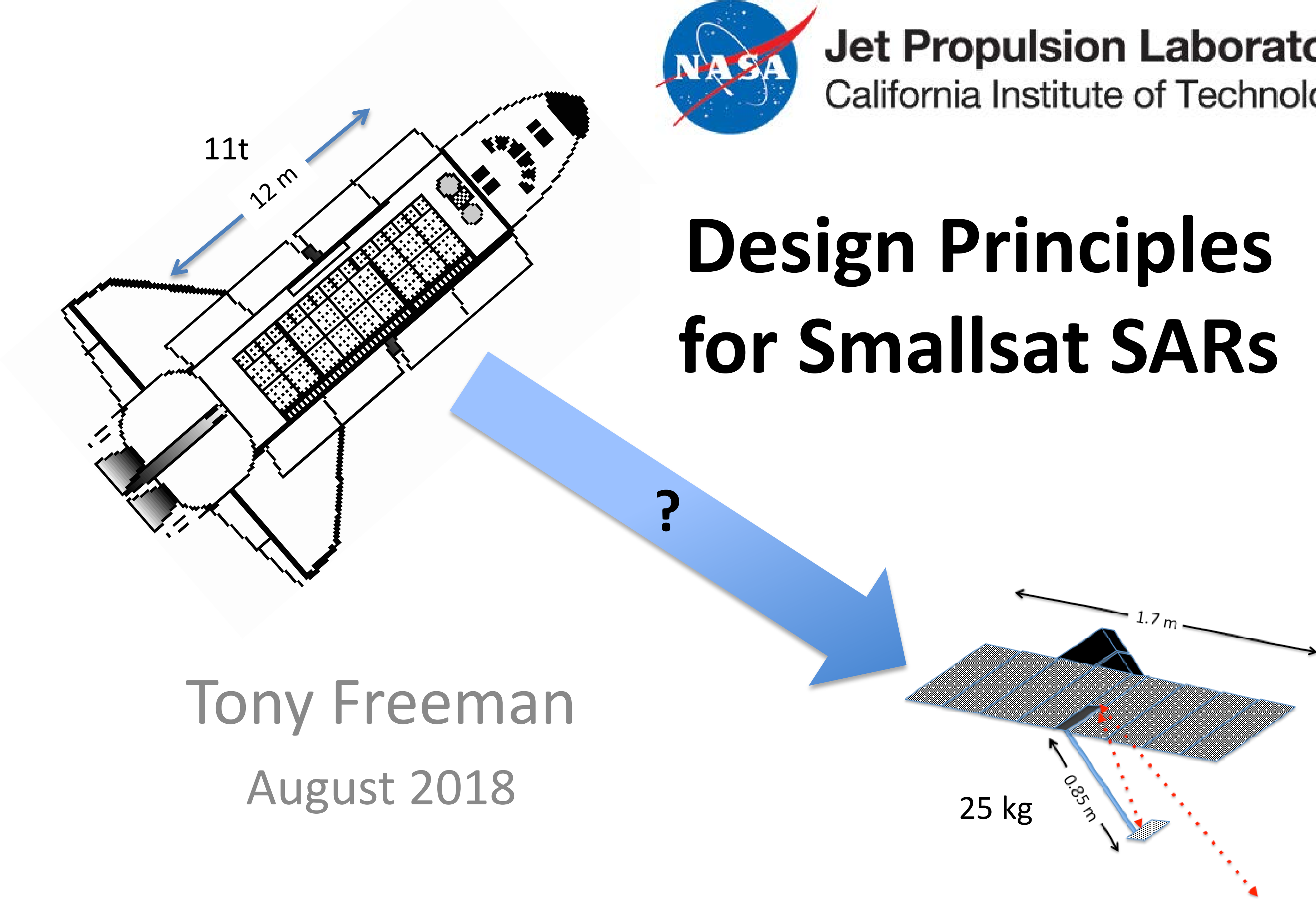
Jet Propulsion Laboratory
California Institute of Technology

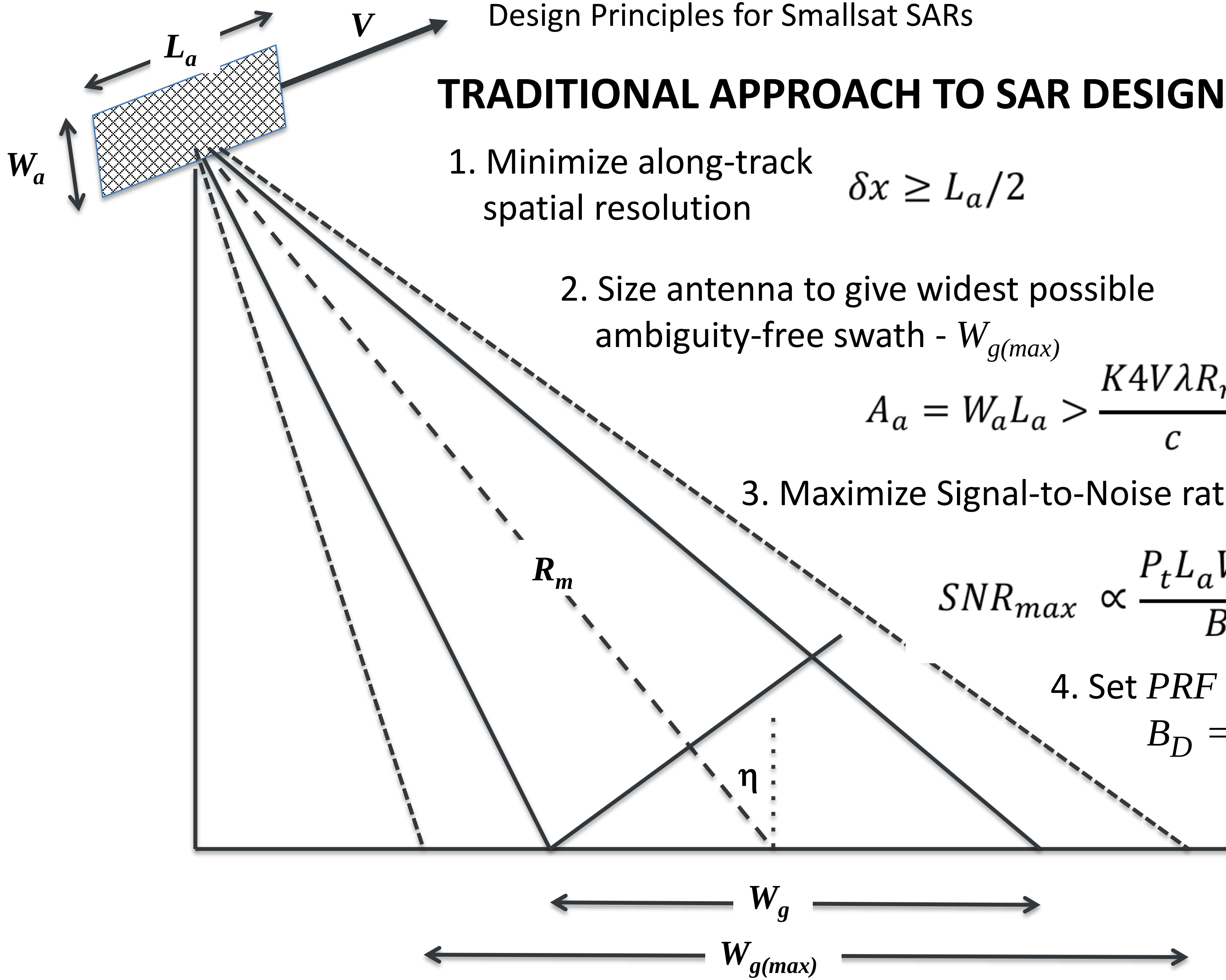
Design Principles for Smallsat SARs



Tony Freeman

August 2018

TRADITIONAL APPROACH TO SAR DESIGN



1. Minimize along-track spatial resolution $\delta x \geq L_a/2$

2. Size antenna to give widest possible ambiguity-free swath - $W_{g(max)}$

$$A_a = W_a L_a > \frac{K4V\lambda R_m}{c} \tan\eta$$

3. Maximize Signal-to-Noise ratio

$$SNR_{max} \propto \frac{P_t L_a W_a^2 \tau_p}{B_n}$$

4. Set $PRF > B_D$

$B_D = 2V/L_a$

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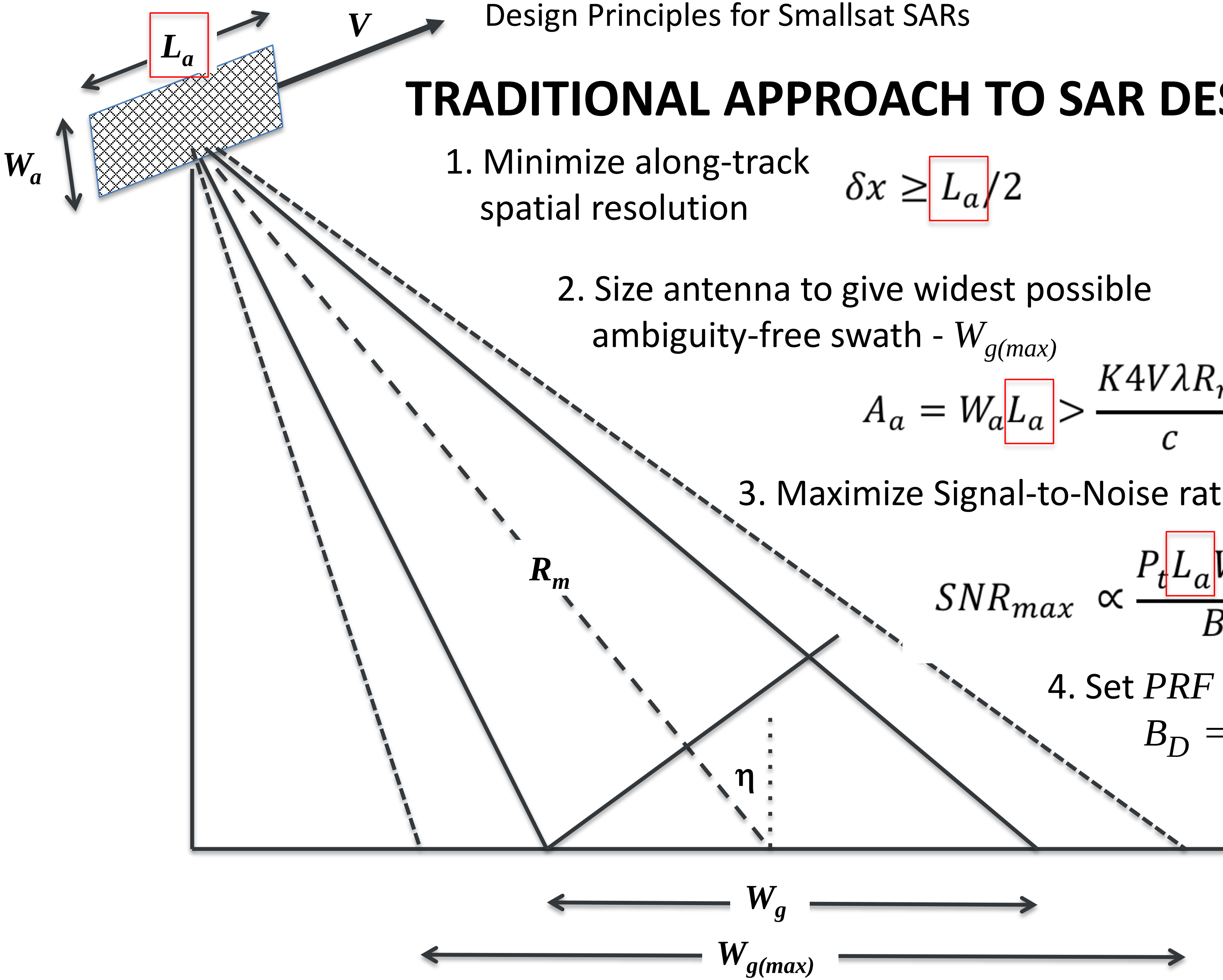

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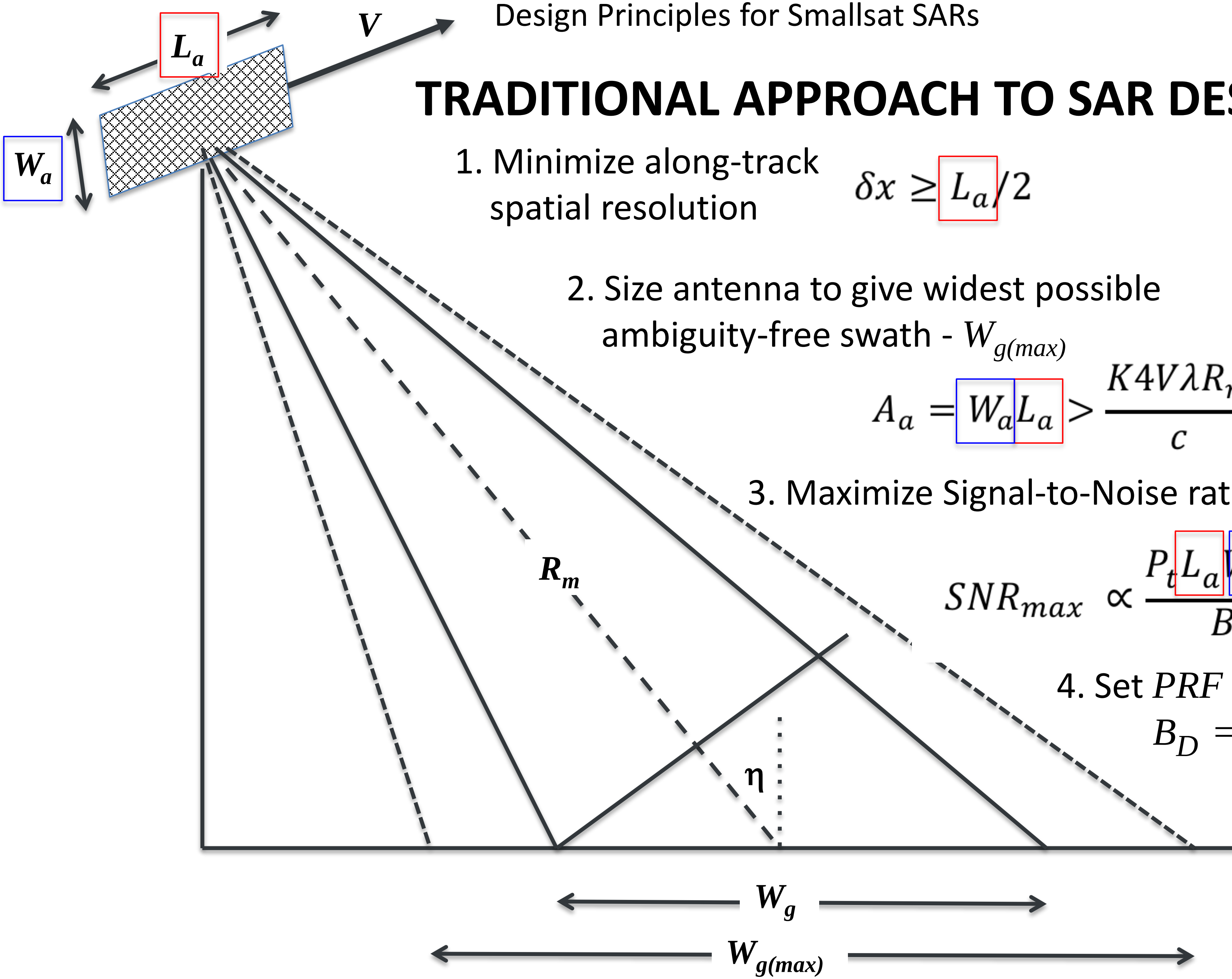

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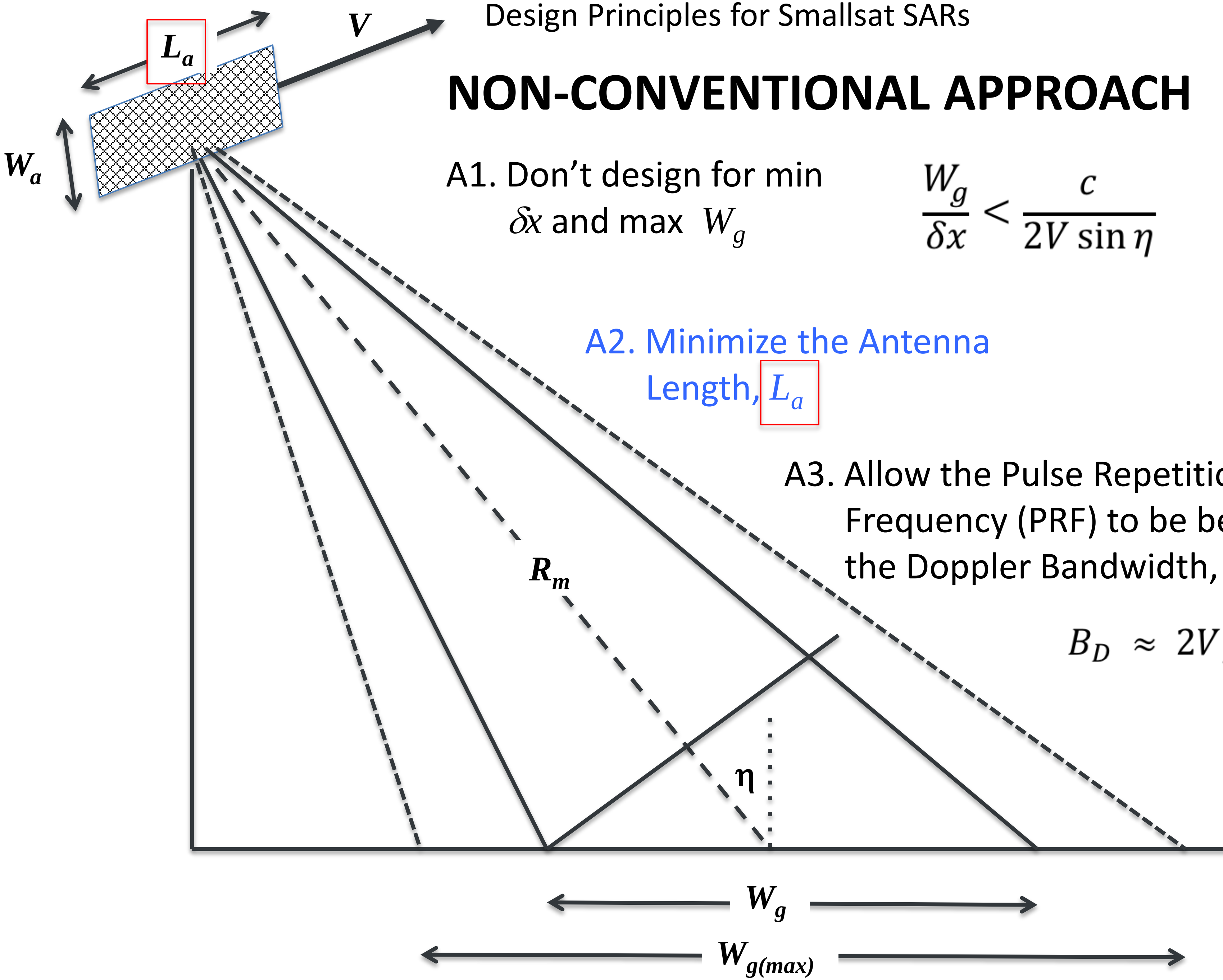
NON-CONVENTIONAL APPROACH



A1. Don't design for min δx and max W_g

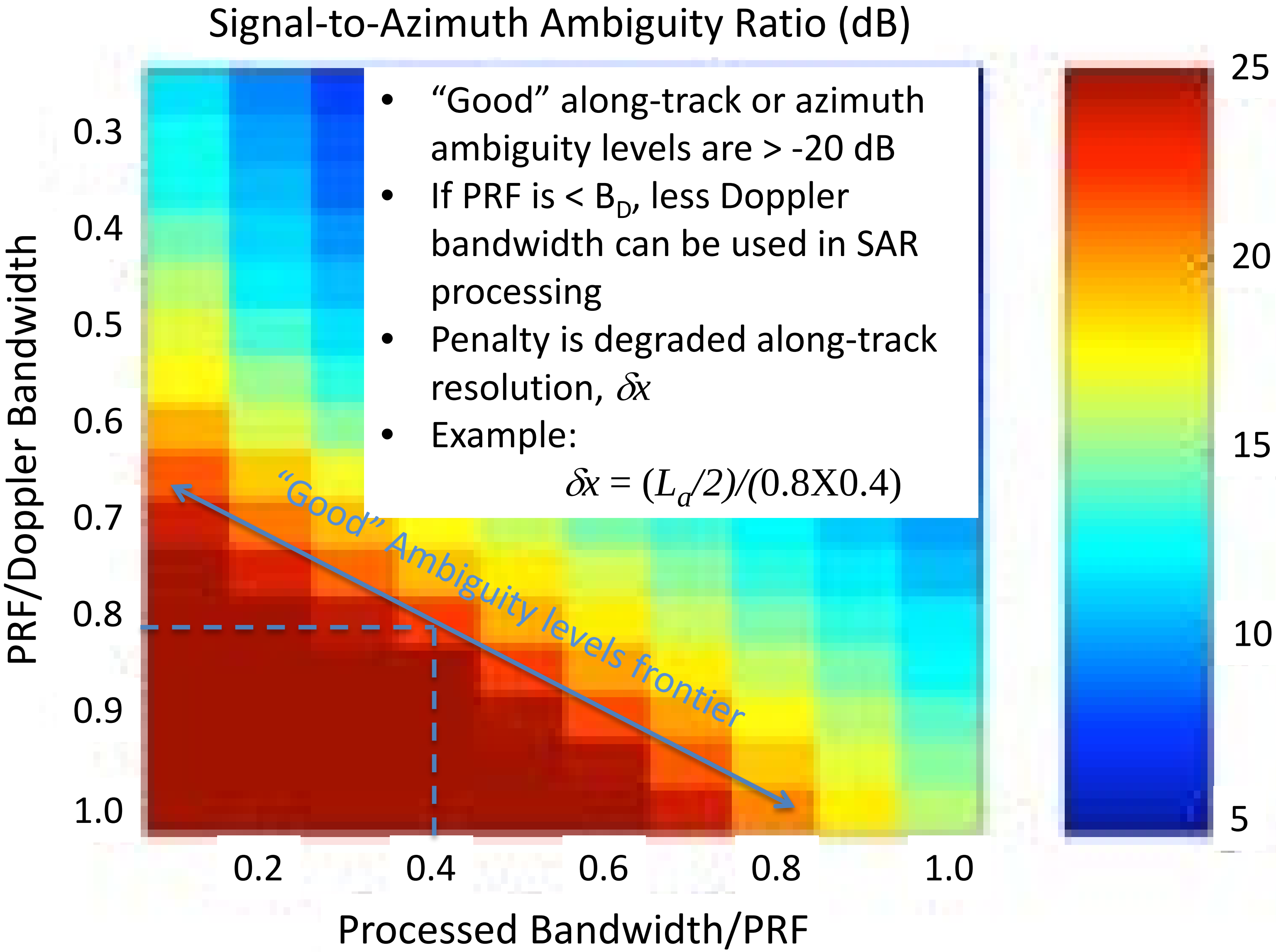
$$\frac{W_g}{\delta x} < \frac{c}{2V \sin \eta}$$

A2. Minimize the Antenna Length, L_a

A3. Allow the Pulse Repetition Frequency (PRF) to be below the Doppler Bandwidth, B_D:

$$B_D \approx 2V / L_a$$

TRADE-OFFS



- "Good" along-track or azimuth ambiguity levels are > -20 dB
- If PRF is < B_D, less Doppler bandwidth can be used in SAR processing
- Penalty is degraded along-track resolution, δx
- Example:

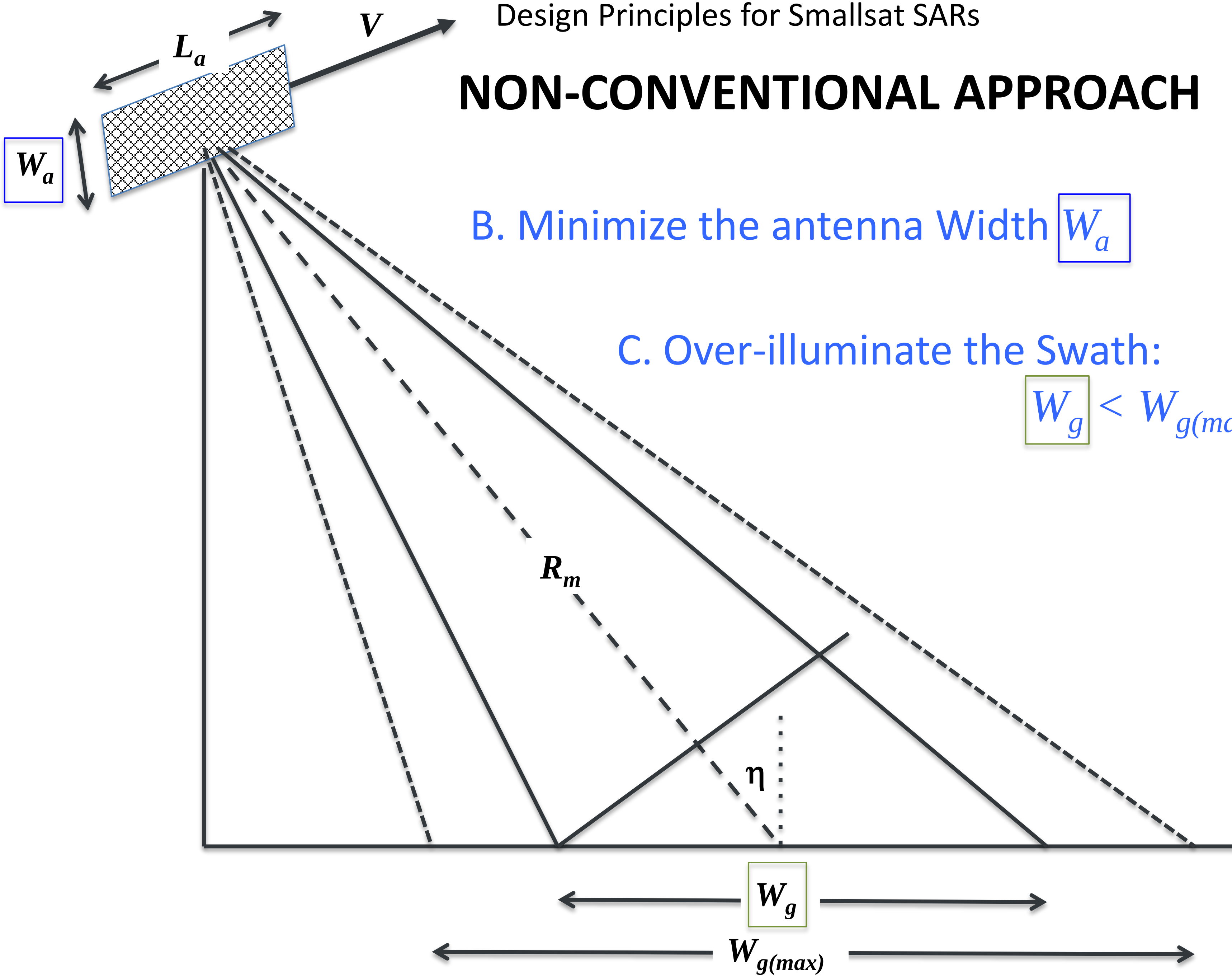
$$\delta x = (L_a/2)/(0.8X0.4)$$

NON-CONVENTIONAL APPROACH

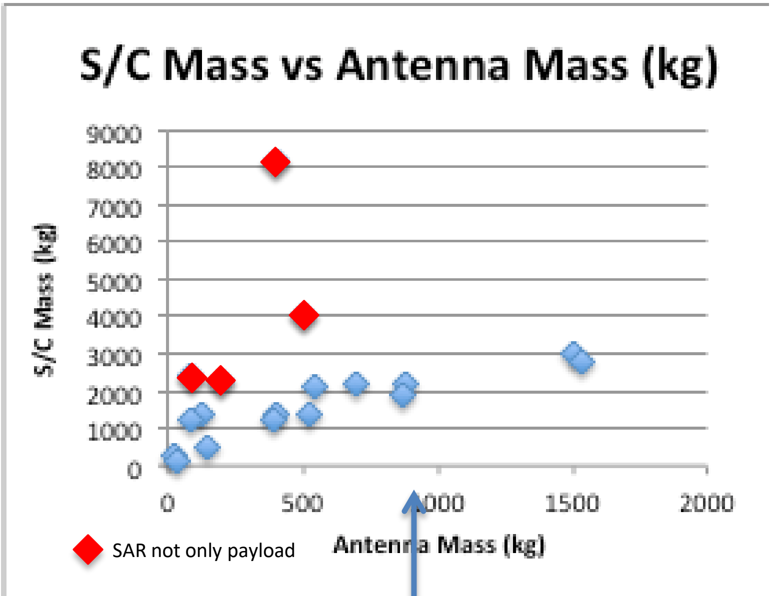
B. Minimize the antenna Width W_a

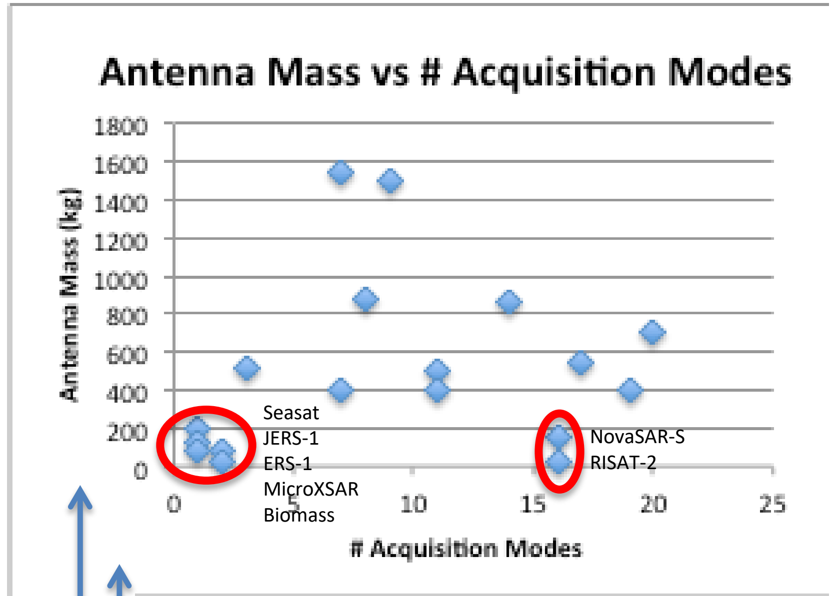
C. Over-illuminate the Swath:

$W_g < W_{g(max)}$

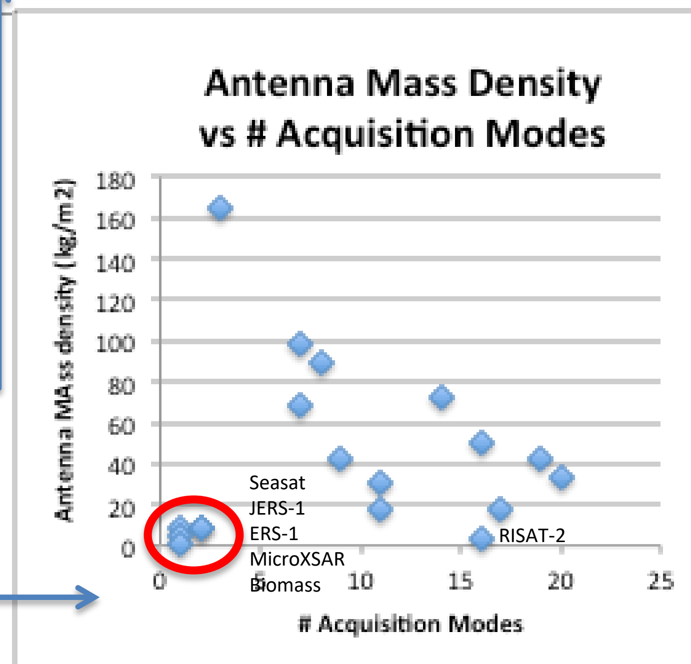


PAST, PRESENT AND NEAR-TERM FUTURE SARS





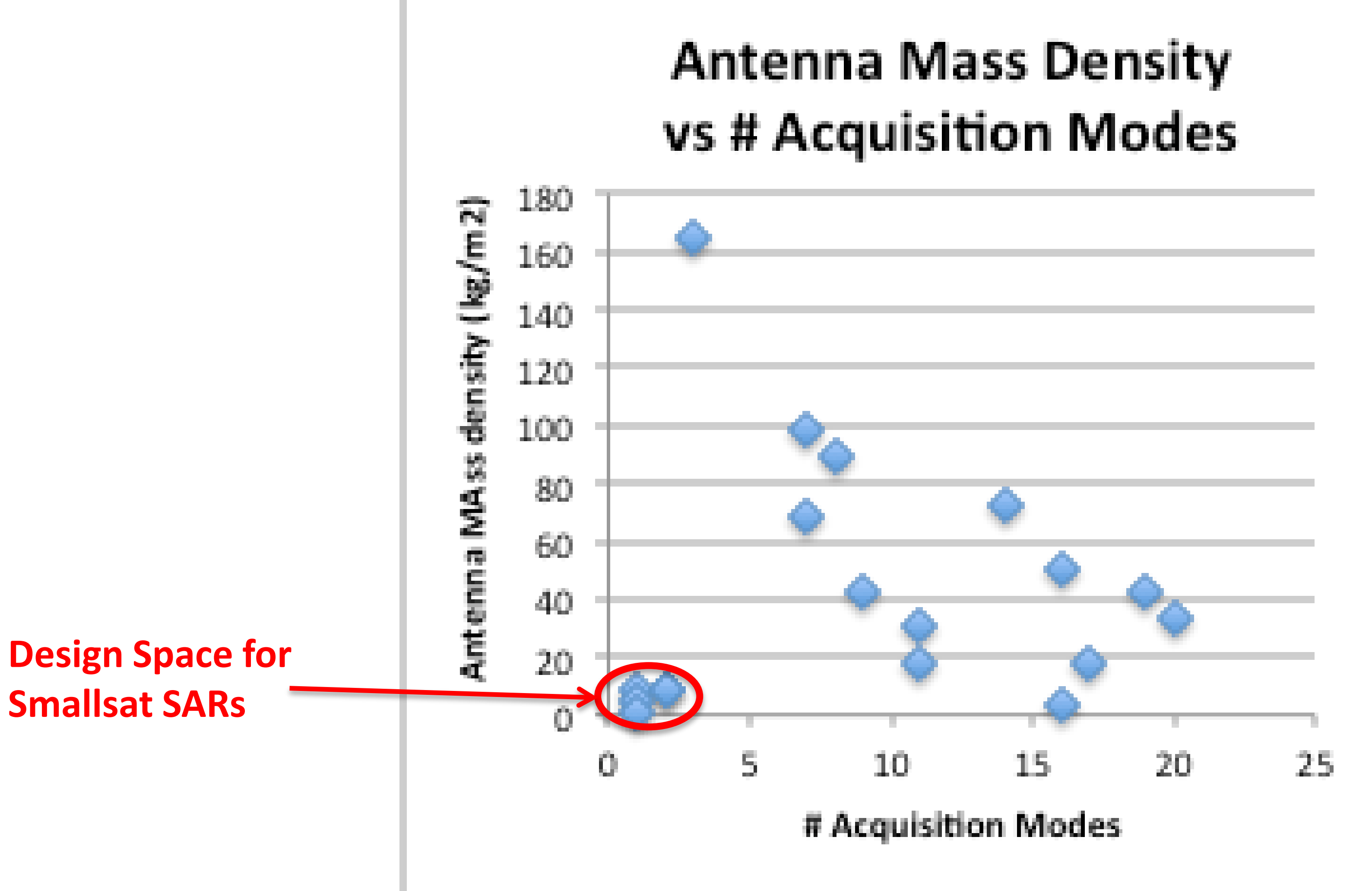
- For single-instrument SARs, Antenna Mass and S/C Mass are well-correlated
- Antenna Mass < 200 kg *mostly* for antennas that are NOT phased arrays
- NOT phased arrays means microstrip patches, slotted waveguides, and reflector antennas
- Really low antenna mass densities correlate with small # modes, except RISAT-2 which is a reflector antenna + phased array feed



ANTENNA MASS DENSITY AND # MODES

D) Select the Lowest Mass Density Antenna

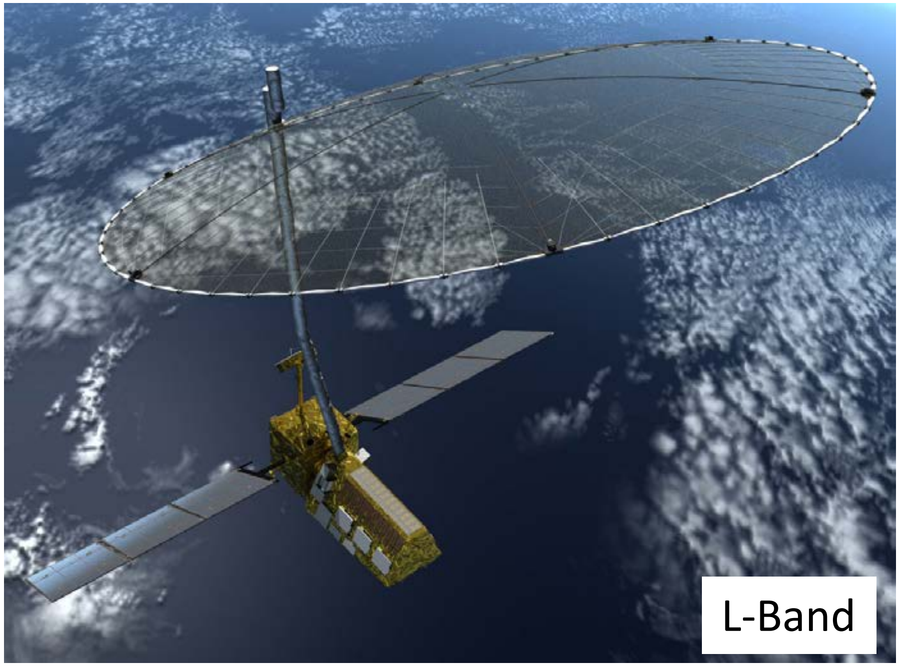
E) Choose the smallest possible number of Imaging Modes



POLARIZATION DIVERSITY

F) Add polarization diversity only when needed to meet the majority of system requirements

NASA/ISRO NISAR



ESA BIOMASS

- Scientists require cross-pol (HV) backscatter measurements because they carry a lot of information at longer wavelengths
- Full polarimetry can help calibrate out Faraday rotation effects

DATA RATES AND POWER CONSUMPTION

G) Select a Data Rate that maximizes on-time per orbit

$$D_R = n \, . \left(\frac{W_s}{c} + \tau_p \right) . n_b f_s \, . \, (PRF / PreSum) \, . F_{OBP}$$

Number of channels, e.g. polarizations (n)

#bits. Reduce using BFPQ (n_b)

Reduce data rate by presumming and/or onboard processing ($PreSum$, F_{OBP})

H) Select an average power consumption that maximizes on-time per orbit (but beware thermal overload)

$$P_{DC} = \left(\frac{P_t \tau_p PRF}{\varepsilon} + P_{rec} \right) \cdot \frac{T_{on}}{T_{orbit}}$$

But, SNR Formula remains unchanged $SNR_{max} \propto \frac{P_t L_a W_a^2 \tau_p}{B_n}$

PUTTING THE DESIGN PRINCIPLES INTO PRACTICE

A. Very short antenna

B. With the widest possible extent (30 cm) at Ka-Band

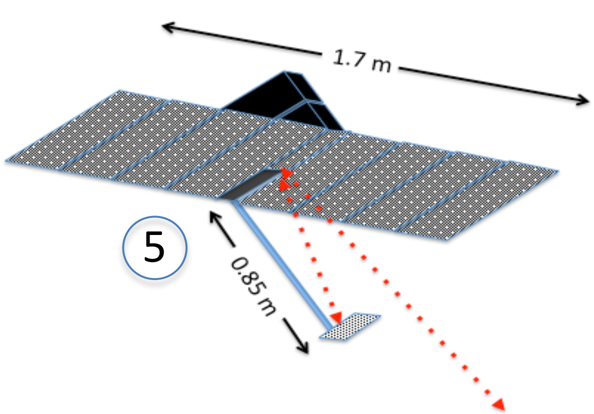
D. Reflectarray antenna was the lowest mass density option available

E. Single imaging mode

F. Single polarization

G. BFPQ of (8:4) and a Presum factor of 3 reduce the data rate

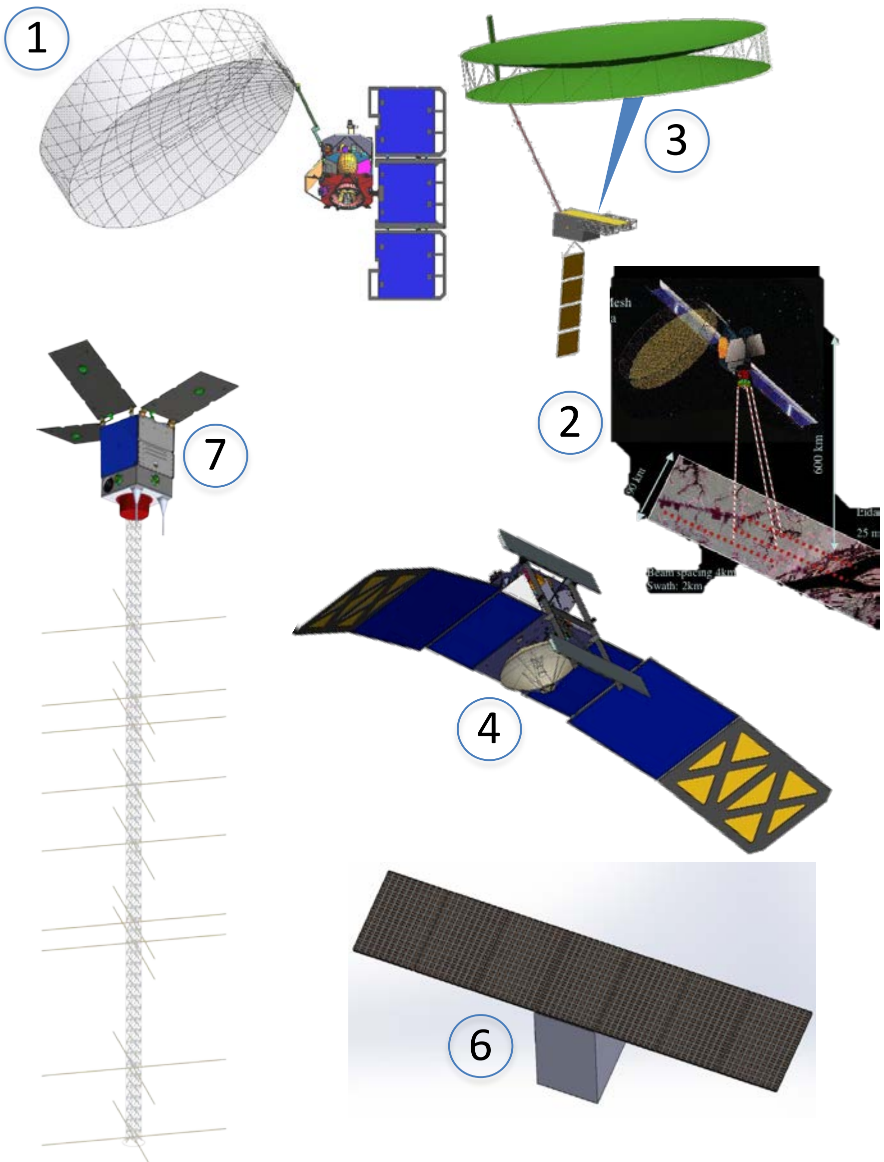
H. Thermal constraints limited the on-time per-orbit for this concept to just 3 mins



Parameter	Value
Orbit altitude	400 km
Center Frequency	35 GHz
Incidence angle	30 degrees
Transmit peak RF power	240W
DC Power	160W
Pulse length	50 microsec
Antenna Dimensions	1.7 X 0.3 m
F/D ratio	0.7
Bandwidth	30 MHz
Data rate	104 Mbps
On-time per orbit	3 mins
Downlink rate	40 Mbps
Noise-equivalent sigma-zero	-17 dB
Spatial resolution/# of looks	10 m/2
Swath width	15 km

5 See following slide

DESIGN EXAMPLES



SAR Design Concept	Features	Antenna Type [Mass Density]
Mars UHF SAR (2003)[50-52] 1	Polarimetry, BFPQ, PreSum, Over-illumination of Swath, single mode	Passive, deployable reflector [2.0 kg/m^2]
Biomass precursor (2004)[53] 2	Short antenna, Polarimetry, BFPQ, PreSum , single mode	Passive, deployable reflector [1.9 kg/m^2]
DESDynI (2009)[42,43] 3	Polarimetry, multiple modes, SweepSAR	Passive, deployable reflector with a phased array feed [3.6 kg/m^2]
VERITAS (2014)[54,55] 4	Single polarization, Short antennas, OBP, single mode	Slotted Waveguide [10.5 kg/m^2]
Ka-band Cubesat SAR (2016)[56] 5	Short antenna, single mode of operation	Slotted Waveguide or Microstrip Patch or *Reflectarray* [7.9 kg/m^2]
S-band Smallsat SAR constellation (2017)[57] 6	Single polarization, Short antenna, BFPQ, PreSum, single mode	Slotted Waveguide or Microstrip Patch [10.0 kg/m^2]
VHF radar sounder (2017)[58] 7	PreSum, OBP, single mode	Yagi [9.9 kg with 10 m crossed dipoles]

SUMMARY OF PRINCIPLES

A) Minimize the Antenna Length

B) Minimize the Antenna Width

C) Over-illuminate the Swath

D) Select the Lowest Mass Density Antenna

E) Choose the smallest possible number of Imaging Modes

F) Add polarization diversity only when needed to meet the majority of system requirements

G) Select a Data Rate that maximizes on-time per orbit

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