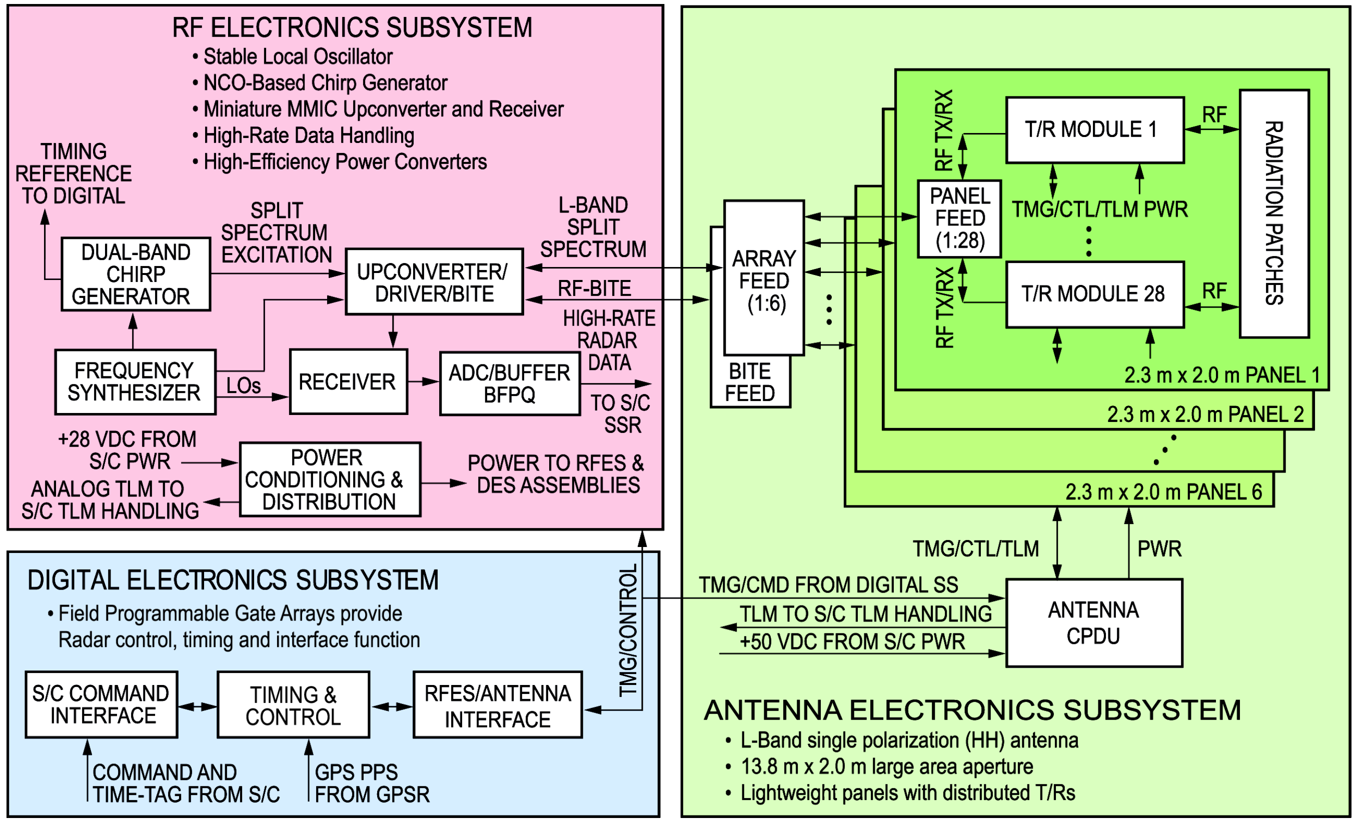


Figure F1-1. Block diagram of the ECHO Radar Instrument. The RFES, DES, and antenna CPDU are block redundant. The antenna panels degrade gracefully.

Table F1-3: System performance for ECHO beams.

Parameter	Near	Mid	Far	Requirement
Swath Width (km)	128	121	96	340 total
PRF (Hz)	1352.6	1263.1	1180.4	-
Boresight Ang (deg)	22.15	29.29	34.63	-
Min Look Ang (deg)	18.00	25.89	32.32	-
Max Look Ang (deg)	26.02	32.42	36.78	-
Range to midswath (km)	829	888	952	-
Start Coverage (km)	249	374	493	-
Stop Coverage (km)	377	495	589	-
Ground-Range Resolution (m)	20.5	15.8	13.6	35
Azimuth Resolution (m) (4-look)	27.6	29.6	31.7	35
Minimum σ^o_{NE} (dB)	-40.2	-38.2	-36.6	-24
Maximum σ^o_{NE} (dB)	-30.5	-31.8	-33.4	-24
Worst Azimuth Ambiguity (dB)	-23.7	-22.0	-20.0	-20
Worst Range Ambiguity (dB)	-38.0	-25.6	-25.6	-25
Ave. Radiated Power (W)	128.0	119.5	111.7	-
DC Power (W) †	199			††
fData Rate (Mbps)	130	144	126	<175

† Avg DC power value assuming 8.5 minutes of data collection per orbit, including 30% contingency
†† See Table G-5 for S/C capability

Table F1-1: Science Traceability Matrix (L-3).

Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirements	Mission Functional Requirements
Understand strain changes leading to and following major earthquakes.	Globally distributed measurement of vector deformation rates to 2 mm yr^{-1} (single component accuracy), which implies deformation accuracy of 5-10 mm at 35-100 m resolution over a 5-year mission.	**Accuracy** • L-band Radar for high coherence. • Split-Spectrum for ionospheric correction. • Noise equivalent so better than -24 dB for radar-dark regions. **Accessibility** • 30 minutes of onboard storage for global accessibility within ground-station constraints. • Electronic beam steering in range **Calibration** • GPS for baseline knowledge and for orbit control. **Mission Duration** • High reliability for 5-year mission.	**Vector Measurement** • Ability to image left and right for vector measurements. **Accuracy & Interferometric Viability** • Orbit maintenance to repeat-tracks to within 250 m for short interferometric baselines (high coherence). • Precise orbit determination. • Instrument pointing to better than 0.05 deg. 1σ. • Frequent observations over a site to average out tropospheric and other noise sources. **Mission Duration** • Sufficient expendables for a 5-year mission duration. • High reliability S/C sufficient to enable 5-year mission duration.
Characterize three-dimensional magma movements to predict volcanic eruptions.	Globally distributed monthly measurements of deformation with 5-10 mm accuracy. Frequent measurements during eruptions.	As above with no additional drivers	As above plus **Accessibility** • 8-day repeat orbit for frequent monitoring of eruptions.
Assess the impact of ice sheet and glacier system dynamics on sea level rise and characterize temporal variability.	Ability to map vector ice motion for Greenland and Antarctica to 1 m yr^{-1} (single component accuracy). 5-year mission to study temporal variability.	As above with no additional drivers	As above plus **Accuracy & Interferometric Viability** • 8-day repeat to avoid temporal decorrelation & aliasing of fast motion. **Accessibility** • Polar orbit & left/right looking to image to both poles.

Table F1-2: Technical maturity matrix (L-2a). All elements of the ECHO radar electronics have direct heritage from SIR-C/SRTM (TRL 9).

Hardware Item	Item Description	Maturity	Maturity Rationale
StaLO/Frequency Synthesizer	Crystal oscillator & PLL frequency multipliers	TRL 7	SIR-C, ARTP
Chirp Generator	NCO-based DDS	TRL 7	SIR-C, ARTP
Upconverter/Driver	MMIC-based upconverter and SSPA	TRL 7	SIR-C, ARTP
Receiver	MMIC-based receiver	TRL 7	SIR-C, ARTP
ADC/Buffer/BFPQ/ Formatter	8-bit ADC/buffer with 8:4 BFPQ	TRL 7	SIR-C, ARTP
Radar Control & Timing	FPGA-based	TRL 7	SIR-C, ARTP
T/R Modules	MMIC-based transmit and receive amplifiers	TRL 7	SIR-C, SRTM
Antenna Panels	Microstrip phased array on honeycomb	TRL 9	SeaSat, SIR-A/B/C, SRTM
Antenna Control Electronics	Timing, serial command & telemetry bus	TRL 7	SIR-C, SRTM
Antenna Structure	Rigid, deep truss, composite tube with titanium end fitting, low CTE truss elements & thermal tape, bond joints, DOF fittings, snubber system	TRL 7	SeaSat, RadarSat-I/II
Deployment Mechanism	Pyrotechnic latch release, bearing design & lubrication, preload mechanisms, drive motor assembly, synchronization linkage, cable/ spring powered elbow mechanism, outboard panel hinge latch	TRL 9	RadarSat

Table F2-1: ECHO instrument information.

Item	Value/Summary	Units
Sensor type	SAR	N/A
Number of instruments (including redundant units and spares)	1 instrument with built-in redundancy	N/A
Number of channels	1	N/A
Size, meters x meters x meters	13.8 x 2.0 x 0.05	m^3
Mass with contingency, kg and %	569 kg (28%)	kg, %
Power with contingency (nominal, peak, duty cycle, standby), watts and %	Nominal 198 W (30%) @ 8.5% Duty Cycle Peak 1793 W (30%) Standby 50 W (30%)	W, %
Data rate with contingency, kbps and %	175 Mbps (30%) (avg. 8.5 minutes/ orbit)	Mbps, %
Mechanical, electrical, and thermal layouts	(see Figs, technical section)	N/A
Optical layout including field of view (if appropriate)	(see Figs, technical section)	N/A
Ground and on-orbit calibration scheme	Geodetic ground control	N/A
Pointing requirements (knowledge, control, and stability), degrees	Knowledge 0.05 deg Control: 0.05 deg Stability: 0.05/10 s	degrees
Command and control requirements	1 radar command per data take	N/A
Flight software architecture and thousands of lines of software code used. Include new and reuse/retest/ redesigned code., KSLOC. (Use of existing or commercial off the shelf or hybrid software shall be identified)	Instrument on/off sequencing runs on S/C control computer. ~100 lines of code	
Definition of instrument operational modes over all science phases with power and data requirements, watts and kbps	Standby, 50 W, 20 kbs Datatake, 1793 W, 175 Mbps	

Table F2-2: Spacecraft bus features that help simplify the radar design.

Spacecraft bus feature	Impact on radar design
Accurate positioning	Allows radar commands to be uploaded well in advance of data-take.
Accurate, stable pointing/ yaw steering	Removes uncertainty in antenna pointing. Simplifies radar timing and control.
Powerful CPU	Removes need for radar CPU.
Solid-state recorder (SSR)	Simplifies buffering scheme/interface for science data stream.
Telemetry handling	Removes need for an additional dedicated radar telemetry processor unit.
GPS one-second time-ticks	Provides accurate timing reference for radar system on/off configuration.

Table F2-3: Radar electronics and antenna potential problems, associated risks, and mitigation plans.

Risk Area	Explanation	Likelihood	Consequence	Mitigation Plan
RFES/DES	Unit failure	L	L	Block redundancy for each subsystem
RFES/DES	Schedule slip	M	L/M	Request for pre-phase B risk reduction phase; schedule reserve
T/R modules	T/R module components difficult to find	M	L	Evaluate part availability early to facilitate mods to SIR-C designs
T/R modules, RFES Drivers	Multipaction enabled by HPA output power	L	H	Evaluate all high-power transmission lines and junctions, modify connectors as on SIR-C
Structure	Structure development schedule lags	L	M	Monitor this major subcontract closely to uncover problems ASAP
T/R module	T/R development schedule lags	L	M	Monitor this major subcontract closely to uncover problems ASAP
Panel	Panel flatness degrades due to large panel size	L	L	Construct panel as symmetrically as practical to minimize thermal distortions
Antenna Structure	Structure does not deploy	L	H	Pre-launch test of proven deployment system, redundant pyrotechnic cutters

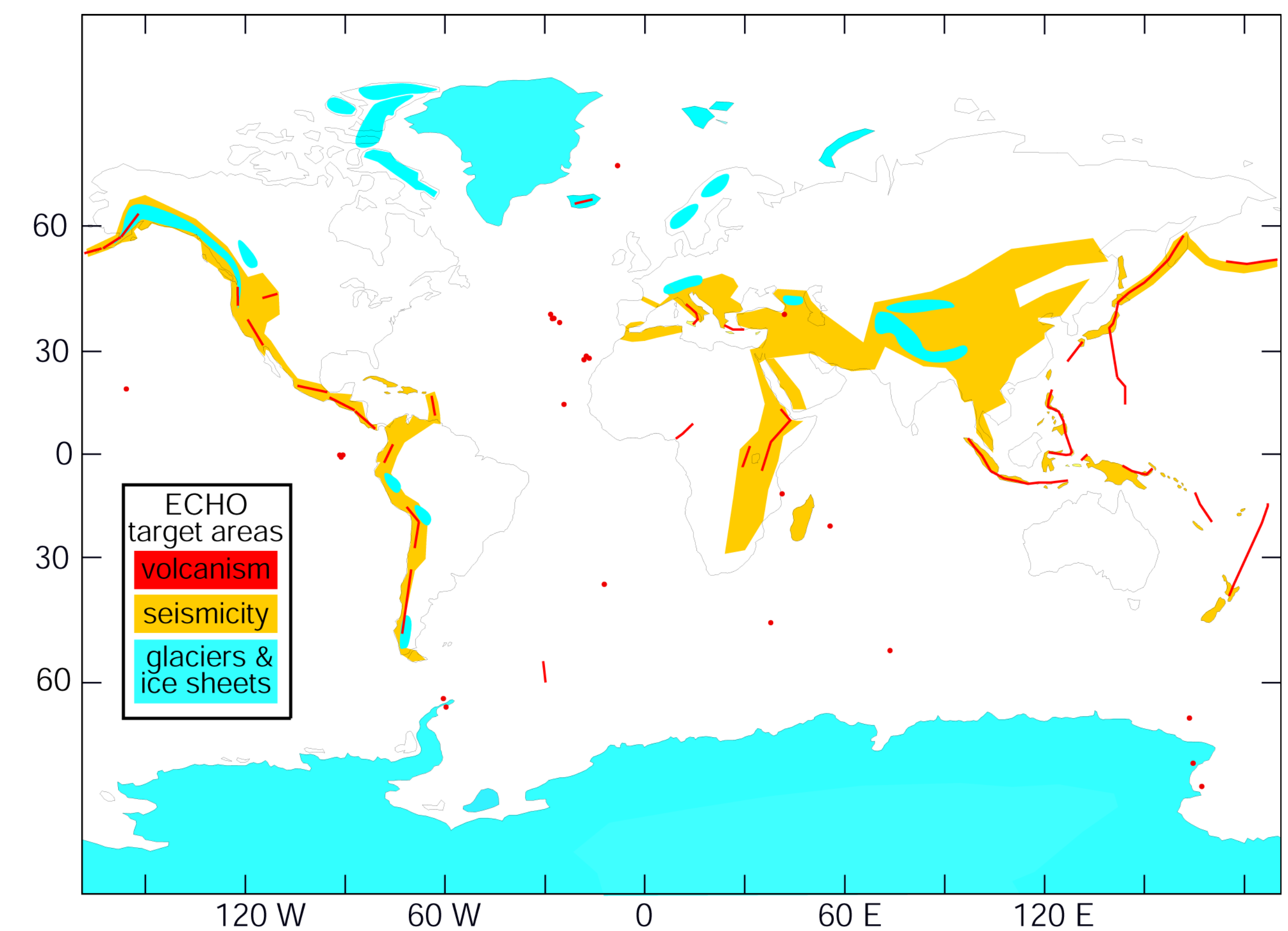


Figure F2-1. ECHO coverage areas for seismic, volcanic, and ice sheet objectives. Data for other natural hazards research can be collected worldwide.

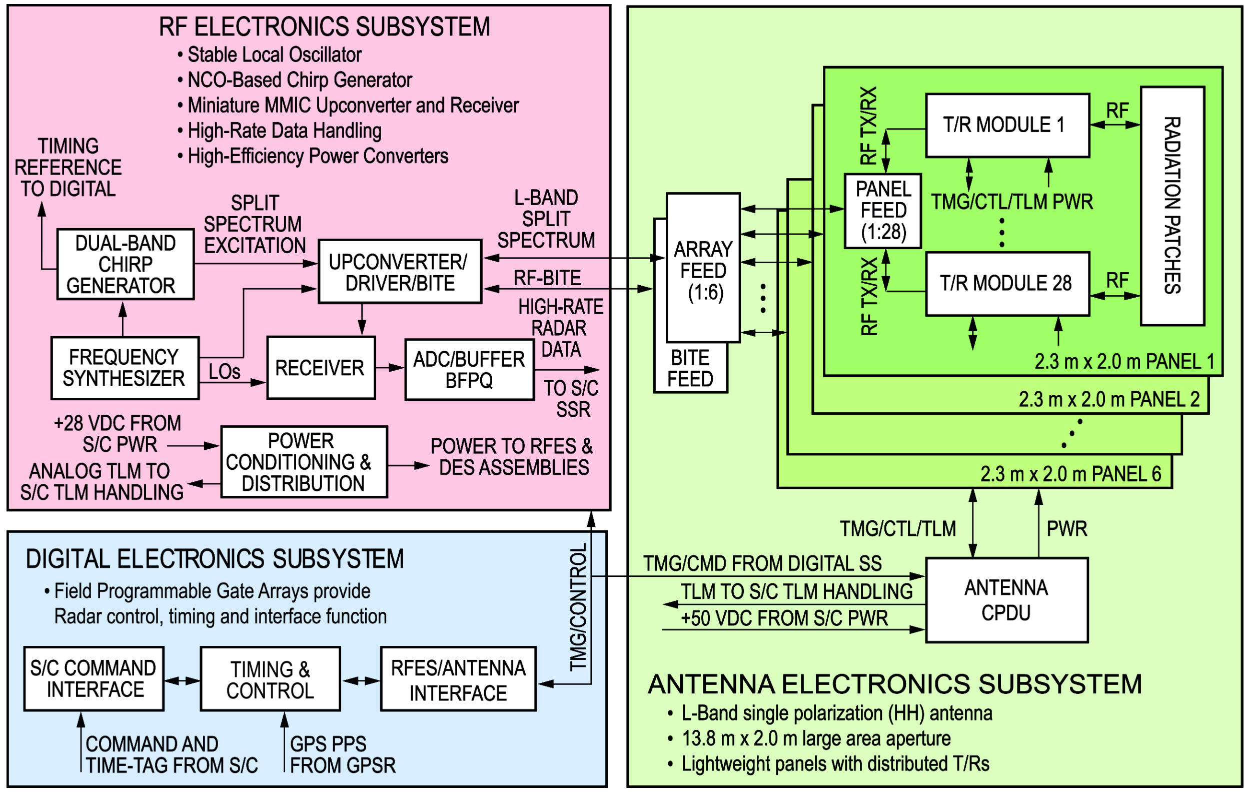


Figure G1-1. Block diagram of the ECHO Radar Instrument. The RFES, DES, and antenna CPDU are block redundant. The antenna panels degrade gracefully.

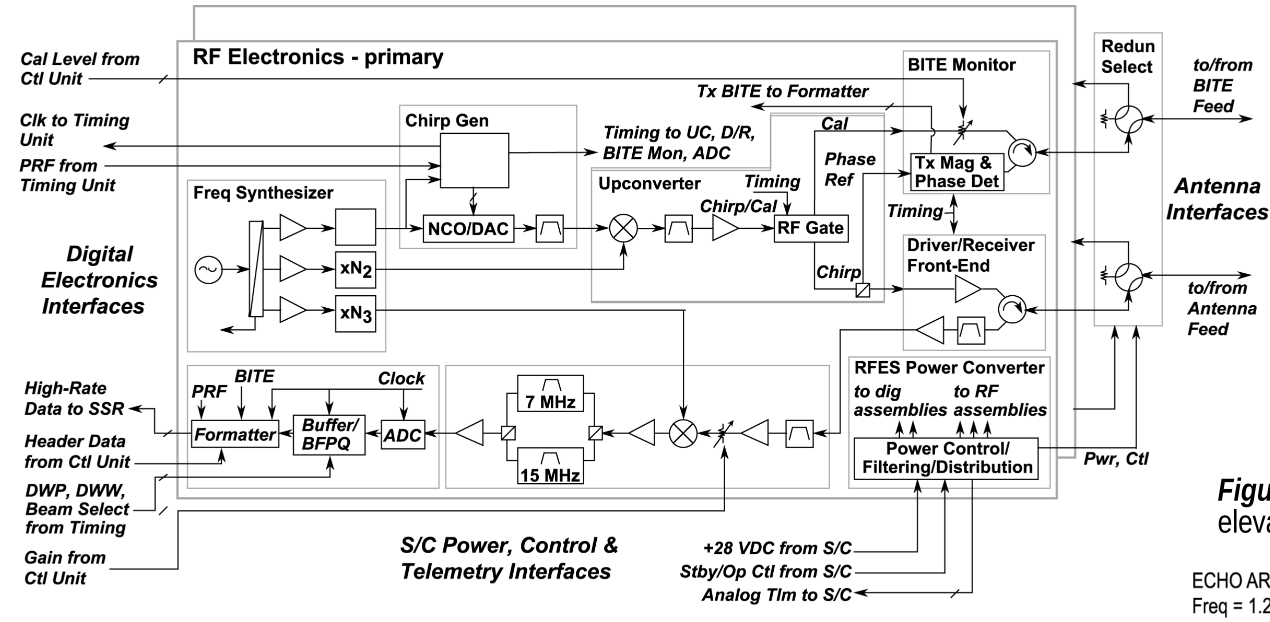


Figure G1-2. Block diagram of the Radar RF Electronics Subsystem. Gray boxes show the 8 RFES subassemblies that are replicated for the Primary and Redundant sides, and the Redundancy Selector subassembly.

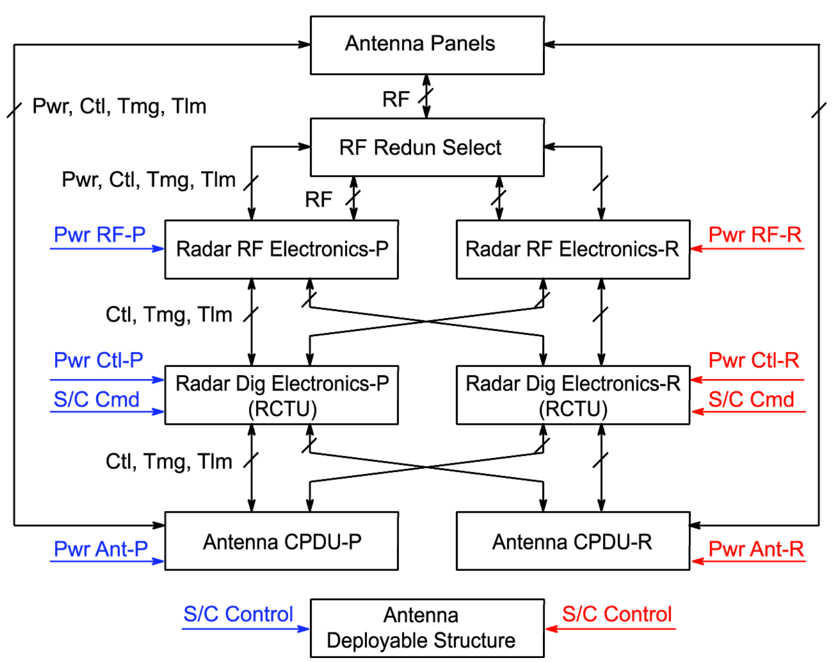


Figure G1-3. ECHO Instrument Redundancy. Redundancy cross-strapping allows for independent selection of primary or redundant RF, Control, and Antenna Interface subsystems so that multiple failures can be tolerated.

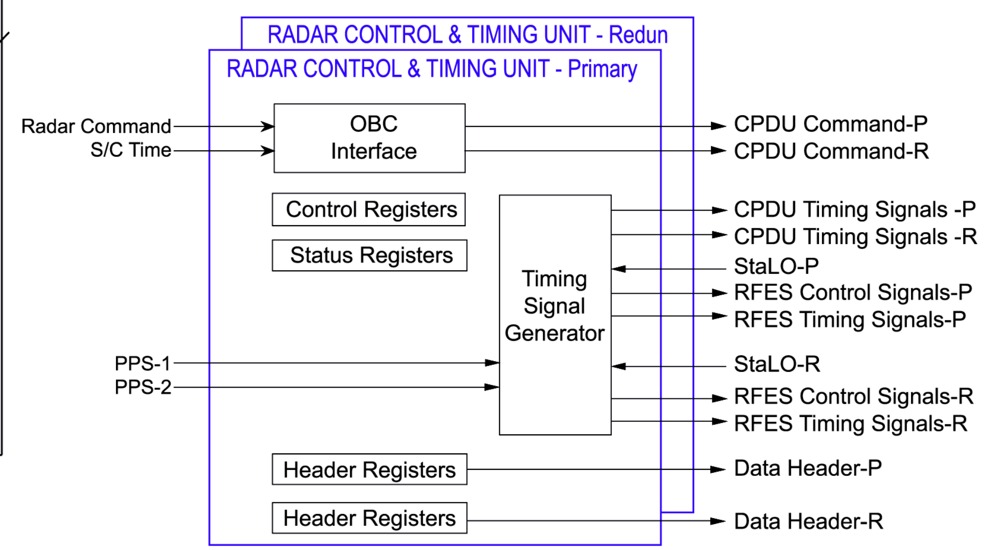


Figure G1-4. Block diagram of the DES RCTU.

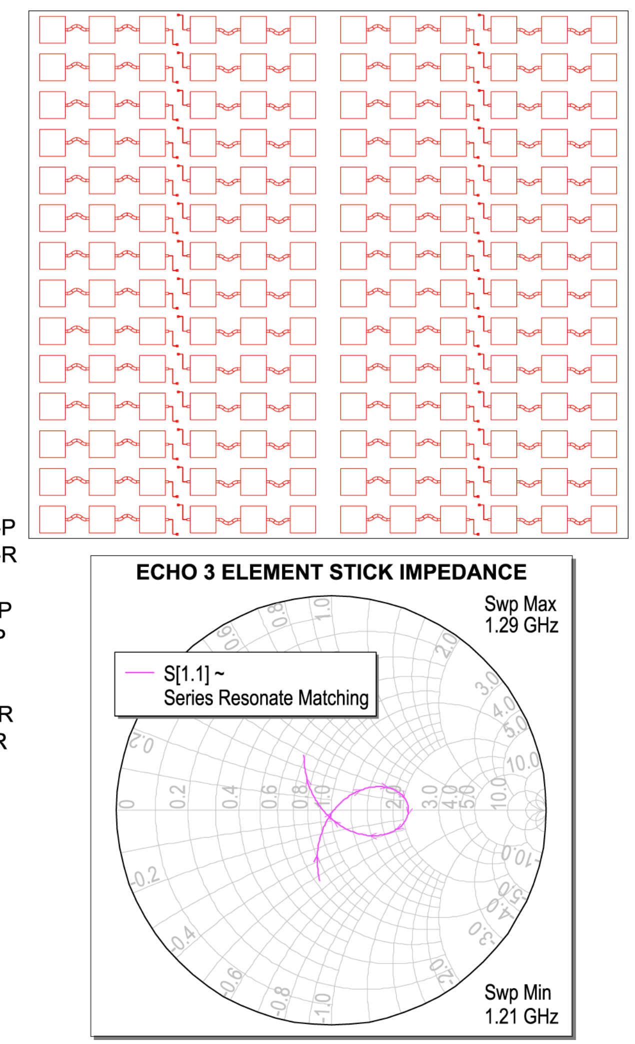
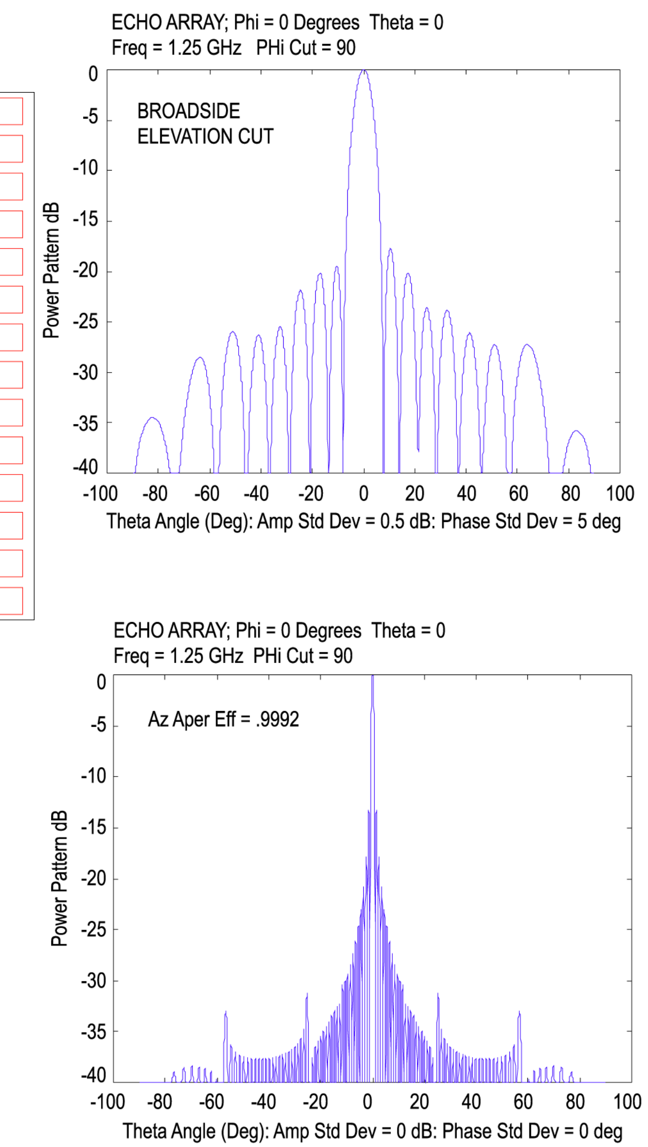


Figure G1-6. Optimized ECHO Antenna Panel is 2.296 m wide × 2.0 m high. Element Stick Input Impedance shows a good match over the radar 80 MHz passband.

Figure G1-5. ECHO Radar Antenna elevation and azimuth one way pattern.



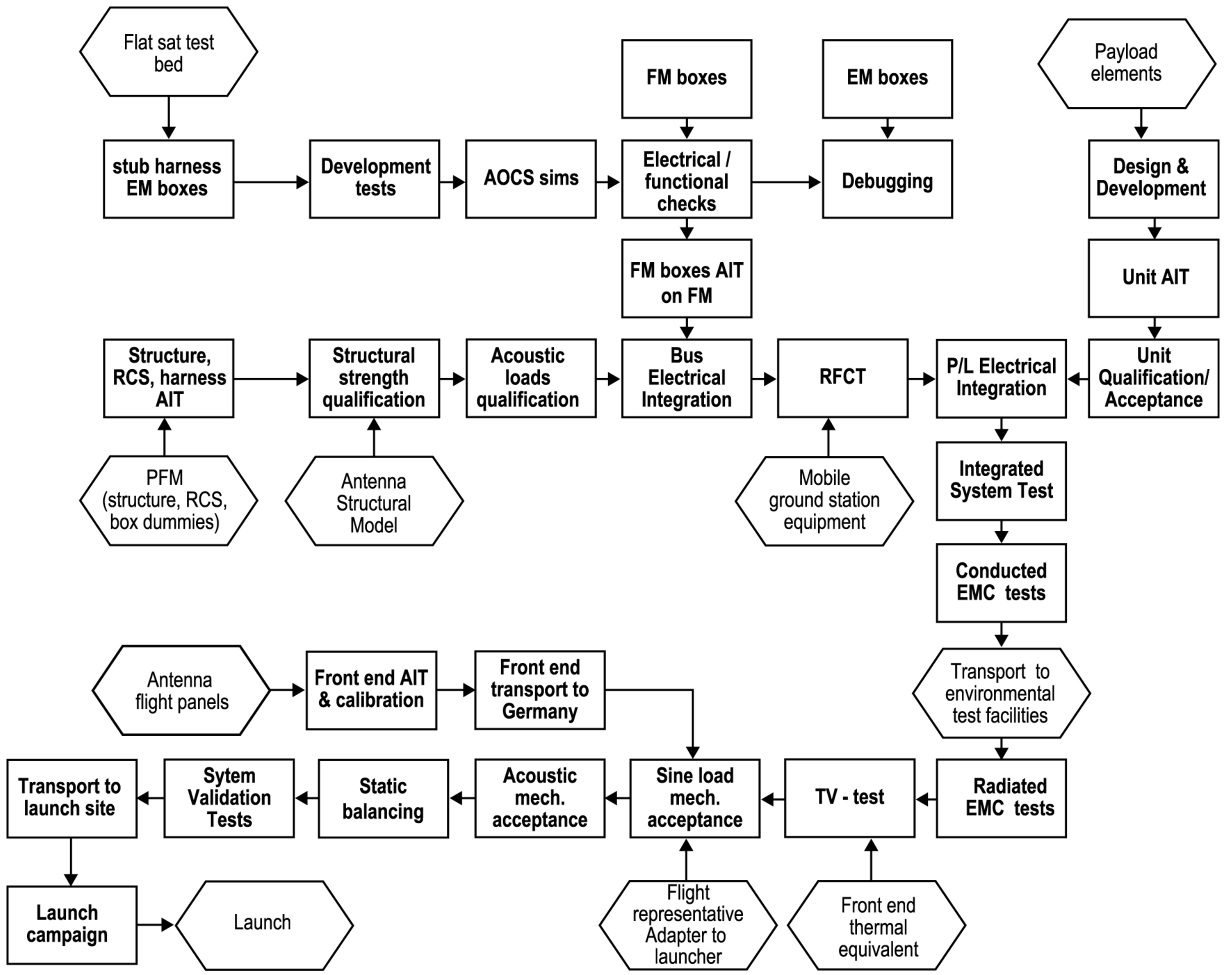


Figure G2-1. Spacecraft Integration and Test Flow.

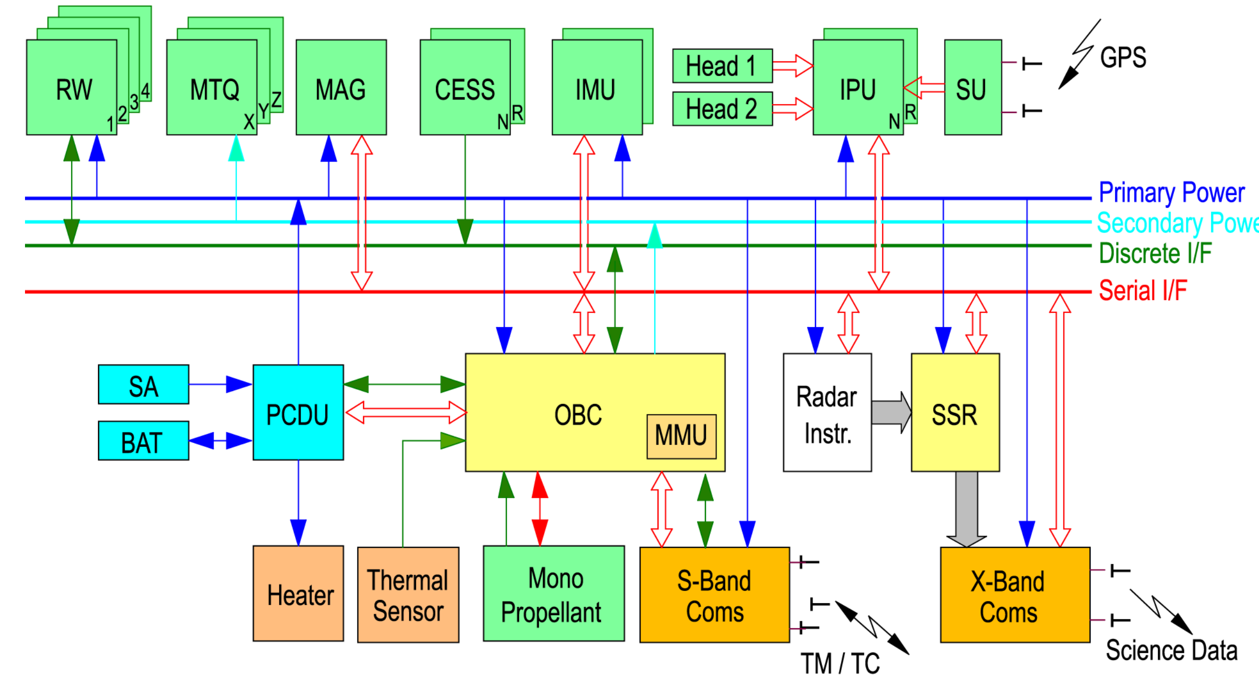


Figure G2-3. Spacecraft Block Diagram.

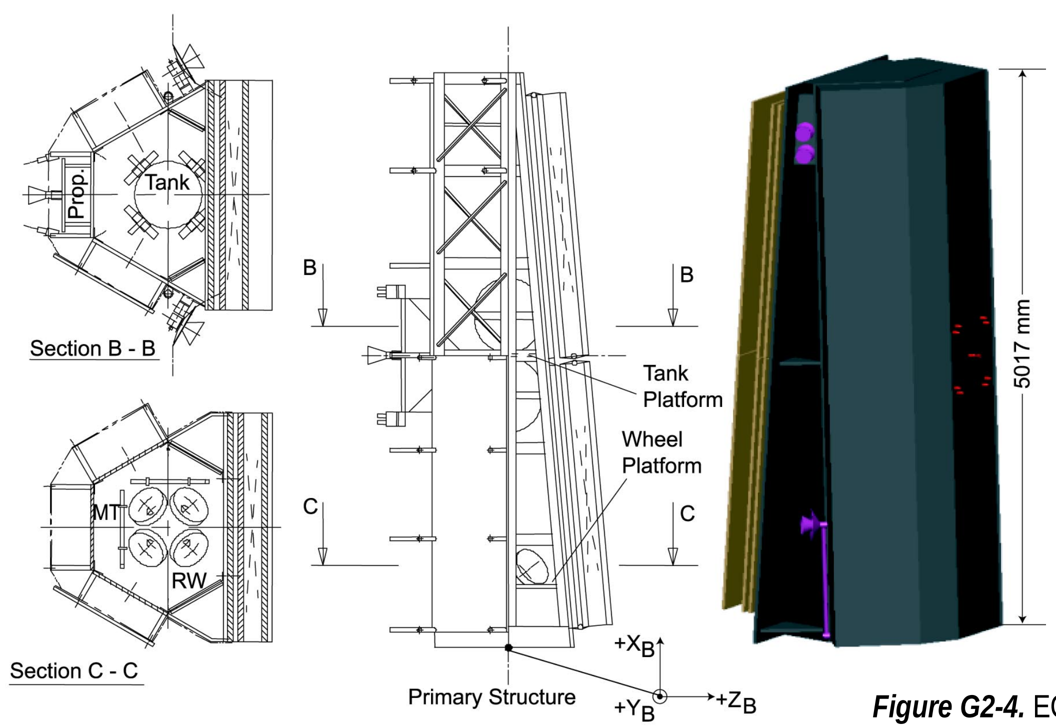


Figure G2-4. ECHO S/C structure.

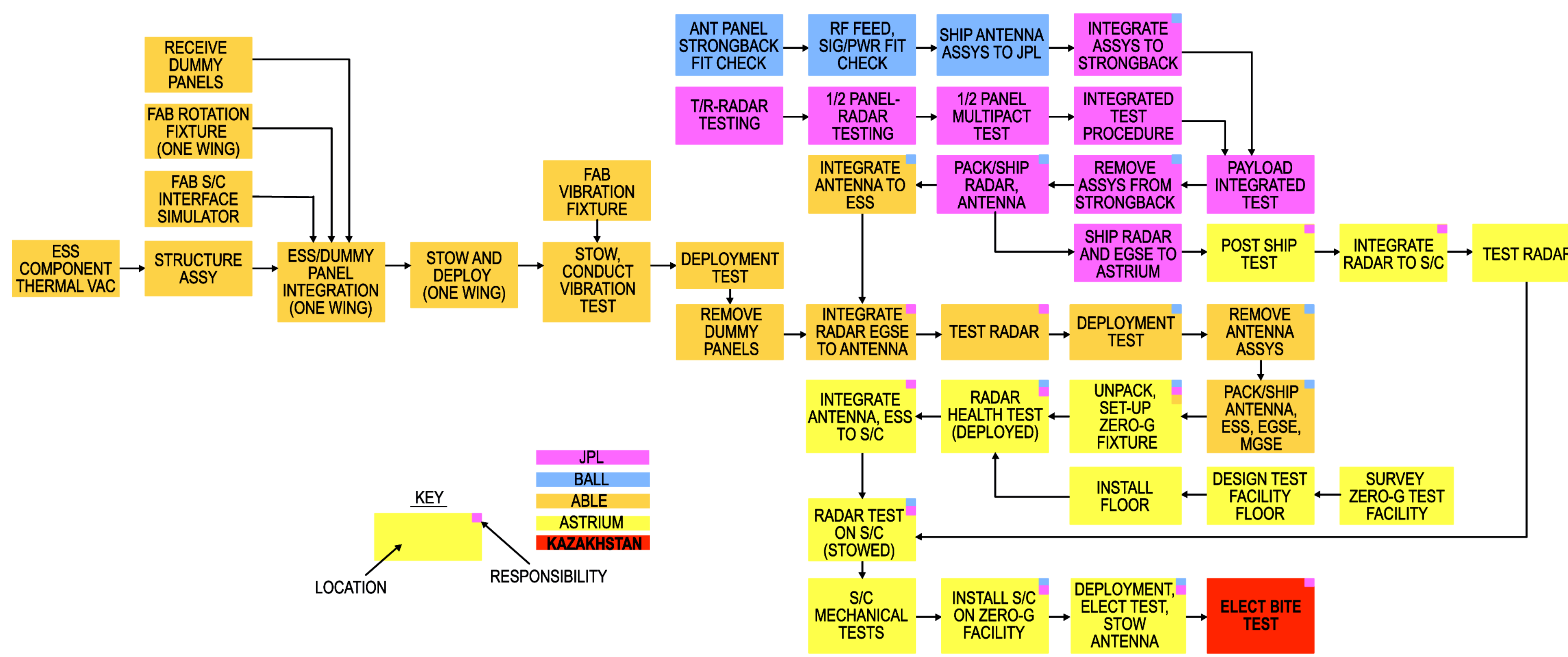


Figure G2-2. Radar Payload Integration and Test Flow