

# Emergency Locator Signal Detection and Geolocation Small Satellite Constellation Feasibility Study

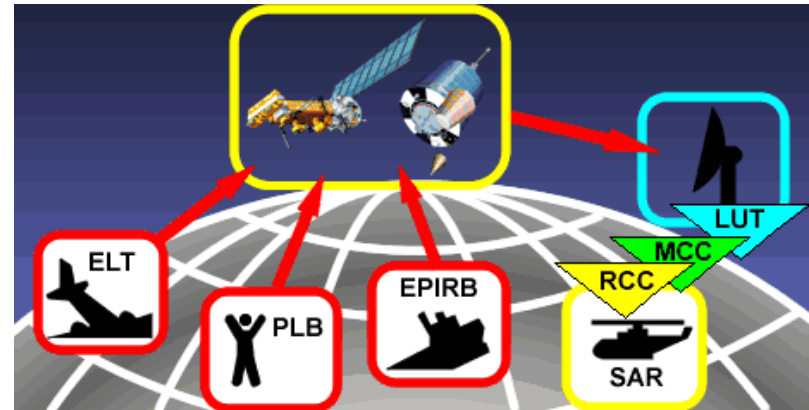
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# Background

## Aircraft Emergency Locator Transmitters (ELTs)

- Vital in helping search and rescue (SAR) teams in locating downed aircraft.
- Uses Cospas-Sarsat constellation.
- Two beacon types
  - Legacy 121.5 MHz beacons
    - No longer satellite supported
    - 97% false alarm rate
    - 20 km accuracy
    - Estimated that 170,000 aircraft around the world still operate.
  - Newer 406 MHz beacons
    - Satellite supported
    - Mandated for commercial use
    - Transmits user specific ID code
    - Some but not all models are GPS capable.



*Small satellites have the capability to fulfill the need for a detection and geolocation satellite constellation (DGSC) due to their low-cost and easily duplicated platform.*

# Requirements

- The DGSC coverage region shall be defined as the surface of the Earth between 70° N latitude to 70° S latitude.
- The DGSC shall detect 121.5 MHz, 0.1 W and 406 MHz, 5 W ELT signals originating in the coverage region.
- The DGSC shall estimate beacon position within 1 km and communicate this data to local user terminals within 15 minutes of signal detection.
- The DGSC shall provide a revisit period within 60 minutes to all points inside the coverage region.

# Mission Risks

## 1. Mission Applicability:

- Diminished demand for 121.5 MHz locator beacons
  - Commercial aircraft mandated to switch frequencies.
  - Many private aircraft are switching to 406 MHz beacons.
  - FCC proposed mandated switch
    - Stopped by FAA and private pilot organizations.

## 2. Software Development:

- Possible hurdles involving the algorithms needed for on orbit geolocation calculations.

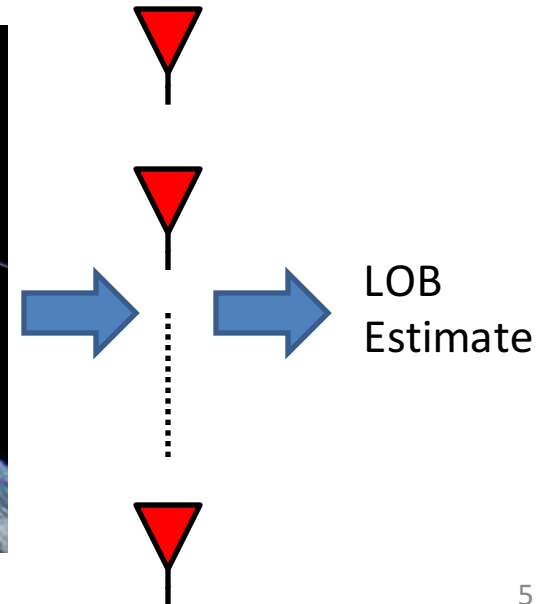
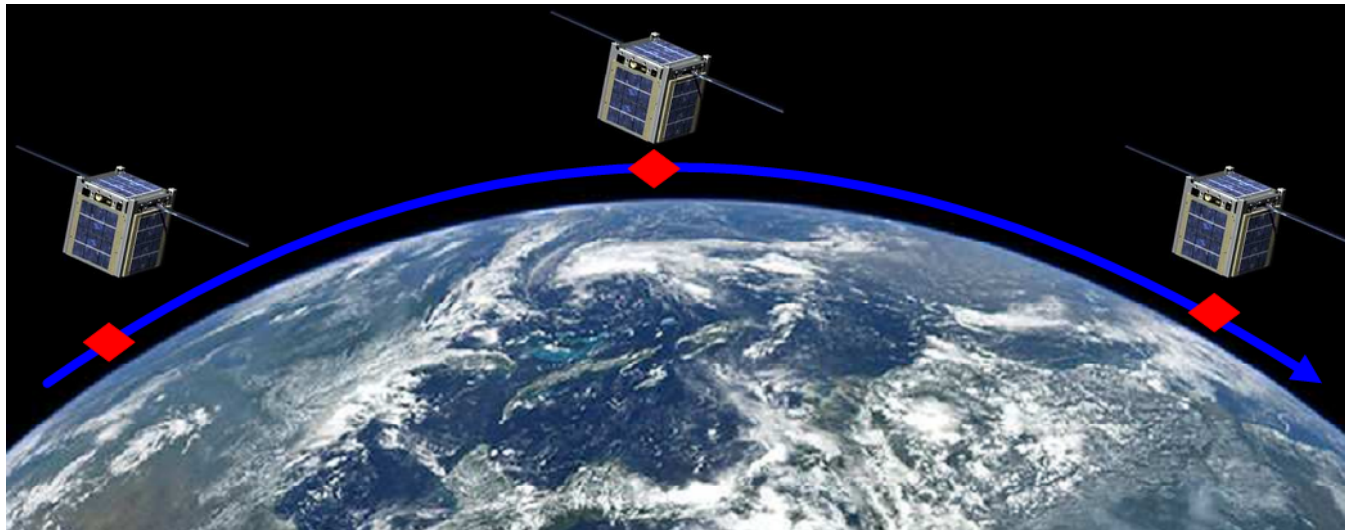
# Geolocation Method

Geolocation is determined by:

- Synthetic Linear Array
- Direction-of-Arrival (DOA) algorithms
- Line-of-bearing estimate (LOB)

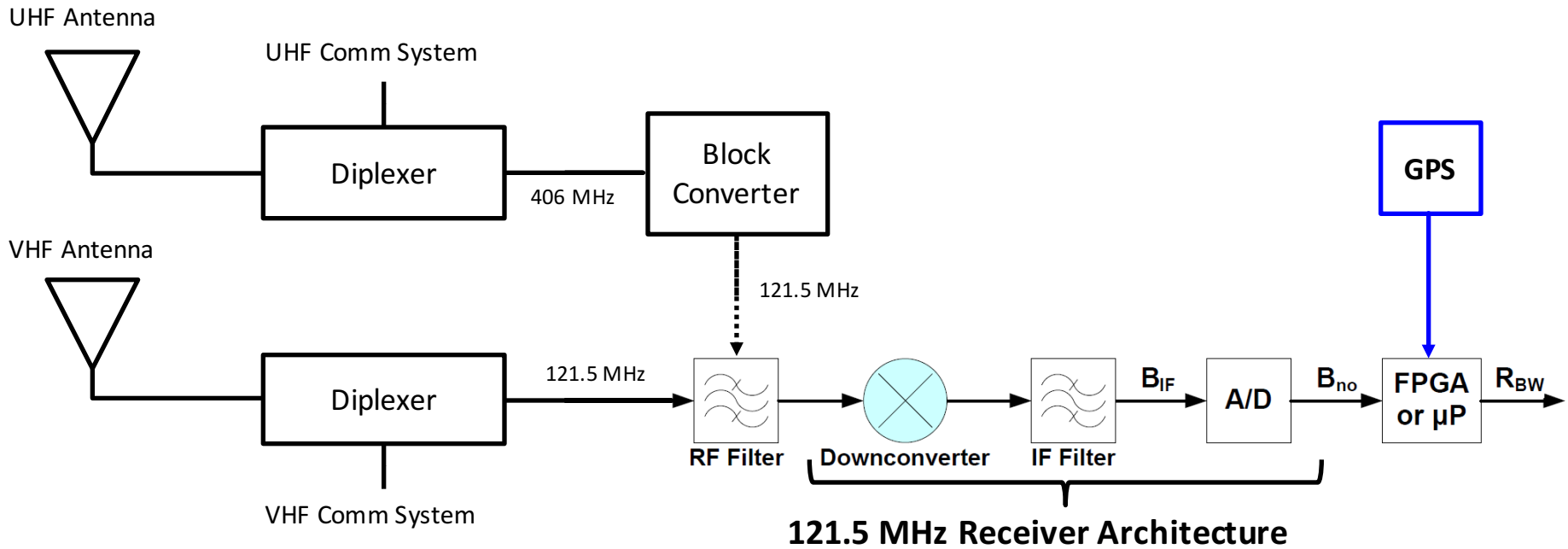
Final location within 1 km can be determined by:

- Using triangulation from multiple satellite passes



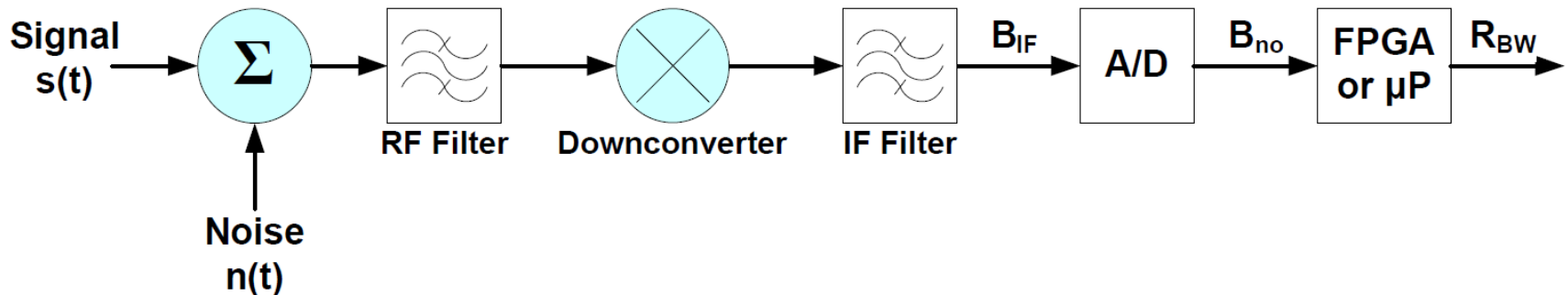
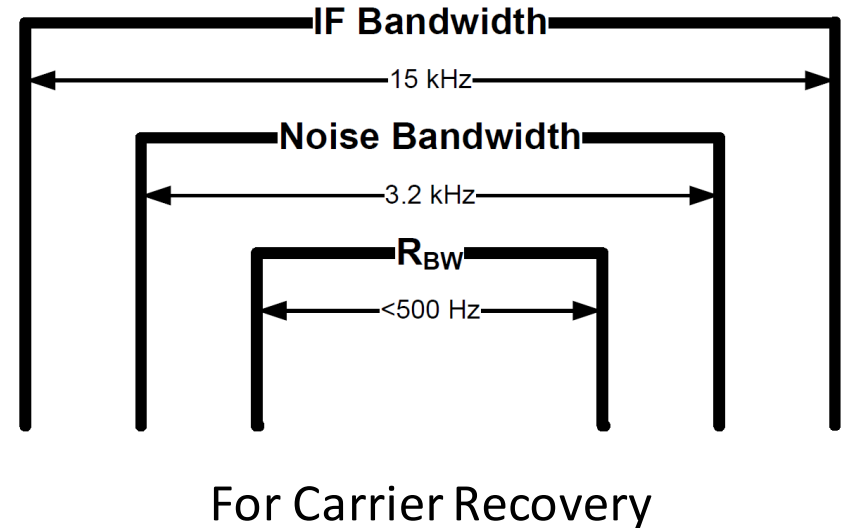
# Receiver Payload

- Each frequency has a different beacon structure and transmission power
- Shared receiver architecture to reduce the amount of electronics and hardware needed for both frequencies
- Shared antennas with the satellites normal Telemetry Tracking & Control Comm System to reduce need for additional antennas
- Digital Signal Processing (DSP) will differ for each beacon type



# Receiver Payload

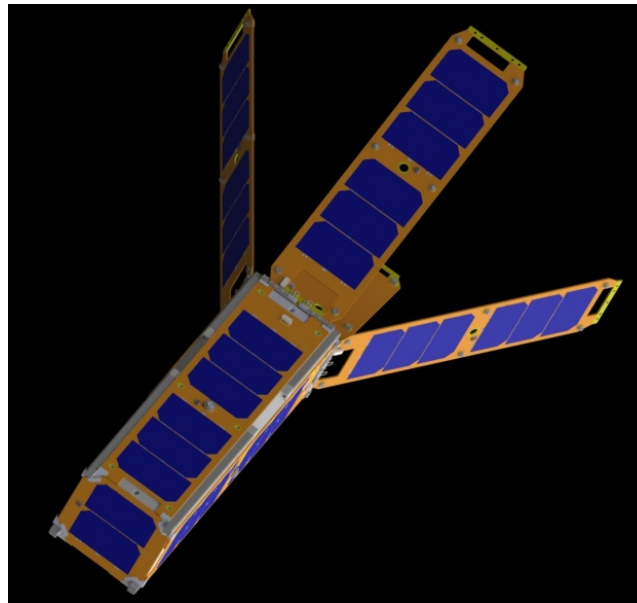
- 121.5 MHz ELT
  - A3X modulation
  - AM carrier
  - 1600 to 300 Hz “chirp” 📢
  - Positive Link Margin
- 406 MHz ELT
  - Bi-Phase-L Modulation (BPSK)
  - Transmits for 500 ms every 50 sec
  - Positive Link Margin



# Spacecraft Configuration

There are several commercial systems available to compile into a single, low-cost, spacecraft bus. 1.5U to 6U

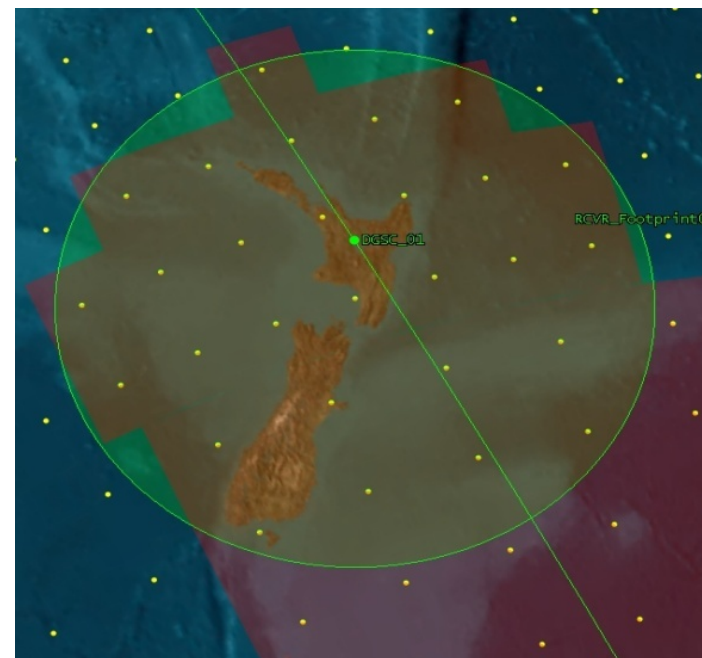
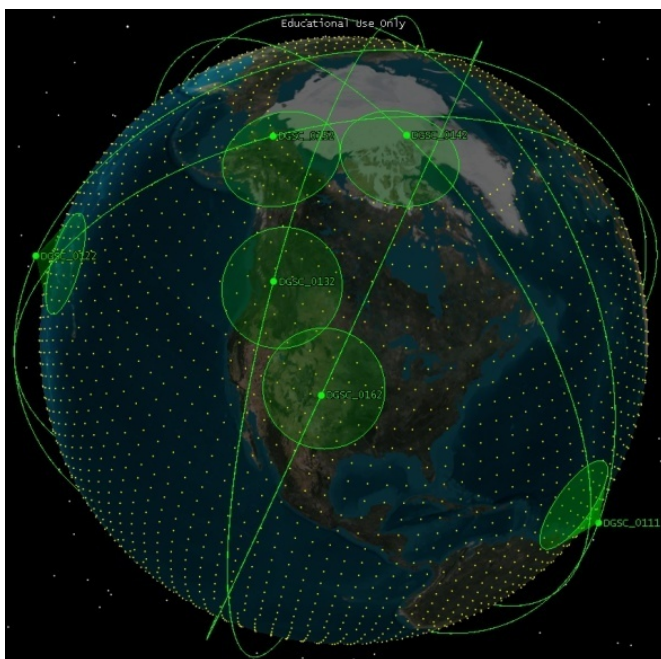
Small package size (diplexer, receiver, and FPGA) may allow flight as secondary payload.

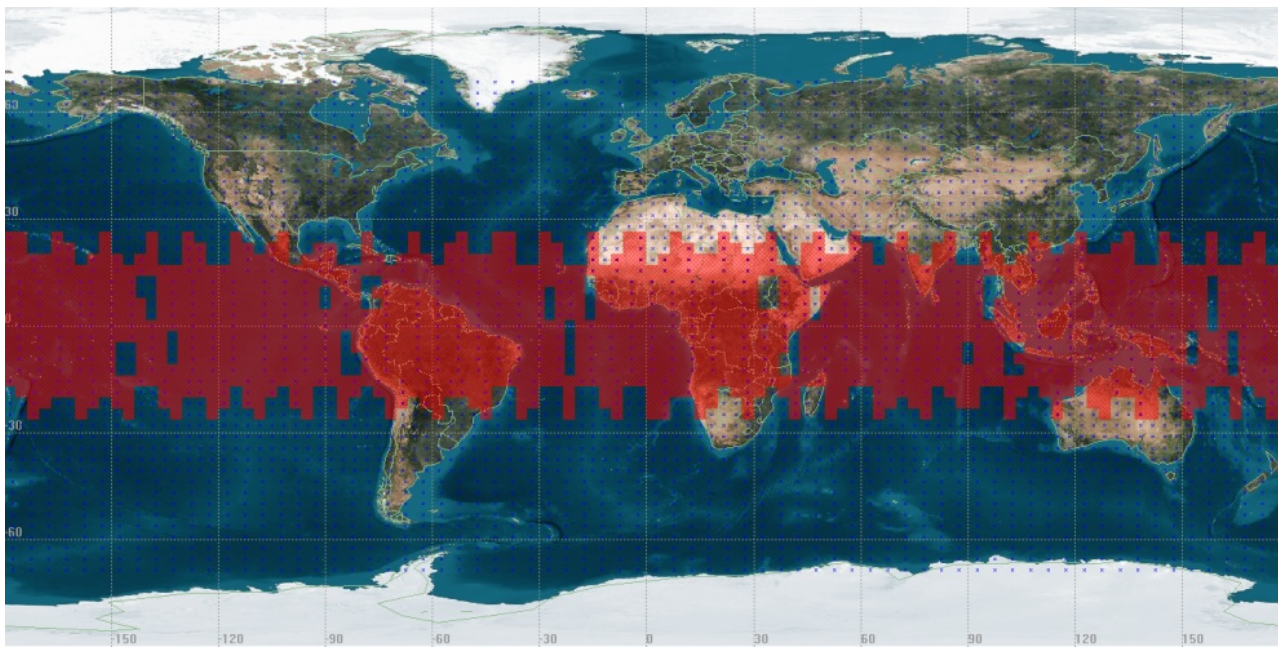




# Satellite Constellation Study

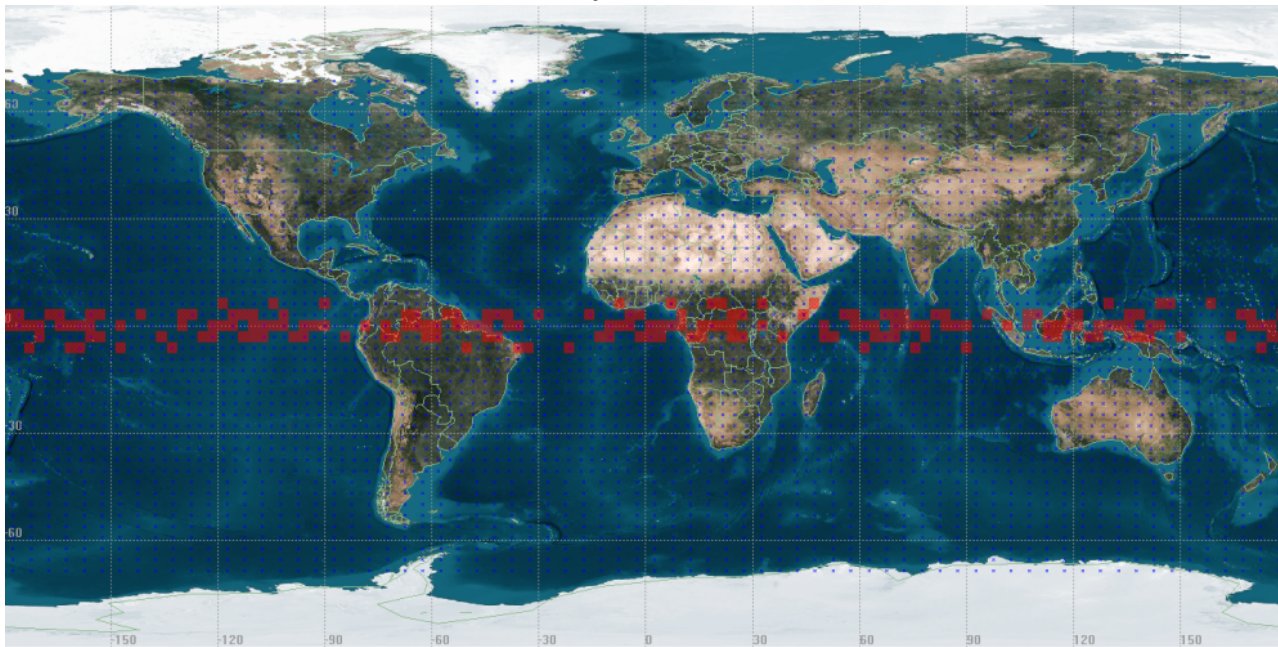
- Model Inputs from Radio Study
  - Analysis period of 1 day
  - Radio footprint: Cone with a solid angle of  $60^\circ$
- STK Parameters
  - Segmented the globe in to  $\sim 4400$  grid cells
  - Coverage area defined by latitude:  $-70^\circ$  to  $70^\circ$





98° Sun-synch at 800 km

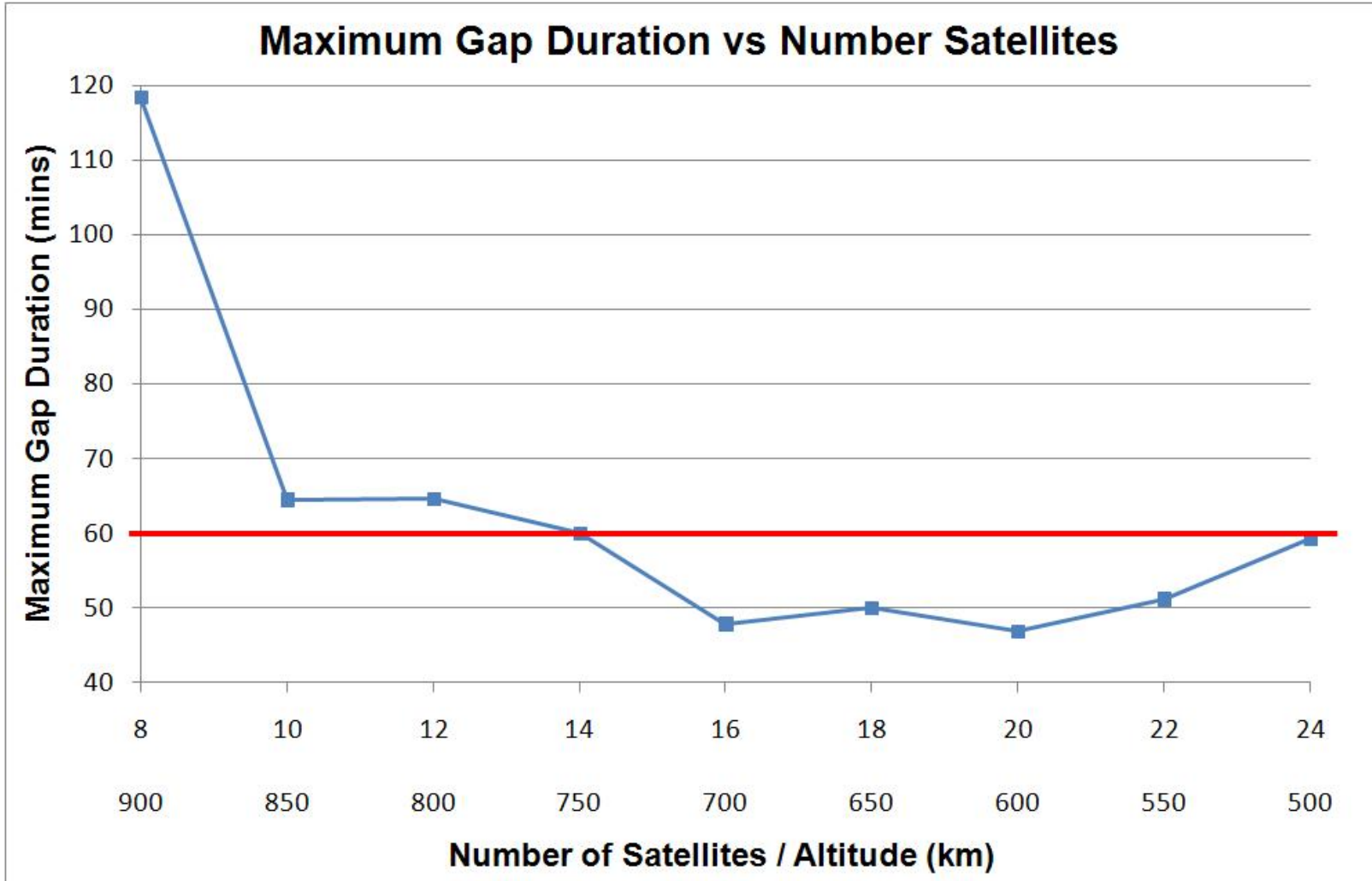
Red: Grid points that fail the 60 min revisit time requirement



70° circular orbit at 800 km

Determined circular orbit preferential to sun-synch

# Satellite Constellation Study



# Conclusions

- Feasible Mission
  - For multiple circular 70° orbits
  - DSP methods provide a positive links
  - Fly as a primary or possibly secondary payload
- Follow 121.5 MHz phase-out closely
  - Still able to provide Non-GPS 406 MHz support

# Acknowledgements

The SI Organization



Lockheed Martin



Analytical Graphics Inc.

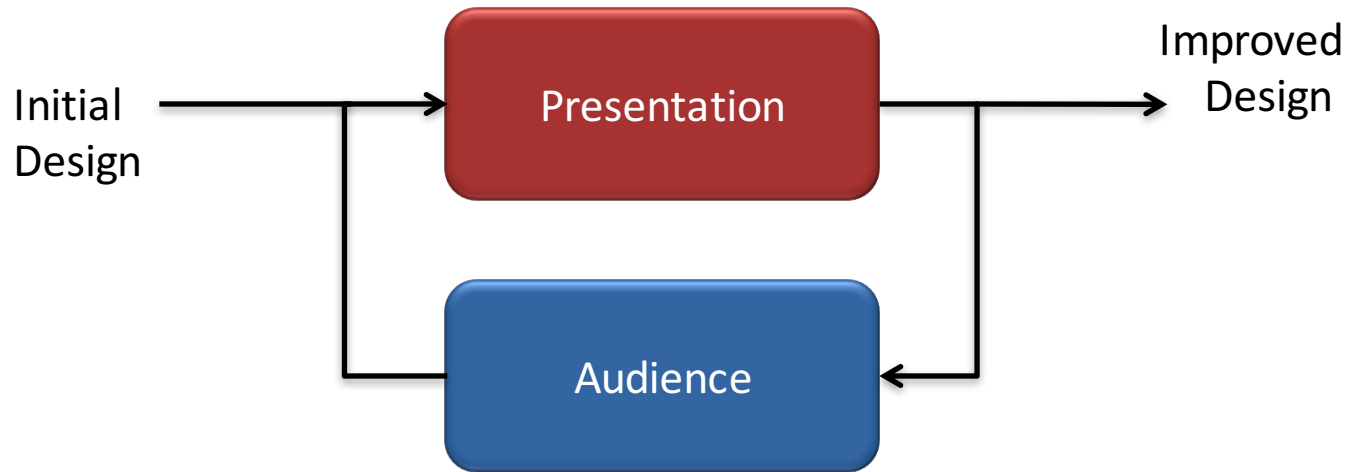


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# Questions?



**BACK UP**

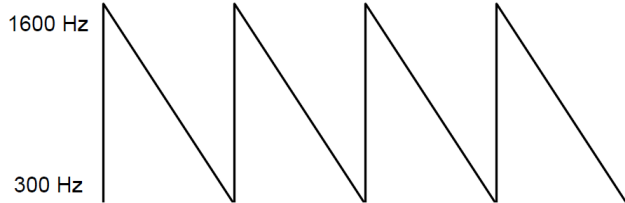
# Abstract

Aircraft Emergency Locator Transmitters (ELTs) are vital in helping search and rescue (SAR) teams in locating downed aircraft. Currently there are two types of ELTs available; one transmits at 121.5 MHz and the other at 406 MHz. The transmitters operating at 121.5 MHz have since been abandoned by satellite tracking systems even though these beacons are still available for non-commercial aviation use. Space based receiver decommissioning of 121.5 MHz systems was largely due to an inefficiency of the Very High Frequency (VHF) transmitter beacons; which have a 97% false alarm rate and only provide aircraft location within approximately 20 km of the transmitter. 406 MHz ELTs replaced the old VHF system but many do not broadcast GPS location data. While the Federal Aviation Administration (FAA) mandates all commercial air traffic use the 406 MHz transmitters, many privately owned aircraft still utilize 121.5 MHz and non-GPS 406 MHz ELTs. Small satellites have the capability of providing global coverage for a geolocation SAR constellation due to their low-cost and easily duplicated platform. This study assesses several identifying factors and risks regarding the implementation of such a small satellite SAR system that supports ELTs. Results from this study show that the need for an emergency locator signal detection and geolocation constellation can be seen as a low-cost solution to the current need for a 121.5 MHz and 406 MHz ELT detection system.



# 121.5 MHz Receiver

- Beacon Structure
  - A3X modulation
  - AM carrier
  - 1600 to 300 Hz “chirp”



- 121.5 MHz signal recovery driven by receiver bandwidth ( $R_{BW}$ )
- Link quality best calculated using the signal-to-noise method:

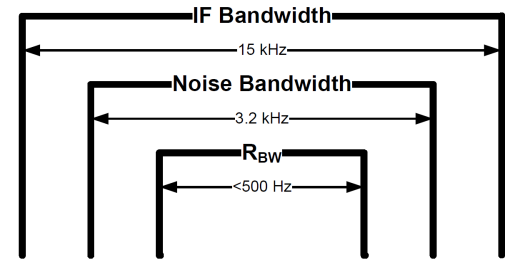
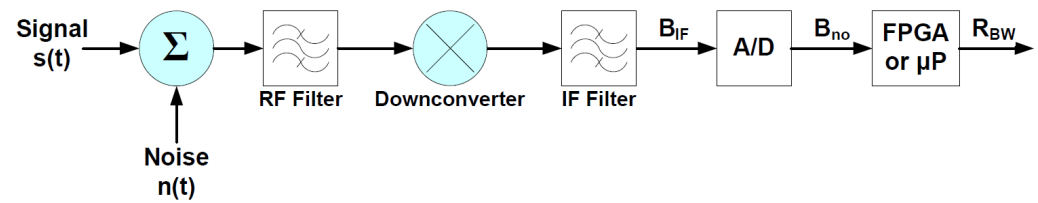
$$S/N = P_{s(dbW)} - K + 10\log(T_{SC}) + 10\log(R_{BW})$$

$P_{s(dbW)}$  : Power seen at receiver input (Signal)  
 $T_{SC}$  : Spacecraft Noise Temperature (290 K)  
 $K$  : Boltzmann’s constant (-228.6 dBW/K/Hz)

- An A/D and DSP reduce the IF bandwidth to an  $R_{BW}$  less than 500 Hz, increasing link margin.

$$R_{BW} = \frac{f_{sample}}{N} B_{res} = B_{no} = \frac{f_{sample}}{N}$$

- $f_{sample}$  and  $N$  will need to be defined based on future testing.



# 406 MHz Receiver

- Beacon Structure
  - Bi-Phase-L Modulation (BPSK)
  - Transmits for 500 ms every 50 seconds
- 406 MHz signal recovery driven by:
  - Modulation bandwidth ( $B_m$ )
  - Oscillator stability of the ELT ( $\pm 5$  kHz)
- $B_m$  function of spectral efficiency ( $\eta$ ) and data rate ( $R$ )

$$\eta = 1/2 = R \text{ (bps)} / B_m \text{ (Hz)}$$

$$B_m = 2R = 808 \text{ Hz}$$

- Link quality best calculated again using the signal-to-noise method
  - The signal processing stage still largely depends on S/N.

# Satellite Constellation Study

- Walker Constellation Equations:

$$t = s \cdot p, \quad i = (t/p/f), \quad T = f \cdot (360/t)$$

$t$  = total number of satellites

$s$  = satellites per plane

$p$  = number of equally spaced planes

$i$  = inclination

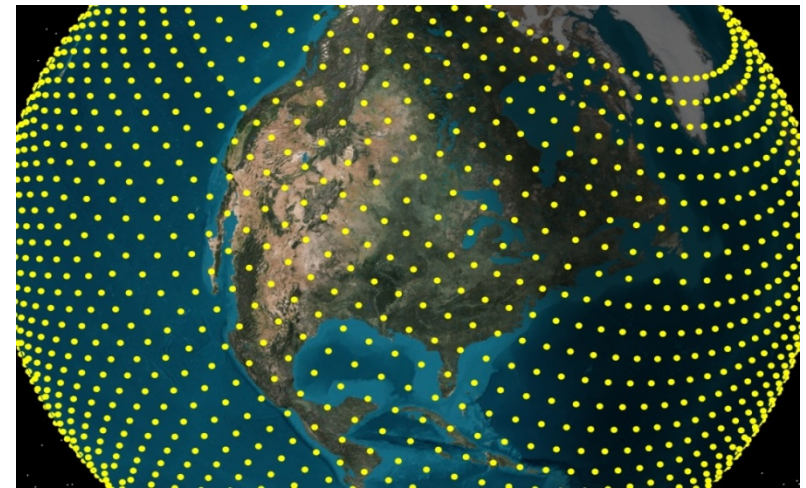
$f$  = inter plane separation (integer value)

$T$  = True anomaly in degrees

STK calculates  $T$ , given  $p$ ,  $s$ ,  $f$ , and  $i$

- The altitudes (500 km and 800 km) were chosen to evaluate best and worst case
  - Design trade-off between Link Margin and Coverage Footprint
  - Initial analysis to better define and minimum and maximum parameters

Parameter	Sun Synch, $i = 98^\circ$		Circular, $i = 70^\circ$	
$p$	12	6	12	6
$s$	2	2	2	2
$f$	1	1	1	1
$t$	24	12	24	12
Altitude	500 km	800 km	500 km	800 km



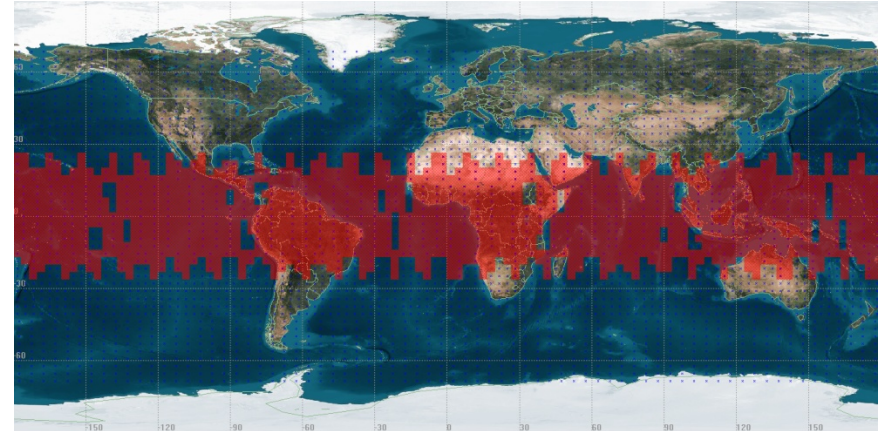
# Satellite Constellation Study

- Revisit time metric – Average Gap Duration:

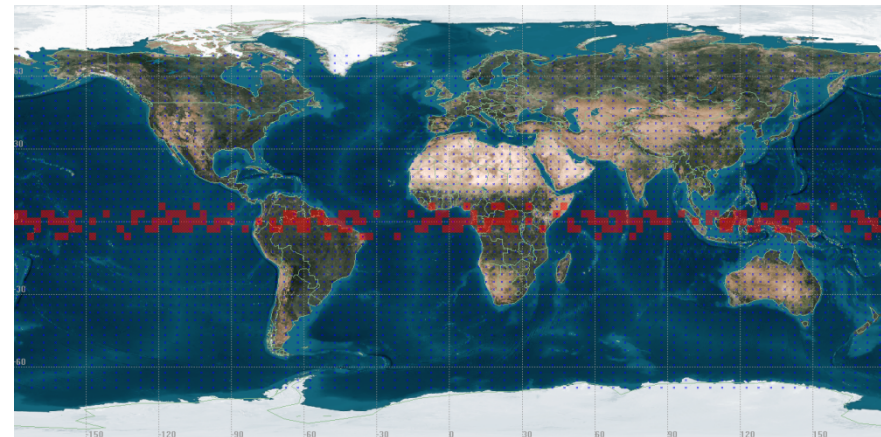
Defined as the average duration of the coverage gaps found at each grid point.

Equation: 
$$\frac{\sum(GapDuration)^2}{ScenarioLength}$$

- Scenario Length = 24 hours
- Calculation performed by randomly sampling the scenario timeline.
- Initial results
  - Red: Grid points that fail the 60 min revisit time requirement
  - Determined circular orbit preferential to sun-synch



98° Sun-synch at 800 km



70° circular orbit at 800 km

# Background

## Aircraft Emergency Locator Transmitters (ELTs)

- Vital in helping search and rescue (SAR) teams in locating downed aircraft.
- Uses Cospas-Sarsat constellation which mainly consists of GOES and POES spacecraft

## Two Types of beacons

- Legacy 121.5 MHz beacons
  - No longer satellite supported as of February 2009
  - 97% false alarm rate
  - 20 km location accuracy
  - Estimated that 170,000 aircraft around the world still operate
  - Mandated non-commercial use
- Newer 406 MHz beacons
  - Satellite supported
  - Mandated commercial and optional non-commercial use
  - Transmits user specific ID code
  - Some but not all models are GPS capable
  - Currently not enough manufactured to replace all 121.5 MHz beacons

There exists a need for a detection and geolocation satellite constellation (DGSC) that can provide accurate location information in support of both 121.5 MHz and non-GPS capable 406 MHz beacons. Small satellites have the capability to fulfill this need due to their low-cost and easily duplicated platform. The objectives of this study is to ensure feasibility of such a constellation.

# Mission Risks

## 3. Spacecraft Components:

Will commercial off the shelf systems work in space environments?

- Lack radiation performance data
  - Not all COTS parts are radiation tolerant

## 4. Utilize a standardized CubeSat bus:

Will this place additional restrictions on the mission?

- If a standard 3U CubeSat bus is to be used incorporate several new restrictions:
  - Weight limitations
  - Size limitations
  - Power Consumption limitations

# Link Budgets

- ELT antennas modeled as isotropic.
- Satellite antennas modeled as  $\frac{1}{2}$  wave dipoles.
- Link budgets calculated using Satellite Toolkit
- Minimum S/N for DSP was conservatively estimated to be 10 dB

121.5 MHz Uplink Budget (S/N Method)	
Orbital Altitude	70°
Orbital Inclination	800 km
Ground Station Power Out:	0.1 W
Modulation:	A3X
Received Power (STK):	-133 dBm
Link Margin (STK):	<b>14 dB</b>

406 MHz Uplink Budget (S/N Method)	
Orbital Altitude	70°
Orbital Inclination	800 km
Ground Station Power Out:	5 W
Modulation:	Bi-Phase-L
Received Power (STK):	-126 dBm
Link Margin (STK):	<b>20 dB</b>

# Other Calculation Methods

- Coverage Contours
  - Defined as the number of accesses to each centroid.
  - Over the period of one day.
- Average Revisit Time
  - Defined as the average interval between accesses.
  - Average Revisit Time is calculated by:

$$\sum_{i=0}^N \frac{GapDuration_i}{N}$$

- Where N is the total number of gaps
- Calculated for each cell over the period of one day



# Mass Budget

Component	Qty.	Unit Mass (g)	CBE (g)	% uncert	Mass uncert	Total (g) (CBE + uncert)
AstroDev Radio	1	78	78.6	10%	7.86	86.46
VHF Antenna	1	15	15	30%	4.5	19.5
UHF Antenna	1	10	10	30%	3	13
Novatel GPS OEMV-1G	1	48	47.8	10%	4.78	52.58
ADACS	1	910	910	30%	273	1183
EPS Board	1	80	80	30%	24	104
EPS Batteries	1	186	186	130%	241.8	427.8
Structure	1	208	208	30%	62.4	270.4
Staking and Coating	1	30	30	30%	9	39
M3 x 11mm standoffs	8	1.2	9.6	10%	0.96	10.56
M3 x 22mm standoffs	12	2.3	27.6	10%	2.76	30.36
Cabling	1	50	50	30%	15	65
Solar Panels	6	100	600	30%	180	780
Payload*	1	1000	1000	40%	400	1400
<b>Total</b>			<b>3252.6</b>	<b>28.125</b>	<b>1229.06</b>	<b>4481.66</b>

Max:	4500	grams
CBE + uncert	4481.66	grams
reserve:	18.34	grams

# Future Work

- Receiver Payload
  - More research into specific algorithms used in DOA estimation
  - Research into geolocation methods other than triangulation
- Constellation Modeling
  - Increase simulation time to one year
  - Increase the grid resolution
  - Further analysis for a range of orbits