Improving the GPS L1 Signal

GPS III Offers the Opportunity
Introducing

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Estimated Signal Availability

Assumes eight IIR-M satellites and average of three successful launches per year

Not Official
First L1C Modernization Question

GPS III offers an opportunity to improve the L1 Civil signal

How?

- Triple Minimum C/A Power
- Add New Modernized Signal

C/A also is Retained
Where To Fit a New L1 Signal?

L1 Spectrum
L1 already will have C/A, P(Y), and M code signals
Finding space for a new signal is a challenge
Compromise is required

Offset from 1575.42 MHz Center Frequency (MHz)
Must “Fit” Between M and C/A Codes

P(Y) is the “old” military signal

So, fitting between C/A and M codes is the focus

Note change in frequency scale

Offset from 1575.42 MHz Center Frequency (MHz)
Such As BOC(1,1) (OK for M and for C/A)

BOC(1,1) Spectral Separation Coefficient (SSC)
For C/A = -67.8 dB/Hz
For M = -82.4 dB/Hz
What’s a BOC?

- BOC = Binary Offset Carrier
- The code is modulated by a square wave
- M code is a BOC(10,5)
  - 5 MHz code modulated with a 10 MHz square wave
- BOC(1,1)
  - 1 MHz code modulated with a 1 MHz square wave

[Diagram showing Code Chips 1, 0, Square Wave, Transmit Signal]
Two U.S. Signal Spectrum Candidates

BOC(1,1)
OK C/A and M Compatibility
Permits 4 MHz receiver bandwidth
The Leading Candidate

BOC(5,1) (?)
Better C/A and M Compatibility
8 dB better code loop S/N
Concern about correlation sub-peaks
Requires >= 12 MHz receiver bandwidth

Government will decide
Loyola de Palacio welcomes the outcome of EU/US discussions on GALILEO

The United States and the European Commission, joined by the European Union Member States, held a successful round of negotiations in Brussels on 24-25 February 2004. The delegations built upon progress made in The Hague and in Washington and were able to reach agreement on most of the overall principles of GPS/Galileo cooperation.

- Adoption of a common baseline signal structure for their respective open services (the future GPS intends to use a BOC 1,1 signal whereas the Galileo open service intends to use a fully compatible optimized version of the same signal which guarantees an high-level of performance).
Autocorrelation Functions (Absolute Value)

BOC(1,1)
- OK C/A and M Compatibility
- Permits 4 MHz receiver bandwidth
- The Leading Candidate

BOC(5,1)
- Better C/A and M Compatibility
- 8 dB better code loop S/N
- Concern about correlation sub-peaks
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Government will decide
Multipath Defined
Narrow Correlator Multipath Error

Not intended to be precise

Short delays generally cause the most trouble

Multipath Mitigation

BOC(1,1)

BOC(5,1)
Multipath Performance

- With multipath mitigation, there is no effective difference in multipath error
  - Requires wide bandwidth receiver processing
- Without multipath mitigation, higher code clock rates do reduce multipath error
  - However, short delay multipath generally causes more trouble and affects all signal options
    - Local reflections tend to be stronger
    - Phase change tends to be much slower, so filtering is less effective (carrier-aided code smoothing)
GPS III Power Control Thinking

Total C/A + L1C (-151.2 dBW Max)

L1C (-153 dBW Max)

Current C/A Measurements

Future C/A (-158.5 dBW Min at 5 degrees El.)
First L1C Modernization Question

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How?

- Triple Minimum C/A Power
- Add New Modernized Signal

C/A also is Retained
Triple Minimum C/A Power (4.77 dB)

**Advantages**
- Simple improvement
- Increase minimum C/A power by 4.77 dB
- No receiver change to benefit
- Helps all C/A users, one launch at a time

**Disadvantages**
- Raises C/A noise floor 1.8 dB
- Net is $4.8 - 1.8 = 3.0$ dB ($x3$ yields $x2$ effectiveness)
- Data also only 3 dB better
- Retains fixed data format
- Unimproved crosscorrelation (Increased strong-to-weak signal correlation may force receiver software updates if not a receiver replacement)
- Not a “competitive” signal

(Also could hurt)
New L1C Signal Improvements

- Twice the minimum C/A signal power
- **Longer codes** *(10,230 chips minimum)*
  - Eliminate cross-satellite correlation interference
  - Reduce effect of narrowband interference
- **Message improvements**
  - Higher resolution, reduced error rate, more flexible
- **Data-less signal component**
  - Pilot carrier improves tracking threshold
  - Better for high precision phase measurements
- **Increase signal bandwidth (code clock rate)**
  - Added interference protection, less code noise
Next L1C Modernization Questions

Add New Modernized Signal at Double the Minimum C/A Power

- Modulation
  - BOC(1,1)
  - BOC(5,1)

- Bit Rate
  - 25 bps
  - 50 bps
  - 100 bps or higher

Demodulation Threshold Compared to C/A at 50 bps:
- 100 bps is +5 - 3 - 3 = -1 dB
- 50 bps is +5 - 3 = +2 dB
- 25 bps is +5 - 3 + 3 = +5 dB

Code Structure?

Presume Equal Power Split between Data and Data-less (pilot carrier) components as in all modern GNSS signals

What New Messages?
L1C Modulation Choices

- Choice will be made by the Government and must balance between interference to legacy C/A users and national security.
- BOC(1,1) seems to be the best compromise.
- BOC(5,1) is better for interference but risks tracking the wrong autocorrelation peak and forces a wide receiver bandwidth.
- Longer codes solve the C/A crosscorrelation problem (strong signal interference with weak signals).
BOC(5,1) Considerations

- Adjacent correlation peaks only 0.9 dB down
  - What is the risk of tracking the wrong peak?
- But, the peaks are 30 meters apart
- Methods exist to convert signal to BPSK(1)
  - Techniques defined by C. Cahn and by P. Ward
    - Convert double sidebands to center frequency
  - No ambiguity in tracking BPSK(1) result
  - If <15 m error, can then track BOC(5,1) center peak
    - Steeper autocorrelation function, more code transitions
- Requires 3x bandwidth of BOC(1,1) receiver
- Multipath mitigation also is less effective
Data Structure Improvements

- A modern signal would share message structure improvements with L2C and L5
- Forward Error Correction (FEC) improves data threshold by 5 dB
- High resolution ephemeris (1 cm)
- Compact almanac (7 satellites in one message block)
- Staggered almanac timing speeds collection
- Message will define the satellite
100 bps Data Rate or Faster

**Advantages**
- Permits additional messages
  - Integrity data?
  - Differential corrections?
- What new messages would you want?

**Disadvantages**
- Requires more signal power to receive any message
- 100 bps requires 4 times more signal power than 25 bps (6 dB)
- Signal must be 6 dB above tracking threshold to obtain messages
  - Autonomous, not assisted, tracking threshold
25 bps Data Rate

Advantages
- Messages can be acquired at the autonomous signal tracking threshold (not Assisted GPS threshold)
- Especially helps in poor signal conditions such as in a forest, on a tree-lined road, indoors, or with interference
- In a tough environment can be the difference between working and not working

Disadvantages
- Requires twice as long to obtain messages compared with 50 bps
  - Clock & Ephemeris in:
    - 18 to 24 sec at 50 bps
    - 36 to 48 sec at 25 bps
- Time To First Fix (TTFF) can be 24 seconds longer than with 50 bps (traditional rate)
Choose One After Each Diamond

What is best for your applications?

- Add Modern Signal at 2X Minimum C/A Power
- Triple Minimum C/A Power

- BOC(5,1)
- BOC(1,1)

- 100 bps or faster
- 50 bps
- 25 bps

What New Messages?
L1C Questionnaire

Name: ___________________________ Date: __________
Title/Position: ___________________________
Organization: ___________________________
Address: _______________________________________
Phone: ___________________________ E-Mail: ________________________

Circle Preferences:

What new messages:

Comments:
# Application Specific Questions

Name: __________________________ Date: ____________
Title/Position: __________________________
Organization: __________________________

## Your Primary Expertise

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<th>Consumer</th>
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## Applications

1. 

## Expected Number of Users in 2005

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## Expected Number of Users in 2020

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## Importance

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