

SWaP optimization for portable instrumentation

Iván Morales

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What is this talk about?

- SWaP optimization: what is it and why?
- SWaP optimization: challenges and limitations
- SWaP optimization: strategies
- SWaP for portable instrumentation
- Beyond SWaP optimization
- The good, the bad, and the ugly...

SWaP optimization

What is it and why?

What is SWaP optimization?

Size, Weight, and Power

- Reduced volume
- Reduced weight/mass
- Reduced power consumption

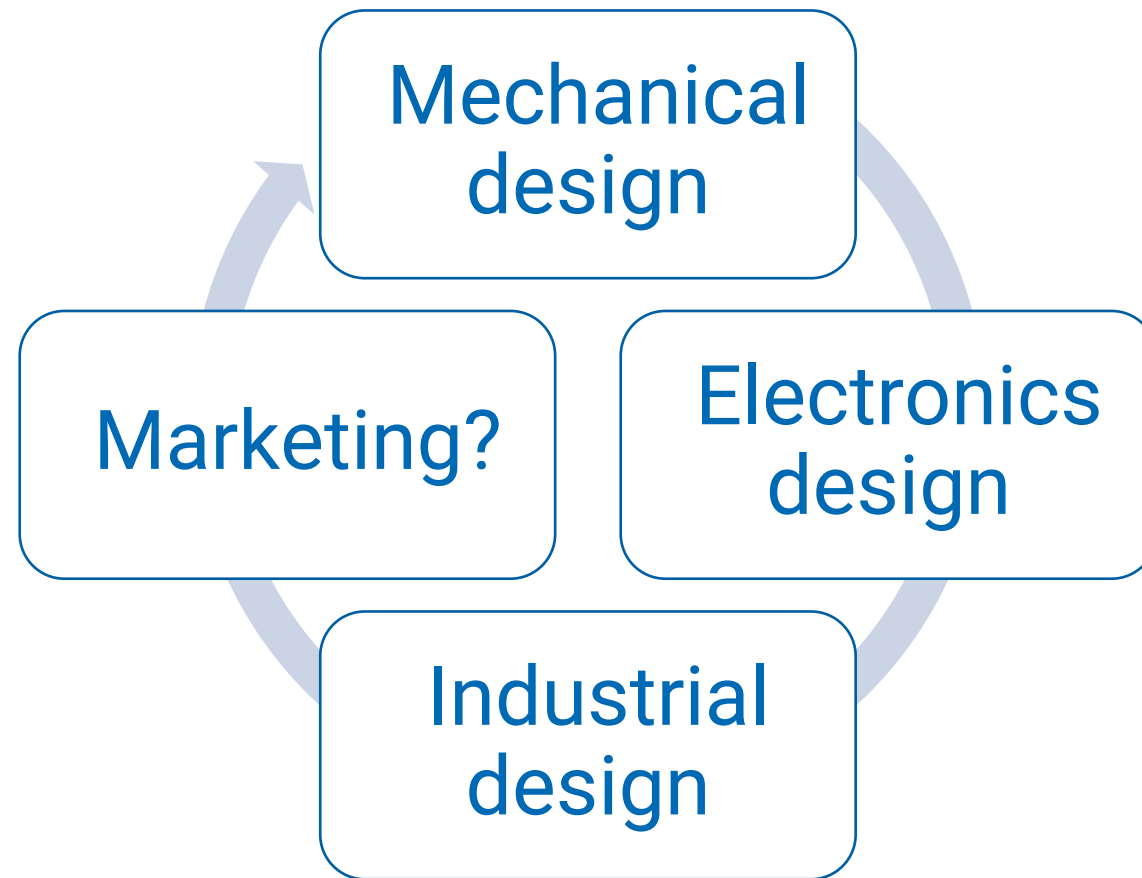
Without compromising

- Performance
- Reliability
- Accuracy



What is SWaP optimization?

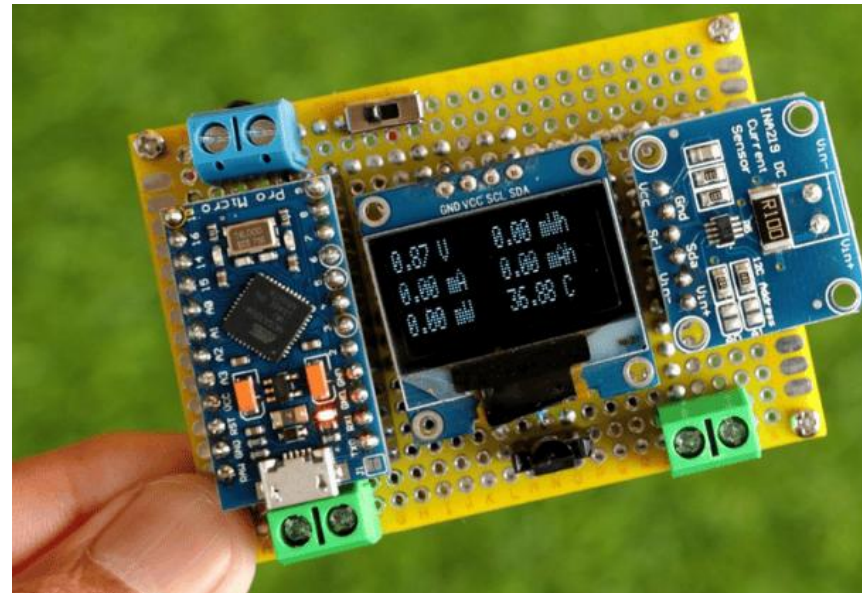
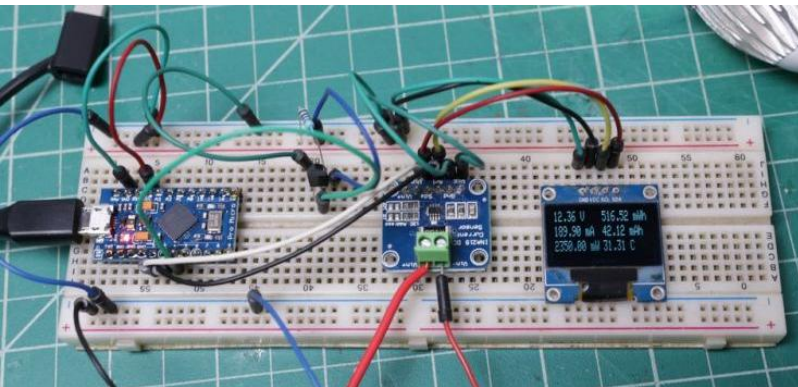
Not a simple engineering task



Why SWaP optimization?

From the Lab to Low-SWaP →

- Field deployment
- Psychological barrier: “2-lb rule”
- Avoid burning the user’s hand
- Practical battery life



SWaP optimization Challenges and limitations

What cannot be SWaPed?

What can't you give up?

- Safety
- Reliability
- EMI compatibility
- Accuracy/sensitivity
- Ergonomics (sometimes)



Low-SWaP challenges

- Physical constraints
 - Heat dissipation
 - EMI compliance
- Portability
 - Transportable $\neq$ portable
 - Battery life, ergonomics
- Innovation
 - Edge computing (Edge AI)
 - Faster, smaller, lighter, longer battery life



SWaP optimization Strategies

SWaP optimization strategies

The SWaP optimization golden rule

Reduce **power** consumption to automatically achieve:

1. Smaller batteries
2. Reduced **weight**
3. Smaller active cooling (or totally passive)
4. Lighter enclosure
5. Reduced overall **size**



SWaP optimization strategies

Electronics

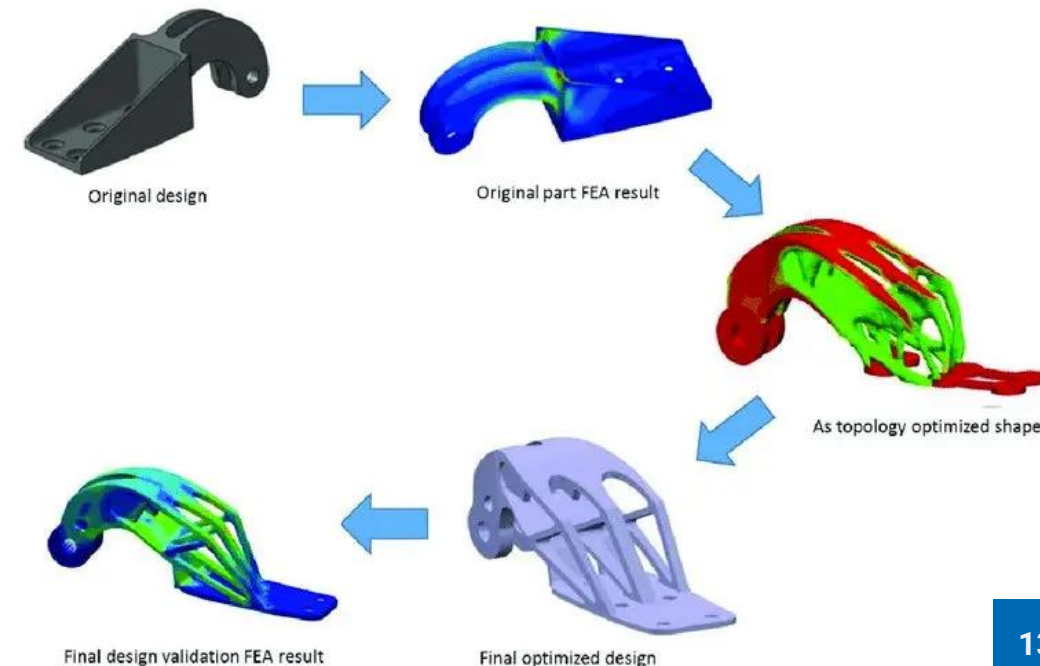
- Highly integrated components (S, W, P)
 - System-on-chip (SoC)
 - FPGAs
- High-density interconnections (S, W)
- Aggressive sleep states (S, W, P)
- Switched over linear regulators/amplifiers (P)
- Flexible circuit boards (S, W)



SWaP optimization strategies

Mechanical design

- Topological optimization w/FEA ([W](#))
- Enclosure materials: carbon-fiber, magnesium alloy ([S](#), [W](#))
- 3D prints: optimize infill pattern and density ([S](#), [W](#))
- Passive cooling ([S](#), [W](#), [P](#))



SWaP optimization strategies

Industrial design

- Organic components arrangement (S, W)
- Apparent weight reduction (W)
 - Heavy components near the user's hand
- User interfaces (S, W, P)
 - Touch instead of physical buttons
 - OLED or ePaper screens
 - Smartphone apps instead of screens



SWaP optimization strategies

Marketing (industry or academia)

Sell the SWaP optimization as premium upgrade.

1. Polished stainless-steel enclosure ([W?](#))
 - Not lightweight, still premium feeling
2. Sell the next year an upgraded titanium enclosure ([W!](#))
 - Now lighter becomes more premium



Low SWaP in portable instrumentation ALARA for SWaP

SWaP for portable instrumentation

Even more than only SWaP

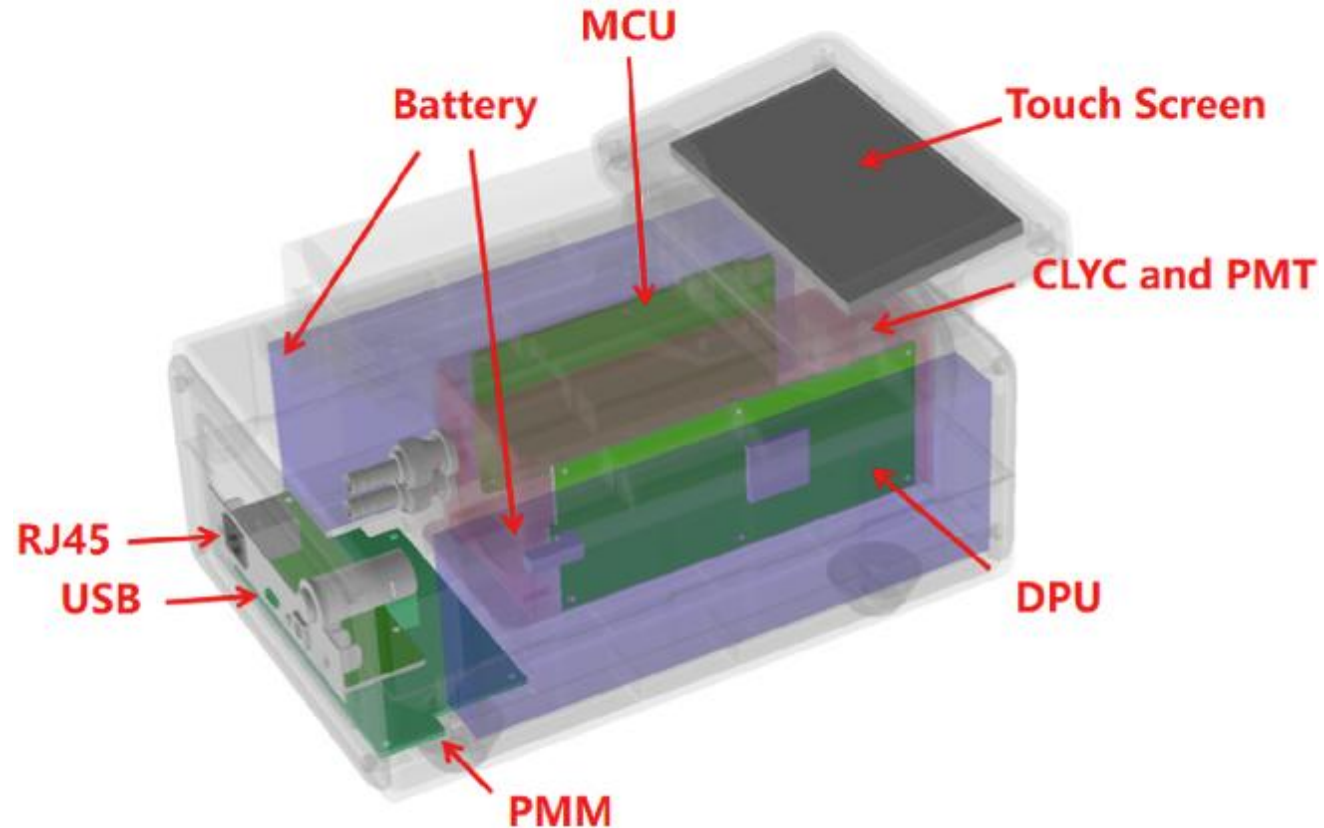
- IP ratings
- Medical certifications
- Military specifications
- Radiation tolerance
- Sensitivity/accuracy
- Performance



ALARA for SWaP

Performance over SWaP

- Gamma/neutron dose-rate meter
- Single detector for mixed radiation fields
- Weights almost **5 kg**
- Volume ~ **4 Liters**
- Long battery life
- High spectroscopic resolution
(4.86% @ 662 keV)
- High dynamic dose rate range (100 nSv/h - 6 mSv/h)



Mechanical design of g/n dose-rate meter. Picture from [1]

ALARA for SWaP

Endurance over SWaP

- IP66 rating: outdoors deployment
- Single detector for mixed radiation fields
- Weights almost **5 kg**
- Volume ~ **1 Liter**
- Onboard communications
- High spectroscopic resolution
(4.86% @ 662 keV)
- Temperature ranges from -15°C to +40°C

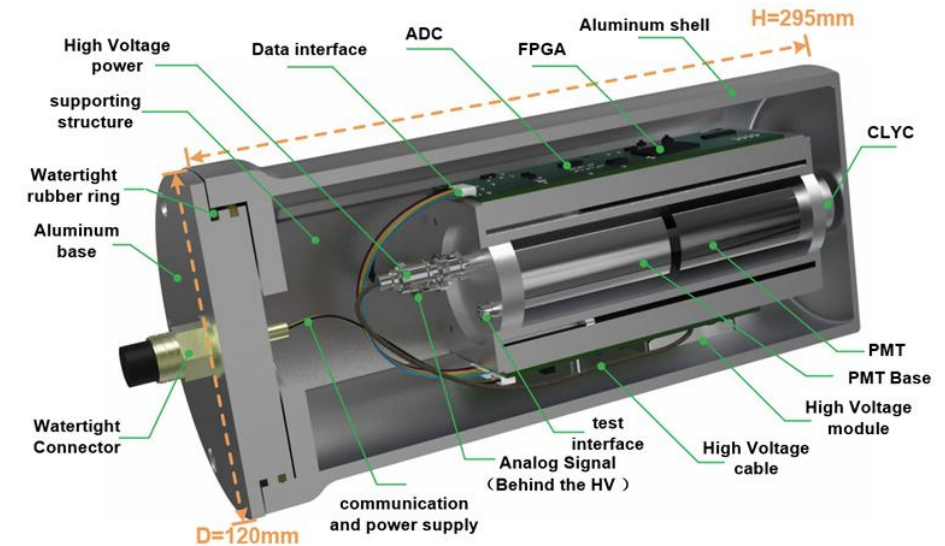
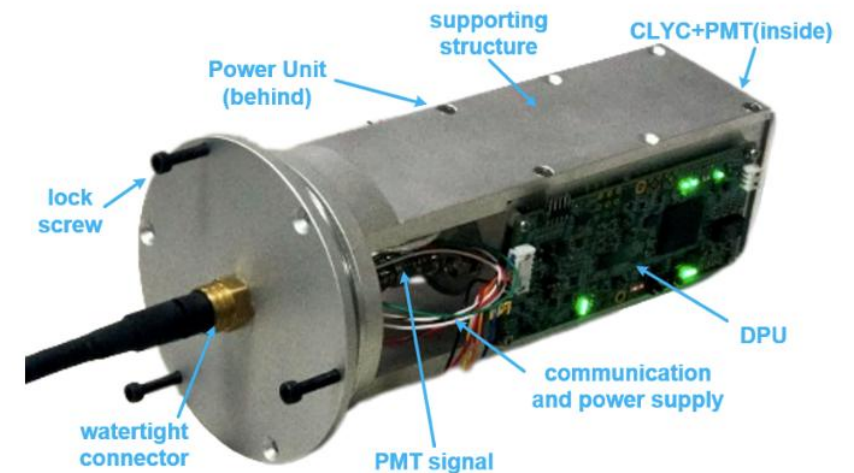


Figure 1. Cross-sectional diagram of the 3D mechanical model of the detector.



Mechanical design of g/n detector
for environmental monitoring.
Picture from [2]

ALARA for SWaP

SWaP over performance

- Poor dynamic gamma dose rate range (10 nSv/h - 250 μ Sv/h)
- Poor gamma energy range up to 1.3 MeV
- Without spectroscopic features
- Single detector for mixed radiation fields
- Excellent battery life: > **300 hrs**
- Weights only **160 g**
- Volume < **0.2 Liters**

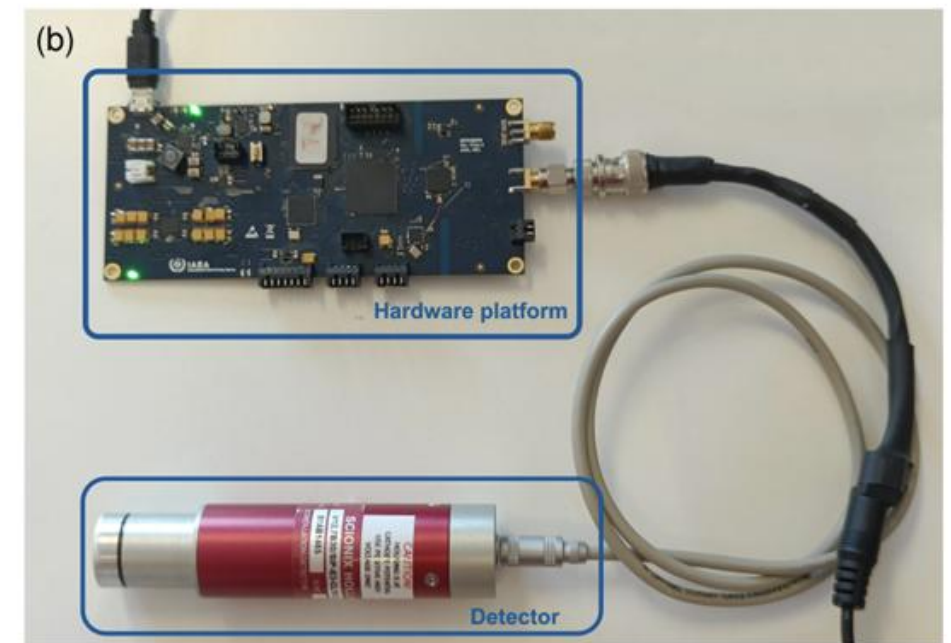
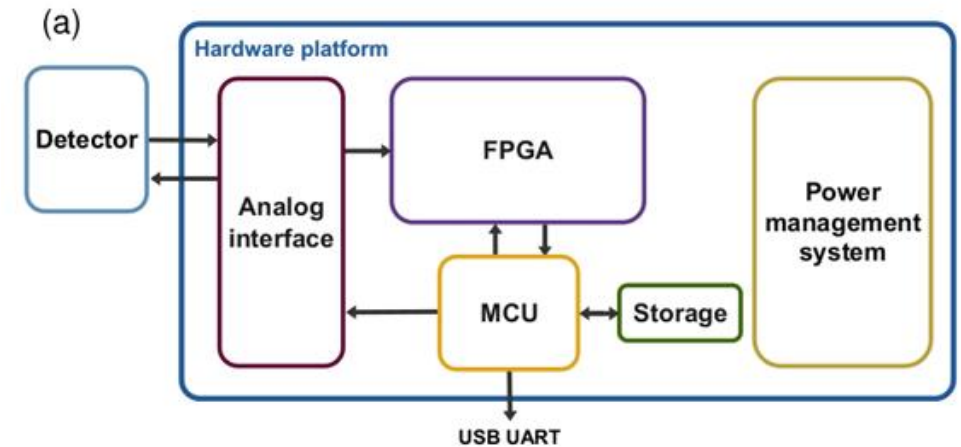


RadEye G/N+ Gamma/neutron pager
from ThermoFischer Scientific

ALARA for SWaP

Balance of SWaP & performance

- Average dynamic count-rate range (< 400 kcps)
- Acceptable energy resolution (~6% @ 662 keV)
- Single detector for mixed radiation fields
- **ML-enabled**: Pile-up rejection and recovery
- Average dead-time: < 2.5 μ s
- Low power consumption: **1.5 Watt**
- Weights **410 g**
- Volume < **0.6 Liters**



G/N online discrimination system with ML for pile-up recovery in high event-rates [3].

The absolute SWaP benchmark for instrumentation

CubeSat nanosatellites

- Power harvesting and management
- Heat dissipation (no convection)
- Low weight and volume
- Communications
- Instrumentation
- Attitude/orientation actuators

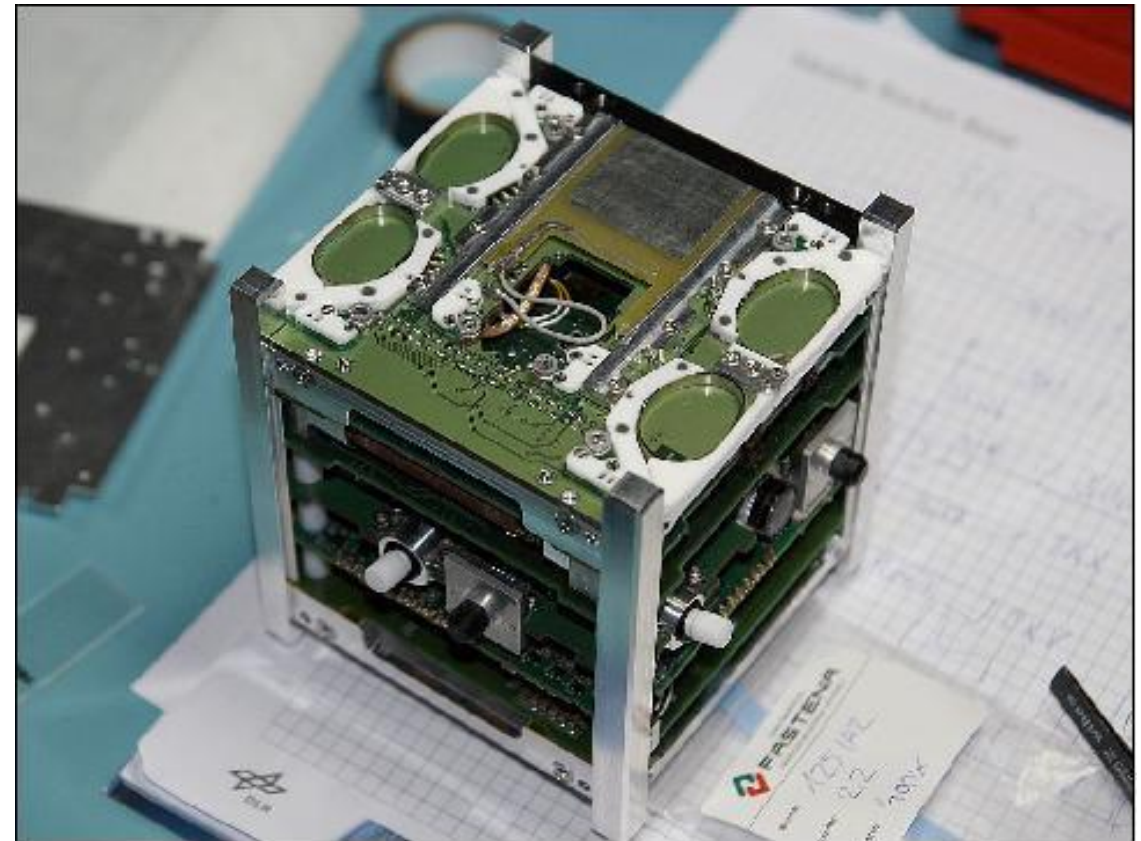


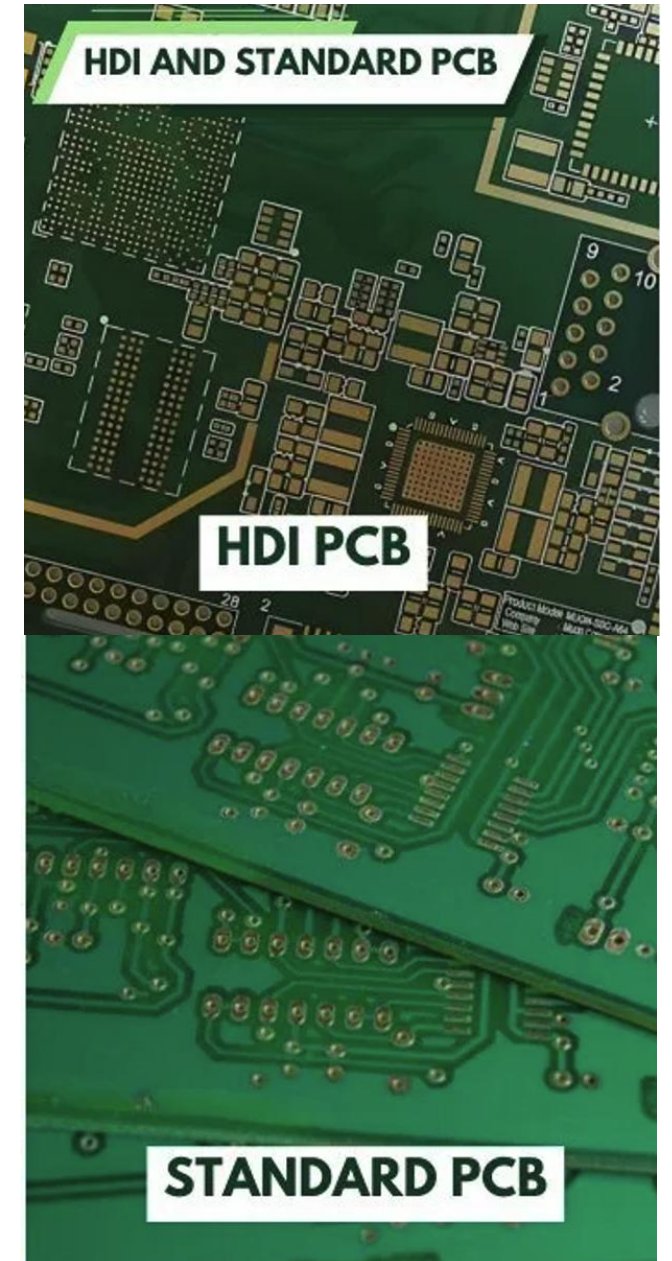
Photo of the skCUBE satellite with antennas wound up in ellipsoid containers
(image credit: skCUBE team)

Beyond SWaP optimization

Beyond SWaP

SWaP-C (costs)

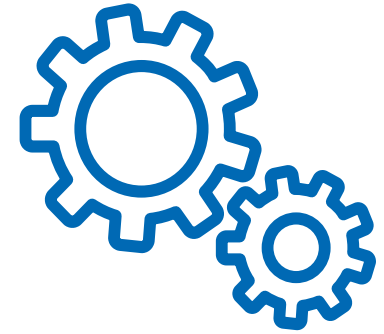
- "Good enough SWaP" might be the best SWaP-C
- Non-recurring Engineering (NRE): R&D, validation
 - Improvements via firmware and software
- Optimize for mass production: BoM, volumes
 - Commercial off-the-shelf (COTS) preferred over custom
 - Magnesium alloys and carbon-fiber become prohibitive
 - Injection-moulded ribbed plastics and FEA optimizations



Beyond SWaP

SWaP-P (performance)

- Usually mutually exclusive
- Custom if COTS not available
- System-on-Chip (SoC) can replace individual microcontrollers/RF/FPGA
- Latency, detection rate, detection resolution, communication range
- Practical example: [3] overtakes the overall SWaP-P metrics of [4]



The good, the bad, and the ugly...

... of SWaP optimization

The good	The bad	The ugly
Base platforms (frame.work computers)	Custom devices	Planning
State-of-the-art contribution	Low production volumes	Longer iterations



Ivan Morales

I.Morales-Argueta@iaea.org

References

- [1] Huang, Y., Zhao, K., Shan, C., Feng, C., Wang, Y., Wang, Z., ... & Liu, S. (2025). Development of a CLYC-based wide dose rate range portable neutron-gamma detector. *Applied Radiation and Isotopes*, 217, 111629. doi: 10.1016/j.apradiso.2024.111629
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- [3] Morales, I. R., Molina, R. S., Bogovac, M., Jovalekic, N., Crespo, M. L., Kanaki, K., ... & Carrato, S. (2024). Gamma/neutron online discrimination based on machine learning with CLYC detectors. *IEEE Transactions on Nuclear Science*, 71(12), 2602-2614. doi: 10.1109/TNS.2024.3498321
- [4] Michels, N. M., Jinia, A. J., Clarke, S. D., Kim, H. S., Pozzi, S. A., & Wentzloff, D. D. (2023). Real-time classification of radiation pulses with piled-up recovery using an FPGA-based artificial neural network. *IEEE Access*, 11, 78074-78083.