Improving the GPS L1 Signal

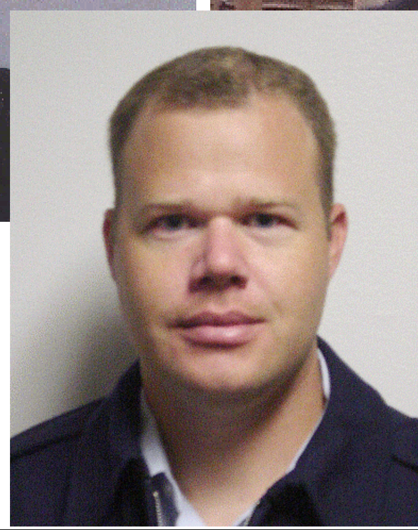
GPS III Offers the Opportunity

U.S. Department of the Interior
U.S. Geological Survey

Introducing

1Lt. Bryan Titus
Co-Chair, JPO

Dr. Ken Hudnut
Co-Chair, USGS



2Lt. Jason Taylor

Tom Stansell

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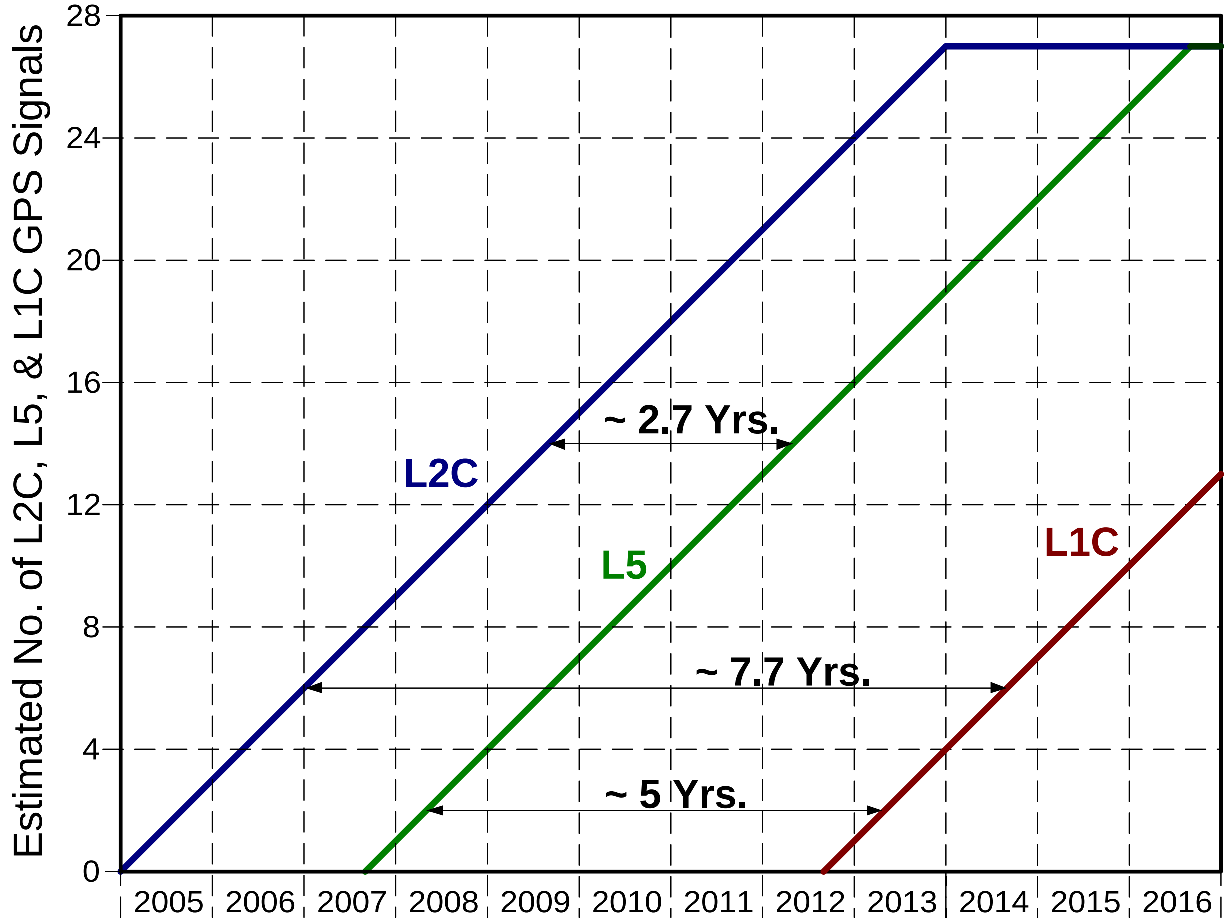
Estimated Signal Availability



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

Not Official

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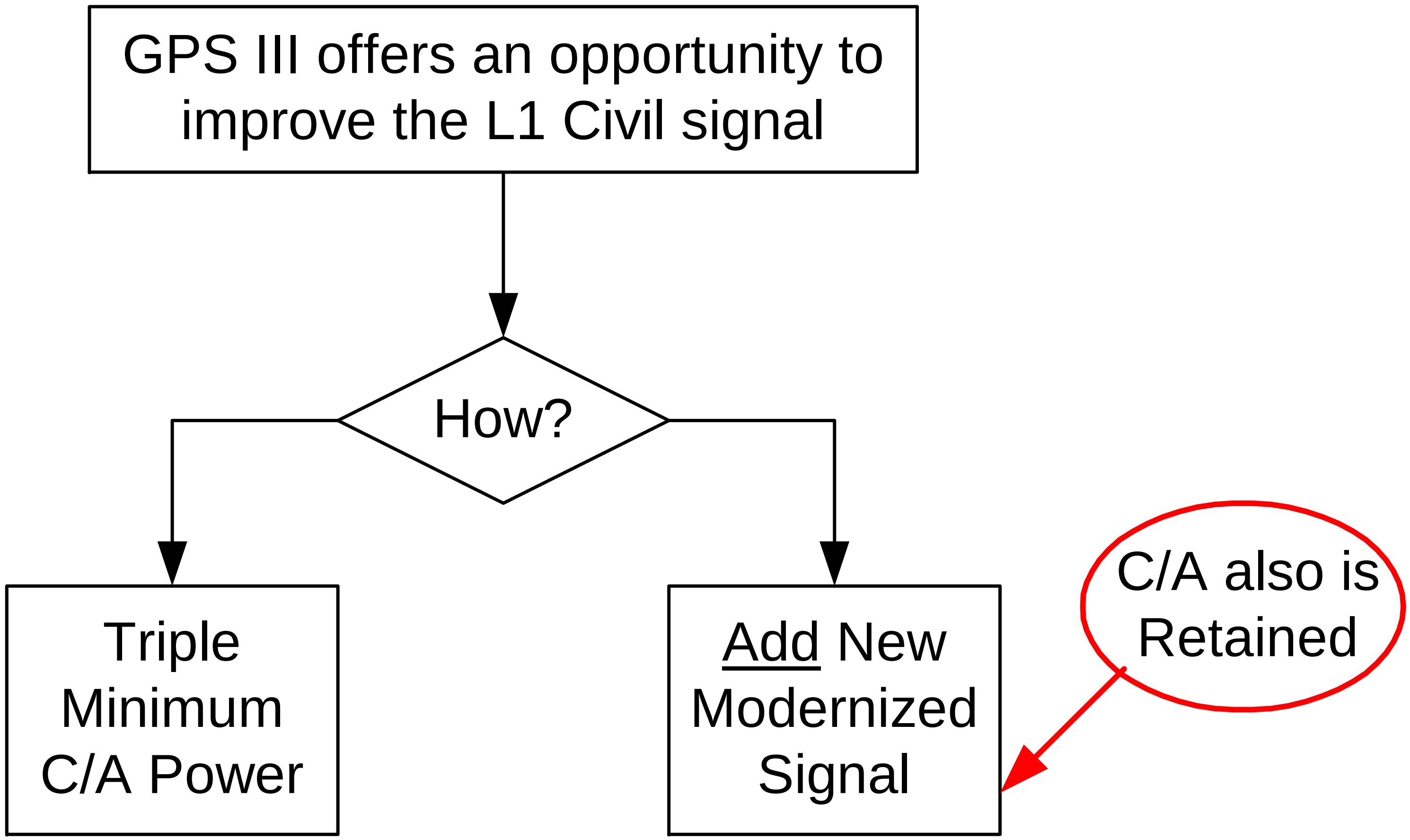
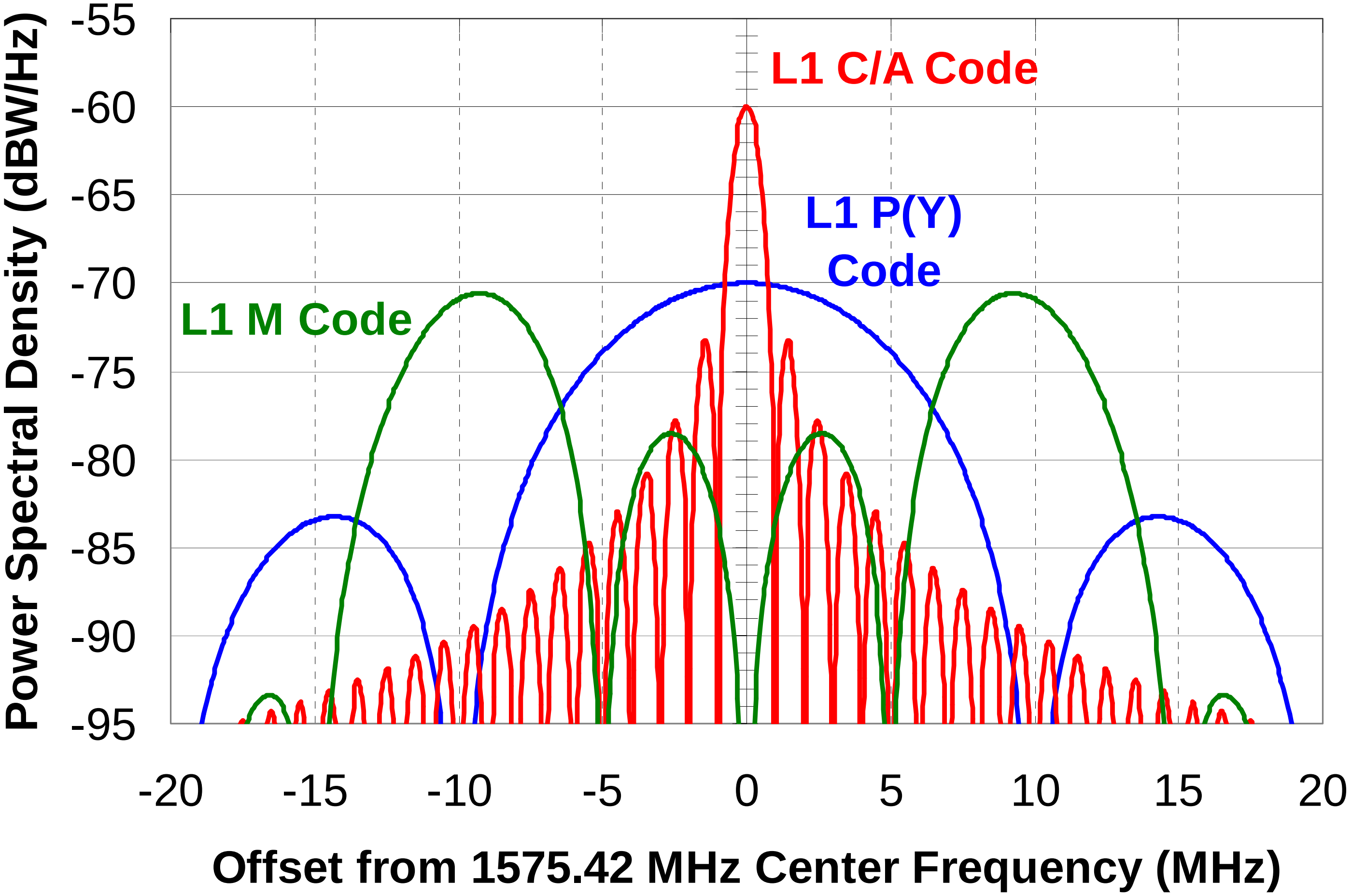
First L1C Modernization Question



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

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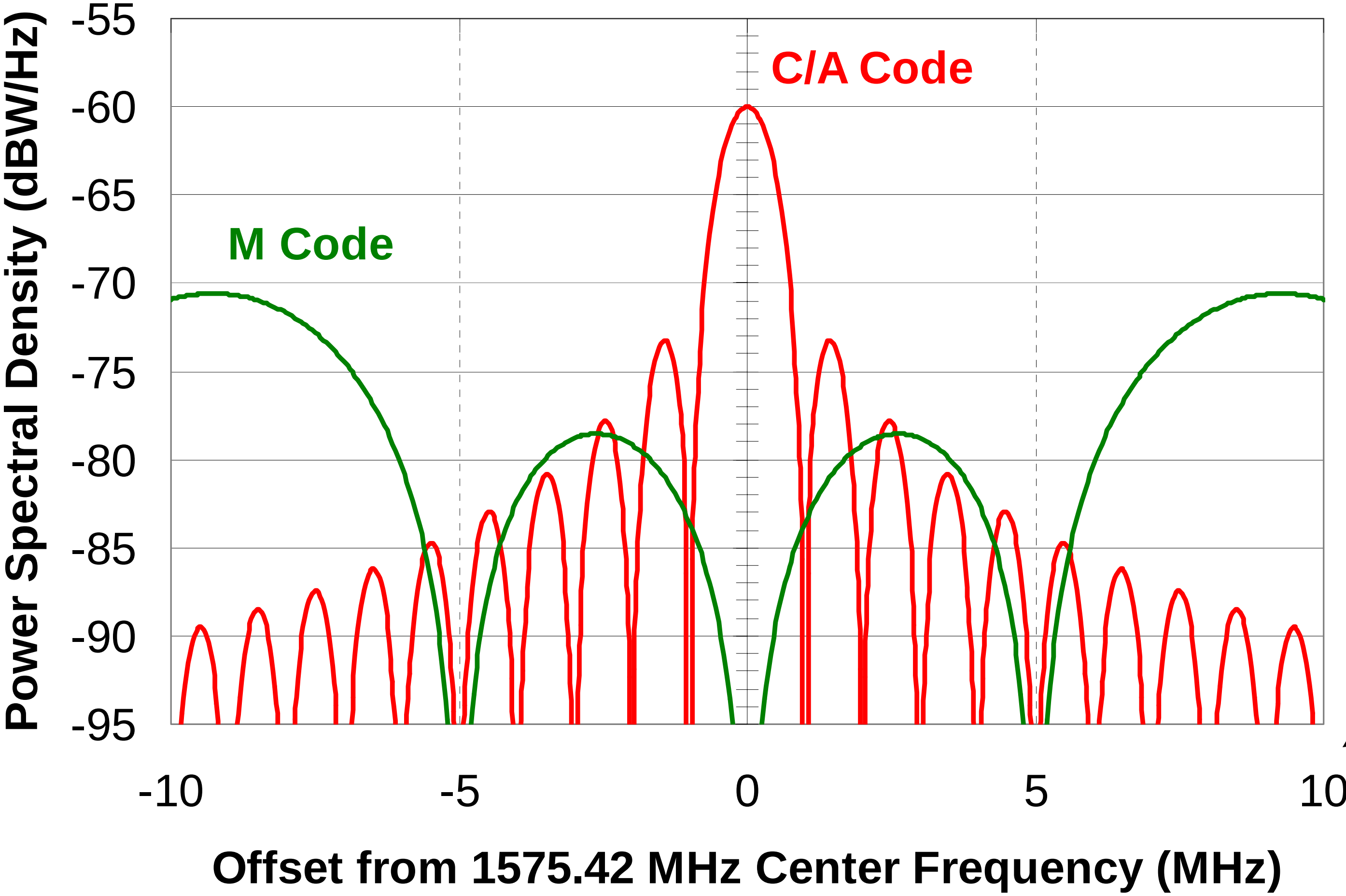
Must “Fit” Between M and C/A Codes



P(Y) is the “old” military signal

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

Note change in frequency scale

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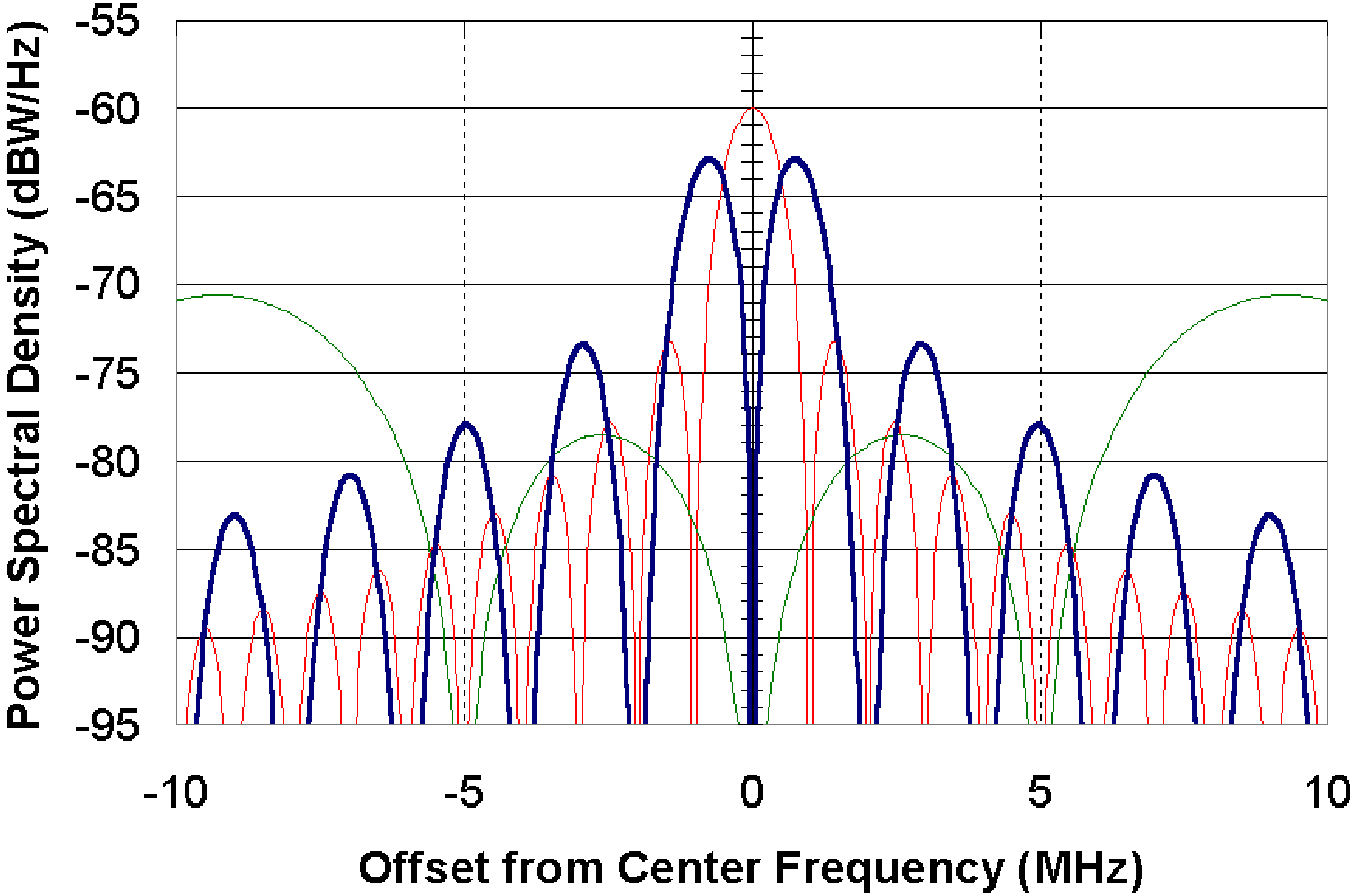
Such As BOC(1,1) (OK for M and for C/A)



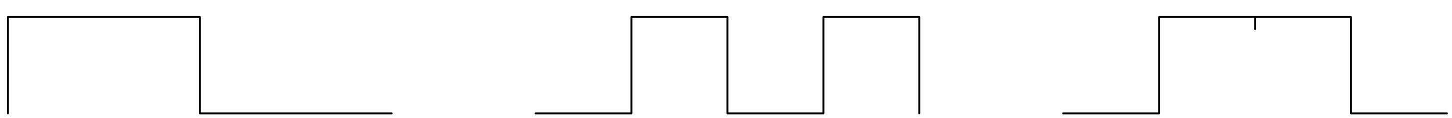
BOC(1,1) Spectral Separation Coefficient (SSC)

For C/A = -67.8 dB/Hz

For M = -82.4 dB/Hz

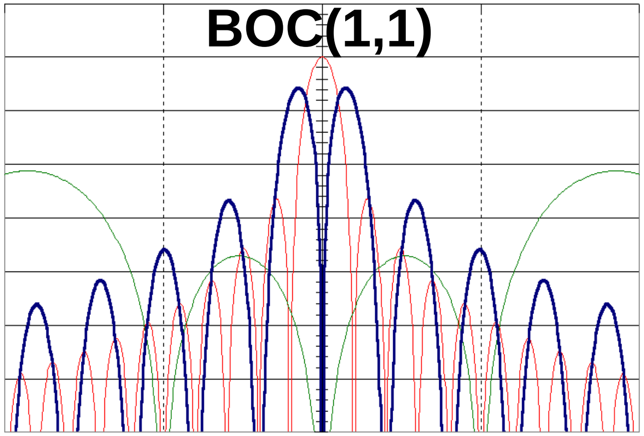
What's a BOC ?

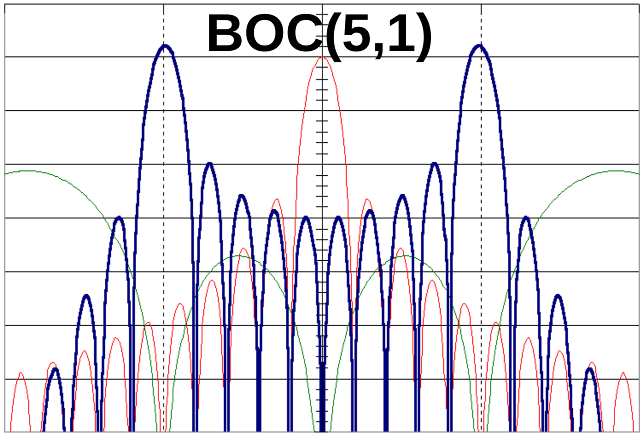
- **BOC = Binary Offset Carrier**
- **The code is modulated by a square wave**
- **M code is a BOC(10,5)**
  - **5 MHz code modulated with a 10 MHz square wave**
- **BOC(1,1)**
  - **1 MHz code modulated with a 1 MHz square wave**



Code Chips 1, 0 **Square Wave** **Transmit Signal**

Two U.S. Signal Spectrum Candidates





Government will decide

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

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

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Galileo Signal Decision

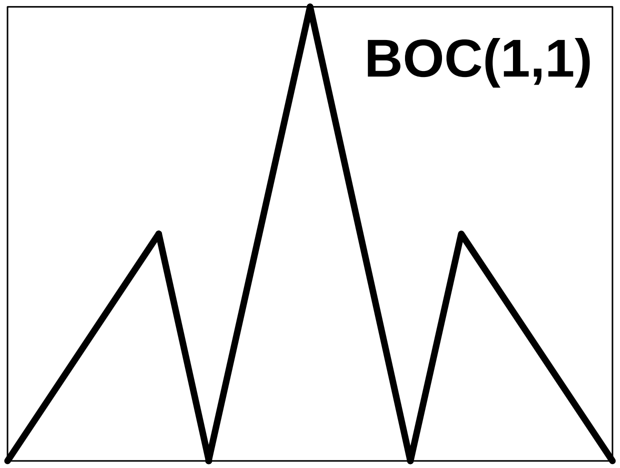
http://europa.eu.int/rapid/start/cgi/guestfr.ksh?p_action.gettxt=gt&doc=IP/04/264|0|RAPID&lg=EN&display=

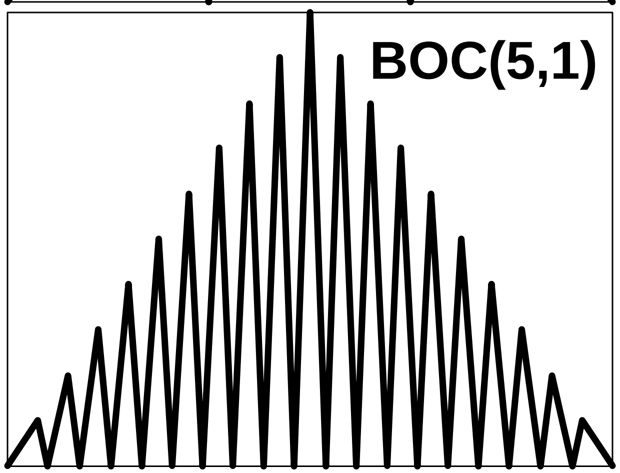
Loyola de Palacio welcomes the outcome of EU/US discussions on GALILEO

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)





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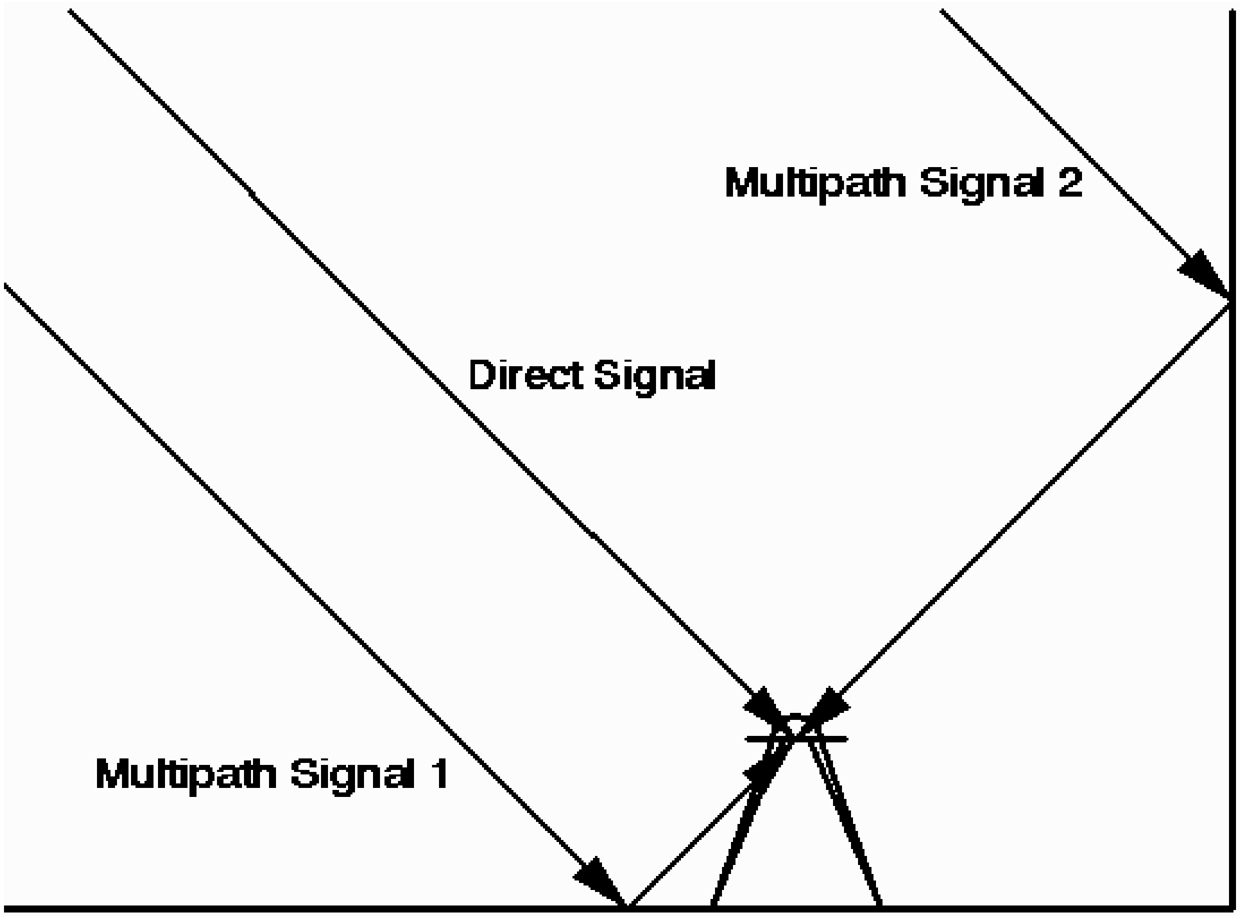
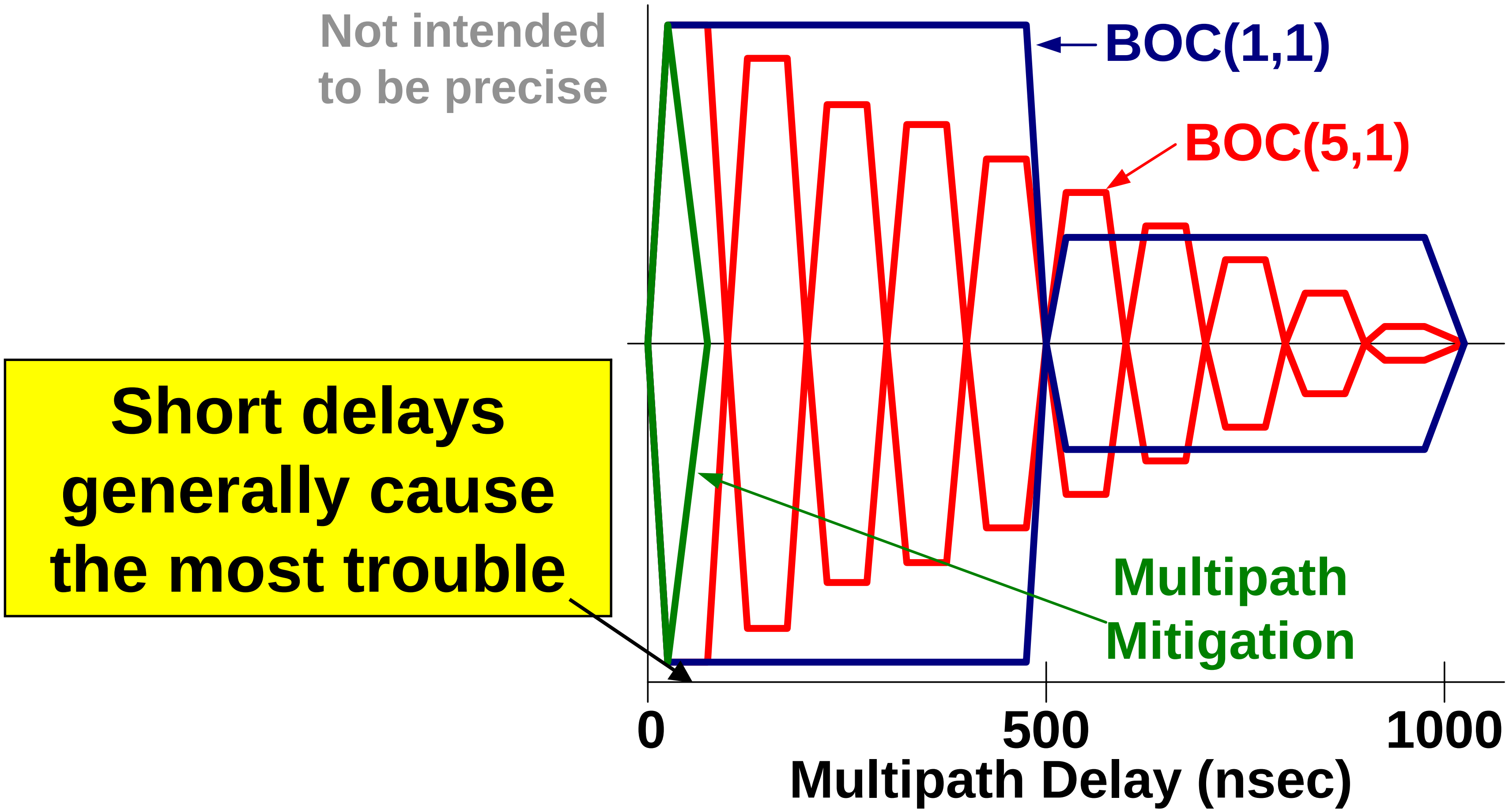
Multipath Defined



Narrow Correlator Multipath Error



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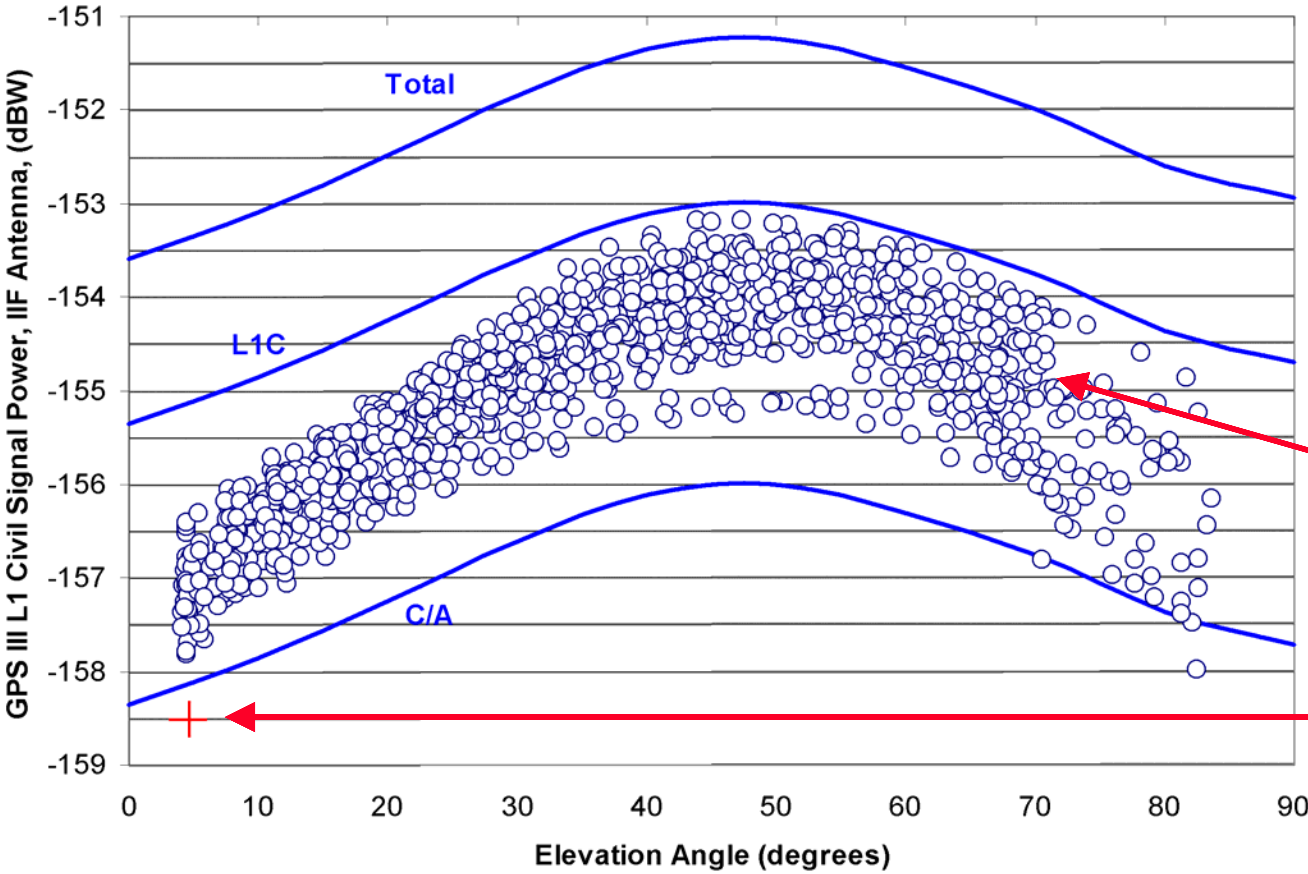
Multipath Performance

- **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.)

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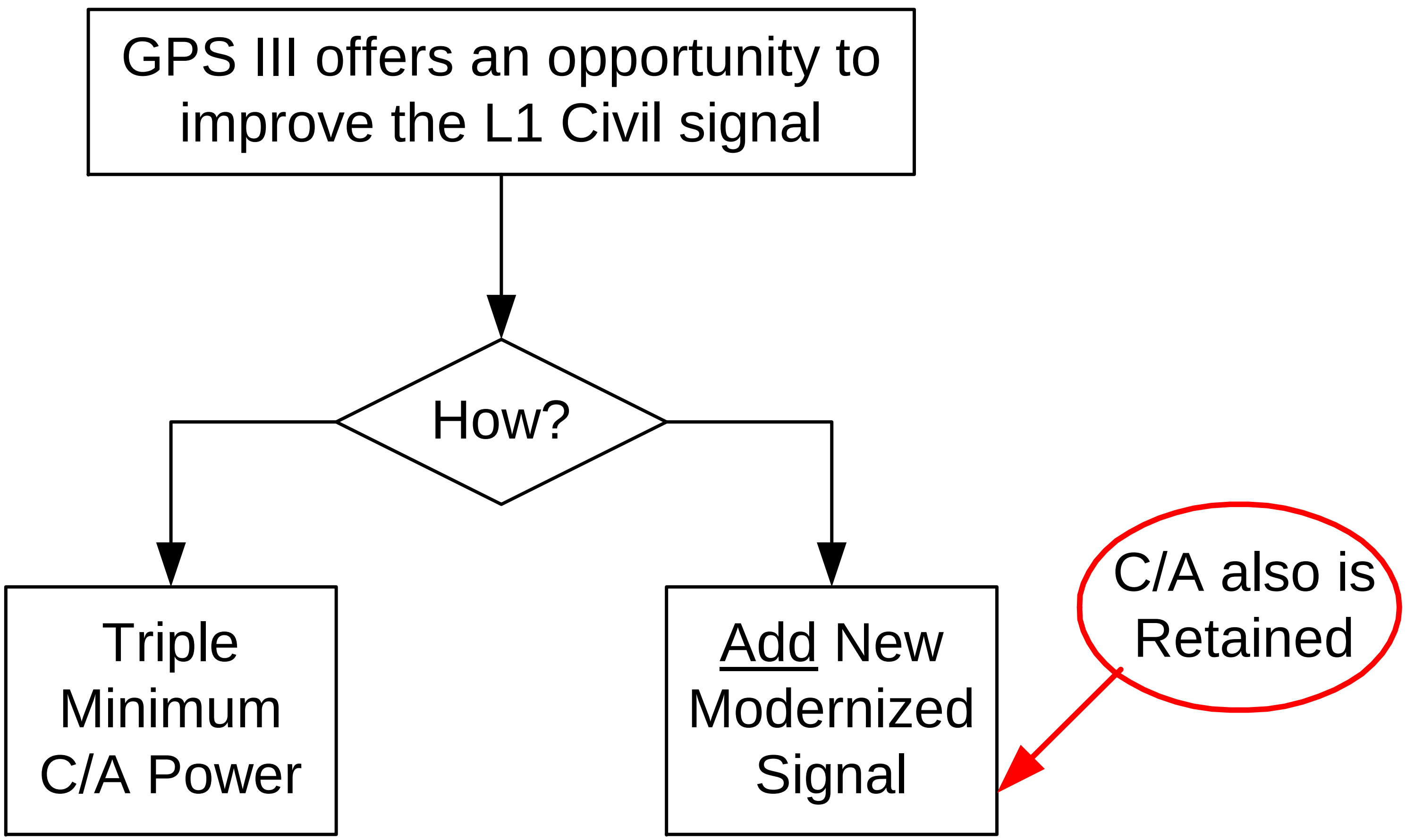
First L1C Modernization Question



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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

(Also could hurt)

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

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

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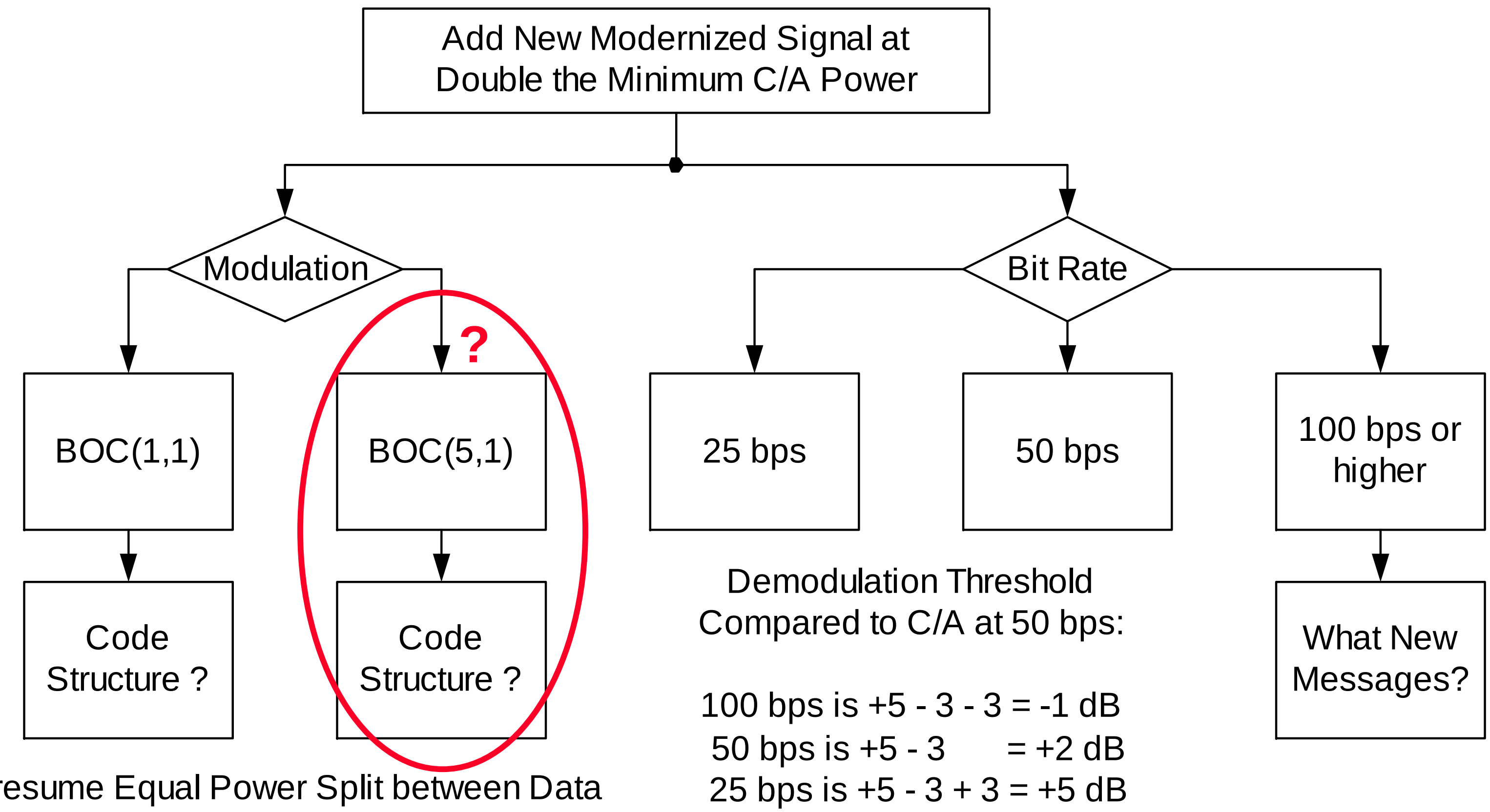
Next L1C Modernization Questions



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

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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)**

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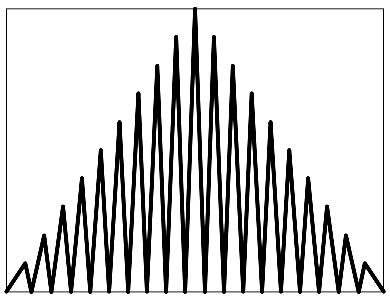
BOC(5,1) Considerations



- **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 <u>resolution</u> 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

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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)

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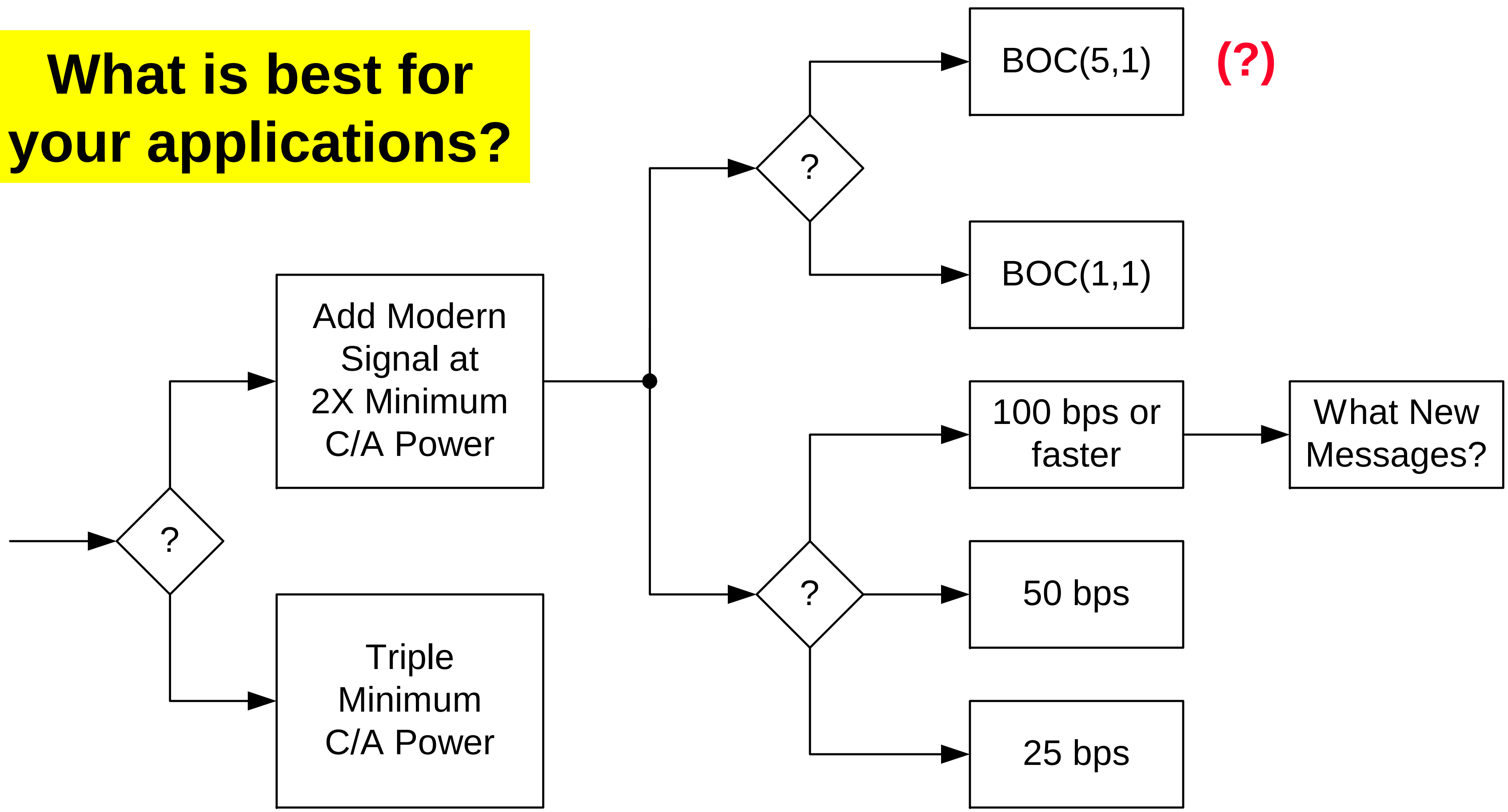
Choose One After Each Diamond

What is best for your applications?



Questionnaire Page 1

L1C Questionnaire

Name: ______________________________ Date: ____________

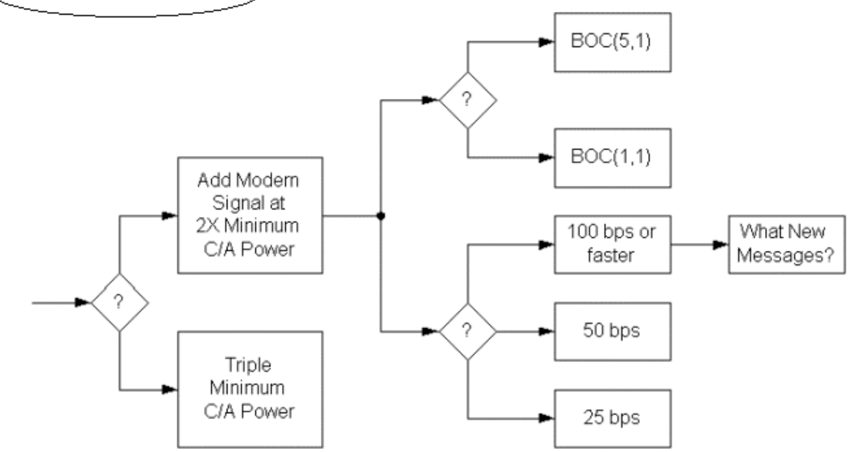
Title/Position ____

Organization ____

Address ____

Phone: ____________________ E-Mail: ____________________

Circle Preferences:



What new messages:

Comments:

Questionnaire Page 2

Application Specific Questions

Name: ______________________ Date: __________

Title/Position ______________________

Organization ______________________

Your Primary Expertise

	Professional & Scientific	Commercial	Consumer
Land			
Sea			
Air			
Space			

Expected Number of Users in 2005

	Professional & Scientific	Commercial	Consumer
Land			
Sea			
Air			
Space			

Expected Number of Users in 2020

	Professional & Scientific	Commercial	Consumer
Land			
Sea			
Air			
Space			

Applications

1.

Importance

Parameter	Best Desired	Worst Acceptable	Importance
Accuracy			
TTFF			
Availability			
Continuity			
Integrity			
Robustness			

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