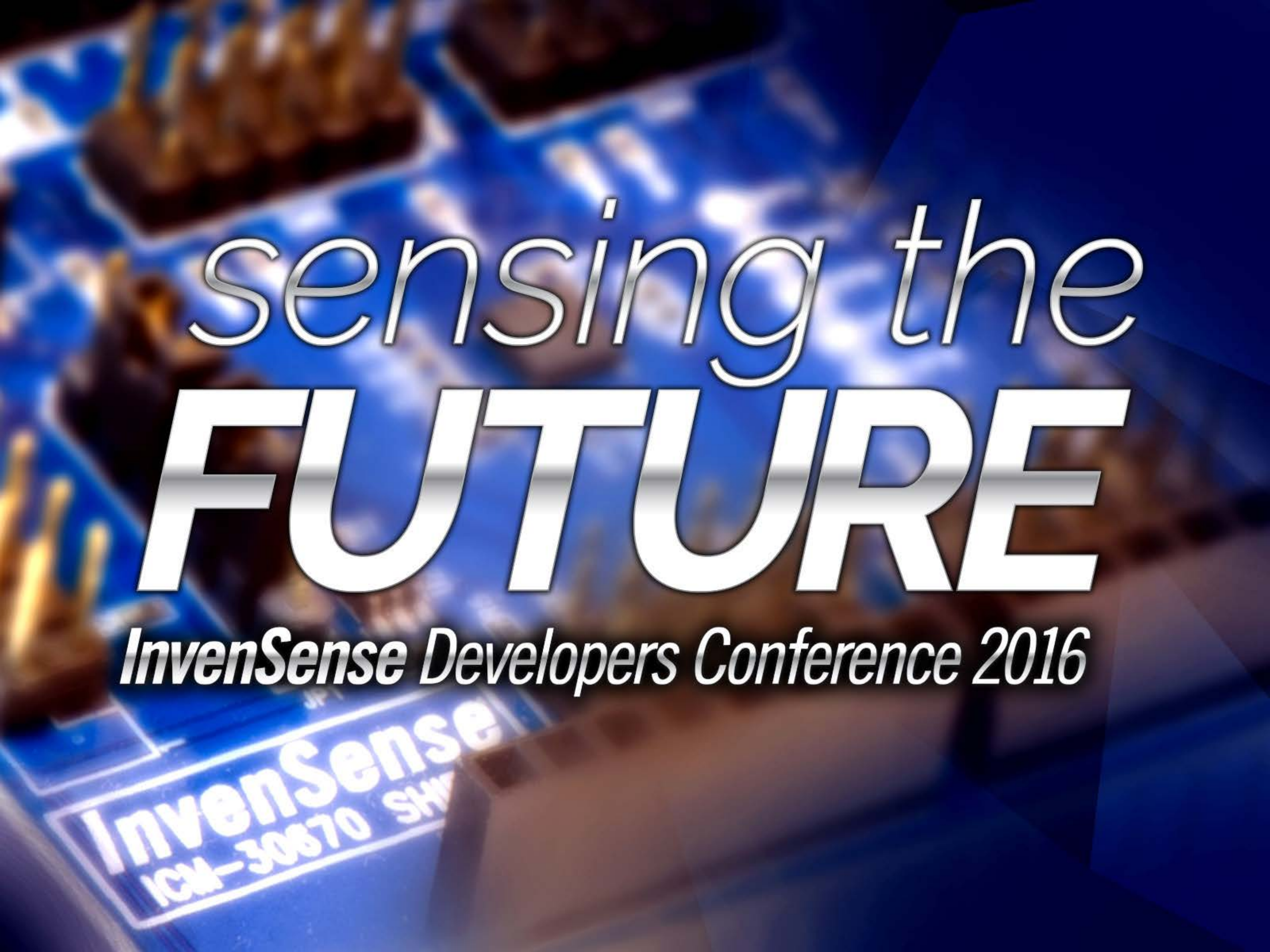
sensing the
FUTURE
InvenSense Developers Conference 2016

Best Practices for Sensor Hardware Applications

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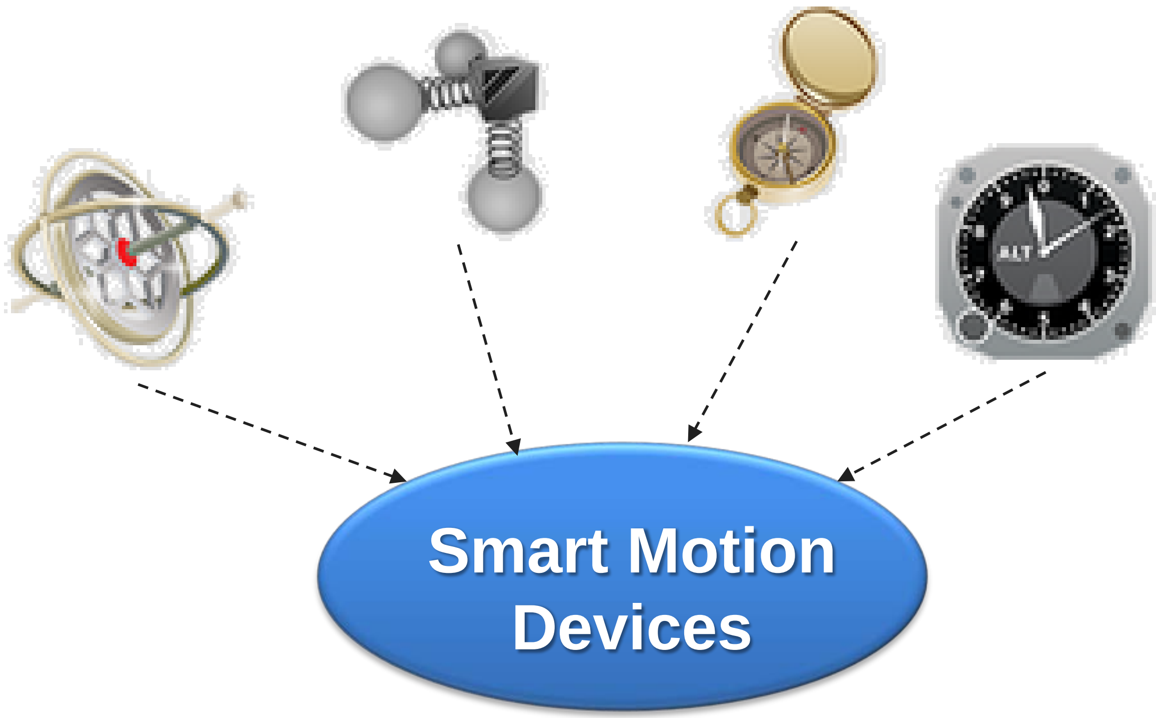
Motion Sensors v. CMOS chips

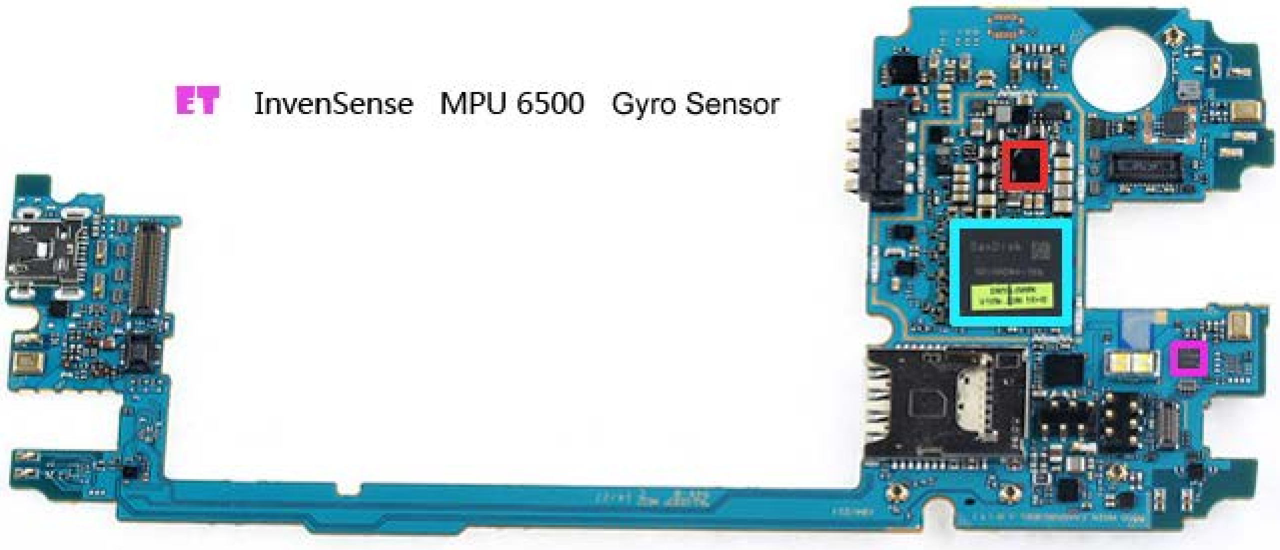
- Motion sensors are electromechanical devices as opposed to purely digital/analog parts
- Are sensitive to motion, vibration, high intensity noise including audio band and ultrasonic
- Sensitive to ambient temperature variation, heat generated from other devices (e.g. AP, power IC)
- Are sensitive to package stress including SMT mounting, PCB warpage and location on a PCB
- Can be damaged by mishandling such as dropping on hard surface at component level

Sensor Integration in System Hardware



Billions of sensors are successfully & reliably used in mobile devices

Motion Sensor In Phone PCBA



Gyro, Accel and barometer are MEMS technology

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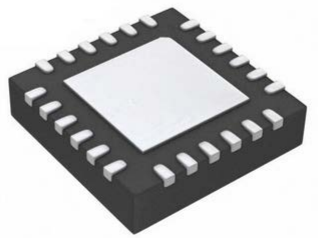
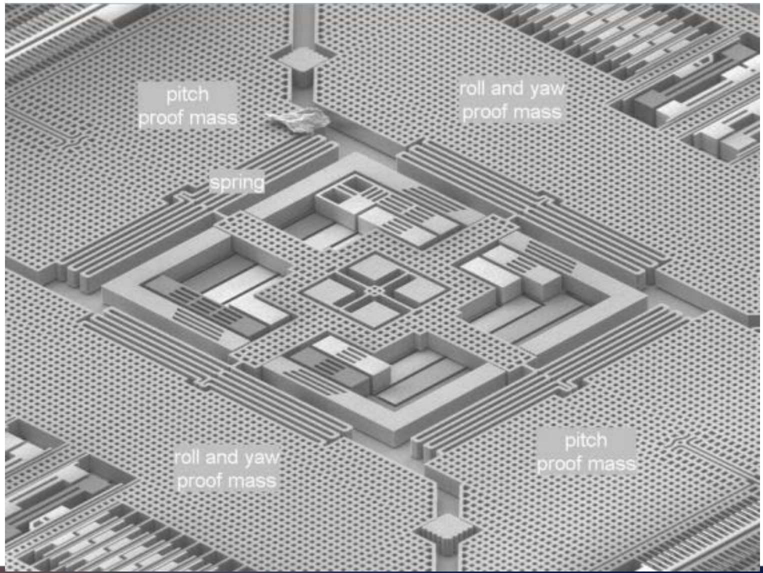
"MEMS Motion Handling and Assembly Guide"
https://store.invensense.com/datasheets/invensense/MEMS%20Motion%20Handling%20and%20Assembly%20Guide.pdf

1. **InvenSense motion sensor is MEMS, a technology that combines CMOS circuit with tiny mechanical devices.**

2. **Any mechanical stress affects sensor measurement result.**
   - **Do not solder exposed die pad to PCB.**
   - **Keep large insertion parts (connector, lock screw, push button, shielding cover solder point and so on) away from sensor.**





Gyro, Accel and barometer are MEMS technology (continued)

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4. **Not all MEMS part supporting ultrasonic clean.**

5. **Good placement alignment is key to reduce gyro and accel crosstalk.**

6. **Do not route active signal trace and via under or near sensor chip.**
   - **Large active electrical signal (battery charger, big current inductor …) may create mechanical harmonic coupling**

7. **Keep sensor chip away from heat source.**
   - **Temperature change affect sensor characteristics.**

Accel placement – where and why

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1. **Accel applications:**

   - **Measure tilt angle**

   - **Measure movement**
     - ✓ **Pure linear movement, such like linear moving car, lift up weight from ground surface vertically, free fall.**
     - ✓ **Human arm swing which is combination of rotation and linear move. In addition of linear movement, Accel detects acceleration from centripetal force also.**

Accel placement – where and why
(continued)

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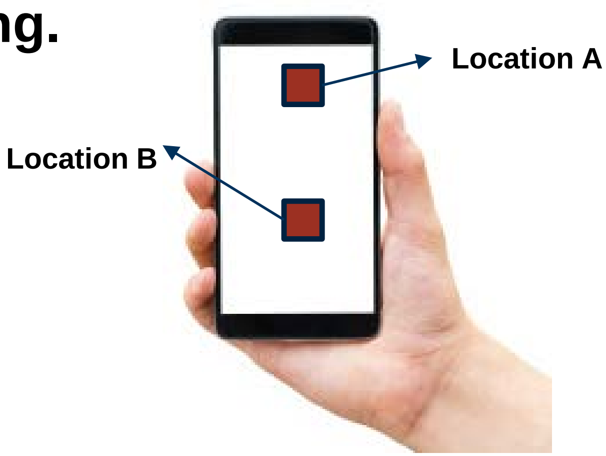
2. Accel location in device:

- **Accel location doesn't matter when measuring**
  - ✓ device tilt angle
  - ✓ pure linear movement without rotation
- **Device rotation create centripetal force. The distance between rotation center and Accel location affects Accel output.**
- **Accel in location A will detect more acceleration than location B for same amount of arm swing.**



Pressure Sensor in Device

1. Pressure sensor is MEMS technology. Avoid mechanical stress is very important.

2. Expose pressure sensor to measured environment in terms of air pressure and temperature. Ensure sensing area good air circulation.

3. Keep away from heat source. Heat affects pressure sensor characters. Heat changes sensing area pressure.

4. Keep sensor open hole clean from dust and water.

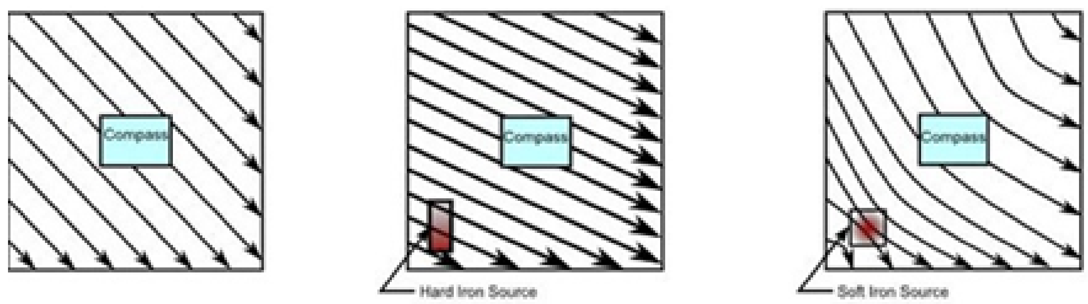
Pressure Sensor in Device (continued)

5. Pressure sensor needs good air circulation, but direct air flow should be avoided.
   - Do not place the sensor with its open hole facing device case open hole (phone jack) directly.
   - Do not place the sensor near a fan.
   - Avoid direct wind flow, large voice or air pressure change from slam a door.

6. There is vacuum cavity and an open hole in pressure sensor, Do not apply big force to avoid damage. Please follow datasheet spec for PCB board assembly pick/place machine force setting.

Magnetic sensor location in device

1. **Distortion source:**
   - **Hard iron:**
     - ✓ **Generated from piece of magnetized iron, like speaker and vibrator.**
     - ✓ **Hard iron changes magnetic sensor's offset. It is big in general, speaker ~=20000μT.**
   - **Soft iron:**
     - ✓ **Soft iron is from metals and high energy electric components, like piece of nickel or iron and high power components/PCB trace. Soft iron distorts surrounding magnetic field which affects magnetic sensor sensitivity.**



Undistorted Field | Hard Iron Distortion | Soft Iron Distortion

Magnetic sensor location in device
(continued)

2. **Integrate magnetic sensor in handheld system hardware device:**

   - **Make sure your sensor full scale range covers surround hard iron offset and application dynamic range.**
   - **Keep >20mm distance from hard iron source.**
   - **Keep >25mm distance from >200mA PCB traces and IC.**
   - **Do not use noise/RF shield cover for magnetic sensor.**

Motion Sensor in Applications

Gyro and Accel in different applications

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1. Gesture/Gaming
   - Need big FSR, 2000dps and 16g for big swing detection.
   - Can tolerance low resolution, low signal bandwidth (around 40Hz or 50Hz is fine) and low ODR (50Hz to 200Hz).

2. Image stabilization
   - Human hand jitter is about 10Hz and 0.5°.
   - High gyro resolution is needed, use 32dps to 250dps.
   - Low noise is important for jitter compensation.
   - Gyro signal latency should be small to get good compensation tracking. Low filter bandwidth gives low noise but longer phase delay.

Gyro and Accel in different applications (continued)

3. AR/VR products:
    - Latency is fundamental for delivering good experience. Too much time elapse between head turning and image updating will cause bad aligned.
    - Use InvenSense sensor build in offset subtraction h/w to save s/w subtraction time.
    - Avoid using low ODR and low bandwidth for short phase delay.

4. Sport Wearable:
    - Power consumption is big concern. Consider to set sensor in low power mode.

Using Pressure Sensor

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1. Pressure Sensor
    - Used to detect altitude, altitude/floor change and weather forecast mainly.
    - Set pressure sensor in low noise mode for floor change or staircase steps detection.
    - For altitude detection during hiking, power consumption is concern. Use the sensor in low power mode.
2. Pressure sensor noise
    - Noise decides sensor final resolution. InvenSense pressure sensor noise can be as low as 1pa which is good to detect one staircase step.

Using Pressure Sensor (continued)

3. Absolute accuracy
    - Absolute accuracy will affect altitude detection accuracy in the use case of hiking and 911 call.
    - 1hpa absolute accuracy will create about10m altitude error.

4. Relative accuracy
    - Relative accuracy will affect altitude change accuracy in the use case of staircase steps counting and floor detection.
    - 2pa relative accuracy will generate about 0.2m altitude change detection error.

Using Magnetic Sensor

1. **Magnetic Sensor in device:**
   - **Find hard iron and soft iron surround your magnetic sensor**
     - ✓ **Place device in parallel with earth surface. Log x and y data while rotating the device 360°.**
     - ✓ **Plot xy data to find offset from hard iron and oval shape from soft iron.**

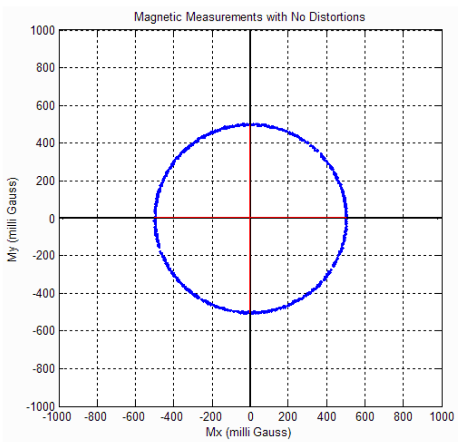


Figure 1. No Distortions

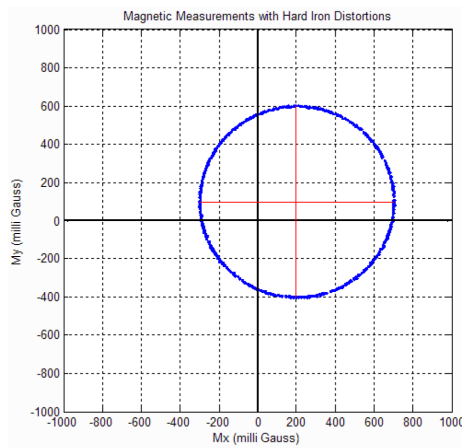


Figure 2. Hard Iron Distortions

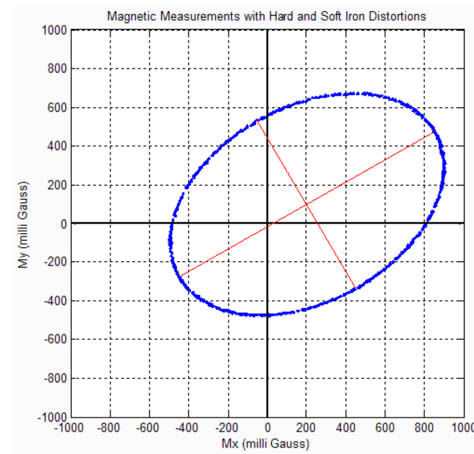
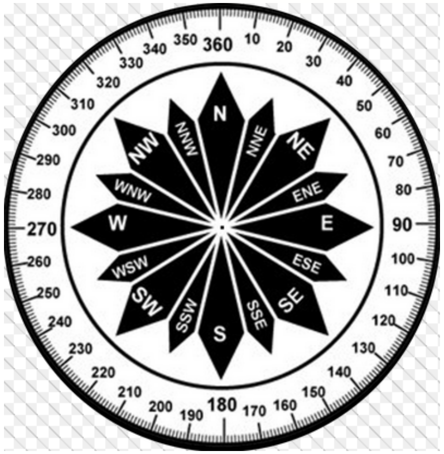


Figure 3. Soft and Soft Iron Distortions

2. **InvenSense has calibration algorithm. Please talk to our FAE.**

   https://store.invensense.com/datasheets/invensense/Compass-Magnetometer%20AN-000011v1-0.pdf

Key Parameters and Measurement



Gyro and Accel noise

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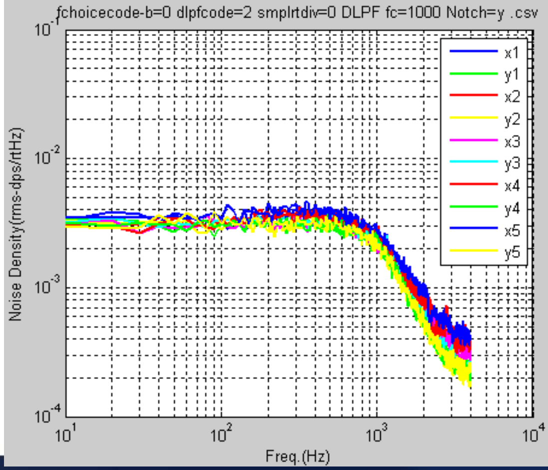
1. Noise spec in datasheet:
   - Gyro and Accel noise is specified as noise density with unit of mdps/√Hz and µg/√Hz.
   - The noise density is constant flat within signal bandwidth zone. It is frequency in domain.
   - Time domain is RMS noise with unit of mdps and mg. RMSnoise = 1σ noise. 6 σ can be used as maximum noise level.

2. Noise measurement:
   - record data with high ODR when gyro is in static statue. Do post data process to calculate noise density (FFT) or RMS (STDEV function in Excel).



Pressure and Magnetic sensor noise

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1. Pressure sensor noise
    - InvenSense pressure sensor has two noise levels.
    - Low noise (0.9 Pa) needs higher power consumption (9μW); higher noise (3.1 Pa) needs lower power (2μW)
    - Record pressure data without environment air flow disturbance (put sensor in a box with box lid half open). In Excel, do STDEV (1σ RMS noise).

2. Magnetic sensor noise
    - Record data without environment magnetic field disturbance (test in a big open outside space). In Excel, do STDEV (1σ RMS noise).

Understand Gyro and Accel AVR Plot

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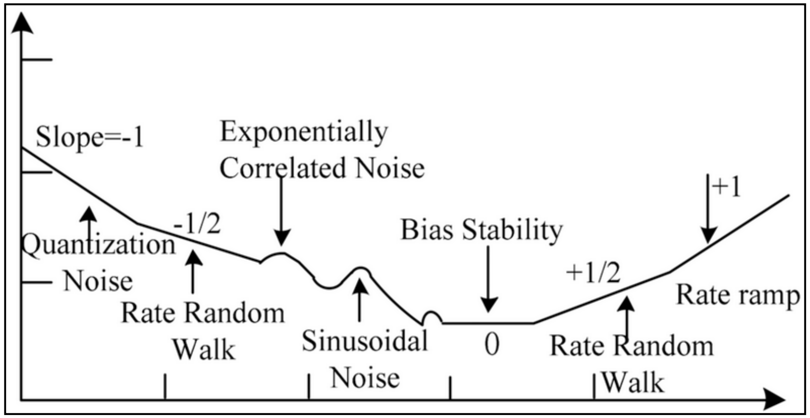
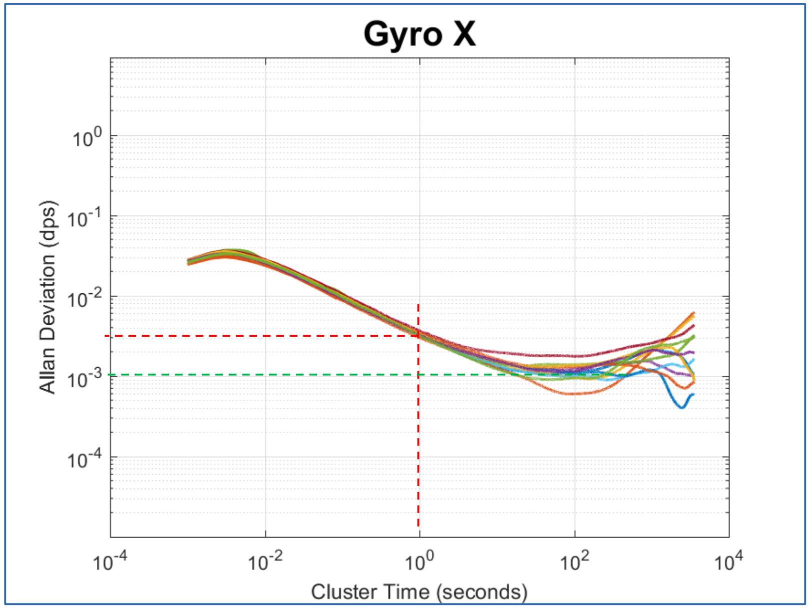
1. **How to read AVR plot**
   - **Random walk: The value when time cluster size = 1s.**
   - **Bias stability: The value when curve becomes flat.**



2. **How to measure AVR**
   - **Leave sensor in static statue and log data with 200Hz ODR for more than 2 hours.**
   - **Post data process to plot AVR.**



Application Level Sensor Calibrations

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1. Offset and sensitivity can be calibrated in application level.

2. Gyro
   - Offset (ZRO): Record gyro data in static statue.
   - Sensitivity: Turning machine is needed to provide reference constant rotation speed. To save calibration effort, InvenSense has sensitivity error =< 1% part. Most of applications can tolerance the 1% error.

3. Accel
   - Offset: Flip Accel in 6 directions parallel with ground surface. Offset (Accel-X) mg = [(X+) + (X-)]/2
   - Sensitivity: Flip Accel in 6 directions parallel with ground surface. Sensitivity Error (Accel-X) % = 100*{[(X+) - (X-)]/2 – 1}/1

Application Level Sensor Calibrations
(continued)

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4. Pressure sensor
    - Pressure sensor has been well calibrated in production. If end user still wants calibration, a good reference barometer is needed. In open area without direct air flow, do one point calibration.

5. Magnetic sensor
    - Before use any magnetic sensor related application, such like compass for heading, “Figure 8” calibration must be performed to compensate current magnetic field environment.
    - InvenSense can provide calibration algorithm. User can develop their own algorithm too.

Thank You