746th Test Squadron

Innovate, Execute, Excel

U.S. AIR FORCE

Testing the Latest Embedded GPS/INS Hybrid Navigation System for the F-16 Fighting Falcon

13 March 2007

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746 Test Squadron
Holloman AFB NM

Integrity - Service - Excellence - Agility

UNCLASSIFIED

Overview

- F-16 LN-260 EGI Test Item
- Approach and Test Methodology
- Test Capabilities Available at 46 Test Group
- LN-260 Overall Test Objectives
- Sequence Selected for Test Beds & Assets
- Truth Reference System to be used
- Summary / Lessons Learned / Conclusions
- Questions

F-16 Fighting Falcon

Integrated INS & GPS Navigation System for USAF and European Participating AF (EPAF)

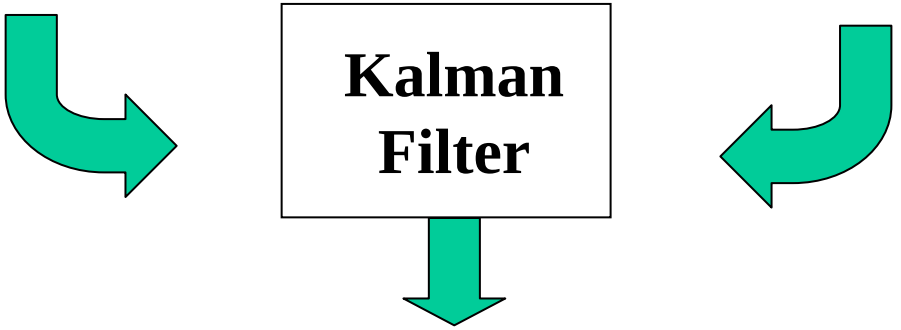
- **Integrated Navigation system provides**
  - **Attitude**
  - **Navigation (PVT)**
    - **Position**
    - **Velocity**
    - **Time**

Current Navigation System

- **Separate GPS and INS units**

INS: Ring Laser Gyro Inertial Navigator

GPS: 5 Channel PPS Satellite Receiver



Blended GPS/INS PVT Solution

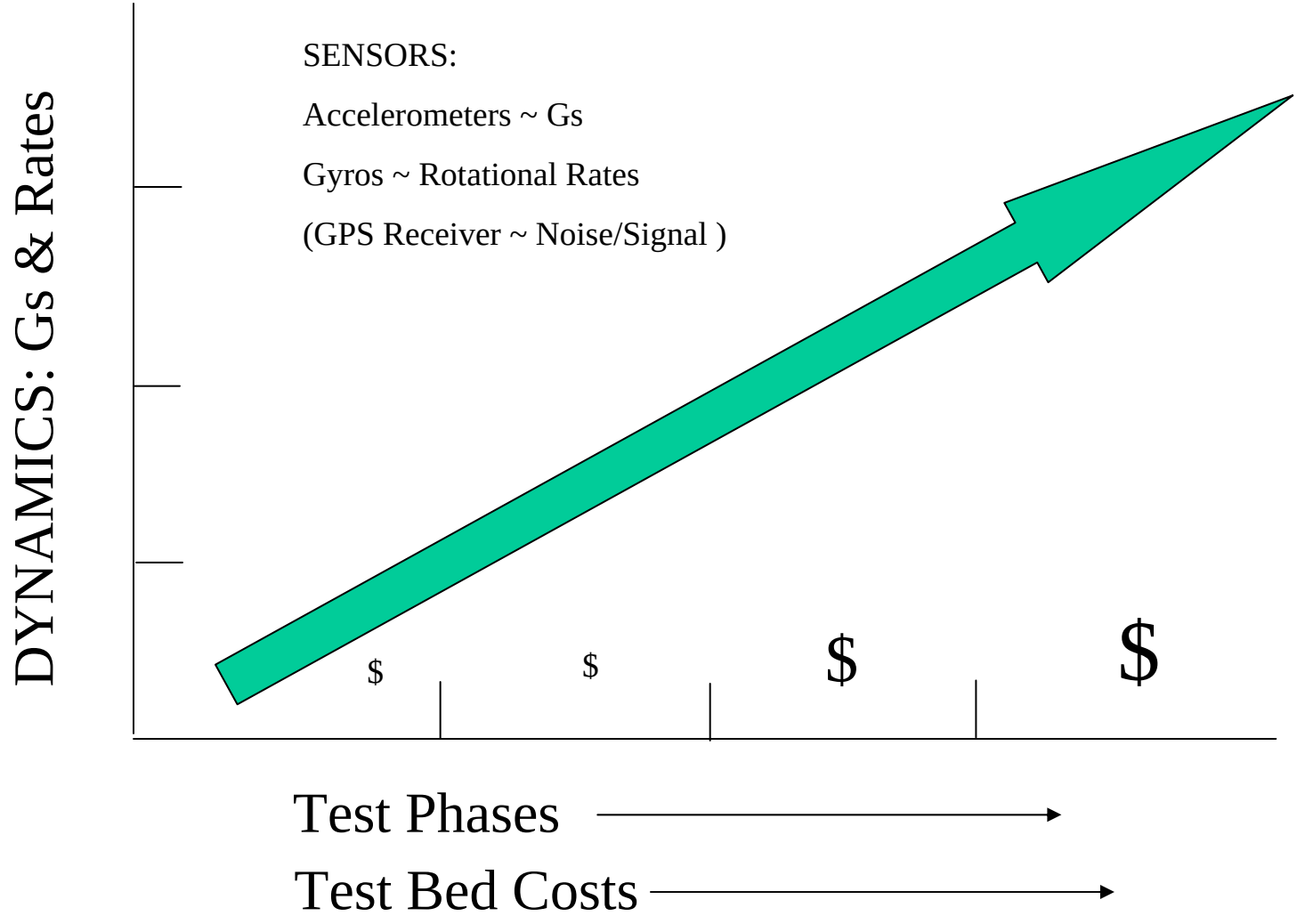
F-16 Hybrid Nav System

- **LN-260 NG Aircraft Navigation and Attitude**
  - **Inertial Navigation System (INS) < .8 nmi/hr RER**
    - **New Fiber Optic Gyros**
  - **GPS: RC GEM-VI, 24 channel L1 & L2 receiver**
  - **Single Unit; smaller size, weight, cost, power use**
- **Embedded GPS in INS (EGI), with Kalman Filter**

LN-260

- **Provides 3 separate solutions:**
  - **INS only, GPS only, Blended**
    - **'Tightly coupled'**
- **Same Performance ?**
- **Effective and Suitable ?**
  - **Requires T&E**

Notional Test Approach



Test Approach

Crawl - Walk - Run

Discover and correct issues <u>early</u> at a <u>lower</u> cost

Mature the system design

- **Methodically verify proper functionality of navigation unit**
  - **Physical and functional checkouts**
  - **Precision three axis table attitude and rotations**
- **Establish baseline performance**
  - **Benign, controlled, repeatable environment**
  - **Recheck as appropriate**

Test Approach (cont)

- **Performance and Characterization**
  - **Gradually increase stresses on sensors and system to the specification limits while measuring performance in realistic profiles that are controlled and repeatable**
  - **The greater the dynamics and signal stress the more exposed existing problems become**
  - **Use state-of-the-art Truth Reference System**

Test Location: 46 Test Group Holloman AFB NM

High Speed Test Track

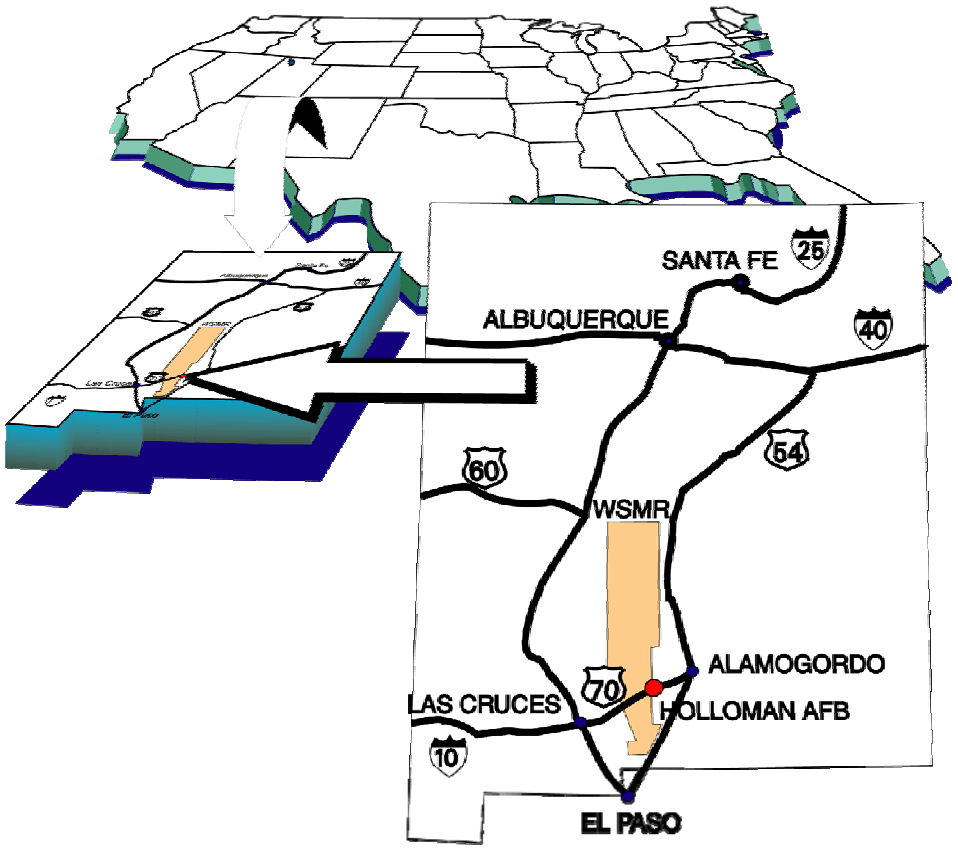
NRTF

Det-1

Flight Test

CIGTF

746 TS



- **State-of-the-art Test Capabilities**
- **746 TS; Central Inertial & GPS Guidance Test Facility (CIGTF)**

46th TG Test Capabilities

- **5 Test Squadrons within 46th Test Group**
  - **586 FLTS: Flight Test Squadron**
  - **746 TS: INS & GPS Guidance Test Squadron (CIGTF)**
  - **781 TS: National RCS Test Facility (NRTF)**
  - **846 TS: Holloman High Speed Test Track**
  - **Det 1: White Sands Missile Range Test Agent**

- **746 TS / CIGTF: Has complete range of GPS & INS Navigation and Guidance test capabilities**
  - **Satellite Ref Station (SRS)**
  - **Mobile SRS (MRS)**

Available Live Nav Test Beds

Dynamic Range Vehicles; Track, Van, Helo, C-12, Fighters

High Speed Precision Test Track

Land Navigation Vehicles

Helicopter

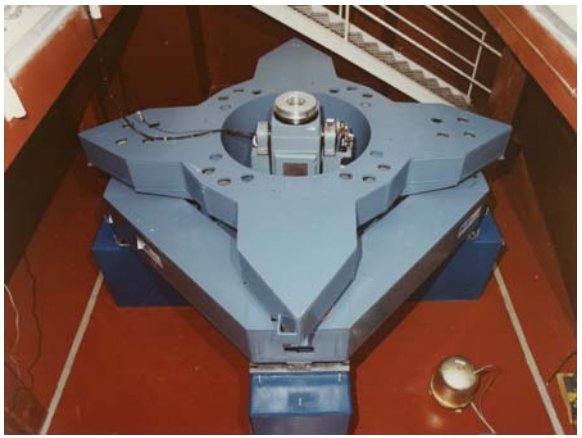
C-12

T-38

F-16, F15

Inertial and GPS Lab Facilities

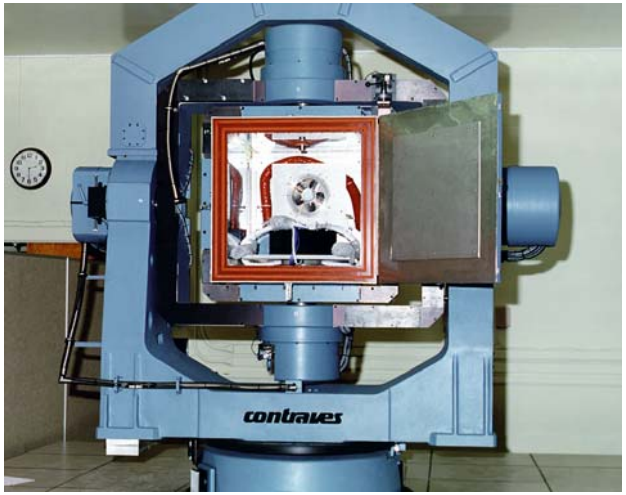
Advanced Inertial Test Lab



Seismically Stable Table

M&S Navigation T&E Lab

Precision 3 Axis tables



with Temperature Chamber

120” Precision Centrifuge

Test Objectives for LN-260 EGI

- **Verify the F-16 LN-260 EGI performance complies with the published specifications and characterize significant aspects without specification**
- **Functional**
  - **Check physical, power and data properties**
  - **Demonstrate operation of interfaces and EGI modes**
  - **Baseline navigation outputs**
- **Performance**
  - **Evaluate the navigation performance under realistic operational and environmental conditions**
- **Characterization**
  - **Characterize calibration errors**
- **Areas of concern include effect of temperature, G and vibration on navigation performance**

Test Bed Progression

- **Bench top physical and functional checks**
- **Precision 3 Axis table position/rotations**
  - **24 position tests at temperature variations**
  - **Inertial sensor calibrations**

Low Cost

Preparatory

- **Modeling and Simulation; NavTEL**
- **Van land navigation vehicle, low dynamics**

Med Cost
Comprehensive
Controlled
environment

- **C-12 cargo aircraft, low-med dynamics**
- **Precision 3 Axis inertial calibration recheck**
- **T-38 Fighter aircraft, med-high dynamics**

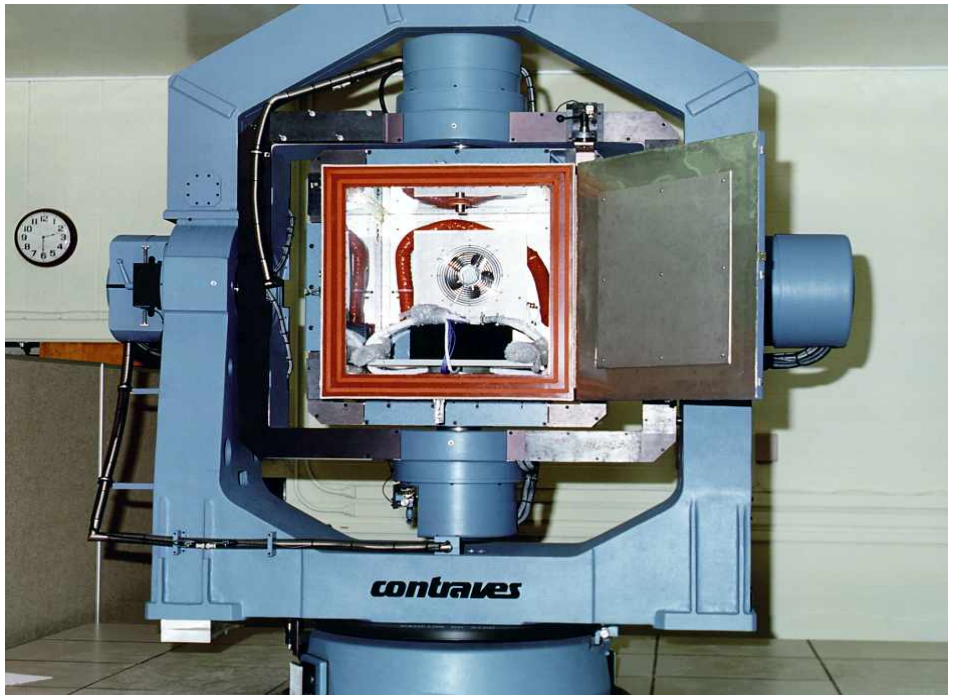
High Cost

Most realistic
environments

- **Environmental: altitude, vibration, high G**

Increased risk

3 Axis Rate Table 53Y

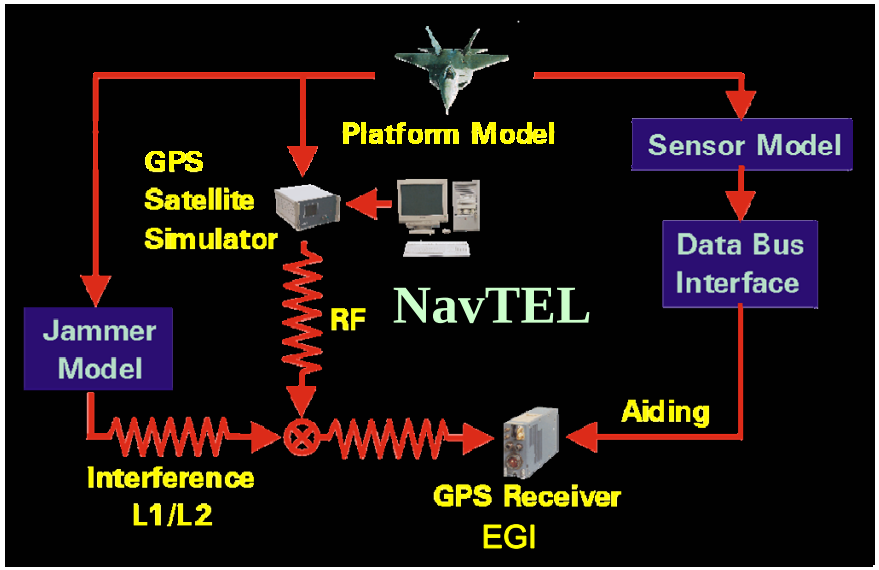


Precision 3 Axis: Position, Rotation, Temperature Tests

- Payload (200 lb)
- Accuracy (1 arcsec)
- Gimbal Rates (±750 deg/sec)
- Chamber (-55 to +85 deg C)

- Functional Alignment and Navigation
- INS Calibration Validation
  -- 24 Positions (1g Environment)
  -- Rotation Rates (20 deg/sec)
- Calibration / sensor baselines

Modeling & Simulation

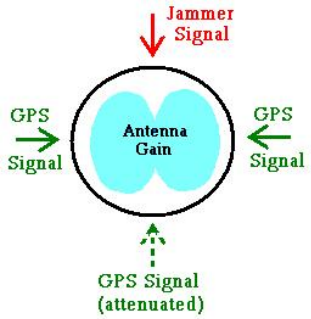


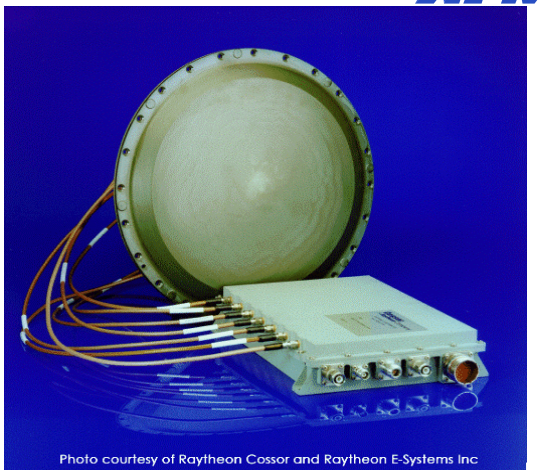
-Controlled Signal Injection
- INS & GPS profiles
- Models: Baro, Doppler, +
- Special Navigation Ops
- Jamming (broad scope)
- RAIM Integrity Monitoring
- SAASM Security Functions

Navigation T&E Laboratory **(NavTEL)**
- Hardware-in-the-Loop Design
- Trajectories (Real & Simulated)
- Models: Sensor & Aiding, w/ Realistic Errors
- GPS Simulators (Spirent 4760 / 7700)
- **EGI** Simulator (CAST) Hybrid, > Fidelity
- Select Parameter Controlled On the Fly
- Interference Signal Generators (Jammers)
- Wave Front Simulator (Multi-Element Antenna Test)

CRPA Wave Front Testing

- Null Steering Antenna Tests
- Embedded Jammer Approach
- Jamming; up to 16 Sources
- Precise and Repeatable Tests
- Coherent Arrival Vectors, GPS and Jamming
- Controlled Signal Location, Timing & Phase

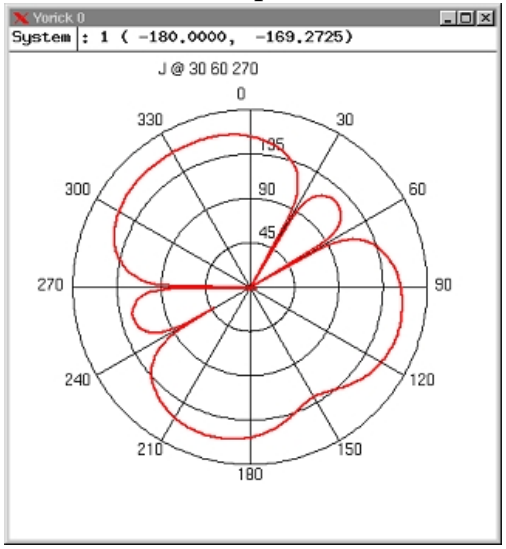




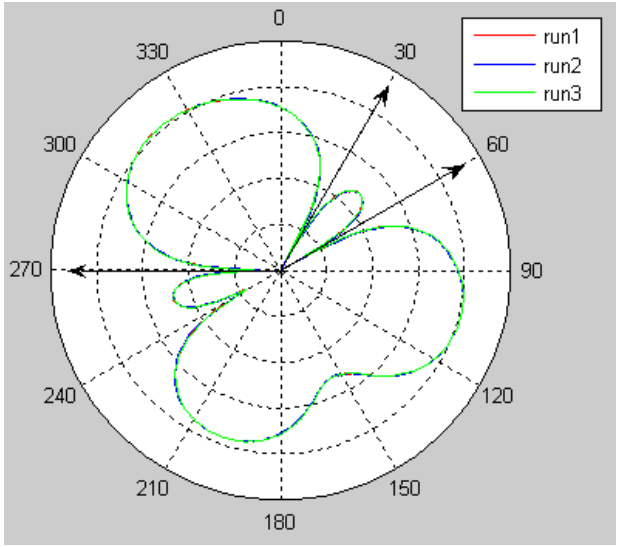
Controlled Reception Pattern Antenna

Coherent Wave Front Sim for GPS and Jamming signals

3 Jammer example: 30, 60, 270



Predicted Model



Measured Results

Operational - Live Performance

AFMC

Low Dynamic Test

Land Navigation Vehicle
- Velocity (26.8 m/sec)
- Acceleration (1g)
- Navigation Modes
- GPS Jamming
- Precision Reference

Medium Dynamic Test

Cargo Aircraft (C-12J)
- Velocity (140-250 kts)
- Acceleration (2.5g)
- Navigation Modes
- GPS Jamming
- Precision Reference

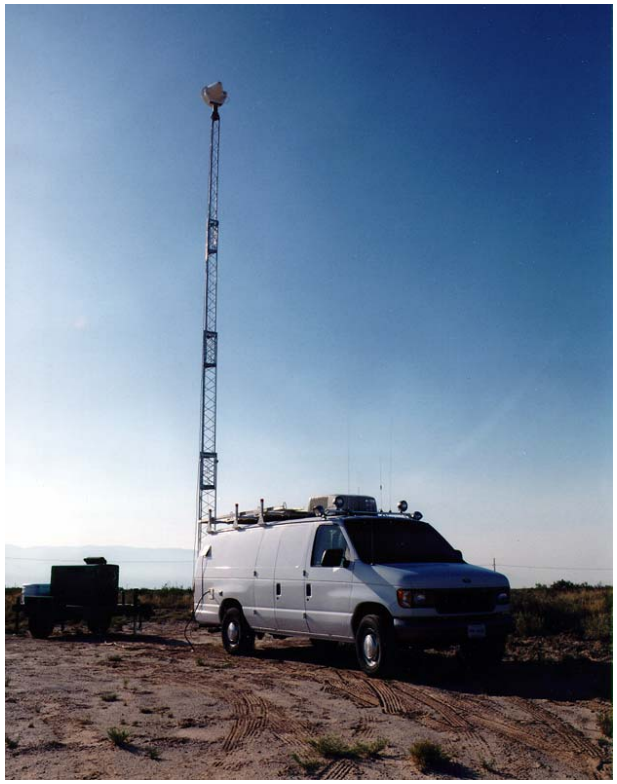
High Dynamic Test

Hi Performance (T-38)
- Velocity (Mach 1.1)
- Acceleration (7.2*g*)
- Air to Grnd scenarios
- Air to Air scenarios
- Precision Reference

Field Jamming Assets

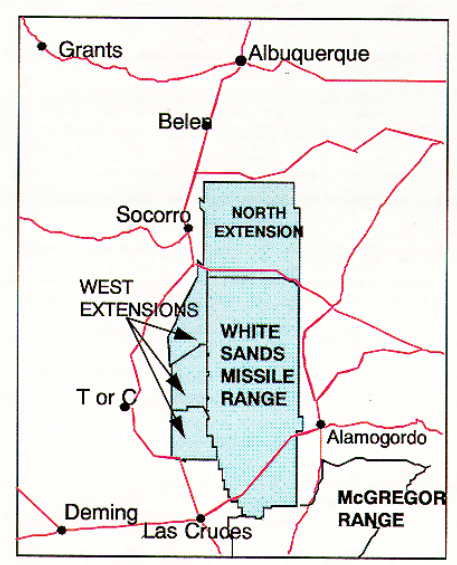
- **GPS Interference; Performance under signal stress**

Jamming Vans

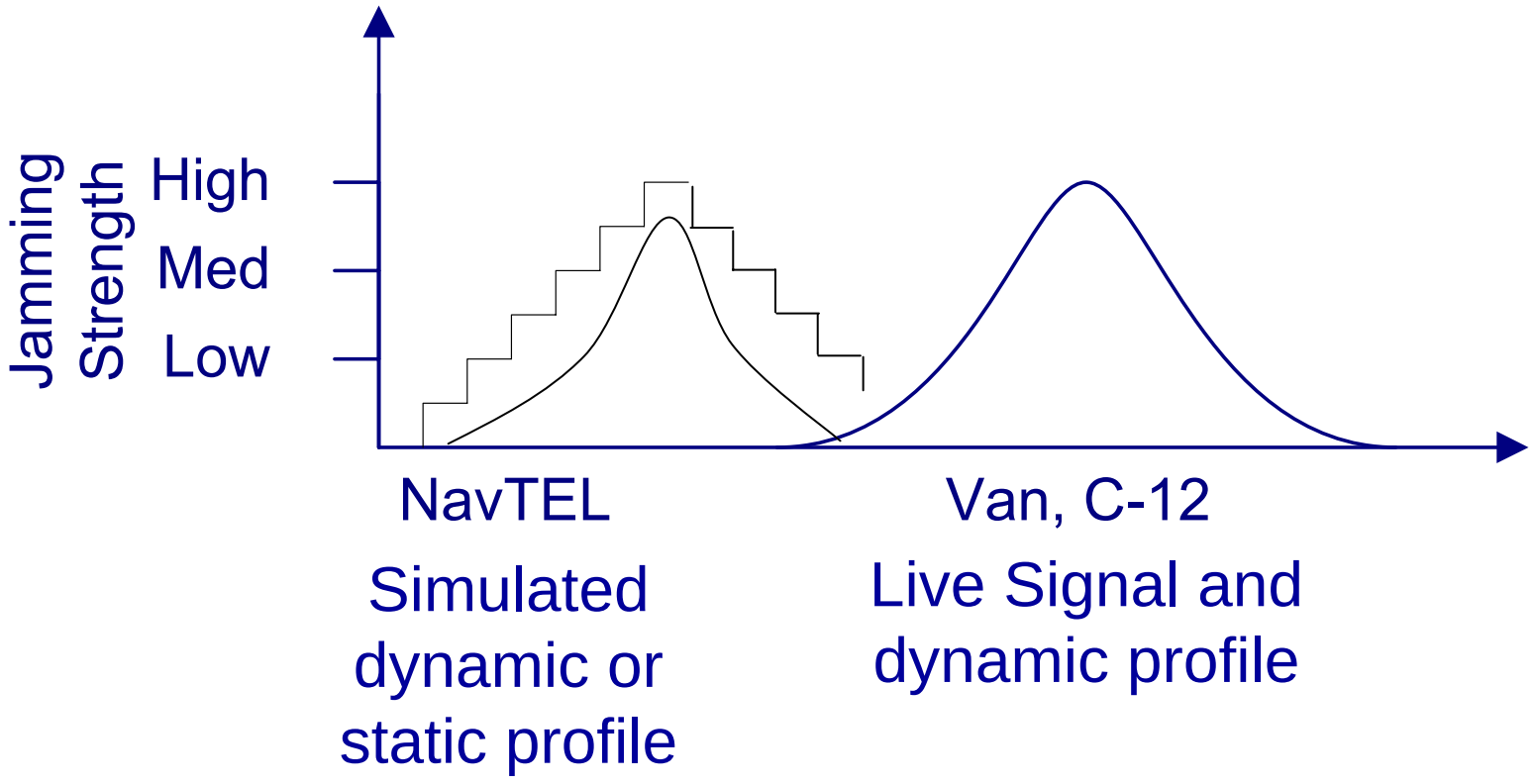


High Gain Antenna

WSMR Test Range



GPS Signal Jamming Stress



Environmental Lab Capabilities

- Test specification requirements not reached on previous test beds

Altitude / Temp Chamber

- Payload Navigating
- Pressure Altitude 80K' +
- 50-60K' planned
- Temp to match altitude
  -100 deg to +350 deg
- Humidity 5% – 95%

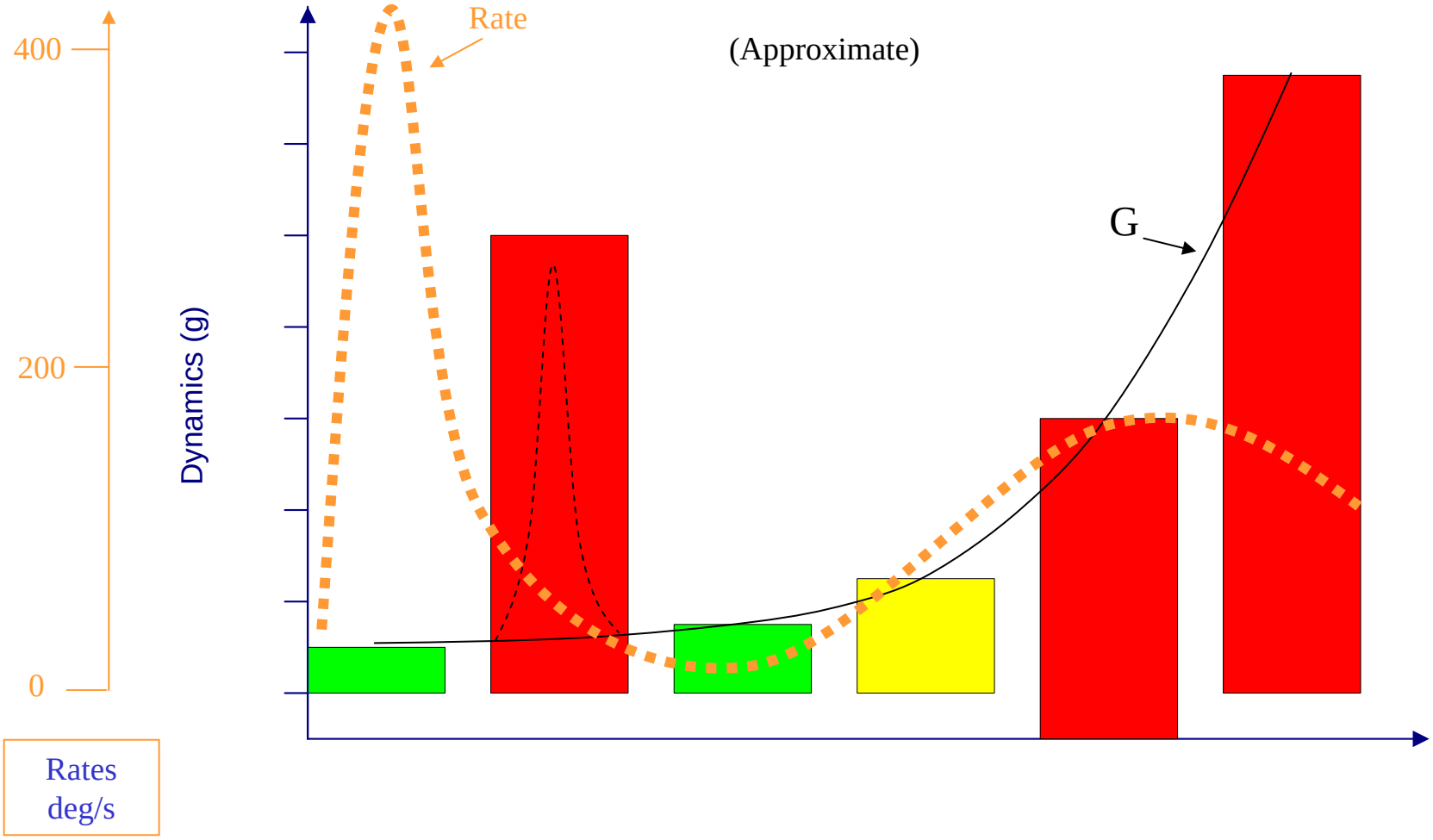
Vibration test beds

- Frequency/G controlled
- F-16 vibration profile
- M-60 Gatling gun
- Up to 1750 lbs force
- 2-2000 Hz (50#, 70g)
- 1 inch travel

Centrifuge 120" Radius

- Payload (100 lb)
- Accuracy (1 ppm)
- Acceleration (0.5 to 50 g)
- 13.5 g planned
- Test Item Fixture:
  - Fixed or
  - Counter- Rotating

Test Bed Gs and Rates



CIGTF Reference System (CRS) - Pallets

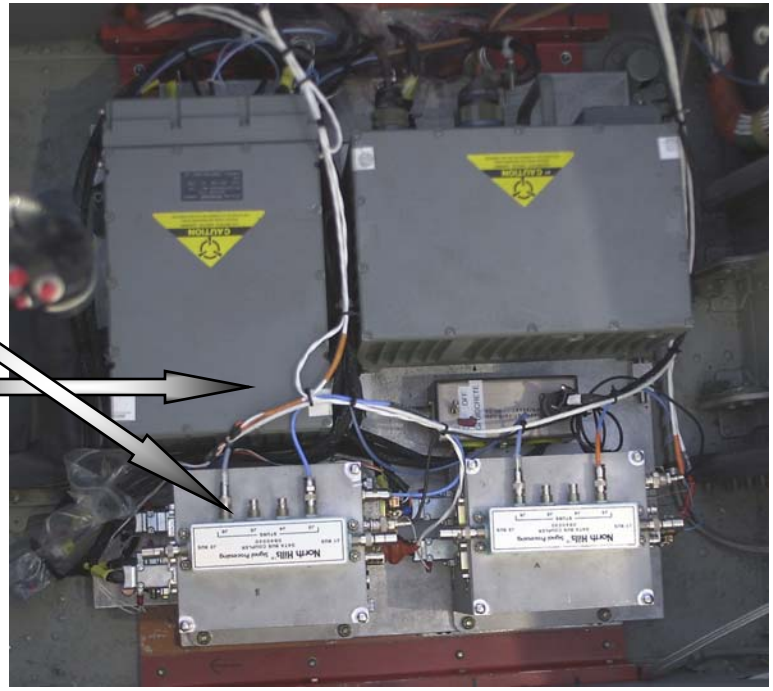
Rack Mount

(C-12J / Van)

DAS

EGI

Standalone



(T-38)

Fighter Inertial Navigation System (FINS)

Rack Mount (Development)

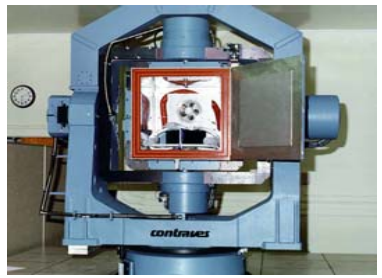
CRS - Subsystem Configuration Accuracy

[Subsystem] Configuration	RMS Position (m)		
	Horz	Vert	3D
[1] [2] GPS Code	**2.00**	**2.25**	**3.25**
[1] [2] DGPS Code [1]	**1.25<>1.75**	**1.0<>1.75**	**1.5<>2.5**
Carrier [2]	**0.30**	**0.20**	**0.35**
[4] RRS / *STARS* STS Absolute / Relative	**1.40 / 0.14** 0.071 / 0.0014	**1.00 / 0.10** 0.05 / 0.0010	**1.7 / 0.17** 0.087 / 0.0017
SRS Range Constraints: [1]300-500nm [2]50-100nm Differential GPS			

[Subsystem] Configuration	RMS Velocity (m/s)			
	East	North	Up	3D
[1] INS (EGI)	**0.010**	**0.010**	**0.010**	**0.017**
[3] INS (ESNU)	**0.005**	**0.005**	**0.005**	**0.010**
Attitude Accuracy: 20 arcsec (Roll, Pitch, Heading)				

SUMMARY

- CRAWL
  - Benchtop physical and functional tests
  - 53Y 24 precision position, attitude and rotations
  - Baseline performance for inertial portion
- WALK
  - NavTEL Modeling & Simulation
  - Van 2D low dynamics, low rates
  - Baseline GPS, INS and Hybrid solutions
- RUN
  - C-12, 3D med dynamics, med rates
  - T-38, 3D high dynamics, high rates
- Environmental
  - Centrifuge; Altitude chamber; Vibration profiles
  - Higher risk and stress modes








Lessons Learned

- **Often PM tendency is to streamline the T&E phases due to Cost and Schedule pressures**
- **Testing WILL find unanticipated problems, guaranteed.**
- **A thorough and systematic government independent T&E approach will actually reduce ultimate cost and schedule by finding/correcting problems early**
  - **"Rely on Independent Government Test"**
  - **"Focus on Performance"**

  (Words of Gen Randolph, JNC 2004)

CONCLUSION

- Follow well planned graduated test approach that manages risk and finds and fixes problems early
- Avoid cutting plan to save time or $, which often increases Cost and Schedule.
- Thorough Benchtop and 3 Axis table tests are valuable in uncovering problems early, prior to van and flight testing
- Match tests to realistic environment as practicable
- Apply increased stress in a controlled fashion
- Place high risk tests at the end to reduce possible early schedule impacts due to system failure

Recap

- LN-260 EGI
- Wide range of test capabilities in house

- Benefits of selected order
  - "Crawl, Walk, Run"
  - Facilitates testers familiarity with test item
  - Establish Baseline performances
  - Comprehensive; identify & isolate problems early
  - Risk managed to reduce 're-fly' schedule impact
  - Mature system design in most cost efficient method
  - Continuity with same team of experts throughout

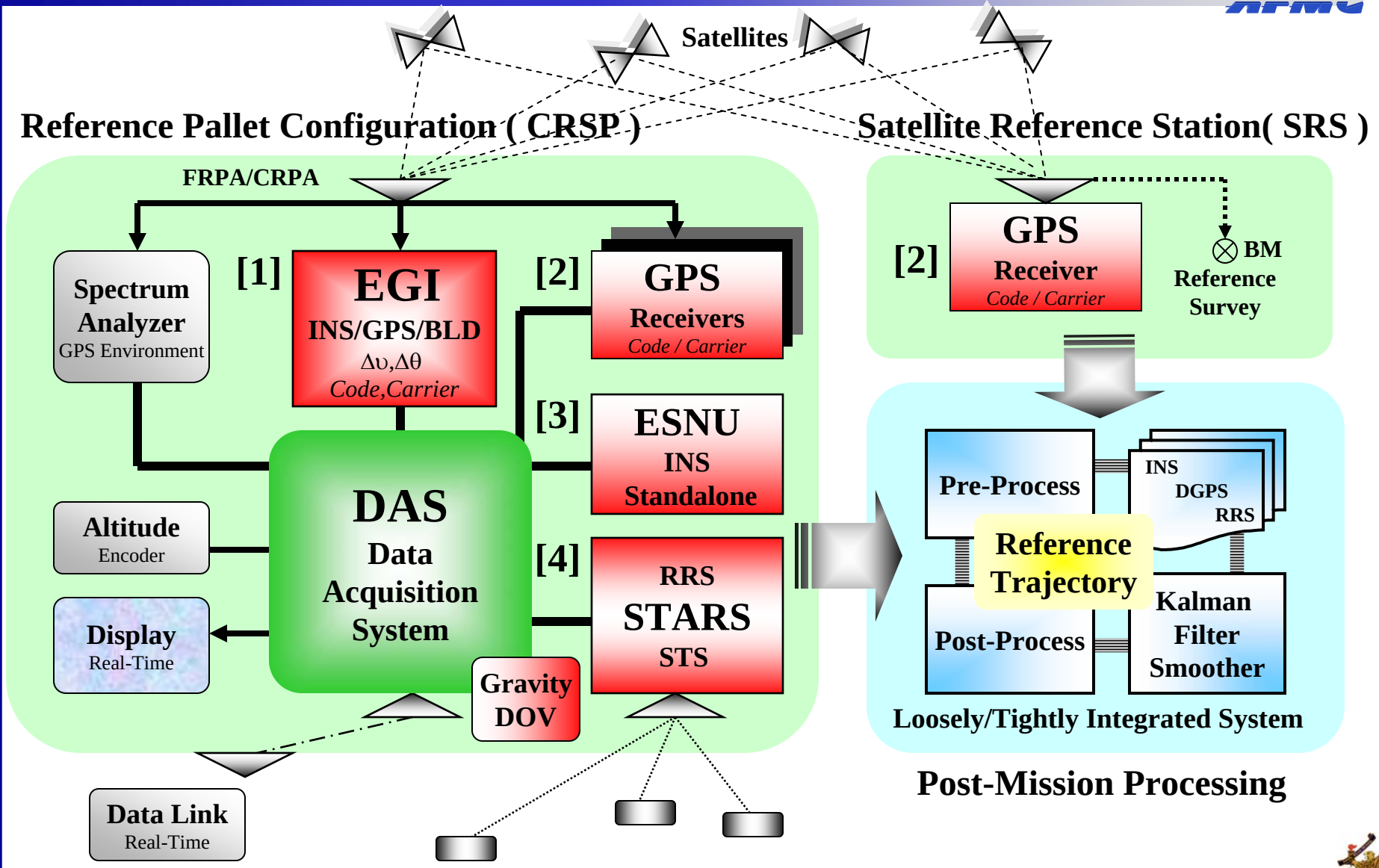
All to support the Warfighter

Questions?

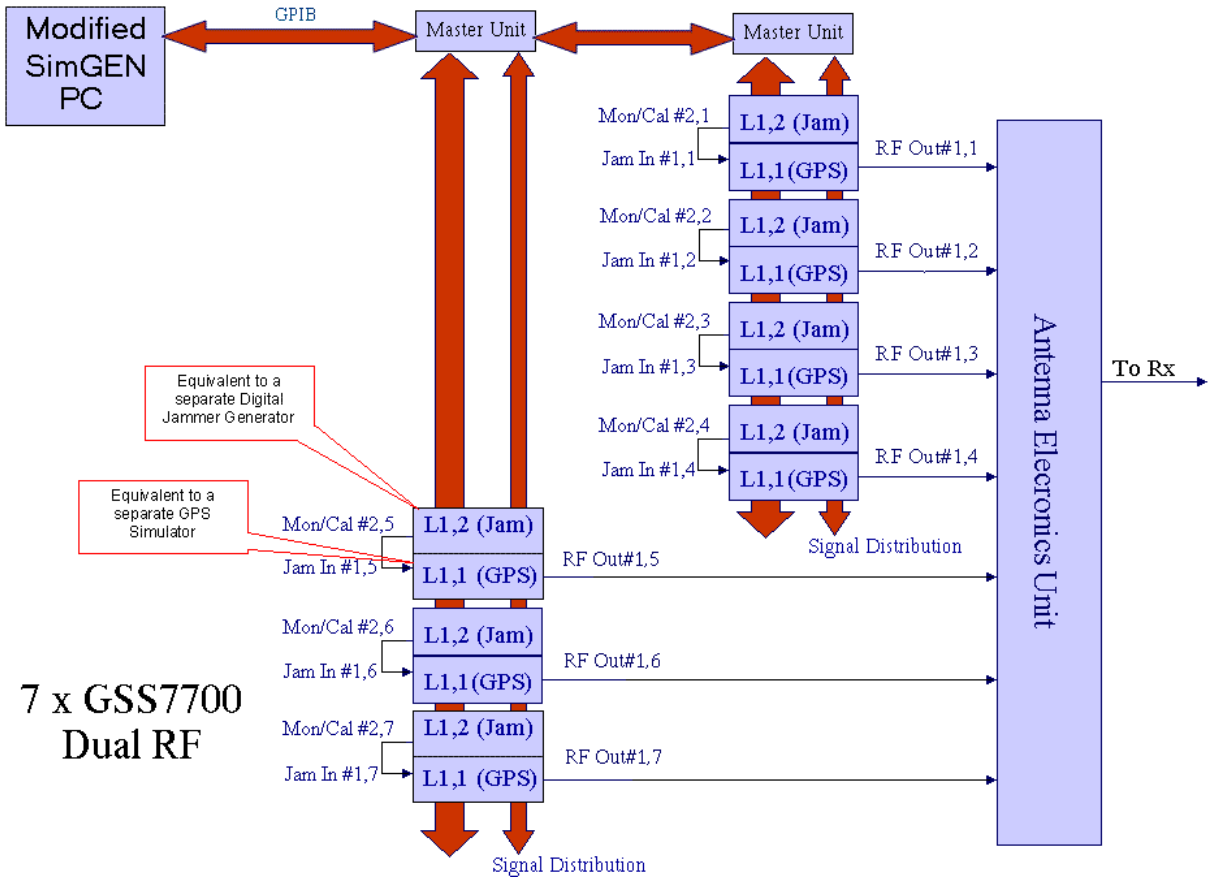
Back Up Slides

- CIGTF Reference System Block Diagram
- CRPA Wave Front System Block Diagram

CIGTF Reference System Architecture



Wave Front CRPA Simulation



Backup Slide