Antenna Autocalibration and Metrology Approach For the AFRL/JPL Space-Based Radar

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Introduction:

The Air Force Research Laboratory (AFRL) and the Jet Propulsion Laboratory (JPL) are collaborating in the technology development for a space based radar (SBR) system that would feature a large aperture lightweight antenna for a joint mission later in this decade. The orbit is 505.8 Km altitude.

The basic architecture of this radar system consists of a 50m x 2m electronically steerable phased array antenna in L-band (1260 MHz, 80 MHz bandwidth). Scan range is ± 45 deg in azimuth and ± 20 deg in elevation. The array is composed of 32, 1.56m x 2m panels. Each panel is composed of 12 x 12 radiating elements, each with its dedicated active Transmit/Receive (T/R) module. Each T/R module includes a power amplifier, low noise amplifier, circulator, phase shifter, programmable attenuator, polarization switch and calibration coupler and switches. The array can be commanded to transmit or receive in either H or V polarization. Each of the 32 panels has its own Panel Radar Electronics Module (PREM) where the RF network is combined (with appropriate true time delays), downconverted and digitized before being sent to the Digital Beam Former (DBF) by way of a fiber optic link. The PREM is also where the transmitted chirp and caltone signals are created and upconverted to L-band.

A block diagram of the radar system is shown in Figure-1.

The radar is designed to operate in a variety of modes include Synthetic Aperture Radar (SAR) modes such as low resolution stripmap, high resolution stripmap and spotlight as well as several Moving Target Indication (MTI) modes. The MTI modes, in particular, have a very stringent requirement on phase center knowledge (a few millimeters) and antenna sidelobe level during receive (-50 dB rms).

Calibration and metrology baseline description:

It is necessary to measure both the electrical phase of the transmit and receive path associated with each radiating element, as well as the physical position of each radiating element with respect to a known reference point. This is due to the large size of the array, the stringent requirements on antenna flatness after compensation, the dynamics of the antenna structure, and the temperature gradients in the array due to self-heating of the electronics as well as non-uniform shading/illumination by the sun. The electrical phase measurements are performed by the Calibration Subsystem and the position measurements are performed by the Metrology Subsystem. The calibration and metrology data are sent to the Calibration Processor, which computes in semi-real-time the necessary corrections in phase and time delay to each transmit/receive path.

These corrections are communicated to the Radar Control Electronics, which translates and incorporates them into commands to the PREMs and the T/R modules.

Figure-2 illustrates the Metrology and Calibration Concept for this large antenna array. Modified star-tracker cameras are mounted in two positions above the center plane of the array. They will continuously measure the physical position of targets adjacent to the radiating elements. The positions of the metrology packs will also be measured relative to the radar coordinate reference. One of the metrology packs will be mounted on the RF calibration tower. The tower is equipped with an omni-directional antenna and a receiver to route the RF calibration signals to the bus electronics for time delay and phase analysis by the calibration processor. Since the tower provides a common path for all the elements of the array, it provides the capability for making relative measurements.

In order to calibrate the relative delays in the transmit path, a sequence will be conducted just prior to a data take, where each element transmitter will be turned on, one at a time and received by the calibration tower. The relative delays will be corrected using panel analog true time delays, T/R module phase shifters and PREM chirp generation and digitizer clock offsets. Since the side lobe rejection requirements for transmit is not as stringent, it is assumed that a measurement prior to data taking, (and after the array had sufficient warm up time) would provide sufficient accuracy. If it is determined later that thermal changes of the radar electronics on the panel still contributes too much error during the data take, then it is possible to use thermal measurement data together with models generated in the laboratory prior to launch to improve the transmit phase estimate. During receive, the requirement for phase knowledge is quite severe. Our plan is therefore to continuously inject calibration tones (generated by the Panel Radar Electronics Module) into each T/R module receive path in sequence. This calibration tone will be embedded in the data and its timing and phase extracted in processing. Since the distribution of signals across the array has unknown phase/delay characteristics, the injection phase of the caltone into each T/R module, will be measured in a relative manner by transmitting the caltone to the calibration tower.

Analysis:

In order to realize this metrology and calibration approach for this antenna, several key analyses are required. First, it is necessary to show that it is possible to transmit from each radiating element on the array to the cal tower without scan-blindness and in such a way that amplitude and phase response of this RF link can be predicted given the positions of the element/tower. This was achieved using electromagnetic simulations for the full field solution.

Second, a position is selected for the cal tower and the secondary metrology pack, such that the impact of these structures on the far-field pattern of the array is not significant and the metrology baseline distance requirement is met.

In parallel with the above analyses, an antenna simulation model was constructed, which has the capability to accept inputs about the antenna physical deformation in addition to calibration and metrology errors. The simulation produces 3D antenna patterns and calculates the rms side lobe level over the hemisphere. The purpose of this simulation is to feed requirements to the calibration and metrology subsystems regarding the acceptable errors in their measurements. How often these measurements need to be taken is a function of external phenomena: the RF calibration has to keep up with the phase and amplitude changes in the electronics that are primarily driven by temperature changes. Thermal analysis of the expected environment as well as analysis of phase vs. temperatures of past space missions (such as Shuttle Radar Topography Mission) are done for this purpose. The spatial and temporal frequency of the metrology measurements are a function of the dynamics of the antenna structure.

Figure-3 shows a comparison between compensated and uncompensated side lobe rejection performance. The black curve represents the antenna pattern when the antenna is heavily deformed (as if the z-fold did not fully deploy), and each panel is offset by 5.4 cm p-p from the plane. The metrology and calibration errors are close to expected and the side lobe rejection is -49 dB. In red, the same situation exists except there is no compensation for the deformation. In this case the rms side lobe rejection is degraded to -47 dB.

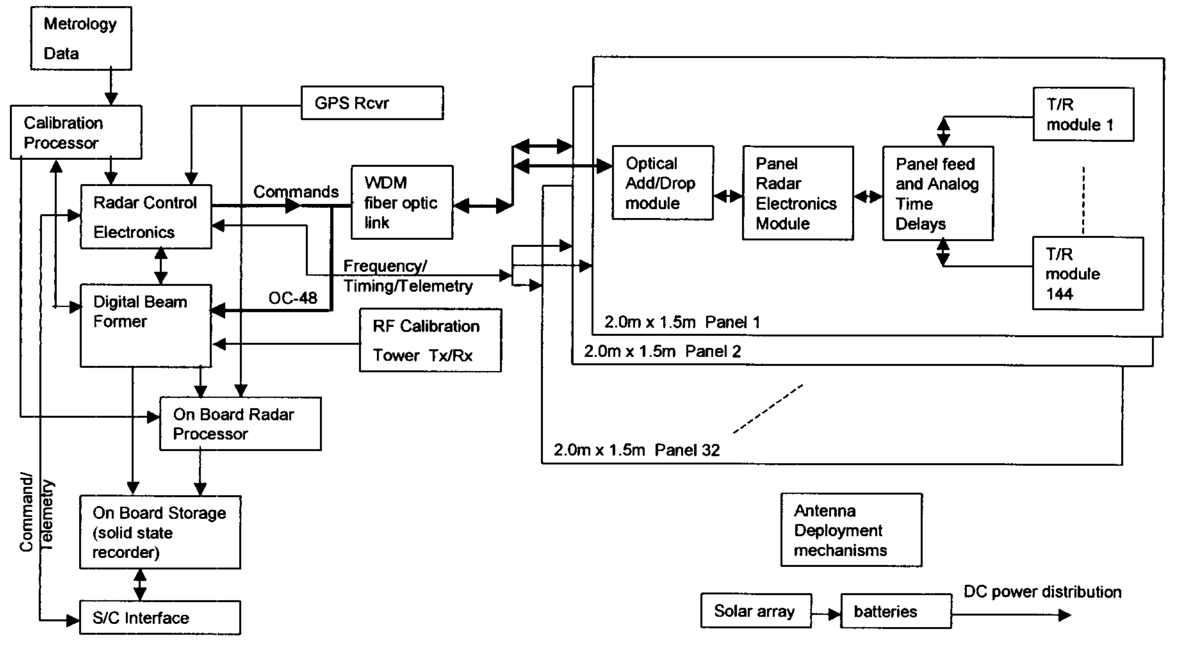


Figure-1: Block diagram of the AFRL/JPL SBR Radar Instrument

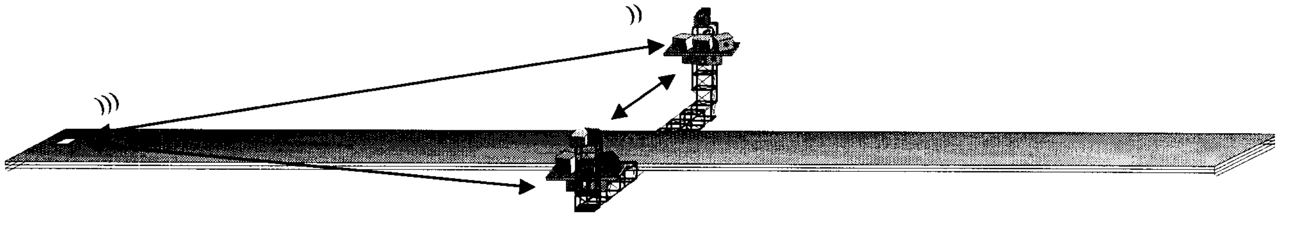
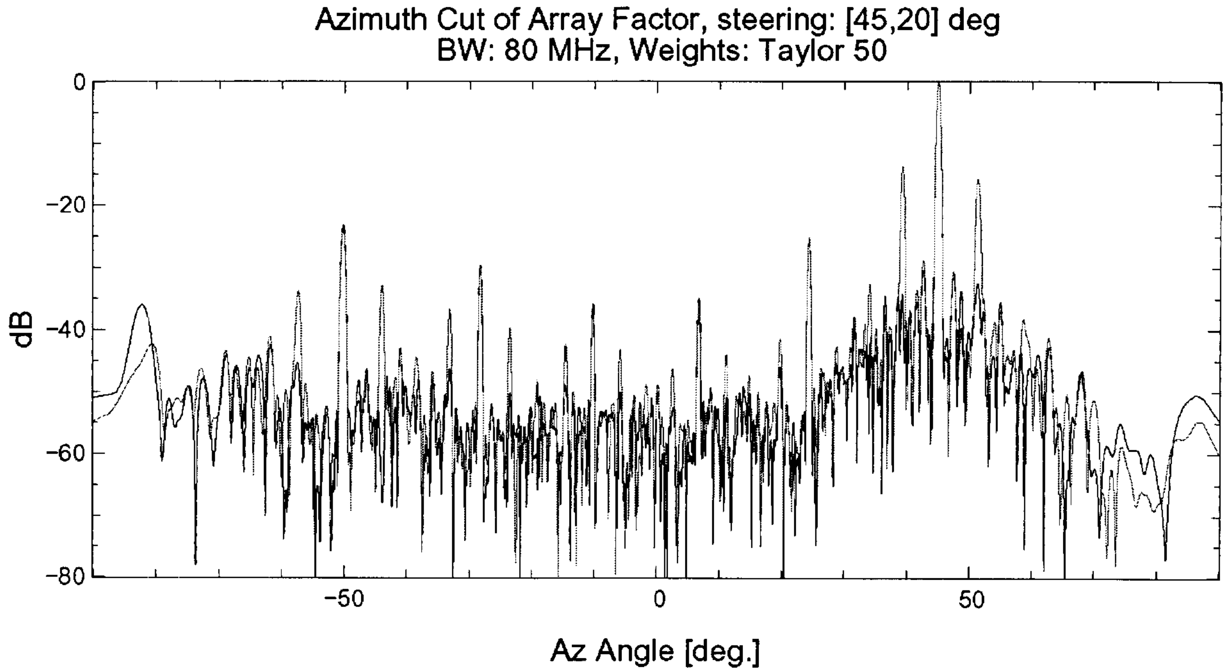


Figure-2: AFRL/JPL SBR Metrology and Calibration Concept



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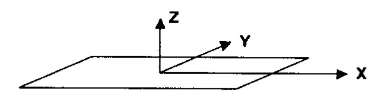

Figure-3: Black: edge of 80 MHz band,
max steering (45deg.Az, 20 deg.El)
cal phase error 0.1 deg. Cal timing error 1ps,
metrology error 0.1, 0.1,0.1 deg. rotation of panels,
2,2,2 mm (x,y,z) panel translational error,
Deformation: triangular deformation 5.4cm per panel as shown (not to scale)
Red: Deformation not compensated for.