The Extended Standard Product 3 Orbit Format (SP3-d)

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INTRODUCTION

   The SP3-d format adds three extensions to the previous SP3-c format: the maximum number of satellites is increased from 85 to 999, there are now an unlimited number of comment records allowed in the header, and the maximum length of each comment record has been increased from 60 characters to 80 characters.

The need for the first change, getting past the 85 satellite limit, was long anticipated but has been accelerated recently by work done for the Multi-GNSS Experiment (MGEX), an effort that was undertaken within the International GNSS Service (IGS) to explore and promote the use of new navigation signals and methods (Montenbruck et al. 2013). One product being discussed by the IGS Multi-GNSS Working Group (MGWG) is a broadcast ephemeris containing most of the existing Global Navigation Satellite System (GNSS) and Satellite-Based Augmentation System (SBAS) satellites. The number of satellites to be included is already over 85. In addition to being offered as a RINEX Navigation Message File, it will also be made available as an SP3-d file for those that might prefer using the broadcast orbits in that format (Montenbruck, 2013).

The second and third changes have also been considered previously. In the past, the various IGS Analysis Center Coordinators who oversee the creation of the IGS combined orbit products have complained about trying to adequately describe the combined orbits using only the four comment lines allowed in SP3-c. If a change is made to allow an unlimited number of comment lines, to increase the amount of comment space available, it also makes sense to go ahead and increase the length of each comment line from 60 characters to 80 characters. Most of the ephemeris data records found after the header are already 80 characters wide, as allowed in SP3-c.

Over the past several years there have been other suggestions/requests for additional features such as: 0.1-millimeter (or better) resolution in satellite coordinates, irregularly-spaced epochs for kinematic LEO orbits, use of both NAVSTAR and PRN ID numbers to uniquely identify each satellite, and the use of quaternions to represent satellite attitude. These features have been included in a proposed format called The ORBit EXchange (ORBEX) format (Hilla, 2010) which is based on a more flexible, expandable design similar to the SINEX format (an idea first proposed by Gerd Gendt). While there are many users who are looking forward to the added features in ORBEX, it is understandable that many of these same users are not looking forward to the work involved in jumping to a completely new format. There is still a lot of work to be done to pare down the current ORBEX Draft Version, and to decide how best to balance brevity versus modularity for ORBEX (i.e., is it better to combine several different types of metadata in one block to save space, or to separate the metadata into separate blocks even if this

Example 1. An SP3-d file with 140 satellites and 5 comment lines.

```
 1 #dP2013  4  3  0  0  0.00000000        96 ORBIT WGS84 BCT MGEX
 2 ## 1734 259200.00000000    900.00000000 56385 0.0000000000000
 3 +   140   G01G02G03G04G05G06G07G08G09G10G11G12G13G14G15G16G17
 4 +         G18G19G20G21G22G23G24G25G26G27G28G29G30G31G32R01R02
 5 +         R03R04R05R06R07R08R09R10R11R12R13R14R15R16R17R18R19
 6 +         R20R21R22R23R24E01E02E03E04E05E06E07E08E09E10E11E12
 7 +         E13E14E15E16E17E18E19E20E21E22E23E24E25E26E27E28E29
 8 +         E30C01C02C03C04C05C06C07C08C09C10C11C12C13C14C15C16
 9 +         C17C18C19C20C21C22C23C24C25C26C27C28C29C30C31C32C33
10 +         C34C35J01J02J03I01I02I03I04I05I06I07S20S24S27S28S29
11 +         S33S35S37S38  0  0  0  0  0  0  0  0  0  0  0  0  0
12 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
13 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
14 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
15 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
16 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
17 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
18 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
19 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
20 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
21 %c M  cc GPS ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
22 %c cc cc ccc ccc cccc cccc cccc ccccc ccccc ccccc ccccc ccccc
23 %f  1.2500000  1.025000000  0.00000000000  0.000000000000000
24 %f  0.0000000  0.000000000  0.00000000000  0.000000000000000
25 %i    0    0    0    0      0      0      0      0         0
26 %i    0    0    0    0      0      0      0      0         0
27 /* Note: This is a simulated file, meant to illustrate what an SP3-d header
28 /* might look like with more than 85 satellites. Source for GPS and SBAS satel-
29 /* lite positions: BRDM0930.13N. G=GPS,R=GLONASS,E=Galileo,C=BeiDou,J=QZSS,
30 /* I=IRNSS,S=SBAS. For definitions of SBAS satellites, refer to the website:
31 /* http://igs.org/mgex/status-SBAS
32 *  2013  4  3  0  0  0.00000000
33 PG01   5783.206741 -18133.044484 -18510.756016      12.734450
   PG02 -22412.401440  13712.162332     528.367722     425.364822
   PG03  10114.112309 -17446.189044  16665.051308     189.049475
   PG04 -24002.325710   4250.313148 -11163.577756     179.333612
   PG05 -15087.153141   8034.886396  20331.626539    -390.251167
   PG06  13855.140409 -11053.269706  19768.346019     289.556712
    .
    .
    .
   PS28   5169.591020  41849.037979      17.421140       0.170452
   PS29 -32240.432088  27155.480094     -12.156456       0.101500
   PS33  -5555.490565 -41739.269117    2093.250932      -0.199099
   PS35 -28749.533445 -30836.454809      -4.729472      -0.008333
   PS37 -34534.904566  24164.610955      29.812840       0.299420
   PS38 -12548.655240 -40249.910397      -3.521920      -0.027787
   *  2013  4  3  0 15  0.00000000
    .
    .
    .
   *  2013  4  3 23 45  0.00000000
   PG01   4340.761149 -17469.395805 -19521.652181      13.021579
   PG02 -22187.015530  13877.264416   2583.141886     425.527461
   PG03   9785.535610 -18824.396329  15333.698561     189.465625
   PG04 -24642.374460   4816.578416  -9365.337848     180.261632
   PG05 -13667.233808   8977.038381  20922.734874    -390.371011
   PG06  13696.828033 -12657.020030  18869.219517     288.240920
    .
    .
    .
   PS28   5172.029472  41849.075534      17.353884       0.346319
   PS29 -32238.862503  27158.965634     -13.223188       0.179982
   PS33  -5561.856798 -41736.409969    2123.557039       0.009913
   PS35 -28751.361488 -30835.144592      -6.745702      -0.006819
   PS37 -34533.867549  24170.548454      28.300343      -0.223601
   PS38 -12549.851291 -40249.647004      -4.471664      -0.003125
   EOF
```

Example 2. A GPS-only SP3-d file with all record types (P, EP, V, EV).

```
 1 #dv2001  8  8  0  0  0.00000000      192 ORBIT IGS97 HLM MGEX
 2 ## 1126 259200.00000000   900.00000000 52129 0.0000000000000
 3 +   26   G01G02G03G04G05G06G07G08G09G10G11G13G14G17G18G20G21
 4 +        G23G24G25G26G27G28G29G30G31  0  0  0  0  0  0  0  0
 5 +          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 6 +          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 7 +          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
 8 ++         7  8  7  8  6  7  7  7  7  7  7  7  7  8  8  7  9
 9 ++         9  8  6  8  7  7  6  7  7  0  0  0  0  0  0  0  0
10 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
11 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
12 ++         0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
13 %c G  cc GPS ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
14 %c cc cc ccc ccc cccc cccc cccc ccccc ccccc ccccc ccccc
15 %f  1.2500000  1.025000000  0.00000000000  0.000000000000000
16 %f  0.0000000  0.000000000  0.00000000000  0.000000000000000
17 %i    0    0    0    0      0      0      0      0         0
18 %i    0    0    0    0      0      0      0      0         0
19 /* AN EXAMPLE ULTRA RAPID ORBIT, GPS ONLY.
20 /* NOTE THE "PREDICTED DATA" FLAGS FOR THE LAST EPOCH (IN COLUMNS 76 and 80).
21 /* CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
22 /* CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
23 *  2001  8  8  0  0  0.00000000
24 PG01 -11044.805800 -10475.672350  21929.418200    189.163300 18 18 18 219
25 EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
26 VG01  20298.880364 -18462.044804   1381.387685     -4.534317 14 14 14 191
27 EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   PG02 -12593.593500  10170.327650 -20354.534400    -55.976000 18 18 18 219     M
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG02  -9481.923808 -25832.652567  -7277.160056      8.801258 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   PG03   9335.606450 -21952.990750 -11624.350150     54.756700 18 18 18 219
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG03  12497.392894  -8482.260298  26230.348459      5.620682 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   PG04 -16148.976900   8606.630600  19407.845050    617.997800 18 18 18 219
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG04 -22859.768469  -8524.538983 -15063.229095     -3.292980 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   PG05  13454.631450  20956.333700   9376.994100    308.956400 18 18 18 219
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG05    392.255680  12367.086937 -27955.768747    -13.600595 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   .
   .
   .

*  2001  8  9 23 45  0.00000000
   PG01 -11044.805800 -10475.672350  21929.418200    189.163300 18 18 18 219  P   P
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG01  20298.880364 -18462.044804   1381.387685     -4.534317 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   PG02 -12593.593500  10170.327650 -20354.534400    -55.976000 18 18 18 219  P   P
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG02  -9481.923808 -25832.652567  -7277.160056      8.801258 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   .
   .
   .
   PG30 -23592.378250   1395.049800 -12524.037100    461.972900 18 18 18 219  P   P
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG30 -13996.847785  -6945.665482  25908.199568      0.364488 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   PG31  17353.533200  15151.105700 -13851.534050     -1.841700 18 18 18 219  P   P
   EP    55    55    55     222  1234567 -1234567  5999999      -30      21 -1230000
   VG31 -16984.306646  -2424.913336 -23969.277677    -14.371692 14 14 14 191
   EV    22    22    22     111  1234567  1234567  1234567  1234567  1234567  1234567
   EOF
```

results in a slightly more verbose file). In the meantime, the MGWG within the IGS needs SP3-d now to get past the 85 satellite limit.

One final note is needed regarding multi-constellation orbit files. Just because one can put GNSS satellites from multiple constellations into the same SP3-c or SP3-d file, doesn't mean it is always a good idea. For example, non-trivial inter-system timing and orbital reference frame differences currently preclude the IGS from making a rigorous GPS+GLONASS product where the two constellations are truly in the same Time System and in the same Reference Frame. For lower accuracy files (like the MGWG broadcast ephemeris SP3 file mentioned above) these differences in Time System and Reference Frame might be ignored, as long as everyone understands the limitations of such a file.

IMPLEMENTATION CONSIDERATIONS

Each of the record types found in an SP3 header has a unique set of characters in columns one and two. This makes it easy to read through the header, even when the number of lines in the header is dependent on the number of satellites and the number of comment records. For example, for any SP3-d file, the first two records (beginning with "#d" and "##") will always be present. The third through seventh lines will always be present as well. For backwards compatibility, every SP3-d file must always have at least: five satellite ID records (beginning with "+ "), five orbit accuracy records (beginning with "++"), and four comments records (beginning with "/*"); even when the number of satellites is less than 85 (see Example 2). If there are more than 85 satellites, there will be more than five "+ " records and these records can be read in until the first "++" record is encountered. There are 17 satellite IDs on each line, and this fact can be used to compute the indices for loading the satellite IDs into an array if required. The last "+ " line may contain zeroes if the number of satellites (given on line three) is not an even multiple of 17. As a check, the number of satellite IDs read in should match the number of satellites given on line three.

There should always be the same number of "++" records as there are "+ " records, since both record types are dependent on the number of satellites. Again, this fact can be used to check the number of "++" records, which can be read in until the first "%c" record is encountered. After the "++" records, there will always be exactly two "%c", two "%f", and two "%i" records. Columns 10-12 in the first %c record define what time system is used for the date/times in the ephemeris. If estimates of the standard deviations for the satellite coordinates and satellite clock offsets are given, then the first "%f" line will hold the floating point base numbers (e.g., 1.25 for the coordinates, and 1.025 for the clock offsets), see Example 2. See also the text regarding line twenty-three in the section below entitled "DETAILED DISCUSSION OF THE SP3-d FORMAT".

After the second "%i" record is read in, the comment records will follow. These comments can be read in until the first "* " record is encountered (i.e., until the first Epoch Header Record is found). This will mark the end of the header, and the beginning of the actual ephemeris part of the file. Although the number of comment records is theoretically unlimited, users are asked to practice constraint. It was considered to limit the number of comment lines to 40 or 400. However, any such limit would seem somewhat arbitrary. The beauty of the SP3 format is really its compactness, and it would seem to go against the spirit of SP3 to see a file with tens of thousands of comment lines and only 3,200 lines of actual data. Please make your comments brief. One can always include a URL or some other reference that points to other files with additional metadata. This is

especially important for any large number of orbit files that will need to be archived.

                          HISTORY OF THE SP3 FORMAT

     For the history of the SP3 format, originally developed by Benjamin W.
Remondi, please refer to Appendices A and B at the end of this document.

              COLUMN-BY-COLUMN DESCRIPTION OF THE SP3-d FORMAT

     Standard Product #3 ASCII SP3 Format Version "d" (see Example 1.)

     Columns   Description   Example   Format
     ----------------   ----------------   ----------------   ---------

     SP3 First Line

     Columns 1-2   Version Symbol   #d   A2
     Column 3   Pos or Vel Flag   P or V   A1
     Columns 4-7   Year Start   2013   I4
     Column 8   Unused   _   blank
     Columns 9-10   Month Start   _4   I2
     Column 11   Unused   _   blank
     Columns 12-13   Day of Month St   _3   I2
     Column 14   Unused   _   blank
     Columns 15-16   Hour Start   _0   I2
     Column 17   Unused   _   blank
     Columns 18-19   Minute Start   _0   I2
     Column 20   Unused   _   blank
     Columns 21-31   Second Start   _0.00000000   F11.8
     Column 32   Unused   _   blank
     Columns 33-39   Number of Epochs   _____96   I7
     Column 40   Unused   _   blank
     Columns 41-45   Data Used   ORBIT   A5
     Column 46   Unused   _   blank
     Columns 47-51   Coordinate Sys   WGS84   A5
     Column 52   Unused   _   blank
     Columns 53-55   Orbit Type   BCT   A3
     Column 56   Unused   _   blank
     Columns 57-60   Agency   MGEX   A4

     SP3 Line Two

     Columns 1-2   Symbols   ##   A2
     Column 3   Unused   _   blank
     Columns 4-7   GPS Week   1734   I4
     Column 8   Unused   _   blank
     Columns 9-23   Seconds of Week   259200.00000000   F15.8
     Column 24   Unused   _   blank
     Columns 25-38   Epoch Interval   __900.00000000   F14.8
     Column 39   Unused   _   blank
     Columns 40-44   Mod Jul Day St   56385   I5
     Column 45   Unused   _   blank
     Columns 46-60   Fractional Day   0.0000000000000   F15.13

     SP3 Line Three

     Columns 1-2   Symbols   +_   A2
     Column   3   Unused   _   blank

```
Columns 4-6        Number of Sats    140              I3
Column  7-9        Unused            ___              3 blanks
Columns 10-12      Sat #1 Id         G01              A1,I2.2
Column  13-15      Sat #2 Id         G02              A1,I2.2
        *
        *
        *
Columns 58-60      Sat #17 Id        G17              A1,I2.2


SP3 Line Four

Columns 1-2        Symbols           +_               A2
Columns 3-9        Unused            _____          7 blanks
Columns 10-12      Sat #18 Id        G18              A1,I2.2
Columns 13-15      Sat #19 Id        G19              A1,I2.2
        *
        *
        *
Columns 58-60      Sat #34 Id        R02              A1,I2.2


SP3 Line Five

Columns 1-2        Symbols           +_               A2
Columns 3-9        Unused            _____          7 blanks
Columns 10-12      Sat #35 Id        R03              A1,I2.2
Columns 13-15      Sat #36 Id        R04              A1,I2.2
        *
        *
        *
Columns 58-60      Sat #51 Id        R19              A1,I2.2


SP3 Line Six

Columns 1-2        Symbols           +_               A2
Columns 3-9        Unused            _____          7 blanks
Columns 10-12      Sat #52 Id        R20              A1,I2.2
Columns 13-15      Sat #53 Id        R21              A1,I2.2
        *
        *
        *
Columns 58-60      Sat #68 Id        E12              A1,I2.2


SP3 Line Seven

Columns 1-2        Symbols           +_               A2
Columns 3-9        Unused            _____          7 blanks
Columns 10-12      Sat #69 Id        E13              A1,I2.2
Columns 13-15      Sat #70 Id        E14              A1,I2.2
        *
        *
        *
Columns 58-60      Sat #85 Id        E29              A1,I2.2
```

Note: If there are more than 85 satellites, there will be more than
       just the required five satellite ID ("+ ") records.

```
SP3 Line Eight

Columns 1-2        Symbols           +_                    A2
Columns 3-9        Unused            _____               7 blanks
Columns 10-12      Sat #86 Id        E30                   A1,I2.2
Columns 13-15      Sat #87 Id        C01                   A1,I2.2
       *
       *
       *
Columns 58-60      Sat #102 Id       C16                   A1,I2.2


SP3 Line Nine

Columns 1-2        Symbols           +_                    A2
Columns 3-9        Unused            _____               7 blanks
Columns 10-12      Sat #103 Id       C17                   A1,I2.2
Columns 13-15      Sat #104 Id       C18                   A1,I2.2
       *
       *
       *
Columns 58-60      Sat #119 Id       C33                   A1,I2.2


SP3 Line Ten

Columns 1-2        Symbols           +_                    A2
Columns 3-9        Unused            _____               7 blanks
Columns 10-12      Sat #120 Id       C34                   A1,I2.2
Columns 13-15      Sat #121 Id       C35                   A1,I2.2
       *
       *
       *
Columns 58-60      Sat #136 Id       S29                   A1,I2.2


SP3 Line Eleven

Columns 1-2        Symbols           +_                    A2
Columns 3-9        Unused            _____               7 blanks
Columns 10-12      Sat #137 Id       S33                   A1,I2.2
Columns 13-15      Sat #138 Id       S35                   A1,I2.2
       *
       *
       *
Columns 58-60      Sat #153 Id       __0                   A1,I2.2


------------------------------------------------------------------


SP3 Line Twelve

Columns 1-2        Symbols           ++                    A2
Columns 3-9        Unused            _____               7 blanks
Columns 10-12      Sat #1 Accuracy   __0                   I3
Columns 13-15      Sat #2 Accuracy   __0                   I3
       *
       *
       *
Columns 58-60      Sat #17 Accuracy  __0                   I3
```

```
SP3 Line Thirteen

Columns 1-2        Symbols            ++                A2
Columns 3-9        Unused             _____           7 blanks
Columns 10-12      Sat #18 Accuracy   __0               I3
Columns 13-15      Sat #19 Accuracy   __0               I3
       *
       *
       *
Columns 58-60      Sat #34 Accuracy   __0               I3


SP3 Line Fourteen

Columns 1-2        Symbols            ++                A2
Columns 3-9        Unused             _____           7 blanks
Columns 10-12      Sat #35 Accuracy   __0               I3
Columns 13-15      Sat #36 Accuracy   __0               I3
       *
       *
       *
Columns 58-60      Sat #51 Accuracy   __0               I3


SP3 Line Fifteen

Columns 1-2        Symbols            ++                A2
Columns 3-9        Unused             _____           7 blanks
Columns 10-12      Sat #52 Accuracy   __0               I3
Columns 13-15      Sat #53 Accuracy   __0               I3
       *
       *
       *
Columns 58-60      Sat #68 Accuracy   __0               I3


SP3 Line Sixteen

Columns 1-2        Symbols            ++                A2
Columns 3-9        Unused             _____           7 blanks
Columns 10-12      Sat #69 Accuracy   __0               I3
Columns 13-15      Sat #70 Accuracy   __0               I3
       *
       *
       *
Columns 58-60      Sat #85 Accuracy   __0               I3

--------------------------------------------------------------------
Note:  If there are more than 85 satellites, there will be more than
       just the required five orbit accuracy ("++") records.


SP3 Line Seventeen

Columns 1-2        Symbols            ++                A2
Columns 3-9        Unused             _____           7 blanks
Columns 10-12      Sat #86 Accuracy   __0               I3
Columns 13-15      Sat #87 Accuracy   __0               I3
       *
       *
       *
Columns 58-60      Sat #102 Accuracy  __0               I3
```

```
SP3 Line Eighteen

Columns 1-2          Symbols              ++          A2
Columns 3-9          Unused               _____     7 blanks
Columns 10-12        Sat #103 Accuracy    __0         I3
Columns 13-15        Sat #104 Accuracy    __0         I3
        *
        *
        *
Columns 58-60        Sat #119 Accuracy    __0         I3


SP3 Line Nineteen

Columns 1-2          Symbols              ++          A2
Columns 3-9          Unused               _____     7 blanks
Columns 10-12        Sat #120 Accuracy    __0         I3
Columns 13-15        Sat #121 Accuracy    __0         I3
        *
        *
        *
Columns 58-60        Sat #136 Accuracy    __0         I3


SP3 Line Twenty

Columns 1-2          Symbols              ++          A2
Columns 3-9          Unused               _____     7 blanks
Columns 10-12        Sat #137 Accuracy    __0         I3
Columns 13-15        Sat #138 Accuracy    __0         I3
        *
        *
        *
Columns 58-60        Sat #153 Accuracy    __0         I3


----------------------------------------------------------------------


SP3 Line Twenty one

Columns 1-2          Symbols              %c          A2
Column  3            Unused               _           blank
Columns 4-5          File Type            M_          A2
Column  6            Unused               _           blank
Columns 7-8          2 characters         cc          A2
Column  9            Unused               _           blank
Columns 10-12        Time System          GPS         A3
Column  13           Unused               _           blank
Columns 14-16        3 characters         ccc         A3
Column  17           Unused               _           blank
Columns 18-21        4 characters         cccc        A4
Column  22           Unused               _           blank
Columns 23-26        4 characters         cccc        A4
Column  27           Unused               _           blank
Columns 28-31        4 characters         cccc        A4
Column  32           Unused               _           blank
Columns 33-36        4 characters         cccc        A4
Column  37           Unused               _           blank
Columns 38-42        5 characters         ccccc       A5
Column  43           Unused               _           blank
Columns 44-48        5 characters         ccccc       A5
Column  49           Unused               _           blank
Columns 50-54        5 characters         ccccc       A5
Column  55           Unused               _           blank
```

```
Columns 56-60         5 characters        ccccc                A5


SP3 Line Twenty two

Columns 1-2           Symbols             %c                   A2
Column  3             Unused              _                    blank
Columns 4-5           2 characters        cc                   A2
Column  6             Unused              _                    blank
Columns 7-8           2 characters        cc                   A2
Column  9             Unused              _                    blank
Columns 10-12         3 characters        ccc                  A3
Column  13            Unused              _                    blank
Columns 14-16         3 characters        ccc                  A3
Column  17            Unused              _                    blank
Columns 18-21         4 characters        cccc                 A4
Column  22            Unused              _                    blank
Columns 23-26         4 characters        cccc                 A4
Column  27            Unused              _                    blank
Columns 28-31         4 characters        cccc                 A4
Column  32            Unused              _                    blank
Columns 33-36         4 characters        cccc                 A4
Column  37            Unused              _                    blank
Columns 38-42         5 characters        ccccc                A5
Column  43            Unused              _                    blank
Columns 44-48         5 characters        ccccc                A5
Column  49            Unused              _                    blank
Columns 50-54         5 characters        ccccc                A5
Column  55            Unused              _                    blank
Columns 56-60         5 characters        ccccc                A5


SP3 Line Twenty three

Columns 1-2           Symbols             %f                   A2
Column  3             Unused              _                    blank
Columns 4-13          Base for Pos/Vel    _1.2500000           F10.7
                      (mm or 10**-4 mm/sec)
Column  14            Unused              _                    blank
Columns 15-26         Base for Clk/Rate   _1.025000000         F12.9
                      (psec or 10**-4 psec/sec)
Column  27            Unused              _                    blank
Columns 28-41         14-column float     _0.00000000000       F14.11
Column  42            Unused              _                    blank
Columns 43-60         18-column float     _0.000000000000000   F18.15


SP3 Line Twenty four

Columns 1-2           Symbols             %f                   A2
Column  3             Unused              _                    blank
Columns 4-13          10-column float     _0.0000000           F10.7
Column  14            Unused              _                    blank
Columns 15-26         12-column float     _0.000000000         F12.9
Column  27            Unused              _                    blank
Columns 28-41         14-column float     _0.00000000000       F14.11
Column  42            Unused              _                    blank
Columns 43-60         18-column float     _0.000000000000000   F18.15


SP3 Lines Twenty five and Twenty six

Columns 1-2           Symbols             %i                   A2
```

```
Column   3            Unused              _                    blank
Columns 4-7           4-column int        ___0                 I4
Column   8            Unused              _                    blank
Columns 9-12          4-column int        ___0                 I4
Column   13           Unused              _                    blank
Columns 14-17         4-column int        ___0                 I4
Column   18           Unused              _                    blank
Columns 19-22         4-column int        ___0                 I4
Column   23           Unused              _                    blank
Columns 24-29         6-column int        _____0               I6
Column   30           Unused              _                    blank
Columns 31-36         6-column int        _____0               I6
Column   37           Unused              _                    blank
Columns 38-43         6-column int        _____0               I6
Column   44           Unused              _                    blank
Columns 45-50         6-column int        _____0               I6
Column   51           Unused              _                    blank
Columns 52-60         9-column int        _____0            I9


SP3 Lines Twenty seven to Thirty one (5 comment lines in example 1)

Columns 1-2           Symbols             /*                   A2
Column   3            Unused              _                    blank
Columns 4-80          Comment             CC...CC              A77


SP3 Line Thirty two (The Epoch Header Record)

Columns 1-2           Symbols             *_                   A2
Column   3            Unused              _                    blank
Columns 4-7           Year Start          2013                 I4
Column   8            Unused              _                    blank
Columns 9-10          Month Start         _4                   I2
Column   11           Unused              _                    blank
Columns 12-13         Day of Month St     _3                   I2
Column   14           Unused              _                    blank
Columns 15-16         Hour Start          _0                   I2
Column   17           Unused              _                    blank
Columns 18-19         Minute Start        _0                   I2
Column   20           Unused              _                    blank
Columns 21-31         Second Start        _0.00000000          F11.8


SP3 Line Thirty three (The Position and Clock Record)
(See example 1)

Column   1            Symbol              P                    A1
Columns 2-4           Vehicle Id.         G01                  A1,I2.2
Columns 5-18          x-coordinate(km)    ___5783.206741       F14.6
Columns 19-32         y-coordinate(km)    _-18133.044484       F14.6
Columns 33-46         z-coordinate(km)    _-18510.756016       F14.6
Columns 47-60         clock (microsec)    _____12.734450       F14.6
Column   61           Unused              _                    blank
Columns 62-63         x-sdev (b**n mm)    __                   I2
Column   64           Unused              _                    blank
Columns 65-66         y-sdev (b**n mm)    __                   I2
Column   67           Unused              _                    blank
Columns 68-69         z-sdev (b**n mm)    __                   I2
Column   70           Unused              _                    blank
Columns 71-73         c-sdev (b**n psec)  ___                  I3
Column   74           Unused              _                    blank
Column   75           E=Clock Event Flag  _                    A1
Column   76           P=Clock Pred. Flag  _                    A1
```

```
Columns 77-78          Unused             __              2 blanks
Column  79             M=Maneuver Flag    _               A1
Column  80             P=Orbit Pred. Flag _               A1
```

If the user wishes to include correlation information between the position
components and the clock correction, then an optional Position and Clock
Correlation Record can be added after each Position and Clock Record. This
record gives the standard deviations for X, Y, Z, and clock correction with
greater resolution than the approximate values given in the Position and
Clock Record in columns 61 through 80.

> SP3 Line Twenty five in Example 2. (The Position and Clock Correlation
> Record)

```
Columns 1-2            Symbols            EP              A2
Columns 3-4            Unused             __              2 blanks
Columns 5-8            x-sdev (mm)        __55            I4
Column  9              Unused             _               blank
Columns 10-13          y-sdev (mm)        __55            I4
Column  14             Unused             _               blank
Columns 15-18          z-sdev (mm)        __55            I4
Column  19             Unused             _               blank
Columns 20-26          clk-sdev (psec)    ____222         I7
Column  27             Unused             _               blank
Columns 28-35          xy-correlation     _1234567        I8
Column  36             Unused             _               blank
Columns 37-44          xz-correlation     -1234567        I8
Column  45             Unused             _               blank
Columns 46-53          xc-correlation     _5999999        I8
Column  54             Unused             _               blank
Columns 55-62          yz-correlation     _____-30       I8
Column  63             Unused             _               blank
Columns 64-71          yc-correlation     _____21        I8
Column  72             Unused             _               blank
Columns 73-80          zc-correlation     -1230000        I8
```

The user can choose to include the optional Velocity and Clock Rate-of-
Change Record, V, after each Position and Clock Record. The clock rate-of-
change units are 10**-4 microseconds/second for cols. 47-60 below.

> SP3 Line Twenty six in Example 2.

```
Column 1               Symbol             V               A1
Columns 2-4            Vehicle Id.        G01             A1,I2.2
Columns 5-18           x-velocity(dm/s)   __20298.880364  F14.6
Columns 19-32          y-velocity(dm/s)   _-18462.044804  F14.6
Columns 33-46          z-velocity(dm/s)   ___1381.387685  F14.6
Columns 47-60          clock rate-chg     _____-4.534317 F14.6
Column  61             Unused             _               blank
Columns 62-63          xvel-sdev          14              I2
                       (b**n 10**-4 mm/sec)
Column  64             Unused             _               blank
Columns 65-66          yvel-sdev          14              I2
                       (b**n 10**-4 mm/sec)
Column  67             Unused             _               blank
Columns 68-69          zvel-sdev          14              I2
                       (b**n 10**-4 mm/sec)
Column  70             Unused             _               blank
```

```
Columns 71-73          clkrate-sdev         191                    I3
                       (b**n 10**-4 psec/sec)
Columns 74-80          Unused               _____                7 blanks
```

If the user wishes to include correlation information between the velocity
components and the clock correction rate-of-change, then a separate Velocity
and Clock Rate-of-Change Correlation Record can be added after each Velocity
and Clock Rate-of-Change Record. This record gives the standard deviations
for the X-, Y-, Z-velocities and the clock correction rate-of-change with
greater resolution than the approximate values given in the Velocity and
Clock Rate-of-Change Record.

SP3 Line Twenty seven in Example 2. - The Velocity and Clock Rate-of-
Change Correlation Record.

```
Columns 1-2            Symbols              EV                     A2
Columns 3-4            Unused               __                     2 blanks
Columns 5-8            xvel-sdev            __22                   I4
                       (10**-4 mm/sec)
Column  9              Unused               _                      blank
Columns 10-13          yvel-sdev            __22                   I4
                       (10**-4 mm/sec)
Column  14             Unused               _                      blank
Columns 15-18          zvel-sdev            __22                   I4
                       (10**-4 mm/sec)
Column  19             Unused               _                      blank
Columns 20-26          clkrate-sdev         ____111                I7
                       (10**-4 psec/sec)
Column  27             Unused               _                      blank
Columns 28-35          xy-correlation       _1234567               I8
Column  36             Unused               _                      blank
Columns 37-44          xz-correlation       _1234567               I8
Column  45             Unused               _                      blank
Columns 46-53          xc-correlation       _1234567               I8
Column  54             Unused               _                      blank
Columns 55-62          yz-correlation       _1234567               I8
Column  63             Unused               _                      blank
Columns 64-71          yc-correlation       _1234567               I8
Column  72             Unused               _                      blank
Columns 73-80          zc-correlation       _1234567               I8
```

SP3 "Last" Line (The End-of-File marker)

```
Columns 1-3            End of File          EOF                    A3
```

If no Velocity and Clock Rate-of-Change Records or Correlation Records are
present, and the number of satellites (NSAT) is less than or equal to 85,
and the number of comment lines is equal to the minimally required 4, and
the number of epochs = NEPCS, then the last line number in the file can be
computed as:

 Last Line number = 22+(NEPCS*(NSAT+1))+1 .

If no Velocity and Clock Rate-of-Change Records or Correlation Records are

present, and the number of satellites is greater than 85, and the number of comment lines (NCOMM) is greater than the required 4, then the last line # in the file can be computed (using the FORTRAN "INT" function) as follows:

Last Line number = 8+2*(INT(NSAT/17.01)+1)+NCOMM+(NEPCS*(NSAT+1))+1 .

DETAILED DISCUSSION OF THE SP3-d FORMAT

Unless otherwise noted, the line numbers used below refer to Example 1. On line one, character two is the format version identification character. This fourth SP3 version has been designated version 'd'. Subsequent versions will use lower case letters in alphabetical order. The first line comprises the Gregorian date and time of day of the first epoch of the orbit, the number of epochs in the ephemeris file (up to 9,999,999), the data used descriptor, the coordinate system used descriptor, the orbit type descriptor, and the agency descriptor. The data used descriptor was included for ease in distinguishing between multiple orbital solutions from a single organization. This will have primary use for the agency generating the orbit. A possible convention is given below; this is not considered final and suggestions are welcome.

        u   -- undifferenced carrier phase
        du   -- change in u with time
        s   -- 2-receiver/1-satellite carrier phase
        ds   -- change on s with time
        d   -- 2-receiver/2-satellite carrier phase
        dd   -- change in d with time
        U   -- undifferenced code phase
        dU   -- change in U with time
        S   -- 2-receiver/1-satellite code phase
        dS   -- change in S with time
        D   -- 2-receiver/2-satellite code phase
        dD   -- change in D with time
         +   -- type separator

Combinations such as "__u+U" seem reasonable. If the measurements used were complex combinations of standard types, then one could use "mixed" where mixed could be explained on the comment lines. In example 1, the file is a combination of orbits from several agencies and so the data used is designated as 'ORBIT'.

The Coordinate System or Reference Frame in which the satellite positions and velocities are given is described by a five character code. In the early years of the IGS, codes such as IER91, IER92, IER93, ITR94, etc. were used. More recent years have used IGS05, IGS08, and IGb08 – which are IGS realizations of the ITRF2005 & ITRF2008 reference frames, respectively. The reference frame "WGS84" is used in Example 1 to stress the fact that the satellite positions are derived from a set of broadcast ephemerides from the various GNSS constellations. In this case, the reference frames used by the GNSS may be different at the centimeter level, but the accuracy of the orbit information itself is at the meter level -- and at that level the frames can be considered coincident.

Orbit type is described by a three character descriptor. At this time only four have been defined: FIT (fitted), EXT (extrapolated or predicted), BCT (broadcast), and HLM (fitted after applying a Helmert transformation). Naturally, others are possible. The computing agency descriptor allows four characters (e.g. _NGS, _IGS, MGEX, etc.).

The second line has: the GPS week; the seconds of the GPS Week elapsed at the start of the orbit (0.0 <= seconds of week < 604800.0); the epoch interval (0.0 < epoch interval < 100000.0) in seconds; the modified Julian

Day Start (where 44244 represents GPS zero time -- January 6, 1980); and fractional part of the day (0.0 <= fractional < 1.0) at the start of the orbit.

The third line to the eleventh line (in Example 1) indicates the number of satellites followed by their respective identifiers. For the SP3-d format, the maximum number of satellites has been increased from 85 to 999. Hence there can now actually be more than five "+ " lines if there are more than 85 satellites. For the sake of backwards compatibility, if an SP3-d file has less than 85 satellites, it must still have five satellite ID ("+ ") lines. The identifiers must use consecutive slots and continue on as many lines as required. The value 0 should only appear after all the identifiers are listed (see Example 1). Satellite identifiers may be listed in any order. However, for ease in reviewing satellites included in the orbit file it is recommended that numerical order be used. Each identifier will consist of a letter followed by a 2-digit integer between 01 and 99. For example, "Gnn" for GPS satellites, "Rnn" for GLONASS satellites, "Lnn" for Low-Earth Orbiting (LEO) satellites, "Snn" for Satellite-Based Augmentation System (SBAS) satellites, "Enn" for Galileo satellites, "Cnn" for BeiDou Navigation Satellite System (BDS) satellites, "Inn" for the Indian Regional Navigation Satellite System (IRNSS) satellites, and "Jnn" for the Japanese Quasi-Zenith Satellite System (QZSS) satellites. For QZSS the nn=PRN-192 rule is applied, for example QZS-1 (PRN=193) is expressed by "J01". Other letters will be allowed for other types of satellites. Lower numbered satellites must always have a preceding zero (e.g., "G09" not "G 9"). The letter, which represents the Satellite System Indicator, must always be present (i.e.," 09" is no longer a valid satellite identifier). This is a significant change from SP3-a and needs to be noted when software is updated to read the new SP3-c or SP3-d format. A list of identifiers created for LEO satellites can be viewed at http://cddis.gsfc.nasa.gov/sp3c_satlist.html . A list of identifiers for the SBAS satellites can be viewed at: http://igs.org/mgex/status-SBAS .

The twelfth to the twentieth lines hold the orbit accuracy exponents. The value 0 is interpreted as accuracy unknown. A satellite's accuracy exponent appears in the same columns within these lines as the identifier on the satellite ID lines. The accuracy is computed from the exponent as in the following example. If the accuracy exponent is 13, the accuracy is $2**13$ mm or ~ 8 m. The quoted orbital error should represent one standard deviation and be based on the orbital error in the entire file for the respective satellite. This may lead to some distortion when orbit files are joined together, or when a file contains both observed and predicted data.

On the twenty-first line, columns 4-5 hold the File Type descriptor. This is a single character left-justified in the two-character field. The currently defined values are: "G " for GPS only files, "M " for mixed files, "R " for GLONASS only files, "L " for LEO only files, "S " for SBAS only files, "I " for IRNSS only files, "E " for Galileo only files, "C " for BeiDou only files, and "J " for QZSS only files. No default values are implied; either "G ", "M ", "R ", "L ", "S ", "I ", "E ", "C ", or "J " is required. On this same line, columns 10-12 hold the Time System Indicator. In order to remove any ambiguity with respect to which time system is being used in mixed files, this field specifies the time system used in each SP3-d file: use "GPS" to identify GPS Time, "GLO" to identify the GLONASS UTC time system, "GAL" to identify Galileo system time, "BDT" to identify BeiDou system time, "TAI" to identify International Atomic Time, "UTC" to identify Coordinated Universal Time, "IRN" to identify IRNSS Time, or "QZS" to identify QZSS Time. No default value is implied; either "GPS", "GLO", "GAL", "BDT", "TAI", "UTC", "IRN", or "QZS" must be specified.

On Line twenty-three, columns 4-13 would hold the floating-point base number used for computing the standard deviations for the components of the satellite position and velocity. Instead of using $2**nn$ as is done in the orbit accuracy lines 12-20 in the header, better resolution can be attained

using a number like 1.25**nn. The units for position and velocity are mm and 10**-4 mm/sec, respectively. Likewise, columns 15-26 would hold the floating-point base number for computing the standard deviations for the clock correction and the rate-of-change of the clock correction. Again, instead of using 2**nnn, one might use a number like 1.025**nnn (see also Example 2). The units for the clock correction and the rate-of-change of the clock correction are picosec and 10**-4 picosec/sec, respectively.

Lines 21-26 (the six lines that begin with the character "%") have been designed so that additional parameters may be added to the SP3 format.

Lines 27-31 in Example 1 are free form comments (comments go in columns 4-80). For backwards compatibility, there will always be at least 4 comment lines. These can be filled with "/* CCCCC…CCC" or with "/* ". The comment lines should be read in until the first Epoch Header Record (i.e. the first time tag line) is encountered.

Line 32 is the first Epoch Header Record, showing the epoch date/time.

Line 33 is the first Position and Clock Record; the first character is always 'P'. The positional values are in kilometers and are precise to 1 mm. A precision of 0.5 mm can be accommodated if rounding is used, i.e., the value shown is never more than 0.5 mm from the computed value. The clock values are in microseconds and are precise to 1 picosecond. Bad or absent positional values are to be set to 0.000000. Bad or absent clock values are to be set to _999999.999999. The six integer nines are required, whereas the fractional part nines are optional.

On Line 24 in Example 2, Columns 62-69 hold the two digit exponents which represent the standard deviations of the satellite coordinates in units of millimeters. For example, if the base floating point number from line fifteen is 1.25, and the two-digit exponent for the X-coordinate is 18, then the standard deviation of the X-coordinate is 1.25**18 = 55.5112 or approximately 56 mm. In a similar manner, columns 71-73 hold a three-digit exponent representing the standard deviation for the clock correction in units of picoseconds. As an example, if the base floating point number from line fifteen is 1.025, and the three-digit exponent for the clock correction is 219, then the standard deviation of the clock correction is 1.025**219 = 223.1138 or approximately 223 picoseconds. An exponent value of 99 or 999 would mean that a standard deviation was too large to represent. If a standard deviation is unknown, its field is left blank. Column 75 is the Clock Event Flag (either 'E' or blank). An 'E' flag is used to denote a discontinuity in the satellite clock correction (this might be caused by a clock swap on the satellite). The discontinuity is understood to have occurred sometime between the previous epoch and current epoch, or at the current epoch. A blank means either no event occurred, or it is unknown whether any event occurred. Column 76 is the Clock Correction Prediction Flag (either 'P' or blank). A 'P' flag indicates that the satellite clock correction at this epoch is predicted. A blank means that the clock correction is observed. Column 79 is the orbit Maneuver Flag (either 'M' or blank). An 'M' flag indicates that sometime between the previous epoch and the current epoch, or at the current epoch, an orbit maneuver took place for this satellite. As an example, if a certain maneuver lasted 50 minutes (a satellite changing orbital planes) then these M-flags could conceivably appear at five separate 15-minute orbit epochs. If the maneuver started at 11h 14m and lasted to 12h 04m, M-flags would appear for the epochs 11:15, 11:30, 11:45, 12:00 and 12:15. A maneuver is loosely defined as any planned or humanly-detectable thruster firing that changes the orbit of a satellite. A blank means either no maneuver occurred, or it is unknown whether any maneuver occurred. Column 80 is the Orbit Prediction Flag (either 'P' or blank). A 'P' flag indicates that the satellite position at this epoch is predicted. A blank means that the satellite position is observed. Since not all of the fields in columns 61 through 80 will be used at every epoch, not every Position and Clock Record will be required to contain 80 columns;

missing columns should be interpreted as blanks. Any program reading an SP3-d file must be prepared to deal with short records (either by padding with blanks, or by some other method).

Line 25 (in example 2) is the optional Position and Clock Correlation Record. This record type always begins with the characters 'EP'. Columns 5-18 give the standard deviations for the X,Y,Z satellite coordinates in units of mm. The standard deviations in this record are given to greater resolution than the approximate values given in the Position and Clock Record. A value of 9999 would mean that a standard deviation was too large to be represented. If a standard deviation is unknown, its field is left blank. Columns 20-26 give the standard deviation of the clock correction in units of picoseconds. A value of 9999999 would mean that the standard deviation was too large to be represented. Columns 28-80 are used to store the correlation coefficients for xy, xz, xc, yz, yc, and zc. Each 8-digit integer would be divided by 10,000,000 to produce a correlation coefficient between -0.9999999 and +0.9999999. If some of the correlation coefficients are omitted, a Position and Clock Correlation Record may contain less than 80 columns.

Line 26 (in example 2) is the optional Velocity and Clock Rate-of-Change Record. This type of record always begins with the character 'V'. When the position/velocity mode flag is set to 'V' in line one, then each Position and Clock Record for a satellite will be followed by a corresponding Velocity and Clock Rate-of-Change Record (although in some cases there may be a Position and Clock Correlation Record in between the two). The satellite velocity components are given in columns 5-46 in units of decimeters/second and have a precision of 10^{**-4} millimeters/second. Columns 47-60 give the rate-of-change of the clock correction in units of 10^{**-4} microseconds/second. The precision of this parameter is 10^{**-16} seconds/second. Bad or absent velocity values are to be set to 0.000000. Bad or absent clock rate-of-change values are to be set to _999999.999999. The six integer nines are required, whereas the fractional part nines are optional. In a manner similar to the Position and Clock Record, columns 62-69 hold two-digit exponents for representing the standard deviation of the X-, Y-, Z-velocities (e.g., $1.25^{**14} = 22.7374$ or approximately 0.0022 mm/sec). Columns 71-73 hold a three-digit exponent for representing the standard deviation of the clock correction rate-of-change (e.g., 1.025^{**191} = 111.7528 or approximately 0.0112 psec/sec). A value of 99 or 999 would mean that a standard deviation was too large to represent. If a standard deviation is unknown, its field is left blank. If one or more fields in columns 61 through 73 are omitted, a Velocity and Clock Rate-of-Change Record may contain less than 73 columns.

Line 27 (in example 2) is the optional Velocity and Clock Rate-of-Change Correlation Record. This type of line always begins with the characters 'EV'. Columns 5-18 give the standard deviations for the X-, Y-, Z-velocities in units of 10^{**-4} millimeters/second. The standard deviations of the velocity components are given to greater resolution than the approximate values given in the Velocity and Clock Rate-of-Change Record. A value of 9999 would mean that a velocity standard deviation was too large to be represented. Columns 20-26 give the standard deviation of the clock correction rate-of-change in units of 10^{**-4} psec/sec. A value of 9999999 would mean that the clock correction rate-of-change was too large to be represented. If a standard deviation is unknown, its field is left blank. Columns 28-80 are used to store the correlation coefficients between the velocity components and the clock correction rate-of-change (xy, xz, xc, yz, yc, and zc). Each 8-digit integer would be divided by 10,000,000 to produce a correlation coefficient between -0.9999999 and +0.9999999. If some of the correlation coefficients are omitted, a Velocity and Clock Rate-of-Change Correlation Record may contain less than 80 columns.

FINAL NOTE: Any software which reads SP3-d files must be prepared to read the 'EP' and 'EV' correlation records if they are present. If the person or agency reading the file decides that the correlation information (and the more accurate standard deviations) are not needed, then these 'EP' and 'EV' records might be simply ignored and skipped over. There may be only a few EP and/or EV records placed in an SP3-d file, i.e., it is not necessary to have EP and/or EV records for every satellite at every epoch. The only rule is: since no satellite IDs are given in the optional EP and EV records, they must immediately follow their corresponding P or V record for that satellite. The satellite order of the P, EP, V, and EV records (or subset of these) must be the same as the order of the satellite ID records (those beginning with "+ ") in the header. Thus the order and the total number of satellites at each epoch must always be the same. This serves as an integrity check on the file -- i.e., satellites must be designated as "bad" or "absent" by intentionally setting their position (and velocity) values equal to zero. There should never be any satellite's Position or Velocity records left out at an epoch. Since not all SP3-d records will contain their maximum number of columns, missing columns should be interpreted as blanks. Any program reading an SP3-d file must be prepared to deal with short records (either by padding with blanks, or by some other method).

ACKNOWLEDGMENTS

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8. The IGEX98 SP3-b format [IGEX Mail-0042, SP3 Modifications (corrigenda)] can be viewed at
http://igscb.jpl.nasa.gov/mail/igexmail/1998/msg00041.html

9. A list of identifiers for Low-Earth Orbiting satellites can be viewed at http://cddis.gsfc.nasa.gov/sp3c_satlist.html

10. A list of identifiers for Satellite Based Augmentation System (SBAS) satellites can be viewed at
http://igs.org/mgex/status-SBAS

11. Hilla, S., 2010: ORBEX: The Orbit Exchange Format, Draft Version 0.08, dated 7 May 2010. Available from ftp://ftp.ngs.noaa.gov/pub/ORBEX
See also IGS-ACS Mail, 07 May 2010, Message Number 369 (access may be limited to the IGS Analysis Center members only).

12. Montenbruck, O., 2013, Personal communication.

13. Montenbruck, O., C. Rizos, R. Weber, G. Weber, R. Neilan, and U. Hugentobler, Getting a Grip on Multi-GNSS – The International GNSS Service MGEX Campaign, pp 44-49, GPS World, July 2013.

APPENDIX A – The History of the SP3 Format

   The original Standard Product 3 format (SP3-a) was first proposed by Benjamin Remondi in (Remondi, 1989) and modified and adopted in (Remondi, 1991). The SP3 format is similar to the original NGS Standard Product 1 format described in (Remondi, 1989 and 1985) but includes additional information: satellite clock corrections, orbit accuracy exponents, comment lines, the GPS week and seconds of week associated with the first epoch, and a more flexible header structure (Spofford and Remondi, 1994).

In 1998, W. Gurtner and M. Rothacher defined an SP3-b format to allow for the combination of GPS orbits and GLONASS orbits (see IGEX Mail 0042, 27-Oct-1998). All of these SP3-b modifications were backwards compatible with SP3-a, with the exception of the satellite identification labels – which were changed from an I3 field to an A1,I2 field to accommodate both GPS and GLONASS identifiers in a manner similar to RINEX files (Gurtner, 2000).

At the 2000 International GPS Service (IGS) Analysis Center Workshop held at the U.S. Naval Observatory, it was suggested to modify the SP3 format still further so that orbit files distributed by the IGS could include some type of clock accuracy information, and so that separate accuracy information would be available for the observed versus predicted parts of the IGS ultra-rapid orbit files. Rather than just putting two sets of accuracy exponents in the header (one for the observed part and one for the predicted part) it was decided instead to put accuracy information at each epoch (for X, Y, Z, and satellite clock correction). Since the original SP3-a and SP3-b formats were only 60 columns wide, this additional information was easily added using columns 61 through 80 in each Position and Clock Record. This was done in such a way as to remain mostly backwards compatible with SP3-a. As

comments were collected from the IGS (orbit) Analysis Centers, additional ideas emerged. It was suggested that a clock event flag be added in column 75 (as currently done by some groups) to denote events like a clock swap on a satellite. It was also suggested to add an orbit event flag, to denote cases where it was known that a satellite went through some type of orbit maneuver. It was also suggested that clock prediction and orbit prediction flags be added. Finally, for the purposes of computing user range errors more accurately for each satellite, it was suggested to add correlation information between the satellite coordinates and the satellite clock correction. These ideas were discussed further at the 2002 IGS Network, Data, and Analysis Center Workshop held in Ottawa (Hilla, 2002).

All of these suggestions were incorporated in the SP3-c format. As a result, there can now be as many as three different sets of satellite position accuracy indicators in any SP3-c or SP3-d file. The first set, the original accuracy exponents in the header, have been kept in SP3-d to maintain backwards compatibility with the SP3-a format and with existing GPS processing software. These exponents are interpreted as 2**nn millimeters. A zero exponent means the accuracy is unknown. The quoted orbit error should represent one standard deviation and be based on the orbital error in the entire file for the respective satellite. The second set, in columns 62 through 69 of the Position and Clock Record, represent the standard deviation of each position component (X, Y, and Z) at that epoch, in millimeters. These are also exponents but use a floating-point base (for example, 1.25**nn) to achieve better resolution for the standard deviations. A zero exponent here represents a 1 millimeter standard deviation. Blank spaces mean the standard deviation is unknown. These first two sets of standard deviations are currently present in all IGS-produced SP3-c files.

A third set of standard deviations can be found in the optional Position and Clock Correlation Record (the EP record). This optional record was added to provide high precision users with the correlation coefficients between the X, Y, Z, and satellite clock correction values. In order to be able to construct the full 4-by-4 covariance matrix for a satellite at an epoch, without any loss of precision, the standard deviations for the X, Y, and Z position components are given here to full millimeter precision using a range of 1 to 9999 millimeters. Blank spaces mean a standard deviation or a correlation coefficient is unknown (blanks would probably only occur for the clock information, unless the EP records were being used to store only standard deviations, or only correlation coefficients).

In this document the format fields for the SP3-d format are defined. These include all of the changes made for SP3-c. The fields that are defined as "blanks" are reserved fields which must remain blank. All times referred to in an SP3-d file are in the SAME time system, even when they are represented as Gregorian Dates or Modified Julian Dates. In SP3-d, the Time System code for the entire file (GPS, GLO, GAL, BDT, TAI, QZS, or UTC) is now specified in the header on line thirteen. The information to convert between GPS Time and Coordinated Universal Time (i.e., the leap seconds and the fractional error in GPS Time) is not provided as part of the SP3 format. The basic format of an SP3 file is a Header, followed by a series of epoch times each with a set of Position and Clock Records listed for each satellite. A second, optional record contains satellite velocities and the clock correction rate-of-change. The Position Record Flag, P, in line one, column 3, indicates that no velocities are included. A Velocity Record Flag, V, in line one indicates that at each epoch, for each satellite, an additional satellite velocity and clock rate-of-change has been computed. SP3-c added two more optional records: a Position and Clock Correlation Record (EP record), and a Velocity and Clock Rate-of-Change Correlation Record (EV record).

APPENDIX B - Modification History of the SP3-c and SP3-d Formats

Note: The original SP3-c format document was dated 5 September 2002.

Note: The IGS began using the SP3-c format for Rapid and Ultra Rapid Products from GPS week 1285.1, and for Final Products from week 1283. See IGSMAIL-5000 sent by Gerd Gendt on 27 August 2004. The new files had the extension ".sp3c". For a time, both the SP3-a and the SP3-c files were made available.

Note: Beginning on 29 January 2006, the IGS made their precise ephemeris files available only in the new SP3-c format.

Note: On 27 September 2006, the sp3c.txt file was updated slightly to add more options for the Time System Indicator. The original version had only "GPS" and "UTC" as options for the Time System Indicator. This new version adds codes "GLO", "GAL", and "TAI". Also, clarifications were made regarding the EP and EV records, and the order of the satellites and records at each epoch.

Note: On 12 February 2007, the sp3c.txt file was modified to include a reference to a new list of LEO satellites available at CDDIS (see the documentation below regarding the satellite identifiers found in the third through seventh lines).

Note: On 17 August 2010, the sp3c.txt file was modified to add satellite system identifiers for J = QZSS and C = COMPASS, and to add "QZS" as a Time System indicator for QZSS Time.

Note: On 8 August 2013, the first draft version of SP3-d was written. This version increases the maximum number of satellites from 85 to 999, allows for unlimited comment records, and increases the length of the comment records from 60 characters to 80 characters. Additional Satellite ID letters were added for Satellite-Based Augmentation System (SBAS) satellites, and for the Indian Regional Navigation Satellite System (IRNSS) satellites: "S" and "I", respectively.

Note: On 17 September 2013, BeiDou system time (BDT) was added and all references to "COMPASS" were deleted.

Note: On 15 January 2016, IRNSS system time (IRN) was added, several URL links were updated, and a few clarifying statements were added. [This third draft version of SP3-d was then sent to the IGS Analysis Centers for comments].

Note: On 21 February 2016, following the adoption of SP3-d by the Multi-GNSS Working Group at the 2016 IGS Workshop in Sydney, Australia, minor grammatical corrections were made, and the word DRAFT was removed from the title.