MEMORANDUM

Date: 21/07/99

To: Rock Santere

Cc: Richard Langley

From: Paul Collins & Peter Stewart

RE: GPS SNR Observations

The following appendices represent our current knowledge on the reporting of signal-to-noise (SNR) values from various makes of GPS receivers. We have chosen not to formalise this information for two main reasons. First, much of this information is semi-proprietary and not easily available to the public at large. As such, we feel that it is subject to the whims of the relevant manufacturer and could change at almost any time through firmware upgrades, etc. Of the five manufacturers represented here, two (Ashtech and Trimble) were extremely reluctant to divulge the algorithms that convert their SNR data to meaningful values. Second, there is no universal way of reporting SNR values for GPS observations, either by the manufacturers themselves, or by the wider GPS community. The other three manufacturers (NovAtel, Canadian Marconi and Allen Osborne Associates) appear to provide more direct SNR values, but there are no exact definitions in their respective user manuals. AOA are the only manufacturers to specify which observations the SNRs refer to (the code ranges). The most comprehensive description we have been able to obtain is from Trimble. This is a useful example of one manufacturer's attitude towards SNR values (or Arbitrary Mystery Units as they call them!) and describes why they are reluctant to divulge the information. As for the generic representation of SNR values, the next update to the RINEX format (v.2.10) will allow them to be reported as observation types 'S1' and 'S2' to represent "*the original signal strength values given by the receiver for L1 and L2 tracking*". How that relates to the AOA (and apparently Ashtech) *code* SNRs is unclear (see *Langley* [1997] for a theoretical description of code and carrier SNR). A more precise definition (and one that will hopefully be receiver-independent as well as specifying units) has been put off for the next version.

Finally, it is worth mentioning that NMEA message type GSV is supposed to report the C/N_0 carrier-to-noise density in dB for the satellites in view. In theory therefore, for those receivers outputting NMEA sentences, we should have access to both the C/N_0 and 'AMUs' so that (in principle) we could determine our own conversion equation.

JPC & PJS

TRIMBLE

From Trimble_Support@Trimble.COM Tue Jul 13 10:41:14 1999
Date: Mon, 21 Jun 1999 15:16:28 -0700

From: Trimble Support <Trimble_Support@Trimble.COM>
To: k4eo@unb.ca
Subject: FW: SNR conversions DO

GPS SIGNAL STRENGTHS IN TRIMBLE RECEIVERS

Most Trimble GPS receivers (especially the 4000 series products) indicate signal strengths in a "somewhat arbitrary" system of units which is determined from measurements made on the signals by the signal processing hardware. The values are the result of integrating the output of a signal correlator that is fed the noisy input signal and our clean local replica of the expected PRN code. The integrated result is a linear indication of the signal-to-noise-ratio, over the bandwidth of the correlated signals. In any particular receiver, this result can vary due to differences in receiver bandwidth and integration time. Thus, we usually scale the result to be consistent across our product line. The resultant values are often refered to as Signal-to-Noise-Counts, or AMUs (Arbitrary Mystery Units) and are scaled to match a measurement made over a 1KHz bandwidth. The 1KHz comes from the fact that many of the early receivers integrated for 1 millisecond, resulting in an effective 1KHz bandwidth.

CONVERTING SNC TO SNR

Normally SNRs are expressed as a power ratio on a logarithmic scale instead of an amplitude ratio on a linear scale. Converting is fairly simple.

```
SNC in a 1KHz bandwidth [in AMUs]
       = (A/sigma) .
       where A = Signal amplitude
       and   sigma is the noise amplitude.

SNR in a 1KHz bandwidth [in dB]
       = 10*Log10( A^2/sigma^2 / 2) )
       = 10*Log10( SNC^2 / 2 )
       = 10*Log10( SNC^2 ) - 3db
       = 20*Log10( SNC ) - 3db
```

CONVERTING TO C/N0

A more technically precise and common measurement of GPS signal strength is known as C/N0 (C-to-N-zero). Some recent Trimble receivers have the ability to display or output values in these units. However, these values are not measured directly, but are calculated from the directly measured SNC count values.

C/N0 is the SNR (usually in dB) in a 1Hz bandwidth. That bandwidth is 1000 times less than our "standard" which implies a 30db change in db-power units:

```
       C/N0 = SNR[db]@1KHz + 30db.

So...  C/N0 = 30 + 10*Log10(SNC^2/2)
            = 30 + 10*Log10(SNC^2) - 3
            = 27 + 20*Log10(SNC)
```

For example,

SNC	SNR(db:1khz)	C/N0(db:1Hz)	
3	6.5	36.5	Very weak signal
5	11	41	
10	17	47	
20	23	53	
30	26.5	56.5	
40	29	59	Very strong signal

Notice that the SNR values are all positive here, which is somewhat counter-intuitive. The GPS signal is below the noise level when looked at over it's entire bandwidth of several Megahertz. This is why you can't just hook up an oscilloscope to an antenna and see the signals. Talking about 1KHz or 1Hz bandwidths is an engineering abstraction.

These formulae are all incredibly approximate. A dB or three of variation is possible, especially at the extremes where things tend to go a little non-linear.

USES FOR SIGNAL STRENGTHS

Please note that comparisons of these types of numbers between different receivers is not recommended. We always hesitate to give out this information because, in the past, users have misused C/N0 values as a criteria to compare the quality of one receiver versus another. This is not valid, since the C/N0 values are only approximate, and don't really determine the ability of a receiver to track and measure signals. That ability is more dependent on integration times, loop bandwidths, and receiver design tradeoffs.

For example, a survey-grade receiver might drop and reacquire signals much sooner than a handheld navigation tool, even though the survey-grade set is a much better receiver. Minor cycle slips that have no effect on general positioning are catastrophic in a survey receiver which is making carrier phase measurements. Thus a survey receiver is much more conservative in making signal-locking decisions.

Also different receivers have quite different input filter bandwidths. An interference spike that is 2 MHz off of the L1 frequency might have little effect on a narrow band receiver, but could be a major effect on a P-code set. These are not easy things to give general rules about.

The only valid uses for SNR measurements are:

> Indication of satellites that are being tracked close the limits of the receiver. AMU readings of 3 or 4 are usually associated with Satellites that are just rising or setting, On some early receivers, this was associated with a greater chance of cycleslips in the carrier phase measurements.

> Indication of relative signal strengths between different satellites. For example, a high elevation satellite with half the SNR-counts of a similar satellite might indicate that there was a Space-Segment problem. Keep in mind though, that different generations of GPS satellites have inherently different signal strengths, which could cause different SNR or C/N0 values with nothing wrong at all.

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Ashtech))) RF Group

I Count Representation in Ashtech Receivers

The I counts are represented in the following ways:

Z-12	MBEN file	$e^{(value/12.5)} = I$	for firmware versions 1A54 and earlier.
	MBEN file	$e^{(value/25)} = I$	for firmware versions after 1A54.
	Screen 1	value*100 = I	for 1 bit, C/A and P code normal mode.
	Screen 1	value*200 = I	for 2 bit, C/A and P code normal mode.
	Screen 1	value*20 = I	for 1 bit, P code in Z-Tracking mode.
	Screen 1	value*40 = I	for 2 bit, P code in Z-Tracking mode.
Super C/A	MBEN file	$e^{(value/25)} = I$	
	Remote data	value*200 = I	for 2 bit C/A.
P-12	B file	value*10 = I	
	Screen 1	value*12.5 = I,	all modes.
MX-II	MBEN File	value*10 = I	
	Screen 1	value*12.5 = I	
Sensor I	SAT message	value*12.5 = I	
	MBEN file	value*10 = I	
Sensor II	SAT message	value*12.5 = I	
	MBEN file	value*10 = I	

C/No Standardization

To find the input SNR:

Step 1: Determine the I count from above.

Step 2: Determine receiver input SNR from the I counts using the following formulas.

Signal	C/No formula
C/A	20*log(I)-C
Z1	10*log(I)-z1
Z2	10*log(I)-z2
P1	20*log(I)-p1
P2	20*log(I)-p2

All logs are base 10.

For the Z-12 and Super C/A, C=30. For the Z-12, p1=24.2, z1= -13.5,z2= -10.5.

Note: This is an INPUT SNR. Any SNR degradation due to any LNA noise or cable losses will degrade the SNR measured by the receiver. E.g. Simulator is set to 45 dB*Hz, a 3 dB Noise Figure LNA is used, then the SNR, when converted from I counts, should be 42 dB*Hz.

CMC ALLSTAR

MESSAGE	BYTE	DESCRIPTION	UNIT	TYPE
23 Measurement Block Data (1, 2, 5, 10 Hz)	5-6 7 8..15	Reserved Number of measurement blocks (N) Predicted GPS Time	N/A N/A seconds	N/A N/A double
	16	bits 0..5 : SV # (0..31) bit 6 : reserved bit 7 : Toggle at each Ephemeris Transmission	N/A	N/A
	17	SNR	0.25 dB/Hz	unsigned char
	18..21	Code Phase range : 0 .. 2095103999	1/1024 half chip	unsigned long
	22..25	Integrated Carrier Phase bit 0-1 : 0 : Ready 1 : Phase Unlock 2 : Cycle Slip Detected 3 : Not Ready	N/A	N/A
		bits 2-11 : Carrier Phase range: 0-1023	1/1024 cycles	N/A
		bits 12-31: Integrated Number of Cycles range: natural roll over	cycles	N/A
	26	Cycle_Slip Counter Increment by 1 every time a cycle slip is detected during a 10ms period range: natural roll over	N/A	unsigned char
		Measurement block #2 . . Measurement block #N	as per meas. block 1	as per meas. block 1
33 Satellite Visibility Data and Status	5	bit 0...3: Total number of Satellites in view bit 4..7: reserved Data transmission of up to 12 satellites in view listed in decreasing elevation order. Satellite visibility data of the 1st SV:	N/A	N/A
	6	Computed data bit map bit 0..4 : SV Number bit 5..6 : SV Status 0 = In View 1 = Tracking 2 = MeasReady 3 = Used by Nav bit 7 : Differential Corrections available	N/A	N/A
	7	Elevation range : -90..90	degree	signed char
	8-9	Azimuth range : 0..360 bits 9-15 : Reserved	degree	word
	10	SNR range : 0..90	dB	byte

Canadian Marconi have told us that:

"C/No and SNR have the same meaning in our system. C/No is the specialization of SNR. SNR must be referred to noise bandwidth. C/No is by default the amount of signal (signal amplitude) when the signal is integrated over one second. The unit of C/No are db-hz.

The C/No and SNR in our system are displayed in 2 windows. Channel Assignment Window (Message 6 and Message 7) and Satellite Visibility (Message 33). The SNR/CNo value are computed in float internally by the receiver. In the Channel Assignment Window, the value displayed is a short float. In the Satellite Visiblity list, the same SNR's computed are quantized and displayed within 1 db-hz resolution."

RGEA/B/C Channel Range Measurements (new format) *51*

The RGEA/B message is a new log and should be used instead of the RNGA/B message. It is smaller than the RNGA/B message and outputs an improved channel status number which contains more information for the user. The RGEC message, where the C indicates compressed, is a compressed form of the RGEB message. It will eventually replace the RQGB message. (The RNGA/B and RQGA/B logs are currently supported for backwards compatibility purposes, but will not be supported in future releases.)

It is important to ensure that the receiver clock has been set and can be monitored by the bits in the rec-status word. Large jumps in range as well as ADR will occur as the clock is being adjusted. If the ADR measurement is being used in precise phase processing it is important not to use the ADR if the "parity known" flag in the tr-status word is not set as there may exist a half (1/2) cycle ambiguity on the measurement. The tracking error estimate of the pseudorange and carrier phase (ADR) is the thermal noise of the receiver tracking loops only. It does not account for possible multipath errors or atmospheric delays.

RGEA

Structure:

```
$RGEA | week | seconds | # obs | rec status
prn | psr | psr std | adr | adr std | dopp | S/N0 | locktime | tr status
:
prn | psr | psr std | adr | adr std | dopp | S/N0 | locktime | tr status
*xx | [CR][LF]
```

Field #	Field type	Data Description	Example
1	$RGEA	Log header	$RGEA
2	week	GPS week number	663
3	seconds	GPS seconds into the week	247893.30
4	# obs	Number of satellite observations with information to follow	7
5	rec status	Receiver self-test status (cf. Table 5-3)	000040F6
6	prn	Satellite PRN number (1-32) of range measurement	26
7	psr	† Pseudorange measurement, in metres	23704623.130
8	psr std	† Pseudorange measurement standard deviation, in metres	0.148
9	adr	† Carrier phase, in cycles (accumulated Doppler range)	-124567967.330
10	adr std	† Estimated carrier phase standard deviation, in cycles	0.010
11	dopp	Instantaneous carrier Doppler frequency, in Hz	2659.351
12	S/N_0	Signal to noise density ratio, where $C/N_0 = 10[\log_{10}(S/N_0)]$, in dBHz	43.0
13	locktime	Number of seconds of continuous tracking (no cycle slipping)	2693.370
14	tr status	Hexadecimal number indicating phase lock, channel number and channel state as shown in Table 5-4	E04
15-23		Next PRN range measurement	
...		Next PRN range measurement	
variable	*xx	Checksum	*73
variable	[CR][LF]	Sentence terminator	[CR][LF]

† These fields are only valid with X51(R) and XX51(R) models.

GPGSV GPS Satellites in View

ℬ

Number of SVs in view, PRN numbers, elevation, azimuth and SNR value. Four satellites maximum per message. When required, additional satellite data sent in second or third message. Total number of messages being transmitted and the current message being transmitted are indicated in the first two fields.

NOTES

Satellite information may require the transmission of multiple messages. The first field specifies the total number of messages, minimum value 1. The second field identifies the order of this message (message number), minimum value 1.

A variable number of 'PRN-Elevation-Azimuth-SNR' sets are allowed up to a maximum of four sets per message. Null fields are not required for unused sets when less than four sets are transmitted.

GPGSV logs will not output until time of first fix.

Structure:

```
$GPGSV # msg msg # # sats
prn elev azimuth SNR
:
prn elev azimuth SNR *xx [CR][LF]
```

Field	Structure	Field Description	Symbol	Example
1	$GPGSV			$GPGSV
2	# msg	Total number of messages, 1 to 3	x	3
3	msg #	Message number, 1 to 3	x	1
4	# sats	Total number of satellites in view	xx	09
5	prn	Satellite PRN number	xx	**03**
6	elev	Elevation, degrees, 90° maximum	xx	51
7	azimuth	Azimuth, degrees True, 000 to 359	xxx	140
8	SNR	SNR (C/N_0) 00-99 dB, null when not tracking	xx	42
9-12		2nd satellite PRN number, elev, azimuth, SNR,	xx,xx,xxx,xx,	16,02,056,40,
13-16		3rd satellite PRN number, elev, azimuth, SNR,	xx,xx,xxx,xx,	17,78,080,42,
17-20		4th satellite PRN number, elev, azimuth, SNR	xx,xx,xxx,xx	21,25,234,00
21	*xx	Checksum	*hh	*72
22	[CR][LF]	Sentence terminator		[CR][LF]
1 - 22		2nd $GPGSV message (optional)		
1 - 14		3rd $GPGSV message (optional)		

Example:

```
$GPGSV,3,1,09,03,51,140,42,16,02,056,40,17,78,080,42,21,25,234,00*72[CR][LF]
$GPGSV,3,2,09,22,19,260,00,23,59,226,00,26,45,084,39,27,07,017,39*78[CR][LF]
$GPGSV,3,3,09,28,29,311,44*42[CR][LF]
```

AOA TURBOROGUE

RINEX files derived from TurboRogue receiver observations usually contain the following comment lines describing how the receiver SNR values are mapped into the RINEX signal strength scale (0-9):

```
SNR is mapped to signal strength [0,1,4-9]                      COMMENT
 SNR:   >500  >100   >50   >10    >5    >0   bad   n/a      COMMENT
 sig:      9     8     7     6     5     4     1     0      COMMENT
```

According to the user manual for the TurboRogue family of receivers the original SNR values are provided for CA, P1 and P2 code measurements in units of volts/volts.

SUGGESTED REFERENCES

The following is a list of references which describe various techniques to utilise SNR values in weighting observations:

Barnes, J.B., N. Ackroyd and P.A. Cross (1998). “Stochastic Modelling for Very High Precision Real-Time Kinematic GPS in an Engineering Environment.” *FIG XXI International Congress*, *Commission 6, Engineering Surveys,* Brighton, UK, 19-25 July, pp. 61-76.

Collins, J.P. and R.B. Langley (1999). “Possible weighting schemes for GPS carrier phase observations in the presence of multipath.” Final contract report for The U.S. Army Corps of Engineers Topographic Engineering Center, No. DAAH04-96-C-0086 / TCN 98151, March, 33 pp. Available on-line at: <http://gauss.gge.unb.ca/papers.pdf/acereport99.pdf>.

Euler, H.-J. and C.C. Goad (1991). “On optimal filtering of GPS dual frequency observations without using orbit information.” *Bulletin Geodesique*, Vol. 5, No. 2, pp. 130-143.

Hartinger H. and F.K. Brunner (1998). “Signal Distortion in High Precision GPS Surveys.” *Survey Review*, Vol. 34, pp. 531-541.

Hartinger, H. and F.K. Brunner (1998) “Attainable Accuracy of GPS Measurements in Engineering Surveying.” *FIG XXI International Congress*, *Commission 6, Engineering Surveys,* Brighton, UK, 19-25 July.

Jin, X.-X. and C.D. de Jong (1996). “Relationship between Satellite Elevation and Precision of GPS Code Observations.” *The Journal of Navigation*, pp. 253-265.

Talbot, N. (1988). “Optimal Weighting of GPS Carrier Phase Observations Based on the Signal-to-Noise Ratio.” *International Symposia, Global Positioning Systems*, Gold Coast, Queensland, 17-19 October, pp. 4.1-4.17.

This paper provides a general desription of the receiver noise on both code and carrier measurements:

Langley. R.B. (1997). “GPS Receiver System Noise.” *GPS World*, Vol. 8, No. 6, pp. 40-45