AXTAL ADVANCED XTAL PRODUCTS

Phase Noise under Vibration Theory and Test Results

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Content

- Theoretical Background
  - Sensitivity to forces and acceleration
  - Sensitivity to vibrations
- Experimental Results
  - AXIOM75-16-60 MHz with AT-cut (HC-43/U)
  - AXIOM75-16A-60 MHz with SC-cut (HC-35/U)
  - AXIOM35-14A-100 MHz with SC-cut (HC-43/U)
  - 100 MHz with SC-cut (HC-43/U) other supplier

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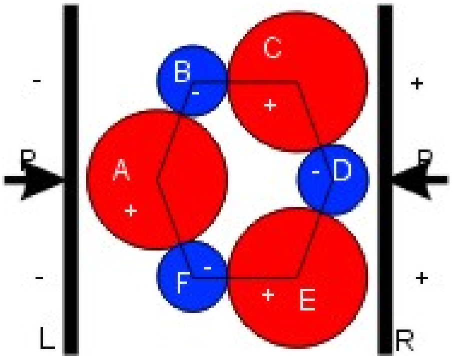
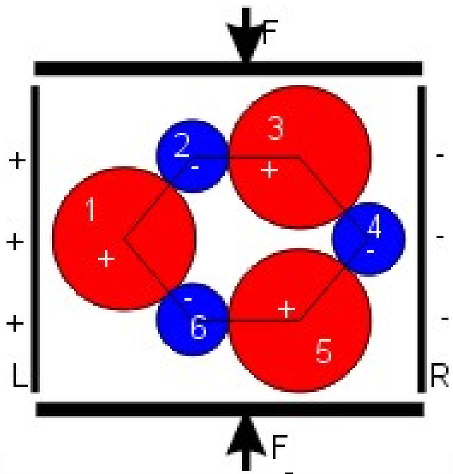
  - 100 MHz with SC-cut (HC-43/U) other supplier

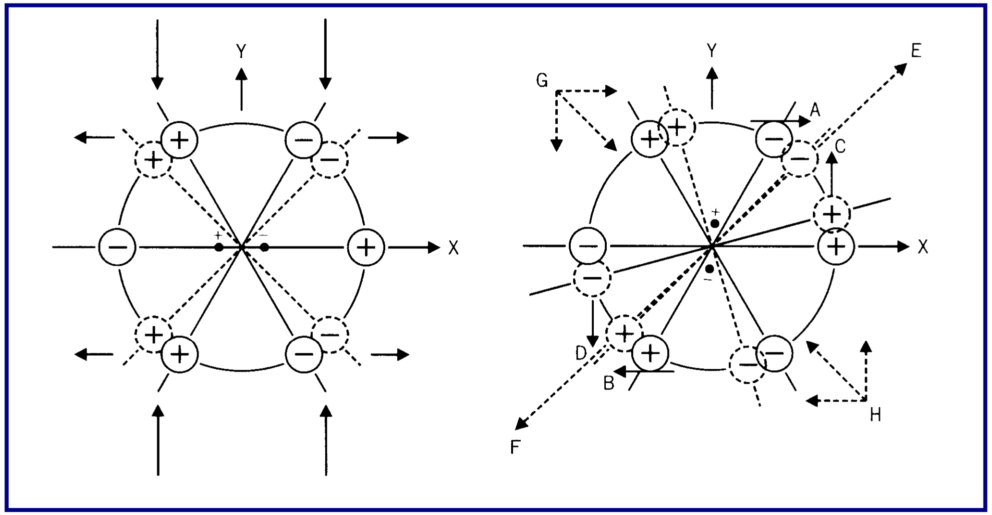
Piezo-electrial Effect



Longitudinal PE



Transversal PE



Mechanical force (pressure) creates electrical charge (voltage) and vice versa

Most popular cuts

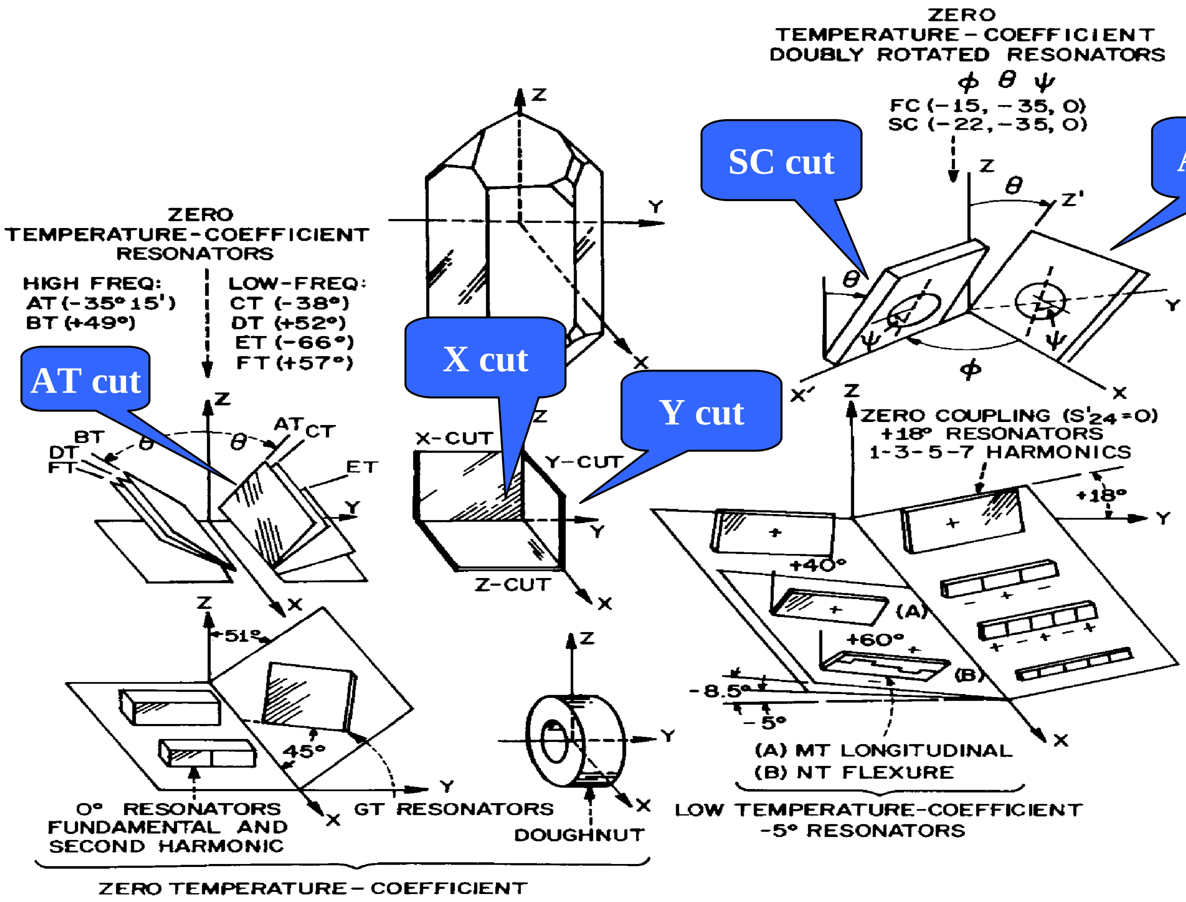
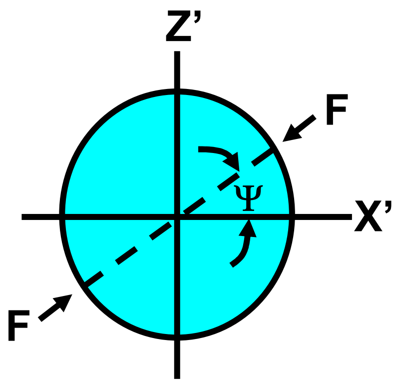


FIG. 2.2-6 Principal cuts of right-hand alpha quartz.

Influence of lateral forces

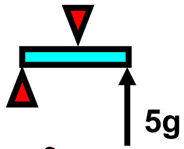


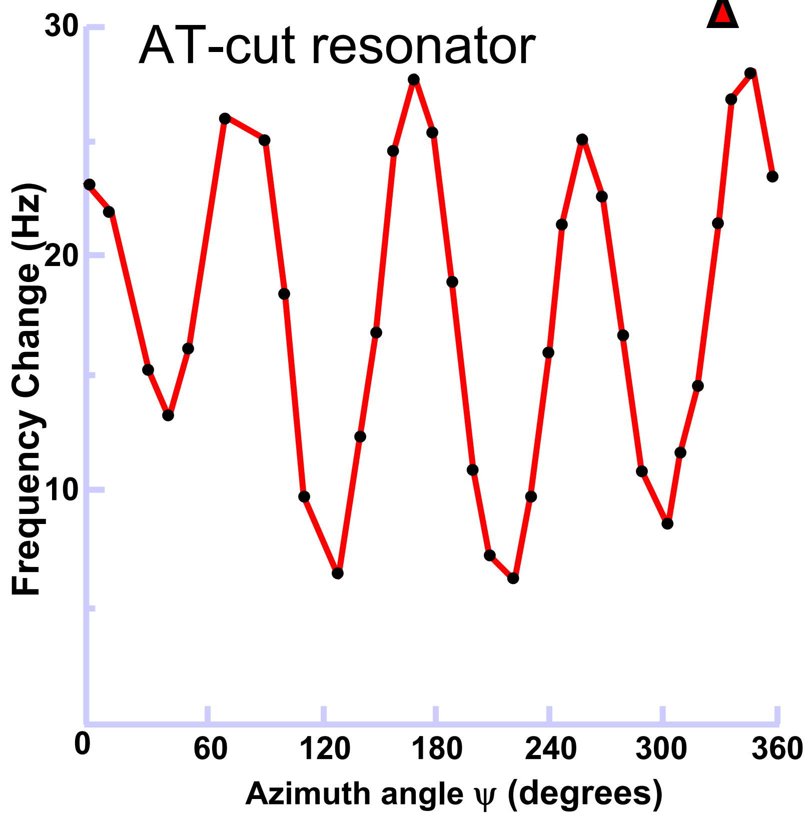
Example:
Resonator 5 MHz 3rd overtone, 14 mm diameter

$$\left(\frac{\Delta f}{f}\right)_{Max} = \begin{cases} 3 \text{ ppm/N} & \text{for AT-cut resonator} \\ 1.7 \text{ ppm/N} & \text{for SC-cut resonator} \end{cases}$$

Influence of bending forces

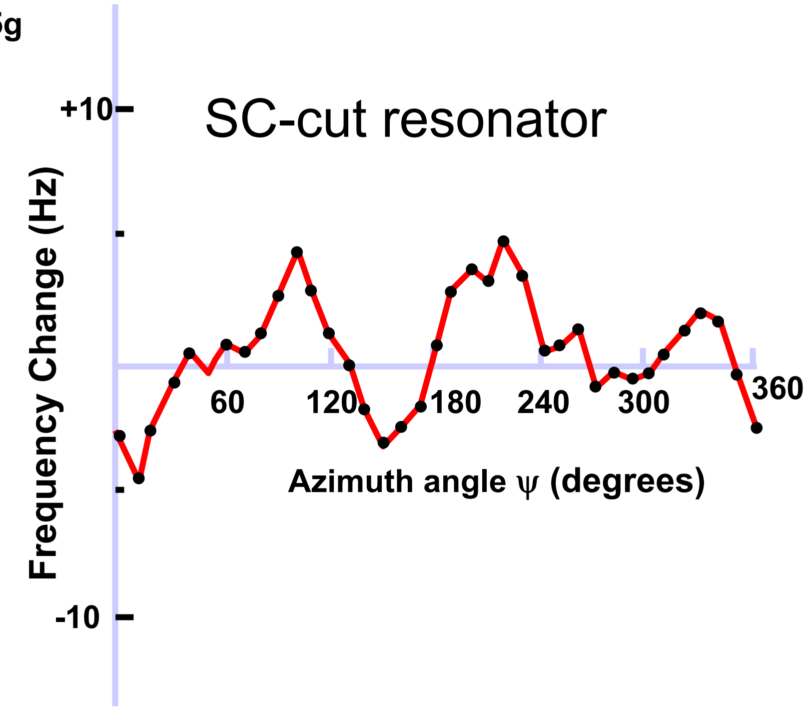
f_o = 10MHz





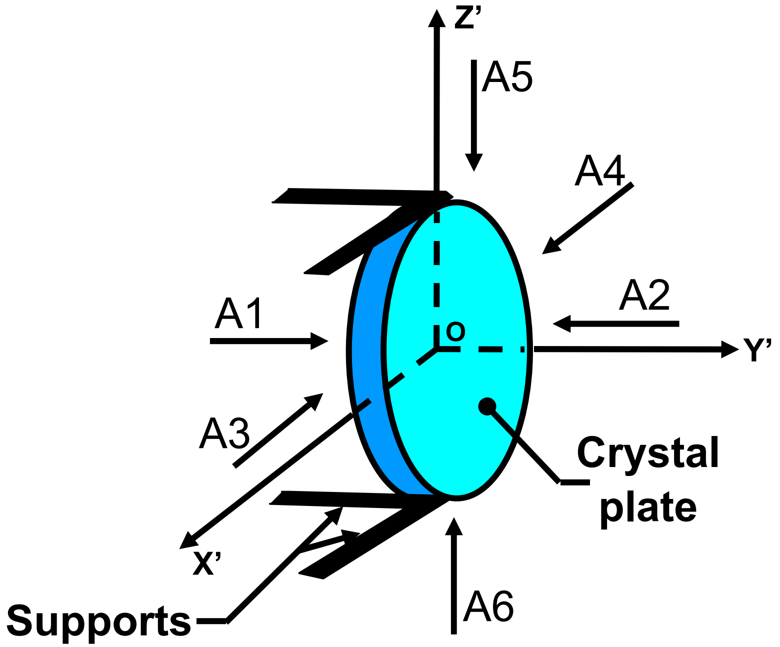
Frequency change for symmetrical bending, AT-cut crystal.

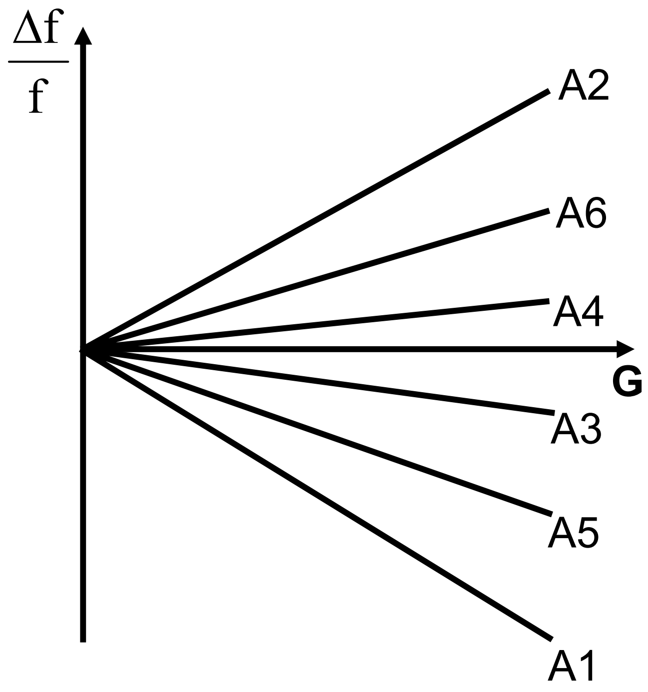
f_o = 10MHz



Frequency change for symmetrical bending, SC-cut crystal.

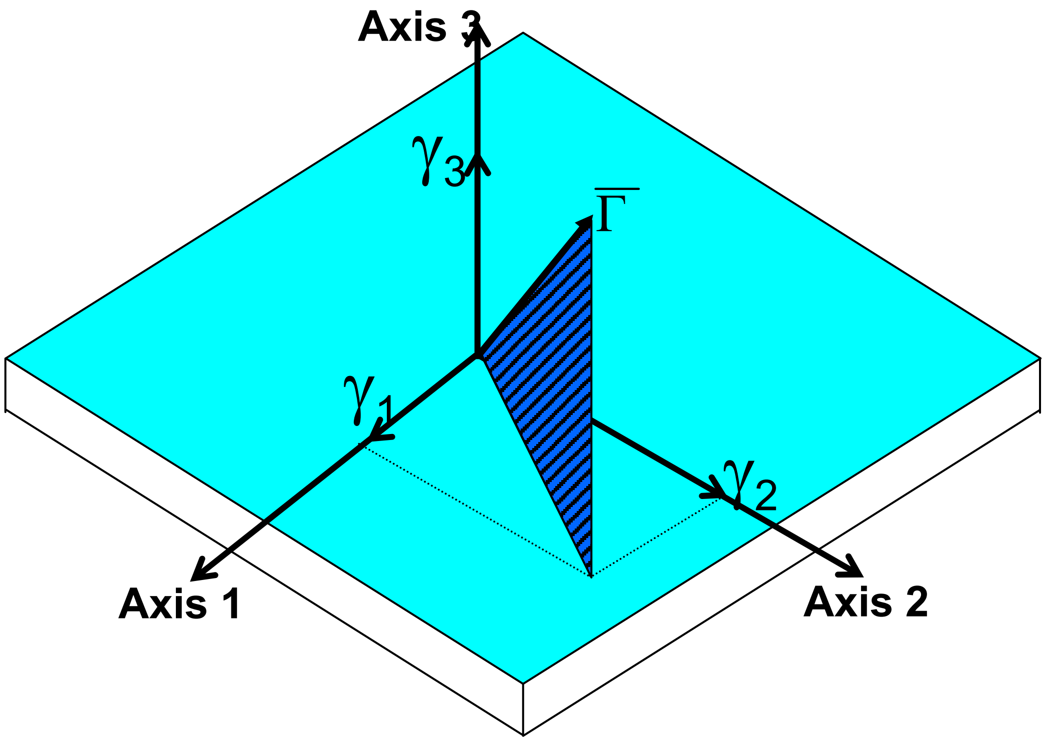
Frequency change with acceleration





Strains due to acceleration cause frequency changes.
Under vibration, the time varying strains cause
time dependent frequency changes, i.e. frequency modulation

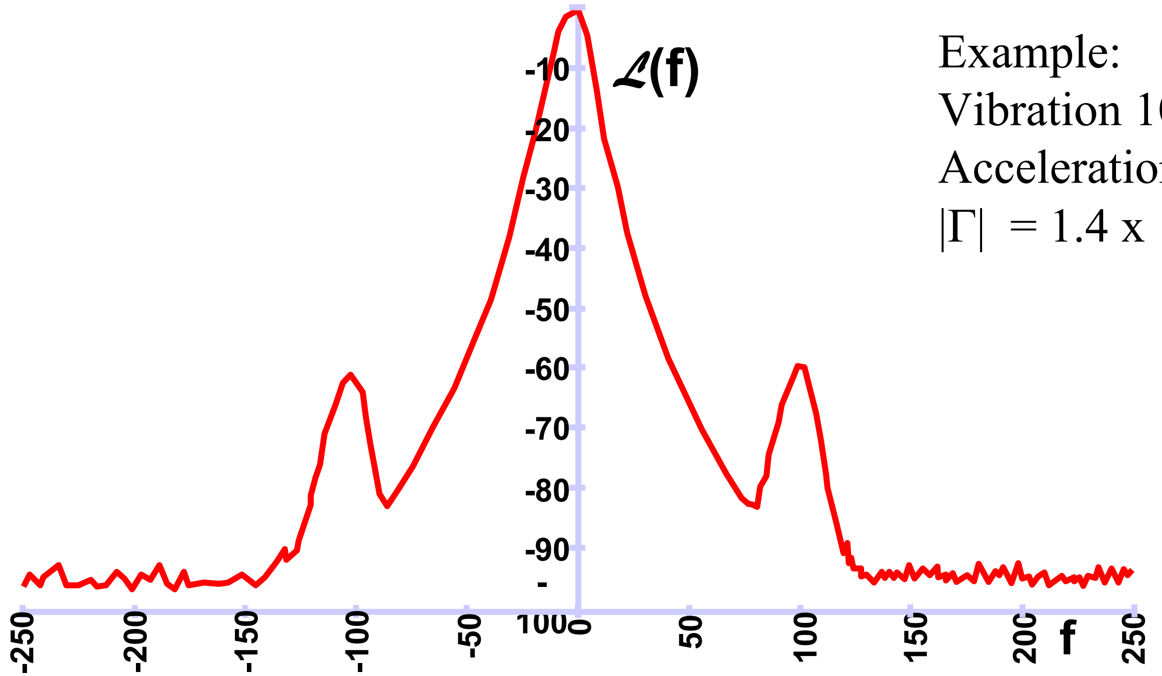
Acceleration Sensitivity Vector



$$\overline{\Gamma} = \gamma_1 \hat{i} + \gamma_2 \hat{j} + \gamma_3 \hat{k}$$

$$\Gamma = \sqrt{\gamma_1^2 + \gamma_2^2 + \gamma_3^2}$$

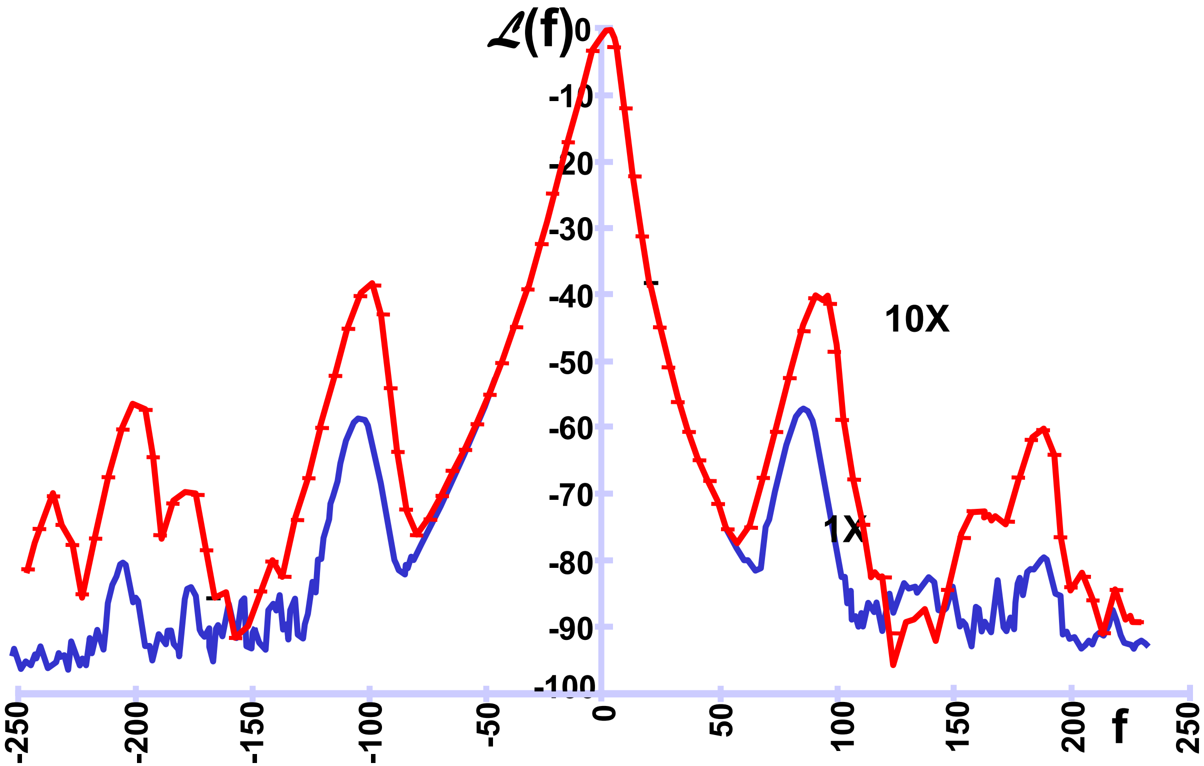
Sine Vibration Induced Sidebands



Example:
Vibration 10 G @ 100 Hz
Acceleration sensitivity vector
$|\Gamma| = 1.4 \times 10^{-9}$ / G

Sinusoidal vibration with vibration frequency fv
produces spectral lines at ± fv from the carrier

Frequency Multiplication



Each frequency multiplication by 10 increases the sidebands by 20 dB

$$\Delta a = 20 \cdot \log(N)$$

Sine Vibration Induced Sidebands

Sinusoidal vibration produces spectral lines at $\pm f_v$ from the carrier, where f_v is the vibration frequency.

$$\mathcal{L}'(f_v) = 20 \log\left(\frac{\bar{\Gamma} \bullet \bar{A} f_0}{2 f_v}\right)$$

e.g., if $|\Gamma| = 1 \times 10^{-9}$/G and $f_0 = 10$ MHz, then even if the oscillator is completely **noise free at rest**, the spectral lines due solely to a sine vibration level of 1G are:

Vibr. freq., f_v [Hz]	**$\mathcal{L}'(f_v)$ [dBc]**
1	-46
10	-66
100	-86
1,000	-106
10,000	-126

Random Vibration Induced Phase Noise

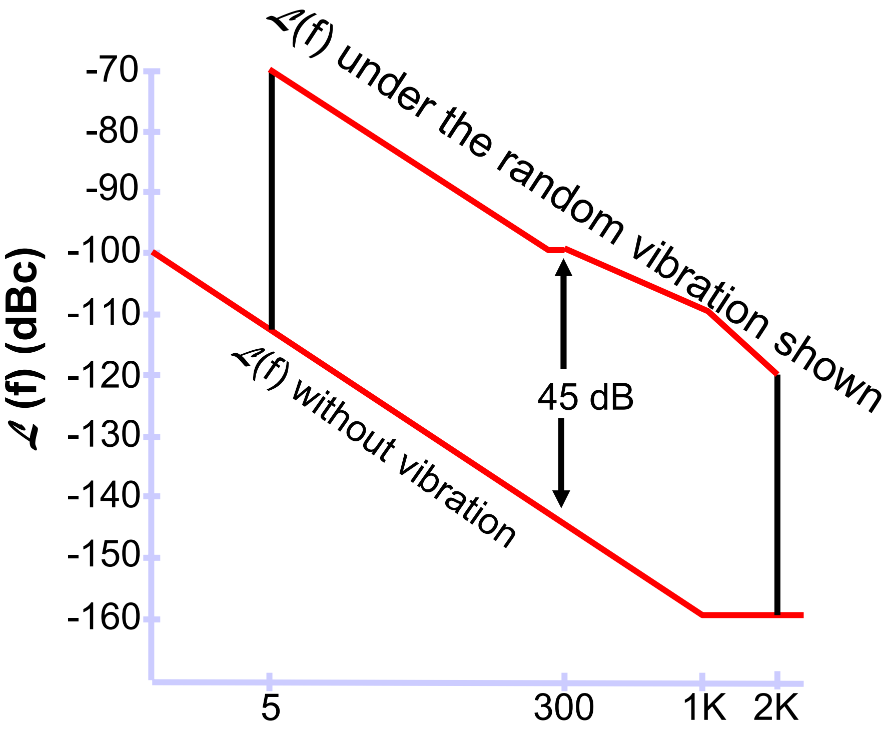
Random vibration's contribution to phase noise is given by:

$$\mathcal{L}(f) = 20 \log\left(\frac{\overline{\Gamma} \bullet \overline{A} f_0}{2f}\right), \quad \text{where } |\overline{A}| = [(2)(PSD)]^{1/2}$$

e.g., if $|\Gamma| = 1 \times 10^{-9}$/G and $f_0 = 10$ MHz, then even if the oscillator is completely **noise free at rest**, the phase "noise" i.e., the spectral lines, due solely to a vibration of power spectral density, PSD = 0.1 g^2/Hz will be:

Offset freq. f [Hz]	$\mathcal{L}'(f)$ [dBc/Hz]
1	-53
10	-73
100	-93
1,000	-113
10,000	-133

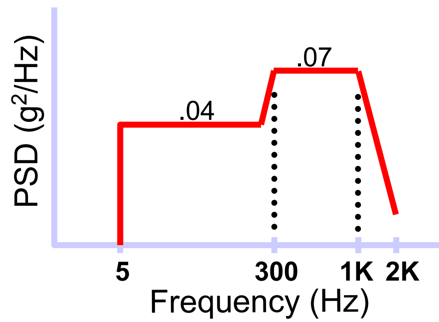
Random Vibration Induced Phase Noise



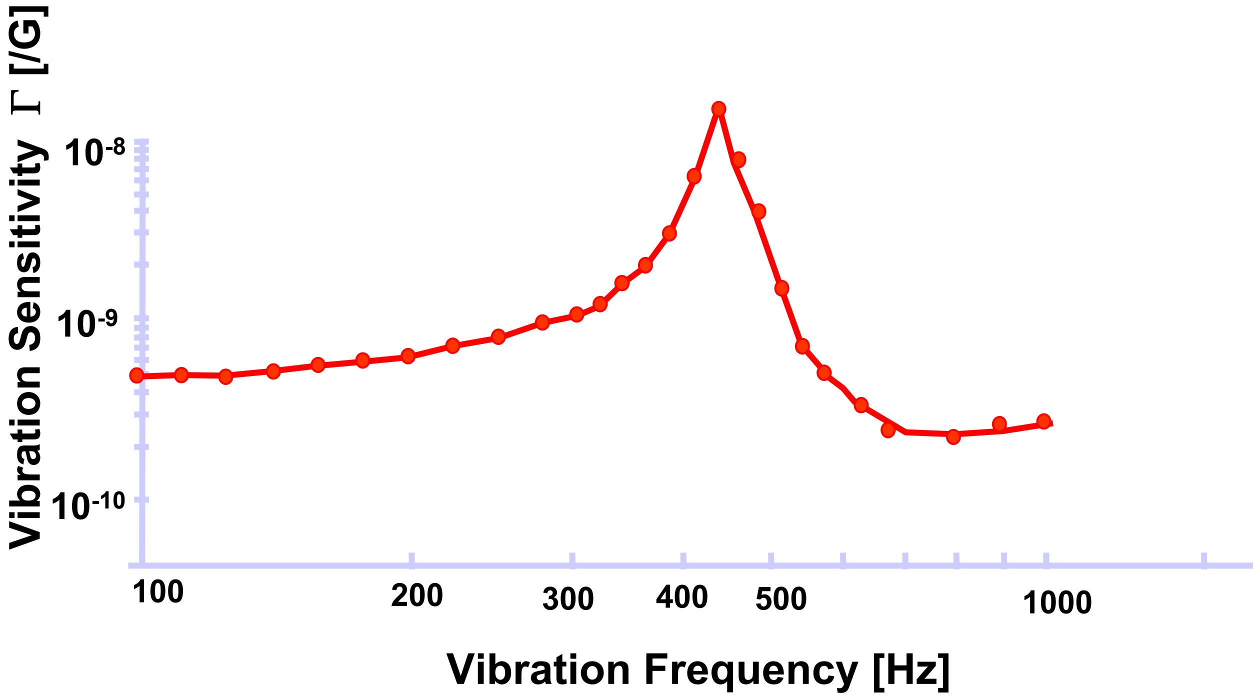
Random Vibration for a Crystal with Vibration Sensitivity of $|\Gamma| = 1x10^{-9}/G$

Osc frequency f_0 = 10 MHz

Vibration profile (aircraft):



Acceleration Sensitivity with Resonances

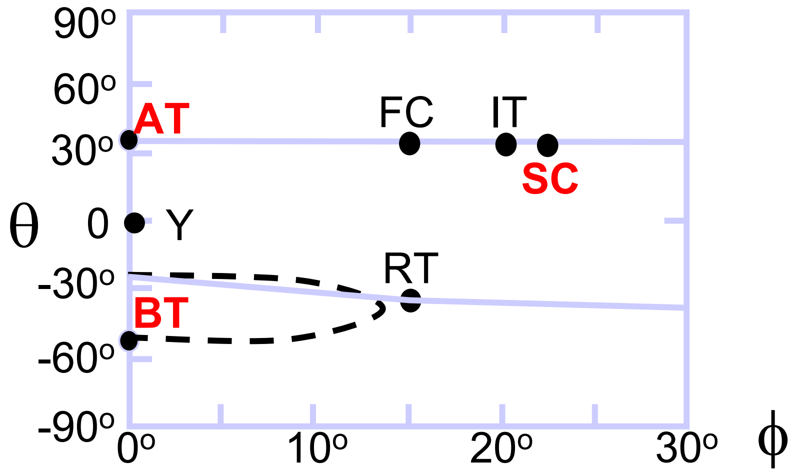


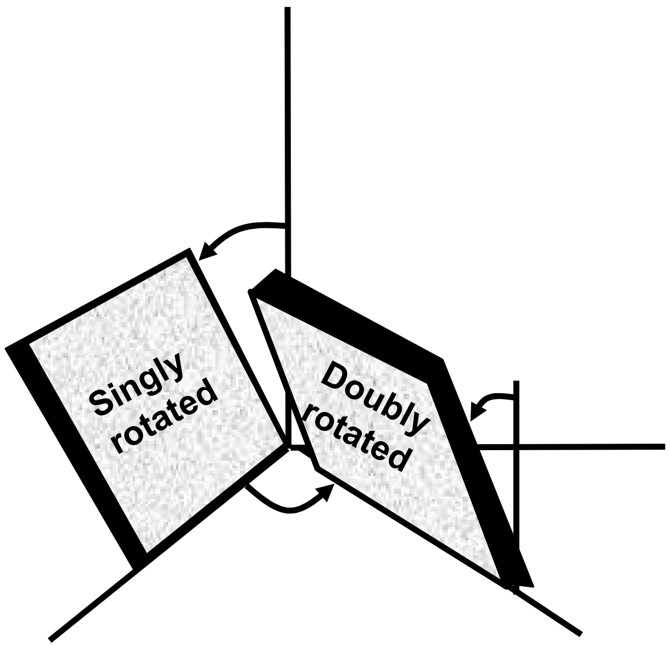
In an ideal oscillator, Γ(f**v)** would be constant, but real oscillators exhibit resonances which increase the Γ in the relevant frequency band

Factors determining Acceleration Sensitivity

- Crystal cut
- Crystal holder
- Mounting structure
- Crystal design
  - symmetrical shape of crystal blank (contour), electrodes and mounting structure
- G-Sensitivity of other components

Cuts with zero TC (Thickness shear)

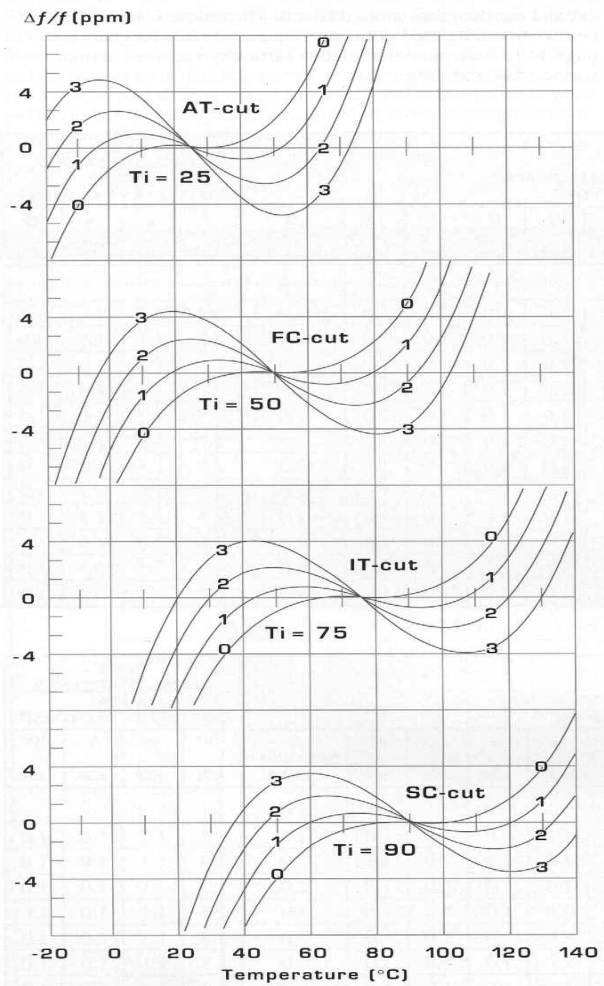




Θ ≈ 35°: **AT cut:** TC = 0 ppm/K at ≈ 25°C
SC cut*: TC = 0 ppm/K bei ≈ 95°C

*SC = **S**tress **C**ompensated

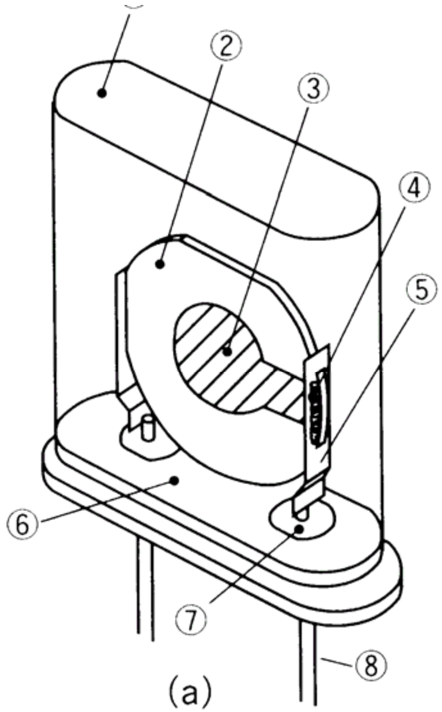
f(T) for doubly rotated cuts

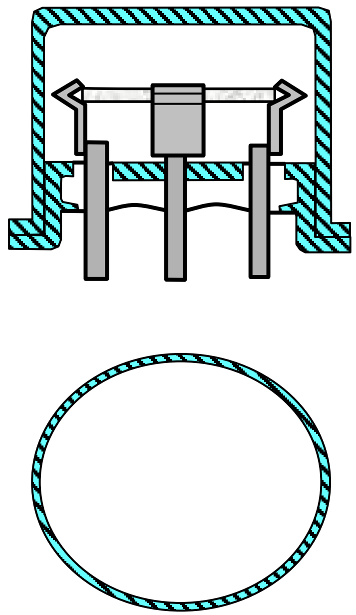


The inflection temperature moves up with increasing 2nd rotation angle Φ.

For Φ ≈ 22° (T_{inv} ≈ 95°C), the so-called SC cut („Stress Compensated) the impact of mechanical stresses on the Resonance frequency compensate

Comparison of Crystal packages



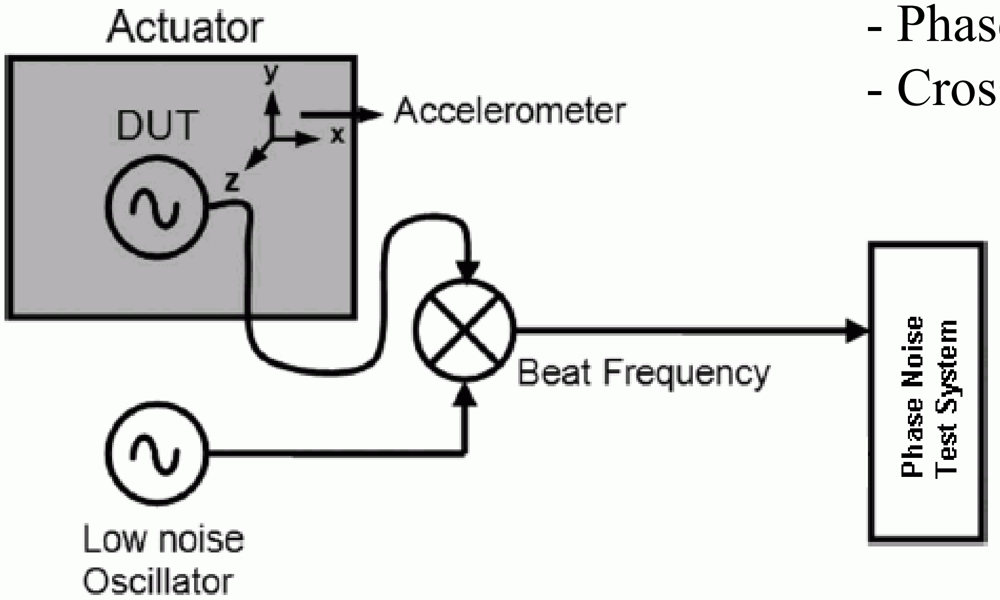


Two-point Mount Package
e.g. HC-43/U or HC-45/U

Three- and Four-point Mount Package
e.g. HC-35/U or HC-37/U

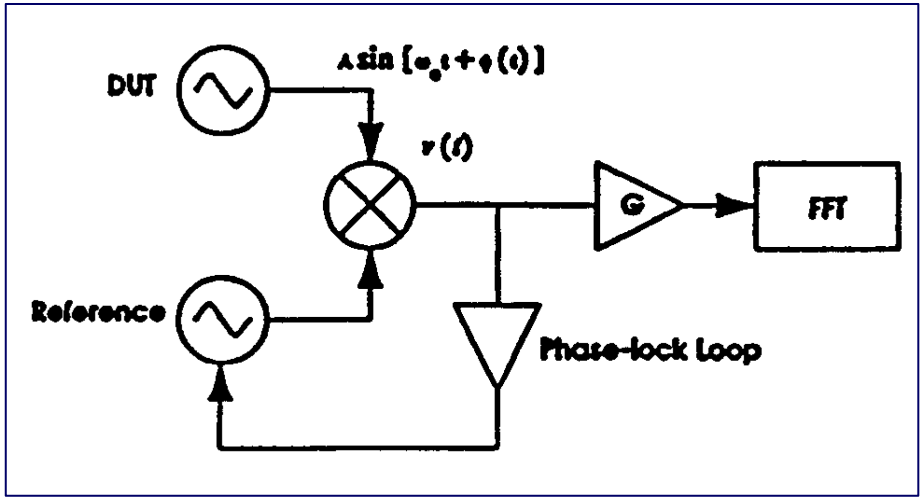
Testing of Vibration Sensitivity

Test Setup



PN Test Systems:
- Phase Quadrature Method
- Cross Correlation

Phase Noise Test



$$\Phi_{det} = K \cdot \left(\Phi(t) - \Phi_{ref}(t)\right)$$

Phase Quadrature Method

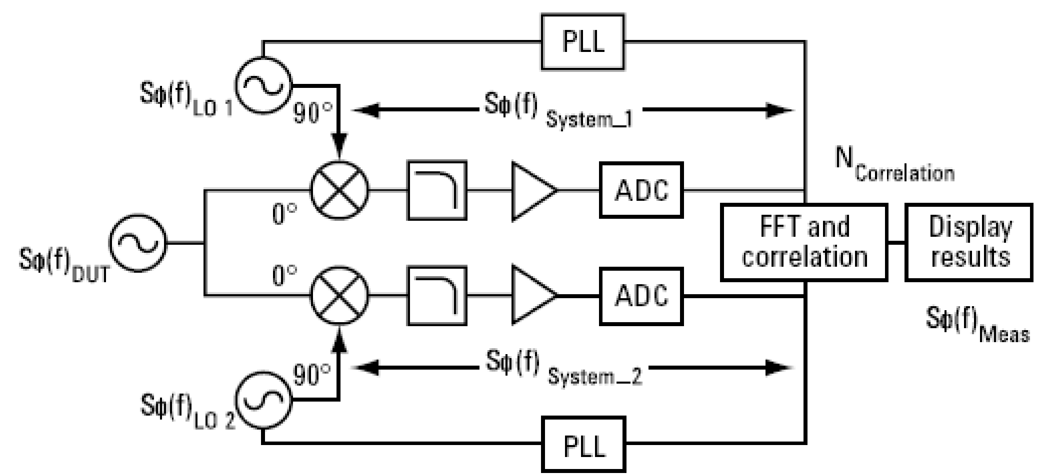
The signal under test and a signal of same frequency from a reference oscillator are combined in a phase detector. The frequency of oscillator #2 is locked to oscillator #1 by a PLL The DC output signal of the phase detector is proportional to the phase difference of the two signals. All noise spectral components, which are „faster“ than the loop filter will be measured by the spectrum analyzer or FFT.

If the reference oscillator has very low phase noise, the measured noise is dominated by the noise of the oscillator under test.

If both oscillators have the same noise, the noise of one oscillator is -3 dB lower than the noise measured with the spectrum analyzer.

Example: Aeroflex PN9000

Phase Noise Test



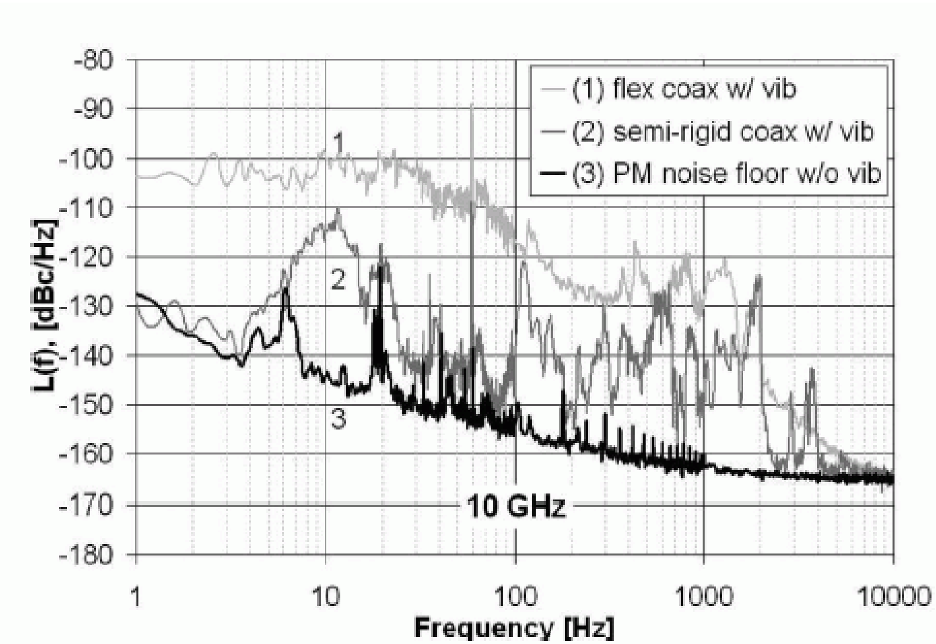
$$S\phi(f)_{Meas} = S\phi(f)_{DUT} + \frac{S\phi(f)_{LO\ 1} + S\phi(f)_{LO\ 2} + S\phi(f)_{System\_1} + S\phi(f)_{System\_2}}{\sqrt{N_{Correlation}}}$$

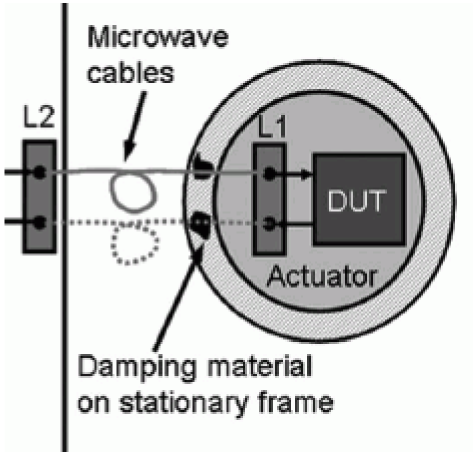
Cross Correlation Method

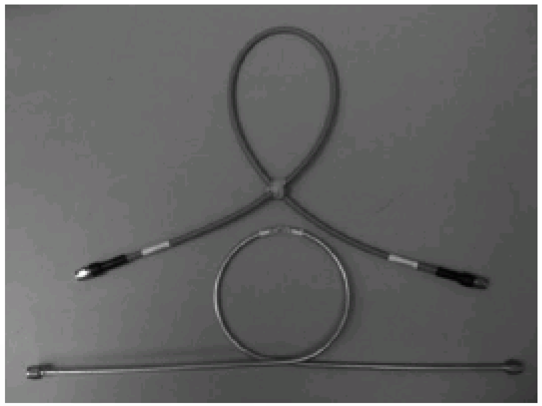
The signal is fed into two phase detectors and both channels are mixed with an internal low-noise reference signal. Both channels are locked to the test signal through a PLL. The noise content of the identical channels is evaluated by mathematical cross-correlation technique. Examples: Agilent Signal Source Analyzer E5052B, Rohde & Schwarz FSUP

Testing of Vibration Sensitivity

- Cables and mounting







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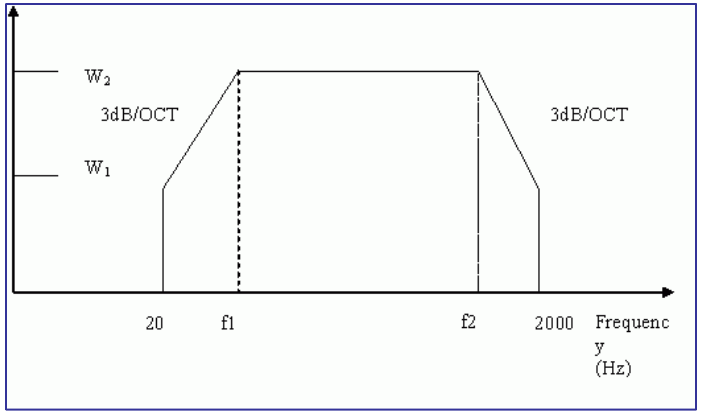
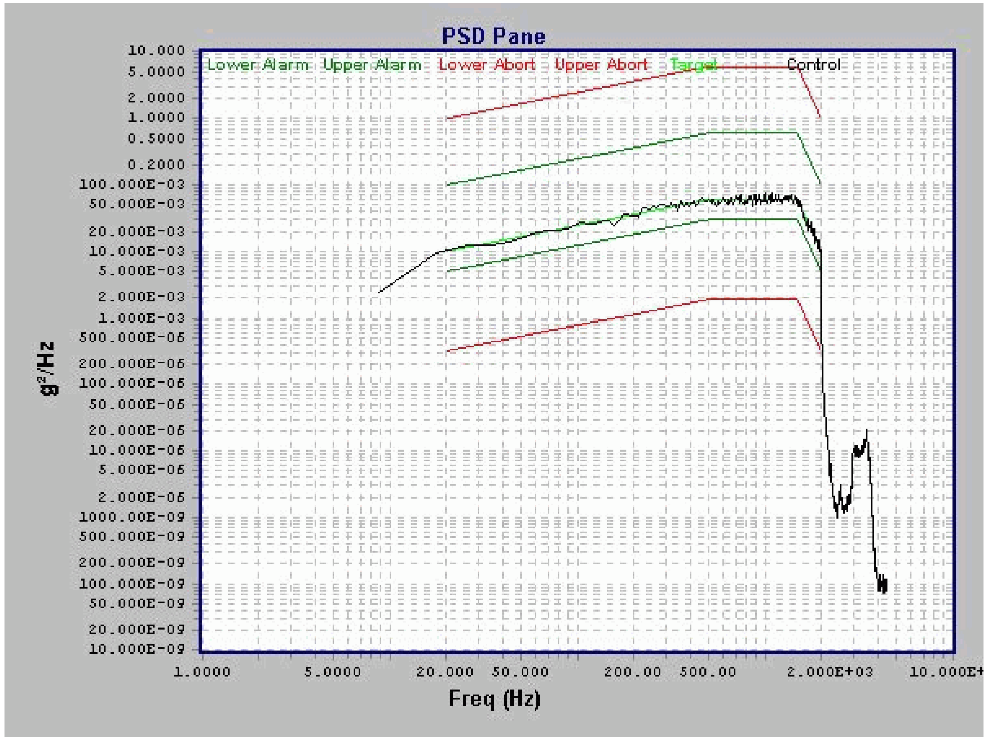
  - 60 MHz with SC-cut (HC-43/U) other vendor

Vibration Spectrum



W1=0.01g2/Hz, W2=0.06g2/Hz

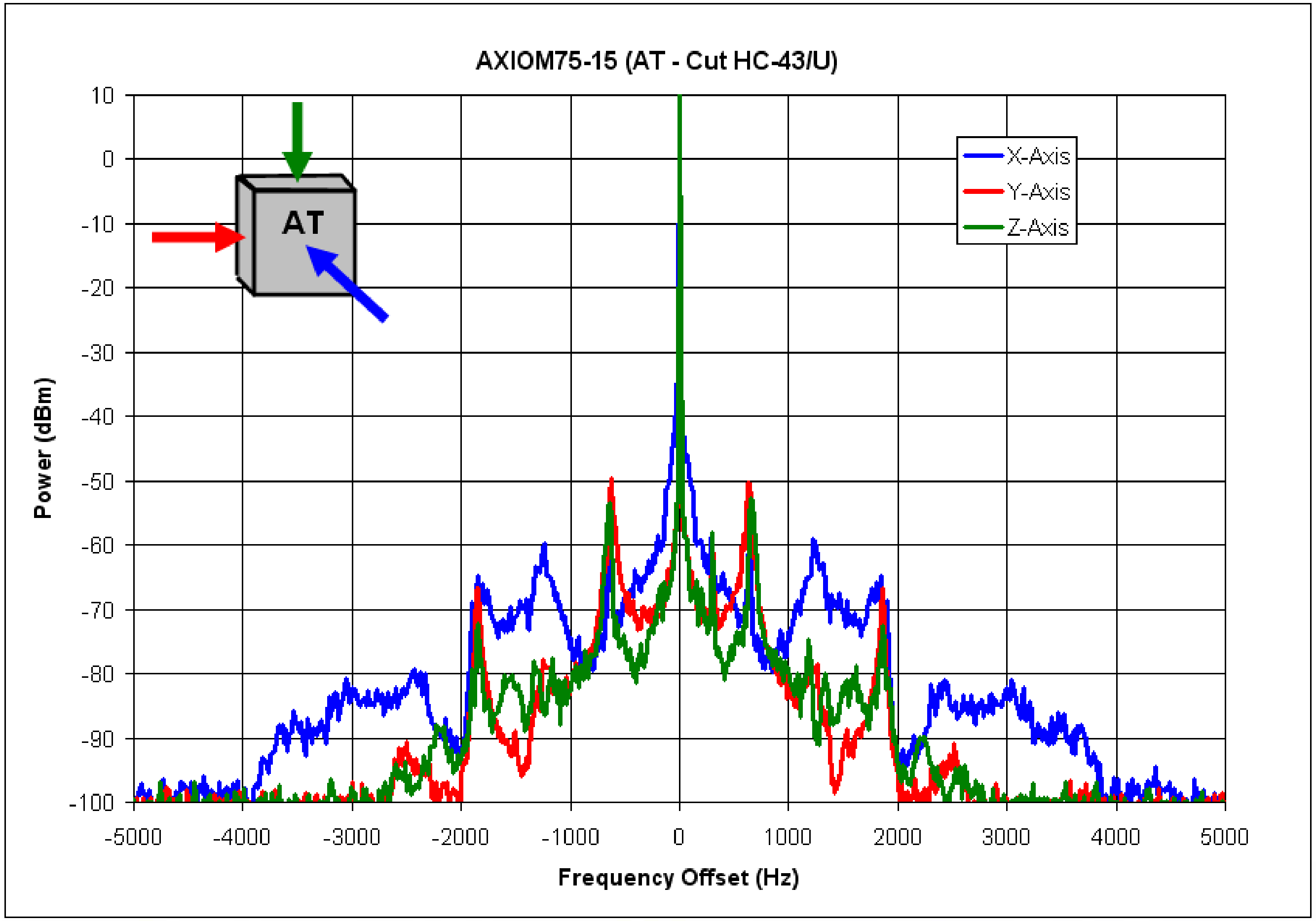
f1=500Hz, f2=1500Hz



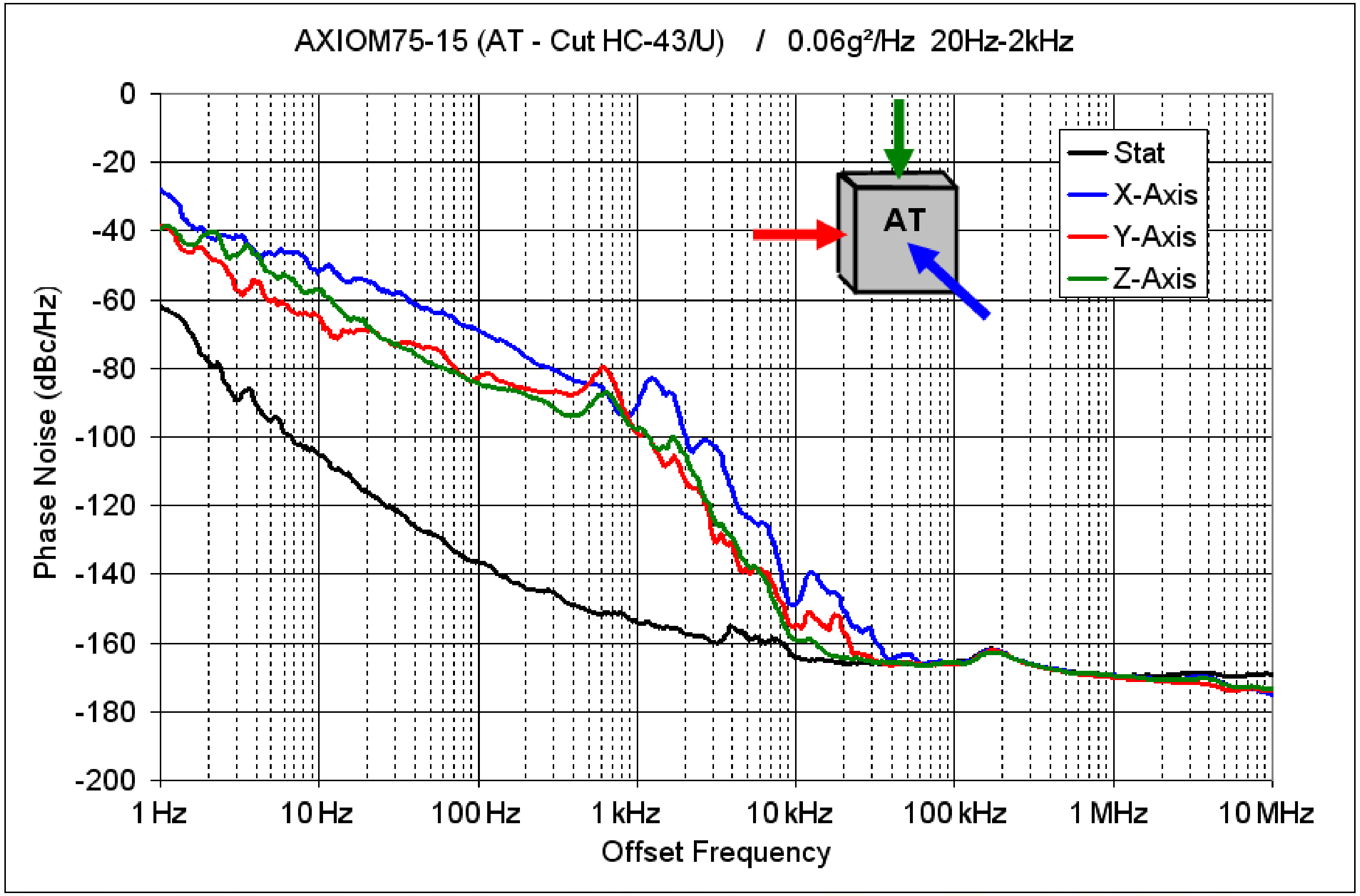
Customer spec

Tested profile

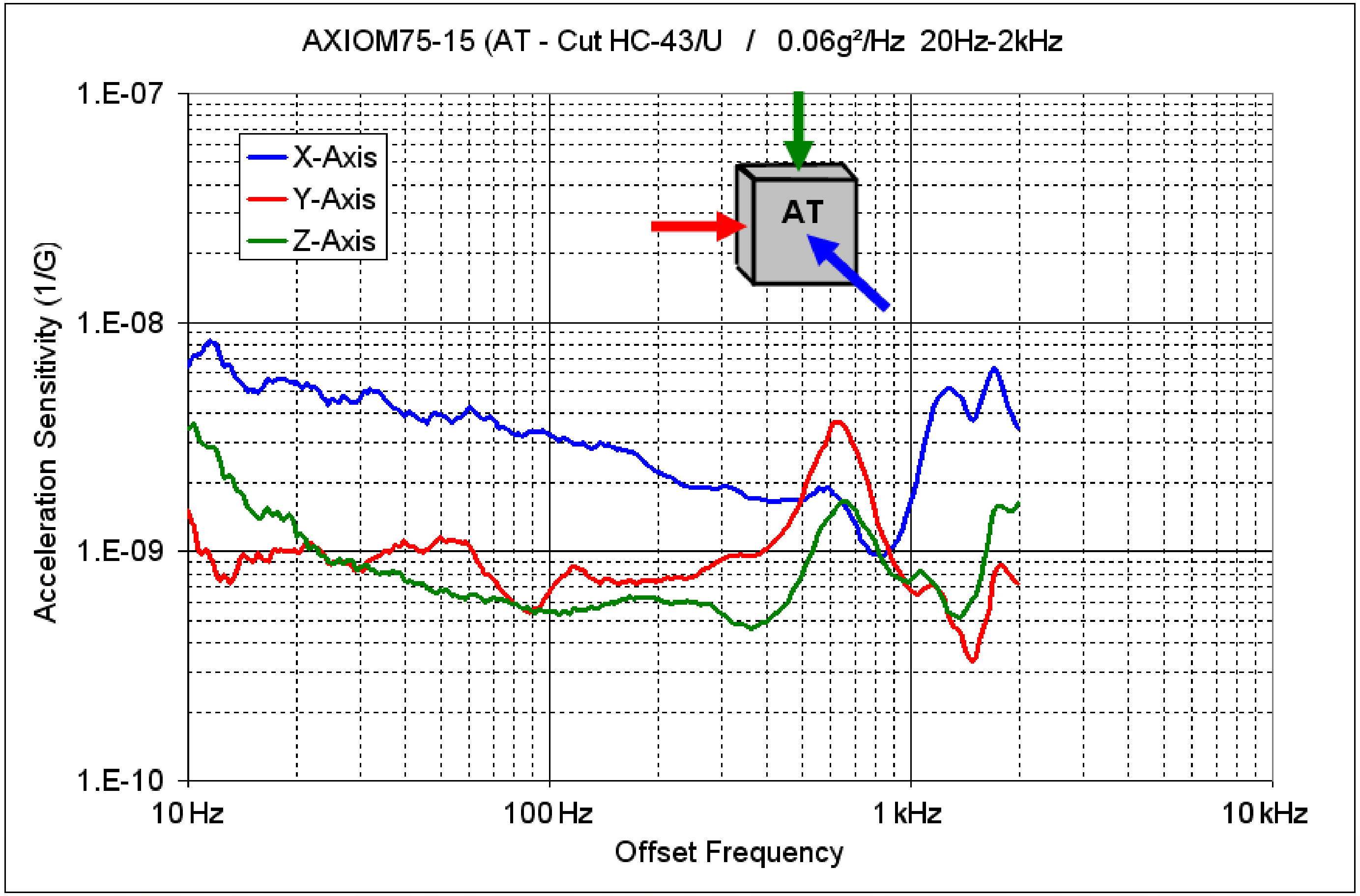
AXIOM75-16-60 MHz AT-cut (HC-43/U) Output Spectrum



AXIOM75-16-60 MHz AT-cut (HC-43/U) Phase Noise

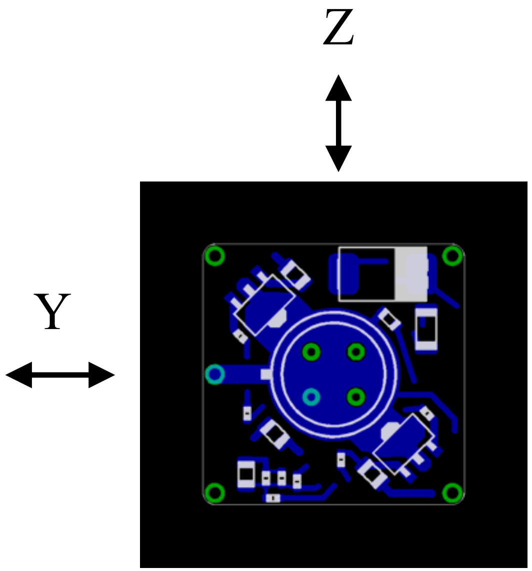


AXIOM75-16-60 MHz AT-cut (HC-43/U) G - Sensitivity



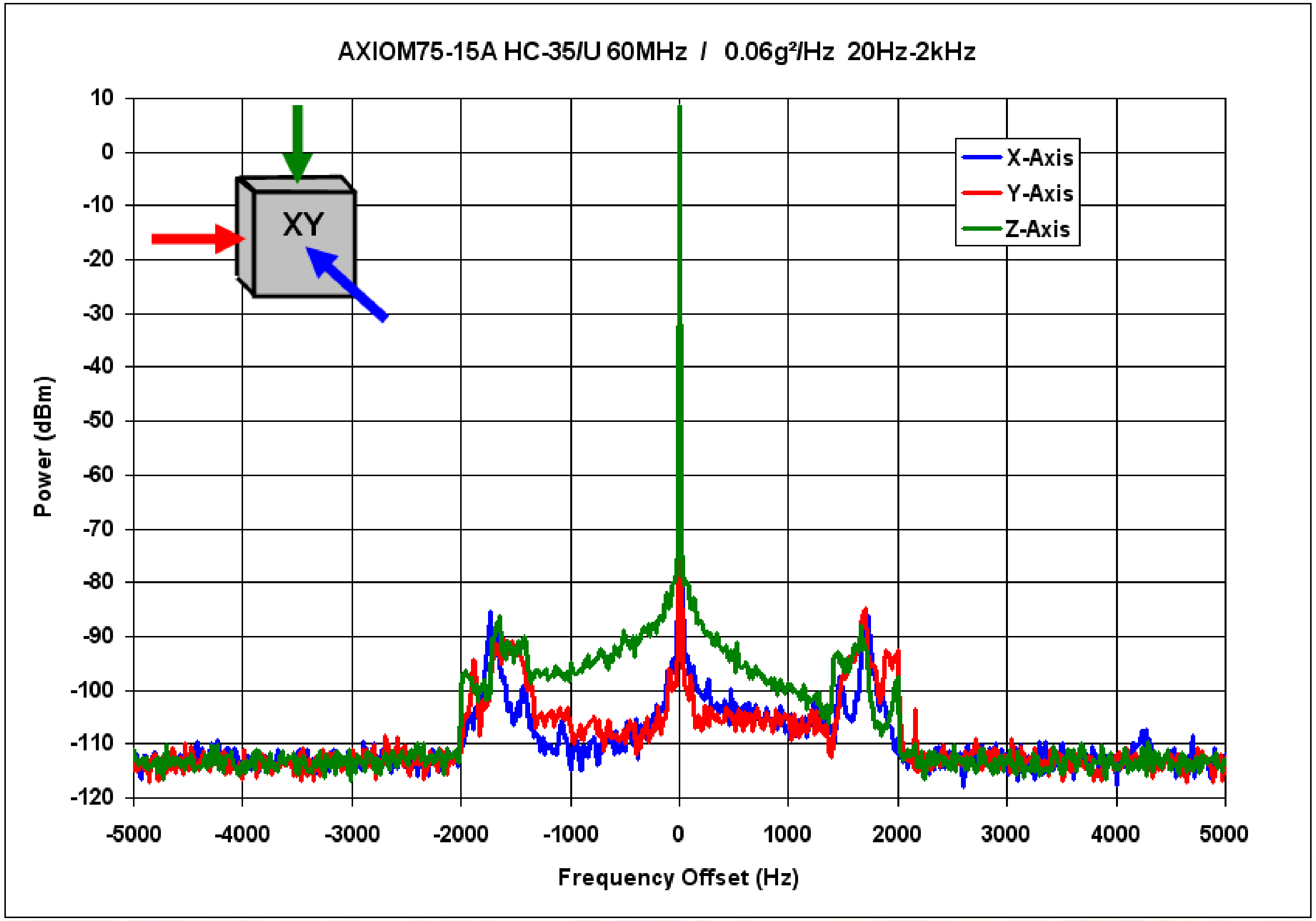
AXIOM75-16A-60 MHz SC-cut (HC-35/U)

Test fixture

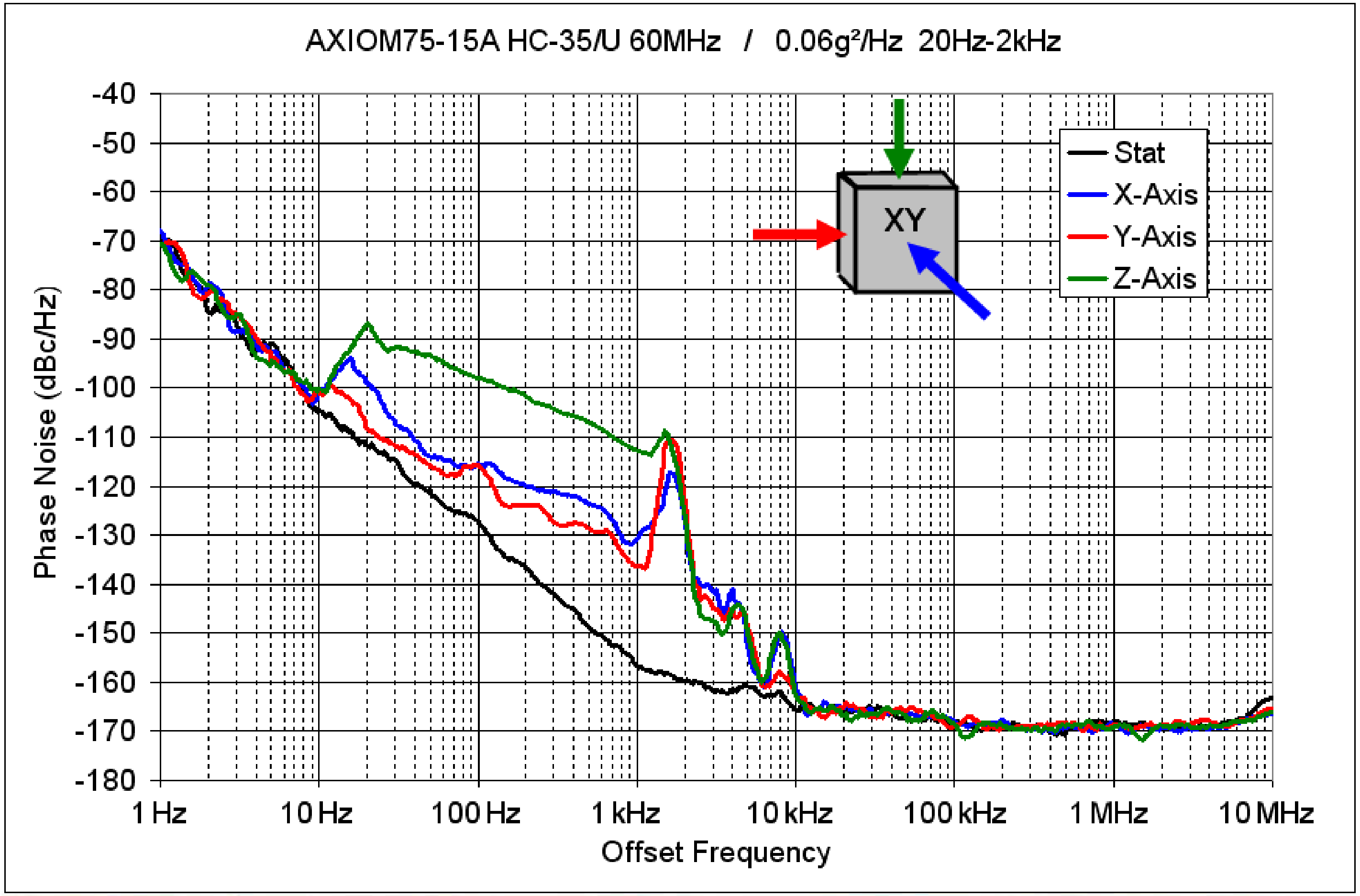


Orientation

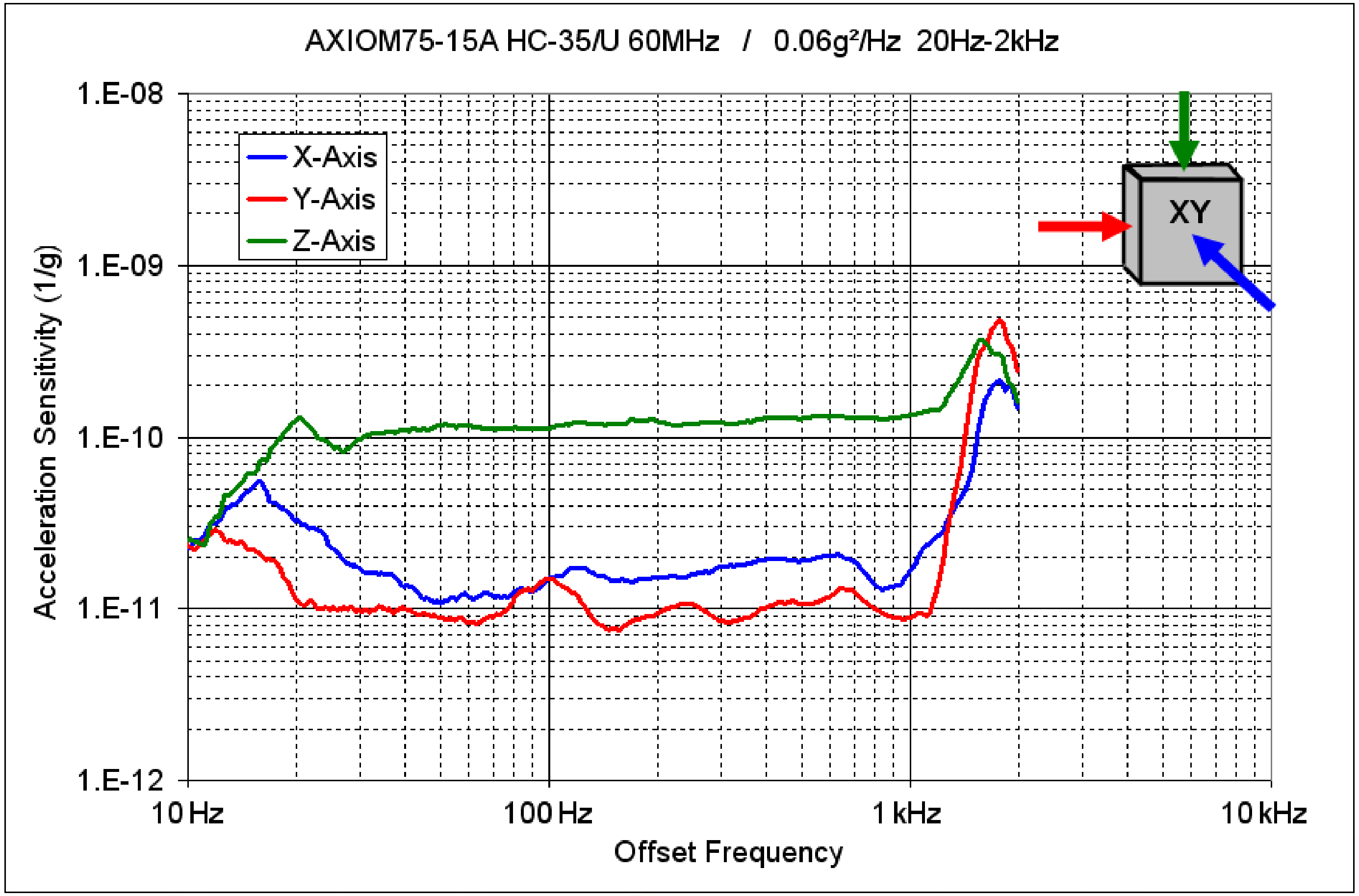
AXIOM75-16A-60 MHz SC-cut (HC-35/U) Output Spectrum



AXIOM75-16A-60 MHz SC-cut (HC-35/U) Phase Noise

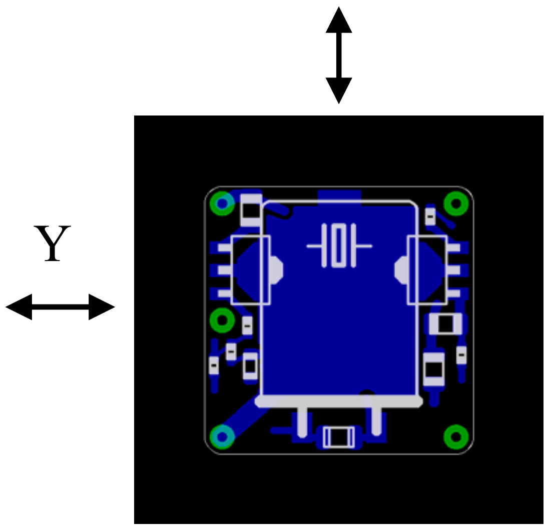


AXIOM75-16A-60 MHz SC-cut (HC-35/U) G - Sensitivity

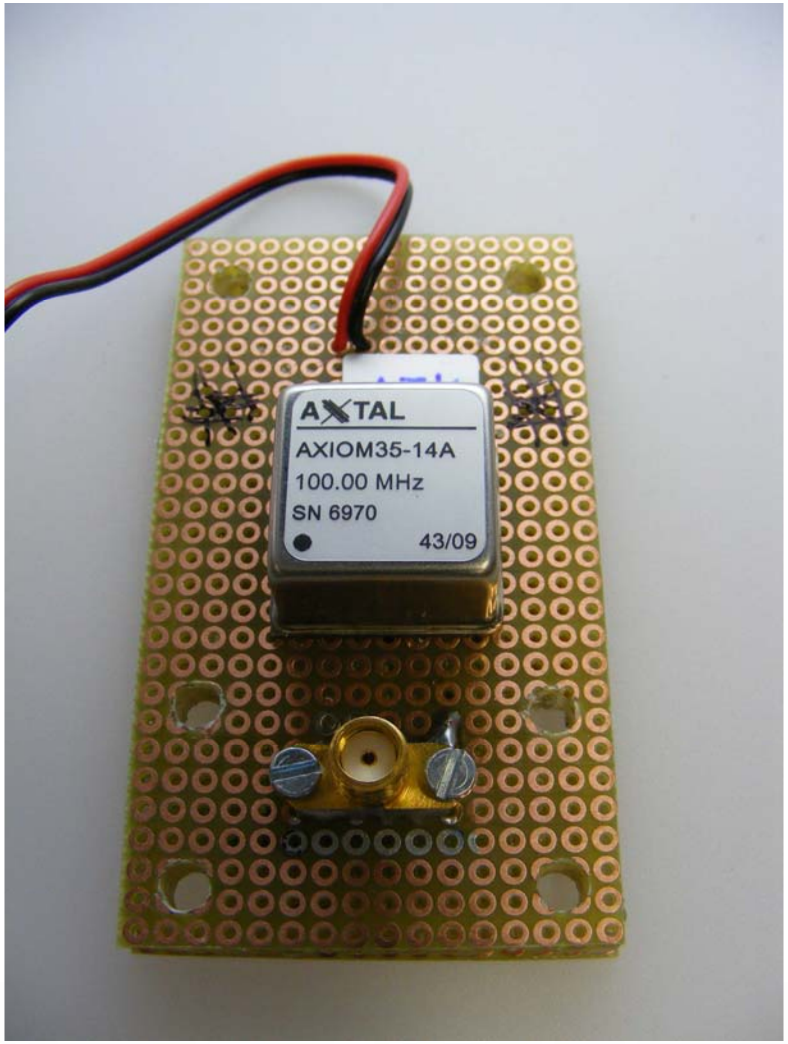


AXIOM35-14A-100 MHz SC-cut (HC-43/U)

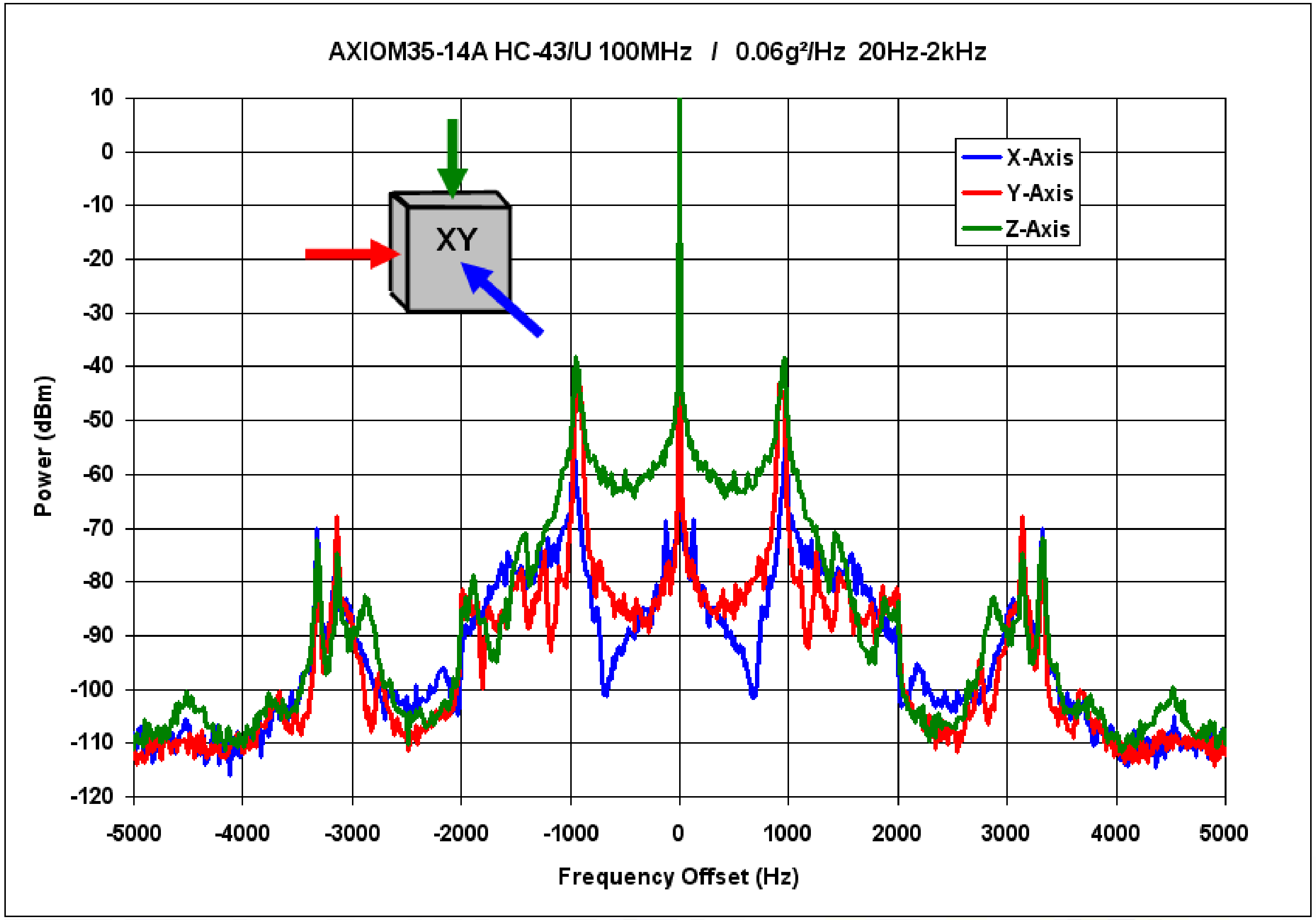
Test fixture



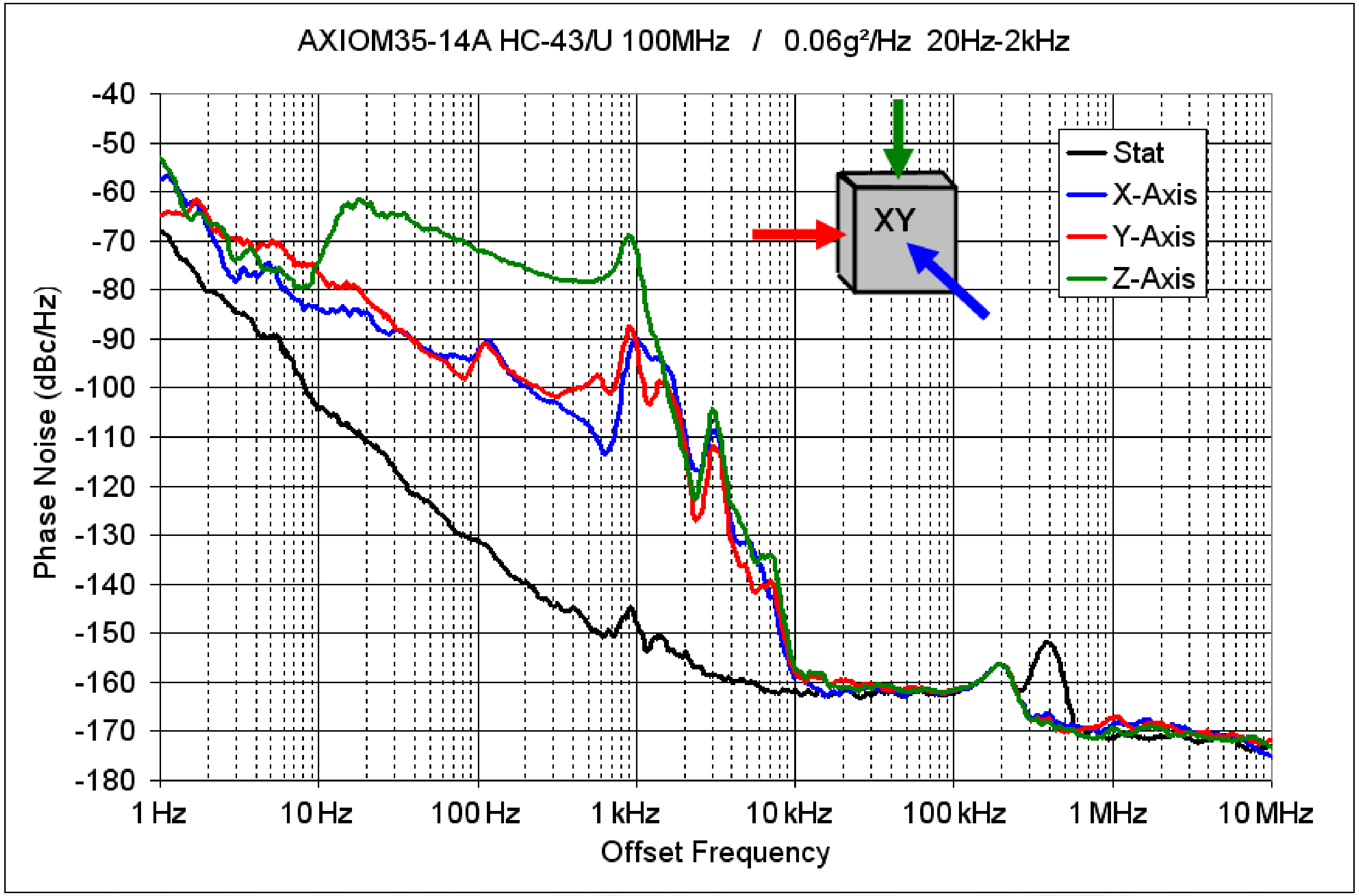
Orientation



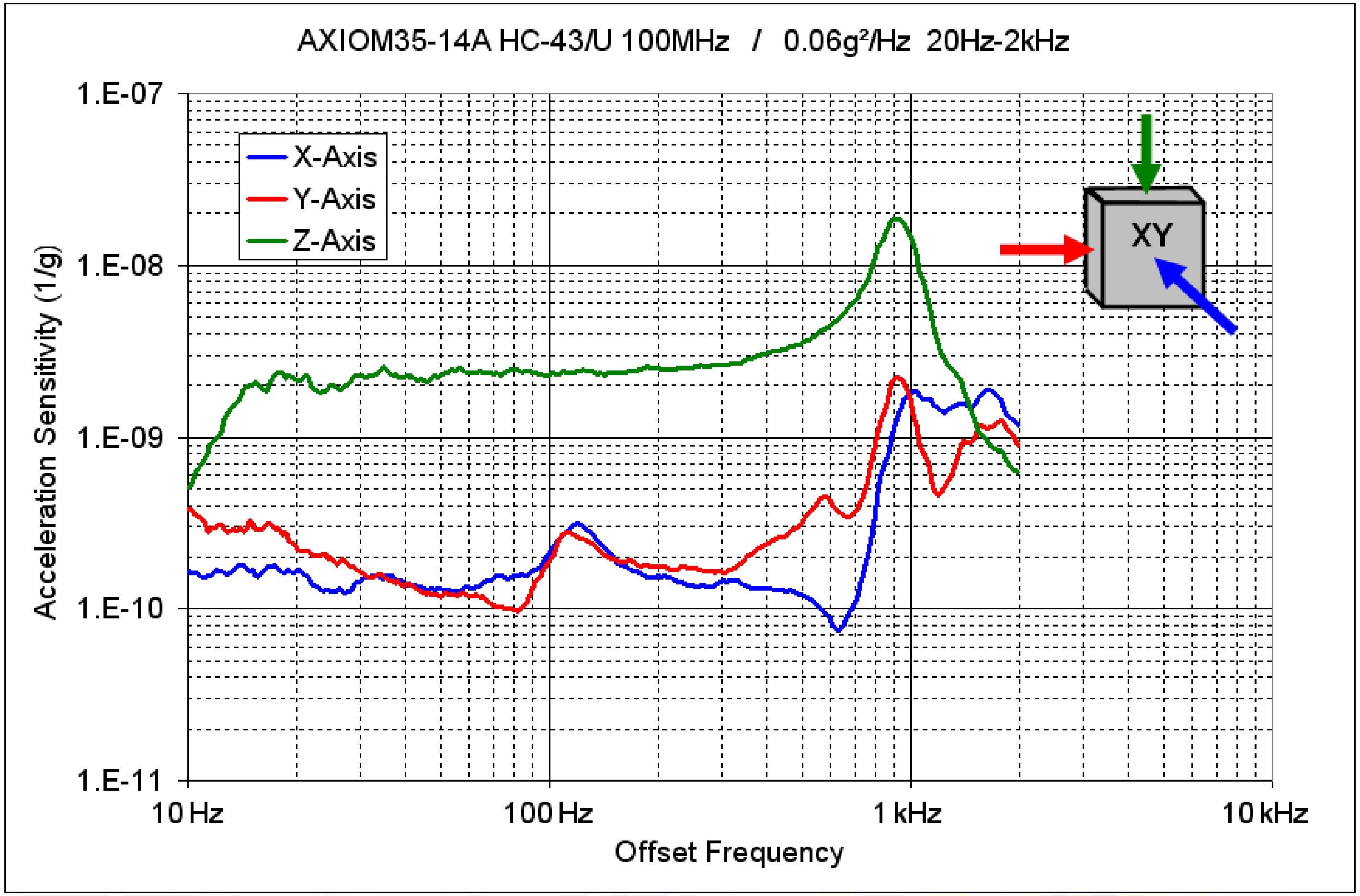
AXIOM35-14A-100 MHz SC-cut (HC-43/U) Output Spectrum



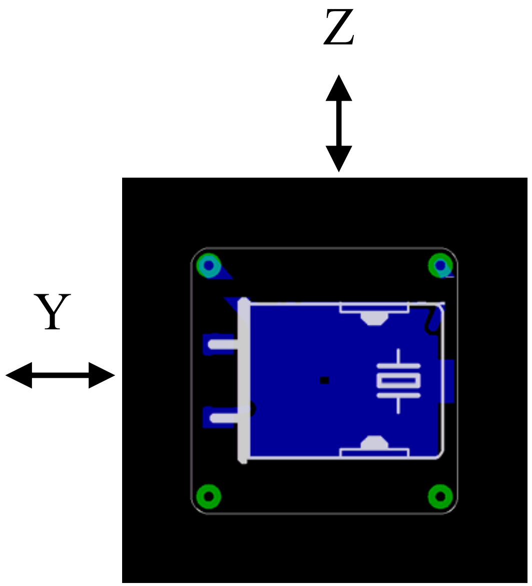
AXIOM35-14A-100 MHz SC-cut (HC-43/U)
Phase noise



AXIOM35-14A-100 MHz SC-cut (HC-43/U) G-Sensitivity

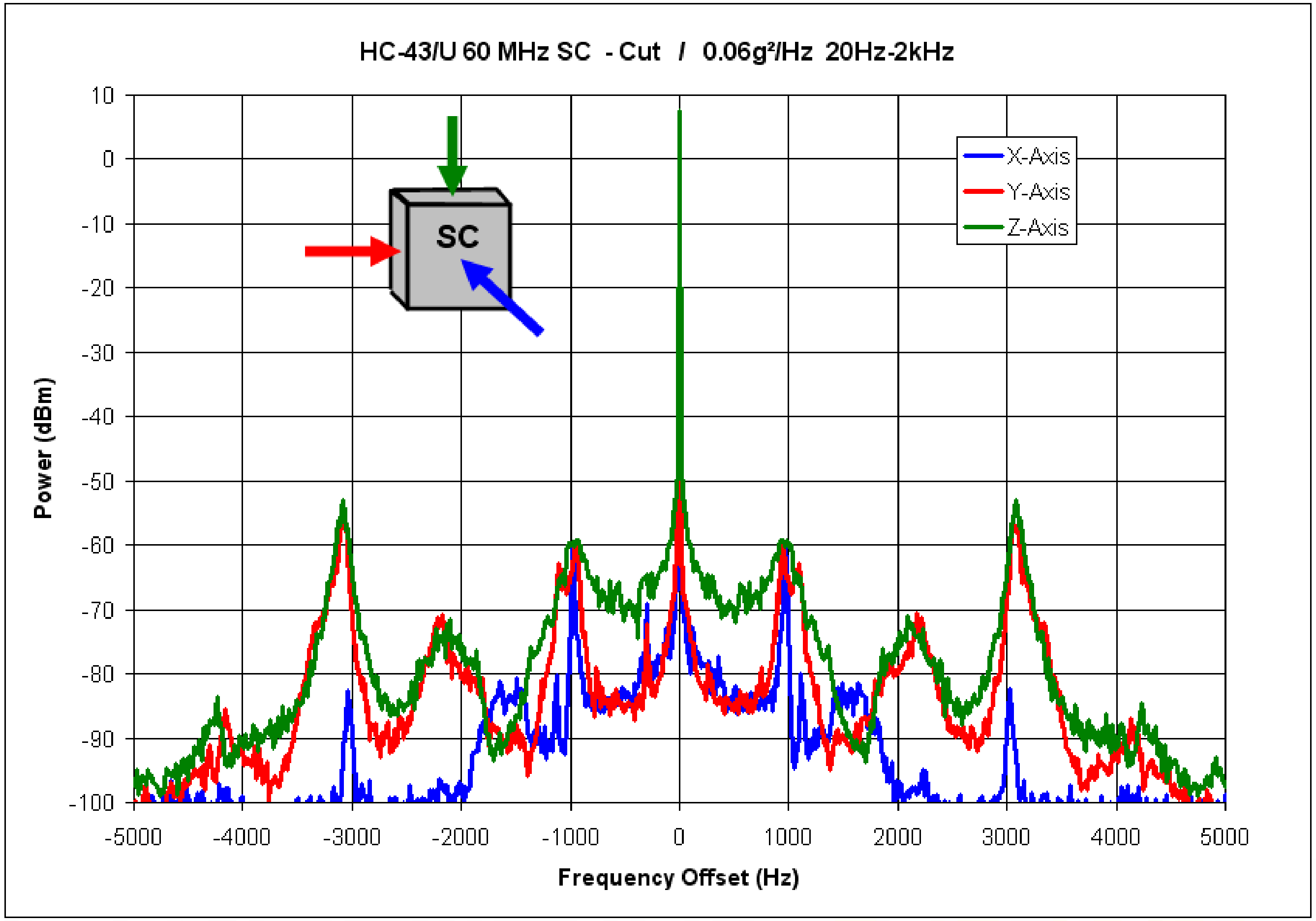


60 MHz SC-cut (HC-43/U) other vendor
Test fixture

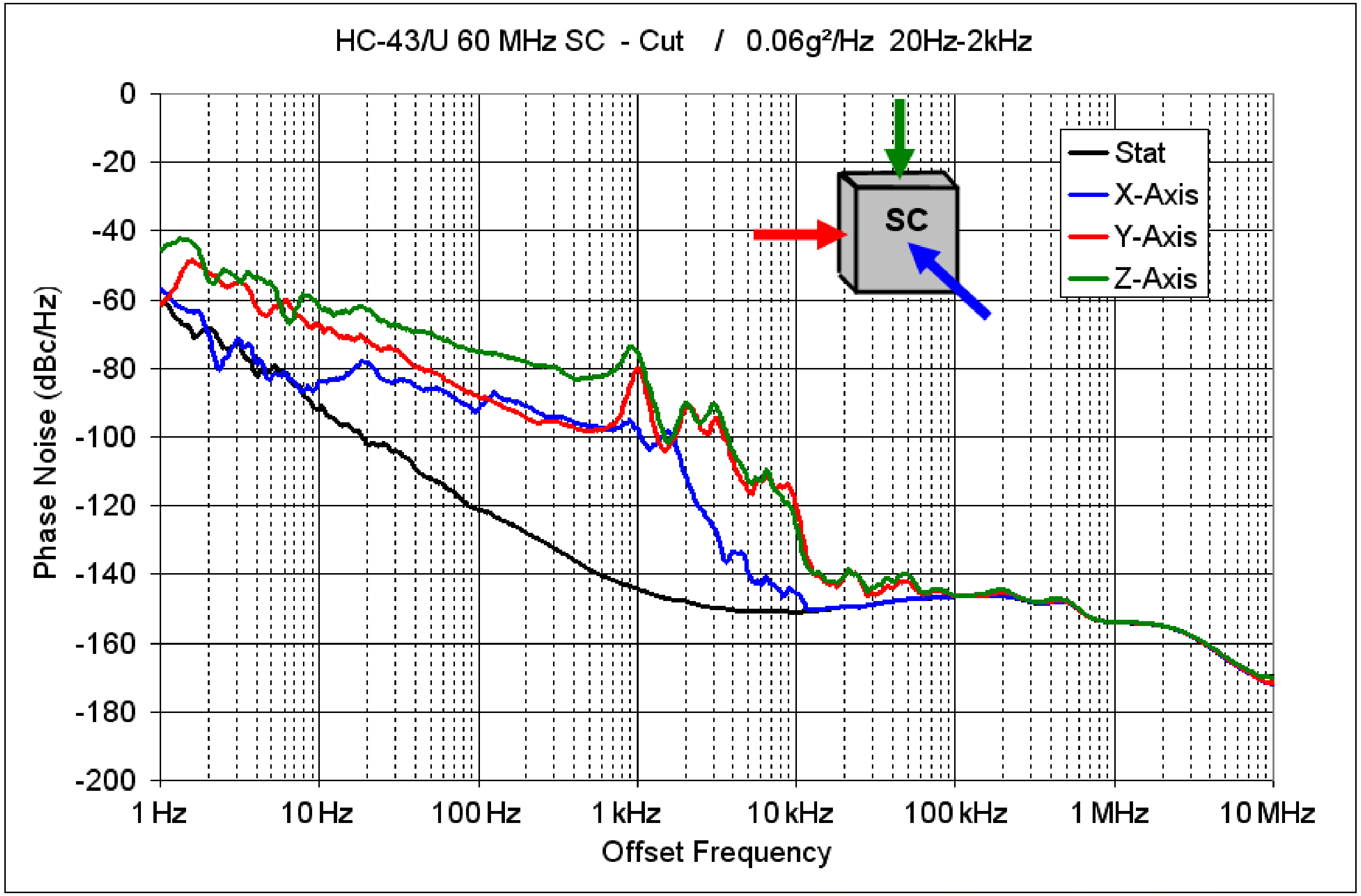


Orientation

60 MHz SC-cut (HC-43/U) other vendor Output Spectrum



60 MHz SC-cut (HC-43/U) other vendor Phase noise



60 MHz SC-cut (HC-43/U) other vendor G-Sensitivity