DGPS data formats

DGPS data formats (general)

Since the emergence of differential GPS applications it has been essential to transmit the information needed for DGPS computation from the reference station to the mobile station. With its Special Committee 104 (SC104), the US Radio Technical Commission for Maritime Services (RTCM) set up a team composed of representatives of US federal authorities, GPS manufacturers and users. Already in the early 1990s, they adopted a first standard for the transmission format and contents for DGPS applications which has been modified, in the following years, to match current developments.

Because these RTCM standards have been supported by leading manufacturers and users, they also spread widely outside the USA and thus developed into an internationally recognized standard. Version 2.1 is the current standard. Version 2.2 with enhancements so as to include GLONASS will be adopted shortly.

The current version of the RTCM standard can be obtained from the

> Radio Technical Commission
> for Maritime Services
> Special Committee 104
> Post Office Box 19037
> Washington, D.C. 20036
> USA

and costs about US$70 in hard copy.

Experience shows that, because of the need for agreement among all the institutions and interested parties involved, standards develop only very slowly. Thus there have always been, and remain, a large number of proprietary solutions (e.g. from Trimble and others) which are not compatible with the RTCM standard. However, from the beginning, Geo++ GmbH has backed the available standards and has implemented any necessary enhancements in a way which is compatible with them.

o Version and rev. status

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Raw data / correction data

Raw data and correction data

In principle, there are two different ways to transmit the necessary information from the reference station to the mobile stations.

The most obvious possibility is the transmission of the raw data in its original form generated by the receiver at the reference station (original observation data). Apart from the obvious advantage that little or no calculation is needed at the reference station, with this form of data it is also relatively easy to use the existing algorithms and GPS post-processing programs for real-time processing, because only slight modifications are needed. However, much additional information, from precise reference station coordinates to the antenna types used, must be supplied to the mobile station.

The other possibility is to supply the necessary information by transmitting only the corrections compared with a theoretical value rather than the original observations. With knowledge of the reference station coordinates and the satellite positions, ranges can be calculated for each of the satellites (neglecting orbit, clock and propagation errors, SA effects, etc.). The differences from the actually measured distances yield, in simplified terms, the correction values which can then be transmitted to the mobile station.

However, this second method generates increased computation workload at the reference station and demands appropriate algorithms able to handle the correction data at the mobile station. Nevertheless, correction data has numerous advantages compared with raw data. On the one hand, correction data formats call for significantly less space than raw data because the number of significant digits needed is less. On the other hand, the correction data is independent of specific reference station parameters, which means that there is no need for the mobile station to know the exact reference station coordinates or antenna parameters. Another advantage is that individual corrections at the reference station, e.g. for azimuth- and elevation-dependent antenna phase centres or for multi-path effects, can be very easily incorporated. More sophisticated models, such as the concept of networked reference stations, cannot be employed at all without correction data.

For DGPS applications, the use of correction data has generally gained acceptance. Probably because it was easier for them to implement, most GPS manufacturers at first adopted the raw data format for PDGPS applications. For its PDGPS solution, Geo++ GmbH recognized the advantages of correction data early on, and since 1994 has implemented the correction data format even for carrier phase operations. In the meantime, other manufacturers also appear to have seen its advantages so that an increasing number of implementations using correction data format are coming onto the market.

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The RTCM data format

The RTCM data format

RTCM data is transmitted as a continuous binary data stream. Typically, a complete RTCM data record is transmitted within one second. RTCM compresses the various contents of a data record in several message types.

Message 1
Message 2
Message 3
Message 4

Table 1: RTCM data record, subdivision into several messages

Every message within a data record comprises a message header and a message body.

Message header	Message body

Table 2: RTCM message, subdivision into header and body

The message type, time information (albeit ambiguous), the reference station ID, the length of the message and further information such as the monitoring status, are all coded in the header. The body comprises the relevant operational data for every data type. The length of a message depends on the data type.

Header and body are protected by parity bits, permitting the relatively reliable recognition of transmission errors.

An RTCM data record does not necessarily have to include every message type. Some message types must be sent every second, others are automatically sent at defined times or at any desired interval. If a complete RTCM data record is shorter than the sending interval, no data will normally be sent during the remainder of the interval.

Because of the real-time requirement, and in case of restricted bandwidth of the transmission channel, there is normally no point in repeating incomplete or defective data records. Instead, it is better to wait for the next data record.

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Update rate

Update rate

An important criterion for the choice of transmission channels is the required update rate with which a complete RTCM data record must be transmitted. For static applications (point positioning), update rates of **several seconds** are permissible although they should be as short as possible to ensure rapid progress of the work. For kinematic applications with a mobile antenna (sea, air and land navigation as well as setting out), an update rate of at least **one data record per second** is necessary because of the dynamic behaviour involved. A slower update rate will yield a poorer accuracy.

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RTCM 2.0

RTCM format Version 2.0

Version 2.0, which is important for DGPS applications, was adopted by the RTCM committee in 1990. It comprises all necessary information to provide correction data and some additional information for DGPS applications.

Amongst the message types defined in RTCM 2.0, the following are important for the SAPOS service:

Typ	Content	Frequency
1	Differential corrections for code observations	in every record, typically once per second
2	Delta corrections, describe differences in the correction data on transition between ephemeris records, because reference station and mobile station may make the transfer with a gap of some seconds	automatically with each ephemeris shift, e.g. for each change of hour
3	coordinates of the reference station	as required, typically at intervals of about 1 minute
16	any desired alphanumeric text, e.g. name and tel. no. of the reference station	as required, e.g. every 10 minutes
59	user-defined message type, any further data, packed in a user-defined format, e.g. to provide additional information or a higher accuracy	as required

Table 3: RTCM Version 2.0 message types relevant to DGPS

RTCM Version 2.0 includes numerous other message types which are important chiefly for special (e.g. maritime) applications.

The DGPS accuracy achievable with RTCM Version 2.0 is about 1 metre. RTCM 2.0 does not contain any carrier phase information so no RTK applications are possible with this version. Thus, RTCM 2.0 is mainly of interest for navigation applications.

If the corrections for all available satellites are to be transmitted, a complete RTCM 2.0 data record will take about 1200 Bits.

Under the SAPOS concept of the AdV (Association of German State Survey Departments), RTCM 2.0 is transmitted within the framework of the EPS service indirectly via the RASANT format (see below) through RDS and through VHF radio transmission as part of the RTCM- AdV format.

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RTCM 2.1

RTCM format Version 2.1

With the emergence of the first PDGPS applications based on centimetre accuracy carrier phase solutions, in 1993 the RTCM committee developed version 2.1 of the RTCM standard. The full content of RTCM 2.0 was retained in RTCM 2.1. The important enhancements consisted of some new message types permitting the transmission of the information needed for PDGPS carrier phase solutions.

Typ	Content	Frequency
1	as in RTCM 2.0	as in RTCM 2.0
2	as in RTCM 2.0	as in RTCM 2.0
3	as in RTCM 2.0	as in RTCM 2.0
16	as in RTCM 2.0	as in RTCM 2.0
18	carrier phase raw data for PDGPS applications	in every record, typically once per second (where type 20 is not used)
19	code phase raw data for PDGPS applications	in every record, typically once per second (where type 21 is not used)
20	carrier phase corrections for PDGPS applications	in every record, typically once per second (where type 18 is not used)
21	code phase corrections for PDGPS applications	in every record, typically once per second (where type 19 is not used)
59	as in RTCM 2.0	as in RTCM 2.0

Table 4: RTCM Version 2.1 message types relevant to PDGPS

For PDGPS applications, either message type 18 (carrier phase raw data) or, preferably, message type 20 (carrier phase corrections) must be transmitted. The advantages of correction data over raw data have already been described above.

The information about the code phases (message types 19 and 21) improves the accuracy of the information transmitted in message type 1 and is especially useful for rapid mobile PDGPS solutions. This should therefore also be transmitted, at least for the L1 code observations.

The required data volume for a complete RTCM 2.1 data record with twelve GPS satellites available simultaneously is more than 4800 bits. Unfortunately, correction data types 20 and 21 have been defined with the same internal structure as the raw data types 18 and 19, so the advantage of the smaller data volume of correction data has not been exploited in the RTCM 2.1 format.

With RTCM 2.1 correction data, an accuracy of one centimetre or better can be achieved. However, the achievable accuracy depends strongly on the distance, such that the accuracy decreases by a factor of about 1ppm of the distance from the reference station.

With RTCM 2.1 raw data, the accuracy is slightly lower because the additional information necessary for the processing of raw data cannot be transmitted in RTCM 2.1 with the required accuracy. The number of digits for reference station coordinates in RTCM message type 3 restricts the resolution to 1cm, so an error of up to 5mm may occur in each coordinate direction. With the concept of correction data, this error effect is eliminated because correction data is invariant in relation to reference station coordinates.

A required update rate of one data record per second demands a transmission rate of 9600 bits per second. Often, baud rates of only 2400 bits per second are available (e.g. with VHF radio transmission), so the RTCM 2.1 format is not operable everywhere without restriction. However, it is the only internationally recognized standard for PDGPS real-time applications.

RTCM 2.1 is made available to mobile PDGPS users by the AdV through its SAPOS programme, within the HEPS service, by means of the SAPOS decoder box (see below).

- Version and revision status

Version and revision status

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RTCM Version 2.2

RTCM format Version 2.2

Version 2.2 of the RTCM standard is now (1996/97) under final discussion by the RTCM committee. Compared with RTCM 2.1, this version will include some enhancements and will prepare the way for the exploitation of satellites of the Russian GLONASS satellite navigation system.

In principle, the intended consideration of datum parameters in RTCM 2.2 is welcome from the point of view of geodetic applications. Unfortunately, it apparently fails to provide the resolution needed to achieve centimetre accuracy.

All in all, RTCM 2.2 will not immediately affect the AdV programme. As soon as developments (e.g. GLONASS) demand it, the features of RTCM 2.2 will be used.

o Version and revision status

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RTCM++ format

The RTCM++ format was developed in 1993 by Geo++ GmbH to overcome the shortcomings of RTCM 2.1, especially with regard to accuracy and to the data volume of the information transmitted.

RTCM++ makes use of the existing redundancy in the correction data under RTCM 2.1 as well as special algorithms to reduce and compress the data. Thus, the data content of message types 20 and 21 is reduced to a fraction of its original size without any loss of information. The compressed data is packed in conformance with the RTCM standard in message type 59, which is reserved for user-specific information. The remaining message types are already packed almost optimally and are therefore included in RTCM++ unchanged in comparison with RTCM 2.0 and RTCM 2.1.

Typ	Content	Frequency
1	as in RTCM 2.0	as in RTCM 2.0
2	as in RTCM 2.0	as in RTCM 2.0
3	as in RTCM 2.0	as in RTCM 2.0
16	as in RTCM 2.0	as in RTCM 2.0
59	Code and carrier phase corrections, identical data content to RTCM 2.1 correction data, with its own subtypes Subtype 1: as in RTCM 2.1, type 20 Subtype 2: as in RTCM 2.1, type 21 Subtype n: networking parameters	in every record, typically once per second

Table 5: RTCM++ message types relevant to PDGPS

Because the content of RTCM++ data is identical with RTCM 2.1 correction data, at least the same accuracy (1 centimetre or better) is achievable. The resolution of the observed quantities in RTCM++ is 1mm, thus offering scope for improvements in accuracy in the future.

Furthermore, the use of message type 59 allows the transmission of additional information to improve accuracy. This includes especially the parameters which provide the mobile station with the results of networking of the reference stations. Thus the achievable accuracy no longer depends on distance, so that one centimetre accuracy can be guaranteed to be largely homogeneous over the whole area covered by a reference station network.

In principle, the RTCM++ format offers numerous further opportunities for special applications, for example the exploitation of mobile reference stations for the relative positioning of two moving vehicles one to the other (so-called relative DGPS or RDGPS).

The importance of the RTCM++ format for the SAPOS concept arises indirectly from the use of RTCM-AdV which has essentially been developed using RTCM++ as a starting point (see RTCM-AdV).

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RTCM-AdV

RTCM-AdV format

The RTCM-AdV format is based on the Geo++ GmbH RTCM++ proprietary format. This format has been provided by Geo++ to the member organisations of the Association of German State Survey Departments (AdV - Arbeitsgemeinschaft der Vermessungsverwaltungen der Bundesrepublik Deutschland) for operation within their SAPOS satellite positioning service. Compared with the RTCM++ format, the RTCM-AdV format allows additional data encryption which is controlled exclusively by the operator. These measures guarantee the independence of the RTCM-AdV format from the proprietary RTCM++ format.

By using the SAPOS ôdecoder boxö (AdV box) at the mobile station, connected between the VHF radio receiver and the PDGPS computer, correction data which fully conforms to the RTCM 2.1 standard may be reconstructed from the RTCM-AdV format. RTCM-AdV is used only for the radio transmission between reference station and mobile station. The interface to the user is the output of the SAPOS decoder box and is thus in RTCM 2.1. In this approach the information for improving accuracy which RTCM-AdV allows (e.g. networking parameters) may also be transmitted to the mobile station, ready for use by the SAPOS decoder box in generating RTCM 2.1.

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RTCM-AdV with network corrections

RTCM-AdV with network corrections

In accordance with their definition already given, the correction data included in RTCM-AdV always refer to one station and contain information on this station only. To improve accuracy, homogeneity and reliability, information on the linking of reference stations (for a multi-station solution) must also be included in the correction data.

This additional information on reference station networking involves the computation of parameters of a two-dimensional model covering both reference and mobile stations (area correction parameters - Flõchenkorrekturparametern (FKP)) and packed in a few free bits of the RTCM-AdV format. The whole format with RTCM-AdV correction data and the additional area correction parameters is called RTCM-AdV FKP, to make it clear that it is essentially the known RTCM-AdV format but that additional information is included.

Geo++ GmbH has developed a provisional specification for this format, which meets the requirements for accuracy and currency with as low a data volume as possible.

This format will be especially important with future developments in communication techniques such as Digital Audio Broadcasting (DAB). This will enable a whole country or region to be supplied with one unified correction data set. For this, the locally optimized correction values will be calculated at mobile stations from the unified data set by means of the area correction parameters. Local VHF transmitters may thus perhaps become redundant.

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RTCM-RSIM

RTCM-RSIM format

On the basis of the RTCM message structure, some message types have been standardized through the RTCM-RSIM format (RSIM= Reference Station Integrity Monitoring) for transmission of controlling, checking and monitoring information (see for example RTCM Special Committee 104: RTCM Recommended Standards for Differential NAVSTAR GPS Reference Stations and Integrity Monitors, Future Version 1.0, Final Draft, August 10, 1993).

These message types may serve as a basis for communication between reference and monitoring stations. Some additional information, not yet (?) provided in the RTCM-RSIM format but indispensable for the efficient and complete transmission of information, has been defined by Geo++ GmbH in largely format-compatible enhancements, as the so-called RSIM++ format.

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RASANT

RASANT

The RASANT correction data format is one realization of RTCM 2.0 correction data for data transmission using the Radio Data System (RDS) for FM broadcasting.

RASANT is similar to RTCM-AdV. Band width problems occur with transmission through RDS. The RASANT format is generated at the reference station before being passed on to the broadcasting channels. At the mobile station, an RDS decoder (in the same way as a car radio with RDS) makes the conversion back into RTCM 2.0 which may then be fed into a DGPS system. FM radios suitable for RDS are already available as PCMCIA plug-in cards.

RASANT contains additional parity bits for error detection and error correction to reduce the error proneness of the RDS channels. Because the bandwidth of an RDS channel is significantly lower than is required for RTCM 2.0, the update rate for RASANT must be reduced accordingly. Thus transmission of a complete correction data record takes several seconds.

For these reasons, RASANT can achieve an accuracy of only about 2-5 metres, thus it is significantly worse than with RTCM 2.0 using a one second update rate.

The RASANT format was first introduced in North Rhine-Westphalia and is now available to all SAPOS operators throughout Germany.

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RINEX

Receiver INdependent EXchange-Format (RINEX)

Already in the 1980s, the RINEX format was defined as a receiver-independent format for GPS raw data, by agreement between various user institutions mainly in research fields. After initially hesitating for commercial reasons, all important GPS vendors now support this format.

Because of its internal structure, the use of RINEX can be recommended only for the archiving of GPS observations. RINEX is not suitable for real-time applications. The most important application area is the post-processing of GPS observations. Static as well as kinematic (from version RINEX-2.0 on) observations can be stored.

RINEX is an ASCII data format with a relatively large number of redundant or superfluous characters. Typically, a RINEX file can be reduced to 50% or less of its original size with simple compression algorithms. Generally, RINEX files are stored on a hard disk at regular intervals of (say) ten minutes or even one hour.

A RINEX file contains one or more multiple-line headers with column-dependent contents. A code word from column 60 on describes the type of header information. The header information itself is contained in columns 1 to 59. The individual data records are stored epoch by epoch in the body of the RINEX file. Each epoch contains an epoch header including the GPS time, the numbers of the observed satellites and further information, followed by the code and carrier phase observations of all satellites for this epoch. For kinematic applications, other elements are added.

RINEX headers
Epoch header
Satellite i observations,
Satellite j observations,
... other satellites ...
Epoch header
Satellite i observations,
Satellite j observations,

... other satellites ...
... other epochs ...

Table 6: Composition of a RINEX file (simplified)

Detailed descriptions of the RINEX format are available in, for example:

> Werner Grurtner, University of Berne (Switzerland)
> Gerald Mader, National Geodetic Survey (USA):
> Receiver Independent Exchange Format Version 2.0
> Astronomical Institute of the University of Berne, 1993

The data contents of the RINEX format are more comprehensive than those of the RTCM-AdV format. Nevertheless a complete RINEX file can be generated from the contents of RTCM-AdV with a little additional information (especially satellite ephemerides and station coordinates). Therefore, for long-term data archiving, the storage of the data contained in the RTCM-AdV format together with the additional information for each station on an internal data basis is sufficient.

For the reconstruction of raw data or RINEX data from correction data, the following steps are necessary:

1. Computation of satellite positions for each epoch from the ephemerides

2. Computation of range, elevation and azimuth from the satellite positions resulting from (a) and from the coordinates of the reference station

3. Computation of the corrections taken from RTCM-AdV for the computation at the reference station: satellite clock error, relativity correction and earth rotation correction, with the inclusion of further correction values such as phase centre eccentricities as necessary.

4. In essence, the raw data are reconstructed from the addition of range correction (from RTCM-AdV) + range (from (b)) + satellite clock error + relativity correction + earth rotation correction (from (c) in each case)

The computation of the satellite positions in 1 demands the knowledge of exactly which satellite ephemerides have been used in generating RTCM-AdV corrections at the corresponding reference stations. The ephemerides are identical for all reference stations and for constant time intervals of one hour because they are emitted uniformly from the GPS space segment. For the short time interval needed for the inevitable changeover between two ephemeris records (e.g. at every change of hour), corresponding information is included in all RTCM data thus enabling the reconstruction of unambiguous connections.

If the reconstruction of the RINEX data is to be carried at a central station, the exact coordinates of the reference station, all applied station-dependent corrections and the correct ephemerides must be available at this central station. Normally, the reference station coordinates are constant but are also included in the RTCM-AdV data with high accuracy. Constant coordinates and (normally constant) station-dependent correction values (e.g. phase centre eccentricities) can be stored in one central database. The ephemerides can either be collected by a dedicated GPS receiver of the simplest type (with output of ephemeris data) at the central station or they must be brought up via direct line from one or more reference stations at regular intervals.

Some particular corrections which are identical for all satellites at one station (e.g. receiver clock error) can not be re-applied later because this information is lost after generating RTCM-AdV corrections. For this reason, the reconstructed RINEX data will differ slightly from RINEX data generated directly at the reference station. Nevertheless, the information content which is relevant for positioning is the same, thus guaranteeing that computation from either data set will always produce the same coordinates.

Starting from correction data with a given data rate (e.g. 1 Hz = 1 data record per second), higher RINEX data rates (e.g. 2 Hz) may also be derived. This is possible because correction data have lower dynamics in comparison with raw data and reference stations naturally possess static coordinates.

The RINEX format is the file interface for GPPS service users within the SAPOS system. The availability of the RINEX files within a few minutes after the observations is an important requirement for this application area. Furthermore, GPPS users require RINEX data to be sampled at intervals as close to exact minutes as possible. This can be achieved if the RINEX files are only generated from the internal data basis after being requested by a user.

The data rate of the outgoing RINEX data must also be selectable. The user requirements for the RINEX data rate range from once per 15 seconds for static point fixation to once per second or even higher for kinematic positioning, for example in aircraft position determination for aerial photography.

Thus the available data should be collected and recorded at the highest possible data rate. Data should be filtered to the required data rate only at the time it is requested. When filtering data, care should be taken to ensure that the flags (e.g. cycle slips) of the filtered-out epochs are correctly taken into account.

- Version and revision status

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