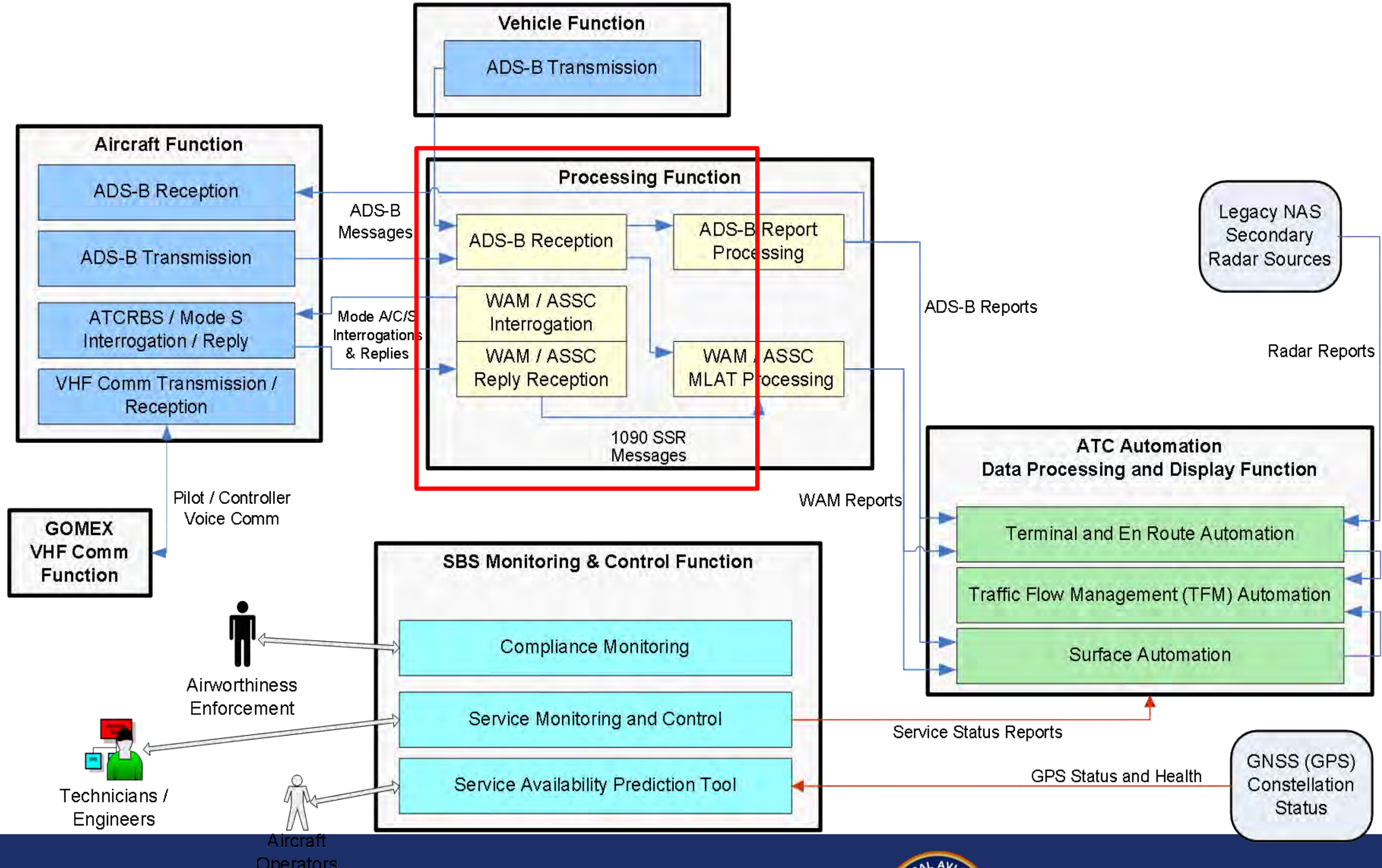
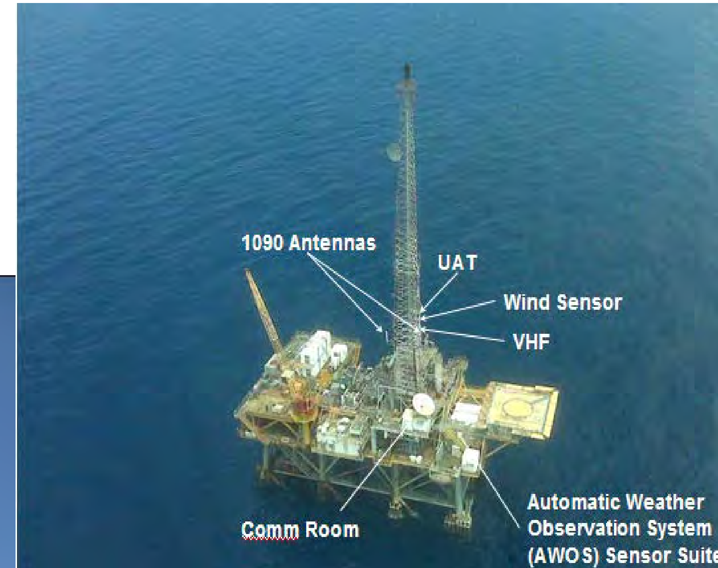
Detailed Overview of Ground Systems

FAA Surveillance Functional Architecture

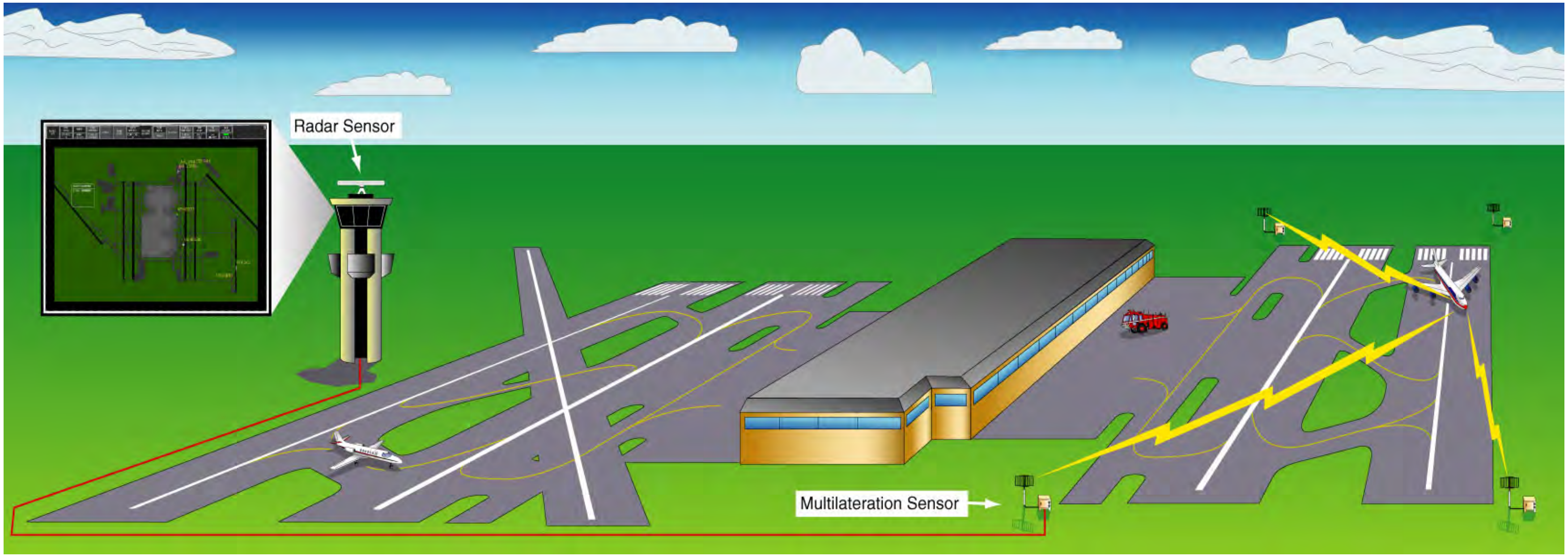


FAA ADS-B Ground Systems



ASDE-X Purpose

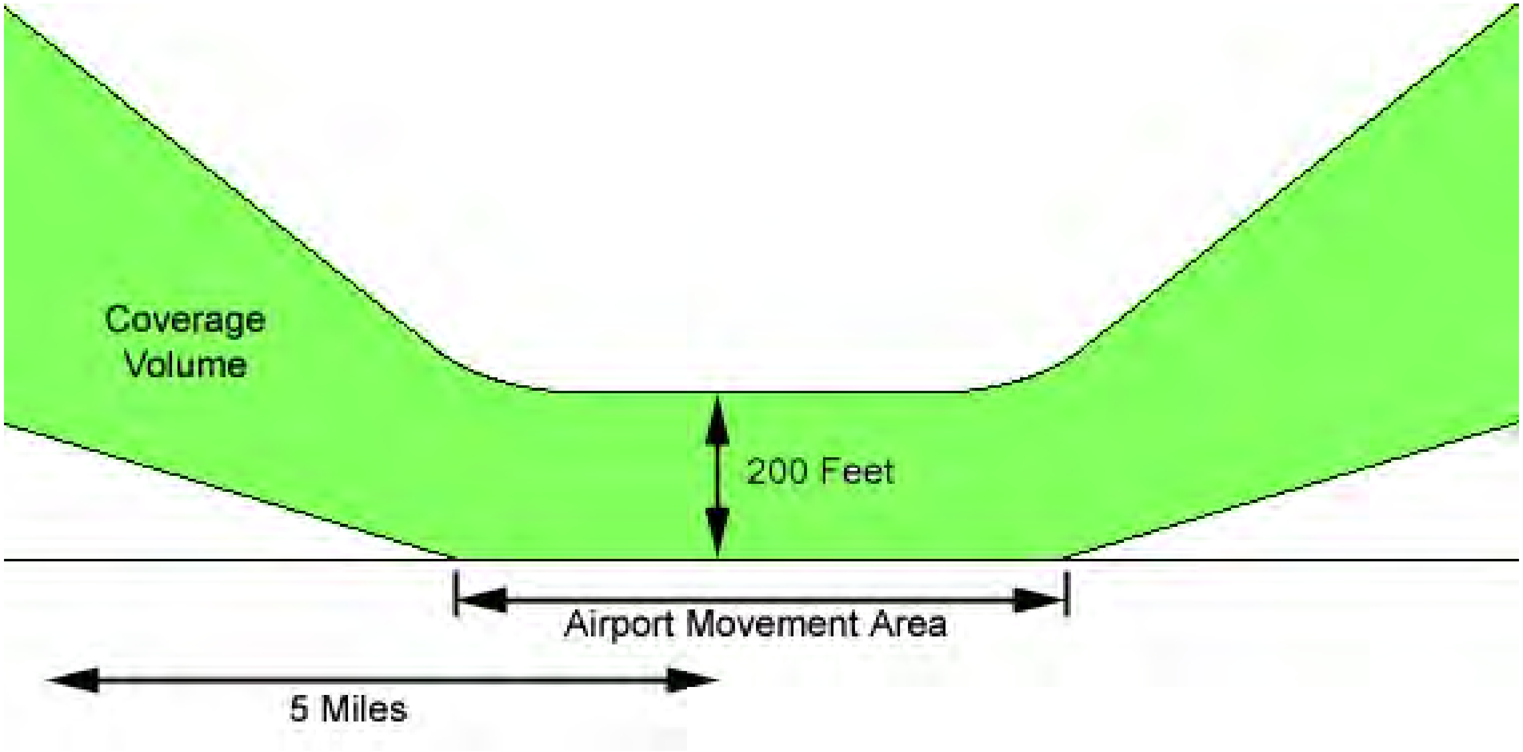
- **Airport Surface Detection Equipment - Model X (ASDE-X) provides multi-sensor surface surveillance with aircraft and vehicle identification**



ASDE-X Purpose

- **System Capabilities**
  - Provide coverage for airport surface and approach areas, out to five nautical miles
  - Track over 200 combined real surface and approach targets, with a peak initiation rate of 20 new targets per second
  - Provide accurate identification of all aircraft on the ground
  - Once a second update rate
  - Quick track initiation, within five seconds after entering coverage area
  - Integrate flight plan information
  - ADS-B target reporting

ASDE-X Coverage Volume



ASDE-X Subsystems

- **Multilateration (MLAT)**
  - "Secondary Surveillance System" that provides position and identification of all transponder equipped aircraft and vehicles
- **Surface Movement Radar (SMR)**
  - "Primary Surveillance System" used to detect surface targets
- **Multi-Sensor Data Processor (MSDP)**
  - Combines all sensor reports for a target, determines target position and tracks the target
- **Tower Display**
  - Provides the data and displays for Air Traffic Controller and Airway Facility Technician use

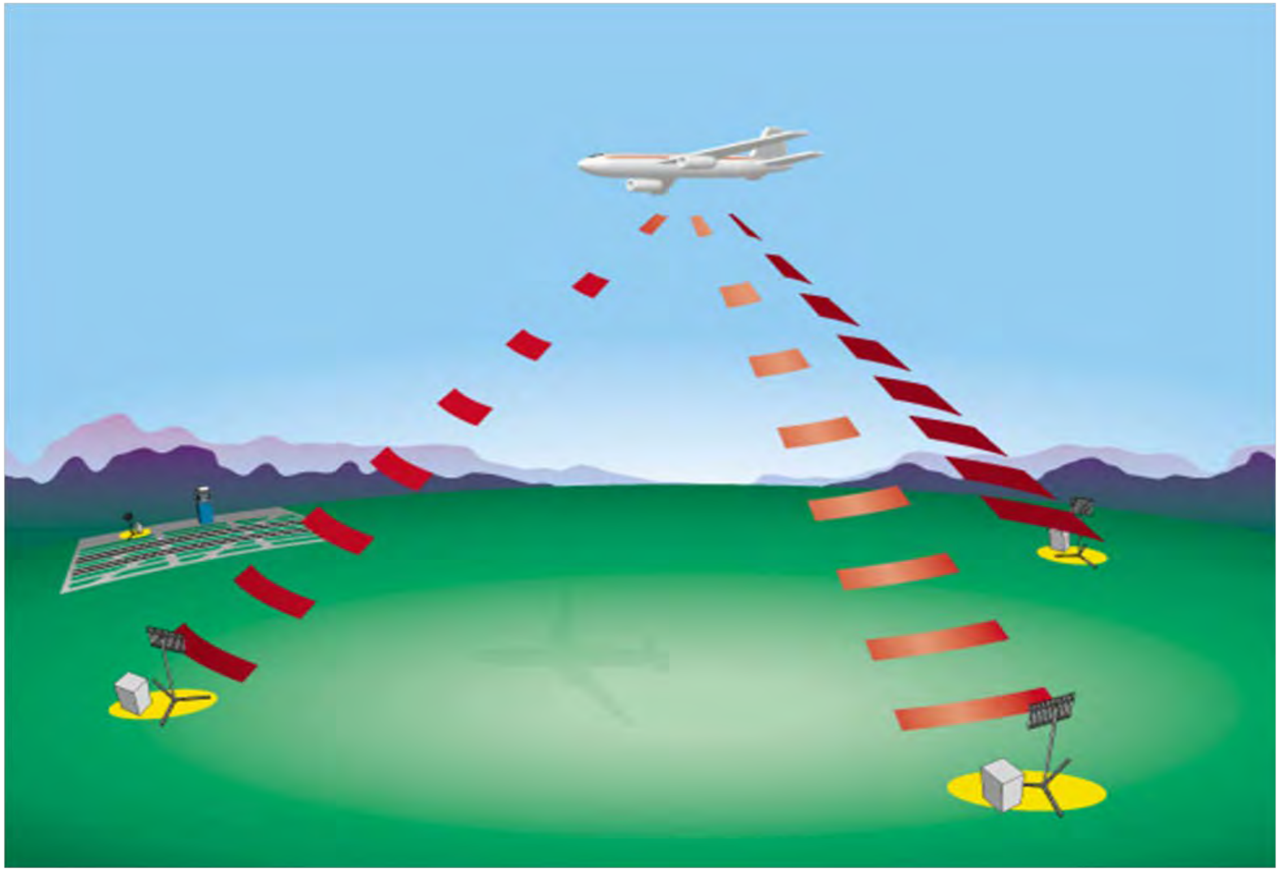
ASDE-X Subsystems

- **Remote Monitoring System (RMS)**
  - Provides the data and displays the Airway Facility Technician uses to monitor, troubleshoot and manage ASDE-X
- **Communications**
  - Provides communications and protocol conversion between subsystems and other information sources such as ASR-9 and ARTS

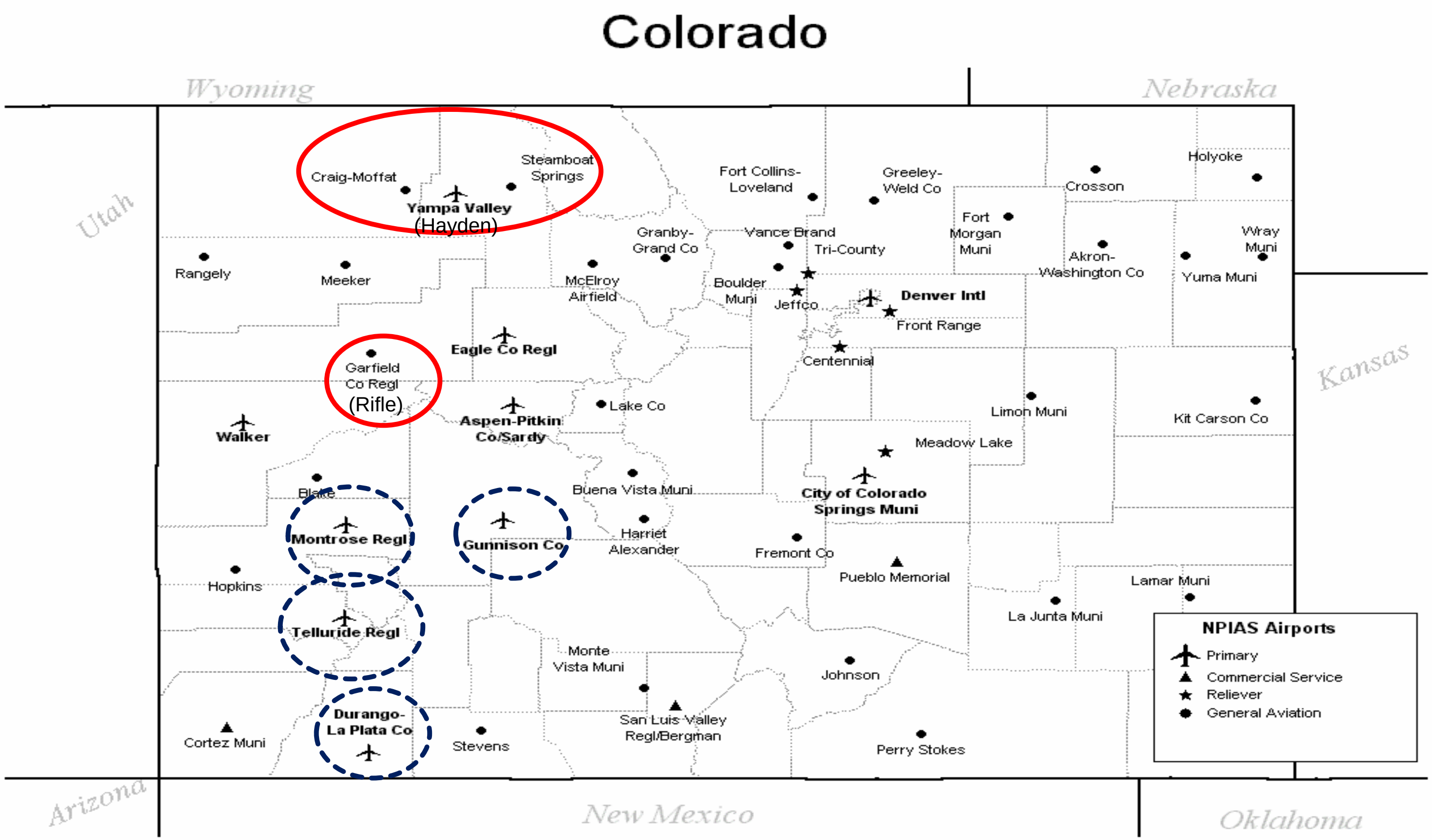
MLAT Surface Implementation (SFO)

Purpose of WAM

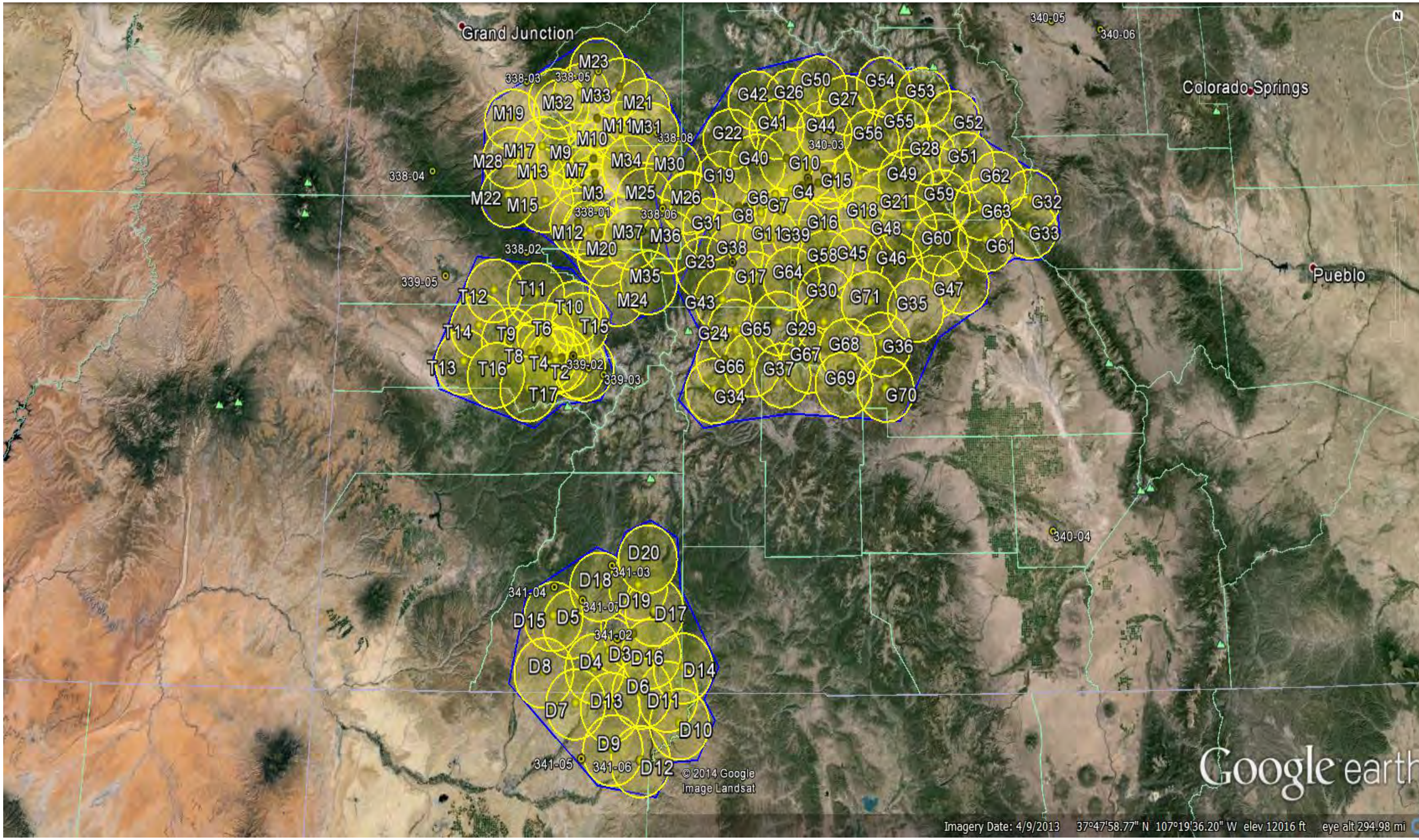
- **WAM provides secondary surveillance with target identification**



WAM Implementation (Colorado)



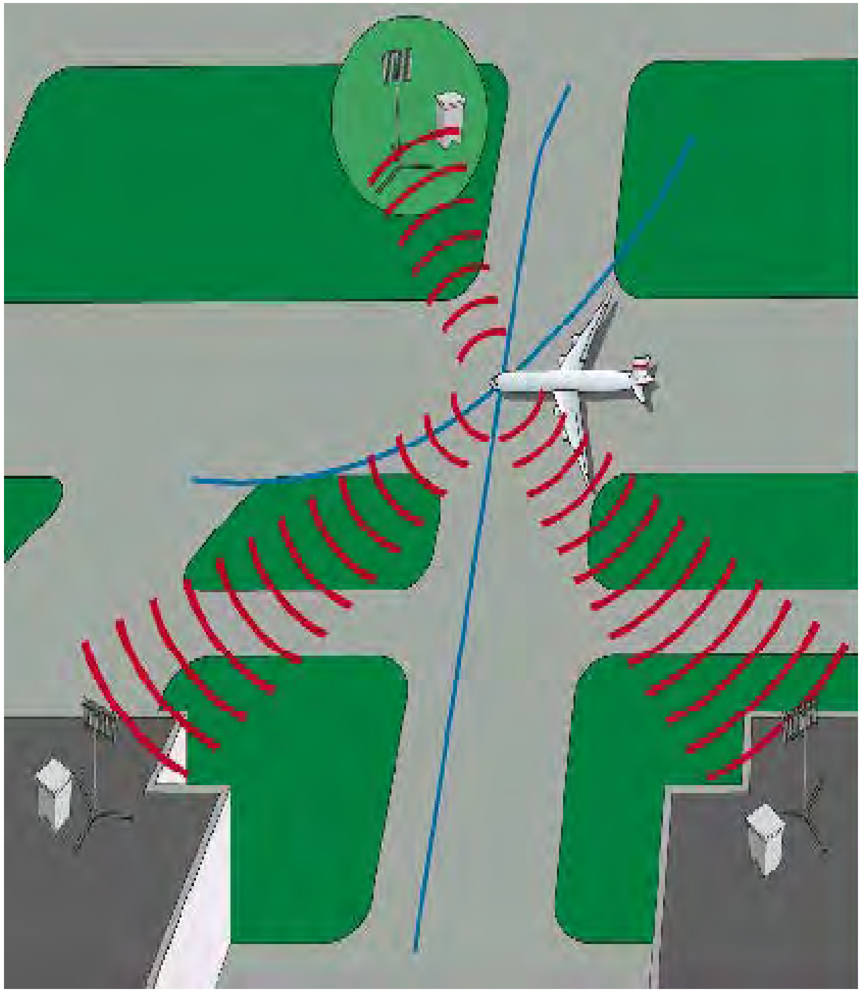
WAM Implementation (Colorado)



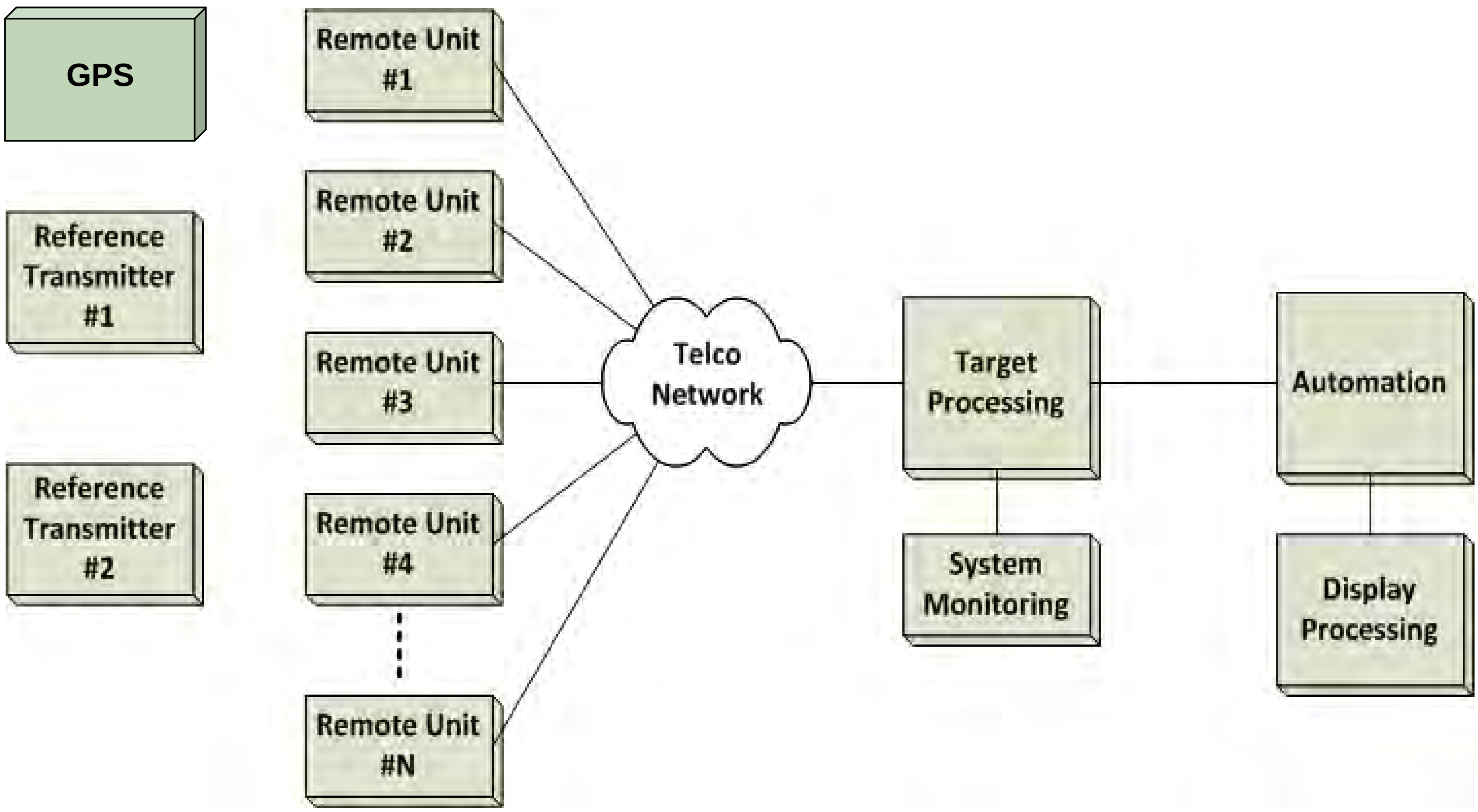
Multilateration Concept

Multilateration Concept

- **Multilateration is based on Time Difference of Arrival (TDOA) processing**
- **The key concepts of a TDOA system include the following:**
  - RF signal is received at multiple Remote Units (RUs). Note: Minimum 3 RUs are needed to track target.
  - Signal is time-stamped at each RU
  - Time stamped signal is sent from each RU to a Target Processor (TP)
  - TP calculates the difference in signal arrival time from one RU to all other RUs and generates solution arcs
  - TP provides an estimated target (transponder) location at a theoretical intersection of solution arcs

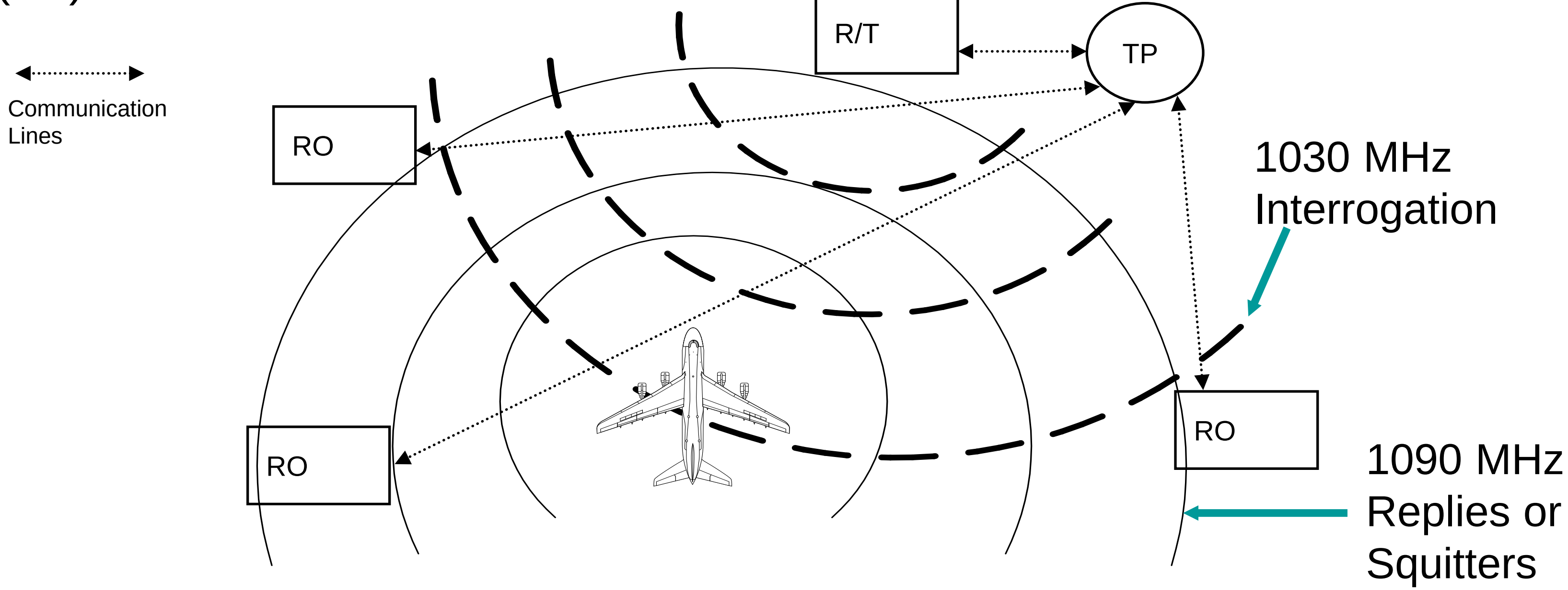


Multilateration Architecture



Multilateration Concept

- **WAM Multilateration Implementation:**
  - Uses aircraft transponder beacon signals
  - Receiver / Transmitter (R/Ts) interrogate aircraft
  - Receive Only (ROs) and Receiver / Transmitter (R/Ts) receive replies and squitters
  - Replies and squitters are time stamped and sent to a Target Processor (TP)

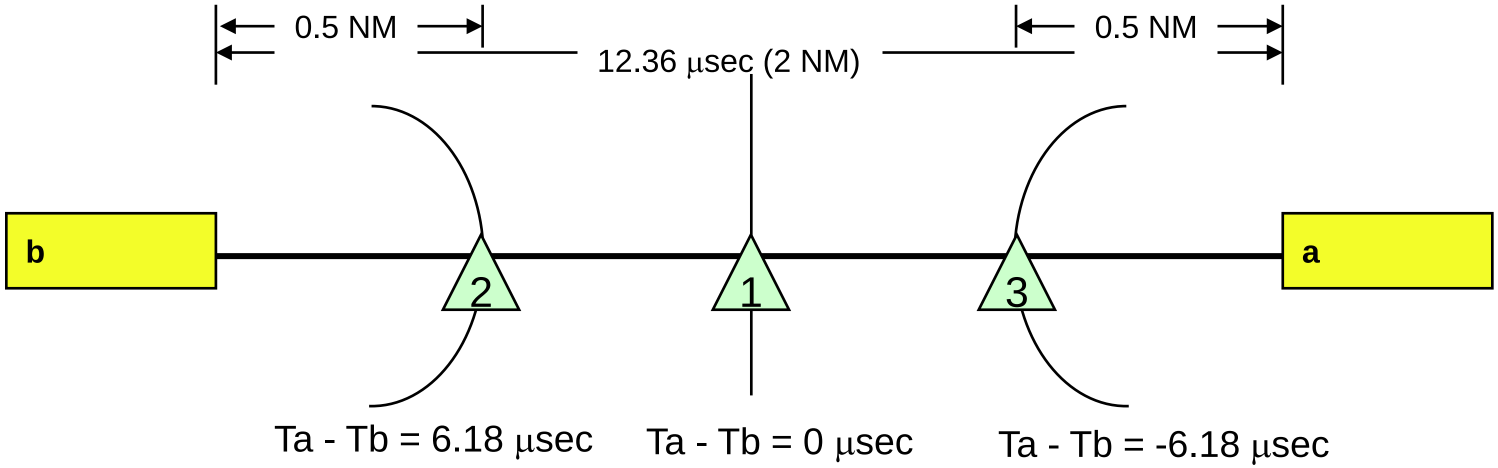


Multilateration Theory

Time Difference of Arrival (TDOA)

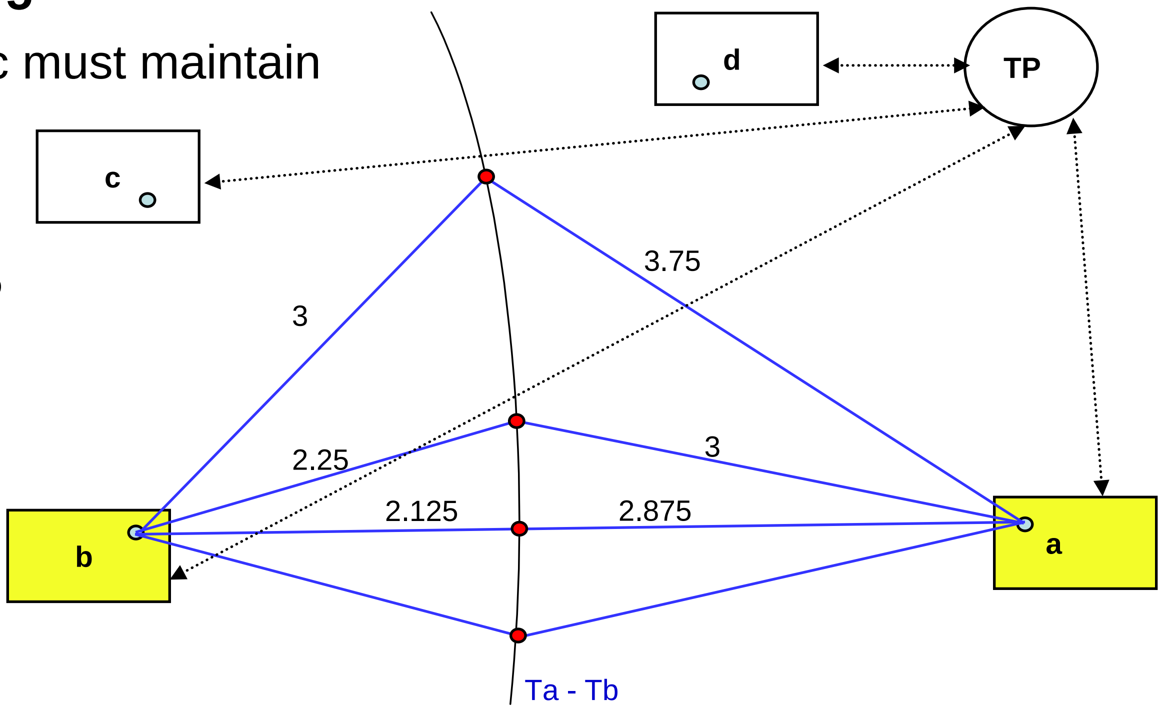
Time Difference of Arrival (TDOA)

- **Calculating the difference in a signal arrival time between two sensors.**
  – Time = Distance
    - RF energy travels at the speed of light
    - RF energy travels 1 NM in 6.18 μsec
  – TDOA = Ta - Tb
    - The difference in arrival time can be plotted on a hyperbolic arc
    - Every point on the arc must maintain this difference



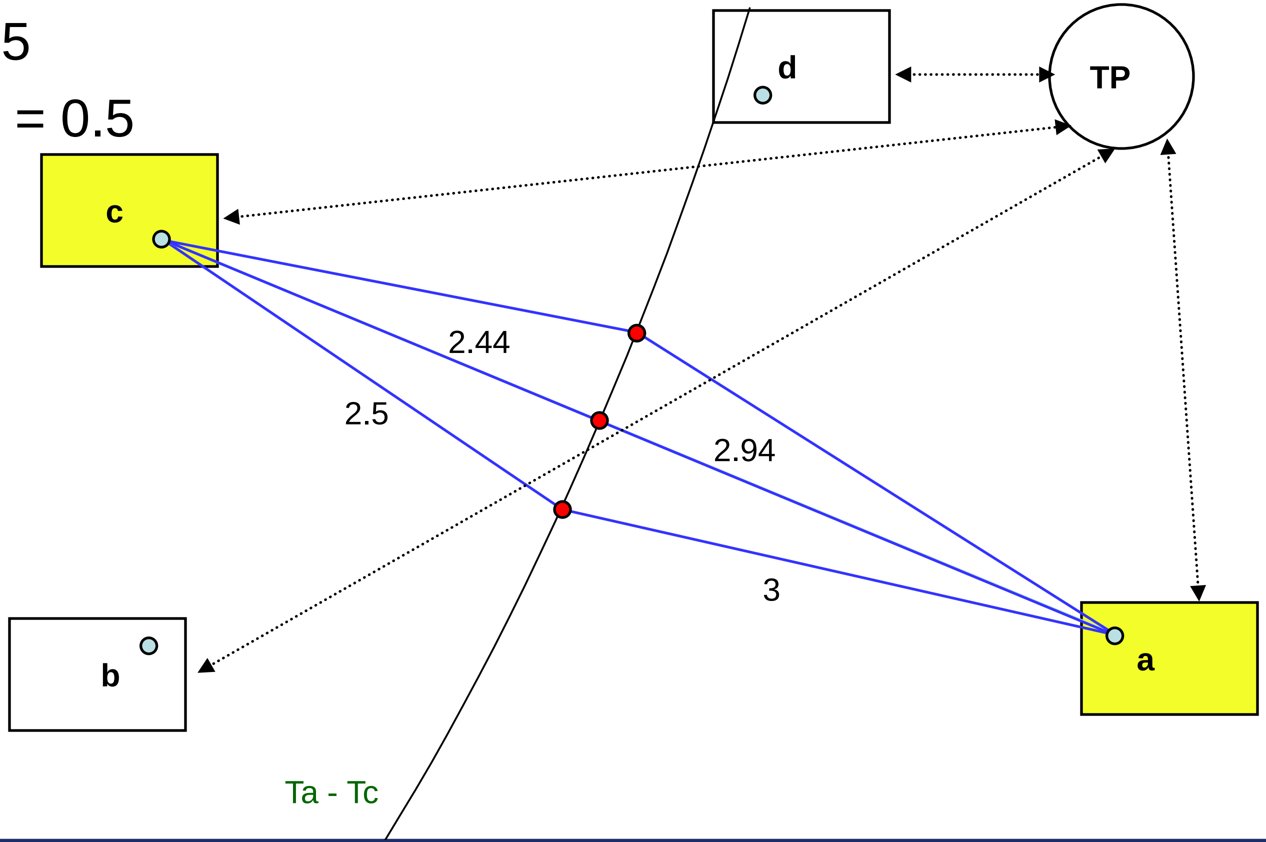
Time Difference of Arrival (TDOA)

- **Target Processor (TP) performs TDOA calculations to generate hyperbolic solution arcs**
  - Transponder must exist somewhere on the arc
  - TDOA = (Time received at RU a) - (Time received at RU b)
  - TDOA = Ta - Tb = 0**.75**
  - Every point on the arc must maintain this time difference
    - 2.875 - ___ = 0.75
    - 3 - ___ = 0.75
    - ___ - 3 = 0.75



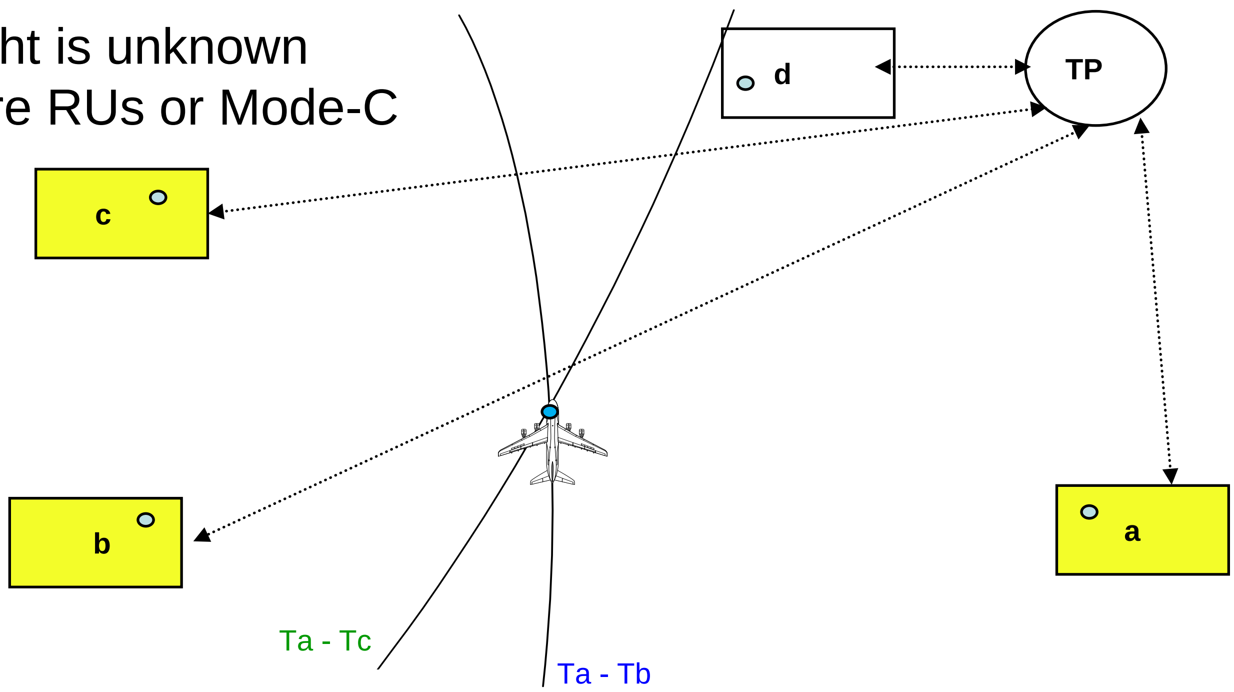
Time Difference of Arrival (TDOA)

- **By itself, one arc provides no useful information.**
  - Calculating second solution arc for RU a to RU c
  - TDOA = Ta - Tc = 0.5
    - 3 - 2.5 = 0.5
    - 2.94 - 2.44 = 0.5



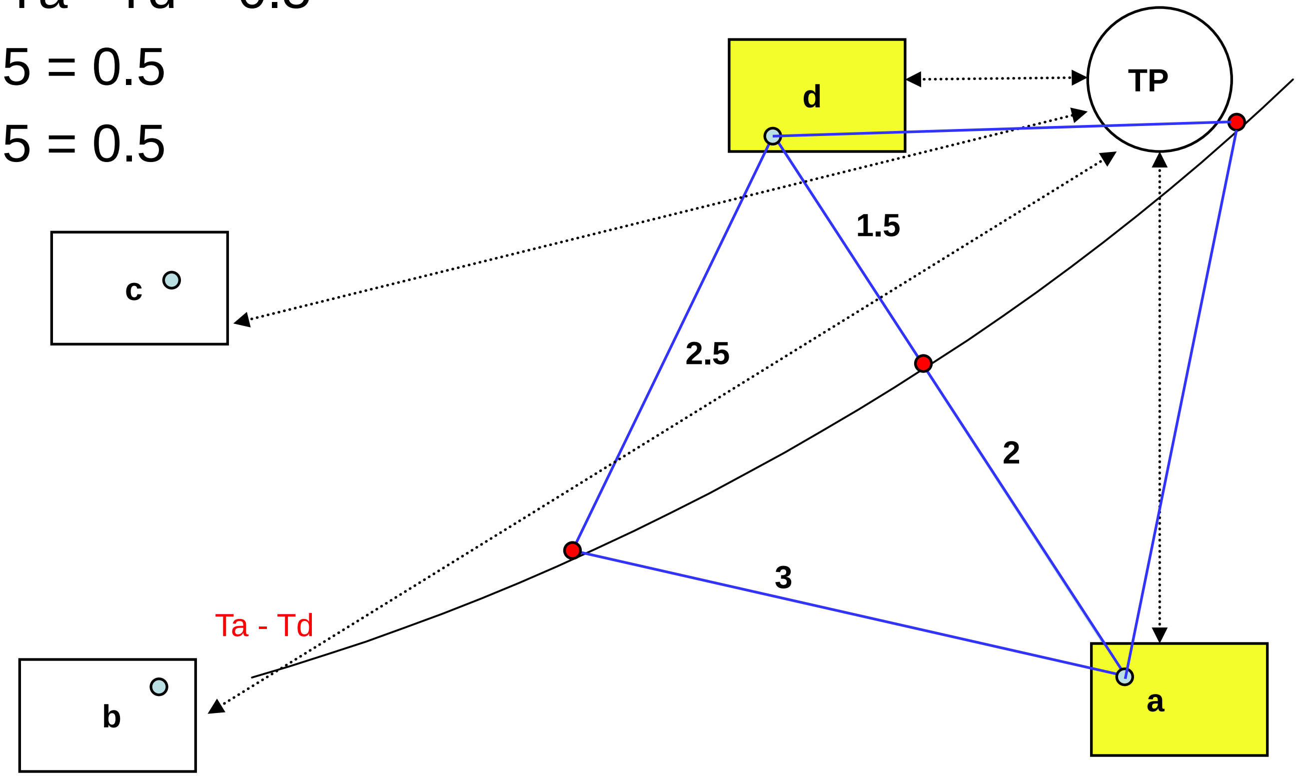
Time Difference of Arrival (TDOA)

- **To get a two dimensional point, three RUs are required.**
  - 3 RUs develop intersecting hyperbola, 2D formula is used (no Z axis)
  - 2d position is generated
    - Gives range and azimuth
    - Target height is unknown without more RUs or Mode-C



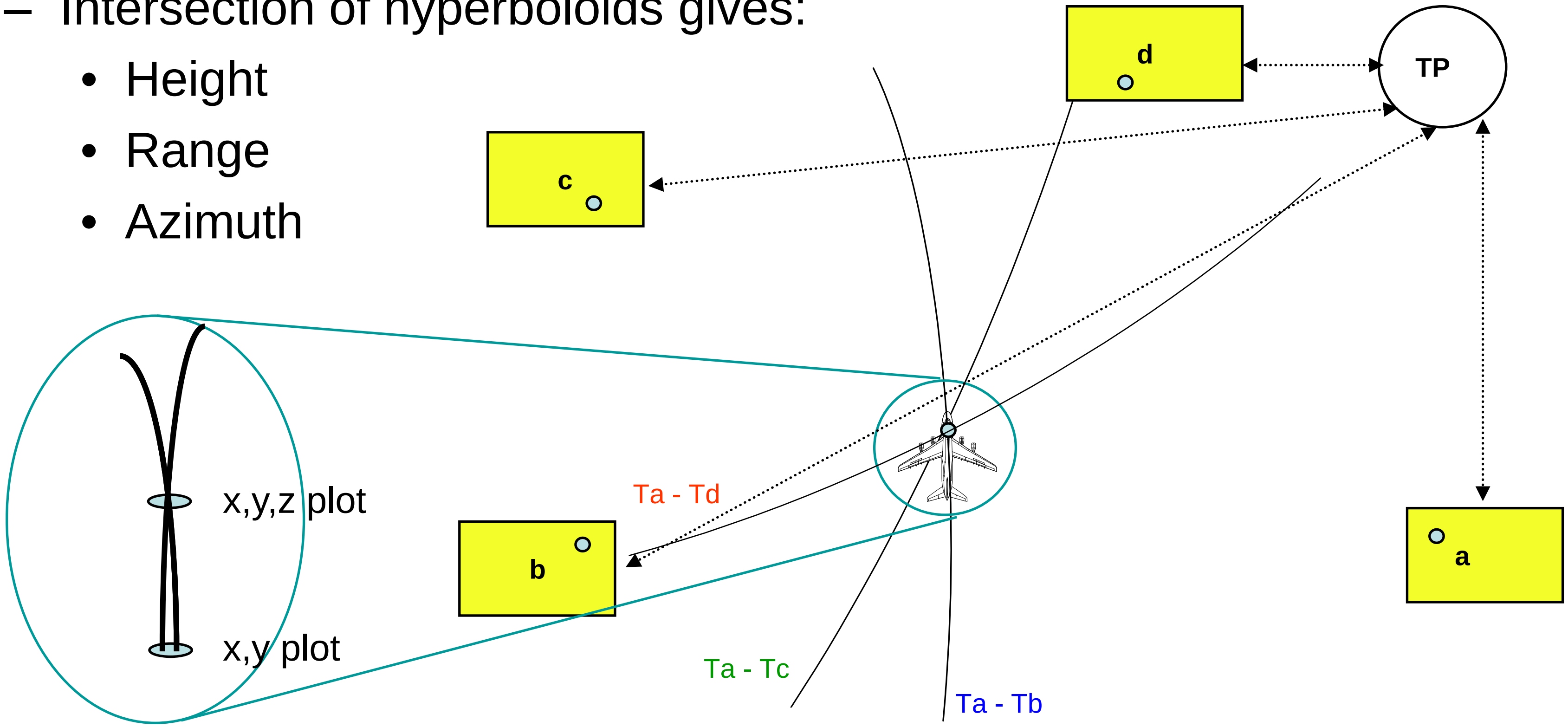
Time Difference of Arrival (TDOA)

- **To get a three dimensional point, four or more RUs are required.**
  - Calculating solution arc for RU a to RU d
  - TDOA = Ta - Td = 0.5
    - 3 - 2.5 = 0.5
    - 2 - 1.5 = 0.5



Time Difference of Arrival (TDOA)

- **With four or more RUs, 3D formula is used**
  - Z axis is calculated
  - Generates hyperboloids (3D hyperbola)
  - Intersection of hyperboloids gives:
    - Height
    - Range
    - Azimuth



Time Difference of Arrival (TDOA)

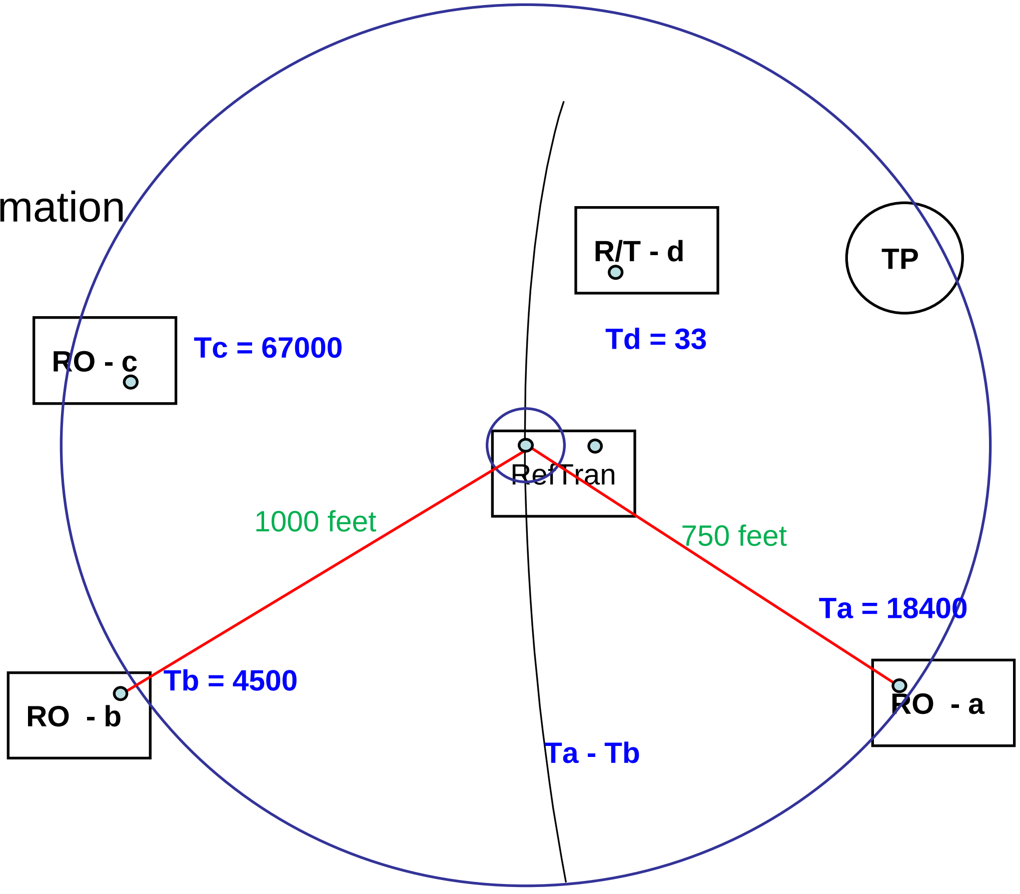
- **WAM systems are capable of using GPS as the primary timing source**
- **If GPS timing is not primary or unavailable, TDOA processing can be performed in the TP using Fine Time Stamps from the Remote Units (RUs)**
  - Each RU has a free running clock
    - Timestamp resolution will affect the accuracy of the solution
    - The free running clocks in the RUs are not synchronized
  - Multilateration is not possible unless the RU clocks are corrected to a common time basis
- **Reference Transmitter (RefTran) provides a known signal to calibrate the TP TDOA function**
  - RefTrans squitter once a second
  - TP knows:
    - RefTran position and Mode S identification
    - RU positions
    - Expected TDOA between all RUs for each RefTran squitter

Time Difference of Arrival (TDOA)

- **TDOA Calibration**
  - Clocks in the RUs have no common time reference
  - TP calculates TDOA on the RefTran squitter
  - TP initiates TDOA calibration upon receipt of the RefTran's unique Mode-S identification
  - TP uses the difference between the expected RefTran TDOA and the calculated TDOA to calculate RU Offsets
    - RU offsets are used to provide a common time base required for Multilateration to take place
  - TP also calculates Drift rates
    - Drift rates account for differences in the RU clock circuits (clock width, speed, skew, etc…)
    - TP uses Drift rates to accurately predict changes in the RU Offset while the RefTran is not squitting
    - Drift rates improve multilateration accuracy during the 1 second period between RefTran squitters

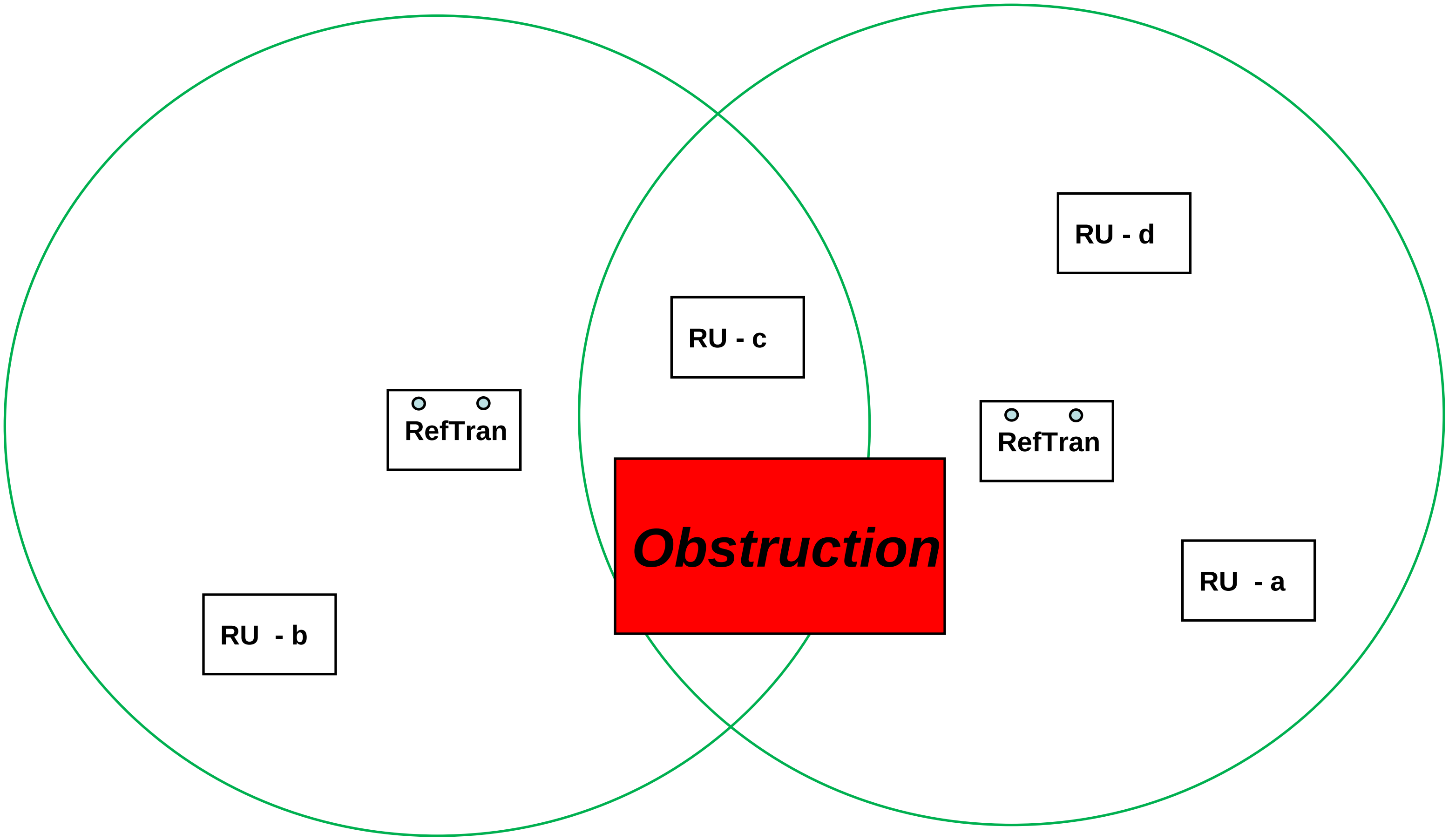
Time Difference of Arrival (TDOA)

- **RefTran Example:**
  - TP uses one RU as a reference and calculates the TDOA for all RUs
  - RU counters provide 31 bits of information
  - 1 clock tick = 10 nsec
  - Example:
    - Expected TDOA
      Ta – Tb = -250 feet
      -250 feet = -250 nsec
      -250 nsec = -25 tics
    - Calculated TDOA
      Ta – Tb = 18400 - 4500
      Ta – Tb = 13900 tics
    - Offset = Calculated – Expected
      Offset = 13900 –(-25)
      Offset = 13925 tics
    - Next return, Drift rates can be calculated

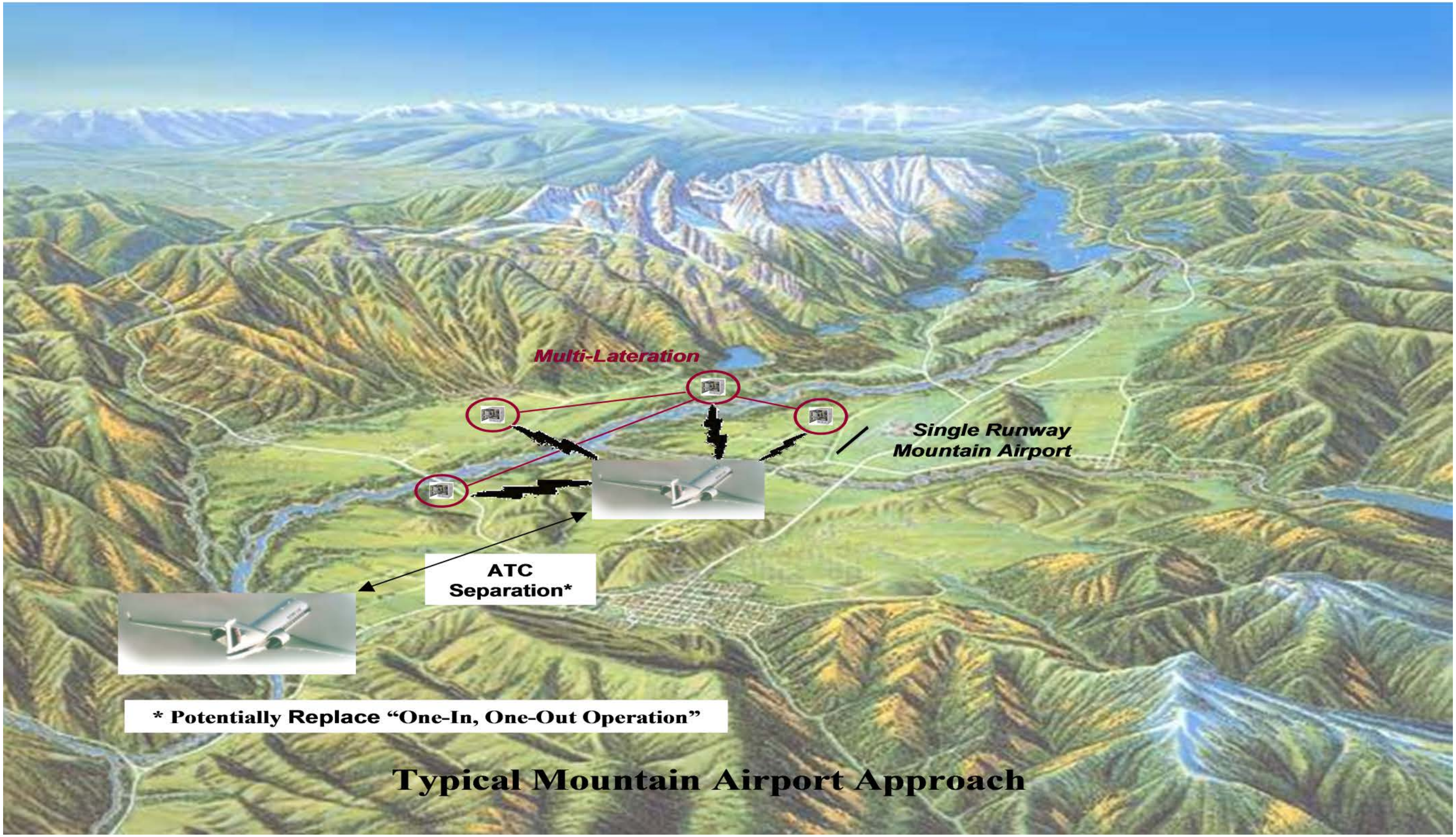


Time Difference of Arrival (TDOA)

- **RefTrans must be seen by more than one RU for TDOA calibration**



Example of MLAT Implementation



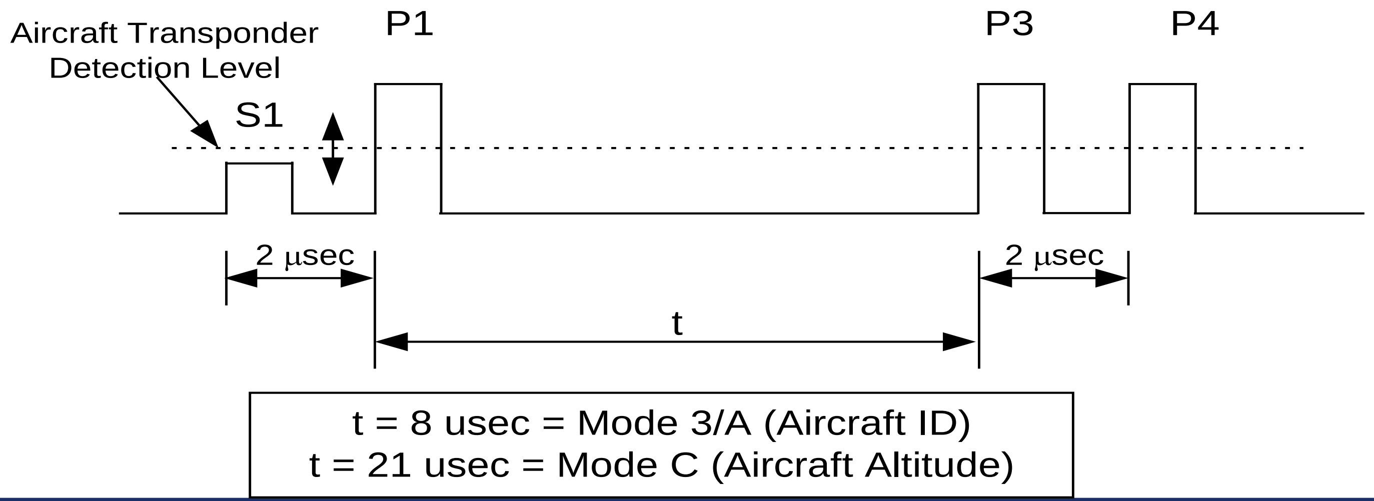
Target Detection and Tracking

Target Detection and Tracking

- **The WAM system performs target detection and tracking on ATCRBS, Mode S, and ADS-B signals.**
- **It can receive, decode and determine an accurate TDOA for:**
  - Air Traffic Control Radar Beacon System (ATCRBS) replies
  - Mode S (Select) signals (squitters and replies)
  - Automatic Dependent Surveillance - Broadcast (ADS-B) signals

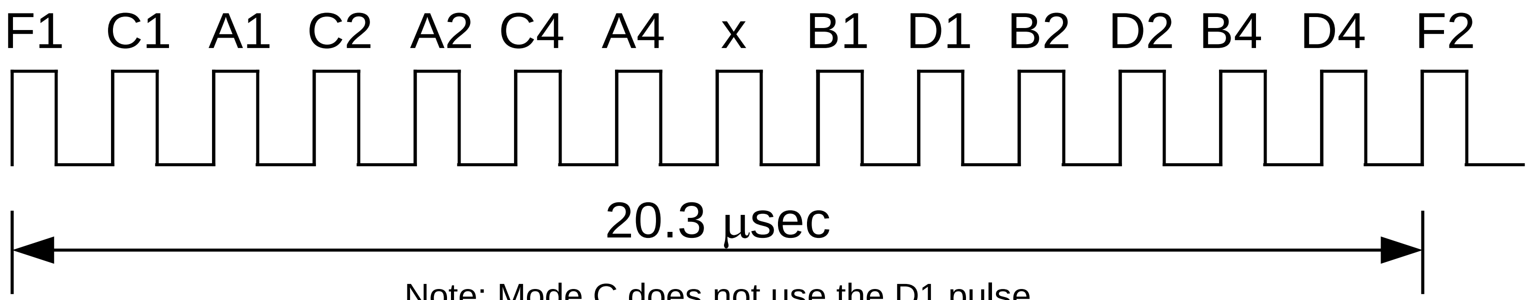
ATCRBS

- **WAM ATCRBS Interrogation**
  - P1 and P3 indicate Mode (3/A or C), they are 0.8 μsec in width and either 8 or 21 μsec apart.
  - P4 trails P3 by 2 μsec and is also 0.8 μsec in width. ATCRBS transponders will not detect P4. Mode S transponders will decode a 0.8 μsec P4 as an ATCRBS only All-Call request (suppressing the Mode S transponder).
  - S1 precedes P1 by 2 μsec and is used to simulate a P1-P2 suppression pulse.



ATCRBS

- **ATCRBS Replies**
  - An ATCRBS reply provides aircraft identification(3/A) or altitude(C) information
  - ATCRBS transponders reply with either their Mode 3/A or C code using a 12 bit reply bracketed by 2 framing pulses
  - Framing pulses are 20.3 μsec apart
  - 12 bit reply consists of four 3 bit numbers, A B C D, decoding provides the reply code



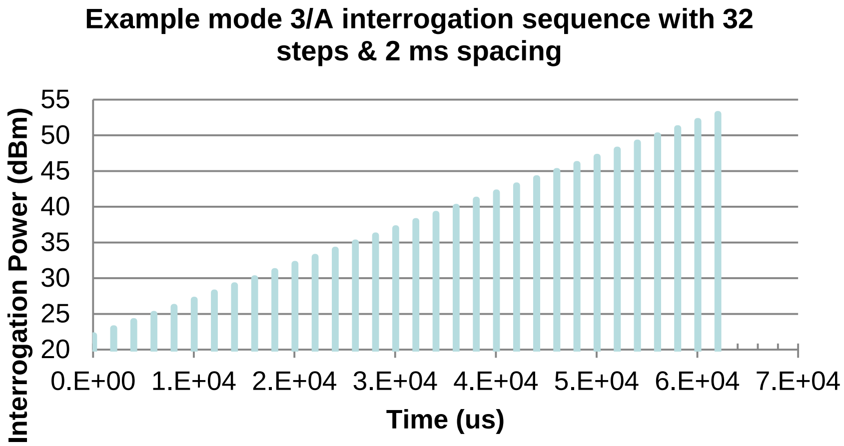
Note: Mode C does not use the D1 pulse

ATCRBS Target Acquisition

- **ATCRBS targets are acquired by using Mode A/A doublet interrogations in a Whisper/Shout Sequence**
- **Doublet Interrogations**
  - A doublet is two interrogations with a close fixed spacing (100s of microseconds)
  - A Mode A/A doublet is two Mode A all call interrogations with close fixed spacing
  - The doublet spacing is fixed at each interrogator within a service volume and allows the replies to be filtered at the receivers to reduce the impact of FRUIT and only deliver relevant replies

ATCRBS Target Acquisition

- **Whisper / Shout (W/S) Sequence (Acquisition)**
  - Series of range-limited interrogations with incrementing power levels
  - Analogous to glancing at darts on a dartboard and identifying groups of darts by their ring number
  - Sequence has low repetition rate (~5 s) at each radio (=> over multiple radios the effective repetition rate is ~2.5 s)

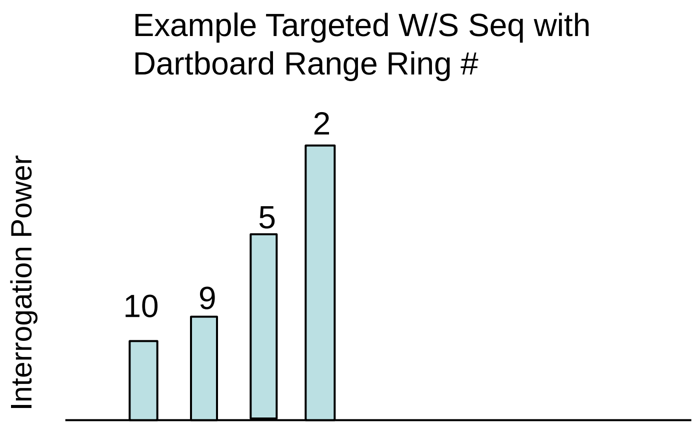


ATCRBS Target Tracking

- **ATCRBS Targets are tracked by using AC doublet interrogations in a Whisper/Shout Sequence**
- **Doublet Interrogations**
  - Doublet Interrogations are similar to the ATCRBS acquisition doublets, but are Mode AC (a Mode A All Call, followed by a Mode C All Call)
  - The fixed doublet spacing for a Mode AC interrogation is the same as a Mode AA relative to each interrogating radio
- **W/S Sequence**
  - The MLAT Server commands only those W/S steps necessary to interrogate previously acquired targets

ATCRBS Target Tracking

- **W/S Sequence (Targeted)**
  - Series of range-limited interrogations with power levels specific to the targets in the region
  - Analogous to selecting groups of darts on a dartboard by their ring number
  - Sequence has higher repetition rate at the radio than the acquisition sequence

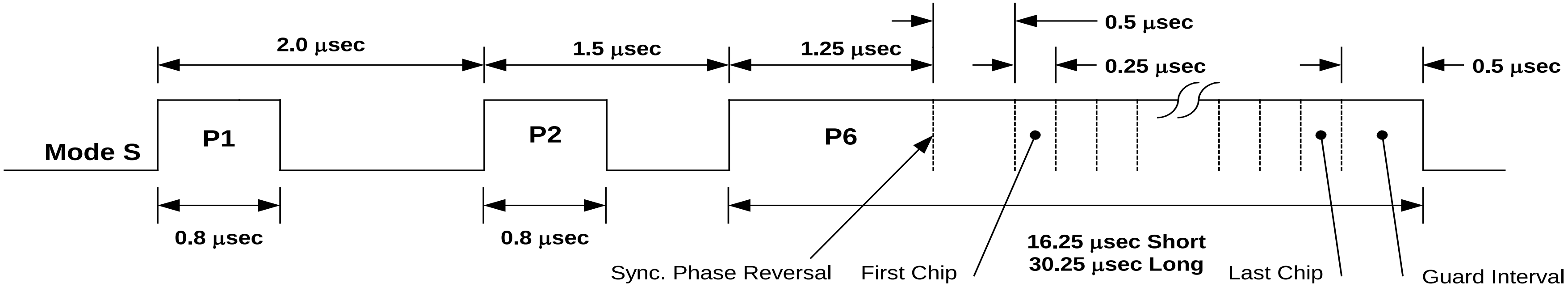


Mode S

- **Mode S**
  - Mode S transponder equipped aircraft assigned a unique ICAO 24-bit address code
  - Mode S aircraft squitter their code once every second
  - Using this unique code, interrogations can be directed to a specific aircraft and replies can be unambiguously identified
  - Mode S uses a combination of “All-Call” and addressed interrogations.
    - WAM uses addressed Mode S interrogations
    - This permits replies from closely spaced aircraft to be received without mutual interference.
  - Mode S signals can contain:
    - Mode S ID (always)
    - Aircraft identification information (Mode 3/A)
    - Altitude information (Mode C)
    - ADS-B

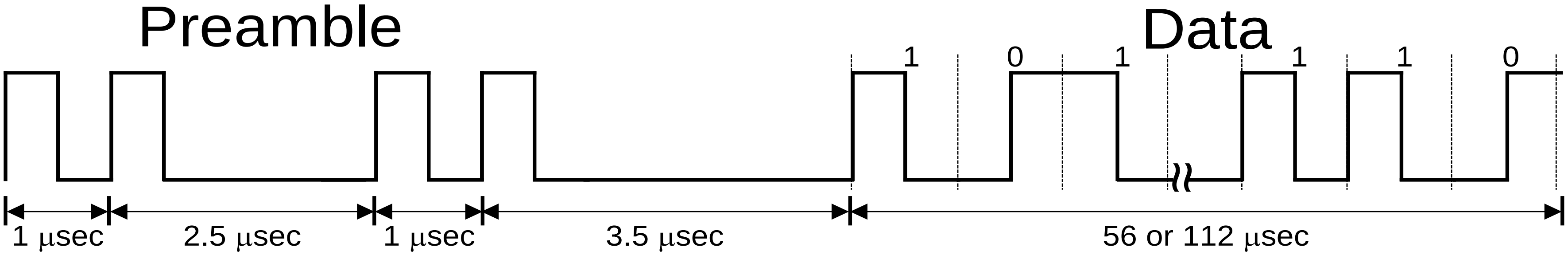
Mode S

- **Mode S Interrogations**
  - Preamble consisting of P1 and P2 pulses (0.8 μsec wide, 2 μsec apart) followed by a 16.25 or 30.25 μsec data block (1.5 μsec after P2).
  - P1 and P2 are used to suppress ATCRBS replies
  - Data block is an RF pulse using phase reversals to represent binary data
    - Called Binary Differential Phase Shift Keying (DPSK) - potential phase reversals called "chips"
    - 180 degree phase reversal = binary 1
    - No phase reversal = binary 0
    - 56 or 112 data "chips"
    - Sync Phase (first phase reversal) 2.75 μsec after P2
    - Data chips start 0.5 μsec after sync phase and can occur every 0.25 μsec
    - Guard Interval last 0.5 μsec



Mode S

- **Mode S Replies**
  - Mode S transponders reply with their address and any other information using a preamble and data block.
  - Preamble consists of four 0.5 μsec pulses separated by 1, 2.5, and 1 μsec.
  - 3.5 μsec after the last pulse is a 56 or 112 μsec data block.
  - A data block is divided into 1 μsec segments. Each segment is a bit.
  - If the first half of the segment has a pulse, the bit is a 1. If the second half of the segment has a pulse, the bit is a 0.



Mode S Uplink and Downlink Formats

Uplink Format/Modes	Downlink Format/Modes	Content
UF 0	DF 0	Short Air/Air Surveillance
UF 4	DF 4	Altitude Request/Altitude Reply
UF 4	DF 20	Altitude Request/Comm B Altitude Reply
UF 5	DF 5	ID Request/ID Reply
UF 5	DF 21	ID Request/Comm B ID Reply
UF 11	DF 11	Mode S Only All-Call/All-Call Reply
UF 16	DF 16	Long Air/Air Surveillance
UF 20	DF 4	Comm A Altitude Request/Altitude Reply
UF 20	DF 20	Comm A Altitude Request/Comm B Altitude Reply
UF 21	DF 5	Comm A ID Request/ID Reply
UF 21	DF 21	Comm A ID Request/Comm B ID Reply
UF 24	DF 24	Comm C/Comm D
	DF 17/18	ADS-B

Refer to RTCA DO-181E Section 2.2.14.1
Refer to ICAO Annex 10 Volume IV, July 2007, Sections 3.1.2.3.2.1.1 and 3.1.2.3.2.1.2

Mode-S Target Acquisition / Tracking

- **WAM utilizes spontaneous Mode S target squitters (DF11s) for target acquisition**
- **WAM performs TDOA calculations on multiple squitters to determine the horizontal position**
- **Flight ID and pressure altitude are determined by UF5/UF4 selective interrogations**
  - The position of the target is utilized to determine which radio is used for interrogations as well as the required power level
  - The rate at which interrogations are transmitted is determined by the update interval and data validity times required to support a given separation standard
- **Interrogations are not scheduled for 1090ES LV2 equipped aircraft.**

ADS-B

- **ADS-B (Automatic Dependent Surveillance – Broadcast)**
  - Is currently transmitted and received using extended Mode S
  - Relies on satellite-based Global Positioning System (GPS)
  - Equipped aircraft broadcast their precise position along with other data, such as airspeed and altitude

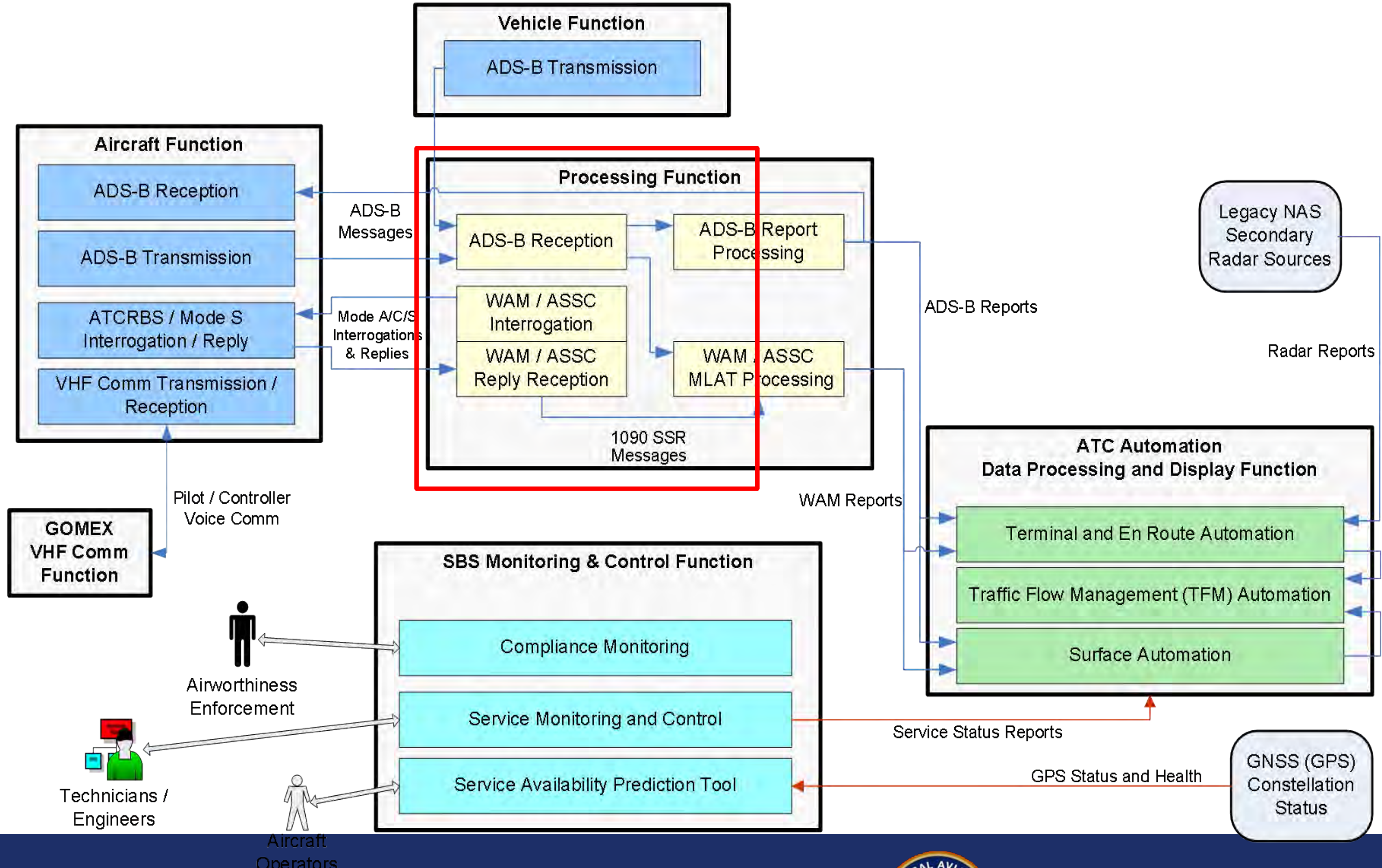
ADS-B Target Acquisition / Tracking

- **WAM utilizes spontaneous ADS-B target squitters (1090ES and UAT) for target acquisition**
- **WAM performs TDOA calculations on multiple squitters to determine the horizontal position**
- **Identification and pressure altitude is extracted from the received squitters**
  - No interrogations will be scheduled for these targets
- **Only ADS-B link Version 2 (260B/282B) targets are supported by this logic**
  - Link V2 is required for ADS-B Rule Compliance
  - Other link versions will require Mode S or ATCRBS interrogations to determine ID and pressure altitude

Height Determination

- **MLAT normally uses 2-D Multilateration solution to make position estimates**
- **The altitude reported by the target is used as height in the MLAT solution**
  - 3-D Multilateration solution is used only when no Mode C is reported
- **Error between actual height and reported altitude can cause horizontal position bias**
  - Altitude correction is often used to minimize the errors
- **Uncorrected height is reported to automation systems**

FAA Surveillance Functional Architecture



Conclusion

- **Multilateration Concept**
  - Based on Time Difference of Arrival (TDOA) Processing
  - Multiple RUs detect signal
  - WAM multilaterates on ATCRBS and Mode S
- **Time Difference of Arrival (TDOA)**
  - Time = Distance
  - RF energy travels 1 NM in 6.18 µsec
  - Difference of signal arrival time at multiple RUs is used to generate solution arcs
  - Three RUs develop hyperbolic solution arcs
  - Four or more RUs develop hyperboloid solution arcs
- **ATCRBS and Mode S**
  - WAM interrogates ATCRBS using Whisper/Shout
  - WAM interrogates Mode S using addressed interrogations
- **Refer to Aeronautical Surveillance Manual DOC 9924**