DUAL ANTENNA USE ON A GPS RECEIVER

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ABSTRACT

Due to vehicle dynamics in mobile systems, GPS signal reception may be blocked by the body of the vehicle. This paper discusses various studies made on some vehicles such as the Space Shuttle, various aircraft, and analyzes the implementation of dual GPS antenna systems. Constructive and destructive interference characteristics of signal combining are considered. The author suggests an approach which uses a delay line on one of the antennas while analyzing the front end C/N0 needed for L1 GPS reception. An embedded Excel spreadsheet provides a front-end Noise Figure (NF) calculation tool based on user selected parameters.

KEY WORDS

GPS Receiver, dual antenna, constructive and destructive interference, signal blocking, multipath, Noise Figure (NF)

INTRODUCTION

Due to the geometry and dynamics of a vehicle (Fig 1) vs. the GPS Space Vehicles (SVs), the challenge is to have a minimum of four satellites in view of the GPS L band antennas located on the receiver structure. Dual antennas receiving the same signal and combining these signals create some challenges due to destructive and constructive interference. When the signal arriving at the two antennas from a single SV reaches simultaneously but at different phases due to geometry (possibly the attitude) of the vehicle, it may double the signal level favorably (equal phase) or cancel the signal detrimentally (opposite phase). We need to understand the implications of combining in various approaches through math, system geometry and dynamics; and recommend the best math driven approach to look at probable correction schemes.

Excel Tools were developed for parametric subsystem Noise Figure, Carrier to Noise density (dB -Hz) and Amplification calculations. In either of the cases (whether the combiner is used or not used, whether the combiner is located in the system prior to Low Noise Amplifier (LNA) or after the LNA) the system provides good NF and amplification margins. In the analysis below, the worst cases are considered. If due to a nearby telemetry transmitter an external diplexer and/or a filter are used, the GPS LNA's filter capability does not have to be as stringent; therefore, the LNA noise figure can be reduced to 1 dB or less at room temperature (and about 0.5 dB more in the full temperature specification range.) Various approaches under this condition are studied.

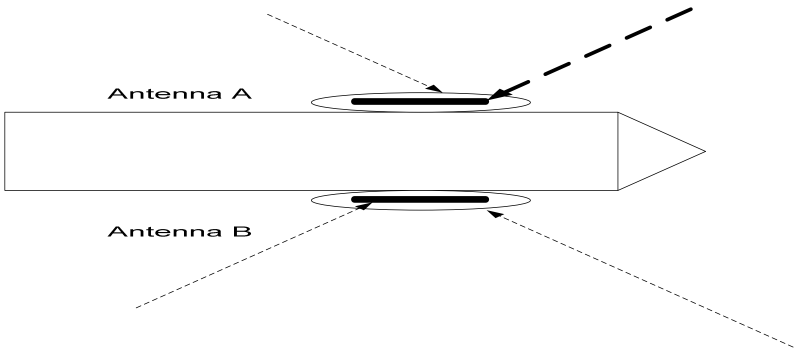

Figure 1 A vehicle carrying two, 180 degree-separated GPS antennas

IMPLEMENTATION

DUAL ANTENNA GPS RECEIVE SYSTEMS

Four major configurations are considered and analyzed:

Case 1: A dual antenna system (180 degree separated antennas) on a space vehicle connected to two separate inputs of the dual channel GPS Receiver subsystem, with a GPS receiver providing dedicated channels for each antenna and LNA (Figure 2):

Figure 2 GPS with two interdependent multi-channel receivers with Common Clock

A common clock could assist the processors for an accurate position calculation. This is achieved through the design of the receiver hardware and software accordingly.

PROS:

- No destructive interference possibility (no signal drops and reacquisition due to combining),
- No need for corrective calculations for carrier smoothing (simpler GPS),
- Input circuit bandwidth could be lowered for lower noise reception,

- Receiver channels utilize SVs (GPS satellites) in view in opposite directions,
- Common clock use eliminates clock bias errors.

CONS:

- Complicated dual receiver (software) combining results from two receiver systems for analysis of the position
- Larger receiver (cost, weight and power)

Case 2. Two completely independent GPS receivers connected to each antenna subsystem, consequently computing positions using pesudorange measurements from both receivers and combining the results (Figure 3).

Figure 3 Two Separate GPSs Resolving Pesudorange

PROs:

- Same as previous paragraph (no destructive interference and dropouts due to cyclic C/N0 due to combining – reference 1 & 4)
- Both receivers can use all the satellites (in every direction)
- Each receiver can provide power through its power port to its in-line LNA

CONs:

- More accurate GPS solution calculations needed
- Complex software and processor hardware,
- Heavier and possibly more expensive system (more weight, space and power)

From the System Noise Figure and System Gain perspective, the two approaches above yield equal results (all receive levels are based on Ref 5)-

With assumed $T_{antenna}$= 100K^0 and T_{sky} =100K^0 and $Loss_{cables}$=0.5 dB, $VSWR_{connectors}$= 1.5:1 and typical -5.5 dB antenna gain (loss) for a worst case reception.
We achieve front end system Noise Figure of NF_{GRFS} = 3.08 dB (326 K^0) and $NF_{overall}$ = 4.35 dB (526 K^0) and C/N_0 = 37.62 dB-Hz minimum (against a desired 4.5 dB NF max and 34 dB C/N_0 minimum.)

NOTE: $NF_{overall}$ includes antenna and cold sky noise temperatures as stated here.

Case 3. Two antennas placed 180 degrees apart, using a passive RF combiner, combining the signals and amplifying the combined signal prior to presenting it to the single GPS receiver (simplest case overall)

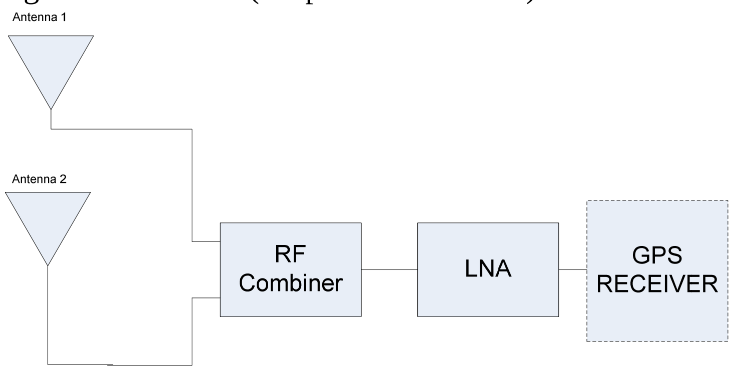

Figure 4 Passively combining RF signals prior to LNA

PROS:

- Lower cost, fewer components, lighter weight hardware
- More common GPS receivers and combiners
- Can supply DC current to LNA through the RF input port (less cabling/power distribution of conditioned +5, +12, +15 or other common LNA input voltages)

CONS:

- Cyclic C/N0 (reference 4)
- Possible occasional tracking drops (destructive interference) either from antennas or from the vehicle body
- GPS receiver must have design features that support handling of a cyclic C/N0 combined signals – multipath discrimination, carrier smoothed pseudorange options, etc

With same assumptions as previous model, the system in Figure 4 yields:

NF_{GRFS} = 3.91 dB (423 K^0) and $NF_{overall}$ = 4.98 dB (623 K^0) and
C/N_0 = 36.65 dB-Hz minimum (against a desired 4.5 dB NF max and 34 dB C/N_0 minimum.)

Case 4. Two antennas with two LNAs then a combiner providing amplified signals to the single GPS receiver

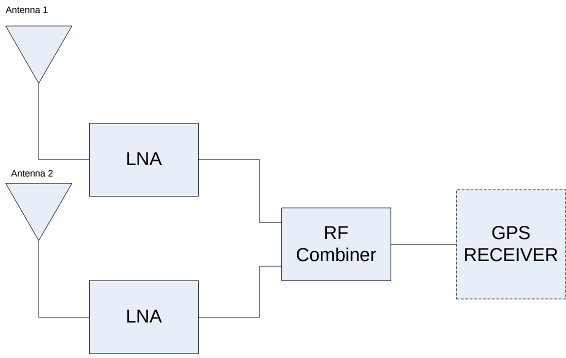

Figure 5 Combining signals after active LNA amplification

PROS:

- Higher G/T than previous approach (LNA first) – min 1 dB better

CONS:

- Same as previous method plus
- More complicated combiner for DC pass through for powering the LNAs
- Higher current (twice) requirement from the GPS receiver port or external conditioned power system
- Heavier and more expensive dual LNAs

With same assumptions this system in Figure 5 yields:

NF_{GRFS} = 3.08 dB (300 K^0) and $NF_{overall}$ = 4.35 dB (500 K^0) and C/N_0 = 37.62 dB-Hz minimum (against a desired 4.5 dB NF max and 34 dB C/N_0 minimum.)

Typical gain and losses one would observe in any one of the cases mentioned above are depicted in the example in Figure 6 (assuming a typical 5.5 dB worst case loss on the antenna):

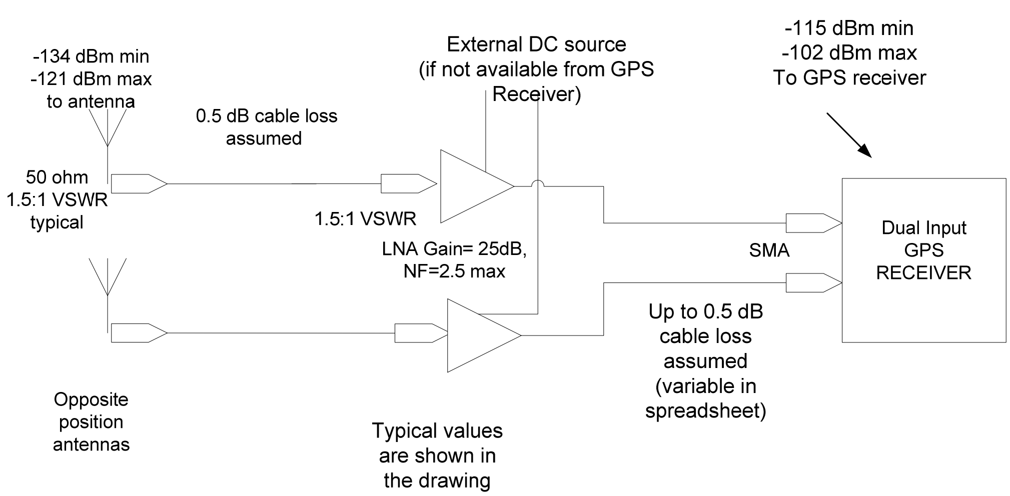

Figure 6 Typical signal levels, gains and losses

These calculations can be repeated by the reader, based on various parameters for a “what if analysis” using the following embedded MS Excel spreadsheets (for single input receiver and dual input receiver respectively.)

D:\Documents and Settings\e227610\My   D:\Documents and Settings\e227610\My

Note on attached EXCEL SPREADHEETS: These Excel spreadsheets provide a practical tool for “What if” analysis for Noise Figure of the RF front end system, along with C/N0 expected at the input to the GPS receiver. In the worksheets, the yellow highlighted areas are for user parameter entry. One can change the VSWR values at certain joints, insertion losses of the parts, cables and antenna noise temperature value, LNA gain, etc. Once the numbers are entered in the yellow shaded areas, the results change automatically. Critical outcomes are indicated in red. Red only means “results.” (Additional internal worksheets in these spreadsheets provide the formulas used for these calculations.) Spreadsheets are not protected.

NOTE : A system variation with diplexer use (in case multimode (S and L1 band) antennas used) should also be considered. (S band is considered 2.2-2.4 GHz, L1=1.57542 GHz)

As the S-band telemetry transmit system either shares or is collocated with the GPS L1 receive antenna, it is highly recommended to use a diplexer by the antenna design group. A 75 Watt S-band signal is considered galvanically or “near-field” coupled to the GRFS, providing approximately 49 dBm OOB interference.

A diplexer or cavity filter provided will bring this signal down by a minimum of 70 dB [80 dB or a “minimum amount equal to 49 dBm + LNA Gain” is the preferred out-of-band filter attenuation.].

i. *If the user prefers not to use the diplexers for separation of the frequencies, the filtered LNA capability with ceramic filters will not provide enough filtering to eliminate coupled out-of-band S-band signals. In this case the GRFS will need to supply a cavity notch filter at every antenna output prior to LNA processing of L1 signals. This addition increases the GRFS Noise Figure (NF) by about 0.5 to 1.2 dB (exactly equal amount to the insertion loss of the notch filter.)*

ii. *It is highly recommended that the S-band signals are pre-Modulation filtered to reduce the significant harmonics that the unfiltered digital stream modulating S-band carrier can cause in the L-band.*

ANALYSIS OF PREVIOUS STUDIES ON DESTRUCTIVE INTERFERENCE

Various studies and experiments independently conducted (1992) by Lockheed Houston and FAA teams can be found in References 1 and 2, respectively. While Reference 1 shows the cyclic nature of the C/N0 when two antennas above and below the Space Shuttle are used with a combiner on the same GPS receiver, Reference 2 discusses an FAA experiment on an airplane and a correction algorithm used to reduce the effect from the two antennas with a power combiner.

The cyclic nature of the C/N0 analyzed by the Lockheed paper indicates, in most of the cases for the front end used, that the C/N0 fluctuated between 45 dB-Hz and 35 dB-Hz with occasional drops to 25 dB-Hz. The cyclic nature of the C/N0 is due to satellites geometry and the receiver antenna positioning towards the satellites. The tracking drops do not happen until the C/N0 drops below 25 dB-Hz or less. Most current GPS Receiver front end specifications support this. A simple comparison of data from the same paper indicates that, with a certain system design and geometry, the C/N0 stays fairly constant in a certain satellite position in the 1.5 hour observation time on earth. A comparison of two signals using PRN 11 is depicted in figures (which figures) resulted in up to 25 meter of errors. However, the data is always delivered. C/N0 is repeated (cyclic) approximately every 2.8 minutes, due to the geometry of the SVs and the ground dual antenna separation. Our geometry calculations verified this dependency. However, the main question due to geometry and dynamics in space, is how often do these additions and subtractions occur. For antennas places approximately 3m apart and are 180 degrees opposite each other, and assuming that in space the vehicle will move at hypersonic speeds, these changes will occur in seconds rather than minutes. A thorough study of this phenomenon, with space flight characteristics introduced into simulation, is recommended.

Reference 4 outlines the studies conducted by the Lockheed team in 1992. These tests were done in a static environment (while, of course, the transmitting SVs are in motion, the two antennas and the receiver were on earth on static ground.) Even in this static case, in 1.5-hour duration there seemed to be two tracking dropouts due to L1 reception. Referenced document concludes that the overall system would not suffer due to dual antenna and a combiner use.

IMPLEMENTATION CONSIDERATIONS

1. Use two port GPS systems with a common clock, combine results received through two separate antennas to eliminate cyclic nature of C/N0. Instead of connecting two antennas to a single receiver input, it is better to have dedicated receiver channels for each antenna. A common clock use would assist an accurate position calculation (through receiver hardware and software design.) An alternate approach is to use two separate receivers and then compute position using pseudo range measurements from both receivers.

2. Each receiver should have minimum of four satellites in view for accurate computation of receiver clock bias.

3. Combine code and carrier measurements (implement carrier-smoothing)

4. Use separate antennas for S-band telemetry transmission and L1 reception and use diplexers.

5. If multi-band antennas are used, separate signals using diplexers

6. Use low-loss cables with good radiation and temperature characteristics; make antenna cable length to both antennas equal to avoid inducing a bias, resulting in a position error.

7. Use wide band (16 MHz bandwidth) front-end and narrow correlators.

8. Use external Al/Cu resonance filters.

ASSUMPTIONS

During calculations the following were assumed:

1. Antennas on the vehicle are 180 degrees apart; however they can possibly see same SVs simultaneously

2. Antenna separation is somewhere between 2 to 3 meters, however the cable lengths from each antenna pair to the GPS receiver are exactly equal. (However, the "lever arm" issue still needs to be resolved. The location of the GPS antennas on the vehicle vs. the location calculation center may not coincide. GPS receivers, unless addressed, resolve the position of the reception antenna rather than the center position of the vehicle.) The length tolerance should be kept under a few centimeters. The bias error equals the difference between the lengths of two cables.

3. If antennas are dual band (S and L), signals are separated by use of diplexers

4. The GPS receivers will have 12 channel SV support for L1 frequencies only. The received signal level from the satellites is averaged at -158.5 dBW (-128.5 dBm) minimum and -150 dBW (-120 dBm) maximum for the calculations. (In most cases -5.5dB loss is added for the lowest antenna gain during reception.) No additional gain or loss considered due to space vehicle's location (in reality, a vehicle is closer to or further away from the SVs in space).

5. The inherent CDMA characteristic with uneven receive level saturation from one channel needs to be taken into consideration. In space this is more like to take place as the space vehicles may fly much closer to "one" of the GPS SVs. This is studied in Reference 6, Chapter 13, Special Topics.

6. Cable insertion losses are expected to be no more than 0.5 dB within the operational temperature range. (Slight phase shift possible at cold temperatures.)

7. LNA noise figure temperature coefficient is not larger than 0.01 dB/C degrees. (ie. for an LNA with a 1.5 dB Noise Figure at 20 degrees C, a NF increase of 0.5 dB maximum for the operation range is expected.)

   NF_{max} (dB)= (Max TºC – spec identified room temperature in ºC) x NF coefficient dB/ºC+ NF (dB) at spec room temperature

8. Antenna gain is expected to be no more than 2 dB. In calculations -5.5 dB antenna gain (therefore a loss) was used, not the best angle of the antenna. However, this is a configurable parameter in the embedded Excel files providing what-if analysis.

9. All I/O and cabling are assumed to have 50 ohms nominal characteristic impedance. (A cable VSWR of 1.01 dB is possible.)

10. No LNA output power splitting is considered. (It is considered during analysis, however, due to its complexity (external power supply need, internal power divider need and additional NF incurred) it was excluded from this analysis.)

11. No multipath from other components in space is assumed.

12. The vehicle dynamics is considered to be to the system's advantage from the destructive addition of signals:

    It is similar to a multipath effect; however both antennas receive equal signal levels (with varying phase differences.) Per Reference 3:

    $\delta\phi = arctg(\frac{\sin\Delta\phi}{\frac{1}{\alpha}+\cos\Delta\phi})$ while $\delta\phi$ is the error in carrier phase measurement

    and while $\Delta\phi$ is the phase shift between the two waves.

Alpha is the difference in-between two signal amplitudes in ratio. Since the two signals arriving are not expected to be different in amplitude (this is not a true multipath), alpha will be 1. The shift in equal signal levels will not be more than 88 degrees. Therefore, there will mostly be a residual signal difference (no complete cancellation). While the phase shift changes between 0 to 180 degrees, we analyze that the 1575.42 MHz carrier (19.04 cm wavelength) arrives at further away antenna far enough in time so that the system shall not be able to correlate two signals, and effectively, not be able to use the late arriving signal for the correlation. This will look like a quick passing artifact to the GPS receiver. In very rare occasions, when the tilt angle of the space vehicle causes the two opposite antennas to be only less than one half wavelength apart (under 19/2 cm=9.5 cm) for the incoming wave from the GPS satellite, then the signals can possibly add in opposite phases. In order to reduce this effect it is recommended that the cables to both antennas be kept equal in length and made multiples of the lambda/2 (multiples of 9.5

cm). Length difference will induce a position error. Pseudo range errors will be as large as the separation depending on the satellite geometry.

CONCLUSION

SUMMARY AND RECOMENDATIONS

In summary, to aid various space users while in flight, various approaches were analyzed for use of a GPS RF Subsystem providing dual antennas, combiner and LNA system to amplify GPS signals from GPS satellites. . The system would be able to obtain GPS signals during orbital flight, ascent and descent to the degree that the hyper-speed-plasma caused “blackout” does not block the antenna reception.

The results strongly suggest that the space vehicle should have four antennas, positioned 180 degrees apart; connected to two GPSs. Signals from these antennas would be carefully summed and then amplified before being connected into the GPS port. For ease of design and installation as well as lowering the part count for reliability, the GPS port would supply the DC power needed for the LNA.

Due to constructive and destructive summing of the signals (in phase and out of phase addition due to system geometry and dynamics), and a resultant cyclic C/N0 between 45 dB-Hz to 25 dB-Hz, tracking dropouts are rare. The measurement errors are slightly larger than desired, 50% of the time. However, the single antenna approach will be worse due to the antenna not seeing the satellites half the time.

A better method offered is to feed the signals into two separate GPS receiver inputs from two oppositely located antennas and, using a common clock, resolve the position calculations either from two separate channels or the two separate GPS systems processing signals. Even though this is a better method, it will be heavier and costly.

FUTURE (FURTHER) STUDIES

Another study could be done connecting two antennas in the format suggested below to validate if the complete system can be considered “the antenna.” (Figure 7) Even though some bias due to separation of the two end antennas may still develop, this can be reduced using carrier smoothing and filtering techniques discussed above while the “destructive” nature of the “dual antenna” solution may be eliminated. This needs to be verified in a lab with a simulator and a quiet (noise free) environment such as an anechoic chamber. The author recommends the addition of a 1 micro-second (1 chip) delay, for a variation, into one of the connection lines in series. This would help identify the second antenna reception as a multipath beyond 300 meters (approximately) and ignore the late arriving side. However, in this case, this delay side will only be used if the early arrival side does not receive the data from a specific GPS SV.

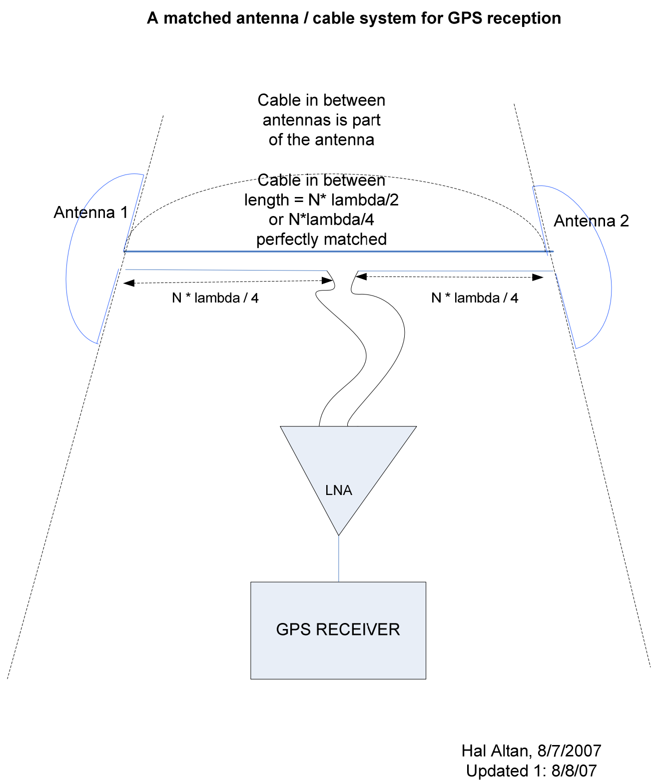

Figure 7 Dual GPS antennas and a cable form a single antenna

ACRONYM LIST

C	Centigrade
C/N0	Carrier to Noise density ratio (dB- Hz)
dBm	dB of power referenced to miliwatts
dBW	dBWatts
DC	Direct Current
Deg/sec	Degrees/second
FAA	Federal Aviation Agency
Fig	Figure
G	Gain
GHz	GigaHertz
GPS	Global Positioning System
GPSR	Global Positioning System Receiver
Hz	Hertz
I/O	Input / Output
km	Kilometers
km/sec	Kilometers/second
L	Loss

LEO	Low Earth Orbiting
LNA	Low Noise Amplifier
mA	Milli Ampere
MHz	Mega Hertz
mph	Miles Per Hour
NF	Noise Figure
OOB	Out-of-Band
PRN	Pseudo Random Number
REF	Reference
RF	Radio Frequency
GRFS	GPS RF Subsystem
SEC	Second
SV	Space Vehicles (GPS Satellite System Space Vehicles)
vs	Versus
VSWR	Voltage Standing Wave Ratio
W	Watt

REFERENCES

Ref 1: The Effects of a Power Combiner with Dual Antenna Input on GPS Pseudorange Measurements and GPS Tracking Performance, NASA, Johnson Space Center Document dated May 1992

Ref 2: Using GPS for Monitoring Air Traffic Separation Standards in International Airspace, Paper by Kim Joyce of FAA, Dated February 28, 1996

Ref 3: Global Positioning System, Signals, Measurements, and Performance, by Pratap Misra/Per Enge, Second Edition, 2006

Ref 4: Power Combiner Operation and the Effects of Phasing with Dual-Antenna Inputs, Prepared by Lockheed Engineering, Johnson Space Center, Dated May 1992.

Ref 5: IS-GPS-200, Rev D NAVSTAR GPS Interface Specification

Ref 6: Space Mission Analysis and Design, Third edition, J. R. Wertz & W. J. Larson