ICG WG-A Interoperability Workshop

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Framing the Workshop

- In general, users don’t understand the implications of differences in GNSS signal structures
- Those who do understand are companies that design and build the user equipment
- For some time, ICG WG-A has been seeking input on what is most important for interoperability
- Today we will receive voluntary input on interoperability from 9 companies and other experts
- The input is valuable and voluntary – THANKS!

Agenda

Num	HST	Dur.	Topic	Organization	Speaker	How
1a	9:00	0:10	Welcome and Introduction	Co-Chair WG-A	Dave Turner	P
1b	9:10	0:05	Welcome and Introduction	Co-Chair WG-A	Sergey Revnivykh	P
2	9:15	0:05	Welcome and Introduction	Nat. Time Service Ctr., CAS	Xiaochun Lu	P
3	9:20	0:10	Framing the Presentations	Stansell Consulting	Tom Stansell	P
4	9:30	0:20	Performance of CNS 100-BGG	BNStar Navigation	Jun Shen	P
5	9:50	0:25	Certified Avionics #1	MITRE/FAA	Chris Hegarty	P
6	10:15	0:25	Certified Avionics #2	Rockwell Collins	Joseph & Wichgers	G
7	10:40	0:25	High Precision #1	Septentrio	Peter Grognard	G
	11:05	0:15	**Break**	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - -	
8	11:20	0:25	High Precision #2	Trimble	Stewart Riley	G
9	11:45	0:25	High Precision #3	John Deere	Ron Hatch	P
10	12:10	0:25	High/Medium Precision	Hemisphere GPS	Brad Badke	P
	12:35	1:15	**Lunch**	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - -	
11	13:50	0:25	GNSS Past, Present & Future	MITRE	John Betz	P
12	14:15	0:25	High Precision #4	Topcon	Ivan De Federico	P
13	14:40	0:10	Consumer Applications #1	CSR plc	Greg Turetzky	G
14	14:50	0:25	Consumer Applications #2	ST Microelectronics	Philip Mattos	S
15	15:15	0:25	Consumer Applications #3	Broadcom	Charlie Abraham	P
16	15:40	0:25	Consumer Applications #4	Qualcomm	Doug Rowitch	P
	16:05	0:15	**Break**	- - - - - - - - - - - - - - - - - - -	- - - - - - - - - - - - -	
17	16:20	0:10	Summary	Stansell Consulting	Tom Stansell	P
18	16:30	0:10	Summary	Nat. Time Service Ctr., CAS	Xiaochun Lu	P
19	16:40	0:10	Summary	Co-Chair WG-A	Sergey Revnivykh	P
20	16:50	0:15	Summary and Conclusion	Co-Chair WG-A	Dave Turner	P
	17:05		**End**			
	How		P=Present, G=GoToMeeting, S=Submitted			

GNSS Modernization and Interoperability

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The Goal of Interoperability

- <u>Ideal</u> interoperability allows navigation with **one signal each** from four or more systems **with no additional receiver cost or complexity**

Interoperable = Better Together than Separate

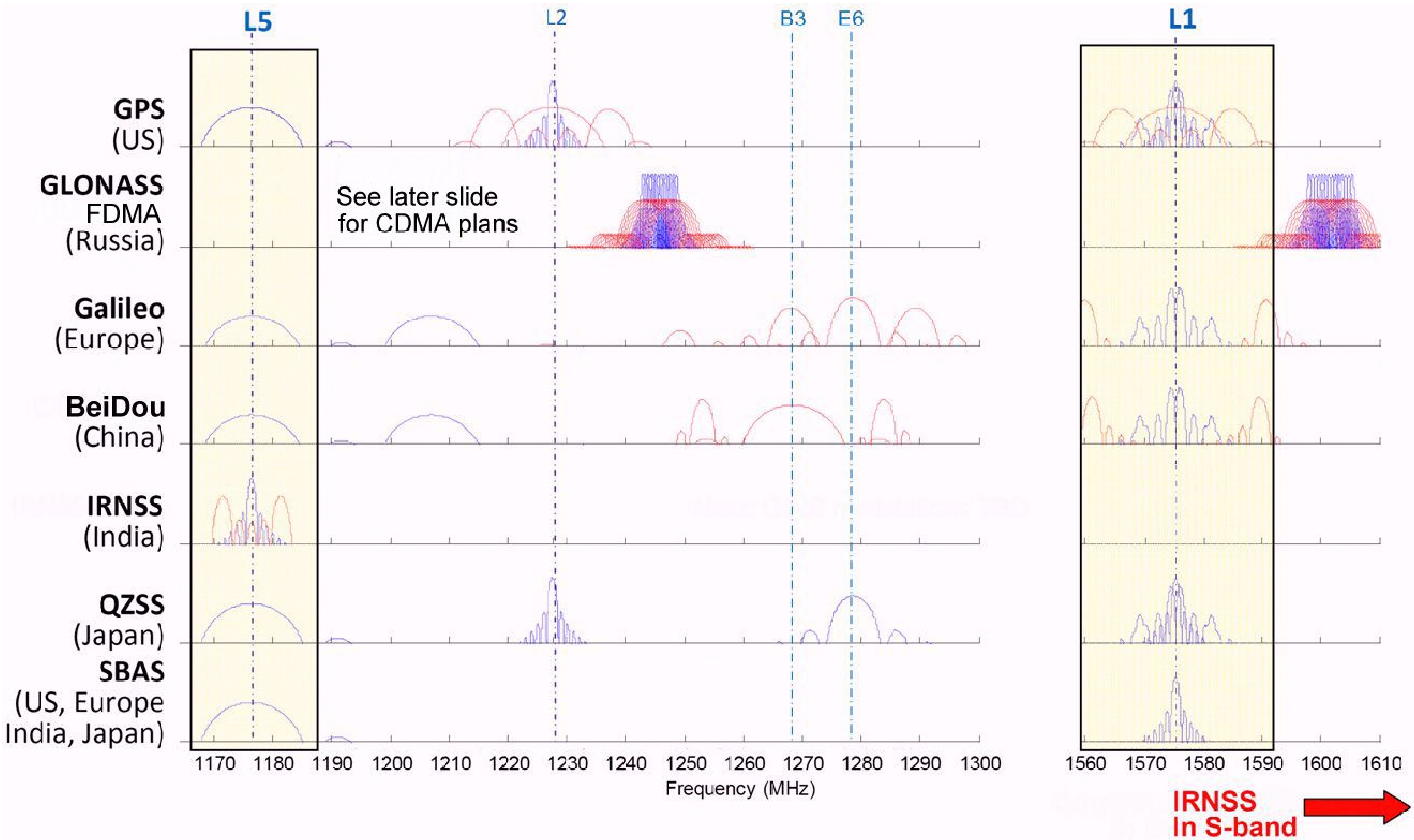
Main Benefits of Interoperability

More Satellites ➔ Better Geometry ➔ Improves:

- **Satellite coverage**
  - ➔ Navigate where could not before
- **Dilution of Precision**
  - ➔ Accuracy is better everywhere
  - ➔ Eliminates DOP holes (with open sky)
- **RAIM***
  - ➔ Integrity checked everywhere, all the time
  - ➔ Eliminates RAIM holes (with open sky)
- **Phase ambiguity resolution**
  - ➔ For survey and machine control applications
- **Accuracy**
  - ➔ Allows higher elevation angle cutoff which reduces multipath, ionospheric, and tropospheric errors

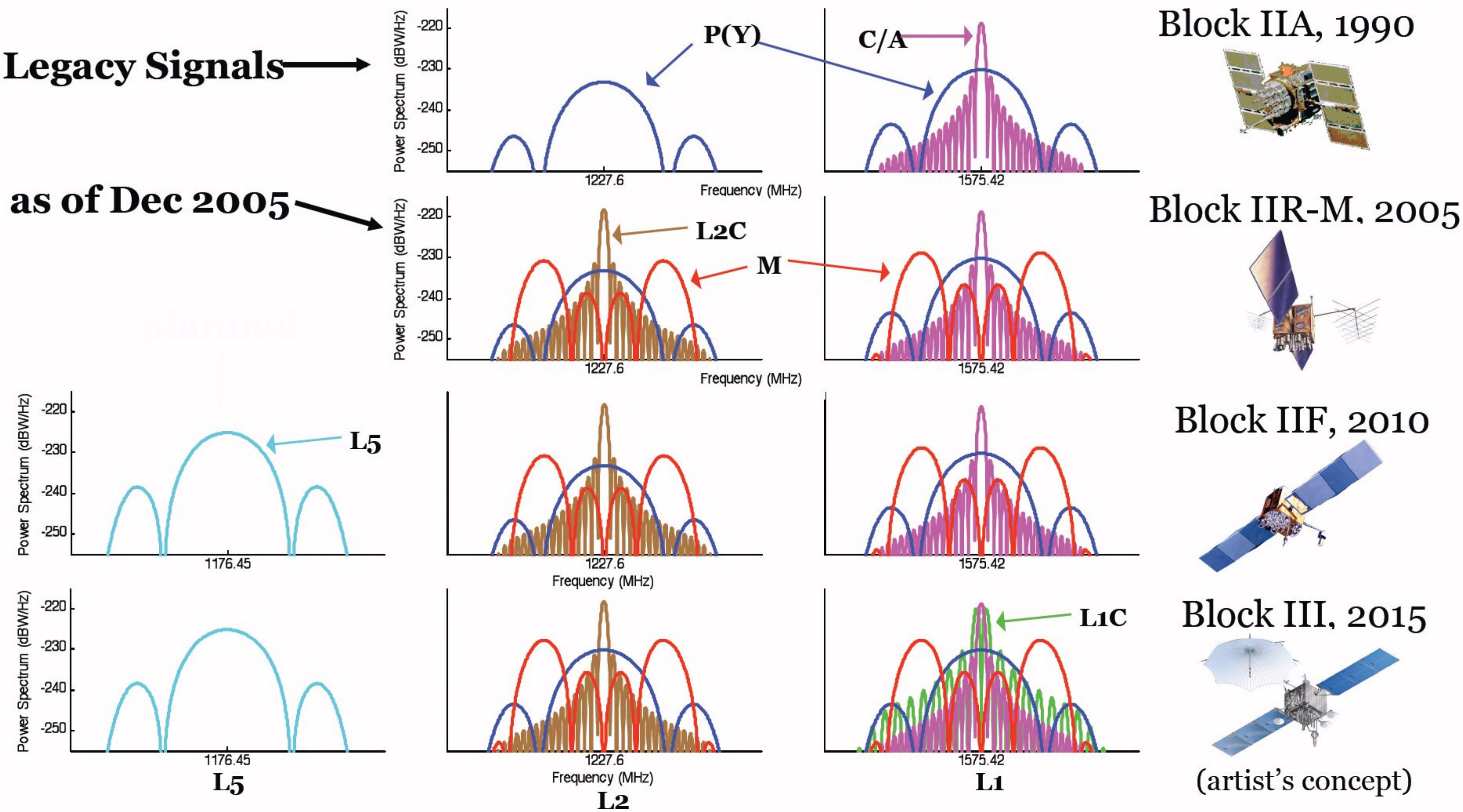
* Receiver Autonomous Integrity Monitoring

Spectrum of GNSS Signals



GPS Signals

GPS Signals (Cont'd)



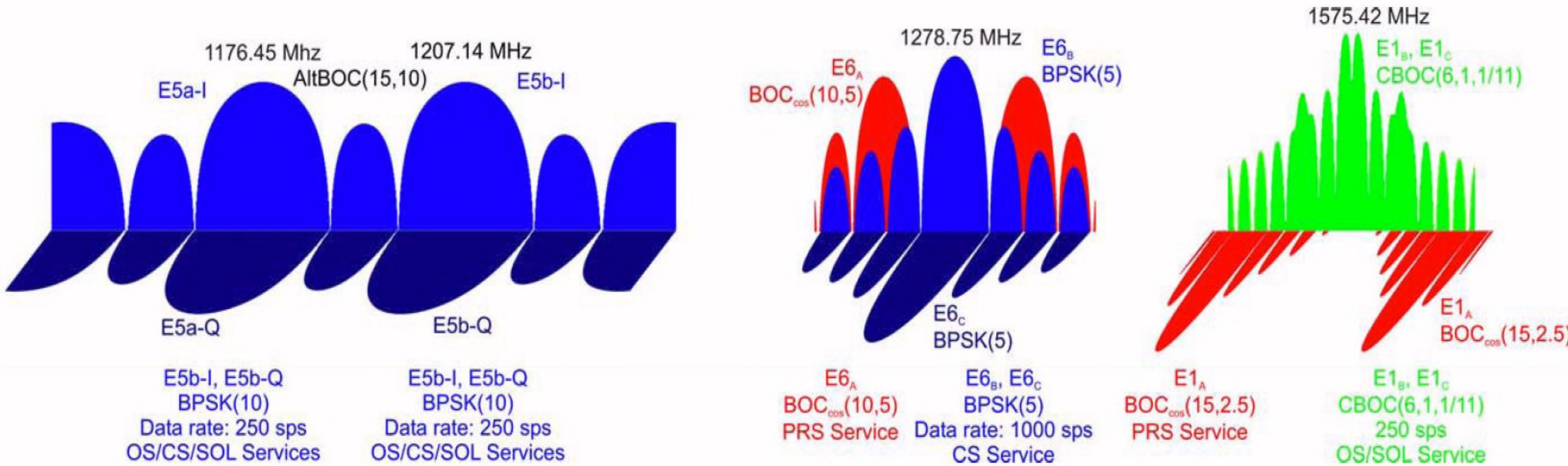
Originally presented December 2008; Updated to current status and plans

GPS Signals Summary

Band	Center Frequency	Signal	Waveform	Notes
L1	1575.42 MHz	C/A	BPSK(1)	Open Service
		P(Y)	BPSK(10)	
		L1C	TMBOC	Open Service, Separate Pilot and Data Channels
		M	BOC(10,5)	
L2	1227.6 MHz	P(Y)	BPSK(10)	
		L2C	BPSK(1)	Open Service, Separate Pilot and Data Channels
		M	BOC(10,5)	
L5	1176.45 MHz	L5	BPSK(10)	Open Service, Separate Pilot and Data Channels

Galileo Signals

Galileo Signal Baseline



- **E5: AltBOC(15,10) – 2 x BPSK(10)**
- **E6: BPSK(5) and BOC_{cos}(10,5)**
- **E1: MBOC(6,1,1/11) and BOC_{cos}(15,2.5)**
  - **Latest joint EU/US decision to implement MBOC in 2007**

Institute of Geodesy and Navigation
Institut für Erdmessung und Navigation

Galileo Signals Summary

Band	Center Frequency	Signals	Waveform	Notes
E1	1575.42 MHz	E1 OS	CBOC	Open Service, Separate Pilot and Data Channels
		PRS	BOC(15,2.5)	
E6	1278.75 MHz	CS	BPSK(5)	Commercial Service, Separate Pilot and Data Channels
		PRS	BOC(10,5)	
E5	1191.795 MHz	E5a & E5b	AltBOC(15,10)	Open Service, Separate Pilot and Data Channels

QZSS Signals

QZSS Service

QZSS Signals

Note: Some signal changes are being evaluated

	Frequency	Notes
L1-C/A	1575.42MHz	➢ Complete compatibility and interoperability with existing and future modernized GPS signals ➢ Differential Correction data, Integrity flag, Ionospheric correction ➢ Almanac & Health for other GNSS SVs
L1C		
L2C	1227.6MHz	
L5	1176.45MHz	
L1-SAIF*	1575.42MHz	➢ Compatibility with GPS-SBAS
LEX	1278.75MHz	➢ Experimental Signal with higher data rate message (2Kbps) ➢ Compatibility & interoperability with Galileo E6 signal

* L1-SAIF: L1-Submeter-class Augmentation with Integrity Function

GLONASS
Signal Plans

GLONASS Modernization

1982 | **2003** | **2011** | **2014**

"Glonass"

- 3 year design life
- Clock stability - $5*10^{-13}$
- Signals: L1SF, L2SF, L1OF, (FDMA)
- Totally launched 81 satellites
- Real operational life time 4.5 years

"Glonass-M"

- 7 year design life
- Clock stability $1*10^{-13}$
- Signals: Glonass + L2OF (FDMA)
- Totally launched 36 satellites
- Another 12 satellites ordered

"Glonass-K1"

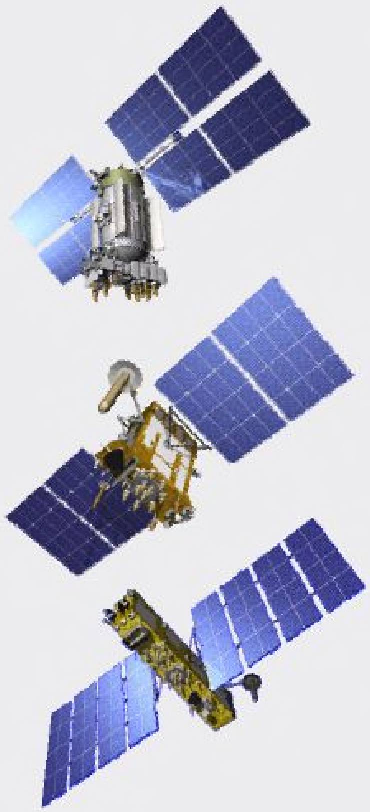
- 10 year design life
- Unpressurized bus
- Expected clock stability $\sim 10 \ldots 5*10^{-14}$
- Signals: Glonass-M + L3OC (CDMA) – test
- SAR

"Glonass-K2"

- 10 year design life
- Unpressurized
- Expected clock stability $\sim 5 \ldots 1*10^{-14}$
- Signals: Glonass-M + full set of CDMA signals
- SAR

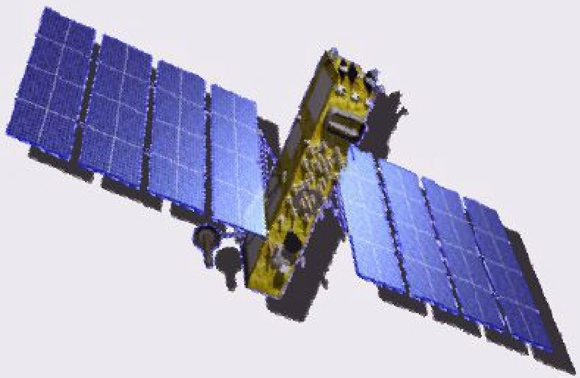
CDMA signals general structure already designed

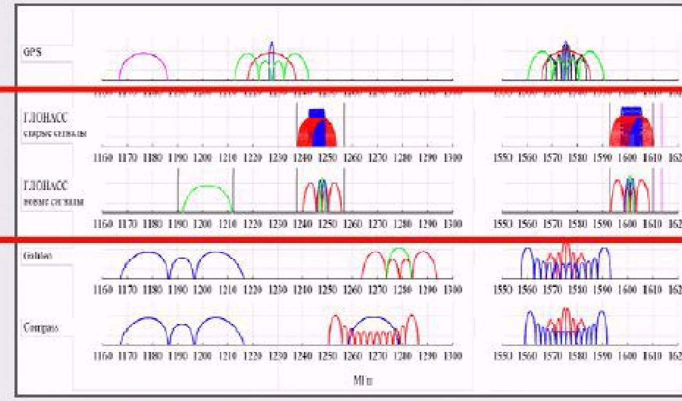
GLONASS Signal Implementation Plan

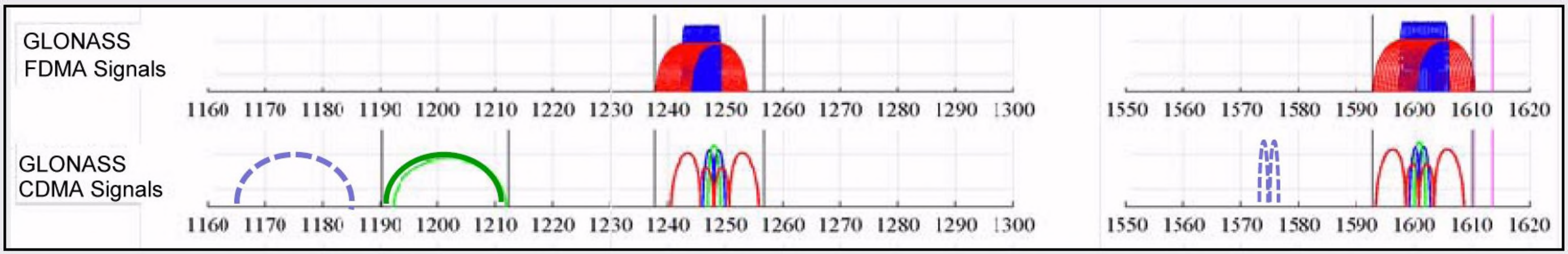


Satellite	FDMA Signals		CDMA Signals		
	L1	L2	L1	L2	L3
«Glonass-M»	L1OF L1SF	L2OF L2SF	-	-	L3OC (c 2014 г.)
«Glonass-K» 1G	L1OF L1SF	L2OF L2SF			L3OC
«Glonass-K» 2G	L1OF L1SF	L2OF L2SF	L1OC L1SC	L2OC L2SC	L3OC

GLONASS CDMA Signals







Signal	L3OC	L5OCM
Central frequency	1202.025	1176.45
Data	BPSK(10)	Study
Pilot	BPSK(10)	Study

Signal	L2SC	L2OCM
Central frequency	1248.06	
Data	BOC(5,2.5)	BPSK(1)
Pilot	BOC(5,2.5)	BOC(1,1)

Signal	L1SC	L1OC	L1OCM
Central frequency	1600.995		1575.42
Data	BOC(5,2.5)	BPSK(1)	Study
Pilot	BOC(5,2.5)	BOC(1,1)	Study

Under study on power, mass, dimension on-board budget capability and user benefits for next generation of GLONASS satellites

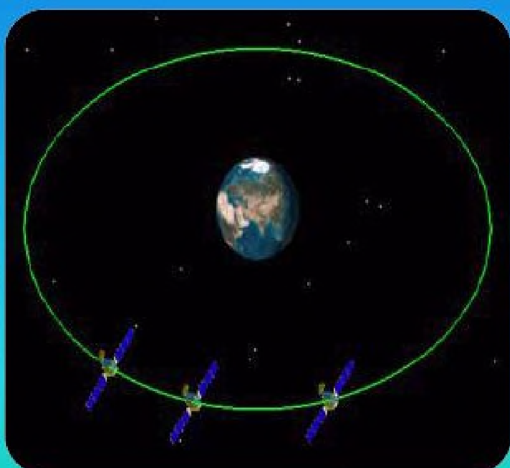
BeiDou

Signal Plans

(From Several Presentations)

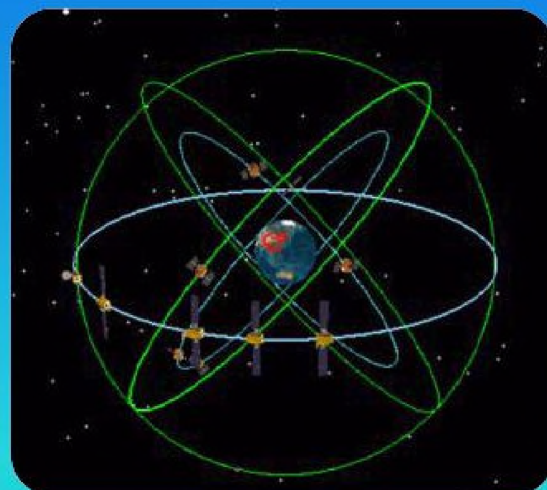
2. Development Plan

1st Step



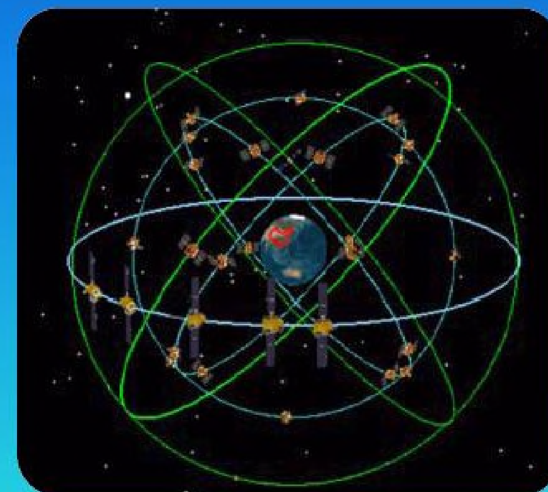
BeiDou Demonstration System

2nd Step



BeiDou Navigation Satellite System

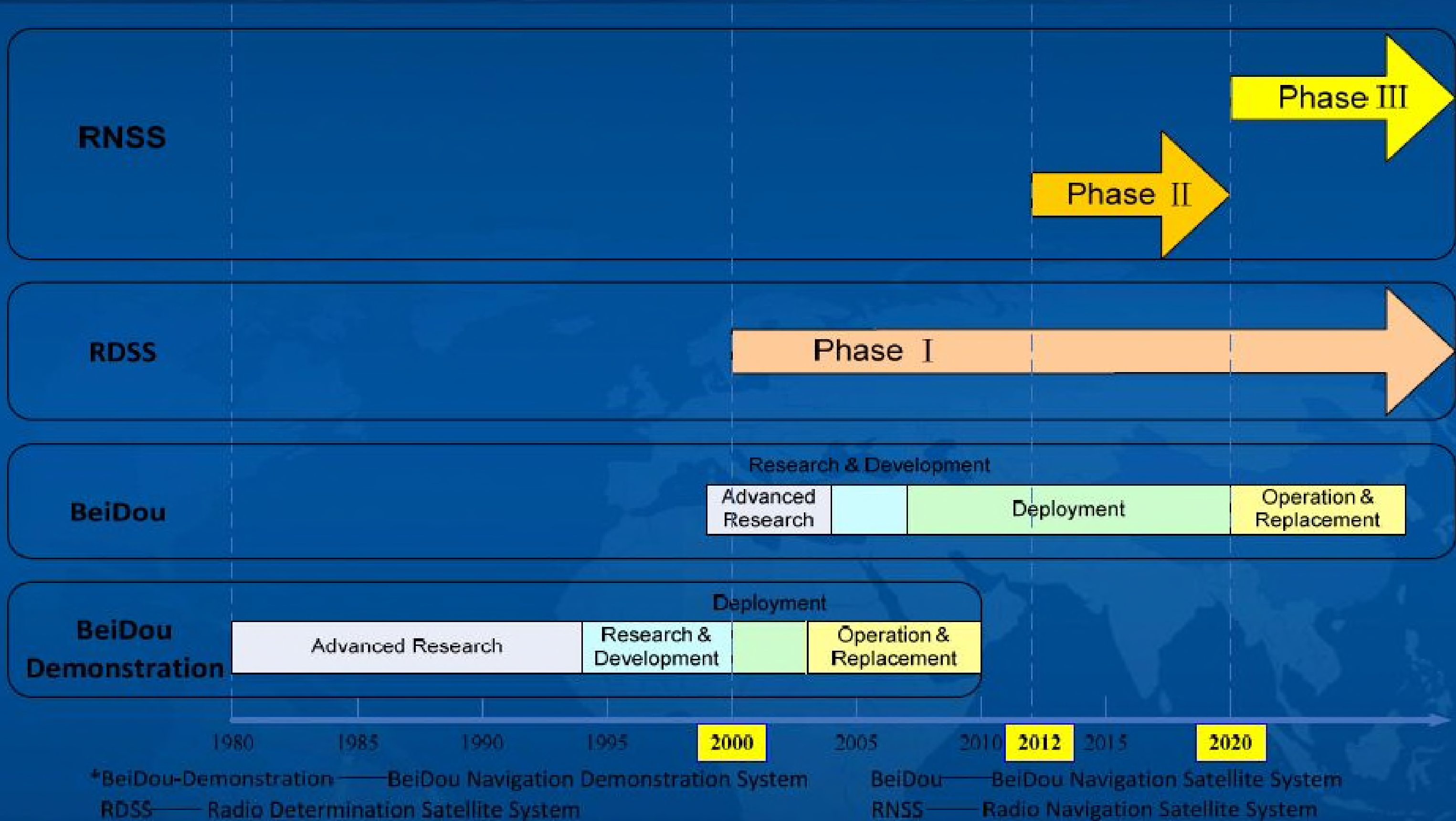
3rd Step



BeiDou Navigation Satellite System

1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020

(1) Development Roadmap



PHASE I : Provided RDSS from 2000;

PHASE II: To provide RNSS for users in China and its surrounding areas, and RDSS with broader coverage from 2012;

PHASE III: To provide RNSS with global coverage and also upgraded RDSS from 2020;

Signal Characteristics

- Frequencies

  B1: 1559.052~1591.788MHz

  B2: 1166.22~1217.37MHz

  B3: 1250.618~1286.423MHz

Till the year	Constellation	Signals (actual emission)
2012	**5GEO+5IGSO+4MEO （Regional Service）**	**mainly COMPASS Phase(CP) II signals**
2020	**5GEO+3IGSO+27MEO （Global Service）**	**mainly CP III signals**

Signal Characteristics

- *CP II: B1, B2, and B3 as below*

Component	Carrier Frequency (MHz)	Chip Rate (cps)	Bandwidth (MHz)	Modulation Type	Service Type
B1(I)	1561.098	2.046	4.092	QPSK	Open
B1(Q)		2.046			Authorized
B2(I)	1207.14	2.046	24	QPSK	Open
B2(Q)		10.23			Authorized
B3	1268.52	10.23	24	QPSK	Authorized

◆CP III: B1, B2 and B3 as below

Component	Carrier Frequency (MHz)	Chip Rate (cps)	Data/Symbol Rate (bps/sps)	Modulation Type	Service Type
B1-C_D	1575.42	1.023	50/100	MBOC(6,1,1/11)	Open
B1-C_P			No		
B1-A		2.046	50/100	BOC（14，2）	Authorized
			No		
B2a_D	1191.795	10.23	25/50	AltBOC(15,10)	Open
B2a_P			No		
B2b_D			50/100		
B2b_P			No		
B3	1268.52	10.23	500bps	QPSK(10)	Authorized
B3-A_D		2.5575	50/100	BOC(15,2.5)	Authorized
B3-A_P			No		

Interoperability

- Possible interoperable signal s
  - B1-C： 1575.42MHz
  - B2a： 1176.45MHz
  - B2b： 1207.14MHz

IRNSS

Signal Plans

IRNSS Signals

L5 Band

Service	Frequency Band	Centre Frequency (MHz)	Allocated Bandwidth (MHz)	Polarization	Modulation	Code rate (Mcps)
SPS	**L5-band**	1176.45	24 MHz (1164.45 - 1188.45 MHz)	RHCP	BPSK(1)	1.023
RS data	**L5-band**	1176.45	24 MHz (1164.45 - 1188.45 MHz)	RHCP	BOC(5,2)	2.046
RS pilot	**L5-band**	1176.45	24 MHz (1164.45 - 1188.45 MHz)	RHCP	BOC(5,2)	2.046

S Band

Service	Frequency Band	Centre Frequency (MHz)	Allocated Bandwidth (MHz)	Polarization	Modulation	Code rate (Mcps)
SPS	**S-band**	2492.028	16.5 MHz (2483.778 – 2500.278 MHz)	RHCP	BPSK(1)	1.023
RS data	**S-band**	2492.028	16.5 MHz (2483.778 – 2500.278 MHz)	RHCP	BOC(5,2)	2.046
RS pilot	**S-band**	2492.028	16.5 MHz (2483.778 – 2500.278 MHz)	RHCP	BOC(5,2)	2.046

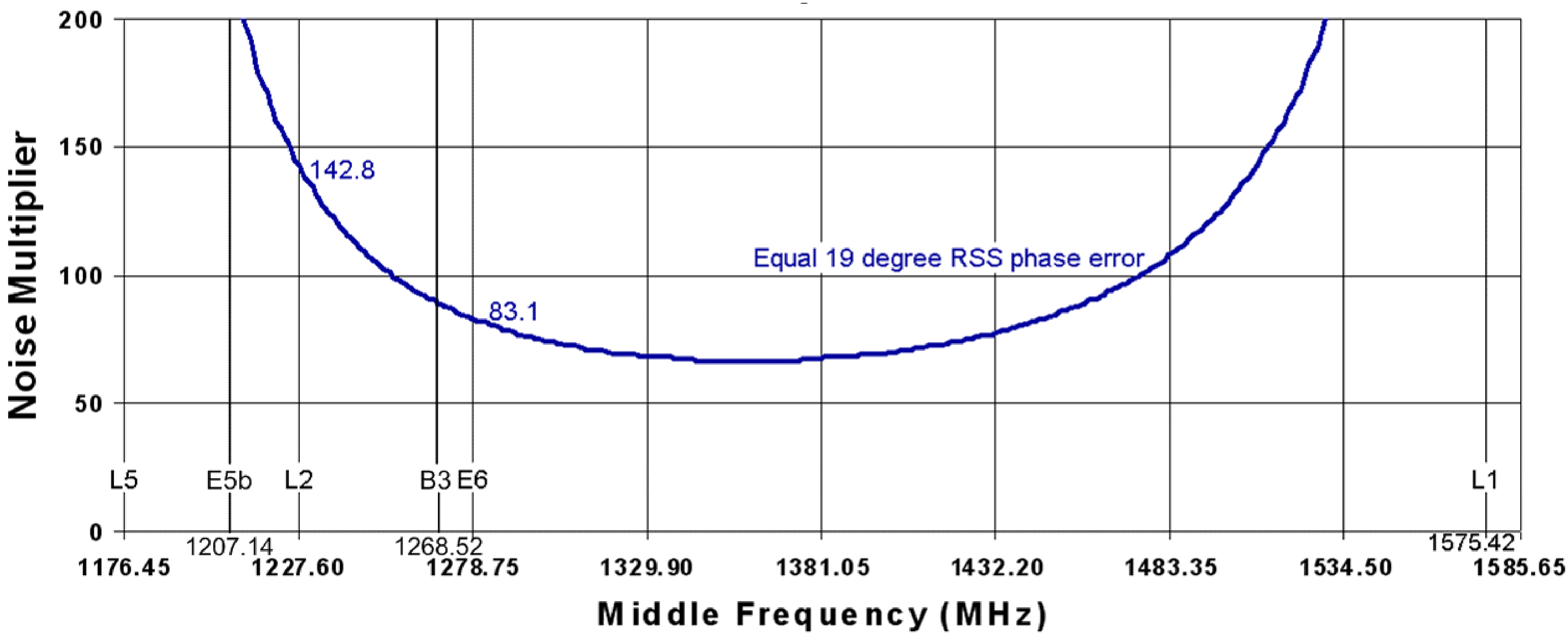
Note: Additional signals are being evaluated

A Third Common Open Service Signal?

Tri-Lane Phase Navigation is Near

- ♦ Over the next decade there will be a dramatic improvement in potential wide area GNSS accuracy
  - Providing reliable 10 cm navigation
  - From wide area differential code and phase corrections
  - Precision agriculture will be the first large scale user
- ♦ Enabled by having three GNSS frequencies
- ♦ Two will be 1575.42 MHz and 1176.45 MHz
  - GPS L1/L5, BeiDou B1-c/B2-a, Galileo E1/E5a
- ♦ What middle frequency or frequencies will be used?

Accuracy Impact of Middle Frequency



- With equal phase noise on each of the three signals
- Noise multiplier using E6 is 83.1
- Noise multiplier using L2 is 142.8
- Noise multiplier using E5b > 200

Adapted from: R. Hatch, "A New Three-Frequency, Geometry-Free, Technique for Ambiguity Resolution" ION GNSS 2006, Fort Worth, Texas, September 26-29, 2006

Inputs to Improve GNSS Interoperability

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Important Opportunity

- Modernized signals from GPS, QZSS, and Galileo are clearly defined by Interface Specifications
  - Interoperability was a key part of the signal choices
- Less is known about future signals from China (BeiDou), Russia (GLONASS), or India (IRNSS)
- Working Group A (WG-A) on Compatibility and Interoperability of the International Conference on GNSS (ICG) will meet in April to encourage better interoperability of emerging modernized signals

For Your Benefit

- GNSS signal providers are seeking your input
  - As odd as that may seem, it's true
- You are being asked to help shape the GNSS future
- Your advice could improve GNSS effectiveness for your clients and for your customers
  - Product and service cost, accuracy, integrity, availability, continuity, interference protection, C/N_0, TTFF, etc.
- Your participation and leadership now can bring significant benefits to your organization in the future
  - Insight, contacts, and a better GNSS

Some Key Issues (1 of 2)

- ♦ Increase of noise floor in GNSS receivers
  - More signals from more satellites in the same band
- ♦ Common or offset <u>center frequencies</u>
  - Frequency diversity vs. frequency commonality
  - How many global systems should share spectrum?
- ♦ Common <u>signal spectra</u> in each band or not?
- ♦ Can minimum elevation limits be raised?
  - Reduces Multipath error as well as Ionospheric and Tropospheric refraction error
- ♦ International clock and geodesy references, or not

Some Key Issues (2 of 2)

- ICAO acceptance of new signals for international aviation
- Transmitter bandwidth to enable better multipath mitigation and code measurement accuracy
- Another common open signal for wide area, high precision, phase-based navigation
- Potential to use existing or planned spare capacity in open service or SBAS messages to increase multi-GNSS interoperability

The following charts provide specific questions for you to address

Your Supported Applications

- What types of applications do your receivers (or receiver designs) support?

Increase in Noise Floor

- Do you see a threat to GNSS receivers due to many more GNSS signals centered at 1575.42 MHz?
- Whether you see a threat or not, do you prefer all new CDMA signals at “L1” to be centered at 1575.42 MHz or have some of them elsewhere, e.g., at 1602 MHz?
- Given that most GNSS providers plan to transmit a “modernized” signal at 1575.42 MHz, what is your long term perspective on whether you will continue to use C/A?
  - Why and How?

CDMA and FDMA

- Once there are a large number of good CDMA signals, will there be continuing commercial interest in FDMA signals?
  - Why or why not?

Compatibility

- Do you prefer signals in different "L1" frequency bands for interference mitigation rather than at one center frequency for interoperability?
  - Why?

What to do About Misbehaving Signals

- If a satellite's signals do not meet quality standards, should they:
  - Be set unhealthy
  - Transmit with a nonstandard code
  - Transmit with reduced signal power (reduce interference)
  - Be switched off
  - What combination of the above"
- To assure only "good" signals, should GNSS providers agree on minimum international signal quality standards and agree to provide only signals meeting the standard?

E5a and E5b

- Given that L5/E5a will be transmitted by most GNSS providers, do you intend to use the E5b signal?
  - If so, for what purpose?

Frequency Steps

- For your applications, are small satellite “frequency steps” (Δf) a problem?
- If so, what interval between “frequency steps” and what Δf magnitude would be excessive?

Interoperable Use

- Assuming signal quality is acceptable from every provider, would you limit the number of signals used by provider or by other criteria? What criteria?
- Is having more signals inherently better or do you think there should be a limit?
- Will the marketplace “force” you to make use of every available signal?
- For best interoperability, how important is a common center frequency? How important is a common signal spectrum?

Another Common Open Service Signal

- ♦ Will you provide “tri-lane” capability in the future?
  - Why?
- ♦ If so, do you prefer a common middle frequency or the combined use of L2 (1227.6), B3 (1268.52), and E6 (1278.75) if B3 and E6 open access is available
- ♦ Would you prefer a common open signal in S Band? In C Band? Why?

Precision Code Measurements

- Does a wider satellite transmitter bandwidth help with multipath mitigation?
- What minimum transmitter bandwidth would you recommend for future GNSS signals in order to achieve optimum code precision measurements?

Added GNSS or SBAS Messages?

- Would you recommend GNSS or SBAS services provide interoperability parameters
  - System clock offsets
  - Geodesy offsets
  - ARAIM parameters
  - Others
- Should they be provided by other means so as not to compromise TTFF or other navigation capabilities

Signal Coherence

- For your applications and for each signal, what amount of drift between code and carrier over what time frame would be excessive?
- For your applications and for two or more signals in different frequency bands, e.g., L1 and L5 (when scaled properly), what amount of relative drift in code and carrier between the signals would be excessive?

Spectrum Protection

- Should the international community strive to protect all GNSS signal bands from terrestrial signal interference?

System Geodesy

- Do the current differences (~10 cm) in Geodesy pose a problem for your users? Why or why not?
- If geodesy differences are a problem, what is the preferred method of compensation:
  - Published values (e.g., on websites)
  - Satellite messages

System Time

- Do you want each system to cross reference the other's time (e.g., with a GGTO type of message) or compare itself to a common international GNSS ensemble time? To what precision?
- Will your future receivers calculate a time offset between systems based on signal measurements or use only external time offset data?
- What is the preferred method of receiving time offsets: Satellite messages, Internet messages, or internally calculated?