Phased Array Feeds for Satellite Communications

Karl F. Warnick and Brian D. Jeffs
Department of Electrical and Computer Engineering
Brigham Young University
Provo, UT 84602

April 5, 2010

1. Introduction

A reflector antenna with a phased array feed (PAF) offers improved performance for satellite communications uplinks and downlinks for direct broadcast satellite (DBS) video, very small aperture terminal (VSAT) voice and data links, and other satcom applications. The standard dish or reflector antennas typically used for these applications are fixed-beam systems, which means that the antenna must be mechanically pointed at a source of interest. Electronically steered phased array antennas can be used to realize automatic source tracking. For satcom applications, a large collecting area is required to achieve adequate signal link margin, which means that a phased array antenna must have many elements and the cost of signal processing electronics can be high. A phased array feed and reflector combines the capability for electronic steering capability with the large, low cost signal collecting area of a reflector antenna.

A phased array feed replaces a standard feed and allows electronic tracking of a moving satellite, correction for dish mispointing, compensation for changes in the environment that degrade signal quality, initial target acquisition and fine tracking for a mechanically steered dish, improved signal to noise ratio for a given dish aperture area. This white paper provides an overview of phased array feed technology and surveys recent key research advancements that have enabled high sensitivity PAFs with performance suitable for satcom applications.

2. Applications of PAFs

Nearly all satellite ground-based transmission and reception systems use a standard fixed-beam feed, which is located at the focal point of a parabolic dish-type reflector and collects the signal after it is focused by the dish. Typically, the feed unit includes electronics to amplify the signal and downconvert it in frequency. The amplified and downconverted signal is transmitted through a coaxial cable to a modem or receiver. The feed unit is commonly referred to as a low noise block downconverter and feed (LNBF). For a transmitting feed, a signal is input to the feed package, upconverted in frequency, amplified to a high power level, and then radiated from the feed antenna to the dish to produce a focused beam aimed at a satellite transponder. Some satellite services use two orthogonal polarizations simultaneously, so standard feeds may also include two feed antennas which receive different polarizations and two sets of electronics to handle signals for the two polarizations. A standard feed has no capability to steer the beam to point at different directions in the sky. Pointing and steering must be accomplished by moving the entire antenna and dish aparatus using a motorized positioner or an adjustable mounting bracket.

A phased array feed consists of an array of many antenna elements instead of a single feed element. For a receiving PAF, the signals from each element of the array are processed in parallel using either digital or analog processing to produce a single, combined output. By adjusting the coefficients used to combine signals from the PAF elements in signal processing, the aiming direction of the beam can be moved over a limited field of view on the sky. Further adjustments can be used to reject interfering signals and improve signal quality.

Markets for phased array feeds range include “side-of-the-house’’ satellite television receivers, VSAT terminals for remote locations without terrestrial connectivity, pop-up mobile newsgathering and public safety satellite links, large data trunk uplink and downlink terminals for internet service providers, satellite links for data and video on private aircraft and commercial airliners, and military communication systems.

3. PAF Research and Development

The Brigham Young University Center for Smart Antenna Systems (CSAS) and Radio Astronomy Systems Research Group, directed by Brian D. Jeffs and Karl F. Warnick, conduct research in the area of phased array feeds for use with large radio telescopes in radio astronomy applications. Phased array feeds have been designed, built, and tested on reflector antennas at a U.S. National Radio Astronomy Observatory Facility in Green Bank, WV. In the field of radio astronomy, phased array feeds offer several advantages over traditional feeds, including electronic beam steering to expand the area of the sky that is visible to the telescope, improved sensitivity to signals from weak deep space objects, and cancellation of interfering signals that would otherwise prevent astronomical observations.

Because radio astronomy and satellite communications both involve detection of weak, non-terrestrial signals, the high sensitivity phased array feeds developed for radio astronomy applications are ideal for satellite applications. Most phased array antennas do not have adequate noise performance and sensitivity for satcom applications, but recent key advances in PAF technology for radio astronomy have made possible PAFs for commercial applications.

A functional block diagram of a typical PAF system is shown in Figure 1. For a receive PAF, the major functional elements include the antenna array, preselect filters, low noise amplifiers, phase and amplitude shifters, a power combiner, downconverter, and a beamformer control unit. A transmit PAF includes an antenna array, power amplifiers, phase and amplitude shifters, a power splitter, upconverter, and beamformer control unit. A bidirectional PAF includes both transmit and receive functions and a shared beamformer control unit.

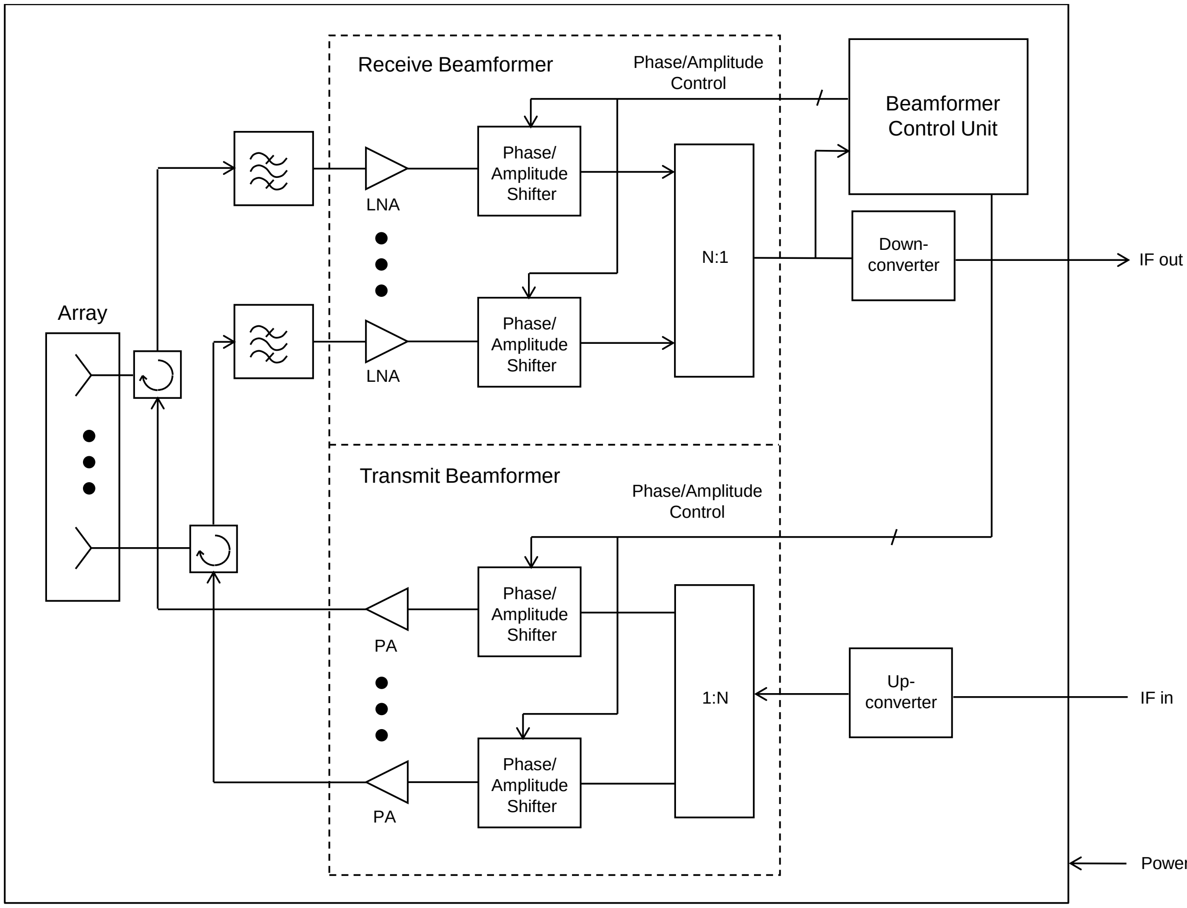

Figure 1. Phased array feed functional block diagram.

Array elements. The elements are similar to the antenna used in a single feed, but are specially designed to account for the mutual interactions between the elements so that signal quality is not degraded by coupling between elements. A small increase in system noise due to poor handling of mutual interactions means that the dish area must be increased proportionately, which is undesirable for satellite communications products. The Radio Astronomy Systems Research Group has developed PAF element designs that compensate for mutual interactions between elements and minimize the overall system noise temperature to acceptable levels for sitcom terminals.

Beamformer and signal processing. The beamformer used to electronically combine signals from PAF elements can be either digital or analog. Digital processing provides maximum flexibility and performance. The cost of digital processing scales with the bandwidth of the signal, so full digital processing may not be cost effective for broadband satellite communications applications. For this reason, analog beamforming is required for low cost commercial products. Analog beamforming is accomplished using a variable gain amplifier and a controllable phase shifter for each element of the array. Phased array antennas (as opposed to phased array feeds) require primarily phase shifting, but phased array feeds require primarily amplitude control and additionally phase shifting for maximum signal quality. After phase and amplitude control, the signals are added in a combiner to produce a single output (per polarization) that is then handled with other electronic components as in a standard LNBF.

Beamformer control. The electronics package for a phased array feed includes a control module to determine the phase and amplitude settings for each element signal path. The control module tracks the signal level and adjusts the phase and amplitude of each signal path to maintain maximum signal level and minimum noise. Tracking algorithms used by conventional mechanically steered antennas can be adapted for use in the phased array feed control module. The controller uses tracking information obtained from the received signal to control the phase and amplitude settings of the transmit beamformer in order to steer the transmitted beam to the same location in the sky as the source of the received signal.

4. Ku Band 60cm Aperture PAF

A Ku band PAF operating at 12 GHz with 19 elements in a hexagonal array pattern has an aperture diameter of 6 cm. With a 60 cm reflector, the PAF has a beam steering range of ±5 degrees away from the reflector boresight in elevation and azimuth. The antenna gain is 36 dB and the sensitivity (G/T) is 19 dB/K. Beams with reduced G/T can be steered further from the reflector boresight for target acquisition and initial beam pointing.

By increasing the number of PAF elements, the beam steering range can be significantly increased, at the cost of more complex signal processing electronics. Asymmetric PAF designs can be used to steer beams on an elongated or rectangular sky footprint.

5. Technology Transfer and Commercialization

Development of commercial PAF technology by the Brigham Young University Center for Smart Antenna Systems is supported by a partnership with Linear Signal, LLC. Linear Signal is a fables semiconductor design house with a family of phased array beamformer chipsets in development. Linear Signal's Ku band beamformer chipset, slated for late summer 2010 availability in sample quantities, provides a path to a low cost PAF system, by integrating the beamformer electronics package. BYU PAF technology for beam steering, array calibration, high sensitivity, and low noise performance will be licensed by Linear Signal and combined with the integrated beamformer chipsets to provide the first commercially available Ku band PAF product.

For More Information

For more information, please contact:

Dr. Karl F. Warnick
Department of Electrical and Computer Engineering
Brigham Young University
warnick@ee.byu.edu
(801) 422-1732

Greg Mockett, President
Linear Signal, LLC
gmockett@linearsignal.com
(801) 473-4512