# A Proposed Array System for the Deep Space Network

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*This article briefly describes the initial design of the proposed array of small-diameter antennas for the Deep Space Network (DSN). It will provide receive capability in deep-space communication bands at 8.4 GHz (X-band) and 32 GHz (Ka-band) equivalent to one 34-m existing DSN beam-waveguide antenna. The array, its expected performance, and initial tests planned to bring up the array and evaluate its performance are described.*

## I. Introduction

We are entering an era in which deep-space communications need much larger data rates from space to the ground than we can currently support. To provide higher downlink data rates, both optical and radio techniques are being explored. Here we will consider only the radio approach.

To receive wide-bandwidth signals from deep space using radio techniques, the Deep Space Network (DSN) needs to have a large $A/T$ (where $A$ is the effective collecting area of the antenna system and $T$ is the system temperature). It is widely recognized that the cost of building large monolithic apertures for providing large $A/T$ increases more rapidly than the aperture diameter for large antennas. Also, it is believed that building an array of a large number of small-diameter antennas is a cost-effective approach for building large receiving capability ($A/T$). Arrays, such as the Very Large Array (VLA) in New Mexico, have been used by radio astronomers to provide high sensitivity ($A/T$) for many years. Arrays also have been successfully used for deep-space downlink telemetry applications. However, there is very little experience in using arrays for routine space communications, and very little work has been done for uplink arraying. To understand the cost of building arrays and to get operating experience, it has been suggested that we build a receive array to provide $A/T$ equivalent to a DSN 34-m beam-waveguide antenna. A separate effort to develop uplink arraying simultaneously also has been proposed.

It has been proposed that we build an Initial Array System (IAS) of twelve 12-m-diameter antennas[2] for deep-space communication at 8.4 GHz (X-band) and 32 GHz (Ka-band) for all telemetry and tracking receive functions performed by the current DSN antennas.

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[1] Tracking Systems and Applications Section.

[2] A recent study by Sandy Weinreb from JPL (personal communication) to minimize array cost for DSN and Square Kilometer Array (SKA) applications suggested that it will be most cost effective to produce a large $A/T$ with an array of antennas of about 12-meter diameter.

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High-level system requirements for the array are taken from those in the requirements document,[3] which are largely derived from the existing DSN 34-m beam-waveguide antennas. The purpose of this article is to describe the current design of the array, the expected performance, and the initial tests to bring up the array and evaluate its performance.

## II. Array System

The operations concept for the Initial Array System is described in [1] and assumes that initially the IAS has to operate using the existing DSN resources. Figure 1 shows interconnections between the array and other systems from the DSN. The array will get source predictions and an observing schedule from existing systems in the Signal Processing Center (SPC) in order to observe a target. It also will get standard frequency and timing system (FTS) signals. The array will provide phased-array IF signals and monitor data to be processed by existing telemetry and other equipment in the SPC; it also will provide correlation data between the array antennas.

### A. System Description

The current baseline plan for the Initial Array System is to have twelve 12-m-diameter antennas in a cluster located in a to-be-determined site in the Southwestern United States. For the present, we will assume it is located at Goldstone. A block diagram of the proposed array system is shown in Fig. 2. The array will provide a receiving capability equivalent in $A/T$ to a 34-m beam-waveguide antenna working at X- and Ka-bands for deep-space communication (telemetry, tracking, and navigation) and other related activities [e.g., radio source catalog, very long baseline interferometry (VLBI)].

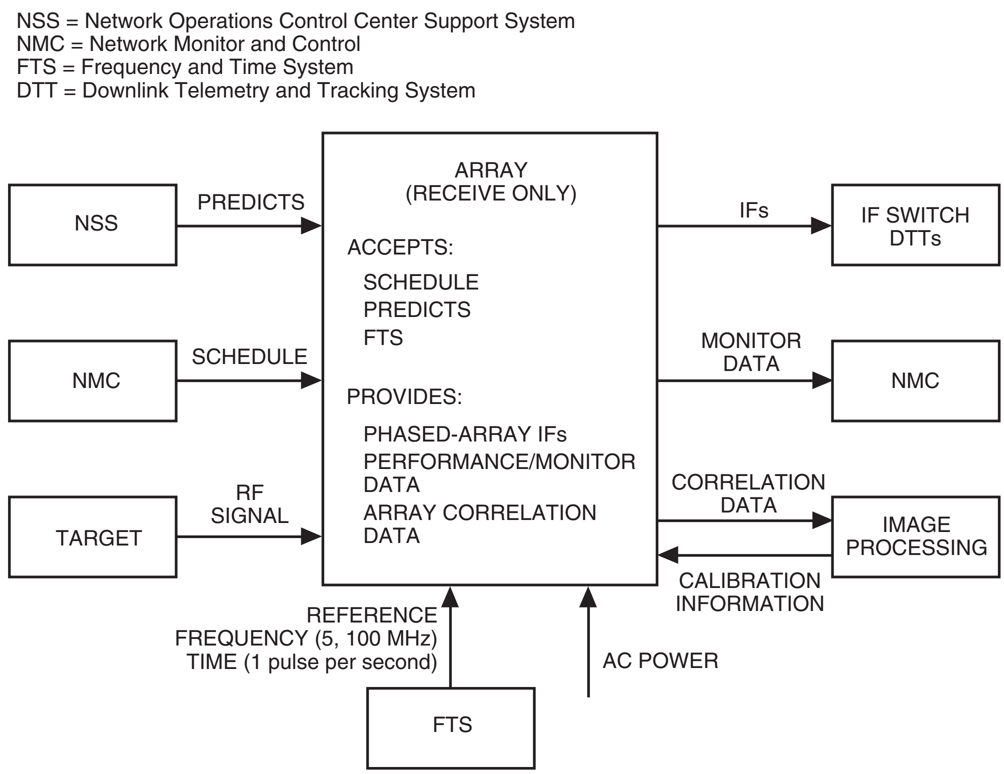


**Fig. 1. Array system and its interface connections.**

[3] M. J. Connally, *Prototype Array System Requirements*, DSMS 828-042 (internal document), Jet Propulsion Laboratory, Pasadena, California, March 25, 2003.

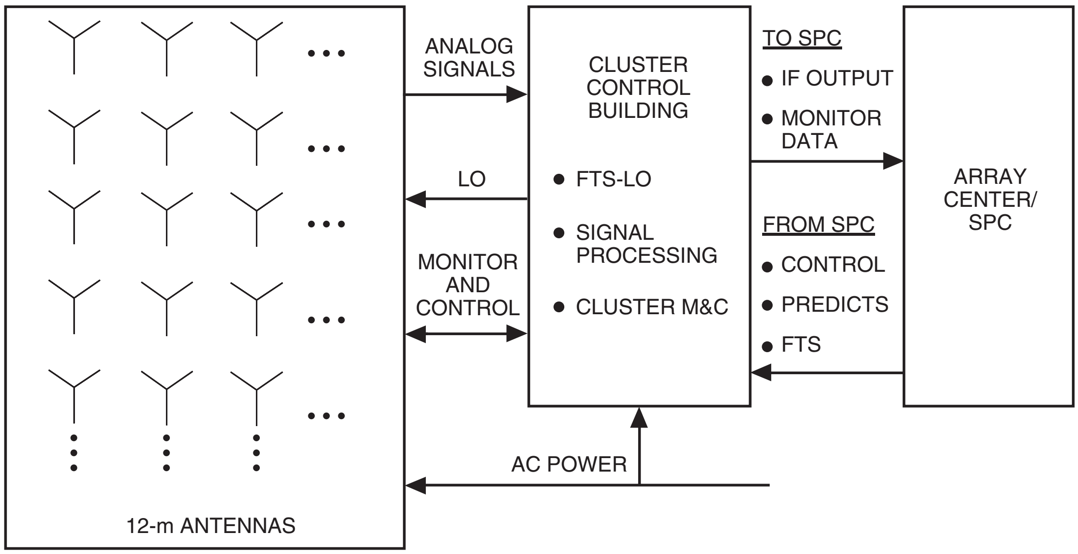


**Fig. 2. Block diagram of the proposed array.**

## B. Operations Philosophy

The IAS operations philosophy is shown in Fig. 3. The array monitor and control (M&C) receives resource requirements, equipment parameters, and target information from the Array Center/SPC. Resources are allocated and information provided to the array and cluster controller. The M&C then oversees the array hardware and manages operation of the array in all aspects, including calibrations. Phased-array IF signals from the clusters then are sent to the Array Center/SPC to be processed.

## C. Design Parameters

The array system design parameters are based on (1) the objectives and functional and performance requirements for the 34-meter beam-waveguide antennas in the DSN and (2) practical array design considerations. They are given below.

**1. Downlink Performance Parameter, *A/T*.** The $A/T$ goal is 18 $m^2/K$ at Ka-band and 44 $m^2/K$ at X-band. This assumes twelve 12-m-diameter antennas, efficiency of 0.55 at Ka-band and 0.65 at X-band, and system temperature, $T_{sys}$, of 40 K at Ka-band and 20 K at X-band, including atmosphere at zenith in average clear (50 percent) weather.

**2. Sky Coverage.** Sky coverage is from 6 to 90 deg in elevation with no requirement to track through zenith, and in azimuth it is from $-270$ deg to $+270$ deg. Slewing rates, as described below, will determine the keyhole through which tracking will not be possible.

**3. Slewing and Tracking Rates.** The slewing rate for both elevation (EL) and azimuth (AZ) is 48 deg/min. The tracking rate is up to 24 deg/min in each axis in any part of the sky except near local zenith. These tracking rates will define the keyhole near local zenith where coverage will not be possible.

**4. RF Coverage, Input Signal Level, and Frequency Response.** The frequency coverage is from 8 to 8.8 GHz at X-band and 31 to 38 GHz at Ka-band. The 1-dB compression point for the input signal is $-45$ dBm, with a goal of $-35$ dBm. No damage to the LNA will occur at signals up to $+10$ dBm. The instantaneous bandwidth is 500 MHz (1 dB nominal). The passband response should have less than 1-dB and 1-ns variation over any 100-MHz bandwidth.

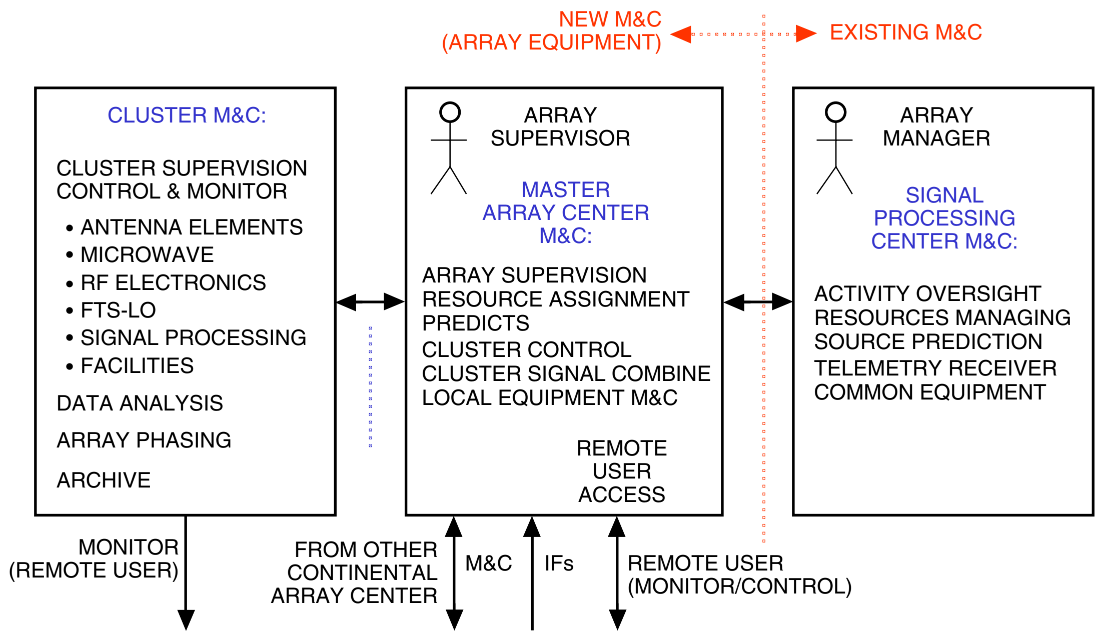


**Fig. 3. Block diagram of the array operations. (Left of the red dashed line is new; right of the line is existing DSN. The array manager at the SPC is essentially the existing link controller function.)**

**5. Polarization and Band Selection.** X- and Ka-bands will be available at both right- and left-circular polarizations. Only two signal paths from an antenna are possible at any one time. These two signals can be any combination of polarizations.

**6. Number of Subarrays.** The local oscillator (LO) system will allow any antenna to tune to one of the two different LO frequencies at each band.

**7. Actively Reconfigurable.** The system will provide capability to add or remove antennas from any subarray/phase array beam without interrupting an ongoing spacecraft track (observation).

**8. Digitization and Sampling for Signal Processing.** Quantization is 8 bits, assuming a needed dynamic range of $\sim$45 dB. Sampling is 1280 megasamples/s, assuming a 1-dB bandwidth about 500 MHz centered at 950 MHz.

**9. Phased-Array Beam Combiners.** The parameters for the phased-array beam combiners are as follows:

(1) The maximum number of phased-array beams for a cluster is 16.

(2) Any antenna can contribute to a maximum of 4 beams.

(3) Each beam (sampling) bandwidth is from 125 kHz to 128 MHz from anywhere in the IF passband.

(4) The beam combiners will be capable of phasing the array using signals from a spacecraft and/or radio source(s).

**10. Correlator.** A correlator is required for calibration, checking the performance of the array, phasing the array using radio sources, and developing a catalog of radio sources for calibrations and navigation. Correlator parameters include

(1) A (sampling) bandwidth from 125 kHz to 512 MHz for each IF signal.

(2) Capability to observe all four parallel and cross-polarization products for half the maximum bandwidth (256 MHz)

(3) Allowing observations in spectral-line mode with a spectral resolution of at least 256 channels for the full 512-MHz bandwidth of each IF signal, and obtaining better spectral resolution with reduced bandwidth (using, for example, the recirculation approach), providing up to 64 k channels per baseline in order to find a lost spacecraft.

**11. Range of Operating Environment.** The parameters for the range of the operating environment are as follows:

(1) Operating temperature: from −18 to +46 deg C.

(2) Survival temperature: from −29 to +57 deg C.

(3) Wind load for full performance: <48 km/h.

(4) Wind load for full function: <72 km/h.

(5) Wind load for survival (stowed): <161 km/h.

(6) Ice (0.5 specific gravity, stowed): <2.54 cm.

(7) Snow (0.1 specific gravity, stowed): <76.2 cm.

(8) Rain: <5.1 cm/h.

(9) Hail: <3.8 cm in diameter.

(10) Relative humidity: 0 to 100 percent.

**12. Array Configuration.** DSN array configurations must be sufficiently compact to allow accurate phase calibration, sufficiently extended to avoid unacceptable levels of shadowing at low elevations, and be able to fit within the size of accessible, reasonably flat areas at Goldstone. Configurations should produce instantaneous synthesized beams with low side-lobe levels in the direction of the ecliptic and should allow flexibility in defining subarrays with similar properties. Configurations also should be scalable such that good performance can be obtained as additional antennas are added. Proposed configuration requirements based on the above constraints are as follows:

(1) Maximum diameter of the area occupied by cluster antennas: 1 km.

(2) Minimum separation between any pair of antennas: 30 m.

(3) Maximum signal-to-noise ratio (SNR) loss due to antenna shadowing at 10-deg elevation: 1.5 dB.

(4) Maximum SNR loss due to antenna shadowing at 20-deg elevation: 0.5 dB.

(5) Root-mean-square (rms) side lobes within the primary beam area near transit (with $N$ antennas): $<1/N$.

(6) Maximum number of antennas (within about a 1-km-diameter area): 500.

## III. Array Subsystem and Functions

This section describes functions of various subsystems of the array (Fig. 4).

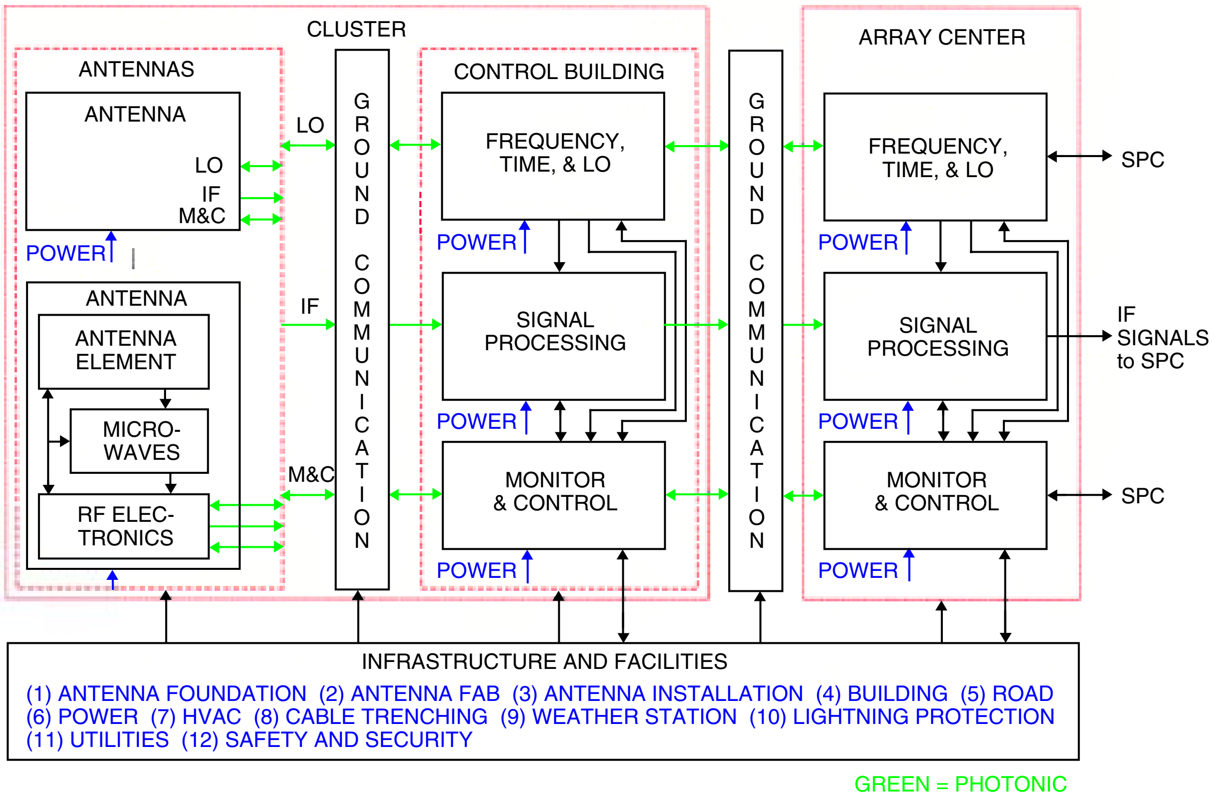


**Fig. 4. Array subsystems and their interconnections (the Array Center may be co-located with the existing Signal Processing Center at Goldstone).**

## A. Antenna (ANT)

The antenna subsystem consists of the primary and secondary reflector systems; the reflector support structure, including the pedestal, and the servo control and drive system. It will point the reflector to a commanded position on the plane of the sky and focus RF energy from a target source onto the secondary focus.

## B. Microwave (MW)

The microwave subsystem will simultaneously receive in the deep-space allocations at X-band and Ka-band, generate both circular polarization signals, and amplify these signals using low-noise amplifiers with approximately 35 dB of gain. The microwave subsystem will get LNA bias signals and noise calibration signals from the RF electronics subsystem. The microwave subsystem will provide both right circularly polarized (RCP) and left circularly polarized (LCP) signals at both Ka-band and X-band to the RF electronics subsystem. The microwave subsystem consists of

(1) Feeds with polarizers

(2) Cryogenics cooler, including compressor

(3) LNAs and directional couplers at the input of the LNAs to inject calibration (noise) signals

## C. RF Electronics (RFE)

The RF electronics subsystem will receive two circular polarization signals at each X-band and Ka-band. It will convert them to IF in the 640 to 1280 MHz range using LO signals on optical fiber cable from the control building. Two of the four IF signals (either both at X-band or both at Ka-band or any one (selectable) at X-band and one at Ka-band) will be sent back on optical fiber to the control building. The RFE also will monitor total power and synchronous detector power in the two IF signals. It will use a reference square-wave signal from monitor and control for modulating the noise diodes and demodulating synchronous detector outputs.

This subsystem consists of

(1) RF-to-IF downconverters at Ka-band and X-band

(2) Local oscillator receiver

(3) IF transmitter

(4) LNA bias module

(5) Calibration noise generators and their controls

(6) Monitor and control interface between the control building and the antenna-based equipment

A block diagram of the proposed microwave and RF electronics is shown in Fig. 5.

### D. Array Signal Processing (ASP)

A block diagram of the signal processing is shown in Fig. 6. It consists of

(1) IF signal conditioning electronics in the control building (e.g., fiber-optic receivers, IF amplifiers, signal level controls, anti-aliasing filters, attenuators, analog-to-digital converters (ADCs), and the coarse delays)

(2) Beam splitters

(3) Beam combiners

(4) Correlator

(5) Electronics needed to send IF signals from clusters to the Array Center/SPC and equipment at the Array Center/SPC to send the IF signals to the existing telemetry (Block V) receiver in the SPC

The signal conditioning receives IF (roughly 600 to 1300 MHz) signals from the antennas on fiber-optic cables, band limits, level controls, and digitizes and samples the signals and delays them appropriately. It has beam splitters, which select the frequency and bandwidth of the signals, align the wave fronts reaching various antennas from a target, and provide the signals to the beam combiners and correlator. The beam combiners coherently add signals from different antennas to form phased-array beams. The correlator correlates signals from various antennas in continuum or in spectral-line mode. The ASP will do the following:

(1) Combine the signals from the appropriate antenna elements (up to a maximum number of antennas) into a single IF per beam for processing by the receivers at the DSN or other equipment

(2) Condition IF signals for input into the DSN standard receivers, i.e., Block V Receiver (BVR), Radio Science Receiver (RSR)

(3) Provide correlation measurements from the beam combiners and correlator, and the total power and synchronization detector monitor data for each IF from every antenna

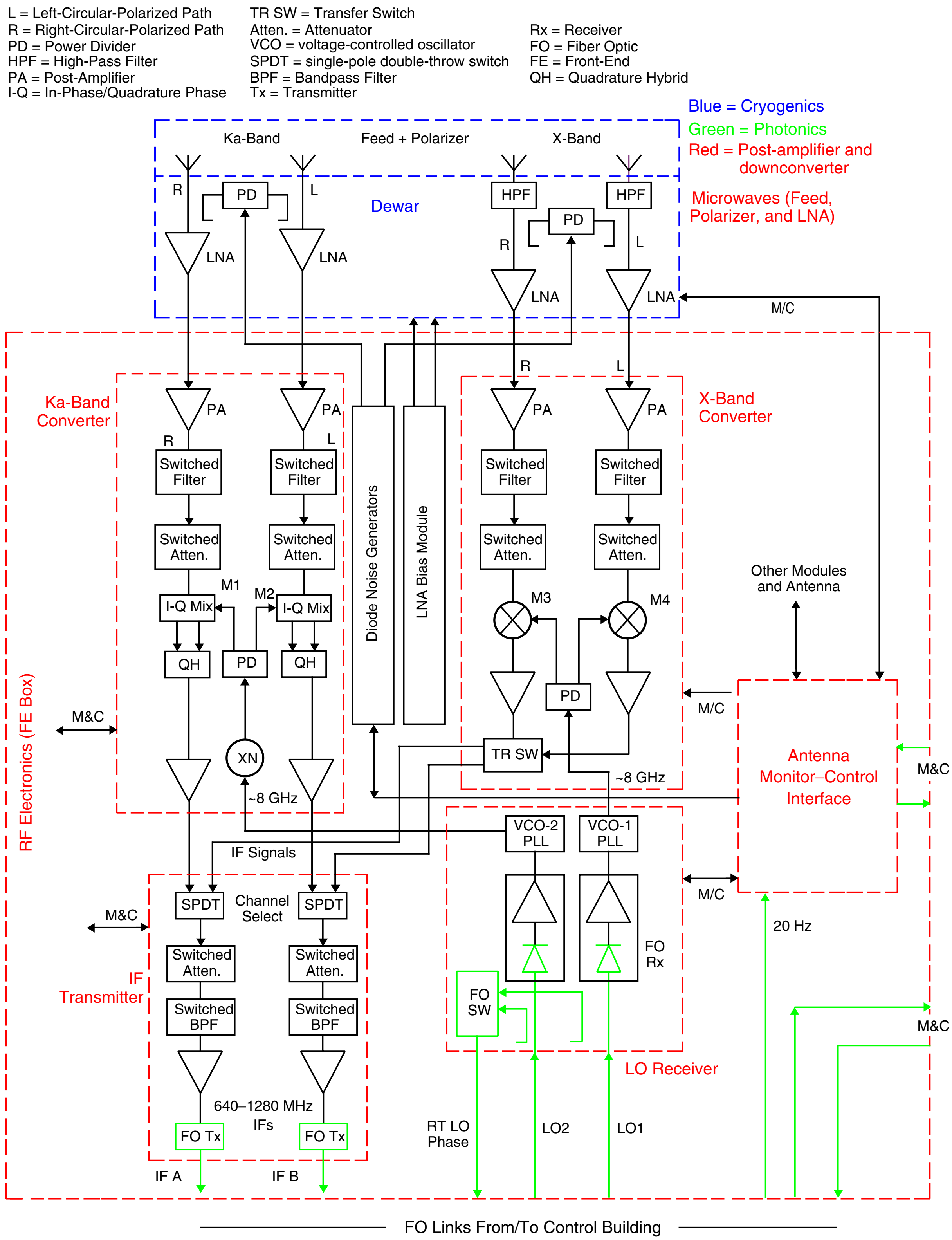


**Fig. 5. Microwave and RF electronics block diagram.**

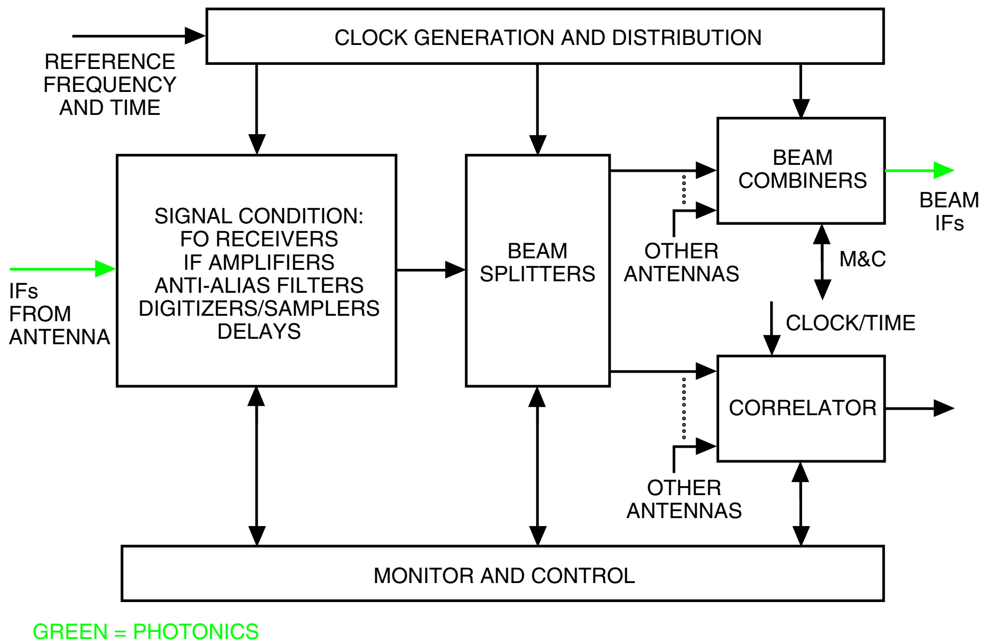


**Fig. 6. Array signal processing block diagram.**

### E. Monitor and Control (M&C)

The M&C will accept control information (link assignments and predicts) from the Network Monitor and Control (NMC) at the SPC and translate them into control data for the other subsystems of the array. This subsystem consists of

(1) The computer hardware and software for the monitor and control of the array

(2) Control of hardware for delivery of data/IF in suitable format to the Array Center/SPC

(3) Array test and calibration software

(4) Array planning and scheduling

(5) Archiving of monitor data

### F. Frequency, Time, and LO (FTL)

The FTL provides LO, reference clock, and timing signals to the antennas, signal processing, and monitor and control subsystems. It provides the interface to the frequency and timing subsystem at the Deep Space Communications Complex (DSCC) for the cluster at Goldstone. At each cluster, the FTL will regenerate all the reference frequency and time signals required by the cluster and distribute them to all subsystems located in the control building. It also will generate two local oscillator signals (7.3 to 9.6 GHz) for both X-band and Ka-band (i.e., a total of four synthesizers) and provide these signals to the ground communications (GC) for distribution to the subsystems located at the antenna elements. This subsystem consists of

(1) Regeneration of the reference frequency signals and the time signal from reference signals from the FTS in the Goldstone Signal Processing Center (SPC 10)

(2) Frequency and time distribution equipment

(3) Frequency synthesizers and LO signal distribution to the antennas

(4) Round-trip-path measurement systems for the SPC/Array Center to the cluster control building and the cluster control building to the antennas

### G. Ground Communications (GC)

The GC will transport data and reference frequency, time, and monitor and control signals between the SPC, Array Center, and cluster control buildings, and between the cluster control building and all the antennas at the cluster. This subsystem contains the fiber-optic cables for transporting signals between the antennas and cluster control building (e.g., LO, monitor and control, and IF signals), and the connection(s) required to transport IF and reference frequency signals between the cluster control building and the Array Center/SPC.

### H. Infrastructure and Facilities (I&F)

The I&F subsystem consists of the control building; roads; power distribution; heating, ventilation, and air conditioning (HVAC); antenna foundation (including lightning protection); weather station; facility security; communications to the outside world (e.g., phone and data lines); and lightning protection for the control building and FO cables. This subsystem will provide

(1) AC power to all the array equipment

(2) HVAC to the central control building

(3) Access roads from an existing paved road to all antenna elements and the central control building

(4) Antenna foundations (including lightning protection)

(5) Trenching for all fiber-optic cables between the central control building and the antenna elements

(6) Water and rest room facilities to the central control building

(7) Office furniture for operations, management, and test personnel

(8) Facility security

(9) Weather station

## IV. System Integration and Calibration

A block diagram of subsystems at the antennas and their interconnections is shown in Fig. 7. For bringing up the first few antennas, we may have to do most of the testing initially in the single-dish mode, as described in Section IV.A. After bringing up a few antennas, some of the single-dish tests described in Section IV.A can be skipped because the same things will be done interferometrically, as described in Section V.B.

### A. Bringing Up Antennas

There will be single-dish checkouts for each antenna element, including the antenna mechanical (including the servo) and electronics subsystems. This includes optics alignment and pointing for the first few antennas in the single-dish mode, and, after a few antennas, in the interferometer mode. When bringing up the antennas, we will

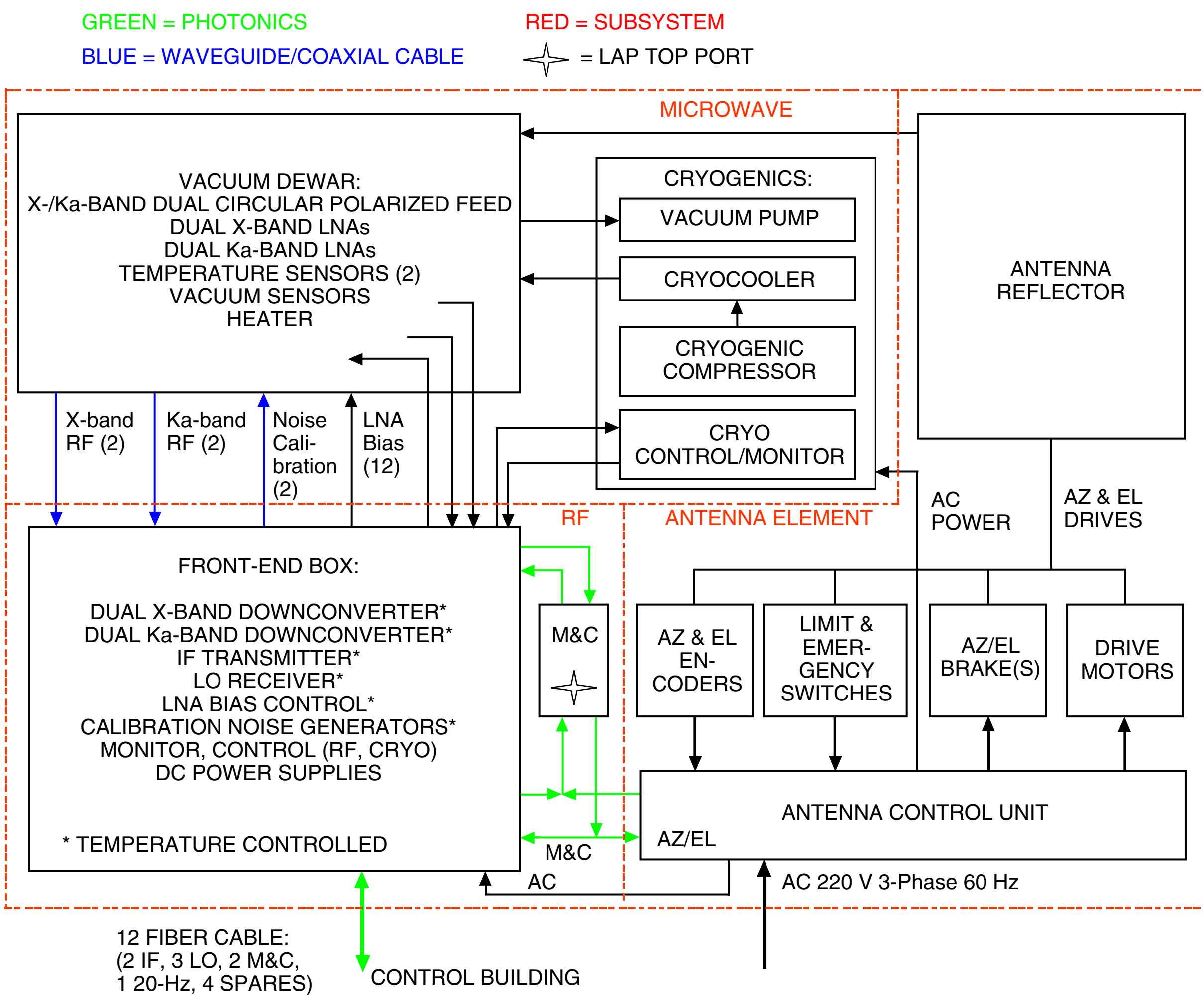


**Fig. 7. Antenna element, microwave, and RF electronics inter-connections.**

(1) Characterize/evaluate the electronics in the laboratory, including in particular the injection noise source stability

(2) Measure the alignment of the antenna (mechanical/structural/optics) and check the servo and antenna pointing

(3) Install the electronics on the antenna and align the feed

(4) Do the following, first at X-band and then at Ka-band:

   (a) Measure the receiver and system temperatures, $T_{rx}$ and $T_{sys}$, using hot/cold loads and determine the injected noise calibration signal, $T_{cal}$.

   (b) Measure the tipping curve and determine spillover.

   (c) Using the Moon, Cassiopia-A, or some other reasonable radio source as a target, measure the antenna main beam characteristics and determine an initial pointing model.

   (d) Measure beam pattern cuts by scanning the antenna. Realign the optics as indicated from the previous step.

(e) Repeat Step (c) to improve the pointing model.

(f) Using flux density calibration radio sources, measure the preliminary antenna gain and efficiency.

(g) Repeat Step (c) but use several radio sources and develop an accurate pointing model for use in all parts of the sky.

(h) With the most accurate pointing models, repeat Step (f) and determine the antenna gain and efficiency.

### B. Adding Antennas to the Array

After single-dish checks, we will determine the antenna pointing, delay, baseline, and antenna efficiency characteristics using interferometry. For each antenna, the receiver temperature, system temperature, and spillover with elevation were determined as described above in the single-dish mode using hot/cold load calibrations. Furthermore, the initial measurements of efficiency and pointing were done in single-dish mode. More rapid measurements of antenna efficiency, pointing, and optics alignment can be done in the interferometric mode. When adding antennas to the array, we will

(1) Survey the location of the antenna and determine its baseline with respect to other antennas.

(2) Check the FTS LO, including ensuring that the LO real-time phase correction is working for the antenna.

(3) Install and test operation of the signal processing hardware for the antenna.

(4) Do the following interferometric tests, first at X-band and then at Ka-band:

(a) Generate interferometric fringes and measure the correlation with different delays to determine the delay offset for each IF.

(b) Check for optics alignment interferometrically, with one antenna on source and the antenna under test with various offsets (we may use holography reduction methods to determine the optics alignment).

(c) Measure the fringe amplitude to provide interferometric efficiency and estimate the coherence.

(d) Repeat fringe measurements on many sources to solve for baseline parameters.

(e) Measure the fringe amplitude/phase on several sources at various elevations to determine the gain, phase stability, and antenna gain variation with elevation (gain curve).

(f) Beam combine (array phasing) and compare the amplitudes with respect to what is expected from the correlator measurements.

(g) Repeat the beam combining test on a spacecraft.

(h) Monitor the spectrum of the beam combiner IF signal from a spacecraft on a spectrum analyzer.

(i) Measure the antenna cross-talk using the correlator.

(j) Using holographic techniques, measure the surface errors (at various elevations).

### C. System Tests and Calibration Procedures

Routine/periodic checks and calibrations procedures for the operational array will have to be developed for routine maintenance and calibration of the array. Most of these tests will be some combinations of interferometric tests (listed above), but calibration procedures will have to be automated to make it routine and efficient.

## V. Performance

### A. Factors Affecting the Array Performance

Major factors affecting the array performance are described in the following.

**1. IF Amplitude and Phase.** Factors affecting array signal amplitude and phase are dependent on antenna efficiency, antenna pointing, and antenna phase center and electronics phase stability.

Antenna efficiency (surface errors, gravity, wind and thermal effects) includes illumination, spillover, blockage, primary surface rms, secondary surface rms, subreflector position, feed position, and resistive losses (in the primary and secondary reflectors, feed and polarizer, and coupler for the noise calibration signal at the input of the low noise amplifier).

Antenna pointing (gravity, wind, and thermal) includes the encoder resolution and alignment; subreflector position; feed position; dish mount (pedestal); system temperature; LNA noise temperature, which is 15 K at Ka-band (32 GHz) and 4 K at X-band (8.4 GHz); and resistive losses in the primary/secondary reflectors, feed, and polarizer of 4 K.

**2. Phase Noise and Allan Standard Deviations (ASDs).** The overall system stability requirements for the phase noise and Allan standard deviations are given in Tables 1 through 4. We will assume that we have a high-quality reference LO and time signals available at each cluster (which may come from the Array Center/SPC on fiber-optic links). At each cluster, there are at least 7 to 9 sources contributing to both phase noise and ASD. Therefore, the contribution from each of these sources should be roughly $\leq$0.3 of the total allowed. Some of these sources are common to all antennas, but others are random from antenna to antenna and, therefore, will add only in a root-mean-square sense in the array signals.

**Table 1. X-band and Ka-band phase noise.**

| | | | | | |
|---|---|---|---|---|---|
| Offset from center frequency, Hz | 1 | 10 | 100 | 1,000 | 10,000 |
| Phase noise spectral density, dBc/Hz | −65.7 | −73.3 | −75.2 | −75.2 | −75.2 |

**Table 2. X-band ASDs.**

| | | | | |
|---|---|---|---|---|
| Time difference, s | 1 | 10 | 1,000 | 3,600 |
| Allan deviation | $3.9 \times 10^{-13}$ | $4.6 \times 10^{-14}$ | $4.5 \times 10^{-15}$ | $4.5 \times 10^{-15}$ |

**Table 3. Ka-band ASDs.**

| | | | | |
|---|---|---|---|---|
| Time difference, s | 1 | 10 | 1,000 | 3,600 |
| Allan deviation | $3.0 \times 10^{-13}$ | $3.0 \times 10^{-14}$ | $1.4 \times 10^{-15}$ | $1.4 \times 10^{-15}$ |

**Table 4. Sources contributing to phase and frequency instabilities at each cluster.**

| Item | Source | Contributes to phase noise | Contributes to ASD |
|---|---|---|---|
| 1 | Cluster reference (100 MHz, 5 MHz) | Yes | Yes |
| 2 | LO synthesizers (for antenna LOs) in control building | Yes | — |
| 3 | LO transmission | — | Yes |
| 4 | LO phase-locked loops (PLLs) in antennas (converter LOs) | Yes | — |
| 5 | Receiver (amplifiers/mixers, filters, etc.) phase stability | — | Yes |
| 6 | Antenna stability (structural) | Yes | Yes |
| 7 | IF transmission to control building | — | Yes |
| 8 | Digitization/sampling | Yes | — |
| 9 | Clock and reference | Yes | Yes |
| 10 | Fringe rotation/delay | Yes | Yes |
| 11 | Phasing updates | Yes | Yes |
| 12 | Power supplies | Yes | Yes |

Consequently, the random components may be somewhat larger, as much as a factor of 3 (assuming we would have at least 10 antennas in a subarray when these requirements are important).

**3. Spectral Flatness and Spurious Signals.** The bandpass amplitude should be flat within 1 dB, and delay variation should be $<1$ ns over any 100 MHz. It is suggested that we have the bandpass flat to within 1 dB over the 700- to 1200-MHz IF. Even if the electronics are perfectly stable, the array bandpass will vary with time due to the following reasons: (1) different bandpasses for various antennas in the array and relative antenna phase changes due to the array phasing errors varying with time, and (2) antenna delay tracking changes with time. This will limit the accuracy of relative angular position measurement using the delta differential one-way ranging (delta-DOR) method. Relative phase variation with time at any two frequencies within the beam former (combined array) IF bandpass should be $<0.2$ deg of phase over approximately one hour of time (required for delta-DOR-type measurements). We also are considering the flattening of each antenna IF bandpass, before the antenna signals are combined in the beam combiners, by adjusting the filter responses in the beam splitters.

**4. Dynamic Range.** The array system will be able to accept signal levels at the input of the LNA at each antenna of $-45$ dBm, with no more than 1-dB compression, and of $-55$ dBm, with no more than 0.1-dB compression, at both X-band and Ka-band. As a goal, to reduce sensitivity to radio frequency interference (RFI), the current 1-dB compression design of approximately $-35$ dBm for Ka-band and $-36$ dBm for X-band should be maintained. The system should be required to accept a signal level of at least $+10$ dBm without sustaining damage.

## B. Expected Contributions to Performance

**1. Expected Performance.** The expected receiver and system temperatures, antenna efficiency, and sources contributing to the expected values are given in Tables 5 and 6.

**Table 5. Antenna receiver and system temperature (in K) and efficiency values.**

| Frequency, GHz | $T_{\mathrm{spill+scat}}$, K | $T_{\mathrm{sky}}$, K | $T_{rx}$, K | $T_{sys}$, K | Efficiency |
|---|---|---|---|---|---|
| 8.4 | 5 | 5 | 10 | 20 | 0.65 |
| 32 | 6 | 12 | 22 | 40 | 0.55 |

**Table 6. Receiver temperature contributions (in K).**

| Frequency, GHz | Resistive losses in reflectors, K | Resistive losses,[a] mW | LNA, K | Noise calibration signal, K | Receiver back-end noise contributions,[b] K | Miscel-laneous, K | Total, K |
|---|---|---|---|---|---|---|---|
| 8.4 | 1 | 3 | 4 | 0.4 | 0.3 + 0.1 + 0.2 | 1 | 10 |
| 32 | 1 | 3.2 | 15 | 0.8 | 0.5 + 0.1 + 0.4 | 1 | 22 |

[a] Feed, window, polarizer, noise coupler, and other waveguide losses.

[b] Downconverter + IF transmitter + fiber-optic link.

**2. Array Phasing Errors.** We expect the total phasing errors at Ka-band (32 GHz) to be 18 deg rms. These errors can be broken down into the various parts described below:

(1) Atmosphere (12 deg rms)

(2) Antenna location (including baseline errors)

(3) Antenna phase center: 0.35 mm (12 deg rms)

(4) Antenna electronics errors: microwave, RF-IF-LO (3 deg rms)

(5) FO link for IF (4 deg rms)

(6) Signal processing (3 deg rms)

  (a) Signal conditioning

  (b) ADC and sampling clock

  (c) Fringe phase and delay update accuracy

(7) FTS-LO, including ground communication (3 deg rms)

  (a) Reference generation and distribution

  (b) LO round-trip phase

**3. Combining Losses.** We are assuming independent phase variations for each antenna due to wind and troposphere. We assume rms phase fluctuations at Ka-band of 12 deg due to tropospheric variations; 12 deg due to 0.35-mm differential variations in antenna phase center due to the combined effects from wind, thermal changes, and gravity; and 6 deg from variations in electronics, giving a total of phase variations for the antennas due to all factors of 18-deg rms. This will give a phasing loss equal to roughly cos 18 deg or about 5 percent (0.2 dB) and will result in signal phase variations for the array IF signal of about 6-deg rms (for a 10-antenna subarray).

**4. Gain Loss and Fluctuations.** In addition to combining losses, there may be antenna gain loss due to the subreflector and feed position offset from the optimum. The antenna gain loss due to deviation from the optimum geometry and the associated pointing effect should be $<0.2$ dB. Therefore, the combined array gain loss due to phasing and loss of antenna gain should be $<0.5$ dB due to 48-km/h wind, tropospheric variations, and other effects. Assuming the variations are random from antenna to antenna, this should give array gain variations of $<0.2$ dB and phase variations of $\leq 6$ deg for an array with more than 10 antennas.

## VI. Summary

This article describes the design parameters, the design considerations, the functions of various subsystems, their interconnections, and the expected performance of the Initial Array System for the DSN.

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