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Permanent Link to Future Wave: L1C Signal Performance and Receiver Design
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By Thomas A. Stansell, Kenneth W. Hudnut, and Richard G. Keegan The new GPS L1C signal will be broadcast by the Block III satellites, with first launches as early as 2014. L1C innovations significantly enhance PNT performance as well as interoperability with other GNSS signals. The authors describe the benefits of its new features and how best to make use of each one. A highly evolved racehorse of a signal with outstanding technical performance, L1C was designed to significantly improve autonomous navigation, and to be interoperable with L1 signals from other GNSS providers. Its structure evolved from the earliest GPS signals: it shares with the C/A signal the L1 center frequency of 1575.42 MHz, coherence between the carrier frequency, the code clock rates, and the data rate, and the provision of a navigation data message. L1C inherited significant improvements from subsequent developments, specifically WAAS, L5, and L2C. WAAS was the first GPS-related signal to use forward error correction (FEC) for its data. L5 was the first open signal design to use longer spreading codes (10,230 chips), to have separate data and data-less (pilot carrier) signal components, to employ an improved navigation message structure (CNAV), and to employ overlay codes to achieve a longer equivalent code length, improve correlation performance, and eliminate the need for bit synchronization. The L2C signal adopted most of these improvements but, instead of an overlay, substituted a much longer pilot carrier spreading code, not only to optimize correlation performance but also to decrease the number of time ambiguities after tracking the spreading codes. The L1C signal design is amazing, not only because of its highly evolved and outstanding technical performance but also because a committee designed this racehorse of a signal rather than it becoming a camel. Table 1 lists key members of the L1C technical committee in alphabetical order. The list has two groups, technical contributors and government chairpersons.

When each new signal aspect is introduced, the key contributor or contributors from this list will be identified. Table 1. Key L1C contributors. L1C is intended to be interoperable with L1 signals from other GNSS providers. To identify its signal type, we note that Galileo officials have identified three types of services, “open”, “commercial”, and “publicly regulated”. An open service is freely available to all users. A commercial service is limited to users who pay a fee to access the signal, which otherwise is denied by encryption. A publicly regulated service (PRS) also is encrypted but intended only for public safety applications. GPS is adopting the open service definition but will continue to distinguish encrypted signals as “military” because there are no encrypted commercial GPS services. L1C will be a new GPS open service signal, joining L1 C/A, L2C, and L5. Although the term “civil signal” often is used, there can be confusion about its meaning. Within the U.S. government it is common to use the word “civil” to mean civil government agencies, e.g., the Department of Transportation (DOT). However, it’s clear the GPS C/A, L2C, L5, and L1C signals are “open” and intended for use by anyone. Therefore, we will use the term “civilian” or “open” in order not to imply that any of these signals is restricted in its use. L1C Signal Development The L1C signal structure has evolved from the earliest GPS signals first launched in 1978. It shares with the C/A signal the L1 center frequency of 1575.42 MHz, coherence between the carrier frequency, the code clock rates, and the data rate, and the provision of a navigation data message. Significant improvements have been inherited from subsequent developments, specifically WAAS, L5, and L2C. For GPS or GPS-related signals, WAAS was the first to use forward error correction (FEC) for its data. L5 was the first open signal design to use longer spreading codes (10,230 chips), to have separate data and data-less (pilot carrier) signal components, to employ an improved navigation message structure (CNAV), and to employ overlay codes to achieve a longer equivalent code length, improve correlation performance, and eliminate the need for bit synchronization. The L2C signal adopted most of these improvements but, instead of an overlay, substituted a much longer pilot carrier spreading code, not only to optimize correlation performance but also to decrease the number of time ambiguities after tracking the spreading codes, i.e., extend the duration of GPS time ambiguity from 1 ms after tracking the C/A code and 20 ms after tracking the L5Q code to 1.5 sec for L2C. Before giving details of the L1C signal in which we identify the primary contributor(s) for each innovation, it’s appropriate to recognize the special contributions of two members of the L1C technical team. The first is Dr. Charles R. (Charlie) Cahn. Cahn has been a major contributor to GPS since before GPS was conceived. In particular, he was a key contributor to the Air Force 621B program which anticipated GPS. (He, Dr. James J. (Jim) Spilker, Dr. Robert Gold, and Mr. Burt Glazer deserve most of the credit for developing the original GPS C/A and P code signal structures, other than the NAV message.) Cahn discussed the merits of having a separate data-less or pilot channel in a 621B report [1], with Stansell he again recommended this for GPS in a 1975 Spartan Study Report, and finally the idea was adopted by the RTCA for L5 in accordance with recommendations from Cahn, Stansell, and Keegan. Also, Cahn was the first to recommend an overlay code on the L5 data signal to eliminate the need for the always problematic bit synchronization process. In a step toward L1C, Cahn was a primary contributor to the L2C design. In particular, he designed the code generators, including the 1.5 sec pilot code, and the chip by chip multiplexing technique which permitted two signal components in one bi-phase signal. In addition to consulting for The Aerospace Corporation and several commercial GPS companies, Cahn recently invented a more effective method to combine multiple signals on one carrier, called Phase-Optimized Constant-Envelope Transmission (POCET) modulation [2]. It is expected to be used on later versions of GPS III satellites to improve transmitter efficiency. The second special recognition is for Dr. John Betz. Betz has played a very significant role for more than a decade in helping define the military M-code, in working with international partners to define and negotiate compatibility and interoperability signal parameters, in helping negotiate a significant part of the 2004 EU/US agreement, and in evaluating and supporting a wide variety of GPS programs and initiatives. Betz was a vital contributor to the overall L1C design through interaction with other team members, development of ways to compare alternatives, suggesting use of new signal processing concepts, and bringing experts from MITRE who performed significant analyses and developed key signal components. Table 2 lists, in order of the authors' judgment of value to user communities, the most important new characteristics of the L1C signal. The list also shows the primary contributor(s) for each characteristic. Table 2. L1C Innovations in order of judged value. Improvements made to the previously modernized civilian GPS signals, L5 and L2C, were a starting point for the L1C design. These included: having a pilot carrier; longer spreading codes (10,230 chips minimum); overlay or long pilot codes to eliminate the need for bit synchronization, to improve correlation properties, and to decrease the number of time ambiguities aft er locking to the spreading codes; use of FEC to improve data demodulation performance and provide bit synchronization; and the flexible and higher precision CNAV message. The following paragraphs describe the additional improvements incorporated in L1C. A key issue was whether additional signals could be added to the L1 carrier without negatively impacting legacy signals. Several combining methods were considered, and it was determined that, with the right combining technique, L1C could be added without detriment. Use of POCET, subsequently invented by Cahn, will further enhance this capability. An "industry standard" rate ½ constraint length 7 convolutional coding method had been adopted for forward error correction (FEC) on WAAS, L2C, and L5 signals. However, the team agreed it was appropriate to consider other possibilities. Betz arranged for Ma to address the team on at least two occasions, providing a good tutorial on other advanced FEC methods which would allow message demodulation at even lower signal-to-noise ratios. While the FEC options were being considered, another breakthrough occurred. Since at least 1999 Stansell had encouraged development of a way to take better advantage of GPS message redundancy. Rising to this challenge, Kovach proposed a modification of the CNAV message structure that he and Art Dorsey (Lockheed-Martin) had developed for L5 and L2C. The modified message, called CNAV-2, is equally flexible, equally precise, but more efficient, allows faster time to first fix (TTFF), and permits message demodulation at signals as weak as the carrier can be tracked. This final attribute requires FEC encoding of entire message blocks (sub-frames) rather than having the continuous process used for L2C and L5. As a result, when signal levels are very weak, bit symbols from two or more messages can be combined to improve the energy available per symbol, i.e., the L1C data demodulation threshold can be improved by combining symbols from two or more messages. As a result of the message format improvements and performance evaluations by Shane, the team settled on the Low Density Parity Check (LDPC) FEC block encoding technique. This technique is as effective as turbo codes but without intellectual property constraints. Software developed by Shane was used by Sklar and Wang to define the specific L1C implementation, with performance simulation help from Kasemsri and Zapanta. The most important new attribute of L1C resulted from a proposal by Betz to take advantage of the improved FEC and message redundancy attributes of L1C by having two separate data messages. Half the total signal power would be in the pilot carrier and the other half would be split evenly between two messages, one with full precision and the second with less precision but which could be acquired more quickly for faster TTFF. Stansell appreciated the opportunity for less power in the message but recommended that instead of having a second message the saved power should be added to the pilot carrier, for a 75/25 split between pilot and data power. The reasoning was that code and carrier measurements on the pilot are vital to navigation whereas messages are redundant, slowly changing, and are becoming available from other sources, such as the Internet and from cell phone networks. The issue was settled by an international survey of manufacturers, universities, and government organizations. The final L1C signal design, with the 75/25 power split, was selected by these experts from a group of five signal options. Another L1C message innovation came about through a collaboration between Kovach and Cahn. The idea was to have a separate message sub-frame with very powerful encoding to identify GPS time of week to within a two hour interval. The sub-frame is called Time of Interval (TOI), and Cahn recommended a 52 symbol (26 bit) BCH code to provide the 9 bits of TOI information. Although orbit parameters may be available from a number of sources, precise and unambiguous time is vital for navigation, and TOI serves this and other purposes. With this level of encoding, TOI can be obtained from just one message at very low signal levels. Furthermore, the identical TOI is broadcast from every GPS satellite at the beginning of every 18 second L1C message. Therefore, it is possible to combine symbols from two or more GPS signals to demodulate TOI even under very adverse signal conditions. After locking to the pilot code and its overlay, one TOI establishes time of week within ±1 hour for all GPS signals. TOI is particularly effective because of a recommendation by Cahn to overlay the pilot spreading code with another code which frames the entire data message. The L1C overlay code is 18 seconds long (the message length) and is unique to each GPS satellite. Because of this, the TOI defines which of the 400 possible 18 second intervals within a 2 hour time span begins at the next message frame, which also is the beginning of the next overlay code. If receiver time is known or can be determined to within an hour, TOI and the GPS spreading codes establish time for all GPS satellites. Although it would have been adequate to adopt spreading codes from the L5 signal design, Betz introduced Rushanan to the L1C technical team and recommended that he study alternate code structures with improved characteristics. After an extensive study, Rushanan recommended a set of length-10223 Weil-codes extended with a fixed 7-bit pad to provide the primary L1C spreading codes. These codes have improved performance characteristics, as detailed in [3], [4], and [5]. In addition, the team asked Rushanan to define the 1800 chip pilot overlay codes, also described in [3], [4], and [5]. Stansell specifically requested that Rushanan optimize the ability to synchronize to the overlay code with as little observation time as possible. As a result, within one or two seconds after a signal is acquired, its 18-second time frame is established. After the first satellite is acquired, the maximum time difference for signals from other satellites is less than ±10 ms for receivers near the earth, so only two possible states of the overlay code must be examined to resolve the 18 second message phase for any other satellite. If the GPS almanac, an estimated position, and even a rough time estimate are available, as usually is the case, message time phase can be resolved even faster for subsequent signal acquisitions. The L1C waveform originally was to have been a pure BOC(1,1) (a 1.023 MHz square wave modulated by a 1.023 MHz spreading code). Negotiations between the U.S. and the European Union (EU) at that time resulted in an agreement [6] that both GPS and Galileo would use a baseline BOC(1,1) signal. However, the EU reserved the right to further optimize their signal within certain bounds. Some of the optimization proposals were known as CBCS and CBCS. However, in further EU/US discussions it was decided that L1C and the Galileo E1 open service signal should have identically the same spectrum. This was a significant challenge because of different baseline signal structures and existing designs. The breakthrough came when Betz proposed what is called MBOC. The MBOC waveform has 10/11th of its power in BOC(1,1) and 1/11th in BOC(6,1). However, L1C and E1 OS achieve this result in very different ways. The Galileo technique is called CBOC, as described in a number of papers. [8], [9], and [10]. The GPS technique is called TMBOC and is defined by IS-GPS-800A [11] as well as by [3], [4], [5], and [8]. Whereas Galileo has a 50/50 power split between pilot and data and includes the BOC(6,1) component in each, GPS includes the BOC(6,1) waveform only in the pilot component by modulating four of every 33 spreading code chips with a 6 MHz square wave and 31 chips with a 1 MHz square wave. With 75% of the power in the pilot, the result is 3/4 x 4/33 or 1/11, as required. It is likely the BOC(6,1) signal component will be ignored by consumer grade GNSS receivers where a narrow RF bandwidth is preferred. Fortunately that is a loss of only 12% (0.56 dB) of the L1C pilot power. However, for commercial and professional grade receivers, the extra waveform transitions (wider Gabor bandwidth) can be used to improve code tracking signal-to-noise ratio, and with certain advanced techniques it should be possible to improve multipath mitigation. This final point depends on careful control or calibration of the transmitted code timing and symmetry. Finally, Dafesh recommended that the team consider data symbol interleaving. The team accepted this suggestion, and Sklar and Wang designed the interleaver. Because of the powerful FEC, by scattering data symbols throughout sub-frames 2 and 3, it is possible to recover an entire message even if portions are blocked by, for example, walking or driving past trees or other obstructions. All team members deserve credit for sharing, challenging, and improving concepts. Particular examples are the strong aviation navigation background provided by Hegarty and the in depth design experience for a wide range of receiver types and civilian applications provided by Keegan. In addition, Yi had the primary responsibility for documenting L1C in IS-GPS-800. It also is important to recognize the contributions of the many professionals who responded to the worldwide survey of manufacturers, universities, and government experts. Stansell conducted each of the survey presentations, some in person and others over the Internet. One or more of the Government Chairpersons also participated, usually Hudnut or Lenahan. There were responses from organizations in 10 countries: Japan

(34), the USA (26), Russia (7), the United Kingdom (5), Canada (4), Australia (1), Finland (1), Germany (1), Switzerland (1), and Taiwan (1). This is not a complete picture because a number of the responses were from individual experts while others were a consensus response from a larger group. Five signal design options were presented, and the preferred design received 62 percent of the 81 responses. As a result, the L1C signal has a 75/25 split between pilot and data power and the data rate is 50 bits per second. L1C Signal Description The official L1C signal description is given by IS-GPS-800; the most recent version A was released on June 8, 2010. Figures 1 and 2 show the L1C power spectral density with, respectively, a logarithmic (dBW/Hz) scale and a linear (Watts per Hz) scale. Figure 3 is the same as Figure 1 but also includes the C/A and M Code signals; it assumes both signals are transmitted with the same total power. Figure 1. Figure 2. Figure 3. These plots illustrate three important aspects of the L1C spectrum. First, L1C is designed to have only a small impact on reception of the legacy C/A signal. This is important for the compatibility of signals with respect to each other. A good way to evaluate the impact of one signal on another is called the Spectral Separation Coefficient (SSC), which quantifies the amount of interfering power from one signal to another, under the assumption that each signal is transmitted with the same power but with different spreading codes. The SSC between a C/A signal and the L1C signal is –68.3 dB/Hz. The spectral separation illustrated in Figures 1, 2, and 3 assures that L1C signals will have very little impact on acquiring and tracking the legacy C/A signals. Therefore, L1C is judged to be compatible with the C/A signal. Figure 3 also illustrates that L1C and the M Code signals have very little impact on each other. The SSC between L1C and M Code is –82.8 dB/Hz. This is important because M-Code power may be substantially higher than the civilian signals, so a larger negative SSC is important to maintaining compatibility. The third aspect of the L1C spectrum is the additional signal power at ±6.138 MHz. This component of signal power differentiates a binary offset carrier BOC(1,1) waveform from the L1C multiplexed BOC or MBOC waveform. Exactly 1/11th of the L1C signal power is a BOC(6,1) component, whereas 9/11th of the power is a BOC(1,1) component. 75 Percent in the Pilot Carrier. Figure 4, which shows the required post-correlator C/N0 required to phase track either the L1C or C/A signals as a function of tracking loop bandwidth, illustrates the main advantages of having 75 percent of the L1C signal power in the pilot component. The carrier-tracking threshold for equivalent signal power using a Costas loop is 6 dB worse than tracking with a phase-locked loop (PLL). A Costas loop is needed for the C/A signal because it is modulated by data, whereas a PLL can be used for the dataless L1C pilot signal. This 6 dB advantage more than compensates for having only 75 percent (-1.25 dB) of the L1C power in the pilot. The vertical displacement between the two curves illustrates the 4.75 dB L1C tracking threshold advantage. Figure 4. Required post Correlator C/N0 versus tracking loop bandwidth. The horizontal displacement of the curves shows another L1C advantage. For a given C/N0 threshold, the L1C loop bandwidth can be increased by a factor of three. In turn, this allows tracking with G forces 32, or nine times higher. For third-order loops capable of tracking acceleration, this allows tracking with 27 times higher jerk. Such differences are likely to be more important than tracking threshold for high-dynamic applications such as machine control. Although Figure 4 assumes the L1C and L1 C/A signals have the same total power, the minimum received L1C signal power specified in IS-

GPS-800A is –157 dBW, and the equivalent for C/A in IS-GPS-200E is –158.5 dBW. In other words, the intent is for L1C to be transmitted with 1.5 dB more power than C/A. Therefore, the figure is conservative by 1.5 dB in evaluating the L1C advantages over C/A. Thus, the actual threshold advantage is 4.75 + 1.5 = 6.25 dB. For narrowband or other receivers not punctual correlating the BOC(6,1) signal component, the pilot carrier is 29/33 or 0.56 dB weaker, so the net advantage is 4.75 – 0.56 + 1.5 = 5.69 dB. LDPC Block Encoding Low-density parity check (LDPC) encoding provides three key advantages. First, to demodulate the critical part of the L1C message with a bit error rate (BER) of 10-5 requires an Eb/N0 (ratio of energy per bit to the noise power in a 1-Hz bandwidth) of 2.2 dB versus 96 dB for the C/A signal. When taking into account that only 25 percent of L1C signal power is in the data component, the required total power of the L1C signal can be 1.4 dB less than the C/A signal for an equivalent BER. As a result, this performance allows the pilot component of L1C to have 75 percent of the total L1C power. Second, LDPC gives near-optimum performance with no intellectual property constraints. Third is the ability to block-encode Subframes 2 and 3 of the L1C message, described next. CNAV-2 Message. Figure 5 compares the L5 and L2C CNAV message structure to the L1C CNAV-2 structure. CNAV was a major step forward compared to the original NAV message in terms of flexibility, precision, time to first fix (TTFF), and integrity. Instead of the fixed 30-second structure of the NAV message, CNAV consists of multiple six-second messages that are differentiated by a message-type number. The sequence of broadcast message types is defined by the GPS control segment, which greatly improves flexibility. The round-off error in the NAV message can affect pseudorange calculations by up to 40 centimeters, whereas the equivalent CNAV error contributes about 3 centimeters. Orbit and clock precision is substantially improved. Because a minimum of three message types are needed for the necessary orbit and clock parameters, as little as 18 seconds is needed to gather the necessary information after locking to a signal. On the other hand, if four message types are being sent sequentially, and the receiver locks just after the beginning of a message, it can take 30 seconds to gather the necessary data. TTFF typically is improved. Importantly, each CNAV message includes a 24-bit cyclic redundancy check (CRC) word that makes it practically impossible to have bit errors in a message that passes the CRC check. Figure 5. CNAV and CNAV-2 message structures. CNAV-2 improvements to the CNAV structure all but guarantee an 18-second TTFF after signal acquisition. Message efficiency is improved by eliminating the need to identify each six-second message, to have complete time-of-week (TOW) information in each six-second message, and to have three rather than two 24-bit CRC words every 18 seconds. Even more important, GPS time is defined modulo 18 seconds upon acquisition of only one signal, and it is defined modulo two hours by decoding only one 26-bit, 0.52-second time-of-interval (TOI) word at the beginning of each message. In addition, TOI is so well encoded (52 symbols for nine data bits) that it can be demodulated in very weak signal conditions, which can be further enhanced by combining the identical TOI symbols transmitted by every satellite at the beginning of every 18-second message. Figure 6 illustrates the ability to combine message symbols from several sequential Subframe 2 data blocks so vital clock and ephemeris data can be demodulated at the weakest signal level the receiver can track. This feature is made possible because the symbols in subframe 2 will not change for at least 15 minutes (50 repeats) and typically no more often than one to two hours (200 to 400 repeats). This provides up to 8.4 dB of message demodulation improvement. The figure also shows other L1C improvements: 4.8 dB of carrier track threshold extension, and a TTFF of 18 seconds after successfully demodulating subframe 2 from the minimum number satellites for a position fix. Subframe 3 of the L1C message contains less time-critical information such as almanac, ionospheric correction terms, and so on. This subframe also is LDPC block-encoded so it is quite robust, although it does not offer the ability to combine symbols from sequential messages. Figure 6. L1C and C/A performance comparison. Pilot Overlay Code Figure 5 shows that the pilot overlay code consists of 1,800 chips that frame the 18-second message. In comparison with the L5 20-millisecond (ms) pilot overlay code, it not only is 900 times longer but also is unique to each satellite. This improves cross-correlation performance in general and particularly when two satellites have the same pseudorange. The long L1C overlay code can be acquired reliably after only one or two seconds of signal lock. Its length does not cause a relevant delay in TTFF, but it provides many advantages. First, synchronizing to the overlay code on one satellite defines GPS time for all satellites modulo 18 seconds (in comparison to 1 ms with the C/A code). Even with infrequent use, the receiver’s RTC, which typically is better than 5 parts per million (ppm), should have sufficient accuracy — better than ± 9 seconds — to completely resolve GPS time with one signal acquisition. In 24 hours with a clock frequency error of 5 ppm the time drift would be less than ½ second. Even if the RTC is in error by several times 18 seconds, resolving accurate time can be done quickly by computing position fixes with multiple time hypotheses spaced 18 seconds apart. Pseudorange changes at rates up to ±1,440 kilometers per 18 seconds. Because some satellites are approaching, others are moving away, and all of them are changing range at different speeds (different Doppler frequencies), determining which position fix is correct out of several 18-second GPS time hypotheses will be straightforward since only one will be reasonable. (Care must be taken to avoid any extremely rare instances where two results may seem reasonable.) The worst clock error with aided GPS (A-GPS) is ±2 seconds, which is adequate to completely resolve GPS time after acquiring only one L1C signal. This capability can aid acquisition of and navigation with other signals, such as C/A or signals from other GNSS providers. The 18-second overlay code will provide benefits as soon as even a few L1C signals are available. The L1C overlay code, in conjunction with the repeating symbols of message subframe 2, also enables data demodulation to begin at any point within an 18-second message. It is not necessary to wait for the message frame to begin. The receiver can begin collecting data symbols at any time, and 18 seconds later it will have assembled all the subframe 2 clock and ephemeris information and can begin to navigate. An exception occurs when the satellite message is updated, between once every 15 minutes to once every two hours. This capability significantly improves TTFF whenever satellite messages are needed for navigation, for example, when they aren’t still valid from a previous collection or aren’t provided by an A-GPS service. Spreading and Overlay Code Designs The L1C MBOC waveform (time-multiplexed BOC, or TMBOC), shown in Figure 7, enabled GPS and Galileo to have open-service L1 signals with an identical spectrum, although implemented quite differently. L1C places all the BOC(6,1) chips in the pilot carrier. This is because the BOC(6,1) component is intended to improve code-tracking performance by increasing code loop signal-to-noise ratio (SNR) and by allowing advanced multipath-mitigation techniques to have the advantage of more code transitions. Because these measurements are made almost exclusively on the three times (4.8 dB) more powerful pilot signal, there is no reason to lose the code tracking benefit by having BOC(6,1) chips in the data signal component. In addition, narrowband receivers such as those predominantly used for consumer applications cannot process BOC(6,1) chips, so it would be undesirable to deny full message signal power to such receivers. Figure 7. The GPS MBOC (TMBOC) modulation. For receivers tracking only the BOC(1,1) component of L1C MBOC, there are on average 43.5 code transitions per 33 chips. For those tracking both components, there are on average 89.5 code transitions per 33 chips. This provides up to 3.1 dB of improvement in code loop SNR for wideband receivers code tracking with both types of chips. (The amount of improvement depends on receiver RF bandwidth.) Classic multipath-mitigation techniques such as the double-delta don't work well with the BOC(6,1) waveform, but recent advances promise improvement by using the extra transitions in the MBOC signal. Some developers worry that the full benefit may not be achieved unless code symmetry and time alignment of the two components is better than the signal specification permits. If the satellites cannot provide the needed signal symmetry and alignment, such problems likely can be overcome by ground calibration of these characteristics, either directly by each receiver or indirectly by an observing network. Symbol Interleaving. Symbol interleaving means that before a message is transmitted, the satellite scatters the 10-ms message data symbols from subframes 2 and 3 throughout these subframes in a fixed and known pattern. After a receiver has demodulated (or otherwise measured) the symbols belonging in a subframe, they are reassembled into the proper order before the LDPC block decoding is performed. In other words, the scattering done in the satellite is undone by the receiver. The objective is to provide a measure of protection against certain types of signal fading. For example, if a sequence of symbols from the satellite is lost because the receiver passes behind an object such as a tree, only half the symbols in this part of the message would be affected if the adjacent symbols in the original message are received either before or after the signal blockage. Thus, with reasonable signal levels and the benefit of powerful LDPC block encoding, the entire message could be reconstructed. Performance Metrics and Comparison A main objective for the L1C signal structure was to significantly improve the autonomous navigation capability for GPS users. Key weaknesses in the current C/A signal include the thresholds for bit synchronization, message synchronization, and data-bit demodulation. To achieve navigation at very low signal levels, users of the L1 C/A signal had to employ external sources for time synchronization, data acquisition, and, to extend the tracking loop threshold, external data-bit aiding to enable phase-locked tracking rather than Costas tracking of the C/A signal. The new signal structure addresses all of these shortcomings and provides a robust autonomous navigation system that requires no external aiding for most commercial applications. Message Frame Synchronization and Time of Transmission. For autonomous navigation, frame synchronization has two important roles. The first is to set GPS time, modulo frame duration, which is required to establish the unambiguous time of transmission. Frame synchronization, or knowledge of frame start, also enables assembly of the received bits into the appropriate data words. In both L1 C/A and L5, frame synchronization is accomplished by recognizing a synch word within a data subframe, which requires accurate demodulation of data bits. For L1C, frame synchronization is inherent in the signal structure and does not require demodulation of data bits. This is very important for two reasons. The first is to establish GPS time of transmission very quickly, especially when the satellite message is not needed, for example, if it was acquired previously or obtained by other means. The second is when satellite ephemeris data is necessary, but the signals are very weak. The L1C message structure facilitates this capability. Overlay Code on Pilot Carrier. One frame of data consists of 1,800 symbols modulated onto the data carrier which, at 100 symbols per second, is 18 seconds long. However, synchronized to this 18-second data frame is a pseudorandom code modulated on the dataless pilot carrier. This 100 chips per second overlay code is a linear-shift-register code that is truncated to be 1,800 chips long. The overlay codes were chosen to have very low minor auto-correlation and cross-correlation peaks so a very short segment of the code can be used to establish its underlying code phase. If a 100-chip segment of the received code is correlated over a replica of the entire code, the proper correlation peak would be easily distinguished, thus establishing the GPS time epoch at the start of the code. Since this code epoch and the start of the data frame are synchronized, the start of the entire data frame is established, modulo 18 seconds. The start of the data frame by definition establishes the GPS time of transmission, also modulo 18 seconds. This is accomplished without decoding a single data bit by using the power advantage of the pilot carrier. However, using the message to resolve the 18-second time ambiguity often is not needed. For example, the receiver’s real time clock (RTC) is likely to be accurate to within ±9 seconds. Alternately, almost any source of external aiding can provide time to within ±2 seconds. In either case, if the receiver already has a valid satellite ephemeris, navigation can begin after receiving a little over 1 second of the stronger pilot carrier signal. Ephemeris data can be available in a number of ways, including prior reception from the satellite, from a separate communications channel, or from one of several predicted ephemeris sources. Message Frame – Data Format. A message frame consists of 1,800 symbols that comprise two distinct data types. The first data type, in subframe 1, is the Time of the Frame (TOI or Time of Interval) modulo two hours. The second data type is further separated into two blocks, subframe 2 containing data that is fixed for a period of time and subframe 3 containing data that can change from frame to frame. Time of Interval Subframe. The TOI is a count of the number of 18-second message intervals in each 2 hour time period. Two hours is the maximum duration of any ephemeris message before being replaced by the satellite. (Fifteen minutes is the minimum.) There are 400 18-second intervals in 2 hours, so it requires 9 bits to represent the 400 intervals. These nine bits are block-encoded into 52 symbols using a BCH(51,8) code, where the 8 data bits are the least significant bits of the TOI. The most significant bit (MSB) of the TOI is then mod-2 added to the BCH codeword and also appended to the resulting codeword as its MSB, resulting in a 52-symbol codeword. This coding provides a BER of 10-5 for an Eb/N0 of –1.9 dB per coded symbol or a C/N0 of +18.2 dB-Hz at the correlator output for the data channel. Since the data channel contains only 25 percent of the total L1C power, the C/N0 of the composite signal would be +24.2 dB Hz. Symbol demodulation is performed using the pilot carrier tracked by a PLL as the phase reference. Since the pilot carrier contains 75 percent of the total power, its C/N0 would be +23 dB-Hz. With a (single-sided) loop-noise bandwidth of 10 Hz, the loop SNR for the carrier channel PLL would be +10 dB. Note that a 10-5 BER is not required for successful demodulation of TOI. Therefore, weaker signals can be used successfully if the PLL loop bandwidth can be smaller in such weak signal conditions. The most straightforward method to decode the TOI is brute force maximum likelihood estimation. All possible code words for the 400 possible data words can be pre-computed. Each then can be compared (correlated) with the received code word. The data word that corresponds to the code word with the highest correlation would be the result of the decoding process. Finally, since all satellites simultaneously transmit the same TOI, the received code word from several satellites can be combined to increase the effective Eb/N0. The target BER of 10-5 thus can be achieved at an even a lower C/N0 than the single satellite value. In this case, the decoding process described above can be performed on a composite code word derived from two or more satellite signals, weighted appropriately for the signal strength from each one. As an example, consider a receiver with access to an external source of the ephemerides. By combining the TOI code word from five satellites, the average C/N0 required per satellite would only be 17.2 dB-Hz, so time could be established to ±1 hour in slightly over 1 second. Because of the 18-second overlay code, decoding TOI is not required for receivers with an internal clock good to ±9 seconds or with external time aiding, the worst of which today is within ±2 seconds. Data Subframes. The remaining data bits are separated into two additional subframes. (TOI is in the first subframe.) The second subframe contains data that does not change for at least 15 minutes, and typically for an hour or two. This subframe provides the satellite ephemeris and the interval time-of-week (ITOW) count, which identifies the start time of the two-hour interval since the beginning of the GPS week, which, in turn, frames the TOI count of 18-second intervals within each two-hour frame. The third subframe contains data that normally changes from frame to frame, such as the satellite constellation almanac. The block of data containing the satellite ephemeris (subframe-2) consists of 576 clock and ephemeris bits along with a 24-bit CRC, for a total of 600 bits. These are encoded with a rate-½ LDPC Block code into 1,200 symbols. The block of data containing variable data (subframe-3) consists of 250 data bits along with a 24-bit CRC, for a total of 274 bits. These are also encoded with a rate-½ LDPC Block code into 548 symbols. The 1,748 symbols of the two data subframes are combined and interleaved using a simple 38 x 46 row-column block interleaver. These interleaved symbols plus the 53 TOI symbols make up the entire 1,800-symbol (900-bit) message frame. Since both the LDPC codes and the interleaver operate on independent blocks of data, the resulting symbols for subframe-2 are identical and in the same location in each message frame for between 15 minutes and two hours. Since the data decoding uses the pilot carrier as the phase reference, the subframe-2 symbols can be coherently combined over many 18-second message frames before decoding to improve BER performance. One reasonable subframe-2 strategy would be to check the CRC after LDPC-decoding the first received message to determine if there are any remaining bit errors. If errors are detected, do the same with the second message. If errors exist in the second message, coherently combine the symbols from the two messages, properly weighted, LDPC-decode the combination, and check the resulting CRC for errors. If necessary, this process can be used on as many messages as needed to obtain a perfect result. Framing the data messages with the pilot overlay code and the repeating characteristic of subframe 2 permits data collection over any arbitrary 18-second interval. It doesn't matter where data collection begins. The overlay code tells the receiver which symbol is which, and the repeating subframe-2 message can be compiled from any place in the previous message to the same place in the following message. The powerful CRC assures that a good message is perfect. When the ephemeris is needed from a satellite, rather than from an alternate source, these characteristics allow TTFF to be slightly over 18 seconds, with assurance the information is correct. Since LDPC FEC has been adopted by the current state-of-the-art wireless standards such as 802.11n and 802.16e, employing it in the latest GPS signal structure should be simple for the receiver designer. In fact, synthesizable cores are available for WiMax LDPC decoders from several sources, and LDPC decoders are as commonplace in wireless signal basebands as Viterbi decoders for the convolutional codes of L2C, L5, and SBAS have become in GPS basebands. For subframe-2 data, the Eb/N0 required to achieve a BER of 10-5 is approximately 2.2 dB. For subframe-3 data, the Eb/N0 required for this same performance is approximately 2.7dB. Signal Structure The L1C signal is a composite of two signals that are phase/frequency coherent with synchronized spreading codes and symbol timing. The pilot signal has 75 percent of the total power, is a carrier-only signal, and is spread by a 10-ms long code plus an 18-second overlay code. The data signal has 25 percent of the total power, is spread by a 10-ms long code, and is data modulated with 10-ms symbols. Spreading Codes. The spreading code for both L1C signals are 10,230 chip codes with a chip rate of 1.023 MHz, producing a 10-ms long code. This corresponds to one symbol for the data carrier and one chip of the overlay code for the pilot carrier. These codes are not linear shift register sequences like all other codes employed by GPS, but are pseudo-random sequences derived from Weil sequences of length 10223. This sequence is extended by a 7-bit sequence 0110100, which is the same for all satellites, to the required length of 10230. The location within the particular Weil sequence where the extension sequence is inserted is called the insertion index. A pair of Weil indices and a corresponding pair of insertions points then determines the pair of codes for each satellite. Synchronization to one of these Weil-based codes can be accomplished with a standard time-domain correlator, but the number of potential hypotheses has increased by a factor of ten compared to the C/A signal. However, this is no different than time-domain correlation for an L5 code, which also are 10,230 chips long. Synchronization also can be accomplished using FFT-based frequency-domain correlation, however it does require an FFT of length 65,536 (for a standard radix-2 implementation) since the FFT must span 2 full code periods at a minimum of 2 samples per code chip (40,920). To compare L1C frequency domain correlation with L1 C/A, a frequency search window and integration time must be hypothesized. A simple example would be a 10-ms coherent integration time and ±250 Hz frequency uncertainty. Table 3 compares the number of complex operations required for L1 C/A vs. L1C. Table 3. Comparison of FFT-based correlation for L1C versus L1 C/A. (Click to enlarge.) For cases where large search window uncertainties exist, and frequency domain correlation provides a computational benefit, an alternate approach to L1C synchronization would be to first obtain L1 C/A synchronization using an FFT-based search, providing frequency and 10 timing hypotheses (perhaps more with potential cross-correlations for L1 C/A). These L1C hypotheses could be tested by simple time-domain correlation that would benefit from the much better cross-correlation properties of the L1C codes. For cases where time uncertainty is not large, a time domain search of the L1C code would be no more difficult than the equivalent for L1 C/A. For cases where the time uncertainty is small but the frequency uncertainty is large, time-domain partial-period correlations could be combined in an FFT structure that would span a large frequency uncertainty with a single time hypothesis. For example, the 10,230 chips could be separated into 62 segments, each 165 chips long. The 62 segments could then be combined using a zero filled 64-pt FFT to produce 64 full correlations spanning ±3 kHz. MBOC Waveform. The L1C spreading code is further modulated with a code clock synchronized 1.023 MHz square wave creating the BOC(1,1) signal that forms the majority of the L1C code symbols. This produces a code that appears as a 1 MHz square wave, synchronized to the Weil-based code edge, whose polarity indicates the state of the Weil-based code chip. This BOC(1,1) sequence modulates all of the data channel chips and 29 of every 33 pilot channel chips. The other 4 out of 33 Pilot channel chips are modulated by a BOC(6,1) code symbol in which a 6 MHz square wave is used instead of the 1 MHz square wave for the BOC(1,1) chips. (Recall that '1' signifies 1.023 MHz and '6' signifies 6.138 MHz.) For receiver designers who choose not to punctual correlate the BOC(6,1) component of the pilot carrier, the pilot carrier power will be reduced by ~0.6 dB. The BOC(6,1) signal component provides an opportunity for better performance of advanced multipath mitigation techniques. The presence of multipath interference not only impacts the code-tracking process of a GPS receiver but also distorts the waveform seen by the phase-tracking process of the receiver. The distortion of the phase of the received signal is most problematic when the reflector creating the multipath signal is very close to the receiving antenna, because the path length of such a multipath signal changes very slowly. Since the path length changes very slowly, it appears as an almost constant bias error in the phase measurements. The only way to observe this distortion, and hence measure its impact on the phase measurements, is to observe the phase of the carrier very close to the code transitions. The estimate of this distortion obviously is better the more frequently it can be observed. This is particularly important because the distortion is not constant but slowly changes. The MBOC signal combination provides just over twice the number of transitions at which to observe the phase distortion than the BOC(1,1) signal alone, which is important for higher fidelity measurements during short intervals when the slowly changing distortion is highly correlated . L1C Status Companies already are designing L1C into their new chipsets, even though the first satellite to carry the signal is not expected before 2014. When will L1C be available from enough satellites to be meaningful? Figure 8 is a guesstimate of how modernized GPS signals will become available over the next decade. The projections assume either two or three successful satellite launches per year, and many observers think two per year may be realistic. Because GPS only launches on need to sustain the constellation, the actual launch rate depends on the lifetime of the satellites now in orbit. The first launch of a GPS III may be delayed until all IIF satellites have been launched, or the first GPS III, if available, may be launched before the last IIF to test the new design in space as soon as possible. Some L1C signal and message characteristics will significantly benefit users of C/A and other GNSS signals by, for example, quickly resolving time for all GNSS signals. Therefore, L1C will provide meaningful benefit as soon as even one signal can be tracked from any location on earth. That might be possible with as few as six GPS III satellites in orbit, depending on where in the constellation they are deployed. Figure 8. Guesstimate of modernized GPS signal availability.   Tom Stansell heads Stansell Consulting, after eight years with the Johns Hopkins Applied Physics Laboratory, 25 years with Magnavox (staff VP), and five years with Leica Geosystems (VP), pioneering Transit and GPS navigation and survey products. He led technical development of the GPS L2C signal and coordinated the GPS L1C project (2004–2006). He is a member of the Editorial Advisory Board of GPS World. Ken Hudnut applies new technologies such as GPS to earthquake research as a geophysicist for the U. S. Geological Survey in Pasadena, California. He served as project manager for the GPS L1C signal design project from 2003. He received his Ph.D. from Columbia University. Rich Keegan has 36 years of experience in radio navigation including Transit, Timation, Omega, Loran C, as well as GPS for the past 28 years. He has been the principal of a consultancy in digital communications and navigation since 2000. He was a member of the L2C and L1C modernization committees.

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Email:JW0_TG7P0d@gmx.com
2021-06-01
Jvc aa-v40u ac adapter 7.2v 1.2a(charge) 6.3v 1.8a(vtr) used,2018 by electronics projects hub,compaq series 2842 ac adapter 18.5vdc 3.1a 91-46676 power supply,.
Email:fpc_d36@outlook.com
2021-05-30
Atlinks 5-2418 ac adapter 9vac 400ma ~(~) 2x5.5mm 120vac class 2,panasonic rp-bc126a ni-cd battery charger 2.4v 350ma class 2 sal.liteon pa-1480-19t ac adapter (1.7x5.5) -(+)- 19vdc 2.6a used 1..lenovo 41r0139 ac dc auto combo slim adapter 20v 4.5a.mobile jammer was originally developed for law enforcement and the military to interrupt communications by criminals and terrorists to foil the use of certain remotely detonated explosive,desktop 420/460pt e191049 ac dc adapter 24v 1.25a 950-302686,.