The New L2 Civil Signal

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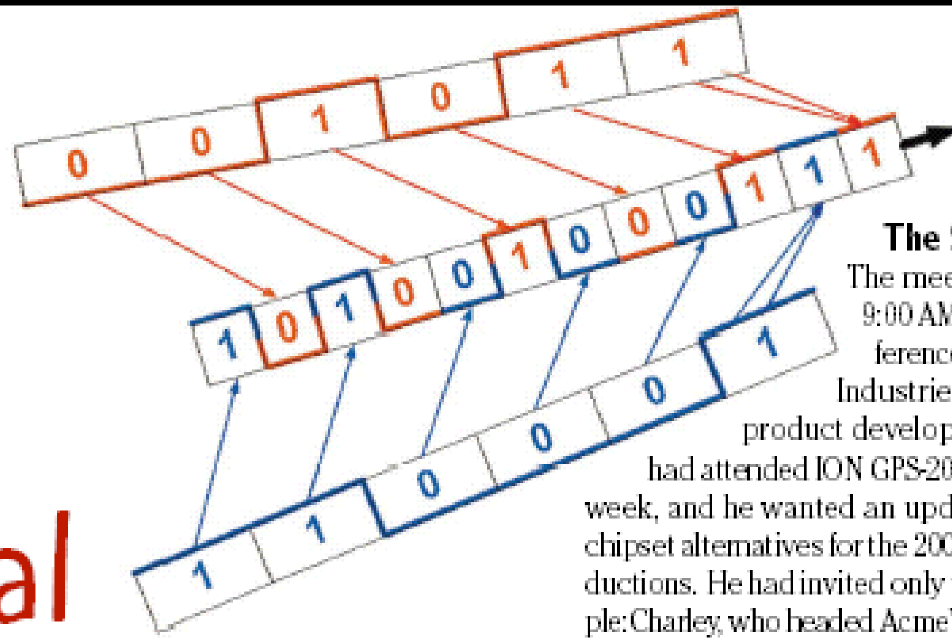
Challenge

SYSTEM

The Modernized L2 Civil Signal

Leaping Forward in the 21st Century

by Richard D. Fontana, Wai Cheung, and Tom Stansell



This article reveals . . .

- how the new L2 signal, scheduled to originate from GPS satellites in space from 2003 onwards, will affect both

A funny thing happened on the road to GPS modernization: a signal suddenly changed.

After years of preparation, modernization called for:

- implementing military (M) code on the L1 and L2 frequencies for the Department of

The Scene: 2008

The meeting started at 9:00 AM in a small conference room at Acme Industries. Fred, Acme's product development manager, had attended ION GPS-2008 the previous week, and he wanted an update on the GPS chipset alternatives for the 2009 product introductions. He had invited only three other people: Charley, who headed Acme's dual-frequency and high precision GPS product developments, Valerie, who headed GPS-based consumer product developments, and Albert, from marketing.

Under Fred's direction, Acme offered a wide array of GPS and non-GPS products for both the professional and consumer markets. Years ago Acme had recognized how important GPS was for many applications, so it acquired a few small companies with expertise in designing and applying positioning technology. By 2008, Acme had become a major supplier of GPS-based equipment for high precision, OEM, and consumer applications, although it had not entered the aviation or military markets.

Topics

- Acknowledgements
- Development framework
- Signal description
- Acquisition and code tracking
- Message options
- Relative signal performance
- Future choice of signals
- Signal characteristics summary
- L2C advantages

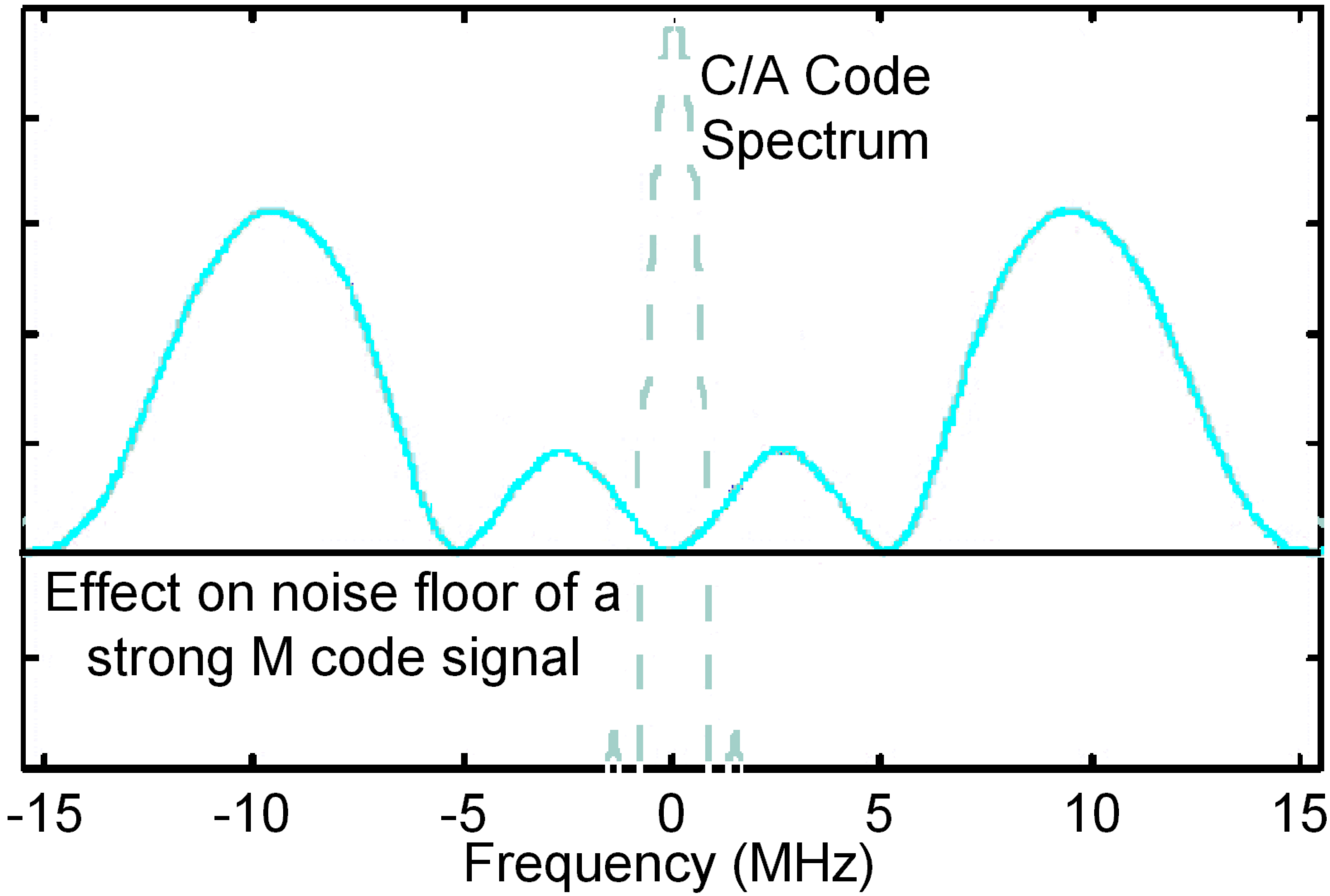
Special Acknowledgements

- Col. Douglas Loverro – why replicate C/A code?
- Steve Lazar – first analysis and R/C code option
- LCDR Richard Fontana – led & coordinated JPO effort
- Wai Cheung – organized, hosted, managed
- Dr. Charlie Cahn – codes, analyses, insight & wisdom
- Dr. Phil Dafesh – lower bit rate & hardware demo
- Rich Keegan – validated receiver feasibility
- Tom Stansell – coherent carrier, guided, presented
- Dr. A.J. Van Dierendonck – alternatives, L5 experience
- Karl Kovach, Soon Yi, Dr. Rhonda Slattery – document

Development Framework

- ♦ **Tight schedule (1.5 months, 3 meetings)**
- ♦ **Limited chip rate (spectral separation)**
- ♦ Bi-phase signal at lower power (shared with P/Y)
- ♦ Application requirements
- ♦ Modern technology (to acquire longer codes)
- ♦ Dramatic increase in new GPS signals

Spectral Separation Limits Civil Chip Rate



Development Framework

- ♦ Tight schedule (1.5 months, 3 meetings)
- ♦ Limited chip rate (spectral separation)
- ♦ **Bi-phase signal at lower power**
  - **L2 civil signal is shared with the military P/Y code**
  - **L5 has 2 bi-phase components in phase quadrature**
  - **L2 civil power is ~ 2.3 dB less than L1 C/A**
- ♦ Application requirements
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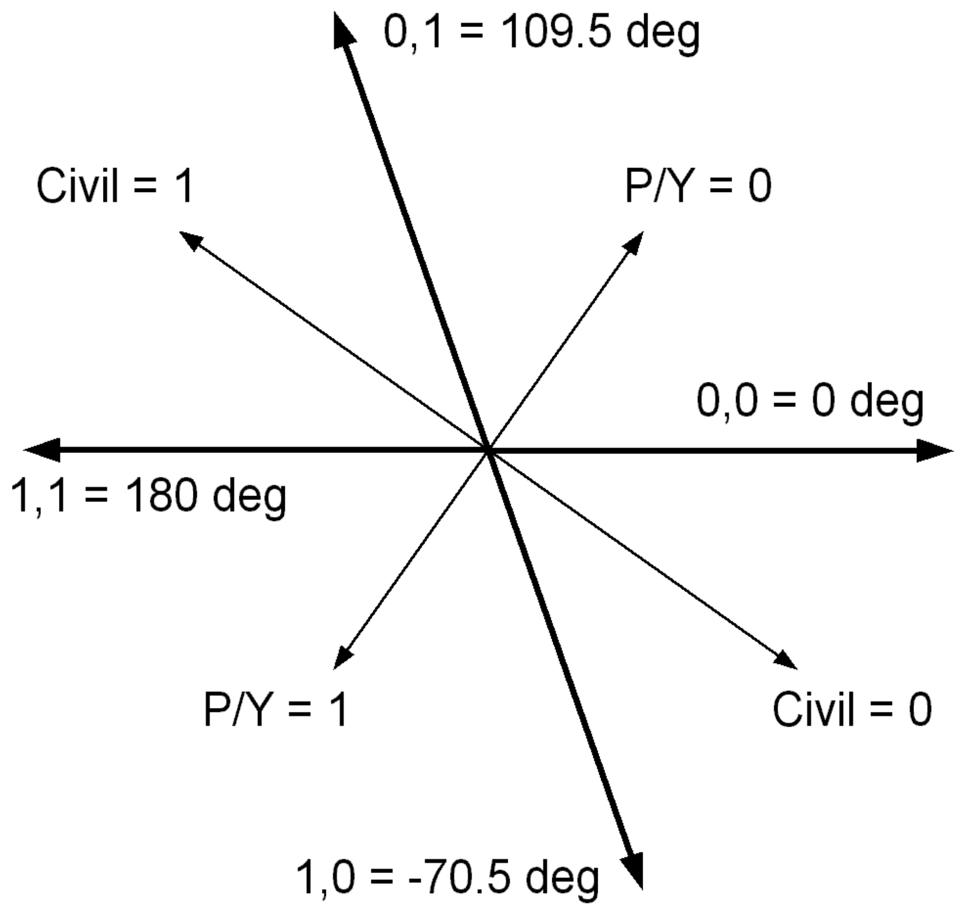
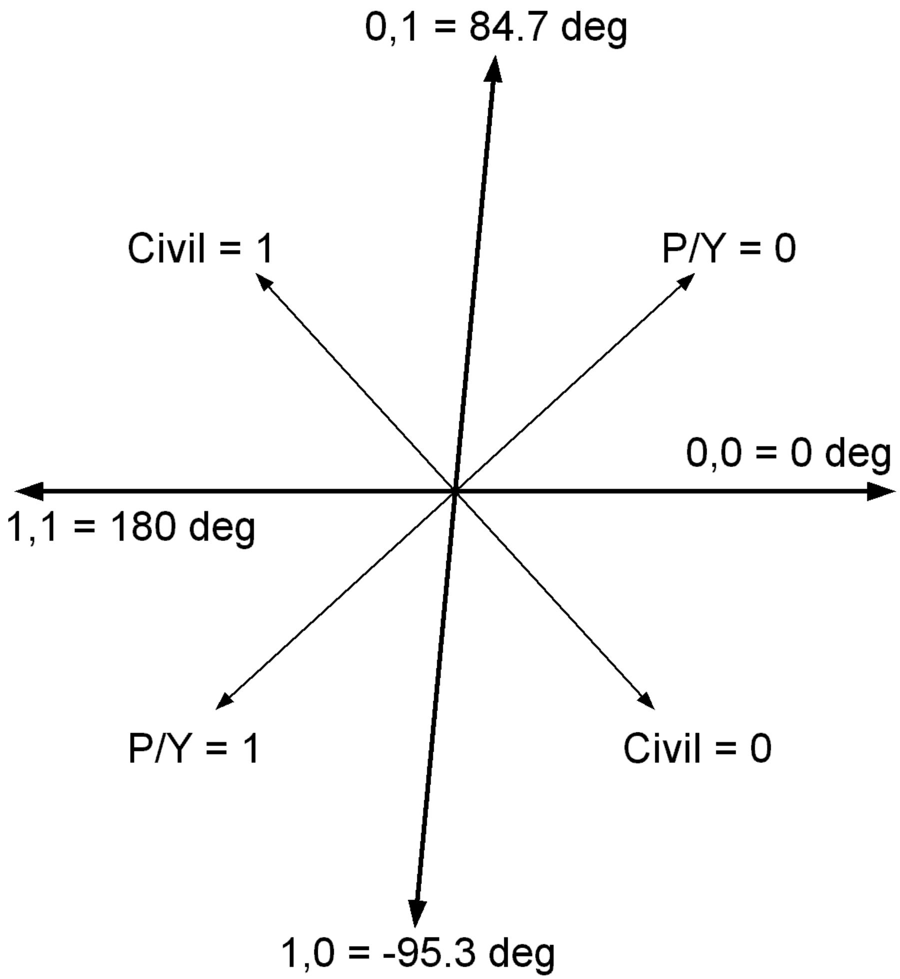
L1 Signal Component Vector Relationships



L1 Phase Relationships
(Civil is 3 dB stronger than P/Y)

L2 Signal Component Vector Relationships



L2 Phase Relationships
(Civil is 0.4 dB weaker than P/Y)

L2 Civil is ~2.3 dB weaker than L1 Civil on IIR-M and IIF Satellites

Development Framework

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Two Primary L2C Application Requirements

- ♦ **Dual-frequency civil users**
  - About 50,000 used for high value applications
    - ➔ Scientific: earthquakes, volcanoes, continental drift, weather
    - ➔ Cadastral and construction land survey
    - ➔ Guidance & control: mining, construction, agriculture
    - ➔ Land and offshore land and mineral exploration
    - ➔ Marine survey and construction
  - Need a civil code to replace semi-codeless tracking
- ♦ **Single frequency with wide dynamic range**
  - Avoid crosscorrelation problems of C/A code
  - E911 inside buildings, forest areas, tree-lined roads

Dual Frequency Transition Issue

- ♦ Is L2 phase, measured with a code, the same as a semi-codeless phase measurement?
  - Semi-codeless L2 phase is L1 C/A phase plus the phase difference between L2 and L1 P/Y phase

$$L2 = L1_{C/A} + (L2_{P/Y} - L1_{P/Y})$$

  - Any difference in the P/Y to C/A quadrature phase relationship between L1 and L2 will cause a bias relative to a code-based phase measurement
    - ➔ Are the differences negligible? For sure?
    - ➔ Can they be calibrated? Are they stable?
    - ➔ How to identify which measurement technique was used?
    - ➔ Should both measurements be made during transition?

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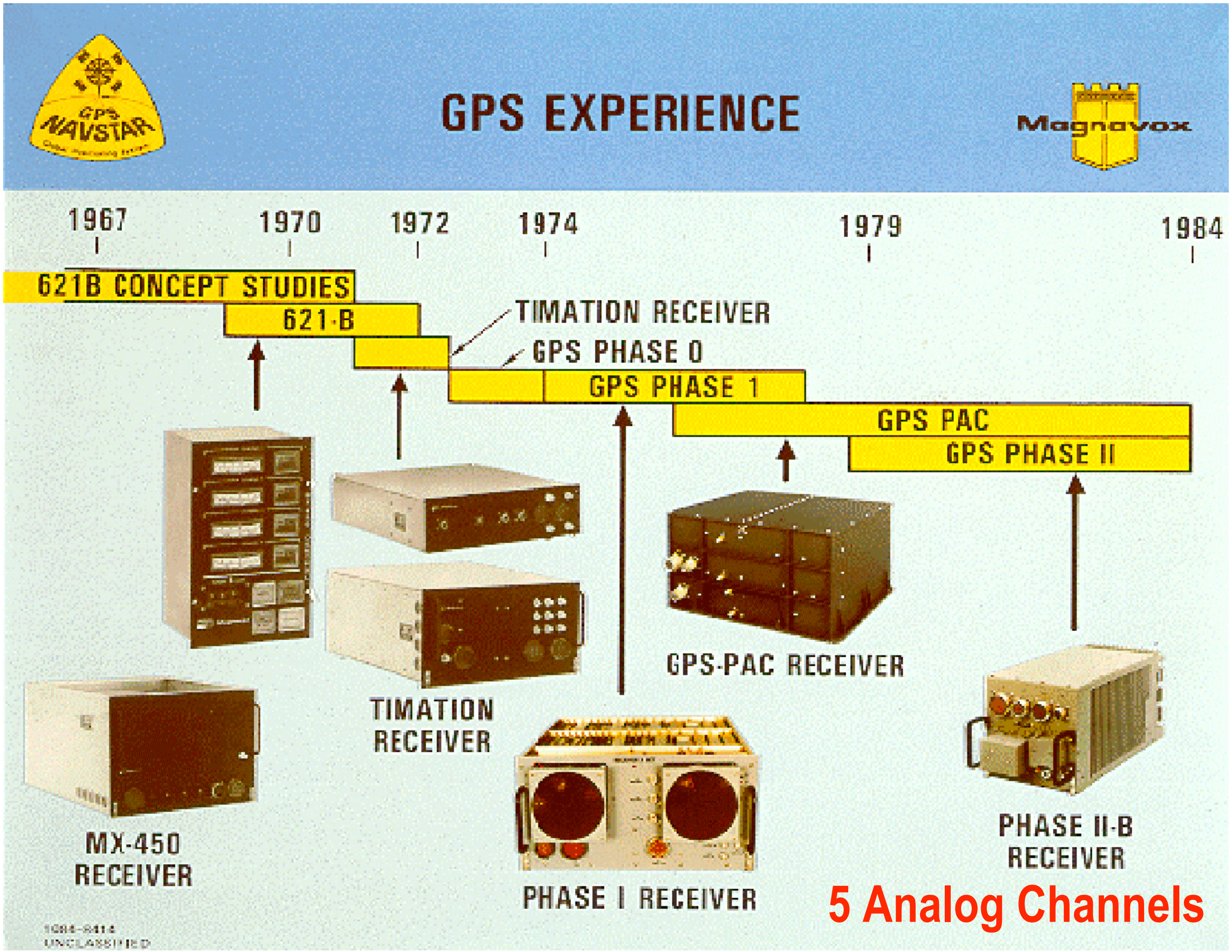
C/A Code Developed for 1970's Technology



Dramatic Technology Progress since the 1970's

Consumer 12 channel with color map

Consumer 12 channel for under $100

Development Framework

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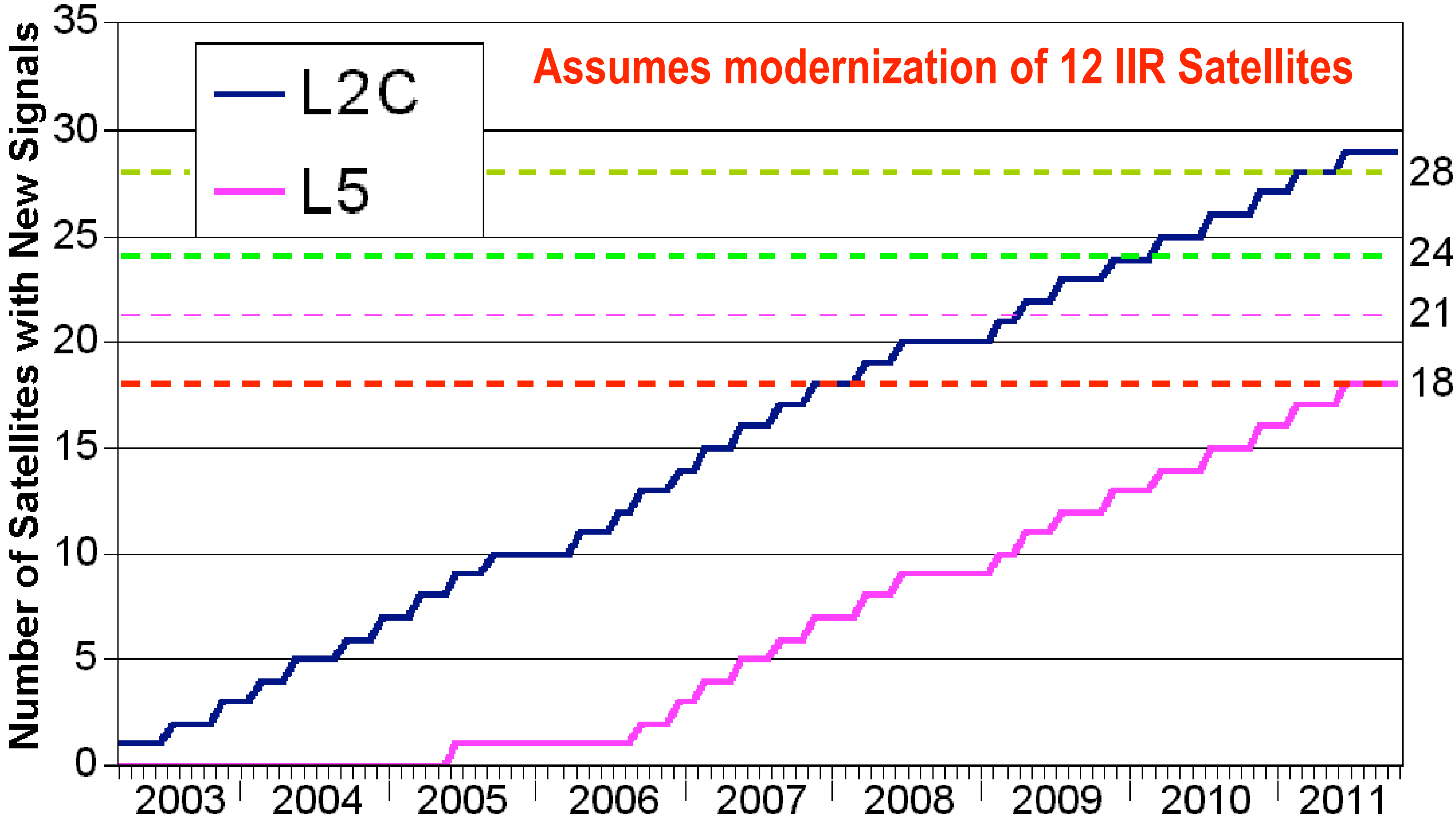
- Application requirements
- Modern technology (to acquire longer codes)
- **Dramatic increase in new GPS signals**

Historic Increase in GPS Navigation Signals

Signal\SV	IIR	IIR-M	IIF
L1 C/A	✔	✔	✔
L1 P/Y	✔	✔	✔
L1 M		✔	✔
L2 Civil		✔	✔
L2 P/Y	✔	✔	✔
L2 M		✔	✔
L5 Civil			✔
	1978 to 2003	2003	2005

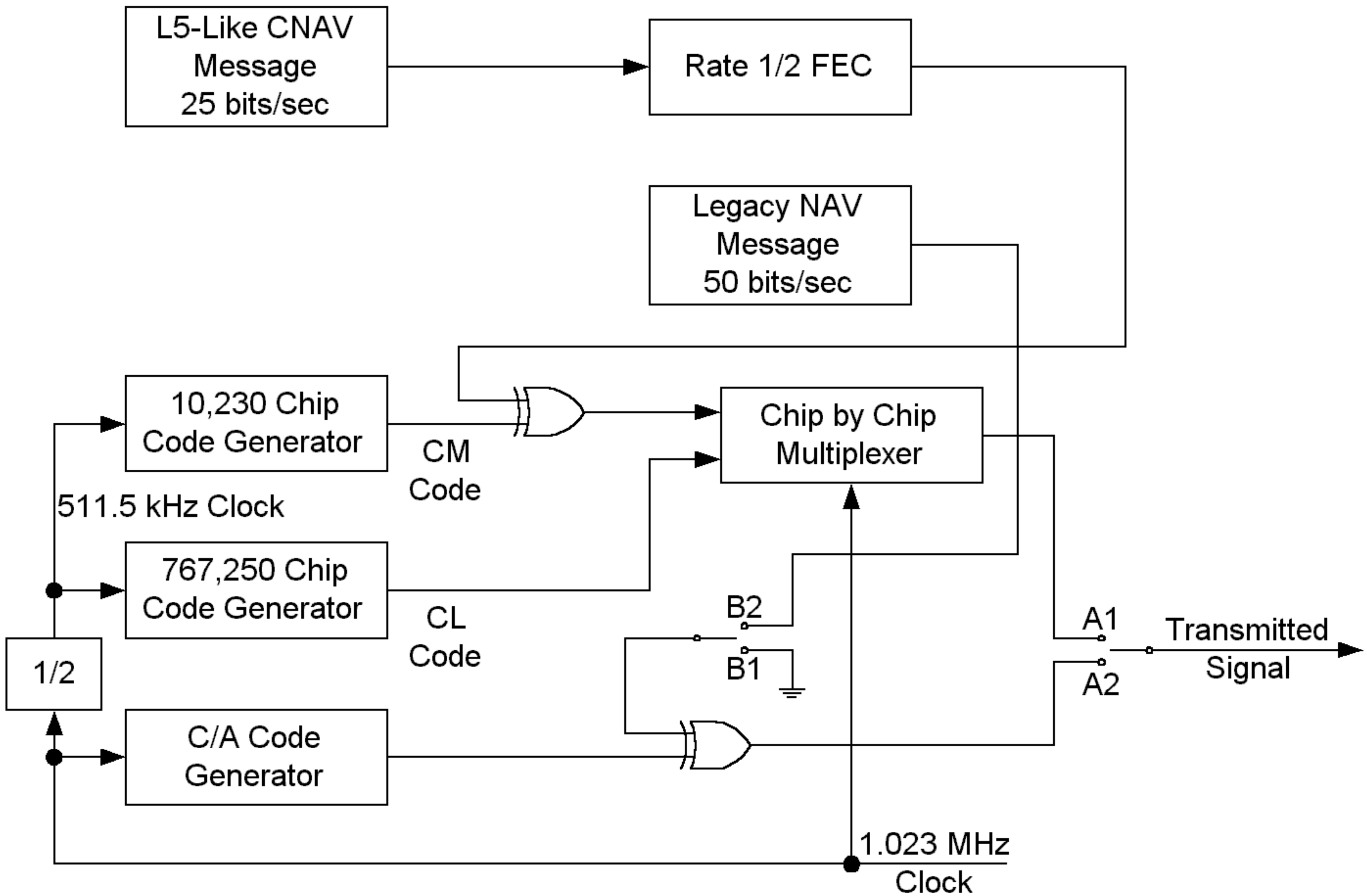
Expected Growth in L2C and L5 Signals



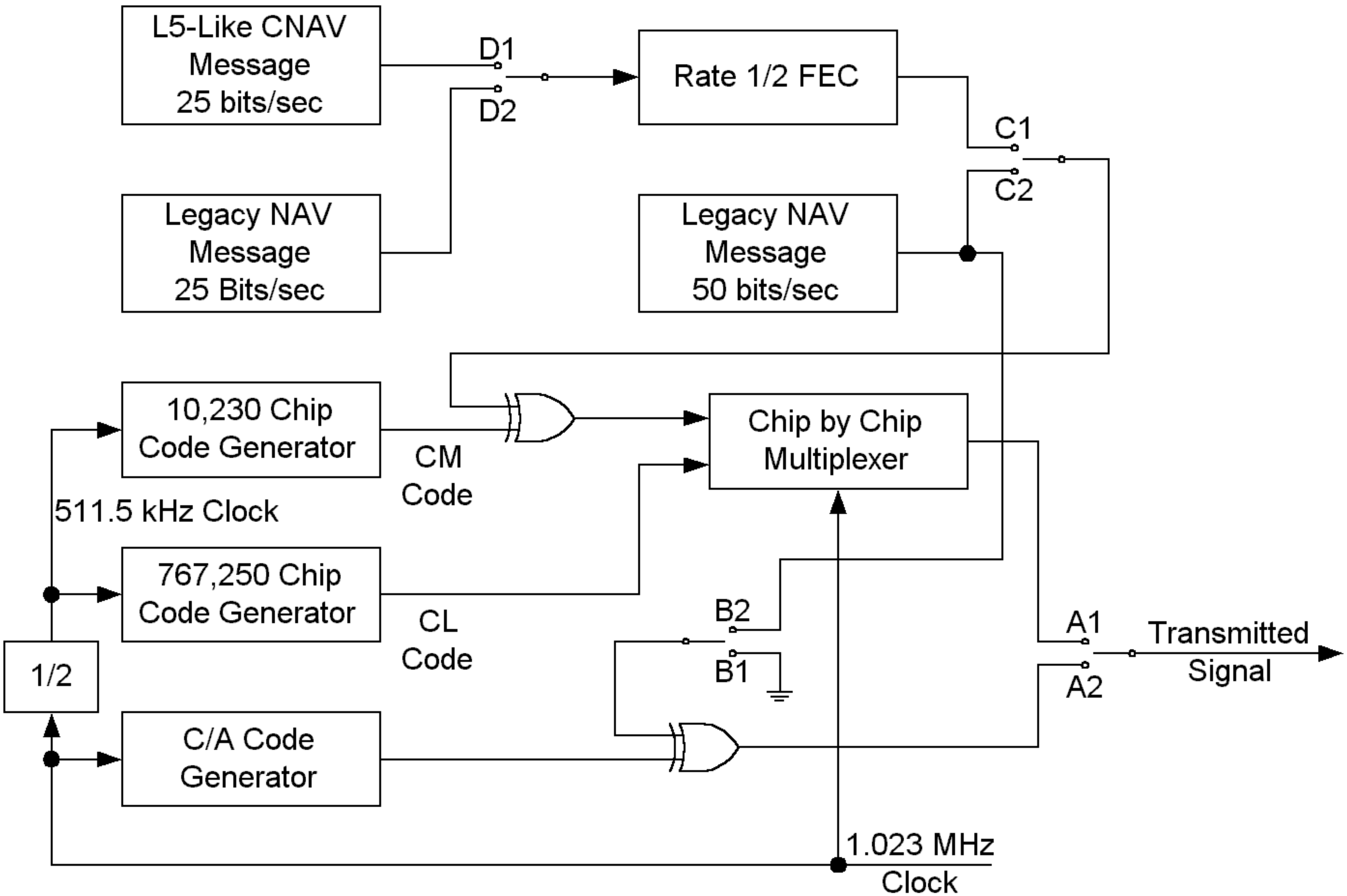
L2C Definitions

- ♦ **L2C** – the new L2 Civil Signal
- ♦ **CM** – the L2C moderate length code
  - 10,230 chips, 20 milliseconds
- ♦ **CL** – the L2CS long code
  - 767,250 chips, 1.5 second
- ♦ **NAV** – the legacy navigation message provided by the L1 C/A signal
- ♦ **CNAV** – a navigation message structure like that adopted for the L5 civil signal

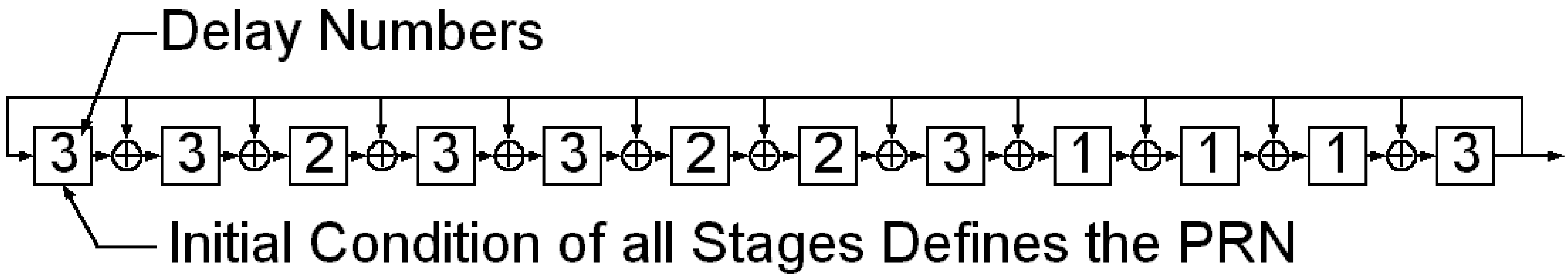
L2C Signal Options on IIF Satellites



L2C Signal Options on IIR-M Satellites



L2C Code Generation and Definitions



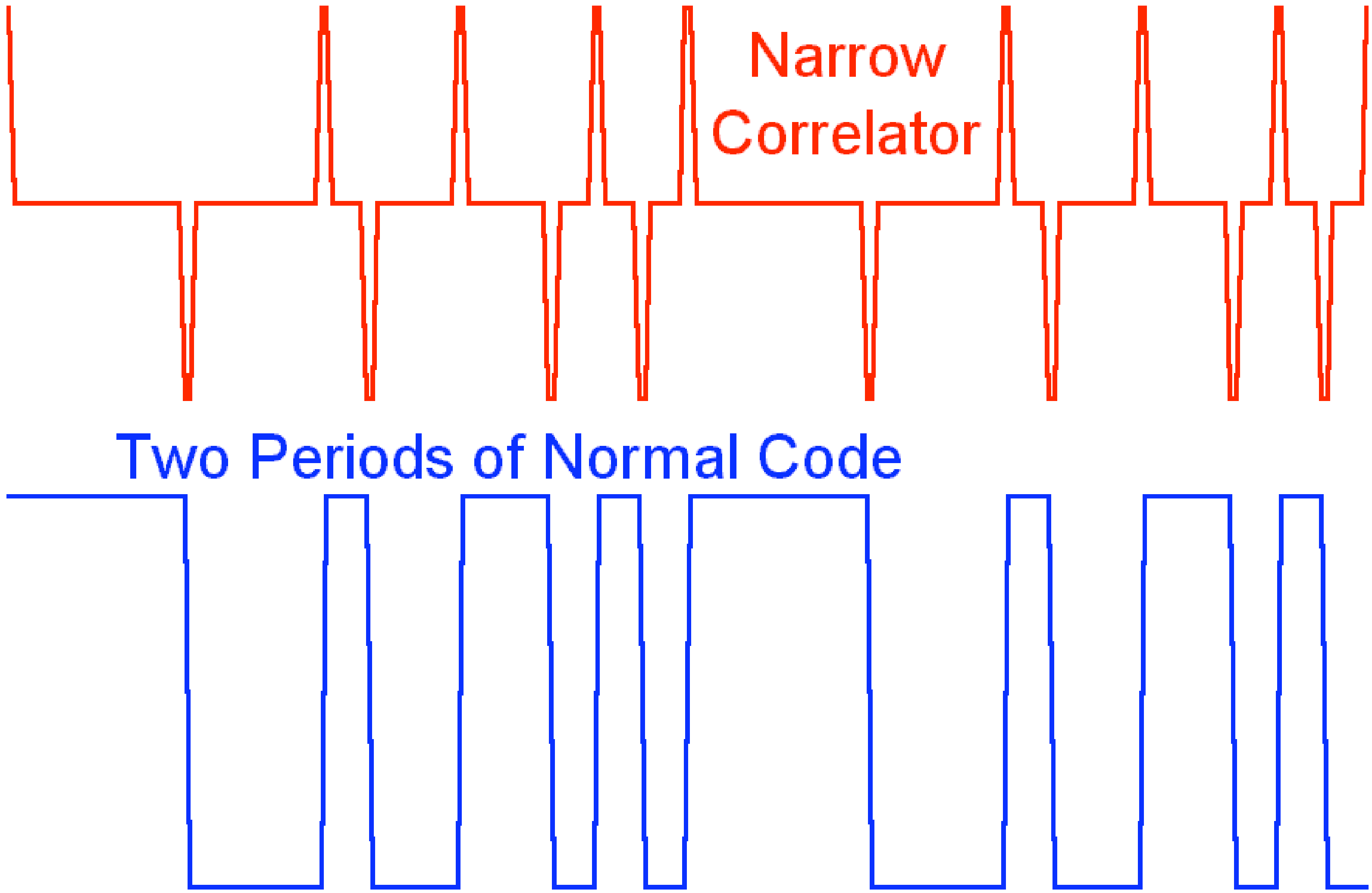
Period=10,230 Chips		
CM Code States (Octal)		
PRN	**START**	**END**
1	742417664	552566002
2	756014035	034445034
3	002747144	723443711
4	066265724	511222013
5	601403471	463055213
6	703232733	667044524
7	124510070	652322653
8	617316361	505703344
9	047541621	520302775
10	733031046	244205506

Period=767,250 Chips		
CL Code States (Octal)		
PRN	**START**	**END**
1	624145772	267724236
2	506610362	167516066
3	220360016	771756405
4	710406104	047202624
5	001143345	052770433
6	053023326	761743665
7	652521276	133015726
8	206124777	610611511
9	015563374	352150323
10	561522076	051266046

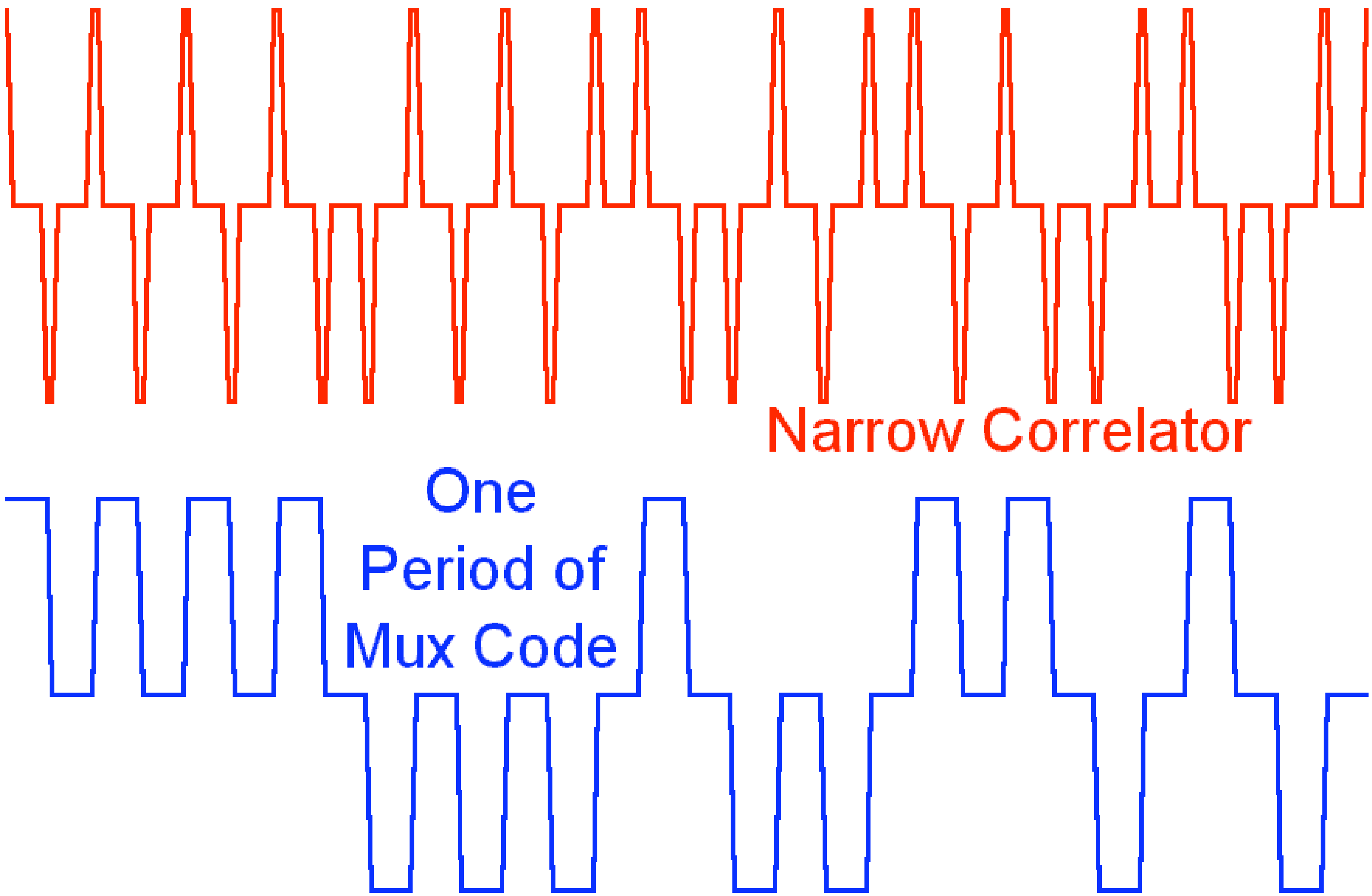
Signal Acquisition and Code Tracking

- Normally acquire L2C using CM code (10,230 chips)
  - CL code is 75 times longer than CM code
  - Employ frequency locked or Costas loop during acquisition
    - ➔ CM has data modulation
  - Test the 75 possible phases of CL
  - Acquire CL, track phase with a simple phase locked loop
    - ➔ Improves threshold by 6 dB relative to a Costas loop
- After the first, it is possible to acquire CL codes directly
  - 19,130 chip search range
  - Allows longer coherent integration time (e.g., FFT with long sample interval)

Tracking Continuous Code



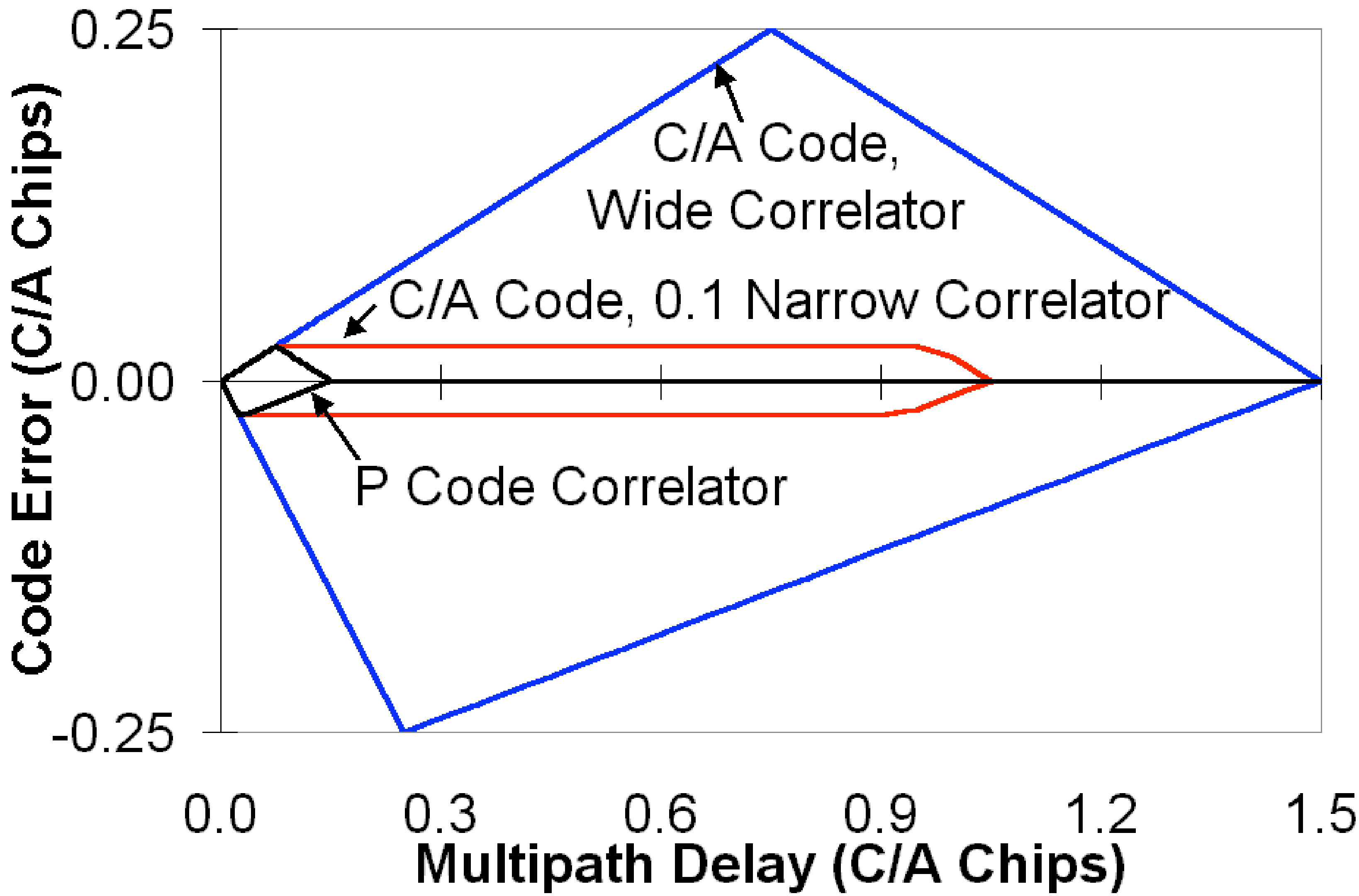
Tracking Chip by Chip Multiplexed Code



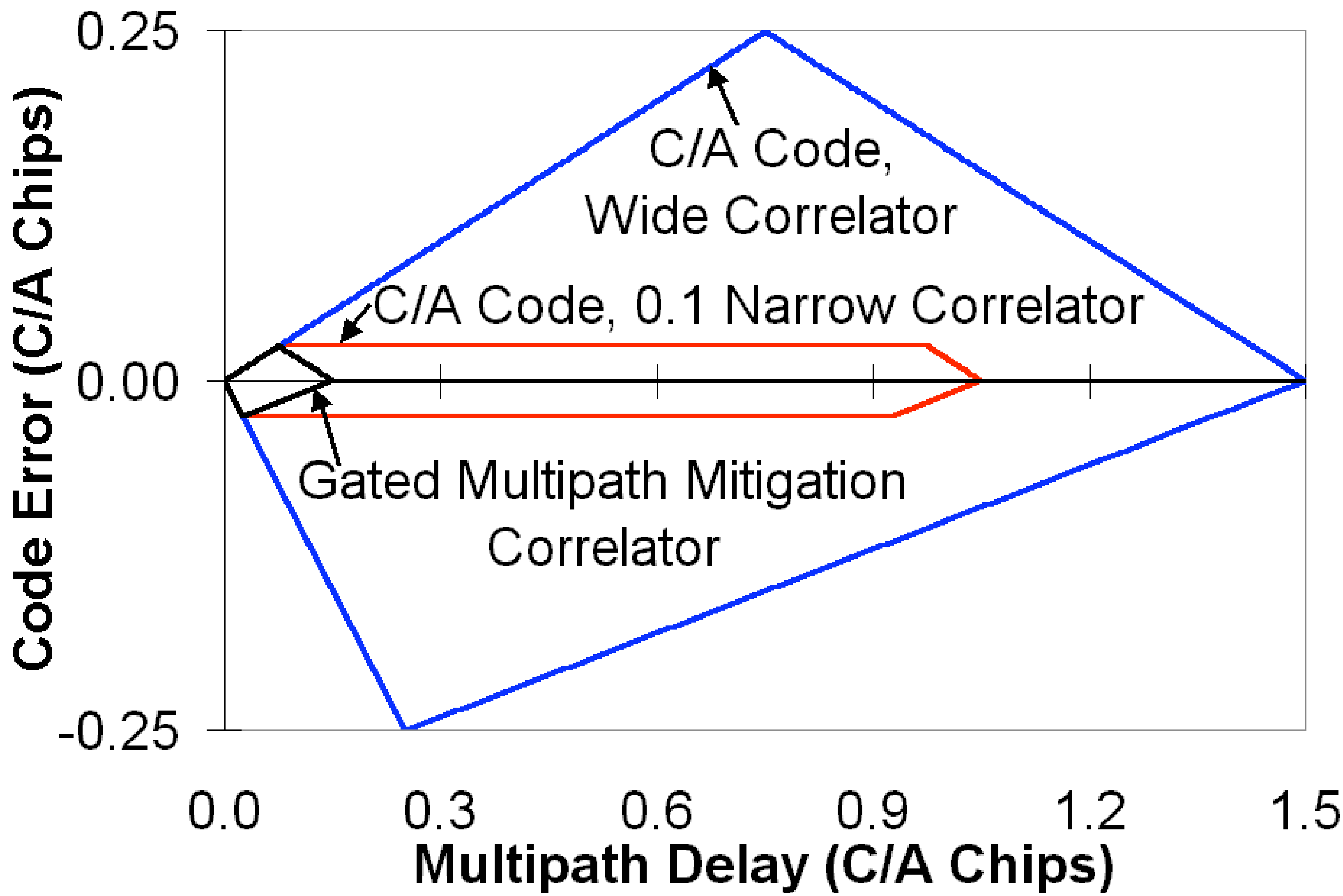
Code Tracking Accuracy

- ♦ Does a lower code clock rate hurt navigation accuracy?
  - Doesn't higher clock improve loop S/N and reduce multipath ?
  - Two factors eliminate this concern
- ♦ High S/N in very narrow bandwidth code tracking loop
  - Carrier aided code loops see only ionospheric dynamics
  - Code loop bandwidth of 0.1 Hz entirely adequate
  - Carrier aided code smoothing ➔ 0.008 to 0.003 Hz BW
  - Zero baseline tests show centimeter level code noise
  - High accuracy does not require better loop S/N
- ♦ Multipath mitigation correlator achieves the <u>same</u> multipath performance of a higher clock rate

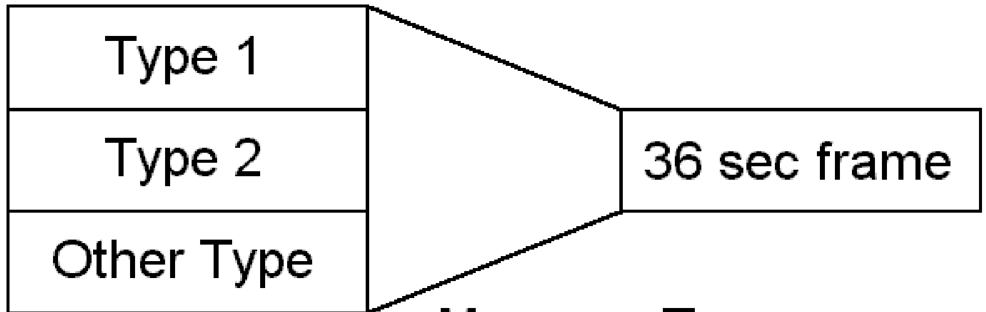
Multipath Error for Three Correlator Types



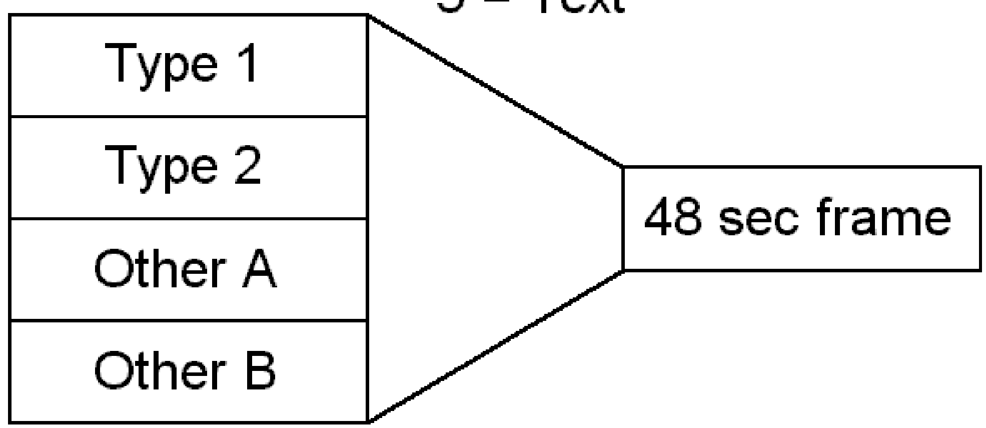
P Code Performance from Gated MM Correlator



Two L2C Message Frame Alternatives



Message Types
1 = Ephemeris A
2 = Ephemeris B
3 = Iono, Bias, Health
4 = Almanac
5 = Text



Potential Message Improvements

- ♦ Almanac with 7 orbits in one subframe
- ♦ New ephemeris message
  - One rather than two subframes
  - Better accuracy
  - Longer validity
- ♦ Both significantly benefit L2C performance because of its 25 bps message rate

L2C vs. C/A on L2

	Relative Data Channel Power	**Relative** Data-Less Channel Power
L2 C/A	0.0 dB	None (Costas)
L2C	-3 dB	-3 dB

	Relative Data Recovery Threshold	**Relative** Carrier Tracking Threshold
L2 C/A	0.0 dB	0.0 dB
L2C	+5.0 dB (FEC = 5 dB) (25 bps = 3 dB)	+3 dB (Phase locked tracking = 6 dB)

L1 C/A vs. L2C vs. L5 with IIR-M and IIF Satellites

	Received Power	**Relative** Total Power
L1 C/A	-157.7 dBW	0.0 dB
L2C	-160.0 dBW	-2.3 dB
L5	-154 dBW	+3.7 dB

	Relative Data Channel Power	**Relative** Data-Less Channel Power
L1 C/A	0.0 dB	None (Costas)
L2C	-5.3 dB	-5.3 dB
L5	+0.7 dB	+0.7 dB

Relative Data and Carrier Tracking Performance

	Relative Data Recovery Threshold	**Relative** Carrier Tracking Threshold
L1 C/A	0.0 dB	0.0 dB
L2C	+2.7 dB (FEC = 5 dB) (25 bps = 3 dB)	+0.7 dB (Phase locked tracking = 6 dB)
L5	+5.7 dB (FEC = 5 dB)	+6.7 dB

Balanced Data & Carrier Tracking Thresholds

Data rate (bps) & FEC rate	Carrier power percent	WER = 0.015 with total C/N_o =	Phase slip = 0.001 with total C/N_o =
50 & None	Costas	26 dB-Hz	25.5 dB-Hz
50 & None	50	29 dB-Hz	23 dB-Hz
25 & None	50	26.5 dB-Hz	23 dB-Hz
50 & ½	50	24 dB-Hz	23 dB-Hz
33.3 & ½	50	22.5 dB-Hz	23 dB-Hz
25 & ½	**50**	**22 dB-Hz**	**23 dB-Hz**
25 & ½	25	24 dB-Hz	26 dB-Hz
25 & ½	75	24 dB-Hz	21 dB-Hz
33.3 & 1/3	50	22 dB-Hz	23 dB-Hz

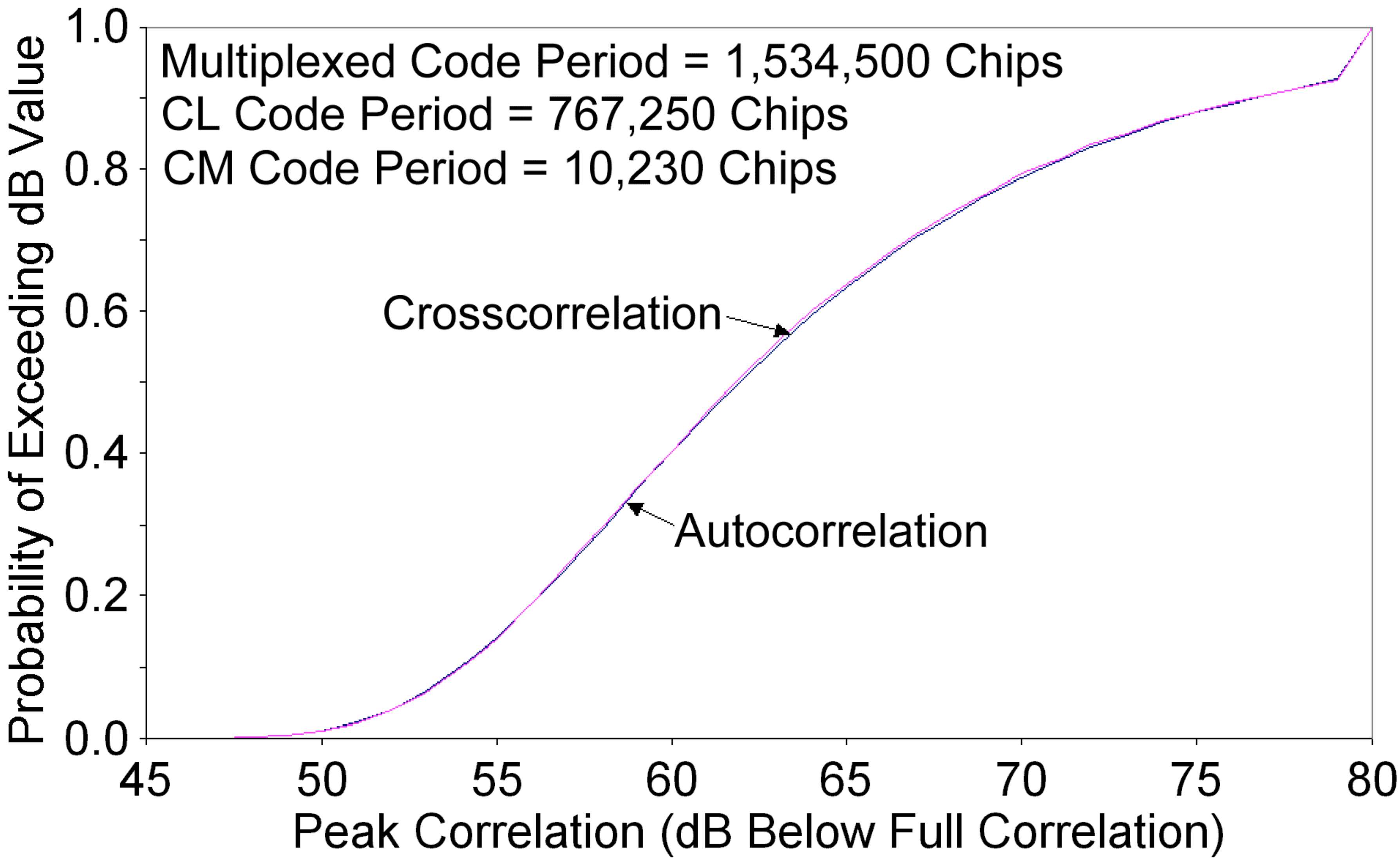
Civil Signal Characteristics

Civil Signal	Carrier Frequency (MHz)	Code Length (chips)	Code Clock (MHz)	Phases	Bit Rate (BPS)	Forward Error Correction
L1	1,575.42	1,023	1.023	Bi-Phase	50	No
L2	1,227.60	10,230 767,250	1.023	Bi-Phase	25	Yes
L5	1,176.45	10,230 10,230	10.23	Quad-Phase	50	Yes

Civil Signal Choices Functional Differences

Civil Signal	Fully Available	Ionospheric Error Ratio	Correlation Protection (dB)	**Relative** Data Recovery Threshold	**Relative** Carrier Tracking Threshold
L1	Now	1.00	> 21	0.0 dB	0.0 dB
L2	~ 2011	1.65	> 45	+2.7 dB (FEC = 5 dB) (25 bps = 3 dB)	+0.7 dB (Phase locked tracking = 6 dB)
L5	~ 2015	1.79	> 30	+5.7 dB (FEC = 5 dB)	+6.7 dB

Correlation Performance



L2C Advantages

- Best crosscorrelation protection (> 45 dB)
  - Aids navigation indoors and in forest areas
  - Provides headroom for increased SV power (GPS III ?)
  - Reduces impact of narrowband interference
- Better tracking and message thresholds than L1 C/A
- Available years sooner than L5
- Lower chip rate than L5
  - Saves power, minimizes thermal rise, better miniaturization
    - → Battery powered use, e.g., cell phone and wristwatch products
  - More flexible RF/IF filter and signal processing options

L2C Bandwidth and Signal Processing Options