V-Band Communications Link Design
For A Hosted Payload
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Outline

1. Introduction
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   – Hosted Payload Locations
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2. Hosted Payload Study
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   – Considerations
   – Satellite Bus Examples
   – Satellite Specification Summaries

3. V-Band Communications Link Design & Analysis
   – Link Budget Description
   – V-Band Considerations
   – MATLAB Data and Results
   – V-Band Data and Results
   – Future Work
1. Introduction
Task Objectives

- Hosted Payload Study
  - Analyze commercial GEO/LEO satellite hosted payload specifications
  - Assess how NASA can use hosted payload capabilities

- V-Band Link Analysis
  - Research, analyze, and determine feasibility of high frequency communications at V-band (50-75 GHz)
  - Defining applications for high-frequency communications
  - Assessing link design and performance based on varying parameters

- V-Band Hosted Payload Application
  - Determining the size and power consumption of the associated communications payload
  - Interpreting the feasibility of implementation within the accommodation constraints of a hosted payload
Hosted Payload Locations & Architecture Design for V-Band User Missions

Title: V-Band Architecture High-Level Operational Concept Graphic

Figure/Table/Type: OV-1

Date: 6/21/2011
Version: 1
Figure: 1

V-band
User Missions

NISN

Hosted Payload Satellite GEO (HPSG)

Hosted Payload Satellite LEO (HPSL)

Station

Low Earth Orbit (LEO)

Geosynchronous Earth Orbit (GEO)
2. Hosted Payload Study
What is a Hosted Payload?

- Refers to the utilization of available capacity on commercial satellites to accommodate additional payloads (e.g., transponders, instruments, etc.)
- By offering "piggyback rides" on commercial communication satellites already scheduled for launch, customers such as government agencies can send sensors and other equipment into space on a timely and cost-effective basis.
- Concept is similar to “ridesharing” but instead partners share a satellite bus, rather than a space launch vehicle.
What is a Hosted Payload?

• Some providers offer specific hosted payload accommodations. However, many providers are open to negotiation for space onboard their satellite buses.
• For our study, based on our research, we used 10-20% of the total satellite capabilities are reserved for payload additions as a rule of thumb.
Hosted Payload Considerations

Advantages

• Principal advantages
  – Faster pacing of commercial programs vs. government programs
    • ~32 months as compared to 5-7 years
  – Lower cost
    • Use of hosted payloads provides a low cost opportunity for access to higher orbit (i.e., GEO, LEO)

• Other advantages
  – Reliable and predictable launch schedule
  – Large choice of launch vehicles
  – Use of existing mission support facilities
  – Primary operator handles operations and maintenance

Disadvantages

• Limitations on payload mass, volume, and power
• Adherence to commercial satellite development and deployment schedules
  – Strict procurement, construction, and launch schedules (Government schedules are typically much longer)
• Coverage is restricted to position of commercial satellite
STAR Bus

- **Payload Mass Capability:**
  - Approx. 60kg, depending on size of primary payload
  - 430 kg total payload mass
- **Available Payload Volume:**
  - Approx. 25” x 30” x 28”
- **Orbit:** GEO
- **Available Payload Power:**
  - Dependent on specific host spacecraft
- **Payload Interface:**
  - Orbital’s SPI Modem interface
  - MIL-STD-1553 bus

An Earth-staring remote sensing hosted payload on the nadir deck of a STAR 2.4 bus
GEO Specifications Summary

• GEO Satellites
  – Average Weight: 2966 kg
  – Power: 5.66 kW
  – Average Dimensions: 40.7 m x 12.4 m x 11.8 m

• Hosted Payloads
  – Weight: 296 – 592 kg
  – Power: 0.566-1.132 kW
  – Estimated Payload Dimensions
    • Length: 4.07 – 8.14 m
    • Width: 1.24 – 2.48 m
    • Height: 1.18 – 2.36 m
LEOStar Bus

- Payload Mass Capability:
  - ≤101 kg
- Bus dimensions:
  - 95.2 cm x 160 cm
- Orbit: LEO (450-1000 km)
- Available Payload Power:
  - 110 W
- Payload Interface:
  - MIL-STD 1553B/RS-422
  - CCSDS

*OrbView-3, which uses the LEOStar bus*
LEO Specifications Summary

- **LEO Satellites**
  - Average Weight: 1405 kg
  - Power: 4.5 kW
  - Average Dimensions:
    1.75 m x 1.7 m x 1.8 m

- **Hosted Payloads**
  - Weight: 140 – 280 kg
  - Power: 0.45 – 0.9 kW
  - Estimated Payload Dimensions
    - Length: 0.175 – 0.35 m
    - Width: 0.17 – 0.34 m
    - Height: 0.18 – 0.36 m
## Future Satellite Launches

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Potential Applications of Hosted Payloads

• Propagation Analysis
• Technology Demonstration
  – i.e., Internet Routing in Space
• Added Capacity in Space
• Space Situational Awareness
  – i.e., Collision Avoidance, Debris Monitoring, Nuclear Detection, Radiation Assessment, Streaming and still imagery
• Sensor Package and Instrumentation
  – i.e., Hyper-Spectral Sounding, Ocean Color Analysis, Ozone Mapping, Earth Staring, and Weather Tracking
• Others...
3. V-Band Communications
Link Design & Analysis
What is V-Band?

- V-Band is an arbitrary designation of a high frequency range approximately between 50-75 GHz
- Although V-Band frequencies are allocated by NTIA, no operational licenses have been issues yet.
- V-Band is also highly attenuated by atmosphere and rain
Advantages

• Increased data rate capabilities for satellite-to-ground communications for shorter download time

• Smaller antennas for higher frequency bands reduce the mass on payload

• High frequency transmissions are less likely to be distorted due to interference and low population of users in higher frequency bands

• The higher the data rate, the higher the level of public interest and engagement. Higher rates allow for high-res images, high-def video, etc...

Disadvantages

• Space-Ground Communications
  – Atmospheric Absorption
    • Increased rain attenuation
    • Resonance of oxygen molecules
    • Increased humidity attenuation
  – Requires more transmission power

• Not suitable for emergency communications due to atmospheric variability

• Need a more precise attitude control system on the flight platform due to the pointing requirements of the narrow beamwidth
Link Design Process

1. **Define Requirements for Each Link**
   - Identify Communications Requirements
   - Specify Alternate Communications Architectures
   - Determine Data Rates For Each Link
   - Design and Size Each Link
   - Document Reasons For Selection

2. **Design Each Link**
   - Select Frequency Band
   - Select Modulation and Coding
   - Apply Antenna Size, Beamwidth Constraints (if any)
   - Estimate atmospheric, rain absorption
   - Estimate Received Noise, Interference Powers
   - Calculate Required Antenna Gains and Transmitter Power

3. **Size the Communications Payload Subsystem**
   - Select Payload Antenna Configuration
   - Calculate Antenna Size
   - Estimate Antenna Mass
   - Estimate Transmitter Mass and Power
   - Estimate Payload Mass and Power
What is a Link Budget?

• A link budget analysis is an analysis of gains and losses within an RF link.

• Gains and losses of the components/factors in the RF path are computed and summed
  – Result is an estimate of the end-to-end system performance in the real world
  – This must be done to determine if a sufficient signal strength will be received to meet data rate requirements
Link Budget

- Link Budget Analysis can be performed for both the downlink and uplink, but the parameters used in the calculation varies including:
  - Uplink power amplifier gain and noise factors
  - Transmit Antenna Gain
  - Receiver Antenna and Amplifier Gains and Noise Factors
  - Atmospheric Attenuation Factors
  - Slant range and corresponding space loss over a distance
Equations for Link Budget

\[
\frac{E_b}{N_0} = E_{\text{IRP}} + L_s + L_a + G_r + 228.6 - 10\log T_s - 10\log R
\]

- \( \frac{E_b}{N_0} \): Energy per bit to noise power spectral density ratio
- \( E_{\text{IRP}} \): Equivalent Isotropic Radiated Power (dB)
- \( L_s \): Space Loss (dB)
- \( L_a \): Atmospheric Losses (dB)
- \( G_r \): Receiver Gain (dB)
- \( T_s \): System Noise Temperature (K)
- \( R \): Data Rate (bps)
Equations for Link Budget

- **EIRP** = **Pt** + **Lt** + **Gt**
- **L_s** = 147.55 – 20logS – 20logf
- **G_t** = **Gpt** + **Lpt**
- **Gpt** = 44.3 – 10log(Ѳ^2)
- **Lpt** = -12(e_t/Ѳ)^2
- **G_r** = **Gpr** + **Lpr**
- **Gpr** = -159.59 + 20logD_r + 20logf + 10logN
- **Lpr** = -12(e_r/Ѳ)^2
- **Ѳ** = 21/fD [f in GHz]

**EIRP** = Equivalent Isotropic Radiated Power (dB)
- **Pt** = Transmit Power (dB)
- **Lt** = Line Loss (dB)
- **L_s** = Space Loss
- **S** = Propagation Path Length(km)
- **F** = Frequency(Hz)
- **G** = Antenna Gain (dB)
- **L** = Antenna Loss
- **D** = Antenna Diameter (m)
- **e** = Antenna Pointing Loss (deg)
- **Ѳ** = Antenna Beamwidth (deg)
- **N** = Antenna Efficiency(% - Decimal)
- **f** = Frequency (Hz)
- **r** = Receiver
- **t** = Transmitter
- **p** = Peak Gain

*Space Mission Analysis and Design*
Types of Atmospheric Absorption

- **Refraction**
  - Slight shift apparent elevation of a satellite depending on atmospheric pressure and water vapor content.
  - Causes off-pointing of receiver antenna.

- **Depolarization**
  - Occurs when the shape of the raindrops causes a signal to be differentially absorbed, causing a rotation or change in the signal’s polarization.
  - Results in power loss at the receiving antenna.

- **Reflection/Multipath**
  - Occurs when a signal is partially reflected

- **Rain Attenuation**
  - Occurs when water droplets diffuse/absorb the RF radiation in a satellite signal
  - Effect is proportional to the rain intensity

- **Molecular Attenuation**
  - Attenuation by oxygen molecules and water vapor in the atmosphere
  - The large absorption band at ~60 GHz make these frequencies attractive for inter-satellite communications (using atmosphere to shield against interference from Earth)
Atmospheric Attenuation

Rain Attenuation

Space Mission Analysis and Design
V-Band Application

Fixed Parameters:
- f: 50-75 GHz
- $L_i$: -6 dB
- $L_s$: Calculate for GEO
- $L_a$: Assume -9 dB (3 dB atmosphere + 6 dB rain loss for 98% availability at >45° elevation angle, SMAD)
- $e_t$ and $e_r$: Assume 3 dB loss
- $T_s$: 300 K (ref. SDO)
- BER: $< 5 \times 10^{-9}$
- Modulation: BPSK
- $E_b/N_0$ Required:
  - 2.8 dB (ref. SDO using BER, Modulation, and Encoding chosen)

Input Parameters:
- $P_t$: 2.5 W – 20W
- $D_t$: 0.05 m – 0.50 m
- $D_r$: 1 m – 5 m
- Bit Rate: 150 Mbps – 350 Mbps

Calculated Parameters:
- EIRP, $L_{pt}$, $L_{pr}$

Link Margin: 6 dB
With the use of Microsoft Excel, we were able to create a simple link budget calculator, utilizing the link budget equations.
MATLAB Script

- MATLAB is a software that allows the user to type code to systems of equations based on the outputs desired.
- By using MATLAB, we have created a calculation program to determine a number of different outputs depending on the user’s known inputs.
Data Graphs

Frequency vs. Transmitter Diameter vs. Transmitter Gain

Transmitter Gain vs. Transmitter Power vs. EIRP
Data Graphs

Receiver Diameter vs. EIRP vs. Link Margin
STK Simulations

- Satellite Tool Kit (STK) is a software tool that allows the user to input the parameters while the equations are calculated by the software.
- To verify the results, we used the MATLAB data to simulate the entire scenario in STK in a static environment.
- To provide a dynamic study of the environment for the link.
# Static Environmental Losses

## STK Results – MATLAB Verification

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<th>Inputs:</th>
<th>Frequency (GHz)</th>
<th>Power (W)</th>
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<th>Receiver Diameter (m)</th>
<th>Data Rate (mbps)</th>
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<th>Eb/No (dB)</th>
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Max Data Rate of 236mbps at 5W for an Eb/No of 2.8

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<th>Frequency (GHz)</th>
<th>Power (W)</th>
<th>Transmitter Diameter (m)</th>
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As Data Rate Doubles, Power Doubles

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<th>Inputs:</th>
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### Additional Constant Inputs:

- System Noise Temperature: 300 K
- Encoding Gain: 3 dB
- Line Loss: -6
- Modulation: BPSK

- Atmospheric Loss: 9 dB
- Parabolic Antenna
- Transmitter and Receiver Pointing Offset: Total 3 dB loss
## Dynamic Environmental Losses
### STK Results

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<th>B (55 GHz)</th>
<th>C (60GHz)</th>
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T = Transmitter, R = Receiver
V-Band Analysis Summary

• Due to the extent of the atmospheric attenuation with V-Band, the feasibility of utilizing the frequency band on a hosted payload between 58-62 GHz is impractical.

• When constrained by hosted payload parameters, the power needed to transmit at these frequencies while keeping a sensible size ground station is unreasonable.

• At 50 and 75 GHz, the atmospheric attenuation is low enough for a transmission from space to ground with a high data rate. However, when using the rain model the loss increases such that the links do not close.
Future Work

- Research components of a Communications Payload
- Design Communications Payload for V-Band
Questions?
References

• Books:
  – Digital Communications Fundamentals and Applications
    • By: Bernard Sklar
  – Introduction to Satellite Communications
    • By: Bruce R. Elbert
  – Space Mission Analysis and Design
    • By: Wiley J. Larson and James R. Wertz

• Mentors:
  – Eric Knoblock, Systems Definition & Communications, DSE
  – David Avanesian, Systems Definition & Communications, DSE
  – Charles Niederhaus, Systems Definition & Communications, DSE
  – David Bittner, Systems Definition & Communications, DSE
Task Description:
Research, analyze, and determine feasibility of high frequency communications at V-band (50-75 GHz) to be accommodated on a hosted payload.
This task includes:
• Assessing link design and performance based on varying parameters
• Research commercial GEO/LEO satellite bus developers
• Determine the feasibility of implementation within the accommodation constraints of a hosted payload

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Mentors
• Eric Knoblock, Systems Definition & Communications, DSE
• David Bittner, Systems Definition & Communications, DSE

Support
• David Avanesian, Systems Definition & Communications, DSE
• Charles Niederhaus, Systems Definition & Communications, DSE

Schedule for V-Band:
Communications Specifications:
• Define Applications, Requirements, and Link Parameters - 7/5/11

Communications Design:
• Analyze/Design Communication Links - 7/15/11
• Size and Design Communications Payloads - 7/21/11

Final Presentation:
• Finalize and Document Analysis and Design - 7/29/11
• Final Presentation at Symposium - 8/4/11

Schedule for Hosted Payload:
Hosted Payload Specifications:
• Document Hosted Payload Accommodation Specifications - 7/5/11

Communications Design:
• Provide accommodation data for link and payload designs - 7/25/11

Final Presentation:
• Finalize and Document Analysis - 7/29/11
• Final Presentation at Symposium - 8/4/11
Verification of Three Programs

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