Designing a SAR Satellite Mission: A Practical Guide.

Designing a Synthetic Aperture Radar (SAR) satellite mission involves many technical layers, trade-offs, and subsystem interdependencies. Whether building your first mission or refining a complex one, mastering these elements is critical for success.

This guide consolidates general satellite mission fundamentals with SAR-specific considerations, culminating in a sample mission designed to detect unauthorized drones in urban environments.

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1. General Requirements for Any Satellite Mission

Before focusing on SAR payloads, every satellite mission needs a robust foundation across several key subsystems:

Subsystem	What's Needed / Considered
Payload	Define primary sensors, resolution, spectral range
Platform (Bus)	Power, thermal control, attitude control, mechanical structure
Onboard Data Handling (OBDH)	Telemetry, software safety, data storage, onboard processing
Telemetry, Tracking & Control (TTC)	Communications, encryption, command uplink/downlink
Power System	Solar arrays, batteries, power distribution and redundancy
Thermal Control	Passive/active cooling, temperature range maintenance
Mechanical & Structural	Mass budget, vibration tolerance, mounting precision
Attitude Determination & Control (ADCS)	Stability, pointing accuracy, jitter limits
Software	Fault detection, safe modes, remote uplink software updates

2. SAR Satellite Specific Considerations

Due to the nature of radar remote sensing, SAR missions have unique payload and system demands:

Parameter	Typical Values / Considerations
Frequency Band	X-band (8-12 GHz), C-band, or L-band, depending on resolution and penetration needs
Spatial Resolution	~1 m for high-resolution imagery, up to 30 m for wide-area surveillance
Swath Width	10–100 km depending on beamforming, antenna size, and orbit altitude
Payload Power	High power demand (hundreds of Watts) to operate radar transmitter
Data Rate	High volume data stream requiring fast onboard storage and high-rate downlinks
Thermal Management	Significant heat dissipation for radar electronics and transmitters
Attitude Control	Very precise pointing and stability for coherent SAR imaging
Onboard Processing	Image formation, data compression to optimize downlink bandwidth

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3. Mission Objectives and Requirements

Defining your mission goal drives all design decisions:

- **Example Objective:** Earth surface imaging for land use, disaster monitoring, maritime surveillance, or drone detection.
- **Key Requirements:** Spatial resolution, swath width, revisit time, spectral or frequency band.

Example for Gulf Region Environmental Monitoring:

- Spatial resolution: 1 to 5 meters (to detect vegetation and infrastructure changes)
- Swath width: 30 to 100 km (balance coverage/detail)
- Frequency band: X-band (high res) or C-band (moderate penetration)

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4. Detailed Subsystem Choices & Examples

Payload Design (SAR Instrument)

- Frequency: X-band (~9.6 GHz)
- Antenna Size: 2-3 meters for desired resolution
- Power: ~500 W active consumption
- Data Output: ~100 Mbps depending on resolution

Onboard Data Handling (OBDH)

- Solid-state storage >1 TB for data buffering
- Fault-tolerant software supporting safe modes and updates
- Interfaces for payload control and telemetry

Telemetry, Tracking, and Communication (TTC)

- X-band downlink for high-rate data transmission
- S-band uplink with encryption for command and control
- Periodic beacon signals broadcasting housekeeping data

Attitude Determination and Control System (ADCS)

- Star trackers and gyroscopes for attitude knowledge < 0.01°
- Reaction wheels or control moment gyros for pointing stability < 0.001°/s

Power Subsystem

- Solar arrays sized for ~1000 W average power (payload + bus)
- Lithium-ion batteries (~100 Ah capacity)
- Redundant power conditioning and distribution units

Thermal Control

- Passive radiators and multi-layer insulation (MLI)
- Heaters for eclipse period temperature maintenance
- Thermal interface designed to dissipate ~500 W payload heat

Mechanical Structure

- Lightweight aluminum or composite frame
- Vibration isolation mounts for antenna
- Alignment accuracy better than 0.1 mm, stable under thermal cycling

Ground Segment

- Ground station with X-band receiver and high-bandwidth internet
- Automated SAR image processing pipelines for rapid product delivery

5. Example SAR Mission: Drone Detection Over Urban Areas

Subsystem	Selected Specification	Justification
Payload Frequency	X-band SAR (9.6 GHz)	High resolution to detect small drones
Spatial Resolution	0.5 meters	Resolve small drone structures
Swath Width	20 km	Balanced coverage and image detail
Orbit	Sun-synchronous, 500 km altitude	Consistent lighting and revisit suitable for monitoring
Data Handling	Onboard image processing & compression	Reduce data volume before downlink
Communication	X-band downlink with encryption	Secure transmission of sensitive data
Power System	Solar arrays capable of 1 kW, Lithium-ion batteries	Support power-hungry radar transmitter
Thermal Control	Active cooling via heat pipes and radiators	Maintain radar electronics within operational limits
ADCS	High precision reaction wheels & star trackers	Required for accurate SAR imaging
OBDH Software	Safety mode, uplink validation, fault recovery	Ensure mission reliability and remote updates

Summary Table: SAR Mission Design Choices

Subsystem	Choice / Example	Reason / Purpose
Payload Frequency	X-band (9.6 GHz)	High-resolution imaging for small target detection
Spatial Resolution	0.5 – 1 m	Detailed surface monitoring
Swath Width	20 km	Balance between coverage and resolution
Orbit	Sun-synchronous, 500 km altitude	Stable lighting and revisit time
Data Handling	>1 TB solid-state storage, onboard compression	Buffer large SAR data volumes
Telemetry & Command	X-band downlink, S-band uplink with encryption	Secure and high-rate communication
ADCS	Star trackers, reaction wheels	Precise pointing and stability
Power	1000 W solar arrays, Li-ion batteries	Meet high payload power demand
Thermal Control	Passive radiators, heaters	Maintain stable instrument temperatures
Mechanical Structure	Aluminum composite with vibration isolation	Protect payload and maintain precise alignment
Ground Segment	X-band ground station, automated processing	Reliable data reception and rapid product delivery

Final Thoughts

Designing a SAR satellite mission requires an integrated systems engineering approach balancing payload capabilities with spacecraft resources and constraints. Starting from clear mission objectives, selecting compatible subsystem components, and validating their interactions through simulations and trade studies are essential to mission success.