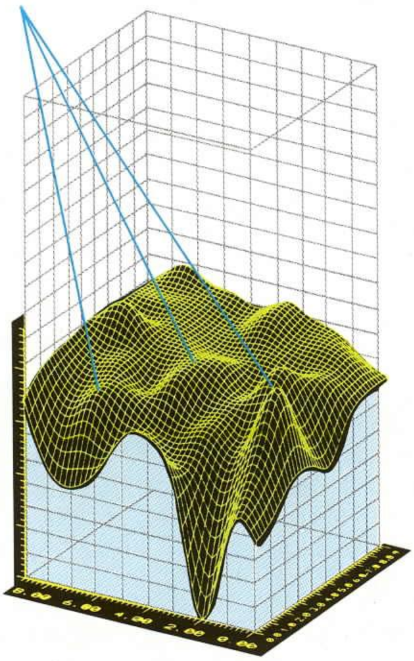

NMEA 0183: A GPS Receiver Interface Standard

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The world of GPS receiver interfaces and data formats is a veritable alphabet soup of acronyms: RS-422-A, RTCM SC-104, AX.25, ARINC 429, TTL, PCMCIA; the list goes on and on. One acronym that has generated a lot of recent interest is NMEA 0183. It is the name of the standard developed by the National Marine Electronics Association for interfacing marine electronic devices, and it has become a standard interface for GPS receivers whether they're used at sea, on land, or in the air. In this month's column, we'll take a brief look at this interface standard and overview its electrical characteristics, data types, and data formats.

"Innovation" is a regular column in GPS World *featuring discussions on recent advances in GPS technology and its applications as well as on the fundamentals of GPS positioning. The column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, and we appreciate receiving your comments as well as suggestions of topics for future columns.*

Most GPS receivers are self-contained units. Within a single enclosure, they typically include the radio and digital circuitry necessary to receive and track the GPS signals, the microprocessor to control all aspects of the receiver's operation, a keypad or touch panel to accept user inputs, and a display of some kind to show what the receiver is doing and indicate the receiver's position, velocity, and heading, as well as other ancillary information. The power supply and antenna may also be in the same package. Such single-unit, autonomous receivers are very convenient especially for applications in which small size and portability are desirable features. However, there are some applications in which it would be useful to store the receiver's position, velocity, or heading externally for record keeping or subsequent analysis or to pass this information on to other devices for display, integration with additional sensor readings, or other purposes. To store data externally, the receiver has to have a communications port and a particular protocol to transfer the data. Each manufacturer of such equipment could devise its own encoding procedure, data rate, signal level, and message format. This could make the connection of equipment from different vendors quite difficult.

In the early 1980s, the National Marine Electronics Association (see NMEA sidebar on page 55) recognized the need for an interface standard to permit easily implemented and reliable data communication among electronic marine instruments, navigation equipment, and communications equipment. NMEA struck a committee to develop the standard that has become known as the NMEA 0183 Standard for Interfacing Marine Electronic Devices. The NMEA committee identified GPS receivers as one type among the different groups of equipment that could adopt the standard, and, in response, most manufacturers have provided their GPS receivers with a data communications port that conforms to the NMEA standard. The standard, as implemented for GPS receivers, has been made sufficiently general that it is finding wide use for nonmarine applications as well as in the marine environment for which it was originally developed.

ELECTRICAL CHARACTERISTICS

The standard is based on the concept of "talkers" and "listeners." A talker is any device, such as a GPS receiver, that sends data to other devices. A listener is any device, such as a computer, that receives the data. The standard is intended to support one-way serial data transmission from a single talker to one or more listeners over a pair of wires: signal lines "A" and "B."

NMEA 0183 data transmissions use plain text with the characters coded using seven-bit ASCII (American Standard Code for Information Interchange). Only ASCII characters with decimal numbers 10 (line feed), 13 (carriage return), and 32 through 126 are valid. To make full eight-bit data bytes, an additional bit is added to each seven-bit character and set to binary 0.

NMEA 0183 data are transmitted in serial, asynchronous form. *Serial* means bits are sent one at a time with one bit following the next. When the bits arrive in series, we need an unambiguous way to separate or delimit them. One method is for the transmitter and receiver to be synchronized using special timing signals. Such synchronous transmission, although it can provide very fast data communications, requires special equipment to provide the timing signals. A simpler approach is to include additional bits in the data transmission to indicate the beginning and end of each character. These start and stop bits frame each character in the transmission. The NMEA standard uses only one stop bit (some formats use one-and-a-half or two stop bits — actually one bit but with the duration of one-and-a-half or two data bits). Some serial asynchronous formats insert a parity bit before the stop bit(s) to detect transmission errors. NMEA 0183 doesn't use parity bits with each character. Instead, another technique, which will be described later, is used to check for errors.

The binary bits making up the signal are transmitted by changing the voltage between the signal lines. Most asynchronous, serial transmissions use a bit-encoding technique known as *NRZ-L* or nonreturn-to-zero level. With NRZ-L, one voltage level indicates a binary 1, and another voltage level indicates a binary 0. The voltage level is constant during a bit interval, and there is no transition interval between bits (no return to a zero voltage level). The NMEA standard specifies that the signal levels indicating a binary 1 or 0 should conform to the Electronics Industries Association's RS-422-A (subsequently termed EIA 422-A) standard, which specifies a two- to six-volt signal. A binary 1 is indicated by a negative voltage on line "A" with respect to line "B" and a binary 0 by a positive voltage. For a margin of safety and compatibility with some earlier interface designs, listeners should be capable of withstanding an applied voltage of 15 volts.

NMEA 0183 data are transmitted at a rate of 4,800 bits per second (bps). This is one instance in data communications in which the bit rate and the modulation rate of the signal are identical. The modulation rate is the rate at which the signal level is changed, which depends on the type of digital encoding used. The modulation rate is expressed in *bauds*, which means *signal elements per second*. With NRZ-L encoding, each signal element contains one bit. High-speed modems used for data communication over telephone lines, for example, use encoding techniques that pack as many as eight or more bits into each symbol. In this way, they can achieve a data rate of 28,800 bps, while their modulation rate is only 3,200 baud.

Note that the datalink protocol of the NMEA 0183 standard is fully compatible with the RS-422-A standard used for the serial port of some computing devices. A direct connection between a navigation device and such a serial port is possible, but for noise immunity, NMEA recommends the use of an optoisolator between talkers and listeners. (An optoisolator, sometimes called an optocoupler, is an integrated-circuit device that uses a light-emitting diode and a phototransistor to provide an optical, rather than an electrical, interface between two electronic circuits. The circuits, which might operate at different voltage levels, are therefore electrically isolated.) Note that the NMEA 0183 standard is not fully compatible with the older RS-232-C standard. For one thing, RS-232-C is designed for data communications over short distances using unbalanced signal lines. For another, the RS-232-C standard specifies that the absolute signal voltage level be at least five volts with respect to signal ground. However, it is possible in most cases to use a computer's RS-232-C serial port to receive NMEA 0183 data streams, although signal level conversion sometimes may be required.

DATA FORMATS

Data are sent from a talker to a listener in the form of sentences with a maximum length of 82 characters. Each sentence begins with the starting delimiter "$" (dollar sign) and is terminated with a <CR><LF> (carriage return, line feed) delimiter. A sentence contains a number of fields made up of an address field identifying the talker and sentence formatter, zero or more data fields, and an optional (for most sentences) checksum field for data transmission error detection. Each field, with the exception of the address and checksum fields, is preceded by a comma delimiter.

The address field consists of five characters. The first two identify the type of talker. For example, a GPS receiver is identified as GP. There are 38 different identifiers, ranging from AG for a general autopilot to WI for weather instruments. The last three characters in the address field are the sentence formatter mnemonic code identifying the particular data type being transmitted. At the present time, there are 60 approved sentence types.

The data fields contain all of the data transmitted in a sentence. Each sentence has a specified number of fields, some of which may be of variable length. If data for a particular field are unavailable or unreliable, a null field of length zero is substituted.

The checksum field is compulsory for only a few sentences. It is a two-character field beginning with an asterisk ("*"). The remaining two characters are the hexadecimal value of the modulo two addition (exclusive OR-ing) of the eight data bits of each character in the sentence between the "$" and "*" delimiters.

Of the currently approved 60 sentence types, nine are specific to GPS receivers. They are

- ALM — GPS almanac data
- GBS — GPS satellite fault detection
- GGA — GPS fix data
- GRS — GPS range residuals
- GSA — GPS DOP (dilution of precision) and active satellites
- GST — GPS pseudorange noise statistics
- GSV — GPS satellites in view
- MSK — MSK (minimum-shift keying) receiver/GPS receiver interface and
- MSS — MSK receiver signal status

The ALM sentence contains the GPS week number and the health and complete almanac data for one satellite in hexadecimal format using the same scaling factors and units of the broadcast navigation message. To cover all satellites in the constellation, a GPS receiver will transmit multiple sentences, one for each satellite. Each sentence, therefore, also contains the total number of ALM sentences being transmitted and the sequence number of the current one.

The GBS sentence is used to report GPS receiver autonomous integrity monitoring (RAIM) information. It contains the UTC (Coordinated Universal Time) of the GGA fix associated with this sentence; the expected position errors; and the PRN number, probability of missed detection, and estimate of bias and its standard deviation of the most likely failed satellite.

The GGA sentence contains the UTC and coordinates of a GPS fix, an indication of

National Marine Electronics Association

At the 1957 New York Boat Show, a group of electronics dealers got together to discuss how to strengthen their relationships with equipment manufacturers. The National Marine Electronics Association (NMEA) was an outgrowth of that meeting. Over the past 38 years, NMEA has evolved into a professional trade association serving all segments of the marine marketplace, including merchant shipping, commercial and sports fishing, offshore oil exploration and production, and recreational boating. Its members are drawn from all segments of the marine and electronics industries including manufacturers, dealers, boat builders, component suppliers, government agencies, and educational institutions, among others.

NMEA is involved in many activities in support of its membership and the general public. Most visible among these — at least from the public's perspective — has been the development of the only uniform interface standard for digital data exchange between different marine electronics devices — the subject of the accompanying article. Another NMEA development with significant impact on the boating public is the Certified Marine Electronics Technician program. This program, introduced in the early 1980s, has established minimum standards of technical competence for technicians and provides a mechanism for testing and certifying them. Other NMEA activities include working closely with the Radio Technical Commission for Maritime Services to monitor government policy making, to inform NMEA members of significant policy developments, and to encourage legislation beneficial to its membership; maintaining an awards program designed to recognize individuals for significant contributions in the marine electronics field; and publishing a series of guidebooks covering different aspects of marine electronics. NMEA also publishes a bimonthly magazine, *Marine Electronics, The Official Journal of the NMEA,* and hosts an annual meeting, where members present and demonstrate the latest technological developments and offer workshops and training seminars. Educating the public in safe and proper use of marine electronics is a primary goal of the association.

Further information on NMEA, its services, and its publications can be obtained from Cathryn C. Moyer, NMEA Executive Director, 7074 Bembe Beach Road, Suite 203, Annapolis, MD 21403, USA, (410) 263-1742, fax (410) 263-1743.

whether it was obtained using a stand-alone receiver or a differential GPS (DGPS) unit, the number of satellites used to compute the fix, the horizontal DOP, the height of the geoid above the geodetic reference ellipsoid at the fix location, and, if it is a DGPS fix, the age of the last DGPS correction message.

The GRS sentence supports RAIM. It includes the UTC of the associated GGA fix, the range residuals for the satellites used in the navigation solution, and a flag identifying the procedure used to calculate the residuals (either before or after the GGA fix computation).

The GSA sentence contains information on the GPS receiver operating mode (whether it is forced to operate in two-dimensional [2D] or three-dimensional [3D] mode or allowed to switch between 2D and 3D automatically and whether the receiver is currently in 2D or 3D mode), the PRN numbers of the satellites being used to compute fixes, and the position, horizontal, and vertical DOPs.

The GST sentence also supports RAIM. Along with the UTC of the associated GGA fix, it includes various statistics related to the pseudorange measurement noise.

The GSV sentence gives the number of satellites in view, and, for each satellite, its PRN number, elevation, azimuth, and signal-to-noise (carrier-to-noise-density) ratio. Data on as many as four satellites may be included in a GSV sentence. Additional satellite data are sent in a second sentence and, if necessary, a third. Each sentence includes the total number of GSV sentences being transmitted in the sequence and the sequence number of the current message (1, 2, or 3).

The MSK and MSS sentences are designed for use with DGPS radiobeacon receivers. These receivers decode the MSK modulated DGPS signals transmitted by certain direction-finding radiobeacons. The MSK sentence is used by a GPS receiver to command a radiobeacon receiver or by the radiobeacon receiver to announce its current operating status. It includes the radiobeacon frequency, the radiobeacon data bit rate, flags for automatic or manual selection of frequency and bit rate, and the interval at which MSS sentences should be transmitted. The MSS sentence is used by a radiobeacon receiver to report the frequency to which it is tuned, the signal strength and signal-to-noise ratio of the received signal, and the received data bit rate.

Another sentence of interest to GPS users is the DTM — datum reference sentence — which is likely to be added to the NMEA 0183 standard this summer. It indicates the datum used for reporting position fixes. It will use a three-character code to identify a particular datum with a one-character country subdivision code.

The NMEA 0183 standard recommends that GPS receivers transmit, at a minimum, the following two sentence types:

- RMB — recommended minimum navigation information

  and
- RMC — recommended minimum specific GPS/Transit data

The RMB sentence contains the recommended minimum navigation information from any navigation device, including a GPS receiver or an integrated navigation system. It includes cross-track error, direction to steer, identification of origin and destination waypoints, the range and bearing to the destination, and indications of a navigation receiver warning and whether a certain "arrival distance" from the destination waypoint has been reached. The checksum is mandatory for this sentence.

The RMC sentence contains the UTC date and time, the latitude and longitude of the position fix, the speed over ground, the course over ground with respect to "true" (astronomical) north, and the magnetic declination. The checksum is also mandatory for the RMC sentence. This sentence is transmitted at intervals not exceeding two seconds and is always accompanied by an RMB sentence when a destination waypoint is active.

A GPS receiver may also transmit additional sentence types such as

- GLL — geographic position (latitude/longitude)
- VTG — course over ground and ground speed
- ZDA — time and date

  and
- ZTG — UTC and time to destination waypoint

To illustrate the general structure of NMEA 0183 sentences, a description of the format of the GLL sentence is given in Figure 1, along with an example of a GLL sentence received from a GPS receiver. This sentence was transmitted at 17 hours, 30 minutes, 37.0 seconds UTC when the GPS receiver was at a latitude of 45 degrees, 57 minutes, 1.46499 seconds, north, and a longitude of 66 degrees, 38 minutes, 30.786582 seconds, west.

The standard allows for proprietary sentences, which may be used by the equipment of certain manufacturers. Such sentences have a proprietary address field of four characters where the first character is the letter "P" followed by a three-character manufacturer's mnemonic code.

A device may request a talker to transmit an approved sentence by issuing a query sentence on a separate bus (pair of wires) from that used by the talker to transmit data. A query sentence has the form

```
$aaaaQ,ccc*hh<CR><LF>
```

where the first "aa" pair identifies the requester, and the second "aa" pair identifies the talker. "Q" is the query character, "ccc"

```
$               Start of sentence
--GLL           Approved address field
,llll.ll        Latitude (where ll are 2 fixed digits of
                degrees, ll are 2 fixed digits of minutes,
                and ll represents a variable number of digits
                for the decimal fraction of minutes)
,a              N/S
,yyyyy.yy       Longitude (as for latitude except with 3
                fixed digits for degrees)
,a              E/W
,hhmmss.ss      UTC of position (where hh are 2 fixed digits
                of hours, mm are 2 fixed digits for minutes,
                and ss.ss are 2 fixed digits for seconds and
                a variable number of digits for the decimal
                fraction of seconds)
,A              Status: A = data valid
*hh             Optional checksum
<CR><LF>        End of sentence

Example:
$GPGLL,4557.0244165,N,06638.5131097,W,173037.0,A*27
```

Figure 1. The NMEA 0183 GLL sentence contains the time-tagged horizontal coordinates (latitude and longitude) of a position fix determined by a navigation device such as a GPS receiver.

identifies the particular sentence being requested, and "*hh" is an optional checksum delimiter and field. A reply to a query is not mandatory, and the time delay between the receipt of the query and the transmission of the reply is not specified.

The time required to transmit a sentence shall not exceed one second, and, according to the standard, it should not be necessary to transmit sentences more frequently than once per second.

Note that the NMEA 0183 protocol implemented by some GPS receiver manufacturers may deviate slightly from the standard. For example, the GGA sentence may not include the geoid height or may provide it with the opposite sign to the standard. GPS users should consult their receiver manuals for the description of each NMEA 0183 sentence as implemented, including any proprietary sentences.

SOFTWARE

Most manufacturers of GPS receivers with an NMEA 0183 data port provide software to record, display, and interpret the data sentences. Software is also available from third parties, including programs that display receiver coordinates on moving-map displays. A simple computer communications program, once it is properly configured, can be used to display NMEA 0183 sentences as received from a GPS receiver. Figure 2 shows a fragment of BASIC code that will achieve the same result.

APRS — Automatic Packet Reporting System — is an interesting shareware software package that uses the NMEA 0183 standard (specifically, the GGA, GLL, RMC, and VTG sentences) to relay GPS receiver coordinates, in real time, over amateur radio packet networks. Software is included to display the coordinates on maps with a variety of scales. Figure 3 illustrates one such map. Packet controllers that interface directly to a GPS receiver through its NMEA 0183 port are also available.

Another interesting use of the NMEA 0183 standard is for the Totally Accurate Clock (TAC) project developed by Dr. Tom Clark of the National Aeronautics and Space Administration for the space geodesy and amateur radio communities. A relatively inexpensive GPS receiver is used to provide timing precisions of 50 nanoseconds or better. The software associated with the TAC uses the GGA, GSA, GSV, and ZDA sentences.

```
CLS
OPEN "COM1:4800,N,8,1,ASC" FOR INPUT AS #1
BEGIN:
INPUT #1, A$
PRINT A$;
GOTO BEGIN
```

Figure 2. This fragment of BASIC programming language code will allow a computer to receive and display the NMEA 0183 sentences it receives at its COM1 serial communications port.

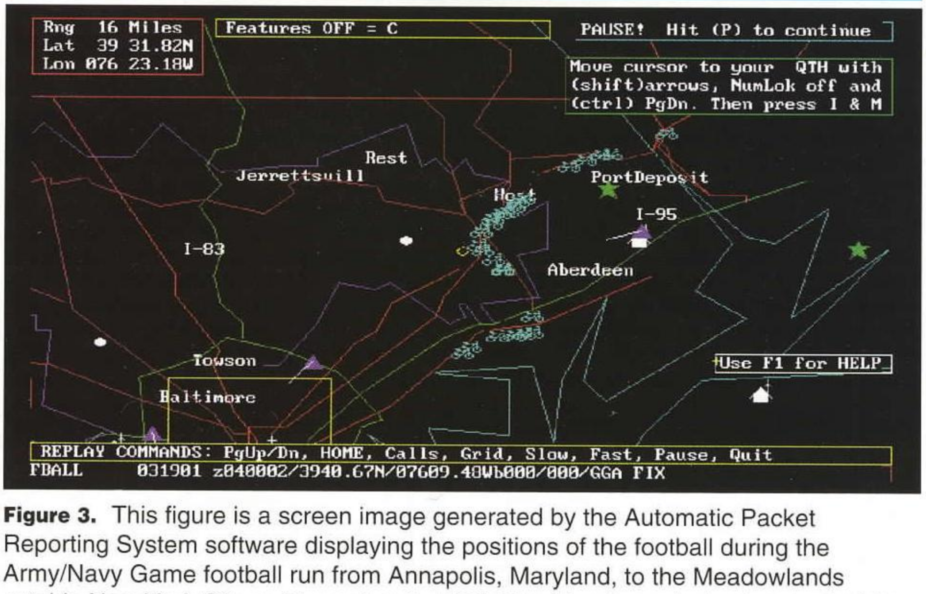

Figure 3. This figure is a screen image generated by the Automatic Packet Reporting System software displaying the positions of the football during the Army/Navy Game football run from Annapolis, Maryland, to the Meadowlands outside New York City on December 3, 1993. The bicycle symbols show part of the path followed by the GPS-equipped football pedalers as relayed over amateur radio packet stations.

CONCLUSION

In this article, we have briefly summarized the features of the NMEA 0183 interface standard and how it is used with GPS receivers. A complete description of the standard is available from the National Marine Electronics Association at the address given in the sidebar on page 55.

ACKNOWLEDGMENTS

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Further Reading

The official document describing the NMEA 0183 standard is

■ *NMEA 0183 Standard for Interfacing Marine Electronic Devices,* Version 2.01, 1994.

For a case history of interfacing electronic equipment using the NMEA 0183 standard, see

■ "Understanding Marine Electronics Interfacing: The Promise, the Problems," by W. Simpson, in *Mainsheet,* the Catalina and Capri Owners Association magazine, May 1991. This article is available, with the author's permission, through the Internet, along with additional NMEA 0183–related information files and software programs, from the following World Wide Web page

■ <ftp://sundae.triumf.ca/pub/peter/index.html>

For a description of the GPS navigation message almanac format, see

■ *Interface Control Document, Navstar GPS Space Segment/Navigation User Interfaces, ICD-GPS-200,* public-release version published by ARINC Research Corp., Fountain Valley, California, July 1991.

For further information on the Automatic Packet Reporting System, see

■ "Automatic Packet Reporting System (APRS)," by R. (Bob) E. Bruninga, in the proceedings of the 13th ARRL Digital Communications Conference, held in Bloomington, Minnesota, in August 1994, publication no. 186 of the Americal Radio Relay League, Newington, Connecticut, pp. 5–11.

For further information on the Totally Accurate Clock, see

■ "Low-Cost GPS Time Synchronization: The Totally Accurate Clock," by T.A. Clark, a paper to be presented at the XXI General Assembly of the International Union of Geodesy and Geophysics, Boulder, Colorado, in July 1995.

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