REPORT DOCUMENTATION I

AD-A255 276

ed
4-0188

2

Public reporting burden for this collection of information is estimated to average hour
gathering and maintaining the data needed, and completing and reviewing the collection
collection of information, including suggestions for reducing this burden, to Washington
Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management

isting data
other aspect of this
orts, 1215 Jefferson
20503

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE 16-18 Sep 1992

Scientific Paper

4. TITLE AND SUBTITLE Proposed Revisions To RTCM SC-104
Recommended Standards For Differential NAVSTAR/GPS
Service For Carrier Phase Applications

5. FUNDING NUMBERS

6. AUTHOR(S) Fred Gloeckler
Dr. A. J. Van Dierendonck
Ronald R. Hatch

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Topographic Engineering Center
ATTN: CETEC-LO
Fort Belvoir, Virginia 22060-5546

8. PERFORMING ORGANIZATION REPORT NUMBER

R-191

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

DTIC
ELECTE
SEP 18 1992
S B D

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release;
Distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Radio Technical Commission for Maritime Services (RTCM) Recommended Standards for Differential NAVSTAR/GPS Service have been widely adopted for code based differential GPS applications. To accommodate the present and expected future growth in use of differential carrier phase technology for high accuracy applications, it has been recognized that revisions to the RTCM standards are needed. A working group has been established to develop changes to the standards for carrier phase data. This is a report on the recommendations of the Carrier Phase Communications Working Group.

14. SUBJECT TERMS Differential GPS; DIfferential Carrier Phase; RTCM Recommended Standards; Carrier Phase Corrections; Pseudorange Corrections.

15. NUMBER OF PAGES 10

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

PROPOSED REVISIONS TO RTCM SC-104 RECOMMENDED STANDARDS FOR DIFFERENTIAL NAVSTAR/GPS SERVICE FOR CARRIER PHASE APPLICATIONS

Fred Gloeckler
U.S. Army Topographic Engineering Center

Dr. A. J. Van Dierendonck
AJ Systems[1]

Ronald R. Hatch
Magnavox Electronic Systems Company

BIOGRAPHIES

Fred Gloeckler received a BSEE from Lehigh University in 1966. Since that time he has worked for the U.S. Army Corps of Engineers. He has participated in the development of several inertial and satellite and airborne radio frequency systems for military and civil positioning. He chairs the RTCM SC-104 GPS Carrier Phase Communication Working Group.

A. J. Van Dierendonck received his BSEE from South Dakota State University and MSEE and PhD from Iowa State University. Currently, he is Principal Sat Nav Advisor with Inmarsat. Previously, he was self-employed, providing GPS expertise to numerous companies, including Inmarsat and NovAtel Communications, for whom he performed work published here. A. J. has 19 years of GPS experience.

Ron Hatch is a principal scientist at Magnavox Advanced Products and Systems Company. He has almost 30 years of experience in the use of satellites for navigation and surveying. Almost 20 years of that experience was gained while employed by Magnavox. He has a BS in Physics and Mathematics from Seattle Pacific University.

ABSTRACT

The Radio Technical Commission for Maritime Services (RTCM) Recommended Standards for Differential NAVSTAR/GPS Service have been widely adopted for code based differential GPS applications. To accommodate the present and expected future growth in use of differential carrier phase technology for high accuracy applications, it has been recognized that revisions to the RTCM standards are needed. A working group has been established to develop changes to the standards for carrier phase data. This is a report on the recommendations of the Carrier Phase Communication Working Group.

INTRODUCTION

The RTCM Recommended Standards for Differential NAVSTAR/GPS Service have been adopted by many GPS manufacturers and system integrators for code based differential (DGPS) applications.

GPS carrier phase measurements routinely are used for determination of precise positions using static, kinematic and pseudo-kinematic differential survey techniques. Recent developments indicate the feasibility of initializing kinematic surveys "on-the-fly" without requiring the roving receiver to occupy known or fixed positions.

Potential applications for precise (few centimeters) carrier phase differential positioning include: construction, dredging, hydrographic survey, land survey, tidal datum determination, aircraft landing approach control, navigation of aircraft on the ground, deformation monitoring, photogrammetric survey control, reference benchmark for land surveys, robotic guidance and control, range control, and calibration of other sensors. Also, there are a number of applications, requiring accuracies in the range of a few decimeters to a meter or two, which are not supported well by the present RTCM standards.

The RTCM standards contain a tentative Surveying Parameters message which incorporates carrier phase data. With present knowledge, the Surveying Parameters message is inadequate to support real-time, carrier phase applications. The Surveying Parameters message does not seem to have been implemented in practice.

---

[1] Currently with Inmarsat, London, UK

92 9 17 039

92-25417

42585

Considering the above, a working group, under SC-104, was established to update the RTCM standards for carrier phase applications. New message formats were developed to transmit raw carrier phase and pseudorange measurements, carrier phase corrections and pseudorange corrections with better representation of data quality. The recommendations of the working group are presented below.

NEW MESSAGE FORMATS

New message formats (message type number) are recommended for: Uncorrected Carrier Phase Measurements (18), Uncorrected Pseudorange Measurements (19), Carrier Phase Corrections (20) and Pseudorange Corrections (21).

One of the ground rules was that new messages would comply with the basic formats established in Version 2.0 of the recommended standards. Therefore, the new messages use the standard two word header. Each data word contains 24 data bits followed by 6 parity bits.

The recommended new messages have similar formats. Word 3, the first data word after the header, contains a GPS TIME OF MEASUREMENT field which is used to increase the resolution of the MODIFIED Z-COUNT in the header. Flags indicate whether the data are L1, L2, ionospheric free pseudoranges or ionospheric difference carrier phases. Word 3 is followed by pairs of words containing the data for each satellite observed.

Detailed definitions of the message formats are contained in the message descriptions shown in Figures 1 through 4. For brevity, data fields are defined only in the message format where they first occur. To ease software development, data fields containing the same or similar information were placed in the same locations in the different messages. We won't discuss all the details of each message type, but will highlight some of the significant characteristics.

TYPE 18 - UNCORRECTED CARRIER PHASE MEASUREMENTS

The Type 18 message allows transmission of raw L1, L2 and ionospheric difference carrier phase measurements. The carrier phase data field is shorter than the maximum measurement length. The user must detect "rollovers" in the data and reconstruct the complete phase measurement. A cumulative loss of continuity indicator is incremented each time continuity in the phase measurement has been lost.

In order for the user to evaluate system accuracy, the working group felt it necessary to provide realistic indicators for reference station errors. The carrier phase data quality indicator is the estimated one sigma phase measurement error indicated by $\frac{1}{256} e^{X/\sqrt{3}}$ cycles where X is the decimal equivalent of the 3-bit data field. The quantization levels are listed in Table 1. The quality indicator was derived from analysis of receiver carrier loop performance. The analysis is given in Appendix I of RTCM Paper 170-92/SC104-92. The same data quality indicator also is used in the Type 20 message.

TABLE 1
CARRIER PHASE QUALITY INDICATOR

CODE (X)	PHASE ERROR (cycles)
000 (0)	≤ 0.00391
001 (1)	≤ 0.00696
010 (2)	≤ 0.01239
011 (3)	≤ 0.02208
100 (4)	≤ 0.03933
101 (5)	≤ 0.07006
110 (6)	≤ 0.12480
111 (7)	> 0.12480

TYPE 19 - UNCORRECTED PSEUDORANGE MEASUREMENTS

The Type 19 message allows transmission of raw L1, L2 and ionospheric free pseudoranges. Both C/A and P-code measurements are accommodated. Raw pseudorange measurements should not be carrier smoothed.

Since reference station code multipath and receiver noise have different temporal characteristics, data quality indicators are provided for both. The pseudorange data quality indicator is the estimated one sigma pseudorange measurement error, caused by ambient noise, indicated as $0.02e^{0.4X}$ meters where X is the decimal equivalent of the indicator code. The quantization levels, listed in Table 2, were derived by analysis of code loop performance.

The multipath error indicator is the estimated residual multipath error indicated as $0.1e^{0.4X}$ meters where X is the decimal equivalent of the indicator code. An X of 15 indicates that multipath error was not determined. The quantization levels are given in Table 3.

The working group recognized the potential to measure and compensate for pseudorange multipath at the reference station. At this time, no schemes for accomplishing this have been endorsed. If compensation is performed, the multipath indicator should reflect the residual multipath remaining in the pseudorange data.

The pseudorange and multipath quality indicators also are in the Type 21 message. Additional information on the development of the pseudorange and multipath indicators can be found in Appendix II of RTCM Paper 170-92/-SC104-92.

TABLE 2
PSEUDORANGE DATA QUALITY INDICATOR

CODE (X)	PSEUDORANGE ERROR (Meters)
0000 (0)	≤ 0.020
0001 (1)	≤ 0.030
0010 (2)	≤ 0.045
0011 (3)	≤ 0.066
0100 (4)	≤ 0.099
0101 (5)	≤ 0.148
0110 (6)	≤ 0.220
0111 (7)	≤ 0.329
1000 (8)	≤ 0.491
1001 (9)	≤ 0.732
1010 (10)	≤ 1.092
1011 (11)	≤ 1.629
1100 (12)	≤ 2.430
1101 (13)	≤ 3.625
1110 (14)	≤ 5.409
1111 (15)	> 5.409

TYPE 20 - CARRIER PHASE CORRECTION

A carrier phase correction is similar to a pseudorange correction, but is computed using reference station carrier phase measurements. At the reference station it is computed as:

CARRIER PHASE CORRECTION = Predicted Satellite to Reference Station Range (in carrier cycles) - Measured Carrier Phase for the GPS TIME OF MEASUREMENT.

TABLE 3
PSEUDORANGE MULTIPATH INDICATOR

CODE (X)	MULTIPATH ERROR (Meters)
0000 (0)	≤ 0.100
0001 (1)	≤ 0.149
0010 (2)	≤ 0.223
0011 (3)	≤ 0.332
0100 (4)	≤ 0.495
0101 (5)	≤ 0.739
0110 (6)	≤ 1.102
0111 (7)	≤ 1.644
1000 (8)	≤ 2.453
1001 (9)	≤ 3.660
1010 (10)	≤ 5.460
1011 (11)	≤ 8.145
1100 (12)	≤ 12.151
1101 (13)	≤ 18.127
1110 (14)	> 18.127
1111 (15)	Multipath error not determined

To generate carrier phase corrections at the reference site, the first step is to add an appropriate number of whole cycles to the carrier phase measurement so that it approximates a true range measurement. One method is to set the whole cycle count such that the carrier phase measurement best agrees with the theoretical range to the satellite at the initial epoch. Alternately, the carrier phase whole cycle value can be set to match the corresponding code measurement when the receiver first acquired the satellite.

The second step is to remove the effect of biases and changes in the reference receiver clock from the corrections to be transmitted. Carrier phase measurements are an integrated measure of the Doppler shift of the received signal and the difference between satellite and receiver clock rates. Therefore, they are much less sensitive to time errors than are pseudorange measurements. If receiver time recovery is held to one microsecond or less,

DTIC QUALITY INSPECTED 3

☑
☐
☐
Availability Codes
Dist | Avail and/or Special
A-1

time induced carrier phase measurement errors will be a millimeter or better. Some attempts at filtering the clock, for differential carrier phase processing, indicate it can increase the noise in the navigation solution. It appears that even with high quality clocks, the ability to predict phase is poorer than the instantaneous clock solution when carrier phase measurements are employed. When the user solves for an independent clock state at each epoch, any error in the reference receiver clock will simply alias into the user's clock solution without compromising the position solution. In case someone does filter the user's clock state, it is desirable that carrier phase corrections transmitted to the user contain no step changes in the reference receiver clock.

The following method has been used to remove the reference receiver clock bias from the corrections: (1) At the initial epoch, the difference between the computed range and the measured carrier phase range (carrier phase measurement with appended whole cycles) for each satellite is formed. The mean value, across all satellites, of these differences is treated as the clock bias. The clock bias is subtracted from the individual differences for each satellite to form the carrier phase corrections. This procedure causes the mean value of the corrections for the first epoch to be zero. (2) At each subsequent epoch, the difference of the measured carrier phase range change and the computed range change is calculated for each satellite which remained locked over the interval between epochs. The mean value, across all satellites, of these change differences is ascribed to the change in clock bias and added to the prior clock bias value. As long as even one satellite was tracked continuously between epochs this new clock bias will be an acceptable value. Now all satellites which are locked on at the latest epoch are used to form individual differences between the computed range and measured carrier phase range. The new clock bias is removed from each of these satellite differences resulting in the carrier phase corrections for that epoch.

The advantage of using the changes in the measured and theoretical values to generate clock changes is that addition or deletion of a satellite to the set of satellites tracked at the reference site does not cause a step change in the clock bias. The disadvantage of the technique is that as satellites are added and deleted from the set being tracked the mean value of the corrections transmitted will deviate from zero. This deviation from zero mean can be counteracted by a very long (many hour) time constant which adds a small fraction of the mean value of the corrections to the clock bias state. The net result is a smoothly varying carrier phase correction for each satellite. Figures 5 and 6 show examples of carrier phase corrections computed for periods when S/A was inactive and active, respectively.

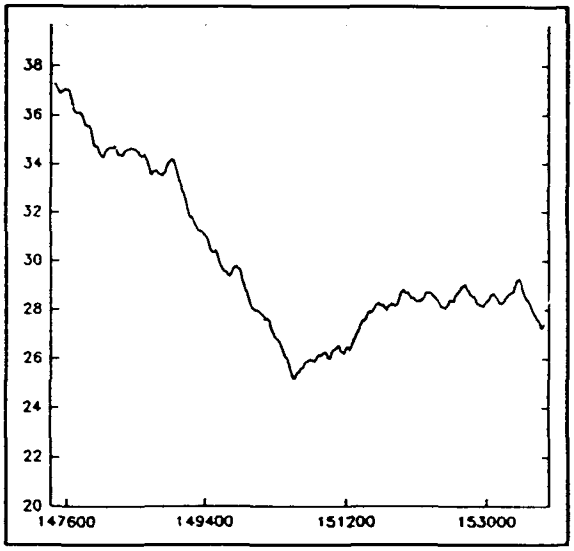

Figure 5 - PRN 2, Site 1

At the user receiver, CARRIER PHASE CORRECTIONs are applied as:

> Corrected User Carrier Phase = Measured User Carrier Phase + CARRIER PHASE CORRECTION.

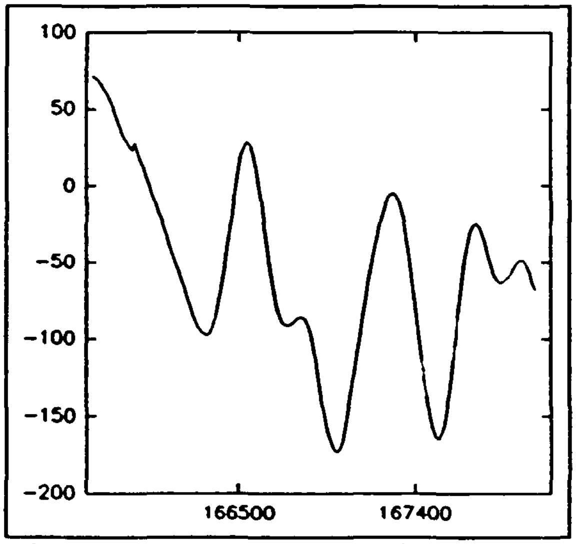

Figure 6 - PRN 11, Site 1

An example of positioning results using carrier phase corrections has been published (Hatch, Keegan and Stansell.)

TYPE 21 - PSEUDORANGE CORRECTIONS

The type 21 message contains the same type of pseudorange and range rate corrections as the present type 1. It allows for transmission of L1, L2 and ionospheric free corrections for C/A and P-codes. It also contains the previously discussed pseudorange data quality and multipath indicators and permits the carrier smoothing interval to be specified.

IMPLEMENTATION ISSUES

a. Satellite Position Computation Accuracy. For precise differential positioning, common satellite positions and satellite clock offsets must have common values (to millimeter accuracy) for both reference and user receivers. When raw measurements are used, generally the same algorithms are used for both sites so that algorithmic errors (nearly) cancel when differenced. When carrier phase corrections are used, the reference and user receivers may use different algorithms. Therefore, a high level of accuracy in computing satellite positions and satellite clock offsets must be assured. The revised standards will include test files which can be used to verify these computations. Test files were generated using the equations provided in ICD-GPS-200B without using approximations, except that Keppler's equation for eccentric anomaly was solved iteratively to an accuracy of 1 x 10^{-12} radians.

Test cases were generated to allow verification of two different methods for correcting for rotation of the coordinate frame over the transmission interval. In one method, the satellite position at time of signal transmission is rotated to the user's coordinate frame at time of signal reception. In the other method, the measured pseudorange is corrected to account for the coordinate frame rotation.

In the first method, the longitude of the satellite is adjusted with the amount in radians

$$\Delta\Omega_k = (\Omega - \Omega_e)\,\frac{R}{c} \qquad (1)$$

where Ω is the rate of right ascension of the satellite, Ω_e is the earth's rotation rate, R is the estimated range to the satellite and c is the speed of light. In the generated test cases, R is set to a constant of 24,000,000 meters. The effect of this correction is an adjustment in the east-west direction of a few meters in the satellites position, thus changing both the X and Y coordinates, but not the Z coordinate. Although a constant range is not realistic, it is appropriate for the test case since it can be set at this maximum value, and thus, is not sensitive to a user's location.

In the second method, the correction made to the pseudorange measurement, is given as

$$\Delta R = \frac{\Omega_e}{c}\,(X_s Y_u - Y_s X_u) \qquad (2)$$

where X_s and Y_s are the coordinates of the satellite in the ECEF coordinate frame at the time of transmission and X_u and Y_u are the estimated coordinates of the user in the ECEF coordinate frame at the time of reception. In this case, no earth's rotation correction is made to the satellite's coordinates, which is the same as making a correction with an estimated range of 0. In fact, this is the method used for this second case, and the quantity of Equation 1 was not computed.

b. Antenna Phase Center Stability. The apparent phase center location of an antenna may vary with direction of signal incidence. The phase center stability characteristics can differ for different antenna designs and ground plane configurations. For precise (centimeter level) positioning, the phase center characteristics of the reference and user receiver antennas must be matched or differences compensated. For local use systems, this often is accomplished by using the same antenna and ground plane design at both locations. Common variations in phase center shift cancel when differenced. The system designer may have little control over the phase shift characteristics of antennas used with public access systems. In this case, the reference station operator must provide the reference station antenna characteristics so users can select antennas with similar characteristics or make appropriate compensations when processing the data. An alternative would be to compensate the reference station carrier phase data to a fixed antenna phase center based on antenna calibration data. At this time, no standards for antenna phase center stability are proposed. The system designer must insure the errors are within the system error budget.

c. Issue of Data. When using broadcast ephemeris and satellite clock correction data, the same issue of data must be used at the reference and user sites. When raw measurements are processed for differential positioning, usually the same ephemeris data is used for all sites. When corrections are computed at the reference station and applied at the user's site, the possibility exists that they may be different. Rather than computing and broadcasting corrections for two different issues of data, it is recommended that the reference station wait 60 seconds after acquiring a new issue of data before transmitting corrections computed with the new issue of data. This allows the user receiver sufficient time to acquire the new data set. The issue of data used to compute corrections is always transmitted with the corrections.

d. Bad Reference Station Data. Erroneous or invalid data for any satellite should not be included in any messages sent by the reference station.

MESSAGE FORMAT STATUS

The Working Group believes the recommended new message formats are useful for their intended purposes. However, the formats have not yet been implemented and tested in practice. Therefore, it is recommended that the proposed formats be given "tentative" status for a period of one year. If no problems are found with the formats, it is recommended the status be changed to "fixed" at the end of that year. The temporary "tentative" status is intended to provide time to find and correct any problems in the formats, not to add new features. Equipment manufacturers and system developers are encouraged to provide feedback on the recommended message formats.

It also is recommended that the present Message Type 4 - Surveying Parameters (Tentative) be retired.

SUMMARY

The GPS Carrier Phase Communication Working Group has developed and documented four new message formats for transmission of raw carrier phase and pseudorange data and carrier phase and pseudorange corrections. The formats provide the flexibility to use L1 and L2 and C/A, P-code and codeless data and contain indicators for data quality and multipath. Test files for verification of satellite position computations were also developed.

ACKNOWLEDGEMENT

Development of standards is a group effort. Many individuals contributed to the efforts and discussions which resulted in the recommendations of the working group. We also would like to acknowledge the support of the working group members' employers who made this endeavor possible and the efforts of the RTCM staff which made the meeting arrangements and handled the publication and mailing chores.

REFERENCES

Hatch, R.R., R. Keegan, and T.A. Stansell, "Kinematic Receiver Technology from Magnavox," Proceedings of the Sixth International Geodetic Symposium on Satellite Positioning, Columbus, Ohio, March 17-20, 1992.

RTCM Paper 134-89/SC104-68, RTCM Recommended Standards for Differential NAVSTAR GPS Service, Version 2.0, Radio Technical Commission for Maritime Services, Post Office Box 19087, Washington, DC 20036, January 1, 1990.

RTCM Paper 170-92/SC104-92, Recommendations of the Carrier Phase Communications Working Group to RTCM Special Committee 104 (SC-104), Radio Technical Commission for Maritime Services, Post Office Box 19087, Washington, DC 20036, August 10, 1992.

FIGURE 1

MESSAGE TYPE 18 - UNCORRECTED CARRIER PHASE MEASUREMENTS (tentative)

WORD				
3	F	SPARE	GPS TIME OF MEASUREMENT	PARITY
	1 2	3 4	5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	25 - 30

2N+2	H	P	R	SATELLITE ID	DATA QUAL.	CUM. LOSS OF CONTINUITY	CARRIER PHASE	PARITY
	1	2	3	4 5 6 7 8	9 10 11	12 13 14 15 16	17 18 19 20 21 22 23 24	25 - 30

2N+3	CARRIER PHASE	PARITY
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	25 - 30

F = FREQUENCY COMBINATION INDICATOR

L1 = 00, L2 = 10, IONOSPHERIC DIFFERENCE = 01, SPECIAL = 11

(SPECIAL indicates a special purpose or experimental application. Users must insure data indicated as SPECIAL are compatible with their system.)

GPS TIME OF MEASUREMENT RESOLUTION: 1 microsecond RANGE: 0 to 599999 microseconds

Expanded Time of Measurement = GPS TIME OF MEASUREMENT + MODIFIED Z-COUNT (from header). The time shall be referenced to GPS time.

All CARRIER PHASEs in the message shall be determined for the Expanded Time of Measurement. The GPS TIME OF MEASUREMENT for a message containing L2 or ionospheric difference data shall be the same as that in the corresponding message containing L1 data.

N = Data set (one per satellite) number.

H = HALF/FULL L2 WAVELENGTH INDICATOR FULL = 0, HALF = 1 H shall be set to 0 for L1.

P = C/A-Code/P-Code INDICATOR C/A-Code = 0, P-Code = 1

L1 C/A-code and P-code carriers are transmitted in quadrature. Transmitted L1 P-code uncorrected phase measurements shall not be adjusted to C/A-code equivalent measurements or vice versa. The C/A-Code/P-Code INDICATOR shall indicate whether the L1 C/A-code or P-code carrier was used to compute an ionospheric difference. Ionospheric difference measurements shall not be adjusted for differences in quadrature.

R = Reserved for future expansion of Satellite ID

SATELLITE ID RESOLUTION: 1 RANGE: 1-32 (Satellite number 32 is indicated by 0.)

DATA QUALITY See Table 1

CUMULATIVE LOSS OF CONTINUITY INDICATOR RESOLUTION: 1 RANGE: 0 to 31

The CUMULATIVE LOSS OF CONTINUITY INDICATOR shall be incremented each time continuity of the CARRIER PHASE measurement is lost (unfixed cycle slip or loss of lock.) For ionospheric differences, the CUMULATIVE LOSS OF CONTINUITY INDICATOR shall be incremented each time continuity of either or both of the L1 or L2 carrier phase measurements is lost.

FIGURE 1 (continued)

CARRIER PHASE **RESOLUTION: 1/256 Full Cycle, 1/128 Half Cycle**
RANGE: ±8,388,608 Full Cycles, ±16,777,216 Half Cycles

$$\Phi_{IONODIFF} = \frac{60}{77}\,\Phi_{L1} - \Phi_{L2} \qquad \text{(full wavelength L2 cycles)}$$

$$\Phi_{IONODIFF} = \frac{120}{77}\,\Phi_{L1} - \Phi_{L2} \qquad \text{(half wavelength L2 cycles)}$$

Where: $\Phi_{IONODIFF}$ = Ionospheric Difference Phase Measurement
Φ_{L1} = L1 Carrier Phase Measurement
Φ_{L2} = L2 Carrier Phase Measurement

Full cycle carrier phase data shall not be transmitted until the correct polarity has been resolved.

FIGURE 2

MESSAGE TYPE 19 - UNCORRECTED PSEUDORANGE MEASUREMENTS (tentative)

WORD				
3	F	SPARE	GPS TIME OF MEASUREMENT	PARITY
	1 2	3 4	5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	25 - 30

2N+2	S	P	R	SATELLITE ID	DATA QUALITY	MULTIPATH ERROR	PSEUDORANGE	PARITY
	1	2	3	4 5 6 7 8	9 10 11 12	13 14 15 16	17 18 19 20 21 22 23 24	25 - 30

2N+3	PSEUDORANGE	PARITY
	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24	25 - 30

F = FREQUENCY COMBINATION INDICATOR
L1 = 00, L2 = 10, IONOSPHERIC DIFFERENCE = 01, SPECIAL = 11

S = Spare

DATA QUALITY and MULTIPATH ERROR See Tables 2 and 3.

PSEUDORANGE RESOLUTION: 0.02 meter RANGE: 0 to 85,899,345.92 meters
Ionospheric free pseudoranges shall be calculated from dual frequency measurements, not computed from single frequency measurements and the broadcast ionospheric model parameters.

FIGURE 3

MESSAGE TYPE 20 - CARRIER PHASE CORRECTIONS (tentative)

```
WORD
      ¦ F   ¦SPARE¦                    GPS TIME OF MEASUREMENT                        ¦ PARITY ¦
  3   ¦     ¦     ¦                                                                    ¦        ¦
        1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  -  30

      ¦H ¦S ¦R ¦    SATELLITE    ¦  DATA   ¦ CUM. LOSS OF ¦        ISSUE OF DATA        ¦ PARITY ¦
 2N+2 ¦  ¦  ¦  ¦       ID        ¦  QUAL.  ¦  CONTINUITY  ¦                             ¦        ¦
        1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  -  30

      ¦                    CARRIER PHASE CORRECTION                                    ¦ PARITY ¦
 2N+3 ¦                                                                                ¦        ¦
        1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  -  30
```

DATA QUALITY See message type 18.

CARRIER PHASE CORRECTION RESOLUTION: 1/256 Full Wavelength, 1/128 Half Wavelength
RANGE: ±32768 Full Wavelengths, ±65536 Half Wavelength

CARRIER PHASE CORRECTION = Predicted Satellite to Reference Station Range (in carrier cycles) - Measured Carrier Phase for the GPS TIME OF MEASUREMENT.

In order to avoid large biases in the phase corrections, the initial whole cycle value of the phase measurements shall be set to the code value at the initial GPS TIME OF MEASUREMENT. Alternatively, it can be set such that the phase correction at the initial time has a whole cycle value of zero. CARRIER PHASE CORRECTIONs shall be corrected for reference station receiver clock offset at the GPS TIME OF MEASUREMENT. L1 and L2 carrier phase corrections shall not be adjusted for ionospheric delay. Carrier phase corrections shall not be adjusted for tropospheric delay.

$$\Phi_{IONODIFF} = \frac{60}{77}\,\Phi_{L1} - \Phi_{L2} \qquad \text{(full wavelength L2)}$$

$$\Phi_{IONODIFF} = \frac{120}{77}\,\Phi_{L1} - \Phi_{L2} \qquad \text{(half wavelength L2)}$$

Where: $\Phi_{IONODIFF}$ = Ionospheric Difference Phase Correction
Φ_{L1} = L1 Carrier Phase Correction
Φ_{L2} = L2 Carrier Phase Correction

L1 CARRIER PHASE CORRECTIONs shall be full wavelength and shall not be transmitted until the correct polarity has been resolved. P-code L1 carrier phase measurements, used to compute L1 or ionospheric difference CARRIER PHASE CORRECTIONs, shall be corrected for quadrature to match the C/A code carrier phase. (L1 Corrected Phase = L1 P-Code Phase - 90 degrees.)

FIGURE 4

MESSAGE TYPE 21 - PSEUDORANGE CORRECTIONS (tentative)

```
WORD
     | F   |SMOOTH|          GPS TIME OF MEASUREMENT                          | PARITY |
 3   |     |      |                                                           |        |
       1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  -  30

     |SF|P |R | SATELLITE |  DATA    | MULTIPATH |     ISSUE OF DATA          | PARITY |
2N+2 |  |  |  |    ID     | QUALITY  |   ERROR   |                            |        |
       1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  -  30

     |           PSEUDORANGE CORRECTION             | RANGE RATE CORRECTION | PARITY |
2N+3 |                                              |                       |        |
       1  2  3  4  5  6  7  8  9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25  -  30
```

SMOOTH Indicates the interval for carrier smoothing of pseudorange data.

SMOOTH CODE	Smoothing Interval (Minutes)
00 (0)	0 to 1
01 (1)	1 to 5
10 (2)	5 to 15
11 (3)	Indefinite

SF = Scale Factor See PSEUDORANGE CORRECTION and PSEUDORANGE RATE CORRECTION below.

DATA QUALITY and MULTIPATH ERROR See message type 19.

PSEUDORANGE CORRECTION RESOLUTION: 0.02 meter when scale factor = 0
0.32 meter when scale factor = 1
RANGE: ±655.36 meters when scale factor = 0
±10485.76 meters when scale factor = 1

PSEUDORANGE CORRECTION = Predicted Satellite to Reference Station Range (in meters) - Measured Pseudorange for the GPS TIME OF MEASUREMENT.

PSEUDORANGE CORRECTIONs shall be corrected for Reference Station receiver clock offset at the GPS TIME OF MEASUREMENT. Corrections for tropospheric delay shall not be applied. L1 and L2 PSEUDORANGE CORRECTIONs shall not be adjusted for ionospheric delay. Ionospheric free PSEUDORANGE CORRECTIONs shall be calculated from dual frequency measurements, not computed from single frequency measurements and the broadcast ionospheric model parameters. Corrections for multipath may be applied. Residual multipath errors shall be reflected in the MULTIPATH ERROR INDICATOR.

PSEUDORANGE RATE CORRECTION RESOLUTION: 0.002 meters/second for scale factor = 0
0.032 meters/second for scale factor = 1
RANGE: ±0.256 meters/second for scale factor = 0
±4.096 meters/second for scale factor = 1