Integration of Satcom and GPS into a Technology Curriculum

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Abstract

Satellite communication systems (Satcom) represent the state-of-the-art in advanced communication of digital voice and data. For mobile users, the system requires a high-technology antenna capable of locking on and tracking a geostationary satellite orbiting the earth, as well as a device capable of both transmitting and receiving modulated information to and from the satellite.

Penn State Erie, the Behrend College is working on integrating into their curriculum Satcom technology. This year, two industrial sponsored senior design projects involve electrical engineering technology (EET) students. These projects provide the students involved with hands-on Satcom experience in solving real-world industrial problems. In the first project, one EET student is working with two electrical engineering (EE) students as interdisciplinary teammates to test the link margin effects of a Satcom receiver due to environmental conditions such as rain, snow, ice, etc. In the second project, two EET students are also teamed with two EE students to test bit error rates for a newly-designed Satcom receiver. In the future, it is anticipated that the need for technologists who understand Satcom systems will allow Penn State Behrend to offer a technical elective to teach the design, operation and maintenance of Satcom systems.

In addition, the Satcom technology could be expanded to include global positioning satellite (GPS) systems. GPS systems are primarily used for state-of-the-art navigation, position, velocity and precise time information. Systems are now being used in automobiles as intelligent vehicle systems to provide position tracking and speed sensing. They are also used in aircraft for precision approaches, attitude information and will soon provide a means for enhanced detection of terrain obstacles and next-generation air traffic control systems. Other applications exist in the fleet management, agriculture and construction industries.

The combination of Satcom and GPS provides the student with an exceptional background to work in the ever-changing communications industry.

Satellite Communication Systems

Satellite communication systems, like cellular mobile communication systems, allow for wireless transmission of information. The satellite system, unlike the cellular system, requires a direct line of sight between the satellite and the user for reliable communication. However, the satellite system is advantageous because the user does not need to be in proximity to a "cell" (repeater) to maintain communication with the satellite. Thus, wireless communication in remote areas (e.g., at sea) or where cells have not yet been installed requires the use of a satellite system.

Much of today's communications between distant localities involves the use of communication satellites [6]. Communication satellites can be thought of as electronic repeaters located many miles above the earth's surface. Typically, communication satellites can be divided into two types: satellites in geostationary orbit or satellites in low earth orbit (LEO). The geostationary orbit satellites are located farther into space. Since the satellite is geostationary, only one is required in general for users to communicate. One geostationary satellite can cover approximately 42% of the earth's surface [6]. Three geostationary satellites can cover approximately 90% of the earth's surface. The LEOs, being located closer to the earth, require less power to communicate and smaller data latency (i.e., the data is transmitted faster). However, more satellites are required (ranging from 66 for Iridium to 840 for a proposed global internet and mobile telephone service) [6].

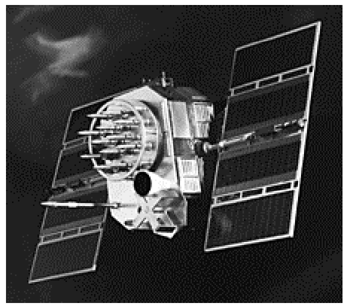
Two main technologies are currently used to send multiple-channel data. They are frequency division multiple access (FDMA) or time division multiple access (TDMA). Satellites can also be networked. An example of a satellite network is the advanced communications technology satellite (ACTS) system.

Satellite communication systems are expected to dominate the data communications industry for long distance links. These systems are being adopted for Internet access in lower orbit satellite clusters, continuing to grow and improve as technology meets demand [6]. They provide a logical solution for many remote GPS applications where position, velocity and time are required for a user or an application.

Global Positioning System (GPS)

GPS navigation presents opportunity for standardized worldwide civil aviation operations using a common navigation receiver. GPS is a space-based positioning, velocity, and time system that has three major segments: space, control and user. [3]

GPS Space Segment



The GPS Space Segment is composed of 24 satellites in six orbital planes. The satellites operate in near-circular 20,200 km (10,900 NM) orbits at an inclination angle of 55 degrees to the equator, and with approximately a 12-hour period. The spacing of satellites in orbit is arranged such that a minimum of five satellites, with a position dilution of precision (PDOP) of six or less, will be in view to users worldwide. PDOP is a measure of the error contributed by the geometric relationships of the GPS satellites as seen by the GPS receiver. Each satellite transmits on two L-band frequencies: L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a precise (P) code and a coarse/acquisition (C/A) code. L2 carries only the P code. A navigation data message is superimposed on these codes and the same navigation data message is carried on both frequencies. [2]

GPS Control Segment

The Control Segment has five monitor stations, three of which have uplink capabilities. The monitor stations use a GPS receiver to track all satellites in view, accumulating ranging data from each satellite. The information from the monitor stations is processed at the Master Control Station (MCS), located in Colorado, to determine satellite orbits and to update the navigation message of each satellite. This updated information is transmitted to the satellites via ground antennas, which are also used for transmitting and receiving satellite control information.

GPS User Segment

The User segment consists of an antenna and receiver, which provides position, velocity, and precise time to the user. Computing the user's position and time information requires the simultaneous solution of pseudorange equations found in Reference [2].

Normally, the user equipment needs to acquire and maintain lock on four satellites in order to compute a 3-D position fix and the clock bias C_B. The GPS pseudorange between the user and each satellite is computed based on knowledge of time (the master GPS clock) and a unique signal format which is broadcast by each satellite. Once the four pseudoranges are known, a recursive algorithm is used to compute the user's position.

GPS provides the satellite positions in the Earth-Centered Earth-Fixed (ECEF) coordinate frame as shown in Figure 1. From the ECEF frame, conversions to latitude, longitude and height with respect to World Geodetic Survey (WGS84) latitude, longitude and height can be calculated with the final result illustrated in Figure 2. A matrix which converts vectors from the ECEF frame to the East, North, Up (ENU) frame can be found in [4].

Typically, the up-axis, which is perpendicular to the earth's surface in the ENU reference frame, needs additional conversion, so that the altitude will be referenced to mean sea level (MSL) instead of with respect to the ellipsoid. The GPS receiver is able to perform this conversion, because it can also calculate latitude and longitude directly from its ECEF parameters. By knowing latitude and longitude, the GPS receiver either uses a look-up table or a specific ellipsoid-geoid algorithm to compute the distance from the ellipsoid, to the geoid (which is also the MSL reference). This distance between the ellipsoid and geoid is noted as $\pm N$. For positive values of N, the geoid is above the ellipsoid. This additional conversion of the GPS altitude variable, brings the [e,n,u] vector into the [*e*,*n*,*a*] frame, where, the variable *a*, is the GPS measured height with respect to MSL. Additional information, regarding MSL and geoids are illustrated in reference [4].

GPS Error Sources

The accuracy of the GPS solution is a function of several error sources. For example, the GPS errors that have been documented are generally due to the following:

- ionosphere,
- troposphere,
- multipath,
- selective availability,
- receiver noise,
- satellite ephemeris,
- clock bias and
- clock scale factor errors of the user equipment and satellite vehicles.

Details regarding these errors can be found in [5]. An excellent source of information regarding selective availability (the dominating error source for commercial GPS equipment), as well as current methods to mitigate all previously mentioned errors, can be found in [2].

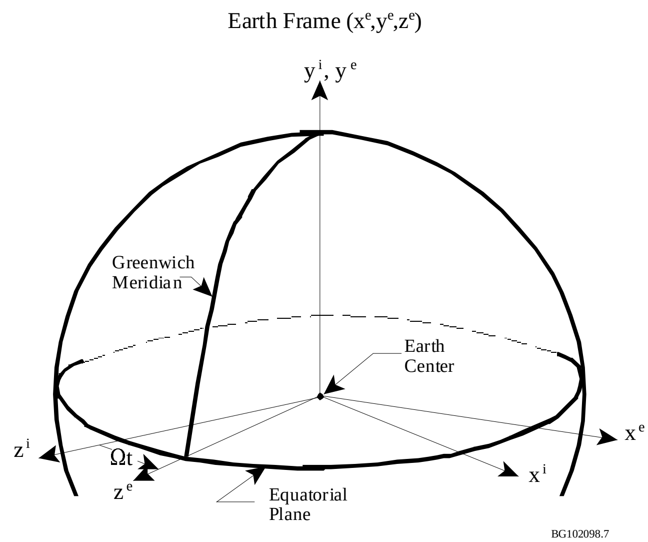


Figure 1. Earth Frame

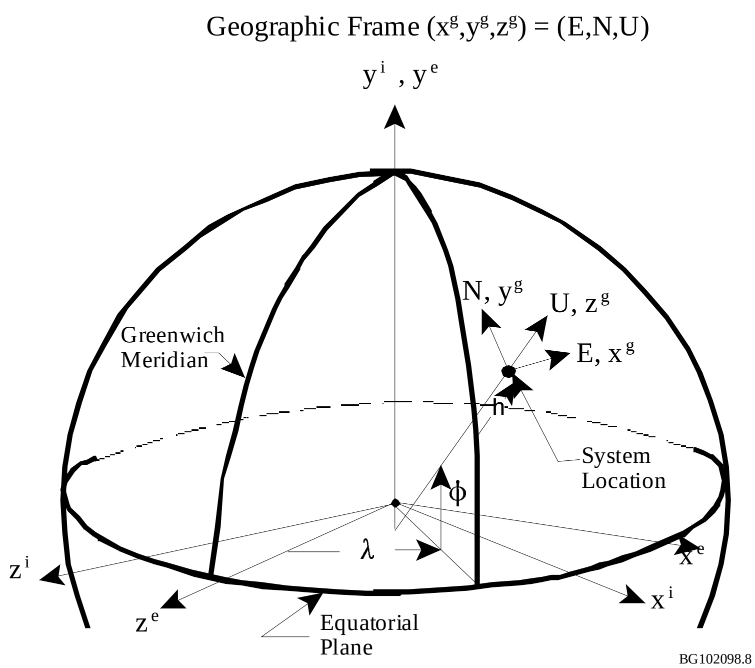


Figure 2. Geographic Frame

Employment Opportunities for EET Students

Electrical engineering technologists with an understanding and background in Satcom and GPS systems have excellent career opportunities. Test & Evaluation, repair, integration, service and maintenance of these systems, along with product design, are among the major areas where EET graduates can contribute to the field.

Companies are now offering satellite communication systems with essentially worldwide coverage. Both the companies offering the service as well as the companies which have developed the technology (e.g., Motorola, Westinghouse, GE, Honeywell, etc.) will need trained personnel. The companies offering the service will need customer service professionals to help market the product and deal with customer issues. The companies which have developed the technology will need technologists to upgrade and/or redesign the existing hardware for better reception, better coverage or more features (e.g., integrated voice, data, video, internet, etc.).

In the GPS area, the number of applications is yet to be fully explored. Golf courses are using GPS systems in their golf carts to determine the distance the cart is from the pin. Surveyors are using GPS systems for cartography applications. Mariners are using the GPS technology for precise position information at sea. Aircraft and locomotive manufacturing companies are employing GPS systems to communicate position, velocity as well as remote diagnostic information (e.g., engine oil pressure). Automobiles and aircraft are also using GPS technology for navigation, mapping and position location. Any company which requires an accurate measure of time can also use a GPS system, since the technology is accurate to 1 second over 70,000 years [1]. All of these applications require someone who can take the GPS technology and integrate it into the company's strategic plan. The information provided by a Satcom/GPS class will provide a student with the necessary understanding to accomplish this goal.

Senior Projects

Two projects, involving three EET students in an interdisciplinary setting with electrical engineering students, have been developed and industrially sponsored. They allow the students both design and hands-on experience. These projects are:

A. Satellite communication system and GPS link margin effects, due to materials on top of the radome, and;
B. A bit error rate (BER) test & evaluation of at least two different Satcom transceivers and antenna designs for fixed and mobile use.

In the first project, the effect of materials such as coal, dirt, water and ice on the system will be evaluated. An important result from this project is that link budget, signal to noise ratio and bit error rate analysis will be predicted a priori in a classroom environment, then measured in the real world. This exercise allows the students to ask "what-if questions", then seek out solutions. The project involves knowledge in the following areas:

- antenna design,

- electromagnetics, and
- tracking and pointing algorithms of the outgoing RF beam to an orbiting satellite

In the second project, the students work together as a team to determine the feasibility of a satellite communication device for a given application. Engineering tradeoffs need to be evaluated by the students. Project details include the following:

- hardware costs,
- antenna design and mounting issues,
- probability of maintaining a circuit switched link given a manufacturers system,
- system operation in varying environmental conditions (temperature, vibration, EMI),
- field installation issues,
- bit error rate tests,
- lifetime maintainability of the equipment in the field,
- warranty evaluation,
- actual hardware demonstrations and
- reasoning (trade-offs) when selecting a satellite provider (Iridium, AMSC, etc.)

Potential Course Topics

The logical extension of senior design projects involving SATCOM and GPS is to eventually design a technical elective in the EET curriculum which delves into both topics. Other campuses are offering GPS classes through a geology department, but these authors were unable to locate a campus which offered a more thorough technical discussion of the topics discussed above. Such a class would cover the following over a semester schedule:

Satcom:

- Comparison and contrast of satellite and cellular communications
- Satellite design
- Inertial navigation
- Satellite power supplies
- Satellite manufacturers/service providers
- Satellite coverage
- Satellite orbits
- Satellite networking
- Methods of communication
- Antenna design
- Transponders/repeaters
- Frequency allocation
- Satellite communication standards
- Link budget analysis

GPS:

- Reference frames
- Geometry
- Dilution of precision
- Introduction to GPS
- Three main parts of GPS systems
- Satellites
- Pseudolites
- Orbits
- GPS signal structure and tracking
- Selective availability
- Ionospheric effects
- Integrity monitoring
- GPS receiver
- Spread spectrum and correlation
- Differential GPS
- WAAS and LAAS
- GPS applications

Conclusion

Satellite communications and global positioning satellite systems are becoming an everyday part of our lives. Wireless communication in remote areas (e.g., at sea) or where cells have not yet been installed requires the use of a satellite system. Most transportation systems are now installing GPS receivers to track position, speed and time. Therefore, the need for technologists who understand these technologies for product design, repair, service, sales and maintenance is growing. Penn State Erie, The Behrend College is preparing to meet this need by including in their curriculum senior design projects, and developing a technical elective, such that graduates will have an edge in employment in these areas.

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Robert Gray, Ph.D. is an Assistant Professor of Engineering at Penn State University, Erie, PA and has been active in the navigation field since 1981, when he enlisted in the USAF as an avionics inertial navigation & doppler radar technician. In addition to researching new methods of enhancing flight safety by use of digital terrain elevation data, Robert is working with GE and NASA regarding next-generation navigation systems.