“Ever wondered what is on the Orbcomm Satellite Downlink?”

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Dec 2002 – Minor corrections.

Introduction

Ever since the first pair of Orbcomm spacecraft were launched in 1995, I have been intrigued by what information there might be on the downlink transmissions that now occupies so such of the 137 to 138 MHz band [3]. This paper outlines the downlink format, as I have been able to decipher it and is at most, is just a guess at actually what it is. General information on the Orbcomm system and spacecraft can be found at [1].

The Downlink

The Orbcomm satellites have a VHF band Subscriber Transmitter (STX) that provides a continuous 4800 bps stream of packetised signal to the Subscriber Communicators (SC). The SC uses this signal to detect the presence of the satellite and then to receive authorised uplink frequencies. The STX also broadcasts its satellite state vector (position and velocity) to the SCs to use in calculation of their geographic position. The satellite ephemeris is generated every four seconds by the Attitude Control subsystem (ACS) which processes the on-board Rockwell MPE-II GPS receiver fix data [14]. The STX transmitter is agile in power level, data rate and frequency. The output power can be varied between 10 and 40 Watts. The data rate can be set to either 4800 or 9600 Baud and the transmitter can be commanded to any frequency between 137 and 138 MHz in 2.5 KHz steps. The EIRP is approximately +12 dBW. Root Raised Cosine (RRC) filtering, with $\alpha = 0.4$, is used to limit spectral occupancy. The downlink transmission is Right Hand Circular Polarised (RHCP)

SDPSK

The Downlink modulation is Symmetrical Differential Phase Shift Keying (SDPSK).

Prior to modulation, each information bit is differentially encoded by an “exclusive or” operation with the previous bit. The encoded bit b_n is generated by $b_n = b_{n-1}$ XOR I_n. This encoding is also known as NRZ-M (Non Return to Zero – Mark).

The actual RF carrier phase or physical symbol that is sent for each encoded bit is defined as a negative 90° shift of carrier phase for a 0 bit and a positive 90° phase shift for a 1 bit. This gives 4 possible carrier phases or symbols (0°, 90°, 180° and 270°). This means that for a string of consecutive 1s or 0s, the carrier phase will rotate counter-clockwise in the 0s case or clockwise in 1s case. SDPSK has a fundamental spectral component at the symbol rate and this can be extracted by a PLL or FFT for symbol synchronization. [28]

N	1	2	3	4	5	6	7	8
Data bit	1	1	1	1	0	0	1	0
Symbol	90°	0°	270°	180°	270°	0°	270°	0°
Vector	↑	→	↓	←	↓	→	↓	→

ORBCOMM Downlink Data Format

- Synchronous data at a Bit rate of 4800 bps
- Differentially Encoded - NRZ-M
- Word size – 8 bits
- LSB transmitted first
- Minor Frame is 600 words or 4800 bits in 1 second
- Major Frame is 16 minor frames

Minor Frame Format

A Minor Frame consists of 50 packets of 12 words each. A packet is made up of a Packet Type word, followed by 9 data words and 2 Fletcher Checksum (FCS) words. In each Minor Frame, there is one Synchronization packet, one null filled Fill packet and 48 other packets being either Fill, Command, Poll or Message packets. A minor frame has duration of one second.

The downlink does not transmit command and message data all the time so it has to maintain synchronism by sending Fill packets. These Fill packets contain "random" data that repeats every 49 packets. Command and message packets are inserted into the data stream by the spacecraft instead of the Fill packets as required.

Packet Type	Function
65	Synchronization packet [1]
1A	Single and Multi-line message packets
1B	Uplink information in 1 packet format [3]
1C	Downlink information in 3 packet format [3]
1D	Network Control Centre (NCC) information in1 packet format [3]
1E	Fill packet
1F	Ephemeris in 2 packet format [2]
22	Orbital Elements in one packet format[4]
Note 1. transmitted every second Note 2. transmitted every 4 seconds Note 3. transmitted every 8 seconds Note 4. transmitted every 4 minutes	

Minor Frame Synchronisation - Packet Type 65

Sync Code			ID		F	MV				FCS	
65	A8	F9	16	10	64	70	00	00	00	B0	50

Type										FCS	
1E	00	00	00	00	00	00	00	00	00	B6	2C

The first packet of minor frame is used for word and frame synchronisation.

- Words 1, 2 & 3 make a 24 bit minor frame synchronisation word (65A8F9 hex).
- Word 4 is the spacecraft identification (ID), 01 hex to 24 hex, ie. FM-1 to FM-36.
- Word 5 is a fixed value of 10 hex.
- Word 6, F, are the least significant nibbles of the downlink channel number, N. The most significant nibble is 0 for F between 50 hex and FF hex and 1 for F between 00 hex to 40 hex. Also see Downlink Packet description.
- Word 7 has a 4 bit Minor frame counter, M, (0 to F hex) in the upper nibble and a flag, V, 0 or 1 in the lower nibble. The flag, V, is usually 1 but on some spacecraft, it goes to 0 in Minor Frame 0.
- Words 8, 9 & 10 are all 00 hex.
- Words 11 & 12 are Fletcher Checksum (FCS) words. The recalculated FCS is zero if the packet is received error-free. The FCS algorithm is in [5] and Appendix B.

The second minor frame packet contains a zero filled Fill Packet with the Packet Type in word 1 (1E hex), 00 hex in words 2 to 10 and the Fletcher Checksums in words 11 & 12. (B6 hex and 2C hex). The “zeros” in this packet causes the audible “blip” every second on a receiver in FM mode.

Message packets – Packet Type 1A

Type	NP									FCS	
1A	30	01	82	BD	60	C4	88	6B	BB	D3	D1
1A	31	41	1C	B0	A2	67	AB	B8	B2	F8	92
1A	32	F1	EB	BA	00	00	00	00	00	BD	7D

Word two (NP) indicates the number of packets in the message or command (upper nibble) and a zero-based packet counter (lower nibble)

Message packets have been seen with NP values of 10 hex to 54 hex. See Appendix C2.

The data unit of these packets are in byte-reversed order and consist of three 20-bit words and a 4-bit pad of 0000 or 0001. These 20-bit words have a range of values (0000 hex to 18ff hex) in two distinct groups, 00000 hex to 458ff hex and 82000 hex to c58ff hex. These words are encoded, compressed or encrypted in an unknown manner.

BB6B8 8C460   BD820 1
B2B8A B67A2   B01C4 1
00000   00000   BAEBF 1

Uplink channel packet – Packet Type 1B

Type	NP									FCS	
1B	10	54	35	F2	23	00	00	00	00	2B	0C

Word 2 (NP) indicates the number of packets in the message or command (upper nibble) and a zero-based packet counter (lower nibble)

Word 3 (54 hex) is fixed. According to [16], this is the number of re-tries (5) and the number of Acquire/Communicate (A/C) slots available(4).

Words 4 to 10 are up to four 4 uplink channels, each three nibbles long and byte reversed (Usually only 2 channels are given). The packet is repeated at least twice per minor frame. The packet may indicate the current UL channel(s) to be used for the Acquire/ Communicate random access protocol where the frequency is given by 148.00 + N x 0.0025 MHz.

00 00 00 00 23 F2 35 → 0 000 000 23F 235 → N = 0, 0, 575, 565 → 149.4375 and 149.4125 MHz

Downlink channel packets – Packet Type 1C

Type	NP									FCS	
1C	30	B0	00	05	64	00	14	1D	01	98	D1
1C	31	13	01	0B	09	71	12	B8	00	07	49
1C	32	5A	00	00	00	00	00	00	00	AE	AA

Word 2 (NP) indicates the number of packets in the message or command (upper nibble) and a zero-based packet counter (lower nibble)

Word 3 to 10. 5 downlink channel numbers in binary per packet, each 3 nibbles long and byte reversed.

Received order		Reverse order		Nibble order
B0 00 05 64 00 14 1D 01	→	01 1D 14 00 64 05 00 B0	→	0 11D 140 064 050 0B0
13 01 0B 09 71 12 B8 00	→	00 B8 12 71 09 0B 01 13	→	0 0B8 127 109 0B0 113
5A 00 00 00 00 00 00 00	→	00 00 00 00 00 00 00 5A	→	0 000 000 000 000 05A

The Subscriber Downlink frequency is given as 137.0000 + N * 0.0025 MHz where channel number (N) is 0 to 400 decimal. Only Channel Numbers 80 to 320 are used.

Eg. 0B0 hex = 176 = 137 + 176 * 0.0025 = 137.4400 MHz (this satellite's downlink frequency)
113 hex = 275 = 137 + 275 * 0.0025 = 137.6875 MHz (1 of 10 other s/c downlink frequencies)
05A hex = 90 = 137 + 90 * 0.0025 = 137.2250 MHz (another other s/c d/l frequency)

List of Channel numbers vs. Downlink frequencies

Channel Number (decimal)	Channel Number (hex)	Downlink Frequency (MHz)
80	050	137.2000
90	05A	137.2250
100	064	137.2500
115	073	137.2875
125	07D	137.3125
159	09F	137.3975
176	0B0	137.4400
184	0B8	137.4600
265	109	137.6625
271	10F	137.6275
275	113	137.6875
283	11B	137.7075
285	11D	137.7125
295	127	137.7375
320	140	137.8000

Orbcomm has an arrangement with NOAA, ESA and others users of the 137-138 MHz band regarding non-interference with existing and future meteorological satellites.
These operate or will operate in the band segments:

130.025-137.175 MHz	NOAA/METOP/Meteor LRPT on 137.10 MHz
137.373-137.425 MHz	Meteor on 137.4 MHz
137.475-137.525 MHz	NOAA APT on 137.5 MHz
137.595-137.645 MHz	NOAA APT 137.62 MHz
137.825-137.875 MHz	Meteor on 137.85 MHz
137.825-137.975 MHz	NOAA/METOP/Meteor LRPT on 137.9125 MHz

Orbcomm downlink transmissions currently do not transmit in these band segments.

NCC packet – Packet Type 1D

Type	NP									FCS	
1D	10	00	00	00	00	00	00	00	00	21	B2

I suspect that this indicates that there are no Gateways visible in my area and that the spacecraft are in GlobalGram "store & forward" mode.

Fill Packet – Packet Type 1E

Type										FCS	
1E	8C	69	F6	3A	73	99	1A	A6	36	D2	E9

See Appendix C6 for a list of Fill packets. During 2000, the Fill packet changed from the 48 pattern to the one shown above, on all spacecraft except for FM-2. This change is responsible for the "harsh" buzzing sound of the downlink on a FM receiver.

Ephemeris Packet – Packet Type 1F [1]

A 24 word Ephemeris packet is sent every 4 seconds. It contains the spacecraft identification with spacecraft Time and Orbit data in byte reversed order.

Type	ID	Orbit data									
1F	0F	76	C6	72	26	AC	83	80	D4	C8	73

Orbit data					Time of Week			Week Number		FCS	
46	BE	01	46	43	9F	3C	04	1C	04	6F	3F

From this example, the spacecraft ID is 0F hex = 15 ie. FM-15
Putting rest of the data in byte reversed order gives:

Week Number	Time of Week	Orbit Data
04 1C	04 3C 9F	43 46 01 BE 46 73 C8 D4 80 83 AC 26 72 C6 76

Week Number is weeks since 00Z 6 January 1980 (GPS Week Number (WN) Zero).
041C hex = 1052 = Sunday 5 March 2000

Time of Week is the number of seconds since 00Z Sunday
043C9F hex = 277663 seconds = 3 days 5 hours 7 minutes 43 seconds
i.e. Current date and time = WN + TOW = Wed 8 March 2000 at 05:07:43 UTC

The on-board GPS receiver provides a satellite position and velocity state vector in the ECEF (Earth Centred Earth Fixed) co-ordinate system [13]. This has the +x axis through 0° East (Greenwich), +z through the North Pole and +y through 90°East. The Orbit data can be re-arranged into 6 words of five 4-bit nibbles each. By comparing received Orbit data values with predicted spacecraft position and velocity, it was determined that the data is in offset binary format (00000 hex is negative maximum, 80000 hex is zero and FFFFF hex is positive maximum). These data are converted to 2's compliment format by inverting the sign bit. The 20-bit values are sign extended to 32-bit format. The physical value is obtained by a 4 bit left shift (x16). For example, using Value 6 from the table below:

2C676 $\rightarrow$	AC676 $\rightarrow$	FF FA C6 76 (-342410) $\rightarrow$	FF AC 67 60 (-5478560 metres)
20 bit data	invert sign bit	32 bits with sign ext	x16

In my region (Southern Australia), z should always be negative. z is at a maximum negative value for orbits that reach maximum South latitude (equal to the spacecraft inclination). At this same time, zdot goes from small negative values to small positive values. Y values should be positive and decrease to zero when the spacecraft crosses the Dateline (180° East). X values should reach a negative maximum crossing the Dateline. By inspection and graphical plotting, it was determined that the values are in the order of zdot, ydot, xdot, z, y and x. The Root Square Sum of the position components give the spacecraft radius vector (R), $R = \sqrt{(X^2 + Y^2 + Z^2)}$ = 7,200,111m so height = R – Earth radius = 7,200,111m - 6,378,150m = 821,861m or 821.861 km. Likewise, the spacecraft velocity vector is $V = \sqrt{(XDOT^2 + YDOT^2 + ZDOT^2)}$ = 7,715 m/sec or 7.715 km/s.

Orbit Data Table

Orbit data	Value 1	Value 2	Value 3	Value 4	Value 5	Value 6
Off Bin	43460	1BE46	73C8D	48083	AC267	2C676
2s Comp	C3460	9BE46	F3C8D	C8083	2C267	AC676
Decimal	-248736	-410042	-50035	-229245	+180839	-342410
Shifted < 4	-3,979,776	-6,560,672	-800,560	-3,667,920	+2,893,424	-5,478,560
Parameter	Z dot m/s	Y dot m/s	X dot m/s	Z m	Y m	X m

The FCS is calculated over the 2 packets.

[1] **Footnote added December, 2002**. The method described in the shaded section has been found to be incorrect. It calculates the spacecraft height and velocity lower than expected. The correct algorithm for height and velocity determination is provided in Revision F of [5], dated April 24 1999 which only became available to me in December 2002. I have retained this section to show my methodology.

Element packet – Packet Type 22

Type	SCID		MA			MM				FCS	
22	02	02	D4	8F	A4	80	82	CA	F7	2F	E1

This packet provides 2 orbital elements for its own spacecraft, a couple of others and FM02. The same packet is repeated at about 4 minute intervals.

SCID, Word two and three (word two repeated), is the spacecraft identification to which the elements apply.

MA (Mean Anomaly) is a 24-bit value in reverse byte order.

$MM° = (value/2^{24}-1) * 360.0000$
Value = A48FD4 hex = (10784724/16777215)*360.0000 = 231.4151°

MM (Mean Motion) is a 32-bit value in revere byte order.

$MA_{revs/day} = (value/2^{32}-1) * 15.00000106$
Value = F7CA8280 hex = (4157244032 /4294967303) * 15.00000106 = 14.51900806 revs/day

The value, 15.00000106, was determined empirically**.**

References and collected papers: (Note: The www links as of May 2000)

The Orbcomm System

1. Orbcomm Global LP. Homepage http://www.orbcom.com

2. Orbcomm Subscriber Communicator Air Interface Specification A80TD009. Listed for completeness only. This document is proprietary and is available only to Subscriber Communicator manufactures on a non-disclosure basis and is not in the public domain.

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14. Rockwell Collins MPE-I Specification Sheet http://www.collins.rockwell.com/content/pdf/826.pdf

15. M. Deckett, "A description and Status of the LEO Satellite Data Communication System", AIAA-94-1135-CP

Subscriber Communicators

16. Panasonic GX-7100 SC Command Specification Version 1.3 February 2000 http://www.panasonic.com/industrial_oem/satcom/download.html

17. Stellar EL-2000 SC user manual http://www.stellar-sat.com/

18. Magellan Satellite Modem brochure http://www.orbistar.com/

19. Magellan OM200 Satellite Modem Reference Guide http://www.magellangps.com/PDFs/S@ModDKMan.pdf

20. Magellan Satellite Communicator Development Kit Reference Guide http://www.magellangps.com/PDFs/ref_manual.pdf

21. Quake Wireless LeoLink OEM Module data sheet http://www.quakewireless.com/core.pdf

22. Scientific Atlanta http://www.sciatl.com/content/prd/Pages_sat/LEO/LEO.htm

23. Satellite Smart Solutions SatSmart-2000 SC http://www.sat-smart.com/products_text.html

SDPSK modulation

24. Orbcomm Air Interface Subscriber Communicator SDPSK modem ASIC http://csc.postech.ac.kr/project/orbcomm

25. K. Gilad, "Satellite Network Simulator" http://tochna.technion.ac.il/project/sat/html/chapters/sat.html

26. A.A. Masoud and A.G. Qureshi, "Robust, FFT-based, Blocked Demodulation in the Presence of Symbol synchronization Jitter using Symmetric Differential Phase Shift Keying (SDPSK), IEEE International Conference on communication, Volume 2, pp. 1278-1284, 1999.

Appendix A

Orbcomm Ground Earth Station (GES) Locations (adapted from [7])
Refer http://www.orbcomm.com/worldwide/worldwide.htm and http://194.177.100.132/PU3b_co.htm.

GES	Latitude	Longitude	GCC	NCC ID	Status
Chandler, Arizona	34.46 N	109.56 W	USA	001	Active
Tifton, Georgia	31.50 N	83.20 W	USA	001	Active
Arcade, New York	42.52 N	78.38 W	USA	001	Active
Wenatchee, Washington	47.55 N	120.17 W	USA	001	Active
Curacao, Netherlands Antilles	12.50 N	69.00 W	USA	001	Active
Quito, Ecuador	00.13 S	78.30 W	USA		3Q 2000
Matera, Italy	40.65 N	16.70 E	Italy	120	Active
Maghreb, Morocco	33.53 N	7.68 W	Italy	120	Active
Kitaura, Japan	36.05 N	140.31 E	Japan	130	Active
San Luis, Argentina	33.83 S	65.18 W	Brazil	123	Active
Rio de Janerio, Brazil	22.69 S	42.87 W	Brazil	123	Active
Kijal, Malaysia	4.63 N	103.75 E	Malaysia	121	Active
Chong Ho Won, Korea	37.14 N	127.66 E	Korea		Inactive
Abidjan, Cote d'Ivoire	5.19 N	4.02 W	South Africa		1Q 2000
Cape Town, South Africa	33.56 S	18.22 E	South Africa		2Q 2000
Dar El Salaam, Tanzania	6.48 S	39.17 E	South Africa		3Q 2000
Izmir, Turkey	38.25 N	27.09 E	Saudi Arabia		4Q 2000
Jiddah, Saudi Arabia	21.30 N	39.12 E	Saudi Arabia		2Q 2000
Islamabad, Pakistan	33.42 N	73.10 E	Saudi Arabia		2Q 2000
Bangalore, India	12.58 N	77.36 E	India		2Q 2000
Delhi, India	28.36 N	77.12 E	India		3Q 2000
Shanghai, China	31.14 N	121.28 E	China		3Q 2000
Harbin, China	45.45.N	126.41 E	China		4Q 2000
Lhasa, China	29.40 N	91.09 E	China		2Q 2001
Moscow, Russia	55.75 N	37.58 E	Russia		4Q 2000
Kiev, Ukraine	50.50 N	30.47 E	Ukraine		4Q 2000

Appendix B

Routine from [5], Orbcomm Serial Interface Specification, Appendix F.

```
fletcher_encode (buffer, count)
unsigned char * buffer;
long count;
{
int i;
unsigned char c0 = 0;
unsigned char c1 = 0;
*(buffer + count – 1) = 0;
*(buffer + count – 2) = 0;

for (i = 0; i < count; i++)
        {
        c0 = c0 + *(buffer + i);
        c1 = c1 + c0;
        }
*(buffer + count – 2) = c0 + c1;
*(buffer + count – 1) = c1 + 2 * c0;
}

long fletcher_decode (buffer, count)
unsigned char * buffer;
long count;
{
int i;
unsigned char c0 = 0;
unsigned char c1 = 0;

for (i = 0; i < count; i++)
         {
        c0 = c0 + *(buffer + i);
        c1 = c1 + c0;
        }
return ((long)(c0 + c1)); /* returns zero if buffer is error-free*/
}
```

Appendix C1 -Example Packets

```
Command and message packets with Synchronisation and Fill packets removed
The trailing zero indicates a valid FCS for that packet

Note that the ephemeris (1f) packet occur every 4 seconds

1f 176abce357c60ee354f456f288e2d33c9f24042004 c3fc 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 105403522800000000 fd07 0
1a 108128a90000000000 daaa 0
1f 1702ba7305c61cdf4438571f84920f3da324042004 d451 0
1b 105403f22300000000 bbae 0
1b 1054a3f22300000000 bb0e 0
1f 179eb7c3b2c52edb547c57527f924b3da724042004 85a8 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 1054a3f22300000000 bb0e 0
1f 173eb5c35fc543d784c0578b7ad2873dab24042004 c2e7 0
1a 10018b990000000000 b2ff 0
1f 17e2b2730cc55cd3d40458c97562c43daf24042004 9463 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 1054a3f22300000000 bb0e 0
1f 178ab0e3b8c479cf5449580d7142013eb324042004 dd19 0
1b 1054a3b22c00000000 45bb 0
1b 1054bdb12c00000000 7c6b 0
1f 1736ae1365c499cbe48d58566c623e3eb724042004 06d4 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 1054bdb12c00000000 7c6b 0
1f 17e6abf310c4bcc7a4d258a567d27b3ebb24042004 146f 0
1f 179aa993bcc3e4c3841759f96282b93ebf24042004 de1d 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 1054bdb12c00000000 7c6b 0
1a 105100ac0000000000 b524 0
1f 1752a7e367c30fc0745c59535e92f73ec324042004 86bf 0
1b 1054bd712600000000 60cd 0
1d 0b10d6cd6bba652f4c 908f 1f3
1b 105495712600000000 a0b5 0
1f 170ea5f312c33dbc94a159b359d2353fc724042004 ea79 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 105495712600000000 a0b5 0
1f 17cfa2c3bdc270b8c4e659195562743fcb24042004 7dd5 0
1f 1793a04368c2a5b4242c5a845042b33fcf24042004 c63e 0
1d 100000000000000000 21b2 0
1c 30b000056400141d01 98d1 0
1c 3113010b097112b800 0749 0
1c 325a00000000000000 aeaa 0
1b 105495712600000000 a0b5 0
22 171721693a965be6f2 a281 0
1b 105495312a00000000 4849 0
1f 175b9e8312c2dfb094715af54b62f23fd324042004 f4a6 0
1b 10543f322a00000000 f1f5 0
1f 17289c83bcc11cad24b75a6b47d23140d724042004 668a 0
```

Appendix C2 - Examples of multi-line message packets

```
1a 30 01ccb87083b92a21 be7c 0
1a 31 81029e53e352b2b8 dec4 0
1a 32 d107b730f3136da9 9841 0

1a 30 0182bd60c4886bbb d3d1 0
1a 31 411cb0a267abb8b2 f892 0
1a 32 f1eba00000000000 bd7b 0

1a 40 e0afb60b58bb7abe 40cb 0
1a 41 7069b643908b00a4 50c4 0
1a 42 c094a67b6cfbfeba 0c04 0
1a 43 f004b8fd24bb88b8 16c5 0

1a 50 c000a4b3abe8f1ba 162b 0
1a 51 706585cb608a3bba 0e83 0
1a 52 3075b65feaa8d4b2 10b2 0
1a 53 c00f0fa434fb82bb 3f66 0
1a 54 3021a843850b0000 f3d3 0

1a 50 f036bdfeb2eb5ebd c934 0
1a 51 7021ba9da59bc4b6 9f54 0
1a 52 1046a767002a48ba ff05 0
1a 53 d0eaac7bce5b2d91 5378 0
1a 54 b060b5d8c20a0000 75b4 0
```

Appendix C3 - Examples of Uplink packets

```
1b 10 54 2d301600000000 0707 0
1b 10 54 41301600000000 6793 0
1b 10 54 41301600000000 6793 0
1b 10 54 31311600000000 e029 0
1b 10 54 31312a00000000 688d 0
1b 10 54 31312a00000000 688d 0
1b 10 54 31312a00000000 688d 0
1b 10 54 7d302a00000000 0f9b 0
1b 10 54 7dd01b00000000 0910 0
1b 10 54 7dd01b00000000 0910 0
1b 10 54 7dd01b00000000 0910 0
1b 10 54 2dd01b00000000 89e0 0
1b 10 54 2d302a00000000 8f6b 0
1b 10 54 2d302a00000000 8f6b 0
1b 10 54 2d302a00000000 8f6b 0
1b 10 54 9f312a00000000 f88f 0
1b 10 54 9f311600000000 702b 0
1b 10 54 9f311600000000 702b 0
1b 10 54 7d301600000000 8737 0
1b 10 54 7d301600000000 8737 0
1b 10 54 7d302a00000000 0f9b 0
1b 10 54 7d302a00000000 0f9b 0
1b 10 54 99322a00000000 216b 0
1b 10 54 99d20200000000 b163 0
1b 10 54 99d20200000000 b163 0
1b 10 54 9fd10200000000 8887 0
```

Appendix C4 - Example of Downlink packets

```
1c 30 2701056400141d01 6190 0
1c 31 13010b097112b800 0749 0
1c 32 5a00000000000000 aeaa 0
```

Appendix C5 - Examples of GES packet

```
1d 10 0000000000000000 21b2 0
```

Appendix C6 - Fill packets - A Complete Minor Frame with “Fill” packets

```
65 a8f91910b090000000 3061 Sync packet
1e 000000000000000000 b62c Fill packet with all zeros
1e 5a8c1a5e354ce775c6 a33e 48 Fill packets follow
1e 6fe4a5f1ddc8b12cad e5e5
1e 567dc3683187453d72 8dab
1e 463e5d5fb36a15e680 0109
1e 78a312ae82b1ab1bf3 9586
1e 3dc48db144c09af1c2 1a38
1e ed34e377bdc0e111fd 6893
1e a38003aca0479dc30d 12aa
1e 3c4cec45b4af3662d0 2e30
1e c8eed0cd49cff8ebad b136
1e a1f27df45a07ef620d 1b04
1e 7b6ee7e16b3c9ec27c 4767
1e 4836b6de32ddd24ceb bff9
1e b3489015957f14f39c c3c8
1e d9b2b6a2eb952c9a23 ade9
1e 5bc7b2637b71598432 7937
1e 5884e57e8defd2c12d 2a3d
1e 8c69f63a73991aa636 d2e9
1e 6be5ebcad8571c9d89 81eb
1e 56b412d99ce9e3148f 6c76
1e 5bcffc07b64820cbb1 e13a
1e 199f6bf20eeac99574 7e85
1e 414ce5337241c243dd 7731
1e f0a75ea9ae31032602 5ddd
1e 34921be10c6fd924a5 0003
1e 60e43784840896bf93 a3cc
1e 2daf89852278c41ba2 19c4
1e 483e6b7369e174f69b 78b7
1e d1c3ce158e877b7276 896a
1e efb9b7ef01f3bd2ec8 cb22
1e 62d0cf10e6c6eb5b41 2975
1e 8f08f3cc94bfc83898 8120
1e 3cce1007d74ef60ad9 378c
1e dab7bafdc2bb293df7 8c34
1e 817a13e6cae0ec9108 f1ce
1e 0b10d6cd6bba652f4c 908f
1e 4916c0aeb77d0064fa 790a
1e ae5492d6697134638b d2aa
1e 85dfa48c4a2baf54fc 7664
1e 036428e3816dc5c5a0 d583
1e 530472dfc6a98e8ac8 5497
1e 8c3cba9958b8185b26 be60
1e 39fa4b5a83a0fd35df 6175
1e c2099bbd647969ae4a d7aa
1e ead481e2ac38d6c65d 6480
1e 3815d1c5f70756e3ee 14c6
1e 5bf2cd2afebd2b5bdd fc84
1e 1b3958a56a1a7a9be0 ed2b
```

The 1st Fill packet in the this sequence is “1e 19f1d8528e1ef9701d ed8f”. It has been replaced by the zero-filled packet after the Sync packet in the example above.

During 2000, the 48 “random” Fill packets after the Sync and Zero Fill Packets were replaced with 48 packets of the same pattern, 1e 8c69f63a73991aa636 d2e9, on all spacecraft except FM2.

This fixed Fill pattern results in a “harsher” sound of the downlink on a FM receiver.

Appendix C7 - Examples of Ephemeris packets

```
1f 14 1dd2a12d9dc3a0b5fe4cf7648371cc 671104 2004 cd89 0
1f 14 20cf31e89c44a565694d4863d39ecc 6b1104 2004 cecb 0
1f 14 2accb1a29cc7a945d44d9c61c3cbcc 6f1104 2004 1102 0
1f 14 39c9215d9c4dae653f4ef55f73f8cc 731104 2004 4746 0
1f 14 4fc671179cd5b2c5aa4e525eb324cd 771104 2004 92ba 0
1f 14 b7bdc1459b7dc0e5ed4f835993a7cd 831104 2004 f5c6 0
```