

Phase Noise Under Vibration In Crystal-based Systems

Wenzel Associates Overview "Quietly the Best"

Crystal Oscillators RF and Microwave Synthesizers Blue Tops Systems Crystals at Croven Crystals

Integrated Engineering and Manufacturing Company

- Located in Austin, Texas and Whitby, Ontario
- •68,000 Sq Ft Combined Facilities
- •25 Year History of designing the Lowest Phase Noise Products
- Proven Military and Space Legacy

Phase Noise Under Vibration

The Shock and Vibration Environment

Vibration Isolation and Compensation

Calculating Phase Noise Under Vibration

Low Frequency Vibration Damping

Measuring Phase Noise Under Vibration

Design for Vibration

The Shock and Vibration Environment

Vibration Profile – MIL-STD-810F Helicopter Minimum Integrity



Vibration Profile – MIL-STD-810F Jet Aircraft



Vibration Profile – MIL-STD-810F Propeller Aircraft



Random Vibration Profile – MIL-STD-167-1A Shipboard



Vibration Specifications

http://assist.daps.dla.mil/quicksearch/										
MIL-STD-167-1A Rev A	2-Nov-05	MECHANICAL VIBRATIONS OF SHIPBOARD EQUIPMENT								
		(TYPE I E	(TYPE I ENVIRONMENTAL AND TYPE II INTERNALLY EXCITED)							
MIL-STD-167-2A Rev A	21-May-02	MECHANI	CAL VIBRA	ATIONS OF	SHIPBOAF	RD EQUIPN	/IENT (REC	IPROCATI	NG MACHI	NERY AND
		PROPULS	SION SYST	EM AND S	HAFTING) 1	IYPES III, I	V, AND V (CONTROL	LED DISTR	IBUTION)
MIL-STD-202 Rev G	8-Feb-02	ELECTRO	NIC AND E	ELECTRICA	L COMPON	IENT PAR	ſS			
		201A Vibra	ation							
		204D Vibra	ation, High	Frequency						
		207B High Impact Shock								
		214A Random Vibration								
MIL-STD-810 Rev F	1-Jan-00	ENVIRON	MENTAL E	NGINEERI		DERATIONS	6 AND LAB	ORATORY	TESTS	
MIL-S-901 Rev D	17-Mar-89	SHOCK TI	ESTS. H.I.	(HIGH-IMP/	ACT) SHIPE	BOARD MA	CHINERY,	EQUIPME	NT, AND S	YSTEMS
RTCA/DO-160	7-Dec-04	ENVIRON	MENTAL C	ONDITIONS	S AND TES	T PROCED	URES FOR	R AIRBORN	NE EQUIPM	1ENT

Vibration Environment Categories MIL-STD-810F

				MIL-STE)-810F	ΤA	BLE 514.5-I					
Life Phase	Platform		Category	Level &	Test		Life Phase	Platform		Category	Level &	Test
				Duration	1/						Duration	1/
				Annex A							Annex A	
Manufacture/	Platform	1	Manufacture	2.1.1	2/		Operational	Aircraft	15	Jet	2.3.4	IV
Maintenance	Manufacture/		Maintenance					Stores	16	Jet	2.3.5	I
	Maintenance		processes						17	Propeller	2.3.6	IV/I
		2	Shipping, handling	2.1.2	2/				18	Helicopter	2.3.7	IV/I
		3	ESS	2.1.3	2/			Missiles	19	Tactical	2.3.8	IV/I
Transportation	Truck/	4	Restrained Cargo	2.1.1						Missiles		
	Trailer/	5	Loose	2.2.2	Ш			Ground	20	Ground	2.3.9	I/111
	Tracked		Cargo							Vehicles		
		6	Large Assembly	2.2.3				Watercraft	21	Marine	2.3.10	I
			Cargo							Vehicles		
	Aircraft	7	Jet	2.2.4				Engines	22	Turbine	2.3.11	I
		8	Propeller	2.2.5	I					Engines		
		9	Helicopter	2.2.6	1			Personnel	23	Personnel	2.3.12	2/
	Ship	10	Surface Ship	2.2.7	I							
	Railroad	11	Train	2.2.8	1		Suplemental	All	24	Minimum	2.4.1	1
Operational	Aircraft	12	Jet	2.3.1						Integrity		
		13	Propeller	2.3.2	1			All Vehicle	25	External	2.4.2	2/
		14	Helicopter	2.3.3	I					Canilevered		
1/ Test procedure	- see paragraph 4	ŀ										
2/ See Annex A r	eference											

Vibration Isolation and Compensation

Isolate Sensitive Components

Crystals - Piezoelectric

Filters – Critical mechanical dimensions

Chokes – Proximity to other components

Microwave Components



Vibration Isolators



Vibration Isolated Oscillator Carrier



Assembly with VHF Crystal Oscillator





Oscillator Detail



Selecting and Using Isolation Mounts

- Minimal to no heat transfer
- Induced vibration through cabling and harnesses
- Shock excursions may require snubbers
- Isolator fatigue
- Dynamic sheer spring rate, radial axial spring rate

Selecting and Using Isolation Mounts (Cont'd)

- **Temperature range**
- **Center of gravity**
- **Platform strength**
- **Resonant frequency**
- **Chassis Amplification**
- Non-linear isolator response to low vibration levels
- Higher level isolation systems with resonances

Isolator Selection Guides

http://www.barrycontrols.com/defenseandindustrial/isolatorselectionguide/

http://www.lord.com/Home/ProductsServices/Catalogs/AerospaceCatalogOverview/tabid/ 3783/Default.aspx



Calculating Phase Noise Under Vibration

Random Vibration Profile – MIL-STD-202G Jet Aircraft

EXAMPLE

MIL-STD-202G



TABLE 214-II. Values for test-condition II. 1/

Characteristics							
Test condition letter	Power spectral density	Overall rms G					
A B C D E F G H J	.02 .04 .06 .1 .2 .3 .4 .6 1.0	6.21 8.78 10.76 13.89 19.64 24.06 27.78 34.02 43.92					

Airborne - Without Vibration Isolators



Airborne - Vibration Isolation with 40 Hz Resonance



Airborne - Vibration Isolation with 100 Hz Resonance



Vibration Induced Phase Noise in Crystal Oscillators

Random Vibration Profile – MIL-STD-167-1A Shipboard



TABLE I. Vibratory displacement of environmental vibration.

Frequency range (Hz)	Table single amplitude (inch)
4 to 15	0.030 ±0.006
16 to 25	0.020 ±0.004
26 to 33	0.010 ± 0.002



Shipboard – Without Vibration Isolators



Shipboard - Vibration Isolation with 40 Hz Resonance



Shipboard - Vibration Isolation with 8 Hz Resonance



Vibration Induced Phase Noise in Crystal Oscillators

Vibration Induced Phase Noise Spreadsheet Link

http://www.wenzel.com/documents/spread1.htm

Thanks to Charles Wenzel



Low Frequency Vibration Damping

Very Low Frequency Isolators Acceleration Compensation Active Compensation Bootstrap Compensation Bootstrapping a PLL for Better Performance. Charles Wenzel http://www.wenzel.com/pdffiles1/pdfs/bootstrp.pdf

Bootstrapped PLL Reduces Oscillator Instabilities





Bootstrap Oscillators



Bootstrap Implementation



Bootstrap Performance Data



Measuring Phase Noise Under Vibration

LDS Vibration System with Slip Table Dactron Vibration Control Software



Phase Noise Test Configuration



PHASE NOISE TEST CONFIGURATION

Testing Under Vibration

Induced vibration through cabling and harnesses Induced electrical noise in the phase noise test set Large magnetic fields are present Sensor location Fixture resonances Eye and Ear protection





Airborne Frequency Source for Agile Radar





AN/NPG-68 (V)9 Fire Control Radar Reference Fast Switching Local Oscillator for the F/A-18G Prowler



AH-64D Apache Longbow Fire Control Radar Source



Advanced Technology Microwave Sounder Reference for Space



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