



From cell phones to PDAs to cars: unleashing GPS for the masses

Highly integrated chip sets, such as the ST20-GP1 from STMicroelectronics, track orbiting satellites and provide precise location, velocity, and time.

In a quest for ubiquitous GPS deployment, IC vendors have a multipronged approach to proliferate the technology. Higher integration is lowering the cost of stand-alone receivers and making GPS a viable peripheral, even for PDAs, and a melding of technologies will ultimately yield GPS-enabled cell phones and other consumer devices.



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At first glance, you might consider Global Positioning System (GPS)-IC technology to be relatively stagnant, but, truth be told, IC vendors are furiously pursuing long-term plans to horizontally integrate GPS and other functions. Just a few years ago, vendors sold almost all GPS ICs via turnkey modules. Today, even designers that lack RF experience can design GPS ICs into a system. Moreover, proposed standardized software layers could make interacting with the ICs even easier. Whether you design PCs; embedded systems; handheld computers; automobile systems; or wireless devices, such as cell phones, keep your eye on GPS, because some of your customers will want this technology.

Note that if you've used GPS in the past, you might need to revisit any installed systems. The infamous Y2K problem can adversely affect GPS receivers. Of perhaps more importance, however, is that GPSs face a GPS-specific, date-related

problem next August. The system will complete its first 1024-week epoch, and some receivers could report inaccurate date and position information because of such issues as Y2K and end-of-week (EOW) rollover (**sidebar** "GPS receivers tackle Y2K and EOW-rollover issues").

The emerging GPS-IC market

About 18 months ago, *EDN* covered the birth of the GPS-IC industry (**Reference 1**). Around that time, vendors began offering GPS in chip form. Before that, the combined complexity of GPS implementations resulted in manufacturers with GPS expertise offering turnkey GPS modules. A GPS receiver requires a complex RF front end; a real-time, multi-channel, spread-spectrum correlator that can track eight to 12 satellites; and a computation function that can take the incoming satellite data and calculate time, position, and velocity. Unless you are familiar with the GPS industry, take

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the time to review **Reference 1**. (You can find it in *EDN's* archives at www.ednmag.com.) The **reference** summarizes the GPS-IC vendors and details pertinent points of comparison. For other GPS background, see Trimble's Web site (www.trimble.com) and Red Sword Corp's site (www.redsword.com/gps). Nobody appears to regularly maintain the Red Sword site, but it includes a wealth of information, including a slightly dated list of GPS-equipment manufacturers.

So why, you may ask, will GPS have such far-reaching appeal—even in embedded systems? For starters, it's cheap. Handheld receivers already sell for as little as \$100 at discount. They provide position data that's vital to many professionals and hobbyists. The price even makes using a receiver as a clock viable; combined with more expensive time and frequency references, these receivers can provide accuracy approaching that of an atomic clock (see **sidebar** "GPS enables precision time references"). A key FCC mandate in the United States could well further accelerate GPS technology into our

@a glance

- Furious GPS activity centers on alliances with PC and consumer-electronics companies.
- GPS receivers could be susceptible to Y2K and GPS-specific date problems.
- Because of RF complexity, you won't see a cost-effective single-chip receiver.
- One IC and one RF module can constitute a complete GPS receiver and can host a custom application.

everyday lives. This mandate will likely force manufacturers of cell phones to include a GPS receiver in each phone by 2001 (for more information, see **sidebar** "E911 mandates precise cell-phone location").

Engineers that need to design a GPS receiver into a product can turn to a growing list of vendors. GEC Plessey, Motorola, Philips Semiconductor, Rock-

well Semiconductor, STMicroelectronics (formerly, SGS-Thomson Microelectronics), and SiRF Technology remain key players in GPS ICs. Trimble also has GPS-IC technology, although customers know the company more for its Trimble-brand modules and receivers. Analog Devices has also joined the fray with reference designs and software that turn its DSPs into GPS receivers. In fact, all DSP vendors, such as Texas Instruments (www.ti.com) and Lucent Technologies (www.lucent.com) are potential players down the road.

Even though only a handful of new GPS ICs have appeared in the last 18 months, GPS-IC companies have been busy trying to fit their technology into a viable product category. Moreover, it's clear that alliances have become important, tying GPS expertise to fab and distribution specialists, GPS-IC companies to the PC community, and GPS-IC companies to consumer-electronics companies, such as cell-phone manufacturers. Consider the newer GPS products, the alliances, and an evolving group of application



E911 MANDATES PRECISE CELL-PHONE LOCATION

In the United States, the FCC has been working on Enhanced 911 (E911), a new mandate for wireless phones. Like today's land-line 911 emergency calls, future wireless 911 calls will automatically transmit the caller's location to the emergency-dispatch center that takes the call. The FCC is now phasing in this capability by transmitting cell-site location with the call. By Oct 1, 2001, however, the E911 system must pinpoint a caller's location to within 125 ft. For more information on this mandate and ongoing updates, changes, and news, go to www.fcc.gov and search for data on docket number 94-102.

Cellular-service providers and phone manufacturers are exploring several options for delivering E911 capabilities. Presumably, when three or more sites are in range of a handset, a cellular system could calculate a position based on strength, time of arrival, and angle of arrival of a handset signal. Such a system would still require a Global Positioning System (GPS)-based precision clock, such as those discussed in the **sidebar** "GPS enables precision time references." Using such a system could eliminate any changes to cellular handsets. But the scheme also presents some problems. Cellular users aren't always within range of three cells. Moreover, the mixture of analog and digital cellular schemes working in two frequency bands would complicate the logistics. CDMA systems, in particular, could prove problematic, because the interference-limited spread-spectrum scheme varies

transmitting power based on the distance between a handset and a cell site. Even if the systems solve all of the technical issues, E911 systems based on triangulation will still require a significant investment by cellular-service providers. The cost could be as much as hundreds of thousands of dollars per cell site and billions of dollars nationwide.

Three approaches to E911 that use GPS receivers inside handsets have also emerged. To minimize handset costs, phone companies could integrate a simple GPS correlator and analog front end in each handset. The handset could transfer the raw GPS data to a cell site for processing. The second approach adds a more complete GPS receiver to the handset but still relies on a GPS receiver in the cell site for the ephemeris, or satellite-position data. This approach allows a phone to quickly lock onto the satellite signals. The final approach would embed a fully functional GPS receiver in each cell phone.

GPS-IC companies are betting that the receiver will move into the phone and any additions in cell-site infrastructure will only augment the handset position data. In fact, companies such as SiRF claim that the capability will enable cellular-service providers to offer new types of service, such as real-time traffic data, fleet management, and child/elderly-location services. For a summary of the E911 problem, contact SiRF and ask for its technology white paper, "FCC's E911 Mandate."

GPS ICs

categories to see how you can best deploy GPS.

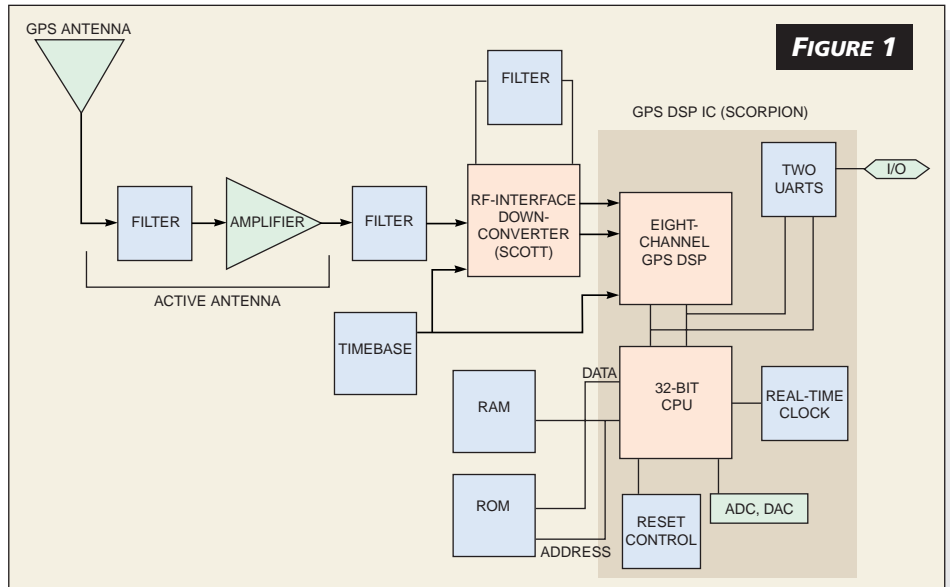
Vendors target three classes. Start with determining where vendors target their ICs and how those targets have changed. Until now, most GPS receivers have been GPS-centric. In other words, designers of marine GPS receivers aim them at the GPS task, and vendors sell them for navigation. The model is changing. Today, IC vendors can target three application scenarios:

- GPS as a peripheral to a PC, personal digital assistant (PDA), or auto PC;
- GPS melded into another product, such as a cell phone, wireless modem, or wireless-LAN adapter; and
- a traditional GPS-centric device, albeit one that could also execute some additional

custom applications in embedded systems.

No single GPS-chip-set architecture can efficiently and cost-effectively serve

in each of these scenarios. In fact, no single chip set can best serve all the applications that fit within any one of the three segments. For example Trim-



The Sierra chip set from Trimble Navigation includes an RF front end and a digital IC that integrates a correlator and a μ C.

GPS RECEIVERS TACKLE Y2K AND EOW-ROLLOVER ISSUES

Like many μ P-based devices, Global Positioning System (GPS) receivers may be susceptible to malfunctions come the end of 1999. The much-discussed Y2K bug caused by two-digit representation of the year in computer calendars could, at best, cause a GPS receiver to output an erroneous date. At worst, the date error could significantly degrade the accuracy of the position data that the receiver calculates. Moreover, GPS receivers have a second date-based problem that will precede the Y2K event. Called the "end-of-week" (EOW) or "week-number rollover" (WNRO), the problem is that GPS satellites will reset the calendar back to time 0 at midnight on Aug 21, 1999.

Most likely, you're familiar with the Y2K event, but the GPS EOW event may merit more detail. The problem isn't inherent in the way GPS operates; rather, some equipment is not designed to fully meet the GPS spec. The GPS calendar started at time 0 at midnight on Jan 5, 1980. The satellites transmit an offset from that date rather than transmitting an absolute date. The GPS week field increments using a modulo 1024 count, so, slightly less than 20 years after it began operation, the week count will go to 0. Properly designed receivers will record the end of the first epoch on Aug 21, 1999, and will start updating the date based on an offset of epochs plus weeks. In other words, a similar event will occur every 1024 weeks, or about every 20 years.

You might wonder why a date error is critical in a GPS receiver that aims primarily to deliver position data. For

starters, many people use GPS receivers as precision time references. But correct date and time are also critical in accurate position calculations. The calculations depend on precise knowledge of the position of orbiting satellites that obviously varies with time.

So, how might the Y2K and EOW events affect you? You probably needn't worry about new GPS designs, because the ICs and modules that vendors sell now are largely prepared for both events. However, installed receivers—in applications from navigation to surveying to custom embedded systems—merit an evaluation. More than likely, you'll need to contact the manufacturer of the receiver, module, or chip set in question to find out whether the date-based events will cause errors. Trimble Navigation has a section on its Web site (www.trimble.com/y2kwnro/index2.htm) dedicated to the events. Trimble is a leading manufacturer of both Trimble-brand receivers and OEM ICs and modules. The Web site includes a table that specifies each of the company's products as compliant, upgradable, or noncompliant.

You can also get more information on the Y2K and EOW events and on how they might affect GPS systems from several government Web sites. The US Air Force site (www.laafb.af.mil/SMC/CZ/homepage/y2000/index.html) details military concerns. The US Coast Guard site (www.navcen.uscg.mil/gps/geninfo/y2k/) details potential problems and solutions for civil receivers and provides a contact list for manufacturers of GPS receivers.

GPS ICs

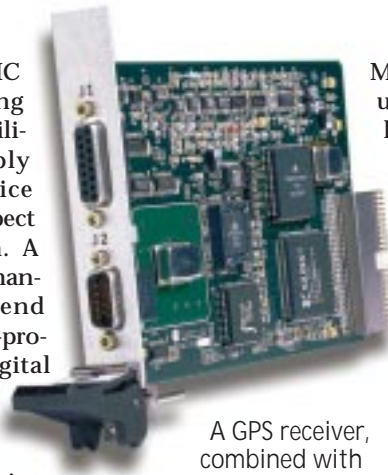
ble's Sierra chip set maps into a GPS-receiver design (Figure 1). The chip set is among the most highly integrated: It combines a the eight-channel GPS DSP correlator with a μ P in one IC. The μ P performs position and time calculations based on raw data derived by the correlator.

The Sierra approach targets the GPS-centric application. In fact, the embedded 68330 μ P likely has little bandwidth to handle a custom application in addition to the GPS calculations. The correlator capabilities are also fixed at eight channels. In reality, eight channels should be more than enough for handheld GPS receivers or even marine-navigation receivers. Some precision applications, such as surveying, however, require 12-channel receivers. STMicroelectronics offers the ST20-GP1, which combines a 12-channel correlator with a 32-bit RISC μ P. Philips offers the SC1575 with an eight-channel correlator and an 8051 μ C.

A single-chip GPS receiver would better serve GPS-centric applications, espe-

cially low-end ones. IC vendors with strong mixed-signal capabilities could probably build such a device today, but don't expect one anytime soon. A process that could handle the RF-front-end needs would be cost-prohibitive for the digital section of such a chip. Moreover, even the Trimble RF front end requires external analog components for filters and amplifiers.

Motorola, however, has moved one step closer to a totally integrated approach. In September, the company introduced the RF Oncore—a $24 \times 40 \times 10$ -mm module that contains the entire RF front end. You can mount the RF Oncore on a circuit board just as you would an IC and can sweep together all of the analog components.



A GPS receiver, combined with frequency reference boards, such as these Datum products, can provide time with 100-nsec accuracy.

Manufacturers of high-volume GPS products that have internal RF experience may prefer to design their own RF front ends at the component level. Conversely, RF Oncore allows anyone to do a GPS design regardless of RF experience. Embedded-system designers will find the module useful, and even high-volume manufacturers may prototype with the module.

In even better news for embedded-system designers, Motorola

this month introduced a companion digital chip that combines a 12-channel correlator with an MCore RISC μ C. The MMC-2003 IC includes all of the features of the MC2001 μ C, including a 16-MHz, 15-MIPS core; 32 kbytes of SRAM; and a variety of peripherals. Together, the MMC2003 and PSRF-

GPS ENABLES PRECISION TIME REFERENCES

Only a few years ago, engineers struggled to synchronize and maintain time sources in projects from data-acquisition systems to telecomm networks. In fact, accurate timing in geographically wide theaters, such as missile ranges, could require air transportation of portable cesium atomic clocks to different areas before tests. Today, Global Positioning Systems (GPSs) allow relatively simple synchronization of sites because GPS-based time references offer accuracy within 100 nsec of the Universal Time Coordinated (UTC) atomic clock.

Using GPS for timing, however, requires significantly more horsepower than standard GPS receivers afford. Some such receivers that sell for as little as \$100 can display time but with errors in the tens of seconds. A number of companies have developed time and frequency references that take the one-pulse/sec output from standard GPS receivers and generate 100-nsec accuracy. The time standards deliver this accuracy despite the fact that civil GPS receivers have to deal with selective availability of GPS signals. Dave Robinson, president of Datum's Bancomm-Timing Division, claims that a Datum unit working with a military GPS receiver could deliver approximately 25-nsec accuracy. Applications for such timing products abound. For example, wireless telecomm networks use such references in every cell site. Even enterprise data networks need time references to track data-packet traffic. Untold numbers of custom embedded systems can use the timing technology.

Like the old saying "time is money" goes, these precision time references don't come cheap. An industrial-strength reference with a rubidium oscillator can sell for around \$10,000. Vendors of such products include Trimble, Odetics, Datum, and TrueTime. You do have lower cost options. From these vendors, you can buy everything from STDbus to PCI-bus to CompactPCI to VMEbus modules.

Generally, products are similar, so consider the Datum bc635/637PCI receiver module. A PC with the card installed can generally read time across the PCI bus with 100-nsec accuracy. The card also offers a digital event input that can trigger time stamps based on external events with 10-nsec precision. The card requires an external GPS receiver and sells for around \$3000. If you have several PCs, you can synchronize all of them with one GPS receiver. One PC in the group requires the \$3000 bc637PCI card and connects to the GPS receiver. The other PCs use the \$2000 bc635PCI card and receive time-code inputs from an IRIG (InterRange Instrumentation Group) output on the bc637PCI card.

If you want to design your own GPS-based time or frequency reference, you can find some help on the Internet. Engineer Brooks Shera has published the results of such a project at www.rt66.com/~shera/. The design lacks many of the features of commercial products, but Shera claims you can build a frequency standard for around \$75 in parts plus the cost of a GPS receiver and a local oscillator.

GPS ICs

1111A RF module constitute the MGP-SCS-A1 chip set and offer the highest level of integration for GPS-centric devices. Moreover, the GPS task takes less than 10% of the on-chip processing power, leaving ample bandwidth for other applications. Motorola claims that it will ramp the clock speed to 33 MHz down the road and has already done so in the MMC2001.

Although the GPS-centric market will continue to grow, you can expect the nascent GPS-as-a-peripheral market to do equally well. Whether the GPS receiver is a peripheral to a desktop PC, PDA, or car PC, the internal architecture will almost assuredly differ from the GPS-centric architecture. Look to modems as an example. First, there were stand-alone modems, then modems that used host resources as a controller, and finally modems completely implemented in software running on a PC. GPS ICs targeting peripheral applications will rely on host cycles when possible to reduce cost. If queried today, most GPS experts would insist that the correlator function will forever remain in dedicated hardware, whereas the calculation functions can certainly move to the host. On the other hand, many of us never thought

we'd see a host-based modem. In its NAV-2100 reference design, Analog Devices manages to host a correlator on a pair of ADSP-2181 fixed-point DSPs. In the future, a PC processor will have the needed cycles—it's just unclear whether the processor can meet the real-time correlation requirements.

Host-based GPS calculations

Today, SiRF leads the pack in designing GPS chip sets for peripheral-type applications. The SiRFstar1/LXj, which the company announced in October 1997, includes the GRF1/LX RF front end and the GSP1/LX GPS signal processor for correlation. With previous-generation chip sets, SiRF used a Motorola 683xx-based μ C as a companion IC, but, with the SiRFstar1/LX, the company moved to the Hitachi (www.hitachi.com) SH family. SiRF has a reference design for stand-alone receivers using the SH1 but chose the SH family because of the popularity of the SH2 and SH3 in Windows CE applications. The SH2 and SH3 in a Windows CE device could handle the GPS calculation tasks. SiRF has also ported its calculation code to the Pentium, allowing

this code to run on the host in Windows CE, 9x, and NT environments. Finally, SiRF and Intel (www.intel.com) announced an alliance in May to apply the WinSiRF technology to Intel's automotive-PC efforts.

The SiRFstar1/LX also requires much less power than competing chip sets. The chip designers cut power consumption by two-thirds that of SiRF's previous offerings by moving to 3.3V, 0.35- μ m IC technology. Running at full power, the two-chip set requires 360 mW. SiRF also parlayed its considerable advantage in fast reacquisition of a GPS signal to develop the "TricklePower" power-management mode. The SiRF1/LX chip set can reacquire a GPS signal in 100 msec, whereas many GPS chips require a full second. Meanwhile, GPS receivers typically update position only once every second. The TricklePower mode allows the new chip set to maintain the 1-sec update rate, yet the chip set enters a sleep mode for almost 90% of each 1-sec cycle. This technique results in an average power demand of 75 mW for the GPS circuitry. And power concerns abound in GPS applications that are regularly portable and battery-powered.



FOR MORE INFORMATION...

For more information on the GPS products discussed in this article, circle the appropriate numbers on the Information Retrieval Service card or use EDN's Express Request service. When you contact any of the following manufacturers directly, please let them know you read about their products in EDN.

Analog Devices Inc
Norwood, MA
1-781-329-4700
www.analog.com
Circle No. 334

Datum Inc
San Jose, CA
1-408-578-4161
www.datum.com
Circle No. 335

GEC Plessey
Scotts Valley, CA
1-408-438-2900
Wiltshire, UK
+441 1793 51800
www.gpsemi.com
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www.motorola.com/mcore/gps
Circle No. 337

Odetics
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www.odetics.com
Circle No. 338

Philips Semiconductors
Sunnyvale, CA
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Rockwell Semiconductor
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GPS ICs

Cost is the biggest difference between the first two aforementioned application scenarios and the scenario in which GPS integrates with other products or functions. According to most silicon vendors, the bill of materials for GPS must drop to about \$20 before cell-phone economics will support the integration of GPS. It's not that customers in the other markets have money to spare but that they will pay more for GPS. Today, turnkey GPS modules sell to OEMs for \$50 to \$60 in high volume. The bill of materials for such a module is \$40 to \$50 in high volume, so designing directly to a circuit board can lower cost a little. A design that relies on host processing might hit \$30, but cell phones require an even lower price.

Horizontal integration

You can see that single-chip GPS receivers are infeasible, and that route is typically how the electronics industry minimizes price. Therefore, designers of devices such as cell phones will have to take a different route to lower costs. In fact, they will horizontally integrate functions to reach an appropriate price. For example, cell-phone designers could combine the RF analog front end for the cell phone with the GPS receiver. At the same time, both the cell phone and the GPS receiver need signal-processing capabilities in a digital IC, so designers could combine those functions as well. Two ICs equal two

functions, so you get the equivalent of single-chip economics. You can see the same scenario playing out today with PC audio and modems (**Reference 2**). Designers will leverage the Audio Codec '97 standard to ship a digital IC that provides audio and modem functions and a combo audio/modem analog codec. With GPS ICs, a number of products might be suitable for such horizontal integration. Primarily, other wireless devices, such as wireless-LAN adapters or wireless modems, could prove good combination targets.



As you might guess, however, combining functions such as a GPS receiver and a cell phone could be difficult logistically. Companies such as Motorola or Rockwell may own both technologies, but GPS specialists need a phone partner. This need for horizontal integration will lead to companies establishing alliances. For example, SiRF has announced a partnership with Nokia (www.nokia.com) and Ericsson (www.ericsson.com) to promote GPS in cell phones. Other companies can increase their leverage by allying themselves with semiconductor vendors. For example, Trimble and Siemens (www.smi.siemens.com) announced a partnership that will ultimately give both companies rights to sell future GPS ICs. Moreover, Trimble can take advantage of Siemens' presence in markets such as automotive and telephony.



Motorola's new MGPCSC-A1 chip set offers the industry's highest level of integration, and Motorola is standardizing an application-programming interface for easy access to the feature of the chip set.

GPS software layers

As these alliances occur, you can expect more integrated GPS ICs to roll out in the next year. Moreover, the GPS-IC industry will move to 18-month or shorter design cycles as the peripheral and integrated markets heat up. Assuming that such proliferation happens, designers will likely find themselves needing new software tools to interface with the more capable and more flexible chip sets. GPS-centric devices typically have a UART interface to an external

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processor that can access a limited amount of data. With host-based chip sets and more integrated products, however, a programmable processor will set parameters and even intercept the raw GPS data stream.

Given that many people think GPS is a burgeoning market, it wouldn't be far-fetched to expect Microsoft (www.microsoft.com) to establish an application-programming interface (API) and try to control the software interface. In the meantime, however, Motorola is taking just such a step coinciding with the release of the MGPSCS-A1 core. The company has developed a standard API that it hopes the market, including competitive chip-set manufacturers, will adopt. Such an API would likely prove most useful for designers of embedded systems by simplifying the interaction between the GPS receiver and the rest of a custom application. Motorola promises a beta version during the first quarter of 1999. A software standard could be the final puzzle piece that unleashes GPS for the masses. **EDN**

References

1. Wright, Maury, "Time, position, and velocity? Just ask your GPS chip set," *EDN*, March 3, 1997, pg 50.
2. Wright, Maury, "Divide & conquer, AC'97's sound strategy for multimedia PCs," *EDN*, July 16, 1998, pg 50.

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