NavCom NMEA GBS/MDE Message

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1. Introduction

The GBS message ('GNSS Satellite Fault Detection') in the NMEA 0183 Version 3.00 specification is poorly defined. This document offers NavCom Technology's proposal for interpreting the intended purpose of the NMEA GBS specification and its implementation in NavCom's products.

To begin, we start with language taken directly from the NMEA specification that attempts to describe the purpose of the GBS message:

> "Given that a GNSS receiver is tracking enough satellites to perform integrity checks of the positioning quality of the position solution, a message is needed to report the output of this process to other systems to advise the system user. With RAIM in the GNSS receiver, the receiver can isolate faults to individual satellites and not use them in its position and velocity calculations. … This message shall be used for reporting this RAIM information."

Oddly enough, there is no clear mechanism defined in the GBS message for reporting when a fault is detected for a particular epoch and when one is not. Likewise, it is not clearly defined which fields need to be reported when a fault is detected and which fields should be reported when a fault is not detected. In the absence of this information, we propose the definitions shown in Table 1.

Field #	NMEA Field Description	Value when fault detected	Value when fault not detected
1	UTC time	Current UTC time	Current UTC time
2,3,4	Expected Errors in lat, lon, height	One-sigma estimated error[1]	One-sigma estimated error[1]
5	ID number of most likely failed satellite	PRN of outlier satellite	PRN of most likely failed satellite
6	Probability of missed detection	0.0	estimated probability[2] (0.0001 to 0.9500)
7	Estimate of bias for failed satellite	One-sigma estimated range error[3]	One-sigma estimated range error[3]
8	Estimate of noise for failed satellite	One-sigma estimated noise[4]	One-sigma estimated noise[4]

[1] Refer to the Eq. 18 in the 2.4section for computational methods.

[2] Refer to the Eq. 20 in the 2.6 section, where type II error is output.

[3] Refer to the Eq. 13 in the 2.4 section and

[4] Refer to the Eq. 14 in the 2.4 section.

Table 1 Proposed Definitions of GBS Fields when Faults are or are not Detected

In NavCom's RAIM approach, four scenarios exist for GBS messages:

1. No detected outliers and valid navigation
   - A single GBS message is output when 5 or more measurements are used in navigation and a reasonable PDOP (i.e. < 10) exists. This is done to report the most likely failed satellite and to show the integrity of the navigation solution.
2. One or more detected outliers and valid navigation
   - Up to three GBS messages are output when faulty measurements are identified as outliers and excluded from the navigation solution. If more than three exist, the receiver outputs the worst three. (i.e. if 12 satellites were available, 5 outliers detected and 7 left in navigation, the worst 3 are output)
   - An additional GBS message reports the most likely faulty satellite remaining in the navigation solution (i.e. for the case of 7 left above, the most likely left in the 7 used for navigation)
3. Insufficient redundancy
   - In case there is insufficient redundancy or the satellite constellation geometry is beyond user-specified threshold, a null GBS message is output
4. Invalid navigation
   - No GBS message is output

The navigation algorithms in NavCom's GPS receiver products have multiple layers of protection to detect faulty measurements. These tests are performed on an epoch by epoch basis for each satellite qualified to be used in the navigation. In the final level of measurement quality evaluation, a RAIM technique is used based on a chi-squared test described in Section 2. If the chi-squared test statistic passes (i.e. the computed chi-squared value is less than the tabulated threshold for a 95% significance level for the appropriate degrees of freedom), it indicates that no fault is detected, and fault isolation is not performed. If the chi-squared test fails an iterative process is performed to remove the faulty satellites using the maximum correlation coefficient. This iterative process is repeated until the chi-squared test passes, insufficient redundancy occurs, or navigation fails.

The NavCom GPS receiver products include one fast nav and several slow nav modules. The slow nav modules include RTK, StarFire, WAAS and non-differential modes to compute the position forward at 1Hz rate. Fast nav uses delta-carrier phase to propagate the slow nav position forward in time at a high rate and contains RAIM similar to Slow Nav that is tailored specifically for accurate velocity calculations.

The GBS messages are calculated and reported from Slow Nav RAIM as Slow Nav residuals drive the position solution.

RAIM Fault Detection and Isolation Methods

Figure 1 and Figure 2 show flowcharts of the fault detection and isolation processes implemented in NavCom's GPS products. Embedded links reference equations and further definitions.

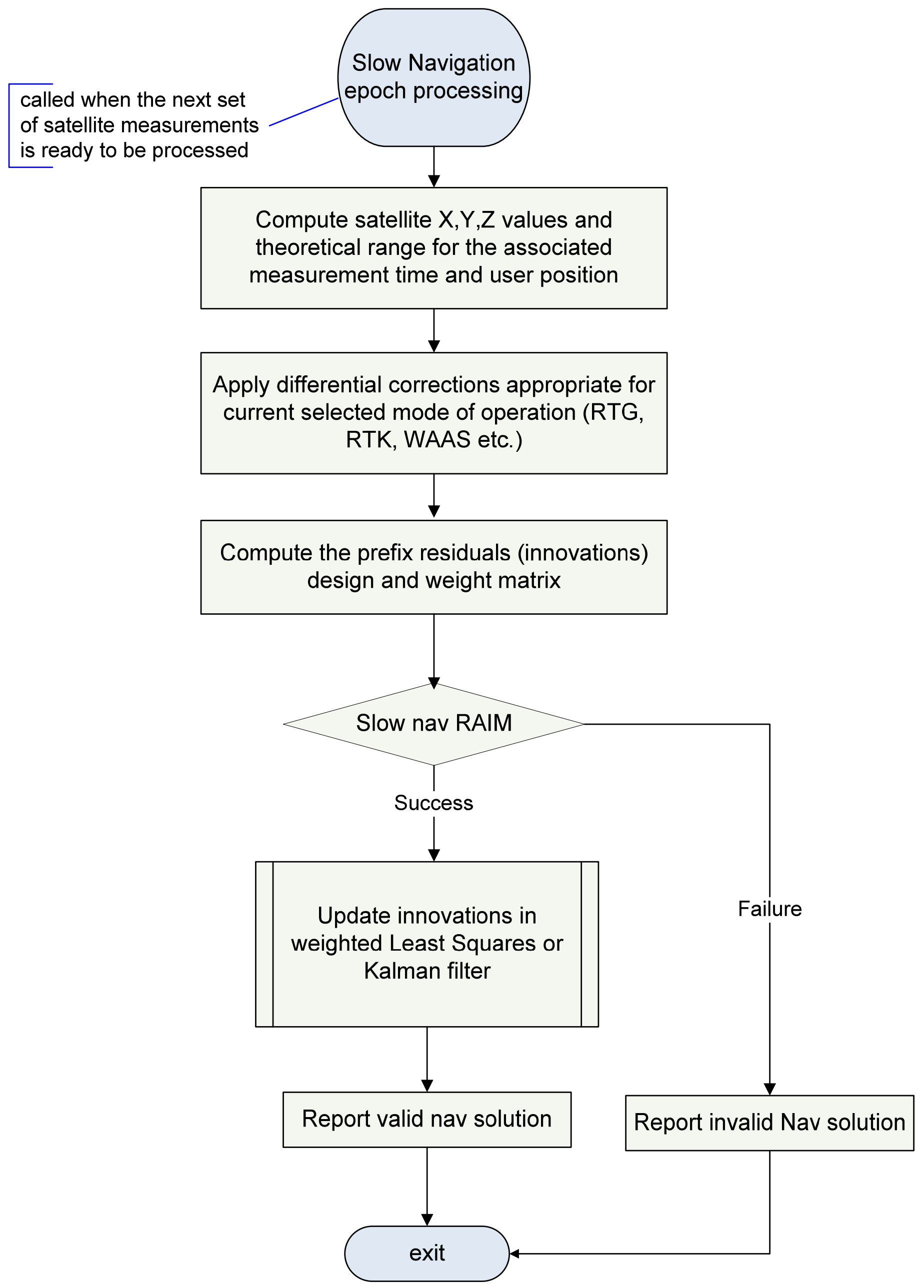

Figure 1 Top Level Flowchart of Navigation Epoch Processing

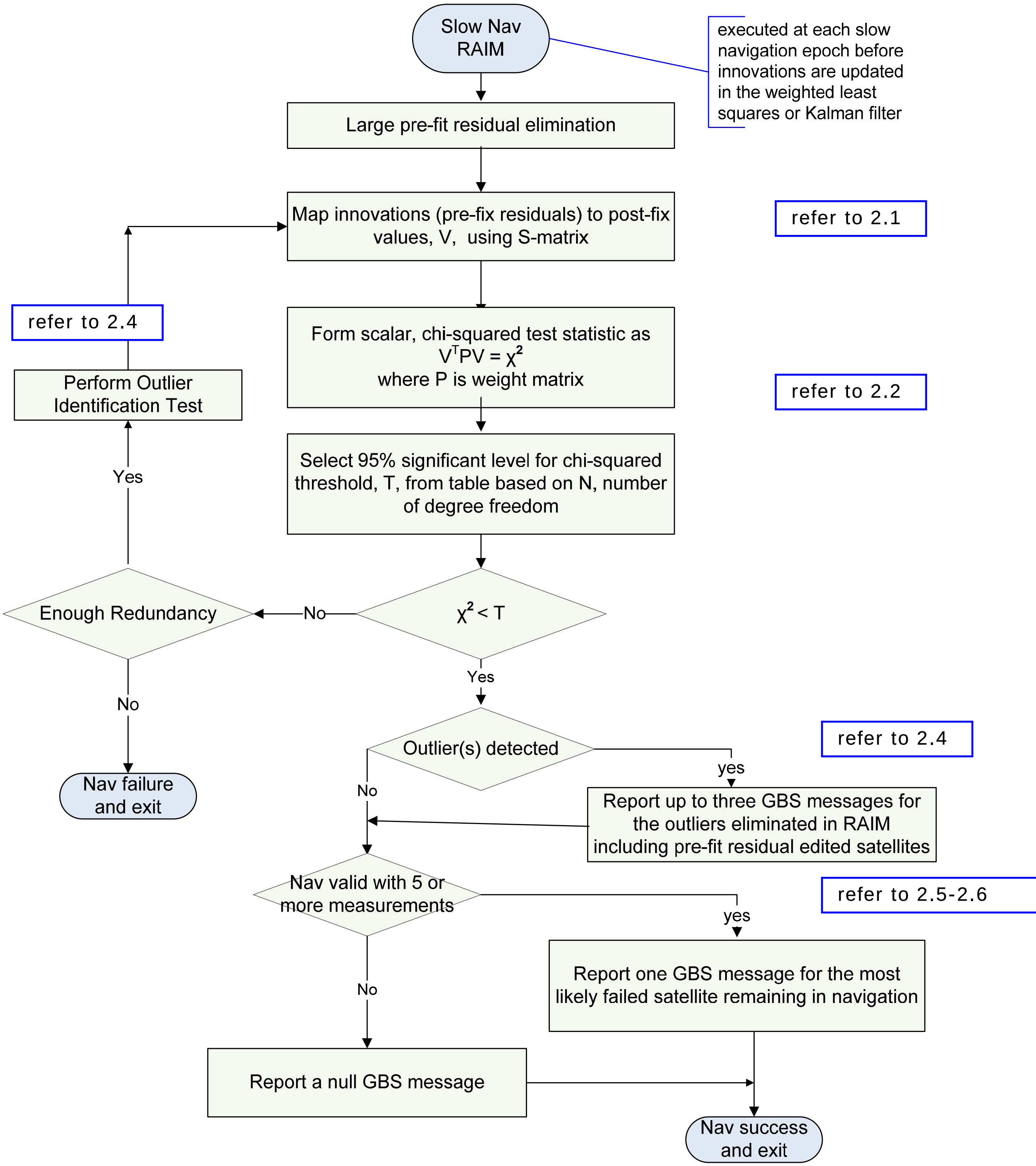

Figure 2 Slow Nav RAIM Processing

2. Slow Nav Fault Detection and Fault Isolation Algorithms and Procedure

The following sections contain descriptions of the individual sections of the Slow Nav RAIM algorithm referenced by the links in Figure 2.

2.1 Mapping Prefix Residuals (innovations) to Postfix Values Using the S-matrix

The linearized measurement equation is given by

$V = HX - Z$ with $P = R^{-1}$ (1)

where:

X is the state correction vector (containing the change in position and clock) matrix to be computed

H is the measurement sensitivity vector, which characterizes the effect of any errors in the state vector upon the measurement

Z is the measurement innovations, i.e. the difference between the measurement and the expected value of the measurement given the current estimate of the state vector (position and time).

V is post-fit residuals after least-square adjustment

R and $P = R^{-1}$ are measurement variance and weight matrix respectively.

Equation (1) can be solved for classical least-squares estimate method or Kalman Filter approach. $\hat{X}$ is the new correction to position and clock.

$$\begin{aligned}\hat{X} &= (H^T PH)^{-1} H^T PZ \\ &= \mathrm{K}Z\end{aligned} \qquad (2)$$

$$\mathrm{K} = (H^T PH)^{-1} H^T P \qquad (3)$$

where K maps the pre-fix residuals into the solution, and is called the projection matrix in LS or gain matrix in Kalman filter.

The post-fix measurement residuals (disagreement between the measurements and the expected measurements given the newly adjusted position and clock) are needed in the subsequent processing and are given by:

$$\begin{aligned}V &= HX - Z \\ &= (H(H^T PH)^{-1} H^T - P^{-1})PZ \\ &= -(I - HK)Z \\ &= -SZ\end{aligned} \qquad (4)$$

$$\mathrm{S} = (P^{-1} - H(H^T PH)^{-1} H^T)P = I - HK \qquad (5)$$

where I is identity matrix and S is used to map pre-fix residuals into post-fix residuals. The **S** matrix is square and the number of rows and columns are equal to the number of satellite measurements. *S* is a matrix (to be described below) with a row (and column) corresponding to how a variation in the measurement from each satellite would affect the residuals. As shown in equation (5) the residual sensitivity matrix, *S*, can be used to directly map the pre-fix residuals (innovations), ***z***, into the post-fix residuals, ***V***. This allows one to detect a potential problem with a solution before the actual solution has been computed and before the update of the position and clock state has been performed. The *S*-matrix is also integral to the RAIM process as subsequently described.

2.2 Formation of the Chi-Squared Test Statistic

Reliable results are dependent on the appropriateness of the stochastic model of the observations with respect to the functional model. After the $V^T PV$ is computed and the chi squared statistics test can be performed in Eq. 6

$$V^T PV \le chi(NDF,1-\alpha) \qquad (6)$$

The diagonal variance matrix P is assigned based on the empirical values. NDF is the number of degrees of freedom which equals the number of satellites less 4. In the above, *α* is the probability of false alarm and 1- *α* is significance level of chi-square test. The $chi(NDF,1-\alpha)$ is obtained from a look-up table given the significance level 1- *α* and is95%.If the statistics test in Eq.6 does not pass, it indicates that there exists outlier(s). If the functional and stochastic modeling is correct in Eq. 1 which is called null hypothesis test, the statistics in Eq.6 should satisfy. If it fails to meet the chi2 statistics, original functional and stochastic should be rejected and the outlier detection procedures should be applied because the outliers may exist in the pseudo-range or/and carrier phase observations, which are caused by multipath or system biases, or the stochastic model does not reflect the actual accuracy of the observation.

2.3 Fault Isolation Using Maximum Correlation from S-matrix

Assuming a single fault, which is by far the most probable situation, the specific measurement at fault can be determined by forming the correlation between the residuals and each column (or row) of the S-matrix. Multiple outliers can be located through an iterative procedure. The correlations coefficient between S and V can be computed as Eq. 7

$$\rho_{S_j,V} = \frac{\sum_{i=1}^{n}(s_{ij}-\bar{s}_j)(v_i-\bar{v})}{\sqrt{\sum_{i=1}^{n}(s_{ij}-\bar{s}_j)^2 \sum_{i=1}^{n}(v_i-\bar{v})^2}} \qquad (7)$$

where $\bar{v}$ is the average of the post-fit residuals vector; $\bar{s}_j$ is average jth row of the S matrix; s_{ij} is element of S matrix at ith row and jth column. The v_i is ith post-fit residual. $\rho_{S_j,V}$ is correlation coefficient between V and the jth row vector of the S matrix.

If the number of (observed satellites) minus (number of lost satellites) minus (number of detected slips) is greater than 4, the post-fit residual with the largest correlation coefficient will be marked as cycles slips satellites. Otherwise residual editting has failed and navigation must be declared invalid for this Epoch

2.4 Estimating the Magnitude (bias) and Variance (noise) of the Faulty Measurement

There is two different ways to deal with outliers. One way is to assume that outliers have different mean values and the same variance as specified in the covariance matrix. Another approach is to treat the outliers as the same mean values, but different variance, i.e. advanced robust estimation. What we chosen is first classical approach. In the presence of outliers or cycle slips located in 2.3 Section, Equation (1) must be extended in order to estimate cycle slips or outliers and is presented in Equation (8) below, which is called alternative hypothesis.

$$V = HX + GY - Z \tag{8}$$

$$P = R^{-1} \tag{9}$$

Where:

Y is the estimated cycle slip or outlier vector with size p,

G is known n x p coefficient matrix.

The least-squares solution to Equations (8-9), estimates the effect of outliers and cycle slips and is designed to minimize $V^T PV$.

$$\begin{aligned} \frac{\partial(V^T PV)}{\partial X} &= 2V^T P \frac{\partial V}{\partial X} = 2V^T PH = 0 \\ \frac{\partial(V^T PV)}{\partial Y} &= 2V^T P \frac{\partial V}{\partial Y} = 2V^T PG = 0 \end{aligned} \tag{10}$$

Substituting Equation (9) into Equation (10) yields the following:

$$\begin{pmatrix} H^T PH & H^T PG \\ G^T PH & G^T PG \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix} = \begin{pmatrix} H^T PZ \\ G^T PZ \end{pmatrix} \tag{11}$$

By eliminating **X** in Equation (11), following Equation (12) can be derived:

$$G^T P(P^{-1} - H(H^T PH)^{-1} H^T)PGY = G^T P(P^{-1} - H(H^T PH)^{-1} H^T)PZ \tag{12}$$

Outliers or cycle slips represented by the vector **Y** can be estimated through

$$Y = (G^T PSG)^{-1} G^T PSZ = (G^T UG)^{-1} G^T UZ \tag{13}$$

Where $U = PS = P - PH(H^T PH)^{-1} H^T P$ is symmetry matrix

Variance of the estimated Y vector can be derived as the following Equation (14)

$$Q_Y = \left(G^T PG - G^T PH\left(H^T PH\right)^{-1} H^T PG\right)^{-1} = (G^T UG)^{-1} \tag{14}$$

Substituting Equation (13) into Equation (11) yields the following:

$$X = (H^T PH)^{-1} H^T P(Z - GY) = K(Z - GY) \tag{15}$$

Equation (15) estimates the effect of outliers and cycle slips. Variance of X can be deducted as

$$
\begin{aligned}
Q_X &= (H^T PH)^{-1} + (H^T PH)^{-1} H^T PG(G^T PSG)^{-1} G^T PH(H^T PH)^{-1} \\
&= (H^T PH)^{-1} + KGQ_Y G^T K^T
\end{aligned}
\quad (16)
$$

Post-fit residual can be derived after outlier or cycle slips are estimated.

$$
\begin{aligned}
V &= HX + GY - Z \\
&= HK(Z - GY) - (Z - GY) \\
&= -(E - HK)(Z - GY) \\
&= -S(Z - GY)
\end{aligned}
\quad (17)
$$

The final solution bias caused by the slips or outliers can be derived as Equation (18)

$$
\delta X = -KGY \quad (18)
$$

2.5 Detect most likely failed satellite

In order to show the external reliability of RAIM algorithm, the most likely failed satellite and its statistics are outputted in GBS message. The methodology to detect this satellite and to calculate its statistics is equivalent to the approach used in RAIM algorithm, but this satellite is not excluded in navigation solution (Sect. 2.3 – 2.4.)

2.6 Computing the Probability of the Missed Detection

In order to compute the probability of missed detection, a hypothesis test must be constructed.

The hypothesis test is stipulated as:

H_0 – Null Hypothesis	No measurement outliers remain in the navigation solution
H_1 - Alternative Hypothesis	There is a measurement outlier that remains in the navigation solution

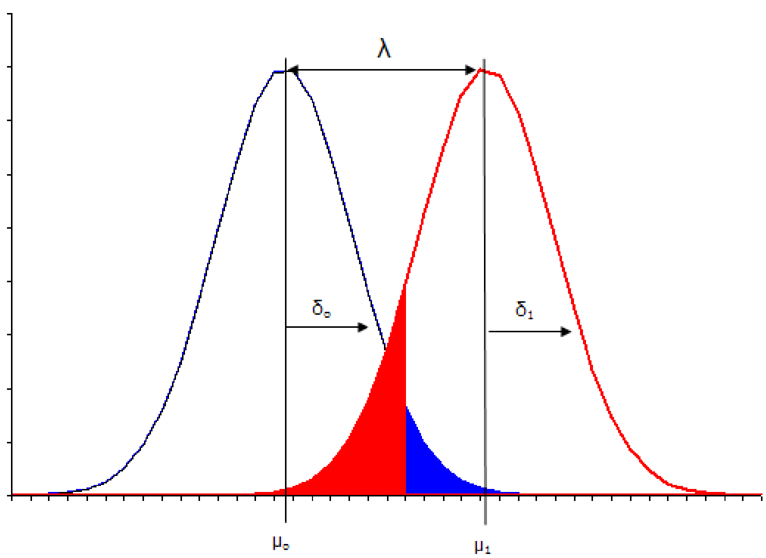

Figure 3 – Two Residual Distributions for Hypothesis Test

In order to mathematically construct the hypothesis test, the following assumptions are required. Under each hypothesis, the worst remaining satellite measurement belongs to a close to perfect stochastically modeled distribution. The characteristics of each distribution are listed below:

- H_0 (Null Hypothesis, represented by the blue distribution in Figure 3)
    i. Has a normalized μ_0 (mean) of zero
    ii. Has δ_0 (unit variance) of 1.0
- H_1 (Alternative Hypothesis, represented as the red distribution in Figure 3)
    i. Has a normalized μ_1 (mean)
    ii. Has δ_1 (unit variance) of 1.0

Given that the unit variance of each distribution is identically assumed, it follows that outlier distribution in H_1 with δ_1 will satisfy the same chi squared variance test in section 2.2.

In order to relate the two distributions, the Theorem of Non-Centrality is employed to relate the two distributions such that $\mu_0 = \mu_1 - \lambda$.

For the non-centrality parameter λ defined as

$$\lambda^2 = Y^T Q_Y^{-1} Y \tag{19}$$

where Y is outlier vector and Q_Y is variance of the estimated Y vector.

If the stochastic modeling is close to perfect, as is assumed, the unit covariance can be expected the known value one of 1. For a given known unit-variance δ_0, each outlier has the following statistics $\sqrt{T_1}$ as the Eq. 20

$$\sqrt{T_1} = \frac{Y(i)}{\delta_0 \sqrt{Q_y(i,i)}} \sim N(\lambda - \sigma_I, 1) \tag{20}$$

Where σ_I is factor of the probability of false alarm which can be computed for a given probability of false alarm (i.e. σ_I is 1.96 for a %5 two-tailed false alarm test). The statistic $\sqrt{T_1}$ should meet the standard normal distribution. The probability of detection power $1-\beta$ can be computed by using standard normal distribution as Eq-20. Then the probability of missed detection (i.e. type II error β) can be obtained. For a given 5% false alarm test σ_I is 1.96. The probability of missed detection for two extreme cases is given in Table 2.

Table 2: Examples of probability of the missed detection and power of test

Case	λ	Power of test	Probability of missed detection
Case I (no outlier)	0	5%	95%
Case II(extreme outlier)	$\propto$	100%	0%

To summarize probability of missed detection and false alarm, the following table is given:

Table 3: Probability of false alarm and missed detection

Probability	Acceptance (no outliers)	Rejection
No outlier	$1-\alpha$ (significant level)	α (false alarm, type I error)
Outliers exist	β (missed detection type II error)	$1-\beta$ (detection power)

3. Two examples for NavCom proposed GBS information

The above GBS approach has been implemented in the latest NavCom GPS navigation modules and gone through real-time testing. A data set from NavCom Technology dynamic testing which occurred on May 20th, 2008 is used to demonstrate GBS report information in both WAAS and StarFire RTG dual mode.

The first case shows that all satellites are healthy and no faults are detected by RAIM (in WAAS-differential mode) and the second case shows an abnormal condition where one satellite contains a blunder (in StarFire RTG dual mode). Note that CA code residuals are reported for WAAS-differential mode and the refraction corrected carrier phase or code residuals are reported for dual frequency StarFire when forming the GBS message.

3.1 WAAS mode

The following example shows the receiver operating in WAAS Code Dual operating normally

```
$GPGBS,215643.00,0.1190,-0.0872,-0.3320,13,0.9009,-0.8342,2.3281*46
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215643.00,3348.537323,N,11820.878328,W,2,09,1.2,23.103,M,-34.730,M,2.0,0134*4C
$GPGBS,215644.00,0.1198,-0.0878,-0.3341,13,0.9005,-0.8394,2.3277*4A
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215644.00,3348.537324,N,11820.878337,W,2,09,1.2,23.128,M,-34.730,M,2.0,0134*4B
$GPGBS,215645.00,-0.5213,-0.3604,0.8744,31,0.8952,1.1331,2.9038*60
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215645.00,3348.537327,N,11820.878344,W,2,09,1.2,23.144,M,-34.730,M,3.0,0134*46
```

3.2 StarFire Dual Mode

The following example shows the receiver operating in StarFire Dual where it rejects PRN 30 due to refraction corrected code measurement outlier but maintains normal operations.

```
$GPGBS,194140.00,-0.3447,-0.8757,0.8715,30,0.0000,22.8500,5.5713*5F
$GPGBS,194140.00,-0.0204,0.0058,-0.0021,20,0.8745,0.0307,0.0617*4E
$GPGSA,A,3,11,14,19,20,22,23,30,31,,,,,1.7,1.2,1.2*3B
$GPGGA,194140.00,3350.900592,N,11820.712396,W,2,09,1.2,31.583,M,-34.649,M,10.0,0402*7C
$GPGBS,194141.00,-0.3388,-0.8637,0.8526,30,0.0000,22.9790,5.5675*54
$GPGBS,194141.00,-0.2115,-0.0728,-0.1559,19,0.8779,-3.1798,6.6194*35
$GPGSA,A,3,11,14,19,20,22,23,30,31,,,,,1.7,1.2,1.2*3B
$GPGGA,194141.00,3350.900572,N,11820.712388,W,2,09,1.2,31.494,M,-34.649,M,10.0,0402*7B
$GPGBS,194142.00,-0.3285,-0.8408,0.8210,30,0.0000,22.7795,5.5639*54
$GPGBS,194142.00,-0.0229,0.0075,-0.0047,20,0.8566,0.0353,0.0609*38
$GPGSA,A,3,11,14,19,20,22,23,30,31,,,,,1.7,1.2,1.2*3B
$GPGGA,194142.00,3350.900604,N,11820.712382,W,2,09,1.2,31.425,M,-34.649,M,10.0,0402*7A
```

4. NavCom Proprietary NMEA MDE Message for Reliability Definition and Computation

Reliability refers to the consistency of the results provided by a system, dictating the extent to which they can be trusted, or relied upon. More specifically, in terms of GNSS RAIM, reliability comprises the ability of the system to detect outliers, referred to as internal reliability, and measures of the influence of undetectable outliers on the parameter estimations, referred to as external reliability.

4.1 Internal ad External Reliability Definition and Computation

The measure of internal reliability is quantified as the Minimal Detectable Error (MDE) and is indicated by the lower bound for detectable outliers. The MDE is the magnitude of the smallest error that can be detected for a specific level of confidence and power test and is determined, for correlated measurements as Eq. 21.

$$MDE = \frac{\sigma_0}{\sqrt{(G^T UG)}} \quad (21)$$

where $\sigma_0 = \sigma_I + \sigma_{II}$ is the non-centrality parameter in Figure 4 which depends on the given Type I σ_I and Type II errors σ_{II}. G is a unit vector in which the i^th component has a value equal to one and dictates the MDE measurement to be computed. It is usual practice to hold the power of the test fixed at a value of say 80% and the given confidence level (say 95-99%) for the test for the determination of MDE.

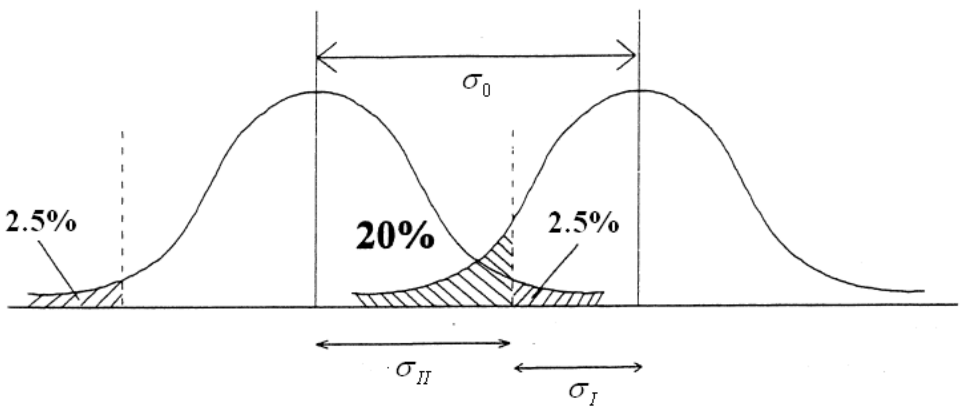

Figure 4

External reliability of the system is characterized by the extent to which the MDE has affected the estimated parameters. External reliability measures are evaluated as Eq. 22

$$\delta X = -K \cdot G \cdot MDE \quad (22)$$

We propose the MDE definitions shown in Table-4

Field #	NMEA Field Description	Notes
1	UTC time	Current UTC time
2	PRN	GPS satellite ID number[1]
3	Measurement type	Range from 0-6[2]
4	W-test statistic	The test statistic computed in Eq. 20
5	Minimal Detectable Error	MDE for a given type I and type II errors in

		meters [3]
6,7,8	Positional MDE in lat, lon, height	One-sigma estimated error in meter

Table 4 Proposed Definitions of NMEA MDE proprietary message

[1] refers to Satellite ID numbers. To avoid possible confusion caused by repetition of satellite ID numbers when using multiple satellite systems, the following convention has been adopted:

a) GPS satellites are identified by their PRN numbers, which range from 1 to 32.

b) The WAAS system has reserved numbers 33 – 64 to identify its satellites.

[2] refer to measurement type

0: CA pseudo range
1: P1 pseudo range
2: L1 carrier-phase
3: P2 pseudo range
4: L2 carrier-phase
5: P1/P2 refraction corrected code
6: L1/ L2 refraction corrected carrier-phase

[3] refer to type I error (5% by default) and type II error (20%, i.e. power of test 80%)

4.2 GSA and MDE Reporting Relationship

Several situations arise where the GSA will report a satellite included in the navigation solution but may not be accompanied by a corresponding MDE message. This is due to the manner in which the GSA message is created. The GSA message is the maximum number of available satellites that have useable measurements (C/A, L1, P1, P2, L2) which contribute to the solution. The MDE messages are reported according to the Differential Navigation Mode in which the receiver is operating.

For example, if the receiver is operating in StarFire RTG Dual (which requires refraction corrected measurements), using a sufficient number of satellites for redundancy, but a specific PRN solely has C/A pseudo range it will be reported as used in the GSA but the receiver will be unable to generate an MDE for this satellite so one will not be output for it. An example of this discrepancy is shown below when the receiver transitions from WAAS to StarFire Dual mode.

```
$PNCTMDE,194701.00,11,0,0.000,19.839,7.688,16.843,15.158*44
$PNCTMDE,194701.00,14,0,-0.006,42.907,-53.995,-14.219,-16.311*7C
$PNCTMDE,194701.00,20,0,-0.014,22.526,-5.403,-1.634,0.127*62
$PNCTMDE,194701.00,22,0,-0.008,66.825,61.815,-5.716,96.009*40
$PNCTMDE,194701.00,30,0,0.069,50.959,1.680,-2.185,9.875*6C
$PNCTMDE,194701.00,31,0,0.000,34.201,5.224,-10.830,-69.091*45
$GPGSA,A,3,11,14,20,22,30,31,,,,,,,2.1,1.5,1.5*37  GSA count is 6
$GPGGA,194701.00,3350.796365,N,11820.699787,W,2,03,2.1,31.461,M,-34.652,M,2.0,0134*4E
$PNCTMDE,194702.00,,,,,,,*62 Insufficient Refraction Corrected Carrier Phase to calculate MDE
$GPGSA,A,3,11,14,20,22,30,31,,,,,,,2.1,1.5,1.5*37
$GPGGA,194702.00,3350.789785,N,11820.696875,W,2,07,1.5,30.834,M,-34.652,M,11.0,0402*7E
$PNCTMDE,194703.00,,,,,,,*63
$GPGSA,A,3,11,14,20,22,30,31,,,,,,,2.1,1.5,1.5*37
$GPGGA,194703.00,3350.782593,N,11820.694978,W,2,07,1.5,31.156,M,-34.652,M,10.0,0402*72
$PNCTMDE,194704.00,,,,,,,*64
```

4.3 MDE Examples

There are multiple MDE messages per epoch. The number of records per epoch is equal to the number of satellites used in navigation solution. It should be noted that there is no MDE message for outlier(s) being rejected in navigation solution.

4.4 WAAS mode

The following examples show how MDE reports the reliability information in WAAS Code Dual mode during a period of sufficient redundancy.

```
$PNCTMDE,215646.00,07,0,0.085,9.032,0.508,0.235,1.828*7F
$PNCTMDE,215646.00,11,0,0.099,6.038,1.253,0.478,1.966*7C
$PNCTMDE,215646.00,13,0,-0.174,6.516,-0.931,0.682,2.593*79
$PNCTMDE,215646.00,16,0,-0.107,4.583,0.844,-1.558,0.608*73
$PNCTMDE,215646.00,20,0,0.080,5.265,-0.142,1.172,-7.042*7A
$PNCTMDE,215646.00,23,0,-0.074,4.628,-1.740,1.118,-1.520*5D
$PNCTMDE,215646.00,25,0,0.035,4.920,1.042,0.980,0.706*7E
$PNCTMDE,215646.00,31,0,0.083,8.131,-3.740,-2.586,6.273*7C
$PNCTMDE,215646.00,32,0,-0.055,4.428,1.532,-0.955,-1.361*58
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215646.00,3348.537345,N,11820.878363,W,2,09,1.2,23.113,M,-34.730,M,2.0,0134*47
$PNCTMDE,215647.00,07,0,0.064,9.028,0.508,0.235,1.828*7A
$PNCTMDE,215647.00,11,0,0.084,6.039,1.253,0.478,1.966*70
$PNCTMDE,215647.00,13,0,-0.207,6.515,-0.931,0.682,2.592*7D
$PNCTMDE,215647.00,16,0,-0.076,4.583,0.843,-1.558,0.607*7D
$PNCTMDE,215647.00,20,0,0.049,5.264,-0.141,1.172,-7.041*7F
$PNCTMDE,215647.00,23,0,-0.029,4.628,-1.740,1.118,-1.520*54
$PNCTMDE,215647.00,25,0,0.069,4.920,1.041,0.980,0.705*76
$PNCTMDE,215647.00,31,0,0.074,8.131,-3.739,-2.585,6.272*79
$PNCTMDE,215647.00,32,0,-0.069,4.428,1.532,-0.955,-1.360*57
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215647.00,3348.537351,N,11820.878364,W,2,09,1.2,23.134,M,-34.730,M,2.0,0134*41
$PNCTMDE,215648.00,07,0,0.065,9.024,0.508,0.236,1.829*7A
$PNCTMDE,215648.00,11,0,0.087,6.040,1.253,0.478,1.966*72
$PNCTMDE,215648.00,13,0,-0.217,6.514,-0.931,0.683,2.591*70
$PNCTMDE,215648.00,16,0,-0.114,4.583,0.843,-1.558,0.606*76
$PNCTMDE,215648.00,20,0,0.048,5.264,-0.141,1.171,-7.040*73
$PNCTMDE,215648.00,23,0,-0.033,4.628,-1.740,1.118,-1.521*51
$PNCTMDE,215648.00,25,0,0.074,4.919,1.041,0.980,0.704*7E
$PNCTMDE,215648.00,31,0,0.084,8.130,-3.738,-2.585,6.270*7B
$PNCTMDE,215648.00,32,0,-0.041,4.428,1.533,-0.955,-1.358*58
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215648.00,3348.537358,N,11820.878335,W,2,09,1.2,23.112,M,-34.730,M,2.0,0134*47
$PNCTMDE,215649.00,07,0,0.083,9.020,0.509,0.236,1.829*76
$PNCTMDE,215649.00,11,0,0.049,6.041,1.253,0.478,1.967*71
$PNCTMDE,215649.00,13,0,-0.217,6.513,-0.931,0.683,2.591*76
$PNCTMDE,215649.00,16,0,-0.104,4.582,0.842,-1.558,0.605*75
$PNCTMDE,215649.00,20,0,0.044,5.264,-0.141,1.171,-7.039*70
$PNCTMDE,215649.00,23,0,-0.031,4.628,-1.741,1.118,-1.522*50
$PNCTMDE,215649.00,25,0,0.098,4.918,1.041,0.981,0.703*7A
$PNCTMDE,215649.00,31,0,0.081,8.130,-3.737,-2.584,6.269*79
$PNCTMDE,215649.00,32,0,-0.043,4.429,1.533,-0.955,-1.356*54
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
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$GPGGA,215649.00,3348.537353,N,11820.878309,W,2,09,1.2,23.102,M,-34.730,M,2.0,0134*43
$PNCTMDE,215650.00,07,0,0.078,9.016,0.509,0.236,1.830*77
$PNCTMDE,215650.00,11,0,0.040,6.041,1.253,0.477,1.967*7F
$PNCTMDE,215650.00,13,0,-0.223,6.512,-0.931,0.683,2.590*79
$PNCTMDE,215650.00,16,0,-0.100,4.582,0.842,-1.557,0.604*77
$PNCTMDE,215650.00,20,0,0.041,5.263,-0.141,1.170,-7.038*7A
$PNCTMDE,215650.00,23,0,-0.030,4.628,-1.741,1.118,-1.522*59
$PNCTMDE,215650.00,25,0,0.114,4.918,1.041,0.981,0.703*77
$PNCTMDE,215650.00,31,0,0.082,8.130,-3.736,-2.584,6.268*72
$PNCTMDE,215650.00,32,0,-0.047,4.429,1.533,-0.955,-1.355*5B
$GPGSA,A,3,07,11,13,16,20,23,25,31,32,,,,1.7,1.2,1.3*30
$GPGGA,215650.00,3348.537354,N,11820.878300,W,2,09,1.2,23.050,M,-34.730,M,2.0,0134*43
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4.5 StarFire mode

The following examples show how MDE reports the reliability information in StarFire Dual mode during a period of sufficient redundancy. It is important to note that the MDE messages output for StarFire Dual navigation is driven by the availability of refraction corrected carrier phase measurements.

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$GPGSA,A,3,07,11,13,16,20,23,25,31,,,,,1.8,1.2,1.3*3E
$GPGGA,215611.00,3348.537104,N,11820.878433,W,2,09,1.2,23.714,M,-34.730,M,10.0,0000*74
$PNCTMDE,215612.00,07,6,0.525,0.192,0.017,0.004,0.059*71
$PNCTMDE,215612.00,11,6,-0.209,0.151,0.044,0.005,0.030*55
$PNCTMDE,215612.00,13,6,0.054,0.169,-0.043,0.029,0.077*5C
$PNCTMDE,215612.00,16,6,-0.085,0.174,0.063,-0.079,-0.013*5C
$PNCTMDE,215612.00,20,6,0.224,0.154,0.016,0.021,-0.197*50
$PNCTMDE,215612.00,23,6,-0.250,0.129,-0.052,0.032,-0.038*5C
$PNCTMDE,215612.00,25,6,-0.160,0.129,0.028,0.022,0.001*5C
$PNCTMDE,215612.00,31,6,0.030,0.207,-0.084,-0.067,0.142*7E
$GPGSA,A,3,07,11,13,16,20,23,25,31,,,,,1.8,1.2,1.3*3E
$GPGGA,215612.00,3348.537103,N,11820.878436,W,2,09,1.2,23.714,M,-34.730,M,10.0,0000*75
$PNCTMDE,215613.00,07,6,0.574,0.192,0.017,0.004,0.059*74
$PNCTMDE,215613.00,11,6,-0.054,0.151,0.044,0.005,0.030*5E
$PNCTMDE,215613.00,13,6,0.157,0.169,-0.043,0.029,0.077*5F
$PNCTMDE,215613.00,16,6,-0.164,0.174,0.063,-0.079,-0.013*53
$PNCTMDE,215613.00,20,6,0.380,0.154,0.016,0.021,-0.197*5E
$PNCTMDE,215613.00,23,6,-0.466,0.129,-0.052,0.032,-0.038*5E
$PNCTMDE,215613.00,25,6,-0.388,0.129,0.028,0.022,0.001*59
$PNCTMDE,215613.00,31,6,0.083,0.207,-0.084,-0.067,0.142*77
$GPGSA,A,3,07,11,13,16,20,23,25,31,,,,,1.8,1.2,1.3*3E
$GPGGA,215613.00,3348.537109,N,11820.878437,W,2,09,1.2,23.715,M,-34.730,M,10.0,0000*7E
$PNCTMDE,215614.00,07,6,0.318,0.192,0.017,0.004,0.059*7F
$PNCTMDE,215614.00,11,6,-0.066,0.151,0.044,0.005,0.030*58
$PNCTMDE,215614.00,13,6,0.139,0.169,-0.043,0.029,0.077*50
$PNCTMDE,215614.00,16,6,-0.085,0.174,0.063,-0.079,-0.013*5A
$PNCTMDE,215614.00,20,6,0.219,0.154,0.016,0.021,-0.197*58
$PNCTMDE,215614.00,23,6,-0.295,0.129,-0.052,0.032,-0.038*53
$PNCTMDE,215614.00,25,6,-0.197,0.129,0.028,0.022,0.001*52
$PNCTMDE,215614.00,31,6,0.041,0.207,-0.084,-0.067,0.142*7E
$GPGSA,A,3,07,11,13,16,20,23,25,31,,,,,1.8,1.2,1.3*3E
$GPGGA,215614.00,3348.537112,N,11820.878437,W,2,09,1.2,23.710,M,-34.730,M,10.0,0000*76
$PNCTMDE,215615.00,07,6,0.337,0.192,0.017,0.004,0.059*73
$PNCTMDE,215615.00,11,6,-0.223,0.151,0.044,0.005,0.030*5A
$PNCTMDE,215615.00,13,6,0.039,0.169,-0.043,0.029,0.077*50
$PNCTMDE,215615.00,16,6,0.034,0.174,0.063,-0.079,-0.013*7C
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$PNCTMDE,215615.00,20,6,0.050,0.154,0.016,0.021,-0.197*56
$PNCTMDE,215615.00,23,6,-0.031,0.129,-0.052,0.032,-0.038*5E
$PNCTMDE,215615.00,25,6,-0.081,0.129,0.028,0.022,0.001*55
$PNCTMDE,215615.00,31,6,-0.033,0.207,-0.084,-0.067,0.142*57
$GPGSA,A,3,07,11,13,16,20,23,25,31,,,,,1.8,1.2,1.3*3E
$GPGGA,215615.00,3348.537109,N,11820.878436,W,2,09,1.2,23.715,M,-34.730,M,10.0,0000*79
$PNCTMDE,215616.00,07,6,0.390,0.192,0.017,0.004,0.059*7D
$PNCTMDE,215616.00,11,6,0.010,0.151,0.044,0.005,0.030*76
$PNCTMDE,215616.00,13,6,0.046,0.169,-0.043,0.029,0.077*5B
$PNCTMDE,215616.00,16,6,-0.069,0.173,0.063,-0.079,-0.013*5D
$PNCTMDE,215616.00,20,6,0.177,0.154,0.016,0.021,-0.197*51
$PNCTMDE,215616.00,23,6,-0.153,0.129,-0.052,0.032,-0.038*58
$PNCTMDE,215616.00,25,6,-0.319,0.129,0.028,0.022,0.001*54
$PNCTMDE,215616.00,31,6,0.017,0.207,-0.084,-0.067,0.142*7F
$GPGSA,A,3,07,11,13,16,20,23,25,31,,,,,1.8,1.2,1.3*3E
$GPGGA,215616.00,3348.537106,N,11820.878437,W,2,09,1.2,23.720,M,-34.730,M,10.0,0000*72
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