GPS And Other GNSS Signals

GPS Signals And Receiver Technology MM9
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GPS Signals MM9-MM15

- MM9 | GPS and other GNSS signals
- MM10 | GPS signals - Code Generation and Carrier Generation
- MM11 | GPS signals - Acquisition of the GPS Signal
- MM12 | GPS signals - Carrier Tracking
- MM13 | GPS signals - Code Tracking
- MM14 | GPS signals - Navigation Data Decoding
- MM15 | GPS signals - Calculation of Pseudoranges and Positions

http://gps.aau.dk/educate/receiverTechnologyPart3.htm
Today's Subjects

• Spread Spectrum Technique
  – Correlation and other signal properties
  – PRN Codes

• GPS Signal
  – Codes, carriers, navigation data
  – Signal Bandwidth
  – Signal generator

• Overview of today's and future GNSS signals
The Problem

• How to receive 4 to 10+ signals?
  – Multiple systems (cross interference)
  – Multiple bands
  – Near-far problem
Direct-Sequence Spread Spectrum Features

• Allows many transmitters to share the same frequency band
• Signal cannot be received or detected if the spreading code is not known (depends on the signal design)
• Hard to jam (depends on the signal design)
• The spreading codes are also exploited to measure distance to the satellite
Properties Of A Single Chip

\[ f(t) = \begin{cases} 
1, & |t| \leq \frac{T}{2} \\
0, & \text{otherwise}
\end{cases} \]

\[ r_f(\tau) = \begin{cases} 
T \left(1 - \frac{\tau}{T}\right), & \text{for } |\tau| \leq T \\
0, & \text{otherwise}
\end{cases} \]
Some Ideas Behind DSSS

• Replace one data bit with a sequence of chips

\[
\text{mean}(\text{signal}) = 0.4270 \\
\text{sum}(\text{signal}) = 341.6046 \\
\text{mean}(\text{signal}) = 1.0069 \\
\text{sum}(\text{signal}) = 805.5447
\]
Properties Of A Random Sequence

- Number of pulses can be combined to generate sequences of pulses
- Amplitude of pulses is ±1 with equal probability
- Such random sequences have autocorrelation function similar to autocorrelation of a pulse

\[ r_x(\tau) = \begin{cases} 
1 - \frac{|\tau|}{T}, & \text{for } |\tau| \leq T \\
0, & \text{otherwise}
\end{cases} \]

\( R_f(\tau) \)

N = 7 (number of chips)
\( T_c \) – chip (pulse) duration
\( \tau \) – time
Pseudo Random Noise (PRN)

- Noise-like properties ➔ Very low cross-correlation with other signals
- PRN sequences (codes) are almost orthogonal ➔ High auto correlation only at 0 lag and very low cross correlation
- PRN (also called spreading code) is a sequence of random pulses. PRN can be reproduced, there is an algorithm to generate this random sequence
- PRN codes used in GPS belong to family of Gold codes and are created by shift registers of length n
Pseudo Random Noise (PRN)

• Length of PRN sequence is calculated as: $N_{DS} = 2^n - 1$

• Code length defines
  – How many unique codes can be generated
  – How small is code cross correlation

• It takes more time to acquire long codes

• Bit boundaries limit code length

• Higher chipping rates (wider bandwidth signals) yield better positioning measurements
Autocorrelation And Cross Correlation Of PRN Codes

- **Autocorrelation peak** (n=10 for GPS):

\[ r_{kk,\text{peak}} = 2^n - 1 = 1023 \]

- **Cross correlation max:**

\[ |r_{kk}| \leq 2^{(n+2)/2} + 1 \]

\[ |r_{kk}| \leq 65 \]
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Memory Codes

- Galileo will use memory codes for some of its signals
- Memory codes are random sequences like PRN, but do not have a common code generator algorithm
- Memory codes are hard for reverse-engineering
- Memory codes are stored in receiver memory
  - Receiver memory is more expensive comparing to code generators
  - A lot of memory is required for a full system support
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Code Division Multiple Access (CDMA) Systems

- The frequency spectrum of the signal is spread with a noise like code (sequence)
- All users transmit on the same frequency
- Spreading codes have very low cross-correlation and are unique for every user (low interference with other signals)
- Transmission bandwidth is much higher than information bandwidth (but several users can share the same band)
GPS Signals
GPS Signals

- Transmission frequencies:
  - L1 = 1575.42 MHz = 154 x 10.23 MHz
  - L2 = 1227.6 MHz = 120 x 10.23 MHz
  - (Upgrade) L5 = 1176.45 MHz = 115 x 10.23 MHz (for civil, SOL use)
  - (Upgrade) New military signal (M-code) and a new civil signal (L2CS)
GPS Signal Spectrum

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GPS Signal

- **C/A codes**
  - Chipping rate of 1.023 Mcps
  - Length of 1023 chips
  - Chip duration ~ 1µs, wave length ~ 300 m
  - Repeats every millisecond
  - 32 different sequences assigned to GPS satellites

- **P(Y) codes**
  - Chipping rate of 10.23 Mcps
  - Length ~ $10^{14}$ chips
  - Chip duration ~ 0.1µs, wave length ~ 30 m
  - Repeats every week
  - Anti-spoofing (Signal authentication)

- **L1 carrier**
  - ~ 0.1903 m
GPS Navigation Data

- Bit-rate of 50 bps (GPS C/A, 25 bps for L2C)
- Data contents:
  - Ephemerides, clock information (repeated every 30 sec.).
  - Satellite status, health and accuracy
  - Almanac
  - UTC conversion
  - Ionospheric information
  - Repeated every 12.5 minutes

More details in MM14…
GNSS Signal Generators
Block Diagram Of A GPS Signal Generator

- X 120: 1227.6 MHz
- X 154: 1575.42 MHz
- Limit: f_e = 10.23 MHz
- P(Y) code generator
- C/A code generator
- Data Information
- Data Generator
- 50 bps data
- 50 Hz
- 1000 Hz
- ±20
- 1227.6 MHz
- -6dB
- -3dB
- BPSK Modulator
- L2 Signal 1227.6 MHz
- L1 Signal 1575.2 MHz
- Switch
- C/A code + data
- P(Y) code + data
- P(Y) code
GPS Signal

- Signal transmitted by a GPS satellite $k$ is

$$s_k^k(t) = \sqrt{2P_C} \left( C_k^k(t) \oplus D_k^k \right) \cos(2\pi f_{L1} t)$$  
$$+ \sqrt{2P_{PL1}} \left( P_k^k(t) \oplus D_k^k \right) \sin(2\pi f_{L1} t)$$  
$$+ \sqrt{2P_{PL2}} \left( P_k^k(t) \oplus D_k^k \right) \sin(2\pi f_{L2} t)$$

- **Note:**
  - L2 can be configured to transmit P(Y) code without data or to transmit C/A signal with data
  - New generation satellites are transmitting L2C civil signal on L2 and new M code signals on L1 and L2
  - Also L5 signal is being deployed ("SVN49", 2009)
**Spreading Operation**

- Data signal is multiplied by a PRN code (XOR operation for binary signals)
- The result signal has PRN like properties
- An example of a spreading operation and the BPSK modulation:

![Diagram](Diagram.png)

1 bit period

Data bits

DSSS code chips

Data * DSSS code

Carrier

Carrier after BPSK

1 chip period
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Galileo Signal

• Due to Galileo signal complexity only signal on L1 is shown

\[
s_{L1}^k(t) = \frac{\sqrt{2}}{3} \cdot \left( e_{E1-B}^k(t) - e_{E1-C}^k(t) \right) \cdot \cos(2\pi f_{L1} t) \\
- \frac{1}{3} \cdot \left( 2 \cdot e_{E1-A}^k(t) + e_{E1-A}^k(t) \cdot e_{E1-B}^k(t) \cdot e_{E1-C}^k(t) \right) \cdot \sin(2\pi f_{L1} t)
\]

\[
e_{L1-A}^k(t) \quad \text{content is classified} \quad \text{PRS}
\]
\[
e_{L1-B}^k(t) = C_{L1-B}^k \cdot sc_{L1-B} \cdot D_{L1-B}^k \quad \text{Data}
\]
\[
e_{L1-C}^k(t) = C_{L1-C}^k \cdot sc_{L1-C} \quad \text{Pilot}
\]
Other GNSS Signals
WAAS And EGNOS

- Provide facilities to obtain better position accuracy by:
  - Correction of ephemerides errors
  - Providing more accurate ionospheric model
- GPS C/A type signals (same modulation, frequency and spreading codes)
- Much higher data rate (500sps - 250 bps)
- Data message structure is different from GPS
- Forward Error Correction (MM14)
- Due to this data rate one symbol in SBAS contains only 2 PRN codes, while in GPS one bit contains 20 PRN codes
- Much lower Doppler (<210Hz instead of 5kHz)
Galileo

- More signals transmitted on each frequency (comparing to today’s GPS)
- Longer spreading codes
- Data less signals
- BOC modulation
- Forward Error Correction (MM14)
- Block Interleaving (bit scattering) - to make the long data losses manageable (MM14)
- Uplink emergency signal
- Signal authentication for SOL users
BOC Signal

- It is derived by mixing of the data/code signal and a sub-carrier (a square wave for BOC)
- The "traditional" BPSK spectrum is divided into two parts
Galileo Spectrum

- The Galileo spectrum is made to minimize interference to GPS by use of BOC modulation
- Wider signal bandwidth can yield a better positioning performance
- The frequency of the sub-carrier defines distance between main peaks = \(2f_{\text{subcarrier}}\) Hz

Galileo will use an enhanced version of BOC(1,1) based signal. Figure shows only BOC(1,1) signal.
GLONASS

- Two frequencies
- Separate carrier frequency per satellite.
- 0.511 Mcps civil signal and 5.11 Mcps military spreading codes
- 12 satellites operating + 4 GLONAS-M (2006)
- New generation (GLONAS-M): upgraded signals, intersatellite links, many other improvements
- Next generation GLONAS-K (2005 - 2010)
Spectrum of All GNSS Signals/Carriers

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List of all GPS And Galileo Signals and Parameters

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• http://www.navcen.uscg.gov/gps/modernization/
• http://gps.faa.gov/Programs/WAAS/waas.htm
• http://www.esa.int/esaNA/galileo.html
• http://www.esa.int/esaNA/egnos.html
• http://www.glonass-ianc.rsa.ru/

Refer to Interface Control Documents (ICD) for detailed description of the GNSS signals
Questions and Exercises