A Low Cost TDRSS Compatible Transmitter Option

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ABSTRACT

The NASA Space-based Telemetry and Range Safety (STARS) program has developed and tested a low cost Ku-Band transmitter alternative for TDRSS applications based on an existing IRIG shaped offset quaternary phase shift keying (SOQPSK) transmitter. This paper presents information related to the implementation of this low cost system, as well as performance measurements of the alternative TDRSS transmitter system compared with an existing QPSK TDRSS transmitter.

KEY WORDS

TDRSS, Ku-Band, SOQPSK, STARS, Low Cost TDRSS Transmitter

INTRODUCTION

The STARS study was established to demonstrate the capability of a space-based platform to provide range user (telemetry) and range safety support to supplement remote ground-based assets and to do so with a significant increase in the range user system data rate. The savings in ground-based support is a factor in realizing goals of an order of magnitude reduction in payload costs for the next generation launch technology reusable launch vehicle (RLV). The STARS study is an attempt to develop the hardware required to implement a reliable space-based high data rate communication link and to demonstrate an order of magnitude increase in data transmission rates compared to present day systems.

The current range user systems do not have the performance to meet requirements for NASA's future launch vehicles. These systems are limited in data rate and have a rigid format (IRIG-106). [1] Furthermore, because the current systems require the operation and maintenance of remote ground-based sites, the operational cost is high.

The STARS Phase 1 flight demonstration [2], completed in 2003, utilized existing S-Band hardware in order to baseline the performance of current systems and evaluate operation considerations for future space-based ranges. STARS Phase 2 planning [3] included the development of a high data rate Ku-Band transmission system utilizing an Internet Protocol (IP) data format and high gain phased-array antenna in order to demonstrate the capabilities required for future space-based ranges. The range user (telemetry) transmitter portion of this system is based on an existing TDRSS IV design. However, early on in the project it was determined that alternative, low cost, transmitter options should also be considered. Therefore, both a TDRSS IV and low cost alternative transmitter systems were developed for flight testing.

The Tracking and Data Relay Satellite System (TDRSS) is designed for use with binary phase-shift keying (BPSK), quaternary phase-shift keying (QPSK) and offset quaternary phase-shift keying (OQPSK) modulation schemes. Unfortunately currently qualified TDRSS-compatible transmitters are extremely expensive and there are limited transmitter options, especially for K-band applications. NASA Goddard Space Flight Center (GSFC) (Greenbelt, Maryland) has conducted simulations of Inter Range Instrumentation Group (IRIG) Tier 1 modulation and similar waveforms that promise the possibility of a low cost alternative for TDRSS applications. These waveforms also offer a secondary benefit of reduced bandwidth requirements.

The data presented indicates that IRIG-based hardware should be capable of providing a low cost TDRSS option for Ku-Band and S-Band TDRSS return link applications. Although the existing IRIG transmitter hardware is not currently space qualified, it can satisfy TDRSS transmitter requirements for terrestrial and suborbital applications. One area of interest for NASA Dryden Flight Research Center (DFRC) (Edwards, California) is Uninhabited Aerial Vehicle (UAV) applications, since cost and weight are a significant concern for UAVs.

OVERVIEW OF PHASE-2 OBJECTIVES

The baseline range user system performance for current expendable launch vehicles (ELVs) is inadequate in two areas. First, the data rate that can be achieved with an omnidirectional antenna is limited because of the free space loss involved in satellite transmission. The preferred option to increase this data rate would be the use of a phased-array antenna system. Second, the link implemented for the first flight demonstration was a standard IRIG-106 data link. The preferred option for future satellite telemetry data links would be an IP based link allowing uplink command and control, real-time changes in data format, and repeat requests of corrupted data.

The primary range user system objective for the STARS Phase-2 is to increase the achievable data rates through the development of improved data transmission hardware. The greatest weakness in current satellite telemetry systems is the vehicle transmit antenna. Currently most RLVs and ELVs utilize multiple omnidirectional antennas. These systems may be supplemented by switching hardware to direct transmitter power to the antenna pointed at the “receive” satellite, however, these are limited by the transmitter power available and low gain antenna utilized. UAVs often make use of steerable dish antennas to achieve increased gain and therefore improved data rates.

However, these systems result in the requirement for a radome well above the vehicle surface resulting in thermal problems for launch vehicle applications or limited look angles if recessed in the vehicle.

TRANSMIT SYSTEM OPTIONS

Three transmitter options were investigated, including the development of a BPSK Ku-band TDRSS IV transmitter, use of a newly developed SOQPSK transmitter with a Ku-band up-converter and amplifier, and a commercial QPSK modulator with a Ku-band up-converter and amplifier. The first two options were developed for possible flight test.

LOW COST SYSTEM OPTION

The SOQPSK option, Figure 1, offered the advantage of a spectrally efficient transmitter that is already qualified for the aircraft environment and is compatible with the current IRIG-106 standard Tier 1 transmitter hardware. SOQPSK is offered in two versions, A and B. [4] Compatibility simulations at NASA GSFC have demonstrated that SOQPSK (Version B) offers a 1dB to 2dB TDRSS implementation loss advantage over SOQPSK (Version A). The implementation loss characterizes compatibility issues the TDRSS receivers may have with the transmit system utilized. [5] Therefore, the selected SOQPSK transmitter used for STARS flight demonstrations are SOQPSK (Version B). This loss required a firmware change to the transmitter modulator currently commercially available, SOQPSK (Version A), to allow the use of existing low cost flight-qualified hardware.

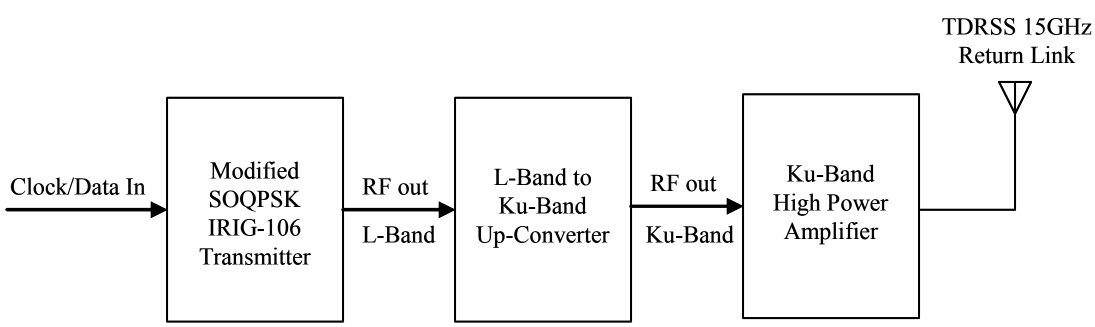

Figure 1: Low Cost Transmitter Option

The SOQPSK transmitter selected was an L-Band unit with the RF amplifier removed, which resulted in an output power of approximately 10 mW. This lower output power simplified development of the up-converter and reduced vehicle EMI and RFI concerns. The up-converter utilizes a 13.5 GHz local oscillator (LO), which when mixed with a transmitter output set to 1503.5 MHz results in a frequency component at 15.0035 GHz. Although the nominal TDRSS center frequency is 15.0034 GHz the TDRSS receiver can be tuned to 15.0035 GHz, making use of the low cost system feasible.

The high power amplifier (HPA) amplifies the up-converter output to 20 Watts and feeds a phased-array antenna [6] which provides sufficient gain to close the link to TDRSS at data rates greater than 5 Mbps.

TDRSS IV TRANSMITTER OPTION

The TDRSS IV transmitter option utilized existing components from a previous TDRSS IV BPSK development effort. The system does differ from the previous system in that it was flight-test qualified, while the previous unit was only developed as a bench test proof-of-concept effort. However, with minor changes in the assembly and fabrication process the unit was qualified for flight testing. The TDRSS IV system, figure 2, utilizes the same HPA and phased-array as the low cost transmit system and is also capable of data rates greater than 5 Mbps.

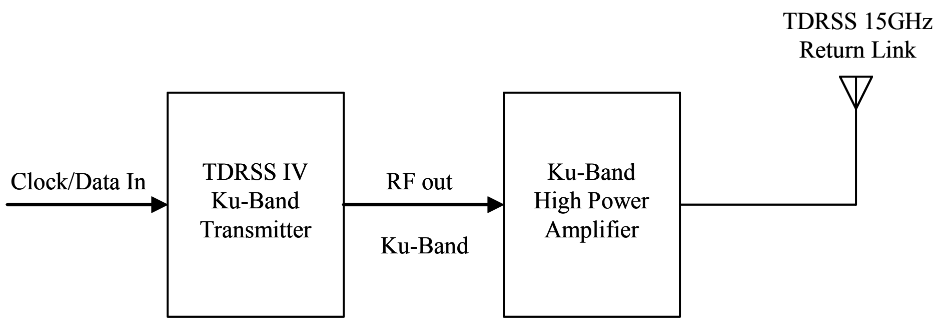

Figure 2: TDRSS IV Transmitter Option

COMPATIBILITY TEST RESULTS

The TDRSS IV and Low Cost transmitter systems were both compatibility tested in the TDRSS Compatibility Test Laboratory at the NASA Goddard Space Flight Center. Testing indicated that both systems are compatible with Ku-Band TDRSS operation.

TDRSS IV TRANSMITTER RESULTS

The BPSK TDRSS IV transmitter tests utilized the Ultra High Rate Demodulator (UHRD) at the White Sands Complex (WSC) (Las Cruces, New Mexico). This demodulator is used for BPSK at greater than 3 Mbps and QPSK if the I or Q channel rate is greater than 3 Mbps. The 5 Mbps bit error rate (BER) compared with the ratio of bit energy to power spectral density (Eb/No) plot for the TDRSS IV transmitter compared to an ideal transmitter is shown in figure 3. The transmitter performed as expected and is to be utilized as the primary option for STARS flight demonstration #2 testing.

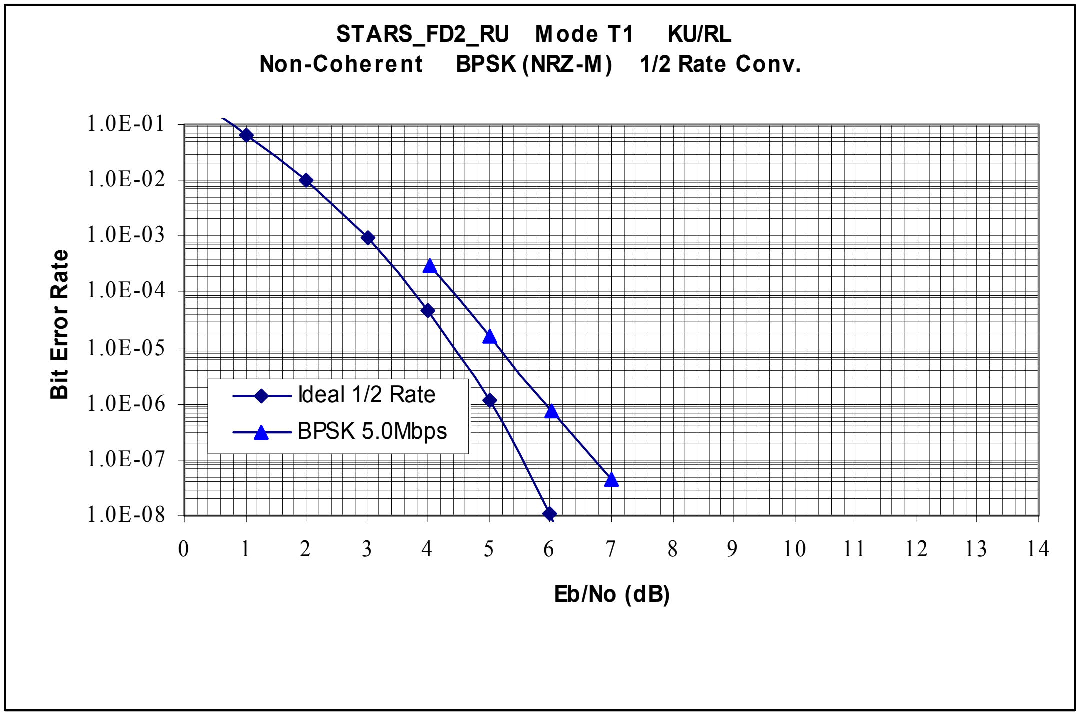

Figure 3: TDRSS IV 5Mbps BER Test Results

LOW COST TRANSMITTER RESULTS

The Low Cost SOQPSK transmitter compatibility test used the integrated receiver (IR) at WSC. The IR was utilized as the I and Q channels were at 2.5 Mbps for a 5 Mbps data rate, which is less than the 3 Mbps threshold requiring use of the UHRD. Since the IR was used, there is a slight performance improvement as compared to the BPSK TDRSS IV transmitter approach that utilizes the UHRD. The resulting BER plots of data collected at 5 Mbps, 3 Mbps and 1 Mbps for the low cost transmitter are shown in figures 4, 5, and 6.

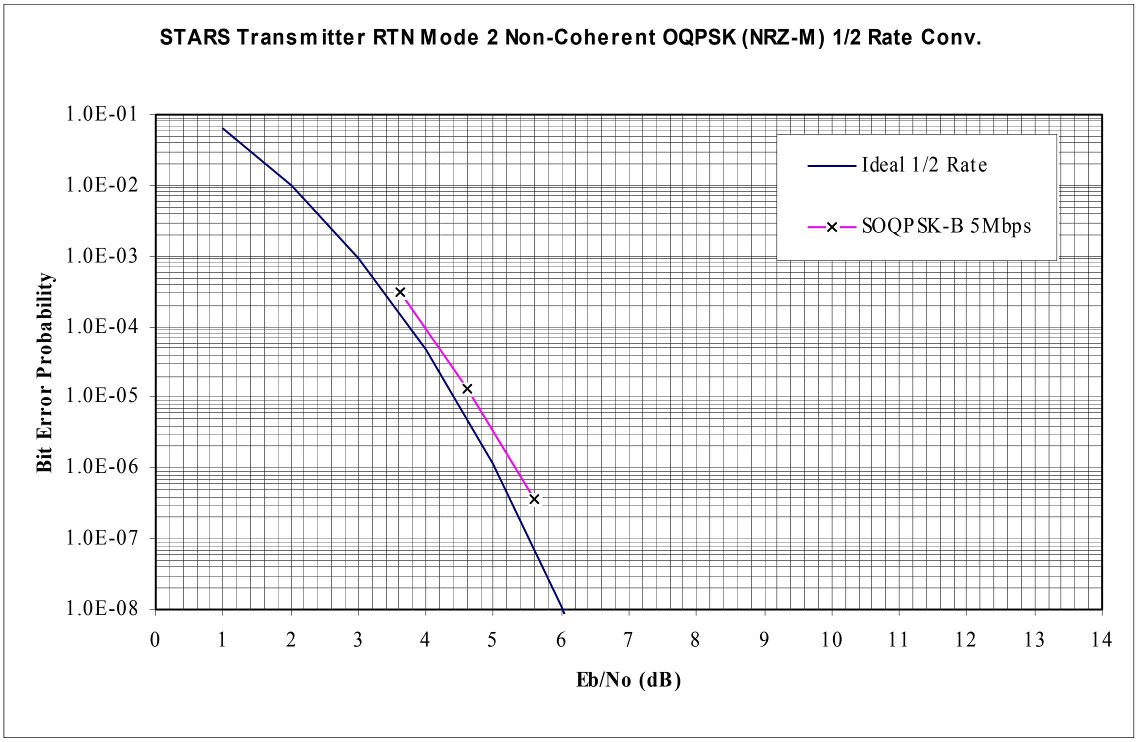

Figure 4: Low Cost Transmitter 5 Mbps BER Test Results

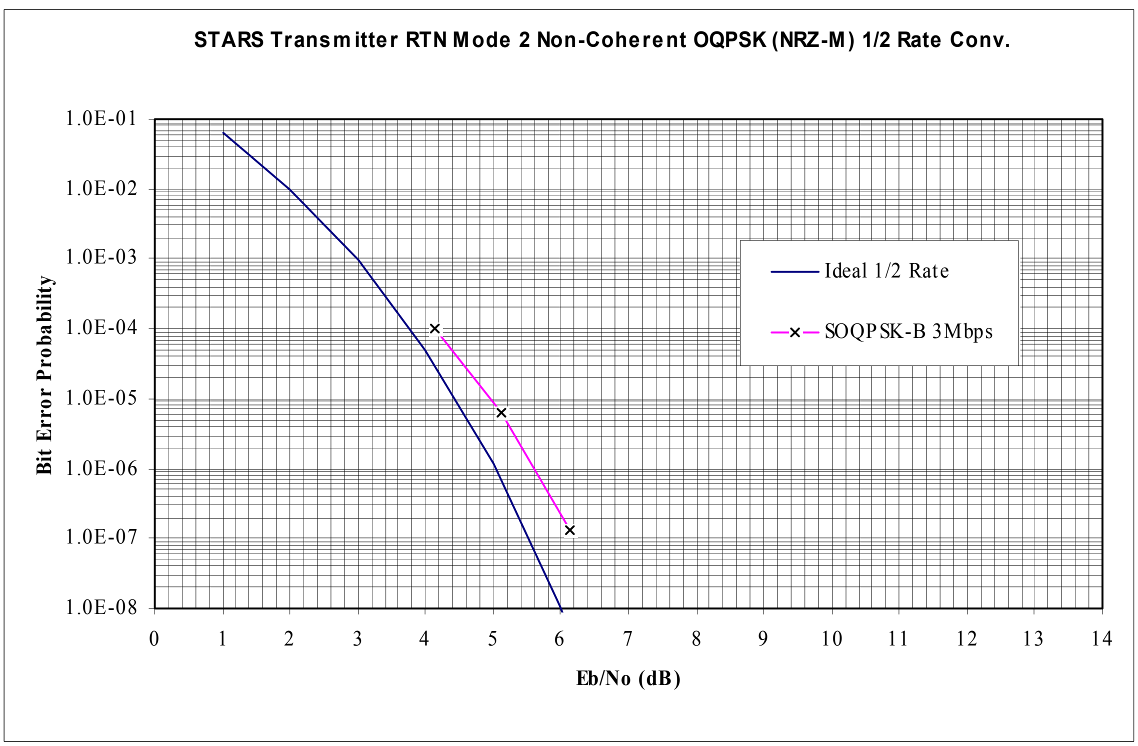

Figure 5: Low Cost Transmitter 3 Mbps BER Test Results

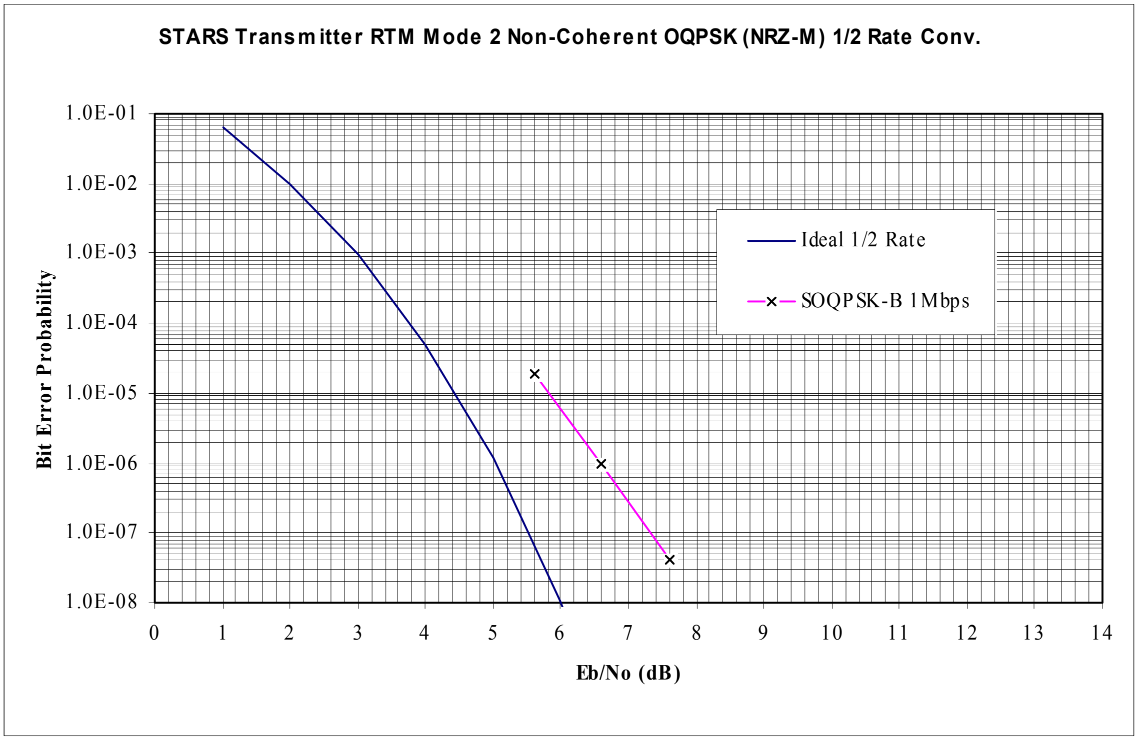

Figure 6: Low Cost Transmitter 1 Mbps BER Test Results

The low cost transmitter BER plots indicate that performance is similar to that of the TDRS IV transmitter. The reduced SOQPSK performance at lower bit rates has been observed in the IRIG Tier 1 system tests and is most likely related to receiver performance. Phase noise adversely affects the receiver carrier tracking loop and increasing the receiver bandwidth tends to improve detection performance. Although this may not be the case with the TDRSS receiver, it is the most likely cause. The performance data collected at 1 Mbps appears to agree with prior GSFC simulations.

CONCLUSION

The Tracking and Data Relay Satellite System (TDRSS) compatibility test results indicate that the proposed low cost approach is feasible and can result in an order of magnitude cost savings. Some minor operational issues were encountered with the TDRSS receiver when using this transmitter for the first time, but these problems were quickly resolved. Although testing has not been completed to date, it is also likely that current IRIG Tier 1 S-Band transmitters can be used with TDRSS, with minor firmware modifications resulting in a very low cost and readily available option for S-Band TDRSS. These transmitters are also an especially interesting low cost option for future UAV applications.

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