TRANSMISSION CHARACTERISTICS OF MARINE DIFFERENTIAL GPS (DGPS) STATIONS

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1. Introduction

The Global Positioning System (GPS) and the GLObal NAvigation Satellite System (GLONASS) are satellite-based positioning systems, generically called Global Navigation Satellite Systems (GNSSs). The positioning accuracy of these systems is influenced by various effects. Some GNSS errors are:

- satellite ephemeris prediction errors,
- ionospheric delay errors,
- tropospheric delay errors at the reference station,
- artificial errors induced by Selective Availability techniques (SA; GPS only).

These errors can be largely reduced by applying corrections to the “pseudoranges” (the raw distance to a GNSS satellite, containing time as an unknown quantity) computed by the satellite navigation equipment. The correction data is derived from satellite receivers at a *reference station* with known geographic location, from where it is distributed to the users. This method is known as Differential GNSS (DGNSS). A coding standard for DGNSS services has been defined by the “Radio Technical Commission For Maritime Services” (RTCM), Special Committee No. 104 [1].

After SA has been turned off “permanently” in May 2000, interest in DGNSS has declined somewhat. But still the positioning error can be reduced from about 30 metres to below 3 metres by DGNSS.

Numerous DGNSS services exist. At present, however, most of them are pure DGPS services, with no reference to GLONASS. Data is distributed over satellites, FM broadcast stations (Radio Data System, RDS), dedicated VHF transmitters, on shortwave and longwave, as well as via LORAN navigation transmitters [2]. Of particular interest are marine radiobeacons operating on frequencies near 300 kHz. These are not commercial services, but operated by government authorities. Usage is free of charge and the broadcasts are not encrypted. Furthermore, a simple coding is used. While all DGNSS services use RTCM messages, marine DGPS stations transmit them “plain”, without additional data layers. The beacons have nominal ranges from 40 to 300 nautical miles, but can often be received at much greater distances during the night.

This paper is intended for radio enthusiasts who wish to build their own decoder, or who are just curious about these transmissions. Designers of DGNSS equipment are referred to the original RTCM documents [1].

2. Radio broadcast characteristics

Marine DGPS radiobeacons are operating in in frequency range 284.5 - 325 kHz. In ITU Region 1 (Africa, parts of Asia and Europe), the band extends from 284.5 to 315 kHz. Station lists are available on the Internet, see [3] and [4].

DGPS broadcasts utilise Minimum Shift Keying (MSK) modulation, a frequency shift keying mode with very small bandwidth. The 99 percent power containment bandwidth of the signal is 1.17 times the bit rate [5]. The peak-to-peak frequency deviation equals half the bit rate, which is either 100 or 200 bps. These facts are illustrated by some measurement results shown in figure 2.1 and 2.2.

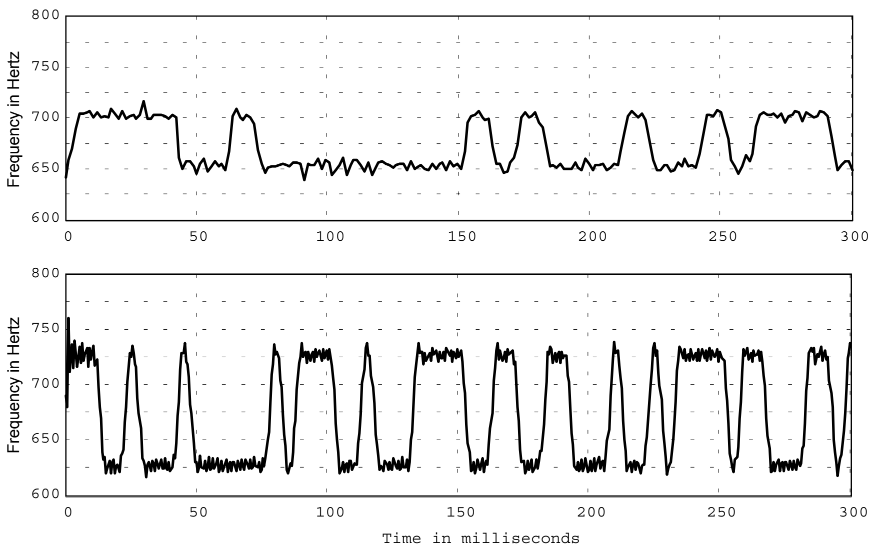

Figure 2.1. Instantaneous frequency vs time for DGPS beacons transmitting at 100 bps (upper trace) and 200 bps, measured with a quadrature demodulator implemented in software (MATLAB). The receiver’s center frequency was approximately 675 Hz.

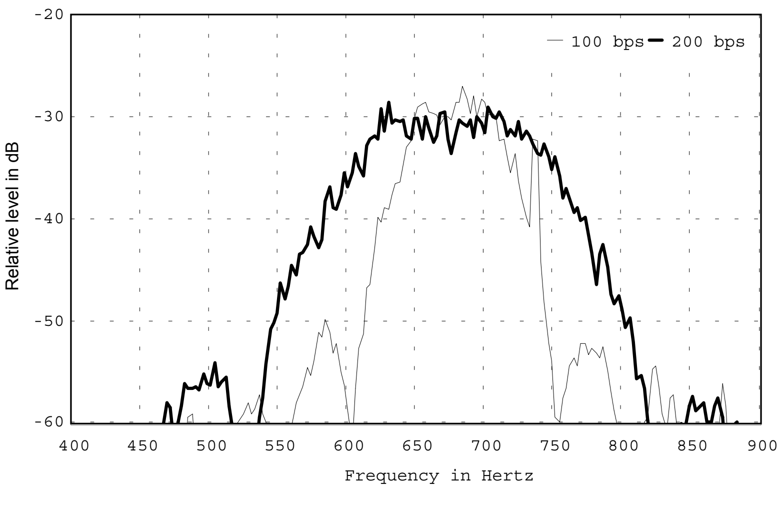

Figure 2.2. Measured spectra of 100 and 200 bps DGPS stations.

3. General message format

3.1 Message header

The DGNSS format is similar to the GPS data format; it has the same word size of 30 bits and employs the same parity algorithm. Each message is N + 2 words long, a header of two words, and N words containing data (figure 3.1 and table 3.1).
N varies with message type, and sometimes also within a message type.

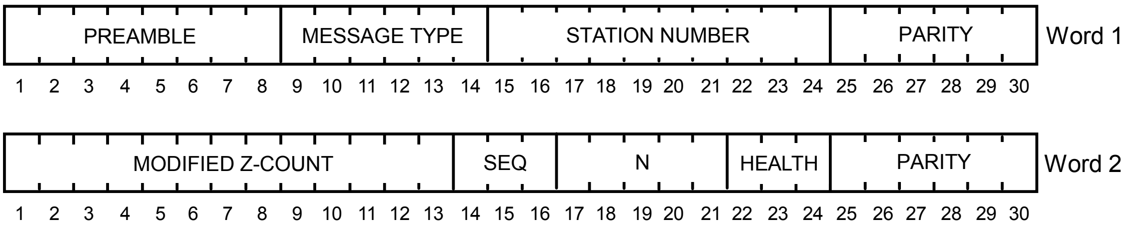

Figure 3.1. Two-word header for all message types. Bits are numbered 1 through 30; bit 1 is transmitted first.

Parameter	Bits	Meaning
PREAMBLE	8	fixed bit pattern 0110 0110
MESSAGE TYPE	6	message type; 0 - 63
STATION NUMBER	10	reference station number; 0 - 1023
MODIFIED Z-COUNT	13	counts from 0 to 6000; increments every 0.6 seconds
SEQ	3	counts from 0 to 7; increments on each message
N	5	number of data words following; 0 - 31
HEALTH	3	0 = UDRE scale factor = 1.0 1 = UDRE scale factor = 0.75 2 = UDRE scale factor = 0.5 3 = UDRE scale factor = 0.3 4 = UDRE scale factor = 0.2 5 = UDRE scale factor = 0.1 6 = transmission not monitored 7 = reference station not working
PARITY	2 x 6	see section 3.3

Table 3.1. Header content. UDRE is the “User Differential Range Error”. For details see section 4.1.

3.2 Station numbers

The station number in the first header word helps to identify the received beacon. Two numbers exits: 1. GPS reference station number and 2. DGPS broadcast station number (Table 3.2). The numbers itself are not part of the RTCM standard, but are assigned by IALA [3]. Some authorities stick to the RTCM standard and send the reference station number, others use the broadcast station number. DGPS beacons in the UK, Norway and Denmark, for example, transmit reference station numbers, while those in The Netherlands, Germany, Sweden and Finland send the broadcast station number. This confusion has not been resolved so far.

Broadcast station ID	**Geographical area**	**Reference station ID**
000 - 099	Russian Federation, Commonwealth of Independent States	000 - 199
100 - 199	Indian Ocean	400 - 599
200 - 299	Africa	200 - 329
300 - 399	Mediterranean, North Africa	400 - 599
300 - 329	Italy	400 - 439
330 -339	France	460 - 479
340 -349	Portugal	480 - 499
350 - 370	Spain	500 - 540
400 - 539	Northern Europe, Baltic	600 - 899
400 - 409	Finland	600 - 619
410 - 419	Iceland	620 - 639
420 - 429	Netherlands, Belgium	640 - 659
430 - 439	Ireland	660 - 679
440 - 449	United Kingdom	680 - 699
450 - 459	Denmark	700 - 719
460 - 469	Sweden	720 - 739
480 - 489	Poland	740 - 759
490 - 499	Germany	760 - 779
500 - 529	Norway	780 - 839
600 - 699	China, Japan, Korea	600 - 799
600 - 629	China	600 - 659
630 - 659	Japan	660 - 719
660 - 674	Korea	720 - 749
700 - 799	Australia, New Zealand, South East Asia	000 - 299
700 - 729	Australia	000 - 059
730 - 759	New Zealand	060 - 119
800 - 899	USA	000 - 299
900 - 949	Canada	300 - 399
950 - 999	Caribbean, Mexico, Central & South America	400 - 559
951 - 960	Caribbean	400 - 419
961 - 970	Mexico	420 - 439
971 - 980	Central America	440 - 459
981 - 990	South America	460 - 479
1000 - 1023	Pacific Ocean	300 - 399

Table 3.2. Assignment of station numbers.

3.3 Parity algorithm

Bit 25 through 30 of each message word are parity bits. Transmitted bits D1 - D30 are computed from the original data bits d1 - d24 according to the GPS parity scheme [6]:

```
D1 = d1*D30'
D2 = d2*D30'
D3 = d3*D30'
...
D24 = d24*D30'

D25 = D29'*d1*d2*d3*d5*d6*d10*d11*d12*d13*d14*d17*d18*d20*d23
D26 = D30'*d2*d3*d4*d6*d7*d11*d12*d13*d14*d15*d18*d19*d21*d24
D27 = D29'*d1*d3*d4*d5*d7*d8*d12*d13*d14*d15*d16*d19*d20*d22
D28 = D30'*d2*d4*d5*d6*d8*d9*d13*d14*d15*d16*d17*d20*d21*d23
D29 = D30'*d1*d3*d5*d6*d7*d9*d10*d14*d15*d16*d17*d18*d21*d22*d24
D30 = D29'*d3*d5*d6*d8*d9*d10*d11*d13*d15*d19*d22*d23*d24
```

The asterisk in these equations denotes an exclusive-or operation. D1 - D30 are now also the received bits. If the received parity bits D25 - D30 do not equal the computed D25 - D30, an error has occurred. D29' and D30' are D29 and D30 of the preceding word. To recover the original data d1 - d24, the received bits D1 - D24 must be inverted, if D30’ = 1, see equations for D1 - D24. This has to be done *before* the parity bits are computed.

As a consequence of this scheme, the data polarity of the receiver output is irrelevant: inverting the bit stream affects both D29’/D30’ and all other bits, and the result for the recovered d1 - d24 remains the same. Hence when receiving marine DGPS beacons with a communications receiver, either sideband can be used.

4. Message types

33 of 64 possible message are defined in RTCM-104 V2.2, see table 4.1. Marine DGPS beacons transmit either message type 1 or type 9, as well as types 3, 6, 7 and sometimes type 16. A few stations also include types 2 and 5.

Message type no.	Status according to [1]	Name
1	**Fixed**	**Differential GPS Corrections**
2	Fixed	Delta Differential GPS Corrections
3	**Fixed**	**GPS Reference Station Parameters**
4	Tentative	Reference Station Datum
5	**Fixed**	**GPS Constellation Health**
6	**Fixed**	**GPS Null Frame**
7	**Fixed**	**DGPS Radiobeacon Almanac**
8	Tentative	Pseudolite Almanac
9	**Fixed**	**GPS Partial Correction Set**
10	Reserved	P-Code Differential Corrections
11	Reserved	C/A-Code L1, L2 Delta Corrections
12	Reserved	Pseudolite (Pseudo-Satellite) Station Parameters
13	Tentative	Ground Transmitter Parameters
14	Tentative	GPS Time of Week
15	Tentative	Ionospheric Delay Message
16	**Fixed**	**GPS Special Message**
17	Tentative	GPS Ephemerides
18	Fixed	RTK (Real-Time Kinematic) Uncorrected Carrier Phases
19	Fixed	RTK Uncorrected Pseudoranges
20	Tentative	RTK Carrier Phase Corrections
21	Tentative	RTK/High-Accuracy Pseudorange Corrections
22	Tentative	Extended Reference Station Parameters
23 - 30	–	Undefined
31	Tentative	Differential GLONASS Corrections
32	Tentative	Differential GLONASS Reference Station Parameters
33	Tentative	GLONASS Constellation Health
34	Tentative	GLONASS Partial Differential Correction Set or Null Frame
35	Tentative	GLONASS Radiobeacon Almanac
36	Tentative	GLONASS Special Message
37	Tentative	GNSS System Time Offset
38 - 58	–	Undefined
59	Fixed	Proprietary Message
60 - 63	Reserved	Multipurpose Usage

Table 4.1. Message types. Details are given in the following sections for types in boldface.

4.1 Message type 1 – Differential GPS Corrections

The content of this message is shown in figure 4.1 and table 4.2. This is the primary message type which provides the pseudorange corrections PRC(t) for any user GPS measurement time t:

$$PRC(t) = PRC(t_0) + RRC * (t - t_0),$$

where $PRC(t_0)$ is the 16-bit pseudorange correction, RRC is the 8-bit range-rate correction (the rate of change of the pseudorange correction), and t_0 is the modified Z-count from the second header word. Now the pseudorange PRM(t) measured by the user can be corrected:

$$PR(t) = PRM(t) + PRC(t)$$

The message contains data for all satellites in view of the reference station. A similar message. with groups of typically three satellites, is the type 9 message.

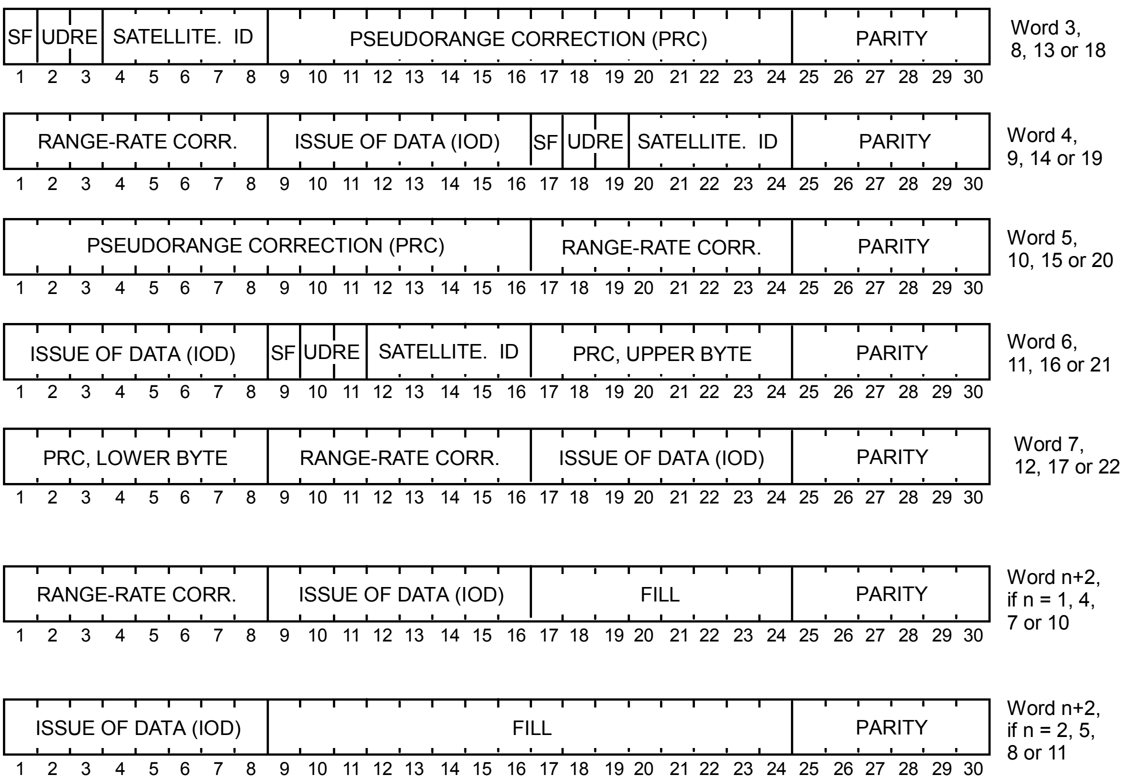

Figure 4.1. Structure of message type 1; n = Number of Satellites. Since 40 bits are required for each satellite, there will not always be an integer number of 30-bit words. In these cases, “fill” words with 8 or 16 fill bits are necessary at the end of the message.

Parameter	Bits	Scaling	Remarks
SCALE FACTOR (SF)	1		
USER DIFFERENTIAL RANGE ERROR (UDRE)	2	00: $\varepsilon \leq 1$ m, 01: 1 m < $\varepsilon \leq 4$ m, 10: 4 m < $\varepsilon \leq 8$ m, 11: $\varepsilon > 8$ m	The one-sigma differential error ε shall be multiplied by the UDRE scale factor in the message header, see figure 2.1.
SATELLITE ID	5		binary 00000 = satellite no. 32
PSEUDORANGE CORRECTION (PRC)	16	0.02 m if SF = 0, 0.32 m if SF = 1	2's complement. Binary 1000 0000 0000 0000 indicates a problem. This satellite should not be used.
RANGE RATE CORRECTION (RRC)	8	0.002 m if SF = 0, 0.032 m/s if SF = 1	2's complement. Binary 1000 0000 indicates a problem. This satellite should not be used.
ISSUE OF DATA (IOD)	8		If not equal to the IOD received from the satellite, satellite state has changed and this satellite should not be used.
FILL			alternating 1's and 0's
PARITY			see section 3.3

Table 4.2. Content of a type 1 message.

4.2 Message type 3 – GPS Reference Station Parameters

This message contains the reference station's geographical location in GPS coordinates (Earth-Centered-Earth-Fixed, ECEF). It consists of four data words (figure 4.2 and table 4.3). These data are not necessary for common navigation purposes and they are ignored by many GPS receivers. The transmission period for message type 3 varies from one service provider to the next; intervals of 3 minutes to 30 minutes are common.

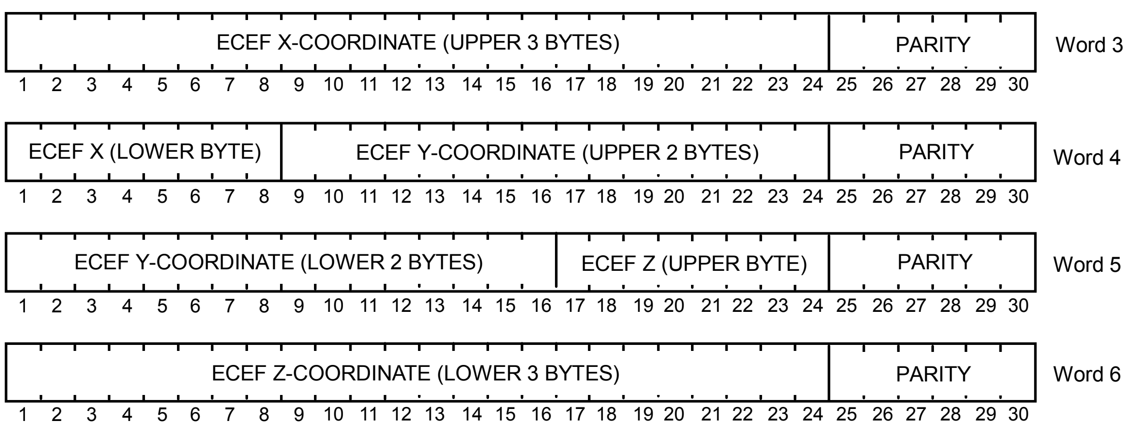

Figure 4.2. Message type 3.

Parameter	**Bits**	**Scaling factor**	**Remarks**
ECEF X-COORDINATE	32	0.01 m	2’s complement; range = ±21 474 836.47 m
ECEF Y-COORDINATE	32		
ECEF Z-COORDINATE	32		
PARITY	4 x 6		see section 3.3

Table 4.3. Content of type 3 message.

Conversion of ECEF values X, Y, Z to latitude φ, longitude λ and ellipsoidal height h is straightforward according to the following formulas [7]:

$$\lambda = \arctan \frac{Y}{X} ,$$

$$\varphi = \frac{Z + e'^2 b \sin^3\theta}{p - e^2 a \cos^3\theta} ,$$

$$h = \frac{p}{\cos\varphi} - N ,$$

where

$$\theta = \arctan \frac{Za}{pb},$$

$$e^2 = \frac{a^2 - b^2}{a^2} ,$$

$$e'^2 = \frac{a^2 - b^2}{b^2} ,$$

$$N = \frac{a^2}{\sqrt{a^2 \cos^2\varphi + b^2 \sin^2\varphi}} ,$$

$$a = 6\ 378\ 137\ m ,$$

$$b = 6\ 356\ 752.3142\ m.$$

a and b are the semiaxes of the WGS-84 reference ellipsoid. Note that h is not the height above sea level, but the height above the reference ellipsoid, which is only an approximation of the earth’s surface. Differences of 50 m to the local height a.s.l. are common. Conversion between h and “orthometric” height requires sophisticated models and is beyond the scope of this paper. Conversion between WGS-84 and local coordinate systems is treated in detail in [8].

Some examples for ECEF coordinates and corresponding latitudes and longitudes are shown in chapter 5, ”DGPS example messages”.

4.3 Message type 5 – GPS Constellation Health

The information provided by this message can assist in the operation of DGPS user equipment. A type 5 message can contain information for one or more satellites (figure 4.3 and table 4.4). The primary use is to notify the user equipment that a satellite which is deemed unhealthy by its current navigation message is usable for DGPS navigation. Type 5 messages are transmitted rather infrequently.

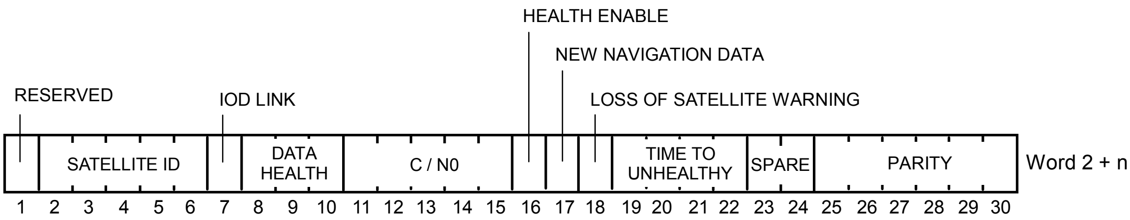

Figure 4.3. Message type 5. One data word is transmitted for each satellite (n = number of satellites).

Parameter	Bits	Meaning
RESERVED	1	Reserved for possible future expansion to satellite numbers beyond 32
SATELLITE ID	5	00000 = satellite no. 32
IOD LINK	1	Bit set to 0: This information refers to data with IOD in message type 1, 9, 20 and 21. Bit set to 1: Information refers to data with IOD in message type 2.
DATA HEALTH	3	Copy of the three most significant bits of the 8-bit health status word in the GPS almanac message. Any non-zero bit indicates that some or all satellite navigation data is bad. See [6] for deails.
C/N_0	5	Satellite signal-to-noise ratio measured at reference station. Scale factor is 1 dB, range is 25 to 55 dB; bit 15 is LSB. A value of 00000 indicates that the satellite is not being tracked by the reference station. 00001 = 25 dB, 11111 = 55 dB.
HEALTH ENABLE	1	Bit set to 1 indicates that the satellite can be considered healthy despite the fact that satellite navigation data indicates the satellite is unhealthy.
NEW NAVIGATION DATA	1	Bit set to 1 indicates that new satellite data is being acquired. A new IOD will soon appear in the type 1 or type 9 message.
LOSS OF SATELLITE WARNING	1	Bit set to 1 indicates that a change in the satellite's state to "unhealthy" is scheduled. The remaining "healthy" time is estimated by the following 4 bits.
TIME TO UNHEALTHY	4	See bit above. Scale factor is 5 minutes, range is 0 to 75 minutes; bit 22 is LSB.
SPARE	2	not yet defined
PARITY	n x 6	see section 3.3

Table 4.4. Content of a type 5 message.

4.4 Message type 6 – GPS Null Frame

This message has no parameters (N = 0, header only) and is used as transmission fill, if required. If an uneven fill is needed, N = 1 is also possible. The 24 data bits in the following word are then filled with alternating 1's and 0's. In practice, however, type 6 messages with N = 1 are hardly ever observed.

4.5 Message type 7 – DGPS Radiobeacon Almanac

The purpose of message type 7 is to provide a properly equipped GPS receiver with the capability of automatically selecting the optimum DGPS transmitter. Its structure is shown in figure 4.3 and table 4.4. It can also provide an identification of the broadcast station. Transmission intervals of 10 to 30 minutes are common for this message type.

4.6 Message type 9 – GPS Partial Correction Set

This message has the same format as type 1. But unlike type 1, with data for the whole satellite set in view, type 9 messages contain data for smaller groups of satellites, most often three. Type 9 is useful in the presence of SA for providing additional updates for satellites whose pseudorange corrections are changing fast. Moreover, type 9 messages provide a higher noise immunity than type 1, since headers are transmitted at a much higher rate and allow a faster resynchronization. This is probably the main reason why the majority of marine DGPS beacons transmits type 9 rather than type 1 messages.

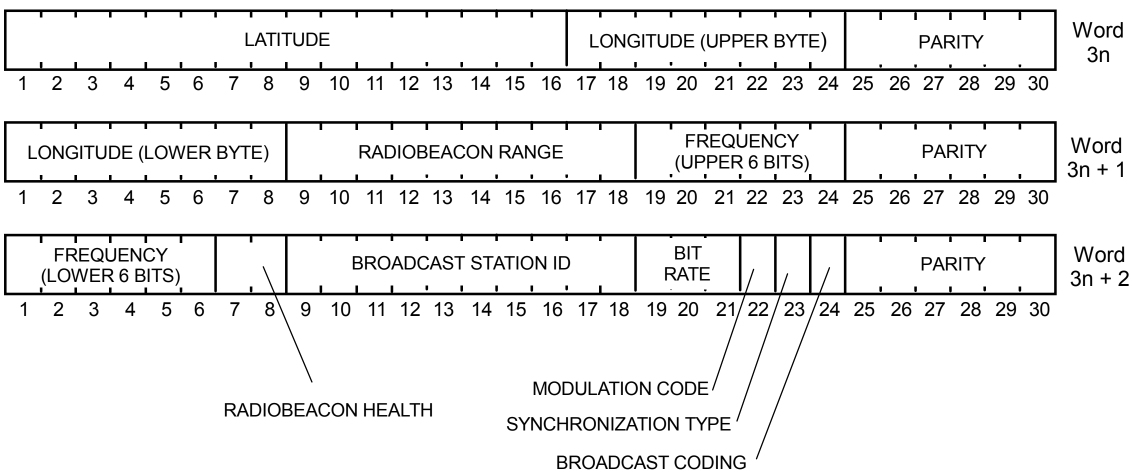

Figure 4.3. Message type 7. Three data words are used for each radiobeacon (n = number of beacons in the message).

Parameter	**Bits**	**Scaling factor**	**Range**	**Remarks**
LATITUDE	16	0.002747°	±90°	2’s complement
LONGITUDE	16	0.005493°	±180°	2’s complement
RADIOBEACON RANGE	10	1 km	0 - 1023 km	
FREQUENCY	12	100 Hz	0000000000000000 = 190 kHz to 1111111111111111 = 599.5 kHz	channel spacing is usually 500 Hz
RADIOBEACON HEALTH	2		00: radiobeacon operation normal 01: no integrity monitoring 10: no information available 11: do not use this radiobeacon	
BROADCAST STATION ID	10		0 to 1023	
BROADCAST BIT RATE	3		000: 25 bits/sec 001: 50 bits/sec 010: 100 bits/sec 011: 110 bits/sec 100: 150 bits/sec 101: 200 bits/sec 110: 250 bits/sec 111: 300 bits/sec	common values for marine DGPS beacons are 100 and 200 bits/sec
MODULATION CODE	1		0 = MSK, 1 = FSK	usually 0
SYNCHRONIZATION TYPE	1		0 = asynchronous, 1 = synchronous	
BROADCAST CODING	1		0 = no added coding 1 = FEC coding	usually 0
PARITY				see section 3.3

Table 4.4. Content of message type 7.

4.7 Message type 16 – GPS Special Message

This is a plain text ASCII message (figure 4.4). It can be up to 90 characters long. Fill bits may be necessary at the end of the message. Fill pattern is 00000000, not 10101010 as in some other message types.

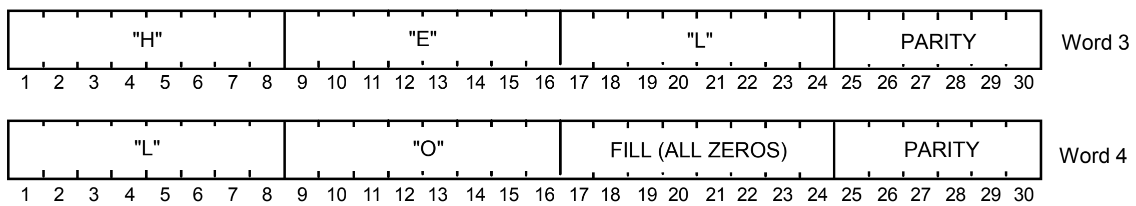

Figure 4.4. Example of a type 16 message.

5. DGPS example messages

This chapter provides some decoded DGPS messages received in Europe. The messages are shown in an arbitrary format, actually the output format of the decoding software: One line with information derived from the header words is followed by indented lines with the major data from the message body.

```
Id: 815    Type:  1    Z: 4083    Seq: 1    N: 14    Health: 0
   Sat = 24    PRC =   -4.76 m  + .012 m/s    IOD = 207    UDRE < 4 m
   Sat =  4    PRC =    1.66 m  - .022 m/s    IOD =   0    UDRE < 1 m
   Sat = 25    PRC =   -2.54 m  + .050 m/s    IOD = 120    UDRE < 4 m
   Sat =  1    PRC =    4.52 m  - .008 m/s    IOD =  58    UDRE < 1 m
   Sat = 19    PRC =   -6.62 m  + .010 m/s    IOD = 181    UDRE < 4 m
   Sat = 20    PRC =     .48 m  + .000 m/s    IOD =   6    UDRE < 4 m
   Sat = 13    PRC =    1.60 m  + .022 m/s    IOD =   5    UDRE < 1 m
   Sat =  7    PRC =  -12.20 m  - .038 m/s    IOD =  58    UDRE < 4 m
Id: 815    Type:  1    Z: 4091    Seq: 2    N: 14    Health: 0
   Sat = 24    PRC =   -4.74 m  + .010 m/s    IOD = 207    UDRE < 4 m
   Sat =  4    PRC =    1.72 m  - .006 m/s    IOD =   0    UDRE < 1 m
   Sat = 25    PRC =   -3.00 m  - .044 m/s    IOD = 120    UDRE < 4 m
   Sat =  1    PRC =    4.56 m  - .002 m/s    IOD =  58    UDRE < 1 m
   Sat = 19    PRC =   -6.60 m  + .006 m/s    IOD = 181    UDRE < 4 m
   Sat = 20    PRC =     .68 m  + .048 m/s    IOD =   6    UDRE < 4 m
   Sat = 13    PRC =    1.48 m  - .004 m/s    IOD =   5    UDRE < 1 m
   Sat =  7    PRC =  -12.08 m  - .010 m/s    IOD =  58    UDRE < 4 m
Id: 815    Type:  1    Z: 4100    Seq: 3    N: 14    Health: 0
   Sat = 24    PRC =   -5.04 m  - .060 m/s    IOD = 207    UDRE < 4 m
   Sat =  4    PRC =    1.48 m  - .052 m/s    IOD =   0    UDRE < 1 m
   Sat = 25    PRC =   -3.20 m  - .076 m/s    IOD = 120    UDRE < 4 m
   Sat =  1    PRC =    4.84 m  + .054 m/s    IOD =  58    UDRE < 1 m
   Sat = 19    PRC =   -6.28 m  + .062 m/s    IOD = 181    UDRE < 4 m
   Sat = 20    PRC =     .46 m  + .004 m/s    IOD =   6    UDRE < 4 m
   Sat = 13    PRC =    1.62 m  + .030 m/s    IOD =   5    UDRE < 1 m
   Sat =  7    PRC =  -12.30 m  - .048 m/s    IOD =  58    UDRE < 4 m
```

Figure 5.1. Sequence of type 1 messages. PRC values are typically within ± several ten metres. The value following the PRC and the "+" or "-" sign is the range rate correction RRC.

```
Id: 705    Type:  9    Z: 1802    Seq: 6    N:  5    Health: 0
   Sat = 24    PRC =  -15.42 m  + .190 m/s    IOD =  61    UDRE < 1 m
   Sat =  6    PRC =    9.36 m  + .180 m/s    IOD = 125    UDRE < 1 m
   Sat =  5    PRC =   -1.00 m  + .228 m/s    IOD =  83    UDRE < 1 m
Id: 705    Type:  9     Z: 1805     Seq: 7    N:  5    Health: 0
   Sat = 25    PRC =    5.82 m  + .150 m/s    IOD = 135    UDRE < 1 m
   Sat = 29    PRC =  -18.88 m  + .384 m/s    IOD = 239    UDRE < 1 m
   Sat = 30    PRC =    4.38 m  + .032 m/s    IOD =  98    UDRE < 1 m
Id: 705    Type:  9    Z: 1808    Seq: 0    N:  5    Health: 0
   Sat =  4    PRC =    7.12 m  - .238 m/s    IOD =  45    UDRE < 1 m
   Sat =  9    PRC =  -17.92 m  + .544 m/s    IOD = 232    UDRE < 1 m
   Sat = 24    PRC =  -15.38 m  + .176 m/s    IOD =  61    UDRE < 1 m
Id: 705    Type:  9    Z: 1812    Seq: 1    N:  5    Health: 0
   Sat =  6    PRC =    9.50 m  + .162 m/s    IOD = 125    UDRE < 1 m
   Sat =  5    PRC =    -.54 m  + .224 m/s    IOD =  83    UDRE < 1 m
   Sat = 25    PRC =    5.84 m  + .150 m/s    IOD = 135    UDRE < 1 m
```

Figure 5.2. Type 9 messages recorded in April 2000, before SA was turned off. RRC's are much larger than in figure 5.1.

```
Id: 428    Type:  9    Z: 3675    Seq: 6    N:  4    Health: 0
   Sat = 14    PRC =  -11.86 m  - .002 m/s    IOD =  24    UDRE < 1 m
   Sat =  4    PRC =   -8.18 m  - .008 m/s    IOD = 192    UDRE < 1 m
Id: 428    Type:  6    Z: 3673    Seq: 7    N:  0    Health: 0
Id: 428    Type:  6    Z: 3673    Seq: 0    N:  0    Health: 0
Id: 428    Type:  9    Z: 3675    Seq: 1    N:  5    Health: 2
   Sat =  5    PRC =    2.26 m  + .006 m/s    IOD = 142    UDRE < 0.5 m
   Sat = 30    PRC =    2.72 m  + .002 m/s    IOD = 111    UDRE < 0.5 m
   Sat = 24    PRC =     .74 m  - .002 m/s    IOD = 180    UDRE < 0.5 m
Id: 428    Type:  9    Z: 3678    Seq: 2    N:  5    Health: 0
   Sat =  6    PRC =    -.26 m  + .002 m/s    IOD = 234    UDRE < 1 m
   Sat = 29    PRC =   -5.10 m  - .002 m/s    IOD =  46    UDRE < 1 m
   Sat = 25    PRC =    -.90 m  + .000 m/s    IOD =  70    UDRE < 1 m
Id: 428    Type:  9    Z: 3680    Seq: 3    N:  4    Health: 0
   Sat = 14    PRC =  -11.86 m  + .006 m/s    IOD =  24    UDRE < 1 m
   Sat =  4    PRC =   -8.10 m  - .006 m/s    IOD = 192    UDRE < 1 m
Id: 428    Type:  9    Z: 3681    Seq: 4    N:  5    Health: 2
   Sat =  5    PRC =    2.22 m  + .004 m/s    IOD = 142    UDRE < 0.5 m
   Sat = 30    PRC =    2.70 m  + .000 m/s    IOD = 111    UDRE < 0.5 m
   Sat = 24    PRC =     .68 m  - .004 m/s    IOD = 180    UDRE < 0.5 m
```

Figure 5.3. Another type 9 sequence. This station utilises the UDRE scaling factor in the header to specify UDRE values below 1 m. Note the type 6 fill messages at Z = 3673.

```
Id: 492    Type:  3    Z: 5021    Seq: 7    N:  4   Health: 0
   X =  3705136.80 m    Y =   514898.59 m    Z =  5148735.87 m
   54°10'59"n    7°54'42"e    52.2 m ellipsoidal height

Id: 705    Type:  3    Z: 2289    Seq: 2    N:  4    Health: 0
   X =  3579683.44 m    Y =   508397.25 m    Z =  5236838.89 m
   55°33'28"n    8°05'00"e    99.9 m ellipsoidal height

Id: 815    Type:  3    Z: 4166    Seq: 4    N: 4    Health: 0
   X =  3252028.07 m    Y =   277209.65 m    Z =  5461558.56 m
   59°18'24"n    4°52'20"e   121.2 m ellipsoidal height
```

Figure 5.4. Type 3 messages from three radiobeacons, showing examples for ECEF coordinates and corresponding latitudes and longitudes.

```
Id: 425    Type:  7    Z: 5728    Seq: 0    N:  3    Health: 0
   52°00'n   4°07'e   120 km   287.5 kHz   Health 0   Tx 425   200 bps

Id: 469    Type:  7    Z: 5547    Seq: 3    N: 12    Health: 0
    0°00'n   0°00'e   150 km   305.5 kHz   Health 0   Tx 469   200 bps
   56°18'n  12°27'e   150 km   293.5 kHz   Health 0   Tx 466   200 bps
   57°42'n  10°35'e   150 km   298.5 kHz   Health 0   Tx 453   100 bps
   59°01'n  10°31'e   150 km   288.0 kHz   Health 0   Tx 500   100 bps

Id: 491    Type:  7    Z: 3021    Seq: 6    N:  3    Health: 0
   54°11'n   7°55'e   200 km   313.0 kHz   Health 0   Tx 492   200 bps
```

Figure 5.5. Type 7 messages. Stations 425 just identifies itself. Station 469, recorded during a test phase, refers to 466, 453 and 500, but does not tell its own location. Stations 491 refers to 492 without mentioning itself. Note that all three stations transmit the broadcast station number in the header, not the reference station number, see section 3.2.

6. Interfacing of DGPS receiver and GPS equipment

Marine instrumentation like GPS navigation equipment, compasses etc. are often interconnected through a serial interface according to the NMEA-0183 standard [9]. This is preferably a symmetrical RS-422 line, but asymmetrical RS-232 operation is also supported. Standard baud rate is 4800, but other values are possible as well. Small GPS receivers, especially handheld devices, are often fitted with an RS-232 interface, rather than with the more costly RS-422.

The RTCM standard [1] provides some rules how to convert from the synchronous DGPS data stream to an asynchronous serial transfer. The most important ones are the *byte format rule*, the *most significant bit first rule* and the *bit slip rule*. These rules can be summarised as follows:

The DGPS receiver will assemble the received bits into 8-bit bytes. No byte or word synchronisation should be assumed; the GPS unit is responsible for synchronising to the 30-bit word boundaries, for error detection etc. Six DGPS bits are packed into a byte. The bit received first (the most significant bit, MSB) is put into the least significant bit (LSB, bit 0) of the asynchronous interface. As RS-232/422 transmits LSB first, “MSB first” is maintained on the asynchronous serial line. Bit 6 is set to 1 and bit 7 is set to 0. This process is illustrated in figure 6.1.

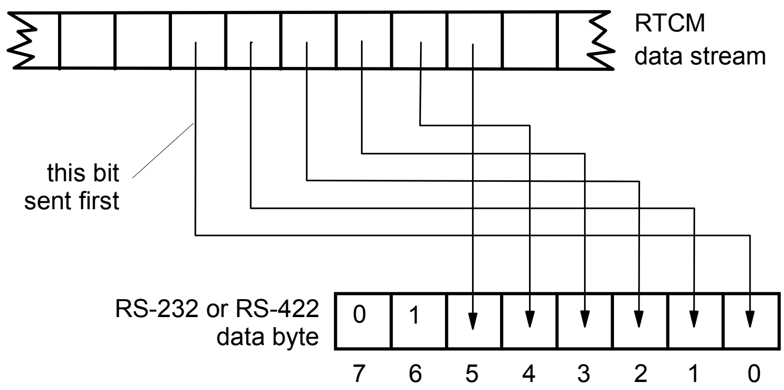

Figure 6.1. Transmitting DGPS data on a serial asynchronous line.

The reason for the MSB first rule is not obvious. It introduces the need for a “byte roll” for both transmitter and receiver. However, this is a simple operation compared to synchronisation, word reassembly, error detection and data extraction.

7. References

[1] Radio Technical Commission for Maritime Services: RTCM RECOMMENDED STANDARDS FOR DIFFERENTIAL GNSS (GLOBAL NAVIGATION SATELLITE SYSTEMS) SERVICE, Version 2.2. Alexandria, VA, USA, January 1998. See also http://www.rtcm.org.

[2] Northwest European Loran System. See http://www.nels.org

[3] International Association of Lighthouse Authorities: DGNSS Reference and Transmitting Stations in the Maritime Radionavigation (Radiobeacons) Band. Issue 7, August 1999. http://www.iala-aism.org

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[7] B. Hofmann,Wellenhof, H. Lichtenegger, J: Collins: GPS Theory and Practice. Second Edition. Springer Verlag Wien New York 1993.

[8] U.S. National Imaging and Mapping Agency (NIMA): DEPARTMENT OF DEFENSE WORLD GEODETIC SYSTEM 1984 – Its Definition and Relationships with Local Geodetic Systems. Third edition, January 2000. NIMA Technical Report 8350.2. Available at http://164.214.2.59/GandG/wgs-84/ or http://www.nima.mil

[9] National Marine Electronics Association (NMEA): http://www.nmea.org