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# SPACEBORNE IMAGING RADAR-C INSTRUMENT

BRYAN L. HUNEYCUTT  
Jet Propulsion Laboratory  
California Institute of Technology  
4800 Oak Grove Drive, Pasadena, California 91109

**Abstract** - The Spaceborne Imaging Radar-C is the next radar in the series of spaceborne radar experiments, which began with Seasat and continued with SIR-A and SIR-B. [1-4] The SIR-C instrument has been designed to obtain simultaneous multifrequency and simultaneous multipolarization radar images from a low earth orbit. [5] It is a multiparameter imaging radar that will be flown during at least two different seasons. The instrument operates in the squint alignment mode, the extended aperture mode, the scansar mode, and the interferometry mode. The instrument uses engineering techniques such as beam nulling for echo tracking, pulse repetition frequency hopping for Doppler centroid tracking, generating the frequency step chirp for radar parameter flexibility, block floating-point quantizing for data rate compression, and elevation beamwidth broadening for increasing the swath illumination.

## I. INTRODUCTION

The Spaceborne Imaging Radar-C (SIR-C) is a dual-frequency, quad-polarization imaging radar, designed to fly on the Space Shuttle in a low Earth orbit, and to operate from a stable platform located in the Orbiter payload bay. [6] Several flights are currently planned for SIR-C beginning in 1994. SIR-C has been designed to operate simultaneously at both L-band and C-band frequencies, and to utilize quad-polarization returns at each frequency. [6] SIR-C effectively has four separate radars: L-band horizontal  $L_H$ , L-band vertical  $L_V$ , C-band horizontal  $C_H$ , and C-band vertical  $C_V$ . In the nominal mode, SIR-C operates each of its four radars by radiating at broadside, utilizing a fully focused antenna aperture, much like the previous experiments, except that now there are really four radars operating simultaneously. The important SIR-C instrument parameters related to the operating modes and techniques are given in Table 1.

Fully instrumented testing of these various modes and techniques will occur at the experiment developer's facility, and not at the Shuttle launch site. Transmission from the full aperture and reception at far range is not planned even at the experiment developer's facility, due to the complicated and costly logistics of erecting such a large structure in an environmentally protected range. The SIR-C antenna is presently planned to be delivered into the integration flow at the launch site in its ready-to-launch configuration.

TABLE I  
SIR-C INSTRUMENT CHARACTERISTICS

Parameter	L-Band	C-Band
Azimuth Coalignment (arc min)	$\pm 8$	$\pm 2$
Azimuth beam steering (degrees)	$\pm 2$	$\pm 1$
Extended aperture beams	127	127
Extended aperture dwell time (ms)	20	20
Scansar beams	4	4
Scansar dwell time (ms)	30	30
Interferometry phase center offset (m)	N/A	4
Beam null ratio	1/PRF	1/PRF
PRF hopping dwell time (s)	1	1
Number of selectable PRF's	16	16
Elevation beamwidth	5-18°	5-18°
Number of selectable beamwidths	8	8
Digital chirp pulsewidth ( $\mu s$ )	8.4, 16.9, 33.8	8.4, 16.9, 33.8
Digital chirp bandwidth (MHz)	10,20	10,20
Quantization (bit)	8	8
BFPQ subset (bit)	4	4
BFPQ block length (samples)	128	128
PRF (Hz)	1240-2160	1240-2160
Stalo frequency (MHz)	89.994240	89.994240
Data steering	offset video	offset video
Number of high rate record channels	4	4

Functional tests of the SIR-C instrument will occur during integration with the Shuttle.

## II. ANTENNA OPERATION AND TECHNIQUES

SIR-C will operate in modes, which were previously not possible, without electronic beam steering. Figure 1 illustrates the target illumination geometry corresponding to these operating modes.

### A. Squint Alignment

Electronic beam steering in azimuth may be needed to align the H and V polarization swath illuminations, even though the antenna design calls for an azimuth electrical-to-mechanical boresight error of less than 4 arc minutes. Azimuth steering allows SIR-C to take data at a given squint angle, whereby the azimuth angle is fixed to one side or the other with respect to broadside. The H-polarization and V-polarization illuminations can be unintentionally

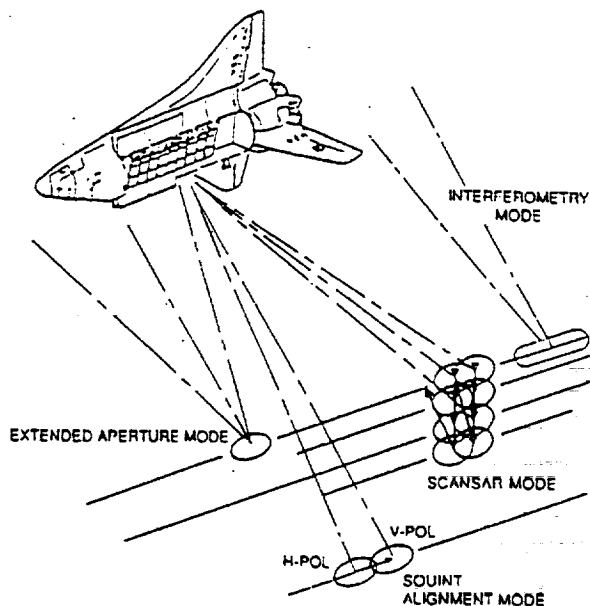


Fig. 1. SIR-C target illumination by modes.

offset due to mechanical tolerances in manufacturing and environmental effects in space such as uneven thermal distribution and zero gravity unloading. The beams can then be commanded to different azimuth squint angles until they are coaligned to within 4 arc minutes. The shape of the azimuth spectrum of the cross-polarization return can be used to verify proper co-alignment. Azimuth steering also allows experimenters to collect synthetic-aperture radar (SAR) data at selected fixed squint angles.

Because of the limited area for locating the electronics on each panel, a single transmit/receive (T/R) module and phase shifter pair feeds a subarray, and not individual elements. The stick-like subarray contains 6 radiating elements for L-band and 18 radiating elements for C-band. This restricts the azimuth steering to only a few degrees. Electronic beam steering can be accomplished for only  $\pm 1$  deg in azimuth for C-band, and  $\pm 2$  deg in azimuth for L-band; beyond these limits, the side lobes increase, the main lobe broadens, and grating lobes occur at unacceptable levels. [6]

#### B. Extended Aperture

Azimuth steering allows SIR-C to take data in the extended aperture mode, or "spotlight" mode, whereby the same scene on the

ground is illuminated as the Shuttle passes the scene, and the effective aperture is thereby extended. This technique increases the effective azimuth Doppler bandwidth to improve the image quality. This increased bandwidth permits: (1) finer spatial resolution by utilizing the full bandwidth and (2) reduced speckle by incoherently adding more azimuth looks. To implement this extended aperture mode, as an example, the antenna beam is first squinted ahead at the full range positive squint angle, and then decremented in small uniform steps of squint angle at uniform time increments, until the antenna beam is looking behind at the full range negative angle.

#### C. Scansar

Electronic beam steering in elevation allows SIR-C to image in a scansar mode, whereby the antenna beam is steered to as many as four previously selected elevation angles during each synthetic aperture interval. This dramatically increases the width of the swath which can be imaged during a data take. The beam is electronically steered in elevation as in azimuth by varying the phase-front across the aperture via the microprocessor-controlled phase shifters. The SAR processor must treat the data from each elevation angle as burst data. The azimuth resolution of the processed bursts of data is degraded by a factor of 4; however, the swath width illumination is increased by about the same factor. Since the synthetic aperture interval increases with the look angle off nadir, the dwell time at each of the four elevation angles increases with the look angle.

#### D. Antenna Beamwidth Broadening

For a uniformly illuminated aperture, the aperture dimension and RF wavelength determine the antenna beamwidth. SIR-C uses a technique of tapering the power in elevation, which provides lower side lobes (approximately -18 dB side lobes) than for the uniform illumination case. This configuration uses less T/R modules, and thus less power. Lower side lobes are achieved in elevation. The resultant antenna pattern is lower in amplitude and has a wider beamwidth.

Within the constraints of the Shuttle payload bay volume, the aperture sizes were optimized to have sufficient aperture gain, yet sufficiently low azimuth and range ambiguities over the pulse repetition frequencies (PRFs) selected. The sizes of the full apertures

are 12.1 m x 2.95 m for L-band and 12.1 m x 0.75 m for C-band, which yield a fully focused elevation beamwidth of 4.7 deg for each frequency. Variable beamwidths in elevation can be accommodated by selecting a pre-programmed phase function across the array. One of eight selectable beamwidths from 4.7 deg to 18.0 deg is selected by an uplink command. The amplitude decreases and the side-lobe levels increase slightly with increasing beamwidths. The beamwidth is optimized for swath illumination at the various look angles.

#### E. Beam Nulling

The phase shifters in one half the array will be periodically shifted 180 deg in elevation, thereby nulling the elevation beam pattern. This is an echo-tracking technique to determine the roll angle, and thereby accounts for the elevation antenna pattern in the raw SAR data during amplitude calibration. Results from simulations indicate that beam nulling during one receive interval in each one-second interval is sufficient to determine the roll angle and yet not degrade the image significantly. The roll angle can be determined with an accuracy of a few tenths of a degree.

### III. RF ELECTRONICS

The RF electronics subsystem is located on the pallet in the cargo bay. The RF electronics subsystem accommodates several new techniques not previously used in the SIR series.

#### A. Digital Chirp

To attain fine resolution in range, SIR-C encodes each transmitted pulse, such that each pulse of duration  $T$  can resolve targets as if a much shorter pulse of duration  $T/TBW$ , where  $TBW$  is the time-bandwidth product, had been transmitted. SEASAT, SIR-A, and SIR-B used the passive dispersive delay line (DDL) approach; however, for SIR-C a different DDL would be required for every  $TBW$  required. SIR-C attains this large time-bandwidth product by distributing the energy of each pulse over the frequency bandwidth, stepwise linearly with time. The SIR-C chirp signal is approximated digitally, in that a tone is successively stepped across the bandwidth within the pulse duration, approximating a linear FM (LFM), or chirp, signal. The number of frequency steps varies with the bandwidth, pulse-width, and frequency-step size combination. The 10-MHz, full pulse-width case requires 76 steps; whereas, the 20-

MHz, full pulse-width case requires 152 steps. The number of steps for SIR-C trades off the integrated side-lobe ratio with realistic switching rates. The integrated side-lobe ratio has been measured to be approximately -9.5 dB and the measured impulse response width agrees closely with that of an ideal chirp.

The frequency-step chirp technique provides flexibility in the selection of certain radar parameters: (1) pulse width, (2) calibration tone frequency, and (3) bandwidth. The transmitted pulse width can be decreased by a factor of 2 or 4 to lower the average dc power usage. Fixed frequency calibration tones can be generated from the same digital chirp device, and the frequency of the calibration tone can be selected. The RF bandwidth can be increased from 10 MHz to 20 MHz to improve the range resolution.

#### B. Interferometry Mode

The L-band and C-band apertures are subdivided into 3 equal area sections called leaves. The two outer leaves are unfolded after attaining orbit in order to transmit. The received echo signals from the two extreme C-Band leaves can be coupled into two separate receiver channels in order to accommodate a special interferometry mode. This requires couplers in the C-Band RF feed system at the initial 3-way power combiner, such that the inputs from the two extreme leaves can be routed to two separate receiver channels. The technique provides returns from the two existing extreme leaf apertures, whose phase centers are separated by the distance of one leaf in the azimuthal direction. Processing of the interferometry data from ocean returns, for example, can provide ocean current direction. [7]

### IV. DIGITAL ELECTRONICS TECHNIQUES

The Digital Electronics Subsystem uses engineering techniques required by SIR-C in order to obtain calibrated data and to be much more flexible in radar parameter selection than in previous imaging radar experiments in this series. These techniques are utilized during the normal operation of the radar.

#### A. Alternating Pulse Mode

The SIR-C exciter operates in an alternating pulse scheme such that the oppositely polarized pulse is delayed by half an inter-

pulse period. The radar effectively operates at twice the nominal PRF. For quad-polarization operation, both like- and cross-polarization echoes are received in the same channel.

#### B. Block Floating-Point Quantizing

The offset video output from each of the four receivers is digitized to 8 bits per sample with uniform quantization at a constant rate of 45 MHz. A SIR-C feature allows formatting the raw samples as 4 bits, 8 bits, or an (8,4) floating-point block. The block floating-point quantizer (BFPQ) derives its name from "blocks" of data being uniformly quantized and subsets of the available bits being selected by a predetermined algorithm, equivalent to moving the "floating point" marker in binary data. If the data transmission rate to the onboard recorders is held constant, then doubling the number of bits per sample approximately halves the swath width, therefore trading off dynamic range for swath width.

The (8,4) BFPQ is a data rate compression technique. The (8,4) BFPQ method provides an output rate similar to a 4-bit uniform scheme but with the dynamic range of an 8-bit system. For each block of data, a series of bits are transmitted, including the sign bit, followed by the optimally selected 3 contiguous bits per sample, followed by a common exponent for the block. The block size is 128 samples of raw data. The formatted data are transmitted as 8-bit parallel words. The distortion noise for the (8,4) BFPQ is about 24 dB higher than for the 8-bit uniform quantizer (UQ); however, the range of return signal level for which the distortion noise is almost constant is about 24 dB wider than that for the 8-bit UQ. [6] Therefore, the performance of the (8,4) BFPQ is less sensitive to the typically widely varying level of the return echo.

#### C. Digital Data Steering

In normal data takes, each receiver output is directed to a previously selected, separate digital data handling assembly (DDHA) for digitizing, buffering, and formatting. This steering occurs at offset video. Once the individual offset video signals have been digitized, formatted, and serialized, there is flexibility in steering to a redundant on-board Payload High Rate Recorder (PHRR). This data steering allows for recovery in case one or more of the DDHAs or the PHRRs should fail.

In extended swath data takes, one receiver output is directed to two DDHA's, such that the resulting data represent an image swath twice that of a single DDHA. The SAR processor will have all four channels combined on one tape cassette.

#### D. Integer PRFs

SIR-C has incorporated integer PRFs, whereby there are an exact integer number of PRF pulses in one second. SEASAT, SIR-A, and SIR-B used a countdown scheme to derive PRFs from the STALO, a stable local oscillator, without regard for whether the PRFs were integral. The SIR-C integer PRF facilitates timing for the radar since the PRF and timing circuitry provides basic control of the radar for PRF changes, receiver gain, exciter timing, digital window position, and data channel switching, all of which change state synchronously on one-second time ticks (OSTTs). Also, SIR-C chose the PRFs such that there are an integer number of 8-bit bytes in a range line. This feature facilitates ground processing. Since the PRFs are derived from a very stable STALO, the requirement of integer PRFs affects the choice of the STALO frequency. By analysis, it was determined that by using a STALO with frequency 89.994240 MHz, there were at least 16 integer PRFs in the range from 1240 Hz to 2160 Hz, which were compatible with the altitude and look-angle range of SIR-C.

#### E. PRF Hopping

SIR-C uses a PRF hopping technique, or multiple PRF technique, whereby the azimuth Doppler spectrum can be located unambiguously. For the PRF hopping technique, if the azimuth spectrum is offset in frequency because of pointing errors, for example, the centroid of the spectrum falls into different portions of the azimuth processing bandwidth when sampled at various PRF rates. By knowing the ambiguous location of the centroid for three different PRFs, the location of the unambiguous location, and thereby the yaw angle, can be calculated. The PRF hopping will occur at the beginning and end of each data take. There will be a one-second dwell at each of the three PRFs.

#### V. Summary

Several operating modes and engineering techniques used in the SIR-C instrument have been described: squint alignment, extended aperture, scansar, interferometry, beam nulling, PRF

hopping, antenna beamwidth broadening, generating frequency-step chirp signals, block floating-point quantizing, integer PRF's, and digital data steering.

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