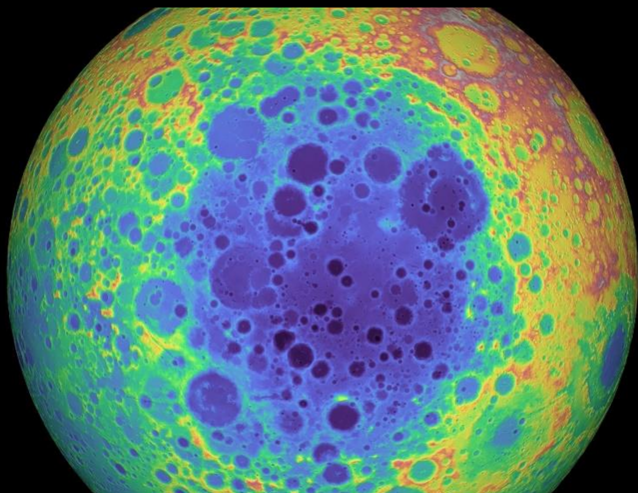

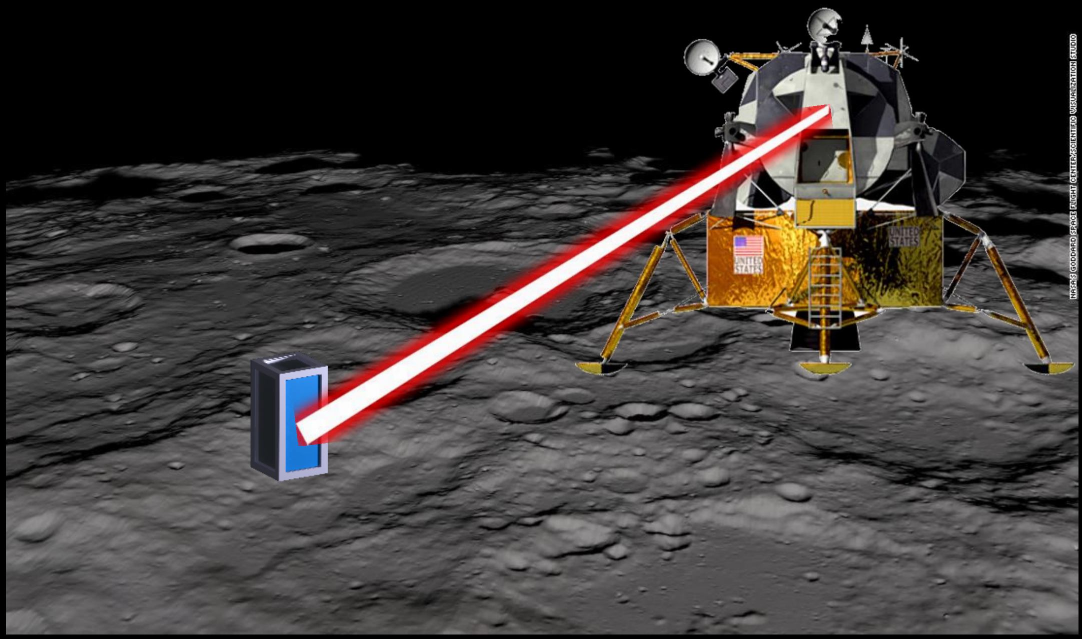

NASA Big Idea 2020: Lunar Autonomous Scalable Emitter and Receiver (LASER) System –FemtoSat Design

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Introduction

- We have been studying the surface of the Moon since the mid-1960s – “surface bone dry”.
- 2009 NASA’s M^3 onboard the Chandrayaan-1 detected water and results were confirmed in 2018
- New evidence for evolution of water on the Moon
  - Transport from mid-latitude to poles over eons.
- Water on the Moon is a “make or break” moment in terms of space economics.

Renewed hope lunar resources will kick-start the space economy.

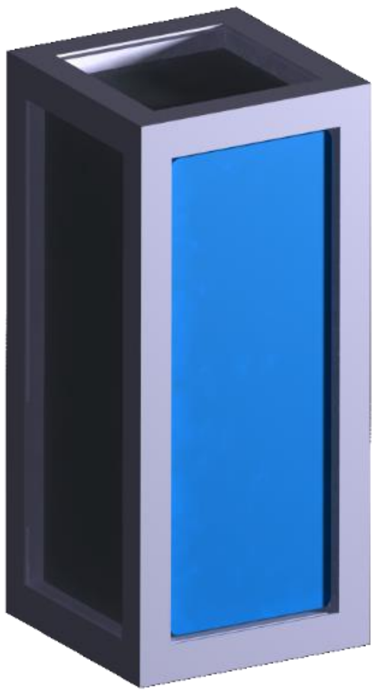
Motivation

- Burgeoning tendency to miniaturization
  - Reduced cost and weight
- Secondary payloads
  - Advance science at reasonable cost
- LASER aims to charge a Smart device positioned in the PSR using a laser beam
  - How to use something small and cheap for this? → FemtoSats

Looking for new opportunities

Objective

- Design a 2F FemtoSat
  - RF localization
  - Charge battery
  - Data transmission
  - Keeping it low-cost



Related work

- Femto concept → SunCube
- Solar panel miniaturization → DHV technologies
- Charge devices with laser → ASU/Univ. of Arizona (2014), Univ. of Washington (2018)
- Arduino platform

Mission Requirements

- Survive the extreme temperatures: [-153, 107] °C
- Charge a battery with a laser
- RF localization
- UHF data transmision
- Perform tasks for at least 12 hours
- Total mass per FemtoSat under 100g
- Cost under $350

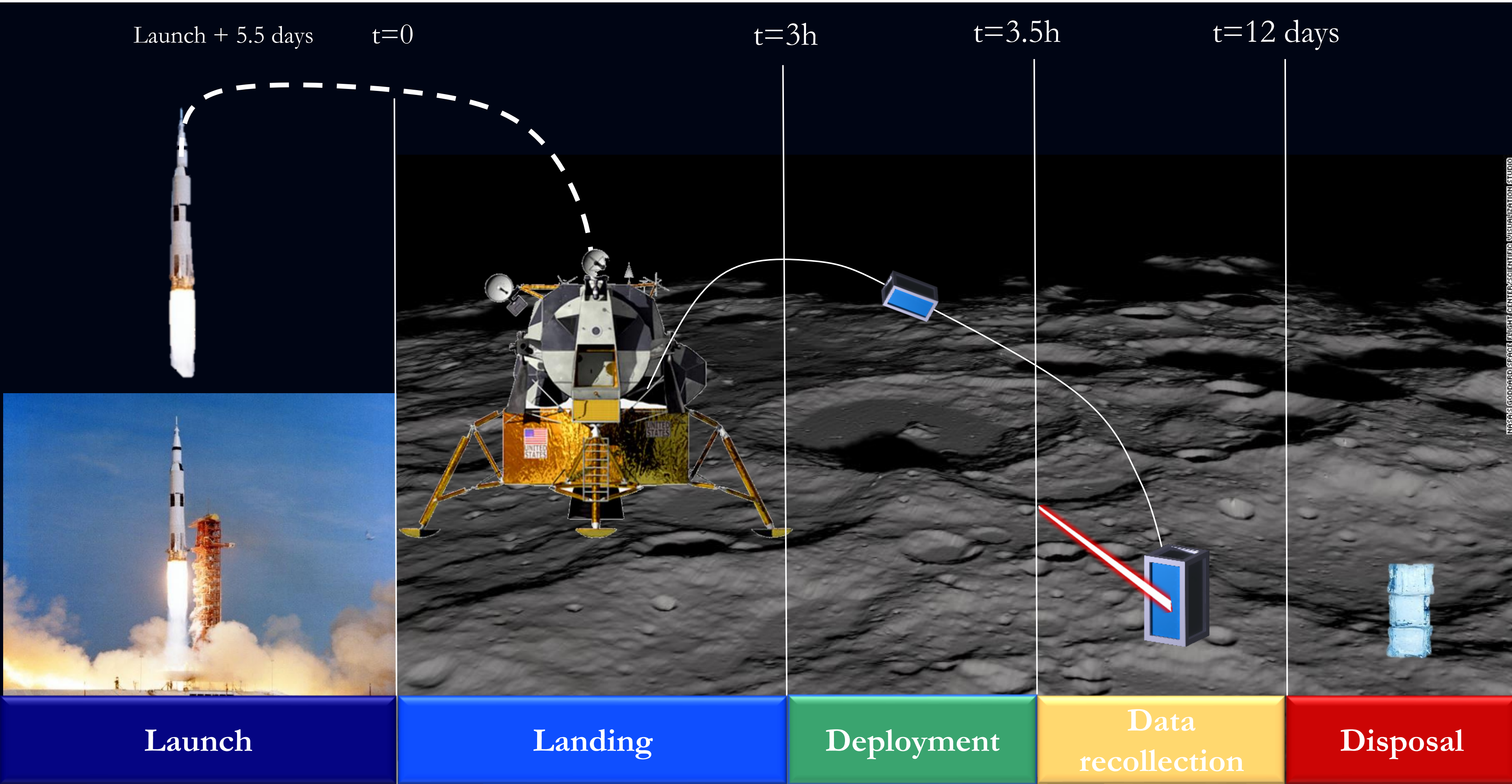
Low cost approach to obtaining first look inside PSR region.

Challenges

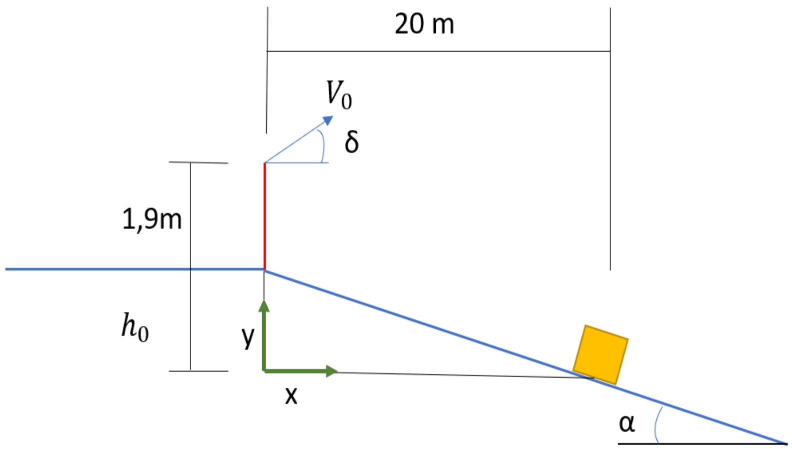
- Technology limitations
- Coupling
- Extreme conditions

It is never easy

Concept of Operation



Design Part I: launching survival



Conservation of energy model

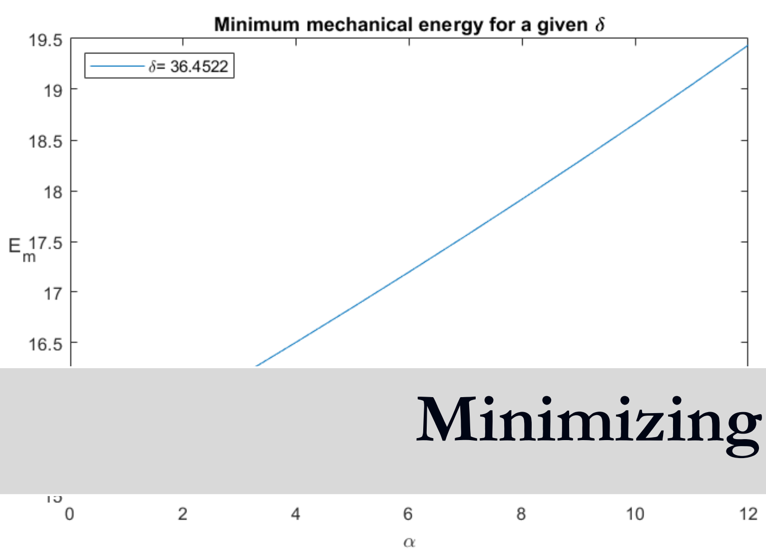
$$\sin 2\delta\,(20\tan\alpha + 1.9 + 20\tan\delta) = 20$$

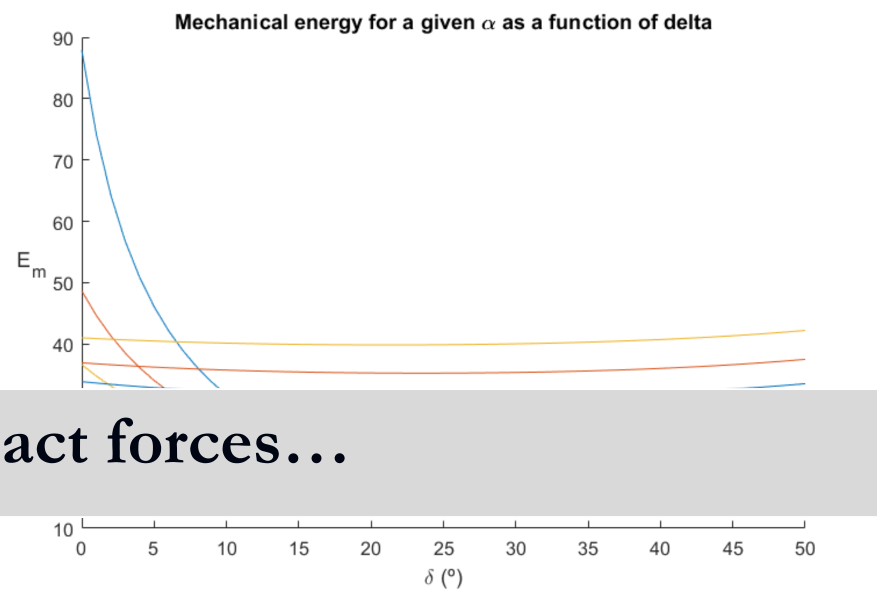
Results:

- $v_0 = 4.97\ \mathrm{m/s}$
- $\delta = 36.45º$
- $h_0 = 4.25\ m$

Earth testing:

$$H_E = \frac{E_m}{m g_E} \cdot SM = 2.18\ m$$





Minimizing impact forces…

FemtoSat Architecture

Dimensions: 2F (60mm x 30mm x 30mm)

Elements:

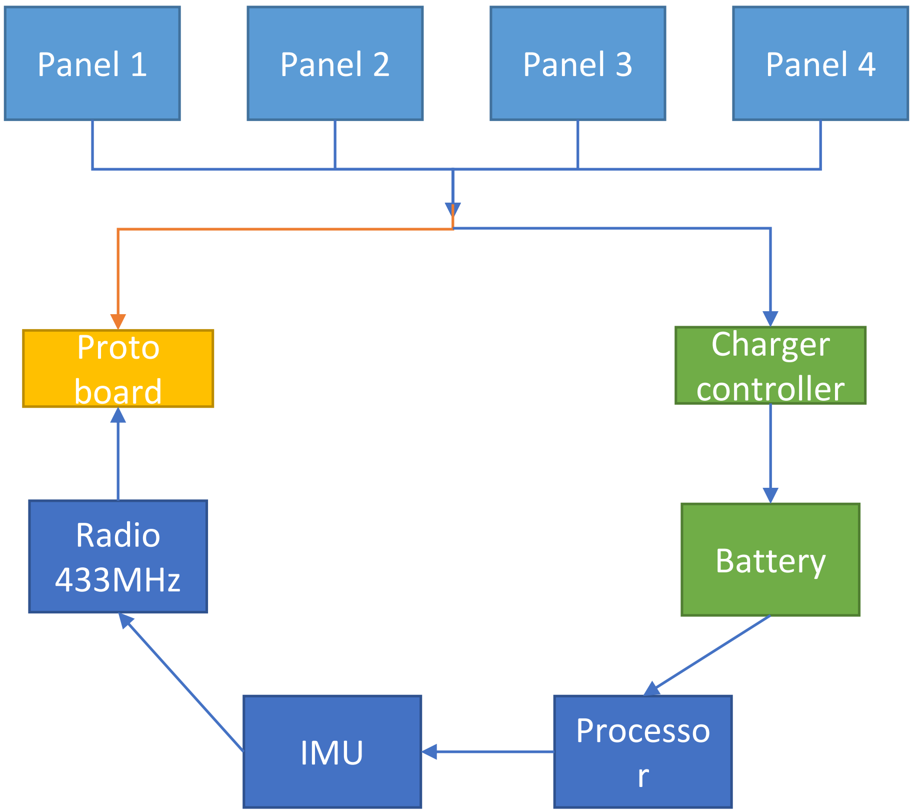
- Case (green) [60,30,30]
- Gorilla glass [54.8, 24.8, t: 0.4]
- Solar panels [51, 21, t: 1.6]
- Aluminum box [54.8, 23.8, 23.8, t: 0.5]
- Insulation (MLI) [53.8, 23.8, 23.8, t: 2,3]
- Hardware [20, 20, 30]

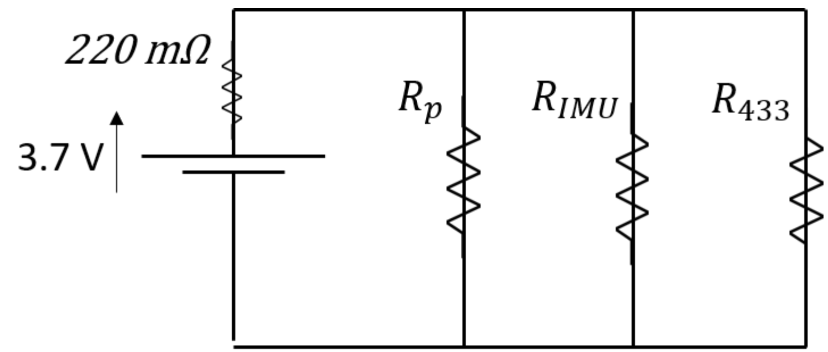
All dimensions are in mm

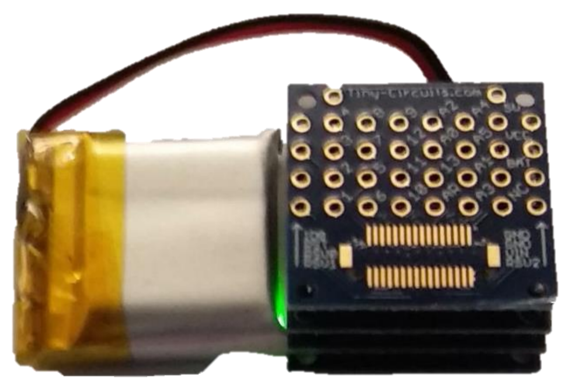
FemtoSat Architecture

	Element	Mass (g)	Volume (mm)
Hardware	Processor board (TinyZero)	1.4	20x20x2.9
	~~Processor board (TinyDuino)~~	~~1.10~~	~~20x20x2.9~~
	IMU	1	20x20x5.11
	Radio + (antenna)	1.15+0.26	20x20x5.11 (+177)
	Battery (150 mA, 3.7V)	3.77	20x20x5
	Proto Board	0.85	20x20x5.11
Solar array	Charger controller	0.54	14x9x3.7
	~~Short panels (Test) 2x~~	~~~5.6~~	~~21x21x2~~
Structure	Long panels (Test) 4x	~27	51x21x2
	TPU case	9	60x30x30
Insulation	Box (aluminum)	9	54.8x24.8x24.8 (t=0.5)
	MLI		53.8x23.8x2 23.8x23.8x2
Total	Aerogel		
		53.97	60x30x30 (2F)

Circuit Design







Solar panels design

- ## Requirements:

A	4.41
	10.71
Φ_S^{STD}	1367
Φ_S	1322 (summer)
	1414 (winter)
Φ_L	4444.44
T	107 (sun lluminated)
	-153 (shadow)
T^{STD}	28
$\frac{dV}{dT}$	-5.6
	-13
$\frac{dJ}{dT}$	$9 \cdot 10^{-3}$

- ## Boundaries:

Battery	I_{MP}^{min}	30 mA
	I_{MP}^{max}	150 mA
	V_{MP}^{min}	4.2 V
	V_{MP}^{max}	5 V
Charger controller	I_{MP}^{min}	15 mA
	I_{MP}^{max}	500 mA
	V_{MP}^{min}	4.2 V
	V_{MP}^{max}	6 V

- ## Equations:

$$I_{MP} = n_1 \cdot \frac{\Phi}{\Phi^{STD}} \left(I_{MP}^{STD} + \frac{\delta J}{\delta T} (T - T_{STD}) A \right)$$

$$V_{MP} = n_2 \cdot \left(V_{MP}^{STD} + \frac{\delta V}{\delta T} (T - T_{STD}) \right)$$

Solar panels design

- **One cell (n_1=1, n_2=1)**

Area	Phi	dV/dT	T	Imp	Vmp
4,41	1322	-5.6	107	30,11	4,2
4,41	4444	-5.6	107	101.23	4.2
4,41	4444	-5.6	-153	67,68	5.65
4.41	1414	-5.6	107	32.21	4.2
10,71	1322	-5.6	107	34.44	4,2
10,71	4444	-5.6	107	115.79	4.2
10,71	4444	-5.6	-153	34.31	5.65
10,71	1414	-5.6	107	36.84	4.2

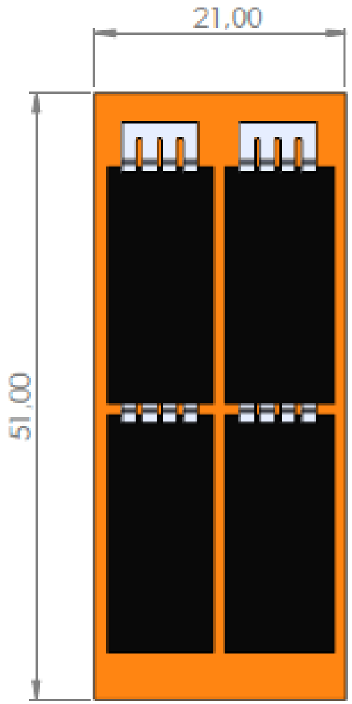
I_{MP}^{STD}	28 mA
V_{MP}^{STD}	4.64 V

- **Four cells (n_1=2, n_2=2)**

Area	Phi	dV/dT	T	Imp	Vmp
4,41	1322	-5.6	107	64.09	3.1
4,41	4444	-5.6	107	215.46	3.1
4,41	4444	-5.6	-153	148.36	6.01
4.41	1414	-5.6	107	68.55	3.1
10,71	1322	-5.6	107	72.75	3.1
10,71	4444	-5.6	107	244.59	3.1
10,71	4444	-5.6	-153	81.63	6.01
10,71	1414	-5.6	107	77.82	3.1

I_{MP}^{STD}	28 mA
V_{MP}^{STD}	1.99 V

Solar panels: market analysis (DHV technologies)



Solar Array Electrical Parameters BOL @ standard conditions 28 deg C	
Voc	2,65 V
Isc	0,032 A
Vmp	2,33 V
Imp	0,031 A
Pmp	0,07 W

Concept	Amount
3 Long panels	1.834,60 €
Non recurrent engineering	1.100,00 €
Packaging, shipping and insurance	750,00 €
TOTAL	3.684,60 €

Long Panel (2S2P)

Solar Array Electrical Parameters BOL @ standard conditions 28 deg C	
Voc	5,30 V
Isc	0,065 A
Vmp	4,66 V
Imp	0,061 A
Pmp	0,29 W

Concept	Amount
14 Long panels plus 8 short panels	18.440,05 €
Packaging, shipping and insurance	1.500,00 €
TOTAL	19.940,05 €

DHV technologies a viable option for Deep Space Exploration

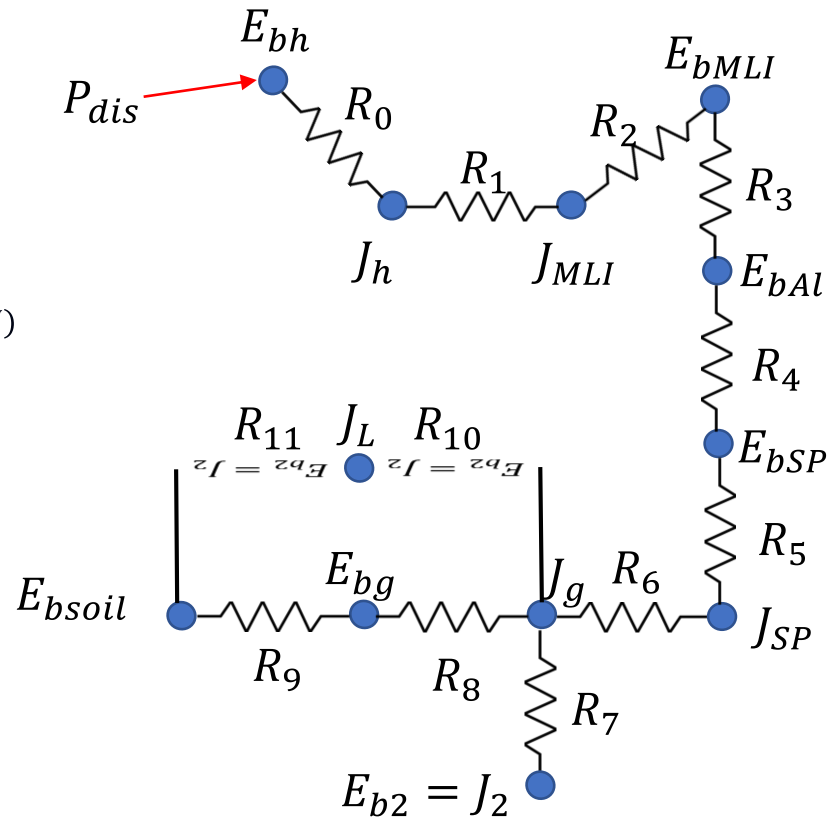
Data from DHV technologies

Thermal Analysis

$$\frac{E_{bMLI} - E_{bh}}{\Sigma_{i=0}^{2} R_i} + P_{dis} = 0 \qquad (I)$$

$$P_{dis} = \frac{E_{bMLI} - E_{bSP}}{R_3 + R_4} = \frac{T_{MLI} - T_{SP}}{\frac{t_{MLI}}{A_{MLI} k_{MLI}} + \frac{t_{Al}}{A_{Al} k_{Al}}} \qquad (II)$$

$$E_{bSP}\left(\frac{1}{R^*} + \frac{1}{R_7}\right) = \left(\frac{E_{bsoil}}{R^*} + \frac{E_{b2}}{R_7}\right) + P_{dis}\left[1 + (R_5 + R_6)\left(\frac{1}{R^*} + \frac{1}{R_7}\right)\right] \qquad (III)$$



Results:

- $P_{dis} = 10.99\ mW$ ($k_{MLI} = \infty$)
  - $T_{SP} = -145$ ºC
  - $T_{SP} = -134$ ºC
- $P_{dis} = 290\ mW$ ($k_{MLI} = 0{,}01$)
  - $T_{SP} = -67$ºC
  - $T_{SP} = -19$ ºC
- $P_{dis} = 155\ mW$ ($k_{MLI} = 0{,}001$)
  - $T_{SP} = -93$ ºC
  - $T_{SP} = -18$ ºC

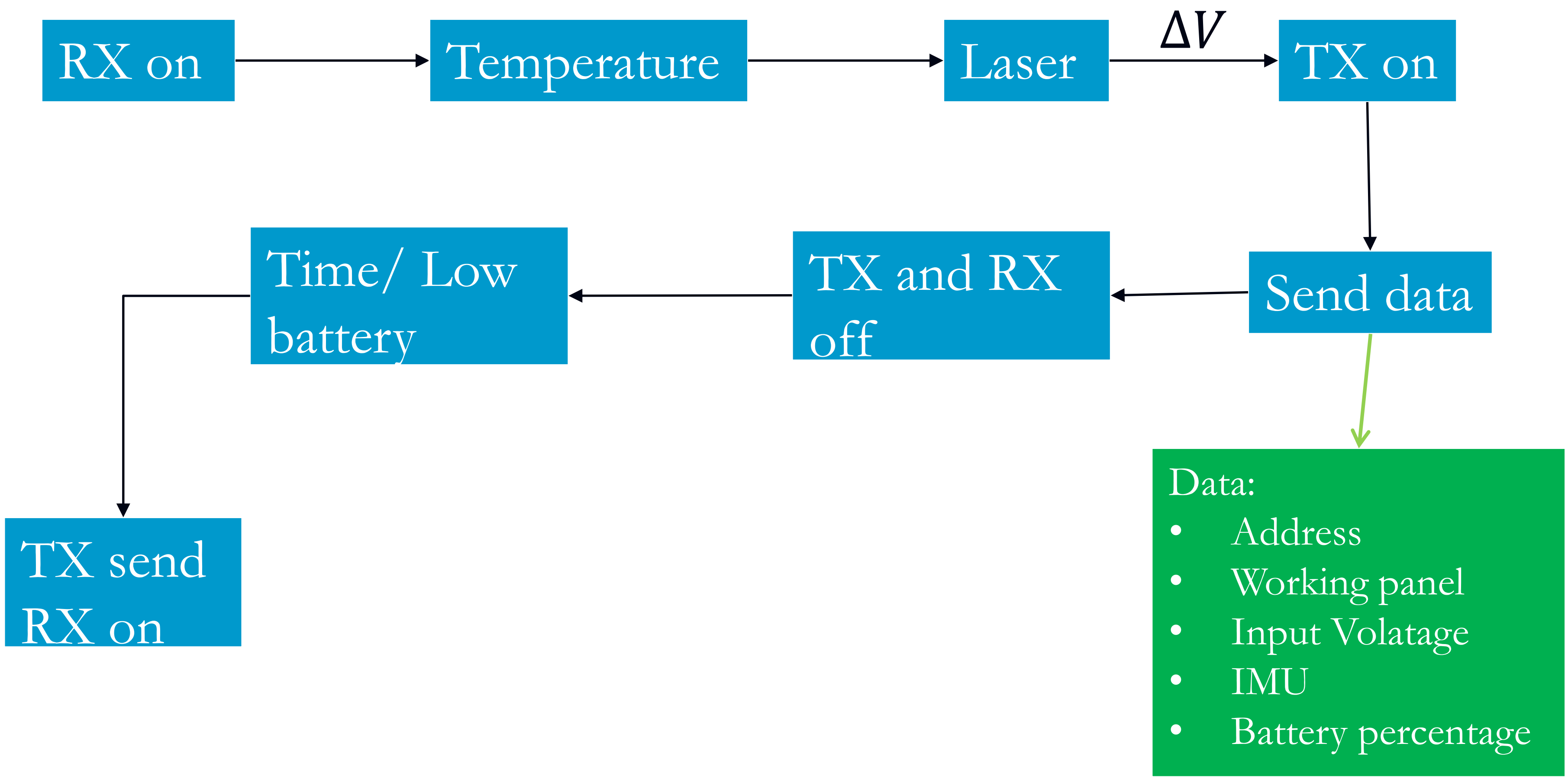
Simplyfied model for thermal anlysis

Radio frequency localization

- Clock transmission and triangulation: too much error. Need new method for localization
- Decawave: DWM1000 – UWB Localization → However, antenna too big
  - Foldable?

Option for new development

Arduino platform



Discussion

- Future work:
  - Close future: build a model for laser testing
  - Iterate on the thermal design to minimize power consumption
  - Upgrade the FemtoSat equipment to perform more complex mission.
  - Locate the FemtoSat

Conclusions

- Improvement in technology gets us closer to FemtoSat design
- Highly coupled systems but feasible design
- Attempt to extend solar panel miniaturization
- Limited working temperatures range

SpaceTREx

LABORATORY

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