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NEW MILLENNIUM DEEP SPACE TINY TRANSMITTER: FIRST PHASE OF A DIGITAL TRANSPONDER

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ABSTRACT

An advanced technology X- and Ka-band (8 and 32 GHz) Tiny Transmitter is being developed at JPL, for the New Millennium program and is described in this paper. The Tiny Transponder is the first phase of development of the Tiny Transponder which will incorporate recent advancements in miniaturization and flexibility of radio systems by utilizing digital radio techniques. These techniques incorporate digital technology and algorithms to perform many functions which have traditionally been performed by analog circuits and allow the complexity of the RF portion of the radio to be minimized. The Tiny Transponder will be able meet the needs of almost all deep space missions presently being planned for launch after the year 2000.

OBJECTIVES OF THE DEEP SPACE MINIATURE TELECOM DEVELOPMENT PROGRAM

While deep space communications performance has increased dramatically over the last three decades, the size, mass and cost of spacecraft telecommunications subsystems have also increased. Present subsystems will not meet the needs of many future missions which will have much lower budgets and mass, volume and power capability. However, the telecommunications performance requirements of these future missions are not substantially different from those of present larger deep space missions. The most expensive and complex component of the spacecraft radio electronics is the deep space transponder. The transponder includes the radio receiver which receives and demodulates commands from NASA's Deep Space Network (DSN) and the transmitter which provides telemetry and ranging information from the spacecraft to the DSN. In addition, the

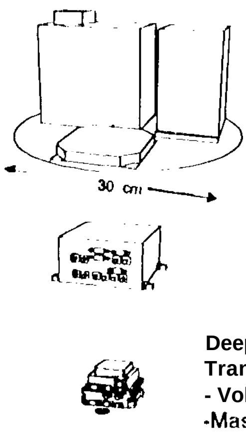

Figure 1 - Deep Space Transponder Evolution

transponder provides navigation capability to enable the measurement of the spacecraft range, range rate, and radio science functions to enable measurement of the propagation path.

The greatest cost and size reduction of deep space telecommunications systems can be achieved by reducing the cost and size of deep space transponders. The Tiny Transponder [1] is designed to achieve these goals. Figure 1 shows a comparison of the Tiny Transponder with other recently developed deep space transponders. The Cassini transponder will be used on the Mars Pathfinder and NEAR missions, as well as the Cassini mission, The Small Deep Transponder will be flown on the New Millennium Deep Space 1 mission and represents an interim effort to reduce costs and size. The Tiny Transponder will further reduce cost and will reduce mass and volume by almost an order of magnitude relative to the Cassini transponder.

The Tiny Transponder will be developed in two phases, the first of which is the development of the Tiny Transmitter which is presently under-way. This Transmitter will be used as a building block of the Tiny Transponder. The

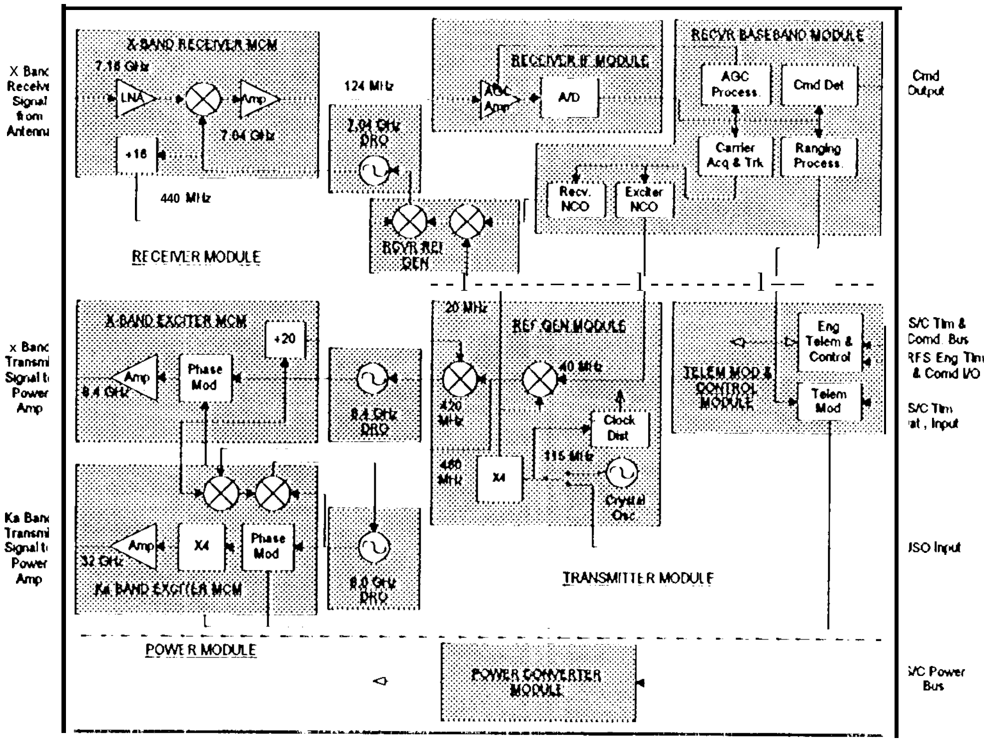

Figure 2- Tiny Transponder Block Diagram

Transponder will be developed during the second phase and will be flown on a later New Millennium flight.

TRANSPONDER ARCHITECTURE DESIGN APPROACH

The Tiny Transmitter architecture was derived from the Tiny Transponder. The key receiver specifications of the Tiny Transponder are:

- Receiver Frequency: 7,145 MHz to 7,190 MHz
- Carrier threshold: -155 dBm
- Dynamic range: 70 dB (threshold to -85 dBm)
- Acquisition and tracking rate: 500 Hz/s @ -110 dBm
- Tracking range: ±100 kHz
- Tracking error: <1° /40 kHz @ -110 dBm
- Command demodulation Data rate: 7.8125 bps to 2,000 bps
- Bit error rate: 10^{-5} @ E_b/N_o = 10.5 dB

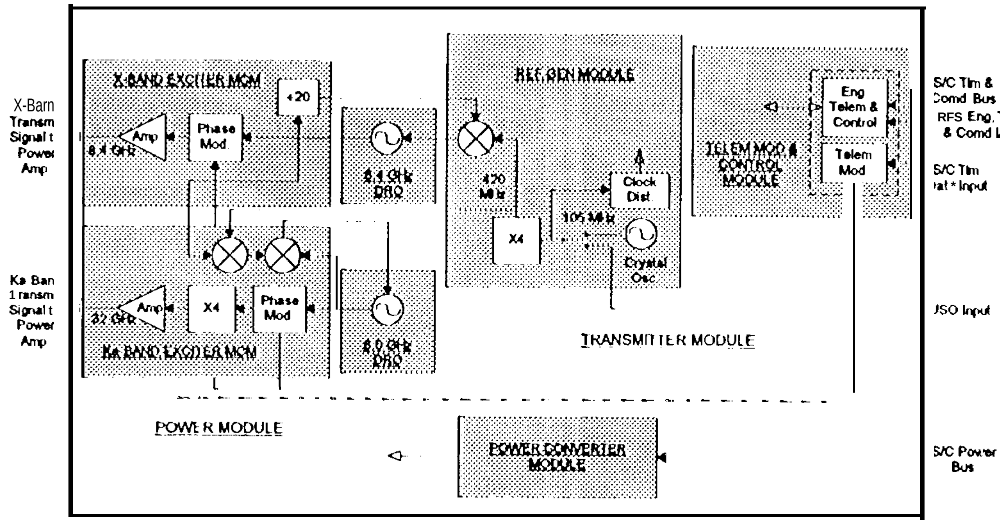

Figure 3- Tiny Transmitter Block Diagram

The key transmitter specifications are:

- X-band downlink frequency: 8,400 MHz to 8,450 MHz
- X-band power: 12dlhn(16 mW)
- Ka-band downlink frequency: 31,909 MHz to 32,121 MHz
- Ka-band power: >10 dBm (>1 O mW)
- Telemetry modulation:
  - ♦ Subcarrier frequencies: 22.5 kHz to 2.88 MHz (in steps of factors of 2)
  - ♦ Modulation index: 40° to 80°
  - ♦ Data rates: 10 bps to 2.2 Mbps

A block diagram of the Tiny Transponder is shown in Figure 2 and a similar block diagram of the Tiny Transmitter is shown in Figure 3. The key elements of the Tiny Transponder design are the Receiver Module, the Transmitter Module and the Power Module. The Tiny Transmitter will utilize only the Transmitter Module and the Power Module. Note that the Reference Generator Module in the Tiny Transponder and Tiny Transmitter are slightly different, but these two versions of the Reference Generator will have the same package design and will have the same interfaces.

TINY TRANSMITTER DIGITAL DESIGN

Telemetry Modulator and Control Module Design (TMCM)

The Telemetry Modulator and Control Module (TMCM) is the main interface between the Tiny Transponder and the spacecraft computer. The TMCM and the spacecraft computer communicate via the spacecraft data bus. The TMCM functional block diagram is shown in Figure 4 and will be implemented in a CMOS ASIC chip. The TMCM receives all the mode control commands to the transponder and transmitter from the spacecraft computer. It then routes these mode control commands to their destinations. The TMCM also collects analog and digital engineering telemetry from the radio subsystem and transponder modules and routes them to the spacecraft computer.

A second major function of the TMCM is to generate the composite modulating signal for the X- and Ka-band downlink carriers. This modulating signal is composed of spacecraft telemetry data, regenerated ranging signals, one-way ranging signals, and status signals.

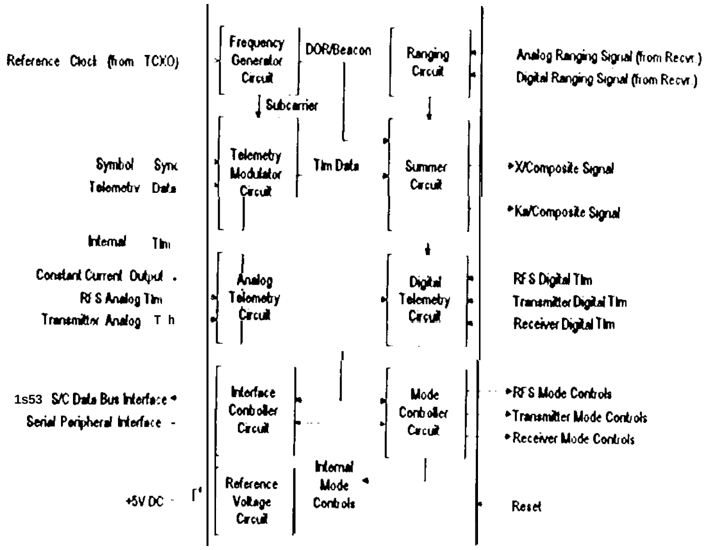

Figure 4- TMCM Block Diagram

The telemetry modulator encodes the spacecraft telemetry data and modulates a telemetry subcarrier with the encoded data, The TMCM functions will be implemented in a full custom ASIC chip which will use a macro ccl] library developed at JPL.

Low Spur Numerically Controlled oscillator Design

The low spur numerically controlled oscillator (NCO) [2] provides direct digital synthesis of the receiver local oscillator and exciter reference. This eliminates the need for voltage-controlled oscillators that require tuning and extra circuitry to correct for frequency drifts during the flight. The NCO functional block diagram is shown in Figure 5. The phase increment input, 0, is equivalent to the desired base band synthesis frequency when operating in the exciter mode or is supplied directly from the digital phase lock loop when operating in the

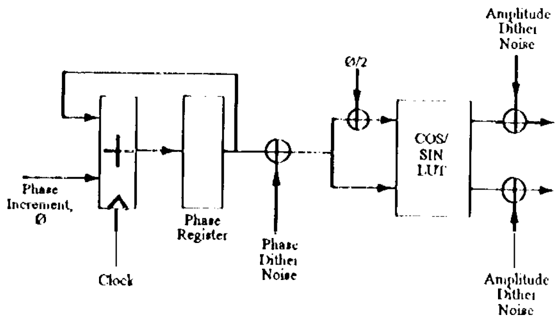

Figure S - NCO block diagram.

transponder mode. The input increment phase is then accumulated and loaded into a phase register.

"1'0 significantly reduce output spur levels without compromising complexity, phase dithering is used after phase accumulation. In this process, a periodic phase dither signal is added to the output of the phase accumulator, The resultant is then truncated to a small number of bits (typically 8 bits are adequate in this design) prior to the sine and cosine table lookups (SIN/COS LUTs). This permits a smaller number of phase bits addressing the SIN/COS LUTs resulting in an exponential decrease in system complexity. Furthermore, analytical and numerical studies presented in [2] show that the phase dithering method provides a spur reduction of 6(M+1) dB per phase bit when the periodic phase dither signal comprises M additive and independent pseudo-noise (PN) sequences. Amplitude dithering following the SIN/COS LUTs reduces the output digital data paths from the NCO without generating significant spurs. This simplifies the design of the subsequent circuitry, i.e., the digital-to-analog converters. The NCO will be implemented in a full custom design ASIC chip which will use the macro cell library developed internally at JPL.

TINY TRANSMITTER MICROWAVE AND DESIGN

Microwave Multi Chip Modules (MCMs)

The microwave circuitry of the Tiny Transponder will be packaged in multi chip modules (MCMs) to enable substantial size reduction. The Tiny Transmitter will utilize two of these modules, one for the X-band and the other for the Ka-band transmitter frequency. The functions of these modules are two-fold: to provide an integral package for the voltage controlled dielectric resonator oscillator (DRO) circuit and remaining exciter circuitry and to provide the interconnecting traces, isolation, and support structure for the various MMICs and other components within the exciter.

The X-band exciter microwave MCM layout is shown in Figure 6 and the Ka-band MCM is of similar design, The planned approach to the design of these MCMs is to utilize multi-layer

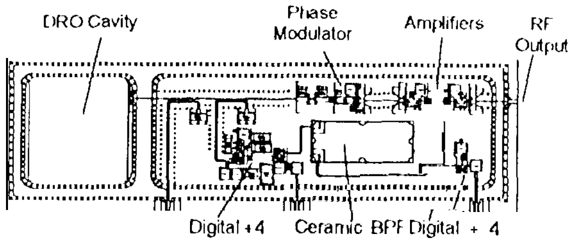

Figure 6- The Physical Layout of the X-Band MCM

low temperature co-fired ceramic (LTCC) substrate with a seal ring brazed to the top surface. A hermetically sealed cover is then welded to the seal ring. The lower surface of the MCM will be bonded to a heat spreader of either kovar or aluminum silicon carbide metal matrix material. Microwave transmission lines in the substrate will consist of buried stripline with microstrip transmission line interface pads where the signal connects to the active devices. The MMICs will be bonded with traditional eutectic solder or silver epoxy. Wedge and/or ball bonding techniques will be used to complete the electrical connections. Traces to external connections will be buried within the substrate as stripline conductors then transition to co-planar waveguide in the LTCC structure once the signal is outside the hermetic seal ring.

The Tiny Transmitter X-band MCM will contain seven MMIC chips, a miniature ceramic microwave filter, and two power dividers. These devices will be placed in cavities in the LTCC structure with access from the top for mechanical and electrical bonding. Internal DC regulator chips, mounted on the top surface above the upper stripline ground plane, will provide low ripple, low noise DC power to the active MMICs. Via holes to lower layer interconnects will distribute DC power to the lower layers where the active MMICs are mounted. The overall size of the X-band MCM including the DRO cavity, as shown in Figure 6, is 65,6 by 19.6 mm The height of the completed MCM is 10.4 mm over the DRO cavity stepping down to 6.5 mm over the rest of the MCM.

Miniature Dielectric Resonator Oscillators (DROs)

The Tiny Transmitter uses two voltage-tunable DROs which will generate the transmitter's two downlink signals at X-band (8.4 GHz) and Ka-

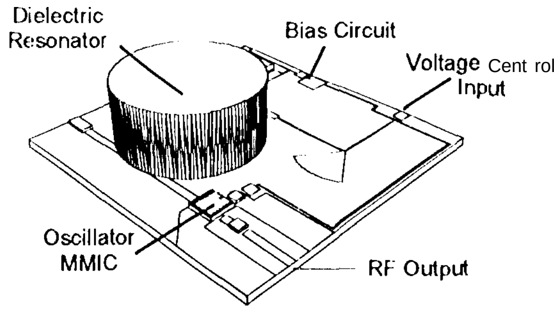

Figure 7- Layout of Typical Voltage Controlled DRO

band (32.0 GHz). The voltage controlled DRO in the Ka-band exciter is generated from an X-band signal (8.0 GHz) which is quadrupled to produce the final 32 GHz Ka-band downlink signal. The DROS are part of two phase-lock loops, each of which is frequency-locked to a 421 MHz signal.

The design of the DROs is based on a Pacific Monolithic OTIO5O MMIC voltage controlled DRO design. It uses a 1 by 1 mm Pacific Monolithics VA1712 MMIC amplifier chip which provides, at its input, the negative resistance conditions necessary for oscillation, The overall size of the resulting DRO layout, shown in Figure 7, is 1.3 by 1.3 mm. This board will be bonded into the MCM board illustrated in Figure 6.

Reference Frequency Generator

A block diagram of the Reference Frequency Generator is shown in Figure 8. It will be designed in two versions. For the Tiny Transmitter tbe Reference Frequency Generator takes a 105.3 MHz output signal from the crystal oscillator and multiplies its frequency by a factor of four to produce a 421 MHz signal. This signal is then filtered, amplified and divided into three equal power signals which are distributed to other modules of the Tiny Transmitter.

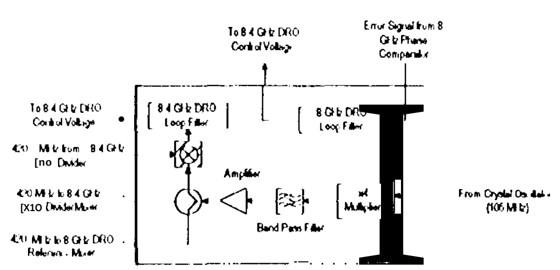

Figure 8 - Reference Frequency Generator Block Diagram

The frequency quadrupler is implemented with two cascaded MMIC mixers which are connected with the same frequency feeding both their RF and LO ports to act as doublers. The filter that follows the quadrupler is a four pole band pass filter which uses lumped capacitors and inductors, The amplifier is a MMIC and the three-way power splitter is implemented as a simple resistive network, to minimize its size. The two loop filters are implemented with single op-amps. The phase detector is a standard double-balanced design that uses diodes and miniature inductor-transformers. This circuit is planed to be implemented using a LTCC circuit board containing hermetically scaled die.

PACKAGING APPROACH

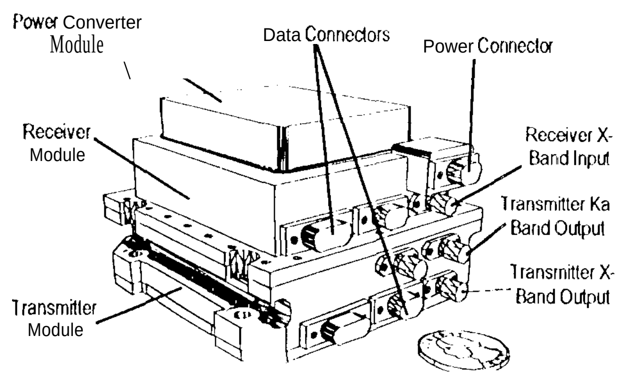

Figure 9- Tiny Transponder Package Concept

The word "Tiny" implies major packaging constraints. The volume goal is < 500 cm^3 and the mass goal is < 700 g. The transponder will operate at both X-band (8.4 GHz) and Ka-band (32GHz) requiring special handling of a number of high frequency signals with low loss, controlled impedance connections. The dual port MIL-STD-1553 interface bus requires significant current outputs and bulky transformers. To minimize cost, a goal was set to minimize the need for custom connectors, beat straps, exotic materials or special machining techniques.

The chassis will be made of 6061 aluminum, using steel inserts for threads. The design , shown in Figure 9 has a 9.3 cm by 9.9 cm mounting area. The package has three layers of circuitry with a total height of 5.2 cm. The power converter, which is 5.0 cm x 6.3 cm x 1.25 cm, is mounted on the top of the stack The total module outside dimensions are 9.3 cm wide x 9.9 cm long x 6.5 cm height. The power converter is mounted external to the module to save volume and mass. Digital and analog input and output signals will usc standard micro 'D' connectors, while the RF connectors arc low leakage SMA and 2.4 mm types, placed for best isolation. A 1553 data bus interface will be integrated into a micro 'D' shell.

SUMMARY

The Tiny Transponder and the Tiny Transmitter will meet the challenging requirements for lower cost, small size and mass of future small deep space missions. These designs will aggressively utilize simplified design architectures, state of the art digital techniques, miniature microwave techniques and advanced packaging Low cost will be achieved by minimizing the number of parts, utilizing custom ASICs for implementing the major transponder functions. It is anticipated the Tiny Transponder will have an order of magnitude lower mass and volume compared with the Cassini Deep Space Transponder at a recurring cost of less than one-fifth of Cassini. The Deep Space Tiny Transponder will be able to meet the needs of the majority of deep space missions and is planned to be available for operational mission in the year 2000 time frame.

ACKNOWLEDGEMENT

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