configuration that is presented is a point design and may not necessarily be the design that will be chosen for implementation.

## 2. Antenna Overview

The DESDynI antenna system takes a different approach to the traditional phased array - it combines a smaller, electronically-switched array with a large deployable reflector to create an active, electronically-scanned reflector (AESR) antenna. This affords an antenna with a large area directivity (on the order of 46 dBi) and low areal mass density (on the order of 4.4 kg/m$^2$ for the reflector-feed assembly in the current point design). This performance is superior to prior spaceborne SAR antenna systems and is competitive with future-oriented technology such as [11] and [12]. Arguably, the AESR approach is at a higher technology readiness level (TRL) and is more cost-effective than comparable phased array systems.

The DESDynI feed antenna is a planar microstrip patch array consisting of 24-by-2 elements. The antenna elements are constructed as modular tiles in a manner similar to that of the UAVSAR aperture [7]. The feed, which has a total length of approximately 5m, is arranged so that the center of the array is located at the focal point of the reflector. The elements are fed pair-wise in azimuth with separate TRMs for horizontal and vertical polarization. On transmit, the entire feed antenna is excited uniformly, resulting in a narrow beam in the elevation direction that grossly under-illuminates the reflector. This results in a wide beam in elevation, which for a synthetic aperture radar corresponds to the cross-track direction. The reflected radar signal is received sequentially by each pair of elements along the feed. Since each antenna pair is offset (in elevation) from the reflector focus, the received beams are effectively scanned (in one dimension) across the cross-track swath.

The scan range for the DESDynI antenna is ±8°.

This radar mode, termed *SweepSAR*, is a novel approach to electronically-scanned large-aperture radar imaging [13]. The SweepSAR concept proffers significant system-level and implementation advantages over conventional spaceborne SAR systems; particularly with respect to areal mass density, radar performance, and cost. In the SweepSAR mode of operation, all TRMs for one polarization transmit simultaneously. This has the advantage of leveraging the full available power of the feed while minimizing thermal gradients in the modules (which simplifies the calibration approach). In comparison, a reflector-based ScanSAR antenna would operate by transmitting sequentially from subsets of TRM at a time, thus underutilizing the full EIRP capability of the antenna. The key components of the SweepSAR antenna system are described in the following segments.

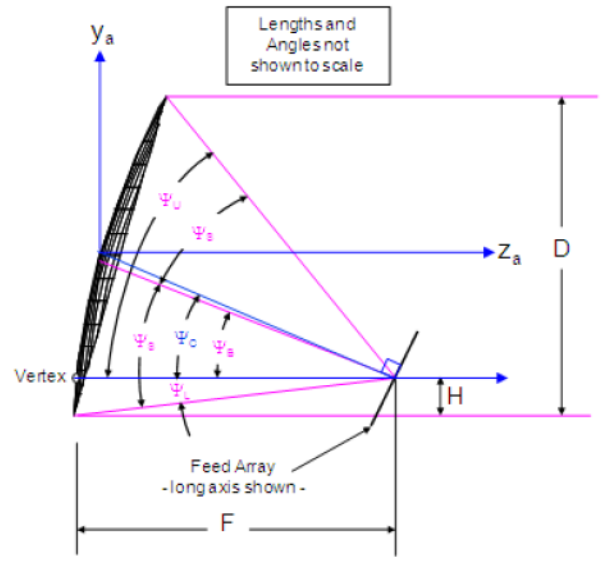
## 3. Antenna Optics

The DESDynI antenna consists of an array-fed 15m deployable mesh parabolic reflector. An F/D of 1.0 and offset height of -2m was selected to achieve ±8° elevation beam scan with minimal feed blockage in a package consistent with stowage and gravity gradient requirements. At least two patch elements are needed to meet the 55° aperture illumination requirement. In the azimuth plane, the feed column element spacing is chosen to over-illuminate the reflector in order to achieve < 1.0° azimuth beamwidth. The elevation beamwidth may be selected by exciting multiple rows of elements through the electronic control of T/R modules. In operation, at least two elevation rows are utilized so that, although spillover loss is relatively large in the azimuth plane, the total aperture efficiency remains relatively high.

The feed partially blocks the lower portion of the reflector, which results in a multiple bounce effect that causes slight gain variation versus elevation scan angle. However, multiple bounce PO analysis shows that this effect is not significant for the selected configuration.

## 4. Antenna Mechanical and Thermal

The DESDynI mechanical configuration consists of the feed structure (Figure 2), a 15m diameter deployable mesh reflector, and a deployable boom that holds the 15m reflector at the prescribed distance and orientation relative to the feed (Figure 3). The deployable reflector and the deployable boom will both be provided by a commercial vendor and already have a high technology readiness level and flight-proven architecture. No new technology developments will be required for either the 15m reflector or the associated boom. The areal density of the 15m reflector is substantially less than what could be achieved for a conventional phased array due to the use of a passive and low-mass reflective mesh instead of an array of active radar components. The estimated mass of the reflector-feed assembly (without contingency) is 780 kg.




| Parameter | Description | Value |
|---|---|---|
| D | Projected aperture | 15 m |
| F | Focal Length | 15 m |
| H | Edge offset | -2.0 |
| $C_o$ | Center offset | 5.5 m |
| $\Psi_c$ | Center angle | 20.78° |
| $\Psi_U$ | Upper edge angle | 46.86° |
| $\Psi_L$ | Lower edge angle | -7.63° |
| $\Psi_B$ | Bisector angle | 19.61° |
| $\Psi_s$ | Half subtended angle | 27.24° |
| $\Theta_B$ | El Illumination beamwidth | 54.49° |

**Figure 1**. Reflector antenna optics.

The DESDynI feed structure is a tapered structure composed primarily of composite panels. These materials provide both thermal stability and high stiffness, both of which improve the pointing accuracy and stability of the radar. The stowed 15m reflector and associated boom are supported by the feed structure during launch. The wide interface to the bus provides a load path from the structural panels of the feed to the structural walls of the bus, and the tapering of the structure provides the high stiffness required for launch while keeping structure mass and blockage of the radar beam acceptably low. The cross section of the feed is trapezoidal, which allows the TRM electronics to be mounted as close as possible to the patch antennas, reducing cable lengths. The trapezoidal cross section also minimizes multiple reflections of radar energy between the structure

and the 15m reflector.

The radar electronics are mounted to the exterior of the feed, providing access to the electronics and cables during instrument assembly and testing as well as allowing each electronics module to directly radiate dissipated heat to space using a radiator mounted to each electronics module. Having each electronics module directly radiate heat to space decouples and simplifies what would otherwise be a complex thermal management task. The trapezoidal cross section of the feed structure reduces the view of the Earth by the various electronics thermal radiators, reducing the required size of the radiators.

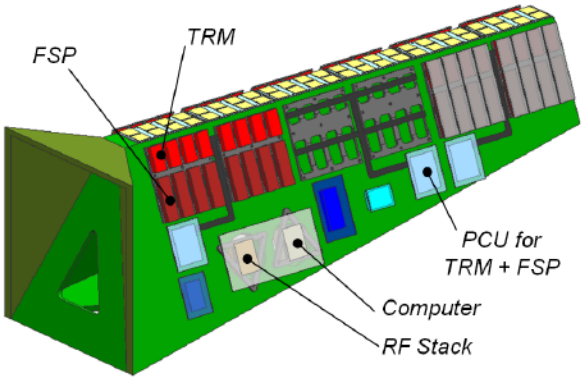



**Figure 2**. DESDynI antenna feed showing patch antenna elements mounted on top surface and various electronics modules mounted on sides for thermal dissipation.

## 5. Antenna Electronics

The array feed electronics comprise 48 analog TRMs which are paired with 48 digital First Stage Processors (FSPs). JPL is leveraging its experience with TRM development on UAVSAR [8] and on the Mars Science Laboratory Terminal Descent Sensor [9] to develop a new class of high-efficiency TRMs for DESDynI. Each TRM transmits 51 dBm peak RF power. The power amplifiers utilize Gallium Nitride (GaN) transistors for efficiency. Preliminary GaN amplifier breadboard measurements have yielded total power-added efficiencies of 60%. Efficient use of power, both on transmit and receive, is key to the passive thermal management approach of the antenna system. Each TRM includes an Energy Storage System (ESS), which converts and conditions DC power from the spacecraft bus to supply the RF power amplifiers. Power Conditioning Units (PCUs) supply a bank of 8 TRMs and FSPs with DC power.

The antenna electronics are configured so that radar can operate in quad-pol, dual-pol, or single-pol modes. On receive, each TRM amplifies and filters the signal from its respective pair of antenna elements. The amplified signals are digitized at RF and are then immediately down-converted to baseband I/Q samples in the associated FSP. In quad-pol mode, the total DC power consumption of the antenna feed is 1.5 kW.

## 6. Digital Beamforming and Calibration

Digitization of individual receive channels enables digital beamforming (DBF), which is an important aspect of the JPL SweepSAR design. The advantages of DBF include increased processing gain, decreased ripple across the elevation pattern (or radar swath), and greater flexibility in configuring operating modes. Additionally, DBF naturally provides a means of calibrating the antenna on receive, without the need for analog phase shifters and attenuators. The candidate DBF algorithm, a variant of conjugate field matching (CFM), is implemented in real-time by on-board FPGAs. The downlink communication channel lacks sufficient capacity to transmit all of the digitized receive channels. Consequently, preliminary DBF is done on-board by combining five receive channels which are then transmitted to the ground for final processing.

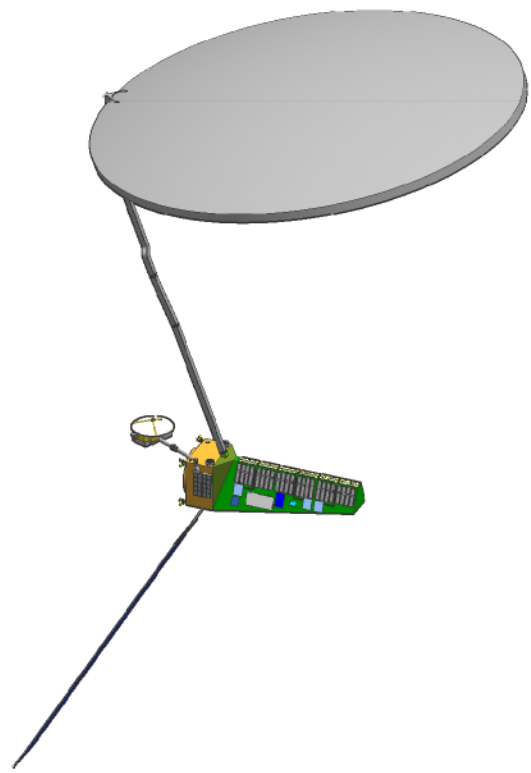


**Figure 3**. DESDynI antenna configuration, showing deployed reflector boom assembly, antenna feed, deployed solar panel assembly, and deployed communications antenna.

Calibration of antenna feed occurs during pre-launch testing as well as on orbit, utilizing data from calibration signals passed through the TRM continuously. Circuitry inside the TRMs provides separate receiver and transmitter calibration, with each calibration network being controlled by its associated FSP. On transmit, the FSP commands the TRM to adjust phase though a digitally-controlled analog phase shifter. On receive, calibration is implemented digitally in the FSP, where both signal amplitude and phase are adjusted prior to beamforming.

## 7. Preliminary Antenna Performance

Antenna performance of the DESDynI antenna system has been assessed using GRASP software. The analysis utilizes the methods of physical optics (PO) and physical theory of diffraction (PTD) for the large structures, such as the reflector, feed structure, and spacecraft bus. The method of moments (MoM) is utilized to model structures that have smaller dimensions (relative to a wavelength) such as the reflector boom.

patterns are generated for the purposes of radar system modeling. Various configuration trades and tolerance analyses have been assessed in this manner.

It should be emphasized that the transmit patterns correspond to simultaneous radiation from all 24 feed elements, whereas the receive patterns correspond to a single pair of elements along the feed antenna. The receive gain in Table 1 is for a scan angle of -0.3° (i.e. close to boresight) – the gain varies by 1.8 dB over the scan range.

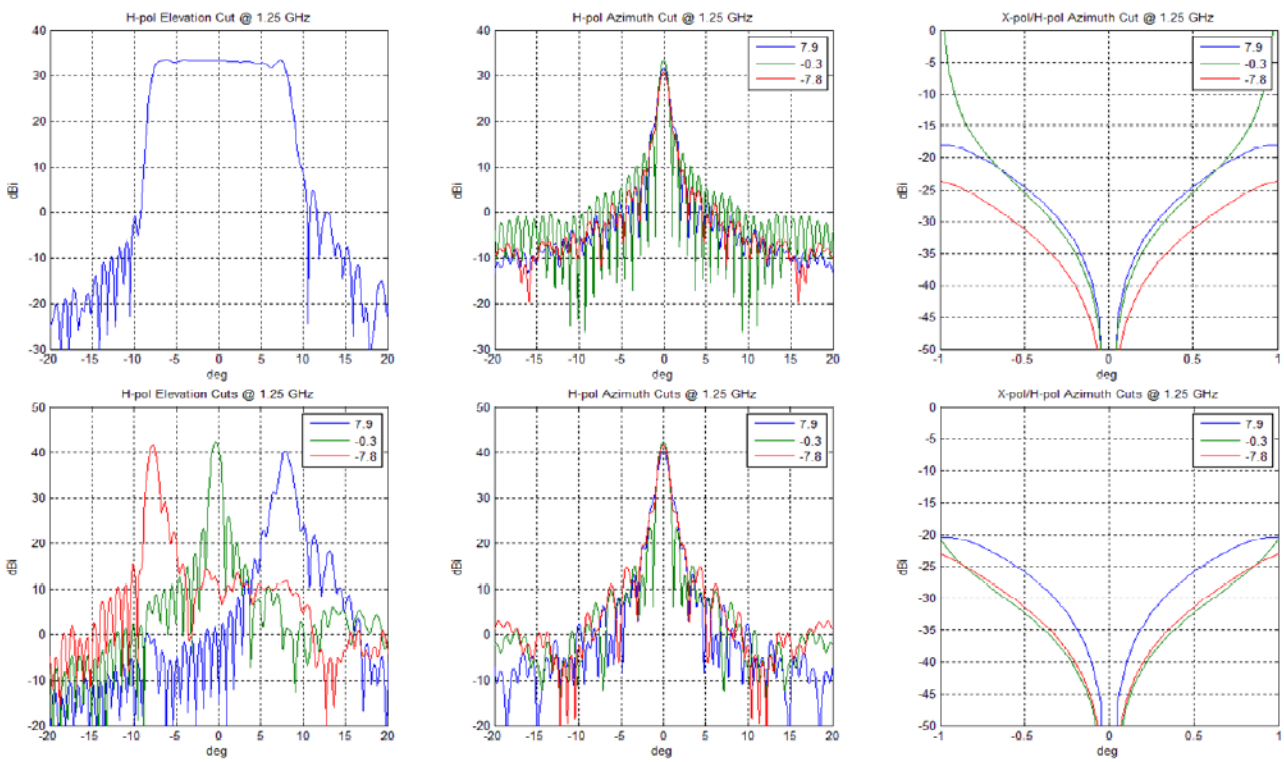



**Figure 4**. Predicted far-field patterns for DESDynI array-fed antenna reflector. Top: horizontally-polarized transmit patterns. Bottom: horizontally-polarized receive patterns for three different scan angles.

| | | Tx | Rx |
|---|---|---|---|
| Scan range | deg | N/A | ± 8 |
| Directivity | dBi | 33.3 | 42.3 |
| Loss | dB | 1.7 | 1.7 |
| Gain | dBi | 31.6 | 40.6 |
| HPBW az | deg | 1.0 | 1.0 |
| HPBW el | deg | 15.9 | 1.0 |
| Cross Pol | dB | -25 | -25 |
| EIRP | dBW | 65.4 | N/A |
| Noise Figure | dB | N/A | 3 |

**Table 1**. Key antenna performance parameters.

The feed is modeled with both native GRASP patch array models and imported feed models from HFSS. The analysis includes multiple backscattering; including the triple bounce consisting of feed-to-reflector-to-feed-to-reflector-to-space. Simulated antenna patterns for transmit and receive are shown in Figure 4 and a summary of predicted performance is shown in Table 1. Additionally, partial sphere antenna

The transmit gain is lower than the receive gain (nominally by 9 dB) because the reflector is grossly under-illuminated when all 24 elements radiate simultaneously in the SweepSAR mode. This is compensated by the additional power when radiating from 24 elements simultaneously. The net EIRP gain from transmitting on all modules (compared to one module) for this AESR antenna system is therefore $10\log_{10}(24)-9 = 4.8$ dB.

The number of TRMs and their associated output power have important implications in terms of EIRP and redundancy of the system (preferring a larger number of modules), as well as complexity and cost (preferring a lower number of modules). Additionally, thermal management issues tend to drive the design as the density and output power of the TRMs increase. The 24-module design of the DESDynI antenna system is the result of an extensive trade study involving all of these variables.

## 7. Concept Validation

As with any new concept, it is important that the technology is matured and proved on the ground before committing to a flight system and ultimately a mission. To this end, JPL has implemented an ongoing SweepSAR technology demonstrator experiment. The experiment utilizes a Ka-band slotted waveguide antenna that was developed for the UAVSAR / Glistin testbed [10]. The slot antenna comprises seventeen rows (or sticks), sixteen of which are connected to digitizing receivers. The seventeenth stick is used for transmitting. The array was calibrated by aligning it with a broad-beam CW source. The calibration was verified by rotating the slot array antenna azimuthally (sticks aligned vertically) relative to the fixed CW source. The digitally-formed antenna patterns from this measurement have a beamwidth of 0.5˚, a scan range of ±3˚ and are shown in Figure 5.

Following this verification process, the antenna was oriented with the waveguide sticks horizontally, looking down at an angle of 85˚ on a scene adjacent to the JPL antenna range. A radar pulse was emitted from the transmit stick and individual reflected signals were recorded from each of the 16 receive channels of the slot array. The recorded signals were post-processed with the previously established DBF coefficients in order to resolve the various scattering centers of the scene. The digitally-formed beams and measured cross-track profile are shown in Figure 5. The primary scattering centers correspond to DBF scan angles of -2˚,-1˚,0˚,1˚, and 2˚. Note that this result is considerably affected by topography of the scene being imaged. The next step in the demonstrator experiment will be to verify the concept on an airborne platform, using elements of the UAVSAR / Glistin testbeds and an offset-fed paraboloid reflector scaled (at Ka-band) to the dimensions of the DESDynI reflector. These activities are planned for late 2010.

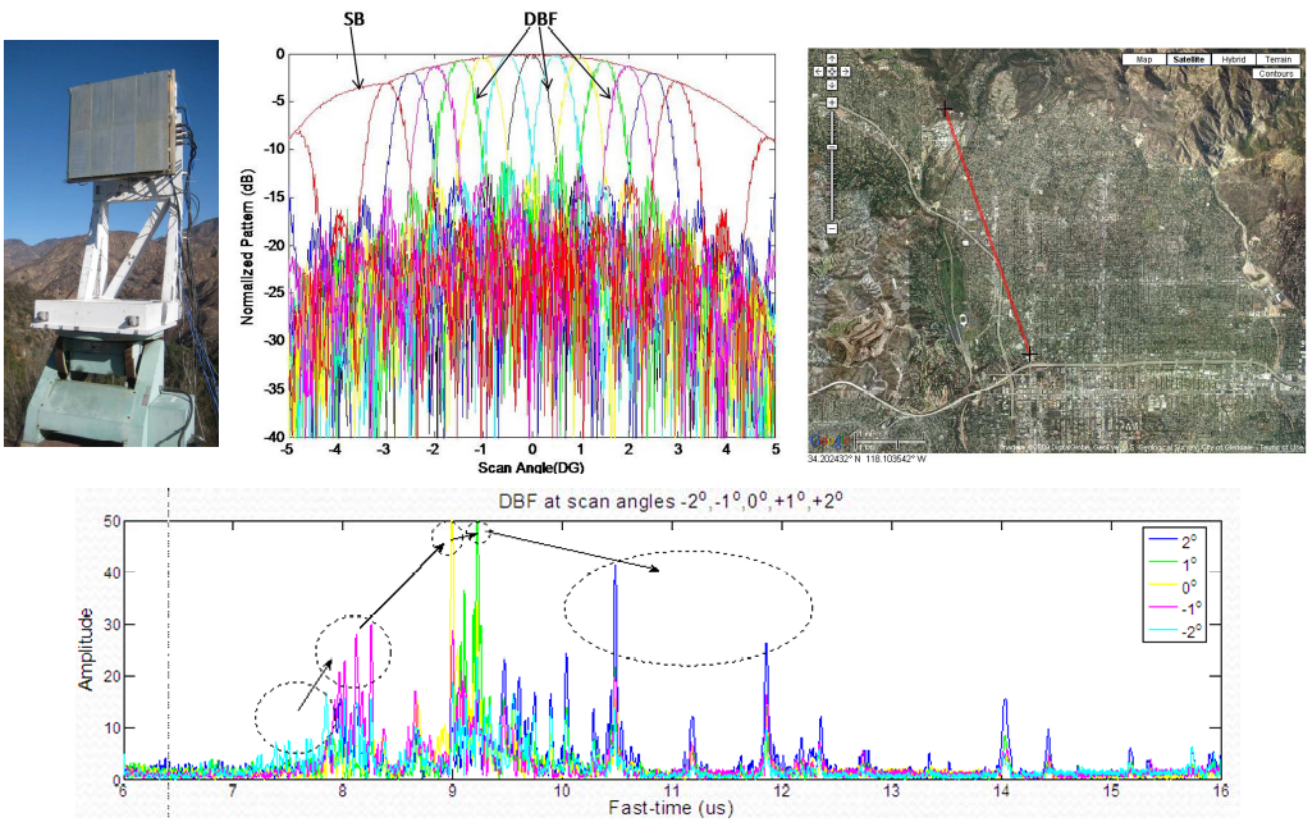



**Figure 5**. Top left: Glistin antenna array mounted for azimuth scanning. Top center: Digitally formed receive antenna patterns from azimuth scan. Top right: test scene and line of sight of antenna. Bottom: Measured down-range profile.

## 8. Concluding Points

This paper discusses the DESDynI active electronically-scanned reflector (AESR) antenna that facilitates a new mode of synthetic aperture radar imaging termed *SweepSAR*. This antenna system affords large-aperture spaceborne radar imaging at a cost and technology readiness level that is competitive with comparable phased array systems. Various aspects of the antenna design have been outlined, including the optical design, mechanical configuration, and electronics configuration, along with preliminary estimates of antenna performance. Preliminary results from an ongoing technology demonstrator experiment to verify the SweepSAR digital beamforming concept were also presented.

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