An Interference Avoidance Waveform for the UHF Downlink on the New NOAA GOES-R Satellite

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Presentation Outline

- Introduction
- Interference Profile
- NOAA Waveform Requirements
- Interference Avoidance Waveform
- Simulation Results
- Project Status

Introduction

- November 19, 2016

– GOES-R Launch

– ULA ATLAS V vehicle

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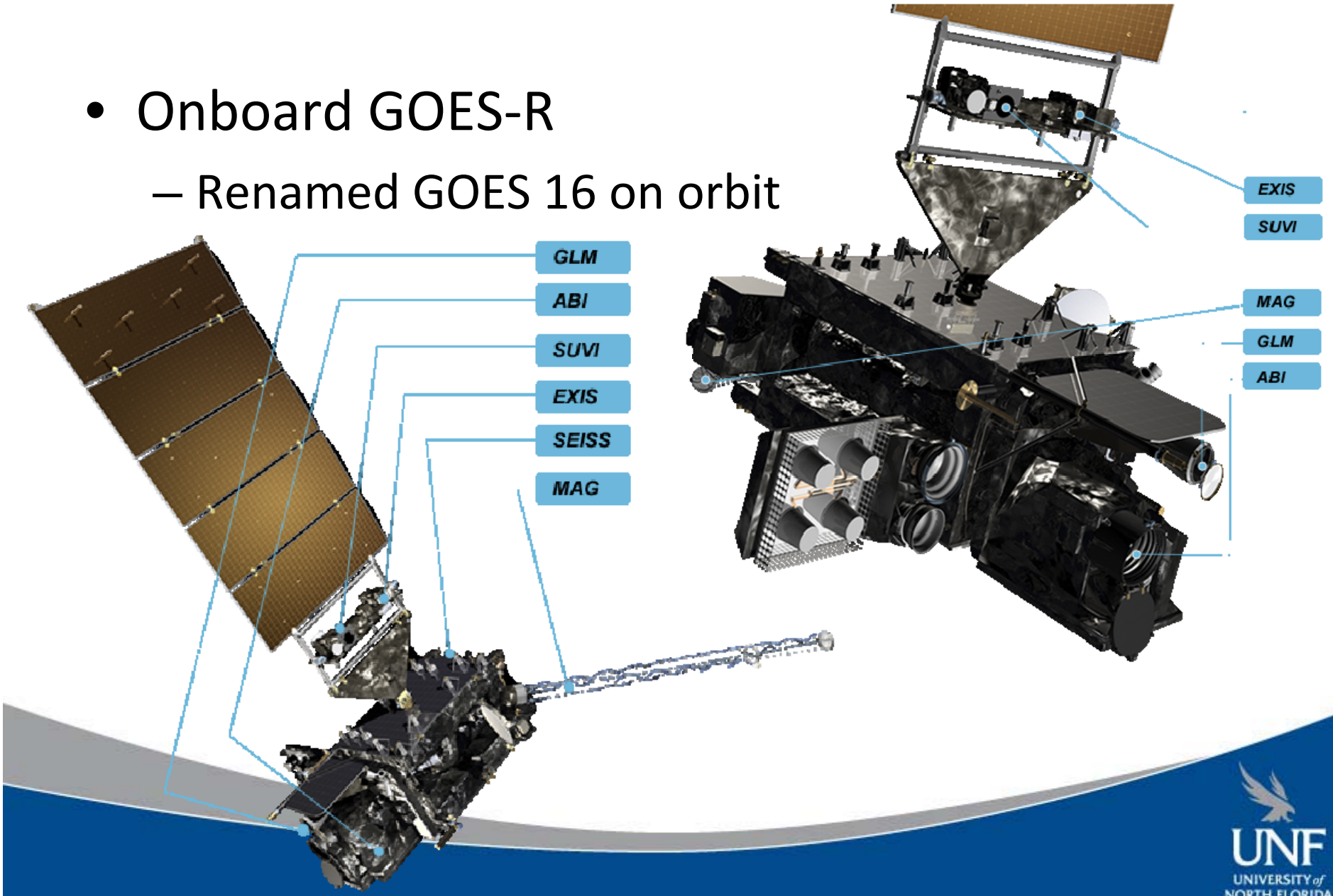
Introduction

- Onboard GOES-R
  - Renamed GOES 16 on orbit



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Introduction

- GOES-16 Ground Segment

NSOF Suitland MD, and

WCDA Wallops Island, V

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Introduction

- NOAA Data Collection System
  - Established 1974, on all GOES satellites
  - One-way transmission of environmental data
  - FDMA/TDMA with GPS timing reference
  - 300 or 1200 bps data using 8-PSK, rate 2/3 TCM, with scrambling and interleaving (150/600 coded sps)
  - 10 second time slots for self-timed messages
  - 500 reply channels at 401-402 MHz, 750Hz apart
  - GOES East monitors odd channels
  - GOES West monitors even channels

Introduction

- NOAA Data Collection System
  - ~25000 deployed Data Collection Platforms (DCPs) in western hemisphere
  - Europe, India, China and Japan operate similar systems

- Bridge mounted DCP in Florida

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Introduction

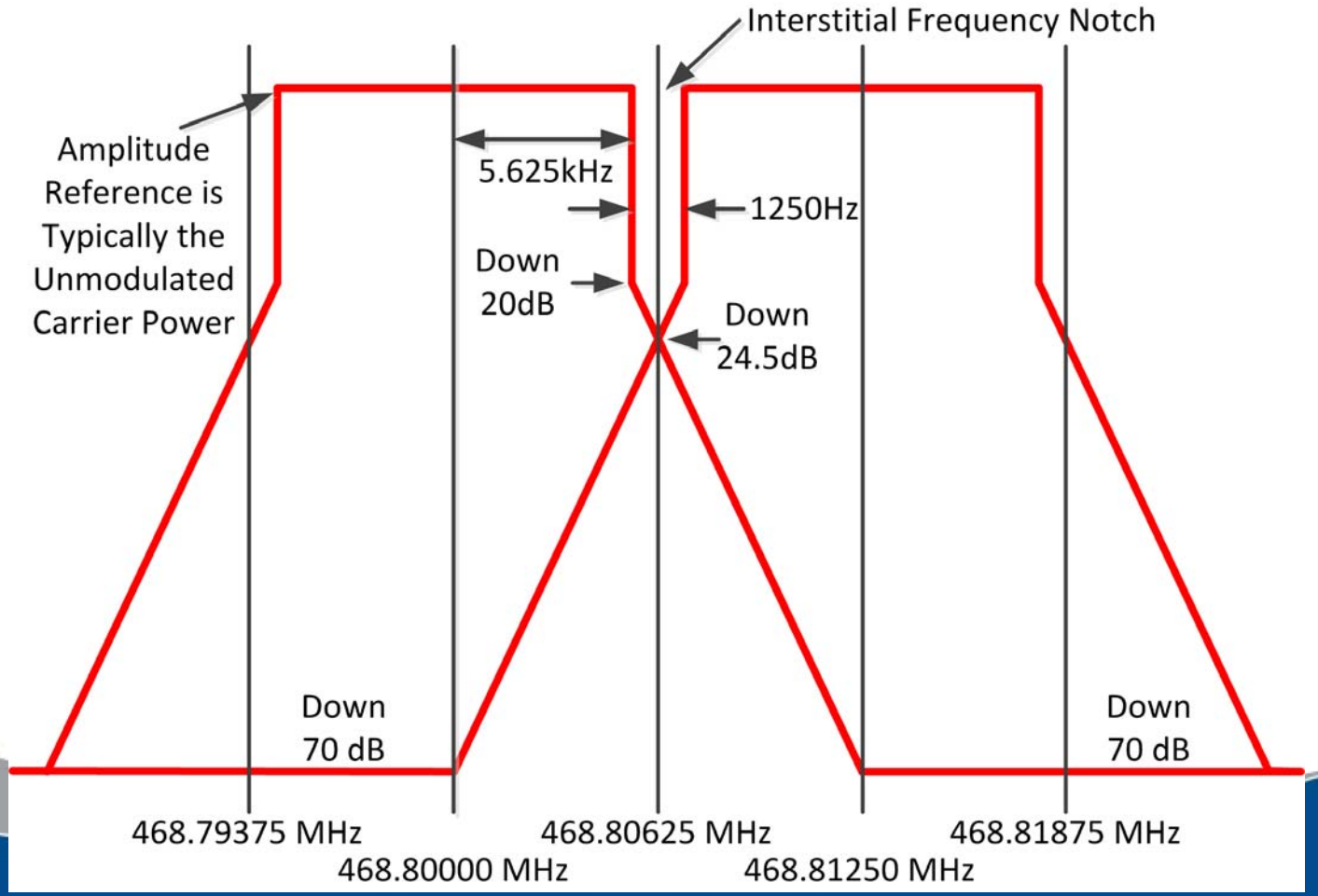
- Two-way comms with DCPs is now possible
- GOES 16 has a new S-Band/UHF transponder to send commands to DCPs
- Assigned frequency is 468.8MHz +/- 50kHz
- NOAA use is “secondary” to commercial LMR radio systems on the same frequency
- Same frequency range is used by LMR mobile and portable subscriber units that typically transmit up to 50 Watts (for mobile units)
- The GOES 16 UHF TX transmits ~100 Watts EIRP

Interference Profile

- To the NOAA DCP command channel, the LMR signals are “interference”
- Two main types of LMR signals:
  - Analog NBFM in ~11kHz BW
  - Digital Mobile Radio (DMR) in 7.6kHz (4800 sps 4FSK with RRC pulse shaping)
- LMR channels at 468.8MHz are for industrial and business use
- LMR systems are coordinated into channels that are 12.5 kHz apart

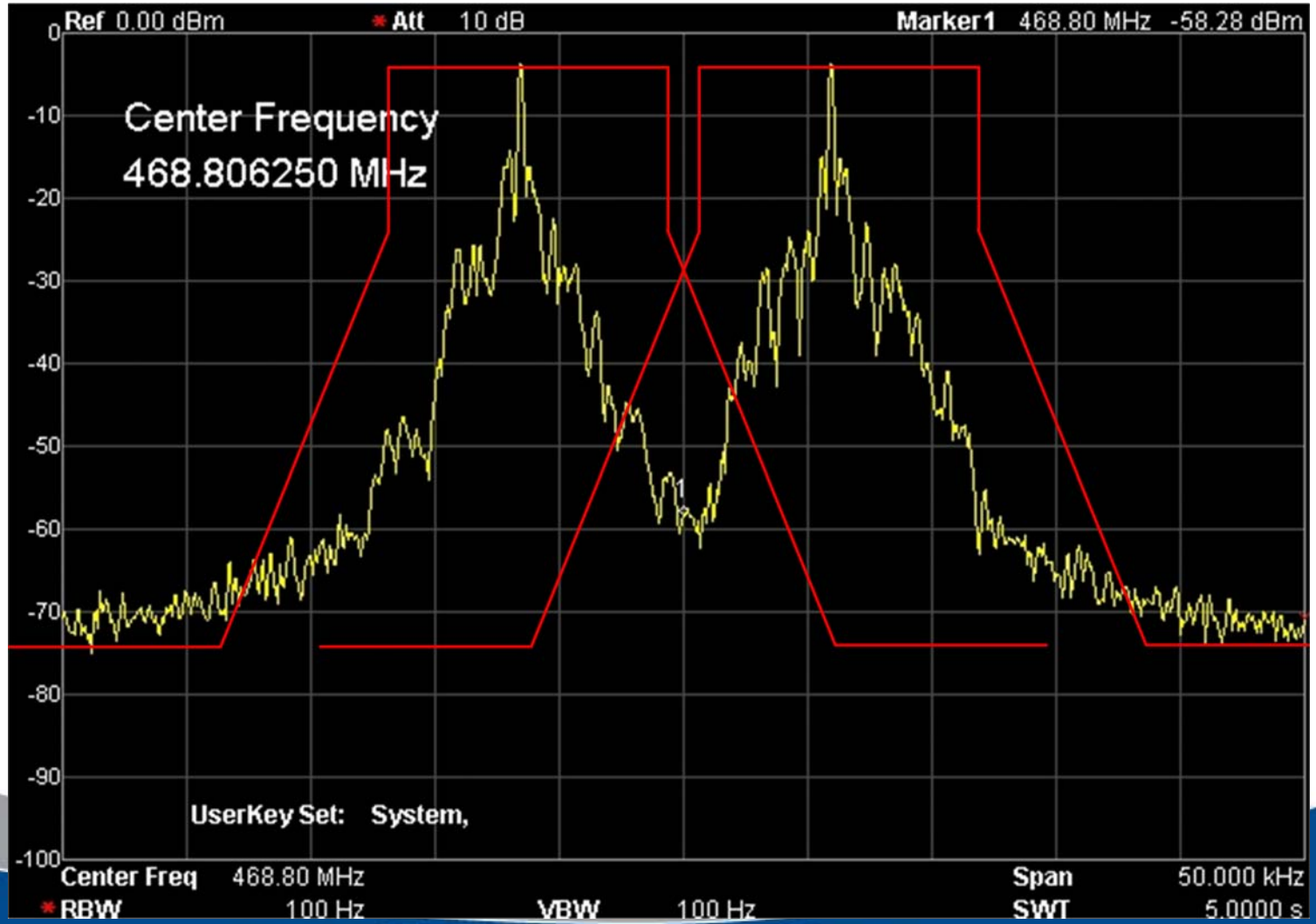
Interference Profile

- LMR signals must conform to an emission mask (Emission mask D for 12.5kHz spacing)



Interference Profile

- Emission masks with 2 NBFM LMR signals



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Interference Profile

- In the 100 kHz centered at 468.8 MHz that NOAA will use, there are 9 LMR 12.5 kHz channels
- Using busy hour radio usage probabilities we can estimate how often the 100kHz will experience “interference” from LMR users
- Two sets of studies available for usage data
  - FCC circa 1980 national study
  - Illinois Institute of Technology 2008 Chicago study
- Rough average busy hour probability of 14%

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Interference Profile

- Probability of having an active LMR signal in the 100kHz at 468.8 MHz, during the busy hour

Number of Active Land Mobile Channels	Number of Licensed Channels in a Particular Location								
	9	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*
At least 1	74.3	70.1	65.2	59.5	53.0	45.3	36.4	26.0	14.0
At least 2	36.6	31.1	25.6	20.0	14.7	9.7	5.3	2.0	
At least 3	12.0	8.9	6.2	3.9	2.2	1.0	0.3		
At least 4	2.7	1.7	0.9	0.5	0.2	0.0			
At least 5	0.4	0.2	0.1	0.0	0.0				

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Interference Profile

- For a given location it is possible to determine how many LMR systems are licensed by searching the FCC license database
  - Urban locations have more licenses
  - Rural locations have fewer licenses
- In the US there are over 8000 licensed LMR systems on the 9 LMR channels centered at 468.8 MHz, representing roughly 400,000 subscriber units (w/ avg 50 units per system)

NOAA Waveform Requirements

- A DCP command waveform must meet certain requirements:
  - Power flux density at earth's surface (per NTIA)
    < -152dBW/m^2/4kHz
  - Desired bit rate of 200-400 bps at 10^{-6} BER
  - Support for a 2 satellite constellation (GOES east and GOES west)
  - 100 kHz transponder BW
  - Transponder supports RRC with 1.0 roll-off factor

Interference Avoidance Waveform

- Slow, Frequency-Hopped, Spread-Spectrum
- Exploit the ~40 dB interstitial notch between 12.5kHz LMR channel assignments
- There are 8 notches in the 100kHz BW at 468.8MHz
- If no LMR signal is transmitting, the notch and surrounding spectrum are clear

Interference Avoidance Waveform

- Use all 8 notches with a sequential hop pattern
- Keep command channels for GOES east and GOES west on different notches
- Initial test modulation is BPSK at 200 sps (move to QPSK after initial testing)
- Hop time is 0.1 second (chosen to match FCC rules regarding LMR FHSS requirements)
- 20 BPSK symbols per hop
- RRC with 1.0 roll-off factor
- Notch BW controlled by modulation, not hop speed

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Interference Avoidance Waveform

- Transmitter sync'ed to GPS
  - Data, hop pattern, and carrier frequency sync'ed
  - Includes offset adjustment for average propagation delay through GOES satellite
  - TX bits and hop patterns are sync'ed with clock
  - 200 bps, 10 hops/sec, 5 8-hop patterns/4sec
- DCP command receivers have GPS
  - Know their location and they know the time
  - Can correct for propagation delay
  - Know when hop starts within < 5% of symbol time

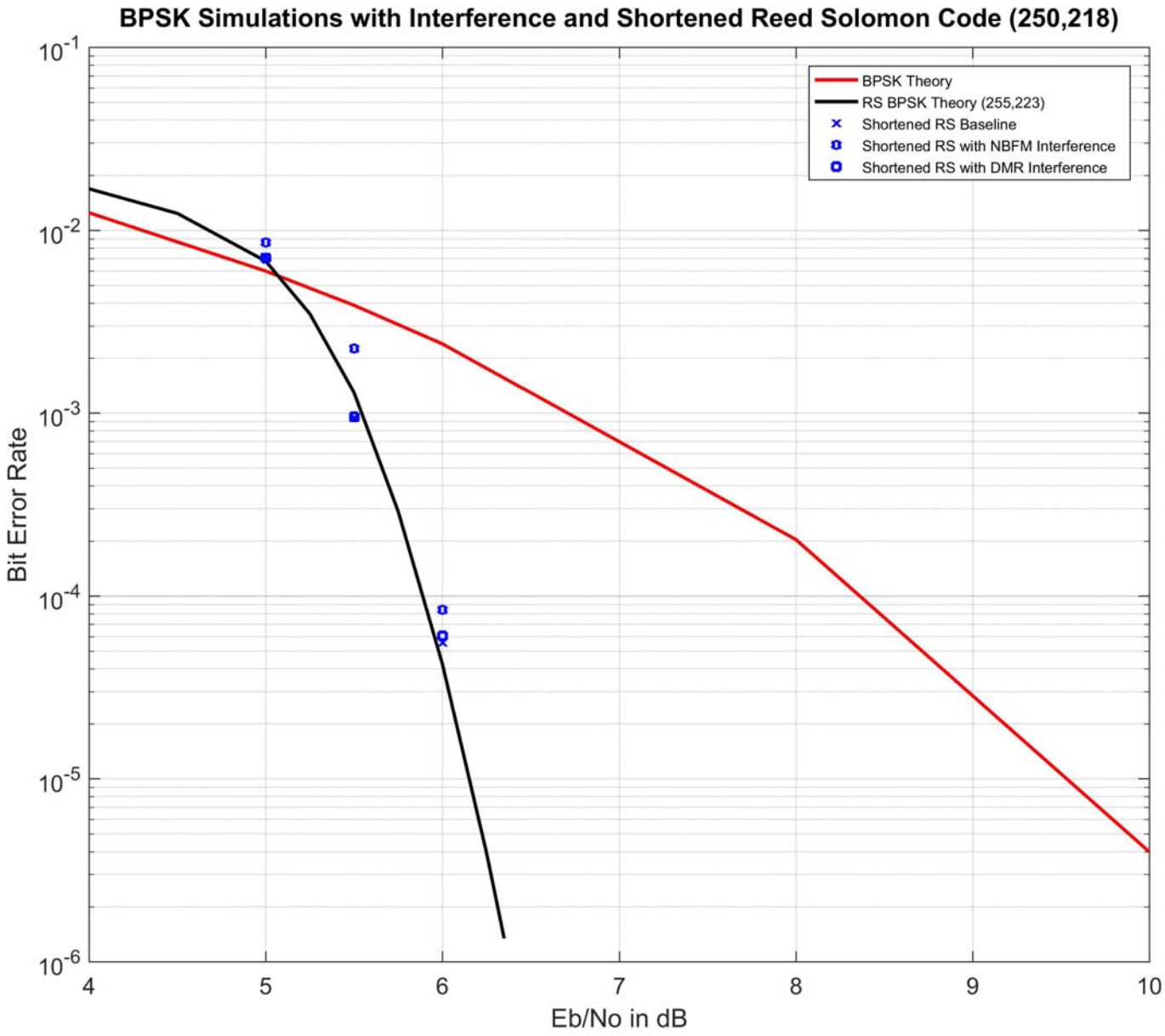
Interference Avoidance Waveform

- DCP command receivers can be coherent
  - GPSDO for received carrier frequency accuracy
  - DDS Frequency synthesizers
  - 2-3 stage receiver w/ commercial IF (e.g. 455kHz)
  - Modified Costas carrier tracking loop maintains frequency lock through hop changes
  - Very small freq/phase step at hop boundary that is within loop BW, also no cycle slipping
  - Carrier tracking loop uses RRC filters with initial sample times from GPS soft lock. Enhanced with bit sync hard lock. Optional LP filters for searches

Interference Avoidance Waveform

- Reed Solomon block code is included for potential burst errors when hopping next to an interference signal
- Standard (255,223) RS code shortened to (250,218) to permit GPS-based frame sync
  - 2000 coded bits per RS frame
- Assuming a coded symbol rate of 200 sps, RS frames are sent at 10 second intervals

Simulation Results



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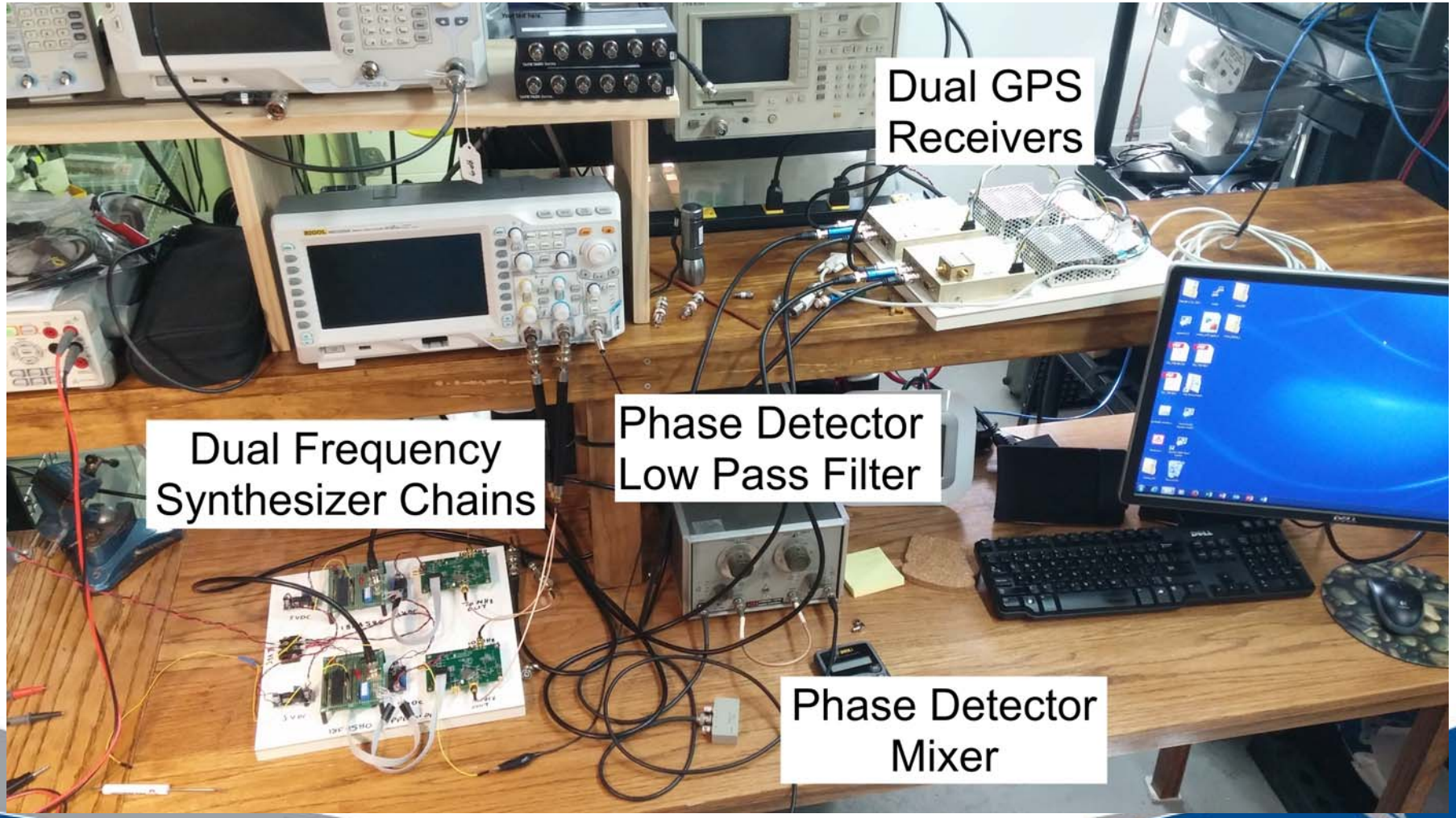
Project Status

- Development of test transmitter is complete
- Development of system monitoring receiver is underway
  - Coherent hop sync concept tested with parallel DDS platforms
  - Receiver is being developed using an ARM microcontroller (TI TM4C123G)

Project Status

- Coherent hop sync test stand



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