Nibbles

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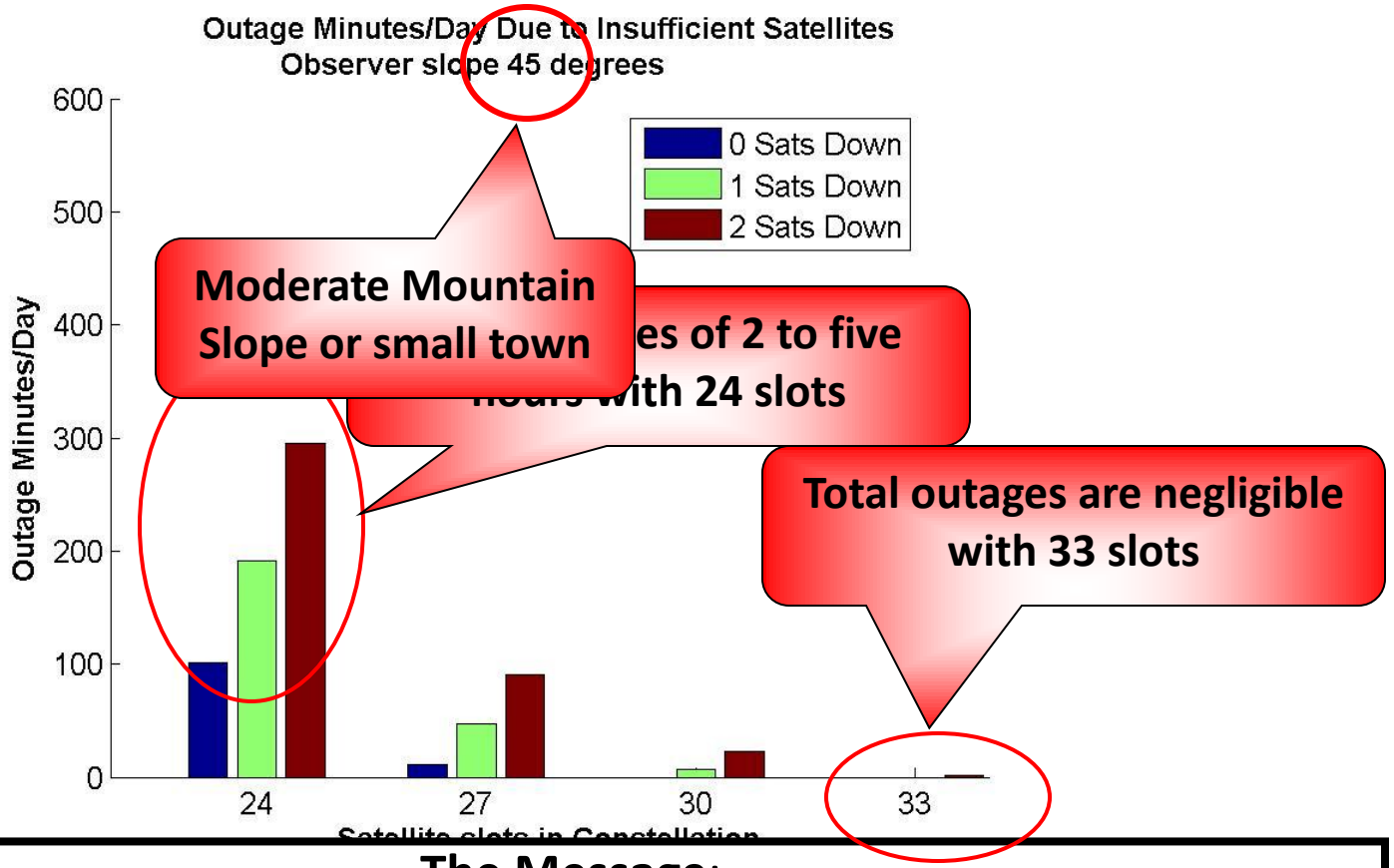
Three Essential Attributes for any GNSS: the Three A's.

- **A**vailability (Metric- minutes of ***unavailability per day***) Drivers:
  - Satellite Geometry
  - Clear and truthful Reception
- **A**ffordability – (Metrics: 1. Total Amortized ***cost per satellite-year*** [on orbit], 2. Cost of User Equipment [with req. interference resistance])
  Drivers:
  - Cost of Satellite (driven by complexity and SWAP)
  - Cost of Booster and Satellites/Booster
  - Satellite Lifetime
- **A**ccuracy – (Metrics: 1. **PNT 2σ accuracy** , 2. **Inaccuracy "bound"** (3 or 4σ), 3. "Integrity" - Probability that PNT Safety of Life value [10^{-7} ?] is exceeded)
  Drivers:
  - Satellite Geometry
  - Ranging Accuracy

Geometric (un)Availability is strongly dictated by number of slots in GPS Constellation

Geometric Availability: First Measure of Effectiveness

(Unavailability of GPS due to Constellation size and *Moderate* Terrain or obstructions)

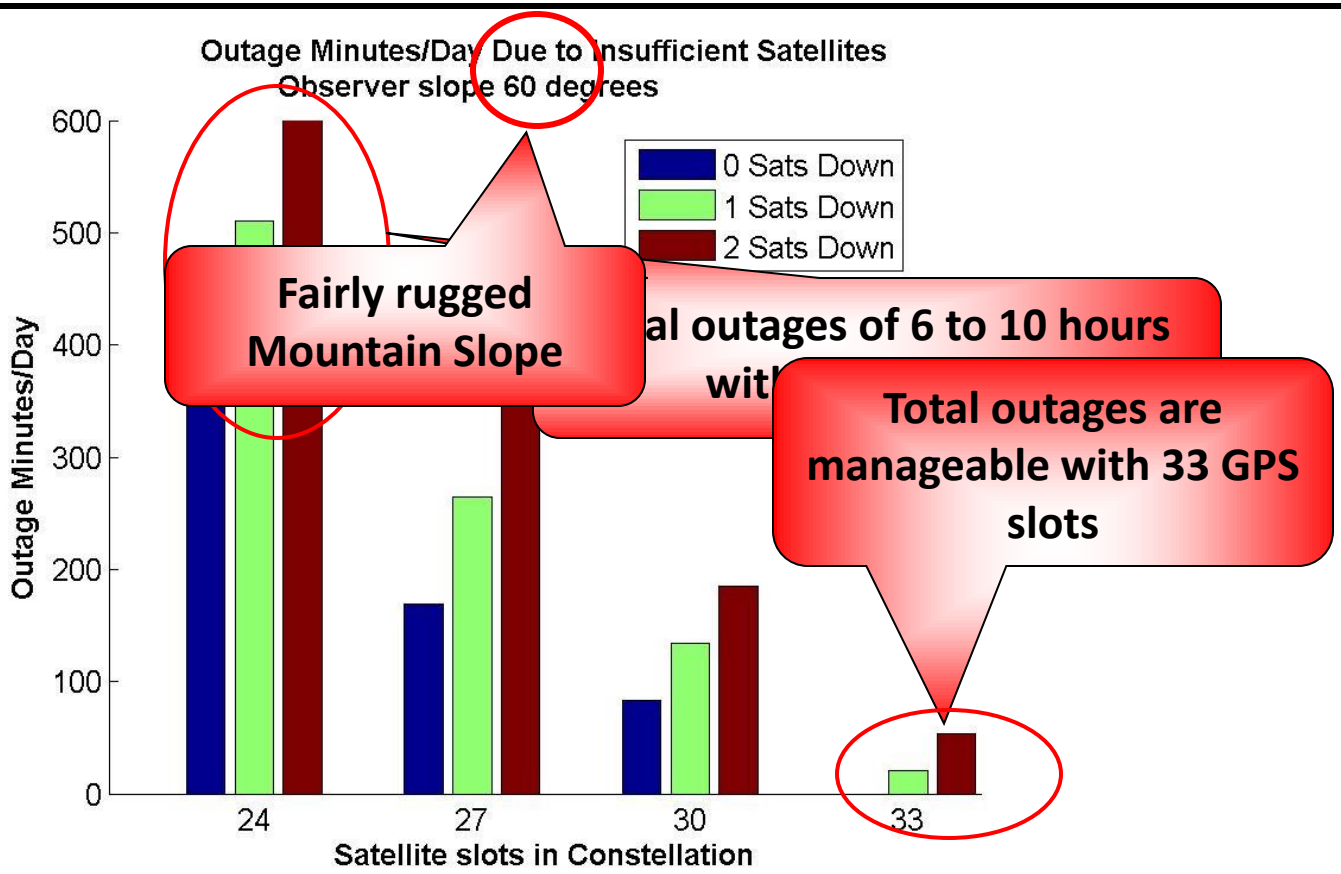


The Message:

Require at least a 30 slot constellation for reasonable availability for a *"sky-impaired"* GPS user in typical small town or mountain terrain (and possibly on airports near buildings)

First Measure of Effectiveness

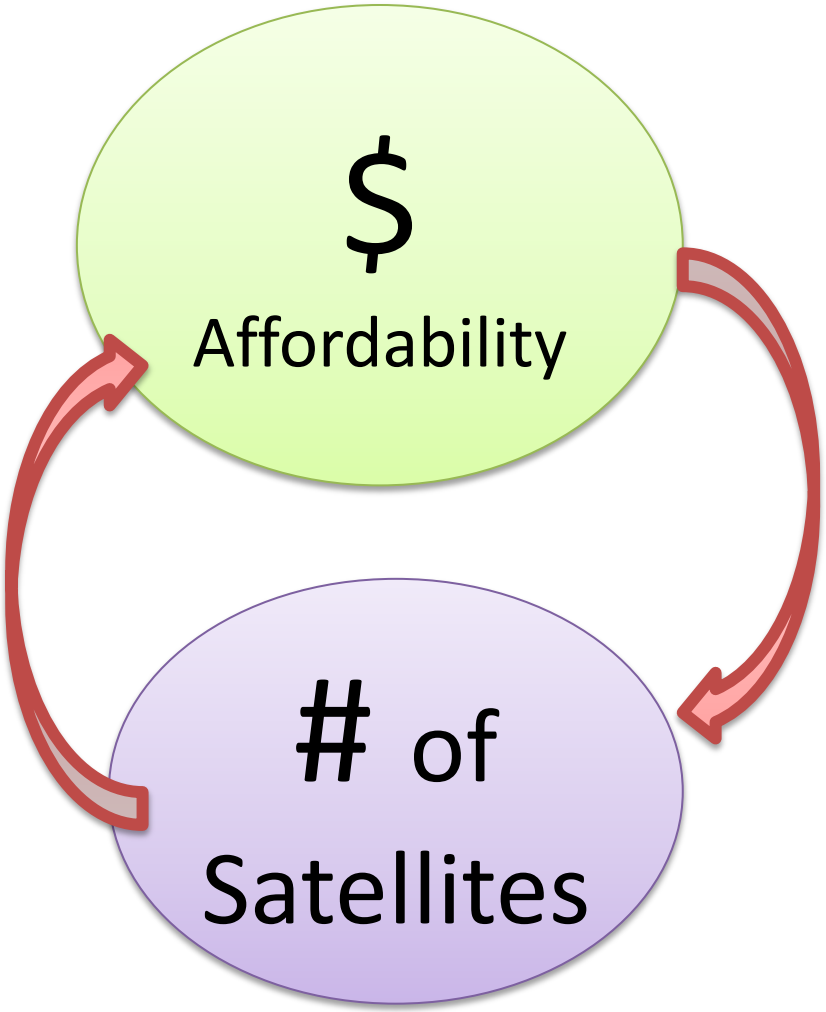
(Unavailability of GPS due to Constellation size and *Steeper* Terrain)



The Message:

A ***33 slot constellation*** is required for reasonable availability when user is *"sky impaired"* in cities or rugged terrain

Affordability and *Geometric* Availability *Co-Dependency*



Simplistic Math

If: Cost/Sat = $C_{SAT + LAUNCH}$

Then ~

#/Year = (Budget/Year)/C

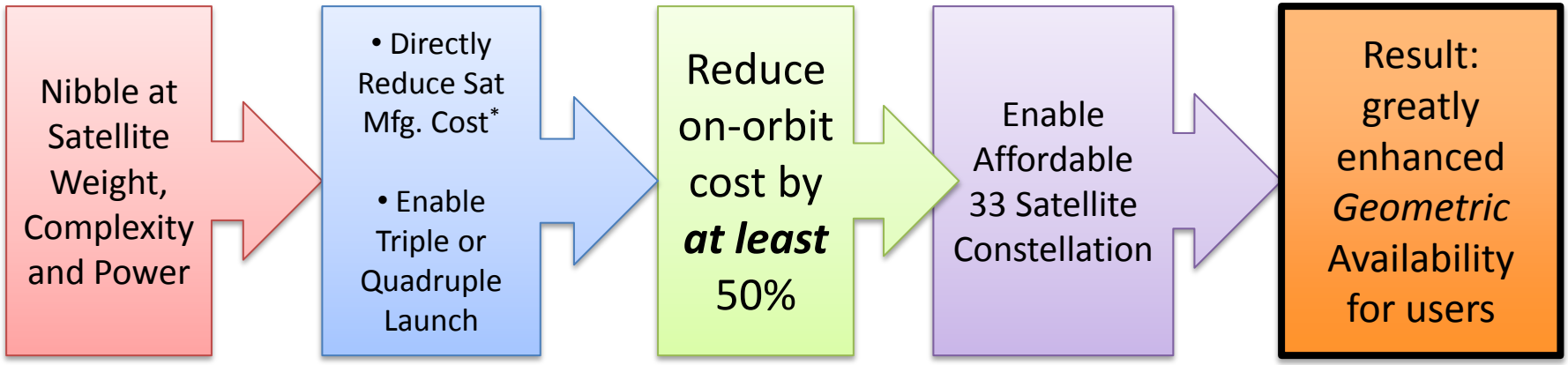
Or

(#/Year) * C ~ Constant

(Inversely Proportional)

First set of Nibbles (aim for 33+X sats):

- **Guidelines**
  - 15 to 18 Full-up Satellites
  - The Nibbles: additional 15 to 18 GPS only Satellites,
    (***all*** Navigation signals but no surge power or addl payloads except laser reflectors)
- **Goal**
  - Greatly Reduced Cost per Satellite year ***on-orbit***
- **Approach**:



* Could be an inexpensive single sat booster as well

Nibbles – Satellite SWaP

Design Architecture

- Only “additional” payload is Laser Reflector
- Smaller Commercial Bus

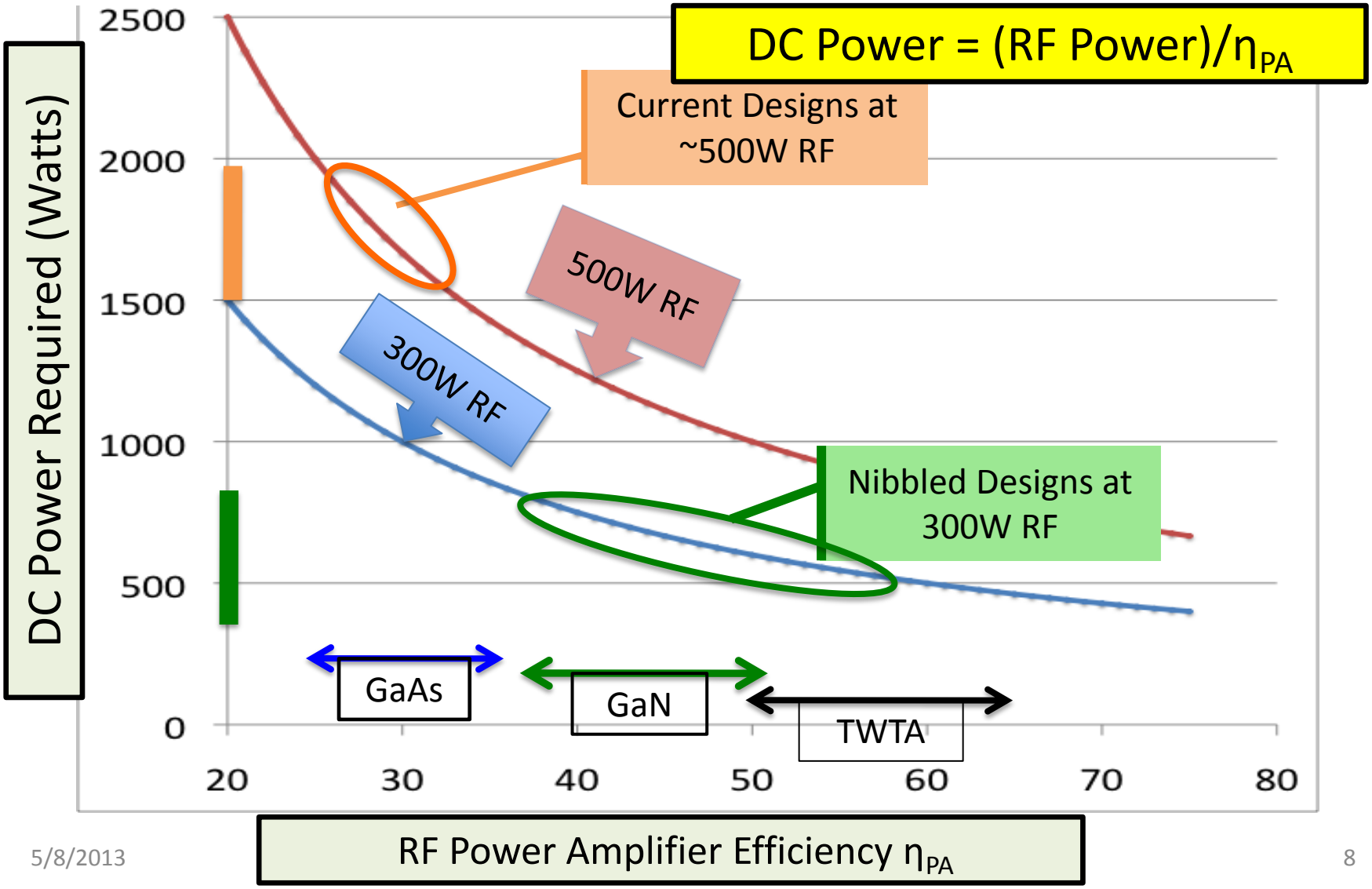
Power Requirements (Current Payload ~2200W)

- Shading Angle Spec 5^{o} changed to 20^{o}
  - With affordable 30+X, many Satellites above 20 degrees
  - Reduce Satellite antenna complexity (12 to 4 Elements?)
  - Total Power reduced ~ 0.6 dB
- Spec RF Power at 20^{o} Elevation reduced by 1.5dB
- Total reduction 40% (2.1dB)

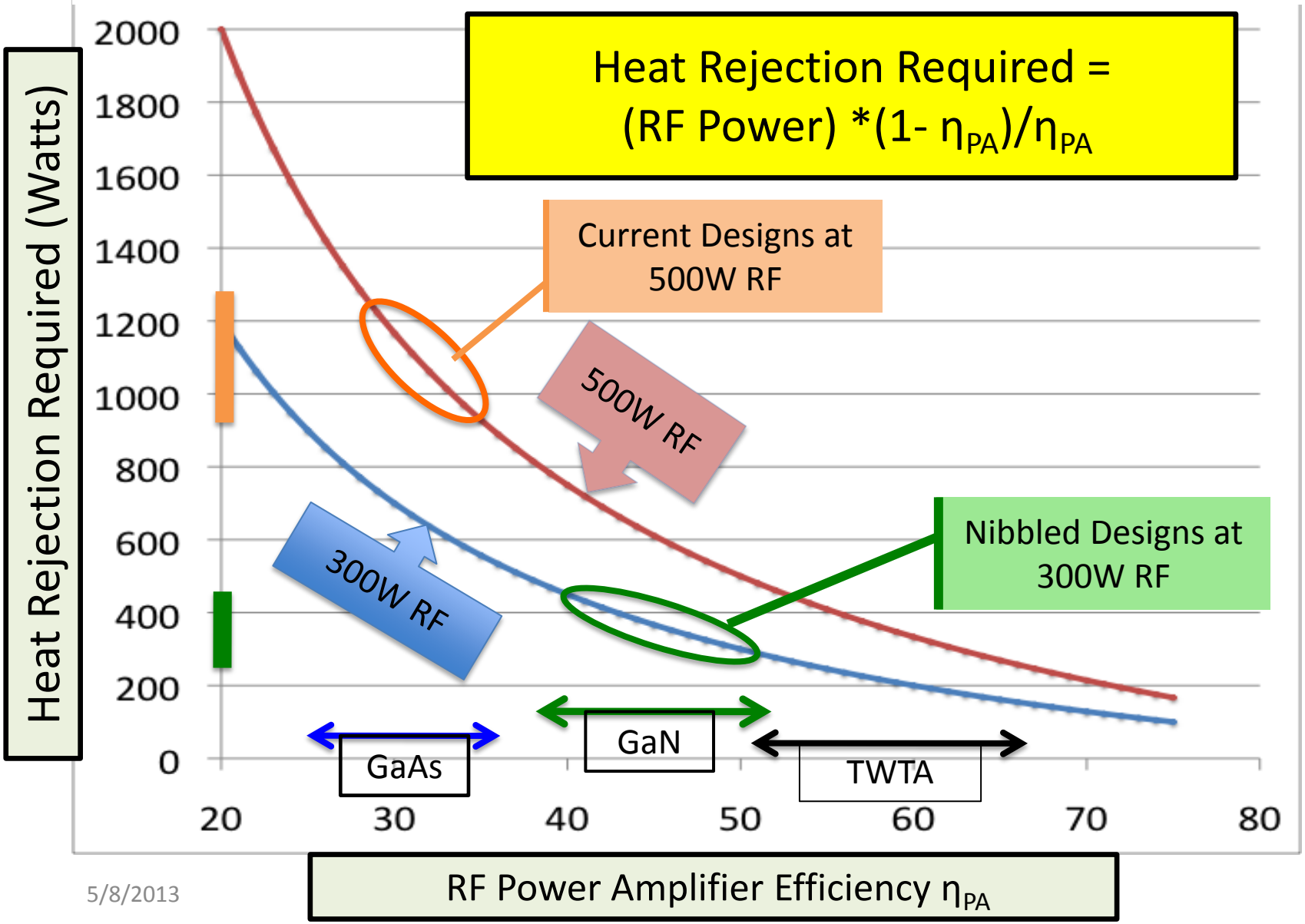
RF Power Conversion Efficiency

- Convert from GaAs (25-30%) to GaN (35-50%) or TWTAs (50-65%)

Solar Array Power for Various Amplifier Efficiencies- (η_{PA})



Nibbles can greatly reduce the Satellite Heat Rejection Requirement



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- Power Efficiency
  - Convert from GaAs (30%) to GaN or TWTAs
- Additional Nibbles
  - Lithium Ion Batteries
  - State of Art Solar Array Efficiency
- Power Reduction leads to Proportionate Overhead Reductions
  - Battery Size
  - EOL Reserves for Solar Array
  - S/A Failure Reserves and Design Margin

Cautions and Decisions

- Must Maximize use of “existing” designs and components
- Some “overhead” is hard to shrink
- TWTA’s
  - Subtle consequences for a Nav Ranging Signal?
- Degrees of
  - Hardening
  - Redundancy (Design Life)
- Nibblesats do not have added payloads

Estimated Value of Nibbles

(All in Brad $, exact exchange rates to US$, Euros or Yen not determined)

Type	Satellite Cost (Amortized)	Sats/ Booster	Booster Cost	"C" Cost of Sat on Orbit	~Number of Sats for $500M/yr
Current	$220M	1	$230M	$450M	~ 1
III Dual	$220M	2	$240M	$340M	~1.3
"Nibbled"	**$60M**	**2**	**$200M**	**$160M**	**3**
	$55M	**3**	**$210M**	**$125M**	**4**
	$50M	**4**	**$240M**	**$110M**	**Almost 5**

The argument for NibbleSats

- At $450M/$150M, can trade 3 for 1, incremental cost.
- If basic is 18 IIIAs at 450M*18 = $8.1B
- Alternatives for Additional Satellites
  - 6 IIIAs at $450M = $2.7B (total 24 Sats)
  - 12 NibbleSats at $150M = $1.8B (total 30 Sats)

What about the small reduction in Radiated power with "nibbled" Satellite?

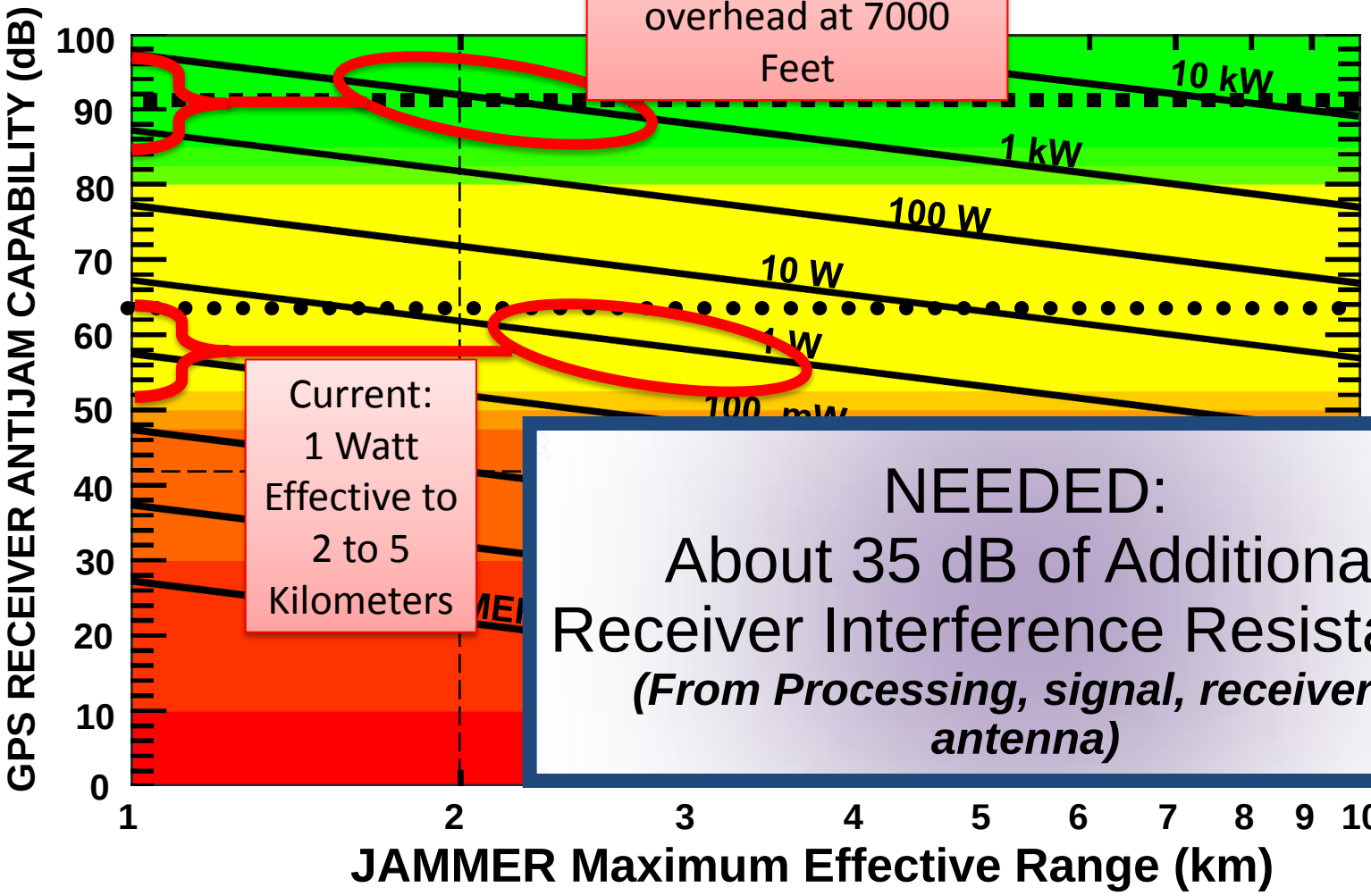
- **A**vailability (Metric- minutes of ***unavailability per day***)
  - Geometry
  - ***Clear and truthful Reception***

Leads to Nibbles Part 2

  - Cost of User Equipment (interference resistance)
- **A**ccuracy – Metrics: PNT 2σ, Inaccuracy "bound" (3σ), Probability that PNT Safety of Life value is exceeded ("integrity')
  - Geometry
  - Ranging Accuracy

Payoff of Jam stance

Desired: A ***1kW*** jammer ineffective to Aircraft flying overhead at 7000 Feet



Current: 1 Watt Effective to 2 to 5 Kilometers

NEEDED:
About 35 dB of Additional Receiver Interference Resistance
(From Processing, signal, receiver & antenna)

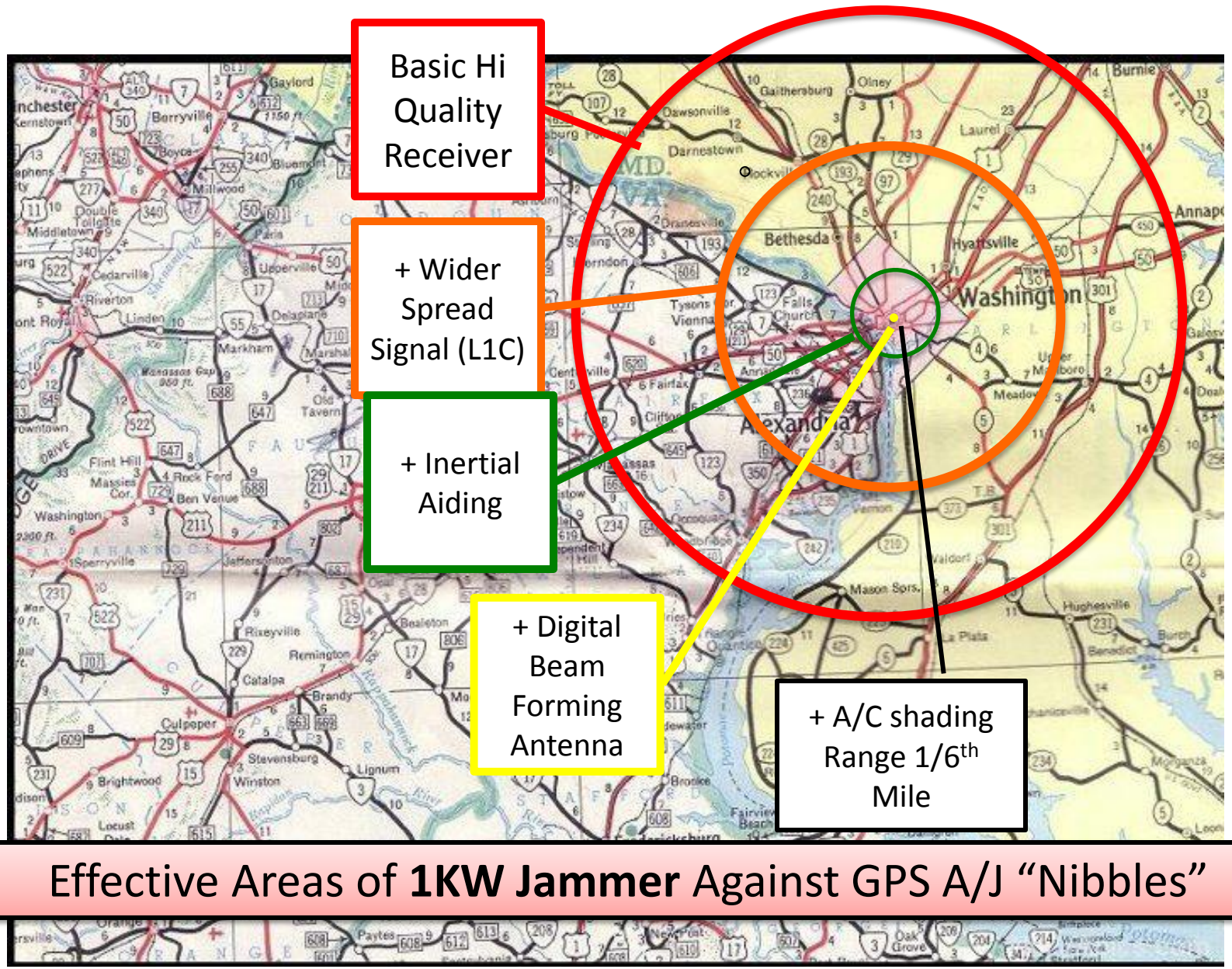
“Nibbles” Part 2 - Jam Resistance Techy-talk

How to get > 35 dB of Improved Receiver Performance ***for Commercial Aircraft***

Technique	Range of improvement
Aircraft Shading	5-10 dB
Inertial And Averaging (MEMS, CSAC, Kasovich Devices)	8-12 dB
Wider Spreading GNSS Signal (e.g. L1C)	5 dB
Digital Beam Forming Antenna	20-30 dB
“Spilker” Vector Receiver (A powerful form of frequency diversity)	At least 10 dB
Potential Total Improvement	**48 –67 dB**

In addition – A credible reliable *backup* should be included:

Recommended **– Either selectively Retained (upgraded) DME or eLoran**



Effective Areas of **1KW Jammer** Against GPS A/J "Nibbles"

Nibbles Part 2 – Considerations for Receiver improvements

- Affordability
  - Safety of Life - vastly different Threshold of $ Pain
  - Synergy with WB Aircraft Antenna Inertial Pointing
  - Expanded market drives down cost (cell phone camera)
- FAA Role – push for Interference-Resistant Receiver Specs
- Industry Role
  - Prototype and Develop Robust Receivers

Summary – Nibbling to improve the Three Essential Attributes

- **A**vailability (Metric- minutes of ***unavailability per day***)
  - Deploy ~ ½ Nibbled Satellites for ≥ **30+X constellation**
  - Focus on Nibbled Technology for Receivers
- **A**ffordability – Metrics:
  - Nibble on size weight and power to insure **multiple-Launch**, Affordable Satellites
  - Ride ***Digital Wave*** for Beam Steering plus Vector Receiver
- **A**ccuracy – Metrics: PNT 2σ, Inaccuracy "bound" (3σ), Probability that PNT Safety of Life value is exceeded ("integrity')
  - Affordability leads to **Improved Geometry** (Esp. Sky Impaired users)
  - Multiple Frequencies and L1C Improves Ranging Accuracy

Accolades to Groups developing "Nibbling" Plans and Programs to improve the 3 A's

- The GPS Directorate at SMC
- Various Contractors
- Advocacy by GPS IRT
- Support by USAF Space Command

Questions?

Payoff of Jamming Resistance