

HORIZON HOBBY, LLC.

Specification for Spektrum® X-Bus Telemetry Sensors

Enabling Use of Non-Spektrum Sensors

Rev E

2016 February 16

Specification for communicating on the X-Bus so that data from non-Spektrum devices can be displayed on the AirWare™-based transmitters.

Specification for Spektrum[®] X-Bus Telemetry Sensors

1 INTRODUCTION

With the advent of third-party display (J-Link), annunciation (vSpeak), and data display systems (Robo-Software), we feel it is in everybody's best interests to open the telemetry system by sharing correct implementation data. With that mindset, the purpose of this document is to enable third-party telemetry sensors, both commercial and hobbyists, that can use the Spektrum X-Bus telemetry system as a data transport mechanism for custom sensors including items such as:

- an ESC,
- fuel flow meter,
- high-current battery “fuel gauge” (mAh),
- digital status (for example, landing gear status lights),
- thrust/strain gauge,
- air tank pressure, or
- an individual cell monitor for LiPo batteries.

The intent is that publication of this document will ensure that these third-party devices can inter-operate with one another and with Spektrum products in a non-interfering, cooperative manner. Spektrum will provide an interface to allow generic data display and alarms on certain levels of transmitter products, although they obviously cannot be as thoroughly integrated into the radios as Spektrum products are.

2 AUDIENCE

This document is intended for non-Horizon personnel to be able to develop sensors which function correctly in the Spektrum X-Bus Air Telemetry System. This document includes sufficient information to allow a sensor to be created such that it reports data useful to the users.

This document does not provide information that can be used to access data contained in a Spektrum telemetry file (.TLM). The STi application provides this capability for Apple iPhone and related products. Robo-Software has developed a Windows- and Mac-based shareware product which provides excellent capabilities for post-flight data analysis.

3 RELATED DOCUMENTATION

All necessary technical information is contained within this document, including diagrams and source code guidance.

4 LEGAL INFORMATION

Spektrum X-Bus Telemetry Data Application

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Specification for Spektrum X-Bus Telemetry Sensors

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Specification for Spektrum X-Bus Telemetry Sensors

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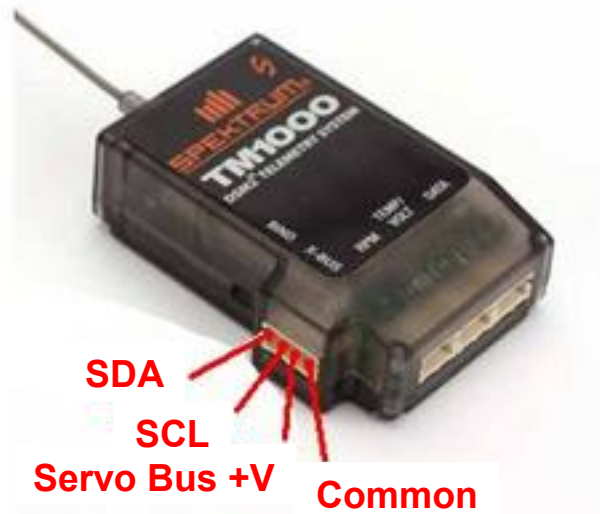
Horizon Hobby, LLC
Legal Department
4105 Fieldstone Road
Champaign, IL 61822 USA

5 ELECTRICAL DATA

All sensors are powered by the X-Bus. The X-Bus port bus provides the servo bus voltage (3.5 to 9.6V) at a current limited by the JST contact rating (1A). The operational limit in an application may be quite a bit lower, depending upon the method of powering the servo bus.

The X-Bus uses I2C to communicate. Termination resistors are in the TM1000. The pins are defined according to this picture:

Specification for Spektrum X-Bus Telemetry Sensors



Every device shall be responsible to regulate the supply to a level useful for its operation. The I2C signals must be 3.3V logic, and the pins in open drain mode so as to not interfere with the logic levels.

In order to maintain compatibility with other products, it is strongly urged that any sensors include two X-Bus ports to allow them to be daisy-chained in the same manner as Spektrum sensors.

The connector used in the TM1000 and all Spektrum sensors is JST part number S4B-ZR(LF)(SN) or Digikey part 455-1671-ND.

6 HARDWARE-LEVEL PROTOCOL

The TM1000 is an I2C master device talking at 100kHz to the slaves. For best future compatibility, devices should support 400kHz as well.

Every device shall reply to a poll with a 16-byte message, the first byte of which is always the polled I2C address. The remaining bytes are defined in the section on the telemetry header file.

Shortly after the TM1000 starts, it polls all addresses on the bus. During this enumeration phase, the attached devices must reply with their address as the first byte of the reply. The remainder of the first message will be discarded by the TM1000, but the full 16-byte message must be available for the TM1000 to clock in. If a device does not answer the enumeration correctly, the TM1000 will not poll it any more. It is therefore of utmost importance that the first I2C message be answered correctly. The TM1000 allows clock stretching per the I2C specification, which allows slow-to-start devices to enumerate properly in the system. If your device will be slow to start, it is recommended that you first select a higher address, and second that you use the stretched clock.

The TM1000 transmits data to the ground at a rate of one message per 22ms. The time between polls for any single device is dependent upon the number of sensors which enumerated on the bus. Note that the TM1000 reserves two addresses for its internal use, so the maximum rate at which a device is polled will be no less than 44ms. If timing is a critical function for a particular device, it is necessary that the device provide its own clock source and not utilize the X-Bus for timing.

7 ADDRESSING & DEVICE TYPES

The Appendix includes the telemetry header file used by all Spektrum AirWare-based transmitters. It defines the device type codes for all Spektrum products and known reserved values. The device type codes are used as I2C bus addresses by default, but the protocol also provides a means for them to differ.

Spektrum reserves the right to use addresses not listed as we deem necessary. We do not intend to interfere with other products, and therefore urge anybody making a device to provide a mechanism to select different addresses should the need arise. Commercial vendors are urged to contact Spektrum in order to coordinate addresses and prevent interference.

Note that Spektrum is the owner of all address assignments, and does not guarantee that any unused address will be available in the future. Only addresses specifically assigned are guaranteed not to change. Addresses 0x09 and below shall not be used by any third-party devices.

For each of the messages in the header file it should be noted that they begin with the fields *identifier* and *sID*. The *identifier* field is always under all circumstances an exact match to the I2C address, and needs to be the first byte of any reply as noted in the hardware-level section. The second byte, *sID*, serves as a way to allow either multiple devices of the same type to live on the bus, or for a device to retain its type code when there is a conflict of the addresses. At this time, none of the AirWare radios properly display data from multiple instances of the same device type.

Use of the *sID* field is quite simple:

When *sID* is zero, then the device type (TELE_DEVICE_xxx) is the same as the bus address *identifier*. This is the norm for all Spektrum products. If *sID* is non-zero, then *sID* is the device type and *identifier* serves only to provide a unique I2C address.

8 DATA FORMATS

All third-party sensors shall report their data in big-endian format (MSB at lower address) if they are to be displayed on the transmitter screens. All data shall binary 8, 16 or 32 bits. Spektrum uses BCD for JetCat and GPS but does not support these formats for third-party products.

The TM1100 module notifies the transmitter that it is in use by setting the high bit of the *identifier* field. This is informational-only to the transmitter and does not affect operation.

The DSMX Ultra Micro receivers provide Flight Log data only, using the standard QoS record structure. The receiver voltage field is fixed at 0xFFFF, indicating “no data” to the transmitter.

The transmitter uses two sentinel values to indicate that there is “no data” for a field. For an unsigned value, a value with all bits set to one (ie, 0xFFFF or 0xFFFFFFFF) indicates this. For a signed value the “no data” value is denoted by all bits set except the sign bit, i.e. 0x7FFF or 0x7FFFFFFF.

These values and standards are also utilized by post-flight systems to properly display logged data.

9 ELECTRONIC SPEED CONTROL

The AirWare-based transmitters may include support for a generic Electronic Speed Control (ESC) device. Spektrum does not sell a device which conforms to this telemetry standard, but is instead providing a common interface which may be supported by ESC manufacturers.

The ESC configuration screen provides the same functions available to other devices, that is, whether the status is actively monitored on the display. Alarms are available for the following conditions:

- Input Voltage too low
- Motor current too high
- FET temperature too high

The units and ranges for each of the fields in the telemetry message are found in the appendix in the definition for the ESC structure. The transmitter does not provide any filtering of data for any ESC fields.

10 FUEL FLOW METER

The AirWare-based transmitters may include support for a generic fuel flow and capacity metering device. Spektrum does not sell a device which conforms to this telemetry standard, but is instead providing a common interface which may be supported by third-party manufacturers.

The “Fuel” configuration screen provides the same functions available to other devices, that is, whether the status is actively monitored on the display. Alarms may be available for some of the following conditions:

- Tank 1 capacity consumed > user-defined value
- Tank 2 capacity consumed > user-defined value
- Fuel flow 1 too low
- Fuel flow 1 too high
- Fuel flow 2 too low
- Fuel flow 2 too high
- Temperature 1 too low
- Temperature 1 too high
- Temperature 2 too low
- Temperature 2 too high

The units and ranges for each of the fields in the telemetry message are found in the appendix in the definition for the FUEL structure. The transmitter does not provide any filtering of data for any fields.

11 HIGH-CURRENT BATTERY CAPACITY

The AirWare-based transmitters include support for a generic battery current and capacity metering device. Spektrum does not sell a device which conforms to this telemetry standard, but is instead providing a common interface which may be supported by third-party manufacturers.

Specification for Spektrum X-Bus Telemetry Sensors

The “mAh” configuration screen provides the same functions available to other devices, that is, whether the status is actively monitored on the display. Alarms are available for the following conditions:

- Battery 1 capacity consumed > user-defined value
- Current 1 too high
- Temperature 1 too high

The units and ranges for each of the fields in the telemetry message are found in the appendix in the definition for the MAH structure. The transmitter does not provide any filtering of data for any fields.

12 DIGITAL INPUT AND AIR PRESSURE SENSOR

The AirWare-based transmitters may include support for a generic digital input and air pressure metering device. Spektrum does not sell a device which conforms to this telemetry standard, but is instead providing a common interface which may be supported by third-party manufacturers.

The “Air” configuration screen provides the same functions available to other devices, that is, whether the status is actively monitored on the display. Alarms may be available for the following conditions:

- Digital Bit set (bits 0-16)
- Digital Bit clear (bits 0-16)
- Pressure too low
- Pressure too high

The units and ranges for each of the fields in the telemetry message are found in the appendix in the definition for the DIGITAL_AIR structure. The transmitter does not provide any filtering of data for any fields.

13 THRUST/STRAIN GAUGE

The AirWare-based transmitters may include support for a generic thrust or strain metering device. Spektrum does not sell a device which conforms to this telemetry standard, but is instead providing a common interface which may be supported by third-party manufacturers.

The “Strain” configuration screen provides the same functions available to other devices, that is, whether the status is actively monitored on the display. Alarms may be available for the following conditions:

- Single Strain too high (any input above threshold)
- Sum Strain too high (sum of active strains above threshold)
- Strain Imbalance (delta of min/max strains on active inputs is above threshold)

The units and ranges for each of the fields in the telemetry message are found in the appendix in the definition for the STRAIN structure. The transmitter does not provide any filtering of data for any fields.

14 INDIVIDUAL CELL MONITOR

The AirWare-based transmitters may include support for a generic multi-tap voltage monitoring device. Spektrum does not sell a device which conforms to this telemetry standard, but is instead providing a common interface which may be supported by third-party manufacturers.

NOTE: The Common (Ve-) connection of the X-Bus is connected to the receiver, which in an electric model is likely connected directly to the negative terminal in the battery string. It is strongly recommended that the voltage measurements be galvanically isolated from the battery pack being measured so as to prevent short circuits and ground loops. This isolation also permits battery packs of more than 6 cells to be monitored accurately and without concern for wiring problems.

The “CellMon” configuration screen provides the same functions available to other devices, that is, whether the status is actively monitored on the display. Alarms may be available for the following conditions:

- Cell too low (any cell below threshold)
- Cell too high (any cell above threshold)
- Cell imbalance (delta of min/max cells on active inputs is above threshold)

The units and ranges for each of the fields in the telemetry message are found in the appendix in the definition for the LIPOMON structure. The transmitter does not provide any filtering of data for any fields.

15 ATTITUDE & MAGNETIC COMPASS

The AirWare-based transmitters may include a facility to display data from an attitude and magnetic compass. This is currently envisioned as an information-only device which may be of use in certain applications but unable to generate alarms. Data which is unavailable due to limitations of the sensor hardware shall report a value of 0x7FFF to indicate “No data available.”

16 3-AXIS GYRO

The AirWare-based transmitters may include a facility to display data from a 3-axis gyro system. This currently is envisioned as an information-only device which may be of use in certain applications, but unable to generate alarms. Data which is unavailable due to limitations of the sensor hardware shall report a value of 0x7FFF to indicate “No data available.”

17 USER-DEFINED DEVICES IN THE TX

The AirWare-based transmitters may include a facility to display data from user-defined sensors according to four “user” structures defined in the Appendix. The four structures are associated with four different *identifier* field values.

Transmitters may have generic screens to show the data for each structure type. The transmitters would allow the user to specify a short title for the screen, but not for individual fields, nor would it allow specification of units. Display of individual fields may be only turned on or off using the configuration screen. It is up to the user to know the representation of each field shown on the transmitter for these

Specification for Spektrum X-Bus Telemetry Sensors

custom devices.

These devices do not have any alarm capability.

The transmitter does not provide any filtering of data for any fields.

APPENDIX – HEADER FILE DATA

Note that some device types cannot be used by third-party devices, in particular voltage (0x01) and temperature (0x02), as these are reserved for internal use within the transmitter. The text below has been re-formatted for tabs that look good on the page. If you copy/paste them into your code, you will probably want to re-tab them.

```
////////////////////////////////////
//
//      Copyright 2013 by Horizon Hobby, Inc.
//      All Rights Reserved Worldwide.
//
//      This header file may be incorporated into non-Horizon
//      products.
//
////////////////////////////////////

#ifndef TELEMETRY_H
#define TELEMETRY_H

////////////////////////////////////
//
//      Assigned I2C Addresses and Device Types
//
////////////////////////////////////

#define TELE_DEVICE_NODATA          (0x00)    // No data in packet
#define TELE_DEVICE_VOLTAGE        (0x01)    // High-Voltage sensor (INTERNAL)
#define TELE_DEVICE_TEMPERATURE    (0x02)    // Temperature Sensor (INTERNAL)
#define TELE_DEVICE_RSV_03         (0x03)    // Reserved
#define TELE_DEVICE_RSV_04         (0x04)    // Reserved
#define TELE_DEVICE_RSV_05         (0x05)    // Reserved
#define TELE_DEVICE_RSV_06         (0x06)    // Reserved
#define TELE_DEVICE_RSV_07         (0x07)    // Reserved
#define TELE_DEVICE_RSV_08         (0x08)    // Reserved
#define TELE_DEVICE_RSV_09         (0x09)    // Reserved
#define TELE_DEVICE_PBOX           (0x0A)    // PowerBox
#define TELE_DEVICE_AIRSPEED       (0x11)    // Air Speed
#define TELE_DEVICE_ALTITUDE       (0x12)    // Altitude
#define TELE_DEVICE_GMETER         (0x14)    // GForce
#define TELE_DEVICE_JETCAT         (0x15)    // JetCat interface
#define TELE_DEVICE_GPS_LOC        (0x16)    // GPS Location Data
#define TELE_DEVICE_GPS_STATS      (0x17)    // GPS Status
#define TELE_DEVICE_ENERGY_DUAL    (0x18)    // Dual Coulomb counter
#define TELE_DEVICE_JETCAT_2       (0x19)    // JetCat interface, msg 2
#define TELE_DEVICE_GYRO           (0x1A)    // 3-axis gyro
#define TELE_DEVICE_ATT_MAG        (0x1B)    // Attitude and Magnetic Compass
#define TELE_DEVICE_AS3X_LEGACYGAIN (0x1F)    // Active AS3X Gains for legacy mode
#define TELE_DEVICE_ESC            (0x20)    // ESC
#define TELE_DEVICE_FUEL           (0x22)    // Fuel Flow Meter
// DO NOT USE                      (0x30)    // Reserved for internal use
// DO NOT USE                      (0x32)    // Reserved for internal use
#define TELE_DEVICE_MAH            (0x34)    // Battery Gauge (mAh)
#define TELE_DEVICE_DIGITAL_AIR    (0x36)    // Digital Inputs & Tank Pressure
#define TELE_DEVICE_STRAIN         (0x38)    // Thrust/Strain Gauge
#define TELE_DEVICE_LIPOMON        (0x3A)    // Cell Monitor (LiPo taps)
#define TELE_DEVICE_VARIO_S        (0x40)    // Vario
#define TELE_DEVICE_RSV_43         (0x43)    // Reserved
#define TELE_DEVICE_USER_16SU       (0x50)    // User-Def, STRU_TELE_USER_16SU
#define TELE_DEVICE_USER_16SU32U    (0x52)    // User-Def, STRU_TELE_USER_16SU32U
#define TELE_DEVICE_USER_16SU32S    (0x54)    // User-Def, STRU_TELE_USER_16SU32S
#define TELE_DEVICE_USER_16U32SU    (0x56)    // User-Def, STRU_TELE_USER_16U32SU
#define TELE_DEVICE_RSV_60         (0x60)    // Reserved
#define TELE_DEVICE_RSV_68         (0x68)    // Reserved
#define TELE_DEVICE_RSV_69         (0x69)    // Reserved
#define TELE_DEVICE_RSV_6A         (0x6A)    // Reserved
```

Specification for Spektrum X-Bus Telemetry Sensors

```
#define TELE_DEVICE_RSV_6B      (0x6B)    // Reserved
#define TELE_DEVICE_RSV_6C      (0x6C)    // Reserved
#define TELE_DEVICE_RSV_6D      (0x6D)    // Reserved
#define TELE_DEVICE_RSV_6E      (0x6E)    // Reserved
#define TELE_DEVICE_RSV_6F      (0x6F)    // Reserved
#define TELE_DEVICE_RSV_70      (0x70)    // Reserved
#define TELE_DEVICE_FRAMEDATA    (0x7D)    // Transmitter frame data
#define TELE_DEVICE_RPM          (0x7E)    // RPM sensor
#define TELE_DEVICE_QOS          (0x7F)    // RxV + flight log data
#define TELE_DEVICE_MAX          (0x7F)    // Last address available

#define TELE_DEVICE_SHORTRANGE   (0x80)    // Data is from a TM1100

////////////////////////////////////
//
//      Message Data Structures
//
////////////////////////////////////

////////////////////////////////////
//
//      Electronic Speed Control
//
////////////////////////////////////
typedef struct
{
    UINT8  identifier;          // Source device = 0x20
    UINT8  sID;                 // Secondary ID
    UINT16 RPM;                 // RPM, 10RPM (0-655340 RPM).      0xFFFF --> "No data"
    UINT16 voltsInput;          // Volts, 0.01v (0-655.34V).      0xFFFF --> "No data"
    UINT16 tempFET;             // Temperature, 0.1C (0-999.8C)  0xFFFF --> "No data"
    UINT16 currentMotor;        // Current, 10mA (0-655.34A).    0xFFFF --> "No data"
    UINT16 tempBEC;             // Temperature, 0.1C (0-999.8C)  0x7FFF --> "No data"
    UINT8  currentBEC;          // BEC Current, 100mA (0-25.4A). 0xFF ----> "No data"
    UINT8  voltsBEC;            // BEC Volts, 0.05V (0-12.70V).  0xFF ----> "No data"
    UINT8  throttle;            // 0.5% (0-127%).                0xFF ----> "No data"
    UINT8  powerOut;            // Power Output, 0.5% (0-127%).  0xFF ----> "No data"}
STRU_TELE_ESC;

////////////////////////////////////
//
//      (Liquid) Fuel Flow/Capacity (Two Tanks/Engines)
//
////////////////////////////////////
typedef struct
{
    UINT8  id;                  // Source device = 0x22
    UINT8  sID;                 // Secondary ID
    UINT16 fuelConsumed_A;       // Integrated fuel consumption, 0.1mL
    UINT16 flowRate_A;           // Instantaneous consumption, 0.01mL/min
    UINT16 temp_A;               // Temperature, 0.1C (0-655.34C)
    UINT16 fuelConsumed_B;       // Integrated fuel consumption, 0.1mL
    UINT16 flowRate_B;           // Instantaneous consumption, 0.01mL/min
    UINT16 temp_B;               // Temperature, 0.1C (0-655.34C)
    UINT16 spare;                // Not used
} STRU_TELE_FUEL;

////////////////////////////////////
//
//      Battery Current/Capacity (Dual Batteries)
//
////////////////////////////////////
typedef struct
{
    UINT8  id;                  // Source device = 0x34
    UINT8  sID;                 // Secondary ID
```

Specification for Spektrum X-Bus Telemetry Sensors

```
    INT16    current_A;           // Instantaneous current, 0.1A (0-3276.8A)
    INT16    chargeUsed_A;        // Integrated mAh used, 1mAh (0-32.766Ah)
    UINT16    temp_A;             // Temperature, 0.1C (0-150.0C,
                                   // 0x7FFF indicates not populated)

    INT16    current_B;           // Instantaneous current, 0.1A (0-6553.4A)
    INT16    chargeUsed_B;        // Integrated mAh used, 1mAh (0-65.534Ah)
    UINT16    temp_B;             // Temperature, 0.1C (0-150.0C,
                                   // 0x7FFF indicates not populated)

    UINT16    spare;              // Not used
} STRU_TELE_MAH;

////////////////////////////////////
//
//      Digital Input Status (Retract Status) and Tank Pressure
//
////////////////////////////////////
//
typedef struct
{
    UINT8    id;                  // Source device = 0x36
    UINT8    sID;                 // Secondary ID
    UINT16    digital;            // Digital inputs (bit per input)
    UINT16    pressure;           // Tank pressure, 0.1PSI (0-6553.4PSI)
} STRU_TELE_DIGITAL_AIR;

////////////////////////////////////
//
//      Thrust/Strain Gauge
//
////////////////////////////////////
//
typedef struct
{
    UINT8    id;                  // Source device = 0x38
    UINT8    sID;                 // Secondary ID
    UINT16    strain_A;           // Strain sensor A
    UINT16    strain_B;           // Strain sensor B
    UINT16    strain_C;           // Strain sensor D
    UINT16    strain_D;           // Strain sensor C
} STRU_TELE_STRAIN;

////////////////////////////////////
//
//      LiPo Cell Monitor
//
////////////////////////////////////
//
typedef struct
{
    UINT8    id;                  // Source device = 0x3A
    UINT8    sID;                 // Secondary ID
    UINT16    cell_1;             // Voltage across cell 1
    UINT16    cell_2;             // Voltage across cell 2
    UINT16    cell_3;             // Voltage across cell 3
    UINT16    cell_4;             // Voltage across cell 4
    UINT16    cell_5;             // Voltage across cell 5
    UINT16    cell_6;             // Voltage across cell 6
    UINT16    temp;               // Temperature, 0.1C (0-655.34C)
} STRU_TELE_LIPOMON;

////////////////////////////////////
//
//      THIRD-PARTY 16-BIT DATA SIGNED/UNSIGNED
//
////////////////////////////////////
//
typedef struct
{
    UINT8    id;                  // Source device = 0x50
    UINT8    sID;                 // Secondary ID
    INT16    sField1;             // Signed 16-bit data fields
```

Specification for Spektrum X-Bus Telemetry Sensors

```
        sField2,
        sField3;
    UINT16 uField1,          // Unsigned 16-bit data fields
        uField2,
        uField3,
        uField4;
} STRU_TELE_USER_16SU;

////////////////////////////////////
//
//      THIRD-PARTY 16-BIT SIGNED/UNSIGNED AND 32-BIT UNSIGNED
//
////////////////////////////////////
//
typedef struct
{
    UINT8  id;                // Source device = 0x52
    UINT8  sID;               // Secondary ID
    INT16  sField1,           // Signed 16-bit data fields
        sField2;
    UINT16 uField1,           // Unsigned 16-bit data fields
        uField2,
        uField3;
    UINT32 u32Field;          // Unsigned 32-bit data field
} STRU_TELE_USER_16SU32U;

////////////////////////////////////
//
//      THIRD-PARTY 16-BIT SIGNED/UNSIGNED AND 32-BIT SIGNED
//
////////////////////////////////////
//
typedef struct
{
    UINT8  id;                // Source device = 0x54
    UINT8  sID;               // Secondary ID
    INT16  sField1,           // Signed 16-bit data fields
        sField2;
    UINT16 uField1,           // Unsigned 16-bit data fields
        uField2,
        uField3;
    INT32  u32Field;          // Signed 32-bit data field
} STRU_TELE_USER_16U32SU;

////////////////////////////////////
//
//      THIRD-PARTY 16-BIT UNSIGNED AND 32-BIT SIGNED/UNSIGNED
//
////////////////////////////////////
//
typedef struct
{
    UINT8  id;                // Source device = 0x56
    UINT8  sID;               // Secondary ID
    UINT16 uField1;           // Unsigned 16-bit data field
    INT32  u32Field;          // Signed 32-bit data field
    INT32  u32Field1,         // Signed 32-bit data fields
        u32Field2;
} STRU_TELE_USER_16U32SU;

////////////////////////////////////
//
//      POWERBOX
//
////////////////////////////////////
//
typedef struct
{
    UINT8  identifier;        // Source device = 0x7D
    UINT8  sID;               // Secondary ID
    UINT16 volt1;             // Volts, 0v01v
```

Specification for Spektrum X-Bus Telemetry Sensors

```
    UINT16 volt2;                // Volts, 0.01v
    UINT16 capacity1;            // mAh, 1mAh
    UINT16 capacity2;            // mAh, 1mAh
    UINT16 spare16_1;
    UINT16 spare16_2;
    UINT8 spare;
    UINT8 alarms;                // Alarm bitmask (see below)
} STRU_TELE_POWERBOX;

#define TELE_PBOX_ALARM_VOLTAGE_1 (0x01)
#define TELE_PBOX_ALARM_VOLTAGE_2 (0x02)
#define TELE_PBOX_ALARM_CAPACITY_1 (0x04)
#define TELE_PBOX_ALARM_CAPACITY_2 (0x08)
// #define TELE_PBOX_ALARM_RPM (0x10)
// #define TELE_PBOX_ALARM_TEMPERATURE (0x20)
#define TELE_PBOX_ALARM_RESERVED_1 (0x40)
#define TELE_PBOX_ALARM_RESERVED_2 (0x80)

////////////////////////////////////
//
//      DUAL ENERGY
//
////////////////////////////////////
//
typedef struct
{
    UINT8 id;                    // Source device = 0x18
    UINT8 sID;                  // Secondary ID
    INT16 current_A;             // Instantaneous current, 0.01A (0-328.7A)
    INT16 chargeUsed_A;          // Integrated mAh used, 0.1mAh (0-3276.6mAh)
    UINT16 volts_A;              // Voltage, 0.01VC (0-16.00V)
    INT16 current_B;             // Instantaneous current, 0.1A (0-3276.8A)
    INT16 chargeUsed_B;          // Integrated mAh used, 1mAh (0-32.766Ah)
    UINT16 volts_B;              // Voltage, 0.01VC (0-16.00V)
    UINT16 spare;                // Not used
} STRU_TELE_ENERGY_DUAL;

////////////////////////////////////
//
//      HIGH-CURRENT
//
////////////////////////////////////
//
typedef struct
{
    UINT8 identifier;            // Source device = 0x03
    UINT8 sID;                  // Secondary ID
    INT16 current,               // Range: +/- 150A
        dummy;                  // Resolution: 300A/2048 = 0.196791 A/tick
} STRU_TELE_IHIGH;

#define IHIGH_RESOLUTION_FACTOR ((FP32) (0.196791))

////////////////////////////////////
//
//      VARIO-S
//
////////////////////////////////////
//
typedef struct
{
    UINT8 identifier;            // Source device = 0x40
    UINT8 sID;                  // Secondary ID
    INT16 altitude;              // .1m increments
    delta_0250ms,               // delta last 250ms, 0.1m/s increments
    delta_0500ms,               // delta last 500ms, 0.1m/s increments
    delta_1000ms,               // delta last 1.0 seconds
    delta_1500ms,               // delta last 1.5 seconds
    delta_2000ms,               // delta last 2.0 seconds
    delta_3000ms;               // delta last 3.0 seconds
```

Specification for Spektrum X-Bus Telemetry Sensors

```
} STRU_TELE_VARIO_S;

////////////////////////////////////
//
//    ALTIMETER
//
////////////////////////////////////
//
typedef struct
{
    UINT8    identifier;
    UINT8    sID;                // Secondary ID
    INT16    altitude;           // .1m increments
    INT16    maxAltitude;        // .1m increments
} STRU_TELE_ALT;

////////////////////////////////////
//
//    AIRSPEED
//
////////////////////////////////////
//
typedef struct
{
    UINT8    identifier;
    UINT8    sID;                // Secondary ID
    UINT16    airspeed;           // 1 km/h increments
    UINT16    maxAirspeed;        // 1 km/h increments
} STRU_TELE_SPEED;

////////////////////////////////////
//
//    GFORCE
//
////////////////////////////////////
//
typedef struct
{
    UINT8    identifier;         // Source device = 0x14
    UINT8    sID;                // Secondary ID
    INT16    GForceX;            // force is reported as .01G increments
    INT16    GForceY;            // Range = +/-4000 (+/- 40G) in Pro model
    INT16    GForceZ;            // Range = +/-800 (+/- 8G) in Standard model
    INT16    maxGForceX;         // abs(max G X-axis)    FORE/AFT
    INT16    maxGForceY;         // abs (max G Y-axis)   LEFT/RIGHT
    INT16    maxGForceZ;         // max G Z-axis        WING SPAR LOAD
    INT16    minGForceZ;         // min G Z-axis        WING SPAR LOAD
} STRU_TELE_G_METER;

////////////////////////////////////
//
//    JETCAT/TURBINE
//
////////////////////////////////////
//
typedef struct
{
    UINT8    identifier;         // Source device = 0x15
    UINT8    sID;                // Secondary ID
    UINT8    status;             // See table below
    UINT8    throttle;           // (BCD) xx Percent
    UINT16    packVoltage;        // (BCD) xx.yy
    UINT16    pumpVoltage;        // (BCD) xx.yy
    UINT32    RPM;                // (BCD)
    UINT16    EGT;                // (BCD) Temperature, Celsius
    UINT8    offCondition;        // (BCD) See table below
    UINT8    spare;
} STRU_TELE_JETCAT;

enum JETCAT_ECU_TURBINE_STATE {          // ECU Status definitions
    JETCAT_ECU_STATE_OFF = 0x00,
```

Specification for Spektrum X-Bus Telemetry Sensors

```
JETCAT_ECU_STATE_WAIT_for_RPM = 0x01, // (Stby/Start)
JETCAT_ECU_STATE_Ignite = 0x02,
JETCAT_ECU_STATE_Accelerate = 0x03,
JETCAT_ECU_STATE_Stabilise = 0x04,
JETCAT_ECU_STATE_Learn_HI = 0x05,
JETCAT_ECU_STATE_Learn_LO = 0x06,
JETCAT_ECU_STATE_UNDEFINED = 0x07,
JETCAT_ECU_STATE_Slow_Down = 0x08,
JETCAT_ECU_STATE_Manual = 0x09,
JETCAT_ECU_STATE_AutoOff = 0x10,
JETCAT_ECU_STATE_Run = 0x11, // (reg.)
JETCAT_ECU_STATE_Accleleration_delay = 0x12,
JETCAT_ECU_STATE_SpeedReg = 0x13, // (Speed Ctrl)
JETCAT_ECU_STATE_Two_Shift_Regulate = 0x14, // (only for secondary shaft)
JETCAT_ECU_STATE_PreHeat1 = 0x15,
JETCAT_ECU_STATE_PreHeat2 = 0x16,
JETCAT_ECU_STATE_MainFStart = 0x17,
JETCAT_ECU_STATE_NotUsed = 0x18,
JETCAT_ECU_STATE_KeroFullOn = 0x19,
// undefined states 0x1A-0x1F
EVOJET_ECU_STATE_off = 0x20,
EVOJET_ECU_STATE_ignt = 0x21,
EVOJET_ECU_STATE_acce = 0x22,
EVOJET_ECU_STATE_run = 0x23,
EVOJET_ECU_STATE_cal = 0x24,
EVOJET_ECU_STATE_cool = 0x25,
EVOJET_ECU_STATE_fire = 0x26,
EVOJET_ECU_STATE_glow = 0x27,
EVOJET_ECU_STATE_heat = 0x28,
EVOJET_ECU_STATE_idle = 0x29,
EVOJET_ECU_STATE_lock = 0x2A,
EVOJET_ECU_STATE_rel = 0x2B,
EVOJET_ECU_STATE_spin = 0x2C,
EVOJET_ECU_STATE_stop = 0x2D,
// undefined states 0x2E-0x2F
HORNET_ECU_STATE_OFF = 0x30,
HORNET_ECU_STATE_SLOWDOWN = 0x31,
HORNET_ECU_STATE_COOL_DOWN = 0x32,
HORNET_ECU_STATE_AUTO = 0x33,
HORNET_ECU_STATE_AUTO_HC = 0x34,
HORNET_ECU_STATE_BURNER_ON = 0x35,
HORNET_ECU_STATE_CAL_IDLE = 0x36,
HORNET_ECU_STATE_CALIBRATE = 0x37,
HORNET_ECU_STATE_DEV_DELAY = 0x38,
HORNET_ECU_STATE_EMERGENCY = 0x39,
HORNET_ECU_STATE_FUEL_HEAT = 0x3A,
HORNET_ECU_STATE_FUEL_IGNITE = 0x3B,
HORNET_ECU_STATE_GO_IDLE = 0x3C,
HORNET_ECU_STATE_PROP_IGNITE = 0x3D,
HORNET_ECU_STATE_RAMP_DELAY = 0x3E,
HORNET_ECU_STATE_RAMP_UP = 0x3F,
HORNET_ECU_STATE_STANDBY = 0x40,
HORNET_ECU_STATE_STEADY = 0x41,
HORNET_ECU_STATE_WAIT_ACC = 0x42,
HORNET_ECU_STATE_ERROR = 0x43,
// undefined states 0x44-0x4F
XICOY_ECU_STATE_Temp_High = 0x50,
XICOY_ECU_STATE_Trim_Low = 0x51,
XICOY_ECU_STATE_Set_Idle = 0x52,
XICOY_ECU_STATE_Ready = 0x53,
XICOY_ECU_STATE_Ignition = 0x54,
XICOY_ECU_STATE_Fuel_Ramp = 0x55,
XICOY_ECU_STATE_Glow_Test = 0x56,
XICOY_ECU_STATE_Running = 0x57,
XICOY_ECU_STATE_Stop = 0x58,
XICOY_ECU_STATE_Flameout = 0x59,
XICOY_ECU_STATE_Speed_Low = 0x5A,
XICOY_ECU_STATE_Cooling = 0x5B,
XICOY_ECU_STATE_Igniter_Bad = 0x5C,
XICOY_ECU_STATE_Starter_F = 0x5D,
XICOY_ECU_STATE_Weak_Fuel = 0x5E,
```

Specification for Spektrum X-Bus Telemetry Sensors

```
XICOY_ECU_STATE_Start_On = 0x5F,
XICOY_ECU_STATE_Pre_Heat = 0x60,
XICOY_ECU_STATE_Battery = 0x61,
XICOY_ECU_STATE_Time_Out = 0x62,
XICOY_ECU_STATE_Overload = 0x63,
XICOY_ECU_STATE_Igniter_Fail = 0x64,
XICOY_ECU_STATE_Burner_On = 0x65,
XICOY_ECU_STATE_Starting = 0x66,
XICOY_ECU_STATE_SwitchOver = 0x67,
XICOY_ECU_STATE_Cal_Pump = 0x68,
XICOY_ECU_STATE_Pump_Limit = 0x69,
XICOY_ECU_STATE_No_Engine = 0x6A,
XICOY_ECU_STATE_Pwr_Boost = 0x6B,
XICOY_ECU_STATE_Run_Idle = 0x6C,
XICOY_ECU_STATE_Run_Max = 0x6D,

TURBINE_ECU_MAX_STATE = 0x74
};

enum JETCAT_ECU_OFF_CONDITIONS {          // ECU off conditions. Valid only when the
ECUStatus = JETCAT_ECU_STATE_OFF
JETCAT_ECU_OFF_No_Off_Condition_defined = 0,
JETCAT_ECU_OFF_Shut_down_via_RC,
JETCAT_ECU_OFF_Overtemperature,
JETCAT_ECU_OFF_Ignition_timeout,
JETCAT_ECU_OFF_Acceleration_time_out,
JETCAT_ECU_OFF_Acceleration_too_slow,
JETCAT_ECU_OFF_Over_RPM,
JETCAT_ECU_OFF_Low_Rpm_Off,
JETCAT_ECU_OFF_Low_Battery,
JETCAT_ECU_OFF_Auto_Off,
JETCAT_ECU_OFF_Low_temperature_Off,
JETCAT_ECU_OFF_Hi_Temp_Off,
JETCAT_ECU_OFF_Glow_Plug_defective,
JETCAT_ECU_OFF_Watch_Dog_Timer,
JETCAT_ECU_OFF_Fail_Safe_Off,
JETCAT_ECU_OFF_Manual_Off, // (via GSU)
JETCAT_ECU_OFF_Power_fail, // (Battery fail)
JETCAT_ECU_OFF_Temp_Sensor_fail, // (only during startup)
JETCAT_ECU_OFF_Fuel_fail,
JETCAT_ECU_OFF_Prop_fail,
JETCAT_ECU_OFF_2nd_Engine_fail,
JETCAT_ECU_OFF_2nd_Engine_Diff_Too_High,
JETCAT_ECU_OFF_2nd_Engine_No_Comm,
JETCAT_ECU_MAX_OFF_COND
};

typedef struct
{
    UINT8  identifier;          // Source device = 0x19
    UINT8  sID;                 // Secondary ID
    UINT16 FuelFlowRateMLmin;    // (BCD) mL per Minute
    UINT32 RestFuelVolumeInTankML; // (BCD) mL remaining in tank
    // 8 bytes left
} STRU_TELE_JETCAT2;

////////////////////////////////////
//
//      GPS
//
////////////////////////////////////
//
typedef struct
{
    UINT8  identifier;          // Source device = 0x16
    UINT8  sID;                 // Secondary ID
    UINT16 altitudeLow;         // BCD, meters, format 3.1 (Low bits of alt)
    UINT32 latitude;            // BCD, format 4.4,
                                // Degrees * 100 + minutes, < 100 degrees
    UINT32 longitude;           // BCD, format 4.4,
                                // Degrees * 100 + minutes, flag --> > 99deg
```

Specification for Spektrum X-Bus Telemetry Sensors

```
    UINT16  course;                // BCD, 3.1
    UINT8   HDOP;                  // BCD, format 1.1
    UINT8   GPSflags;              // see definitions below
} STRU_TELE_GPS_LOC;

typedef struct
{
    UINT8   identifier;            // Source device = 0x17
    UINT8   sID;                   // Secondary ID
    UINT16  speed;                 // BCD, knots, format 3.1
    UINT32  UTC;                   // BCD, format HH:MM:SS.S, format 6.1
    UINT8   numSats;               // BCD, 0-99
    UINT8   altitudeHigh;          // BCD, meters, format 2.0 (High bits alt)
} STRU_TELE_GPS_STAT;

// GPS flags definitions:
#define GPS_INFO_FLAGS_IS_NORTH_BIT    (0)
#define GPS_INFO_FLAGS_IS_NORTH      (1 << GPS_INFO_FLAGS_IS_NORTH_BIT)
#define GPS_INFO_FLAGS_IS_EAST_BIT    (1)
#define GPS_INFO_FLAGS_IS_EAST      (1 << GPS_INFO_FLAGS_IS_EAST_BIT)
#define GPS_INFO_FLAGS_LONG_GREATER_99_BIT    (2)
#define GPS_INFO_FLAGS_LONG_GREATER_99      (1 << GPS_INFO_FLAGS_LONG_GREATER_99_BIT)
#define GPS_INFO_FLAGS_GPS_FIX_VALID_BIT    (3)
#define GPS_INFO_FLAGS_GPS_FIX_VALID      (1 << GPS_INFO_FLAGS_GPS_FIX_VALID_BIT)
#define GPS_INFO_FLAGS_GPS_DATA_RECEIVED_BIT    (4)
#define GPS_INFO_FLAGS_GPS_DATA_RECEIVED      (1 << GPS_INFO_FLAGS_GPS_DATA_RECEIVED_BIT)
#define GPS_INFO_FLAGS_3D_FIX_BIT    (5)
#define GPS_INFO_FLAGS_3D_FIX      (1 << GPS_INFO_FLAGS_3D_FIX_BIT)
#define GPS_INFO_FLAGS_NEGATIVE_ALT_BIT    (7)
#define GPS_INFO_FLAGS_NEGATIVE_ALT      (1 << GPS_INFO_FLAGS_NEGATIVE_ALT_BIT)

////////////////////////////////////
//
//      GYRO
//
////////////////////////////////////
//
typedef struct
{
    UINT8   identifier;            // Source device = 0x1A
    UINT8   sID;                   // Secondary ID
    INT16   gyroX;                  // Rotation rates of the body - Rate
                                    // is about the X Axis which is
                                    // defined out the nose of the
                                    // vehicle.
    INT16   gyroY;                  // Units are 0.1 deg/sec - Rate is
                                    // about the Y Axis which is defined
                                    // out the right wing of the vehicle.
    INT16   gyroZ;                  // Rate is about the Z axis which is
                                    // defined down from the vehicle.
    INT16   maxGyroX;               // Max rates (absolute value)
    INT16   maxGyroY;
    INT16   maxGyroZ;
} STRU_TELE_GYRO;

////////////////////////////////////
//
//      ATTITUDE & MAG COMPASS
//
////////////////////////////////////
//
typedef struct
{
    UINT8   identifier;            // Source device = 0x1B
    UINT8   sID;                   // Secondary ID
    INT16   attRoll;                // Attitude, 3 axes. Roll is a
                                    // rotation about the X Axis of
                                    // the vehicle using the RHR.
    INT16   attPitch;              // Units are 0.1 deg - Pitch is a
                                    // rotation about the Y Axis of the
                                    // vehicle using the RHR.
```

Specification for Spektrum X-Bus Telemetry Sensors

```
    INT16      attYaw;           // Yaw is a rotation about the Z
                                   // Axis of the vehicle using the RHR.
    INT16      magX;             // Magnetic Compass, 3 axes
    INT16      magY;             // Units are TBD
    INT16      magZ;             //
} STRU_TELE_ATT_MAG;

////////////////////////////////////
//
//      Transmitter Frame Data
//
////////////////////////////////////
//
typedef struct
{
    UINT8      identifier;       // Source device = 0x7D
    UINT8      sID;              // Secondary ID
    UINT16     chanData[7];      // Channel Data array
} STRU_TELE_FRAMEDATA;

////////////////////////////////////
//
//      RPM/Volts/Temperature
//
////////////////////////////////////
//
typedef struct
{
    UINT8      identifier;       // Source device = 0x7E
    UINT8      sID;              // Secondary ID
    UINT16     microseconds;     // microseconds between pulse leading edges
    UINT16     volts;             // 0.01V increments
    INT16      temperature;       // degrees F
} STRU_TELE_RPM;

////////////////////////////////////
//
//      QoS DATA
//
////////////////////////////////////
//
// NOTE: AR6410-series send:
//       id = 7F
//       sID = 0
//       A = 0
//       B = 0
//       L = 0
//       R = 0
//       F = fades
//       H = holds
//       rxV = 0xFFFF
//
typedef struct
{
    UINT8      identifier;       // Source device = 0x7F
    UINT8      sID;              // Secondary ID
    UINT16     A;
    UINT16     B;
    UINT16     L;
    UINT16     R;
    UINT16     F;
    UINT16     H;
    UINT16     rxVoltage;        // Volts, 0.01V increments
} STRU_TELE_QOS;

////////////////////////////////////
//
//      UNION OF ALL DEVICE MESSAGES
//
////////////////////////////////////
//
```

Specification for Spektrum X-Bus Telemetry Sensors

```
typedef union
{
    UINT16          raw[8];
    STRU_TELE_QOS   qos;
    STRU_TELE_RPM   rpm;
    STRU_TELE_FRAMEDATA frame;
    STRU_TELE_ALT   alt;
    STRU_TELE_SPEED speed;
    STRU_TELE_ENERGY_DUAL eDual;
    STRU_TELE_VARIO_S varioS;
    STRU_TELE_G_METER accel;
    STRU_TELE_JETCAT jetcat;
    STRU_TELE_JETCAT2 jetcat2;
    STRU_TELE_GPS_LOC gpsloc;
    STRU_TELE_GPS_STAT gpsstat;
    STRU_TELE_GYRO gyro;
    STRU_TELE_ATT_MAG attMag;
    STRU_TELE_POWERBOX powerBox;
    STRU_TELE_ESC escGeneric;
    STRU_TELE_FUEL fuel;
    STRU_TELE_MAH mAh;
    STRU_TELE_DIGITAL_AIR digAir;
    STRU_TELE_STRAIN strain;
    STRU_TELE_LIPOMON lipomon;
    STRU_TELE_USER_16SU user_16SU;
    STRU_TELE_USER_16SU32U user_16SU32U;
    STRU_TELE_USER_16SU32S user_16SU32S;
    STRU_TELE_USER_16U32SU user_16U32SU;
} UN_TELEMETRY; // All telemetry messages

#endif
```

REVISION HISTORY

Rev E