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SIR-C, THE NEXT GENERATION SPACEBORNE SAR

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I. INTRODUCTION

The decade between 1976 and 1986 has seen a period of steady development in the use of a Synthetic Aperture Radar (SAR) in remote sensing applications. The technology which was originally developed for airborne use was extended to space with the launch of Seasat in June 1978, followed by the Shuttle Imaging Radar-A (SIR-A) in November, 1981 and SIR-B in October 1984. These three SAR missions had a common heritage: Seasat, a free flyer, which demonstrated for the first time the feasibility of operating a SAR at orbital altitudes, thus setting the stage for acquiring SAR data on a global scale. SIR-A and SIR-B were derivatives of the SEASAT technology which was adapted for the Space Shuttle era and capitalized heavily on the original hardware design. All three featured a single wavelength: 23.5 cm (1.27 GHz), single polarization: HH (Horizontal transmit and receive), and a corporate fed, passive planar array antenna. The parameters which differed for the three missions were: look angle: 20° for Seasat, 45° for SIR-A and 15° to 60° for SIR-B (by means of a mechanical antenna tilt mechanism); range bandwidths which were 19 MHz, 6 Hz and 12 MHz respectively; and data handling: analog link for Seasat, on-board Optical Recorder for SIR-A and Digital Data link and recorder for SIR-B.

Advances in technology in recent years now make it appropriate to take the next evolutionary step in expanding the capabilities of the next generation Spaceborne SAR. What follows is a description of the SIR-C instrument, its major elements and the capabilities which have been incorporated into the design in response to the requirements and goals identified by the SIR-C Science Steering Committee and stated in the SIR-C Science Plan[1].

II. SYSTEM DESCRIPTION

SIR-C takes a significant departure from the previously flown SAR systems in several areas.

Firstly: it is a multiple frequency sensor system capable of operating in L-Band (1.2 GHz), C-Band (5.3 GHz), or both simultaneously.

Secondly: Each frequency can transmit and receive in either or both of two polarizations: Horizontal and Vertical. This feature permits acquisition of SAR data in the quad-polarization mode, i.e., transmit alternating pulses in H and V and receive like-polarized echoes; HH and VV as well as the cross-polarized echoes HV and VH. Recent work by H. Zebker[2] at JPL, based on similarly acquired SAR data with an airborne SAR demonstrated a technique for synthesizing any arbitrary polarization, given the data set obtained in the quad-polarization mode. This method makes possible the use of polarization effects for SAR data extraction and image interpretation.

Thirdly: The SIR-C antenna is an active aperture phased array or distributed SAR. The antenna contains individual transmitter/receiver modules mounted directly behind the radiating elements. The array geometry can thus be tailored to optimize system performance. There is an additional benefit which results from this configuration: the ability to steer the beam electronically.

In addition to the L- and C-Band systems described above, a third system operating at X-Band will fly along with SIR-C, provided jointly by the German Space Agency, DFVLR, and the Italian Space Agency, CNR/PSN. XSAR will use a passive waveguide array antenna with vertical polarization. The cost of implementing the distributed SAR concept at X-Band is prohibitive with the current state of technology, but could be considered for the EOS time frame.

III. PAYLOAD CONFIGURATION

SIR-C is being configured similarly to SIR-A and SIR-B. The electronic assemblies will be mounted on a pallet in the cargo bay of the Space Shuttle. The main difference is the size of antenna: 4.2 m x 12.0 m (SIR-B was 2.1 m x 10.7 m). To reduce the space occupied in the cargo bay, the 12 meter length of the antenna is divided into 3 segments, each 4 meters long with two fold hinges. The 4.2 meter width of the folded antenna will span across the cargo bay from sill to sill. Figure 1 shows the SIR-C payload configuration. Although the L-Band and C-Band arrays both have the capability of electronically pointing the beam, a mechanical tilt mechanism has been included in the design of the antenna mount to provide a means of pointing the antenna in elevation without perturbing the Shuttle's attitude. This latter feature was deemed necessary to accommodate XSAR which has a fixed beam and in consideration of other earth viewing sensors which may be flying along with SIR-C.

IV. SYSTEM CAPABILITIES

SIR-C has been designed to meet the requirements and goals identified in the SIR-C Science Plan to the extent allowed by the present state of the art. The system's characteristics are presented in Table I. Aside from the conventional modes of operation in either single, dual or quad-polarization modes at either or both frequencies, the ability to steer the antenna beam electronically will permit collecting SAR data in several unconventional ways. These are listed below along with a brief description of each mode.

Squint Mode - In this mode, the antenna beam is electronically steered to a fixed azimuth angle other than broadside either forward or rearward relative to the line of flight.

Scan-SAR Mode - In this mode, the antenna beam is sequentially stepped in elevation (cross-track) over a set of up to four positions within one synthetic aperture in order to illuminate a wider strip and thus increase swath beyond the antenna elevation beam limit. The trade-off of course is a slight degradation in azimuth resolution in direct proportion to the increase in swath.

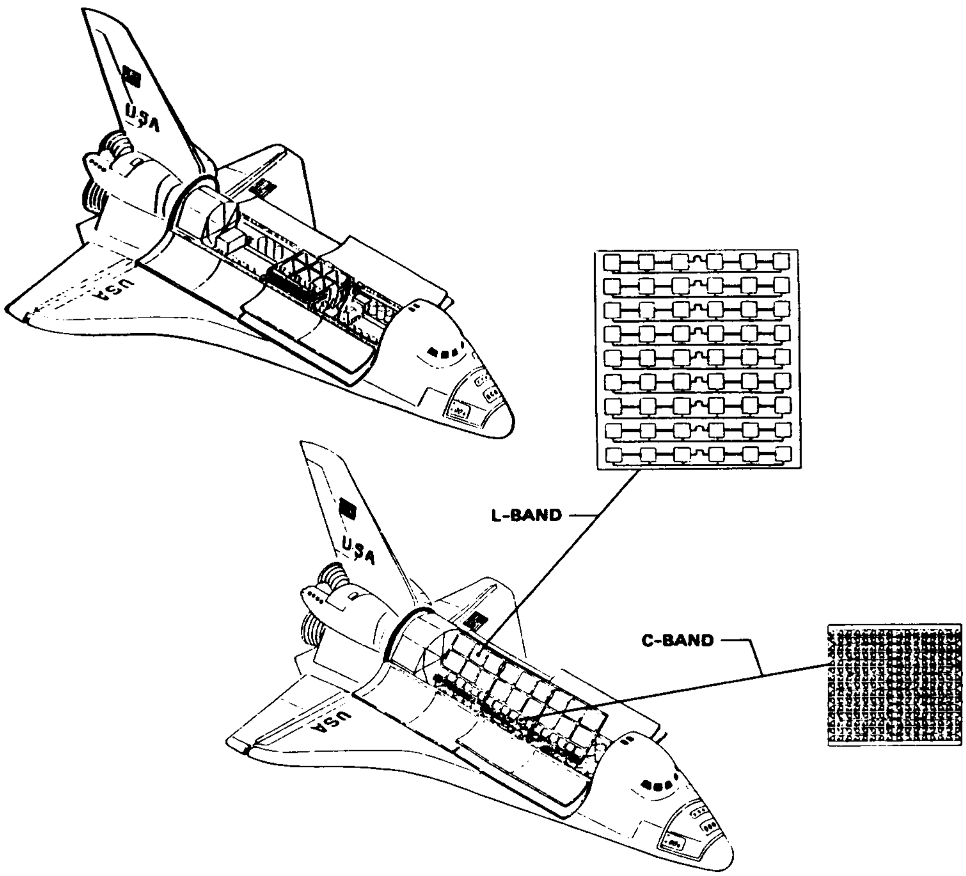

Fig. 1. SIR-C payload configuration: upper, stowed; lower, deployed

Extended Aperture Mode - This is a mode which uses electronic beam steering in azimuth to extend the time that a scene is kept in the antenna beam. This technique will increase the available number of azimuth looks which will improve image quality. Figure 2 depicts the various imaging modes for SIR-C.

V. ANTENNA SUBSYSTEM

The SIR-C antenna aperture has been partitioned so as to accommodate the three frequencies L-, C-, and X-Band with similar elevation beamwidths. The ratios of the antenna widths are thus scaled to the ratio of the frequencies. The array lengths for all three frequencies are identical: 12 meters. Since the ultimate single look resolution for a SAR is equal to 1/2 the antenna length, each of the SARs will have the same azimuth resolution: 6 meters.

Table I. SIR-C instrument characteristics

Parameter	SIR-C L-band	SIR-C C-band
Transmitter power	3600 W peak+	2235 W peak+
Modulation	Linear FM pulse	Linear FM Pulse
Pulse width	33 μs	33 μs
RF center frequency	1248, 1254 MH	5298, 5304 MHz
Bandwidth	10, 20 MHz	10, 20 MHz
Rcvr noise temperature	366 K+	417 K+
Rcvr gain	56 to 101 dB+	56 to 101 dB+
Antenna size	12.08 x 2.92 m	12.08 x 0.75 m
Polarization	HH, HV, VV, VH	HH, HV, VV, VH
Antenna gain*	37 dBi	43.2 dBi
Mechanical antenna pointing to nadir	15 to 60°	15 to 60°
Electronic-beam steering	±23° El, ±2° Az	±23° El, ±2° Az
Recording	Digital	Digital
Number of high-rate record channels	4	4
Bit rate/channel	45 Mbits/s	45 Mbits/s
Data processing	Digital	Digital
Range resolution	8.6 to 58 m	8.6 to 58 m
Azimuth resolution	25 m	25 m
Number of azimuth looks	4	4

*Referenced to antenna port at sensor electronics.
+Referenced to antenna element feedthrough points.

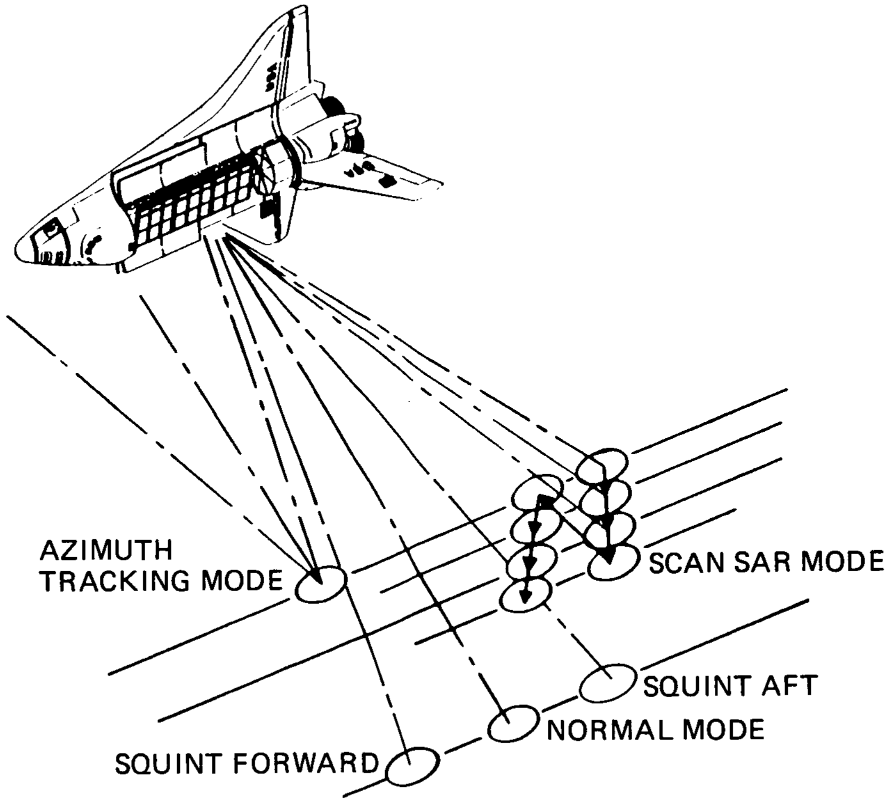

Fig. 2. SIR-C imaging modes

The L- and C-Band arrays are of microstrip design with square radiating elements with orthogonal feed points for H and V polarization. The isolation between the H and V ports of the array will be 20 dB or better. Figure 3 shows a layout of a typical L-Band and C-Band dual polarized subarray. Figure 4 shows the partitioning of the antenna area in panels. For ease of manufacturing, all L-Band panels are identical and interchangeable. The same is true for C-Band.

The array geometry chosen for SIR-C results in a uniformly illuminated aperture in azimuth. In elevation, a staircase approximation of cosine squared weighting is used. This is accomplished with use of power dividers as shown in Figure 5. The predicted patterns are shown in Figure 6 and Figure 7. Several advantages result from configuring SIR-C as a distributed SAR. First is the elimination of the feed losses between the transmitter/receiver and the radiating elements. This pays off both in a more efficient use of transmitter power and an increase in sensitivity by reducing the losses in front of the low noise amplifiers. The noise temperature predicted for SIR-C is 366 K for L-Band and 417 K for C-Band. The array gains are 37 dBi and 43.2 dBi, respectively. These correspond to G/T (gain over temperature) figures of 11.37 dB and 17 dB and EIRP (Effective Isotropic Radiated Power) of 72.5 dBw for L-Band and 76.3 dBw for C-Band. These factors play an important role in acquiring cross-polarized data. Cross-polarized returns are typically 1 dB weaker than like-polarized returns. To achieve the same performance, a conventional SAR would need about 10 times the transmitter power of a distributed SAR.

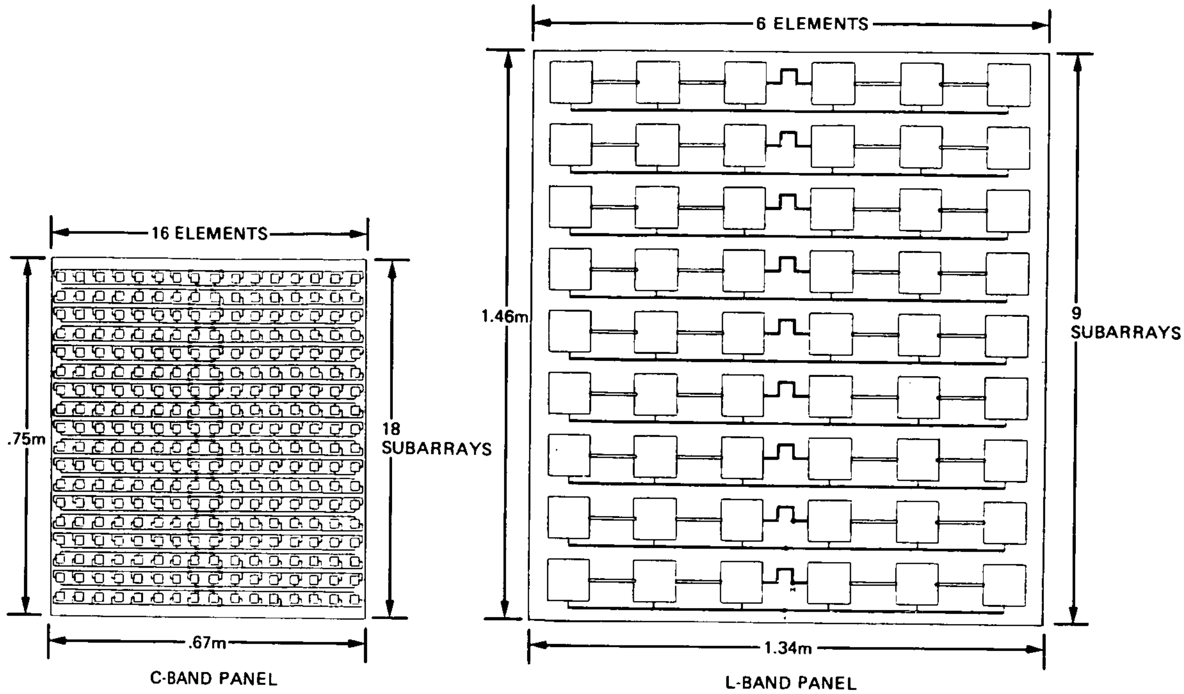

Fig. 3. C-Band and L-Band panel geometry

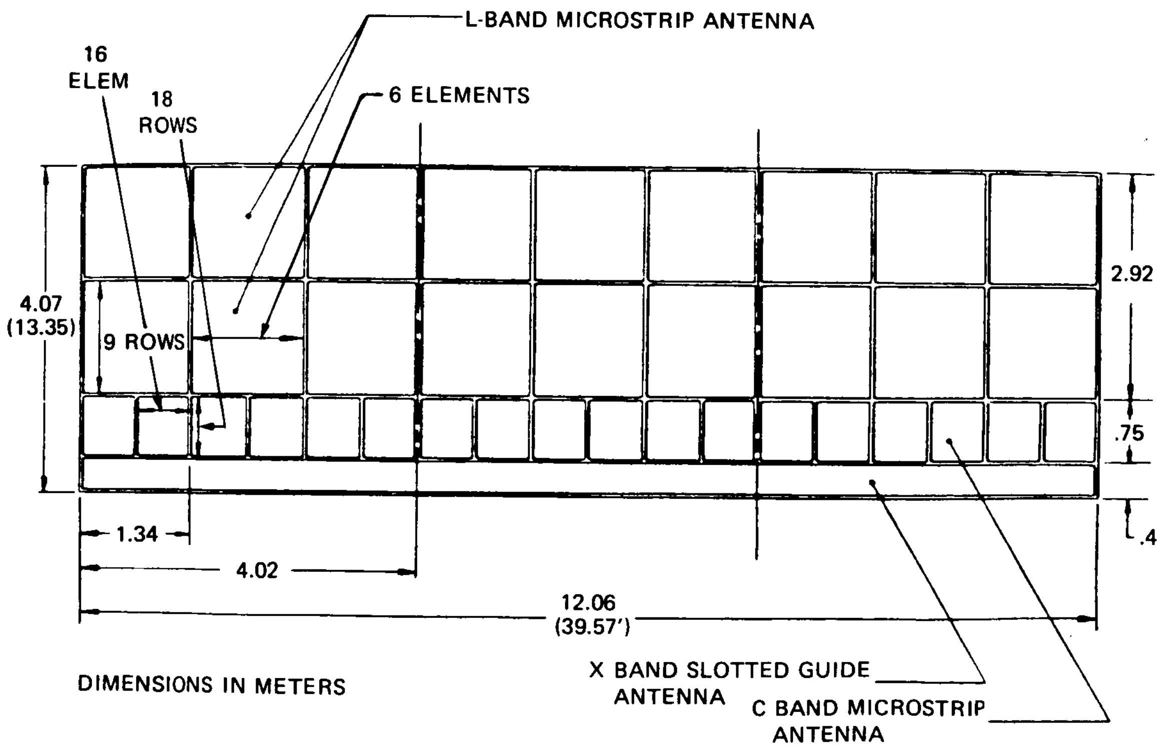

Fig. 4. SIR-C aperture partitioning

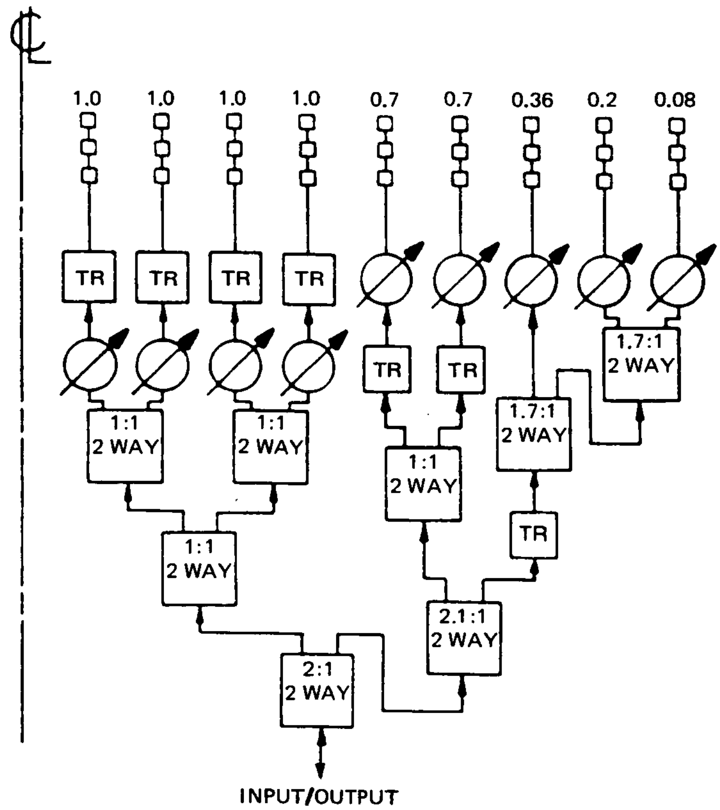

Fig. 5. Elevation aperture weighting

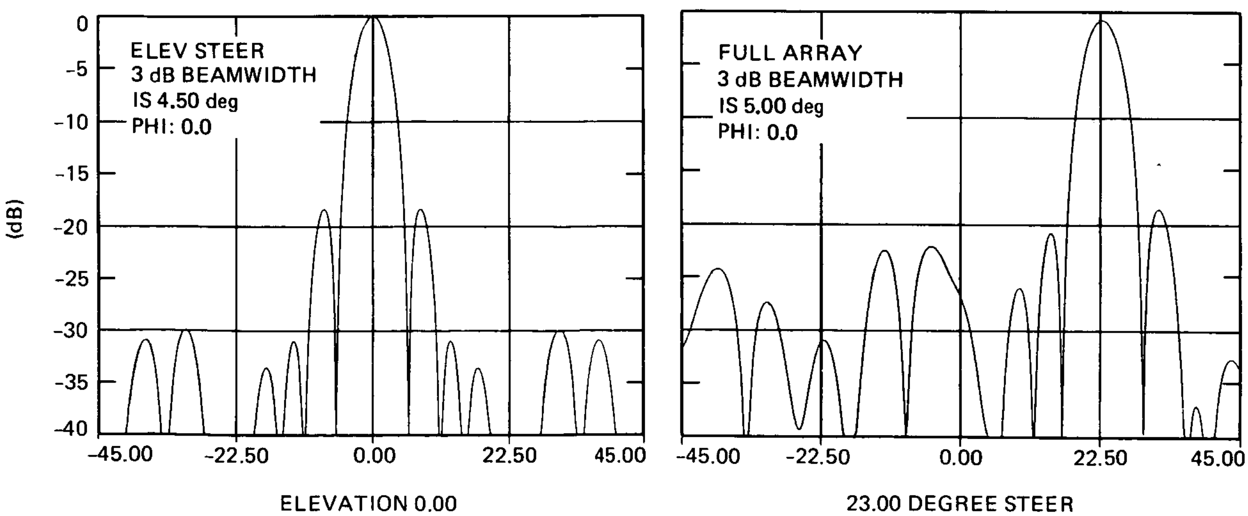

Fig. 6. Typical L- and C-Band weighted pattern in elevation: left, broadside; right, 23° steering

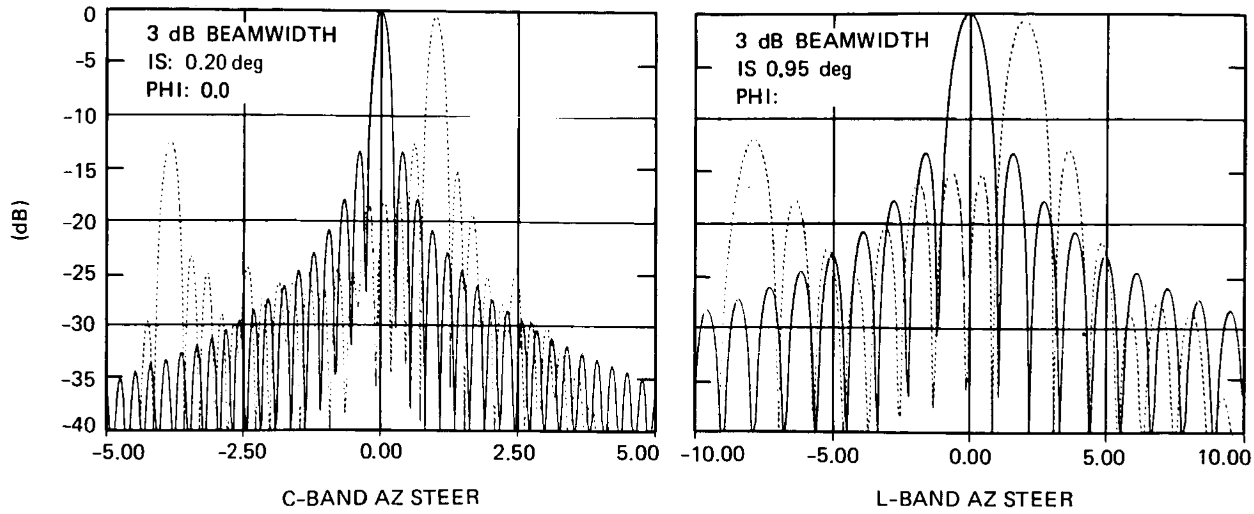

Fig. 7. Typical azimuth broadside and steered patterns: left, C-Band; right, L-Band

Another advantage of a distributed SAR is its inherent tolerance to random failures in the T/R modules. Loss of 10% of the T/R modules only degrades the performance by less than 1 dB.

Finally, the ability to steer the antenna beam electronically increases the flexibility of operating in a variety of unconventional modes previously described. In addition, electronic control of the phase of the antenna elements allows control of the antenna elevation beamwidth to optimize the swath illumination over the full range of look angles from 15 to 60 degrees. Figure 8 shows a set of beamwidths achievable with phase control.

VI. RF ELECTRONICS SUBSYSTEM

The RF electronics subsystem for the L- and C-Band SAR are based on a common design. The exciter chain produces a linear FM pulse. SIR-C will have two selectable chirp bandwidths: 10 MHz and 20 MHz with corresponding range resolutions of 15 and 7.5 meters. The chirp signals will be amplified to a level sufficient to drive the T/R modules on the antenna. There are four receiver channels designated L-Horizontal, L-Vertical, C-Horizontal, and C-Vertical. Again, common designs are shared by both frequencies with appropriate up and down converters. A functional diagram of the SIR-C Flight Instrument is shown in Figure 9.

VII. DIGITAL ELECTRONICS SUBSYSTEM

The SIR-C digital electronics data subsystem is an upgraded version of the SIR-B design with two significant improvements. First is the upgrading of the ADC from 6 bits to 8 bits. Second is the incorporation of a Block Floating Point Quantizer (BFPQ). The increase from 6 to 8 bits in the ADC results in a 12 dB improvement in dynamic range.

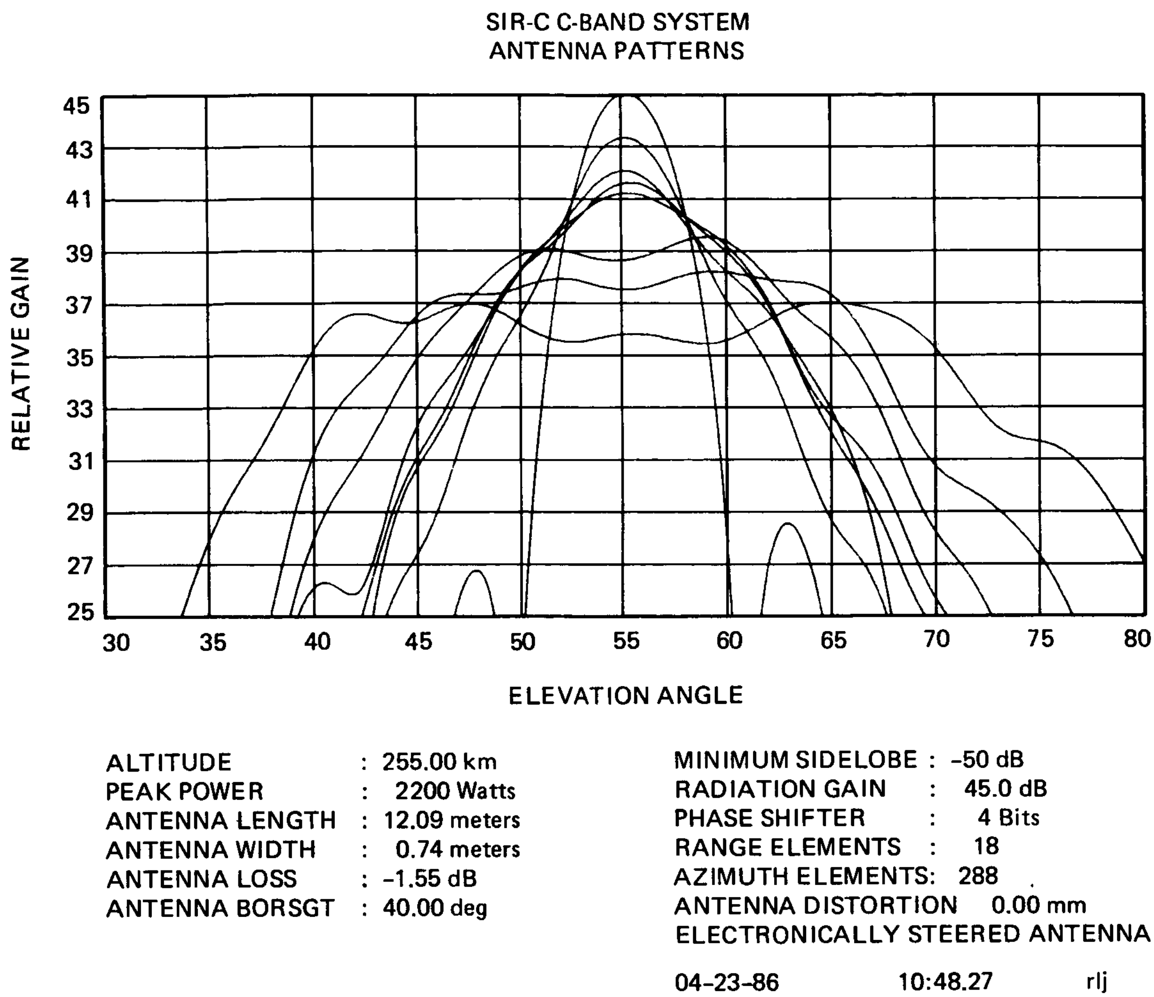

Fig. 8. Elevation beam broadening by phase control

Dynamic Range can be approximated by: [6(N-1)+3] dB where N = the number of ADC quantization bits.

The dynamic ranges for a 6 and 8 bit ADC are thus:

6 (6-1) + 3 = 33 dB for N = 6

6 (8-1) + 3 = 45 dB for N = 8

For a data rate limited system (limited by the present shuttle Ku-Band link to 50 MBPS and on-board data recorders to 50 MBPS per channel), an increase in quantization bits from 6 to 8 would result in a 33% reduction in image swath width.

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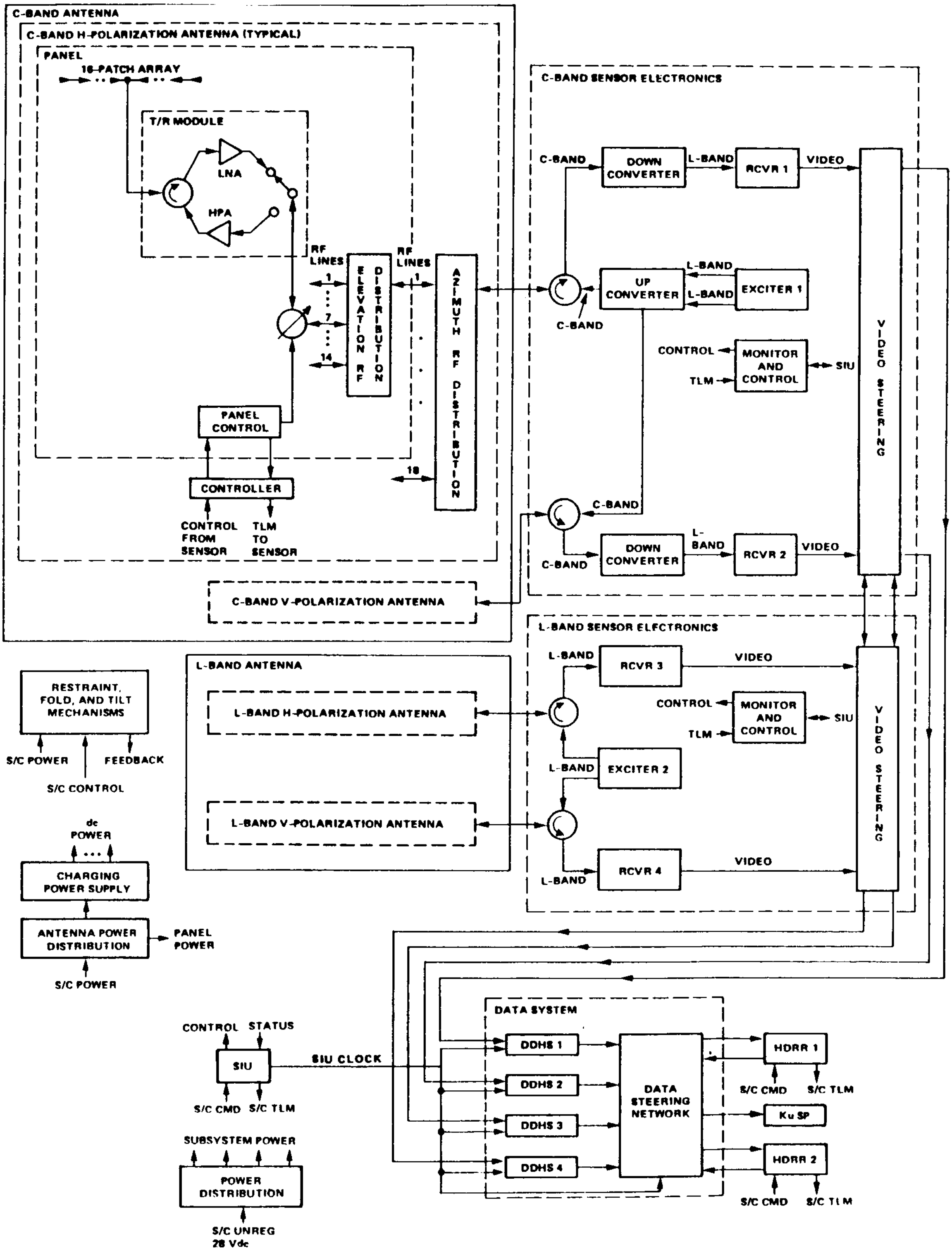

Fig. 9. SIR-C Flight Instrument functional diagram

The BFPQ overcomes this swath width penalty with a data compression scheme which acts as an adaptive scaler. The digitized 8 bits are statistically compared to a predetermined set of thresholds in memory and only the most significant bits along with the appropriate multiplier are sent to the output formatter. In SIR-C, the format chosen is 8 bits reduced to 4 significant bits plus multiplier. An 8 bit error protected code for the multiplier is included in each data block and represents the scaling factor to be applied to that particular block. Data block lengths of 256 to 2048 have been simulated with very good results. The multiplier overhead is thus very low. What results is an output data rate equivalent to a 4 bit system which approaches the dynamic range of an 8 bit system without sacrificing swath. J. Curlander[3] and Q. Nguyen[4] have described this scheme in detail in the reference. Figure 10 shows a functional diagram of an 8/4 BFPQ. Figure 11 shows a comparison between the signal to distortion noise ratios of an 8 bit uniform quantizer, a four bit uniform quantizer and an 8 to 4 bit BFPQ. The 8/4 BFPQ has a broad region of nearly constant noise level with a 20 dB SNR while retaining the intrinsic wide dynamic range of the 8 bit ADC. This results in a higher degree of tolerance to system gain setting errors or large variations in the backscatter intensity in the image scene. The SIR-C Digital Data Subsystem will provide the investigator a commandable option of formatting the data in 8 bits uniform, 4 bits uniform or 8/4 BFPQ.

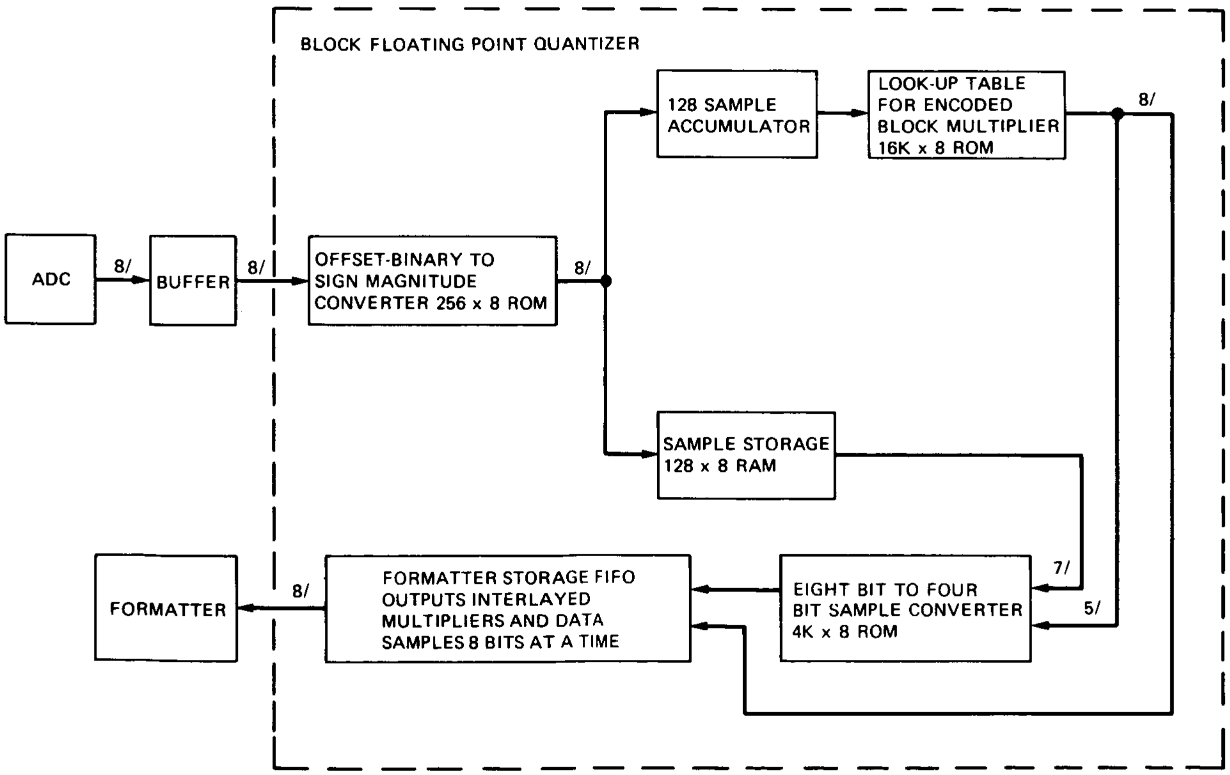

Fig. 10. Functional diagram 8 to 4 Bit Block Floating Point Quantizer

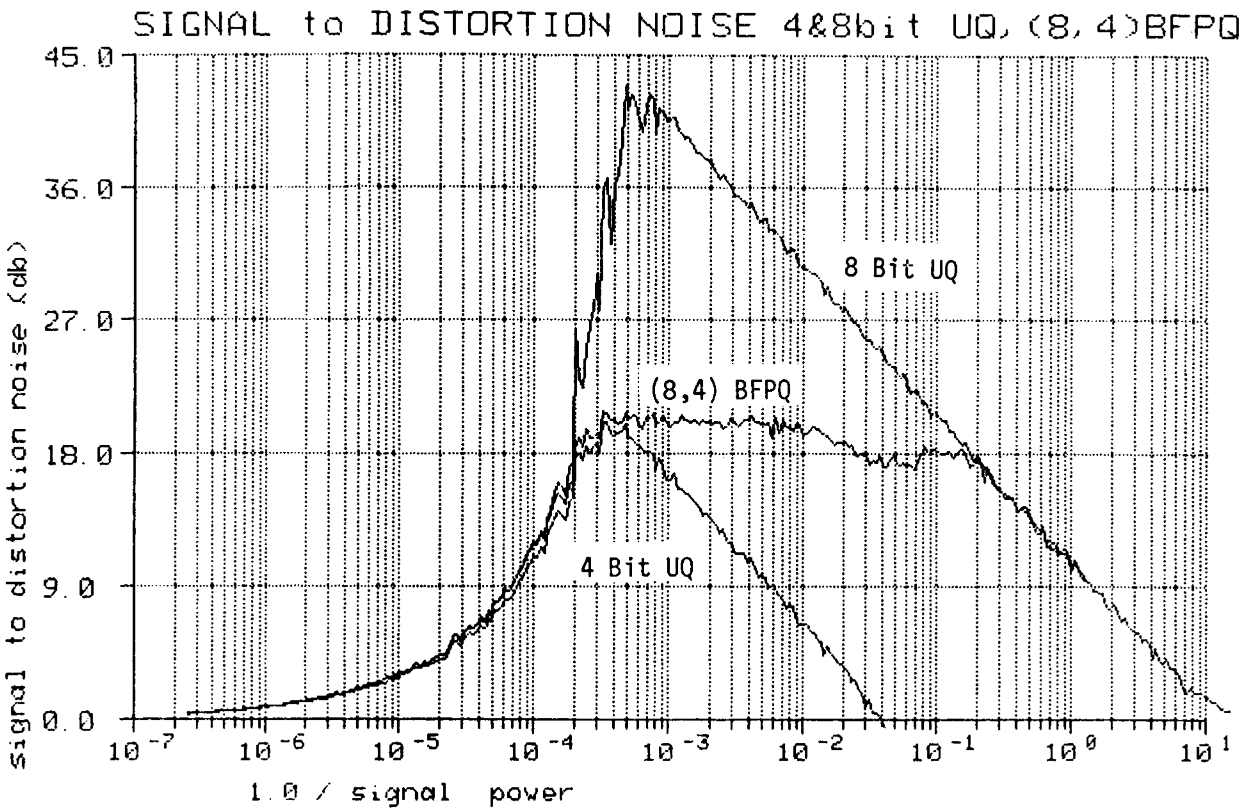

Fig. 11. Comparison between the Signal to Distortion Noise Ratio of an 8 Bit Uniform Quantizer, a 4 Bit Uniform Quantizer, and an 8 to 4 Bit Block Floating Point Quantizer. Note the broad region of nearly constant Signal to Distortion Noise Ratio exhibited by the 8/4 BFPQ over a wide range of signal power.

Four Digital Data Handling Assemblies (DDHA) will digitize and format the receiver outputs at a rate of 45 Megabits per second per channel. The four serial data streams will be routed to a Data Steering Network (DSN) which will then deliver the data to High Data Rate Recorders. The DSN can selectively route any one of the serial data streams to the Ku-Band link for real-time transmission via TDRS to a ground station. The Data Recorders for SIR-C will be located in the crew cabin in order to give the orbiter crew access to the recorders for tape changing. A functional diagram of the SIR-C Digital Electronics Subsystem is shown in Figure 12.

VIII. SHUTTLE INTERFACES

SIR-C has five major interfaces with the Space Shuttle. These are: mechanical, thermal, power, command, and telemetry. The mechanical interfaces are dictated by the physical mounting of the payload in the cargo bay. The thermal interfaces involve an active coolant loop to dissipate the heat produced by the electronics assemblies. D.C. power will be supplied primarily by the orbiter 28 volt bus via the Standard Interface Panels (SIP). Ground command will be through the Payload Signal Processor (PSP) and telemetry will be monitored on the ground via the Payload Data Interleaver (PDI). All of the above are part of the standard accommodations available to payloads which fly in the Space Shuttle. Figure 13 shows the electrical interfaces between SIR-C and the orbiter.

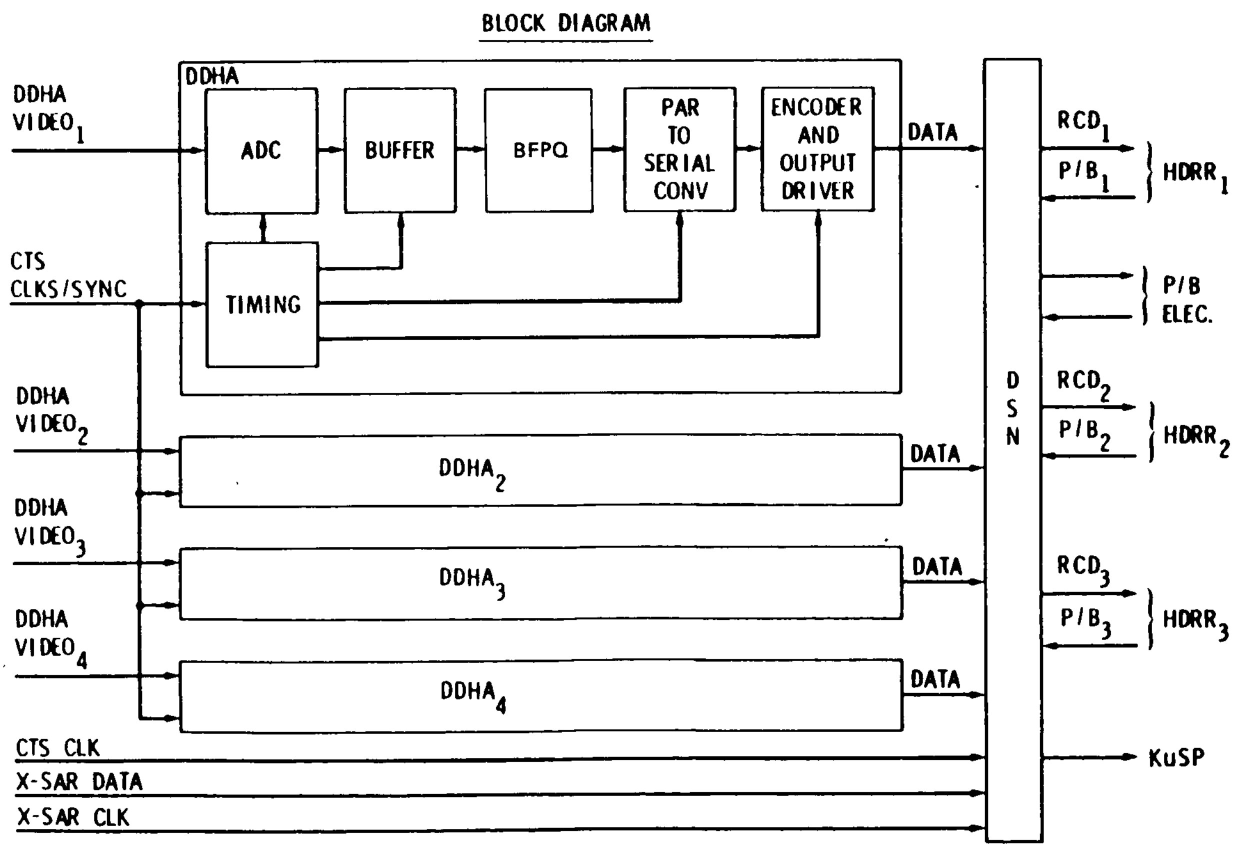

Fig. 12. SIR-C Digital Electronics Subsystem functional diagram

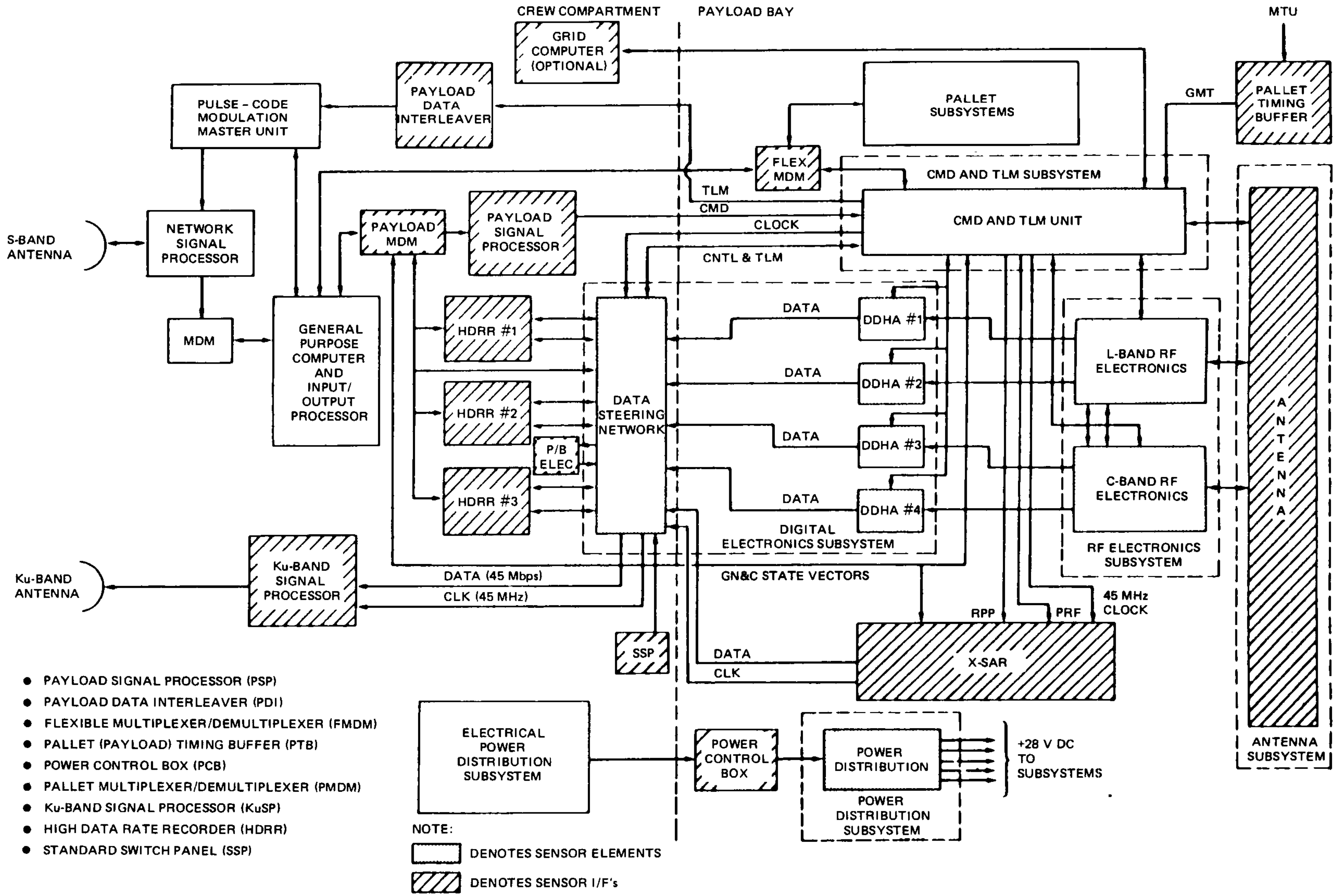

Fig. 13. SIR-C/Orbiter electrical interfaces

IX. SUMMARY

SIR-C represents a significant advance in spaceborne SAR system capabilities. The design approach is responsive to the requirements identified by the Science Steering Committee. The multimode features of the sensor will provide science investigators with new dimensions in acquiring and interpreting scientific data. The flexibility of the SIR-C design will provide a core instrument which will meet the needs of SAR data users into the 1990's and serve as a foundation for ultimate incorporation into the EOS platform.

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