High-End Gyroscopes, Accelerometers and IMUs for Defense, Aerospace & Industrial
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- **Accelerometer Technologies**
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  - 2014 technology breakdown
  - MEMS accelerometer market shares

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INTRODUCTION

2014 inertial sensor industry

This report is an update of Yole’s best-selling “IMU Markets” report, which was first released in 2008. This latest edition is an updated version with minor changes since the last edition:

- The market is quantified for each gyroscope technology, and each company’s yearly shipments are estimated.
- Market metrics are provided for each grade of gyroscopes: each application is positioned according to performance level and corresponding market size.
- Applications are described in a synthetic way in order to provide rapid access to key information (functions, specification, technical solution, geography, trends, and market evolution) and graphical representation of the industrial chain.

This report combines the best of Yole’s knowledge in the high-performance inertial sensor industry. Yole regularly participates in industry conferences and tradeshows worldwide, and has close relations with most market leaders. This report’s data has been validated by industry experts and augmented by the expertise of Mike Perlmutter, a recognized expert in navigation. This report synthetizes the status of the 2014 inertial sensor industry in a thorough manner.
OBJECTIVES OF THE REPORT

The objectives of this report are the following:

To provide market data on high performance MEMS gyroscopes and gyroscope-based systems (gyro assemblies, IMUs…):
Key market metrics and dynamics
- Unit shipments and revenue by type of sensor
- Average selling price analysis and expected evolution
- Market share for each category of application, technology and performance grade

To provide application focus on key existing markets and most promising emerging ones
- Functions that are used, critical specification requirements, level of assembly and technology choices
- What are the major drivers? What will the market look like in 2019?

To provide an analysis on the major technology trends:
- Evolution expected for the current technologies: level of performance, price….
- Insight about new technologies: AO / Cold atom, NMR gyros….

To provide a deep understanding of inertial sensor value chain, infrastructure & players for the inertial business:
- Extensive list of sensor manufacturers worldwide and their technology offer
- List of key integrators worldwide
- Industrial chain information for each application: who supplies to whom
« High-performance » inertial sensors

- This refers to the applications: we take into account all the inertial sensors except the consumer / mobile and the automotive applications.

- We take into account industrial, aerospace, defense applications (even industrial applications are considered as “high-performance” applications, as opposed to consumer ones).

- In some cases: « consumer -grade » MEMS gyroscopes (for instance few °/s bias stability) are used in industrial applications – this is part of the report.

To simplify representation, performance has been divided in 4 parts:

- The only parameter which is considered is the bias stability.

  - In the 50°/h range: « industrial » grade (but it doesn’t mean that this is an industrial applications: for instance often missile and bomb guidance requires moderate bias stability and enter into this category) – ability to get data on angular rates / on motion.

  - In the 1°/h range: « tactical» grade – possibility to get angles.

  - In the 0.1°/h range: « short term navigation » grade – possibility for short term navigation (for GPS outage) and azimuth detection.

  - In the 0.01°/h range: « high-end navigation & strategic » grade – ability to navigate.

Day to day bias stability is considered for navigation grade, this is the most significant parameter in characterizing a navigation system.

In-run bias stability is used for industrial and tactical grade because:

- In the past 20 years, MEMS have appeared and expressed performance in terms of « in-run » parameters.

- Use of inertial sensors is now frequently used in conjunction with GPS, meaning that day-to-day bias repeatability in not significant anymore (for tactical / industrial grade).

Other parameters need to be considered as well: depending on the application parameters such as angular random walk or scale factor might be more important than just bias stability.
This report focuses on Gyro and IMU market for high end applications.

**SCOPE OF THE REPORT**

- **PRICE LEVEL**
  - Accelerometers
  - Gyroscopes
  - Clusters of accelerometers
  - Cluster of gyroscopes
  - Clusters of accelerometers & gyroscopes
  - IMU = 3 mutually orthogonal gyros and accelerometers

**Gyro market**
- Market for stand-alone gyros / assemblies of gyros and market for gyros integrated in IMUs and other systems (AHRS, INS...)

**IMU market**
- (stand-alone and IMUs integrated in systems such as AHRS, INS...)

**What does an IMU consist of?**
- Sensor electronics
- Computer
- X Acool
- Y Acool
- Vehicle
- Zupt, LLC

**AHRS**
- (Attitude and Heading Reference System \(\rightarrow\) IMU + magnetometer + software)

**ADAHRS**
- (Air Data Attitude & Heading Reference System \(\rightarrow\) fusion with air data)

**GADAHRS**
- (GPS aided ADARS \(\rightarrow\) fusion with GPS)

**INS**
- (Inertial Navigation System \(\rightarrow\) IMU + Kalman filter)

**INS / GPS**
- (\(\rightarrow\) fusion with GPS)
The MEMS devices for the consumer market are NOT considered in this report.
# PLAYERS’ MAPPING PER TECHNOLOGY

## Gyroscope Landscape

<table>
<thead>
<tr>
<th>Technology</th>
<th>Major Players</th>
</tr>
</thead>
<tbody>
<tr>
<td>FOG</td>
<td>Northrop Grumman, LITEF GmbH, Honeywell, cielocommunications, Doosan, Fizoptika, OPTOLINK, aselsan, Polyus R&amp;D Institute</td>
</tr>
<tr>
<td>RLG</td>
<td>Safran, Kearfott, IAI, InnaLabs, UTC Aerospace Systems, Raytheon, Anschütz, Sensorix, Gladiolator Technologies, MEGGITT, Sensorex</td>
</tr>
<tr>
<td>DTG &amp; Others Mechanical</td>
<td>safran, UTC Aerospace Systems, Raytheon, Anschütz, Sensorix, Gladiolator Technologies, MEGGITT, Sensorex</td>
</tr>
<tr>
<td>Si / Quartz MEMS</td>
<td>Honeywell, UTC Aerospace Systems, MEGGITT, Sensorex, Northrop Grumman, LITEF GmbH, AOSense, Inc.</td>
</tr>
<tr>
<td>HRG &amp; Emerging technology</td>
<td>Honeywell, UTC Aerospace Systems, MEGGITT, Sensorex, Northrop Grumman, LITEF GmbH, AOSense, Inc.</td>
</tr>
</tbody>
</table>

Many competitors especially in FOG or MEMS technologies

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These technologies are used in high-end gyroscopes, accelerometers, and IMUs for defense, aerospace, and industrial applications.
MEMS + mechanical technologies (from UTC/AIS Goodrich and Sagem) dominate industrial grade.

FOG and Honeywell RLG dominate tactical applications, RLG dominate for higher accuracy.

2014 High-Perf Gyro Market ($M) - Techno breakdown
- Total = $1366M - Bias stability

Yole Developpement © Jan. 2015
High-performance gyroscope market represented a $1.37B market in 2014.

Growing to $1.69B in 2019 with a CAGR 2012-2019 of 4.4%

The largest part of this market corresponds to gyroscopes integrated in IMU or other assemblies.

Note: Gyro in IMU includes the internal production of gyroscopes for IMU makers and the gyroscopes of the open market which are bought by IMU makers.
Industrial applications represent the largest volume...

...We note that part of it corresponds to 2-axis and 3-axis MEMS gyroscopes (counted as 2 or 3-axis but as one gyroscope unit if this is one single package)

Aerospace applications represent a limited volume but prices are high

There is a large variety of defense applications, from reasonable volumes to very small volumes
High end applications have been split among 3 sectors: Defense, Commercial Aerospace, Industrial & civil naval & offshore.

- **Agriculture**
- **AUVs**
- **Freight transport ship**
- **High speed train**
- **Inclinometers**
- **Oil drilling heads**
- **ROV**
- **Satcom antenna stab**
- **Stabilization of optical systems**
- **Survey instruments**
- **UGVs**
- **Vibration monitoring**
- **Business Jets**
- **Civil aircraft**
- **Civil helicopters**
- **Civil and paramilitary UAVs**
- **General aviation**
- **Satellites**
- **Spacecrafts & rockets**
- **Defence ships**
- **Defence transport aircraft**
- **Defence UAVs**
- **Guided munitions**
- **LAV/Artillery Guns**
- **MAV/Tanks**
- **Military & special mission helicopters**
- **Military fighters**
- **Military submarines**
- **Nuclear missiles**
- **Short, medium and long range missiles**
- **Soldier**

**IMU & HIGH PERFORMANCE INERTIAL MEMS**

**Application space**
## DEFENSE APPLICATION: MISSILE GUIDANCE

### Application description

<table>
<thead>
<tr>
<th>Function:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Guidance</td>
</tr>
<tr>
<td>• Alignment procedure for vertical launch missile (until GPS acquisition)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Scale factor very important (for spin stabilized)</td>
</tr>
<tr>
<td>• Bias stability moderate because rely on GPS for most of the flight duration → use time of IMU: a few minutes max</td>
</tr>
<tr>
<td>• Tactical-grade most often: &lt; 40°/h (surface to air, anti-armor, air to surface: 10°/h for short range missiles, 1°/h for aero missiles). &lt;40°/h for air to air. 0.1 to 1°/h for anti-ship. Down to 0.01°/h for missiles used in aircraft</td>
</tr>
<tr>
<td>• 100g shock survivability (up to 50 000g for gun launch)</td>
</tr>
<tr>
<td>• Excellent CSWAP</td>
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<table>
<thead>
<tr>
<th>Inertial solution</th>
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</thead>
<tbody>
<tr>
<td>• IMU coupled with GPS</td>
</tr>
<tr>
<td>• Coupling with additional sensing technologies infrared head detector, magnetometers, and scanners…</td>
</tr>
<tr>
<td>• RLG used to dominate – now MEMS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology trends</th>
</tr>
</thead>
<tbody>
<tr>
<td>• MEMS IMU starting to dominate: HG1930… is now massively implemented in missiles because significant cost savings</td>
</tr>
<tr>
<td>• FOG is used only in more accurate, lower volume applications where performance is critical.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Key gyro players</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Honeywell HG 1930 leader for tactical grade (transitioned from HG 1700)</td>
</tr>
<tr>
<td>• Sagem, NG, Thales, NG Litel, Kearfott, KVH, UTC, Systron Donner</td>
</tr>
</tbody>
</table>

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MEMS now dominate over RLG after year of influence. FOG is used for high accurate applications

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Lockheed Martin Hellfire P+ missile features Honeywell HG 1930 MEMS IMU
DEFENSE APPLICATION: MISSILE GUIDANCE

Market data

**Major gyro integrators**
- Gyro integrated in IMUs by: Honeywell, Sagem, NG, Thales, NG Litef, Kearfott, KVH, UTC, Systron Donner, IAI Tamam, Elop
- End-users: Raytheon, Lockheed Martin, MBDA, DIEHL BGT - Bodensee Geratetechnik, Thales, Saab, Rafael, Kongsberg, TATA Advanced Systems Limited / Nova, Boeing, BraMos Aerospace

**Geographical description**
- For gyros: North America 60% market / Europe 30% / Asia 10%
- For end-users: North America 55% market / Europe 25% / Asia 20%

**Market drivers**
- Emerging markets outside of Europe and US
- New integrators in Asia which target primarily their internal market; e.g. BrahMos Aerospace aims to fulfill the needs of the Indian armed forces and to supply Russia (modified its law which prohibited weapons manufactured outside of Russia from being deployed in the country)

Represented a market of XX Kunits and $XXM in 2014
EMERGING NEW APPLICATIONS

Microsatellites and commercial space flight

New applications require high performance at low-cost and small form factor, 1 candidate → MEMS

1. Geostationary satellite
2. Mid-orbital satellite
3. Micro/Nano-satellite

- Virgin
  - Commercial space flight
  - Market units: 500
- Google
  - Project Loon
  - Market units: 5k
- SpaceX
  - Micro/Nano-satellite
  - Market units: 4k
- Facebook
  - High-altitude drone
  - Market units: 10k

Market units:
- High altitude drone: 500
- Geostationary satellite: 10k
High-performance accelerometers and gyroscope suppliers
- Understand the system level technology trends and requirements for each application
- Evaluate market potential for your components depending on performance and technology
- Understand the differentiated value of your products and technologies
- Identify new business opportunities and partners
- Monitor and benchmark your competitor’s advancements

IMU module and AHRS / INS suppliers
- Evaluate the market potential of your product portfolio
- Define diversification strategies on new applications
- Find the best technologies to integrate and the best suppliers depending on your target markets
- Identify new business opportunities and partners
- Have an exhaustive analysis of the competition on a broad range of IMU field

Material supplier, manufacturing service companies
- Spot new business opportunities and prospects
- Understand the level of activity of your customers
- Understand what are the applications that will drive the volumes in 2017

Integrators of inertial solutions, government agencies
- Find the best technologies to integrate and the best suppliers depending on your target markets
- Understand what will be the future applications to develop and benefit from the recent advances in inertial technologies
- Define technology roadmap / evaluate the benefits of using new technologies in end systems, design architectures for the next generation of systems
- Screen potential new suppliers able to provide new functionalities, or cost and size savings

R&D centers
- Evaluate market potential of future technologies and products for new applicative markets
- Identify the best candidates for technology transfer

Financial & strategic investors
- Understand the structure and value chain of the high-end inertial industry
- Estimate the potential of new technologies (tactical/inertial navigation MEMS, navigation-grade HRG…)
- Get the list of main key players and emerging start-ups of this industry worldwide
Yole Développement

From Technologies to Market
FIELDS OF EXPERTISE

Yole Développement’s 30 analysts operate in the following areas:

- Imaging
- Photonics
- MEMS & Sensors
- Compound Semi.
- LED/OLED
- Power Electronics
- PV
- Advanced Packaging
- Manufacturing
- MedTech
4 BUSINESS MODELS

- **Consulting and Analysis**
  - Market data & research, marketing analysis
  - Technology analysis
  - Strategy consulting
  - Reverse engineering & costing
  - Patent analysis

- **Financial services**
  - M&A (buying and selling)
  - Due diligence
  - Fundraising
  - Maturation of companies
  - IP portfolio management & optimization

- **Reports**
  - Market & Technology reports
  - Patent Investigation and patent infringement risk analysis
  - Teardowns & Reverse Costing Analysis
  - Cost Simulation Tool

- **Media**
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Our analysts provide market analysis, technology evaluation, and business plan along the entire supply chain.

Integrators and end-users

Device makers

 Suppliers: material, equipment, OSAT, foundries...

Financial investors, R&D centers
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