Communications Infrastructure for the MOST Microsatellite Project (excerpt)

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Table 4.7: UoSAT–3 whole-orbit data format header items

Item	Length	Interpretation
Start time	4 bytes	32 bit Unix time
End time	4 bytes	32 bit Unix time
Sample period	2 bytes	sample period in seconds
Number of channels	1 byte	0 to 255

4.3 Whole orbit data

While telemetry beacons can transmit a great deal of information, they may only be received while the satellite is within radio range of a ground station. When details of satellite functions are required for an extended period the satellite gathers its measurements into *whole orbit data*.

In this section we will examine several formats for whole orbit data: UoSAT–3 format, extended UoSAT–3 format, PACSAT format, and UO–11 format. All will be illustrated with samples obtained from satellites.

4.3.1 UoSAT–3 whole-orbit data format

The whole-orbit data format used by many microsatellites today originated with the UoSAT–3 project, launched as UOSAT–OSCAR–14 on 22 February 1990. The system gathered telemetry observations and saved them in files for later download. The format of the files is straightforward and consists of three sections (8):

- File header, including start and end times and sample period.
- List of telemetry channels.
- The telemetry observations themselves.

The file header consists of the items in Table 4.7. Like all items in the UoSAT telemetry systems, multi-byte quantities are stored least-significant byte first. “32 bit Unix time” is the number of seconds since 0000 UTC 1 January 1970.

The header is then followed by the list of channel numbers, each stored as an unsigned byte.

Table 4.8: Decoded header information in a sample UO–22 whole-orbit data file

Parameter	**Raw value**	**Engineering units**
Start time	`0x383dcd85`	000005 UTC 26 November 1999
End time	`0x383e7622`	115930 UTC 26 November 1999
Sample period	`0x001e`	30 seconds
Number of channels	`0x13`	19 channels

The data samples follow the header information. Each is stored as an unsigned 16-bit integer. The underlying data type is actually an unsigned 12-bit quantity; the remaining four bits are used for control functions in the telemetry beacon, but are unused in whole orbit data. The values are recorded in the same order that was stated in the file header.

4.3.2 Sample UoSAT–3 format whole orbit data file

A sample whole-orbit data file was downloaded from UO–22. We may read off the header information in from the first few bytes of the file in Figure 4.5 to produce Table 4.8.

```
85 cd 3d 38 22 76 3e 38 1e 00 13 00 08 10 1a 01
0b 03 06 21 31 11 3c 27 2f 37 15 22 2a 2b 04 00
07 07 05 00 05 00 ad 0b 92 06 aa 02 b8 02 98 03
80 00 a2 0c c4 04 7b 06 0c 09 c0 06 d7 02 75 06
50 07 90 09 04 00 fc 06 05 00 05 00 b7 0b 95 06
aa 02 b7 02 98 03 80 00 a2 0c c9 04 c5 06 61 09
d4 06 d7 02 71 06 36 07 c3 09 04 00 f2 06 05 00
05 00 a7 0b 95 06 aa 02 b7 02 98 03 80 00 a2 0c
```

Figure 4.5: Header information in a UO–22 whole-orbit data file

The list of channels follows, as illustrated in Figure 4.6 and as listed in Table 4.9.

```
85 cd 3d 38 22 76 3e 38 1e 00 13 00 08 10 1a 01
0b 03 06 21 31 11 3c 27 2f 37 15 22 2a 2b 04 00
07 07 05 00 05 00 ad 0b 92 06 aa 02 b8 02 98 03
80 00 a2 0c c4 04 7b 06 0c 09 c0 06 d7 02 75 06
50 07 90 09 04 00 fc 06 05 00 05 00 b7 0b 95 06
aa 02 b7 02 98 03 80 00 a2 0c c9 04 c5 06 61 09
d4 06 d7 02 71 06 36 07 c3 09 04 00 f2 06 05 00
05 00 a7 0b 95 06 aa 02 b7 02 98 03 80 00 a2 0c
```

Figure 4.6: Channel list in a sample UO–22 whole-orbit data file

Table 4.9: Decoded channel list in a UO–22 whole orbit data file

Raw value	**Decimal**	**Channel Description**
`0x00`	0	Array current +X
`0x08`	8	Array current -X
`0x10`	16	Array current +Y
`0x1a`	26	Array current -Y
`0x01`	1	Array voltage
`0x0b`	11	Battery current
`0x03`	3	14 volt bus current
`0x06`	6	Battery temperature
`0x21`	33	Transmitter 0 forward power
`0x31`	49	Transmitter 0 reverse power
`0x11`	17	Battery voltage
`0x3c`	60	OBC186 CPU current
`0x27`	39	Magnetometer 1 X value
`0x2f`	47	Magnetometer 1 Y value
`0x37`	55	Magnetometer 1 Z value
`0x15`	21	Transmitter 1 temperature
`0x22`	34	Receiver 0 received signal strength
`0x2a`	42	Receiver 1 received signal strength
`0x2b`	43	Receiver 1 discriminator voltage

We may then read off the first telemetry sample in the file, as shown in Figure 4.7 and decoded in Table 4.10. Note that not all values decode to "natural" units: some, like the magnetometer values and received signal strength, merely decode to the voltage measured by a sensor.

```
85 cd 3d 38 22 76 3e 38 1e 00 13 00 08 10 1a 01
0b 03 06 21 31 11 3c 27 2f 37 15 22 2a 2b 04 00
07 07 05 00 05 00 ad 0b 92 06 aa 02 b8 02 98 03
80 00 a2 0c c4 04 7b 06 0c 09 c0 06 d7 02 75 06
50 07 90 09 04 00 fc 06 05 00 05 00 b7 0b 95 06
aa 02 b7 02 98 03 80 00 a2 0c c9 04 c5 06 61 09
d4 06 d7 02 71 06 36 07 c3 09 04 00 f2 06 05 00
05 00 a7 0b 95 06 aa 02 b7 02 98 03 80 00 a2 0c
```

Figure 4.7: First sample in a UO–22 whole-orbit data file

4.3.3 Extended UoSAT whole orbit data format

The extended whole orbit data format is derived from the UoSAT–3 format. Like the UoSAT–3 format, the extended format (currently used on TO–31) consists of a header, a list of channels and the telemetry observations. The difference is the expansion of several values to 16 bit quantities, to allow for more than 256 channels of telemetry. Additionally, each telemetry observation is explicitly timestamped, unlike the older format that requires observation times to be inferred.

Attempts to obtain documentation on the format failed, so the information that follows was obtained by reverse-engineering telemetry files downloaded from TO–31.

Analysis showed that the file header contains the following information:

- 7 bytes of unknown function. The value was `0x8134010001be00` in all available files.
- The satellite name, a null-terminated ASCII string padded with `0x00` to 12 bytes.
- A constant byte `0x01`.
- The file description, a null-terminated ASCII string padded with `0x00` to 30 bytes.
- The time of the beginning of the data collection.
- A 16 bit constant `0x0000`.
- The time of the end of the data collection.

Table 4.10: Decoded telemetry observation in a UO–22 whole orbit data file

Channel Description	**Raw value**	**Engineering units**
Array current +X	`0x0004`	7.630487 mA
Array current -X	`0x0707`	532.8304 mA
Array current +Y	`0x0005`	0.5139264 mA
Array current -Y	`0x0005`	7.293801 mA
Array voltage	`0x0bad`	40.62266 V
Battery current	`0x0692`	682.3492 mA
14 volt bus current	`0x02aa`	558.8579 mA
Battery temperature	`0x02b8`	45.61132 C
Transmitter 0 forward power	`0x0398`	1.899261 W
Transmitter 0 reverse power	`0x0080`	0.15648 W
Battery voltage	`0x0ca2`	13.60162 V
OBC186 CPU current	`0x04c4`	117.6798 mA
Magnetometer 1 X value	`0x067b`	2.028127 V
Magnetometer 1 Y value	`0x090c`	2.83131 V
Magnetometer 1 Z value	`0x06c0`	2.11248 V
Transmitter 1 temperature	`0x02d7`	43.37684 C
Receiver 0 received signal strength	`0x0675`	2.020792 V
Receiver 1 received signal strength	`0x0750`	2.28852 V
Receiver 1 discriminator voltage	`0x0990`	2.99268 V

Table 4.11: Decoded header information in a TO–31 whole-orbit data file

Parameter	**Value**	**Engineering units**
Satellite name	`0x544d5341...`	"TMSAT-1"
File description	`0x486f7573...`	"Housekeeping WOD"
Start time	`0x38411942`	120002 UTC 28 November 1999
End time	`0x3841c1e2`	235930 UTC 28 November 1999
Sampling interval	`0x001e`	30 seconds
Number of channels	`0x0014`	20 channels

- A 16 bit constant `0x0000`.
- The sampling interval, a 16 bit integer, in seconds.
- A 32 bit constant `0x00000000`.
- The number of telemetry channels, a 16 bit integer.

The large number of constants in the file header suggests that the format has many other possible functions and parameters which are not currently being used.

A sample telemetry file was downloaded from TO–31. We may read off the header values from Figure 4.8 to produce Table 4.11.

```
81 34 01 00 01 be 00 54 4d 53 41 54 2d 31 00 00
00 00 00 01 48 6f 75 73 65 6b 65 65 70 69 6e 67
20 57 4f 44 00 00 00 00 00 00 00 00 00 00 00 00
00 00 42 19 41 38 00 00 e2 c1 41 38 00 00 1e 00
00 00 00 00 14 00 02 00 11 00 00 02 02 00 0b 00
00 02 02 00 0d 00 00 02 02 00 01 00 00 02 02 00
13 00 00 02 02 00 0e 00 00 02 02 00 26 00 00 02
02 00 04 00 00 02 02 00 14 00 00 02 02 00 08 00
00 02 02 00 1a 00 00 02 02 00 29 00 00 02 02 00
38 00 00 02 02 00 22 00 00 02 02 00 2a 00 00 02
02 00 32 00 00 02 02 00 1c 00 00 02 02 00 0f 00
00 02 02 00 17 00 00 02 02 00 07 00 00 02 43 19
41 38 00 00 01 0d 8f 07 2c 04 13 0c 2e 05 23 00
0b 06 11 05 2d 05 1d 00 94 01 02 02 6e 00 9a 05
d7 07 49 07 e6 03 bd 08 19 07 2d 06 61 19 41 38
00 00 ff 0c 9b 07 2a 04 a4 0b 1c 05 2a 00 c8 04
```

Figure 4.8: Header information in a TO–31 whole-orbit data file

We may then read off the list of channels from Figure 4.9 to produce the list in Table 4.12. Each entry in the list is accompanied by two sets of flags, `0x0200` and `0x0002`, whose function was not determined.

```
81 34 01 00 01 be 00 54 4d 53 41 54 2d 31 00 00
00 00 00 01 48 6f 75 73 65 6b 65 65 70 69 6e 67
20 57 4f 44 00 00 00 00 00 00 00 00 00 00 00 00
00 00 42 19 41 38 00 00 e2 c1 41 38 00 00 1e 00
00 00 00 00 14 00 02 00 11 00 00 02 02 00 0b 00
00 02 02 00 0d 00 00 02 02 00 01 00 00 02 02 00
13 00 00 02 02 00 0e 00 00 02 02 00 26 00 00 02
02 00 04 00 00 02 02 00 14 00 00 02 02 00 08 00
00 02 02 00 1a 00 00 02 02 00 29 00 00 02 02 00
38 00 00 02 02 00 22 00 00 02 02 00 2a 00 00 02
02 00 32 00 00 02 02 00 1c 00 00 02 02 00 0f 00
00 02 02 00 17 00 00 02 02 00 07 00 00 02 43 19
41 38 00 00 01 0d 8f 07 2c 04 13 0c 2e 05 23 00
0b 06 11 05 2d 05 1d 00 94 01 02 02 6e 00 9a 05
d7 07 49 07 e6 03 bd 08 19 07 2d 06 61 19 41 38
00 00 ff 0c 9b 07 2a 04 a4 0b 1c 05 2a 00 c8 04
```

Figure 4.9: List of channels in a TO–31 whole-orbit data file

The first sample from Figure 4.10 is then decoded to produce Table 4.13.

```
81 34 01 00 01 be 00 54 4d 53 41 54 2d 31 00 00
00 00 00 01 48 6f 75 73 65 6b 65 65 70 69 6e 67
20 57 4f 44 00 00 00 00 00 00 00 00 00 00 00 00
00 00 42 19 41 38 00 00 e2 c1 41 38 00 00 1e 00
00 00 00 00 14 00 02 00 11 00 00 02 02 00 0b 00
00 02 02 00 0d 00 00 02 02 00 01 00 00 02 02 00
13 00 00 02 02 00 0e 00 00 02 02 00 26 00 00 02
02 00 04 00 00 02 02 00 14 00 00 02 02 00 08 00
00 02 02 00 1a 00 00 02 02 00 29 00 00 02 02 00
38 00 00 02 02 00 22 00 00 02 02 00 2a 00 00 02
02 00 32 00 00 02 02 00 1c 00 00 02 02 00 0f 00
00 02 02 00 17 00 00 02 02 00 07 00 00 02 43 19
41 38 00 00 01 0d 8f 07 2c 04 13 0c 2e 05 23 00
0b 06 11 05 2d 05 1d 00 94 01 02 02 6e 00 9a 05
d7 07 49 07 e6 03 bd 08 19 07 2d 06 61 19 41 38
00 00 ff 0c 9b 07 2a 04 a4 0b 1c 05 2a 00 c8 04
```

Figure 4.10: First telemetry sample in a TO–31 whole-orbit data file

Table 4.12: Decoded channel list in a TO–31 whole orbit data file

Raw value	**Decimal**	**Channel Description**
`0x0200 1100 0002`	17	Battery Voltage
`0x0200 0b00 0002`	11	Battery Current
`0x0200 0d00 0002`	13	Battery Temp
`0x0200 0100 0002`	1	Array Voltage
`0x0200 1300 0002`	19	PCM Input Curr
`0x0200 0e00 0002`	14	+14V Line Curr
`0x0200 2600 0002`	38	+5V Line Curr
`0x0200 0400 0002`	4	-X Panel Temp
`0x0200 1400 0002`	20	-Y Panel Temp
`0x0200 0800 0002`	8	Array Curr -X
`0x0200 1a00 0002`	26	Array Curr -Y
`0x0200 2900 0002`	41	Tx0 Forward (W)
`0x0200 3800 0002`	56	Tx0 Reverse (V)
`0x0200 2200 0002`	34	Rx0 RRSI (dBm)
`0x0200 2a00 0002`	42	Rx1 RRSI (dBm)
`0x0200 3200 0002`	50	Rx2 RRSI (dBm)
`0x0200 1c00 0002`	28	Tx0 Temp
`0x0200 0f00 0002`	15	NavMag0 Xdir
`0x0200 1700 0002`	23	NavMag0 Ydir
`0x0200 0700 0002`	7	NavMag0 Zdir

Table 4.13: Decoded telemetry observation in a TO–31 whole orbit data file

Channel Description	**Raw value**	**Engineering units**
Timestamp	`0x38411943`	120003 UTC 28 November 1999
Filler	`0x0000`	
Battery Voltage	`0x0d01`	13.95365 V
Battery Current	`0x078f`	232.0696 mA
Battery Temperature	`0x042c`	16.43892 C
Array Voltage	`0x0c13`	41.82845 V
PCM Input Currrent	`0x052e`	423.6486 mA
+14V Line Current	`0x0023`	14.21373 mA
+5V Line Current	`0x060b`	955.6439 mA
-X Panel Temperature	`0x0511`	-0.5762487 C
-Y Panel Temperature	`0x052d`	-2.656706 C
Array Current -X	`0x001d`	12.9023 mA
Array Current -Y	`0x0194`	110.4042 mA
Tx0 Forward Power	`0x0202`	2.0042 W
Tx0 Reverse Power	`0x006e`	0.134376 W
Rx0 RRSI	`0x059a`	-97.08976 dBm
Rx1 RRSI	`0x07d7`	-110.8361 dBm
Rx2 RRSI	`0x0749`	-116.5249 dBm
Tx0 Temperature	`0x03e6`	21.64006 C
NavMag0 Xdir	`0x08bd`	6.758615 V
NavMag0 Ydir	`0x0719`	8.391602 V
NavMag0 Zdir	`0x062d`	15.95264 V

Table 4.14: Channel numbers in AO–16 WOD survey

Channel number	Channel description
0x26	-X array current
0x27	+X array current
0x28	-Y array current
0x29	+Y array current
0x2B	+Z array current
0x2D	BCR (**B**attery **C**harge **R**egulator) input current

4.3.4 AO–16/PACSAT whole orbit data

AO–16's on-board systems predate the now commonly used UoSAT telemetry formats. Since the satellite has worked very well (it ran 1910 days—over 5 *years*—until the onboard computer system went into safe mode on 12 December 1999), the command team have opted to leave it as is and not update the telemetry system (9).

AO–16 uses a unique system for gathering and disseminating whole-orbit data. Unlike newer satellites that gather whole-orbit data continuously, AO–16 only gathers data when instructed to do so by a command station, and then only does it for one orbit. It doesn't place the data in the satellite file system, but instead broadcasts the data on the downlink in a series of special messages. The format of the downlink messages was easily determined by inspection.

There are two kinds of downlink messages involved in the dissemination of whole-orbit data on AO–16. The first message is a simple text listing of telemetry channels, an AX.25 UI frame addressed to `WODCH-0`:

```
WOD:262728292B2D
```

This messages states that a whole-orbit data survey is being broadcast on the downlink, and that the survey includes the telemetry channels decoded in Table 4.14.

The second message transmits the actual telemetry data in AX.25 UI frames addressed to `WOD-0`. Observations are sent in order with a timestamp for each observation. Each timestamp is a 32 bit Unix time and is stored least-significant byte first. A sample WOD packet is illustrated in Figure 4.11.

```
AC AE 02 38 01 6C 01 00 15 66 B6 AE 02 38 00 64
14 00 18 72 C0 AE 02 38 04 5B 34 00 16 7B CA AE
02 38 05 41 50 01 14 84 D4 AE 02 38 03 0D 6B 04
15 6E DE AE 02 38 1F 01 6B 02 16 80 E8 AE 02 38
55 01 51 01 16 8B F2 AE 02 38 6C 00 26 04 16 7B
FC AE 02 38 6D 00 01 00 19 77 06 AF 02 38 6E 04
00 1B 17 81 10 AF 02 38 5E 03 05 50 19 8B 1A AF
02 38 30 03 02 78 18 85 24 AF 02 38 01 00 01 84
1C 73 2E AF 02 38 02 36 04 6E 1D 8C 38 AF 02 38
00 5A 02 47 1C 89 42 AF 02 38 03 6D 04 21 1E 85
4C AF 02 38 02 7B 06 00 1C 75 56 AF 02 38 07 72
36 00 1C 90 60 AF 02 38 06 46 5E 02 1C 90 6A AF
02 38 01 11 73 02 1D 75 74 AF 02 38 11 00 74 00
1E 77 7E AF 02 38 49 01 60 01 1D 8C 88 AF 02 38
6A 01 41 02 19 8E 92 AF 02 38 81 01 16 01 1C 7E
9C AF 02 38 84 02 01 15 1A 7B
```

Figure 4.11: AO–16 whole-orbit data transmission

Table 4.15: Decoded AO–16 WOD sample

Channel description	**Raw value**	**Engineering units**
Timestamp	`0x3802AEAC`	0344444 UTC 12 October 1999
-X array current	`0x01`	-7.5 mA
+X array current	`0x6c`	217.6 mA
-Y array current	`0x01`	-1.7 mA
+Y array current	`0x00`	129.5 mA
+Z array current	`0x15`	26.4 mA
BCR input current	`0x66`	438.1 mA

Each packet in this survey consists of a sequence of 15 observations of 10 bytes each, 4 bytes for the timestamp, followed by 6 bytes of telemetry data. The first telemetry observation in the sample packet is:

```
AC AE 02 38 01 6C 01 00 15 66
```

We may decode this observation, producing the values in Table 4.15.

4.5 Notes and references

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