Automatic Dependent Surveillance Broadcast (ADS-B)

Mode S Extended Squitter

Dr. Vincent A. Orlando

MIT Lincoln Laboratory

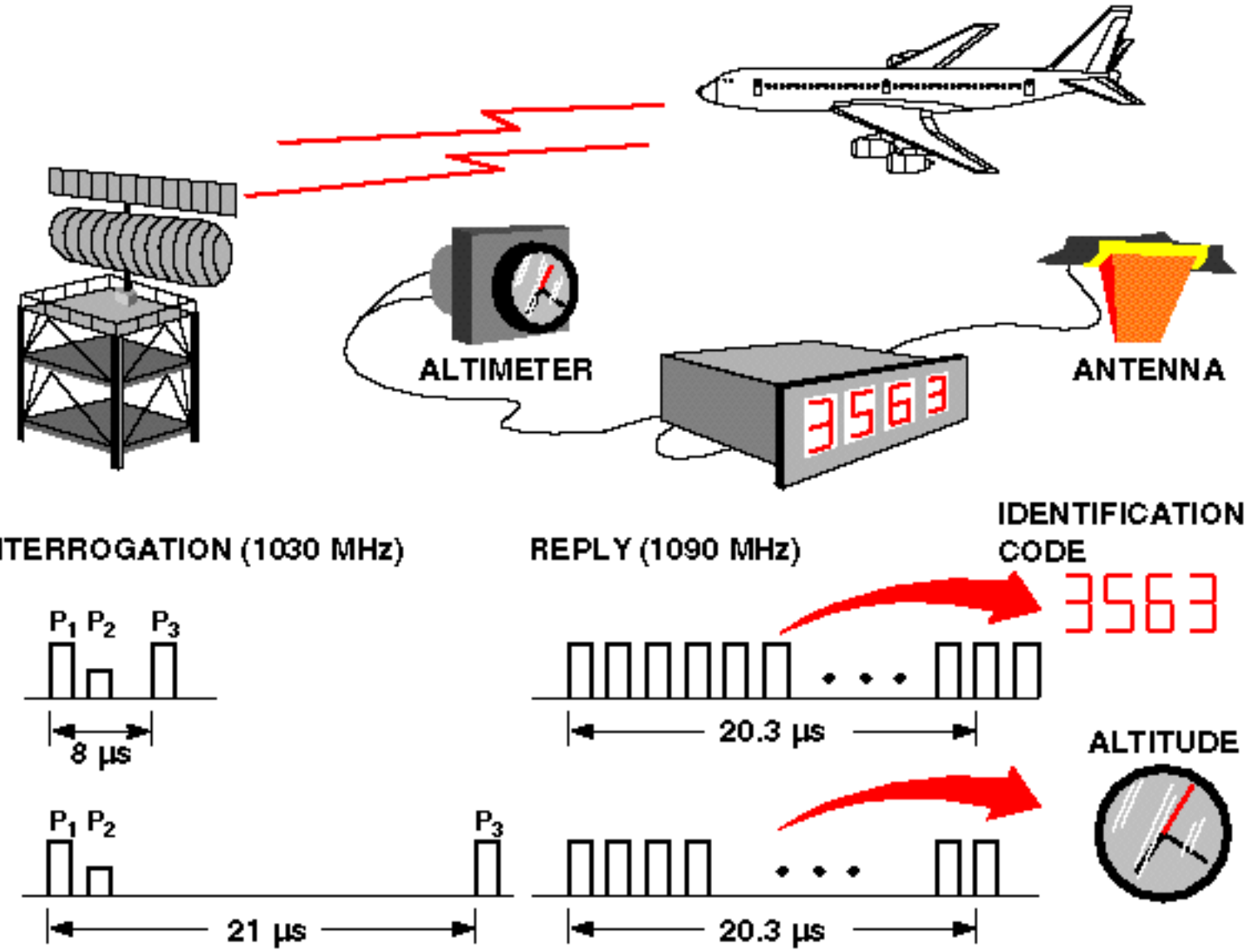
Topics

- Mode S Overview
- Extended Squitter Concept
- Development History
- Improved Squitter Reception
- Range and Capacity
- Summary of Field Validation Activities
- Status of Extended Squitter Standards
- Summary

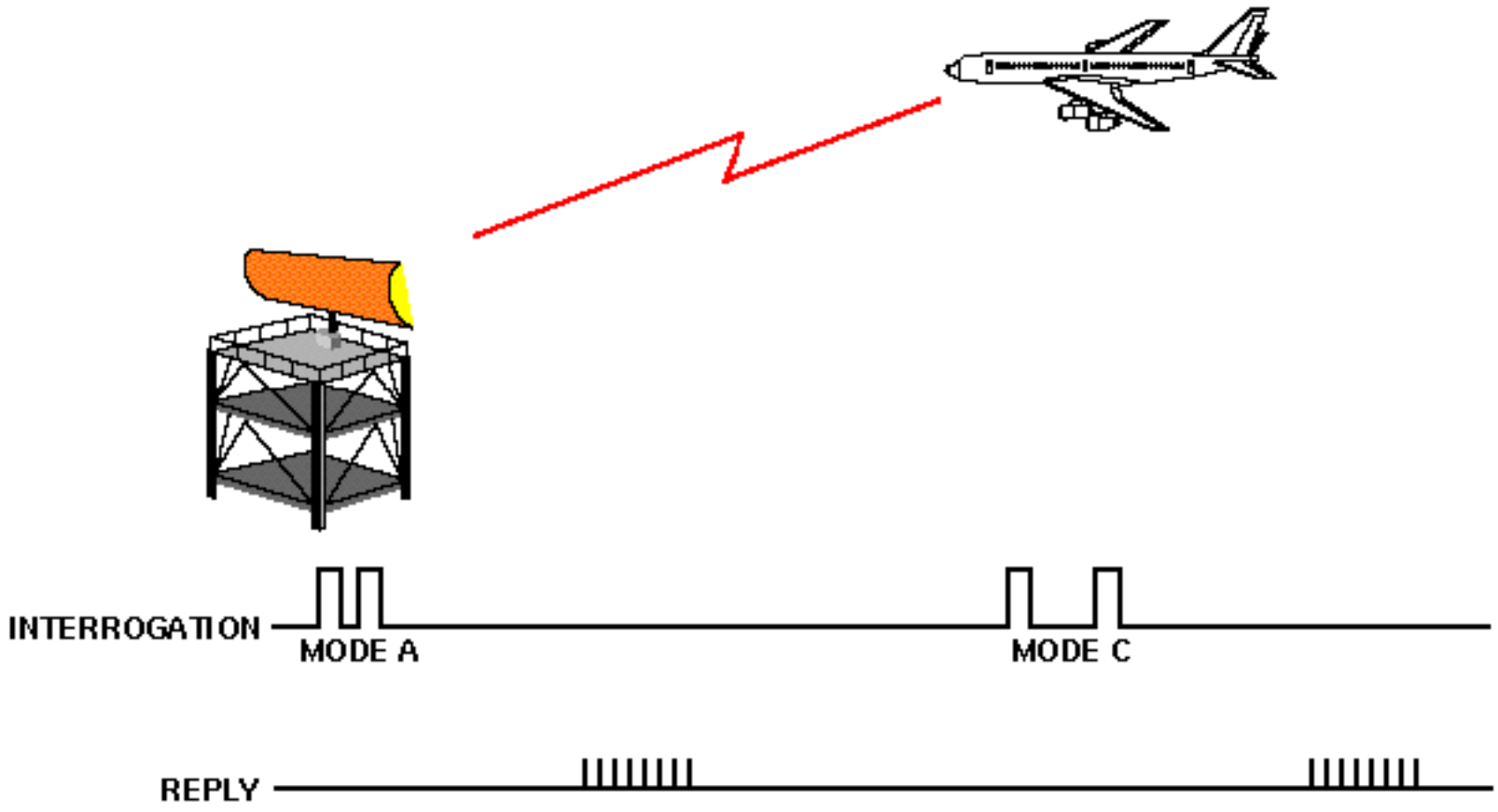
Mode S Overview

- Originally developed as necessary surveillance improvement for Mode A/C secondary surveillance radar
- Concept supported data link, which was incorporated in the original design
- Traffic Alert and Collision Avoidance System (TCAS II) not feasible without Mode S surveillance and data link
- Supports natural extension to ADS-B
- Supports multilateration for surface and approach monitoring
- Mode S is a multi-functional surveillance and communications system

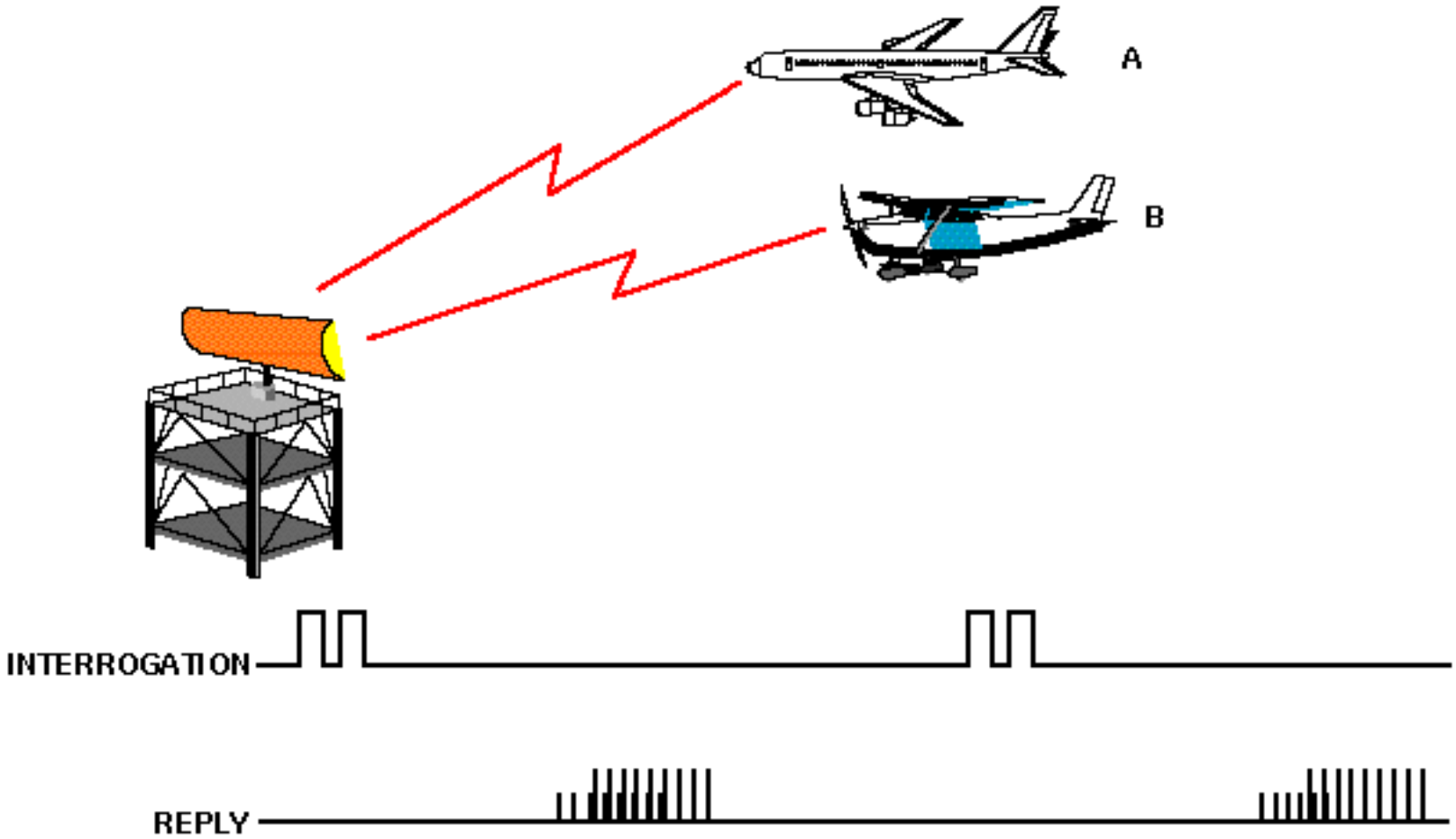
MODE A/C SECONDARY SURVEILLANCE RADAR



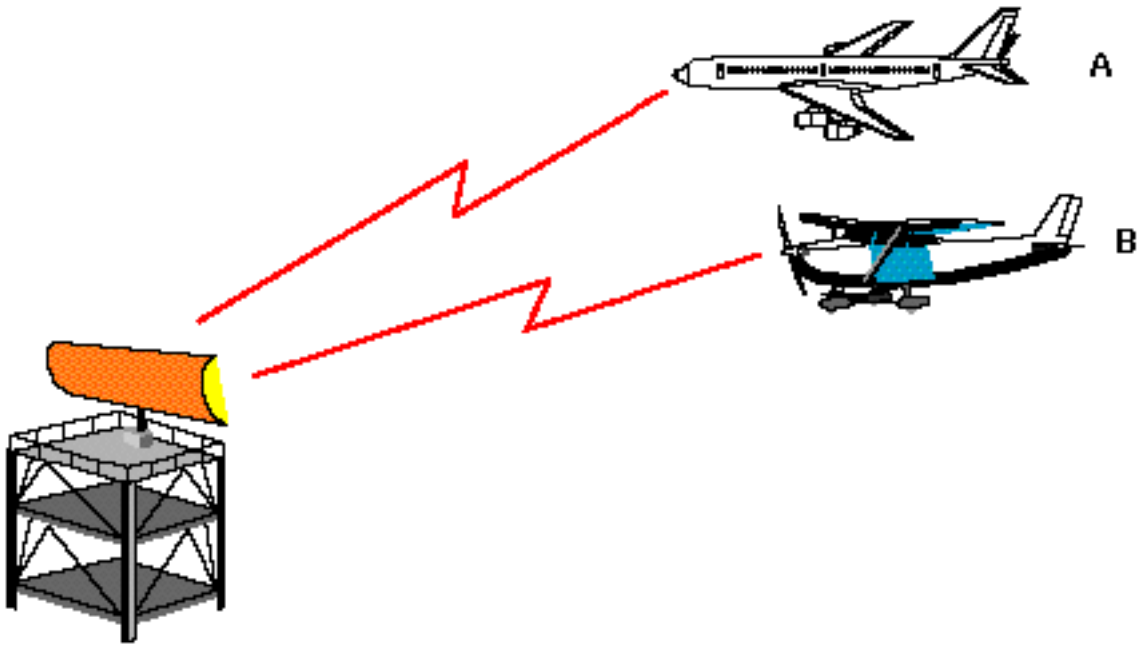
MODE A/C SSR OPERATION

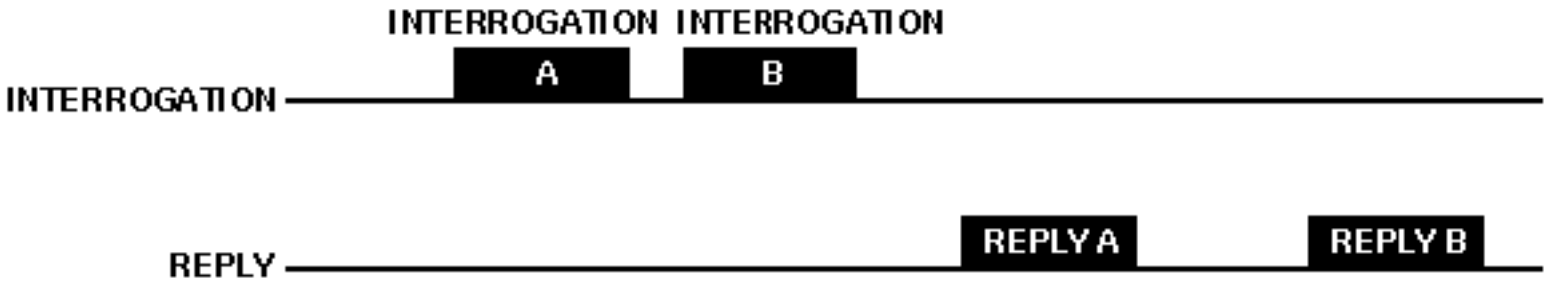


SYNCHRONOUS GARBLING OF MODE A/C REPLIES

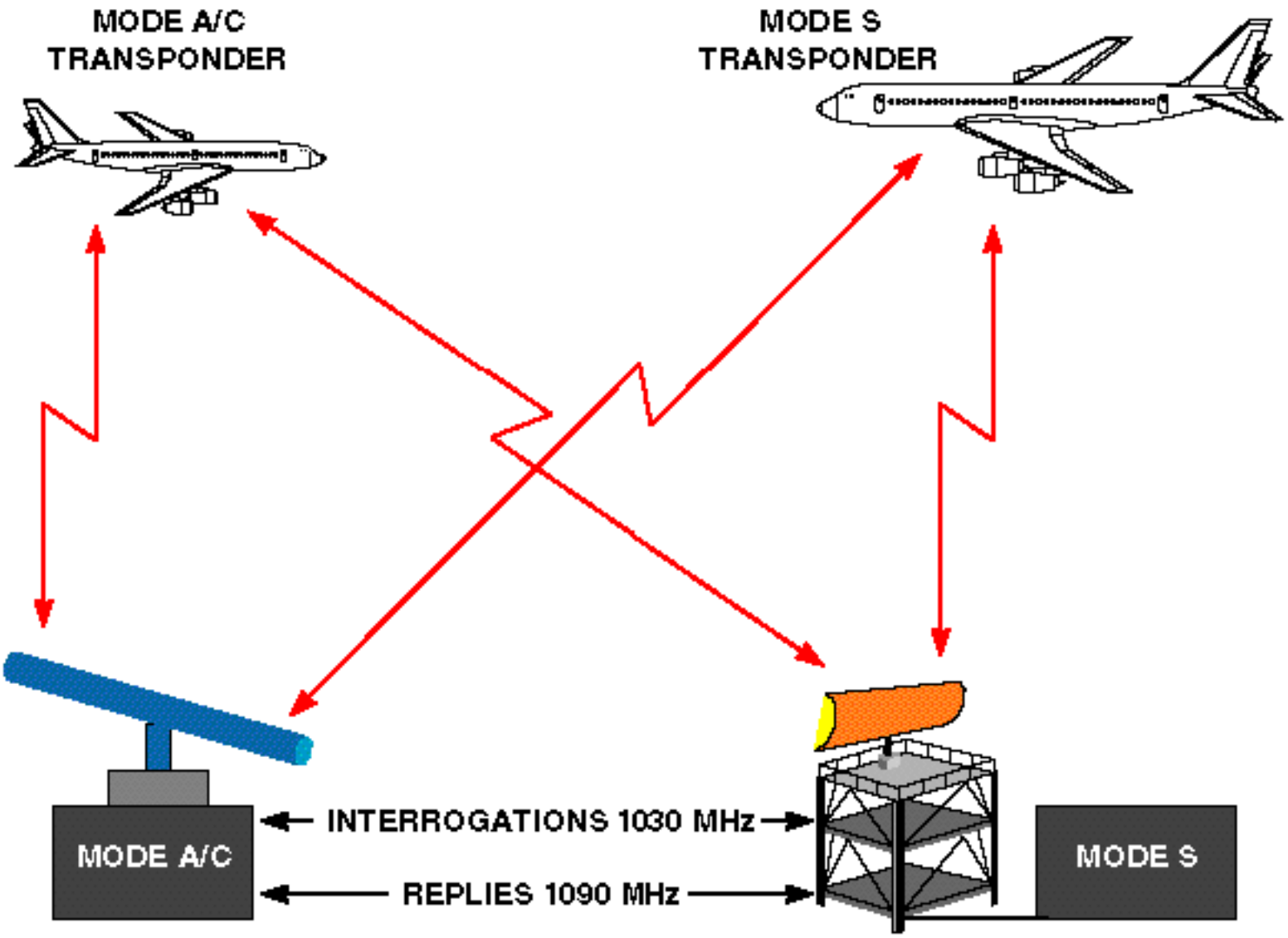


MODE S OPERATION



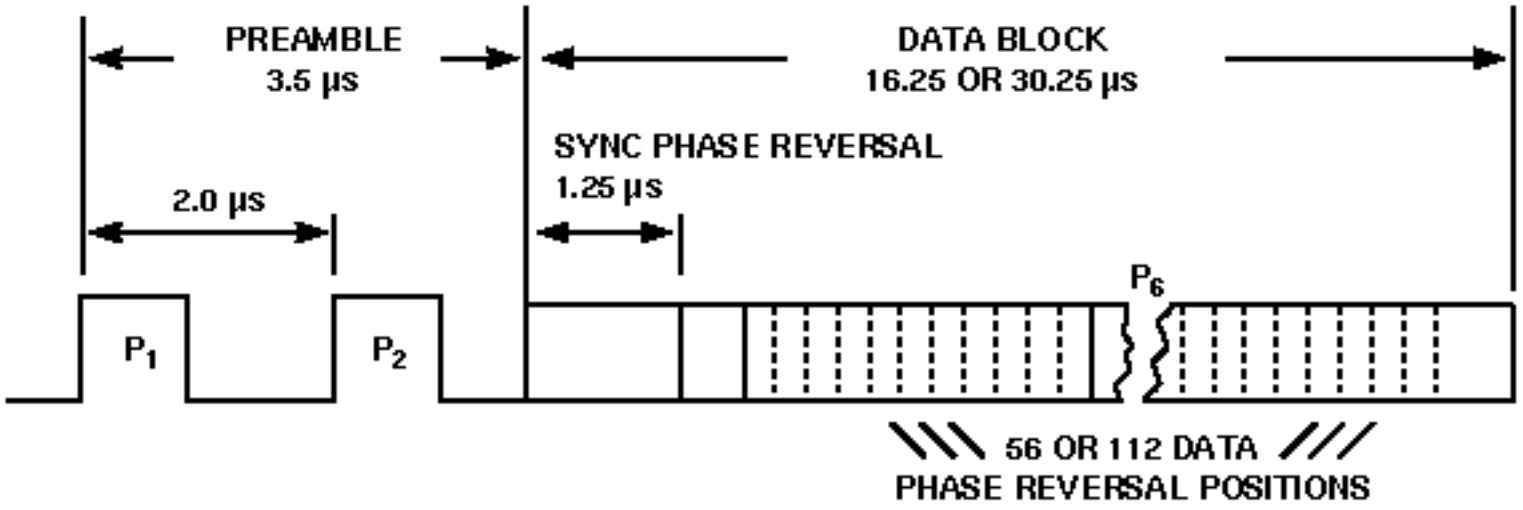


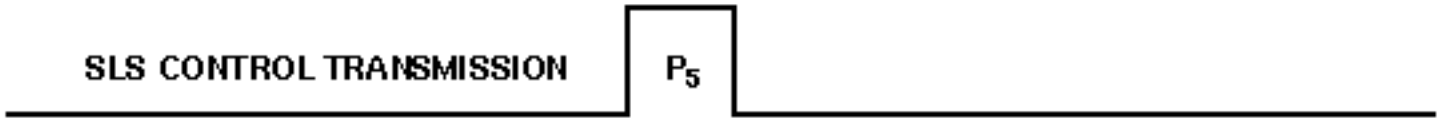
COMPATIBILITY BETWEEN MODE A/C AND MODE S



MODE S INTERROGATION WAVEFORM

1030 MHz

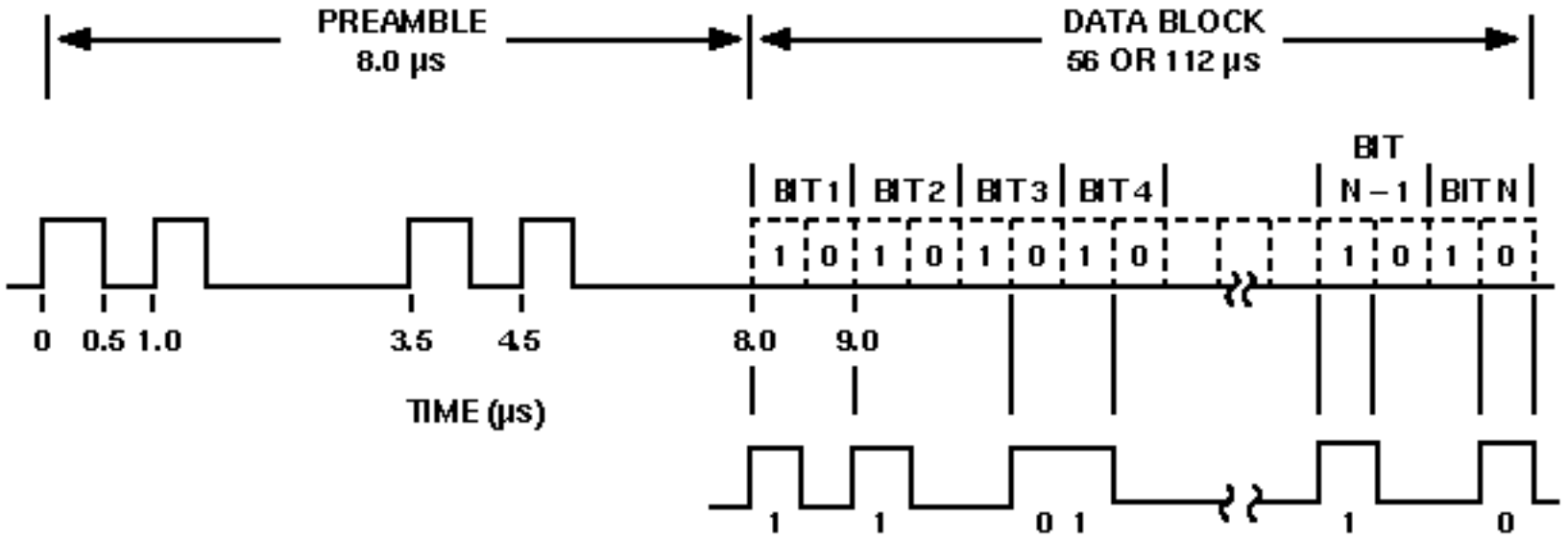




- DIFFERENTIAL PHASE SHIFT KEYING (DPSK) MODULATION
- DATA RATE 4 Mb/s

MODE S REPLY WAVEFORM

1090 MHz



- PULSE POSITION MODULATION (PPM)
- DATA RATE 1 Mb/s

Mode S Data Formats

SURVEILLANCE INTERROGATION AND REPLY

FORMAT NO. (5 Bits)	SURV. & COMM. CONTROL (27 BITS)	ADDRESS/PARITY (24 BITS)

56 BITS

SURVEILLANCE/COMMUNICATION INTERROGATION AND REPLY - COMM-A AND COMM-B

FORMAT NO. (5 Bits)	SURV. & COMM. CONTROL (27 BITS)	MESSAGE FIELD (56 BITS)	ADDRESS/PARITY (24 BITS)

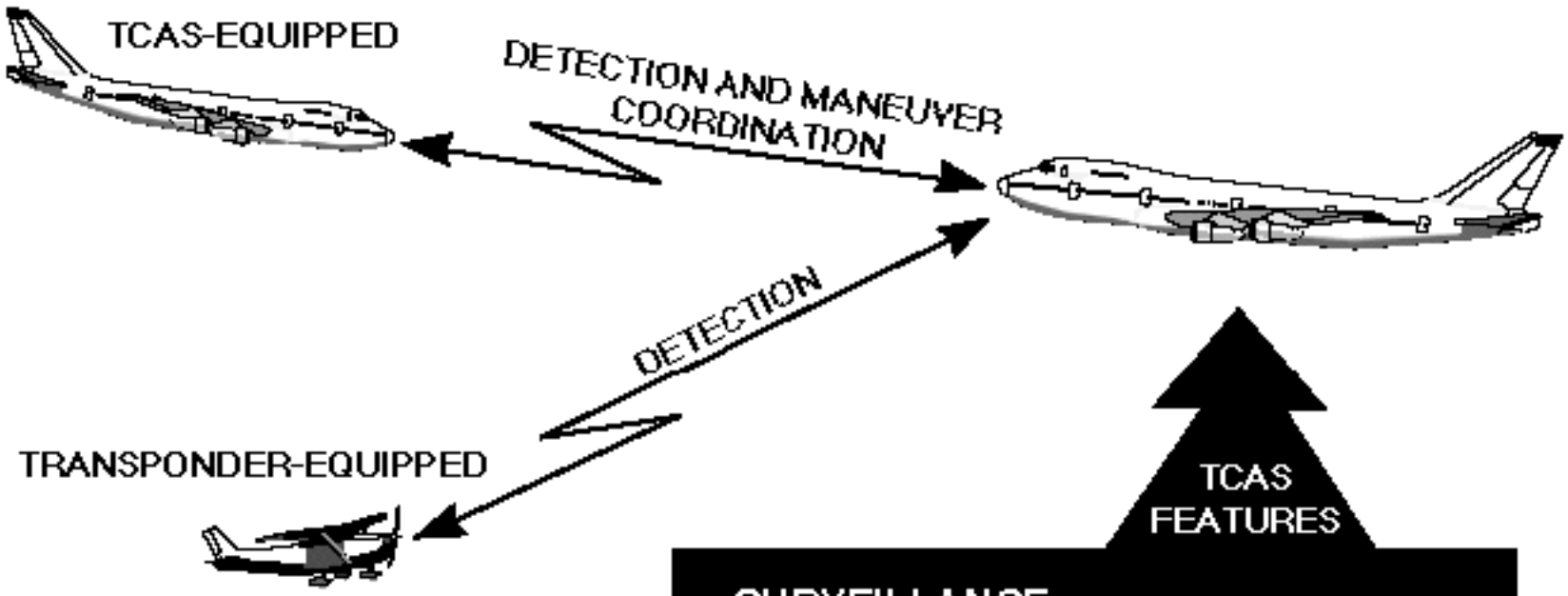
112 BITS

COMMUNICATION INTERROGATION AND REPLY - EXTENDED LENGTH MESSAGE (ELM)

FORMAT NO. (2 Bits)	COMM. CONTROL (6 BITS)	MESSAGE FIELD (80 BITS)	ADDRESS/PARITY (24 BITS)

112 BITS

TCAS – SYSTEM DESCRIPTION



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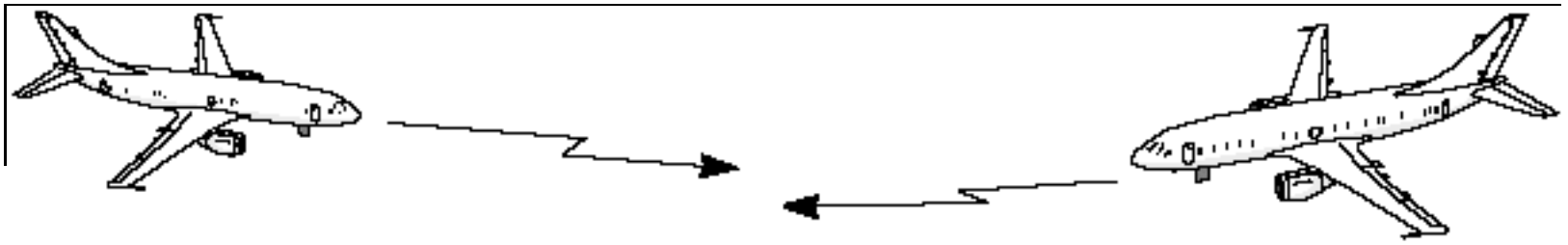
Short Mode S Squitter for TCAS Acquisition

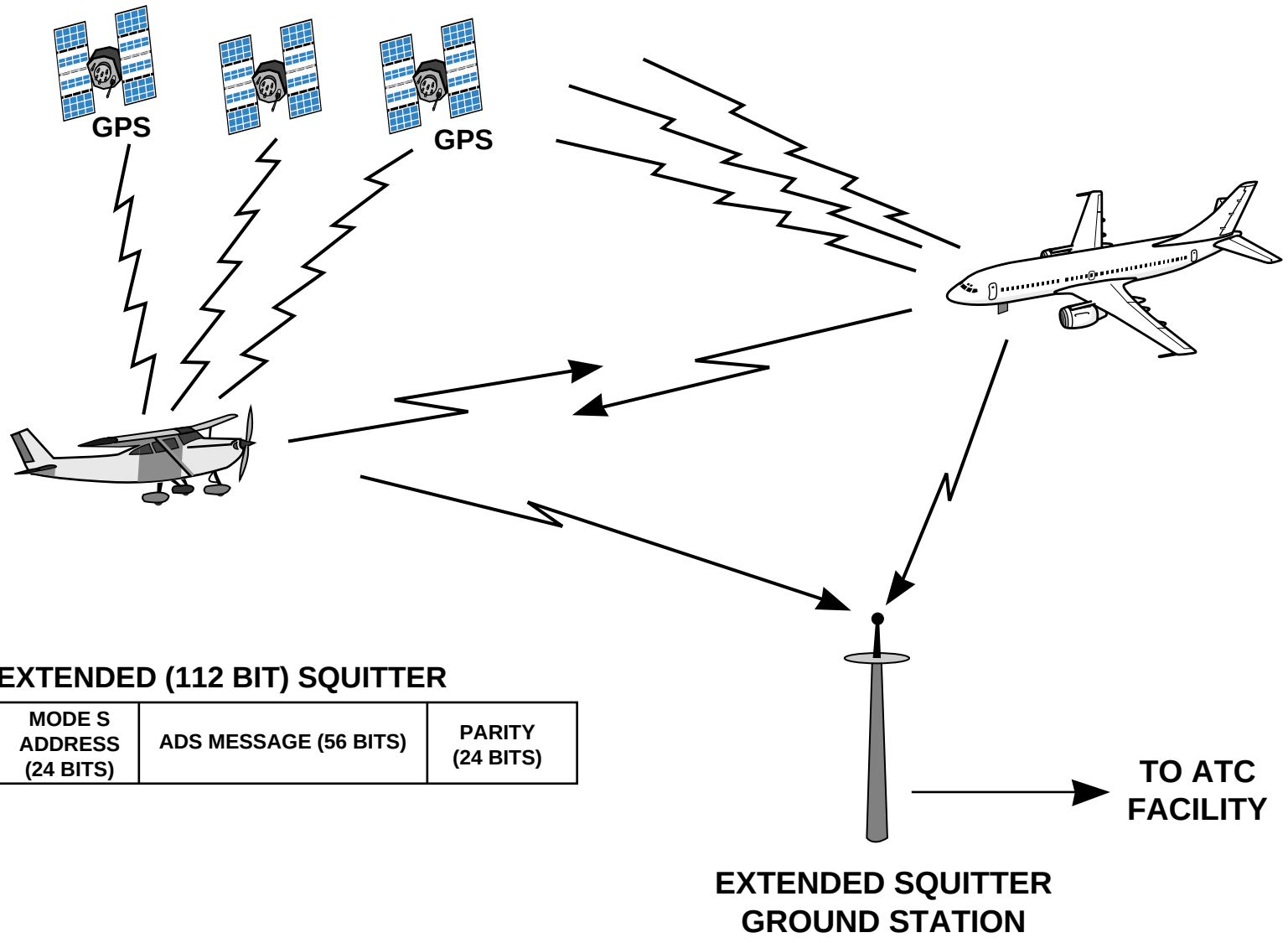


TRANSMITTED ONCE PER SECOND

SHORT SQUITTER (56 BITS)

CONTROL	MODE S ADDRESS	PARITY

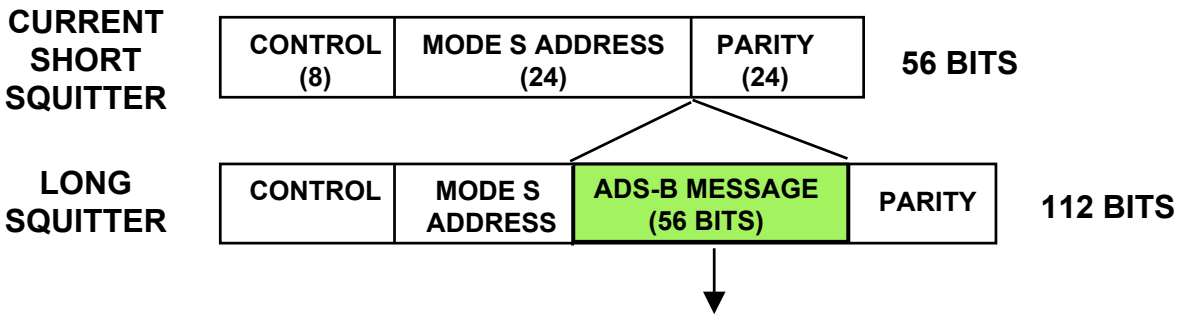
Extended Squitter Concept



EXTENDED (112 BIT) SQUITTER

CONTROL (8 BITS)	MODE S ADDRESS (24 BITS)	ADS MESSAGE (56 BITS)	PARITY (24 BITS)

Extended Squitter Message Structure



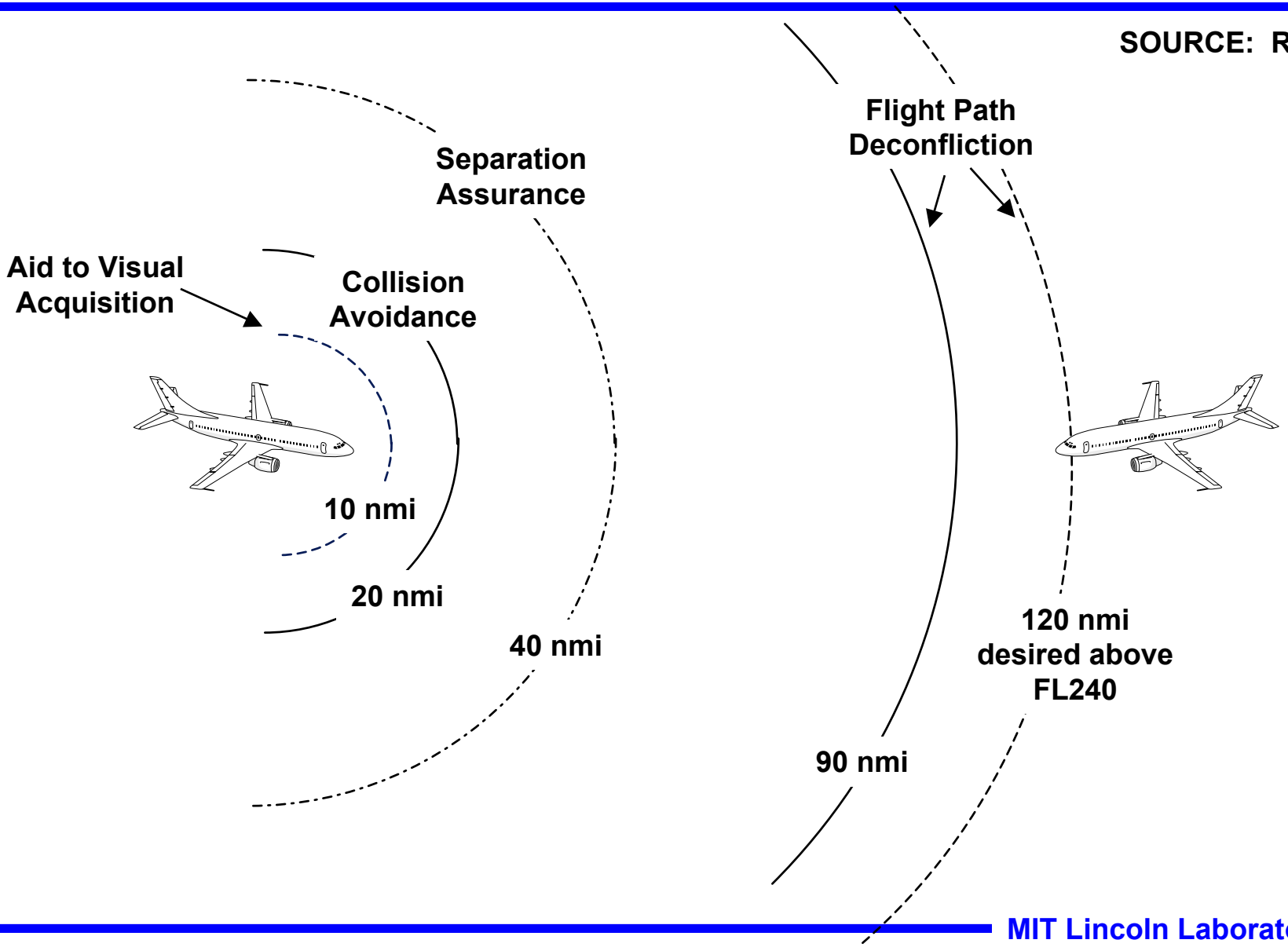
SQUITTER TYPE		BROADCAST RATE (NUMBER/SECOND)
AIRBORNE		
POSITION	TYPE | STATUS | ALTITUDE | SPARE | TIME | LAT | LONG	2
VELOCITY	TYPE | E-W VEL | N-S VEL | TURN RATE | VERT RATE | SPARE	2
SURFACE	TYPE | MOVEMENT | GRD TRACK | SPARE | TIME | LAT | LONG	2
IDENTIFICATION	TYPE | AIRCRAFT CATEGORY | AIRCRAFT CALL SIGN	0.2
EVENT DRIVEN	TYPE | TBD	AS NEEDED

Extended Squitter Applications

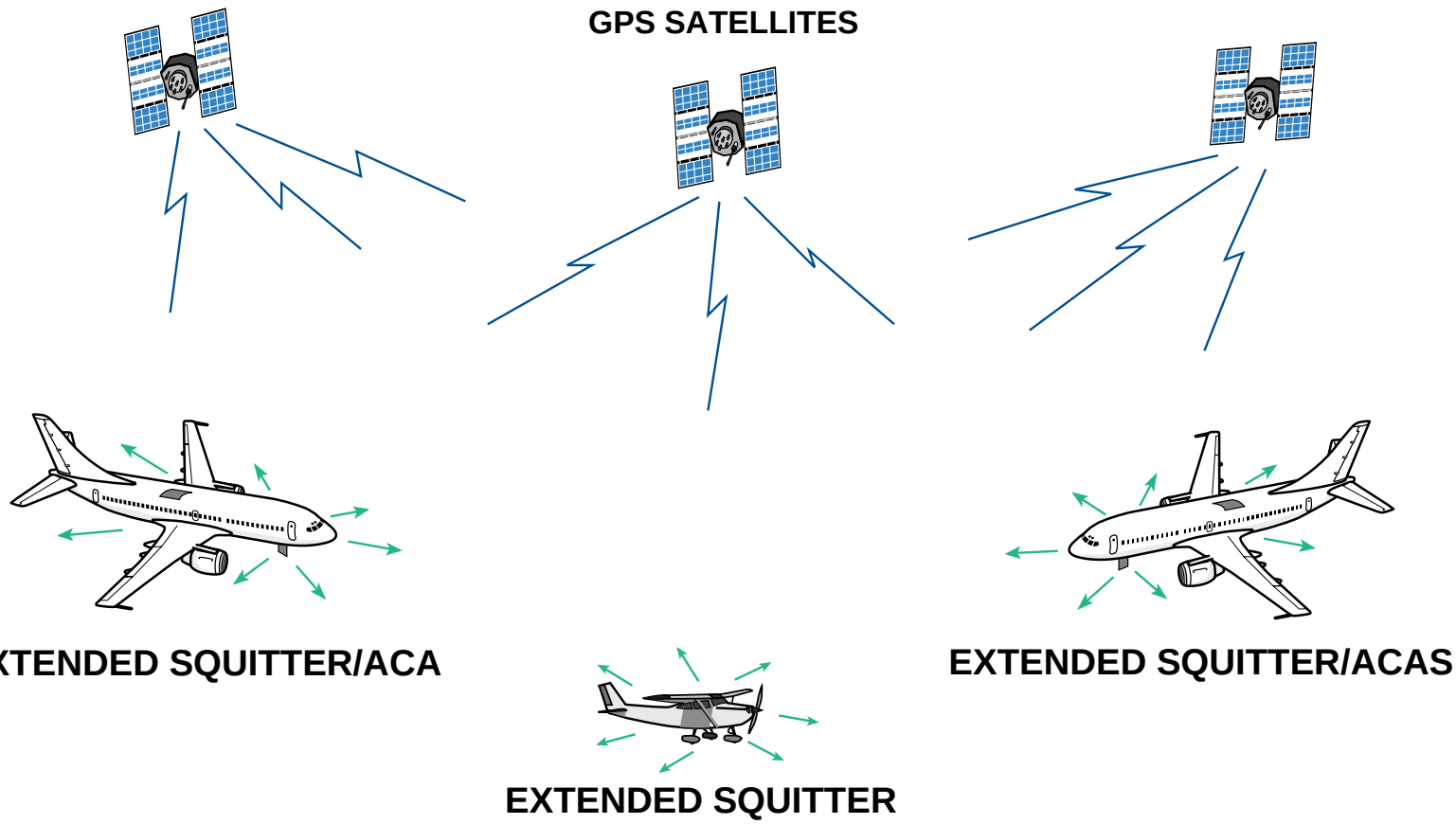
- Air-Air
  - TCAS Hybrid Surveillance
  - Cockpit Display of Traffic Information (CDTI)
- Air-Ground
  - En Route
  - Terminal
  - Precision Runway Monitoring (PRM)
- Surface
  - Runway and taxiway
  - Surface CDTI

ADS-B Application Categories

SOURCE: RTCA



TCAS Use of Extended Squitter



- HYBRID SURVEILLANCE
- INCREASED OPERATING RANGE
- IMPROVED MISS DISTANCE FILTERING

TCAS Hybrid Surveillance

- Validate range and coarse bearing on track acquisition
- Monitor once per 10 seconds
  - Intruder approaches threat status in altitude or range
  - Revalidate range and coarse bearing
- Full active surveillance once per second
  - Intruder approaches threat status in altitude and range
  - Revalidate range, range rate and coarse bearing
- Provides significant reduction in TCAS interrogation rate with no loss of TCAS independence

ADS-B Transition Issues

- TCAS uses range measurement for ADS-B validation
- ATC will need similar validation
  - Range
  - Range and bearing
  - Multilateration
- These techniques also provide backup in the event of individual aircraft or local area loss of GPS capability
- Extended squitter can support the above techniques because it is part of a radar beacon system
- Extended squitter data can be read via GICB protocol

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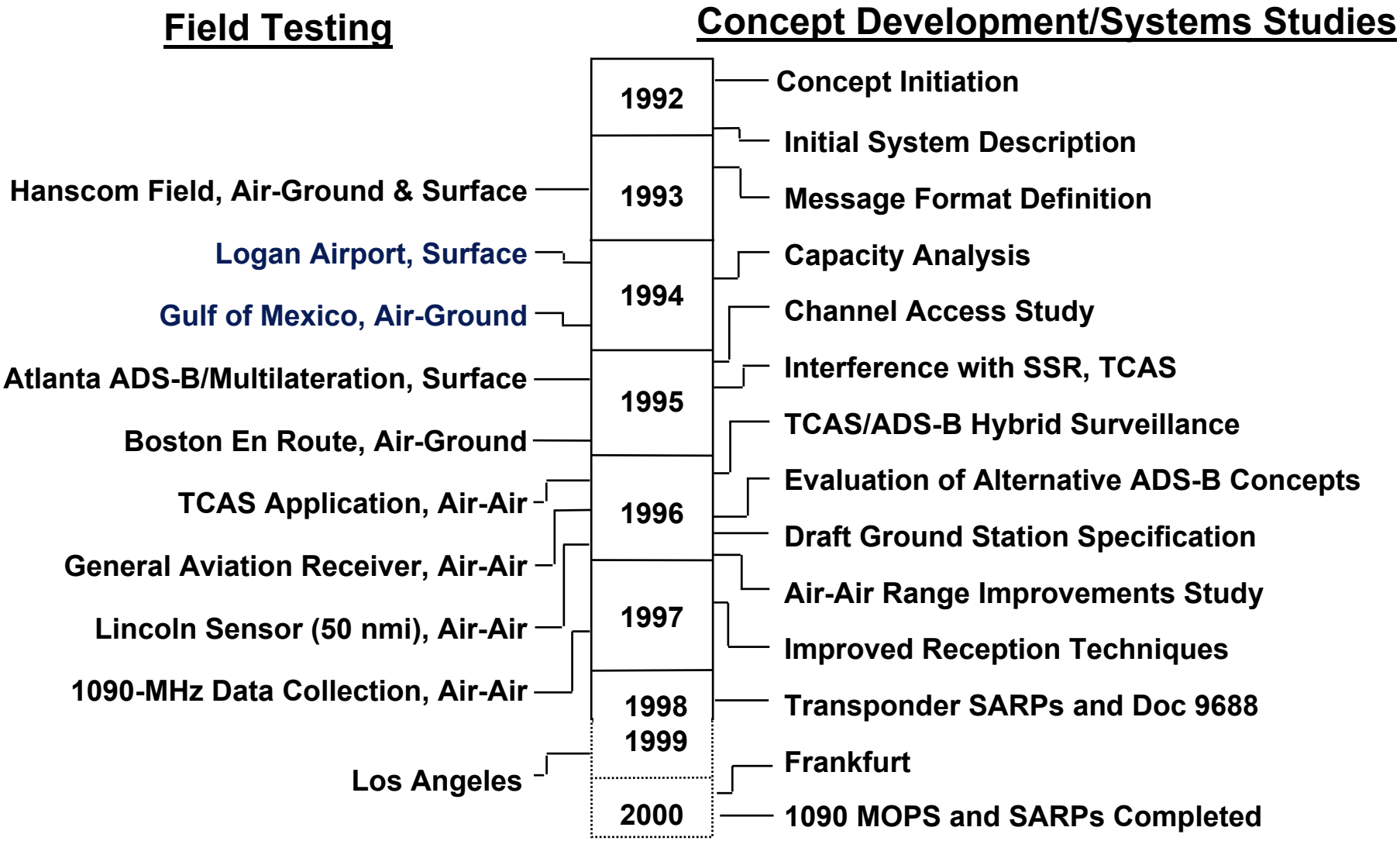
Extended Squitter Development History



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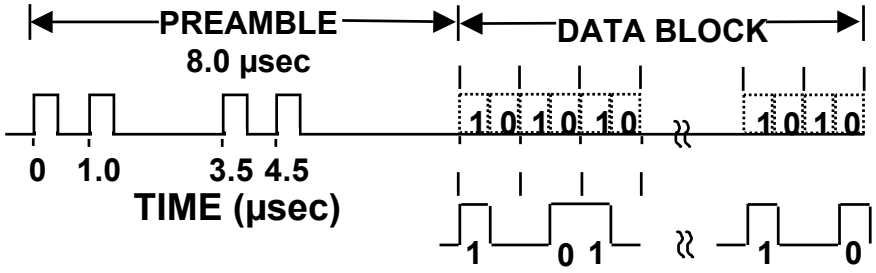
Squitter Reception Techniques



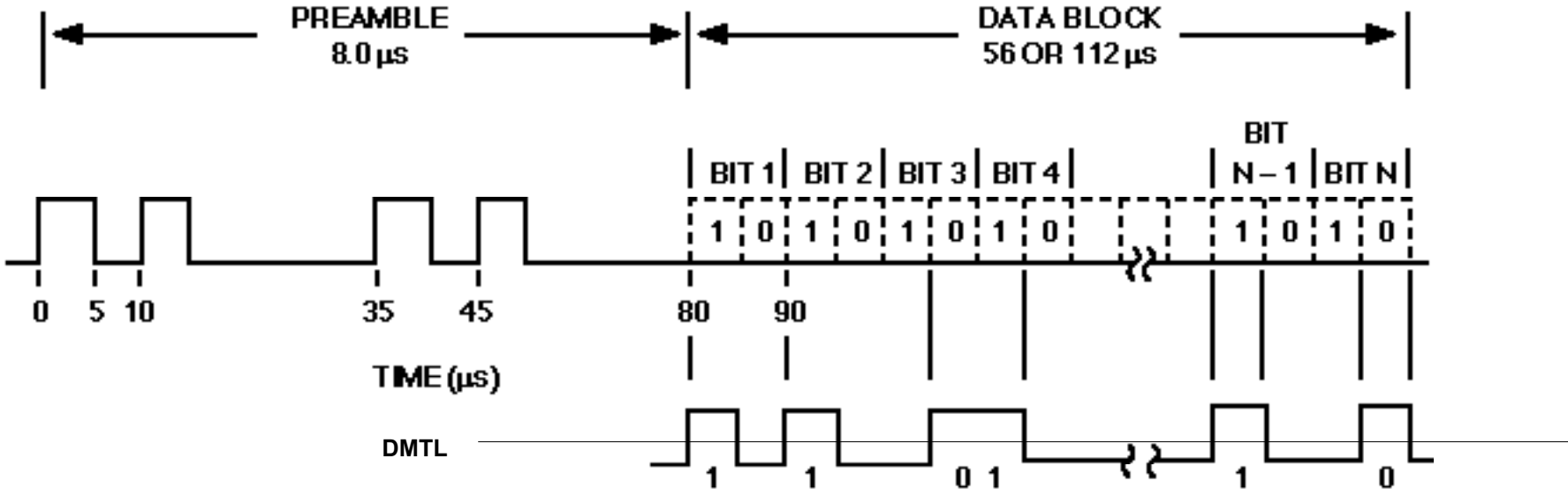
- Squitter reception includes:
  - Preamble detection
  - Bit and confidence declaration
  - Error detection and correction
- Current squitter reception techniques:
  - Intended for narrow-beam or short range TCAS operation
  - Re-evaluation necessary for long range air-air due to higher interference levels
- Improved techniques under development:
  - Use of amplitude to improve bit declaration accuracy
  - More capable error correction algorithms

Current Data and Confidence Bit Settings

- Data value
  - Compare chip center amplitudes
  - Higher power sample is declared
- Confidence value (high or low)
  - DMTL set 6db below preamble level
  - Low confidence if “other” chip sample above DMTL

MODE S REPLY WAVEFORM

1090 MHz

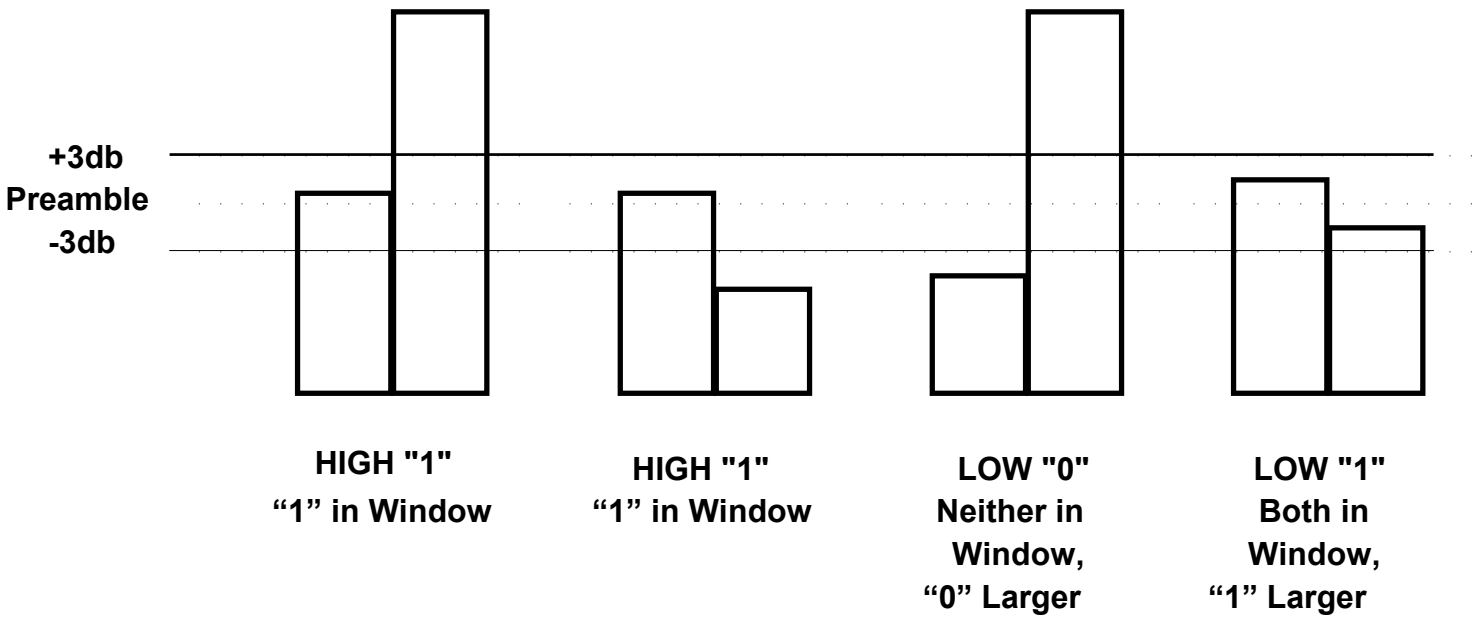


- PULSE POSITION MODULATION (PPM)
- DATA RATE 1 Mb/s

Use Of Amplitude for Bit Declaration

- **Data value**
  - Compare chip amplitudes to preamble level
  - If 1 and only 1 within preamble window, it is declared
  - Otherwise, higher power sample is declared
  - Window width ±3db
- **Confidence value (high or low)**
  - High confidence if 1 and only 1 within preamble window
  - Otherwise set as currently done, using 6dB threshold
- **Effect:**
  - Most bits high confidence even in ATCRBS overlap
  - Low confidence if fruit about same level as Mode S

Bit and Confidence Declaration



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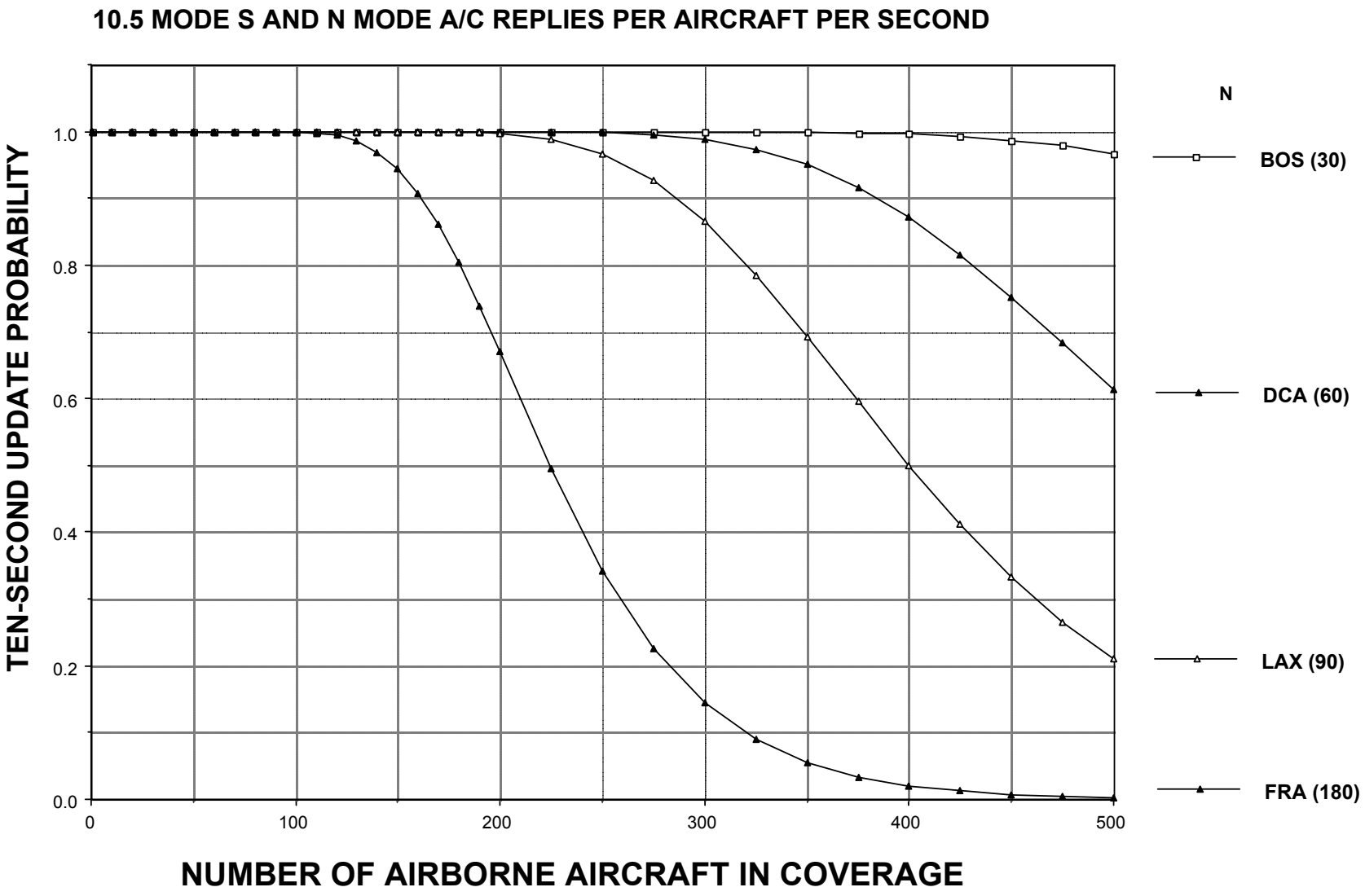
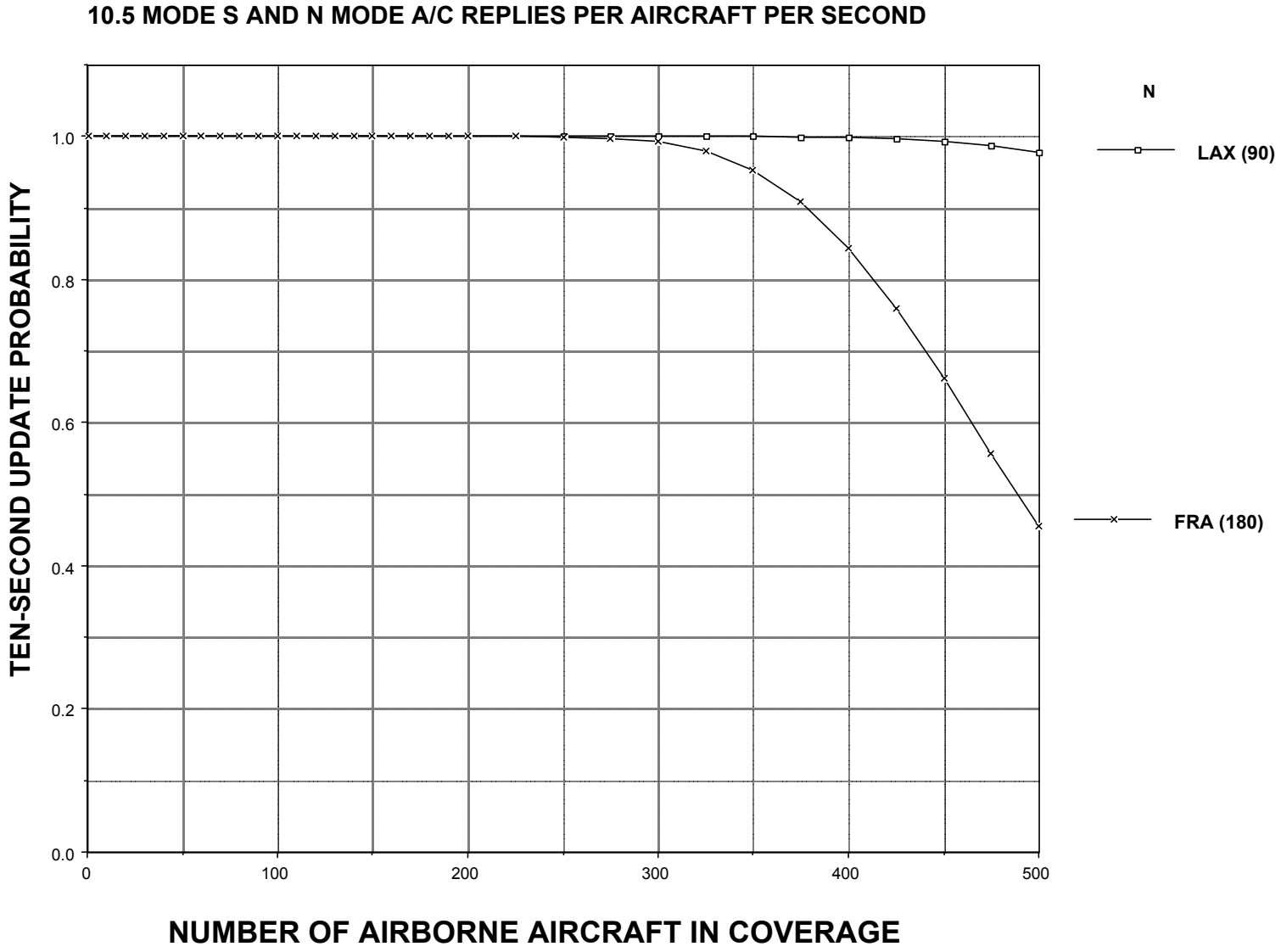
Performance Factors

- Extended squitter air-air or air-ground range depends upon RF link budget
- Extended squitter air-air or air-ground capacity (update rate) depends on Mode A/C fruit rate
  - Current interrogation rates 60 to 90 per second in highest US terminal densities (LA basin, Chicago, Balt/Wash, NY)
  - 30 or fewer Mode A/C interrogations per second for the the rest of the US airspace
- Current squitter reception technique can provide successful decode with one overlapping Mode A/C reply
- Improved technique under development will be able to tolerate multiple overlaps

Air-Air Capacity Current Reception Technique



Air-Air Capacity Improved Reception Technique



Extended Squitter Air-Ground Capacity

5-SECOND UPDATE, PROBABILITY ≥ 99.5%

REPLIES/AIRCRAFT/SEC		MAXIMUM AIRCRAFT CAPACITY					
		OMNI ANTENNA*		6-SECTOR**		12 SECTOR**	
MODE A/C	MODE S	CURRENT	IMPROVED	CURRENT	IMPROVED	CURRENT	IMPROVED
90	10.5	120	300	300	725	525	1325
60	10.5	160	325	400	825	725	1475
0	10.5	375	375	975	975	1750	1750

* 50 - 100 nmi Operational Range
** Greater than 200 nmi Operational Range

Extended Squitter Surface Capacity

- 1.0-SECOND UPDATE RATE
- MULTIPATH FACTOR OF 95%
- 20 AIRBORNE AIRCRAFT PER RECEIVER

SQUITTER RATE	CAPACITY	RELIABILITY
FIXED	250	95%
	500	90%
VARIABLE	500	97%

Link Budget for Extended Squitter Reception

	RANGE			
	AIR-AIR		AIR-GROUND	
	14 NMI	90 NMI	50 NMI	200 NMI
AIRCRAFT TRANSMITTER POWER (dBm)	57	57	57	57
TRANSMITTER CABLE LOSS (dB)	-3	-3	-3	-3
TRANSMIT ANTENNA GAIN (dBi)	0	0	0	0
PATH LOSS FOR 1090 MHz (dB)	-121	-137.5	-132.5	-144.5
RECEIVE ANTENNA GAIN (dBi)	0	0	9	14
RECEIVER CABLE LOSSES (dB)	-3	-3	-3	-3
RECEIVED POWER (dBm)	-70	-85.5	-71.5	-78.5
RECEIVER MINIMUM TRIGGER LEVEL MTL (dBm)	-77	-87	-80	-87
LINK MARGIN (dB)	7	0.5	7.5	7.5

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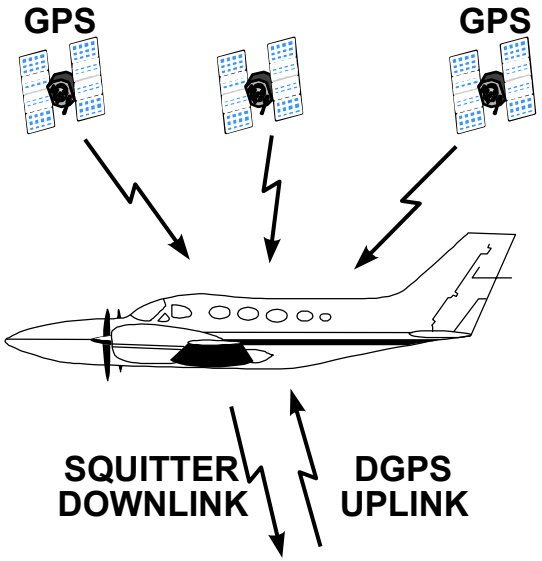
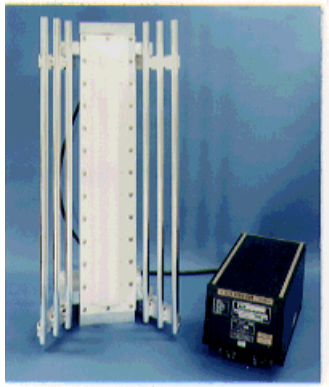
Field Validation Activities

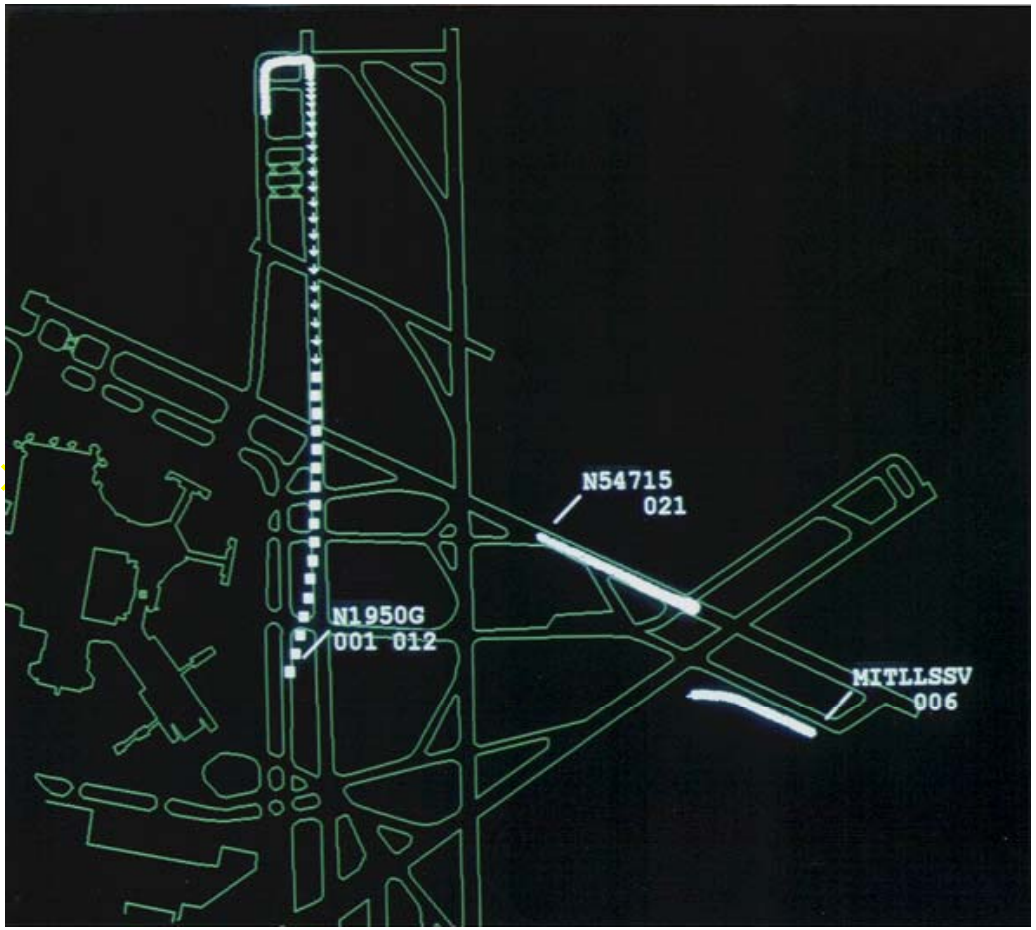
- Hanscom Field (1993)
  - Initial surface measurements
- Logan airport operational demonstration (Jun 1994)
  - Four ground station system
- Gulf of Mexico off-shore sector (Dec 1994)
  - Three ground station system
  - Low altitude over water and long range surveillance
- Los Angeles (Jun 1999)
  - One ground station, multiple aircraft
- Frankfurt (May 2000)
  - Two ground stations, multiple aircraft

Squitter Measurements at Logan Airport



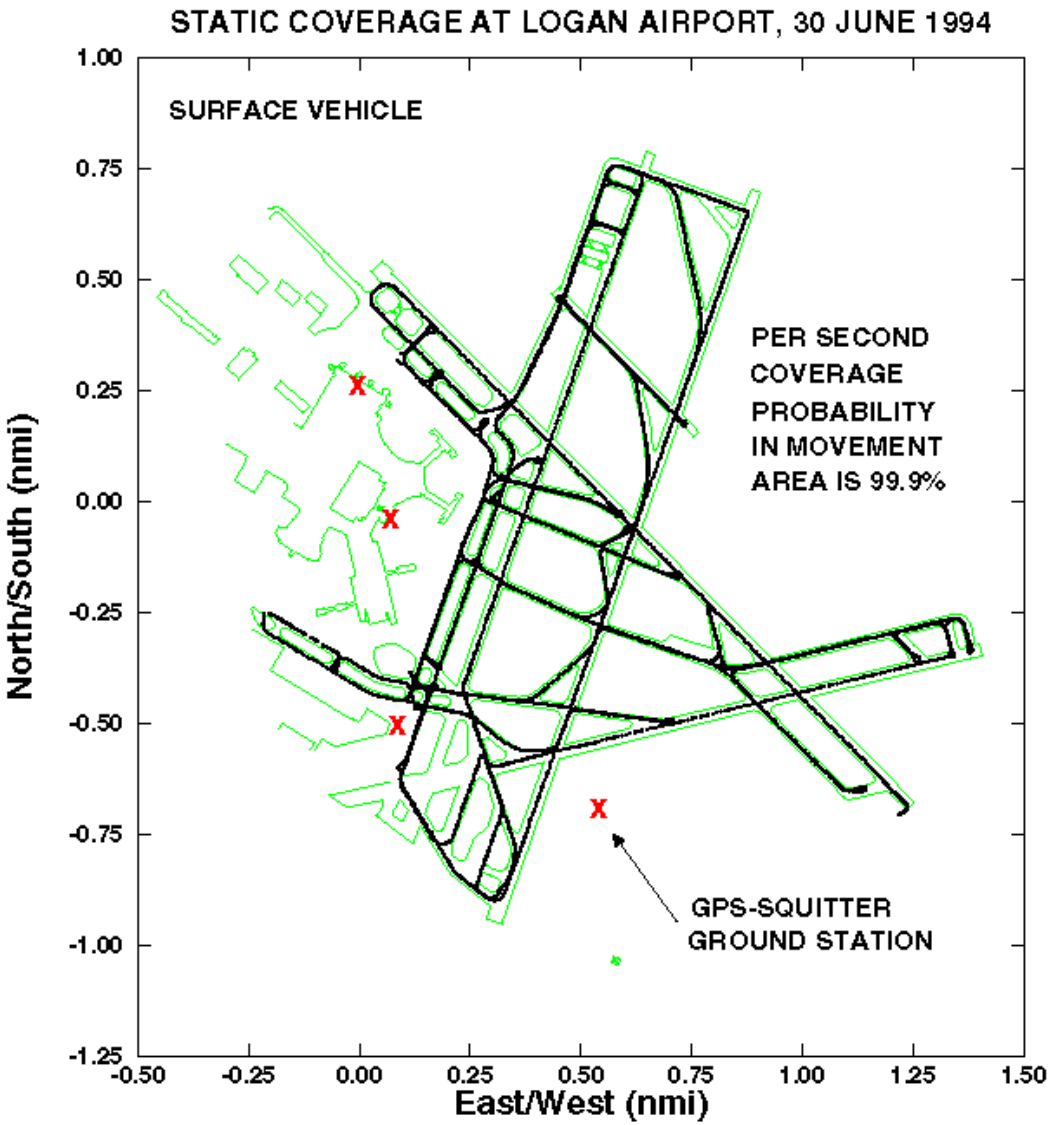


GROUND STATION
(Modified TCAS Unit
and Commercial Antenna)

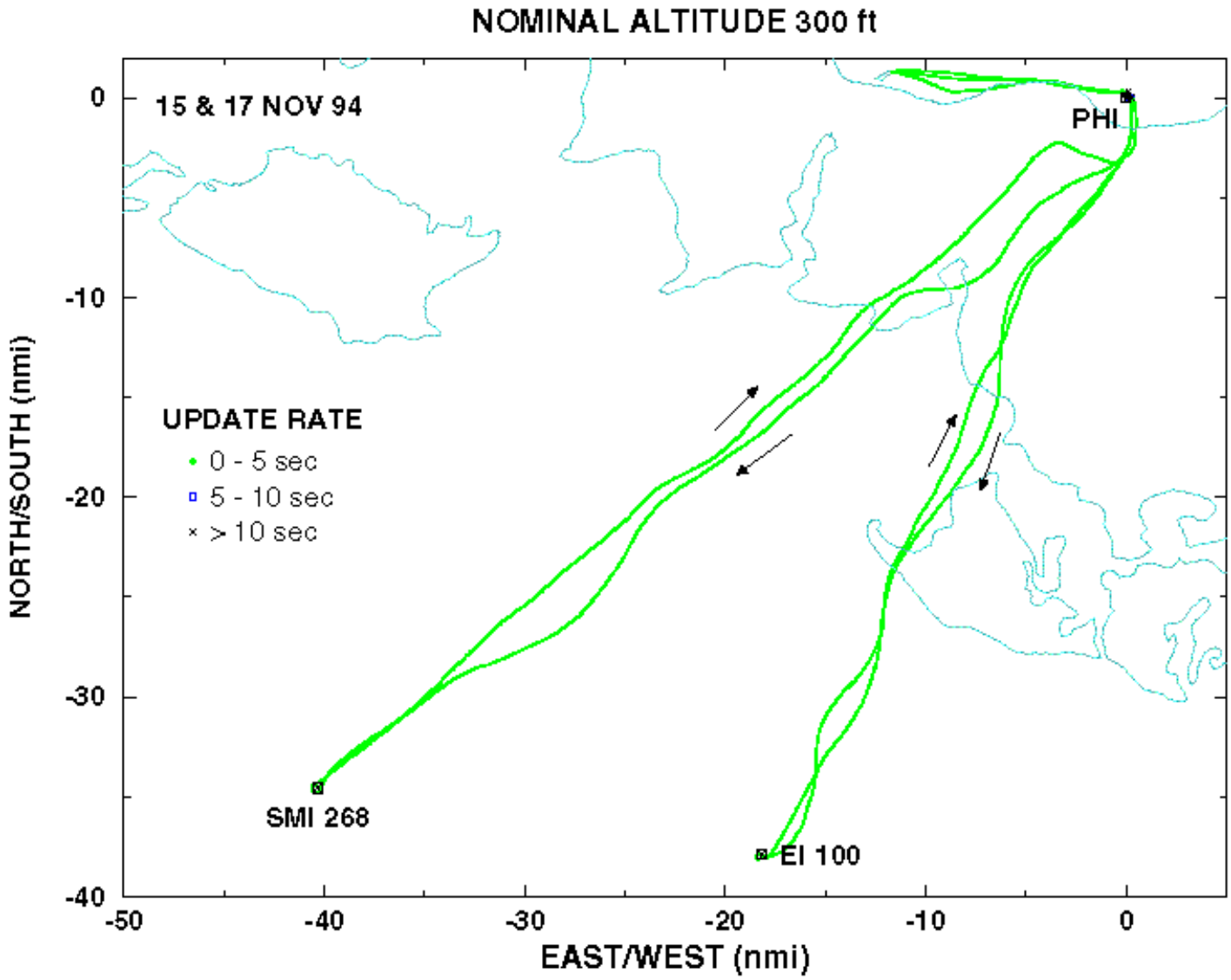


LOGAN AIRPORT

Squitter Measurements at Logan



Low Altitude Squitter Measurements GOM



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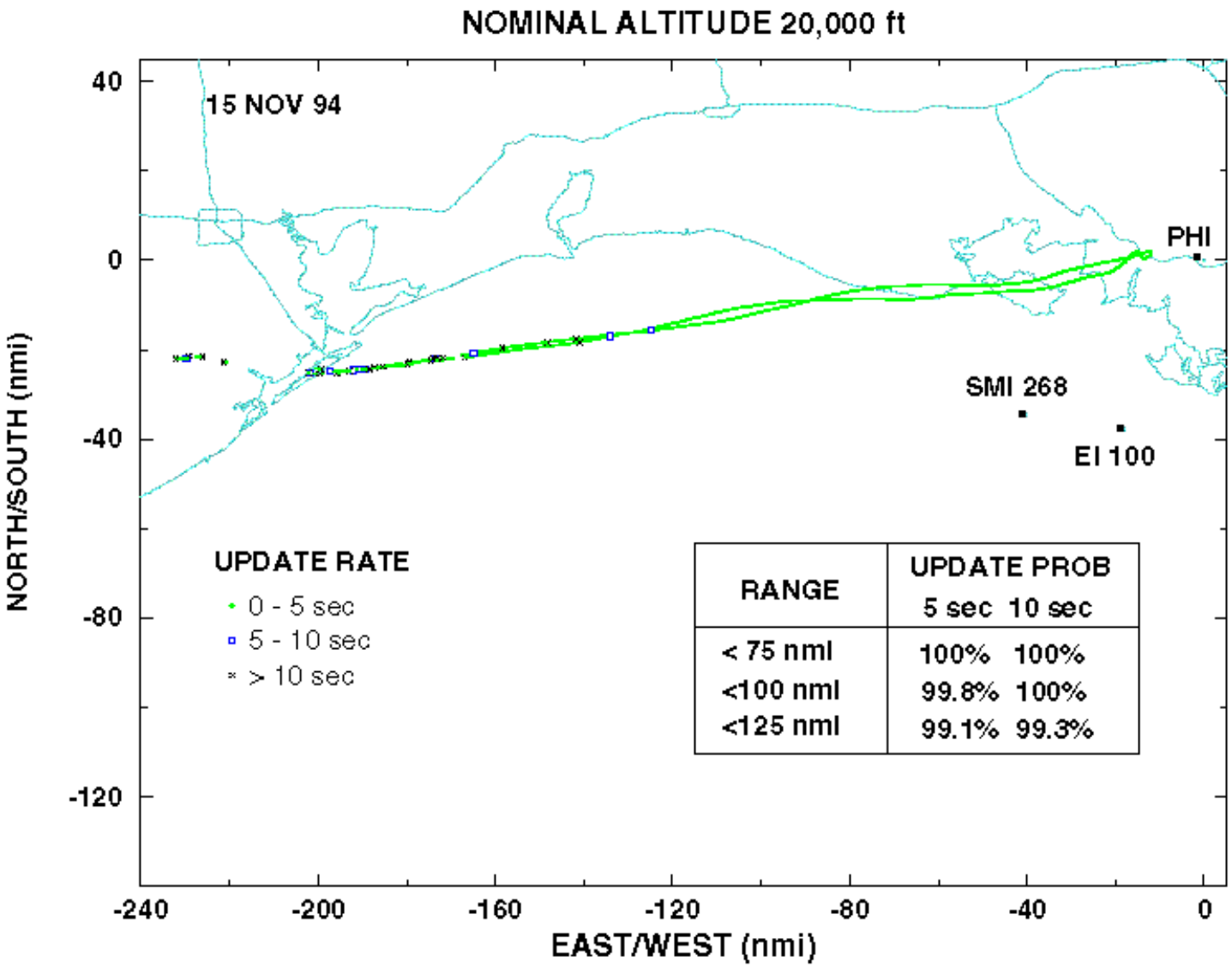
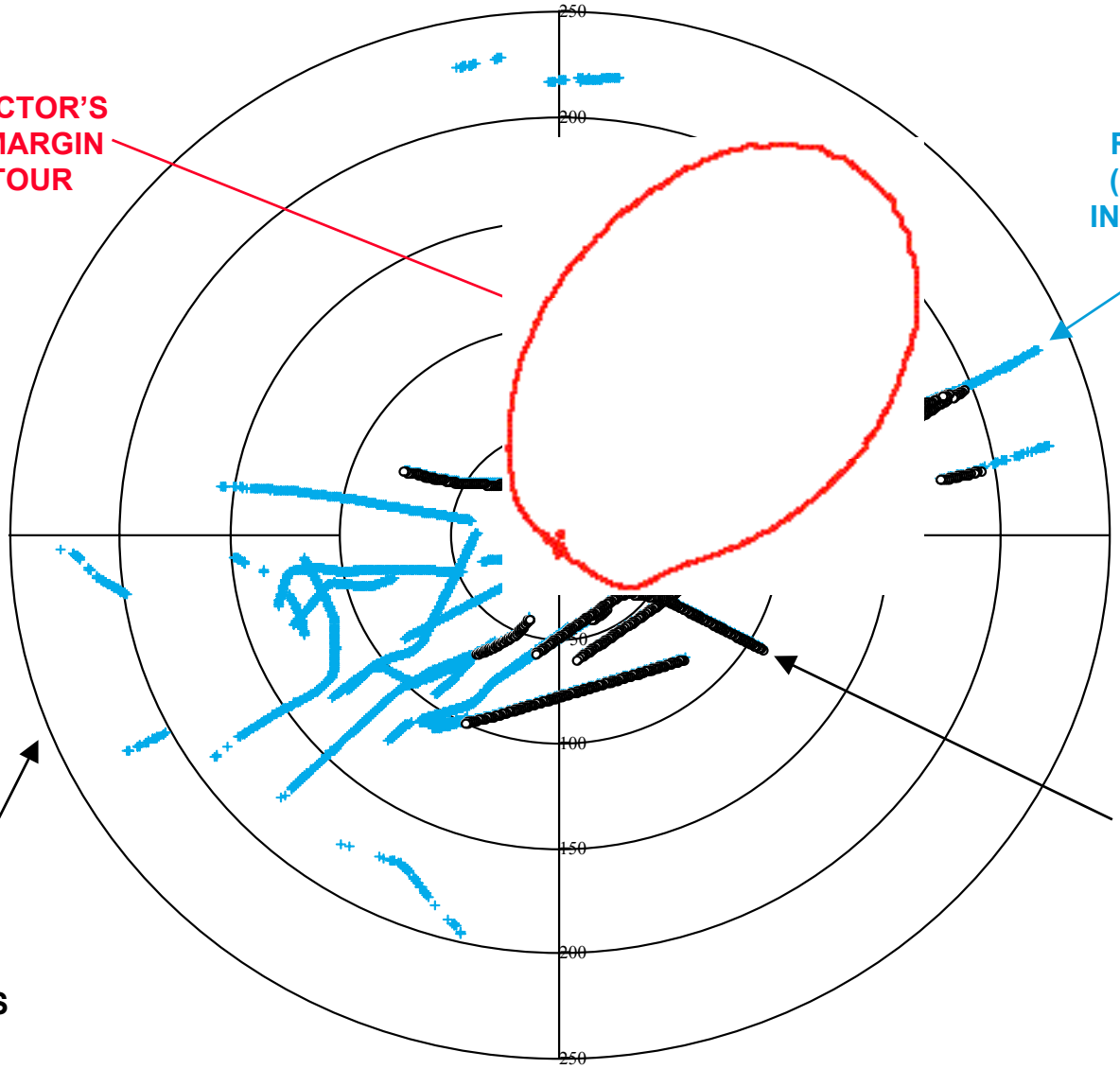


Six-Sector Antenna Testing

Boston Area 1995

- Short squitters from targets of opportunity received using sector antenna
- Receptions correlated with tracks from Mode S SSR at MODSEF
- Good squitter coverage obtained to 200 nmi range

Long Range Air-Ground Results By One Sector of Six-Sector Antenna

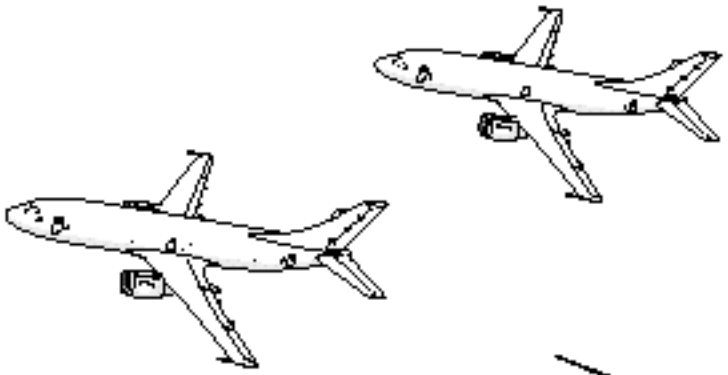


THE SECTOR'S 10-dB MARGIN CONTOUR

MODE S RADAR TRACKS (SURVEILLANCE INTERROGATIONS)

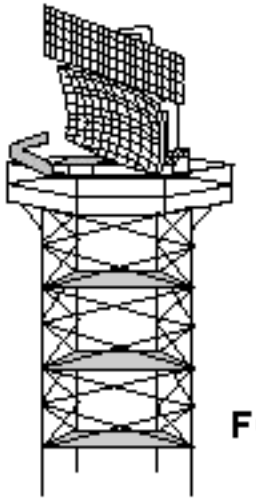
THE SECTOR'S COVERAGE BY SHORT MODE S SQUITTERS

50 NM RANGE RINGS



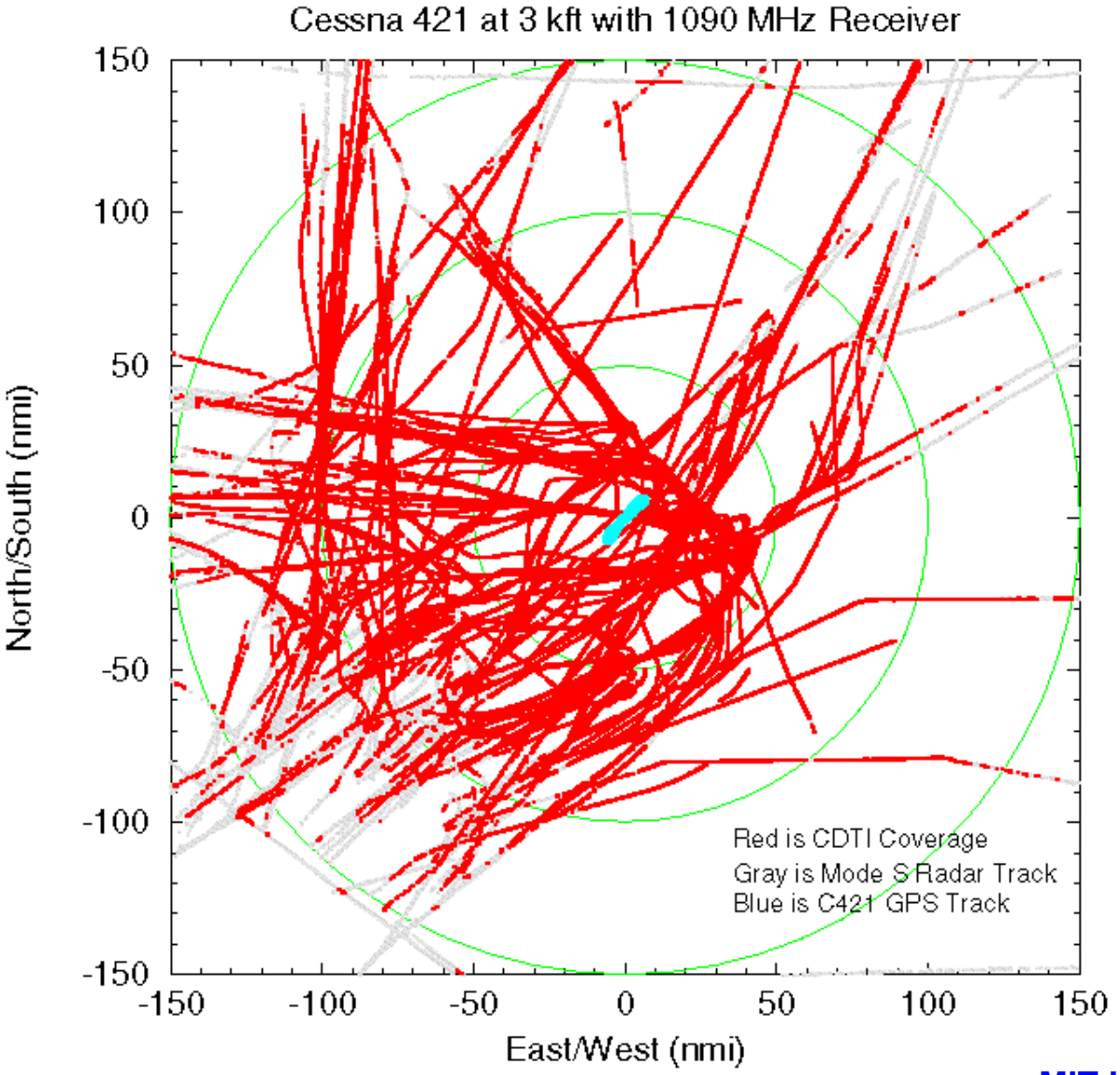
AIR CARRIERS
BROADCASTING SHORT
MODE S SQUITTERS

CESSNA 421
RECORDING RECEIVED SQUITTERS



MODE S SENSOR
FOR POSITION DETERMINATION

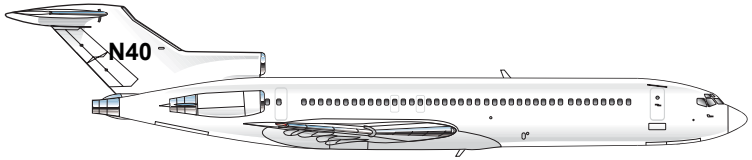
Long Range Air-to-Air Surveillance



Los Angeles Field Measurements

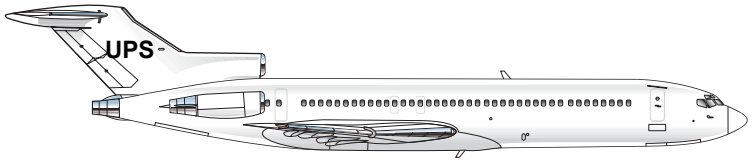
Aircraft and Avionics
Basic Configuration
ADS-B Flight Tests, LA, Aug 98

B-727



- Mode S diversity transponder with ADS-B
- GPS receiver
- TCAS-2000, Honeywell, with recorder
- ADS-B receiver, UPS, with recorder
- DATAS
- Aircraft state recorder

B-727



- Mode S diversity transponder with ADS-B
- GPS receiver
- ADS-B receiver, UPS, with recorder

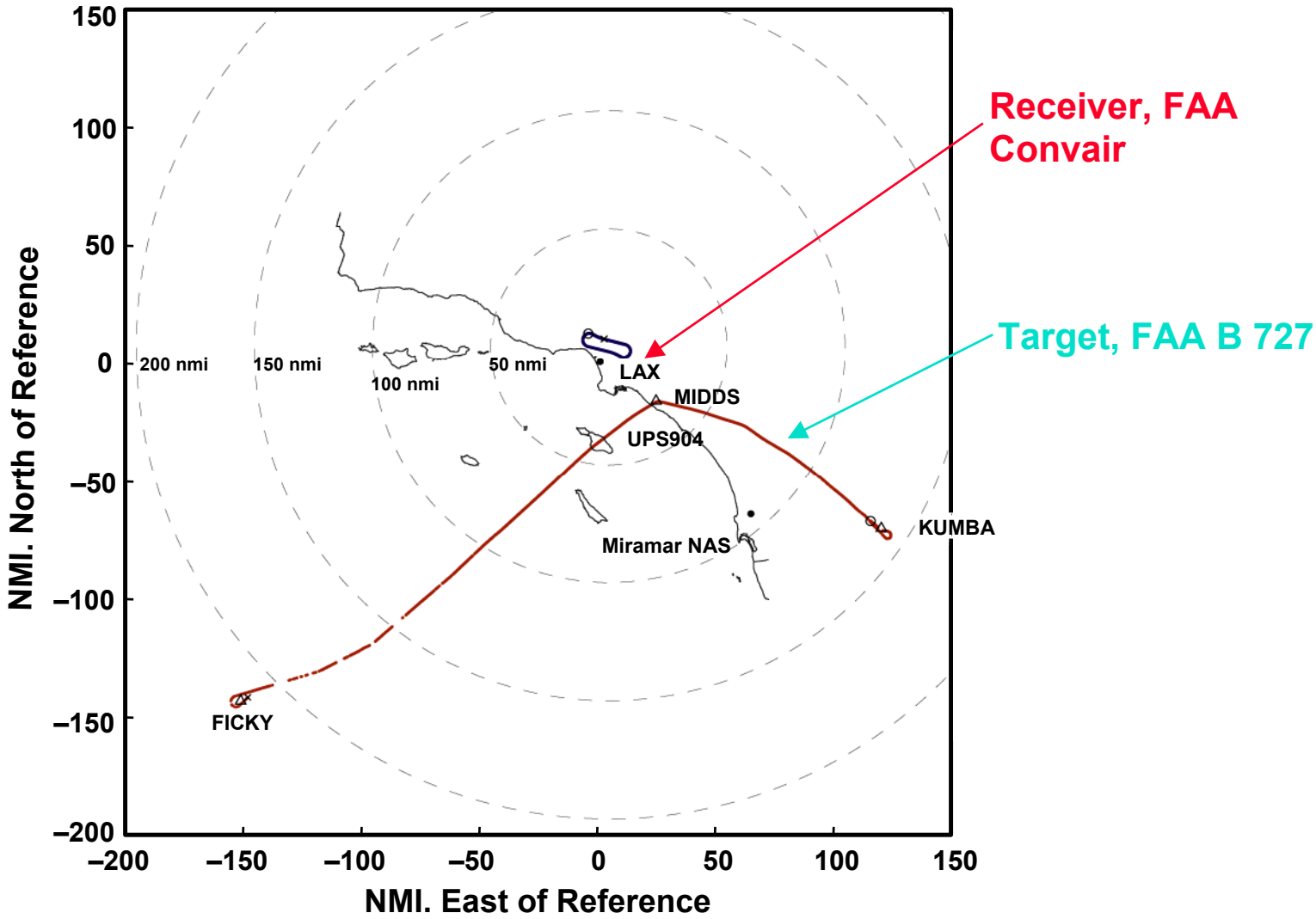
Convair 580

- Mode S diversity transponder with ADS-B
- GPS receiver
- TCAS, Honeywell, 6.04a, with recorder (or TCAS-2000)
- ADS-B receiver, UPS, with recorder
- 1090 MHz testbed, Lincoln Laboratory
- Aircraft state recorder

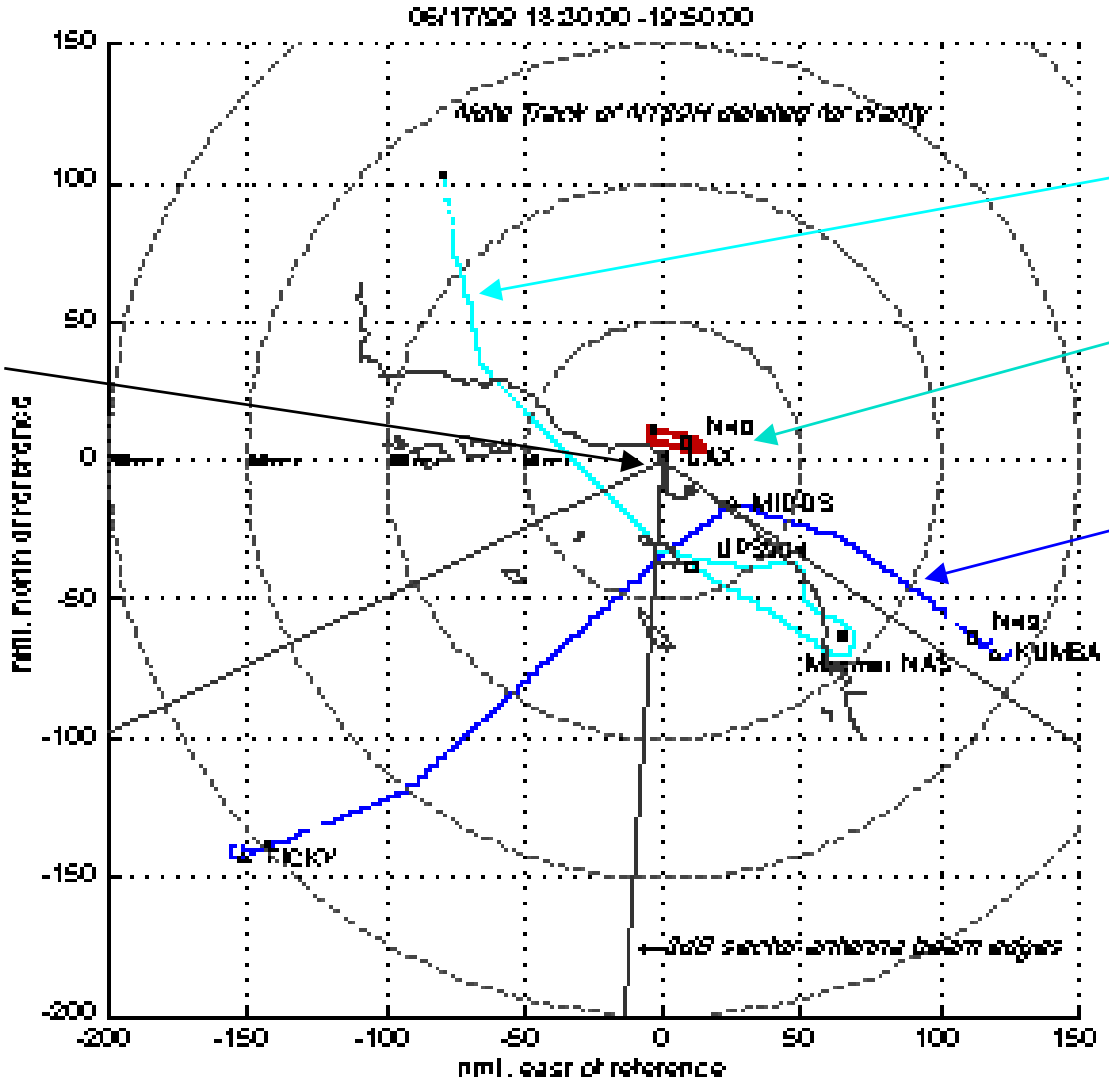
LAX Ground Station

Van, 6-sector antenna, DME antenna

Air-to-air Surveillance Tracks

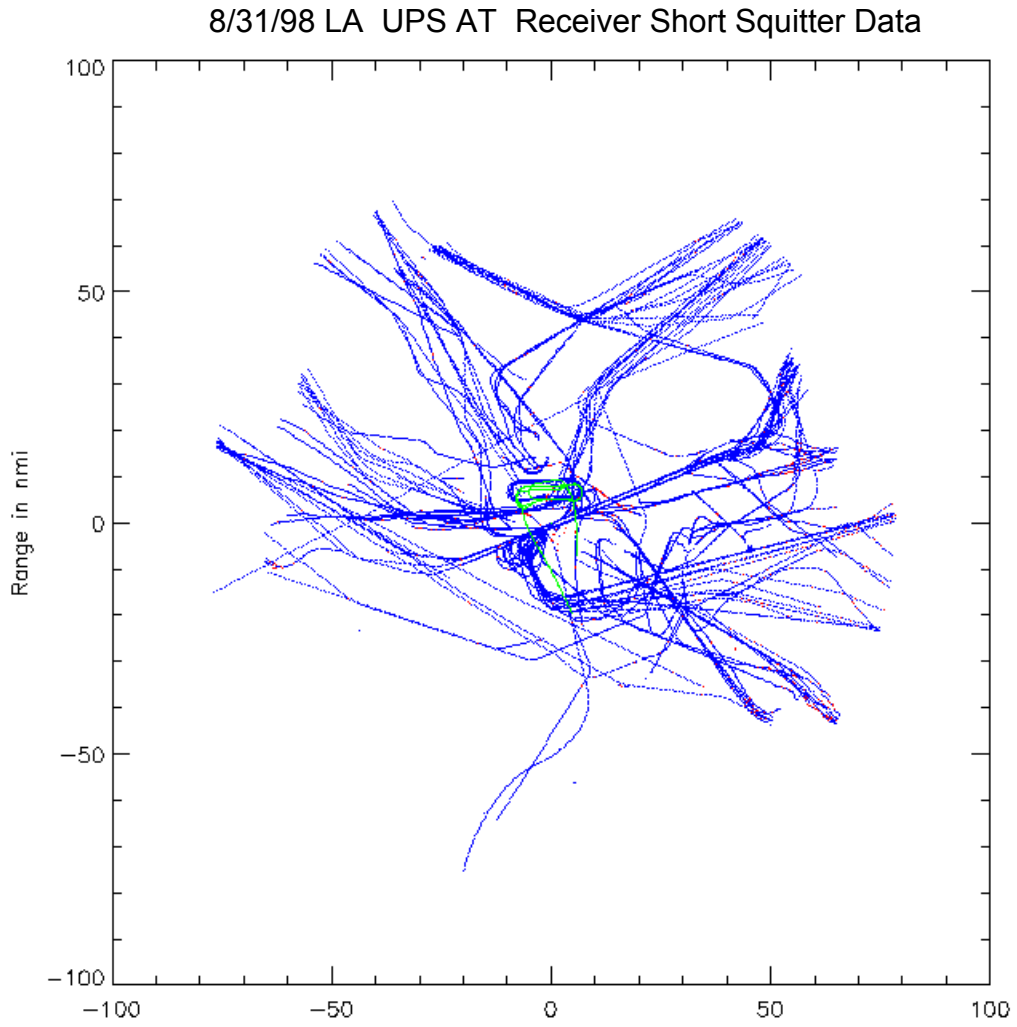


Air-to-ground Surveillance Tracks



LA Field Measurements

Comparison of Mode S Radar Coverage and Short Squitter Reception



Mode S sensor tracks in red

Squitter-reinforced Mode S Tracks in blue

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Status of Standards

- Required standards for implementation
  - RTCA MOPS for national standardization
  - ICAO SARPs for international standardization
  - AEEC Characteristic for airline use
- Status

	RTCA	EUROCAE	ICAO	AEEC
MODE S TRANSPONDER	COMPLETE (DO-181C)	COMPLETE (ED-86)	COMPLETE (ANNEX 10)	COMPLETE (718)
EXTENDED SQUITTER	COMPLETE (DO-260)	COMPLETE (ED-102)	COMPLETE (ANNEX 10)	IN PROCESS (718A)

- DO-260A to be completed by Jun 02

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Summary

- Mode S supports a broad range of surveillance and data link applications
- Mode S and TCAS are mature systems that are well validated through operational experience
- Extended squitter adds ADS-B capability to Mode S
- All standards needed for implementation of extended squitter are in place or nearing completion