Spectrum Technology Assessment
Test Range Spectrum Challenges

Mr. Derrick Hinton

Principal Deputy Director

Test Resource Management Center

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Topics of Discussion

- RF Spectrum Demand Drivers
- RF Spectrum Current Environment
- RF Spectrum Encroachment
- Initiatives & Investments
- Way Ahead
- Assessment of DoD T&E Spectrum Efficient Technology Efforts
- Summary

Game-Changing Technologies

Adaptive EW

Autonomy

Hypersonics

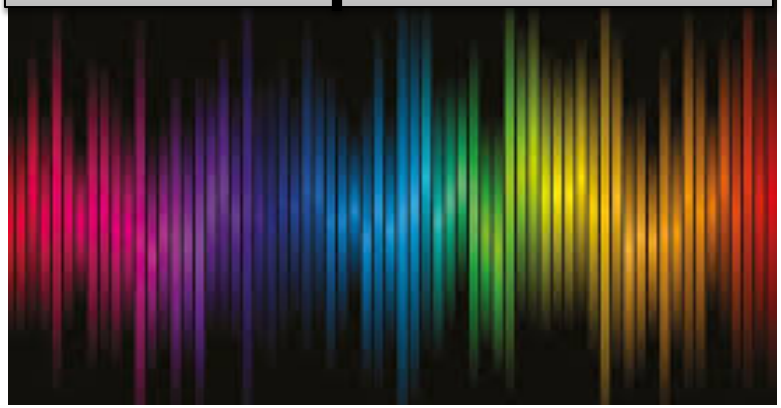
Boost Glide Vehicles

- Game-changing technologies
- Changing warfighting environment
- Increased RF spectrum demand

Game-Changing Challenges

Big Data

RF Spectrum

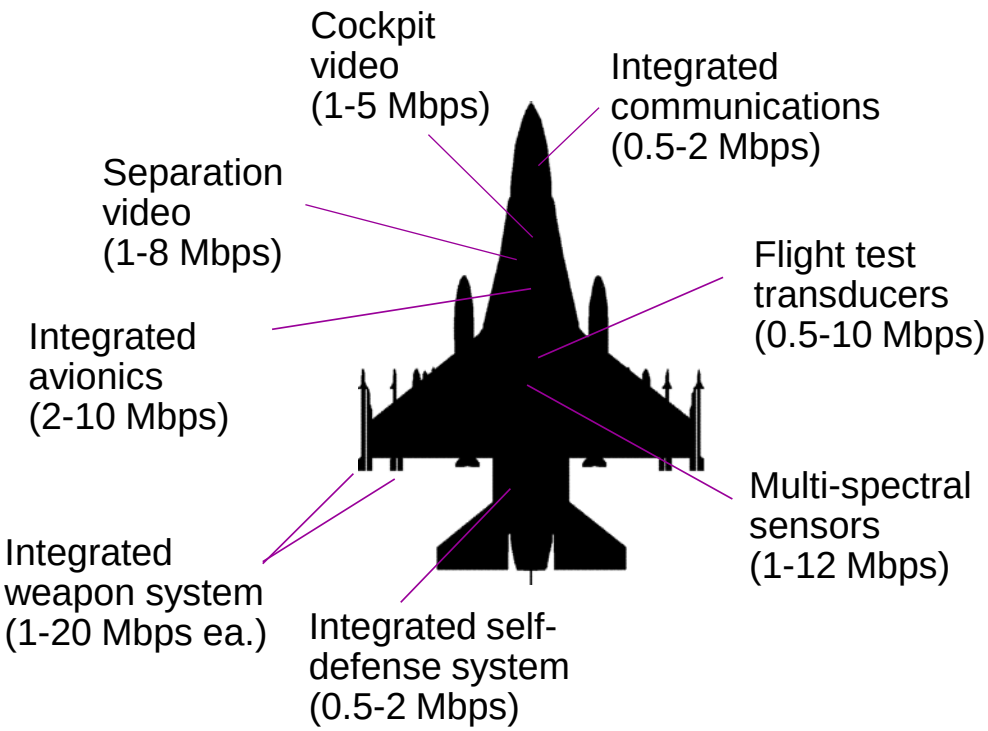


Cyber Security

- Game-changing challenges
- Changing T&E environment
- Better cyber security measures
- More robust, rich, dense RF spectrum environment
- Increased RF spectrum demand

What Drives Demand for Spectrum in Test?

Increased System Complexity

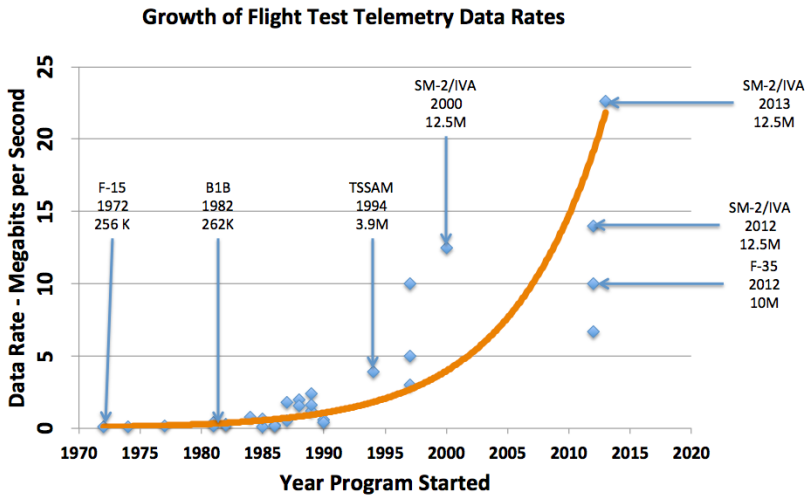


- **Larger Footprints**
  - 4-on-4 test flights (more systems per test)
  - Much faster weapons systems
  - Geographic separation not as effective as it used to be
- **Demand for Shorter Acquisition Cycles**
  - More concurrent testing
  - More real-time analysis
- **Increased System-of-Systems Test Complexity**
  - "Five Futures" (EW, UAV, NCO/W, DE, Hypersonics)
  - Integrated fleet (F-18E/F, E-18G, F-35, SM VI, UAV)
  - Future Combat Systems
  - "Swarming" UAVs

Increasing Data Rates

Factors driving increasing data rates:

- Increasing complexity of weapons
- Increasing pixel density in sensors
- Increasing test complexity
- Increasing use of high-resolution real-time video



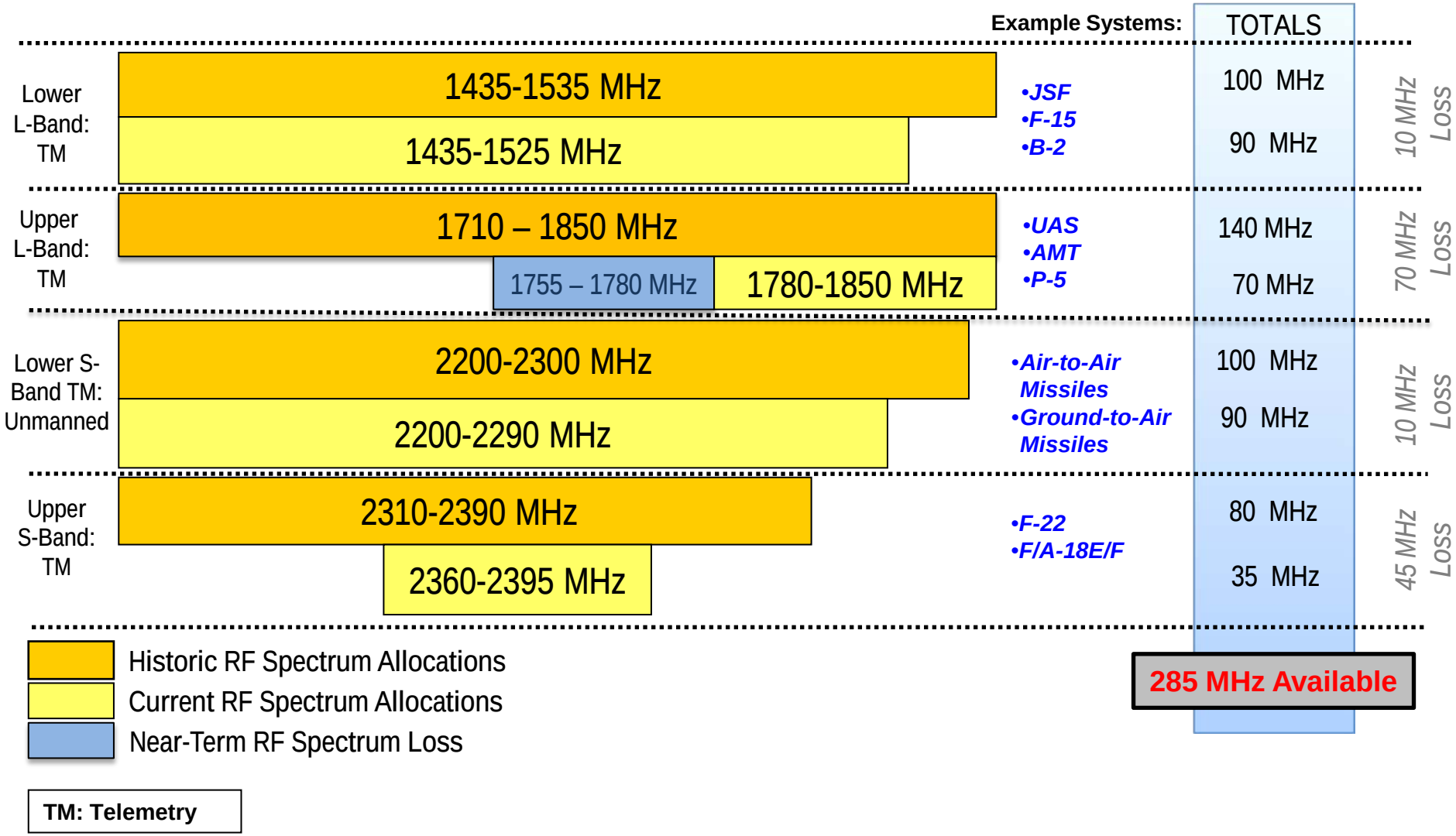
1986: *F-15*

- Data Rate: 256 Kilobits per second (Kbps)
- Transducer data
  - 20 samples/sec
  - Some pre-processing
- Avionics bus data

2012: *F-35 (Atlantic Test Range)*

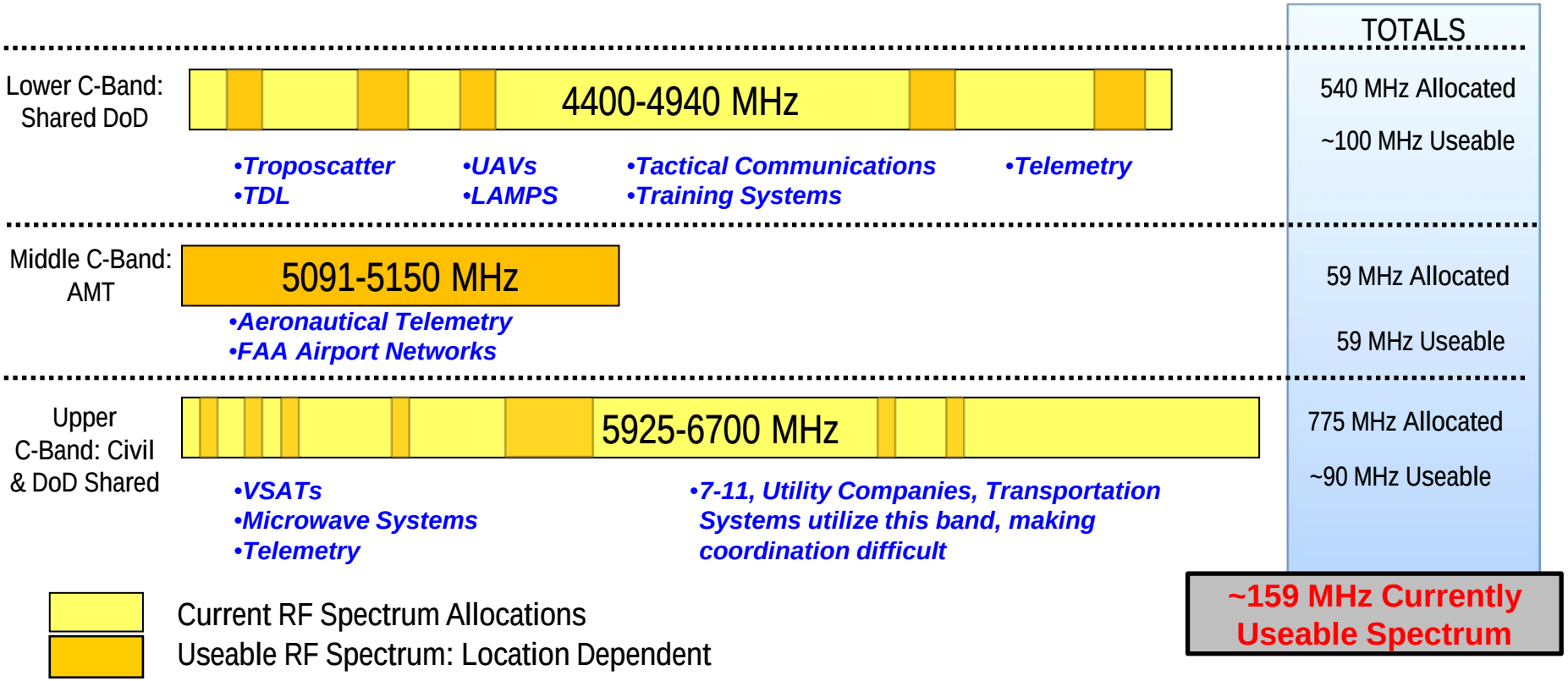
- Data Rate:
  - 7.5 Megabits per second (Mbps) Link 1 (TM)
  - 5 Mbps Link 2 (Video)
- Transducer data
  - 10,000 samples/sec
  - No pre-processing
  - Increased redundancy
- Avionics bus data - Fiber
- Panoramic Cockpit Display data
- High Speed Data Recording (8 Terabytes)

Telemetry Spectrum Allocations



Telemetry Spectrum Allocations

Telemetry Allocation Gained in WRC-07



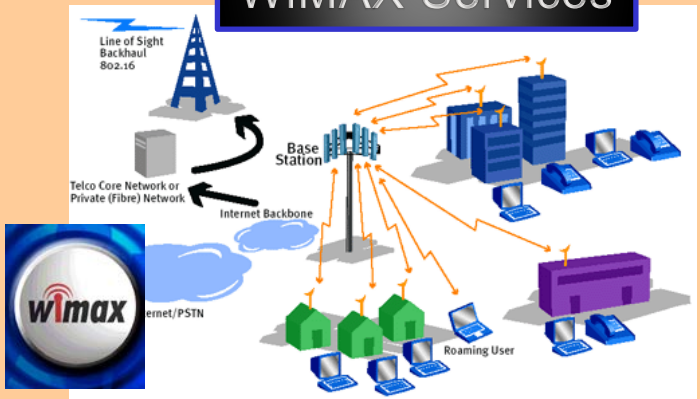
- **DoD has a documented requirement of 865 MHz by 2025 to support telemetry**
  - **Only 445 MHz currently available**
  - ***420 MHz shortfall to meet telemetry requirements***

Commercial Technologies Demanding Spectrum

WiFi Services

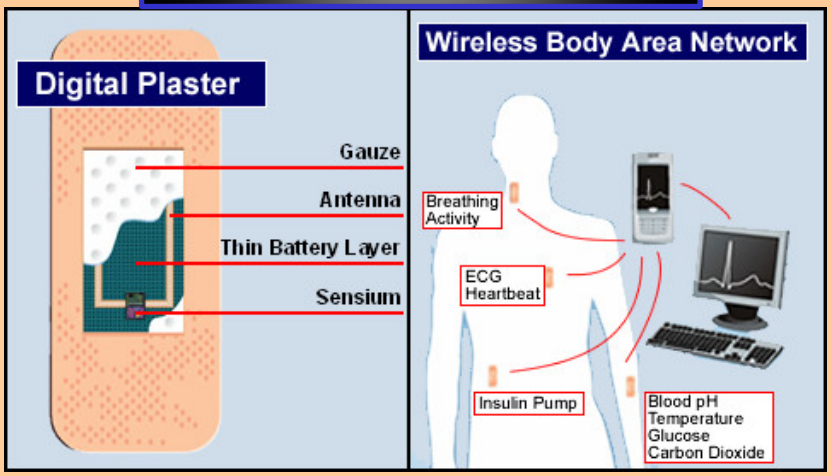
Satellite Radio

WiMAX Services



Cellular Services

Body Sensor Networks



Spectrum Efficient Technology Investments

Investment Focus	Investment to Date	Planned Investment 2015-2019	Technologies
Technology Assessment	$2M	$0.5M	Space-Time Coding, Waveform Analysis, Spectrum Utilization Above 15GHz (e.g. Ka/Ku-Band, FSO)
Technology Maturation	$60M	$45M	Dynamic Spectrum Access, Frequency Agile Hardware, C-Band implementation, Spectrum Management System, Advanced Modulations, Forward Error Correction, Linear Power Amplifier, Wireless Network Protocols, Adaptive Telemetry
Technology Demonstration	$5M	*Technology Demonstration now part of Technology Maturation Process*	Flexible Interoperable Transceiver (FIT) Multi-Band Antenna (MUBAT) Advanced Modulation (ARTM) 2-Way Robust Data Acquisition (2-RAD)
Capability Development: Advanced Modulation	$20M	*"Technology Maturation" required for more advanced modulation schemes*	Successfully Developed & Implemented: ARTM (Tier I & II waveforms, multipath mitigation, improved antenna, data management, IFDS)
Capability Development: Network Enhanced Telemetry	$80M	$25M	Needs Discernment, Identification of Technology Shortfalls, Development of TM Network Architecture Aeronautical Networked TM development and demo
Capability Development: Spectrally Efficient Datalink	$78M	$10M	MSTCS DLT CRIIS Technology Development-Risk Reduction CRIIS EMD (SCA compliant, JTRS core tenets)
Spectrum Stewardship & Regulatory Issues	$18M	$10M	WRC, RSRWG, ICTS, Domestic Threat Response, C-Band Utilization

Way Ahead

- **Implement C-Band telemetry capability**
  - Include full usage of Lower (4400-4940 MHz), Middle (5091-5150 MHz), and Upper (5925-6700 MHz) C-Band
- **Establish a networked telemetry capability**
  - Fully meshed, two-way telemetry link
- **Continue to invest in spectrum efficient technologies**
- **Continue efforts with DoD CIO, NTIA, and FCC to gain access to 5925-6700 MHz**
  - Develop technologies to form usable channel from non-contiguous spectrum
- **Develop methodologies to enable spectrum sharing between test ranges and industry where feasible**

Assessment of DoD T&E Spectrum Efficient Technology Efforts

Achievements and Successes To Date

- **Advanced Modulation Schemes**
  - PCM/FM is legacy telemetry modulation scheme
  - Developed SOQPSK, reduces required bandwidth by **50%** over PCM/FM (used at many test ranges; hardware is ubiquitous)
  - Developed Multi-h CPM, reduces required bandwidth by **25%** over SOQPSK (limited usage at test ranges; limited implementation of ground infrastructure)
- **C-Band Implementation**
  - Modified test infrastructure to support C-Band telemetry
    - Developed and added C-Band antenna to receive antenna
  - Investigated C-Band telemetry link performance in DoD mission domains
  - Developed hardware required to establish a C-Band telemetry capability
    - Developed single C-Band transmitter/antennas, multi-band (L/S/C-Band) transmitters, antennas

Assessment of DoD T&E Spectrum Efficient Technology Efforts

Areas Requiring Greater / Continued Investment to Realize Improvements and Efficiency Gains

- **Networked Telemetry**
  - Reconfiguration of instrumentation during test event
  - Enables transmission of only essential data and reduces number of test flights
- **Advanced Modulation Schemes**
  - Development and application of multi-carrier waveforms
  - Enables spectrum reuse through spatial diversity, allowing support of additional test events
- **Interference Mitigation Techniques**
  - Mitigation of multipath, co-channel interference, and out-of-band-emissions
  - Reduces exclusion zone size and increases spectrum sharing opportunities
- **C-Band Implementation**
  - Technology solution to use 5925-6700 MHz band, potentially leveraging commercial solution to “sum” fragmented spectrum into a usable telemetry channel
  - Enables flexibility in spectrum resource planning, allowing support of additional test events

This Is Where We Need Your Help

Assessment of DoD T&E Spectrum Efficient Technology Efforts

Areas of Future Investment to Identify Additional Improvements

- **Telemetry in Non-Traditional Spectrum**
  - Free space optics telemetry links
  - Telemetry links above 15GHz (Ka/Ku-Band)
  - Enables flexibility in spectrum resource planning and increases spectrum available to support T&E
- **Distributed Test Infrastructure**
  - Cellular-based architecture leveraging wireless carrier technologies
  - Creates additional opportunities for spectrum reuse and reduction in persistent infrastructure costs
- **Technologies Enabling Spectrum Sharing**
  - Dynamic spectrum access technologies, cognitive radio technologies, spectrum/test planning tools, interference mitigation techniques
  - Increases spectrum efficiency, agility and utilization of spectral resources

Assessment of DoD T&E Spectrum Efficient Technology Efforts

Overall Assessment

- T&E ranges have made significant improvements through the development of advanced modulation schemes, the establishment of a C-Band telemetry capability
- Continuing to invest in technologies & capabilities to realize additional improvements (sharing technologies, networked telemetry, non-traditional telemetry spectrum)
- To realize improvements in technologies that foster spectrum sharing, investments are needed in:
  - Frequency agile systems, multi-band / wide-band systems operating in L/S/C-Bands
  - Dynamic spectrum access technologies
  - Directional telemetry antennas
  - Methods to quantify spectrum usage
  - Interference mitigation techniques (out-of-band emission, co-channel)
  - Leveraging commercial technologies for use in telemetry systems

Summary

- **Out-of-Band-Emission & Co-Channel Interference Mitigation Techniques**
  - CIO Top 10 Spectrum Sharing Technology Category: *Interference Tolerance and Hardening Technologies*
- **Spectrum Usage Metrics and Measurement System**
  - CIO Top 10 Spectrum Sharing Technology Category: *Spectrum Situational Awareness (SA), Spectrum Command & Control (C2), and Management of the Electromagnetic Environment (EME) & Modeling and Simulation of the Electromagnetic Environment (EME)*
- **Utilization of Non-Traditional Spectrum to Support Test Requirements (e.g. Free Space Optics, Ka/Ku-Band)**
  - CIO Top 10 Spectrum Sharing Technology Category: *Millimeter Wave and Free Space Optical Technologies*
- **Develop Components to Implement a Modular T&E Infrastructure**
  - CIO Top 10 Spectrum Sharing Technology Category: *Dynamic Spectrum Access (DSA) and Frequency Reuse (FR) Technologies*

Points of Contact

Mr. Derrick Hinton
Principal Deputy Director
Test Resource Management Center (TRMC)
571-372-2761
george.d.hinton2.civ@mail.mil

Thomas O'Brien
Systems Engineer
TRMC Test & Evaluation / Science & Technology (T&E/S&T) Program
571-372-2752
thomas.o.obrien2.ctr@mail.mil

Tom Young
Executing Agent
Spectrum Efficient Technology T&E/S&T Test Technology Area
Air Force Test Center
661-277-1611
tommy.young.1@us.af.mil