Exploring High Performance Design for Communications Links Supporting Exploration Programs

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Overview

- Future human extraterrestrial exploration programs demand reliable high data rate communications links over interplanetary distances.
- A game changing approach: polarization modulation to represent “qubits” that work to improve link reliability while meeting bandwidth demands
- Proposal for a test of the concept using the International Space Station

Future Human Exploration Mission Objectives Mandate High Data Rate Communications Links

- Communications signal delays place a higher premium on each character in a radio transmission.
  - Example: when Earth and Mars are in opposition, signal delays could last as long as 20 minutes.
  - Radio relay satellites will be integral to maintaining a year-round communications link with a distant planetary operations base.
  - The signal delay removes any mission control center from the realtime aspect of command and control.
    - Control center becomes a data terminal, forwarding mission data to an operations base and capturing returned science data.

Future Human Exploration Mission Objectives Mandate High Data Rate Communications Links

- The ISS mission illustrates the additional demand that human exploration places on radio communications.
  - Private family conferences are best supported with video.
  - Medical consultations, both physiological and psychological, can mandate both audio and video.
  - Hi-definition photography and video support payload science and payload operations.
  - E-mail, some social media and sports/news from home support the human aspect of space exploration.
- At this point, a 25 Mbps forward link barely meets mission objectives and we are working on expanding the return link to 600 Mbps.

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Future Human Exploration Mission Objectives Mandate High Data Rate Communications Links

- Future missions could require a control center to maintain much more additional hardware.
  - Unmanned autonomous orbiting vehicles:
    - Unmanned landing/liftoff vehicles that arrive early to support a pending mission
    - Supply vehicles to extend the mission duration or supply the operations base
    - Return-mass vehicles to send planetary samples back to Earth before the human exploration ends
    - Orbiting communications satellites and planetary positioning satellites similar to Earth's GPS
    - Vehicles in solar orbit to maintain a constant communications link

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Future Human Exploration Mission Objectives Mandate High Data Rate Communications Links

- Future missions could require a control center to maintain much more additional hardware (continued).
  - Extra vehicular activities, real planetary exploration, still mandate extensive video coverage
    - Explorer-to-base comm links
    - Base-to-Earth relay – even though delayed
    - Though delayed, the Earth control center may still serve a back-up role for planned commanding that supports anticipated, standardized mission operations.
- Future missions mandate multiple high data rate digital channels but there are natural laws limiting data rate.

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Future Human Exploration Mission Objectives Mandate High Data Rate Communications Links

- The standard link margin equation for digital communications come into play as communications link distances increase:

$$\frac{Eb}{N0} = \frac{Tp * Lp * Ag}{B * Nt * Dr}$$

  - Eb = RF energy per bit
  - Tp = Transmitter power (dB)
  - Lp = Line and space losses (increased distance causes the value to decrease)
  - Ag = Antenna Gain
  - N0 = Noise Density (ambient noise power dB)
  - B = (Boltzmann's constant)
  - Nt = System Noise Temperature (thermal noise)
  - Dr = Input signal data rate
- Point: the greater the distance, the lower the signal-to-noise ratio, the greater the data rate, the lower the signal-to-noise ratio

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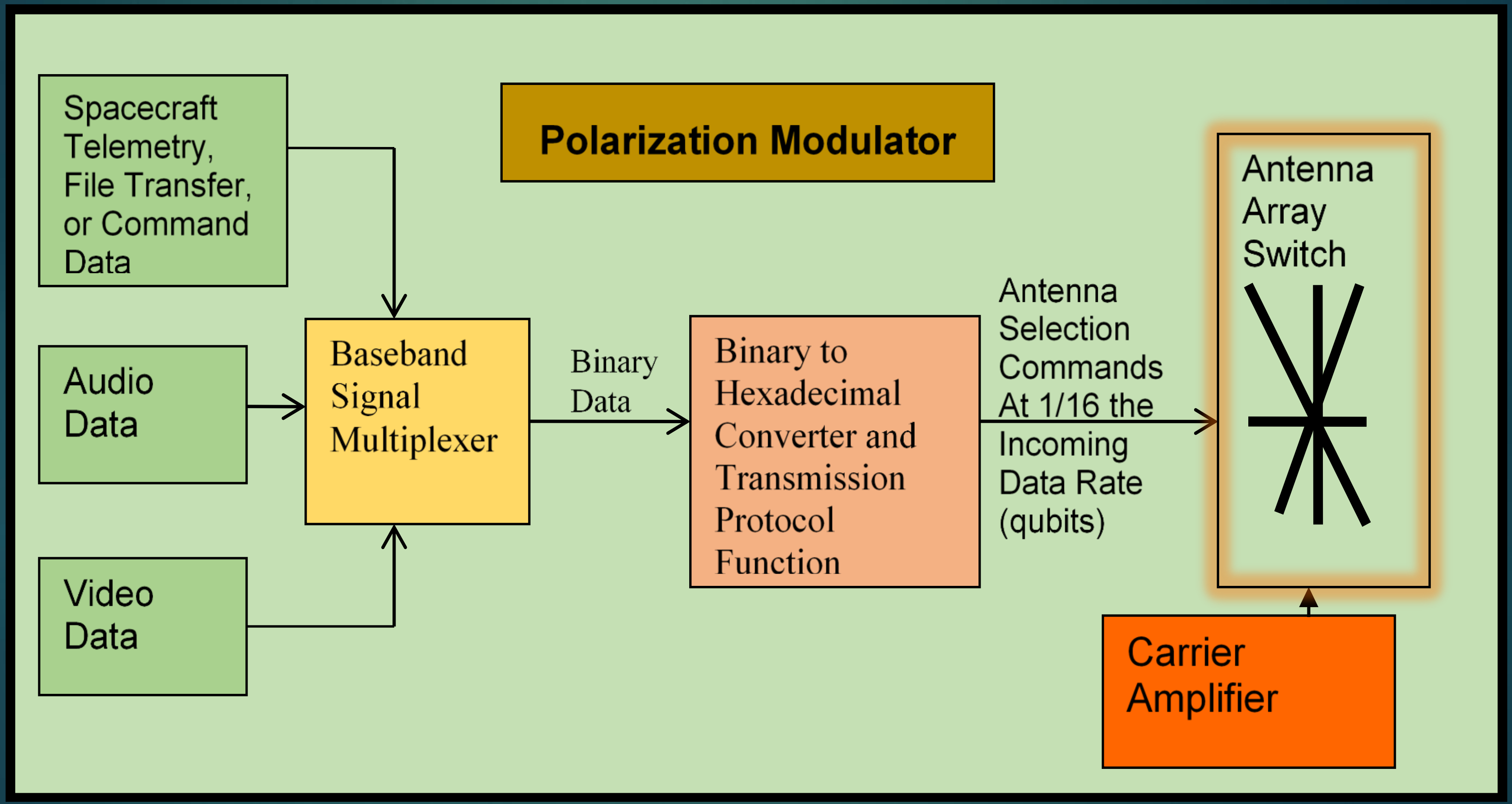
A Game-Changing Approach

- RF polarization modulation borrows from research efforts with fiber optics research intended to increase the available bandwidth over a single comm link.
  - Concept of a “qubit” – represent more than one value in a single character
  - Perhaps use a hexadecimal numbering system for the RF link
  - Permit various RF carrier polarizations to represent various hexadecimal numbers
  - RF carrier frequency or amplitude are not modulated – no spread spectrum limitations
    - All of the transmitted power goes into every “qubit”
    - Link margin equation would represent the worst case for a link like this
    - The best link margin would need to be learned through testing
  - The apparent link data rate is reduced, 16-to-1
- Precedence: scientific satellites used polarization detection techniques to detect the faint remnant vibration from the Big Bang.

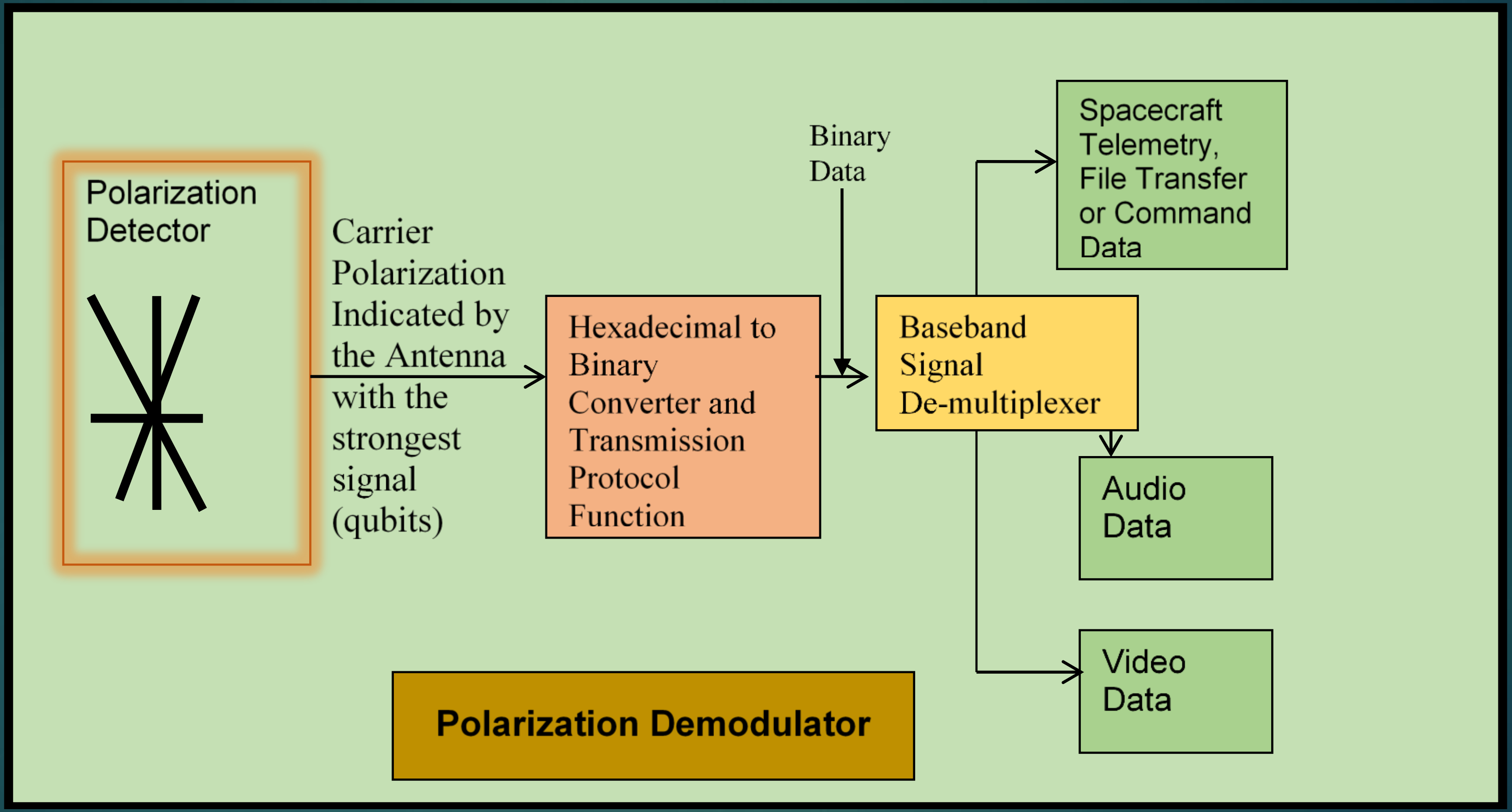
A Game-Changing Approach

- A block diagram illustrates the principle:



A Game-Changing Approach

- A block diagram illustrates the principle (continued):



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A Game-Changing Approach

- Technological challenges.
  - Antenna switching and design to support high-speed selection of polarized transmit antennas (feed horns).
  - High-speed detection of electromagnetic polarization: possible use of receiver antennas that look more like diffraction gratings.
  - Data recovery routines: a lost or dropped qubit represents 16 bits and a routine will be necessary to recover a qubit (re-transmission over a 20-minute delay is not practical)
  - A protocol for the physical layer of the RF link to maintain synchronization.
    - Electromagnetic wave fronts undergo polarization drift as they propagate over interplanetary distances but the very stable dielectric constant of space minimizes this effect.
    - Intelligence is in the physical alignment of the wave front and repetitious “re-defining” of the 0-15 “qubits” will be necessary – a new communications protocol.
    - The new protocol will overcome polarization drift and changes in relative spacecraft attitude.

Proposal for a Test

- Proposal for a test to validate the concept:
  - Polarization modulation has not been used in terrestrial environs because of the unpredicted effect the atmosphere has on electromagnetic wave fronts.
    - However, technology has advanced since the early considerations about comm links
    - We use electronics today to correct for atmospheric aberrations to make land-based telescopes as effective as space based telescopes.
  - The International Space Station could serve as a highly effective testbed for this new type of communication.
    - Already supporting laser communications link tests.
    - A radio transmitter/receiver pair for a polarization comm link could be developed and placed on the ISS.
    - The link could demonstrate the ability to handle all S-band and Ku-band traffic in a single communications link.
    - Test passes over a ground station could be used to perfect corrective techniques regarding polarization drift that could be applied to interplanetary communications links.

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Conclusion

- The promise of highly reliable, high data rate comm links over interplanetary distances justifies an attempt to develop a communications link that uses polarization modulation.
  - Prior experience indicates that much of the concept is more than plausible.
  - The fiber optics industry has been investigating the principle for photons for some time, now.
  - Space-based detection of RF polarization to support scientific exploration has been previously accomplished.
  - We now have the technology to overcome the challenges related to utilizing such a modulation technique.
- A long range polarization modulation comm link could meet future human explorer's data requirements.