Commercial Applications of Global Navigation Satellite Systems

Symposium to Strengthen the Partnership With Industry

The Global Positioning System

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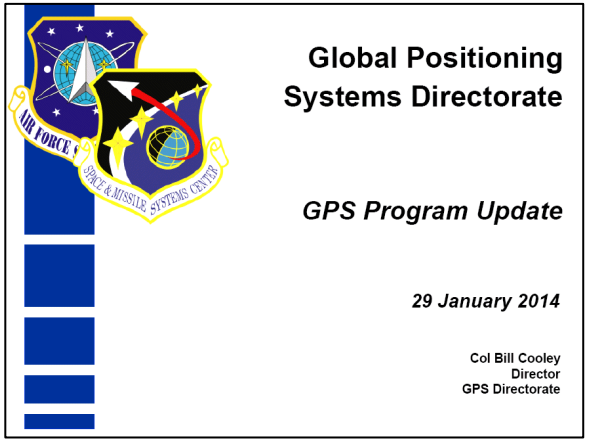
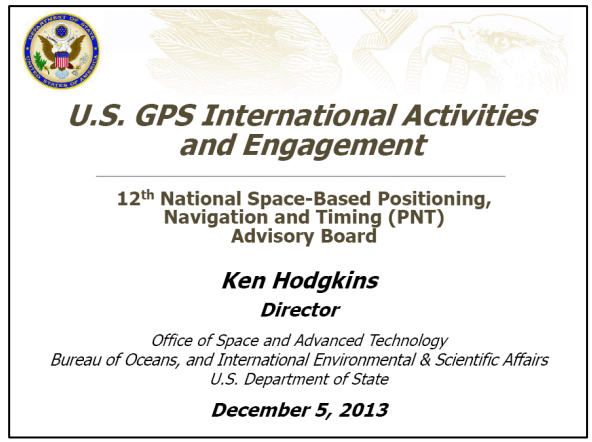
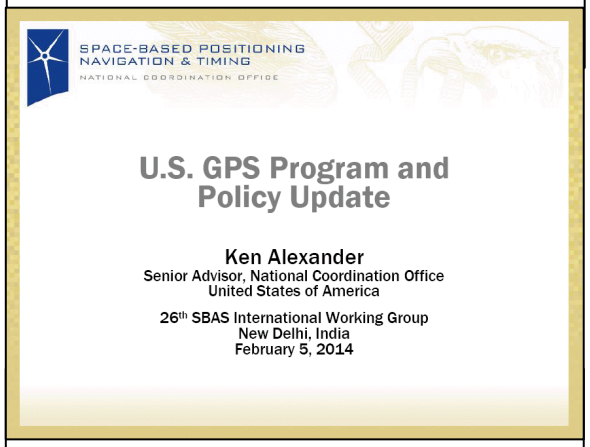
A Composite of Presentations





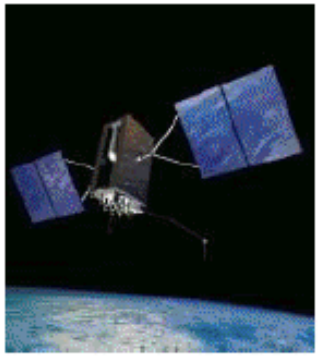


GPS Status Report

Global Positioning Systems Directorate

Mission:

Acquire, deliver and sustain reliable GPS capabilities to America's warfighters, our allies, and civil users



Col Bill Cooley

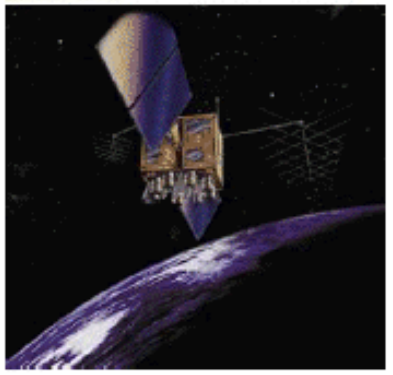
Deliver and sustain Global Navigation and Timing Service

U.S. AIR FORCE

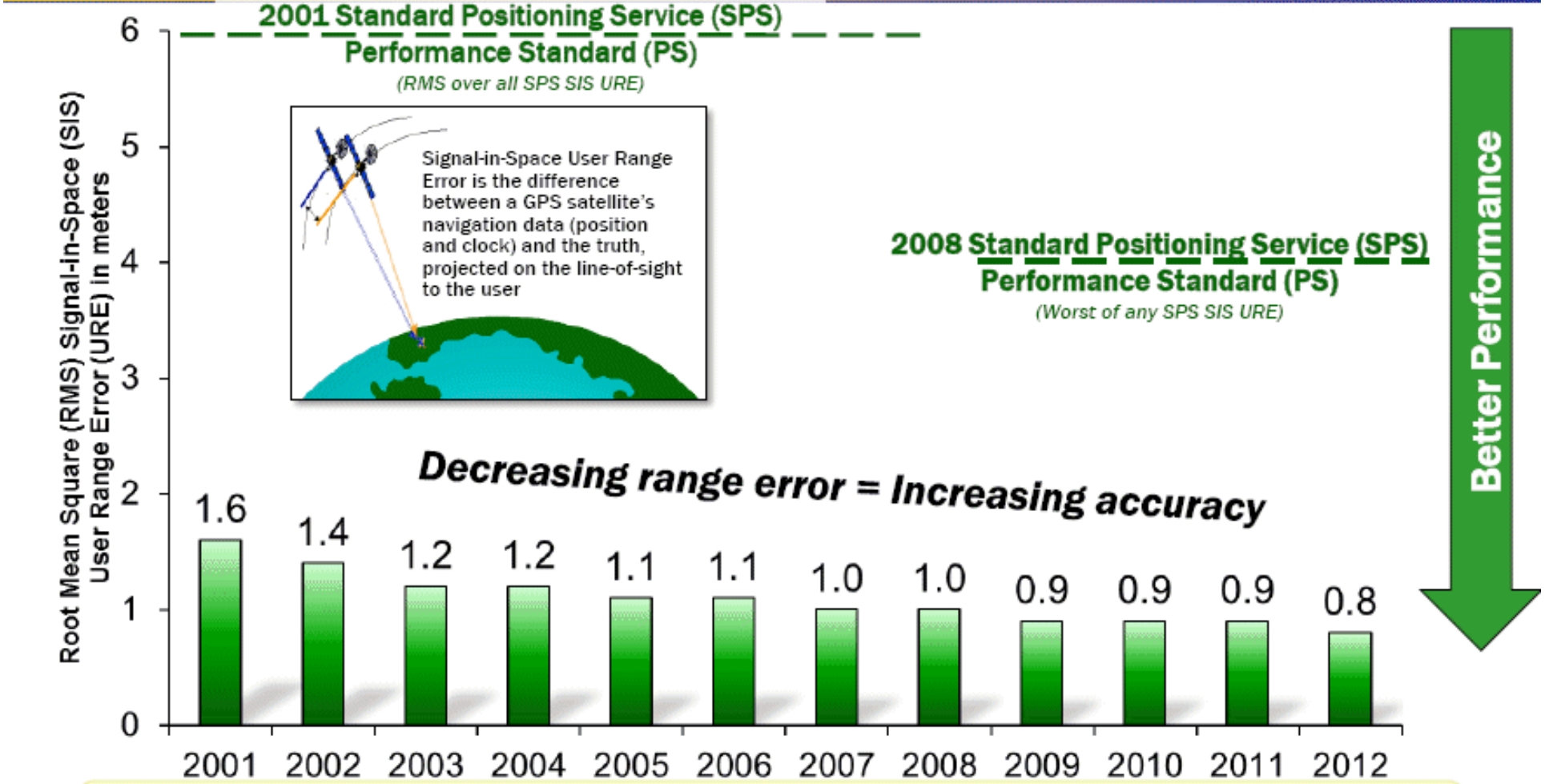
Constellation Snapshot

31 Operational Satellites
(Baseline Constellation: 24)

- 8 Block IIA satellites operational
- 12 Block IIR satellites operational
- 7 Block IIR-M satellites operational (L2C)
- 4 Block IIF satellites operational (L2C & L5)
- U.S. Government continuously assessing constellation health to determine launch need
  - Newest satellites launched
    - IIF-3/SVN 65 – 4 October 2012
    - IIF-4/SVN 66 – 15 May 2013
  - IIF-5 launch scheduled for 17 Oct 2013
- Global GPS civil service performance commitment met continuously since 1993

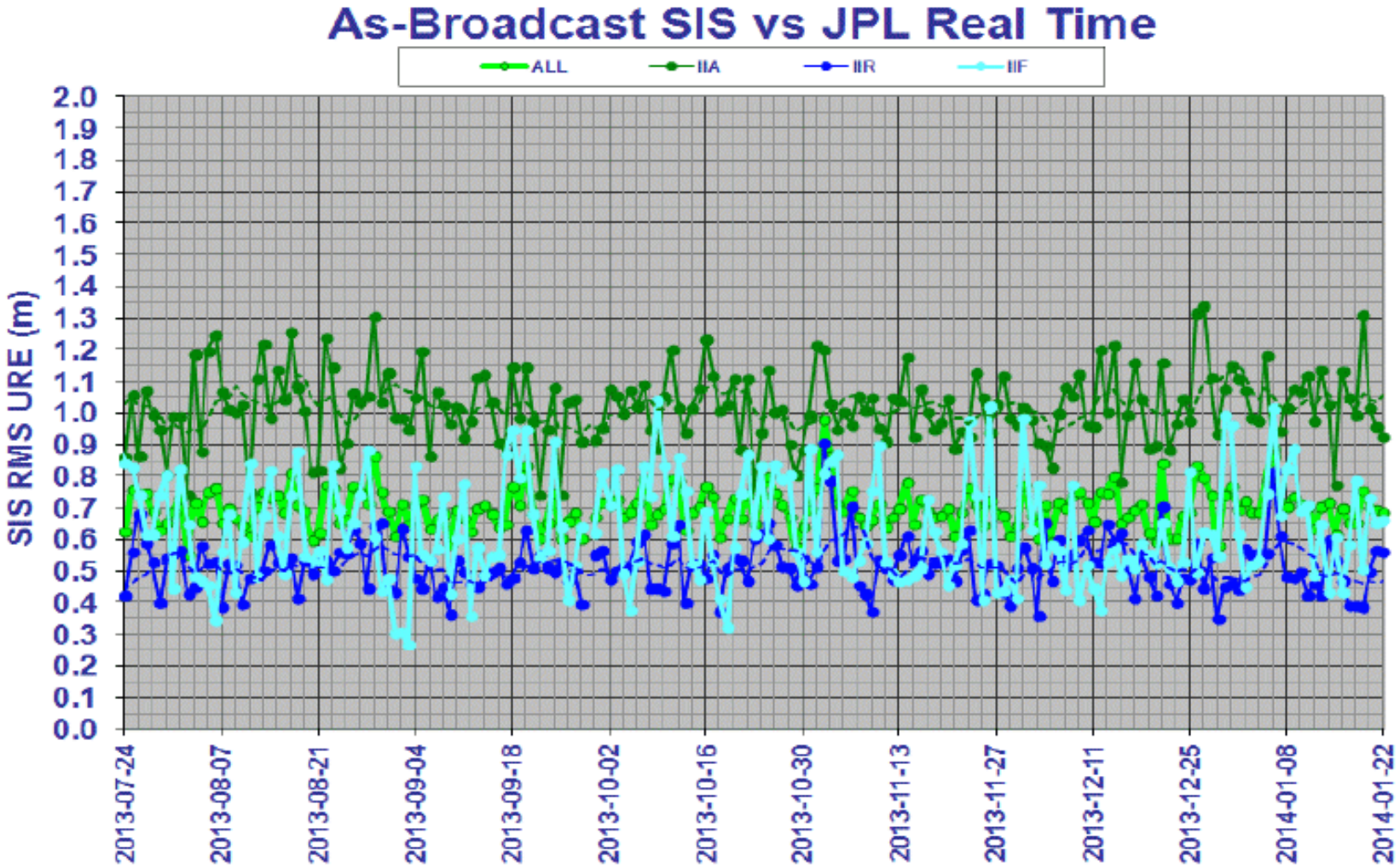


Standard Positioning Service (SPS) Signal-in-Space Performance



System accuracy exceeds published standard

GPS Performance – Past 6 Months



GPS Modernization – New Civil Signals

- **Second civil signal "L2C"**
  - Designed to meet commercial needs
  - Available since 2005 without data message
  - Phased roll-out of CNAV message
  - Currently 11 SVs in operation

- **Third civil signal "L5"**
  - Designed to meet transportation safety-of-life requirements
  - Uses Aeronautical Radio Navigation Service band
  - Currently 4 SVs in operation

- **Fourth civil signal "L1C"**
  - Designed for GNSS interoperability
  - Specification developed in cooperation with industry
  - Launches with GPS III in 2015
  - Improved tracking performance

Urban Canyons

Improved performance in challenged environments

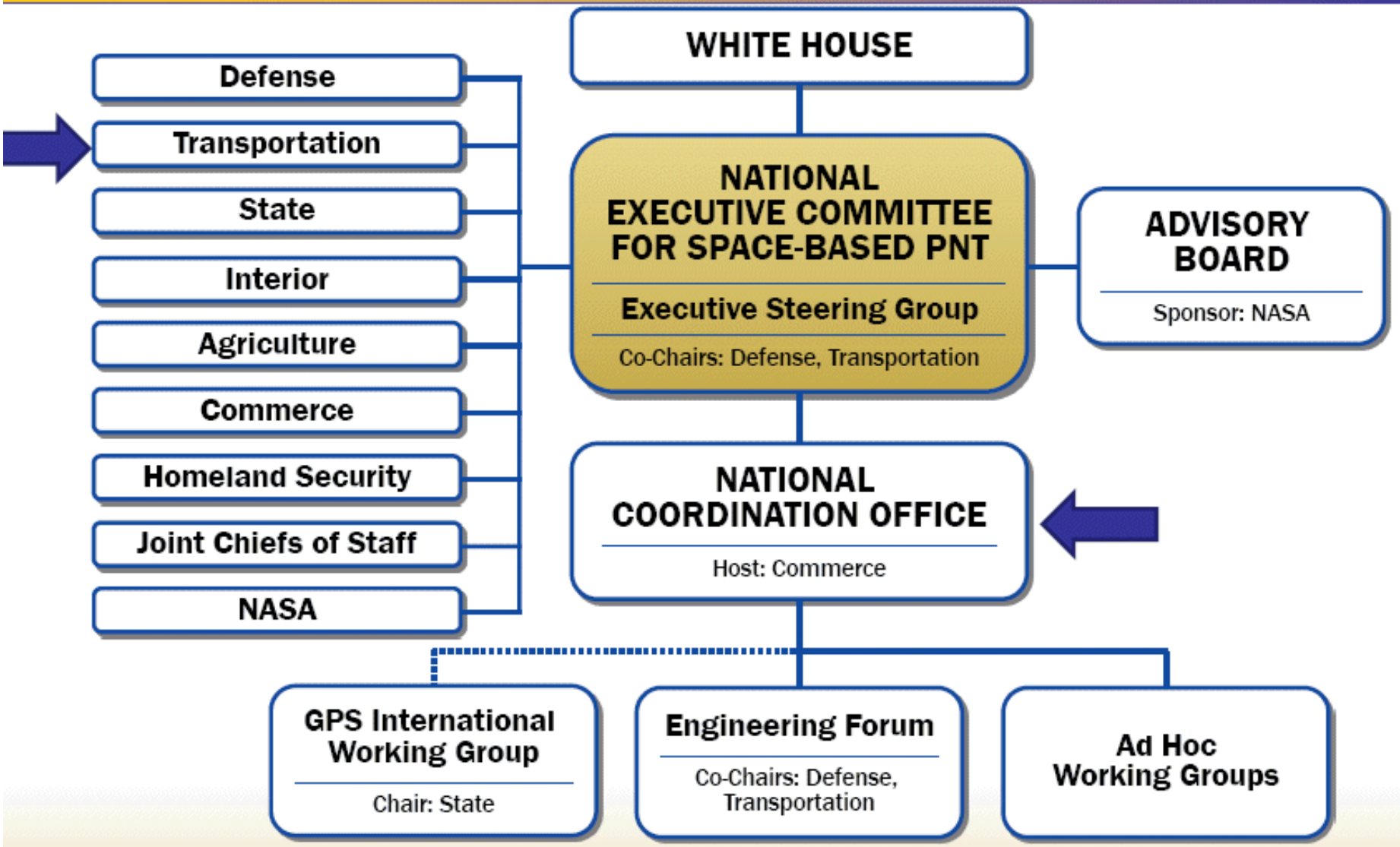
Early CNAV test conducted in June 2013

GPS III Status

- **Newest block of GPS satellites**
  - First satellite to broadcast common L1C signal
  - Multiple civil and military signals; L1 C/A, L1 P(Y), L1M, L1C, L2C, L2 P(Y), L2M, L5
  - Three Rubidium clocks
- **Achieved SV01 initial power turn-on 27 Feb 13**
- **GPS Satellite Simulator delivered to support OCX, 21 May 13**
- **GPS Non-Flight Satellite Testbed accomplished launch processing at Cape Canaveral; shipped back to factory (Dec 13)**
- **Final elements of Navigation Payload are in acceptance test**

U.S. PNT Policy

U.S. Space-Based PNT Organization Structure



U.S. National Space Policy

Space-Based PNT Guideline: Maintain leadership in the service, provision, and use of GNSS

- Provide civil GPS services, free of direct user charges
  - Available on a continuous, worldwide basis
  - Maintain constellation consistent with published performance standards and interface specifications
  - **Foreign PNT services may be used to complement services from GPS**
- Encourage global ***compatibility*** and ***interoperability*** with GPS
- Promote transparency in civil service provision
- Enable market access to industry
- Support international activities to detect and mitigate harmful interference

U.S. Policy Promotes Global Use of GPS Technology

- No direct user fees for civil GPS services
  - Provided on a continuous, worldwide basis
- Open, public signal structures for all civil services
  - Promotes equal access for user equipment manufacturing, applications development, and value-added services
  - Encourages open, market-driven competition
- Global compatibility and interoperability with GPS
- Service improvements for civil, commercial, and scientific users worldwide
- Protection of radionavigation spectrum from disruption and interference

U.S. Objectives in Working with Other GNSS Service Providers

- Ensure **compatibility** — ability of U.S. and non-U.S. space-based PNT services to be used separately or together without interfering with each individual service or signal
  - Radio frequency compatibility
  - Spectral separation between M-code and other signals
- Achieve **interoperability** – ability of civil U.S. and non-U.S. space-based PNT services to be used together to provide the user better capabilities than would be achieved by relying solely on one service or signal
- Promote fair competition in the global marketplace

Pursue through Bilateral and Multilateral Cooperation

U.S. Position on GNSS Intellectual Property

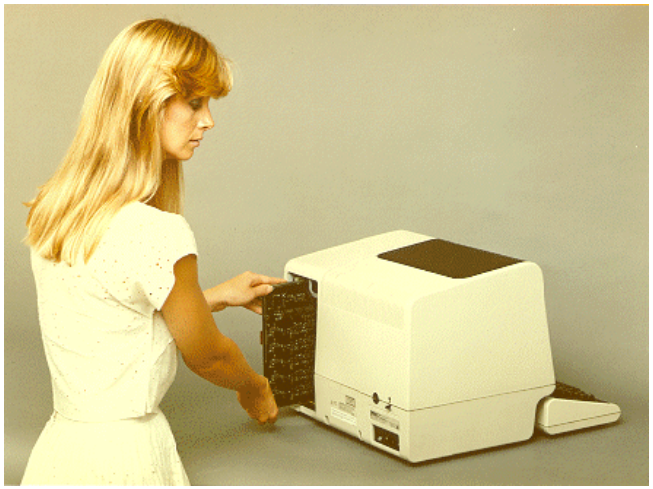
- United States has a longstanding commitment to provide civil open service signals, and technical information necessary to develop and build equipment to use these signals, available worldwide to users at no direct cost (principle of transparency)
- All intellectual property for U.S. GPS civil signal designs and their broadcast from GPS are in the public domain
- Encourage other GNSS providers to make their signals available in same manner
- Those entities that wish to patent technologies or techniques that are specific to receiver design and application development are free to do so
- Approach maximizes private sector innovation and has promoted new applications and great economic benefits

Anticipating the Future?

Early Commercial GPS Receivers

Texas Instruments TI-4100

Trimble 4000-S



Magnavox T-Set

Who in the 1980s could have anticipated the incredible evolution of GPS equipment, applications, and performance?

Who Anticipated GPS in Cell Phones

About a Billion Cell Phone GPS Users

- Sparked by the E911 requirement
- Use of Location Based Services (LBS) is exploding
- Improved by Assisted GPS (A-GPS)
- Better accuracy
- Location in seconds
- Turn-by-turn navigation

Who Anticipated Precision Agriculture

- One to 10 cm accuracy
- Far better productivity, efficiency, and protection of the environment
- Enabled, e.g., by MSS signals for the John Deere StarFire Service

Automatic Steering

Automatic Spray Control

Enable The Future

- We cannot envision future applications
- But we **CAN** enable future applications by:
  - Enhancing interoperability
  - Improving cooperation and transparency
  - Providing civil services free of direct user charges
  - Thinking more globally than regionally

Interoperability Workshop

Framing the Workshop

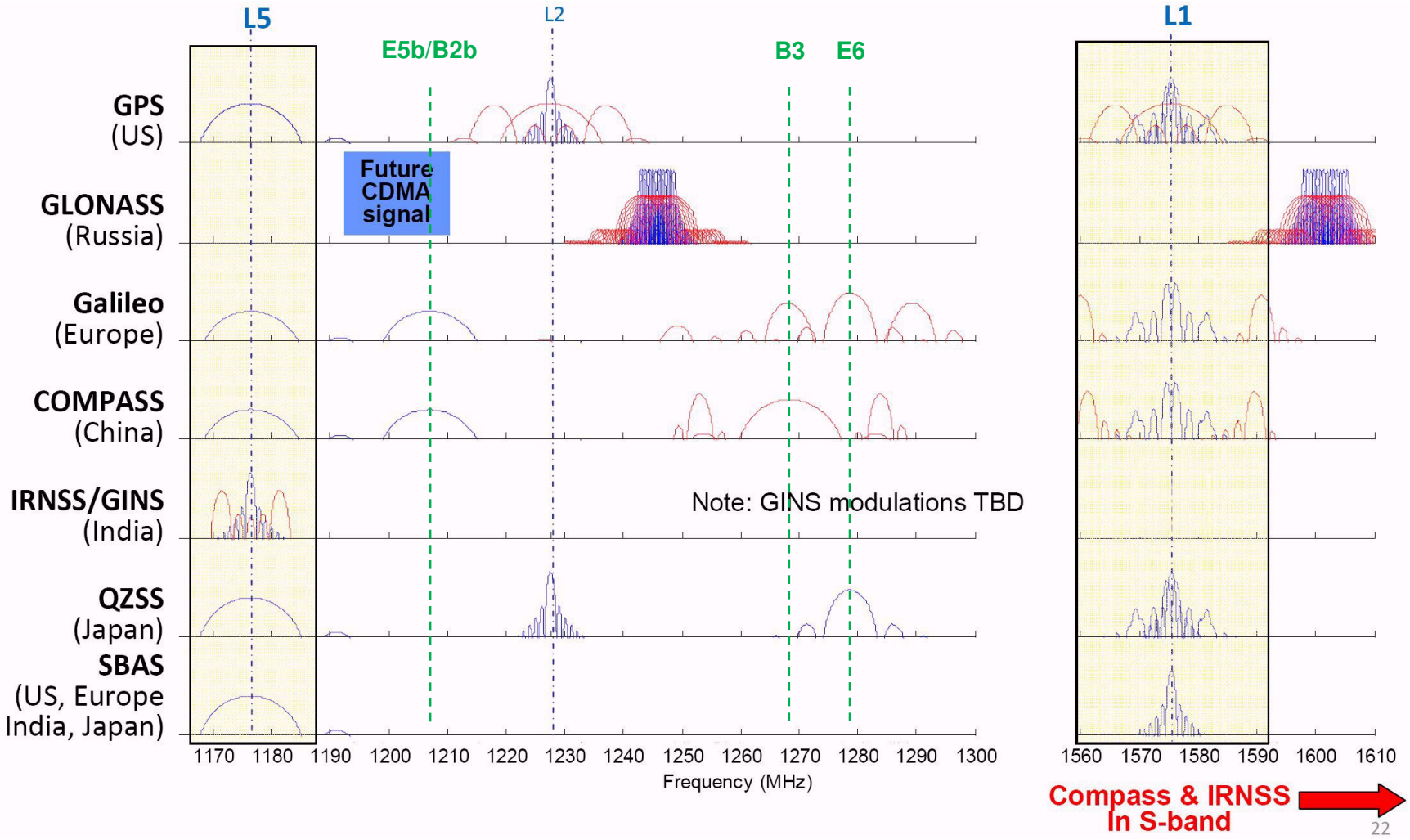
- In general, users don't understand the implications of differences in GNSS signal structures
- Those who do understand are companies that design and build the user equipment
- For some time, ICG WG-A has been seeking input on what is most important for interoperability
- Today we will receive voluntary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

The Goal of Interoperability

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

Interoperable = Better Together than Separate

Spectrum of GNSS Signals



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?

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 center frequencies
  - Frequency diversity vs. frequency commonality
  - How many global systems should share spectrum?
- Common signal spectra 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

Backup – Interoperability Results

ICG-7 Recommendation

- Consistent with the principle of interoperability and its definition, and the implementation of previous ICG recommendations related to interoperability, the ICG should host an interoperability workshop in conjunction with the ION Pacific PNT meeting, April 22-25 2013.
- The ICG will request inputs from potential participants prior to the workshop through existing web sites related to GNSS information dissemination, conferences, major PNT organizations and events.
- The following interoperability subjects may be addressed:
  1. Potential for a common third open service signal
  2. Frequency diversity vs. frequency commonality
  3. DOP improvement with the addition of 2nd, 3rd, 4th, Nth global constellation
  4. System provider time and geodetic reference frame implementation as described by the ICG WG-D templates
  5. Potential opportunities to utilize existing or planned spare capacity in civil/open service or SBAS navigation messages in order to increase multi-GNSS interoperability

Industry Participants

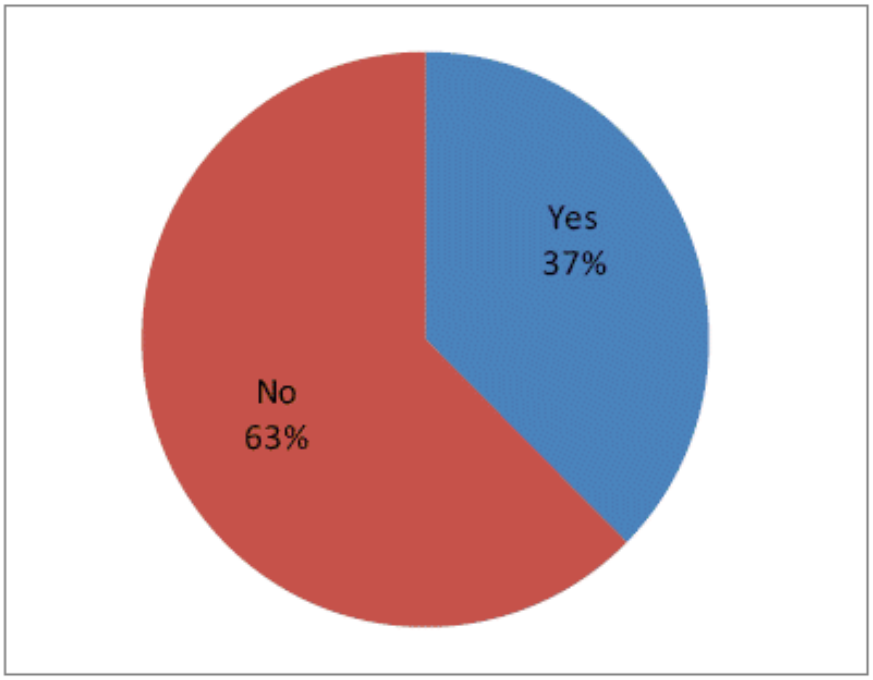
- 11 Industry Representatives/Presentations
  - MITRE (aviation/certified avionics)
  - Rockwell Collins (aviation/certified avionics)
  - Hemisphere GPS (Medium/High Precision Receivers)
  - Septentrio (Medium/High Precision Receivers)
  - Trimble (Medium/High Precision Receivers)
  - John Deere (Medium/High Precision Receivers)
  - Topcon (Medium/High Precision Receivers)
  - CSR plc (Consumer Applications)
  - ST Microelectronics (Consumer Applications)
  - Broadcom (Consumer Applications)
  - Qualcomm (Consumer Applications)

Industry Responses to Questions

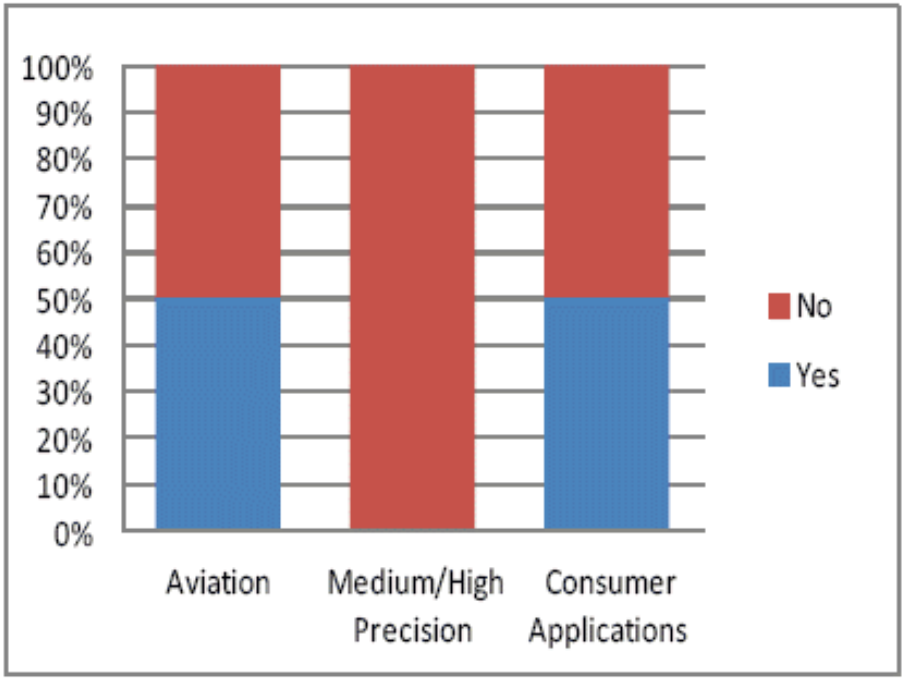
Question #1:

Do you see a threat to GNSS receivers due to many more GNSS signals centered at 1575.42 MHz?

Overall Response*



Response Breakdown by Sector



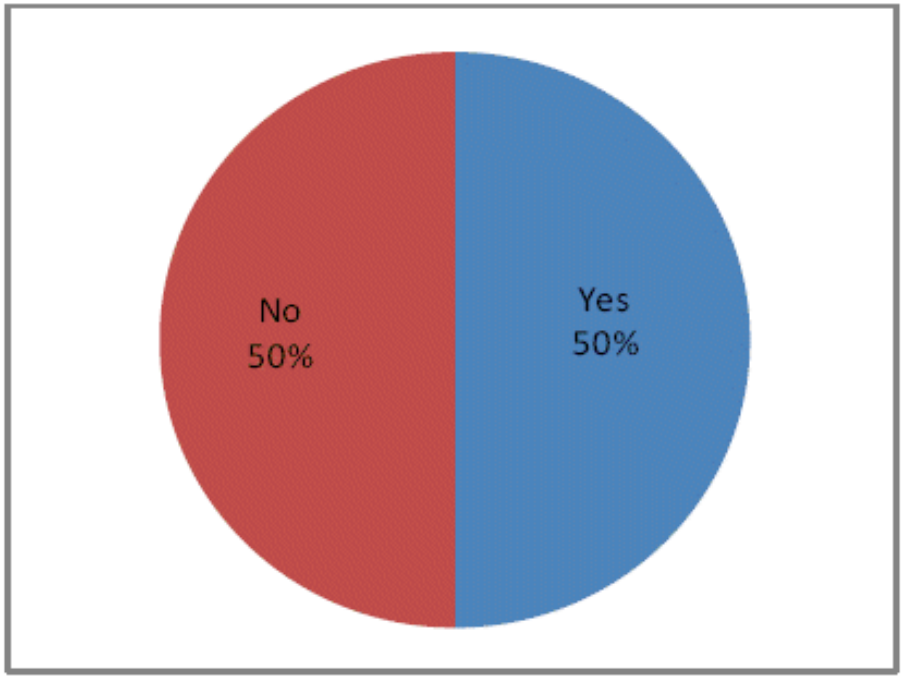
*8 Total Responses to the Question

Industry Responses to Questions

Question #2:

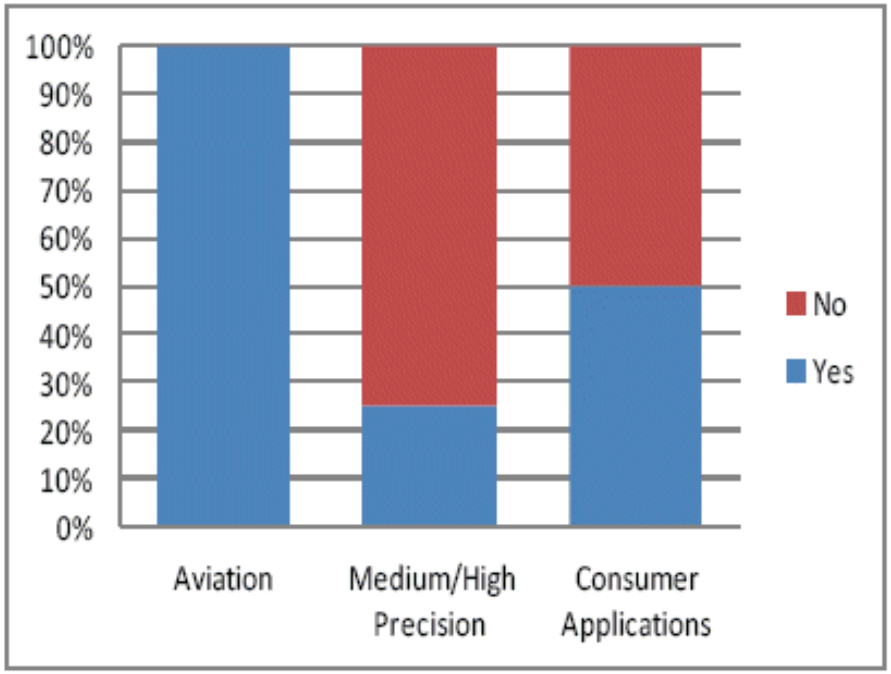
Do you prefer all new CDMA signals at "L1" to be centered at 1575.42 MHz?

Overall Response*



*10 Total Responses to the Question

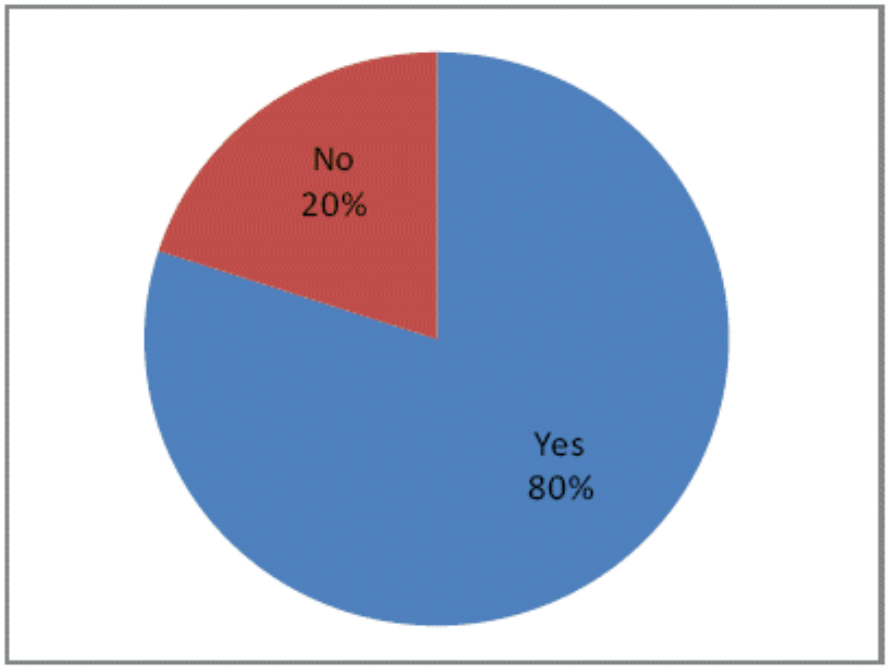
Response Breakdown by Sector



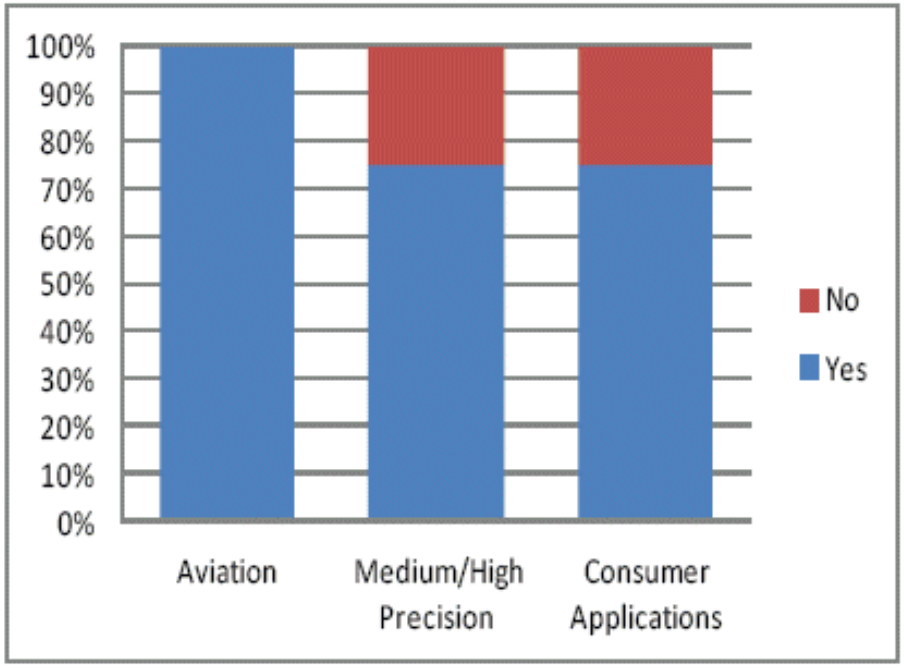
Industry Responses to Questions

Question #3:
Will you continue to use C/A in the longterm?

Overall Response*



Response Breakdown by Sector



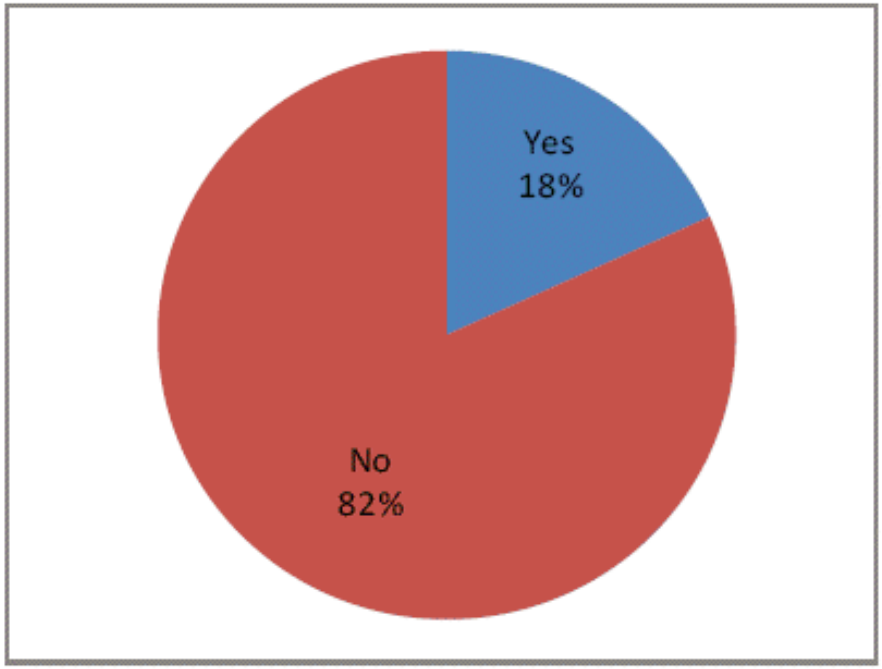
*10 Total Responses to the Question

Industry Responses to Questions

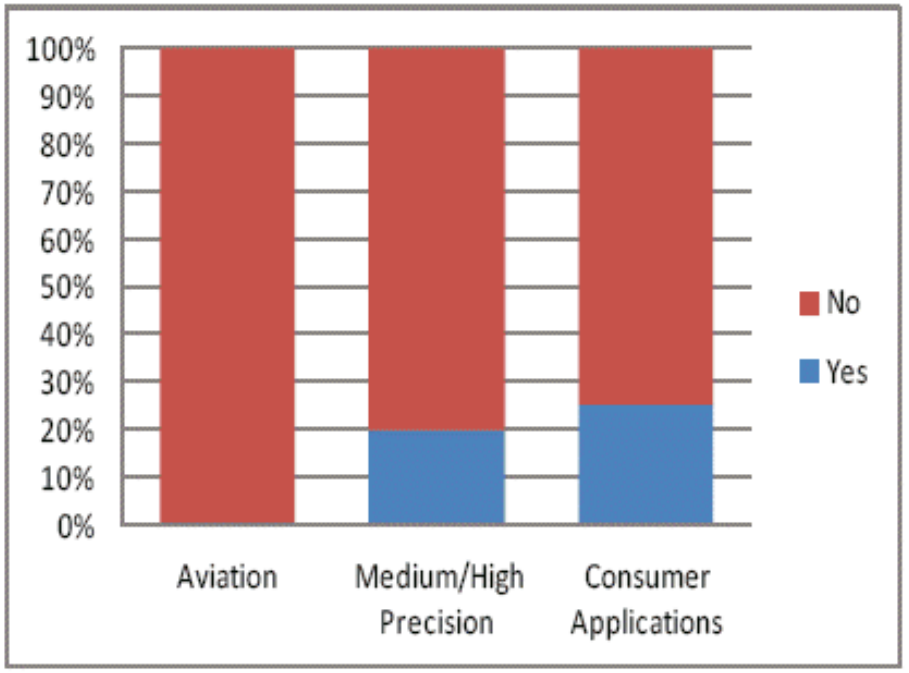
Question #4:

Once there are a large number of good CDMA signals, will there be continuing commercial interest in FDMA signals?

Overall Response*



Response Breakdown by Sector



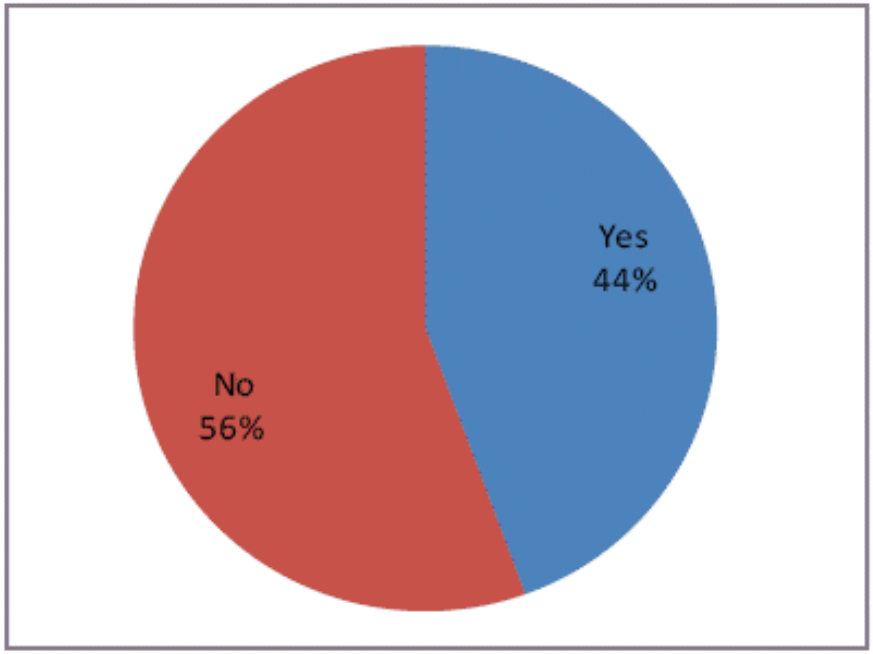
*11 Total Responses to the Question

Industry Responses to Questions

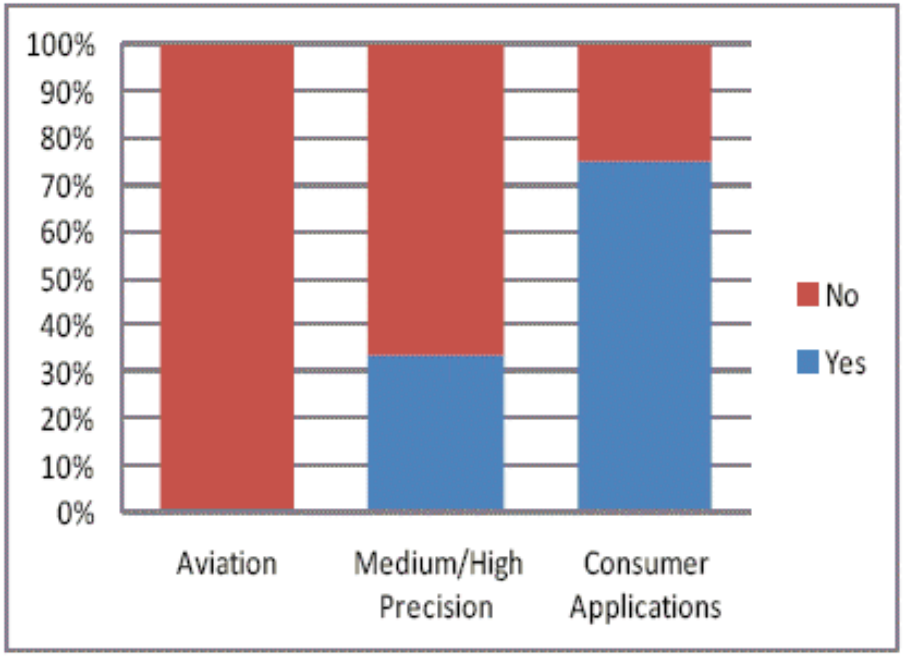
Question #5:

Do you prefer signals in different "L1" frequency bands (rather than at one center frequency)?

Overall Response*



Response Breakdown by Sector

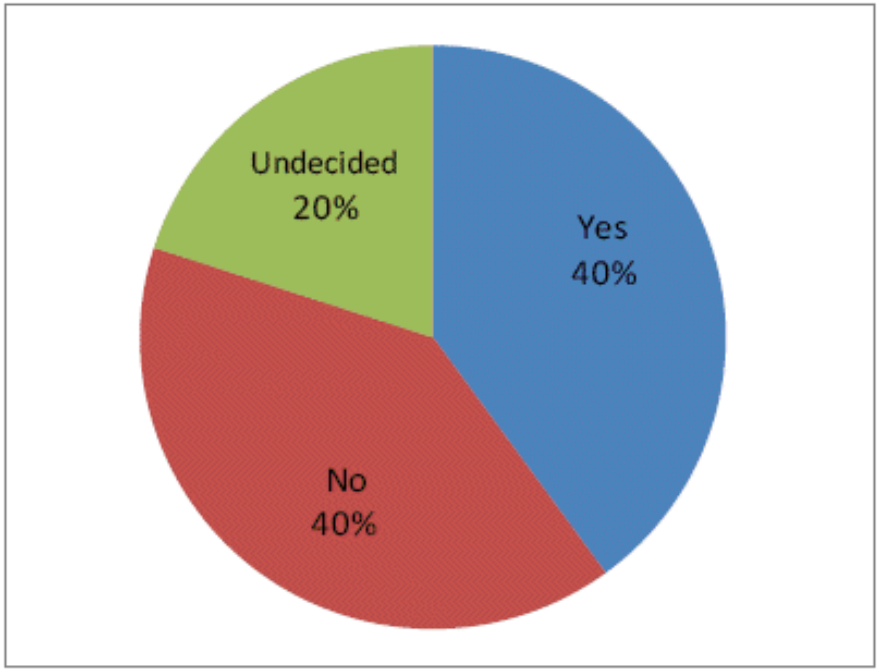


*9 Total Responses to the Question

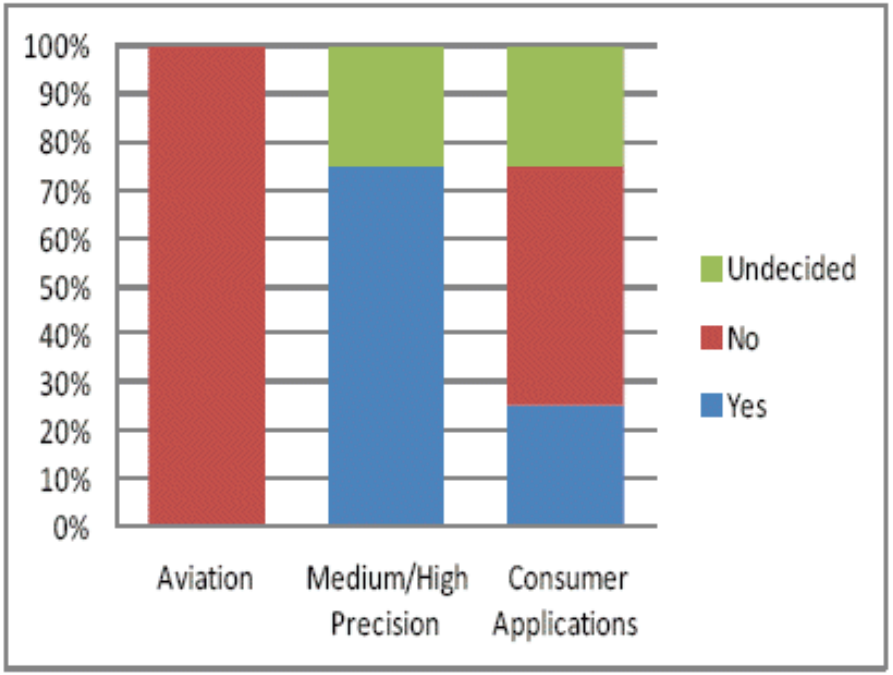
Industry Responses to Questions

Question #6:
Do you intend to use the E5b signal?

Overall Response*



Response Breakdown by Sector



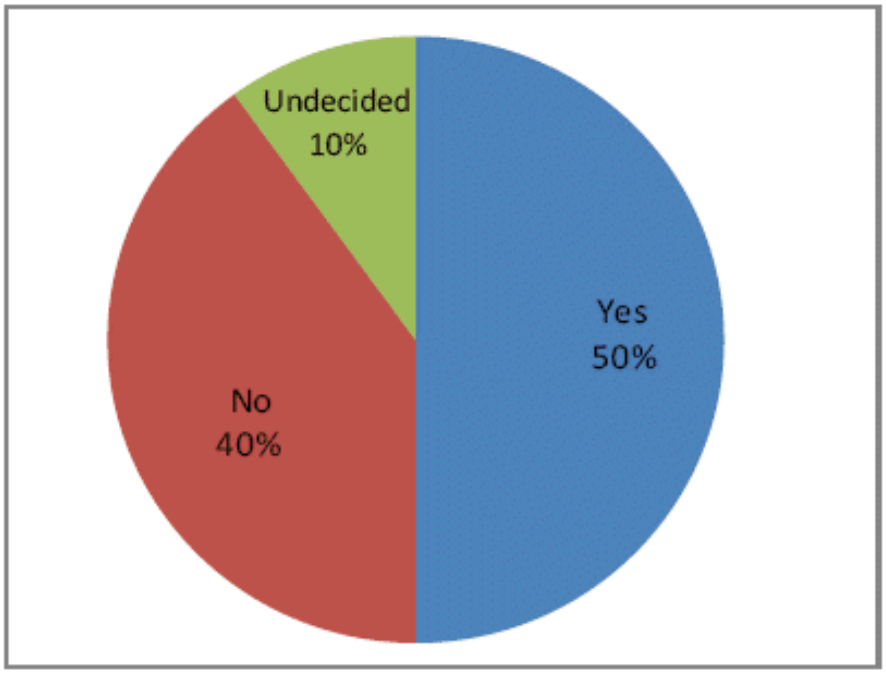
*10 Total Responses to the Question

Industry Responses to Questions

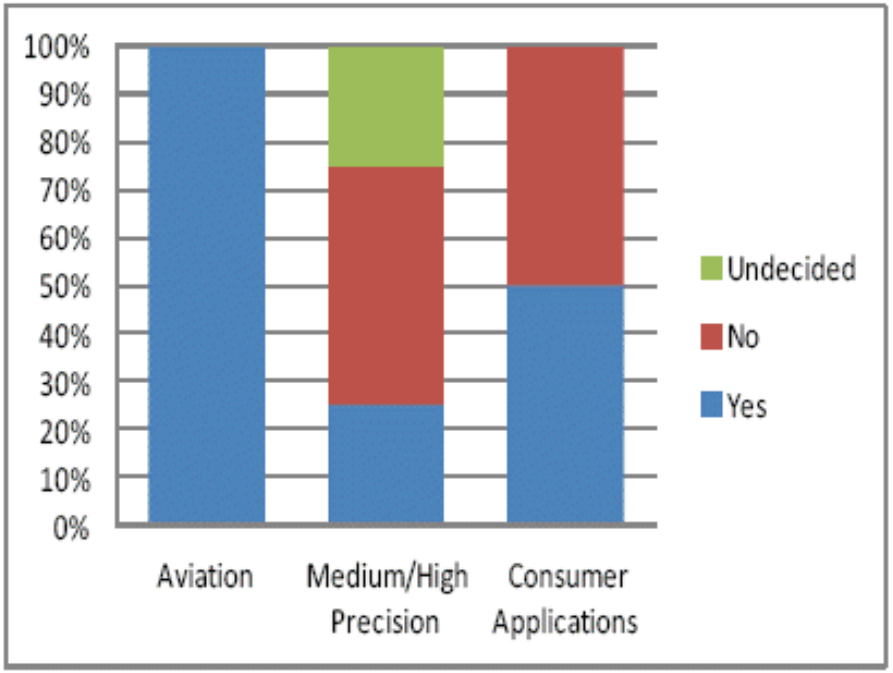
Question #7:

For your applications, are small satellite "frequency steps" a problem?

Overall Response*



Response Breakdown by Sector



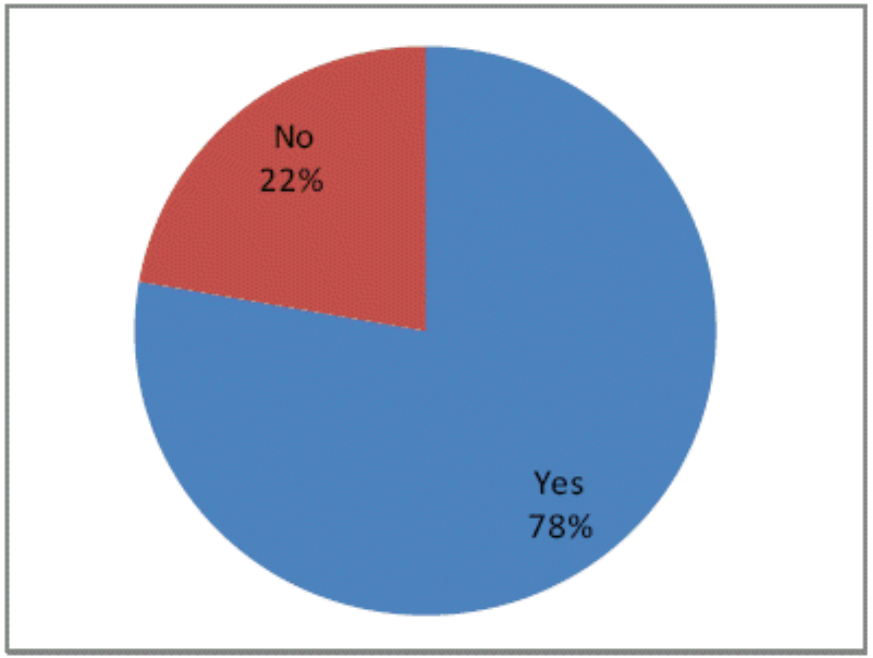
*10 Total Responses to the Question

Industry Responses to Questions

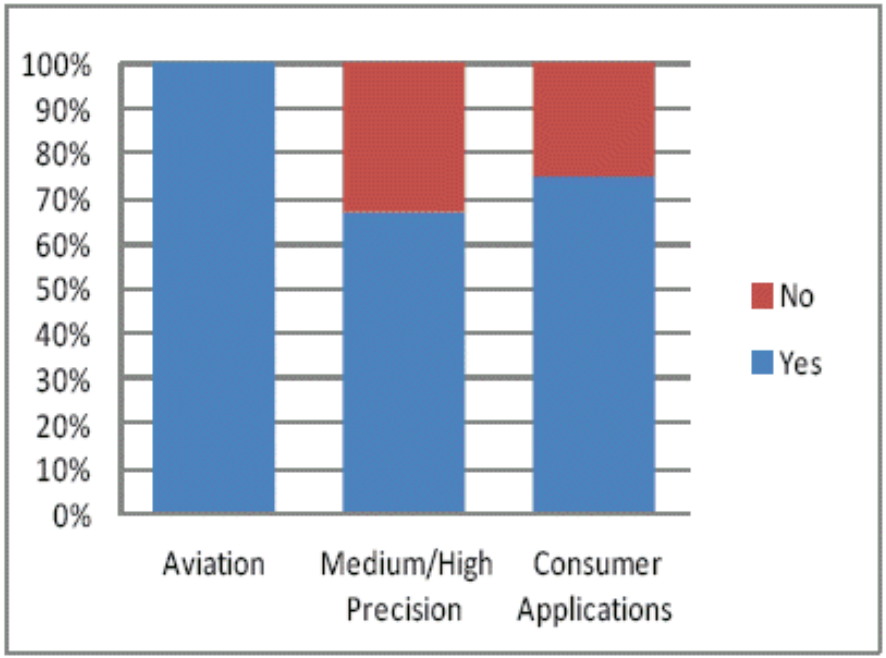
Question #8:

Assuming signal quality is acceptable from every provider, would you limit the number of signals used?

Overall Response*



Response Breakdown by Sector

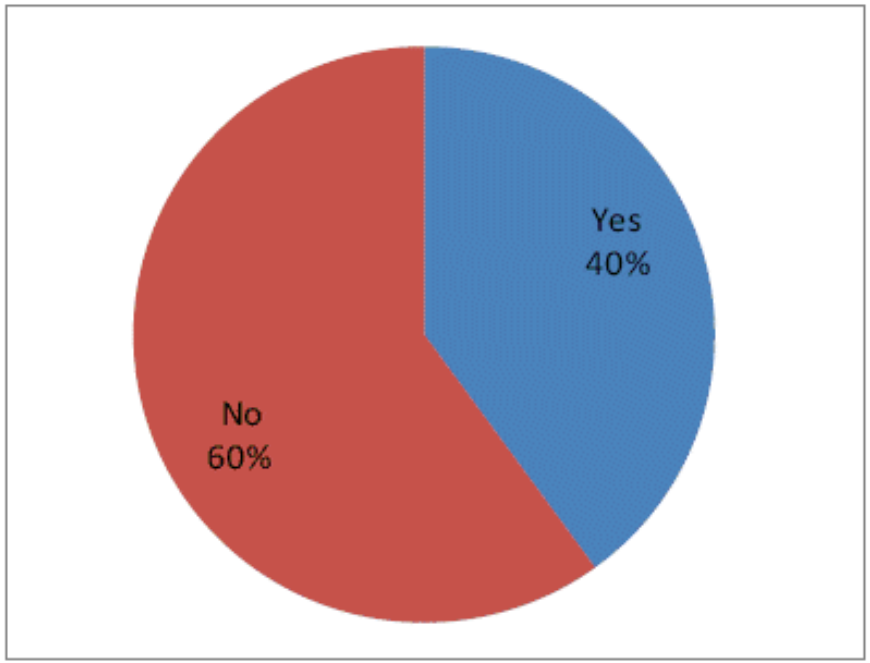


*9 Total Responses to the Question

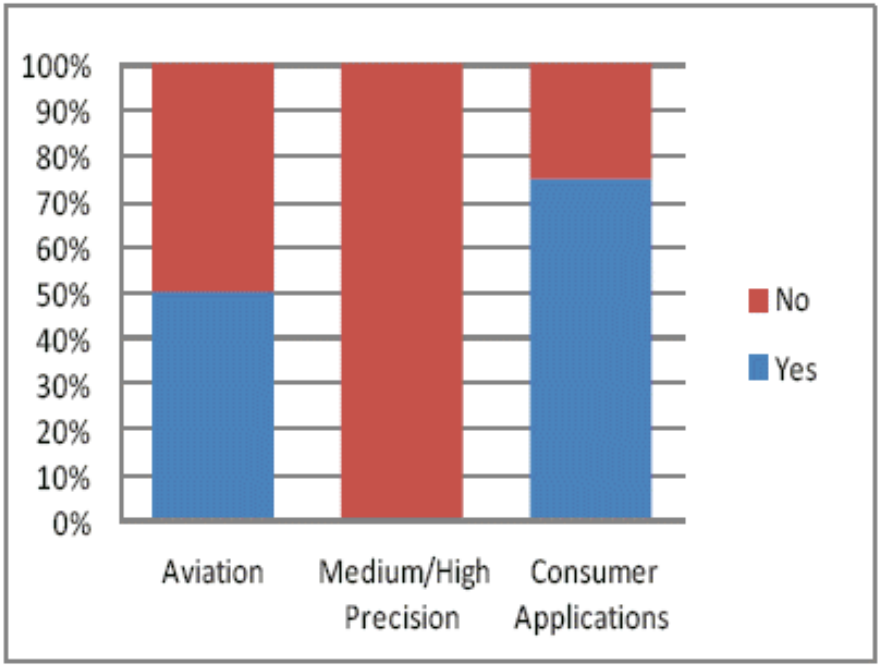
Industry Responses to Questions

Question #9:
Is having more signals inherently better?

Overall Response*



Response Breakdown by Sector



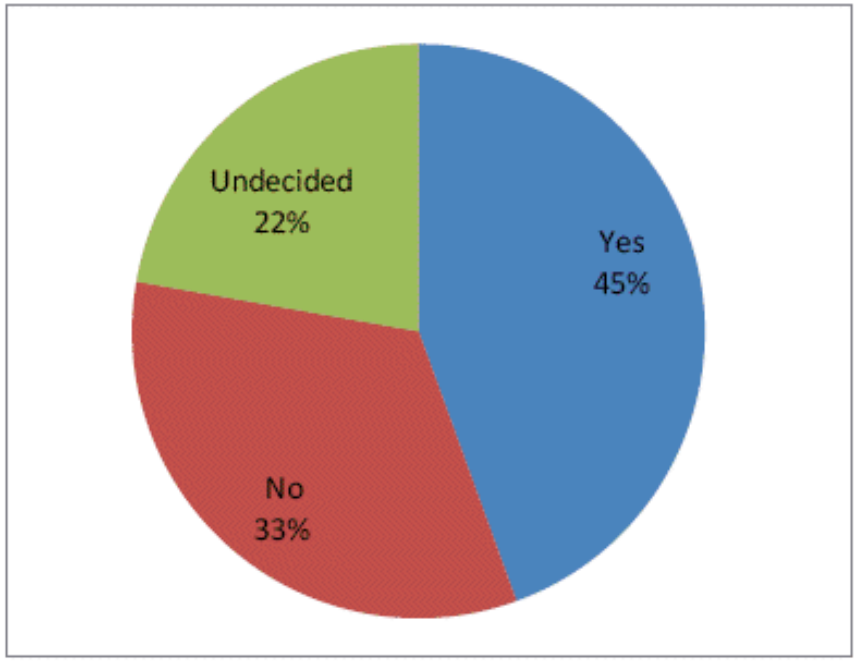
*10 Total Responses to the Question

Industry Responses to Questions

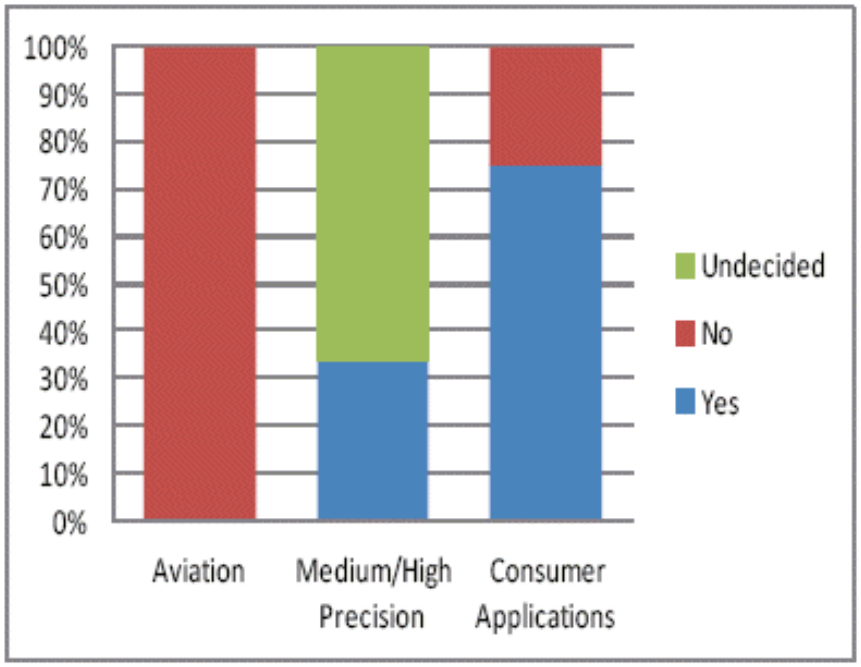
Question #10:

Will the marketplace "force" you to make use of every available signal?

Overall Response*



Response Breakdown by Sector



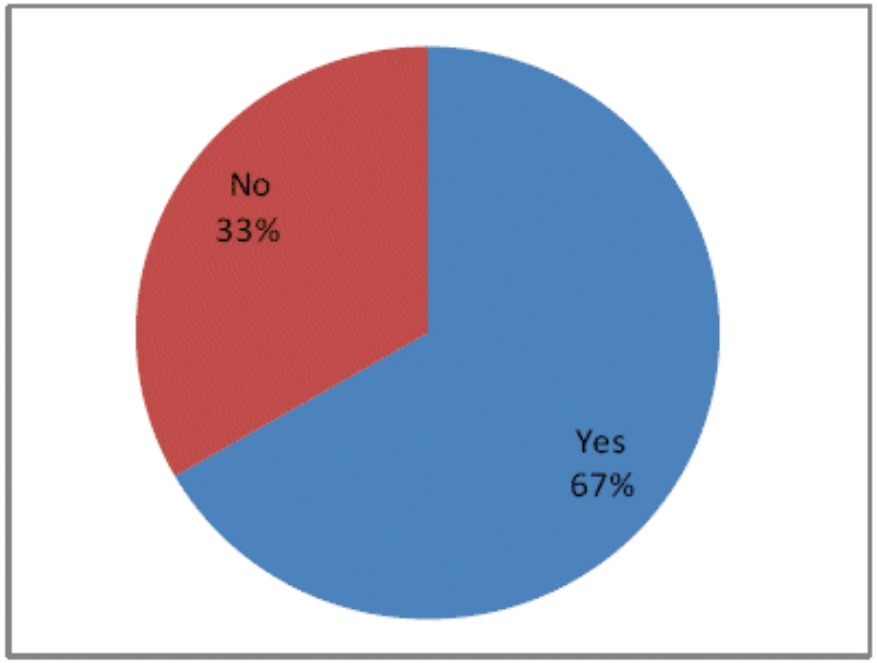
*9 Total Responses to the Question

Industry Responses to Questions

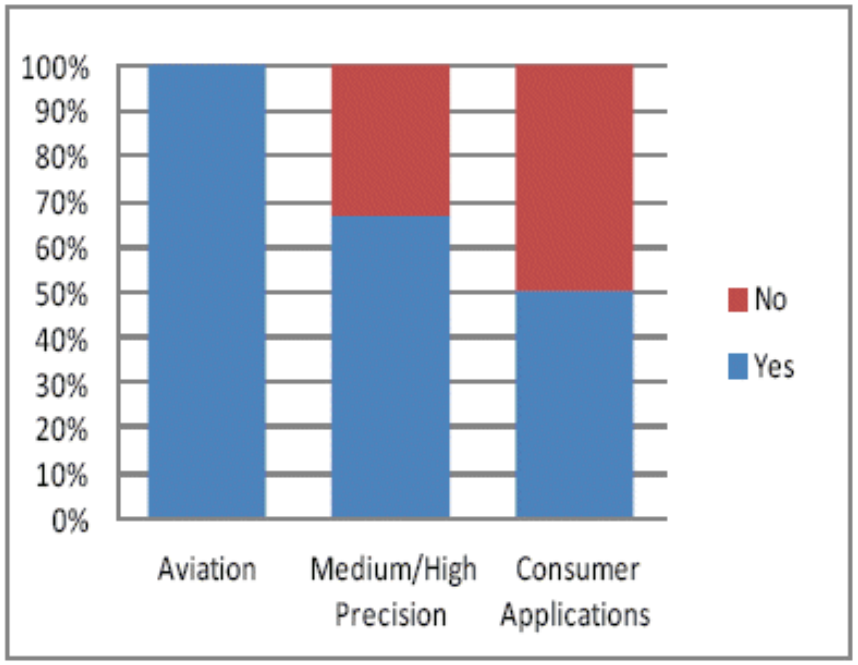
Question #11:

Is having a common center frequency very important?

Overall Response*



Response Breakdown by Sector



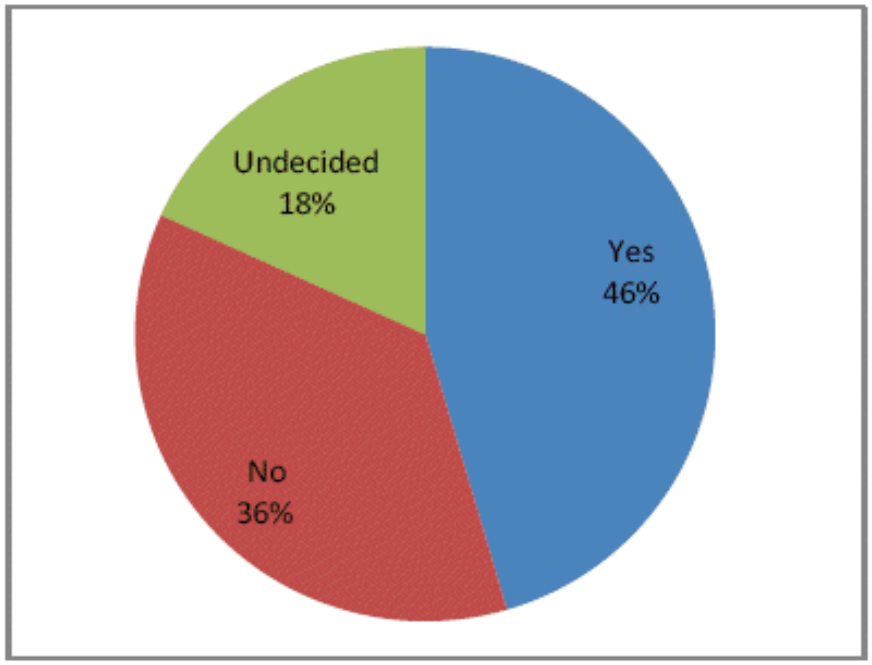
*9 Total Responses to the Question

Industry Responses to Questions

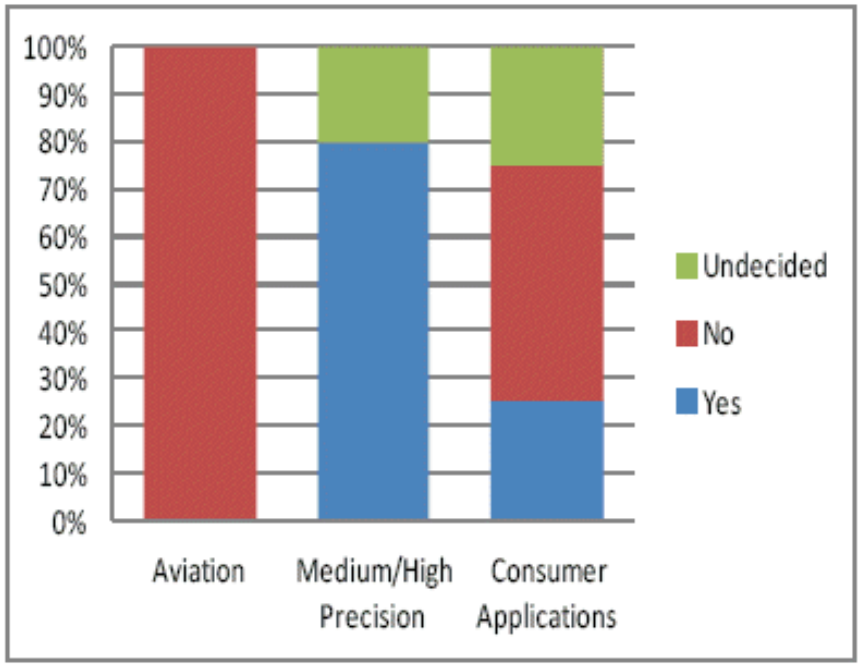
Question #12:

Will you provide "tri-lane" capability in the future?

Overall Response*



Response Breakdown by Sector



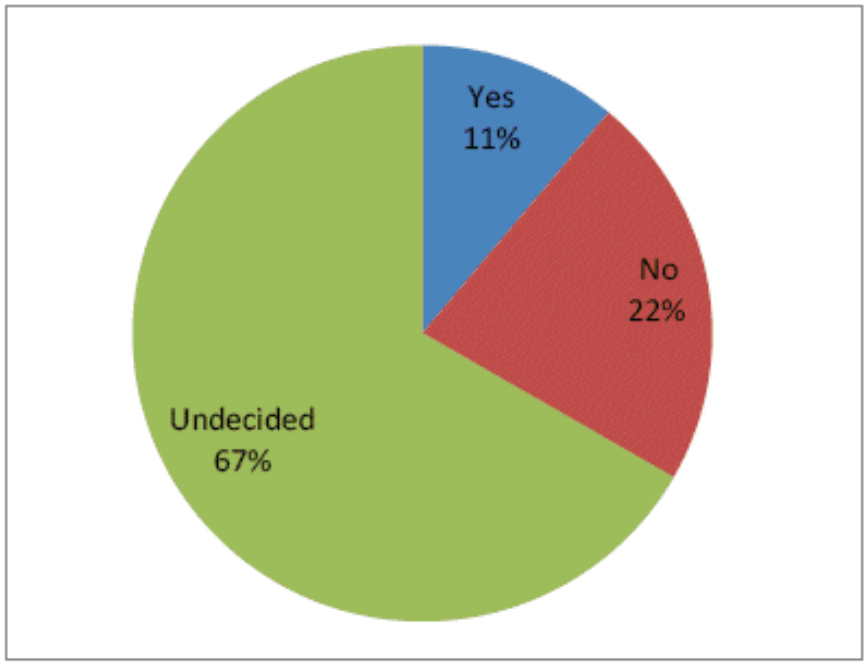
*11 Total Responses to the Question

Industry Responses to Questions

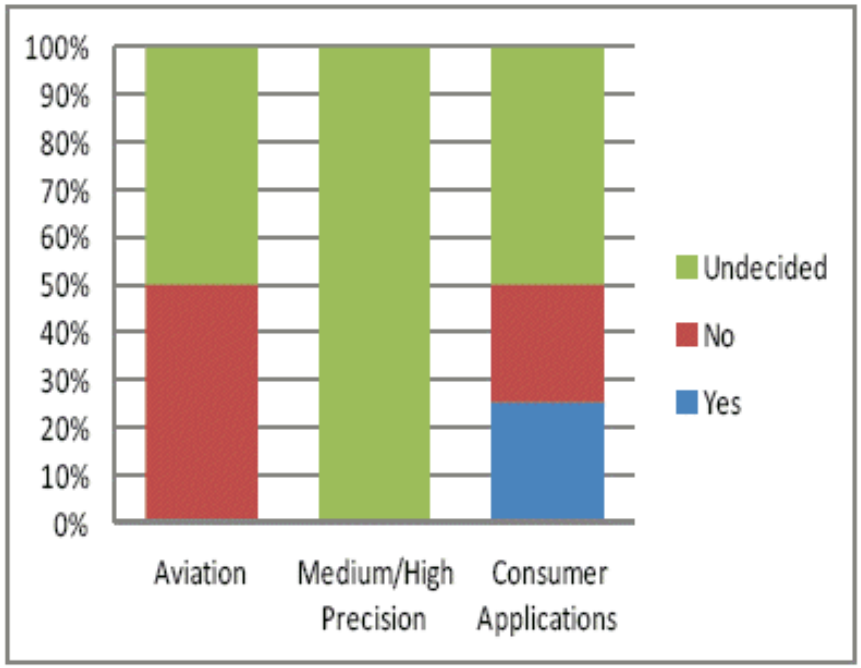
Question #13:

Would you prefer a common open signal in S Band?

Overall Response*



Response Breakdown by Sector



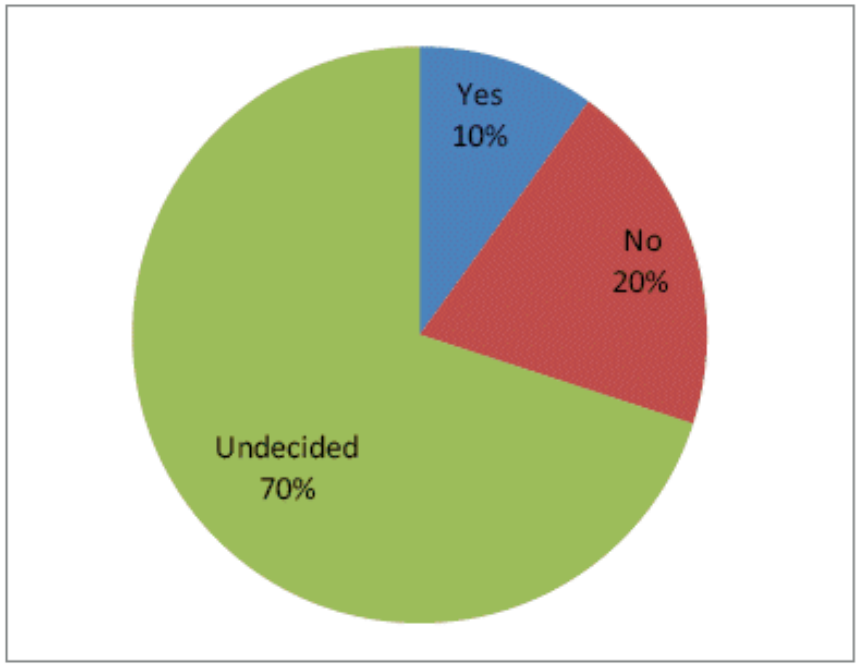
*9 Total Responses to the Question

Industry Responses to Questions

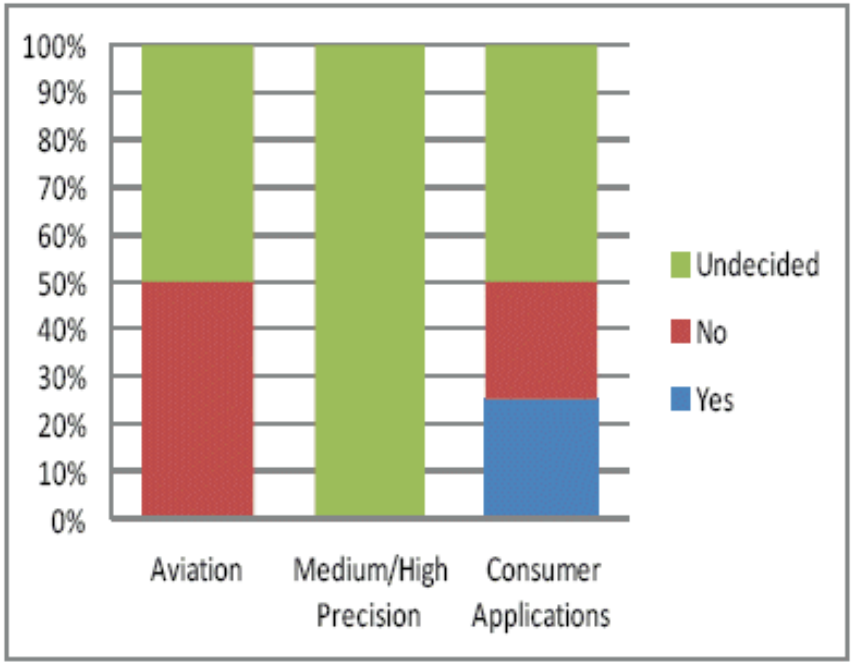
Question #14:

Would you prefer a common open signal in C Band?

Overall Response*



Response Breakdown by Sector



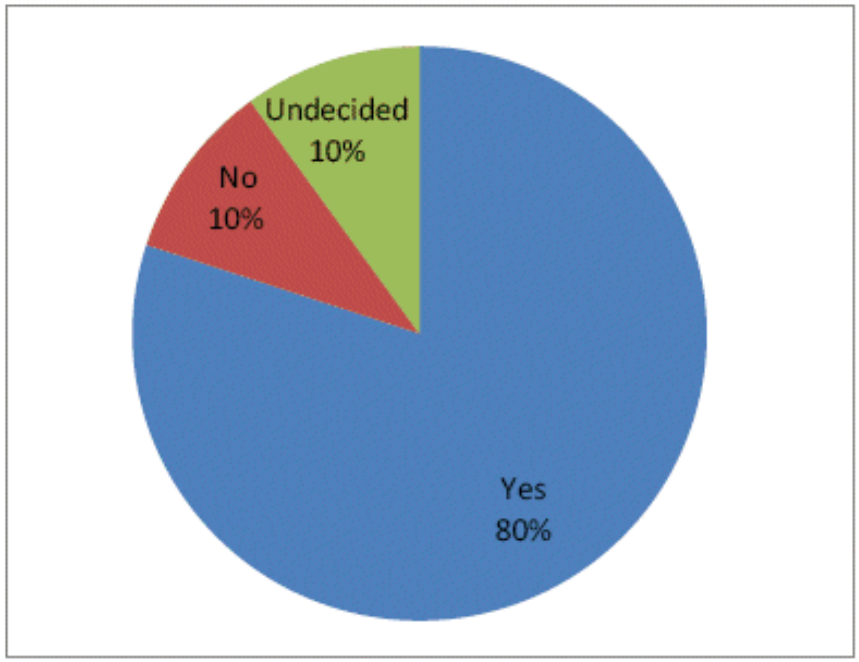
*10 Total Responses to the Question

Industry Responses to Questions

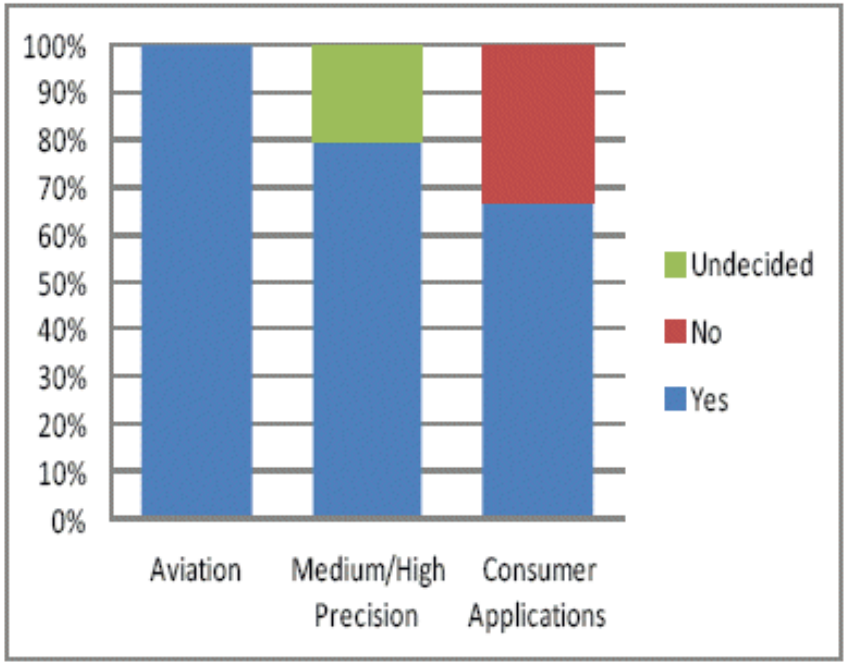
Question #15:

Does a wider satellite transmitter bandwidth help with multipath mitigation?

Overall Response*



Response Breakdown by Sector



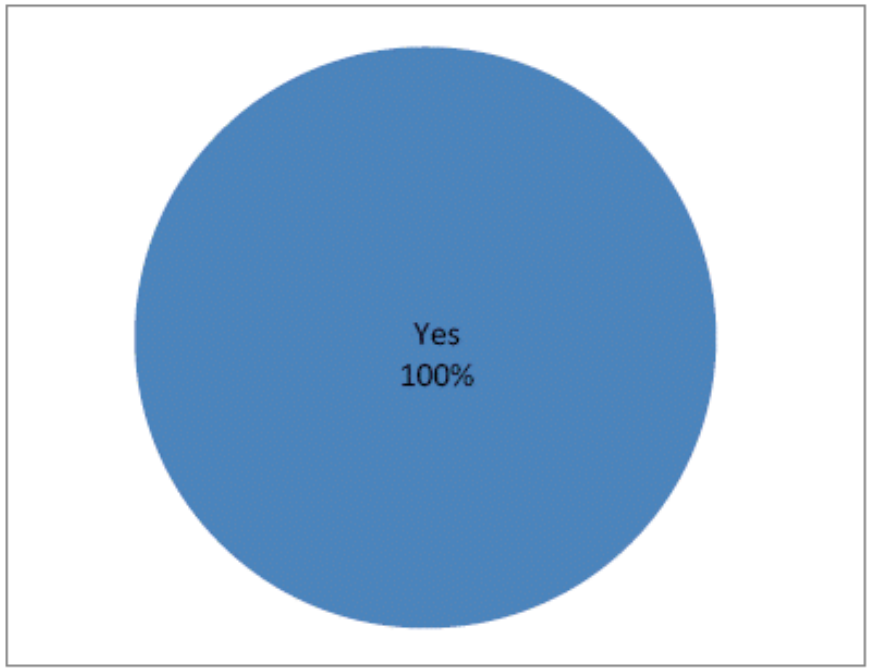
*10 Total Responses to the Question

Industry Responses to Questions

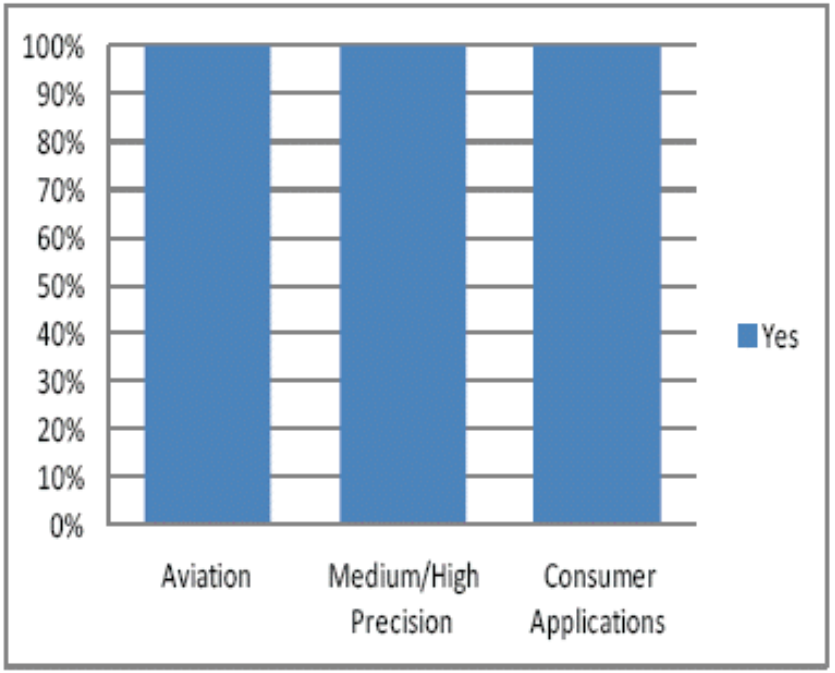
Question #16:

Would you recommend GNSS or SBAS services provide interoperability parameters?

Overall Response*



Response Breakdown by Sector



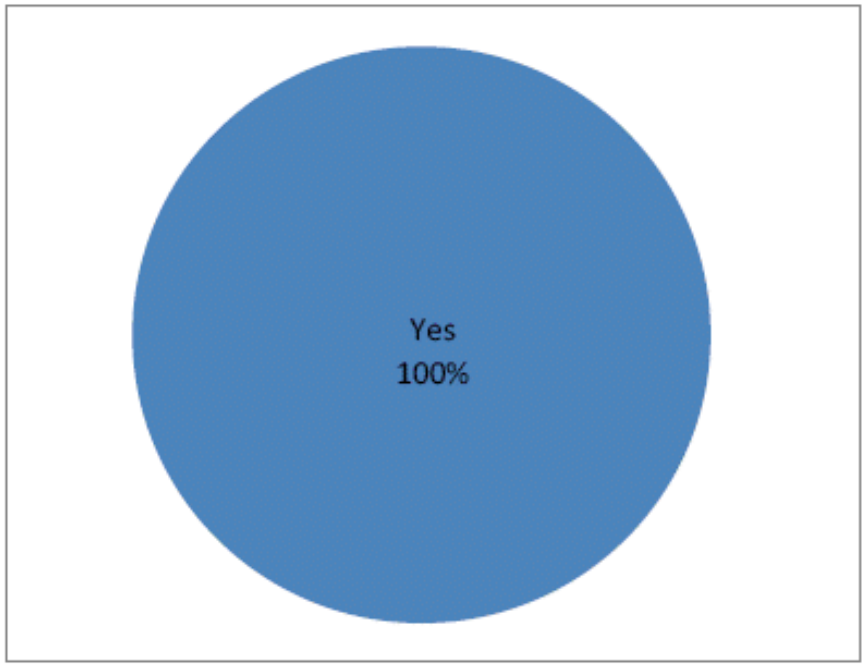
*9 Total Responses to the Question

Industry Responses to Questions

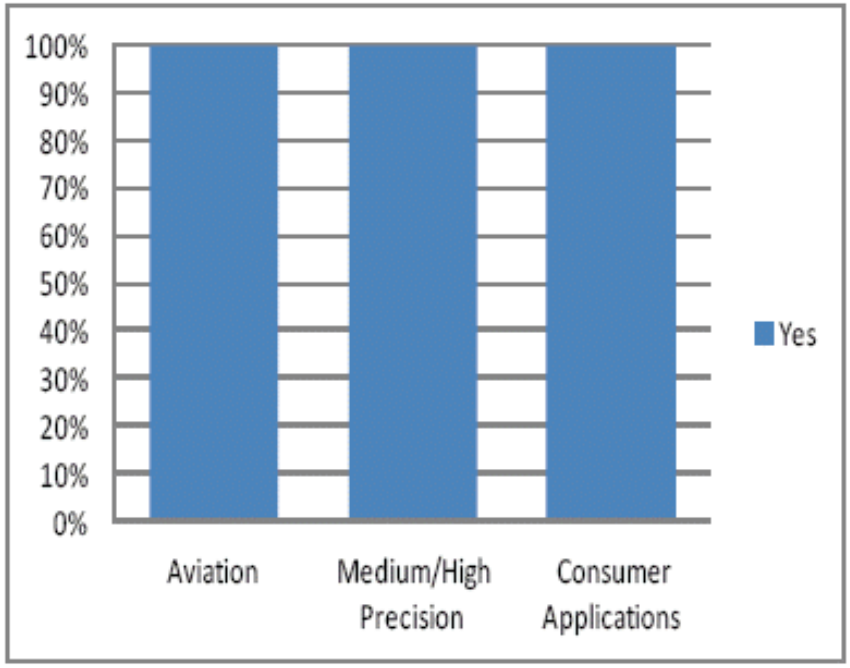
Question #17:

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

Overall Response*



Response Breakdown by Sector



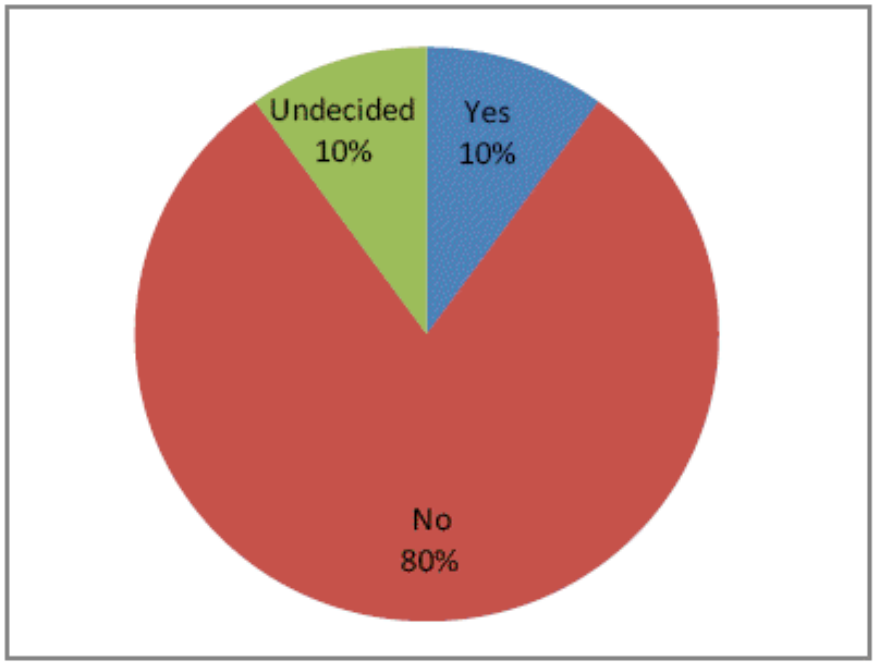
*11 Total Responses to the Question

Industry Responses to Questions

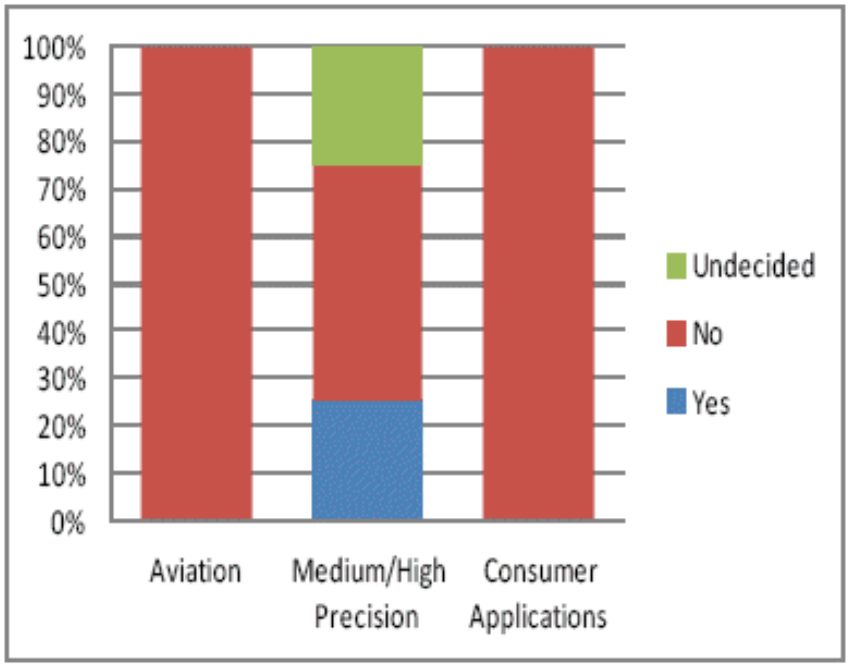
Question #18:

Do the current differences (~10 cm) in Geodesy pose a problem for your users?

Overall Response*



Response Breakdown by Sector



*10 Total Responses to the Question

U.S. Conclusions and Recommendations

- Information is based on a limited number of participants
  - Statistical variations should be considered when interpreting these results
- Results are based on the opinion of experts who represent industry interests
- Each Provider should consider holding their own workshop with results incorporated together
- Each GNSS Provider should carefully evaluate these results and determine what it means to their system