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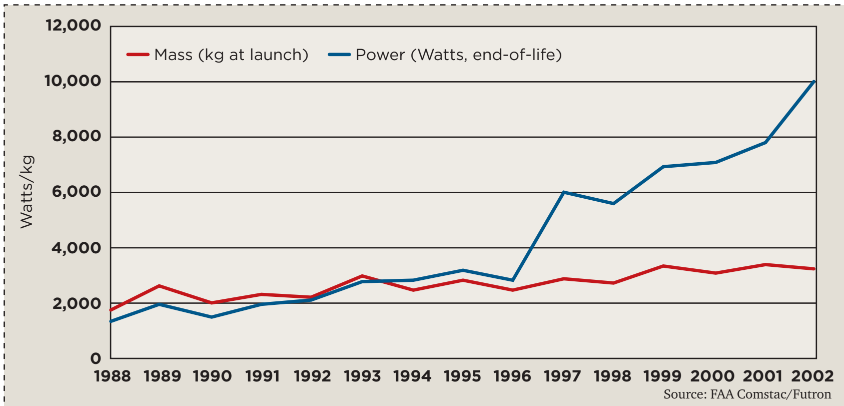
In Focus
GPS and Satellite
Communications

Space-based GPS lowers satellite costs

By Dan Nobbe and Chuck Tabbert

At the turn of the 20th century, nations that possessed battleships were the powers that shaped the military and economic landscape of the world. It was imperative for a superpower to have a strong navy. Today, nations with a robust space capability are considered world powers. The use of space-based technology can provide a global reach that's vital in communications; in the gathering of intelligence, surveillance and reconnaissance; and in pinpoint targeting in world conflicts. And it can also play a role in homeland security.



Prime contractors continue to wrestle with two important satellite metrics: weight and power. Power continues to rise rapidly. The satellite system integrator must constantly monitor the power and weight. Techniques to reduce either are rewarded.

The defense challenges posed in the 21st century demand a responsive space capability that provides near-real-time global awareness and force application. This may entail weapons and space-based sensors that are available for and responsive to the war fighter. "I believe that weapons will go into space. It's a question of time. And we need to be at the forefront of that," Pete Teets, undersecretary of the Air Force and director of the National Reconnaissance Office, told a March 6 conference in Washington, according to a report in *Aerospace Daily*.

Certainly, global-positioning system technology is vital in modern military deployments. It has also brought immense value to the automotive, nautical and aeronautical navigation industry, as well as to surveying, recreational and tracking applications. GPS systems are just taking off in automotive apps but are expected to be included in most vehicles in the future. But there is one high-value GPS application of which most people are unaware: the use of space-based GPS receivers, allowing satellites to be guided by tracking other satellites.

A GPS receiver can provide significant advantages in a satellite maintaining its designated position accurately and autonomously. This makes it possible to eliminate ground support infrastructure to monitor and transmit commands to the satellite for repositioning. The advantages to the satellite developer relate to the cost of development of the satellite's attitude control system. The ACS typically uses an inertial-navigation system based on an expensive inertial-measurement unit, along with other sensors to determine both the orientation of the satellite and the satellite motion or drift, for deciding when a "reposition" command may be required.

This approach provides some level of accuracy to determine the satellite's position but is typically measured in kilometers of error. The primary method of gauging a satellite's position, velocity and orbit determination is through a telemetry link between the ground and the satellite. This requires a significant ground infrastructure that demands 24-hour-a-day manning, tracking and repositioning commands and still results in less-accurate orbital positioning than if a GPS receiver is used for autonomous positioning.

GPS operation

GPS satellites operate in a complex system of navigation and communications, orbiting 14,500 miles above the earth, traveling at a speed of 8,569 mph and completing an orbit every 12 hours. Conversely, geosynchronous satellites—the type used for most weather and communications systems and common in direct-broadcast television systems—are placed in orbits at 22,500 miles above the earth and are required to complete an orbit once every 24 hours, moving at a speed of 6,879 mph.

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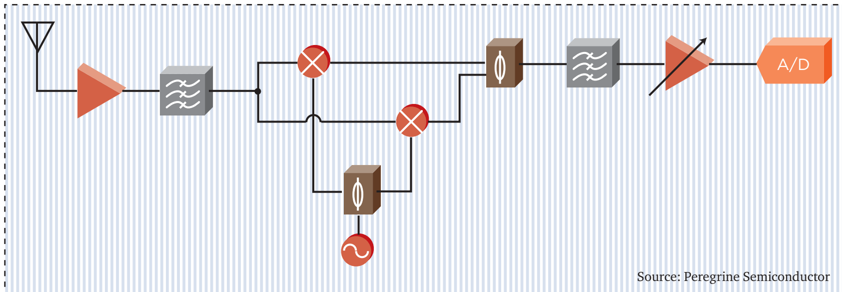
There are other classes of satellite orbits, including low-earth orbits at altitudes of 300 miles above the earth. It is very important to know the exact location of all types of satellites, and the use of GPS receivers is indispensable. GPS satellites have very high-gain antennas that are focused on the earth, emitting very little energy to satellites that may be above them. To gather the four or more GPS signals that are required for accurate location, a GPS receiver at high altitudes will listen to GPS satellites on the other side of the earth. This highlights the need for very sensitive receivers to pick up the GPS signal from distances substantially longer than terrestrial GPS receivers use.

The use of GPS receivers in space is not limited to geosynchronous satellites but is also important in medium- and low-earth-orbit satellites as well as missile systems. When at these altitudes, the spacecraft (in the generic sense of any object that is out of the earth's atmosphere) is subjected to significantly higher levels of radiation that the receivers must accommodate.

GPS receivers in space systems can save millions of taxpayer dollars for upcoming satellite programs. However, the prime contractors for satellite development are limited in their choice of GPS sensors for space because of a significant lack of GPS receiver development for the space market. Furthermore, the prime contractors continue to wrestle with two vitally important satellite metrics: weight and power. The power per satellite has increased dramatically in the past eight years, averaging out costwise at $15,124 per pound. The power comes at a premium in solar panels and heat management.



Commercial GPS receivers have followed recent consumer electronics trends. Low-IF (shown here) and direct-conversion receivers allow the IF filters to be integrated on-chip. The output signal is at or near the baseband, making it easy to digitize and demodulate.

Design of space GPS receivers

The primary characteristics that differentiate space-bound GPS receivers are the architecture, bands of operation, dynamic range and analog-to-digital converter. Obviously the environmental conditions are different also. Military/space GPS receivers have to operate over standard military temperature ranges of –55°C to 125°C and survive in a high-radiation enviroment in space.

Commercial GPS receivers have followed recent trends in consumer electronics such as cell phones and Bluetooth, which use low-intermediate-frequency (IF) or direct-conversion receivers. Low-IF and direct-conversion receivers allow the IF filters to be integrated on-chip. The output signal is at or near baseband and thus is easy to digitize and demodulate.

However, most military and space-based GPS receivers use the tried-and-true conventional superheterodyne receiver with a high intermediate frequency of 50 to 200 MHz. The conventional receiver offers the highest performance possible. A low-IF or direct-conversion receiver is always going to be limited by the linearity performance of the first mixer.

Low-IF receivers have an image that is very close to the desired signal and that is usually removed by an image reject mixer alone, since the RF filters are too wide to reject the image signal. Half-IF signals and other common spurious signals are a problem also. Direct-conversion receivers are susceptible to strong interferers, creating disruptive dc offsets in the baseband signal. The classical high-IF receiver can reject all of these unwanted signals with RF and IF filters and with a high-performance receiver core. The second mixer is frequently absorbed into the A/D converter using a subsampling technique.

Military/space GPS receivers usually receive both the L1- and L2-band signals and must pass the wider precise-encrypted, or P(Y), code. The coarse/acquisition code is broadcast on the L1 band, and the advanced P(Y) code is broadcast on both L1 and L2 bands. Reception of both L1 and L2 allows the receiver to correct for frequency-dependent atmospheric delays but requires two separate receivers. They must also use filters that are an order of magnitude wider than the commercial counterparts (2 to 20 MHz).

The military/space GPS receivers need the best performance possible to extract weak signals and maintain reception as well as to reject other signals nearby, whether accidental or intentional. Because of a spread-spectrum modulation scheme, terrestrial GPS signal levels are well below the thermal-noise floor.

A GPS receiver in a commercial application, even a cell phone, operates in a well-known radio environment. The handset is designed to work over very specific bands with predictable interference. The military/space GPS receiver, on the other hand, has to operate in difficult environments where countless signals may be present in the same assembly, such as a satellite. This doesn't even include the hostile intentions of jammers that place interfering signals directly on the GPS frequency.

Jammers are removed in two distinct ways: using steered antennas to direct the antenna away from the interferer and also through the use of advanced DSP algorithms that can mathematically identify and remove the interferer. For the DSP to function properly, the received signal must be preserved as accurately as possible when translating the signal from the antenna to the DSP. At the receiver level, this translates to high third-order intercept points and low noise figures. Since a jammer can be right in band, the third-intercept-point requirement gives way to the 1-dB compression point and the instantaneous headroom of the receiver at a set automatic gain control (AGC) operating point.

It is desirable to maintain headroom (compression point minus operating point) at any AGC setting, such that peaks induced by jammers don't get clipped before the AGC has time to respond. This requires the radio designer to pay very close attention to gains and compression points of each stage in the receiver over the AGC operating range.

The A/D converter of a military/space GPS receiver needs high resolution. Where commercial GPS receivers use 1 to 3 bits of resolution,military/space GPS receivers routinely use 8 to 14 bits. This is to preserve the GPS signal, which may be far below the level of a jammer. Quite often the receivers employ subsampling or IF-sampling techniques requiring high sampling rates and input frequencies.

One of the primary benefits of GPS receiver integration is obvious: size reduction. In satellites the size reduction at the IC or printed-circuit-board level yields much higher rewards in reductions in mechanical housings, shielding and interconnect.

Vehicle	Cost median ($M)	Average LEO cost/lb	Average GTO cost/lb
Peguasus XL	$25	$25,652	Not available
Minotaur	$13	$8,892	Not available
Athena I	$17	$9,146	Not available
SSLV Taurus	$19	$6,543	$21,591
Taurus 2X10	$34	$11,199	$34,497
Titan II	$35	$8,373	Not available
Athena II	$24	$5,283	$18,490
Delta II 73XX	$56	$9,023	$28,313
Delta II 74XX	$56	$7,881	$22,129
Delta II 79XX	$63	$5,613	$18,090
Delta II 79XX heavy	$70	$5,142	$14,458
Atlas IIA	$80	$4,970	$11,860
Delta III	$85	$4,661	$10,141
Delta IV M	$97	$5,127	$11,305
Atlas IIAS	$98	$5,143	$11,917
Atlas IIIA	$95	$4,972	$10,640
Atlas IIIB	$95	$4,008	$9,594
Atlas V 400	$99	$3,582	$8,955
Delta IV M+	$97	$3,242	$7,204
Atlas V 500	$114	$2,584	$6,319
Titan IVB	$400	$8,386	$21,053
Delta IV H	$155	$2,731	$5,682
Average cost/lb	—	$6,916	$15,124

Note: LEO-low earth orbit, GTO-geostationary transfer orbit

Source: "Final Report: President's Commission on the Future of the United States Aerospace Industry," November 2002

All told, the cost of a GTO satellite launch averages out at $15,124 per pound.

Radio integration also reduces critical launch weight and size in satellites. In addition, the integration results in reduced power. Each block is optimized for performance and power dissipation. No energy is spent overcoming the package and pc-board parasitic losses. Cost reductions are also realized. The integration of the entire receiver minimizes the part-to-part variation of discrete receivers. The integrated receiver is easier to reproduce from product to product, since the precise layout of hundreds of components is not required. Finally, it is easier to manufacture and attain desired yield because the function of the entire receiver has been verified at a chip level.

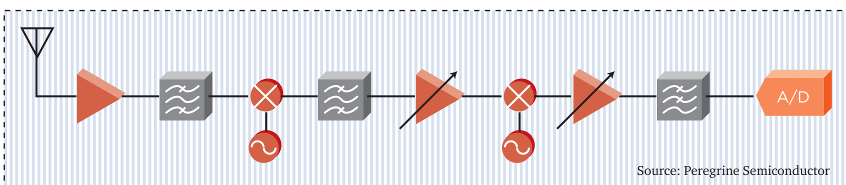
By using the UltraCMOS™ process, it is possible to integrate one, two or four receivers on a single chip. This offers the best receiver-to-receiver matching possible and further reduces size. High-resolution A/Ds have been developed to complement the GPS receiver technology, and 8-bit, 200-Msample/second converters are being integrated into mul-tiple GPS receivers on a single chip.

UltraCMOS technology also allows for a voltage-variable or digital step attenuator for AGC control. The use of digital step attenuators has several advantages, including the precise knowledge of instantaneous gain setting, very high dynamic range, full digital CMOS control, good temperature stability and good matching of receiver gain settings.

Putting all of these advantages together, parts count is reduced by more than 90 percent, pc-board area by 75 percent and power consumption by 50 percent. The silicon-on-sapphire-based UltraCMOS process also has natural radiation-hard properties. The process, plus design know-how, can allow all of the signal chain, from low-noise amplifier through A/D, to be integrated on a single integrated circuit that can withstand the radiation environment in space.

GPS receivers have been used in a plethora of ways in commercial, industrial, military and space markets, with receiver integration leading the way. New levels of radiation-hardened GPS receiver integration in spacecraft are resulting in smaller, cheaper and lower-power solutions, continuing to fuel the quest to own the skies.

Advances in RF CMOS, including the radiation-hardened UltraCMOS technology, will allow space-based GPS receivers to keep pace with the advances in terrestrial GPS receivers. — *Lonnie Morris, director of space GPS products for L3-IEC Corp., contributed to this article.*



While low-IF and direct-conversion receivers have advantages, most military and space-based GPS receivers use the conventional superheterodyne receiver with a high-IF frequency of 50 to 200 MHz. This can reject unwanted signals with filters and high-performance core.

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