Navigation Using Available Communication Systems

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Overview

- Rationale
- Concept
- Application

- Requirements
- Architecture
- Analysis
- Implications

- Summary

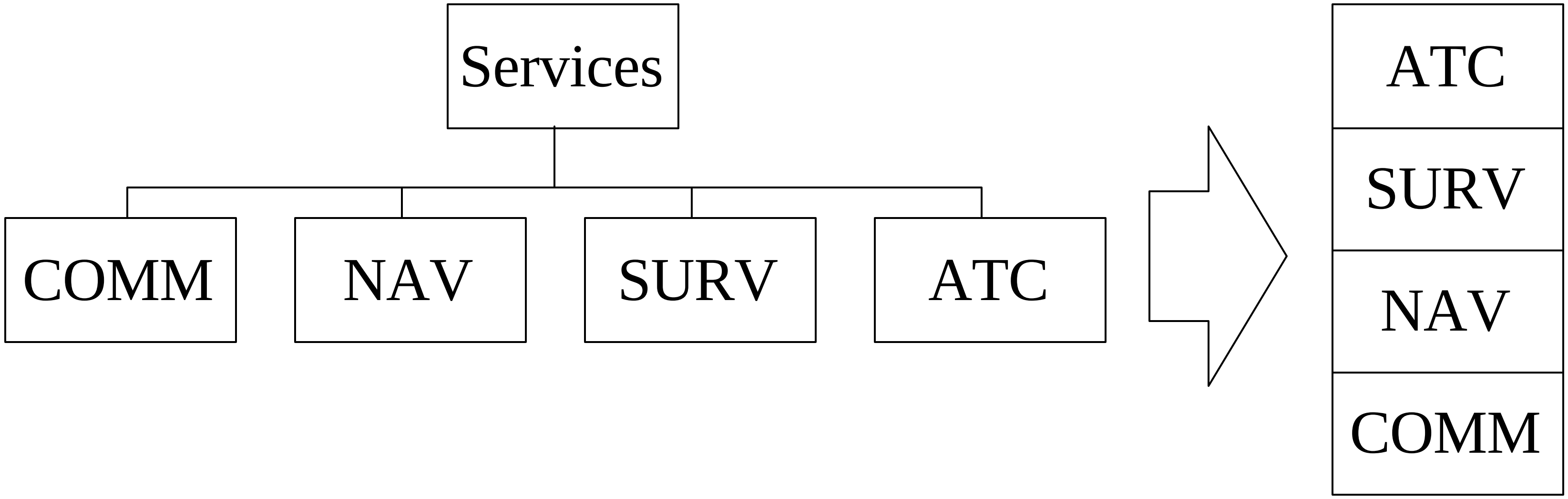
Rationale

- GPS Vulnerability
- Interest in low-cost backups
  - Avoid new avionics
  - Support decommission of existing NAVAIDs

Concept

- **Navigation using communication systems**
  - **Old paradigm: separate functions**
  - **New paradigm: integrated functions**
- **Future navigation will <u>depend</u> on communication system**

Concept (2)



Concept (3)

- **Possible systems**
  - Satcom
  - Cellular
  - VHF
  - Other
- **VHF**
  - Digital voice/data will be widely deployed
  - Analyze as a potential ranging source/navigation aid

Application

- **Augment GPS RAIM**
  - **Potential availability aid**
- **General Aviation**
  - **Low-cost backup to GPS**
  - **Aiding source for Autonomous Navigation System (ANS)**
  - **Low-cost backup for Dependent Surveillance**

Requirements

- Focus on Non-Precision Approach
  - GPS requirements ~ 50m horizontal 1-sigma
    - Normalized by Horizontal Dilution of Precision
    - Integrity estimation drives accuracy requirement
  - Existing NAVAIDs
    - Depends on geometry
    - Integrity monitoring provides “tail-cutting”
    - Some configurations exceed 50m requirement

Architecture

- **Augment Existing Ground Stations**
  - Stable clocks
  - Transmit time monitor for broadcast/one-way ranging
  - Reduced- or low-multipath antennas
  - Network modifications for stable or measured reply delay (two-way ranging)
- **Modify existing airborne equipment**
  - GPS w/ stable clock
  - Digital VHF radio w/ ranging modifications
  - Autonomous Navigation System
  - Auxiliary sensors

Analysis

- **Siting and Operational Environment**
- **Signal format and characteristics**
- **Link budget**
  - **Installed antenna patterns**
  - **Transmit Power and Signal-to-Noise ratio**
- **Ranging error budget**
  - **Multipath effects**
  - **Clock stability**
  - **Averaging**
- **Algorithms**

Siting and Operational Environment

- **Remote Communications Outlet**
  - **Standard VPOL and reduced multipath**
  - **30 feet AGL**
- **NPA**
  - **Minimum Descent Altitude of 300 feet AGL**
- **Barometric altimeter**
  - **Constrain solution for 2-D**

Signal Format and Characteristics

- VHF D8PSK (Mode III, etc.)
- Various network configurations
  - NEXCOM
  - LAAS VBD
  - Other/future
- One-way and two-way ranging

Link Budget

	INPUTS	POWER LEVELS
Transmitter	Gain/Loss (dB)	Sig.(dBm)
Trans.Pwr(dBm)	41.76	41.76
RF Component Losses	-1	40.76
Trans line loss	-1.50	39.26
Trans Ant Gain	1	40.26
ERP		40.26
Channel		
Free Space Loss	-108.19	-67.93
Rain Loss	-0.10	-68.03
Cloud Loss	-0.10	-68.13
Atm loss(etc)	-0.10	-68.23
Multipath Loss	-20.73	-88.97
Rec. Ant Gain	0.00	-88.97
Cable Losses	-3.00	-91.97
RF Component losses	-1.00	-92.97
Receiver Noise Level (12 khz BW, 8 dB NF)		-125.00
S/N		32.03

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Ranging Error Budget (1-Way)

One-way Ranging error calculation

	Input factor	Noise(feet)	Bias (feet)
Aircraft receiver S/N from link budget	32.03		
TOA Noise (per pulse) (seconds)	2.38267E-06		
Number of averaged phase transitions	20		
Resulting 1-sigma noise (seconds)	5.32781E-07		
Noise in feet (1-sigma)		486.84	
Multipath Error (feet)			150.00
Aircraft receiver reply delay variation			50.00
RCO calibration error			50.00
Transmitter quantization noise(100 mhz clock)	1.00E-08	9.14	
Ground Clock Error (seconds)	2.70E-07		246.72
Aircraft Clock Error (seconds)	2.70E-07		246.72
Total Bias Error (rss) feet			**386.31**
Total Noise Error (rss) feet		**486.92**	

45-minute exposure time (IFR reserve)

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Ranging Error Budget (2-Way)

Two-way Ranging error calculation

	Input factor	Noise(feet)	Bias (feet)
Aircraft receiver S/N ratio at 30 miles in rain(db)	32.03		
TOA Noise (per pulse) (seconds)	2.38267E-06		
Number of averaged phase transitions	20		
Resulting 1-sigma noise (seconds)	5.32781E-07		
Downlink Noise in feet (1-sigma)		486.84	
Uplink Noise in feet (1-sigma)		486.84	
Downlink Multipath Error (feet)	150.00		
Updlink Multipath Error (feet) (same both ways)	150		
Total Multipath Error (feet)			300.00
Aircraft receiver reply delay variation			50.00
Ground receiver reply delay variation			50.00
Ground delay calibration error			50.00
Airborne delay calibration error			50.00
Air Transmitter quantization noise(100 mhz clock)	1.00E-08	9.14	
Gnd Transmitter quantization noise(100 mhz clock)	1.00E-08	9.14	
Ground Reply Delay Clock Error (seconds)	2.50E-07		228.44
Aircraft Clock Error (seconds)?	5.00E-07		456.88
Total Range Bias Error (rss) feet			600.77
Total Noise Error (rss) feet		688.61	
Total 2-way Ranging Bias Error (feet)			**300.39**
Total 2-way Ranging Noise Error (feet)		**344.31**	

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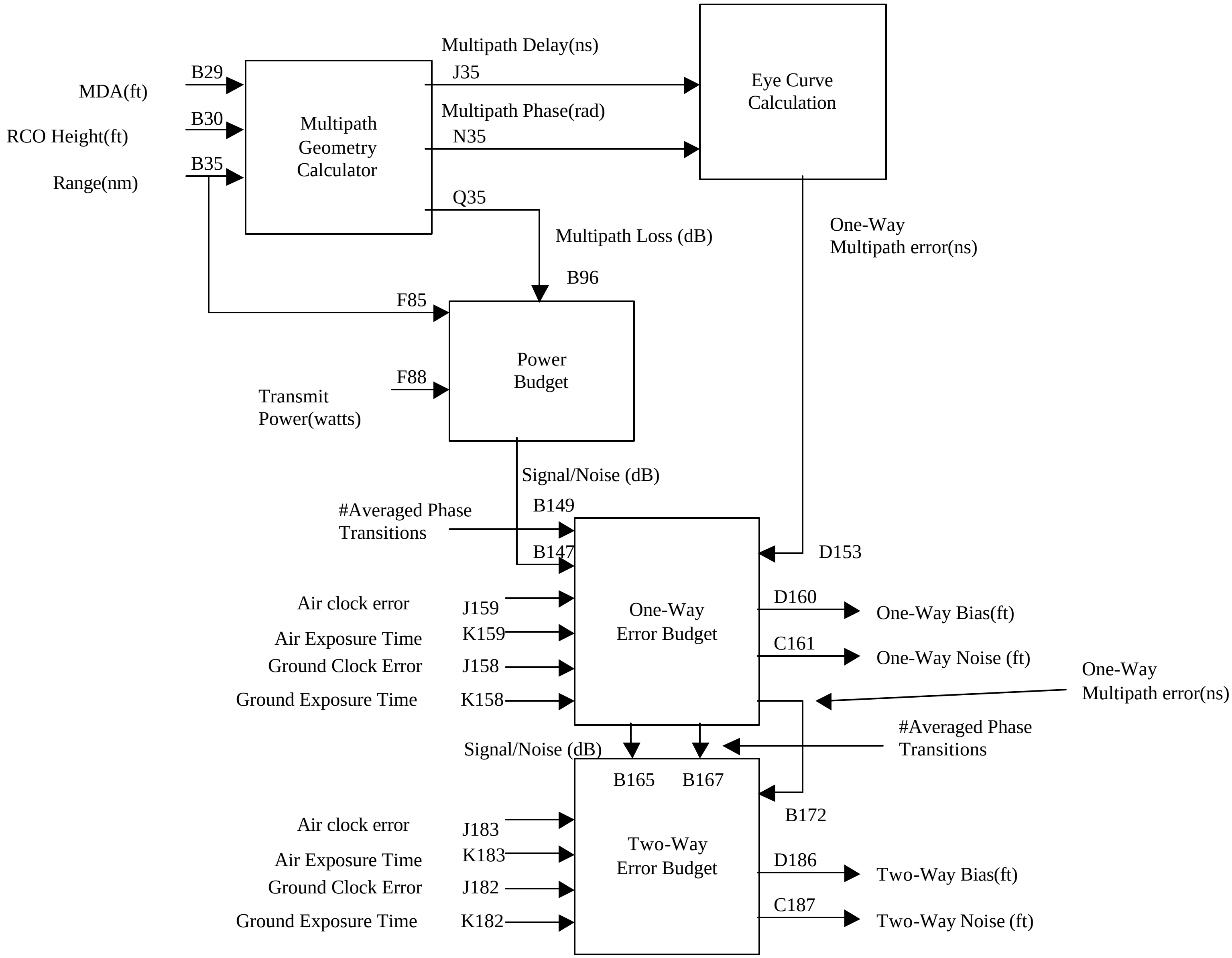
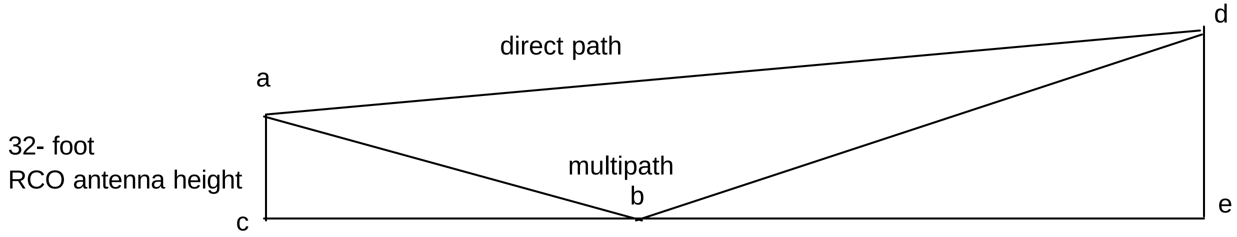
Clock Stability
(Typical)

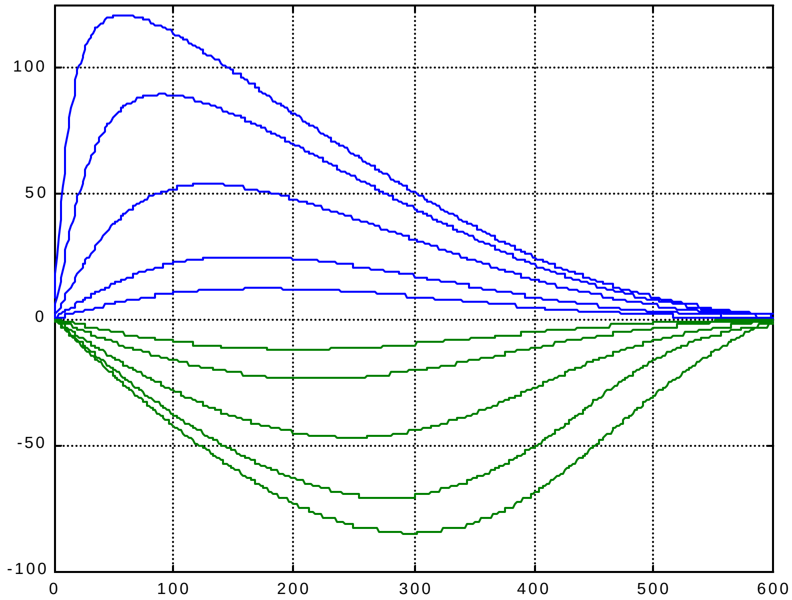
- Crystal
  - 10 ppm, ~$10, small
- TCXO
  - 0.5 ppm, ~$500, <1 cu inch
- DCCO
  - 0.1 ppm, ~$1000, ~1 cu inch
- Portable Rubidium
  - 0.0001 ppm, $~10k+, <1 cu ft
- Cesium
  - 0.00000001 ppm, $75k+, 3 cu ft +

Overall Ranging Budget



Multipath Response





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Typical Results
(One-Way)

	Bias	Multipath Effect
Rubidium Air/Ground	386	-20 ft
Cesium Ground	297	-30 ft
Cesium Air	165	-60 ft

	Noise	Multipath Loss in dB
S/N = 32 db	486	-20 dB
S/N = 50 dB	64	-3 dB

Typical Results
(Two-Way)

	Bias	Multipath Effect
Air TCXO/Gnd DCCO	278	-32 ft
Air DCCO	166	-63 ft
Ground Rubidium	164	-64 ft
With multipath limiting	100 ft	

	Noise	Multipath Loss in dB
S/N = 32 dB	344	-20 dB
S/N = 50 dB	45	-3 dB

ANS Aiding

- Typical configuration
  - Extended Kalman Filter
  - Range measurements as reference calibration
- Potential Enhancements
  - Estimate ranging errors
  - Use large geometry changes to advantage
    - Requires accurate velocity reference
  - Estimate over time using data storage buffers

Summary

- Future navigation will depend on communications services
- VHF digital voice/data will be readily available
  - Potential source of ranging information
  - "Replace" ground-based NAVAIDs vs. "Retire"
- One-way ranging impractical at the needed exposure time
- Two-way ranging could potentially support NPA
  - Initial look: VHF barely meets 50 m 1-sigma accuracy requirement
    - Integrity management more straightforward
  - Ground multipath and clock stability a driving factor
  - Network issues not considered
- Ideal calibration source for Autonomous Navigation System
  - Velocity error requirement to be evaluated