Ubiquitous Location:
challenges and opportunities of enabling all-day, everywhere location for all mobile platforms

Stanford PNT
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Greg Turetzky
Agenda

• Intel is in mobile?
• GNSS market trends for consumers
• Impact of indoor location
  • GNSS system architecture
• Silicon trend impacts
Intel’s Mission

Utilize the power of Moore’s Law to bring smart, connected devices to every person on earth.
Intel’s Vision
If it is smart and connected, it is best with Intel.
Growing Variety of Intel-based LTE Devices

*Other names and brands may be claimed as the property of others
Internet of Things Group

Lead the industry in transforming businesses and the way we live by making it simple to create exciting, new IoT solutions

The Internet of Things: Devices that connect to the Internet, integrating greater compute capabilities using data analytics to extract information
GNSS Mass-Market
GNSS market continues to grow at a rapid pace

Installed base of GNSS devices by region

Source: GSA GNSS Market Report
GNSS – Multi Constellation Trends

Source: GSA GNSS Market Report
GNSS Market Segment - By Revenue

Cumulative core revenue 2012-2022

- LBS: 47.0%
- Agriculture: 1.4%
- Aviation: 1.0%
- Maritime: 0.3%
- Rail: 0.1%
- Surveying: 4.1%
- Road: 46.2%

Source: GSA GNSS Market Report
Alternative Location Technology Shipments
World Market, Forecast: 2010 to 2018

Source: ABI Location Technologies Market Data
Indoor Location Technology Installations, Split by Vertical Market

World Market, Forecast: 2010 to 2018

Highly fragmented supplier base

Source: ABI Location Technologies Market Data
LBS Value Chain

Highly complex ecosystem with each segment looking to differentiate and monetize indoor location

- Venue Owners
- Application Developers
- Service and Content Providers
- Device Vendors
- Operating System providers
- Chipset Manufacturers
Opportunity summary

• The market opportunity for location is clearly huge and still growing
  • It has expanded from GPS to GNSS and now to Location
  • Indoor location is the next big opportunity
    • Not as a standalone opportunity, but rather because it enables “always located” capability
• Always located is a requirement for devices that are always with us and always need context
• Phones, tablets, wearables and internet of things are good examples of known needs
Major shifts in underlying platforms

<table>
<thead>
<tr>
<th>Time</th>
<th>Main Volume Platform</th>
<th>Key Use Case</th>
<th>Featured Specification</th>
<th>Secondary Specification</th>
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</thead>
<tbody>
<tr>
<td>Early 2000s</td>
<td>PND</td>
<td>Urban Canyon</td>
<td>Sensitivity</td>
<td>TTFF</td>
</tr>
<tr>
<td>Mid 2000s</td>
<td>Feature Phone</td>
<td>E911</td>
<td>TTFF</td>
<td>Sensitivity</td>
</tr>
<tr>
<td>2010 - today</td>
<td>Smart Phone</td>
<td>LBS</td>
<td>Active Power</td>
<td>Availability (MultiGNSS)</td>
</tr>
<tr>
<td>Coming Soon</td>
<td>Wearables/IOT</td>
<td>Continuous Location</td>
<td>Energy/Day</td>
<td>Availability (Hybrid)</td>
</tr>
</tbody>
</table>
Requirements Summary

• Always located creates new requirements for devices
  • Availability at 100%
    • Multi-technology fusion since no single technology can achieve this in a reasonable infrastructure cost
  • Power consumption that allows a minimum of 16 hours of usage (full day) between charges
    • Standby power is MORE important than active power
• Accuracy that can vary to support multiple applications
• Size constraints driven by wearables
GNSS Architecture Impact
Projected Number of Satellites
Relationship between the Coherent Period & Number of correlators required to search for 1 satellite in each constellation

±1ppm local oscillator frequency uncertainty

±10 kHz Doppler shift range

50% Doppler bin overlap

1/4-chip correlator spacing
## Test Scenarios – Cold Start Test

-130dBm Cold Start Test with an initial Frequency uncertainty of ±1ppm

<table>
<thead>
<tr>
<th></th>
<th>GPS</th>
<th>GLONASS</th>
<th>Beidou</th>
<th>Galileo</th>
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</thead>
<tbody>
<tr>
<td>Correlator spacing</td>
<td>½ chip</td>
<td>½ chip</td>
<td>½ chip</td>
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<tr>
<td>Number of chips in PRN code</td>
<td>1023</td>
<td>511</td>
<td>2046</td>
<td>4092</td>
</tr>
<tr>
<td>Number of correlator required to search 1 PRN</td>
<td>4092</td>
<td>2044</td>
<td>8184</td>
<td>16368</td>
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<tr>
<td>Code Length</td>
<td>1ms</td>
<td>1ms</td>
<td>1ms</td>
<td>4ms</td>
</tr>
<tr>
<td>Number of Doppler Windows (50% overlap)</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>Number of Satellites in Constellation</td>
<td>32</td>
<td>24</td>
<td>37</td>
<td>30</td>
</tr>
<tr>
<td>Number of correlators required</td>
<td>916,608</td>
<td>171,696</td>
<td>2,119,656</td>
<td>12,767,040</td>
</tr>
</tbody>
</table>

75x Difference!
Test Scenarios – Hot Start Test

-140dBm Hot Start Test with an initial Frequency uncertainty of ±0.2ppm & a 160ms search time

<table>
<thead>
<tr>
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<th>GLONASS</th>
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<th>Galileo</th>
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<tr>
<td>Correlator spacing</td>
<td>⅛ chip</td>
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<td>Number of chips in PRN code</td>
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<td>4092</td>
<td>2044</td>
<td>8184</td>
<td>16368</td>
</tr>
<tr>
<td>Coherent Period</td>
<td>8ms</td>
<td>8ms</td>
<td>1ms</td>
<td>4ms</td>
</tr>
<tr>
<td>Number of Incoherent dwells</td>
<td>20</td>
<td>20</td>
<td>160</td>
<td>40</td>
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<tr>
<td>Number of Doppler Windows (50% overlap)</td>
<td>10</td>
<td>10</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Number of Visible Satellites</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Number of correlators required</td>
<td>409,200</td>
<td>204,400</td>
<td>163,680</td>
<td>982,080</td>
</tr>
</tbody>
</table>
## Typical GPS Spec Sheet

### General Receiver Characteristics

<table>
<thead>
<tr>
<th>Channels</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>L1 band</td>
</tr>
<tr>
<td>Codes</td>
<td>GPS C/A, Galileo BOC, Glonass FDMA1</td>
</tr>
</tbody>
</table>

### Time-To-First-Fix

<table>
<thead>
<tr>
<th>Condition</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold Start (unaided)</td>
<td>27s</td>
</tr>
<tr>
<td>Warm Start (unaided)</td>
<td>27s</td>
</tr>
<tr>
<td>Hot Start (unaided)</td>
<td>1s</td>
</tr>
<tr>
<td>Aided Starts</td>
<td>1s</td>
</tr>
</tbody>
</table>

### Signal Sensitivity

<table>
<thead>
<tr>
<th>Type</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tracking &amp; Navigation</td>
<td>-162 dBm</td>
</tr>
<tr>
<td>Reacquisition</td>
<td>-160 dBm</td>
</tr>
<tr>
<td>Cold Start</td>
<td>-147 dBm</td>
</tr>
</tbody>
</table>

### Navigation

<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max update rate</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Horizontal accuracy</td>
<td>5m</td>
</tr>
<tr>
<td>Time sync</td>
<td>30ns</td>
</tr>
<tr>
<td>Velocity accuracy</td>
<td>0.1 m/s</td>
</tr>
<tr>
<td>Heading accuracy</td>
<td>0.5 degrees</td>
</tr>
<tr>
<td>Maximum Dynamics</td>
<td>4g</td>
</tr>
</tbody>
</table>

### Power Consumption

<table>
<thead>
<tr>
<th>Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply</td>
<td>3V</td>
</tr>
<tr>
<td>Continuous</td>
<td>18.5mA</td>
</tr>
<tr>
<td>1Hz Power Save</td>
<td>4mA</td>
</tr>
</tbody>
</table>
Silicon Design Impact
Impacts of new requirements on silicon design

• Standby power reduction impacts
  • SRAM is the leakiest component of typical design
    • Needs to be reduced or ideally eliminated
  • Non-continuous fix methods
    • Ability to quickly save and restore state information

• Hybrid location solutions
  • Support measurements from multiple radios
    • Need to share radios, not duplicate chains
  • Increased integration of multiple radios on single die
    • Need more interference rejection capability
    • Ability to support concurrent radio operation on single die
Predictable Silicon Track Record

Executing to Moore’s Law

Enabling new devices with higher functionality and complexity while controlling power, cost, and size

Strained Silicon

Hi-K Metal Gate

3D Transistors

90 nm 65 nm 45 nm 32 nm 22 nm 14 nm 10 nm 7 nm
2 Year Technology Cycles

- 90 nm: 2003
- 65 nm: 2005
- 45 nm: 2007
- 32 nm: 2009
- 22 nm: 2011
Transistor Scaling improve performance

0.7x every 2 years

In GNSS, this means more gates and more memory for less cost. Improves TTFF and sensitivity by allowing more search capability.
Scaling also increases speed and reduces power

Higher clock speed provide better search and more complex navigation algorithms
Lower energy improves power consumption in full power tracking modes
But at the expense of increased leakage

This hurts standby power and the ability to save state for lower fix rates and fast restarts
Transistor Performance vs. Leakage

Wider range of transistors to support a wider range of products
Design Challenges for GNSS

• Take advantage of benefits of smaller geometries
  • Higher clock speeds, more memory, lower active power, smaller size
• While greatly reducing standby power from leakage
  • New methodologies at chip and system design level
• Integrate multiple radios on single die to reduce cost and size
  • Without creating interference to a very sensitive GNSS radio
• Integrate multiple radio sources into a single location solution
  • Bring together a disparate value chain
Intel’s plan

• Bring our advanced silicon process technology to location
  • Provide GNSS and Location silicon with best in class performance

• Bring our platform level integration capability to merge multiple location technologies
  • Intel CPU cores provide ideal platform to integrate hardware and software for GNSS, BT, WiFi and cellular

• Bring this capability to multiple products from tablets and phone to wearables

• Ubiquitous location capability will improve the experience of every mobile product
Questions?

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PEG-Wireless Connectivity Solutions

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