Robust, Miniaturized, Avionics Suite for Network-Enabled Deep Space Probes

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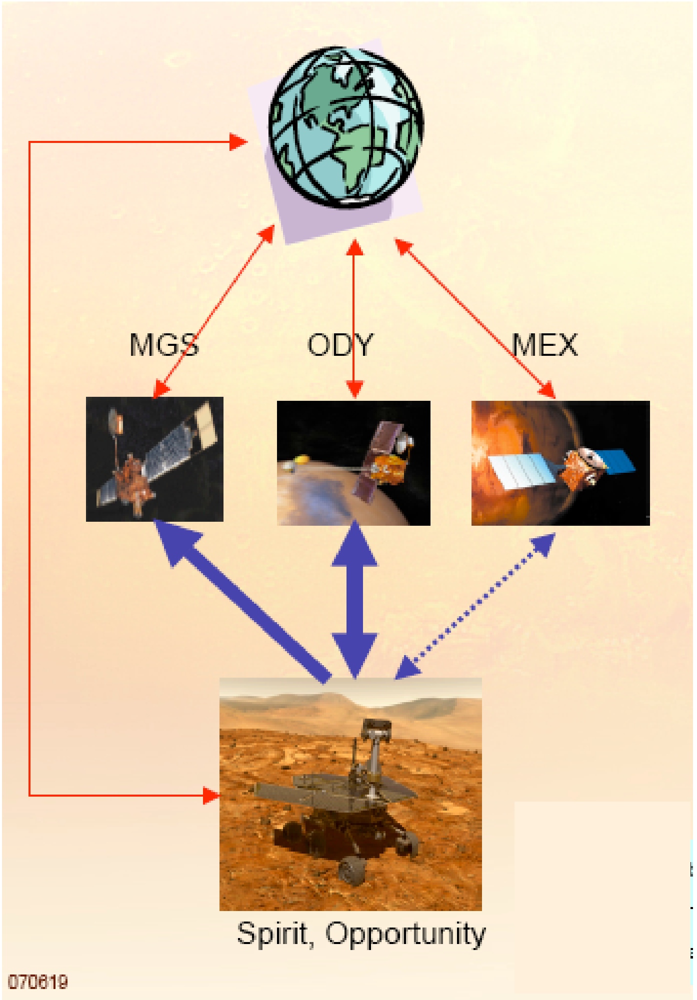
Polly Estabrook, Loren Clare, Norman Lay and Jackson Pang
NASA Jet Propulsion Laboratory
California Institute of Technology

Background

- Current In-Situ Communications at Mars utilizes UHF (400 MHz) frequency band for bi-directional communications between Odyssey, Mars Express and the Mars Exploration Rovers
- MER Radio Specs:
  - Approx 2000 cm^3 volume, 2 kg mass, 45W DC power
- Mars Science Laboratory radio will be based on Mars Reconnaissance Orbiter Software Defined Radio, Electra. Possesses similar mass and power specs as MER radio
- Light, compact, low power radio / avionics assembly desired to enable small planetary probes
- Presentation describes progress on a micro-transceiver development and on the future implementation of new protocol suite to enable seamless file transfer across multiple interplanetary nodes

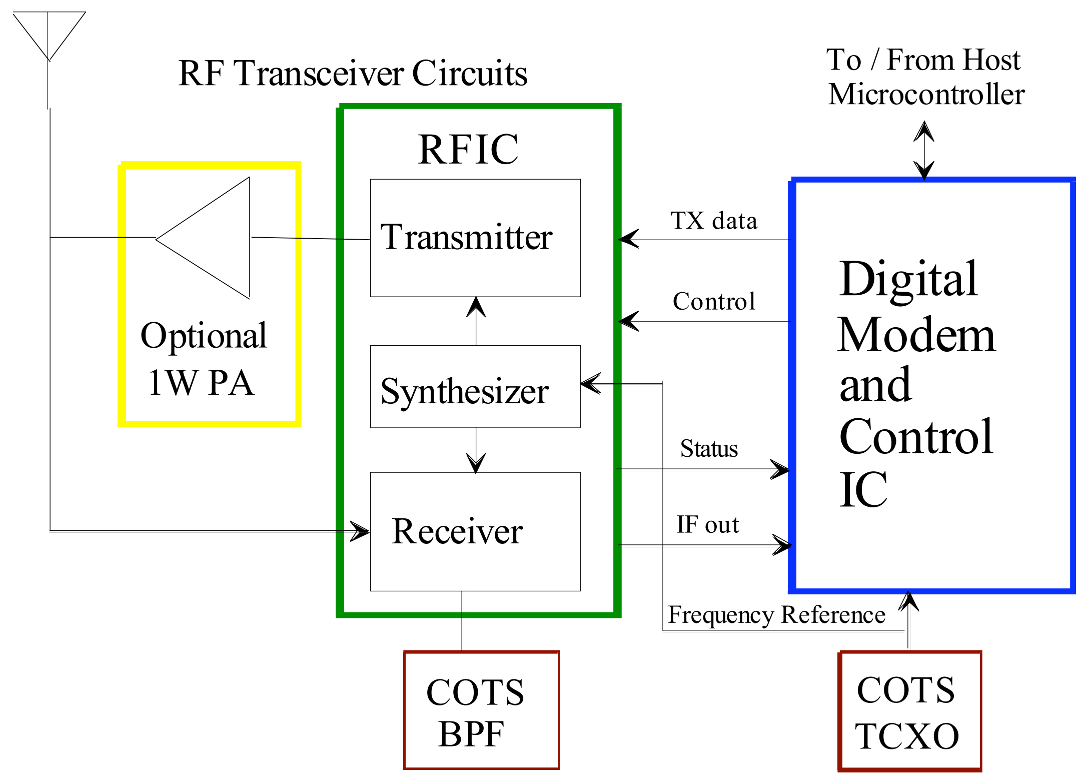


Micro-Transceiver Implementation Challenges

- Micro-transceiver requirements have been developed to support a wide range of new applications such as probes, gliders, small networked landers or sensor networks
- Micro-transceiver goal is to reduce mass, volume and power over current MER and MSL radios by one to two orders of magnitude
- Micro-transceiver desired specifications:
  – Supports telemetry links from 1 - 256 Kbps
  – Receives command links from 2 - 8 Kbps
  – Receive sensitivity < -120 dBm
  – Volume < 10 cm^3
  – Mass < 50 gms
  – Power Consumption < 50 mW (receive); < 100mW - 3W (for RF transmit powers of 10mW to 1 W)
  – Temperature Compensation to -100C
  – Radiation Tolerance to 100 krad

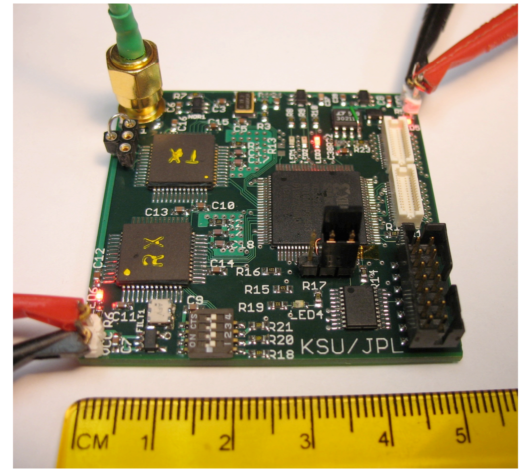
Micro-Transceiver Description

- Micro-transceiver is a two or three chip device utilizing a mixed-signal rad-hard Silicon-on-Sapphire fabrication process
  - The Radio Frequency Integrated Circuit (RFIC) die supports half-duplex communication with low power consumption for receive and transmits either 10 mW or 100 mW power with high DC power efficiency through the use of integrated inductors
  - The optional 1W power amplifier chip will support higher data rates or permit communications at greater distances to the motherspacecraft or orbiter
  - A companion digital modem/control die handles transmit data formatting, receive demodulation, bit/frame-synchronization and implements a practical subset of the Delay Tolerant Networking protocols.

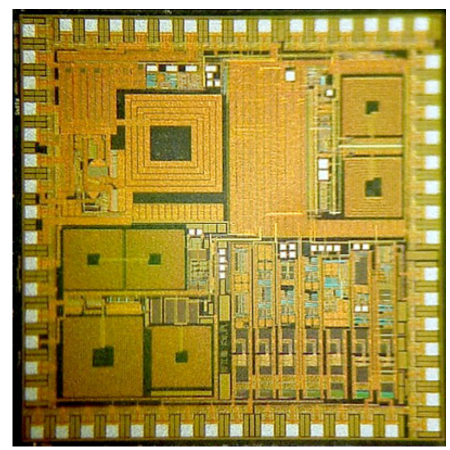


Micro-Transceiver Status

- A demonstration board implementing the full 100 mW transceiver meeting the mass, volume and power performance goals has been tested using early prototype IC s.
  - The digital IC currently implements the Prox-1 protocol used in Mars Communications not the DTN protocol.
- A single-chip 100 mW transceiver built from the prototype circuits tested in the PC board is currently under test.
  - Chip size: 3.2 mm x 3.2 mm
  - Incorporates the RFIC, digital control chip, receive-strength signal indicator (RSSI), on-chip sensor for temperature measurement, and optional analog I/Q transmitter inputs for additional modulation types such as FSK
  - Measurements to-date indicate that the single-chip design meets or exceeds the performance of the System-level PC board



System-level test PC board built from first prototypes plus FPGA



Die-photo of fully integrated single-chip 100 mW transceiver (with Prox-1 protocols)

Probe Communication Channel: Protocol Challenges

- Random Link Outages for probe – mothership communications
  - Harsh environment – physical degradation due to plasma ray
  - Probe movement / orientation of antenna obstructs less than omni view
  - Probe movement obstructed by geometry or physical intervening geological structure
- Collect sensor probe information robustly without gaps or errors in the sensor data stream in spite of these conditions

Probe – Mothership Communications Requirements

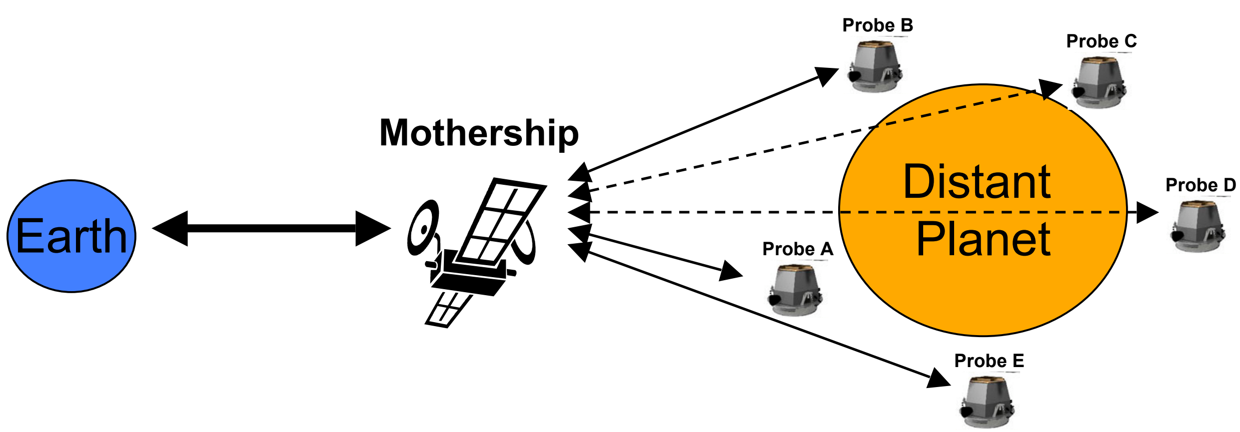
- Automatic link discovery and establishment
  - Detect link presence and establish link session
- Link Error control (Automatic Repeat Request)
  - Transmitted frame received but detected as having error; request retransmit
- Store and forward
  - Store data during link outages, send when link is available
- Network relay for multi-probe missions
  - Combine data collected from multiple probes whenever received, deliver in sorted order to end user

Link Protocol Solutions

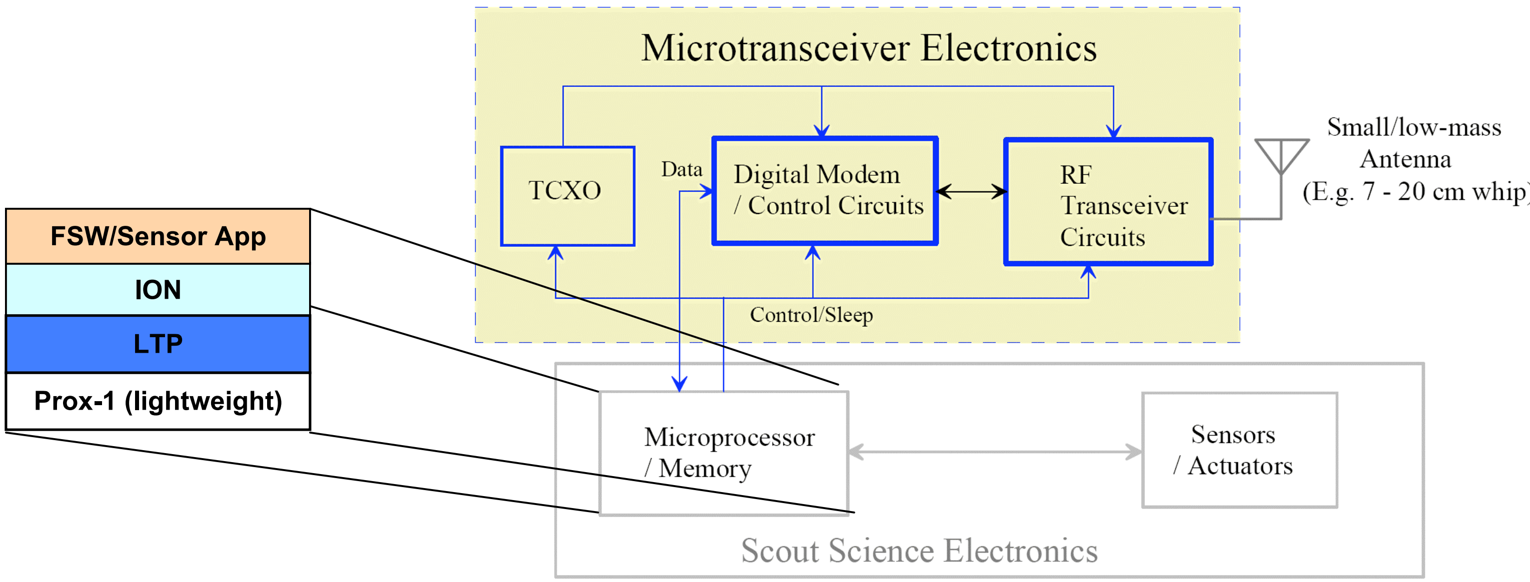
- Link discovery may be accomplished by augmentation of CCSDS Prox-1 hailing and session abort detection mechanisms, and convergence layer for Licklider Transmission Protocol
- Link Error Control Achieved by
  - Licklider Transmission Protocol (LTP)
    - Performs efficiently by only retransmitting those frames that are explicitly identified as missing or a timeout has expired
  - Have flight software implementation of LTP and FPGA implementation underway
    - Flight software implementation allows simpler integration
    - FPGA hardware provides lower power consumption (particularly useful for probes) and higher throughput (particularly useful for mothership serving multiple probes)

Higher Layer Probe Protocol Solution

- Store & forward and network relay achieved via DTN bundle protocol
  - DTN implementation in the Interplanetary Overlay Network (ION), robust and light-weight software implementation
  - Hardware FPGA implementation of the DTN Bundle Spec is underway



System Block Diagram



Conclusion

- Three chip micro-transceiver implementing Proximity -1 protocols and meeting target specifications is expected to be fabricated and tested by end of 2007
- Addition of Delay Tolerant Networking Protocols is being proposed
- New low mass, low volume and low power avionics suite to support small planetary probes, aerobots, and networks of small landed elements is being developed at JPL in conjunction with academic and industry partners