Compact Data Transmission Standard for High-Precision GPS

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BIOGRAPHY

Nicholas Talbot graduated from the Royal Melbourne Institute of Technology, Australia, with a Bachelor of Applied Science, in Surveying and a PhD in Applied Science in 1985 and 1990 respectively. His research expertise is in high-precision GPS positioning and he has been involved in Real-Time Kinematic development at Trimble Navigation since 1991. He has presented and published many papers on the Global Positioning System and is currently a part-time lecturer at the Royal Melbourne Institute of Technology.

ABSTRACT

The performance of a Real-Time Kinematic (RTK) system is highly dependent on the datalink component between reference (base) and rovers. Real-Time Kinematic positioning is widely used for many applications. The reference station broadcasts carrier phase and code phase measurements to one or more rover stations. The rover stations combine locally collected measurements with those from the reference station to obtain position results at a centimetre-level. Frequently the datalink component of a Real-Time Kinematic system takes the form of digital radio/modems, however cellular phones or FM sub-carrier signals on local radio stations may be used. In all datalink mediums, the available data bandwidth is at a premium. The design of a data transmission standard must attempt to minimise bandwidth. Real-Time Kinematic system manufacturers have adopted their own proprietary data transmission standards. Without a published standard, users cannot freely mix reference and rover equipment from different manufacturers. The Radio Technical Commission for Maritime services, Special Committee 104, (RTCM-SC104), addressed this issue by publishing message types 18-21 in their Version 2.1 standard, which support high-precision Real-Time Kinematic users. However, the RTCM messages have a large framing overhead and do not include significant data compression algorithms to make them practical for many datalink options. As community reference station infrastructure is implemented, a compact transmission standard will help Real-Time Kinematic techniques gain favour with users who only wish to purchase a rover unit.

A widely used Real-Time Kinematic data transmission standard is publicly disclosed for the first time so that it can be used by all manufacturers across the industry. The Compact Measurement Record (CMR) format contains packet framing and message types for raw L1 and L2 carrier phase and pseudorange data, plus reference station location and description messages. Details of the compact data transmission standard are documented. Issues relating to mixing different receiver types are raised; of particular concern are carrier phase and pseudorange biases and antenna phase center variations. With nine satellites in view, the new standard allows for dual-frequency carrier phase and pseudorange data to be transmitted once per second in less than 2000 bits. The Compact Measurement Record format requires half the bandwidth of the equivalent RTCM-SC104 messages.

INTRODUCTION

Differential use of the Global Positioning System (DGPS) incorporates a reference station receiver and a rover receiver tracking a common set of satellites simultaneously. When the two stations are closely situated (< 10km), many satellite dependent errors cancel. If the reference and rover receivers are capable of tracking carrier phase and pseudorange measurements, it is possible to resolve the location of the rover station to a few centimeters. Real-Time Kinematic positioning refers to the case where the rover station location is determined in the field while the rover is moving.

The basic components of a Real-Time Kinematic system are illustrated in figure 1. The reference station occupies a fixed site and records carrier phase and pseudorange measurements to satellites in view. The reference receiver then formats these measurements and transmits them to the rover stations via a datalink. At the rover station, a field portable GPS receiver tracks carrier phase and pseudorange in time unison with the reference station. The rover station calculates its location using time-synchronized carrier phase and pseudorange measurements received via the datalink from the reference station. Given an appropriate processing procedure and sufficient data, the rover station location can be calculated to within a few centimeters relative to the reference station coordinates. A handheld interface is then used to portray the position results for navigation or detail surveying purposes.

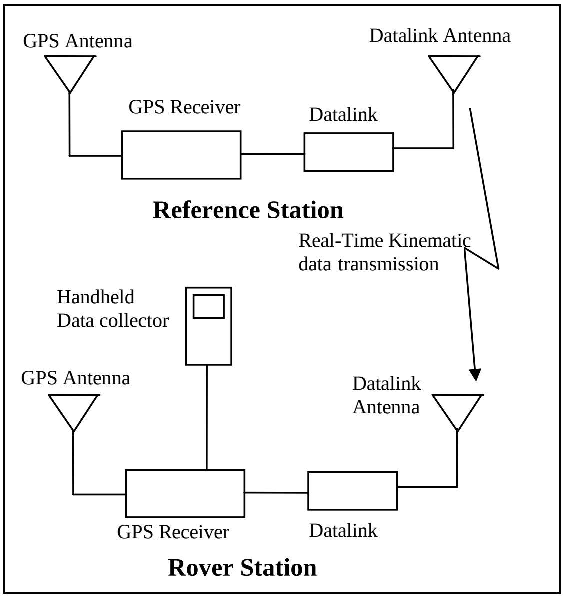

Figure 1. Schematic representation of a Real-Time Kinematic System.

Real-Time Kinematic system manufacturers have developed their own GPS receiver and processing algorithm technology, datalink systems and handheld interfaces to maximise user productivity. Each manufacturer has also developed proprietary protocols for communicating reference station data to the rover stations. As local RTK reference stations are established and the operating range of Real-Time Kinematic positioning extends beyond its current limit of 10km, some users may want to purchase rover-only systems, rather than reference/rover packages. Manufacturers will be compelled to comply to a RTK data transmission protocol which will enable different reference and rover equipment to be mixed. The Radio Technical Commission for Maritime services, Special Committee 104 (RTCM-SC104), convened to address the issue of a Real-Time Kinematic data transmission standard and presented a proposal for carrier phase and pseudorange messages, designated 18, 19, 20 and 21 [1].

The Real-Time Kinematic messages proposed by the RTCM have already been implemented, however there are some significant limitations to the standard which restricts its use [2]. The RTCM SC-104 messages 18 to 21 provide most of the data content required for a successful Real-Time Kinematic system, however the size of the messages and their framing overhead make them inefficient for many commercial applications. An alternate standard is needed which addresses the issue of message length and framing size. The proposed standard has been widely used in a commercial environment since 1993 and is suitable for communication links which have at least a 2400 baud throughput.

DATALINK

The datalink forms an essential component of a Real-Time Kinematic system. Real-Time Kinematic positioning requires regular (typically every second) transmission of reference station data packets and their reception at the rover station(s). Datalink options often used in the field include:

- Radio / modem
- Cellular phone
- FM-subcarrier
- Satellite link

The datalink should be chosen to match the operating conditions for the project. For example, in open undulating terrain, a one-Watt output, spreadspectrum radio/modem setup in the 900MHz band would provide appropriate coverage out to a few kilometers. For greater coverage, users can employ radio repeaters. In built-up residential areas, near line-of-sight radio coverage may be difficult and cellular phone networks could be well used. Commercial operations have taken advantage of available data bandwidth on FM radio station transmissions and broadcast GPS reference station data on FM-subcarrier bands [3 & 4]. Many cities around the world now have FM-subcarrier reference stations for meter-level differential GPS commercial use. In remote locations a satellite link provides excellent radio coverage, even though it is expensive compared to the other systems just mentioned ([5] gives an excellent discussion of DGPS datalink options).

The performance of a Real-Time Kinematic datalink can be judged based on the following parameters:

- Cost
- Datalink range and coverage
- Transmission bandwidth / latency
- Error checking and correction
- Licensing

Cost is typically the driving parameter for commercial applications. FM-subcarrier providers, satellite links and cellular phone networks normally have time-based charges. Careful consideration therefore needs to be given to the cost of timed access versus that of dedicated radio/modem hardware.

The **datalink range** dictates the potential distance that a rover station can operate from a reference station. Equipment manufacturers typically specify an upper limit on the Real-Time Kinematic system range based mainly on the processing algorithms and GPS equipment, not on the datalink. For example, the Trimble GPS Total Station® is specified to 10km. A datalink which matches the performance of the Real-Time Kinematic system is ideal.

The position calculation performed by a rover station normally requires synchronized packets from the reference station to be paired with time-matched measurements from the rover station (this maximizes position accuracy by removing selective availability, satellite and receiver clock errors). Any delay in the reference station data will translate directly into the age or latency of the computed position. *For real-time navigation, users need to know where they are now, rather than where they were some time in the past*. The throughput, or **transmission bandwidth** of the datalink directly affects the latency of the rover position. A datalink that has a 9600 baud transmission bandwidth will get data from reference to rover four times faster than a datalink with a 2400 baud bandwidth.

Some modems have built-in **error detection and correction** algorithms. In a one-way reference-to-rover transmission system, it is important that the datalink provides error detection, and where possible, error correction for reference station packets. Given only one-way transmissions, the rover has no way of acknowledging that packets were successfully received. A radio-based datalink will always suffer from shadowing and signal loss.

Most nations have radio regulatory bodies which strictly govern radio-frequency allocation. Therefore, it is essential to make sure that a **licence** can be obtained for the required datalink. Some GPS manufacturers and datalink suppliers have built radio/modems which use the 900MHz frequency band which does not require a user licence in North America, South Africa, parts of Central America and Australasia.

COMPACT MEASUREMENT RECORD (CMR) FORMAT

The Compact Measurement Record (CMR) format encompasses both a message protocol plus a compression / decompression algorithm for the measurement data. A detailed description of the format is presented in Appendix A. An overview of the CMR format is outlined below along with a description of the approach used for measurement compression.

All CMR message blocks are encapsulated within a six byte framing header / tail. The frame has fields for:

- Start of transmission identifier
- The type of CMR message
- Message length
- Compact Measurement Record Message
- Checksum
- End of transmission identifier

There are presently three messages defined for Real-Time Kinematic positioning:

- Measurements
- Reference Station Location
- Reference Station Description

Within each of the three message types is a header and a data section. The header contains the following information:

- Message version number
- Station identifier
- Message type
- Low battery flag
- Low memory flag
- Epoch time
- Clock offset

Measurement Compression Technique

Measurement data is generally transmitted once per second. Measurements need to be compressed in order to meet the 2400 baud goal. Instead of transmitting very large numbers to high precision, it is possible to transmit number differences, which have a smaller dynamic range. For example, two closely spaced receivers whose time bases are nearly aligned, will observe similar pseudorange measurements to the same satellite. It is preferable to transmit a fractional part of the pseudorange instead of the entire range measurement which can be say 20,000,000m. In the CMR format, the reference station pseudoranges are divided into light-millisecond lanes (1 millisecond times the speed of light = 299,792.458m) and only the fractional portion is transmitted (see figure 2).

A change in range observed with carrier phase over time will approximately match the change in code-pseudorange to the same satellite. Therefore it is possible to represent the carrier phase as an offset to the pseudorange data. The dynamic range of the pseudorange-carrier phase difference is bounded by the ionospheric divergence of the two signals. Measurements taken on the L2 band can be conveniently referenced to L1 data, with considerable bandwidth benefits. The L2 pseudorange is transmitted as a difference against the L1 pseudorange. The L2 carrier phase is given as a difference against the L1 pseudorange.

It would be wasteful to broadcast the full epoch date and time of the reference station packets when the rover has already obtained a very good estimate of these quantities; provision has to be made for likely data transmission delays. In the CMR format, epoch times of measurements are given modulo 240 seconds.

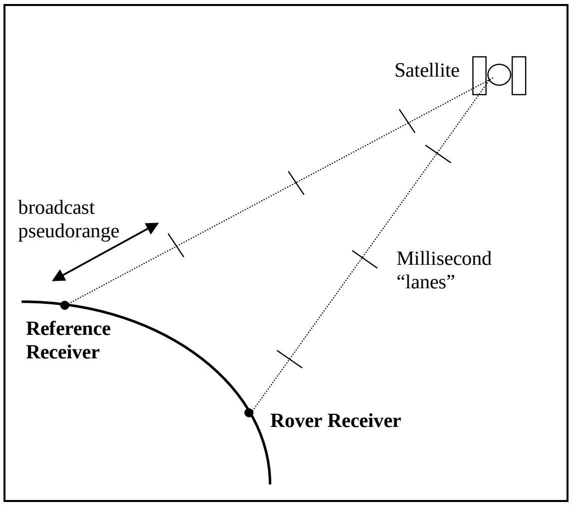

Figure 2. Measurement compression for closely spaced stations.

Satellite Coordinates

Satellite coordinates must be computed for every common satellite tracked at the reference and rover stations. Instead of broadcasting the coordinates for each satellite tracked at the reference station, it is possible to perform all of the necessary calculations at the rover station. Satellite coordinates for the reference station observations can be computed using either the standard Keplerian interpolation algorithm [6], or more expediently, by adjusting the rover satellite coordinates with the satellite velocity components and the difference in signal transmission times for measurement epochs at the reference and rover stations (see figure 3).

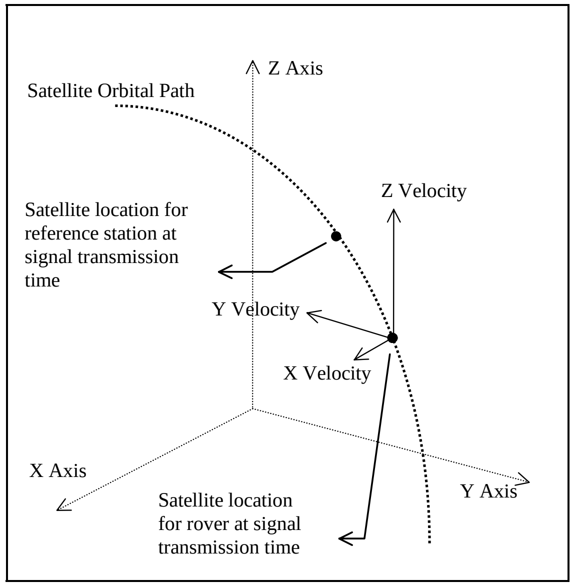

Figure 3. Calculation of the satellite coordinates for the reference station using satellite information available at the rover.

Reference Station Location and Description

The reference station antenna location in the World Geodetic System 1984 (WGS84) is represented in Cartesian coordinates (X,Y,Z) to millimetre accuracy, along with antenna height and antenna offset values (see figure 4). The reference station description is broadcast in terms of ASCII information. The reference station location and description information is only required once during the course of a survey. When working in a one-way reference-station transmission environment, the rover cannot make a request for the reference station location and must wait for it. The frequency at which the reference station location is transmitted to the rover dictates the minimum time-to-start a survey. Currently the reference station location is broadcast every 10 seconds; the reference station description is also broadcast at the same rate, however it is interleaved between the location messages. A peak load on the datalink occurs every time the reference station information is broadcast.

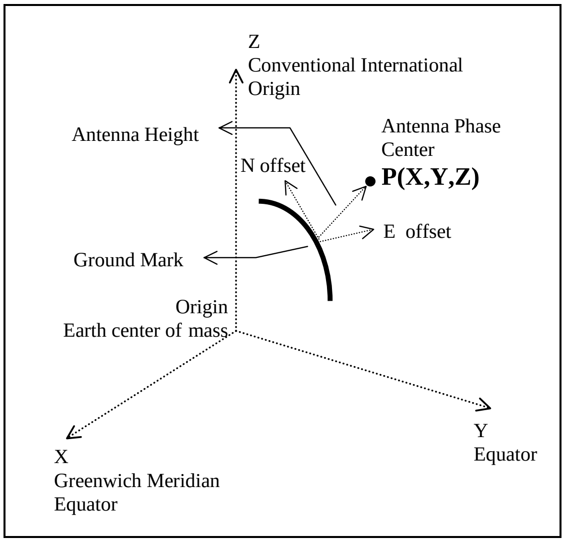

Figure 4. Reference station coordinates and antenna phase centre offsets on the WGS84 reference system.

RADIO TECHNICAL COMMISSION FOR MARITIME SERVICES (RTCM) STANDARD

The RTCM Version 2.1 standard contains four messages specifically for transmission of data for Real-Time Kinematic users. Message types 18 and 19 contain raw carrier phase and pseudorange data respectively, while messages 20 and 21 provide for the transmission of carrier phase and pseudorange corrections. The data correction messages (20 and 21) were originally aimed at reducing the amount of data that needs to be transmitted. Because of the fixed 30 byte word length of the RTCM frame, there is no advantage in terms of size for message types 20 and 21 over 18 and 19. A disadvantage of the correction messages is that they assume that the reference and rover are using the same satellite Issue Of Data Ephemeris (IODE), which often causes complications under IODE-rollover conditions.

When the reference station coordinate message (Type 3), was defined by the RTCM, differential users were working to meter-level and so the X,Y,Z coordinate fields were only defined to 1 cm. For Real-Time Kinematic positioning, an order of magnitude improvement is needed (see [2]).

The RTCM Version 2.1 standard requires at least 4800 bits to transmit dual-frequency data for nine satellites. No indication is given in the RTCM standard as to whether or not L2 data is going to be transmitted. A user must wait until the next epoch of L1 data is received in order to deduce that no L2 data is present [2].

MIXING RECEIVER TYPES

The main motivations for having Real-Time Kinematic data transmission standards are to enable end-users to mix receivers from different manufacturers and to be able to use established reference station systems.

Mixing GPS hardware and software from different manufacturers presents some challenges which need further investigation. GPS system manufacturers often guide users to pair similar antenna types and even orient the reference and rover antennas in the same direction to minimise the impact of any azimuth-dependent signal biases. Fortunately, antenna phase center offsets (difference between the electrical and physical centers of an antenna) of microstrip elements are less than one centimetre for carrier phase data. Group delay (code measurement) variation as a function of azimuth also differs across antenna makes. Investigators have already addressed the issue of mixing receiver types, however additional research is needed to quantify antenna-dependent errors for real-time applications [7].

GPS receiver signal sampling schemes affect the timing and apparent biases in the code and carrier phase measurements. If reference and rover have identical sampling schemes then these errors difference away during baseline processing, otherwise detectable biases may appear in double-differenced observations. **Inter-receiver biases** as large as 0.5 meters for code and 0.01 meters for the carrier measurements are not uncommon between different sampling schemes. Inter-receiving measurement timing offsets are best evaluated using a zero-baseline experiment, whereby both receivers are attached to the same antenna, thus minimising the impact of multipath, ephemeris errors, atmospheric influences and antenna phase centre variations on the differential baseline [8].

Although there are some unanswered questions relating to mixing real-time receiver systems, post-processing packages have been very successful at combining data from mixed receiver types. The Receiver INdependent EXchange format (RINEX) was specifically designed for the purpose of mixing receiver types. Antenna phase-center offsets and inter-receiving measurement timing offsets can be computed using a methodical calibration scheme, however an exhaustive analysis is yet to be published.

CONCLUSION

Real-Time Kinematic positioning is becoming a mature technology in the surveying and mapping industry. Manufacturers are offering a variety of system solutions which can provide centimetre-level precision between matched reference and rover receivers. The next step in achieving wider acceptance of Real-Time Kinematic positioning will require the ability to mix-and-match reference and rover systems from different manufacturers. The Radio Technical Commission for Maritime Services - Special Committee 104 (RTCM-SC104) developed messages specifically for broadcasting carrier phase and pseudorange data for Real-Time Kinematic positioning and designated them messages: 18, 19, 20 and 21, in their Version 2.1 Standard [1]. Although the RTCM proposals have been implemented and are in use, they require at least a 4800 baud datalink between the reference and rover units [2]. The Compact Measurement Record (CMR) format presented, provides a compressed transmission standard, which requires less than half the bandwidth (2400 baud) of the equivalent RTCM messages. By publishing the CMR format, all RTK system manufacturers will be able to take advantage of the compressed standard for general use. Apart from transmission standard issues, system integrators still need to address the issue of mixing antennas from different manufacturers and receivers which have distinct sampling schemes.

ACKNOWLEDGMENTS

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APPENDIX A

COMPACT MEASUREMENT RECORD (CMR) FORMAT[1]

An overview of the Compact Measurement Record Format is illustrated in Table A.1. Each CMR message is surrounded by a (six byte) packet frame. Within each message frame is a header and a data section. Message types are defined for:

- Observables - L1 and L2 carrier phase and pseudorange measurements
- Reference Station Location - WGS84 Cartesian coordinates and antenna offsets
- Reference Station Description - ASCII message for station name and description

The observables message is sent once per second. The reference station location and the reference station description messages are sent every ten seconds, but are interleaved. All of the message types are described in detail below.

Transmission Structure	Size of Transmission
Packet Header	4 bytes
Observables Header {Type 0} (includes Number of Satellites [n])	6 bytes
Satellite 1 L1 Observables (extended L2 data follows)	8 bytes
Satellite 1 L2 Observables	7 bytes
Satellite 2 L1 Observables	8 bytes
Satellite 2 L2 Observables	7 bytes
....	......
Satellite n L1 Observables	8 bytes
Satellite n L2 Observables	7 bytes
Packet Tail	2 bytes
....	
(observables packets)	(**Type 0**: 9 sats = 147 bytes)
....	
Packet Header	4 bytes
Reference Station Coordinates Header {Type 1}	6 bytes
Reference Station Location Fields	7 bytes
Packet Tail	2 bytes (**Type 1**: 19 bytes)
....	
(observables packets)	
....	
Packet Header	4 bytes
Reference Station Description Header {Type 2}	6 bytes
Reference Station Description Fields	75 bytes
Packet Tail	2 bytes (**Type 2**: 87 bytes)
....	
(observables packets)	

Table A.1 Compact Measurement Record Structure.

Compact Measurement Record Packet

Each CMR message is sent within a six byte frame. Details of the packet structure are given in table A.2.

Parameter	Number of Bytes	Description
STX	1	Start of transmission (02h)
Status	1	Status byte (00h)
Type	1	CMR message types: 0 - observables; 1 - location; 2 - description
Length	1	Number of bytes in the data block
Data Block	as per definition	Message data as defined below.
Checksum	1	Data checksum calculated using (Status + Type + Length + Data Block) mod 256
ETX	1	End of transmission

Table A.2 Compact Measurement Record Packet definition.

[1] Trimble Navigation Limited reserves the right to make changes to the Compact Measurement Record format specification without notice.

Although a checksum field is used to provide some protection against packet errors, it is the responsibility of the datalink to provide additional and sufficient error detection mechanisms to ensure that the message content received at the rover station is valid.

Observables (Message Type 0)

The Compact Measurement Record format is divided into a header portion and a data portion. The header is sent at each measurement epoch and contains timing and satellite tracking information that is relevant to the observable block. The observable block is repeated for each satellite tracked at the reference station.

Parameter	# of bits	Range	Units and Scale factor	Description
Version Number	3	0 - 7	dimension-less	Defines the format version and allows for future expansion of the format. Currently version 3 is defined. However some 4000SSE receivers transmit versions 0 ,1 & 2 which impact the interpretation of the Clock Offset parameter shown below.
Station ID	5	0 - 31	dimension-less	Identifies the reference station from others working in the area.
Message Type	3	0 - 7	dimension-less	Describes the information that follows in subsequent data blocks. The observables message type is 0 (zero).
Number of SVs	5	0 - 31	dimension-less	Number of satellites contained in the observable blocks that follow.
Epoch Time	18	0 - 240,000	milli-seconds	Receiver epoch time for the GPS measurements modulo 240 seconds. The epoch time is scaled into milliseconds and transmitted as an unsigned 18 bit integer. It is assumed that the rover receiver has a good knowledge of time and therefore can remove the 240 second ambiguity in the epoch time.
Clock Bias Validity	2	0 - 3	0 - invalid 3 - valid	Indicates that the reference receiver clock offset is valid or invalid.
Clock Offset	12	+/- 0.5 milli-seconds	500 nano-seconds	**Version 0-2**: The clock offset is maintained between 0-1millisecond for these receivers and therefore 0.5 milliseconds is subtracted from the clock offset before it is transmitted. **Version 3**: The clock offset is given in the range -0.5 to +0.5 milliseconds. Receivers that drive their clock onto GPS time should set the clock offset parameter to zero.
Total	48			

```
  m s b                                                                              l s b
   1 5   1 4    1 3   1 2    1 1    1 0     9     8     7     6     5     4     3     2     1     0
 |   V e r s i o n    |        S t a t i o n   I D          |      T y p e      |   N u m b e r   o f   S V s   |
 |< - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -   E p o c h   T i m e   - - - - - - - - - - - - - - - - - - - - - - - - - |
 | - - - - - - > | C l k S t a t e | < - - - - - - - - - - - - - - - - - - - - -   C l o c k   O f f s e t   - - - - - - - - - - - - - - - > |
```

Table A.3 Observables Block Header Structure.

Observables Block

Parameter	Number of bits	Range	Units and Scale factor	Description
SV PRN	5	0 - 31	dimensionless	Satellite Pseudo Random Noise Number identifier
P-code / CA-code flag	1	0,1	0 - CA-code 1 - P-code	Indicates the type of code data being tracked on the L1 or L2 band.
L1 Phase data valid	1	0,1	0 - Invalid 1 - Valid	Indicates the validity of the phase data. Only use phase when the validity flag is set.
Extended L2 data follows	1	0,1	0 - L1 only 1 - L1 & L2	L2 data follows the L1 data if this flag is set.
CA-code pseudo-range	24	0 - 2^{21} L1 cycles	1/8 L1 cycles	The L1 pseudorange is transmitted modulo 1 light millisecond (299792.458m), in units of 1/8 L1 cycles.
Carrier - Code	20	+/- 2^{19} (1/256 L1 cycles)	1/256 L1 cycles	The carrier phase data is referenced against the code measurement field. The carrier phase is quantised in 1/256 L1 cycles and broadcast in the range +/- 2^{19}.
SNR	4	0 - 15	least significant bit = 2 SNR counts	The Signal-to Noise Ratio value is given in the range 0-15 where the least significant bit is equal to 2 SNR counts.
Cycle slip count	8	0 - 255	dimensionless	Incremented every time there is a cycle slip on this satellite. The rover should assume that a cycle slip has occurred if the cycle

				slip count increments between measurement epochs.
Total	64			

```
msb                                                                   lsb
 15  14  13  12  11  10  9  8  7  6  5  4  3  2  1  0
 |<---------SV-------->|P/C| Ph | L2 |<--------- Pseudorange ---------|
 |------------------------- Pseudorange (cont) ----------------------->|
 |<-------------------------- Carrier - Code --------------------------|
 |----------------->|<----- SNR ---->|<------- Cycle Slip Count ------>|
```

Table A.4 Observables Block Contents.

L2 Data

L2 data is appended directly to the L1 observable data for each satellite.

Parameter	Number of bits	Range	Units and Scale factor	Description
L2 code available (A)	1	0,1	0 - no code available 1 - code available	Receivers capable of tracking L2 code during encryption should set this flag to indicate that L2 code data is available.
P-code / X-correlation (B)	1	0,1	0 - P-code 1 - cross correlation	Indicates the type of code data collected on L2. This bit is ignored if no code information is present.
Code Valid (C)	1	0,1	0 - False 1 - True	Indicates the validity of the L2 code information.
Phase Valid (D)	1	0,1	0 - False 1 - True	Indicates the validity of the L2 phase information.
Phase Full (E)	1	0,1	0 - Half Wave 1 - Full Wave	Indicates the wavelength of the L2 phase data. Receivers that track squared L2 carrier phase should clear this flag, while full-cycle L2 receivers should set this flag.
Reserved	3	Reserved	Reserved	Reserved
L2 range - L1 range	16	+/- 2^{15} centimeters	0.01 meters	The L2 range measurement is referenced against the L1 range measurement and broadcast in terms of integer centimeters.
L2 carrier - L1 code	20	+/- 2^{19} (1/256 L2 cycles)	1/256 L2 cycles	The L2 carrier phase measurement is referenced against the L1 code measurement, in a similar fashion to the L1 carrier phase. The units for the L2 carrier minus L1 code is in terms of 1/256 L2 full cycles. For half-cycle data, the units are in terms of 1/256 L2 half cycles.
L2 SNR	4	0 - 15	least significant bit = 2 SNR counts	L2 Signal-to-Noise Ratio, defined in a similar fashion to the L1 SNR.
L2 cycle slip count	8	0 - 255	dimensionless	The L2 cycle slip count is an accumulated sum of the number of cycle slips at the transmitting receiver.
Total	56			

```
msb                                                                   lsb
 15  14  13  12  11  10  9  8  7  6  5  4  3  2  1  0
 | A | B | C | D | E | Reserved |<--------- L2 - L1 Range ---------|
 |---------------------------------->|<-----L2 Phase minus L1 Code---|
 |------------------------------------------------------>|<---- SNR --->|
 |<----- L2 Cycle Slip Count ----->|
```

Table A.5 L2 Data Block Contents.

Earth-Centred, Earth-Fixed Reference Station Co-ordinates (Type 1)

The location of the reference or base station is vital to the location of the rover station. The World Geodetic System (1984) datum is the basis for GPS derived co-ordinates. The reference station location must be known in terms of

WGS84 coordinates to better that 10 meters to maintain a relative positioning accuracy for the rover of one part per million [9]. The Type 1 message in the Compact Measurement Record format contains compacted Cartesian coordinates of the reference station antenna phase center and any offsets to the ground mark.

Reference Station Coordinates (Type 1) Header

Like the Type 0 message for observables, the Reference Station Coordinate, Type 1 message has a header and a data block. The header contains status information regarding the operation of the reference station which may be needed by the rovers. Table A.6 contains a detailed description of the Type 1, Reference Station Coordinate Header.

Parameter	Number of bits	Range	Units and Scale factor	Description
Version Number	3	0 - 7	dimensionless	Defines the format version and allows for future expansion of the format. Currently version 3 is defined
Station ID	5	0 - 31	dimensionless	Identifies the reference station from others working in the area.
Message Type	3	0 - 7	dimensionless	Describes the information that follows in subsequent data blocks. The reference station coordinates message type is 1 (one).
Low Battery Flag	1	0,1	0 - Battery OK 1 - Battery Low	Warns the user when the reference receiver battery levels are low.
Low Memory Flag	1	0,1	0 - Memory OK 1 - Memory Low	Warns the user when the reference receiver memory storage is low (i.e., less than 15 minutes of storage left).
Reserved	1	Reserved	Reserved	Reserved
L2 Enable	1	0,1	0 - L2 disabled 1 - L2 enabled	Indicates if L2 data tracking has been disabled at the reference.
Reserved	1	Reserved	Reserved	Reserved
Epoch Time	18	0 - 240,000	milliseconds	Epoch time for the GPS measurements modulo 240 seconds. The epoch time is scaled into milliseconds and transmitted as an unsigned 18 bit integer. It is assumed that the rover receiver has a good knowledge of time and therefore can remove the 240 second ambiguity in the epoch time.
Motion State	2	0 - 3	0 - Unknown 1 - Static 2 - Kinematic	Defines the motion of the reference receiver. Typically the reference will be static, however the standard allows for cases where both reference and rover receiver are in motion.
Reserved	12	Reserved	Reserved	Reserved
Total	48			

```
msb                                                                           lsb
 15  14  13  12  11  10   9   8   7   6   5   4   3   2   1   0
 |  Version  |     Station ID      |    Type    |Bat|Mem|Rd|L2|Rd|
 |<------------------------------ Epoch Time -----------------------------|
 |------->|Motion |<-------------------- Reserved -------------------->|
```

Table A.6 Reference Station Coordinates Header Structure.

Earth-Centred, Earth-Fixed Coordinates Data Block

The WGS84 coordinates of the reference station antenna phase center and the antenna offsets relative to the ground mark are contained within the data block of the Type 1 message.

Parameter	Number of bits	Range	Units and Scale factor	Description
ECEF X	34 (1 sign)	+/- 8589934592	millimeters	WGS84 X coordinate of the reference antenna phase center
Antenna Height	14 (1 sign)	+/- 8192	millimeters	antenna height from ground mark to antenna phase center
ECEF Y	34 (1 sign)	+/- 8589934592	millimeters	WGS84 Y coordinate of the reference antenna phase center
East Offset	14 (1 sign)	+/- 8192	millimeters	east offset from ground mark to antenna phase center
ECEF Z	34 (1 sign)	+/- 8589934592	millimeters	WGS84 Z coordinate of the reference antenna phase center
North Offset	14 (1 sign)	+/- 8192	millimeters	north offset from ground mark to antenna phase center

Position Coordinate Accuracy	4	0 - 15	see Lookup Table below	3D-Coordinate precision of the geocentric antenna phase center location relative to the World Geodetic System 1984.
Reserved	4	Reserved	Reserved	Reserved
Total	152			

Table A.6 Station Location Message.

```
msb
lsb
 15  14  13  12  11  10   9   8   7   6   5   4   3   2   1   0
 |<---------------------------- ECEF X --------------------------------
-|
 |-------------------------- ECEF X (cont) -----------------------------
-|
 |------->|<-------------------- Antenna Height ------------------------
>|
 |<---------------------------- ECEF Y --------------------------------
-|
 |-------------------------- ECEF Y (cont) -----------------------------
-|
 |------->|<----------------- Antenna Offset (East) --------------------
>|
 |<---------------------------- ECEF Z --------------------------------
-|
 |-------------------------- ECEF Z (cont) -----------------------------
-|
 |------->|<---------------- Antenna Offset (North) --------------------
>|
 |   Position Acc   |     Reserved      |
```

Table A.6 Station Location Message (continued).

Accuracy Parameter	Lookup Value	Accuracy Parameter	Lookup Value
0	Unknown	8	1m
1	5km	9	50cm
2	1km	10	10cm
3	500m	11	5cm
4	100m	12	1cm
5	50m	13	5mm
6	10m	14	1mm
7	5m	15	Exact

Lookup Table

Reference Station Description (Type 2) Header

The reference station description message is directed to survey applications where the user is interested in knowing the alphanumeric name of the reference station. The reference station description header is identical to the reference station location header with the exception of the message type. The reference station description is designated as Type 2.

Station Description Data Block

Table A.7 lists the components of the station description data block.

Parameter	Number of BYTES	Range	Units and Scale factor	Description
Record Length	1	0 - 255	dimensionless	Defines the total length of the station description data. This field is needed because the variable nature of the remarks field.
Short station ID	8	ASCII characters	dimensionless	The short station id / name. The name field is right justified and prefix padded with null characters.
COGO Code	16	ASCII characters	dimensionless	This field is designed to be used for transmitting the reference station point feature code.
Long Station ID / Number	50	ASCII characters	dimensionless	Long name for the reference station.
Total	75 (= 600 bits)			

Table A.7 Station Description Message.