# Tutorial: Phased Array Antennas for Radio Astronomy

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This tutorial presentation will provide a basic introduction to recent applications of phased array antennas for radio frequency astronomical observations. Antenna arrays of four basic types are used for astronomical observations: (1) synthesis imaging arrays, (2) horn cluster feeds, (3) phased array feeds, and (4) aperture arrays. Synthesis imaging arrays are highly sparse arrays of dish antennas with extremely large separation between antennas relative to the electromagnetic wavelength. These kinds of arrays have been used for many decades and are routinely used at various RF and microwave bands at sites around the world. The focus of this presentation is on more recent research and development work on the third and fourth types of array antennas, which involve dense phased arrays combined with digital beamforming for astronomical observations.

Horn cluster feeds and phased array feeds are replacements for a traditional horn-type feed for a large dish antenna with wider angular sky field of view. A dish with a single horn feed might be referred to as a single-pixel telescope. Images are formed by rastering the telescope pointing direction across a sky observation field. Cluster feeds represent a first step beyond a single pixel feed. The physical size of each horn in the cluster is too large for the array to realize a continuous field of view on the sky, and each horn produces a beam that is separated by more than one half power beamwidth from the others, leading to a sparse cluster of pixels on the sky. The next step in feed technology for large dish antennas is a phased array feed (PAF), for which the antenna elements are electrically small and closely spaced. Unlike the cluster feed, phased array feed elements cannot individually illuminate the reflector efficiently. By combining output signals from multiple elements with appropriate phase and gain weights, a high efficiency illumination pattern can be obtained. The key advantage of a phased array feed is that multiple beams can be formed simultaneously in digital signal processing, leading to continuous coverage of the array field of view. In principle, a patch of sky can be imaged with a single telescope pointing. Assuming equal sensitivities, this leads to higher survey speeds than single pixel feeds. The price for this improved imaging capability comes in two ways: (1) strong mutual coupling between array elements and (2) the cost of the digital hardware required to process array output signals and form beams. Whereas a phased array feed is used to collect signal from a reflector antenna, aperture arrays have a direct view to the sky. Synthesis arrays have elements spaced many electromagnetic wavelengths apart, and are electrically sparse, but aperture arrays are dense, with elements spaced on the order of one half wavelength apart. A number of aperture arrays operating at low frequencies below around 500 MHz are currently in construction around the world, and some work on L band aperture arrays has also been done.

The presentation will survey key requirements, constraints and design considerations for efficient, highly sensitive array feeds and aperture arrays. Prototypes and experimental results from research and development efforts around the world will be highlighted, along with fundamental aspects of signal processing, beamforming algorithms, and various types of calibration required for array feeds and aperture arrays.