# SWITCHED TELEMETRY SYSTEM (SwTS) STANDARD FOR BIDIRECTIONAL TELEMETRY INTEROPERABILITY

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## ABSTRACT

A look at the standardization of bidirectional Switched Telemetry Systems (SwTS) while leveraging existing telemetry receivers and transmitters. This paper will cover how current IRIG standards would include the use of existing telemetry components to support interoperability of bidirectional links across multiple vendors. Key system design aspects in transmit power control, receiver synchronization and RF switching components to allow multiple vendor interoperability are presented. These bidirectional SwTS systems based on upgrading current systems will leverage decades of work by the government and vendors to create error free down-link telemetry links under difficult RF environments. Key design areas providing for multi-vendor compatibility of bidirectional telemetry will be identified which is based on the development and testing of a SwTS system. Standardization of system configuration, in flight status and control required to support fielded SwTS systems will also be covered.

## INTRODUCTION

The IRIG-106 telemetry communications standards provide a common reference for the formatting, transmission, reception and recovery of streaming data during operation on test ranges. These standards first evolved, and continue to evolve, in order to increase the reliability of communication down-links, accommodate new device capabilities, and to overlay packet-based communications into the existing serial streaming telemetry systems. As a part of the nine recently added TmNS telemetry network chapters, chapters 27 and 28 currently introduce a new bi-directional networking waveform to provide up-links to test articles. With transmitter switching requirements supporting ten or more networked transceivers and coupled with a burst waveform format which is not directly supported by current range hardware, new TmNS transceiver device implementations are required which don’t always translate well from the existing streaming telemetry waveform. The focus of this paper is the investigation into a switched telemetry bi-directional capability standardization that would leverage the latest streaming telemetry transmitters and receivers across multiple vendors as an option for providing bi-directional telemetry links. The first section of this paper identifies bi-directional switched telemetry elements in the TmNS standard and the relation to current streaming telemetry components. The second section describes a bi-directional system implementation which leverages current streaming telemetry components. The third section contains some potential areas for standardization in the implementation of a SwTS system. The fourth and final section contains areas of the TmNS standards which are of interest when re-purposing streaming telemetry components when building a TmNS burst waveform compatible transceiver.

# CHAPTER 1 – TEST RANGE BIDIRECTIONAL SWITCHED TELEMETRY

## Background

In a traditional telemetry system test articles and ground systems are configured with one or more frequencies to carry data during test from low gain antennas mounted on mobile platforms to high gain antennas on tracking ground systems. The challenge of closing long rage links with low level RF signals from fast movers, with deep fading and multi-path has evolved into very reliable telemetry data recovery systems. Some of the facilitators of the current capability success are arguably standardization, cross vendor support and incremental introduction of new features. Bidirectional telemetry capabilities, where an up-link capacity is added to the existing down-link capacity is yet to be in wide scale use due to several factors one of is likely the development of bi-direction transceivers by existing vendors. The TmNS standards include description of a burst waveform to provide bi-directional capability though engineering a migration path from current transmitters and receivers can be a challenge.

## TmNS Path to Bi-directional Capability on the Test Ranges

The advantages of adding an up-link capability to the test article in parallel with existing down-links was introduced in the test range community as one part of the TRMC program called iNET [1]. The iNET program and the resulting IRIG 106 TmNS standards [2] have the goal of providing a common framework to provide networking capabilities such as packet-based bidirectional IP addressable communications to meet a common range operational capability defined early in the program. Though the TmNS standard is broader than the challenge of providing an up-link telemetry link it is a key technology that supports many other parts of the standard. The design of the bi-directional capability in the iNET program and TmNS RF standard burst waveform was driven in part by the needs of the larger ranges to support frequency use efficiency while supporting many simultaneous missions without essentially doubling the number frequencies needed. The resulting channel access approach was to share frequencies by time-division creating repeating transmit slots.

## TmNS Based Channel Access

Chapter 28 of the TmNS standard describes an RF Media Access Control Layer to implement transmission segments containing user data and supporting control data. The first part of the standard addresses packing efficiency. In packet-based networks user packets of various lengths up to a maximum size may be received for transmission over a non-continuous transmit channel as occurs in time division channel access. The distribution of user packets over the non-contiguous transmission slots and the resulting efficiency can range based on the methods employed. TmNS performs packing of user packets within the context of an LDPC block and a transmit time which then can hold multiple burst each containing multiple LDPC blocks. The maximum over the air bit rate for one repeating transmission slot is then:

$$\text{RfBitRate} = (\text{codeBlockMax} * \text{codeBlockInfoRate} * 1/\text{slotRepeatRate})$$

Also contained in Chapter 28 is the establishment of a Logical Link Control Layer which describes how transmission slots are assigned and can be dynamically managed based on traffic loads to attempt further efficiency in the use of an allocated frequency. The majority of Chapter 28 does not preclude the use of existing serial streaming telemetry transmitters and receivers if a high-speed external controller is added to implement the data formatting, transmit/receive time synchronization and management protocols. The implementation of the Chapter 28 capabilities in an external controller can be a significant undertaking for a telemetry vendor to add to an existing product line and establishing a bi-directional RF link capability is a key part of the effort.

## TmNS RF Waveform Physical Layer

With the combination of waveform methods used in wireless networks such as 802.11 and current accepted test range modulation of SOQPSK a burst waveform design was developed in the iNET program which was then defined in TmNS Chapter 27. The transmission burst waveform from the standard is shown in Figure 1. The waveform uses the configured LDPC code block information size to set the granularity used for packet aggregation and fragmentation. The LDPC blocks containing packets to be transmitted are assembled into the burst format and sent in an allocated transmission slot. The 128-bit preamble is set from a flushed trellis state containing a repeated period-16 ternary symbol sequence. An attached synchronization marker follows the preamble at the beginning of the RF burst. The code blocks containing the data packets and fragments to be sent have a specified pseudo-randomizer applied to ensure coded symbols are spectrally near white. A transmission slot in which one or more these RF bursts are sent has a standard maximum switching time for transitions as shown in Figure 2. Receive to transmit (R/T) is specified as the time the transceiver switches from receiving data to capable of transmitting the first bit of data $T_{ON}$ which is defined as a maximum of 25uS. For transmit to receive events, the maximum time is specified as the time from when a transmitter is switched off to the point power is no longer present at the output, $T_{OFF}$ is defined as 15uS. These switching times though achievable in a completely new design trading speed over other design criteria, they are not necessary values that support reuse of existing telemetry components where fast switching has not previously been a requirement.

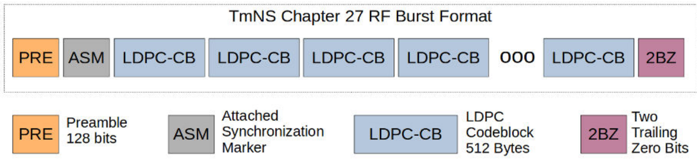


Figure 1: TmNS waveform

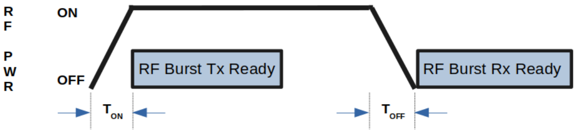


Figure 2: TmNS Transmit-Receive Switching

## TmNS Compatibility Challenges for using Existing Transmitter and Receiver Components

The TmNS time division channel access can be implemented with an external bi-directional controller with sufficient CPU and FPGA bit processing resources inserted between the Ethernet wired interface and the clock and data receiver and transmitter interfaces. An RF switch component is required to multiplex the antenna to the transmitter and receiver when a single antenna is used. The RF switch is operated by the bi-directional controller which coordinates the transmit and receive data operations. One challenge when implementing a TmNS compatible waveform using existing telemetry transmitters and receivers is the synchronization of the physical layer burst waveform with current streaming telemetry. The data interfaces to these standard components are clock and data (or just data for clock free operation) with the transmitters not having any type of synchronization to the input data content. As discussed, the TmNS waveform aligns packets to be transmitted with LDPC code blocks which is a capability not normally required of streaming telemetry transmitters. In addition, the waveform further requires modulation symbol alignment with the initial burst preamble. Changes to the internal operations of transmitters to synchronize to the formatted input burst on modulation bit and LDPC coding levels is required. Likewise, another difference between a streaming and burst waveform, is that the burst receiver needs to use the preamble and ASM marker to resolve a start of packet and frame boundary and synchronize LDPC decoding with the data that follows the ASM instead of synchronization to a continuous stream of LDPC blocks.

### Bidirectional Transmitter and Receiver Switching

With respect to the starting and stopping of data, this is mainly a receiver issue and is not just a TmNS compatibility design issue, in that it applies to any switched telemetry transceiver implementation. Advanced telemetry receiver implementations should already have a fast signal acquisition capability to respond quickly to interruptions to the continuous streaming RF signal. Though the acquisition algorithm and specific methods for the equalization of received signal level need to be adapted a non-contiguous RF signal. The recovery of data quality metric information also needs to be collected only during a valid data reception period. On the transmitter side user data packets need to be inserted within a transmit slot at a time which is coordinated by the transmitter and tracked by the receiver. The tracking of a received waveform can be aided by a pause and hold method in the receiver at the end of the valid data time. For bi-directional links involving multiple transmitters sending to a receiver, the receiver tracking effectiveness can be increased by having the receiver store multiple transmitter source information.

## CHAPTER 2 – SYSTEM IMPLEMENTATION

### Bidirectional Transceiver Overview

The bidirectional transceiver architecture discussed in the previous section which leverages existing transmitters and receivers for switched telemetry capability as well as creating a baseline platform for a switched telemetry TmNS standard capability is shown in Figure 3. The quantitative results of testing this system can be found in [5]. The switched telemetry transceiver is component-based system which includes a bi-directional controller with both CPU processing capability augmented by FPGA resources for high-speed bit processing and control. An operating system with an Internet Protocol (IP) stack provides the basic framework for the bi-directional link application. The receiver selected is a rugged small form factor capable unit for deployment on airborne test articles. The receiver is connected by way of serial data and clock outputs to the bit level processing contained in the bi-directional controller. The transmitter likewise needs to have a small form factor and rugged implementation though is more common in existing telemetry systems. The transmitter has a data interface to the bit level processing and a switchable high power RF output. Transmitters and receivers can be selected based on desired frequency range, modulation and other capability. The antenna configuration can be either a single bi-direction RF interface to a single antenna or separate feeds to separate antennas. The two-antenna configuration is supportive of customization of the up-link design allowing a lower data rate and corresponding antenna gain requirements. Implementations

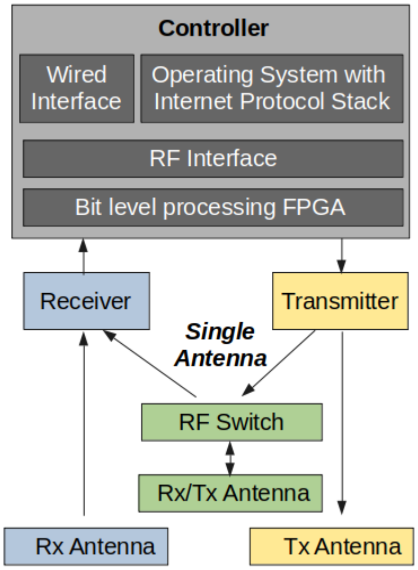


**Figure 3: Bidirectional Transceiver System**

with separate receive and transmit connections also supports the capability of re-configuring a TDD system into a two channel Frequency Division Duplex (FDD) system.

## Bidirectional Controller

The bidirectional controller used was a Quasonix Node Controller Unit which provided a translation between Ethernet and switched serial streaming interfaces of the transmitter and receiver as shown in Figure 4. The node controller maintained the timing between transmit and receive events with control signals to an RF switch. The clocking of packets contained within a serial data stream is handled by bit processing in the bidirectional controller. The controller also coordinated the transmitter and receiver operations to perform the required transmission and receive events. The controller also performs the buffering of packets when in receive mode or during periods when the Ethernet interface receive rate exceeds the RF transmit rate. When required, the controller inserts link control packets along with the user data packets. An example of a control packet which could be sent is a receiver sync message allowing the receiver to recover valid link quality information. The node controller can be designed to pass user packets at the wired interface at layer 2 bridging the ground and test article networks with Ethernet. Alternatively, it can be designed to act as a IP forwarding node accepting and forwarding IP packets that have been sent to it via the wired interface. The switched telemetry application running on the bi-directional controller in this system implementation was configured to create a bidirectional layer 2 Ethernet bridge between the test article and ground network wired connections.

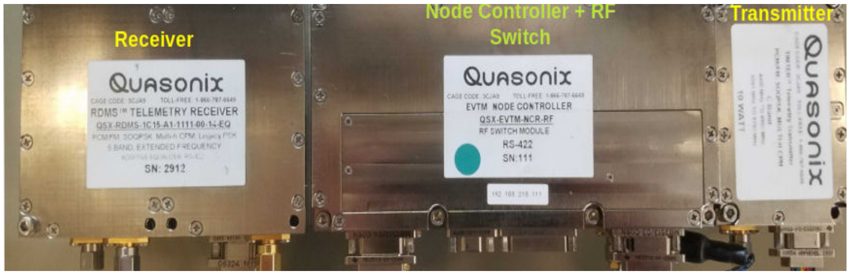


**Figure 4: Bidirectional Transceiver Reference Hardware**

## Receiver

The switched telemetry receiver implementation was a Quasonix RDMS$^{TM}$ compact receiver unit [3] shown in Figure 5. The interface to the receiver consisted of a RS-422 serial data interface, a RS-232 control port and a receiver signal freeze control line. The receiver active receive time was controlled by the bi-directional controller based on receiver freeze state control messages received at the start and stop of a reception window. When the receiver freeze message is received by the bi-directional controller, the state of the receiver active line is set based on the control message type received. In addition to the receiver active message the receiver sync message also used in the reference implementation was an Ethernet packet containing a 14-byte sync word and 36-byte receiver status metadata field. The sync word had no runs of 1s longer than 4 and starts and ends with a 0 to avoid being corrupted by bit stuffing occurring in the bit processing prior to reception by the bi-

**Figure 5: Receiver**

directional controller. It also had good auto-correlation properties and sufficient length to avoid false detection with a correlation threshold set low enough allow detection at relatively high BER.

### Transmitter

The reference implementation used a Quasonix TIMTER$^{\text{TM}}$ transmitter module [4] shown in Figure 6 containing a RS-422 serial data input, RS-232 control interface, transmit power control input line and RF output. The transmitter was configured for the link by serial control connected to the bidirectional controller. A single hardware control line for RF power was used to switch transmit RF power. The switching time of the transmitter was measured by observing the transmitter output RF output switch when a RF off-on-off pulse was applied captured as shown in Figure 7. To achieve the high switching speed the transmitter had a minor hardware modification by reducing the value of a filtering capacitor in an output stage transistor gate bias circuit.

Figure 6: Transmitter

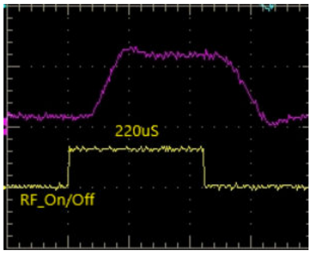


Figure 7: Transmit Switching

### RF Switch

The RF Switch used in the reference system is shown in Figure 8. The RF switch was a Quasonix RF switch component developed for bidirectional telemetry applications. Three external RF interfaces on the RF switch supported the multiplexing of the receiver input and transmitter output with the antenna RF interface. The RF Switch implementation used supported C-band and S-band operation by way of a control line from the Bi-directional controller. The antenna port selection input control was connected to an output line from the bidirectional controller allowing the RF coordination of receive and transmit events.

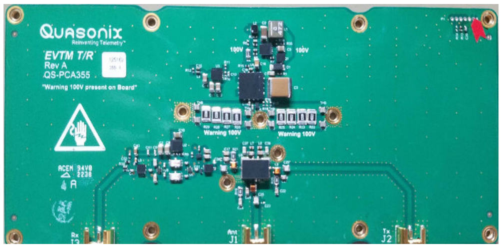


Figure 8: RF Switch Component

### RF Switch Control

For a single antenna application using the RF switch the bidirectional controller sets the timing of the transmitter RF power on and the RF switch port select lines. When the RF power is controlled off a delay is inserted during switching operations to provide isolation protection of the receiver input. The delay protects the high-powered transmitter RF output from damaging the sensitive receiver RF input.

### System Management

To control the transceiver, the browser interface shown in Figure 9 along with a command line interface was used. The control is served directly from the ground station node controller with local and remote status and control. System settings presets are used to load link configurations. For the browser interface the client-side and server-side leveraged HTML5, JavaScript and Python. A standard REST API [6] (also known as RESTful API) embedded server was added for custom application remote command, control and monitoring.

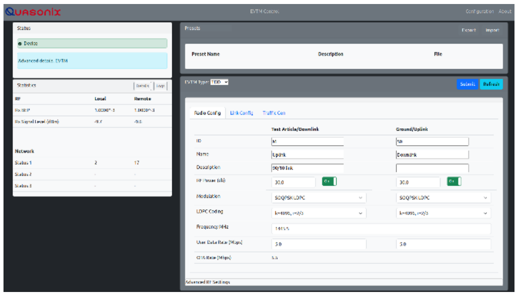
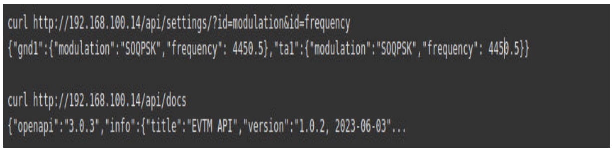


Figure 9: Browser Interface

An example of a REST API command call is shown in Figure 10. This uniform interface supports integration with existing receivers, transmitters and test equipment as well as client-designed interfaces. The embedded REST API was based on the Standard Telemetry Receiver Control Interface (STRCI) for the USAF AFTC and includes embedded OpenAPI 3.0 standardized documentation [7].



```
curl http://192.168.100.14/api/settings/?id=modulation&id=frequency
{"gnd1":{"modulation":"SOQPSK","frequency": 4450.5},"ta1":{"modulation":"SOQPSK","frequency": 4450.5}}

curl http://192.168.100.14/api/docs
{"openapi":"3.0.3","info":{"title":"EVTM API","version":"1.0.2, 2023-06-03"...
```

Figure 10: Rest API Control

# CHAPTER 3 – SWITCHED TELEMETRY STANDARDIZATION AREAS

## Overview

Some of the key switched serial streaming telemetry areas of potential standardization are listed in this section based on the reference system implementation previously described. The areas of potential standardization are not necessarily intended to be a drop in text for a standard, instead they are intended to reveal potential discussion points for developing switched bi-directional systems that support interoperability. Table 1 lists potential areas of interest when implementing a bi-directional transceiver component to a standard interface.

| Area of Interest | Receiver | Transmitter | RF Switch | Controller |
|---|---|---|---|---|
| **SwTS-1 Serialized Packet Framing** | *No* | *No* | *No* | *Yes* |
| **SwTS-2 Asynchronous LDPC** | *No* | *Yes* | *No* | *No* |
| **SwTS-3 Control Messaging** | *Yes* | *No* | *No* | *Yes* |
| **SwTS-4 Time Synchronization** | *No* | *No* | *No* | *Yes* |
| **SwTS-5 RF Switching** | *Yes* | *Yes* | *Yes* | *Yes* |

Table 1: SwTS Areas of Interest

## SwTS-1 Serialized Packet Framing

If serial data-based transmitters and receivers are to be used as the basic framework of sending packet data, then a packet delineation method needs to be employed. Packets to be transmitted in the reference system are serialized and sent within the transmit slot as a serial stream with packets delineated with flag bytes. A light weight marking mechanism [8] derived from the HDLC protocol

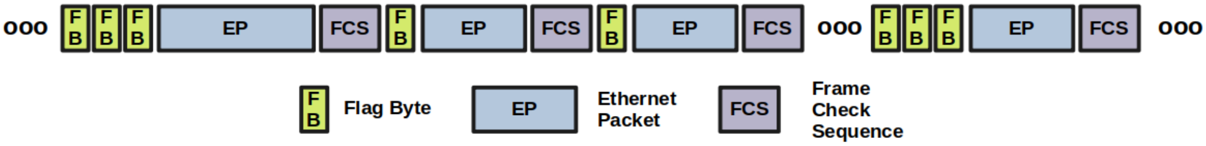


Figure 11: Serialized Packet Framing

was used as shown in Figure 11. The overhead associated with the bit stuffing process adds to the over the air rate requirement though is typically limited to a few percent or less of data rate sent [5]. The bit formatting in the bidirectional controller generates the flag bytes (0x7E) when no packets are ready for transmission. When a packet is ready for transmission a frame check sequence (FCS) is appended at the end of the packet in addition to a flag byte. On the receiving side the bidirectional controller receives a bit stream and searches for a packet start flag byte. The FCS is validated on receive to allow for the removal of corrupted packets.

### SwTS-2 Asynchronous LDPC

In operation when LDPC is enabled, the packet bit streams from the bidirectional controller are loaded into LDPC code blocks for transmission with no relationship between packet data and LDPC code blocks as shown in Figure 12. This allows a transmitter to generate LDPC blocks using existing methods with serial streaming telemetry. The penalty for using this method is that one additional code block size length of time needs to be allocated in the data window with an associated one LDPC code block per transmission window loss of efficiency.

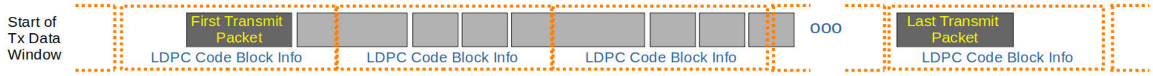


Figure 12: Asynchronous LDPC Operation

### SwTS-3 Control Messaging

The control messaging inserted and processed by the bidirectional controller shown in Figure 13 permits valid data time acquisition by the receiver, generation of time windowed data quality metrics and support for time coordination. A method of relaying receiver freeze control and data quality synchronization was also contained in control messaging. The control messages shown, or other mechanisms used to coordinate the bidirectional link would be candidates for standardization.

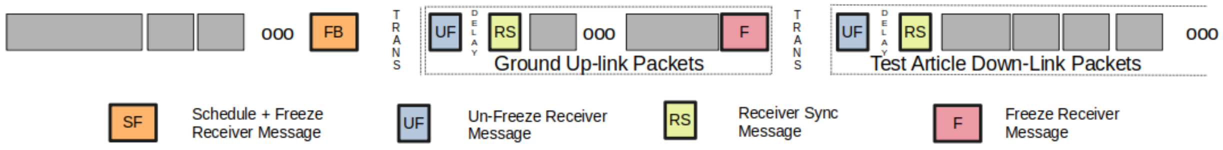


Figure 13: Bidirectional Control Messaging

### SwTS-4 Time Synchronization

An operating mode when the test article sets the timing for up-link transmission which does not require common time-synchronization such as GPS, was implemented in the reference system. In this link mode test articles schedule master node sends a schedule message which sets the timing for the uplink transmissions. One or more ground station nodes then use the arrival time of the message to set the transmit window.

### SwTS-5 RF Switching

The sequence of events that define the direction of the transmit to receive path for a bi-directional link is represented in Figure 14. The switching time of the transmitter and receiver results in a data window where control and user data packets can be transmitted.

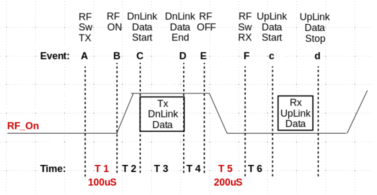


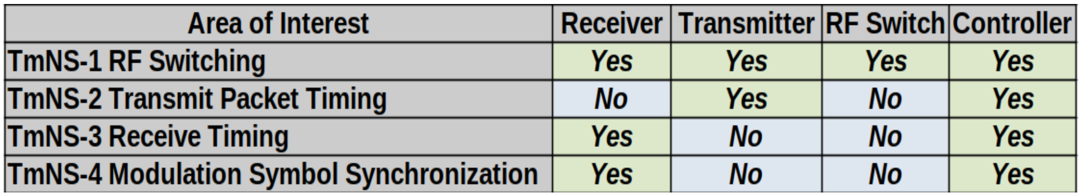
Figure 14: RF Switching

For vendor interoperability the timing values associated with the link switching would have common configuration parameters.

## CHAPTER 4 – TELEMETRY NETWORK STANDARD (TmNS)

### Overview

Some of the key areas which provide elevated levels of engineering when re-purposing streaming telemetry components as TmNS transceivers devices are listed in this section based on an analysis of reference system. These are intended to delineate potential areas of engineering effort when implementing a TmNS design which starts with a streaming telemetry component framework. Table 2 lists these key areas and the corresponding relation to bi-directional transceiver components.



| Area of Interest | Receiver | Transmitter | RF Switch | Controller |
|---|---|---|---|---|
| TmNS-1 RF Switching | *Yes* | *Yes* | *Yes* | *Yes* |
| TmNS-2 Transmit Packet Timing | *No* | *Yes* | *No* | *Yes* |
| TmNS-3 Receive Timing | *Yes* | *No* | *No* | *Yes* |
| TmNS-4 Modulation Symbol Synchronization | *Yes* | *No* | *No* | *Yes* |

**Table 2: TmNS Areas of Interest**

### TmNS-1 RF Switching

The RF switch connects an antenna to either the transmitter or receiver depending on the mode of the transceiver. When reusing existing transmitter and receiver components this would be generally be implemented as an external component under control of the bidirectional controller. The RF switch control line is activated based on the transmit window as determined by the current configuration of the TmNS node. The switching time between receive and transmit ports is dependent on the hardware implementation and is added to the overall system receiver and transmit packet timing. Supporting longer switching times would facilitate re-use of existing RF switch designs.

### TmNS-2 Transmit Packet Timing

The receiver to transmit packet timing is composed of selecting transmit mode on the RF switch, engaging the high-power output on the transmitter and the introduction of the first burst waveform to be transmitted. A high-speed bit processing method is required to create the burst waveform and meet the first packet timing deadlines called out in the standard. Support for receive to first packet transmit times which were on the order of 200uS vs the standard value of 25uS could help facilitate transmitter re-use.

### TmNS-3 Receive Timing

The receiver design changes when going from a streaming telemetry system to a TmNS burst waveform recovery can be significant. The valid burst search and synchronization algorithm and a LDPC block decode operation which is synchronized with the start of frame format both represent changes from an existing streaming telemetry receiver operation. Allowing a receiver to synchronize on one or more non-user data LDPC code blocks at the beginning of a burst as an alternative to processing the start of burst information, might be one method to facilitate receiver re-use.

## TmNS-4 Modulation Symbol Synchronization

As previously discussed, the serial streaming transmitters have no requirement to synchronize data to modulation symbols. If this aspect of the standard could be removed, it would allow standard transmitters to generate the burst waveform data under the control of a bi-directional controller without modification to align the burst data to modulation.

## CONCLUSIONS

A description of the TmNS and switched telemetry methods was given to provide a framework for understanding these two approaches. A switched telemetry transceiver reference design was presented that can be built with low impact to the receiver and transmitter components to provide a bidirectional link. Areas of interest when working towards an inter-operable switched telemetry waveform were then presented. The use of the switched telemetry system facilitates frequency reuse by multi purposing a single transmit frequency for each direction, while eliminating co-sight interference of continuous dual frequency systems [5]. As the switched telemetry TDD based systems are deployed more will be learned to help refine the inter-operable formats and parameters presented. An overview of areas of interest to support the development of a TmNS transceiver using standard streaming telemetry components was also presented.

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