



**An Update on KVH Fiber Optic Gyros and Their  
Benefits Relative to Other Gyro Technologies**

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# An Industry Update on FOGs and Other Gyro Technologies

Precision gyroscopes have become critical components within an expanding array of platforms and applications ranging from guided weapons to unmanned submersibles, camera and radar assemblies to automobiles, gun turrets, and virtual reality simulators. A broad spectrum of gyro systems are available to support these and other applications, with the appropriate technology selected based on such factors as cost, size, precision, accuracy, and durability.

Open-loop fiber optic gyros, such as those developed and manufactured by KVH Industries, offer tactical-grade accuracy, excellent durability, and a small package for a reasonable cost. KVH's family of FOGs was made possible through innovations in several key fields, including:

- proprietary D-shaped optical fiber, with an elliptical core,
- revolutionary 170 micron ThinFiber,<sup>™</sup>
- innovative optical circuit design, component fabrication, and system integration, and
- patented digital signal processing for improved performance.

This combination provides innovative technology and an outstanding cost-to-performance ratio that stack up well against other competing tactical-grade technology currently available on the market.

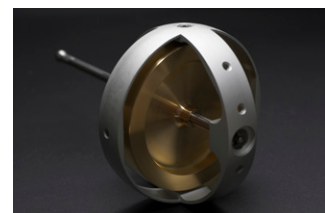
## 1 Evaluating the Spectrum of Gyro Technologies Available Today

### 1.1 Mechanical Gyros

While fiber optic gyros use the physics of light to sense changes in motion, the first gyros used a spinning mass of metal as a way to sense those changes. Perhaps the simplest and most familiar illustration of this concept is a child's spinning top. The term "gyro" (from the Greek gyros meaning "circle" or "spiral") was first applied to a spinning rotor device in 1852 by the French physicist Leon Foucault. A gyroscope is a spinning wheel free to move on three axes — its spin axis, plus vertical and horizontal axes. Foucault first used a pendulum to demonstrate the rotational rate of the earth. He decided, however, that the experiment could be further refined and went on to perfect his earth rate investigation using a gyroscope.

**Figure 1**

*Mechanical gyros can be very precise but they have been largely displaced by modern gyro technologies due to their lack of durability and need for frequent repair or replacement*

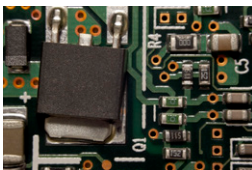


Building on Foucault’s experiments, inventors and technicians devised the gyrocompass, a device that used a combination of a spinning mass and pendulous weights to take advantage of three key forces exerted on a spinning gyro: the rotation of the earth, gravity and a peculiar physical effect called gyroscopic precession. By harnessing these three forces, designers constructed gyrocompasses that provided an effective directional reference for use in navigation. The first gyrocompasses were installed aboard ships in the early 20th century.

Gyrocompasses were an improvement over the magnetic compass in that they did not suffer from the errors induced in the magnetic compass by magnetic variation and deviation — gyrocompasses point at the geographic pole and indicate true direction. The mechanical gyrocompass, however, has substantial drawbacks. A gyrocompass is an intricate electromechanical device composed of finely machined moving parts. As such, gyrocompasses require regular maintenance and are susceptible to wear and breakdown. Gyrocompasses also tend to be large and heavy, restricting their use in devices that require miniaturization and low weight, such as aerospace and subsea applications.

## 1.2 *Micro-electromechanical Systems*

**Figure 2**  
*MEMS gyros have captured many rate gyro applications due to their small size and low cost. However, they lack the precision and dynamic performance needed for many stabilization and navigation applications*



Because the traditional mechanical gyrocompass isn’t a good fit for compact or low-weight applications, designers took a new approach by devising a class of miniaturized heading and orientation sensors called micro-electromechanical systems (MEMS).

MEMS accelerometers utilize a miniaturized circuit design with machined beams of silicon or quartz that bend when the unit is accelerated. The bending causes a change in the voltage passing through the MEMS device proportional to the acceleration. MEMS rate gyros can be constructed in a variety of ways. One method is to use a vibrating silicon ring that reacts to the earth’s Coriolis Effect (the effect that causes moving objects to turn to the right in the northern hemisphere). When the oscillating ring is turned, it produces a slight Coriolis acceleration that can be interpreted as a turn by the operating software. To make a MEMS magnetometer, small silicon elements are coated with magnetic material. As the unit is moved through the earth’s magnetic field, the coated silicon structure picks up the magnetic energy of the field. Used together, these MEMS devices can provide basic rate and direction data for stabilization and navigation applications.

While MEMS units are small and relatively inexpensive, they lack the precision required for many applications. In addition, this technology is also more susceptible to instantaneous shock and vibration errors that will further degrade their performance characteristics in demanding applications, especially those requiring real-time stabilization.

### 1.3 Measuring Light – Ring Laser Gyros and FOGs

Another approach – measuring light itself – offers a powerful combination of size, reliability, and accuracy that can't be matched by either mechanical or MEMS technology. To achieve this, engineers measure the wavelengths of light to obtain rotational information. For example, if you take two discrete beams of light and combine them in a process called interferometry, the resulting interference patterns yield valuable data on the physics of light, which can then lead to precise angular rotation information. Using a diffraction grating, which has slits or openings to allow light through, light beams can be made to combine in distinctive interference patterns, much like ripples on a pond will refract around a small island and create a distinctive interference pattern downstream of the island. Interferometry is used to measure a range of physical properties – from small-scale phenomena such as individual light beams to the large-scale properties of distant stars.

Central to using interference patterns in a gyro is a physical phenomenon called the Sagnac Effect. First discovered in 1913 by Georges Sagnac, the Effect involves sending two beams of light in opposite directions around a closed path and then using a detector to examine the beams when they arrive back at the starting point. If the entire apparatus – light path, light source and detector – is stationary, then both beams will reach the detector at the same time. The beams will recombine constructively in a distinctive interference fringe pattern.

If, however, the apparatus is rotated with the two beams traveling in opposite directions, then the beams will travel different distances before recombining. The beam moving around the loop in the direction of the rotation will have a longer path, while the beam traveling counter to the direction of the rotation will have a shorter path. In effect, the “finish line” is moved closer to the counter-rotational beam, making its trip slightly shorter. Figure 4 on the following page illustrates this concept. The result is another distinctive interference fringe pattern as the two out-of-phase light

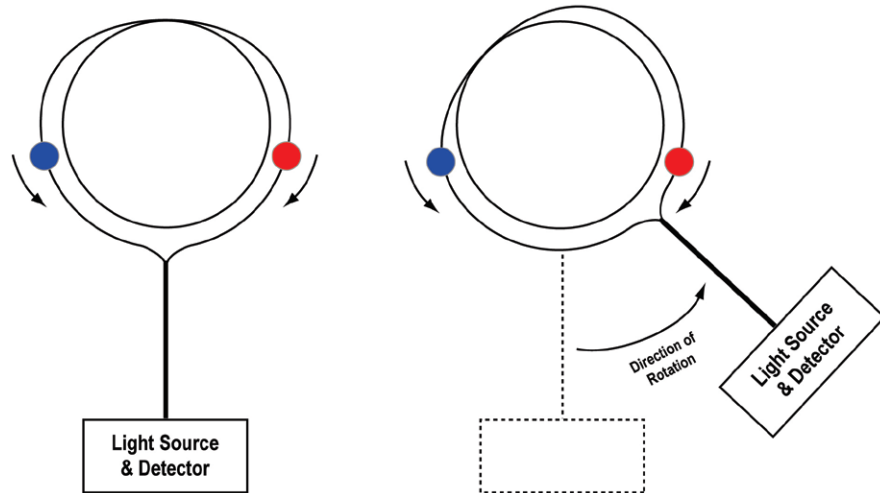
**Figure 3**

*The compact KVH DSP-3000 series of fiber optic gyros is roughly the size of a deck of cards, while the DSP-1750's sensing coil is only 1.7 inches in diameter*



**Figure 4**

*Measuring angular rotation using the Sagnac Effect in a FOG – two beams of light (represented here by red and blue dots) are sent in opposite directions around a coil of optical fiber. If the FOG is stationary, the beams reach the detector at the same time. If the FOG rotates, one beam will have a shorter route and reach the detector first*



beams come together. By harnessing the Sagnac Effect it is possible to build a lightweight device that can accurately measure angular rotation and do so without any moving parts, improving the effective life span of the device.

### ***Ring Laser Gyro (RLG)***

One device that harnesses the Sagnac Effect is the RLG. In a RLG, a laser beam is split and sent in opposite directions around an optical path. The light from the laser travels through a mixture of inert helium/neon gas within a pressurized cavity of specially polished glass. High reflectivity mirrors are used to direct the light beam around the glass cavity. When the light beams recombine at the detector, the interference pattern is measured to determine angular rotation.

### ***Fiber Optic Gyro (FOG)***

Another gyro device utilizing the Sagnac Effect is the FOG. A FOG is similar to a RLG in that it uses a laser diode or superluminescent diode as the light source, along with couplers, polarizers and a light detector. The major difference in the devices, however, lies with the medium in which the light beams travel. A FOG uses a coil of optical fiber for its optical path. FOGs are divided into two types:

1. **Closed-loop:** These systems use an Integrated Optical Chip (IOC), typically made of lithium niobate, to modulate the light within an optical circuit. The use of an IOC results in a highly accurate and controllable sensor but also substantially increases the cost per axis.

2. **Open-loop:** These sensors, such as those developed and manufactured by KVH, use a piezo-electric modulator (PZT) integrated directly into the fiber optic path. This all-fiber approach costs less (typically 40% lower than a closed-loop gyro).

## 2 Accuracy and Errors in Gyro Technology

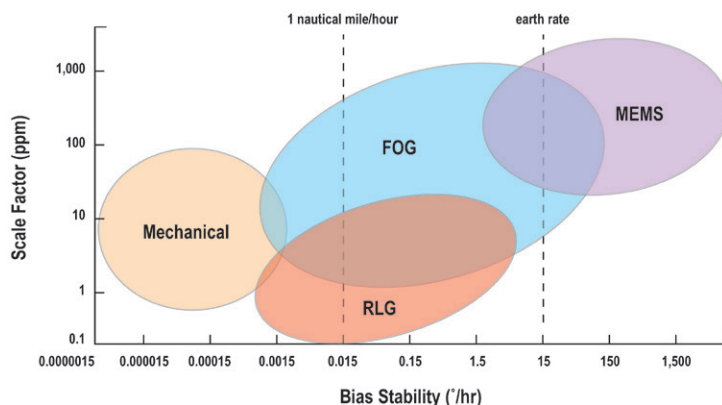
Each class of gyro is faced with its own challenges to its accuracy, reliability, and durability. Mechanical and MEMS gyros, for example, are affected by inertia, shock, and vibration. Fiber optic gyros have a set of inherent errors that FOG manufacturers work hard to mitigate. The transition from analog to digital signal processing has allowed FOG manufacturers like KVH to compensate for some of these errors and produce FOGs with even greater accuracy and improved reliability.

### 2.1 Bias Stability

Like any type of gyro, even when a FOG is stationary it can register some rotation, even when there is none. This is known as “bias error” or drift and it varies with temperature. It also happens to be a repeatable error in KVH FOGs, allowing KVH engineers to build an internal table of bias offset values for each FOG. Two internal temperature sensors, one measuring the temperature of the circuit board and the other sensing the temperature of the laser diode, allow the unit to compare temperature with values stored in this internal lookup table and then subtract them from the result to increase the sensor’s accuracy.

### 2.2 Scale Factor

Scale factor error relates to the rate of rotation of the FOG and is defined as the difference between the input rate and the measured rate output. In other words, if you rotate the FOG 90 degrees, does it register a 90-degree turn? As the rate of rotation increases, the error potential increases.



**Figure 5**

*The primary gyro technologies do overlap with regard to their capabilities as well as their precision, such as when measured by scale factor and bias stability*

*Source: IEEE Sensors Journal, Vol. 1, No. 4, 2001, pp 332-339 (Barbour & Schmidt)*

### **2.3 Angle Random Walk (ARW)**

The output of a FOG includes a broadband random noise element. Angle random walk (ARW) which is defined in terms of degrees/ $\sqrt{\text{hour}}$ , describes the average deviation or error that will occur as a result of this noise element, even when the FOG is at rest and should have an output equal to zero. Major contributors to random noise are the active elements in a FOG, such as the detector and/or light source. KVH continually strives to reduce these errors in its FOGs through next generation technology. In December 2004, for example, KVH was awarded U.S. Patent #6,836,334, “ARW noise reduction in fiber optic sensors using an optical amplifier.” In a bootstrap effect, reducing ARW values also improves the bias offset estimate and the corresponding correction.

## **3 FOGs vs. Other Gyro Technologies**

The value and benefits of any gyro solution will vary based on the requirements of a given application. If the program requires a low cost, small form factor and short-term accuracy, then a MEMS gyro might be the right solution. On the other hand, if the application requires long-term accuracy and precision, as in long-range undersea or airborne navigation, then a strategic-grade RLG may be the best option. But if the application requires the best blend of tight accuracy, small size, and affordability, a KVH FOG might be the perfect fit.

### **3.1 Mechanical Gyros**

Because the classic mechanical gyro relies on a spinning mass to provide rate information, mechanical gyros have a number of drawbacks compared to solid-state units. Mechanical gyros tend to be heavy and complex, with a high number of moving parts that are susceptible to breakdown as well as to the effects of cross-axis motion and inertia. For example, as the bearings supporting the spinning mass wear due to friction, the performance of the gyro degrades. Due to physical constraints, mechanical gyros have enabled alternative technologies to surface as options with increased performance capabilities and improved cost effectiveness, within a smaller form factor. Mechanical gyros are largely becoming unavailable now and, as existing legacy systems fail, they are being replaced with competing FOG technology.

KVH’s solid-state FOGs, with no moving parts, can be built in much smaller form factors. The KVH DSP-3000 package size, for example, is

roughly the size of a deck of playing cards: 3.5 inches long by 2.3 inches wide and 1.3 inches high. It also offers a mean-time-between-failure (MTBF) roughly 20 times better than standard mechanical gyros. Smaller still is KVH's DSP-1750 with an optical sensor diameter of 1.7 inches connected to its power and processing electronics via an interlocking tether.

### **3.2 *Micro Electromechanical Systems (MEMS)***

These ultra-small devices, constructed from silicon or quartz at microchip scale, are valued for their small size and affordability. However, because they tend to have high bias over temperature as well as large noise errors, MEMS may not be a viable solution for high-accuracy applications. Additionally, MEMS can be less operationally robust in conditions that produce high shock and vibration loads, nor do they have the bandwidth required for demanding stabilization or navigation applications.

Highly accurate KVH FOGs, which have much better temperature compensation and lower noise, are much more resistant to shock, vibration and acceleration and will continue to output data even in demanding conditions. FOGs are intrinsically low noise, high bandwidth sensors. As a result, KVH's FOGs are ideal for applications like turret and remote weapon stabilization, an environment dominated by intense shock and vibration conditions, as well as stabilization of optical equipment and antennas.

### **3.3 *Ring Laser Gyros (RLGs)***

While RLGs can score high in accuracy, they are far more expensive than FOGs and are limited in how small they can be built without losing accuracy. In addition, RLGs are prone to an effect called "lock-in" where the RLG cannot discriminate small changes in rotation. To counteract this, RLG manufacturers have used motors to physically dither the RLG to break the unit out of its locked-in state. The RLG is turned and counter-turned to ensure that the angular velocity of the unit does not approach locked-in state.

However, the dithering motor produces noise and vibration that limits the use of RLGs in applications that require silent operation – such as a gyro sensor for a torpedo. In addition, reduced expected operational life and MTBF are issues for RLGs. For example, the HeNe gas in the glass cavity escapes over time, requiring service to refill and re-create the cavity vacuum.

The super-compact DSP-1750 FOG by KVH offers bias stability comparable to that of the much larger and more costly RLG and closed-loop gyros. In addition to the smaller sizes possible with FOG technology, KVH FOGs are solid state and operate without mechanical inputs and their associated noise, vibration and wear. As a result, the lifespan for such systems far exceeds that of RLG technology. In addition to the smaller sizes possible with FOG technology, KVH FOGs are solid state and operate without mechanical inputs and their associated noise, vibration and wear. As a result, the lifespan for such systems far exceeds that of RLG technology.

### 3.4 Closed-loop Gyros

Due to the similarity in operation, closed-loop gyros offer many of the same advantages found in KVH’s open-loop designs along with a higher level of accuracy. However, that comes with a price – a significantly lower operational lifespan and a substantially higher per-axis cost.

## 4 Advantages Offered by KVH FOGs

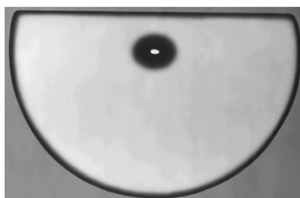
Several key design and manufacturing advantages make KVH FOGs superior to competing products. Taken together, these advantages give KVH FOGs a unique blend of accuracy, reliability, affordability, durability and versatility that few other manufacturers of gyros can match.

### 4.1 Manufacturing and Quality

As a vertically integrated FOG manufacturer, KVH undertakes all aspects of FOG manufacture, from drawing the fiber to manufacturing optical components out of the fiber, to assembly of the optical circuit, and then final integration and testing with the FOG electronics. This gives the company complete control over the various processes involved and ensures the highest level of quality.

**Figure 6**

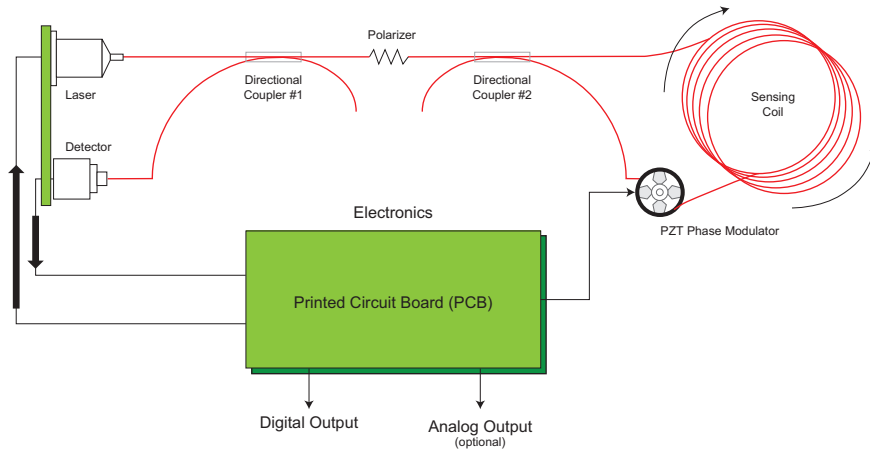
*KVH’s proprietary D-shaped fiber has a unique elliptical core, shown here in this electron-micrograph*



### 4.2 Design Advantages

Topping the list of design advantages held by KVH FOGs is its polarization-maintaining (PM) D-shaped optical fiber. PM fiber provides improved accuracy; light will travel through standard optical fiber in a variety of polarization angles, reducing a FOG’s performance. KVH’s D-shaped PM fiber uses an elliptical cross section (E•Core®) at its center. The elliptical core acts as the conduit for the desired polarization of light, ensuring a strong signal path.

KVH recently developed a thinner optical fiber, the groundbreaking 170 micron E•Core ThinFiber which takes up one-half the volume of KVH’s standard E•Core fiber. This enables KVH to pack twice as much optical fiber into the same size housing to dramatically increase performance, or offer similar performance in an even smaller package. This breakthrough in gyro technology has set a new standard in fiber optic gyros for size, performance and cost. To further improve performance, KVH integrates a polarizer that strips away the unwanted light in the short axis, leaving only the long axis for transmission through the optical circuit. Adding to the overall performance, the D-shape permits easy access to the core when creating couplers and polarizers, and provides an excellent physical surface for mating fibers.



**Figure 7**  
KVH's open loop design gyros offer accuracy, reliability, affordability, durability and versatility

**RED:** KVH-manufactured polarization-maintaining, elliptical core, single mode optical fiber  
**GREEN:** Printed circuit boards

To make its FOGs more accurate, KVH employs a piezo-electric modulator (PZT) that drives the FOG output at 135 kHz. By modulating the FOG with this signal, KVH engineers move the output of the interferometer to a section of the additive/subtractive curve with the steepest slope. Because even small changes along a steep slope are easier to detect, the FOG becomes that much more precise.

Another advantage of using the modulator is the side frequencies produced by the 135 kHz signal. By looking at these lower-power side frequencies – called harmonics – the unit can accurately establish and tune into the optimum operating point on the output curve, while permitting a high bandwidth output. This permits the FOG to receive, process, and output large amounts of data at high rates, resulting in greater accuracy.

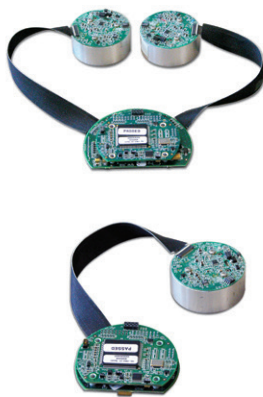
The final essential design element in KVH’s high-accuracy FOGs is the use of the company’s patented DSP technology. Once the optical output from the FOG is picked up at the detector and transformed into a voltage, this voltage is passed through an analog-to-digital converter. The DSP approach allows KVH engineers to devise effective methods for analyzing and correcting this digitized data on the fly, a capability not possible with analog signal processing. A perfect example is the way KVH FOGs monitor their internal temperature and then compensate for temperature errors by using a lookup table stored in memory. These DSP techniques increase the accuracy of KVH FOGs by orders of magnitude by virtually eliminating temperature-sensitive drift and rotation errors, and are covered by several patents.

## 5 A Family of Versatile FOG Solutions

KVH’s FOG product family consists of eight principal units that are suitable for a wide variety of commercial and military applications.

### 5.1 DSP-1750

**Figure 8**  
*The DSP-1750*



The super-compact DSP-1750 fiber optic gyro is the world’s smallest precision FOG. Available in both single- and dual-axis configurations, the DSP-1750 is designed for a wide range of precision navigation, stabilization and pointing applications where low noise and high performance across the entire range of operating temperatures are critical. Ideal for demanding high-performance applications including gimbals, payloads for UAVs, autonomous vehicle navigation, the stabilization of virtually all types of commercial equipment platforms, and GPS/INS and IMU integration. Utilizing KVH’s 170 micron E•Core ThinFiber, the world’s smallest D-shaped optical fiber, it delivers extremely low noise coupled with high bandwidth. With its two-piece design, the DSP-1750 offers extreme integration flexibility. This compact FOG is also highly versatile, available with digital output, single- and dual-axis configurations, and in a choice of performance variants: Standard: input rate of 490°/sec, and High: input rate of  $\pm 1000^\circ/\text{sec}^*$ . Plus it offers bias stability of  $\leq 1^\circ/\text{hr}$ , and is available in magnetically shielded variants.

\*The DSP-1750 is covered by one or more patents. Only the DSP-1750 High (1000°/sec variant) is controlled by the Export Administration Act of 1979, as amended (Title 50, USC App 2401 et seq.) and its implementing regulations, the Export Administration Regulations, 15 CFR 730 et seq. Diversion contrary to U.S. law is prohibited.

## 5.2 DSP-3000

The single-axis DSP-3000 fiber optic gyro is an excellent solution for stabilization, motion sensing, navigation and precision-pointing applications. The all-fiber optical circuit offers exceptional low noise capability, insensitivity to cross-axis error, plus superior resistance to errors from shock and vibration. The reduced package size and modular design of the DSP-3000 make it perfect for applications with size and/or weight restrictions, allowing for installation of single axis units in many configurations and locations.

**Figure 9**

*The DSP-3000*



## 5.3 DSP-3100

Designed for demanding applications requiring high-speed data output, the DSP-3100 offers a powerful high-speed RS-422 interface with 1000 Hz asynchronous in a compact package. A single-axis, fiber optic gyro, the DSP-3100 has an industry-standard Samtec 26-pin connector in a versatile package ideal for installations with tighter installation requirements while not sacrificing performance, reliability or durability.

**Figure 10**

*The DSP-3100*



## 5.4 DSP-3400

The DSP-3400 has a robust modular design which makes it a powerful option for use in applications requiring FOG output to be transmitted over a longer distance. Offering the benefits of a true RS-422 interface and a 1000 Hz synchronous output in a durable shielded package, the DSP-3400 has exceptional bias stability and linearity in a single-axis modular design for multi-axis configurations.

**Figure 11**

*The DSP-3400*



## 5.5 DSP-4000

The DSP-4000 series offers both single- and dual-axis FOGs specifically designed to provide military users with a high-performance, low-cost successor to troublesome mechanical gyros. Unlike mechanical gyros, the DSP-4000 series is insensitive to cross-axis motion and inertia. A solid state design, with no moving parts to wear out, ensures high reliability, superior performance and exceptional vibration, shock and acceleration survivability. Like the DSP-3000 family, the DSP-4000 features low noise, high bandwidth, improved bias stability, and excellent scale factor performance and resolution, making it an economical alternative while delivering superior stabilization and tracking capabilities for gun/turret, antenna and optical stabilization systems. It measures angular rates with extreme precision while its high bandwidth makes it particularly suitable for armored vehicle gun or optics stabilization.

**Figure 12**

*The DSP-4000*



## 6 FOG-based Integrated Inertial Measurement Solutions

Considering the many design, performance and cost advantages that KVH FOGs offer, it follows that these versatile units present ideal solutions for challenges requiring integrated inertial measurement systems. KVH offers both FOG-based inertial measurement systems and inertial navigation systems.

### 6.1 Series 1750 IMU

**Figure 13**  
*The Series 1750 Inertial Measurement Unit*



The Series 1750 IMU is the flagship of KVH's small, advanced navigation and stabilization and guidance systems sensor products. The Series 1750 IMU leverages the technology of the highly successful DSP-1750 fiber optic gyro, the world's smallest high performance FOG, integrated with very low noise MEMS accelerometers. The resulting small size and high performance of the Series 1750 IMU make it ideal for any guidance, stabilization, or navigation applications where size, weight and power consumption are critical parameters.

### 6.2 TG-6000

**Figure 14**  
*The TG-6000 Inertial Measurement Unit*



The TG-6000 inertial measurement unit (IMU) is a high-performance, six degree-of-freedom, FOG-based motion-sensing package ideally suited for motion control and GPS-integrated navigation applications. This highly reliable, strap-down inertial subsystem provides accurate measurement of angular rates and linear accelerations and achieves its excellent performance by employing proprietary algorithms to characterize and correct for the effects of temperature, linearity and axis misalignment. Output data is provided in multiple digital formats (such as RS-422).

### 6.3 CG-5100

**Figure 15**  
*The CG-5100*



The CG-5100 IMU combines highly accurate FOG-based sensors coupled with industry proven MEMS accelerometers – all within a compact single enclosure, providing reliability and long-term compliance to commercial specifications. With its seamless integration of these two highly-reliable navigation components, the CG-5100 provides a ground-breaking low-cost, small form factor commercial solution for inertial measurement. The commercial CG-5100 offers highly accurate rate and acceleration data, fiber optic gyro stability in an affordable, compact design.

## 6.4 CNS-5000

The CNS-5000 from KVH is a self-contained Inertial Navigation System (INS) that combines a FOG-based IMU with highly accurate global positioning system (GPS) technology from NovAtel. Through its seamless integration of two highly reliable navigation systems, the CNS-5000 provides a low-cost, small form factor solution for 3-D positioning, velocity, and attitude measurement. Unlike most GPS/IMU systems that use GPS data to control errors in data from the IMU, the CNS-5000 relies on the inertial data to support the GPS by aiding in satellite reacquisition. The blending of these two powerful technologies results in the CNS-5000 delivering superior GPS tracking and performance.

**Figure 16**

*The CNS-5000*



**Figure 17**

*KVH's DSP-3100 FOGs and DSP-4000 FOGs are used in Remote Weapon Stations fielded worldwide*

## 7 Applications of KVH FOGs

KVH's DSP FOGs are used in an impressive range of military and commercial applications on land and at sea all over the globe.

### 7.1 Stabilization

#### ***Weapon Stabilization***

Military forces around the world are rapidly adopting remote weapon stations (RWS) for their tactical vehicles. These systems allow gunners to operate, aim, and fire turret weapons from inside the safety of their vehicle, taking the gunners out of turret positions where they are exposed to hostile fire. Currently, the world's biggest RWS customer is the U.S. Army, which has ordered more than 10,000 systems for use on many of its combat vehicles in a program called the Common Remotely Operated Weapons Station (CROWS). KVH supplied the fiber optic gyros to Recon Optical for the U.S. Army's original CROWS program in 2005, and later won a contract with Kongsberg for the CROWS II program using the DSP-3100 FOG. The dual-axis DSP-4000 FOG is also integrated within Israel-based Rafael Advanced Defense Systems' RWS, providing critical

**Figure 18**  
*The Merkava tank and other military vehicles employ KVH DSP FOGs for turret stabilization*



**Figure 19**  
*Many U.S. Army missile training simulators use KVH FOGs, improving performance in actual live-fire operations*



photo courtesy of Raytheon

**Figure 20**  
*KVH FOGs are employed to stabilize optical systems, like TV and surveillance cameras*



optical and weapon stabilization capabilities to increase RWS accuracy and effectiveness. KVH is currently working on the development of new, smaller, lower cost designs that it believes will be particularly well suited for the CROWS III and future international RWS programs.

### ***Military Turret Applications***

KVH entered the military turret stabilization market in 2002. KVH FOGs are used in turrets aboard main battle tanks, such as the Merkava, the T-72, the T-85, and for other armored combat vehicles as well. In each case, the onboard FOG is used to stabilize the gun turret while the vehicle is maneuvering, aiming and firing. FOGs enhance the capabilities of mobile forces on the battlefield by combining accurate positioning, firepower stabilization, and hardware durability. Traditionally, mechanical gyros were used in these applications. However, the substantially longer lifespan and accuracy of FOG systems has led to an ongoing replacement of legacy mechanical gyros with form, fit, and function replacements like KVH's DSP-4000.

### ***Motion Tracking and Stabilization for Simulators***

The U.S. military has used KVH FOGs to provide motion tracking, visual stabilization, and image synchronization for the Javelin, Stinger, and Improved Target Acquisition System (ITAS) training simulators. By measuring even the slightest movement and relaying this data to the simulator's computer, KVH FOGs allow the simulator's virtual image to correspond exactly to a soldier's motion. As a result, soldiers can interact with a realistic video-based battle scenario and gain expertise in the use of the weapon system without incurring the costs of live-firing actual missiles.

### ***Optical Systems***

Optical systems are particularly prone to vibration-induced issues, whether it's a surveillance camera mounted on a helicopter and trying to get a precise view of a target, a TV camera in a sports stadium with 65,000 people stomping and cheering, or a night vision system mounted on a ship. KVH's FOGs are ideally suited for and employed in each of these applications. Take for example, your typical National Football League

game. No longer content with simply showing a view of the field, the NFL now superimposes a yellow line to indicate the first down line, a blue line for the line of scrimmage, and other digital overlays to provide information to the viewers. However, for those lines to remain stable and not jitter across your screen, the movement of the cameras, including the minute vibrations caused by those 65,000 people in the stands, must be factored out. That's where KVH gyros come into play, feeding data to the broadcaster's computers and allowing the movement to be factored out on screen, leaving a stable line drawn across the field.

### ***Antenna Stabilization***

The same capabilities that make KVH FOGs ideal for optical stabilization are also valuable to antenna tracking, pointing, and stabilization. For example, KVH FOGs are employed in Super High Frequency satellite communication antennas built for the U.S. Navy's Space and Warfare Systems Command. These large shipboard antennas rely on KVH FOGs to help maintain a precise lock on the satellites at all times and in all sea conditions to ensure uninterrupted, two-way communications.

**Figure 21**

*KVH FOGs provide critical stabilization data for a wide range of antenna systems*



**Figure 22**

*KVH's CNS-5000 is used in Churchill Navigation's ARS moving map technology*



**Figure 23**

*The U.S. Navy MK54 torpedo uses KVH's TG-6000 IMU*



## **7.2 Navigation and Guidance**

### ***Surveying and Real-Time Mapping***

KVH FOGs offer the ideal solution to the challenges of dynamic surveying and aerial mapping used for research, airport facility mapping, forestry inventories, geography and oceanography studies, GPS and topographical surveys, and above- and below-ground mapping by providing stabilized, continuous precise position and orientation data in demanding conditions where GPS is blocked by natural or manmade obstructions or conditions. The compact KVH CNS-5000, a self-contained FOG-based IMU coupled with highly accurate GPS technology from NovAtel, provided the ideal precision pointing and superior GPS tracking performance solution for Churchill Navigation's Augmented Reality System (ARS). This next-generation mapping system provides law enforcement agencies with a menu of viewing options overlaid with vector, parcel and geographical information and more – all with precision pointing and orientation provided by the KVH CNS-5000.

**Figure 24**

*KVH FOG-based systems provide the precision navigation and guidance required by autonomous vehicles*



**Figure 25**

*NASA's Global Hawk carrying a synthetic aperture radar payload on a fully unmanned aerial reconnaissance mission uses internal DSP-1750 gyros from KVH to maintain focused and stable imagery*



**Figure 26**

*KVH FOGs help guide forklifts and inventory control systems*



## ***Munitions Guidance***

The U.S. Navy's next generation MK54 lightweight ASW torpedoes use KVH FOG technology. The TG-6000 IMU, developed through a rapid R&D program to act as a form, fit, and function replacement for an existing IMU, serves as a key component in the guidance system of the MK54, which is deployed from surface ships, helicopters and fixed wing aircraft. The TG-6000 measures rate and acceleration precisely in three dimensions, critical for the navigation of a torpedo or other smart munitions.

## ***Unmanned Systems***

Navigation and precision are critical to successful autonomous decision-making and plan implementation. KVH FOGs provide a wide range of integrated motion-control and precision navigation solutions for applications such as robotics performing perimeter patrols and other security tasks within airports, container yards and other critical locations. KVH FOGs have been used extensively in the Defense Advanced Research Projects Agency's (DARPA) Grand Challenges, in which the objective is to successfully race across 150 miles of Mojave Desert terrain in 10 hours or less. DSP-3000 FOGs were used on a stabilized sensor platform to sense pitch, roll, and yaw angular rates relative to the vehicle's position. Data from the KVH FOGs was used to stabilize the vehicle's navigation and guidance system regardless of uneven terrain and vehicle motion. In addition, KVH's super-compact precision FOGs are finding popularity with designers of advanced unmanned aerial systems where weight and size, as well as accuracy are prime considerations.

## ***Inventory Management Systems***

KVH FOGs have been used in warehouse tracking and material handling systems for forklifts and other vehicles. The tracking setup, in use by a Fortune 50 company, tracks the position of each forklift, its unique cargo identification, and the pick-up and put-down location of the inventory. The KVH gyro was chosen because of its affordable combination of features, including its immunity to the distortions caused by metallic structures and items within the warehouse environment. In this system, the KVH FOGs help ensure that the forklifts transport inventory throughout the facility safely, quickly, and correctly.

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## ***Undersea Vehicles***

KVH FOGs have been employed as a cost-effective solution for underwater remotely operated vehicles (ROVs). These units offer precise control of ROVs in a compact and lightweight design. Ideal for research as well as oil and gas exploration, KVH FOGs provide precision positioning which is especially important underwater where no GPS signal is available.

## ***Train Control Systems***

KVH FOGs have been used in the development of a next-generation Positive Train Control (PTC) system intended to improve railway efficiency, reliability, and safety. A critical element in any PTC system is precise knowledge of each train's position and speed. KVH FOGs have been used with GPS, a tachometer, a track database, and MEMS accelerometers to identify the precise location of a train on the track. KVH FOGs are also used extensively for train track geometry measurement, critical for maintenance of rail lines and safety.

**Figure 27**

*Undersea ROVs regularly employ KVH FOGs for guidance and navigation*



**Figure 28**

*KVH FOG-based systems provide the precise data on train position and speed that high-speed rail systems require*



## **8 Conclusion**

Gyroscope technology has become an integral component within a growing number of platforms and common products. The versatility of a fiber optic gyro, such as those manufactured by KVH, offers a powerful blend of price, precision, and performance suitable for a wide range of applications and environments.

## **For More Information:**

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