Aircraft Intra-Vehicular Channel Characterization in the 5 GHz Band

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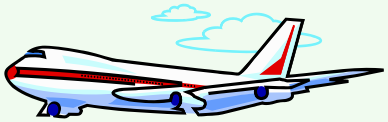
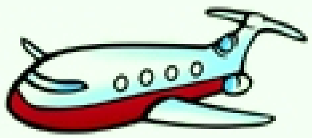
David W. Matolak, Arvind Chandrasekaran
School of Electrical Engineering & Computer Science
Ohio University
Athens, OH 45701

Outline



- Introduction
  - Motivation and applications
  - Importance of channel characterization
- Measurement Description
  - Channel sounder
  - Aircraft characteristics
  - Measurement procedures



- Measurement Results
  - Channel Impulse Response (CIR)
    - ✓ Power delay profile (PDP)
    - ✓ Frequency correlation estimate (FCE)

Outline (2)

- Channel models: tapped delay line (TDL)
  - Tap amplitude statistics
- Summary and future work

Introduction

- Intra-aircraft 50 MHz bandwidth channel characterization results in the 5 GHz band
  - Quantification of delay dispersion and frequency coherence
- Measurements in four Ohio University aircraft, which range from medium to small-sized planes
  - Douglas DC-3
  - Raytheon King Air C90SE
  - Piper Saratoga
  - Cessna Centurion

King Air C90SE

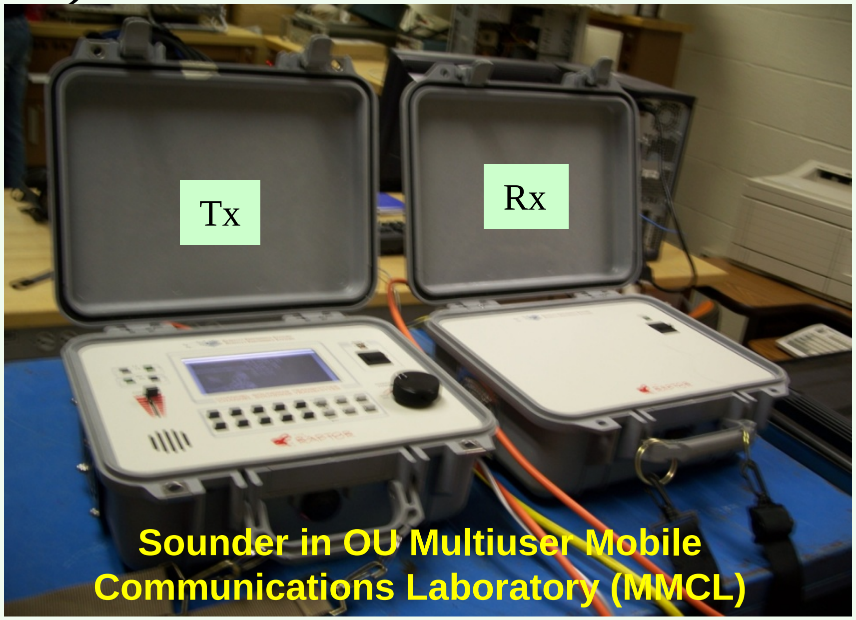
Introduction (2)

- Motivations
  - Band availability (UNII & E-MLS bands)
  - Dearth of data for 5 GHz intra-aircraft channels
- Applications for “within-aircraft” network
  - Passenger network applications
  - Data and file transfer between crew members
  - Wireless sensor networking for monitoring various aircraft health and safety functions
- Channel characterization required to optimize system performance

Measurement Description

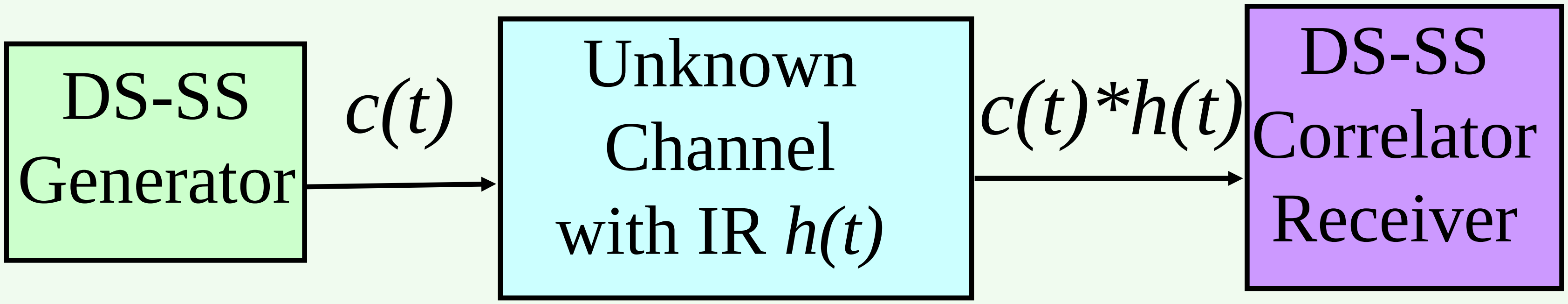
- Test set consists of transmitter (Tx) and receiver (Rx), collectively called the “sounder,” manufactured by Berkeley Varitronics Systems (BVS)
- Spread spectrum stepped correlator, with adjustable center frequency (5.22 GHz) within the 5 GHz band

Characteristic	**Value**
Transmit power	+5 to 33 dBm
Center frequency	5.12-5.22 GHz
Chip rate	50 Mcps
Unambiguous delay range	5.1 μsec
Bandwidth (99% power)	52.76 MHz
Measurement rate	2-60 PDPs/sec
Antennas	Omni monopoles, gain 1.5 dBi



Sounder in OU Multiuser Mobile Communications Laboratory (MMCL)

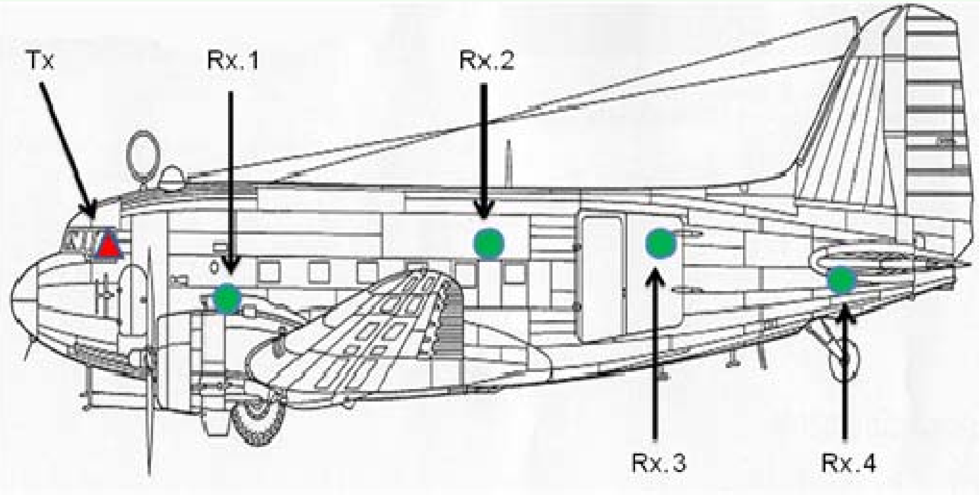
Measurement Description (2)



- Channel is linear, hence characterized by channel impulse response (CIR)
- CIR estimated from measured power delay profiles (PDPs)
- Data post-processed to remove suspected “external” signals

Measurement Description (3)

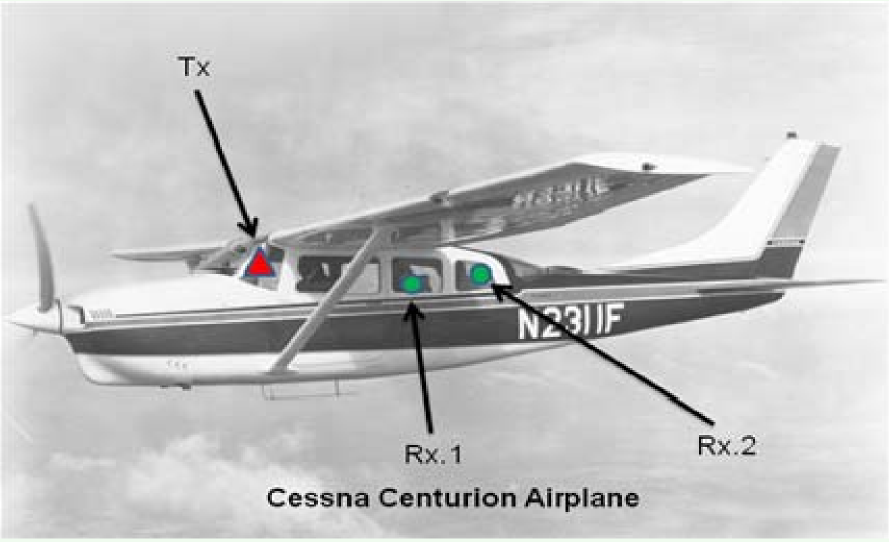
- Rx placed at 4 positions inside the DC-3, 3 positions in King Air, and 2 positions each in the Piper and Cessna
- Tx stationary in the cockpit
- All measurements taken inside aircraft while aircraft parked inside OU Avionics Engineering Center hangar



Measurement Description (4)

- DC-3 not a typical passenger aircraft
  - Several equipment racks mounted
  - Re-modeled windows
- Other aircraft are passenger aircraft

Tx to Rx distance (m)				
Aircraft	Rx Location Number			
	1	2	3	4
DC-3	2.4	5.4	9.1	12.3
King Air	1.8	2.7	4.6	--
Piper	1.7	2.4	--	--
Cessna	0.8	1.9	--	--

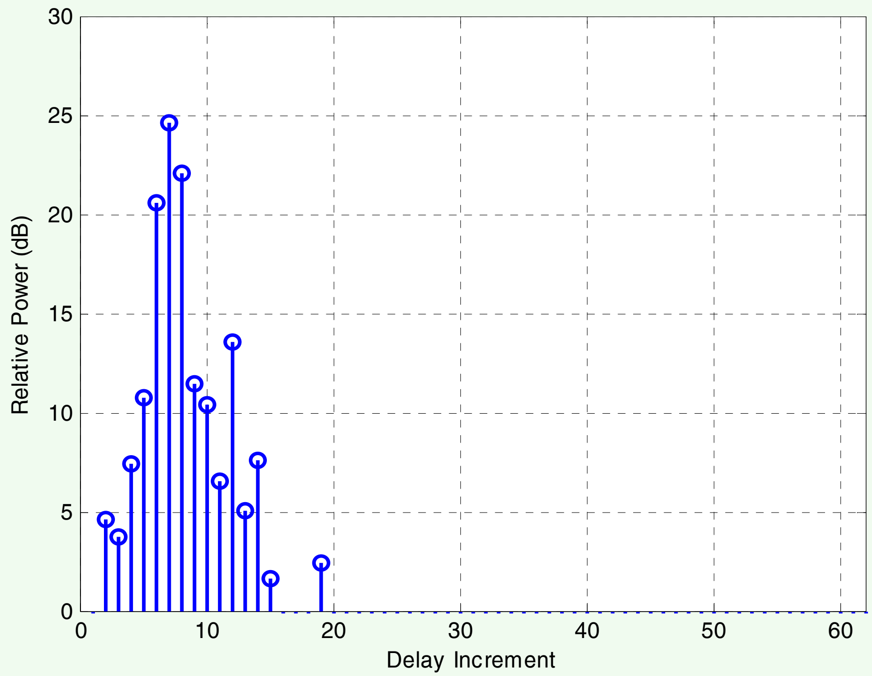


Measurement Procedure

- Sounder calibrated ("trained") overnight to ensure rubidium oscillator locking
- After training, Tx and Rx detached, and Tx placed in position
- Rx then moved to each measurement location and PDPs measured

Measurement Results

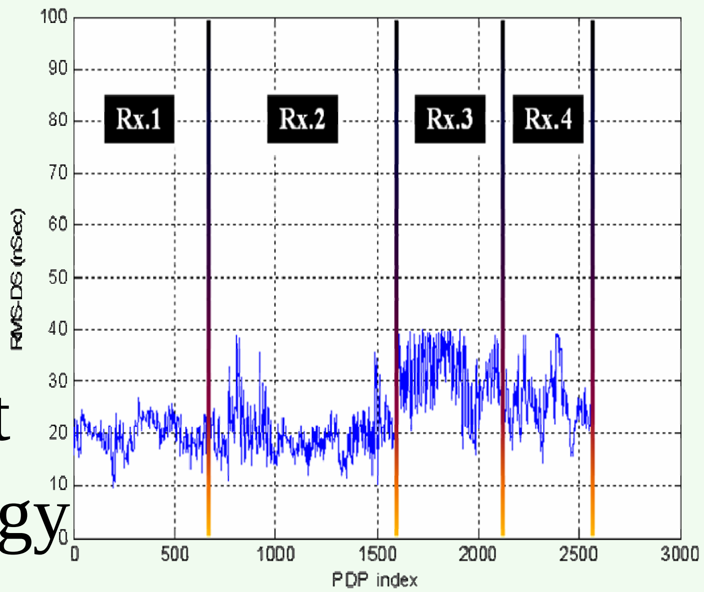
- PDP is received power vs. delay
- Example PDP shows multiple CIR components
- Multipath component amplitudes within 25 dB of maximum
- Delay increment 20 ns
- RMS-DS, $\sigma_\tau = 57\text{ns}$



Measurement Results (2)

- Root mean-square delay spread (RMS-DS) is common measure of spread of the channel energy
- RMS-DS is

$$\sigma_\tau = \sqrt{\frac{\sum_{k=0}^{L-1} \tau_k^2 \alpha_k^2}{\sum_{k=0}^{L-1} \alpha_k^2} - \mu_\tau^2}$$



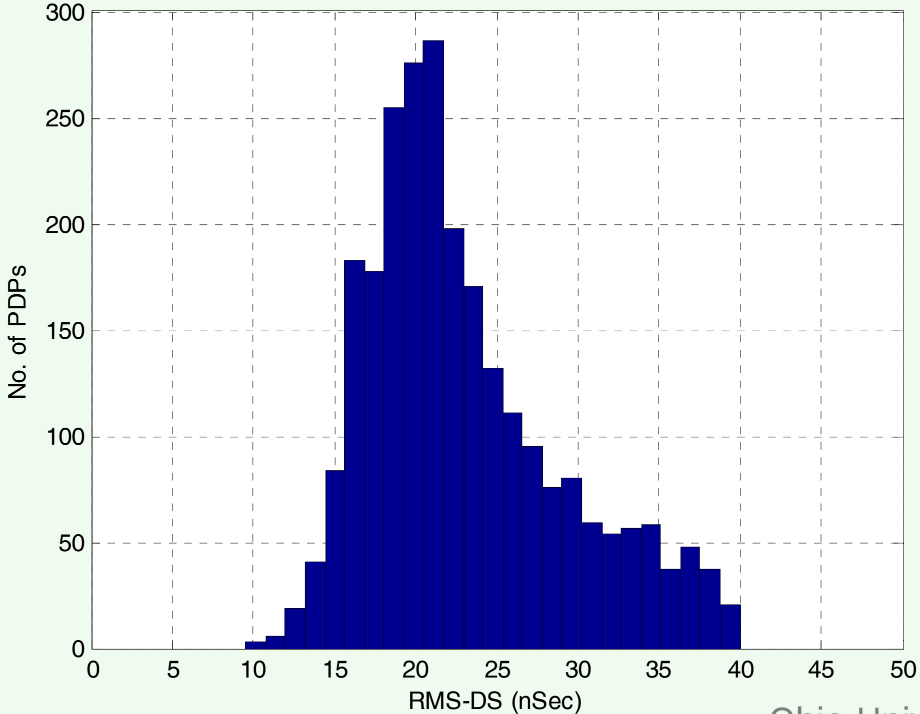
where α_k is multipath component amplitude at delay τ_k. Mean energy delay μ_τ is

$$\mu_\tau = \frac{\sum_{k=0}^{L-1} \tau_k \alpha_k^2}{\sum_{k=0}^{L-1} \alpha_k^2}$$

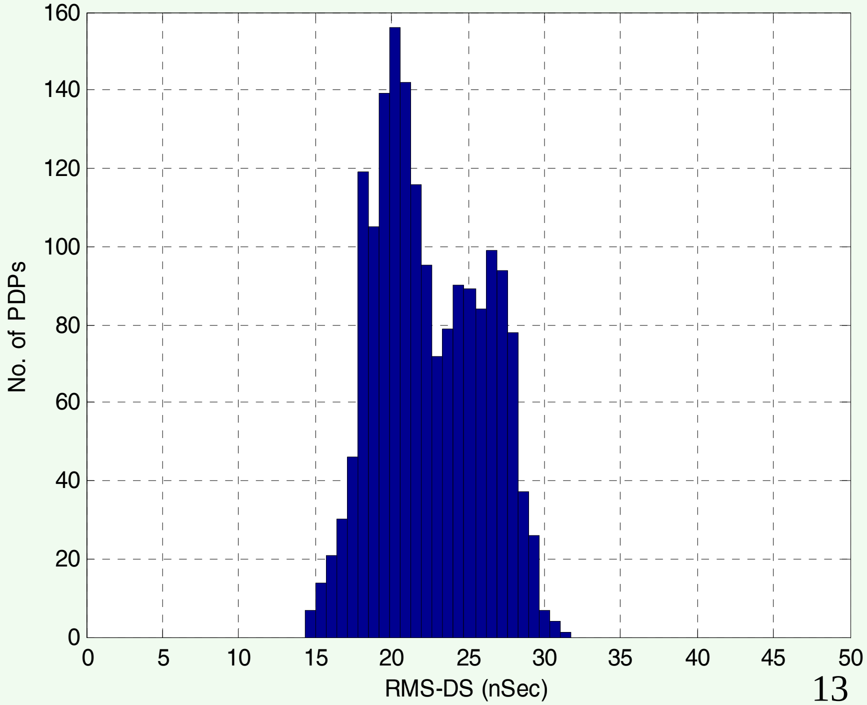
Measurement Results (3)

- Time-variation yields different RMS-DS values
- Plots show RMS-DS histograms for DC-3 and Cessna

DC-3

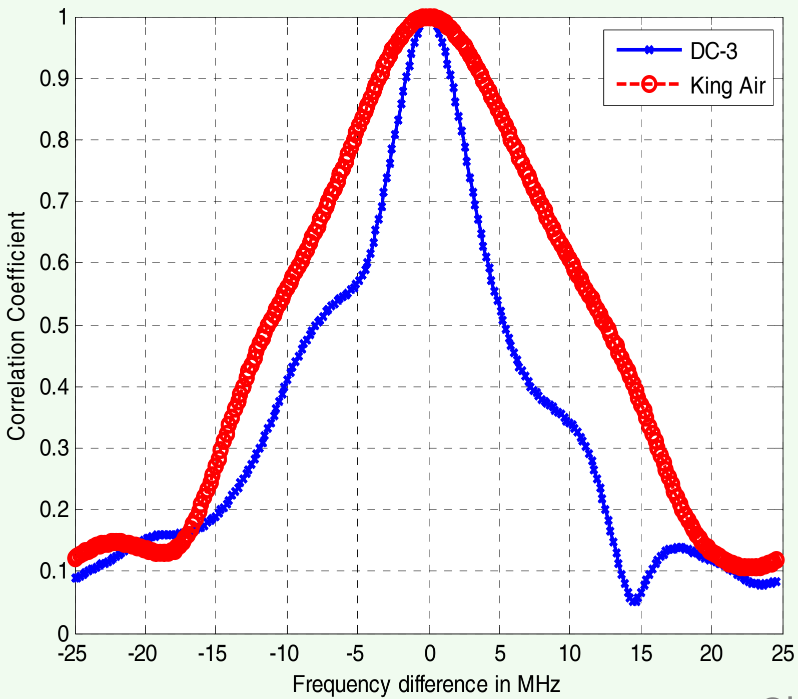


Cessna



Measurement Results (4)

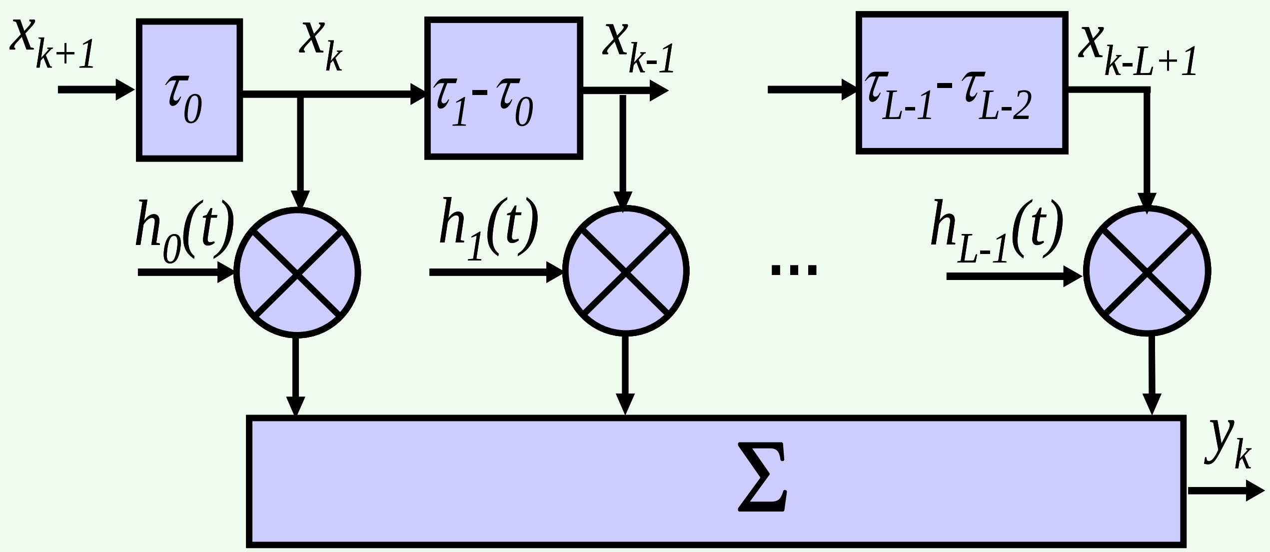
- Frequency correlation estimate (FCE) provides a measure of channel coherence (correlation) bandwidth
- Correlation 0.5 at frequency separation approximately 10 and 22 MHz for DC-3 and King Air, respectively



RMS-DS STATISTIC (ns)	AIRCRAFT			
	DC-3	King Air	Piper	Cessna
Minimum	9.5	9.2	8.8	14.3
Mean	26.3	23.7	29.1	24.2
Maximum	40.0	35.0	45.0	32.0

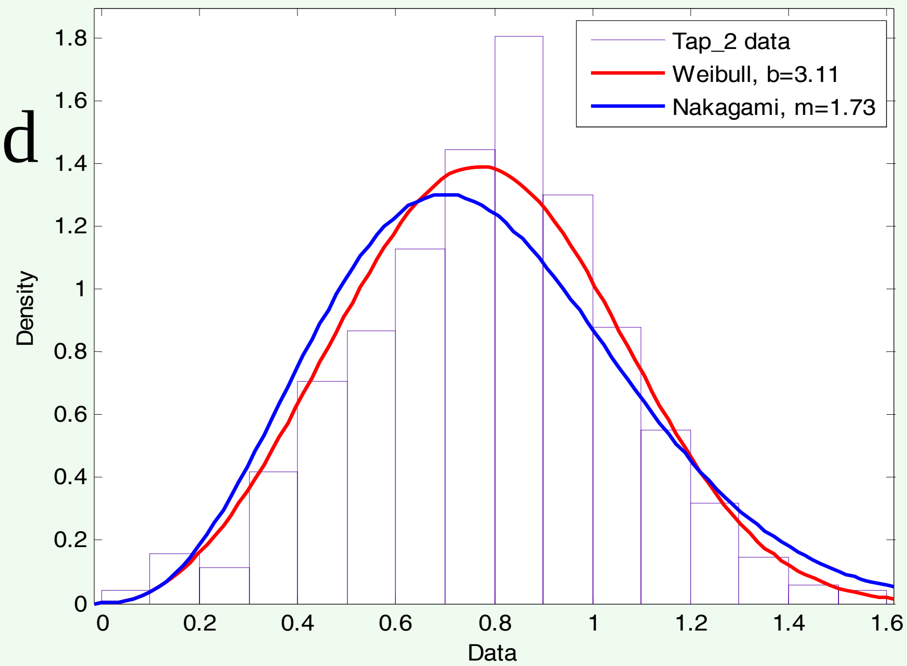
Channel Models

- Statistical models created from data
- Tapped-delay line (TDL) model most common
- Model specification requires the number of taps, and random process model for each tap (*h*)



Channel Models (2)

- Popular statistical models compared with data and the best fit—the maximum likelihood fit—was found
- Weibull and Nakagami probability density function fits for amplitude fading data of a single tap (tap #2) for the DC-3 shown.
- Data for all locations used



Channel Models (3)

- Number of taps calculated from RMS-DS
- Weibull shape factor (*b*) denotes fading severity (smaller *b*=worse fading, with *b*=2 Rayleigh)

Aircraft	Tap Index	Tap Energy	Weibull Shape Factor (b)	Nakagami "*m*" Factor
DC-3	1	0.7065	12.27	26.58
	2	0.1572	3.11	1.73
	3	0.0521	0.92	0.32
King Air	1	0.7038	8.18	13.04
	2	0.1884	1.90	0.76
	3	0.0674	1.54	0.60
Piper	1	0.7013	12.14	65.41
	2	0.1052	0.92	0.32
	3	0.1112	1.85	0.73
Cessna	1	0.5993	13.62	57.34
	2	0.2358	2.95	1.29
	3	0.1282	2.75	1.19

Summary & Future Work

- Channel measurement and modeling results for 5 GHz band intra-aircraft channels presented
- Provided example measurement results in the form of delay dispersion and coherence bandwidths
- Delay spreads are modest, typically within 20-45 ns
- Coherence bandwidths are typically 15 MHz or so, which indicates highly correlated channel effects within any 10 MHz band
- Future work would extend these results to large aircraft, and construct channel models for smaller bandwidths

Thank You !

Thanks for insights –

Susheel Rajendar

Jingtao Zhang