CENTER FOR ADVANCED AVIATION SYSTEM DEVELOPMENT (CAASD)

Potential RF Interference to Control Links of Small Unmanned Aircraft

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Introduction

- **Radio control links of small unmanned aircraft (UA)**
  - **Generally require LOS path to control station (CS)**
    - **Horizontal range typically ≤ 1500 feet**
    - **Ceiling of 400 or 1200 feet AGL**
  - **Generally use 72–73, 902–928, and 2400–2483.5 MHz bands**
    - **Shared with other services**
    - **Potential RF interference (RFI)**
- **Objective of this analysis: Develop methodology for quantitatively estimating RFI to control links of small UA systems (UAS)**

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Approach

- Analyze potential RFI from unlicensed emitters
  - Cordless phones, wireless LANs, baby monitors, etc.
- Analyze potential impacts of licensed emitters
  - Radio transmitters with federally registered frequency assignments

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Typical Link Parameters

Frequency Band (MHz)	72–73	902–928	2400–2483.5
Transmitter Power	0.75 W (29 dBm)	1.0 W (30 dBm)	1.0 W (30 dBm)
Frequency Hopping?	No	Yes	Yes
Channel Width (MHz)	0.02	0.26	0.40
Number of Channels	50	100	208
Signal Received 1500 Feet Away*	–39 to –35 dBm	–60 to –56 dBm	–69 to –64 dBm

* Free-space path loss assumed

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Unlicensed Emitters in 902–928 MHz Band

Category	Est. U.S. Emitters (12/31/2006)	Average Power (Watts)	Avg. Duty Factor at Peak Times	Nationwide Total Avg. Power (kW)	Nationwide Total Avg. kW/MHz	Total Avg. mW/MHz per Person
Cordless Phones	53,000,000	1.000	0.10	5300	204	**0.679**
Baby Monitors	4,400,000	1.000	1.00	4400	169	**0.564**
Data Transceivers	2,500,000	1.000	1.00	2500	96	**0.321**
Wireless Repeaters	2,400,000	5.000	0.20	2400	92	**0.308**
Radio Modems	1,600,000	1.000	1.00	1600	62	**0.205**
Wireless Networks	13,300,000	0.150	0.60	1197	46	**0.153**
33-cm Amateur Radio	136,000	70.000	0.10	952	37	**0.122**
Location & Monitoring	800,000	1.000	1.00	800	31	**0.103**
Amateur Repeaters	6,000	70.000	0.50	210	8	**0.027**
All Others				207	8	**0.026**
			TOTALS:	**19566**	**753**	**2.508**

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Unlicensed Emitters in 2400–2483.5 MHz Band

Category	Est. U.S. Emitters (12/31/2006)	Average Power (Watts)	Avg. Duty Factor at Peak Times	Nationwide Total Avg. Power (kW)	Nationwide Total Avg. kW/MHz	Total Avg. mW/MHz per Person
Embedded Modems	26,000,000	0.450	1.00	11700	140	**0.467**
Wireless Routers/PCs	224,000,000	0.055	0.75	9240	111	**0.369**
Baby Monitors	4,400,000	1.000	1.00	4400	53	**0.176**
Data Link Transceivers	5,000,000	0.500	1.00	2500	30	**0.100**
Cordless Phones	18,000,000	1.000	0.10	1800	22	**0.072**
Bluetooth Devices	300,000,000	0.005	1.00	1500	18	**0.060**
Wireless Access Points	1,400,000	1.000	1.00	1400	17	**0.056**
Video Surveillance	280,000	2.550	1.00	714	9	**0.029**
Amateur TV/Satellite	11,300	100.000	0.50	565	7	**0.023**
All Others				1205	12	**0.046**
			TOTALS:	**35024**	**419**	**1.398**

A Scenario for RFI from a Local Concentration of Unlicensed Emitters

- High-rise apartment with 400 residents emits 11 dBm in an "average" channel in 902–928 MHz band
- UA flies past, 200 feet from building and 1500 feet from its CS
- Undesired-signal power U_r entering UA receiver is –56 dBm

- Received desired-signal power P_r is also –56 dBm
- Link margin $M = P_r - U_r - T$

  where T = interference threshold (10 dB assumed)
- So, link margin in <u>average</u> channel is –10 dB (unsatisfactory)
- However, <u>some</u> channels probably remain relatively clear

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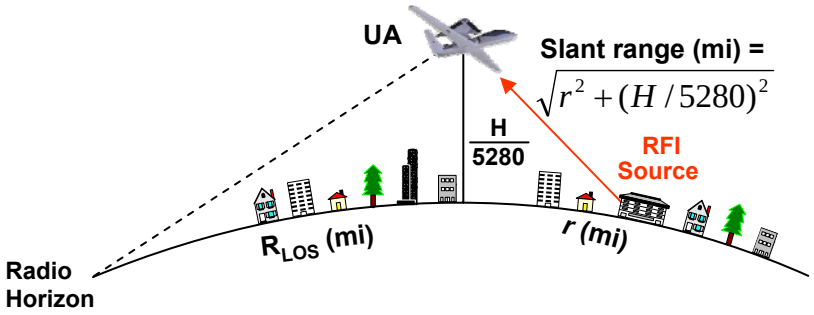
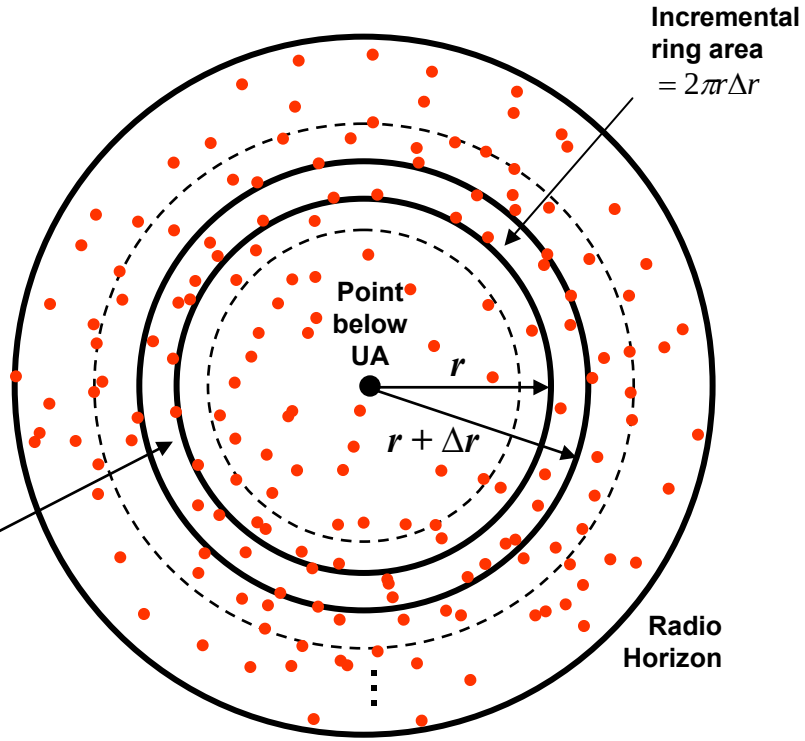
Scenario for RFI from an Area-Wide Distribution of Unlicensed Emitters

Single Interferer (Elevation View)



Multiple Interferers (Plan View)



RFI from all unlicensed emitters in ring *r* :

$$\Delta u_r = \frac{CPB(2\pi r \Delta r)}{a_s a_b a_p a_i(f,r)}$$

where

- ***C*** **= average unlicensed mW/MHz/person**
- ***P*** **= population density (persons/mi²)**
- ***B*** **= channel width (MHz)**
- a_s **= free-space loss**
- a_b **= building-penetration loss**
- a_p **= cross-polarization loss**
- $a_i(f,r)$ **= shadowing loss**

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Uplink Margin in Presence of Distributed Unlicensed RFI

- Find total undesired power u_r in UA receiver channel
  - Integrate Δu_r over all r from 0 to radio horizon
    - Most of the power originates < 1.0 mile from the UA
  - Convert to dBm ($U_r = 10 \log u_r$)
- Compute link margins for various population densities
  - Hundreds of U.S. cities have P in the 1,000–30,000 range

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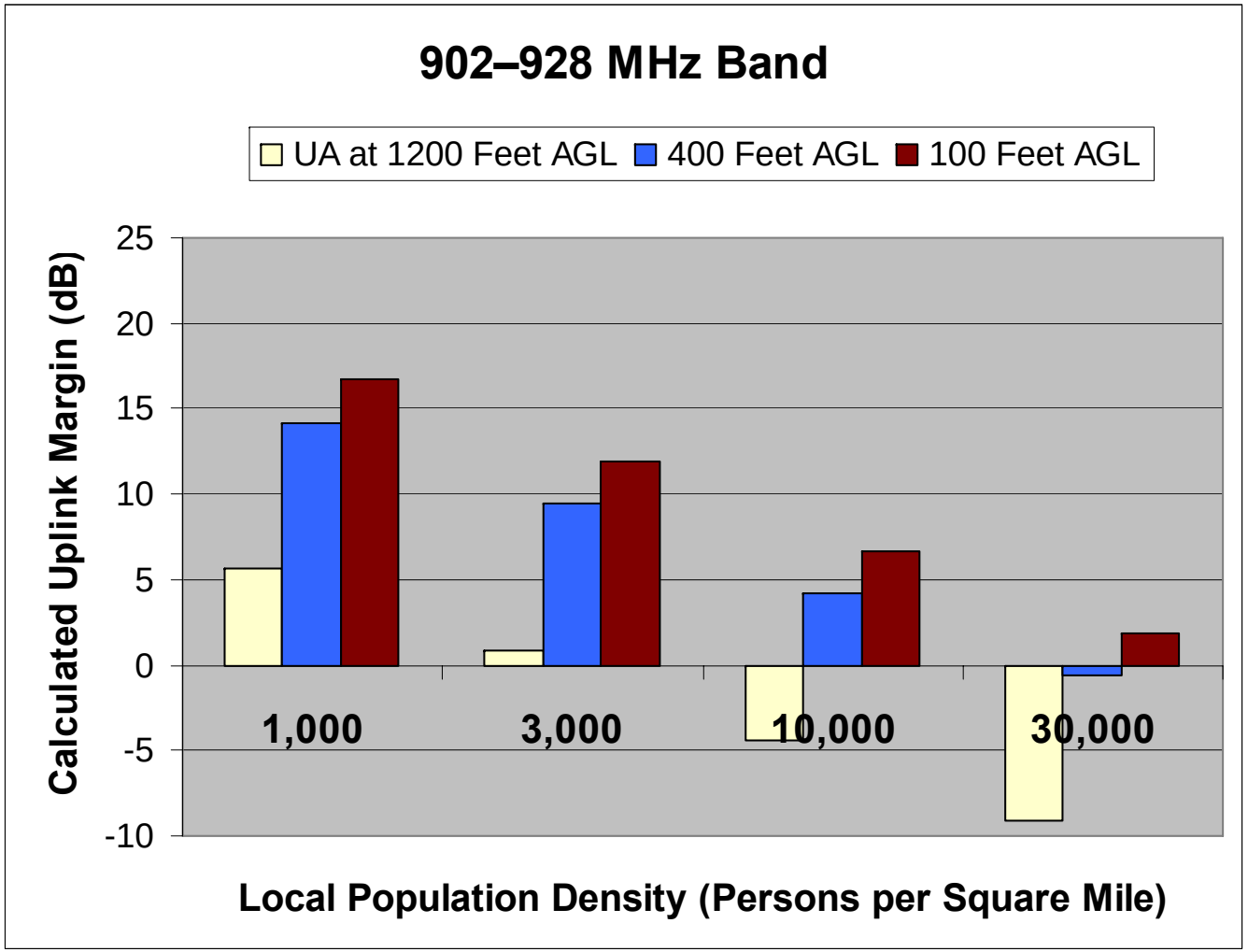
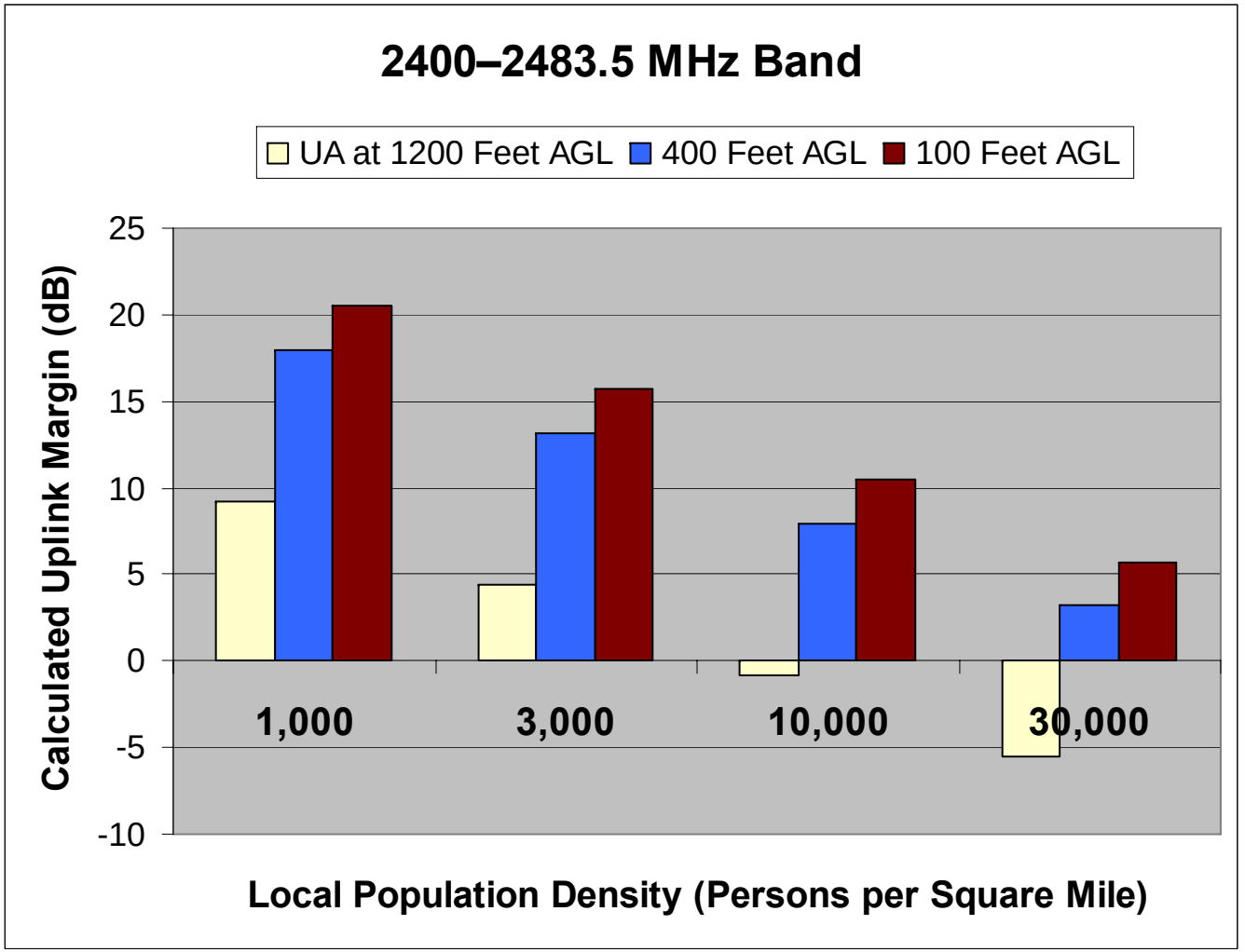
Potential Unlicensed-RFI Impact on UAS Uplink Margin (1 of 2)



Potential Unlicensed-RFI Impact on UAS Uplink Margin (2 of 2)



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Licensed-Emitter Analysis

- MITRE-developed simulation model calculates RF power levels in a UA receiver
  - User-defined UA flight path
  - Ground environment from FCC and Govt. agency files
    - 100% duty factors assumed (worst case)
  - Smooth-earth propagation model
- Simulations performed for one CS location in each of 10 U.S. cities
- UA orbits in circle around each CS location
  - 1500-foot radius
  - 100, 400, 1200 feet AGL

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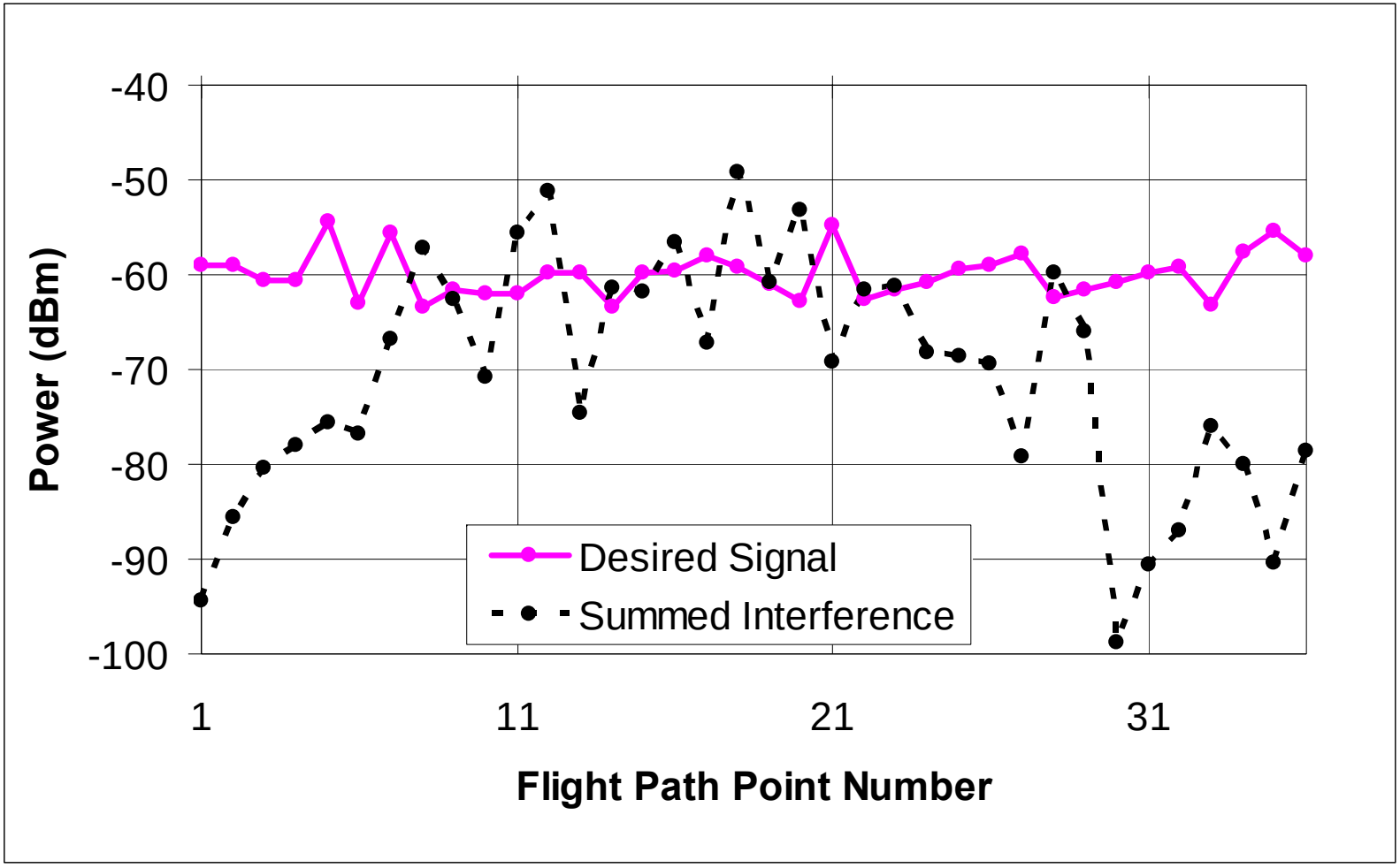
Example of Simulated Signal-Level Variations in a Channel



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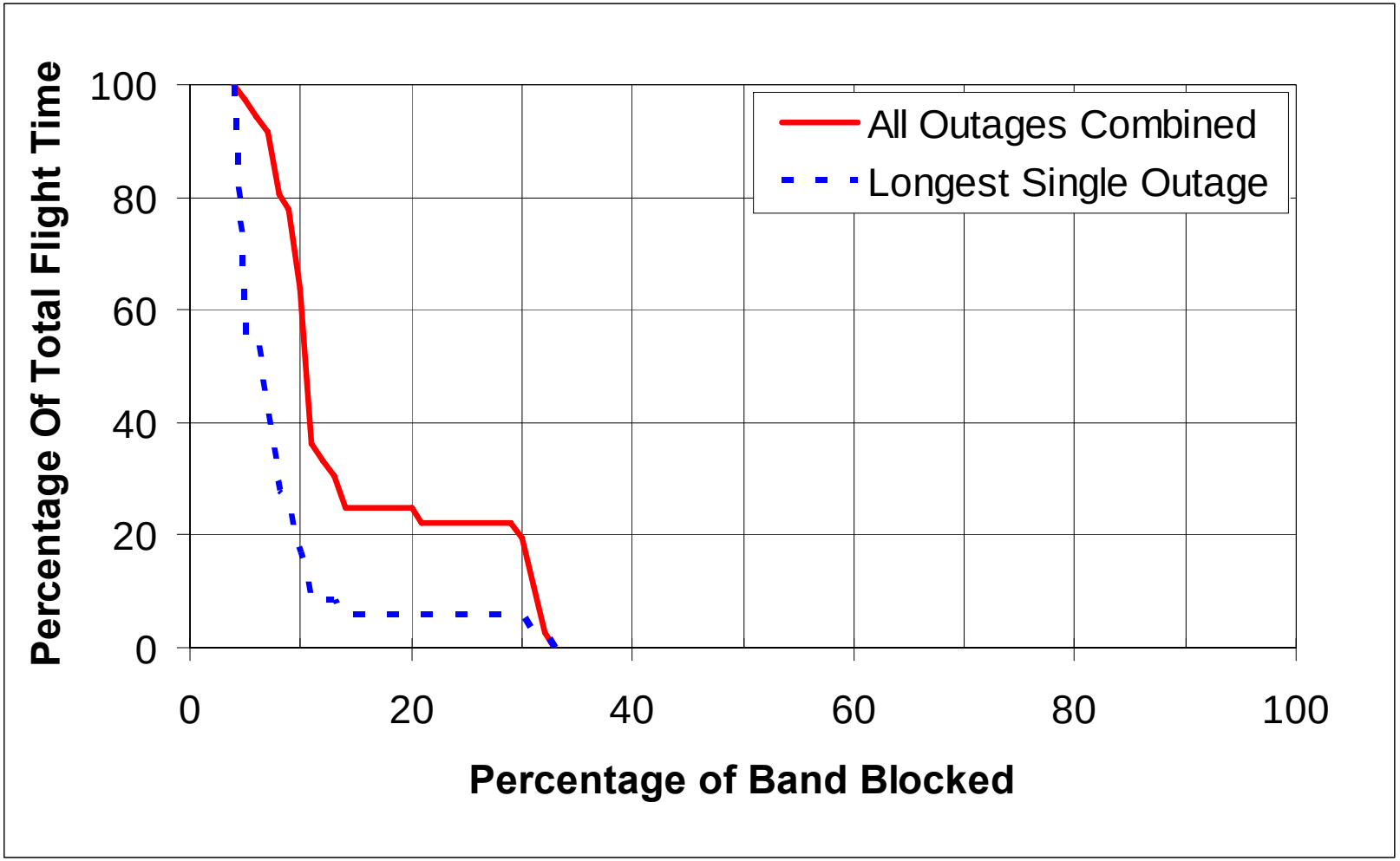
Example of Licensed-RFI Impacts



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Channel Blockage by Licensed Emitters (Simulated UA Flights at 1200 Feet)

Band (MHz)	Largest Fraction of Band Blocked by RFI from Licensed Emitters*		
	Through Entire Flight	During Half the Flight	At Least Once
72–73	0–24%	0–50%	0–60%
902–928	0–36%	0–61%	0–83%
2400–2483.5	0–50%	0–50%	0–50%

* Assuming 100% emitter duty factors and no masking by terrain or buildings

NOTE: Blockage percentages are generally smaller at lower altitudes

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Conclusions

- **Unlicensed RFI may degrade UAS control-link reliability in 902–928 and 2400–2483.5 MHz bands**
- **Licensed emitters may degrade reliability in 72–73, 902–928, and 2400–2483.5 MHz bands**
- **To minimize RFI in frequency-hopping links:**
  - **Use narrowest feasible RF channels consistent with required data rates**
  - **Seek and use "cooler" channels during link operation**
- **Airborne measurements are needed to validate and calibrate our model**
  - **Ambient spectral power densities**
  - **Associated bit error rates**

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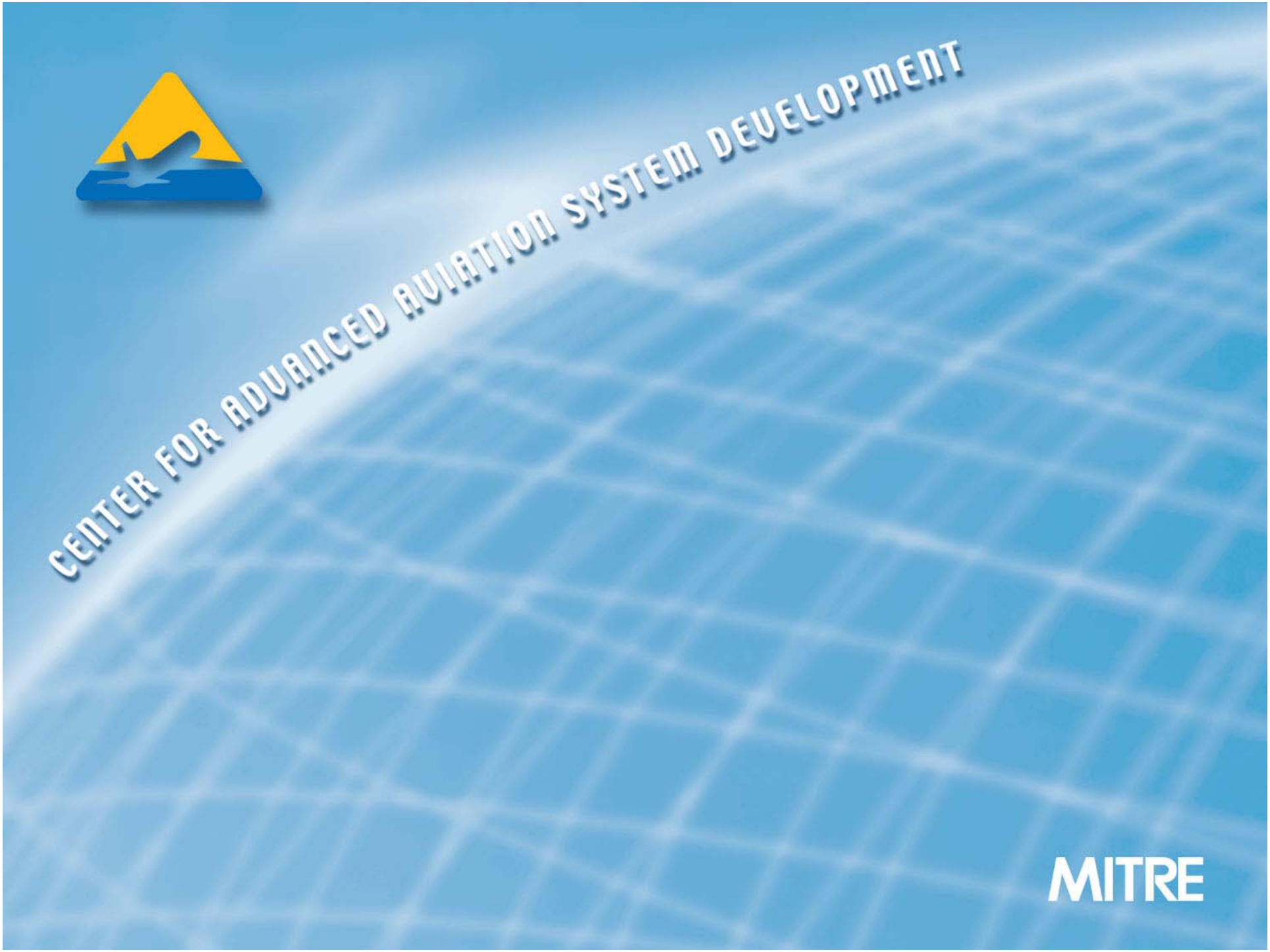
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