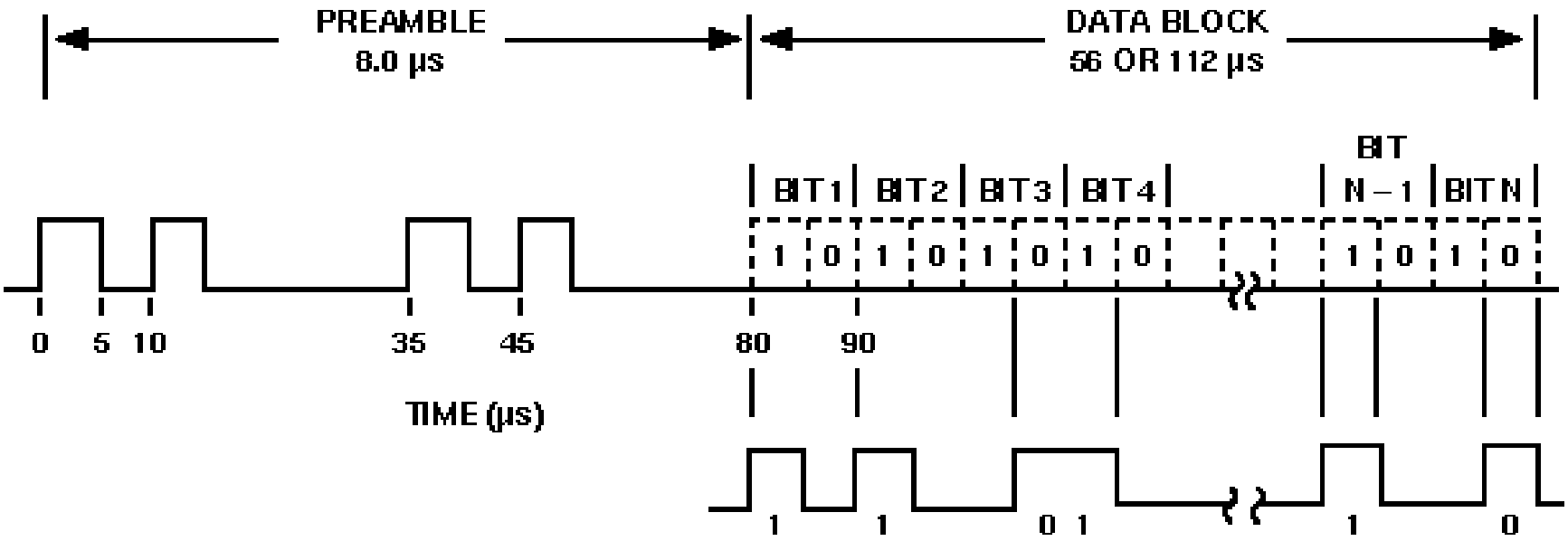
EXTENDED SQUITTER ENHANCED RECEPTION TECHNIQUES

Dr. Jeffrey L Gertz
Dr. Vincent A. Orlando
MIT Lincoln Laboratory

Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

Mode S Reply Waveform



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

Current Mode S Processing Capability

- Designed for:
  - Narrow-beam ground interrogator
  - Short range air-air TCAS
- Simple hardware implementation
  - Within technology of 1970's
- Can tolerate up to one overlapping higher power ATCRBS fruit per Mode S reply
  - Design environment is low interference ATCRBS fruit rate
- Performance drops rapidly in heavy fruit
  - Long range omni squitter receiver in high fruit environment
  - Throughput of accepted replies drops
  - Undetected error rate grows

Current Mode S Reply Reception Process

- Locate 4-pulse preamble & set bit timing reference
- Declare each message bit to be a ‘1’ or a ‘0’
  - Compare chip center samples, higher power sample wins
- Declare each message bit to be high or low confidence
  - High confidence if “other” chip sample below threshold
  - Threshold set 6db below preamble level
- Compute reply error syndrome for declared message
  - 24-bit parity sequence after processing by tapped shift register
  - Similar to software CRC
- If non-zero syndrome, attempt error correction
  - First consider last 24 bit span
  - Only low confidence bits can be changed
- If attempt fails
  - Slide 24-bit window one bit and try again
  - If no correctable error located in any window position, reject reply

Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

Development History

- Improved reply reception development began in 1996
- Stimulated by requirement for long range omni air-air reception in high fruit environment
- Much higher fruit environment than intended for current techniques
- For long range air-air operation, need to
  - improve reply reception probability
  - reduce undetected error probability

Development Approach

- Start with current reply processing techniques
  - Same wave form, same CRC
  - Technique proven in Mode S and TCAS operation
- Improve preamble detection
  - Suppress false fruit preambles that mask Mode S preambles
- Improve bit declaration
  - Absolute rather than relative amplitude
  - Make fewer bit errors
- Improve error correction
  - Modification and extension to current error correction
  - Improve undetected error performance
  - Handle more complex fruit overlap cases

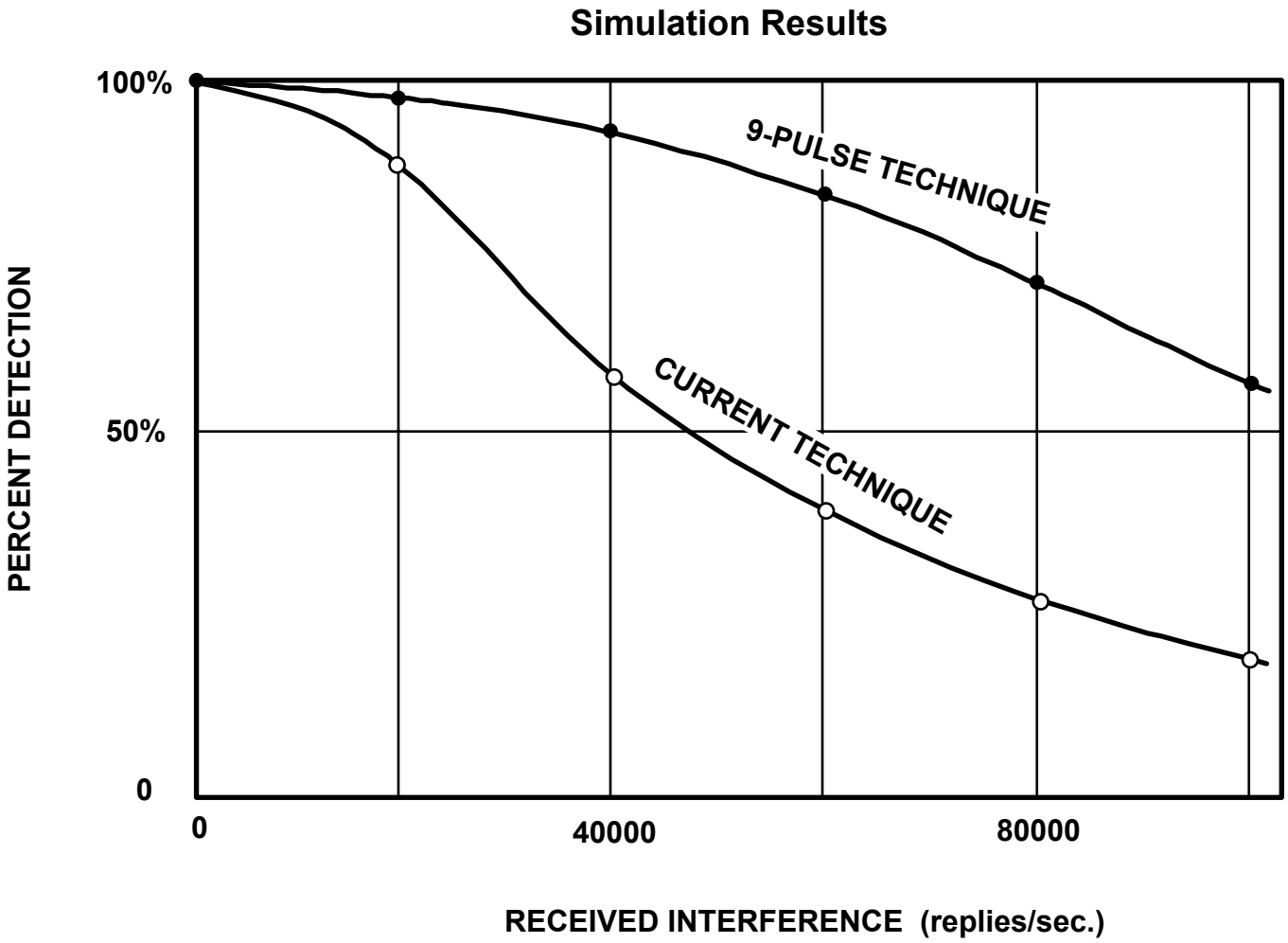
Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

Preamble Detection Considerations

- Require the 4 pulses to be same amplitude?
  - Preamble overlapped by fruit –> lost reply
- Allow amplitude differences?
  - Coincident fruit can create preambles
  - Lose Mode S reply during processing interval of fruit preambles
- Solution - “9 pulse” preamble algorithm
  - First 4 pulses as today, any amplitudes
  - Then require pulses in each of first 5 data positions (DF field)
  - Pulse = 3 or more consecutive samples above threshold
- Result: reduced loss of decodable Mode S, fewer false alarms

Preamble Detection Performance

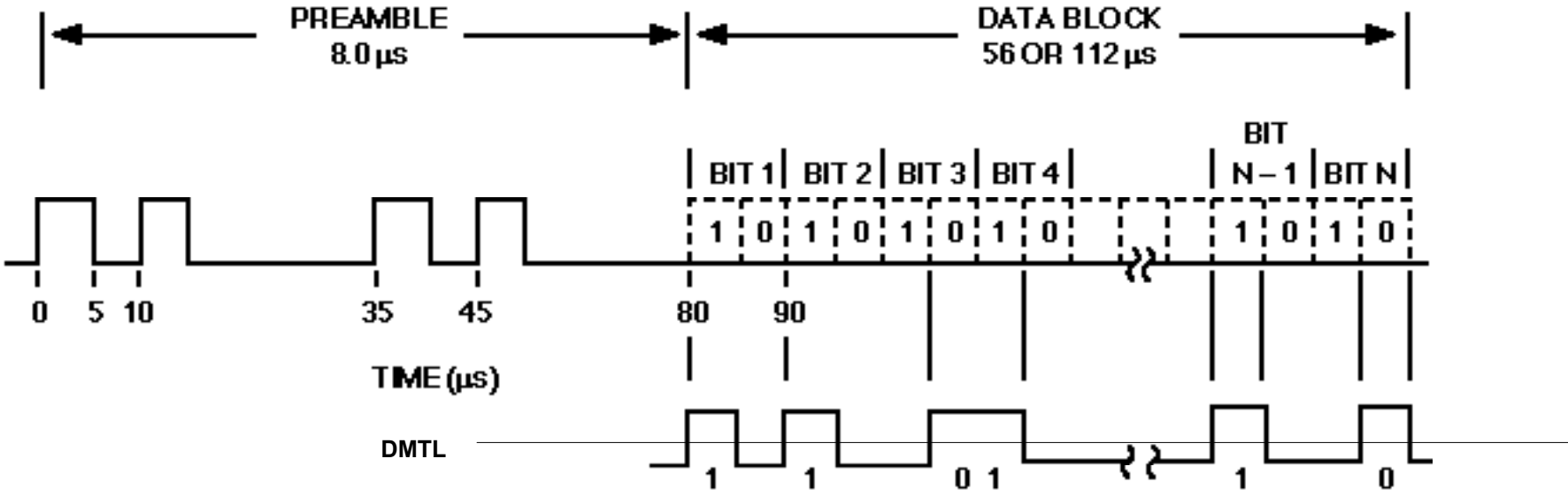


Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

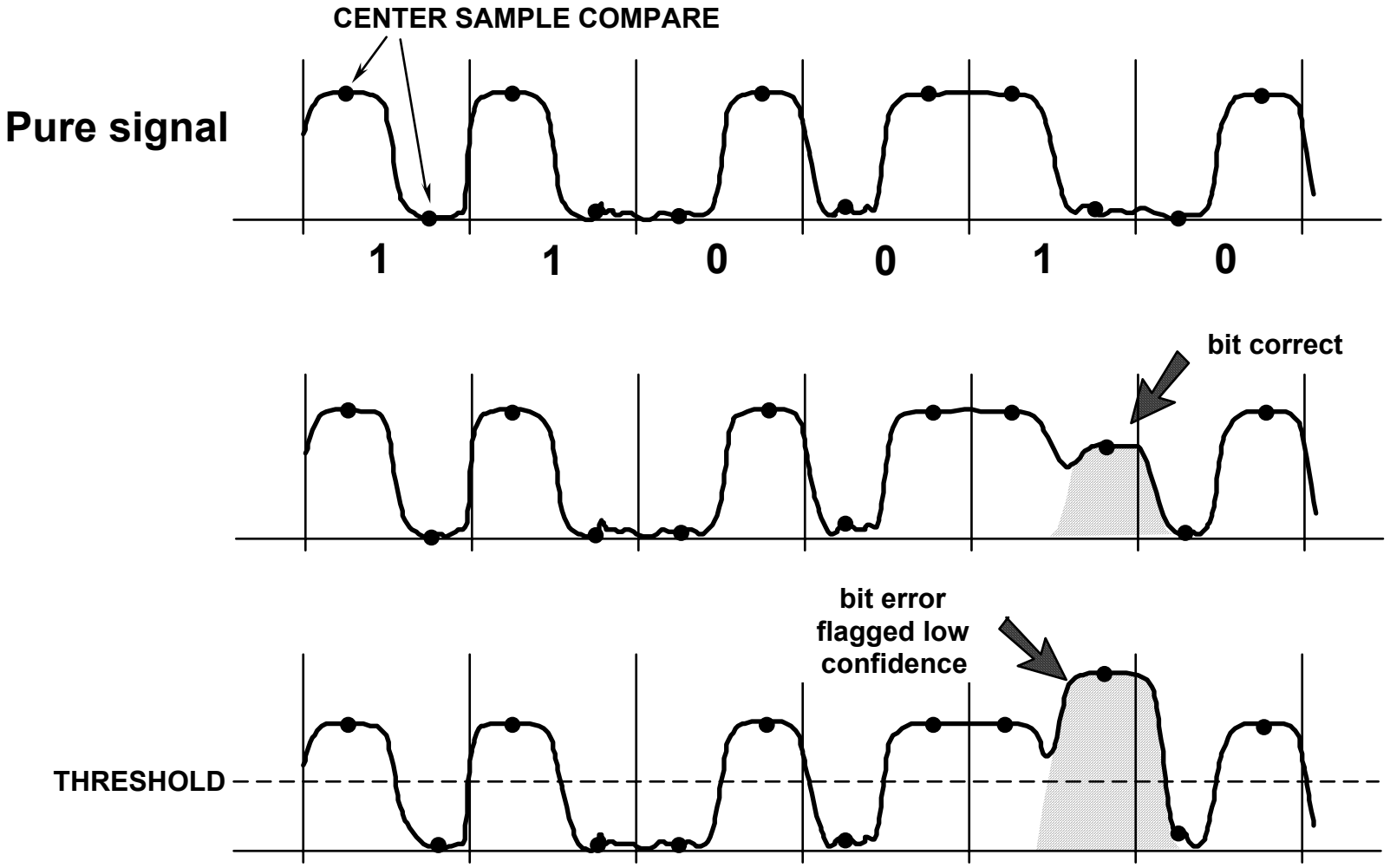
MODE S REPLY WAVEFORM

1090 MHz



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

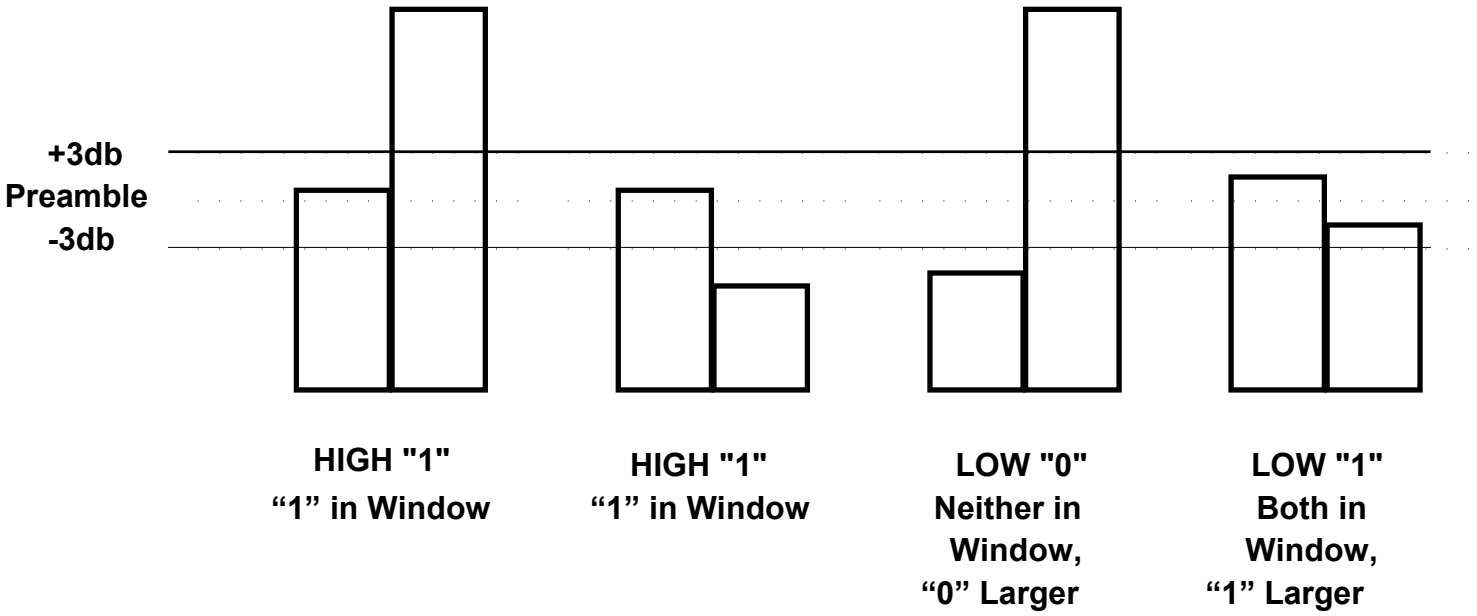
Current Reception Technique



"Center Sample" Technique

- Data value: compare chip amplitudes to preamble level
  - If 1 and only 1 within preamble window, it wins
  - Otherwise, higher power sample wins
  - 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
- High confidence bit error can occur
  - When "Mode S" chip is hit and "other chip" has interference
  - Requires wide ATCRBS pulse or 2 ATCRBS replies
  - Leads to lost reply, not reply error

Amplitude Bit and Confidence Declaration

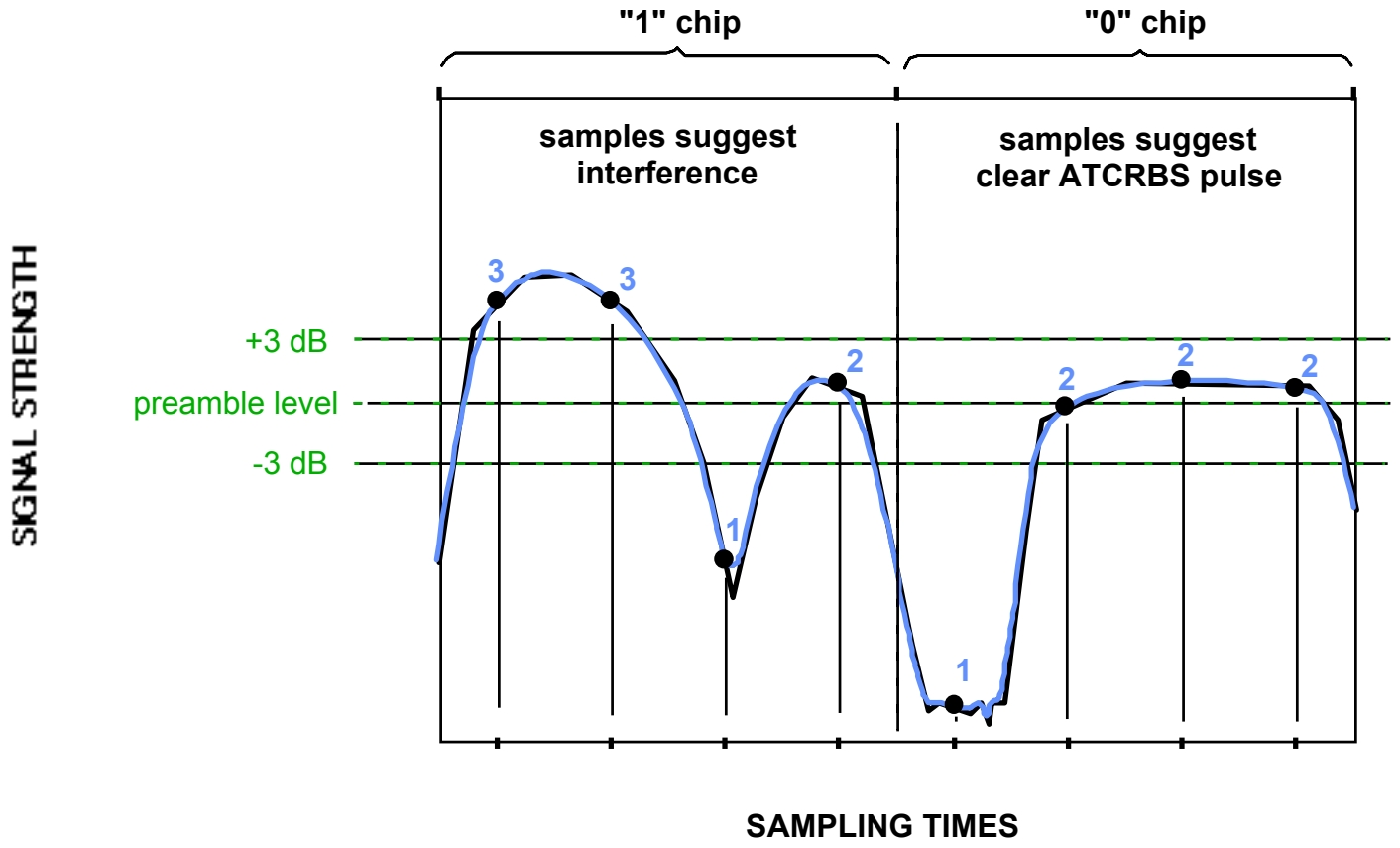


"Multiple Samples" Technique

- Data value: use pattern created by 8 sample amplitudes
  - Each sample can be 1 of 4 values (creating 64k possible patterns):
    - 0: below threshold
    - 1: below preamble window
    - 2: within preamble window
    - 3: above preamble window
- Look up pattern in stored table to see if a '1' or a '0'
  - Stored table created from millions of data runs
- Confidence value: use pattern statistics
  - Use second stored lookup table for confidence
  - If pattern >90% of the time created by a '1' (or '0'), high confidence
- High confidence bit error can occur
  - When high confidence pattern produced by "wrong" bit value
  - Leads to lost reply, not reply error

Example Complex Data Decision

Only ‘0’ Center Sample in Window, But High Confidence ‘1’ Declared



4-4 Multiple Samples Technique

- Simpler implementation variation of multiple samples approach
  - Requires 256 element lookup tables instead of 65536 tables
  - Preferred by manufacturers
  - Produces only slight loss of performance
- 2 sample patterns are determined - odd (1-3-5-7) & even (2-4-6-8)
  - Each has own lookup tables for bit & confidence values
  - Bit declaration value = 0 or 1
  - Confidence = high, medium, or low

    High : >90%, medium : >70%
- Odd & even decisions are combined for final output
  - Higher confidence decision wins

    High confidence result if either is high confidence
  - Both medium & agreement produces high confidence result
  - Disagreement at same confidence level produces low confidence zero

Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

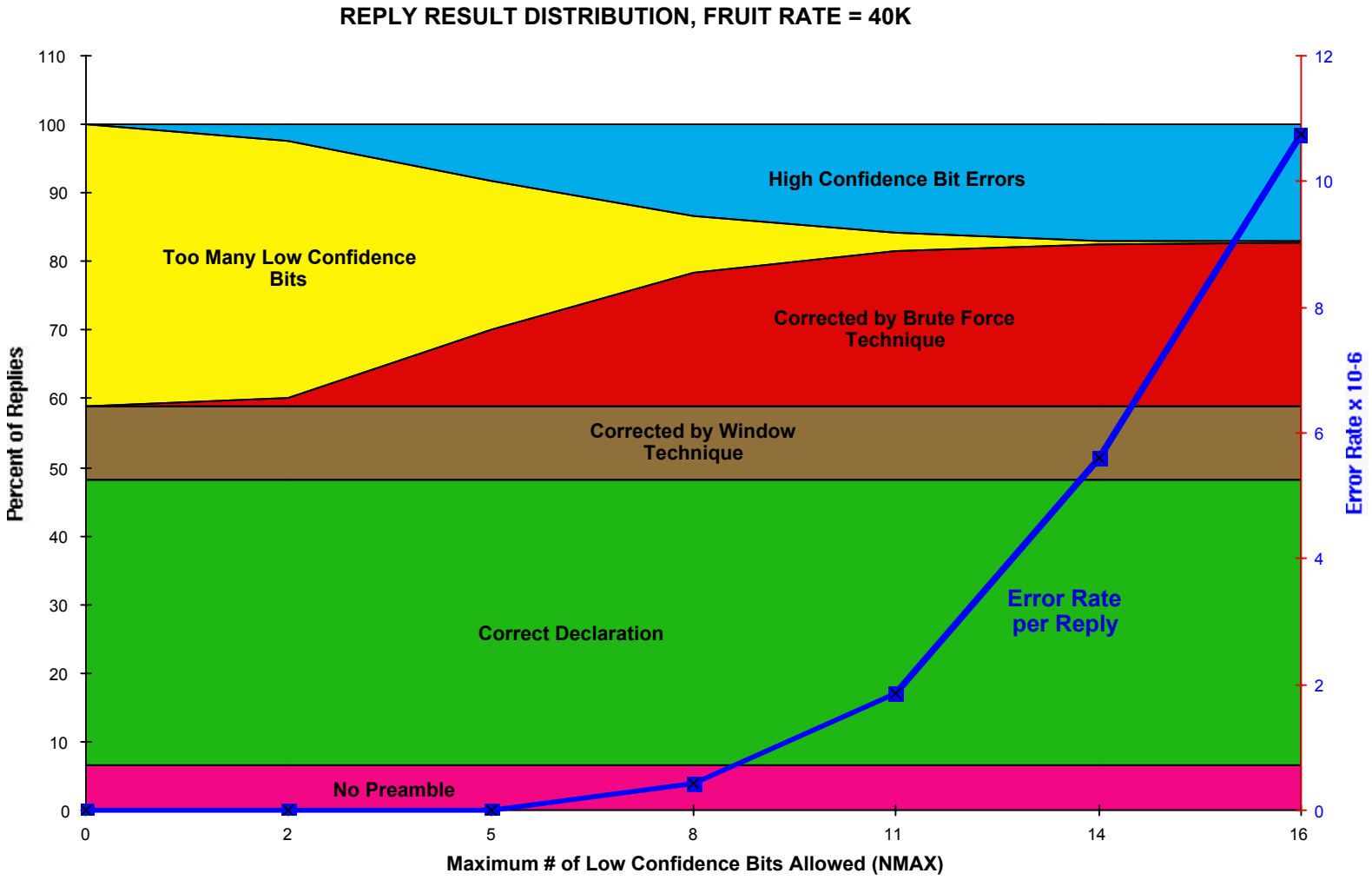
Conservative Mode S Error Correction Algorithm

- Based on current Mode S error correction technique
- Designed to minimize undetected errors
  - Eliminates “sliding window” processing
  - Attempts correction only if all low confidence span <25 bits
  - Residual errors occur only when no error detected
    - Error bits located to produce 0 syndrome
    - Undetected error probability: 1 * 10-7
- Simple hardware modification to current technique
- Drawback
  - Can not handle multiple overlaps
  - Lower reply throughput in high fruit environment

Brute Force Error Correction Algorithm

- Designed to handle any overlap situation
  - Can handle any length error bit span
  - Can correct even if ATCRBS replies overlap each other
- Approach: try all combinations of low confidence bits
  - 2^n combinations if n low confidence bits
  - Correct when only 1 combination matches error syndrome
  - Error possible only when high confidence bit error exists
- Algorithm parameter: max of 5 low confidence bits suggested
  - Control undetected error rate
- Implementation may upgraded processor
  - 32 combinations to try if 5 low confidence bits

Brute Force NMAX Parameter



Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

Technique Performance Comparison

Percent Acceptance Probability with 40K Fruit/Second (-5 to +10 dB)

	ERROR CORRECTION TECHNIQUE		
AMPLITUDE INFORMATION	NONE	CONSERVATIVE MODE S	PLUS BRUTE FORCE WITH N=5
NONE (CURRENT)	3	8	18
CENTER SAMPLE	13	23	36
MULTIPLE SAMPLE	40	52	63

Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

Lincoln Laboratory Simulation Test Bed

Reply Generation

- Permits specification of aircraft distribution
  - Can match recorded squitter power distribution
- Permits fruit rate specification
  - Fruit generated randomly from above aircraft model
- Models Mode S and ATCRBS pulse shapes
  - Can specify receiver bandwidth, pulse widths

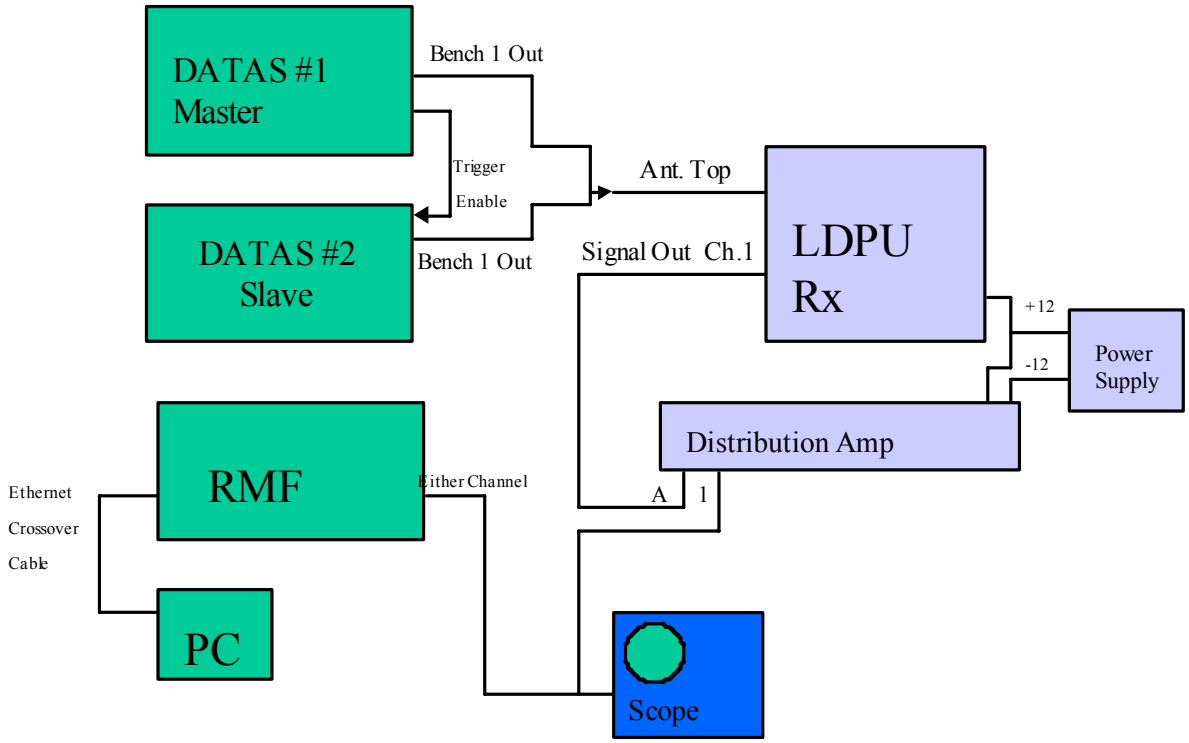
Reception algorithm

- Non real-time implementation of actual algorithms
- Accepts sampled data from simulated Reply Generation
- Accepts sampled data from actual measurements

LL Simulation Statistics

- Mode S acceptance rates
  - Preamble detection
  - Error correction
- Analysis as a function of
  - Power level
  - Receiver threshold
- Can vary algorithm parameters
  - Compare new technique
  - Compare to existing technique
- Tools to determine cause of missed replies
  - E.g., missed preambles located

WJH TC Test Bed Facility



Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

MOPS Tests for Reply Reception

- Based on bench test
  - Inject desired squitter
  - Overlap with ATCRBS fruit replies
  - Measure reception probability
- Same test for current or improved reply processing
  - Difference in the number of fruit injected
  - Will require more fruit generators for improved processor test

Topics

- Current Mode S Techniques
- Development History
- Preamble Detection
- Bit Declaration
- Error Correction
- Technique Performance Comparison
- Simulation and Test Bed Facilities
- MOPS Test for Improved Reply Processing
- Summary

Summary

- Current Mode S reply reception algorithms not suited to long range air-air operation
- New techniques developed as extensions to existing techniques
  - Preamble detection
  - Bit declaration
  - Error correction
- New techniques provide significant improvement in high fruit rate environment compared to current techniques
- Testing of new techniques uses the same test approach as for the current technique, but at a higher fruit rate.