

NASA Noise Floor and UWB Effects Measurement Program

National Spectrum Managers Group

May 18, 2004

James E. Hollansworth

NASA Glenn Research Center

Cleveland Ohio



Program Description

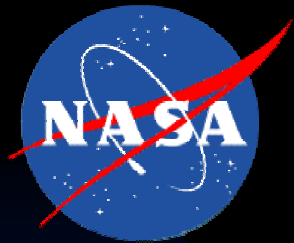
- Noise Floor Measurements
 - ◆ L and S Band measurements of ambient and man-made noise in the San Francisco Bay area

- Measurements of the effects of UWB Devices on Aeronautical Radios



Overview of NASA Study Program

- NASA is undertaking a two-part effort in cooperation with other US Government agencies to
 - ◆ Assess the effects on the noise floor of wideband transmissions and
 - ◆ Quantify the effects of ultra wideband (UWB) signals and of changes in the noise floor on select navigation and communications systems.
- Stanford University with support from Clemson University is leading the noise floor study effort.
- Simultaneously, NASA research centers are conducting focused testing and simulations to determine the effects of wideband transmissions on aircraft communications and navigation systems.



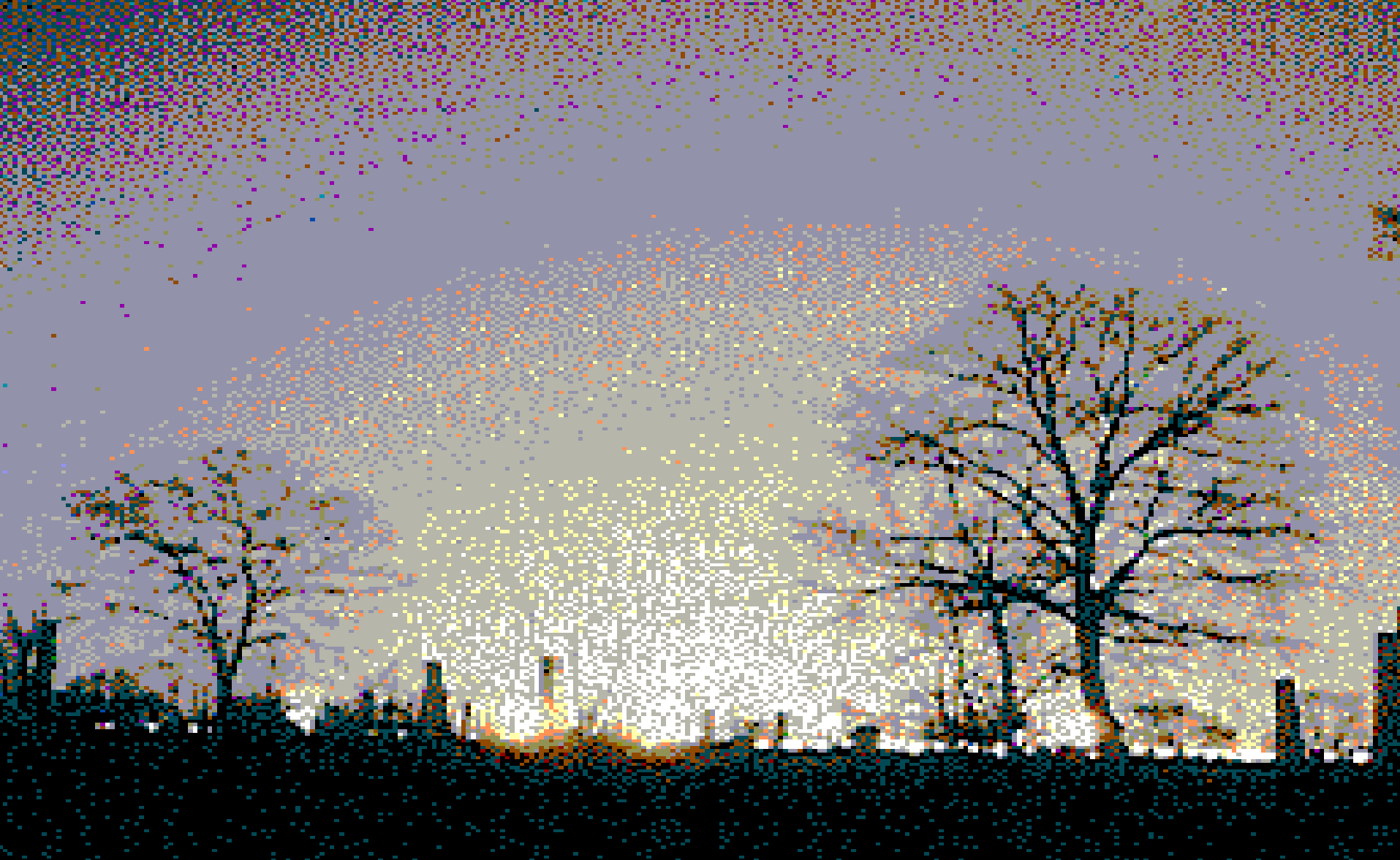
Purpose of the Study

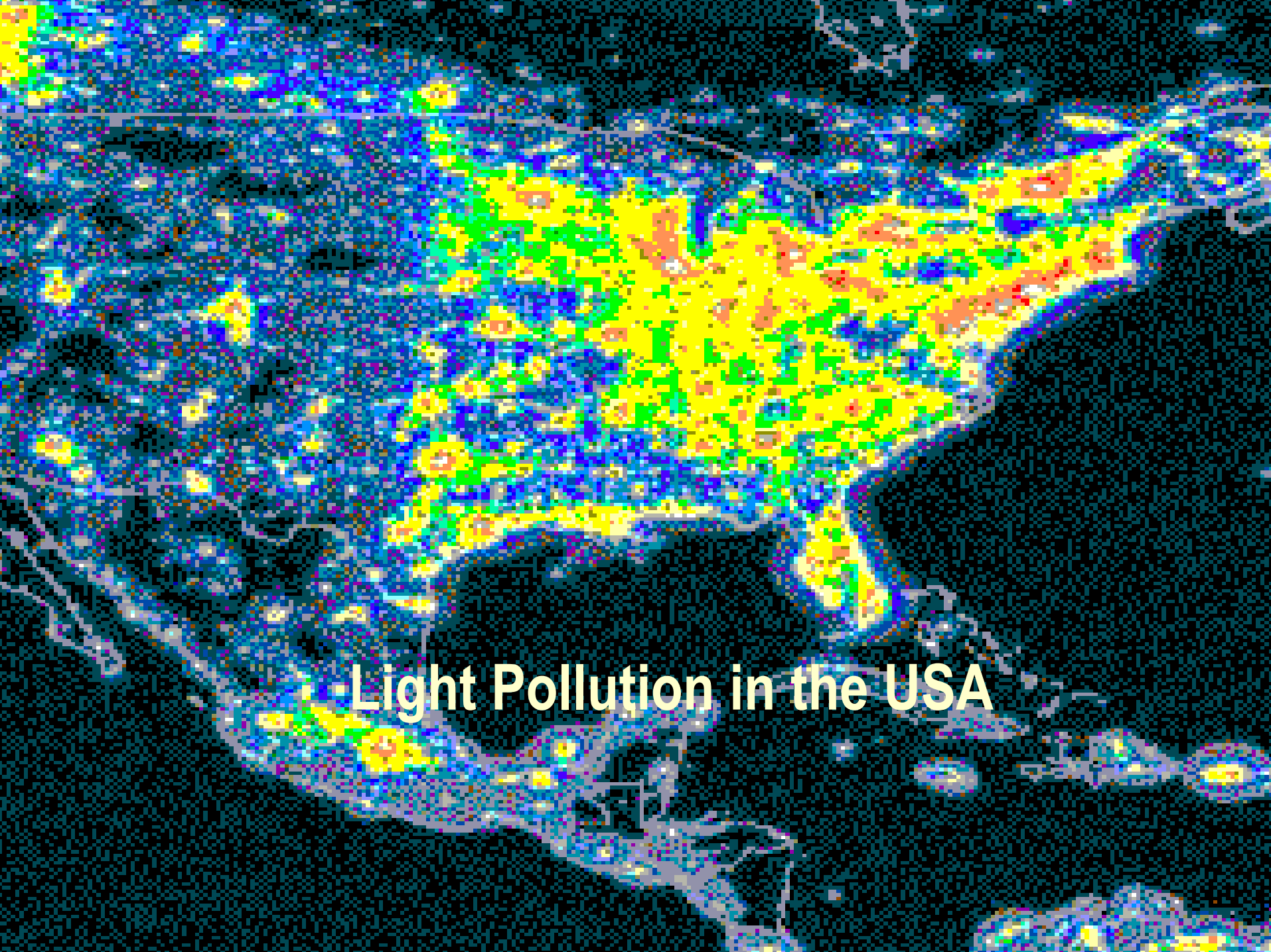
- Provide scientific analysis and test data to
 - ◆ Assist the National Telecommunications and Information Administration (NTIA) and the Federal Communications Commission (FCC) in making informed decisions regarding UWB regulations that affect portions of the frequency spectrum essential to public safety and science.
- NASA expects the test results to become a valuable resource to private industry and to other Government agencies.
 - ◆ The study and results will be available as an openly published, peer-reviewed product.



Optical Effects of Single Light Source

Effects of Multiple City Light Sources





Light Pollution in the USA

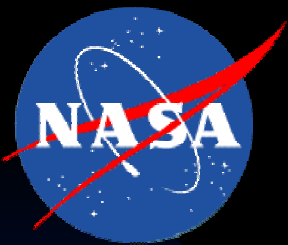


***L and S Band Measurements of
Ambient
and Man-made Noise***



Noise Floor Measurements Objectives

- At sites of operational significance to GPS, measure the radio environment in the GPS L1 frequency band.
- Measure the radio environment at sites of operational significance to Unified S-Band users.
- Measure the radio environment at sites of operational significance to users of the ISM band at 2.4 GHz.
- For all measurements, compare with theoretical values for thermal noise (kT) and identify site-to-site trends.



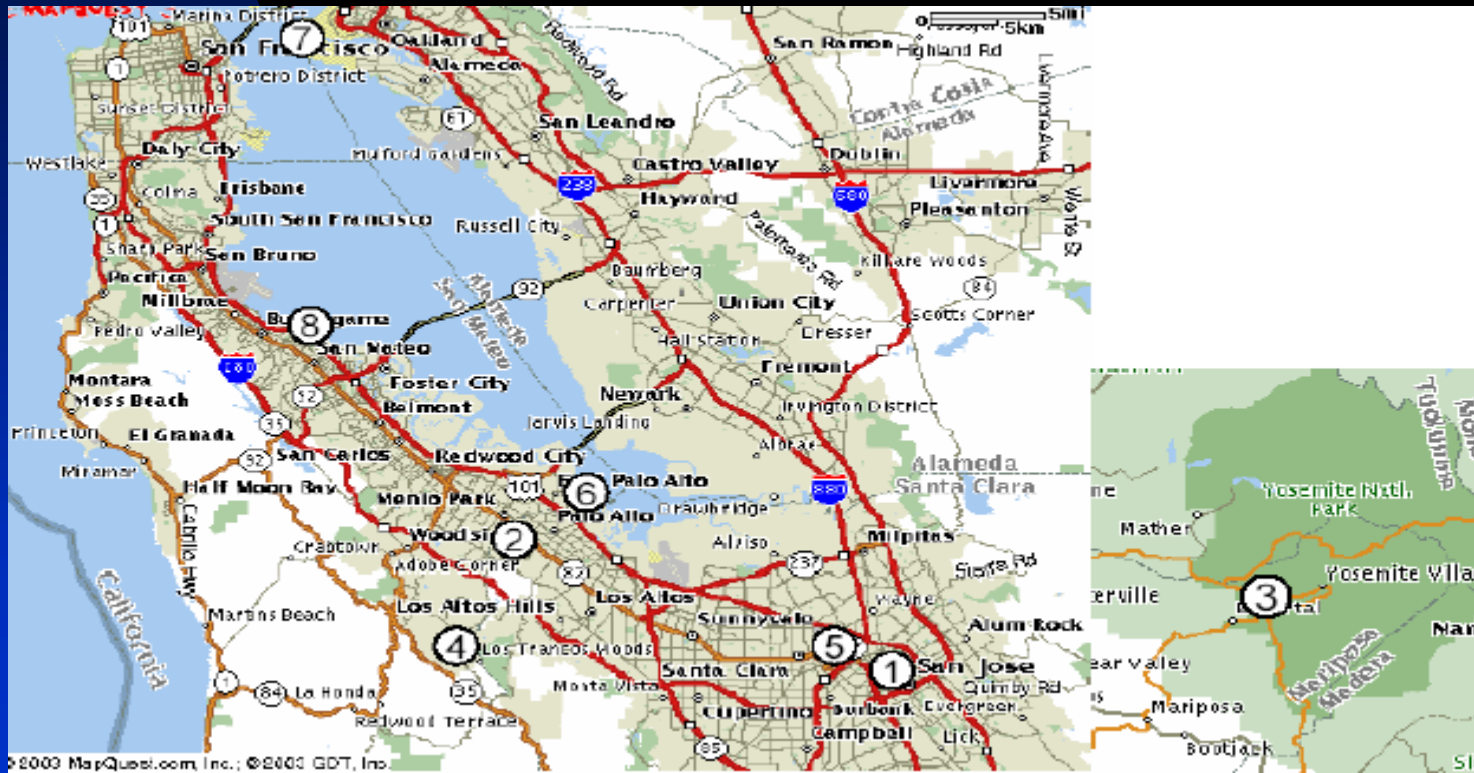
Measurement Bands

Band	Center Frequency [MHz]	Bandwidth [MHz]	Allocation	Regulatory Part
GPS L1 band	1575.42	24	Aero-RadioNav Radionav-Sat	Aviation Part 87
Unified S band	2067.5	85	Space Science Aux Broadcast	Part 74F, Part 78, and Part 101J
ISM 2.4 GHz band	2441.75	83.5	Fixed & Mobile Radiolocation Amateur	Part 18 and Part 97



Measurement Sites

1. San Jose Downtown
2. Palo Alto Downtown
3. Yosemite Park
4. Jasper Ridge Preserve
5. San Jose Airport
6. Palo Alto Airport
7. Port of Oakland
8. Coyote Point Marina





Average Measured Power

Site Category	Measurement Site	GPS L1 Band			Unified S Band		ISM 2.4 GHz Band	
		HOR	VER	GPS	HOR	VER	HOR	VER
Urban	San Jose Downtown	-111.0	-111.7	-112.0	-109.2	-107.9	-83.1	-84.4
	Palo Alto Downtown	-111.5	-110.7	-111.2	-111.4	-110.6	-92.2	-89.8
Rural	Yosemite Park	-112.1	-112.3	-112.5	-111.8	-111.9	-85.1	-82.5
	Jasper Ridge Preserve	-112.1	-112.3	-112.2	-111.7	-111.9	-97.1	-100.8
Airport	San Jose Airport	-112.5	-113.4	-112.8	-77.4	-75.9	-82.2	-89.8
	Palo Alto Airport	-112.3	-112.7	-112.5	-112.0	-112.4	-92.5	-101.7
Harbor	Port of Oakland	-112.9	-113.3	-112.9	-106.9	-101.7	-87.6	-78.7
	Coyote Point Marina	-111.9	-112.2	-112.3	-110.9	-111.4	-88.8	-80.8

* Note: 'HOR', 'VER' and 'GPS' in the table each represent the power measurement by a horizontally polarized horn antenna, a vertically polarized horn antenna and a GPS antenna.

* Note: All numbers are in dBm/MHz.



Percentage of Man Made Signals in Measurement Data

Site Category	Measurement Site	GPS L1 Band			Unified S Band		ISM 2.4 GHz Band	
		HOR	VER	GPS	HOR	VER	HOR	VER
Urban	San Jose Downtown	0.01	0.01	0.01	1.35	1.67	6.08	4.50
	Palo Alto Downtown	0.00	0.02	0.01	0.01	0.06	4.35	3.58
Rural	Yosemite Park	0.00	0.00	0.00	0.00	0.00	0.62	0.78
	Jasper Ridge Preserve	0.00	0.00	0.00	0.00	0.00	2.64	3.67
Airport	San Jose Airport	0.01	0.00	0.00	6.45	8.71	17.12	26.73
	Palo Alto Airport	0.00	0.00	0.00	0.00	0.01	13.68	10.22
Harbor	Port of Oakland	0.00	0.01	0.00	2.23	2.77	34.37	43.30
	Coyote Point Marina	0.00	0.00	0.00	0.40	0.30	7.10	22.31

* Note: All numbers are in percentage (%) and represent the measurement data exceeding the distribution of the natural noise power.



Measurements Summary

- **GPS L1 Measurements**
 - ◆ Total power measured at all sites was not significantly greater than natural radiation
- **Unified S-Band**
 - ◆ Used by NASA for TT&C and broadcasters for TV field operations
 - ◆ Urban areas exhibit increased man-made contributions
- **ISM 2.4 GHz Band**
 - ◆ Used for microwave ovens and unlicensed wireless services such as LAN's and cordless telephones
 - ◆ Man-made signals significantly contribute to the noise floor at all sites



Measurements of the Effects of UWB Devices on Aeronautical Radios

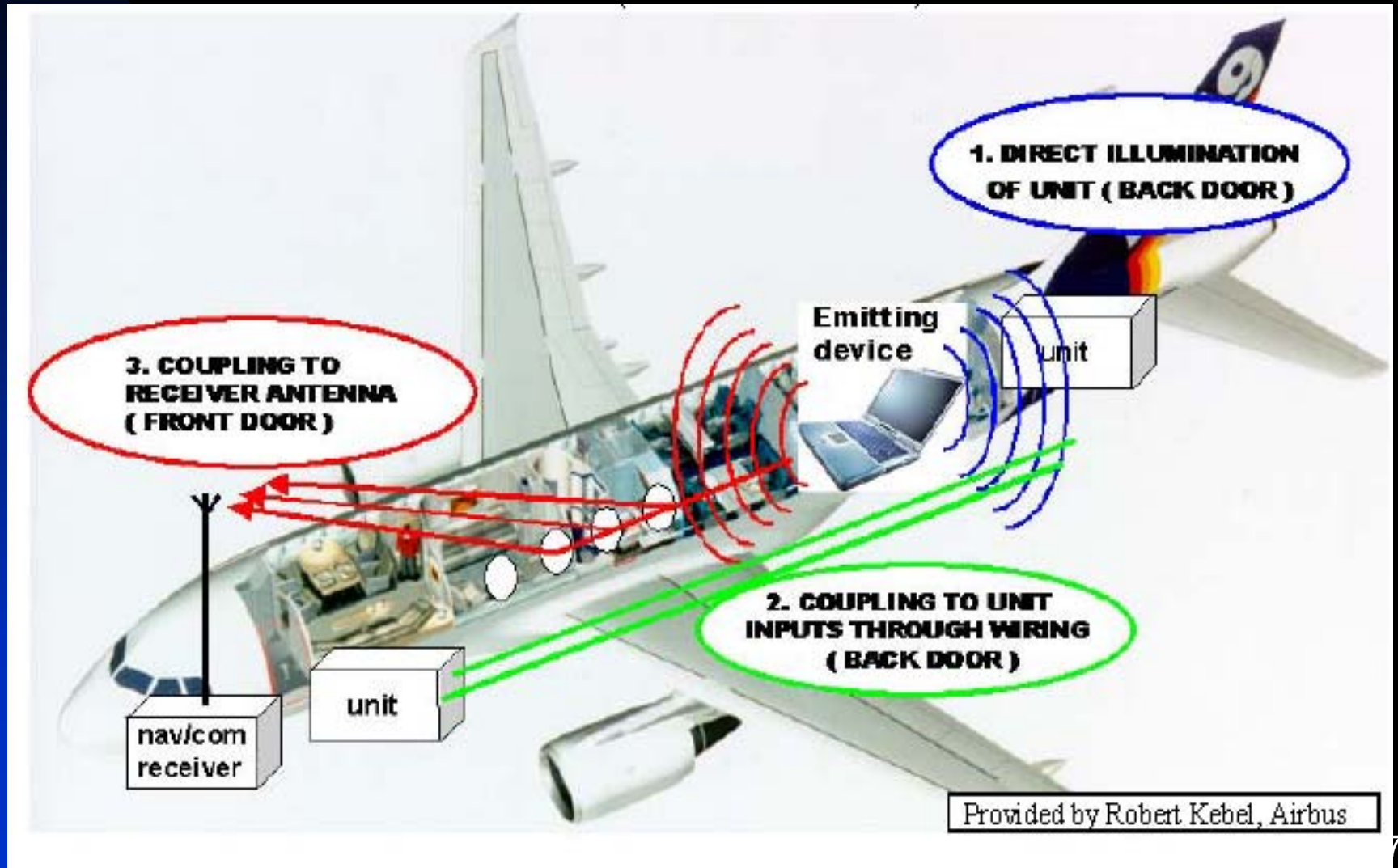


Why Should I Care?





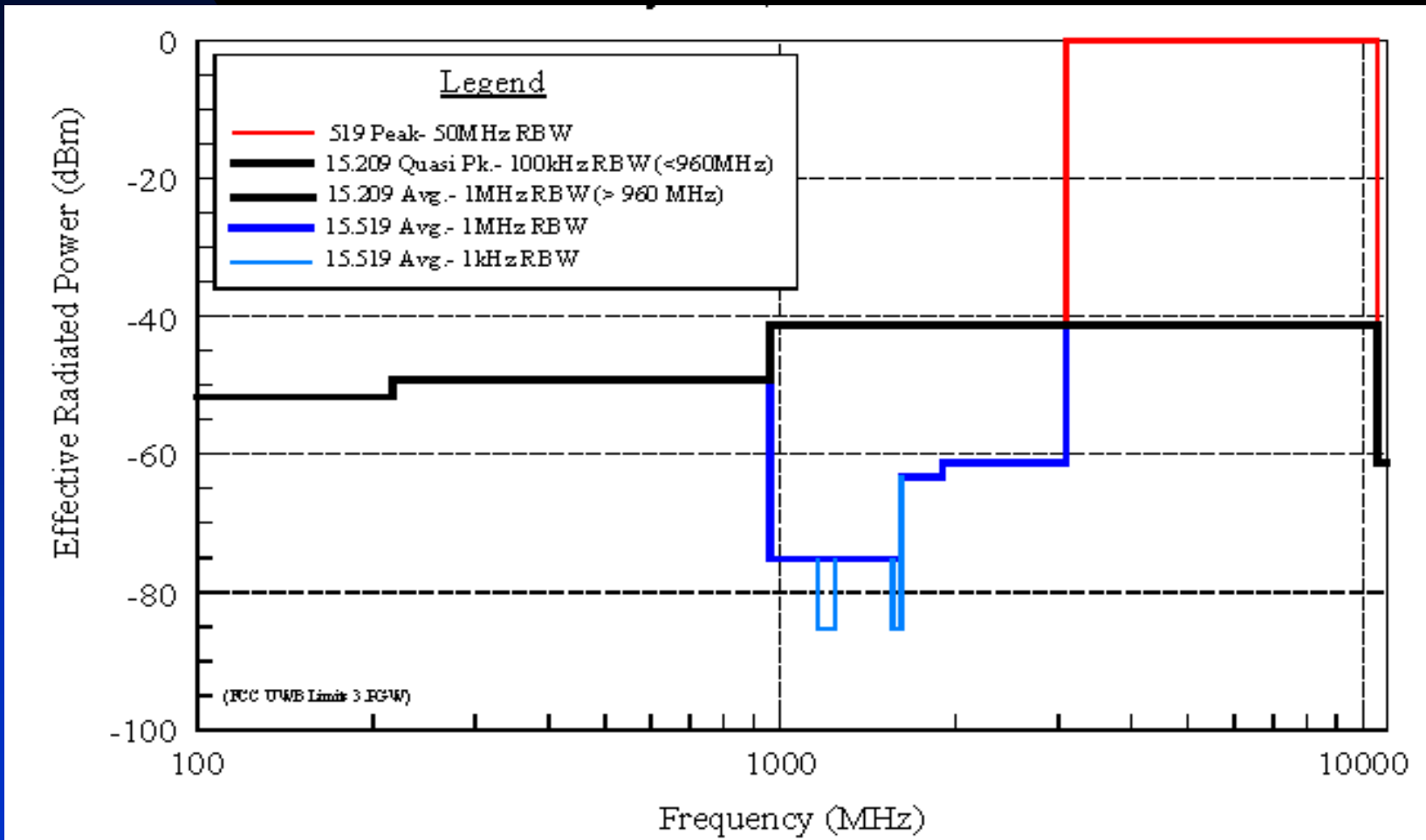
Device Coupling to Aircraft Systems





FCC UWB Radiated Emission Limits

Handheld Systems, 100 MHz to 10.6 GHz





Previous UWB/Aircraft Testing

- Aircraft
 - Boeing 747-400
 - Boeing 737-200
- Radio Systems
 - Limited ATC, TCAS, LOC, GS data
 - Unusable GPS, SATCOM, VOR, VHF Comm data
- Clearly Identified the Need for More Detailed Testing

NASA/TM-2002-211949



Ultrawideband Electromagnetic Interference to Aircraft Radios

Results of Limited Functional Testing With United Airlines and Eagles Wings Incorporated, in Victorville, California

*Jay J. Ely
Langley Research Center, Hampton, Virginia*

*Timothy W. Slaver
United Airlines, Indianapolis, Indiana*

*Gerald L. Fuller
Eagles Wings Incorporated, Mariposa, California*

Report available at:

<http://techreports.larc.nasa.gov/ltrs/PDF/2002/tm/NASA-2002-tm211949.pdf>

October 2002



Objective of Previous Efforts

- **Objective of This Work:**

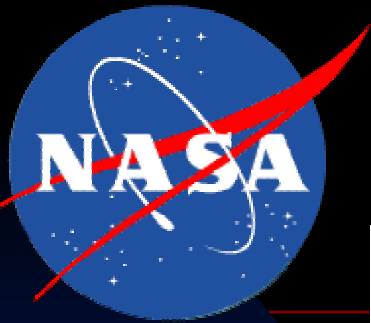
- To implement and report a comprehensive series of tests aimed at determining the nature and extent of any interference to operational aircraft communication and navigation systems from UWB devices meeting FCC-approved and proposed levels for unlicensed handheld transmitters.

NASA Partnership:



Funding:

- NASA Aviation Safety Program
- NASA Headquarters Office of Space Flight
- United States Department of Transportation
- United and Sky West Airlines provided aircraft and facilities.



Aircraft Types and Radio Systems

VHF/UHF

Systems

3/17/03 to 3/24/03
8/5/03 to 8/14/03

L-Band

Systems

2/17/03 to 2/22/03
5/27/03 to 6/4/03
8/5/03 to 8/14/03

- VOR 108-118 MHz VHF OmniRange
- LOC 108-112 MHz ILS Localizer
- VHF-Com 118-138 MHz VHF Communications
- GS 329-335 MHz ILS Glideslope
- ATC 1030 MHz Air Traffic Control Radio Beacon Transponder
- TCAS 1090 MHz Traffic-Alert and Collision Avoidance System
- DME 962-1213 MHz Distance Measuring Equipment
- GPS 1575.4 MHz Global Positioning System
- SATCOM 1530-1559 MHz Aeronautical Mobile Satellite Communications



Airbus 319/320



Boeing 747-400



Embraer 120



UWB/Aircraft Test Findings

- Aircraft radios operating **below** 960 MHz:

Aviation Radio Interference Occurred *At and Below* UWB Levels Allowed by the FCC (15.209 limits)

- Systems affected: VHF Com, VOR, ILS Localizer, ILS Glideslope
- Video of UWB EMI effects
- Test conditions where interference occurred:
 - Handheld UWB devices operated 1 meter from aircraft antenna.
 - Handheld UWB devices operated in the passenger cabin.



UWB/Aircraft Test Findings

- Aircraft radios operating **above** 960 MHz
Aviation Radio Interference Occurred *Above* UWB Levels Allowed by the FCC (15.519 limits)
 - Interference margins would be adversely affected if FCC limits are increased.
 - Systems Affected: DME, ATC, TCAS, GPS, SATCOM
 - Video of UWB EMI effects.



UWB/Aircraft Test Findings

- **UWB modulation cannot be assumed to reduce the likelihood of harmful interference**
 - If modulation is present upon UWB device spurious radiated emissions when the devices are tested according to FCC 15.209 limits, no further reduction of on-channel power caused by modulation can be assumed. In fact, the presence of modulation on UWB spurious radiated emissions would only guarantee channel overlap within aeronautical radio frequency bands.
- **Multiple UWB PRF selections shown to be detrimental to aircraft radios.**
 - Lower PRFs produce more spectral lines with higher probability of overlap with aircraft frequency channels
 - EMI effect is usually dependent upon UWB signal amplitude in aircraft channel passband
- **These tests represent the first experimental field evaluation of aeronautical radio susceptibility to PED spurious emissions at allowable FCC limits.**
 - RTCA SC-202
 - Aviation Security



Simultaneous EMI to Multiple Radio Systems

- **UWB PRFs can be found that place strong interference on multiple system frequencies/channels that could cause simultaneous effects on systems such as VOR, LOC, GS and VHF Com.**
- **If strong enough, EMI from PEDs can interfere with all parallel redundant aeronautical radio systems if they emit significant signals overlaying a particular aircraft radio channel.**
- **Degradation of some L-band COM/NAV systems propagate (often unnoticed) into other systems, affecting their performance.**
 - **ATC beacon failure, resulting in TCAS target loss/failure**
 - **GPS degradation/failure causing Enhanced Ground Proximity Warning System (EGPWS) to degrade or provide false warning indications. “Pull up” warning falsely given due to GPS EMI interference.**
 - **GPS degradation/failure causing the SATCOM to revert to a lesser capacity mode of operation.**



Hidden Performance Impairment Due to EMI

- **COM/NAV system performance degradation effects can occur up to and including system failure on some aircraft systems without the flags, annunciators, or system status displays changing to indicate system failure or loss of capability.**
- **Some systems (especially satellite systems: GPS and SATCOM) have their function status virtually transparent to the crew on most airplanes.**
 - **A wide variability of status information and detailed data available to the crew exists among the aircraft tested. In some cases, less information is provided to the crew in flight than when using special display modes that are available to maintenance personnel during ground testing.**
- **ATC beacon transmitter stops transmitting on all modes.**
 - **By using ATC ramp test sets during interference testing, some system performance degradation could be detected at EMI levels far below when any flight instrumentation or warning system indication occurs.**
- **TCAS targets disappear without any flags, annunciation or status change.**



Evolution of PED's and CNS EMI

PED Technologies

Today

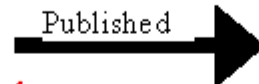
Mobile Phones
(AMPS, IS-95 CDMA, GSM)
IEEE 802.11a, b, g
Bluetooth
FRS/GMRS Radios

Tomorrow

Mobile Phones- (3G, 4G)
UWB
(Wireless USB, IEEE 802.15.3)
Software defined Radio
Cognitive Radio
MIMO Systems
Noise Temperature
??

Interaction?

Some Data
Published



Some
Work in
Progress



CNS Technologies

VHF Com	DME
VOR	ATC
LOC	TCAS
GS	GPS L1
	SATCOM

VHF Com+ (VDL: ADS-B, LAAS, CPDLC, NEXCOM, TIS-B)
UAT (ADS-B, FIS-B)
1090 MHz Extended Squitter (ADS-B)
GPS L5, L2
SATCOM+ (ADS-B, Swift 64, other INMARSAT, ?)
Airborne Internet
(Connexion, AeroSat, Airfone, AirCell, JetConnect, Sirius, XM, EFB, IRIDIUM, etc.)



Current In-Flight Testing

- NASA is currently conducting in-flight testing of a Boeing 747 for susceptibility of its avionics to UWB emissions in cooperation with:
 - ◆ United Airlines,
 - ◆ Eagles Wing Inc.
 - ◆ Department of Transportation
 - ◆ Federal Aviation Administration



Measurements Program Summary

- NASA Noise Floor and UWB Effects Program initiated in response to growing trend for new and untested wireless communications devices.
 - ◆ Many of which will be unlicensed.
- Program of ambient noise measurements expected to be continued as results are assimilated.
- Current UWB/Aircraft avionics measurements are being conducted using operational in-flight B-747.
- Program reports will be made public when efforts are completed.



Questions ?