Trimble

transforming the way the world works

Trimble Use Case Information

A Presentation to DOT
Adjacent Band Compatibility
Workshop #2

December 4, 2014

Transforming the Way the World Works


Agriculture


Heavy Civil Construction


GNSS Real-Time Networks


Geospatial


Transportation & Logistics


Rail


Environmental & Waste


Water Utilities


Electric Utilities


Mining


Forestry


Field Service


Oil & Gas

Telecom, OEM & Consumer


Government

- Trimble Serves Multiple Industries and Users
- GPS/GNSS Performance is critical

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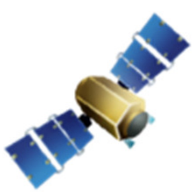
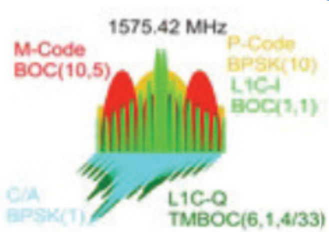
Clock-in-Space Multiplies into Huge Productivity Gains

GPS Satellites
- **USG Investment**
  - Space Segment
  - Control Segment
  - Ground Segment
  - AF Operator
  - GPS ICD



Signal Performance
- GPS SPS Performance Standard

Signal Environment
- Stable protection of RNSS bands
- Noise floor protected to 1 dB



GPS-GNSS Receivers
- Specifications to User Needs
- Accuracy
- Availability
- Integrity
- Continuity

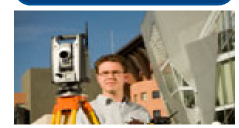
User Applications & Increased Productivity
- Simplified Procedure
- Repeatability
- Eliminate rework
- Work & yield management
- Fleet optimization
- Driver safety
- Environmental
- Time/Cost analyses
- Road/rail alignment
- Design coherency

= Return on USG Investment

Heavy Civil Construction

Agriculture

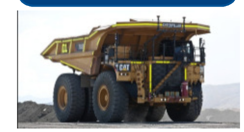
Survey Cadastre



Transportation Logistics

Mining

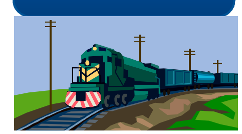
Autonomous Machinery



Marine

Telecom, OEM & Consumer

Rail



Environmental & Waste

Approach

DOT PRESENTATION:	TRIMBLE:
"Volpe will solicit inputs from the FCC, NTIA, GPS Manufacturers, wireless providers, and other stakeholders to inform and improve the Adjacent Band Compatibility assessment process with the primary 2 objectives: • "Open as much adjacent band spectrum as possible for broadband wireless applications" • "Without affecting existing and evolving uses of space-based PNT services""	We can provide: • Use cases
Volpe's primary role as we understand it: • "Conduct analysis, using receiver and antenna data provided by the GPS industry (primarily by GNSS receiver designers) to derive transmit power limits for a given wireless application" • "Conduct limited independent testing (with coordination with the manufacturers) to validate (spot check) receiver test data provided" • "Conduct limited simulations using specs data when provided (and assumed otherwise) in order to assess potential variability of the mask from unit to unit within the same model as well as inferring masks for other broadband signals from the provided masks. " • "Independent rather than coordinated company inputs are desired"	• Receiver & Antenna are a single System • We can provide: A test plan for a receiver-antenna system
"Volpe will issue a final report documenting the objectives, approach, results, and recommendations"	Support as requested

Trimble Receiver Categories

Category	Applicability
General Aviation	**N/A**
Cellular	**N/A**
General location/navigation	**3 Types** • Automotive • Fleet Management • Marine
High precision	**6 Types** • Construction • Agriculture • Surveying • Mining • Autonomous Vehicle • Rail
Timing	**1 Type**
Networks	**1 Type**
Space-based	**N/A**

Set 1 Receiver-Antenna System GNSS L1

Trimble Use Case Overview
(representative – not exhaustive)

- **HEAVY CIVIL CONSTRUCTION**
- **AGRICULTURE**
- **TRANSPORTATION & LOGISTICS**
- **SURVEYING**

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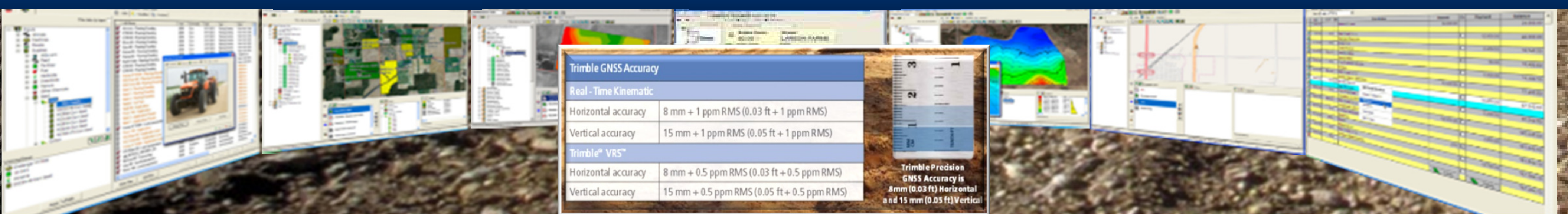
Trimble Use Case Overview

HEAVY CIVIL CONSTRUCTION – PLANNING, DESIGNING, BUILDING AND OPERATING

Enhanced information, decision making and control across the entire project lifecycle, generating benefits including:

- **Faster Completion**
- **Reduced Fuel, Re-work, Labor**
- **Enhanced Worker Safety**
- **Reduced Environmental Impact**

Feasibility and Planning	Survey	Design	Estimation	Earthworks	Construction	Maintenance and Operation



Trimble GNSS Accuracy	
Real - Time Kinematic	
Horizontal accuracy	8 mm + 1 ppm RMS (0.03 ft + 1 ppm RMS)
Vertical accuracy	15 mm + 1 ppm RMS (0.05 ft + 1 ppm RMS)
Trimble® VRS™	
Horizontal accuracy	8 mm + 0.5 ppm RMS (0.03 ft + 0.5 ppm RMS)
Vertical accuracy	15 mm + 0.5 ppm RMS (0.05 ft + 0.5 ppm RMS)

Use Case Overview:
GPS/GNSS Machine Control Systems for Construction

Survey & Design phase – High precision GPS used for site measurement, layout and dimensional control functions. Data is used to create computer model of a job grading plan.

Earthworks phase - Rugged, high-precision GPS receivers mounted on construction machines of various types. GPS system is required to determine the precise position of the machine's blade continuously (24/7) to within one inch or less using on-board computer to continuously compare the blade's precise position to the design plan.

Operator – Role simplified to monitor and safety check.   Operator watches a display in the machine's cab, guides the machine to meet design plan. Machine control system handles the steering and blade positioning automatically through hydraulic interfaces.

Case Studies:
GPS/GNSS Machine Control Systems for Construction

Reduced work and elimination of traditional staking procedure:

A contractor reports ***reduction of rework by 70 %*** using a precision GPS system as well as a 400% increase in productivity measured over a four acre section of parking lot construction ***graded in 1 and ½ days***, which they estimated would have taken ***six days by conventional methods*** driving hubs every 25 feet.

Over $1 million concrete saved on construction project:

A construction project building a 2 million-square-foot footprint of a logistics warehouse for a large national discount retailer reported that finished pad constructed using high precision GPS was ***consistently within a half inch of the plan*** throughout the whole expanse, fully ***one-third of the mandated tolerances***. Accuracy has been increased as operators no longer have to interpolate between grade stakes. The right tolerances of the graded pad made for much smoother placement of concrete - ***a quarter-inch off on two million square feet, is approximately $1 million dollars of concrete***

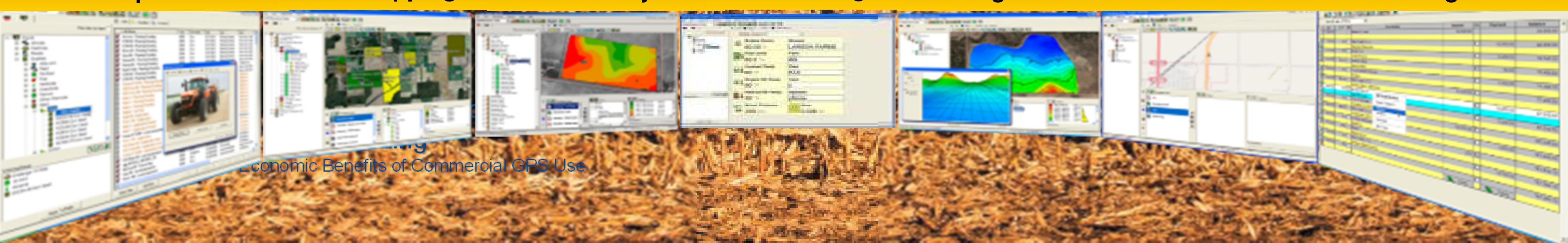
Trimble Use Case Overview

AGRICULTURE – PLANNING, GROWING AND HARVESTING

Enabling more informed decision making, leading to:

- Higher machine utilization
- Lower seed, fuel and chemical costs
- Improved yield and profitability
- Reduced environmental impact

Machine and Worker Optimization	Planning and Mapping	Prescription and Yield Analysis	Asset Monitoring	Topographic Management	Productivity Recommendation	Financial Management



Use Case Overview:
GPS/GNSS Tractor Auto-Pilot, Prescription Spraying, & Implement Control

Precision Agriculture uses high accuracy real-time GPS on-board agricultural machinery to manage distribution of fertilizer and pesticides, and planting and harvesting of crops. Precision agriculture requires 24/7 availability of continuous real time position with accuracies from 1 cm to 10 cm. Repeatability is required across a range of farm machinery throughout the growing cycle, from tilling through harvesting.

Many precision agriculture receivers require a real-time differential data stream, often delivered by integrated L-Band MSS receiver equipment.

Planting – Rows can be planted closer together and with greater precision to increase crop yields and reduce waste due to overlaps or gaps. Example of skip row – Machine guidance enables immediate 12.5% reduction in row overlap.

Cultivation – (Weed and insect control) – Decreased use of potentially toxic pesticides and herbicides by as much as 80 percent.

Harvesting – Precise position data related to crop yields is applied to seeding and fertilization plans for the following season's crops.

Operator – Reduced fatigue, every operator is best operator, enabled night operations

Case Studies:
GPS/GNSS Tractor Auto-Pilot, Prescription Spraying

Increased Yield: A grower in the southern U.S. operates a harvesting machine under foliage so dense that visibility of the rows on the ground is impeded. Using precision GPS guidance on the harvester, this grower can plant crops in ***rows 30 inches apart compared to 37 inches without precision GPS***. The resulting crops ***crop yield has increased by 200 to 400 pounds per acre***.

Increased Yield: A grower in the Southern U.S. uses a high-precision GPS system that produces ***2-4 inch positioning accuracy*** to obtain ***average increase in yield of 200 pounds per acre across 400 acres*** of peanuts.

Repeatability: A grower in the central U.S. deploys high precision GPS machine control to knife anhydrous in the fall with pass-to-pass accuracy of one inch or better—often ***¼ inch to ½ inch which are then required to be repeatable throughout the growing cycle***. Following with the next farm implement, the Nitrogen applicator, relying on repeatable accuracy, the knives drop precisely right back into the same grooves. In the spring, this grower uses high precision GPS machine control on a farm implement to plant. Then this high precision GPS autopilot is transferred to the sprayer for precision application of appropriate amounts of fertilizer.

Case Studies:
GPS/GNSS Tractor Implement Steering

Implement Steering: A Nebraska farmer farms 5,000 acres of corn and soybeans. ***He began using High Precision GNSS for tractor steering eight years ago*** and has found it to be especially beneficial since incorporating strip till farming. Since the farmer strip tills, accuracy is imperative because his fertilizer and seed must be placed in the same band. In the fall, he lays the rows and drops the fertilizer band with his strip till unit. Then in the spring he runs over the exact same fertilizer band to plant. ***"And if it's not within an inch and a half of the band, then you've defeated the whole purpose."***

He added implement steering. "Now the planter and strip till unit stay right on the line, plus I'm less fatigued at the end of the day. I'm able to watch the equipment perform with ease and worry less about driving." He believes ***he has saved between $5 and $15 an acre in fertilizer costs, which represent a six to eight percent fertilizer cost savings***. He also believes the system has resulted in five to ***15 bushel-per-acre increase in yield***. "Because the system has allowed me to put fertilizer right in the band rather than broadcasting it, the fertilizer is more directly available to the plant, and I'm getting more yield out of less fertilizer. That's been one of the biggest savings." He uses the more expensive pell lime to balance the acid in his soil because the system has made the pell lime affordable, since it allowed him to use it in a band rather than broadcast it.

Trimble Use Case Overview

TRANSPORTATION & LOGISTICS

30% Improvement

- Productivity
- Asset Utilization
- Compliance

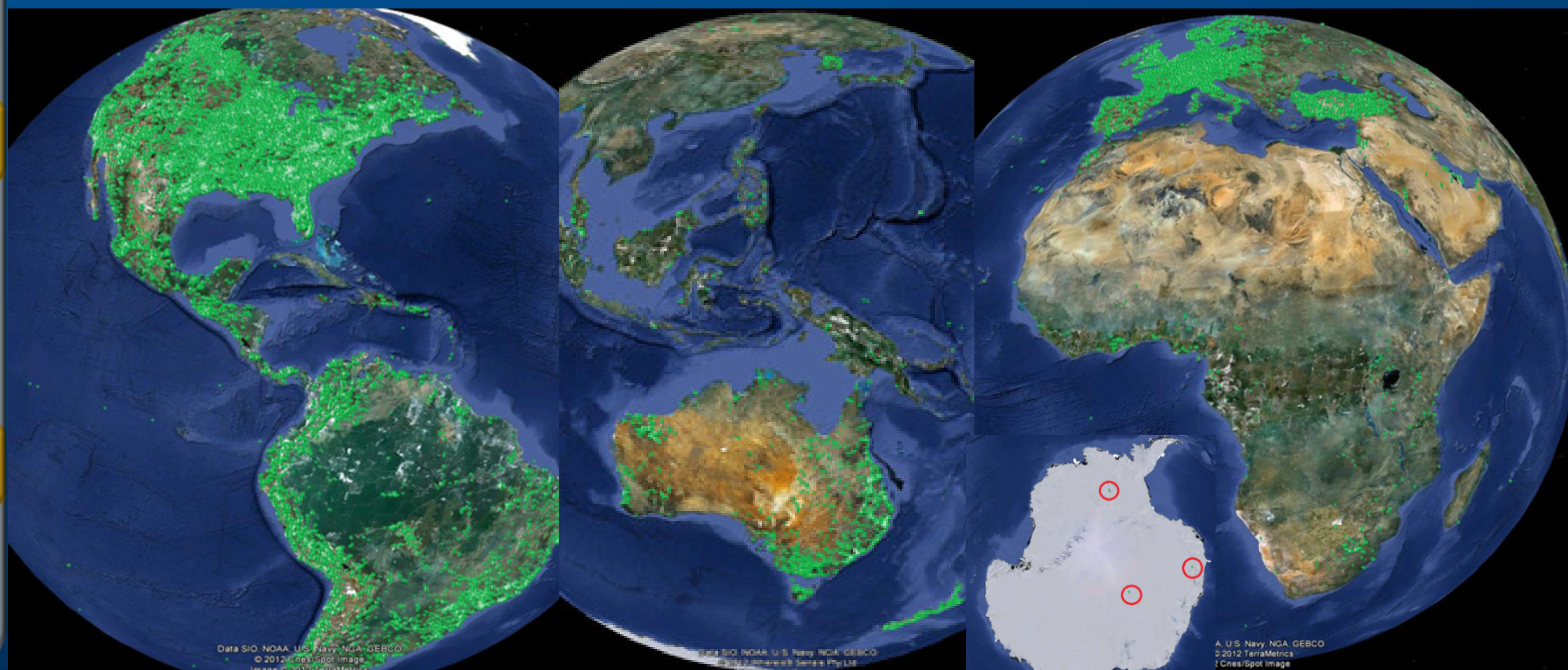
30% Reduction

- Fuel Use
- CO^2 Emissions
- Claims Costs

Empowerment

- Of Field Workers and Customers

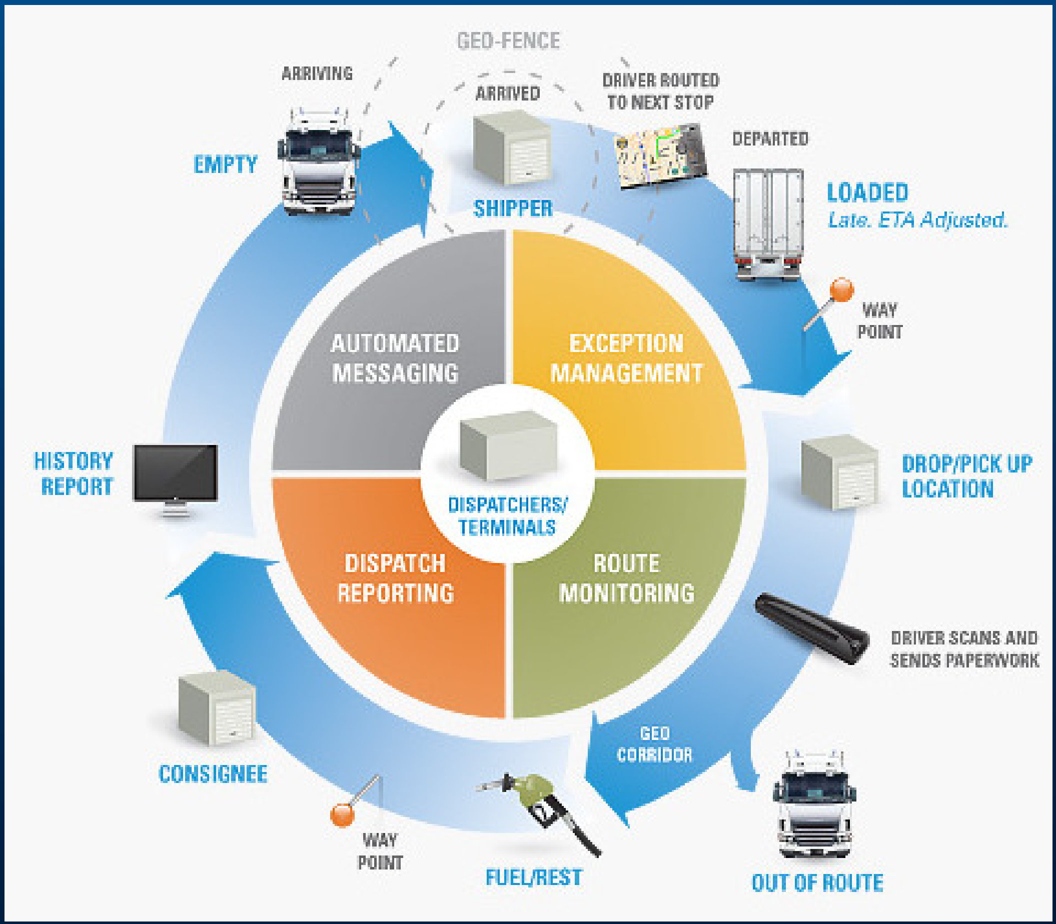
Trimble solutions for long haul trucking, field service management and construction logistics track and manage over 1,000,000 assets globally, operating on every continent.



Long Haul Trucking | Driver Safety | Schedule & Dispatch | Field Service | Diagnostics | Data Analysis | Reporting & Analytics

Use Case Overview:
GPS/GNSS Fleet Management

GNSS-based Fleet Management enables automation across the supply chain, from pick up to delivery. Automated carrier workflow solutions replace current, outdated processes for communicating key in-transit, arrival and departure events. Whether you need to know that a load's on time or only when a driver's going to be late, ***GNSS-based Fleet Management's automated messaging and exception management improves efficiencies, customer service, safety and revenue***.



Case Study:
GPS/GNSS Fleet Management

A for-hire transport company based in Alabama, specializing in flat-bed carriers has ***grown from 20 to 260 trucks since its start in 2004***. All company trucks have GNSS fleet management onboard. When fuel costs spiked to over $4.00 per gallon during the summer of 2008, the company implemented an MPG Guarantee Program that assessed all the various factors impacting fuel efficiency and ***saved the company $105,000 in hard-cost savings in just 45 days-with an average MPG increase of nearly 9%***.

In general, GNSS-based MPG Guarantee Programs have been shown to save individual long-haul fleets anywhere from ***$2,000 to 10,000 per truck***—***improving fuel economy by as much as 15 percent during the first full year*** of a focused fuel management program. In some cases, it has even doubled a firm's profitability.

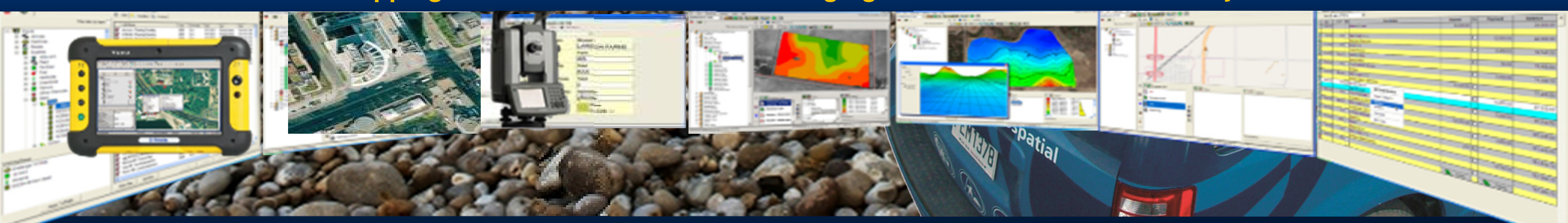
Trimble Use Case Overview

SURVEYING AND GEOSPATIAL

A suite of advanced solutions across the entire data collection, processing, modeling and analysis workflow, leading to:

- Faster Project Completion
- Reduced Re-work, Labor
- Enhanced Quality
- Enhanced Service Capabilities
- Enhanced Worker Safety

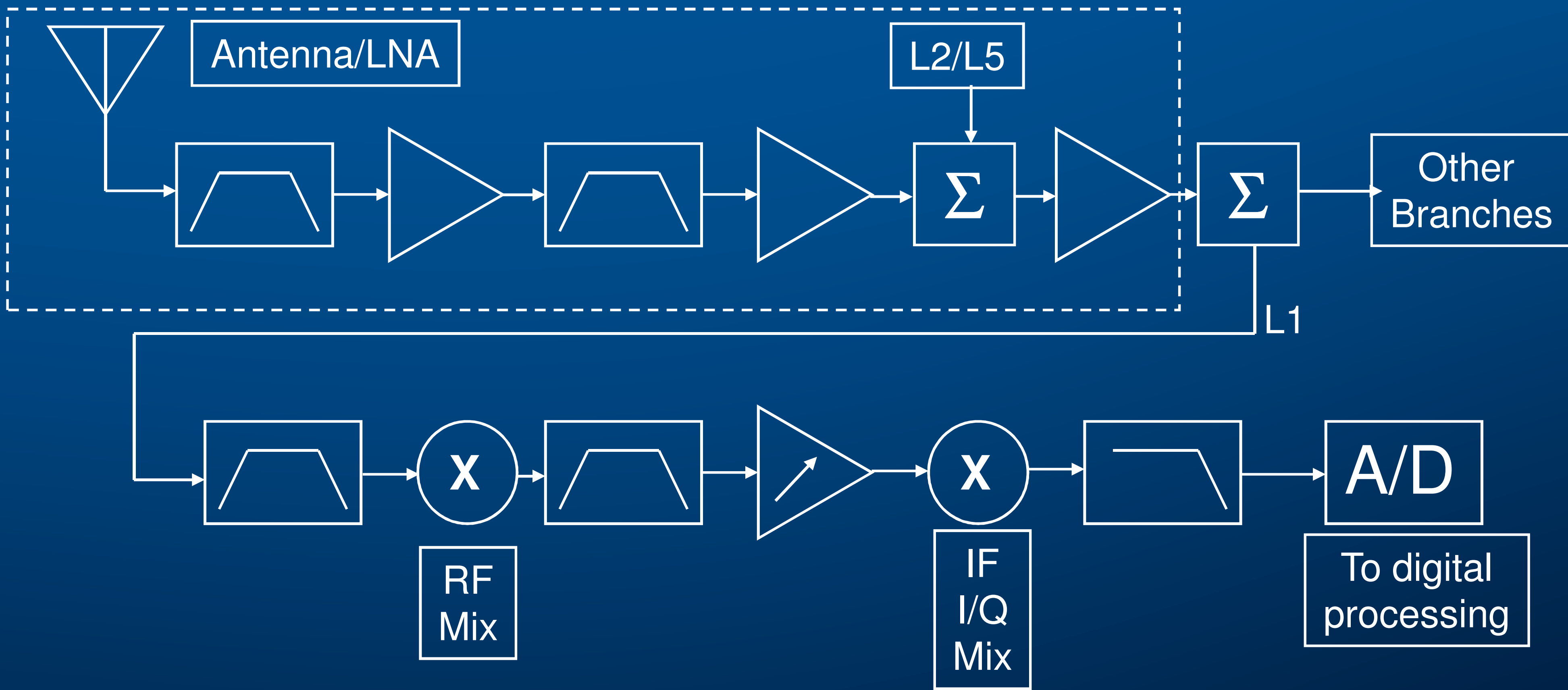
Cadastral & Land Administration	GIS and Mapping	Surveying	3D Modeling & Imaging	Topographic	Data Analysis	Reporting



The difference between Radio Communication and Radio Navigation is a fundamental issue

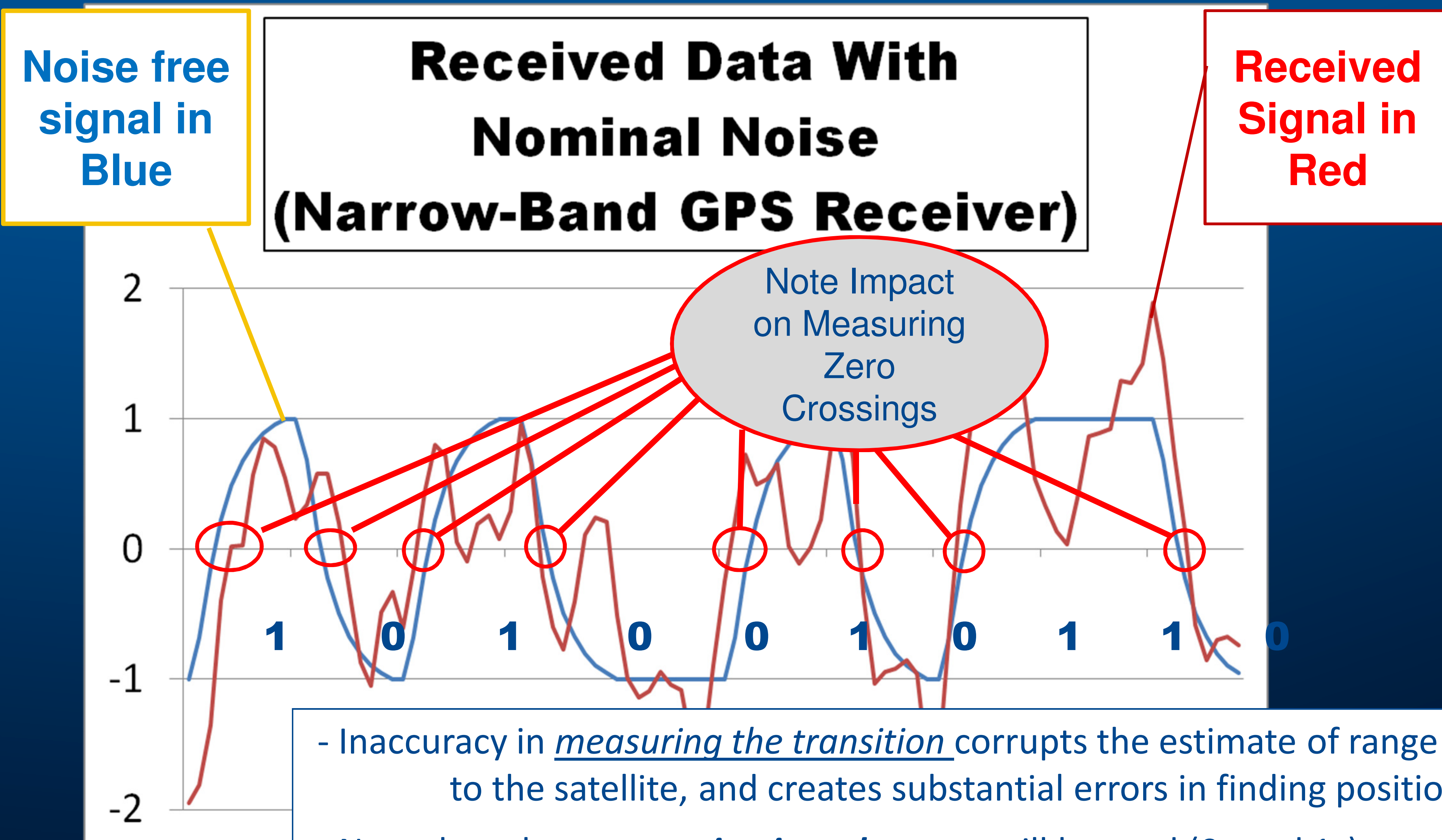
- Digital Radio Communications:
  - Incoming message is not known – finding it is the whole point
  - Must determine whether each signal “bit” is a one or a zero
  - Use sophisticated methods to correct errors
- Digital Radio Navigation:
  - Incoming signal sequence (ones and zeros) is known by user
  - The goal of the user is to precisely time the transition from one to zero (and zero to one)

Precision Receiver Design
Simplified L1 RF Chain shown



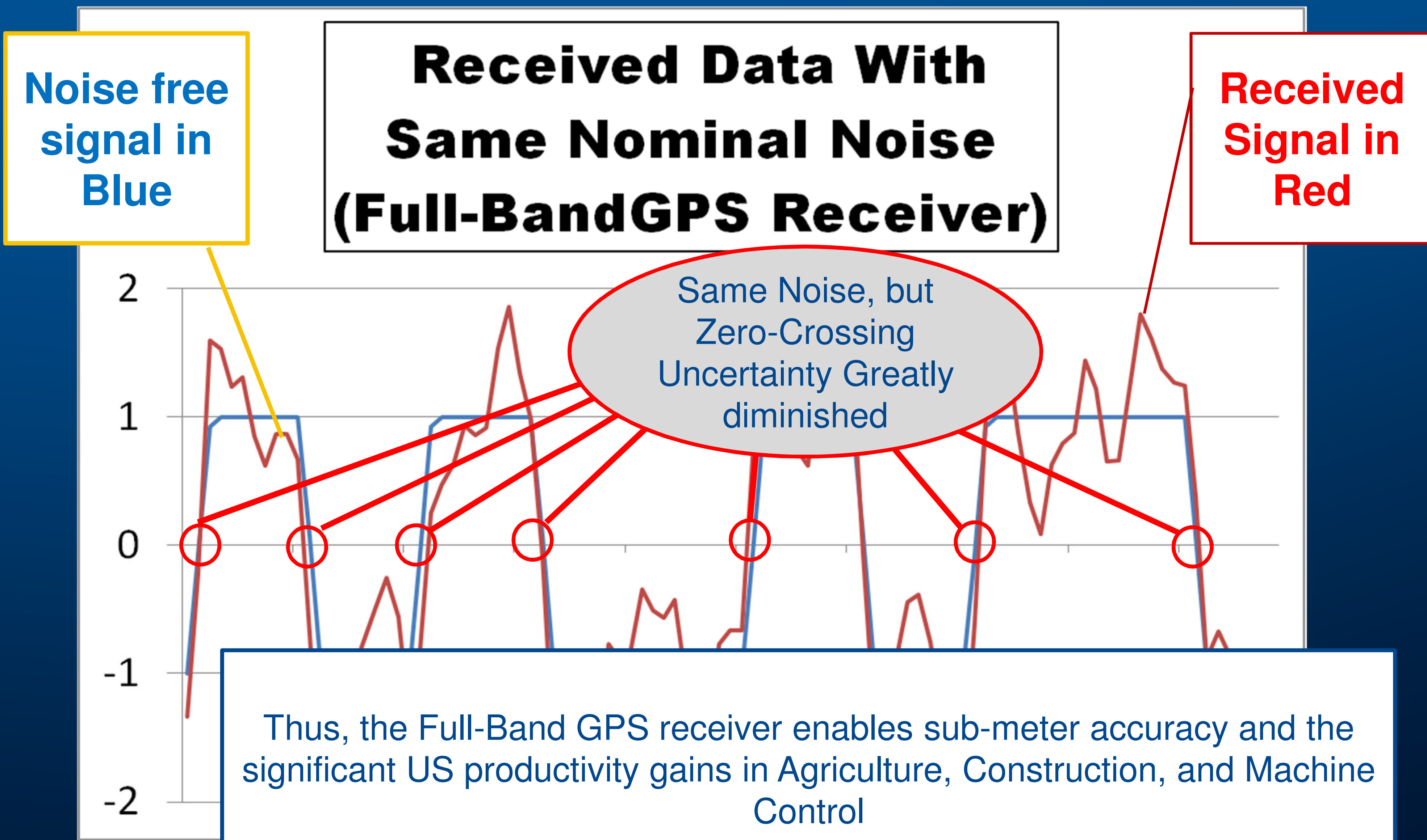
- Multiple filters use most advanced commercially available technology to achieve necessary performance
- Trimble maintains close contact with filter vendors to adopt applicable new technologies

Unfortunately, natural radio noise causes much uncertainty in zero crossings for Narrow Band Receivers



- Inaccuracy in <u>*measuring the transition*</u> corrupts the estimate of range to the satellite, and creates substantial errors in finding position
- Note that the <u>***communications data***</u> can still be read (0s and 1s)

To achieve maximum accuracy, a Full Band GPS receiver has sharper transitions, reducing the effect of noise and allowing a more precise timing measurement



Thus, the Full-Band GPS receiver enables sub-meter accuracy and the significant US productivity gains in Agriculture, Construction, and Machine Control

Why does Hi-Performance GPS need *Full-Band Receivers?*

- **Using Full-Band, the timing uncertainty used for the basic GPS ranging measurement is greatly improved**

- **This is essential for the sub-meter accuracy that is the basis for many of the Productivity-enhancing applications credited with 10s of Billions of Dollars in annual savings**

Full-Band GPS is similar to a fine telescope.
Without Full-Band, the signal is not well focused

Responses to DOT Questions

DOT Questions to GNSS Manufacturers:	TRIMBLE:
❑ What incident power levels as a function of frequency will cause your fielded products to lose 1 dB of GNSS C/N_0 ▪ For interference waveforms of CW and LTE-like 1, 5, 10, 15, or 20 MHz bandwidths (or a subset of these bands if available) ▪ Will the 1 dB criterion protect code measurement precision	• 1 dB criterion protects the code measurement
❑ What GNSS adjacent band antenna gain pattern and polarization should be assumed? Can you provide them in association with each receiver type?	• GPS/GNSS Receiver/Antenna is a single system • Set 1 receivers include all GNSS L1
❑ What propagation loss models should be used	• Free Space Propagation Model (FSPM) & Maximum Irregular Terrain Model (Max ITM) • Used in NPEF testing
❑ How would you limit multi-signal frequency spacing to prevent harmful intermodulation products within the receiver	• Depends on the adjacent band application • Need to account for aggregate signals
❑ How would you recommend protection from multiple signal sources from one or more wireless services	• Aggregate noise must be considered
❑ Define use cases for your products	Overviews provided earlier in the presentation, details to be supplied

DOT Additional Technical Considerations

Additional Technical Considerations Raised by DOT	TRIMBLE Comments
❑ The practical need for sufficient receiver bandwidth to obtain centimeter-level code-phase (pseudorange) measurements ❑ The issue is the rise and fall time of the spreading code transitions	• Machine control applications require real-time, low-latency measurements (Ag, Construction, Mining, Autonomous, UAV, etc) • Full bandwidth of signal is utilized to increase code accuracy • Higher code accuracy translates into improved availability of High Precision, carrier-based solutions (RTK), due to faster ambiguity resolution
❑ High precision access to L1/E1, L2, L5/E5, and E6 signals as well as GLONASS signals	• Products use all available signals to maximize application availability & productivity
❑ Protection of Galileo PRS signals, which fall below 1559 MHz	See Access to MSS (below)
❑ Access to MSS signals for StarFire, OmniSTAR, TerraStar, etc. GNSS differential correction services	• OmniSTAR high precision services • Trimble RTX Highest Precision via satellite
❑ Potential OOBE interference from nearby handsets	• Handset transmissions have potential to impact General Navigation GPS receivers [source NPEF] • Characterization would require actual handsets and aggregate radio frequency interference (RFI) modeling of multiple handset users in a given region • Need to know characteristics of paired Base Station to understand full effect

END