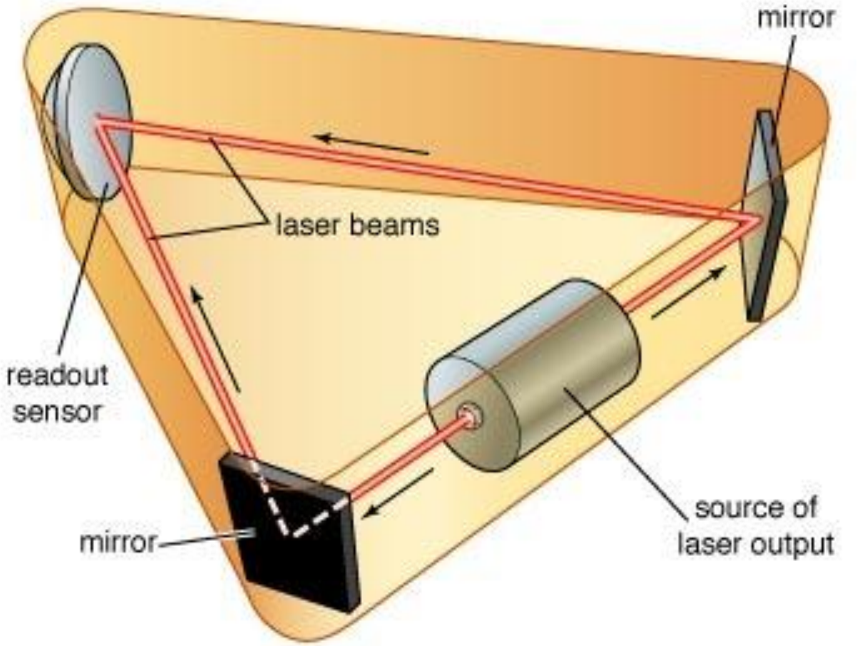
Fiber Optic Gyroscopes

Instrumentation: Sensors and Signals

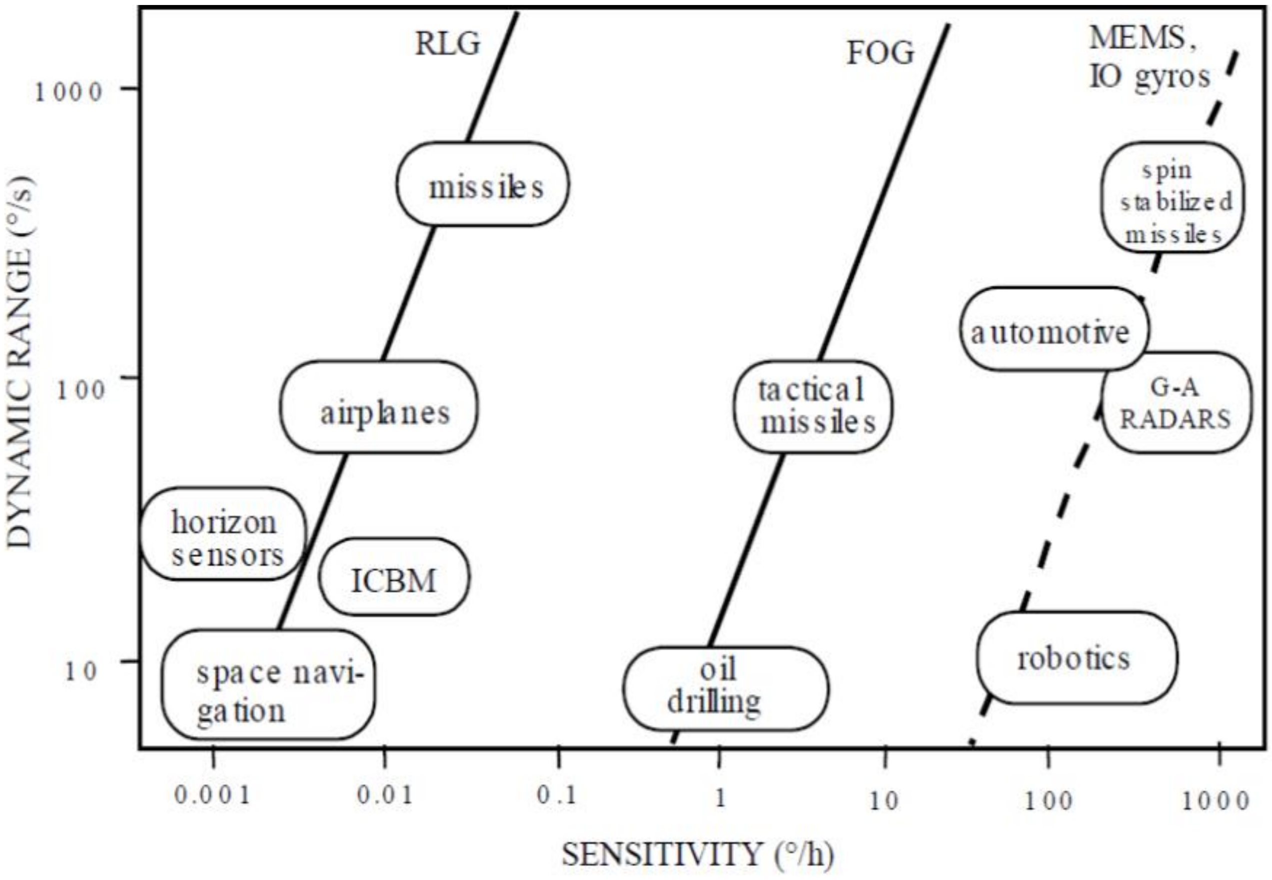
KVH fiber optic gyros, like the DSP-3000, offer the reliability, accuracy, and durability necessary to guide remotely operated and autonomous vehicles under water and on land.

History

- Developed in the 1980s as an alternative to Laser Ring Gyroscopes.
  - More compact
  - Less sensitive



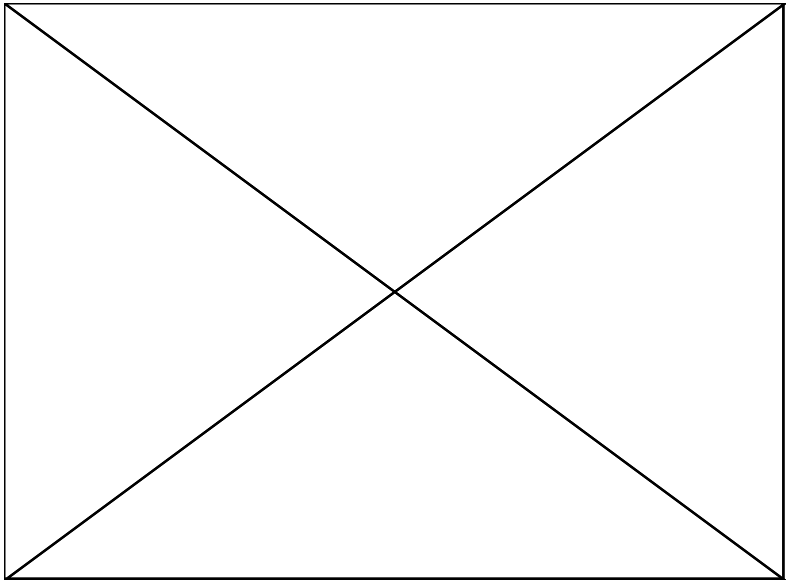
Comparison and applications

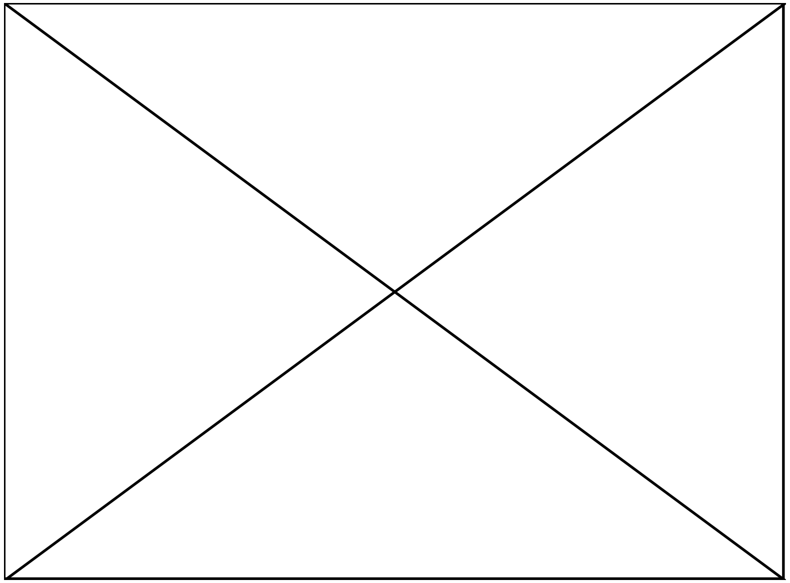


WHOI Puma

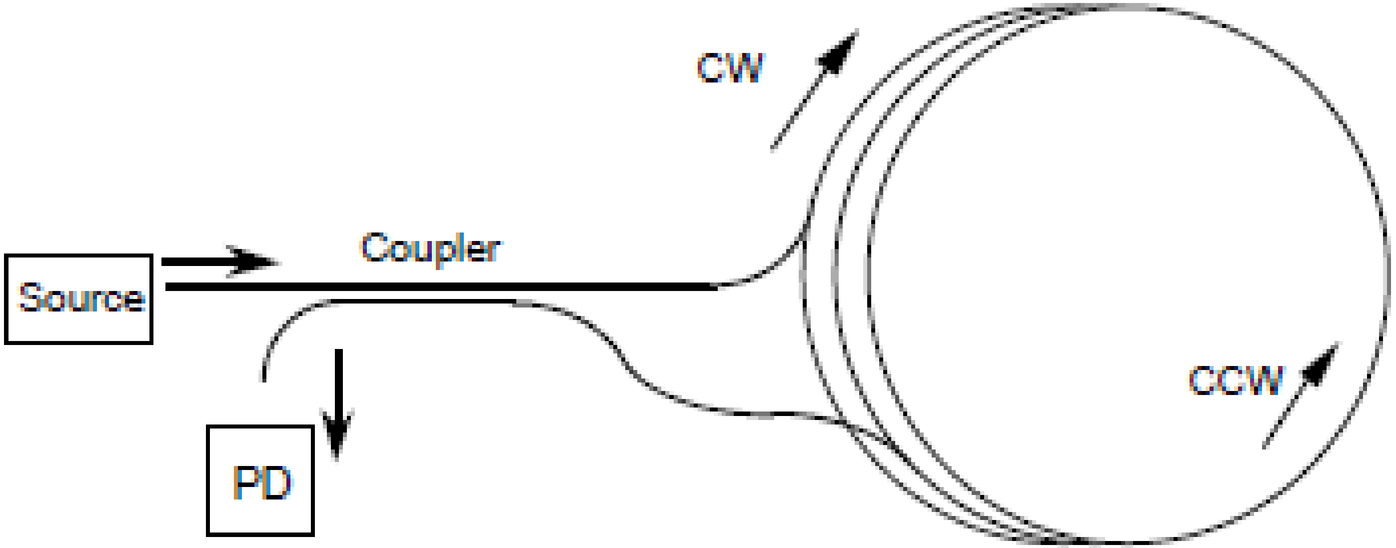
How does a RLG work?

- Based on the Sagnac effect, like the FOG



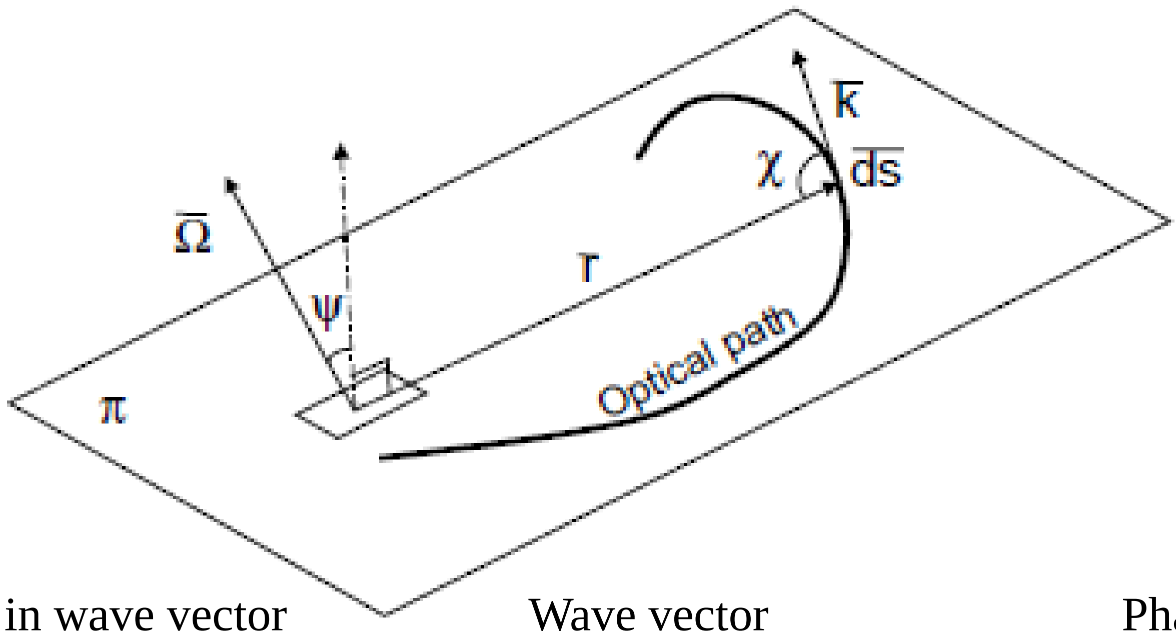


Basic FOG configuration



Classical explanation

- Basics



Variation in wave vector

$$\Delta k = k\frac{\bar{v}}{c}$$

Wave vector

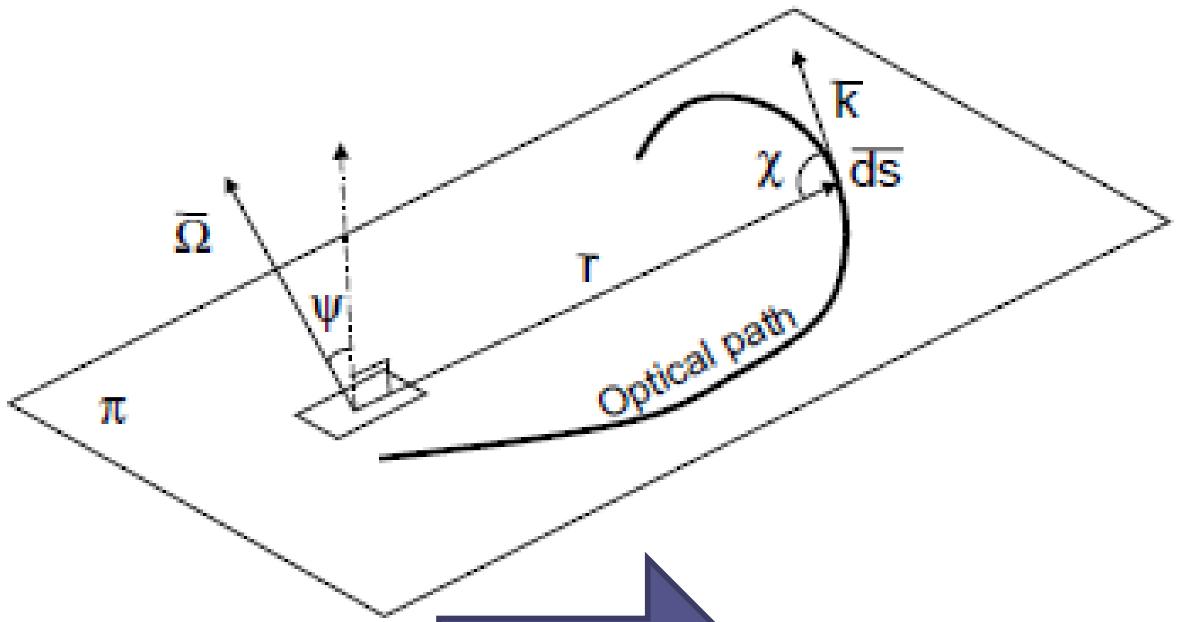
$$\bar{v} = \bar{\Omega} \times \bar{r}$$

Phase shift

$$d\phi = \Delta\bar{k} \cdot d\bar{s}$$

Classical explanation

- Phase difference



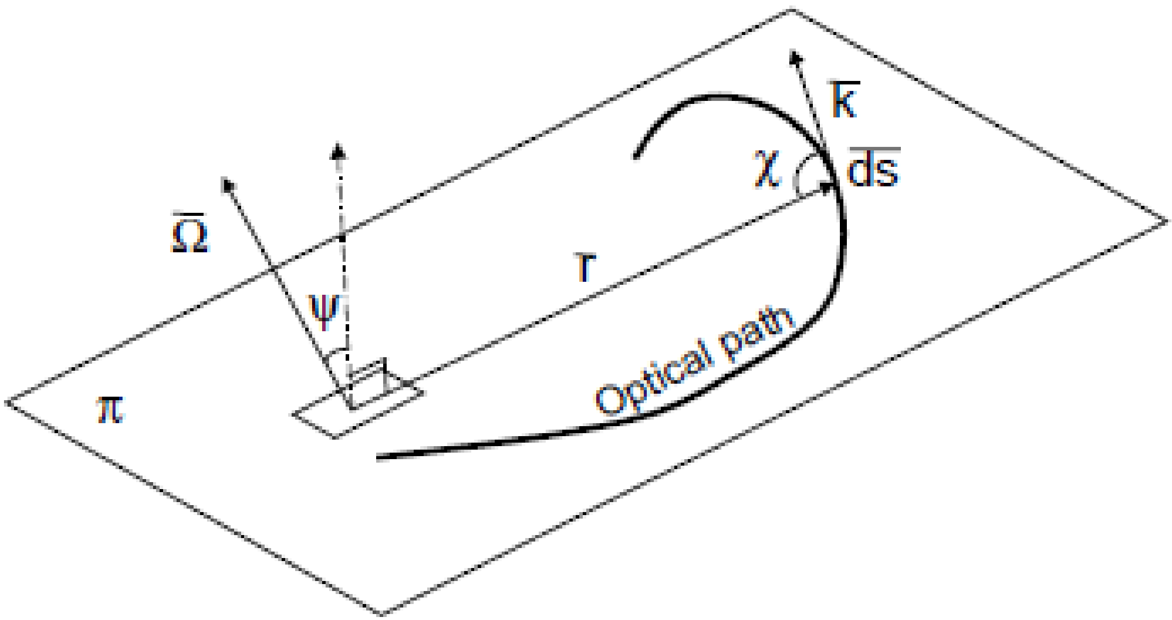
$$d\phi = \frac{[\bar{\Omega} \times \bar{r} \cdot d\bar{s}]k}{c}$$

Using Geometry

$$d\phi = \left(\frac{k}{c}\right)\Omega cos\Psi r sin\chi \mathrm{ds}$$

Classical explanation

- Integrating phase difference along the path length



$$\int r sin\chi\, ds = 2AN$$

$$\Delta\phi = \left(\frac{k}{c}\right)\Omega cos\Psi 2AN$$

FOG Equation

$$\Delta\phi = \left(\frac{k}{c}\right)\Omega cos\Psi 2AN$$

$$\phi_s = 2\Delta\phi$$

$$k = 2\pi/\lambda$$

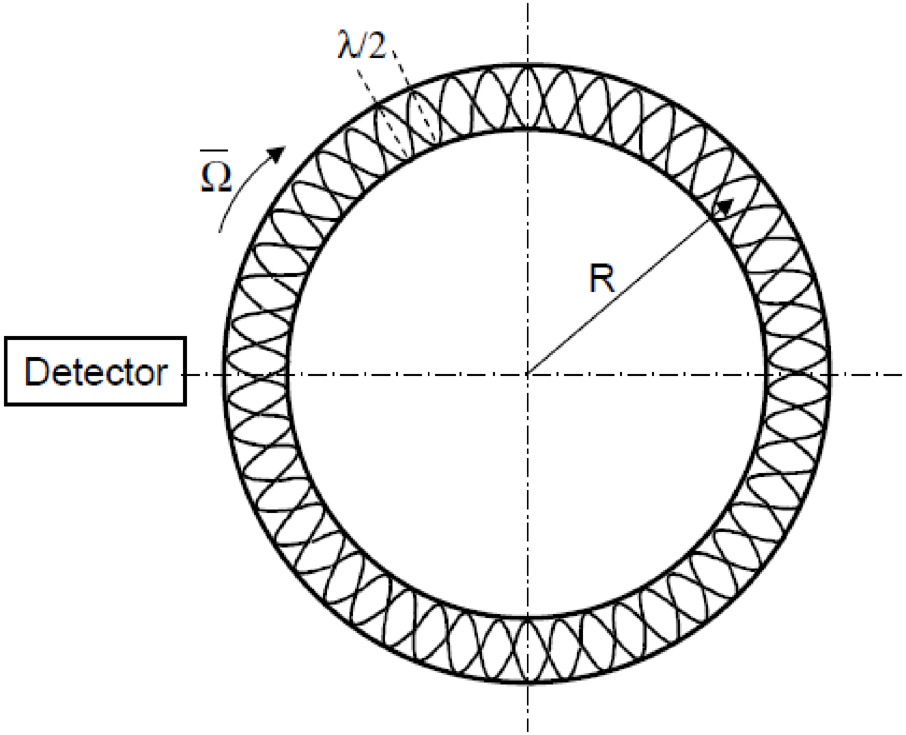
Angular wavenumber

$$\Omega_p = \Omega\cos\Psi$$

$$\phi_s = \frac{8\pi AN\Omega_p}{\lambda c}$$

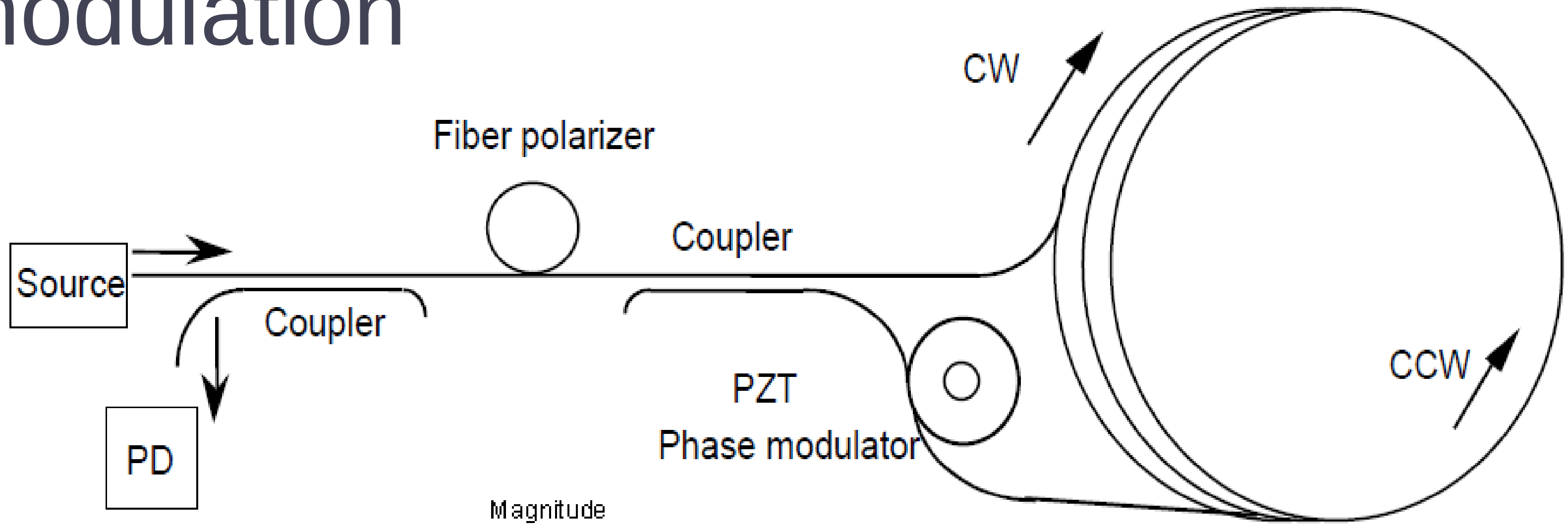
Relativistic Explanation

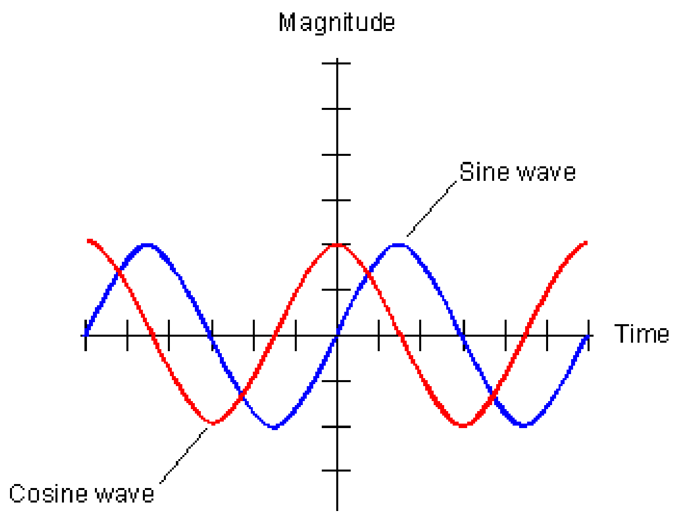
- $\Delta f = 2\Omega_p \frac{R}{\lambda}$
- $\frac{\phi_s}{2\pi} = \Delta f \frac{2\pi R}{c}$
- $\phi_s = \frac{8\pi A\Omega_p}{\lambda c}$*



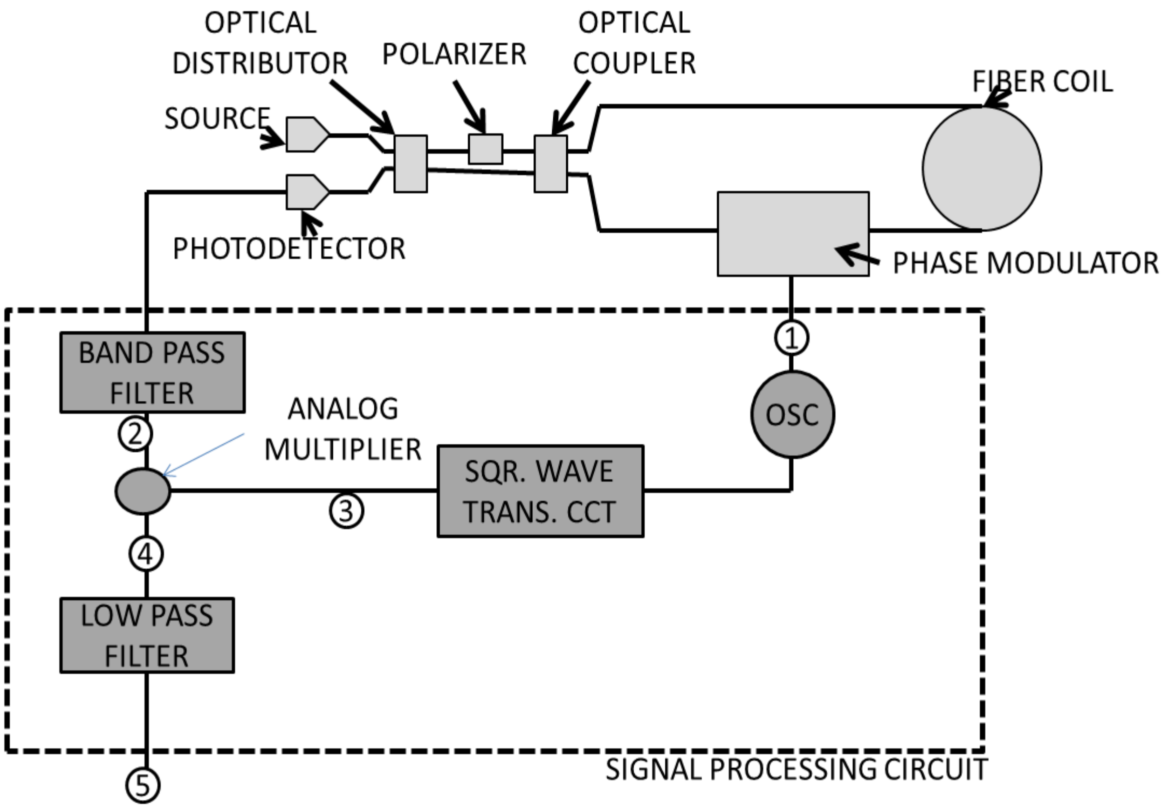
*Only correct if the detector is moving with the gyroscope

Open loop configuration with phase modulation





Analog signal implementation

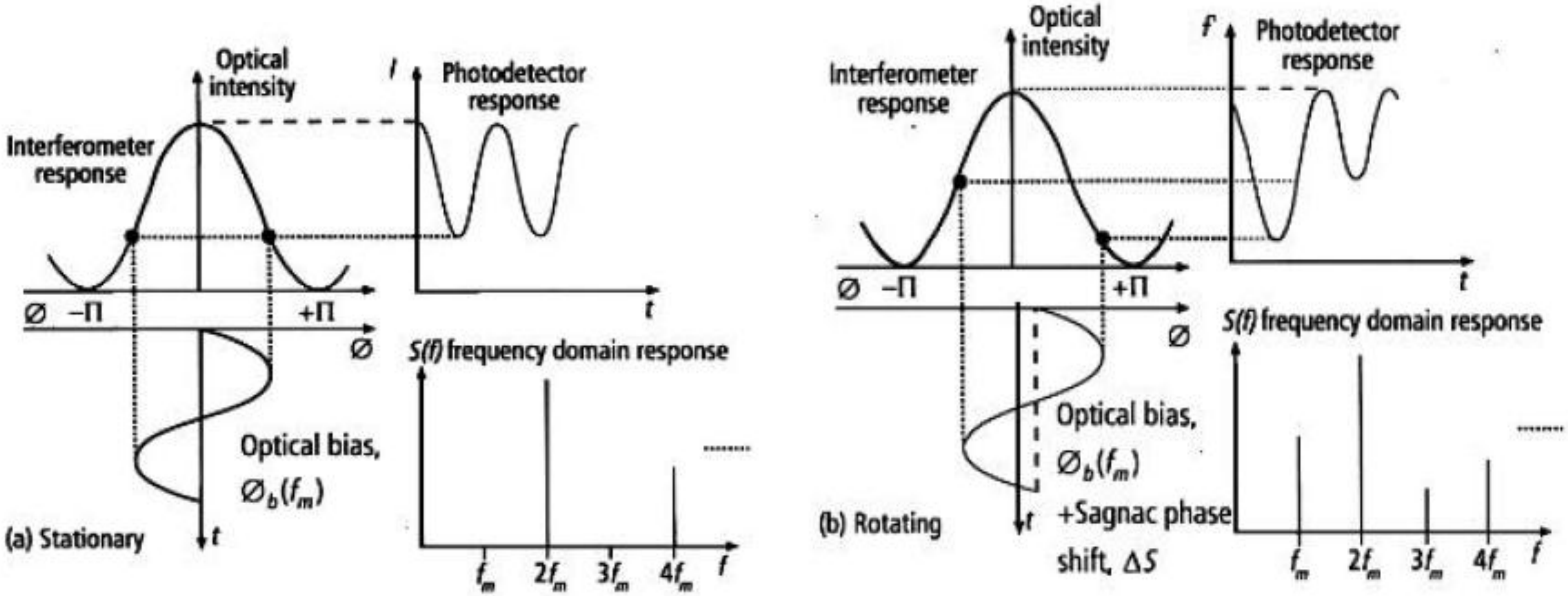


Analog circuit implementation

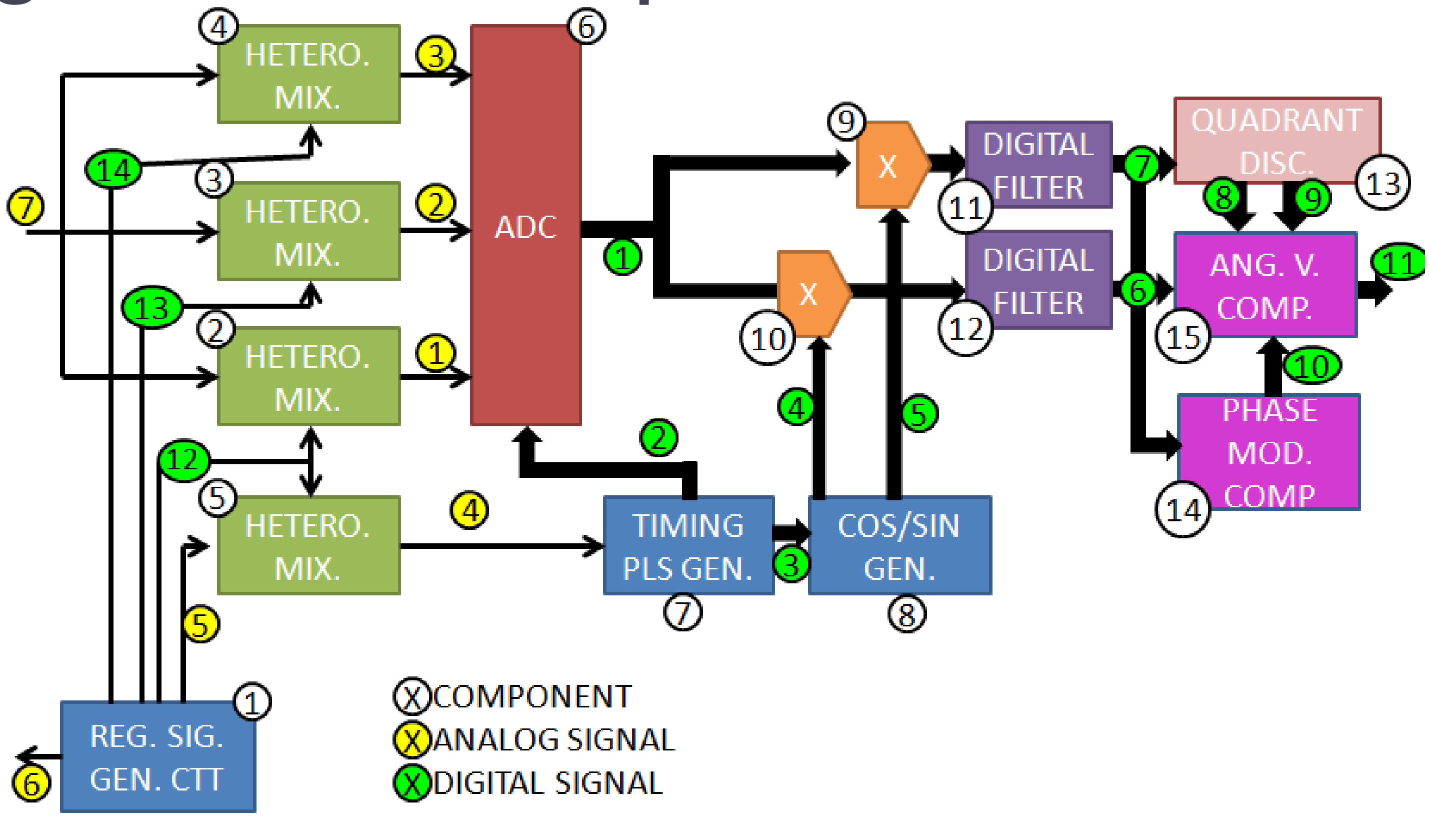
$$\frac{I}{I_0} = 1 + \left[J_0(\Phi_m) + 2\sum_{k-1}^{\infty} J_{2k}(\Phi_m) cos2k\omega_m t \right] cos\phi_s$$
$$+ \left[2\sum_{k-1}^{\infty} J_{2k-1}(\Phi_m)\cos(2k-1)\omega_m t \right] sin\phi_s$$

- Issues:
  - Fluctuations in offset voltages lower bias stability.
  - Detectable angular velocity is limited to $\pm\frac{\pi}{2} rad$
  - Linearity and scale factor stability are easily deteriorated by fluctuations in photodetector intensity.

Signal Processing Used



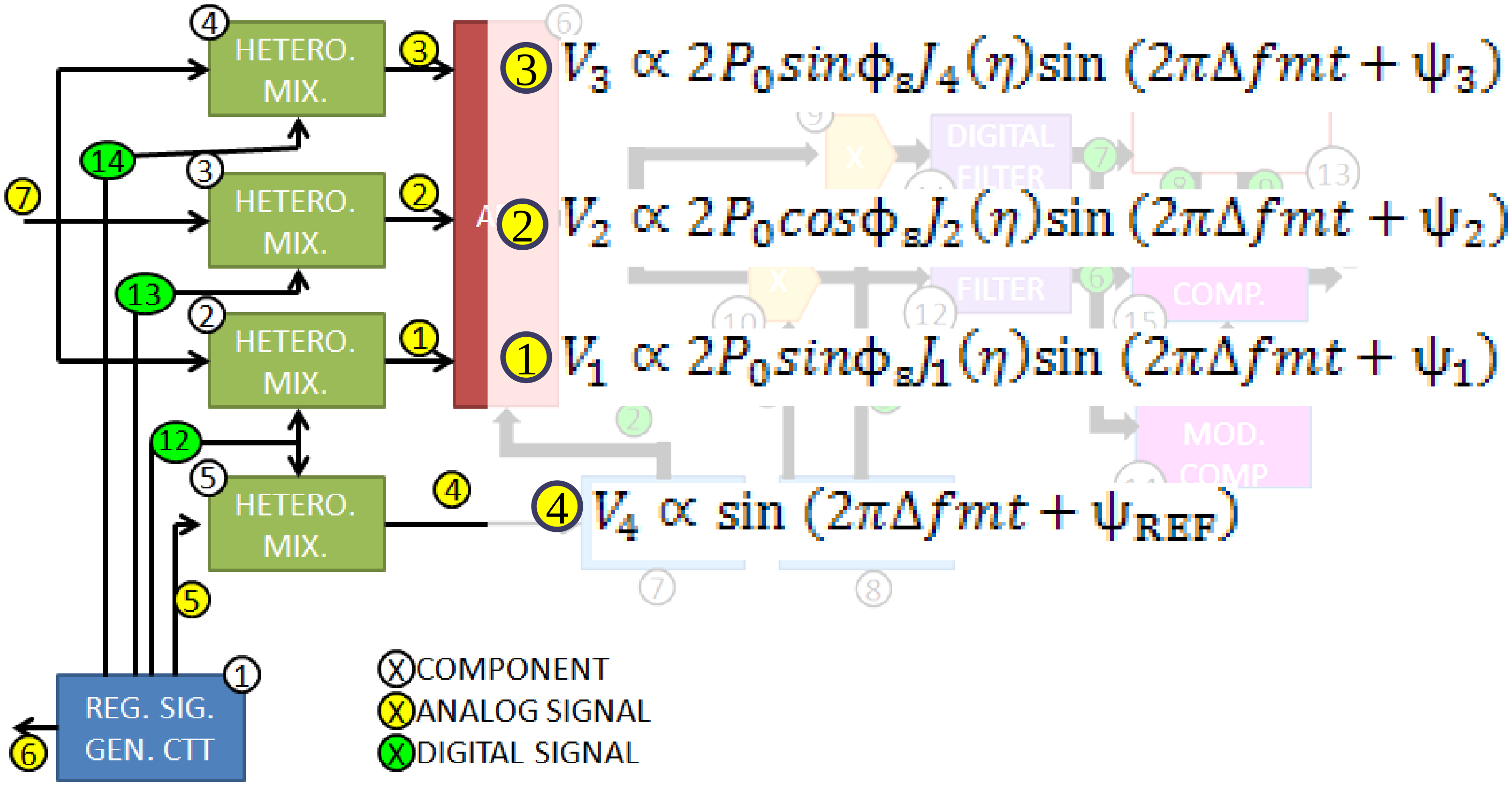
Digital circuit implementation



Digital signal processing apparatus. First to forth heterodyne mixers (2, 3, 4 and 5), an ADC (6), a timing pulse generating unit (7), a cosine/sine signal generating unit (8), first and second digital multipliers (9, 10), first and second digital filters (11, 12), a quadrant discriminating unit (13), an angular velocity computing unit (15), a phase modulation index computing unit (14) and a reference signal generating circuit (1).

Digital circuit implementation

Isolate different harmonics



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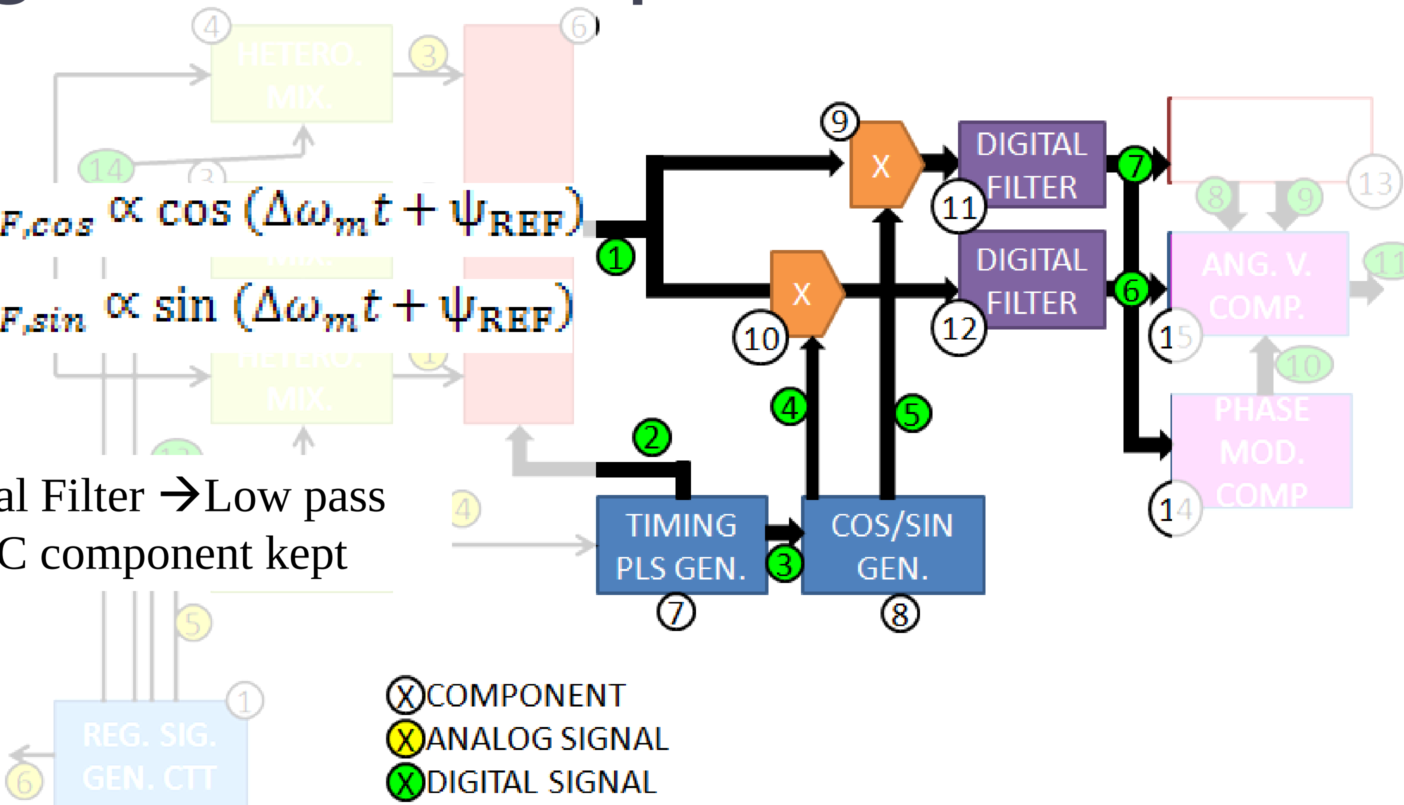
Digital circuit implementation

(4) $V_{REF,cos} \propto \cos(\Delta\omega_m t + \psi_{REF})$

(5) $V_{REF,sin} \propto \sin(\Delta\omega_m t + \psi_{REF})$

Digital Filter →Low pass
=> DC component kept



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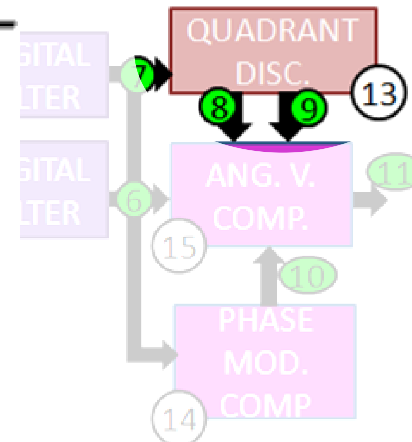
Digital circuit implementation

ϕ s[rad]	sign of signal (101)	sign of signal (102)	mark of quadrant (M)
⋮	⋮	⋮	⋮
$-4\pi \sim -7\pi/2$	Positive	Positive	2
$-7\pi/2 \sim -3\pi$	Positive	Negative	3
$-3\pi \sim -5\pi/2$	Negative	Negative	0
$-5\pi/2 \sim -2\pi$	Negative	Positive	1
$-2\pi \sim -3\pi/2$	Positive	Positive	2
$-3\pi/2 \sim \pi$	Positive	Negative	3
$-\pi \sim -\pi/2$	Negative	Negative	0
$-\pi/2 \sim 0$	Negative	Positive	1
$0 \sim \pi/2$	Positive	Positive	2
$\pi/2 \sim \pi$	Positive	Negative	3
$\pi \sim 3\pi/2$	Negative	Negative	0
$3\pi/2 \sim 2\pi$	Negative	Positive	1
$2\pi \sim 5\pi/2$	Positive	Positive	2
$5\pi/2 \sim 3\pi$	Positive	Negative	3
$3\pi \sim 7\pi/2$	Negative	Negative	0
$7\pi/2 \sim 4\pi$	Negative	Positive	1
⋮	⋮	⋮	⋮



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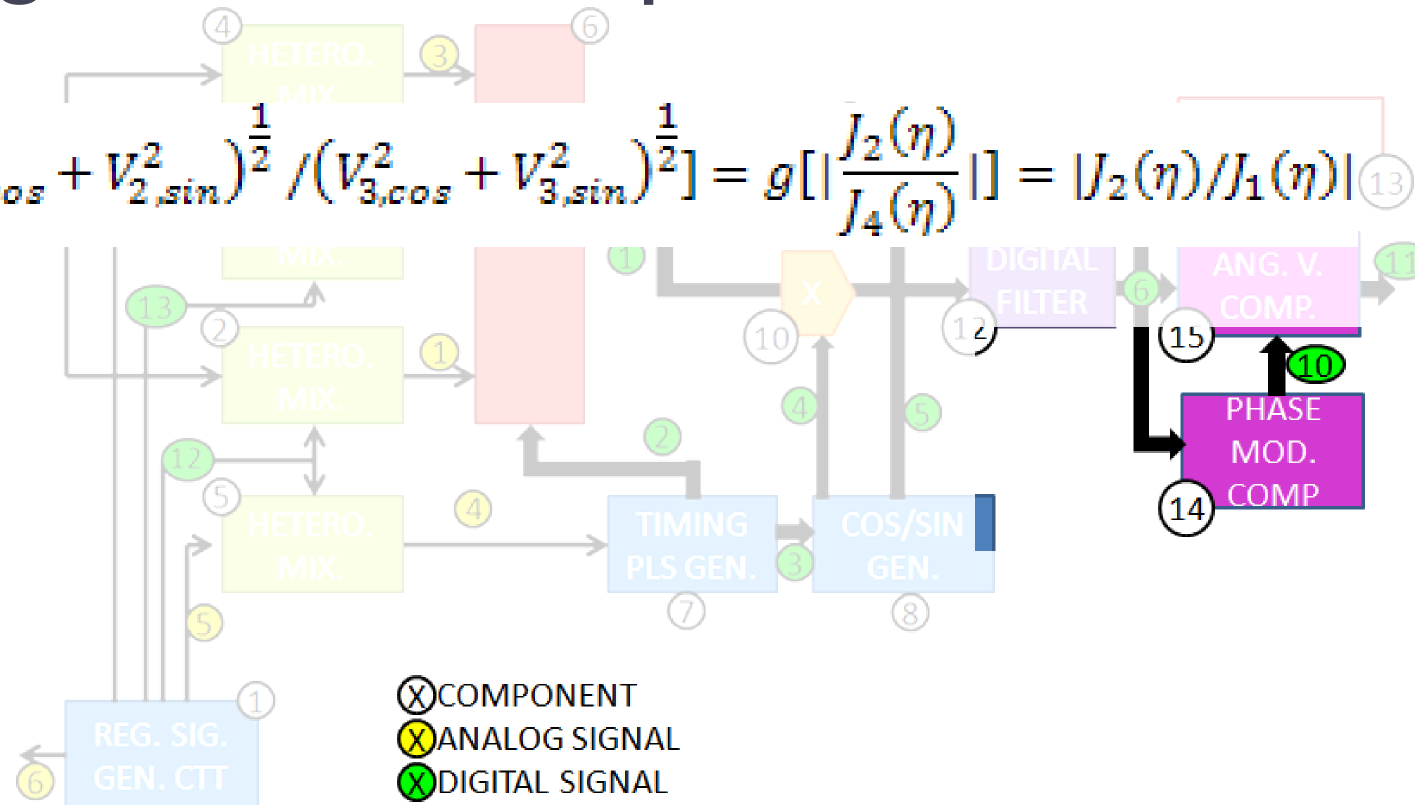
Digital circuit implementation

$$g[V_{2,cos}^2 + V_{2,sin}^2)^{\frac{1}{2}} / (V_{3,cos}^2 + V_{3,sin}^2)^{\frac{1}{2}}] = g[|\frac{J_2(\eta)}{J_4(\eta)}|] = |J_2(\eta)/J_1(\eta)|$$



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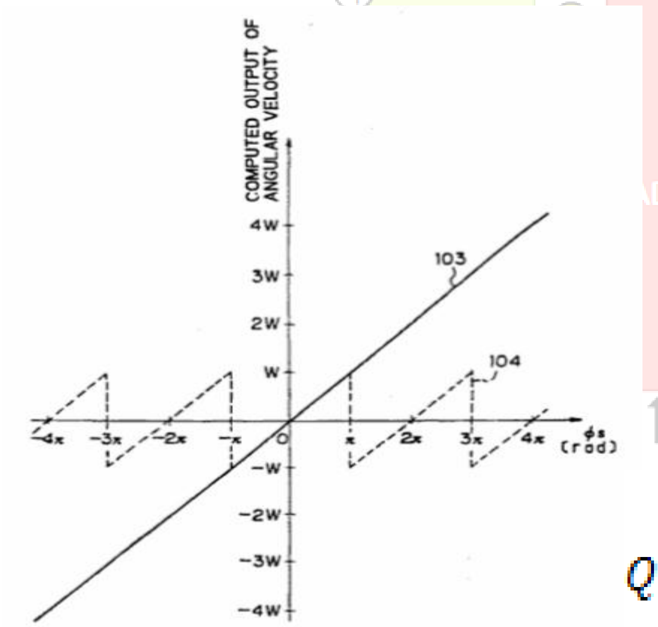
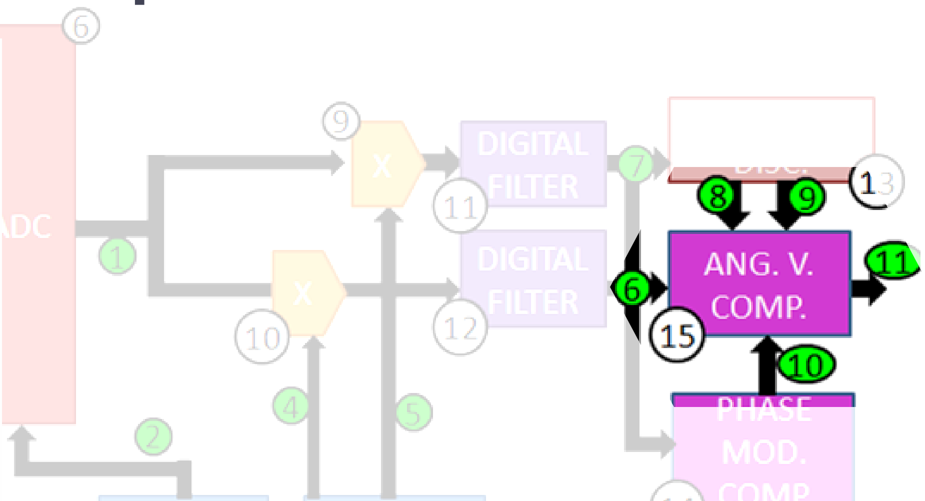
Digital circuit implementation





$$Q = \left|\frac{J_2(\eta)}{J_1(\eta)}\right| \times \left|\frac{\left(V_{1,cos}^2 + V_{1,sin}^2\right)^{\frac{1}{2}}}{\left(V_{2,cos}^2 + V_{2,sin}^2\right)^{\frac{1}{2}}}\right| = |\tan(\phi_s)|$$

Digital signal processing apparatus. First to forth heterodyne mixers (2, 3, 4 and 5), an ADC (6), a timing pulse generating unit (7), a cosine/sine signal generating unit (8), first and second digital multipliers (9, 10), first and second digital filters (11, 12), a quadrant discriminating unit (13), an angular velocity computing unit (15), a phase modulation index computing unit (14) and a reference signal generating circuit (1).

Quantum Theoretical Performance Limit

$$I_{shot} = \sqrt{2eI_0B}$$

$$\phi_n = \frac{I_{shot}}{I_0} = \sqrt{\frac{2eB}{I_0}}$$

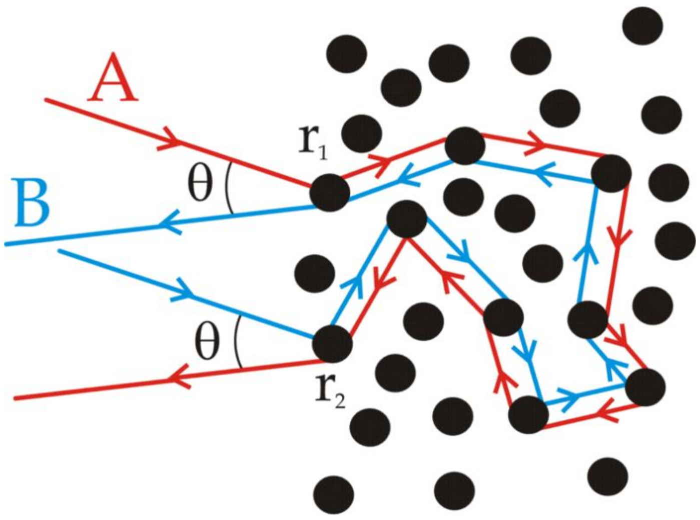
$$NE\Omega = \frac{\lambda c}{8\pi AN}\sqrt{\frac{2hfB}{P_0\eta}}$$

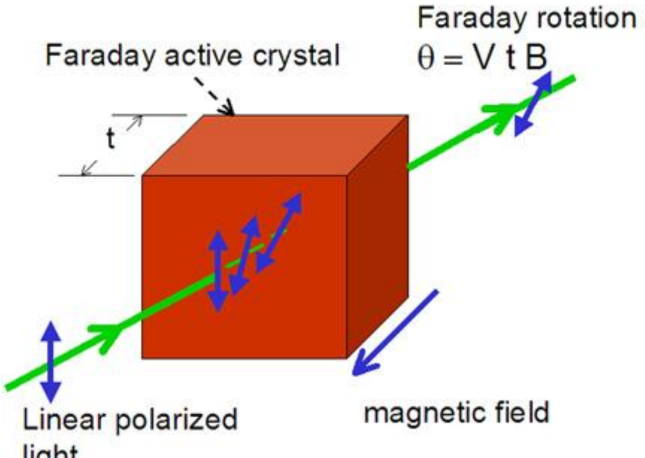
Theoretically

$$34 \cdot 10^{-9} rad/s$$

Sources of nonidealities

- Nonreciprocity – differences in the optical paths of the counter propagating waves
- Polarization
- Backscattering
- Magneto-optical Faraday effect





Case Study: RA2100 (KVH Industries)

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E•Core 2000 Series Fiber Optic Gyros Technical Specifications

Performance		RA2030	RA2100	RD2030	RD2100
Input Rate (max)	± °/sec	30	100	30	100
Resolution Rate	°/sec	0.014	0.014	0.004[1]	0.004[1]
Scale Factor	mv/°/sec	66.7	20	-	-
	°/bit	-	-	0.0000916	0.000305
Nonlinearity	%, rms	0.2	0.5	0.2	0.5
Full Temp	%, p-p	1	2	1	2
Bias Stability					
Constant Temp	°/sec, 1σ	0.0006	0.002	0.0006	0.002
Full Temp	°/sec, p-p	0.06	0.2	0.06	0.2
	°/sec, typ.	0.012	0.04	0.012	0.04
Repeatability	°/sec, p-p	0.006	0.02	0.006	0.02
	°/sec, typ.	0.0012	0.004	0.0012	0.004

Source: ftp://ftp.uni-duisburg.de/Hardware/KVH/ec2k-b.pdf

Performance

Angle Random Walk (noise):	5 °/hr/rt-Hz 0.08 °/rt-hr
Instantaneous Bandwidth:	100 Hz
Turn-on Time:	1 sec

Output

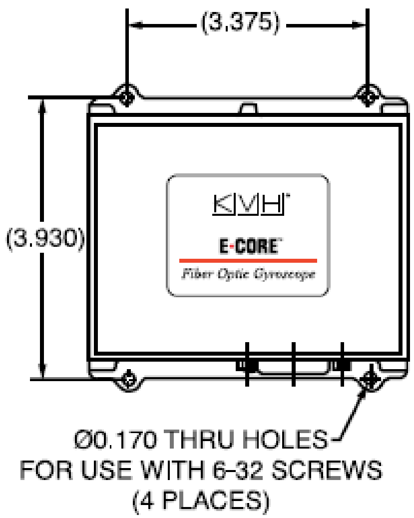
Analog:	+2.5 VDC (zero rotation) ±2 V, into ≥10K Ohm
Digital:	16 bits, serial, RS232 (RS422 optional) 9600 Baud
Update Rate:	10 Hz (optional 100 Hz)

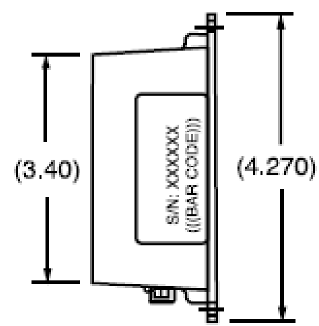
Physical

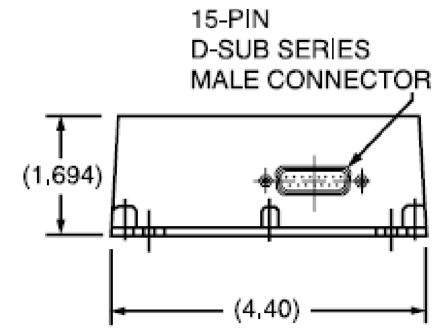
Input Voltage:	12 VDC nominal (24 VDC optional) transient & reverse voltage protected
Power Consumption:	2 watts (analog) 3 watts (digital)
Weight:	0.75 lbs. (0.34 kg)
Size:	4.40" x 4.27" x 1.63" (112 x 108 x 41mm)
Connector Type:	15-pin subminiature D-sub (DA15P)

Environmental

Operating Temperature:	-40°C to +75°C
Storage Temperature:	-50°C to +85°C
Shock:	90 G
EMI/RFI:	CE, IEC 9081-2,3,4
MTBF:	50,000 hour







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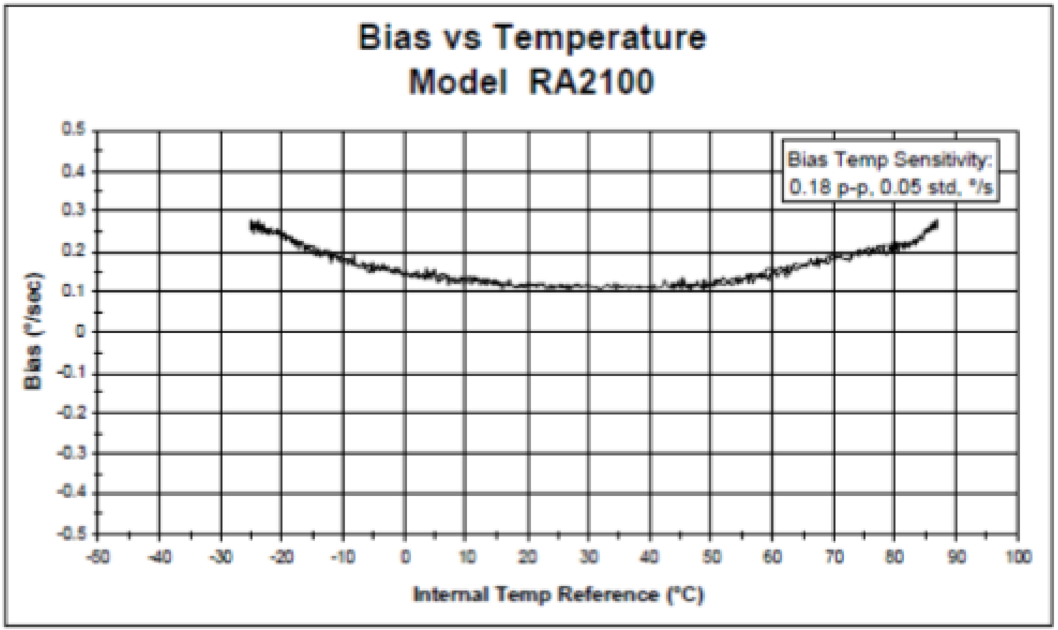
Case Study: RA2100 (KVH Industries)



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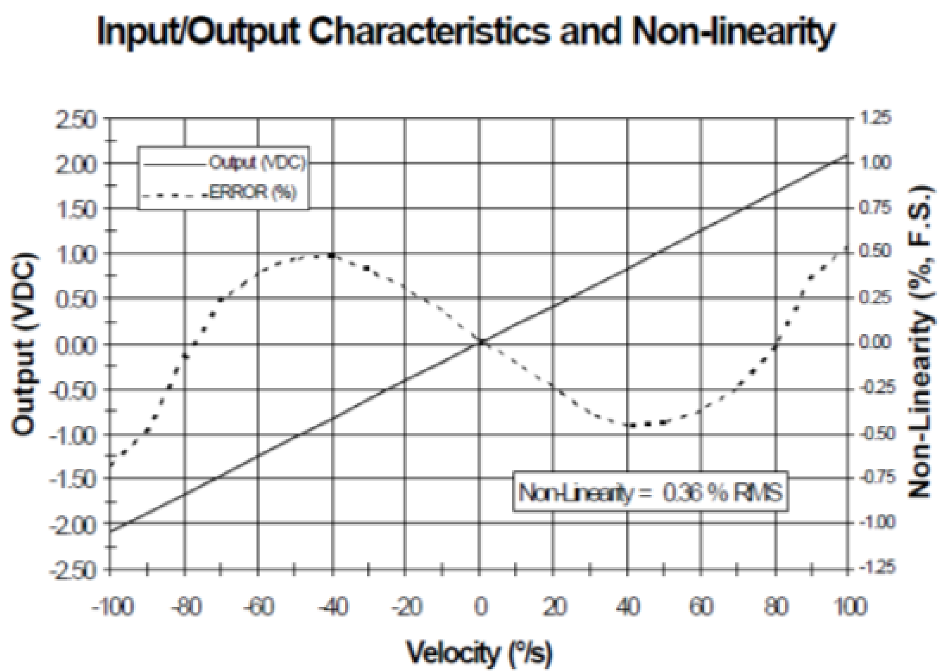

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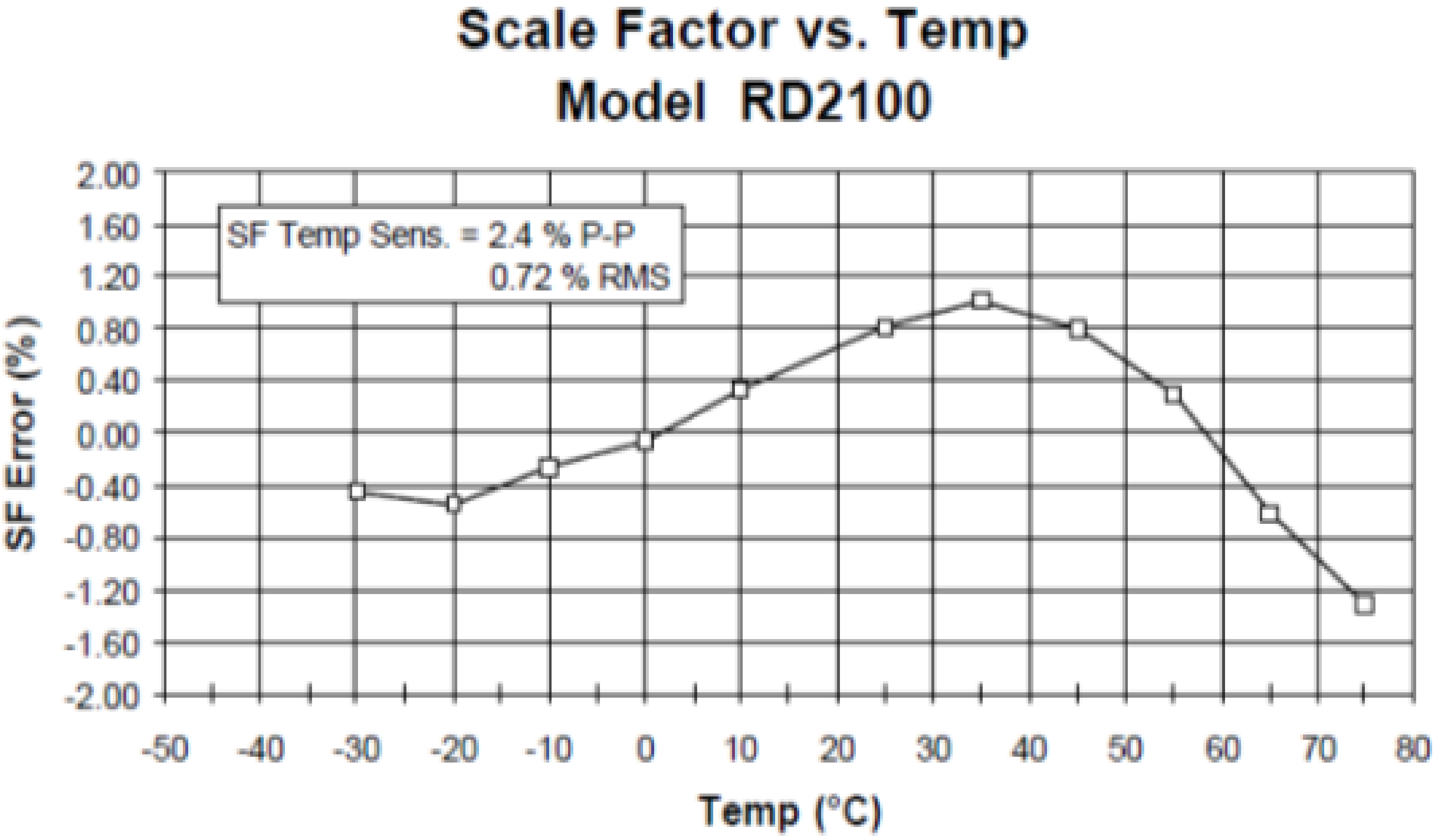

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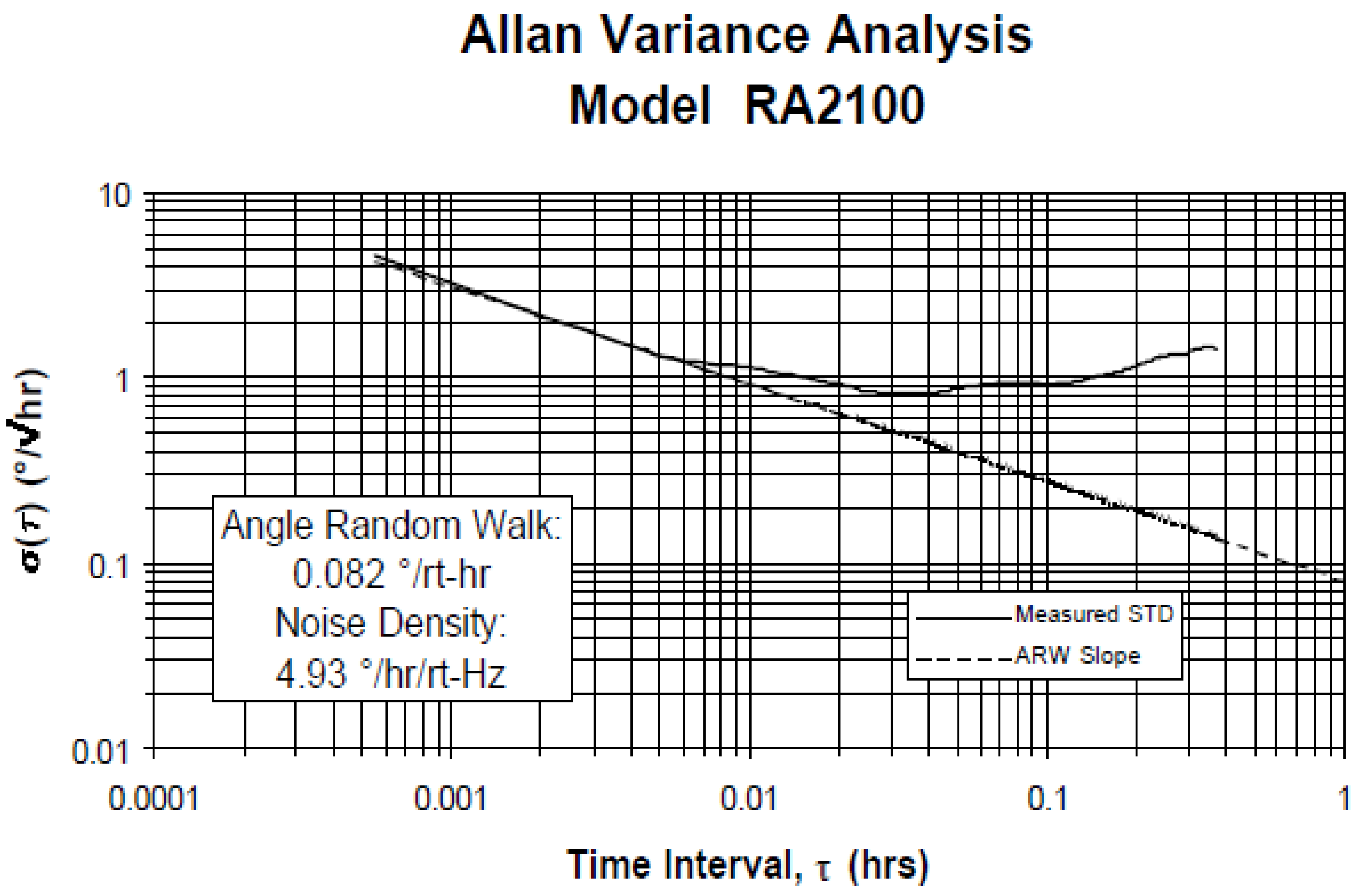

Questions?