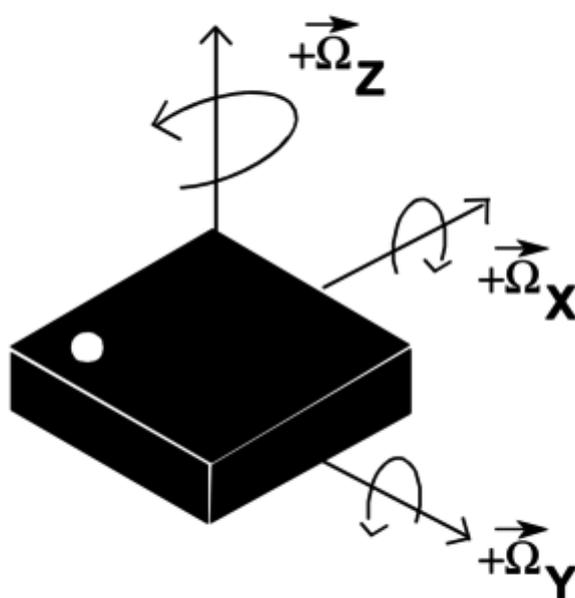




Comparing Gyroscope Datasheets

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<https://learn.adafruit.com/comparing-gyroscope-datasheets>

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Overview

Interpreting datasheets is an art form. Vendors use varying terminology for devices even inside the same company, and across companies the terminology and units can vary widely making it difficult to compare a set of otherwise similar devices to determine which one is the best match for your specific needs.

In this guide, we'll show you how you can compare MEMS gyroscopes from several vendors to determine which device has the least offset error, on the assumption that our goal is to find the most 'precise' or 'accurate' gyroscope within a specific price range for use in an AHRS or orientation system.

The Contenders

We'll be comparing the following three axis gyroscopes, which all have reasonably similar features and are in a comparable price range:

- [L3GD20](https://adafru.it/uXd) (<https://adafru.it/uXd>) 3 Axis MEMS Gyroscope - ST
- [FXAS21002C](https://adafru.it/uXe) (<https://adafru.it/uXe>) 3 Axis MEMS Gyroscope - NXP
- [LSM9DS0](https://adafru.it/uXf) (<https://adafru.it/uXf>) 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - ST
- [LSM9DS1](https://adafru.it/uXA) (<https://adafru.it/uXA>) 9 Axis* MEMES Sensor (Acce + Mag + Gyro) - ST
- [MPU-9250](https://adafru.it/uXB) (<https://adafru.it/uXB>) 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - Invensense
- [BMI055](https://adafru.it/uXC) (<https://adafru.it/uXC>) 6 Axis MEMS Sensor (Accel + Gyro) - Bosch (Used in the BNO055)

* The main goal of this comparison is selecting a gyroscope for an orientation system, so the all-in-one 9-axis devices were also included in the comparison.

Device Overview

The table below show the keys values for the gyroscopes mentionned above, just to illustrate their comparable features:

	Dynamic Range (dps)	ADC
L3GD20	250/500/2000	16 bits
FXAS21002C	250/500/1000/2000	16 bits
LSM9DS0	245/500/2000	16 bits
LSM9DS1	245/500/2000	16 bits
MPU-6250	250/500/1000/2000	16 bits
BMI055	125/250/500/1000/2000	16 bits

Zero Rate Levels

One important value in the gyroscope datasheet is the **Zero Rate Level** (sometimes called the **Offset Calibration Error**). This value indicates "the deviation of an actual output signal from the ideal output signal if no acceleration is present", or more clearly the output value that will be generated when there is no movement on the device.

This value is very important since a large zero rate level will give your system the impression that the device is moving, perhaps a significant amount, when it's in fact perfectly stationary.

The example output below shows what this translates to in the real world. This is taken from the LSM9DS0 set to 250 dps dynamic range. The sensor thinks that there is about -8.5 dps of angular velocity on the Z axis despite the fact that the device is completely immobile:

```

Accel X: -0.84      Y: -0.02      Z: 9.18      m/s^2
Magn. X: -0.04      Y: -0.05      Z: 0.42      gauss
Gyro X: -1.02      Y: -0.39      Z: -8.49     dps
Temp: 25.50 *C
*****
Accel X: -0.85      Y: -0.02      Z: 9.18      m/s^2
Magn. X: -0.04      Y: -0.05      Z: 0.42      gauss
Gyro X: -0.31      Y: -0.61      Z: -8.25     dps
Temp: 25.50 *C
*****
Accel X: -0.86      Y: -0.04      Z: 9.21      m/s^2
Magn. X: -0.04      Y: -0.05      Z: 0.42      gauss
Gyro X: -0.87      Y: -0.62      Z: -8.46     dps
Temp: 25.50 *C

```

While you can compensate for this value with a calibration offset if the error is linear, you generally want **the lowest possible zero rate level you can get**.

In the rest of this section we'll look at the datasheets for the devices we are examining to see what kind of promises the manufacturers can made for zero rate level.

L3GD20

The L3GD20 datasheet shows the zero rate level in dps (degrees per second), which is the unit we generally want to use. The value you want is listed as **DVoff** below:

Table 4. Mechanical characteristics⁽¹⁾

Symbol	Parameter	Test condition	Min.	Typ. ⁽²⁾	Max.	Unit
FS	Measurement range	User-selectable		±250		dps
				±500		
				±2000		
So	Sensitivity	FS = 250 dps		8.75		mdps/digit
		FS = 500 dps		17.50		
		FS = 2000 dps		70		
SoDr	Sensitivity change vs. temperature	From -40 °C to +85 °C		±2		%
DVoff	Digital zero-rate level	FS = 250 dps		±10		dps
		FS = 500 dps		±15		
		FS = 2000 dps		±75		
OffDr	Zero-rate level change vs. temperature	FS = 250 dps		±0.03		dps/°C
		FS = 2000 dps		±0.04		dps/°C
NL	Non linearity	Best fit straight line		0.2		% FS
Rn	Rate noise density			0.03		µps/(√Hz)
ODR	Digital output data rate			95/190/ 380/760		Hz
Top	Operating temperature range		-40		+85	°C

This provides a complete picture of the zero rate error across all output ranges of the sensor, which is nice. As you can see, the higher the output range the more the zero rate error increases (+/-250dps has a lower zero rate error than at +/-2000dps).

- @ +/- 2000 dps = 75 dps
- @ +/- 500 dps = 15 dps
- @ +/- 250 dps = 10 dps

FXAS21002C

The FXAS21002C shows the zero rate error as follows:

Parameter	Symbol	Test Conditions	Min	Typ	Max	Unit
ADC Resolution	n	—	—	16	—	bits
Full-scale range	FSR	CTRL_REG0[FS] = 00	—	±2000	—	dps
		CTRL_REG0[FS] = 01	—	±1000	—	
		CTRL_REG0[FS] = 10	—	±500	—	
		CTRL_REG0[FS] = 11	—	±250	—	
Sensitivity	S ₀	CTRL_REG0[FS] = 00	—	62.5	—	mdps/LSB
		CTRL_REG0[FS] = 01	—	31.25	—	
		CTRL_REG0[FS] = 10	—	15.625	—	
		CTRL_REG0[FS] = 11	—	7.8125	—	
Sensitivity Temperature Coefficient	ε _T	-40 to +85 °C	—	XY: ±0.08	—	%°C
				Z: ±0.01		
Zero-rate Offset	D ₀	CTRL_REG0[FS] = 00	—	±25	—	LSB
Zero-rate Offset, Post-Board Mount ¹	D _{0-PBM}	CTRL_REG0[FS] = 00	—	±50	—	LSB

Table continues on the next page...

This is less helpful than the L3GD20 above since we only have a single value, **DO** (or Zero-rate Offset), with the test condition shown as **CTRL_REG0[FS] = 00**. This means that this is probably the worst case scenario since **CTRL_REG0[FS] = 00** corresponds to +/- 2000 dps.

The value is also give in **LSB** rather than **DPS**, so we need to convert LSB to DPS to have a useful value, which we can do with the content of the Sensitivity entry above:

- At +/- **2000 dps** (CTRL_REG0[FS] = 00), +/- 25 LSB = 25 * 0.0625 = **1.5625 dps**
- At +/- **250 dps** (CTRL_REG0[FS] = 11), we have to assume this is still +/- 25 LSB, which = 25 * 0.0078125 = **0.1953 dps**

This starts to highlight some of the problems with datasheets, though. We have to make assumptions because the manufacturer hasn't provided all the information we might need, but generally the zero rate offset increases with sensitivity so this is a safe assumption in this particular case.

Manufacturer may attempt to hide unfavorable information by only selectively giving numbers, although in this case the values are very good even in the worst case scenario of +/-2000 dps.

To further complicate things, there are two zero offsets present, and the second value (**Post-Board Mount**) has this obscure footnote:

1. Post Board Mount Offset Specifications are based on an eight-layer PCB

I'm not sure what situation wouldn't have the device mounted on a PCB (???), but this doubles the zero offset error, which gives us the following final values:

- @ +/- **2000 dps** = **3.125 dps**

- @ +/- 500 dps = 0.78125 dps
- @ +/- 250 dps = 0.3906 dps

Tricky, although these are very good numbers so I'm not sure why NXP makes you jump through so many hoops to figure out the values, though some doubt remains since only 2000 dps is clearly documented.

LSM9DS0

The LSM9DS0 shows the gyroscope zero offset error in dps:

Table 3. Sensor characteristics (continued)

Symbol	Parameter	Test conditions	Min.	Typ. ⁽¹⁾	Max.	Unit
G_SoDr	Angular rate sensitivity change vs. temperature	From -40 °C to +85 °C		±2		%
LA_TyOff	Linear acceleration typical zero-g level offset accuracy ⁽³⁾⁽⁴⁾			±60		mg
G_TyOff	Angular rate typical zero-rate level	FS = 245 dps		±10		dps
		FS = 500 dps		±15		
		FS = 2000 dps		±25		
LA_TCOff	Linear acceleration zero-g level change vs. temperature	Max delta from 25 °C		±0.5		mg/°C
G_TCOff	Zero-rate level change vs. temperature			±0.05		dps/°C

These numbers surprised me since I was expecting the same values as the L3GD20, but apparently they are using a different device in the all in one L3GD20, with the all in one chip having a clear advantage (although only at 2000dps, the values are 245 and 500 are identical):

- @ +/- 2000 dps = 25 dps
- @ +/- 500 dps = 15 dps
- @ +/- 245 dps = 10 dps

LSM9DS1

The newer LSM9DS1 strangely gives us less information:

G_FS	Angular rate measurement range		±245		dps
			±500		
			±2000		
LA_So	Linear acceleration sensitivity	Linear acceleration FS = ±2 g	0.061		mg/LSB
		Linear acceleration FS = ±4 g	0.122		
		Linear acceleration FS = ±8 g	0.244		
		Linear acceleration FS = ±16 g	0.732		
M_GN	Magnetic sensitivity	Magnetic FS = ±4 gauss	0.14		mgauss/LSB
		Magnetic FS = ±8 gauss	0.29		
		Magnetic FS = ±12 gauss	0.43		
		Magnetic FS = ±16 gauss	0.58		
G_So	Angular rate sensitivity	Angular rate FS = ±245 dps	8.75		mdps/LSB
		Angular rate FS = ±500 dps	17.50		
		Angular rate FS = ±2000 dps	70		
LA_TyOff	Linear acceleration typical zero-g level offset accuracy ⁽²⁾	FS = ±8 g	±90		mg
M_TyOff	Zero-gauss level ⁽³⁾	FS = ±4 gauss	±1		gauss
G_TyOff	Angular rate typical zero-rate level ⁽⁴⁾	FS = ±2000 dps	±30		dps
M_DF	Magnetic disturbance field	Zero-gauss offset starts to degrade		50	gauss
Top	Operating temperature range		-40	+85	°C

1. Typical specifications are not guaranteed
2. Typical zero-g level offset value after soldering
3. Typical zero-gauss level value after test and trimming
4. Typical zero rate level offset value after MSL3 preconditioning

We only get one value at +/- 2000 dps sensitivity, with a note that this is after 'MSL3 preconditioning' (MSL3 stands for [Moisture Sensivity Level 3 \(https://adafru.it/uXD\)](https://adafru.it/uXD)). This is worse than the earlier LSM9DS0 which listed +/-25 dps at 2000 dps sensitivity, proving that newer isn't always better. On the positive side, 2000 dps sensitivity is the worst case scenario, so we can reasonably assume the other sensitivity values are similar or better:

- @ +/- 2000 dps = 30 dps
- @ +/- 500 dps = ???
- @ +/- 245 dps = ???

This seems to be impressive at +/- 1 dps (**Zero-rate Offset** above), but there isn't any information on the relationship to sensitivity. The safe assumption is that this is a best case scenario, meaning the slowest operating speed which is 125dps.

MPU-9250

The MPU-9250 lists the value in the most general of terms:

3.1 Gyroscope Specifications

Typical Operating Circuit of section 4.2. VDD = 2.5V, VDDIO = 2.5V, T_A=25°C, unless otherwise noted.

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Full-Scale Range	FS_SEL=0		±250		°/s
	FS_SEL=1		±500		°/s
	FS_SEL=2		±1000		°/s
	FS_SEL=3		±2000		°/s
Gyroscope ADC Word Length			16		bits
Sensitivity Scale Factor	FS_SEL=0		131		LSB/(°/s)
	FS_SEL=1		65.5		LSB/(°/s)
	FS_SEL=2		32.8		LSB/(°/s)
	FS_SEL=3		16.4		LSB/(°/s)
Sensitivity Scale Factor Tolerance	25°C		±3		%
Sensitivity Scale Factor Variation Over Temperature	-40°C to +85°C		±4		%
Nonlinearity	Best fit straight line; 25°C		±0.1		%
Cross-Axis Sensitivity			±2		%
Initial ZRO Tolerance	25°C		±5		°/s
ZRO Variation Over Temperature	-40°C to +85°C		±30		°/s
Total RMS Noise	DLFCFG=2 (92 Hz)		0.1		°/s-rms
Rate Noise Spectral Density			0.01		°/s/√Hz
Gyroscope Mechanical Frequencies		25	27	29	KHz
Low Pass Filter Response	Programmable Range	5		250	Hz
Gyroscope Startup Time	From Sleep mode		35		ms
Output Data Rate	Programmable, Normal mode	4		8000	Hz

Table 1 Gyroscope Specifications

They indicate an **Initial Zero Tolerance** of **+/-5 dps @ 25°C**, but then go on to say that this can vary up to **+/-30 dps** over temperature with no table to map changes in temperature to ZRO variation. Which means ... we probably just don't know without extensive testing ourselves! :(

We also have no idea what range this ZRO tolerance is at, and if it represents the best or worst case scenario or if it's linear across all ranges (highly unlikely).

This is the perfect case of a vendor (perhaps intentionally, perhaps not) hiding key but potentially unfavorable information from you. It also puts the burden squarely on your shoulders to fully evaluate the unit, and you have no recourse to go back to the manufacturer and point fingers if the numbers come out unfavorably in your final design since they've made only the vaguest possible commitment to you in the datasheet.

Assuming the best case scenario of a controlled temperature environment of 25°C (since 'assuming' is all we can do based on this data), and that there is no 'variation over temperature' included at 25°C, this gives us:

- @ +/- 2000dps = 5dps (???)
- @ +/- 500dps = 5dps (???)
- @ +/- 250dps = 5dps

I find these first two values extremely unlikely, though, since the values will change with sensitivity, and they are almost certainly giving you the best possible case, which is going to be +/-250dps and 5dps zero offset error.

I think we have to consider the values at 500dps and 2000dps 'unknown' and would require testing to determine.

BMI055

Finally, the BMI055 gives us the following information:

OUTPUT SIGNAL GYROSCOPE						
Parameter	Symbol	Condition	Min	Typ	Max	Unit
Sensitivity		Ta=25°C, R _{FS2000}		16.4		LSB/°/s
		Ta=25°C, R _{FS1000}		32.8		LSB/°/s
		Ta=25°C, R _{FS500}		65.6		LSB/°/s
		Ta=25°C, R _{FS250}		131.2		LSB/°/s
		Ta=25°C, R _{FS125}		262.4		LSB/°/s
Sensitivity tolerance		Ta=25°C, R _{FS2000}		±1		%
Sensitivity Change over Temperature	TCS	Nominal V _{DD} supplies -40°C ≤ T _A ≤ +85°C R _{FS2000}		±0.03		%/K
Sensitivity Supply Volt. Drift	S _{VDD}	T _A =25°C, V _{DD,min} ≤ V _{DD} ≤ V _{DD,max}		<0.4		%/V
Nonlinearity	NL	best fit straight line R _{FS1000} , R _{FS2000}		±0.05		%FS
g- Sensitivity		Sensitivity to acceleration stimuli in all three axis (frequency <20kHz)			0.1	°/s/g
Zero-rate Offset	Off Ω _x , Ω _y and Ω _z	Nominal V _{DD} supplies T _A =25°C, slow and fast offset cancellation off		±1		°/s
Zero-Ω Offset Change over Temperature	TCO	Nominal V _{DD} supplies -40°C ≤ T _A ≤ +85°C R _{FS2000}		±0.015		°/s per K
Zero-Ω Offset Supply Volt. Drift	OffΩ _{VDD}	T _A =25°C, V _{DD,min} ≤ V _{DD} ≤ V _{DD,max}		<0.1		°/s /V
Output Noise	n _{rms}	rms, BW=47Hz (@ 0.014°/s/√Hz)		0.1		°/s

This seems to be impressive at +/- 1 dps (**Zero-rate Offset** above), but there isn't any information on the relationship to sensitivity. The safe assumption is that this is a best case scenario, meaning the slowest operating speed which is 125dps.

Final Results

Compiling the zero offset error results in a table, we end up with:

	+/- 250 dps	+/- 500 dps	+/- 2000 dps
L3GD20	10 dps	15 dps	75 dps
FXAS21002C	0.3906 dps	0.78125 dps	3.125 dps
LSM9DS0	10 dps	15 dps	25 dps
LSM9DS1	??? <= 30 dps	??? <= 30 dps	30 dps
MPU-9250	5 dps	???	???
BMI055	? 1 dps ?	???	???

This shows us that at 250 dps and 500 dps, which will be common values in many simple orientation systems, most of these units are comparably noisy with significant zero offset errors. This will translate to your system appearing to constantly 'drift' when stationary and will need to be compensated in SW.

The clear exception, however, is the NXP FXAS21002C which blows the other devices out of the water with almost no meaningful zero offset error, almost requiring no compensation in SW. The BMI055 (used in the extremely popular BNO055 SoC) is a solid second, though the data is ambiguous across the full sensitivity range.

It would be easy to miss these details if you don't look attentively at the datasheet and do a bit of calculation yourself, but if you want to get the easiest to use data out of your gyroscope with limited zero offset error, the FXAS21002C looks to be the best place to start, though you of course need to evaluate other device characteristics, part availability, price, etc.

Updates: User Feedback

Thanks Brian Boschma for some feedback on this guide, specifically the following useful suggestions that users of the LSM9DSx series might find useful:

Positive Feedback : Hi, I have read your spec comparison on the 9DOF sensors you have characterized. Nicely done. As an extensive user of both the LSM9DS0 and LSM9DS1 I too have noted the spec for zero rate gyro drift as having seemingly gone up. In the product manufactured here we calibrate every unit for zero offset, so we capture the value at room temp. The DS0 and the DS1 seem to vary over the production spread about the same amount. The 3 sigma values for both at the 250dps setting is +/- 8 dps. The

average runs about +/- 5 dps. We used to build our own sensor boards. The device is sensitive to stress/strain in the mounting process and required close attention to planarity of the board surface. For example no via's beneath the chip. No solder mask beneath the chip. We are finding that the Adafruit Flora boards do a good job of staying within spec of the manufacturers claimed drift rates. One interesting glitch in going from the DS0 to the DS1 is the magnetometer's offset in the Z Axis. The DS0's always were in the range of about +500 to -500, while the DS1 all range (of the 100 or so measured) between +1000 down to +200. Something changed in the design,, and or software had to change to accommodate this.

Related Links

Part List

- [L3GD20 \(https://adafru.it/uXd\)](https://adafru.it/uXd) 3 Axis MEMS Gyroscope - ST
- [FXAS21002C \(https://adafru.it/uXe\)](https://adafru.it/uXe) 3 Axis MEMS Gyroscope - NXP
- [LSM9DS0 \(https://adafru.it/uXf\)](https://adafru.it/uXf) 9 Axis* MEMS Sensor (Accel + Mag + Gyro) - ST
- [LSM9DS1 \(https://adafru.it/uXA\)](https://adafru.it/uXA) 9 Axis* MEMES Sensor (Acce + Mag + Gyro) - ST
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