The NAC –
A Miniature Atomic Rubidium Clock

An Update
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NAC1 – A Nano Atomic Clock

- **NAC1** is an extremely small and compact Atomic clock providing accuracy of **microseconds/day.**
- **NAC1** is based on the Coherent-Population-Trapping (CPT) phenomenon
- **NAC1** incorporates **a proven traditional glass technology**
- The use of glass technology insures **high reliability**
- The use of glass technology enables an extended operating temperature range of **-40°C to 75°C**

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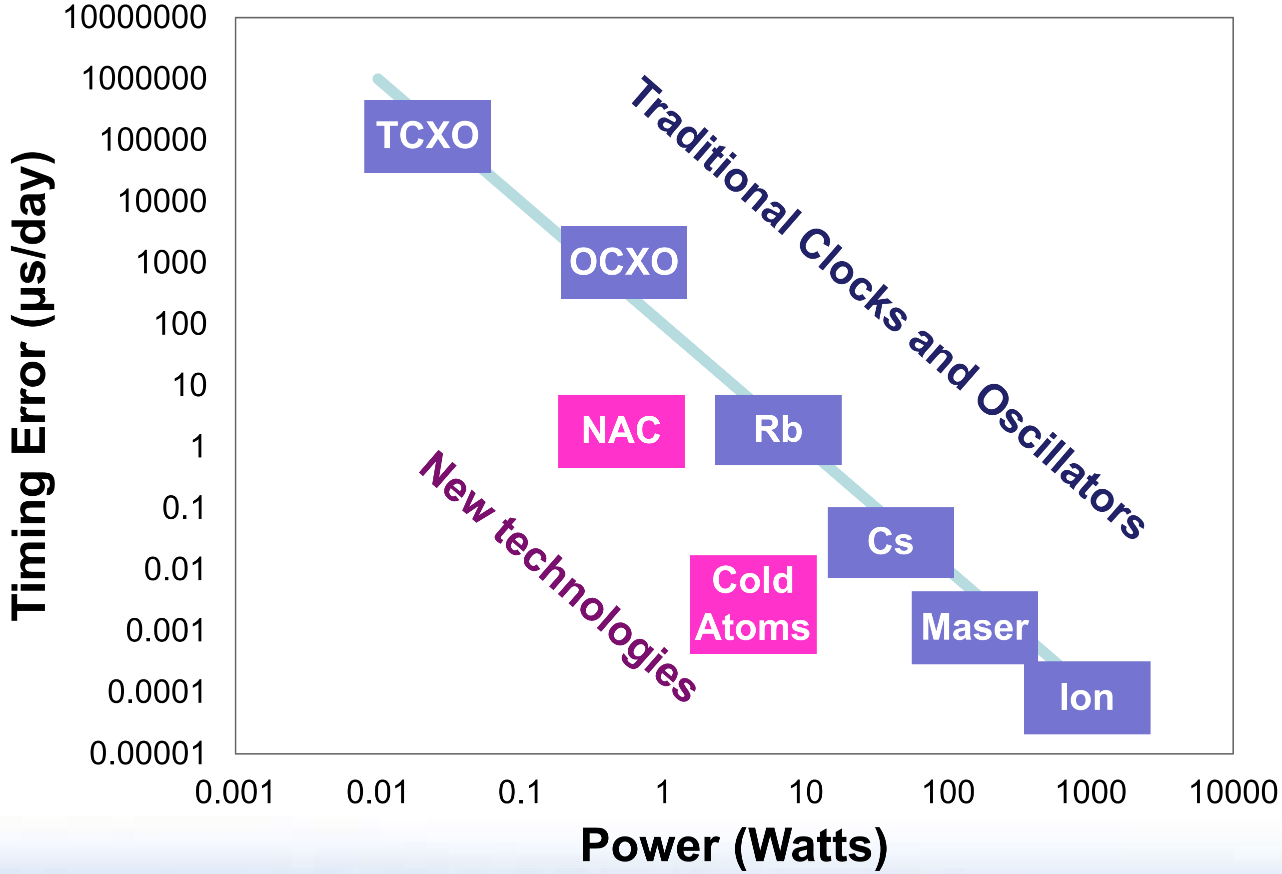
Accurate Frequency & Time

Time Accuracy of Clocks



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Why NAC1?

- **GNSS Receiver**
  - Holdover / Backup.
  - Clean signal (Jitter/ Wander).
  - GPS Spoofing detection.
- **Local Oscillator for timing in network applications**
  - PTP - IEEE 1588.
  - Spoofing / Malware detection in “the physical layer”.
  - Holdover / Backup.
  - Clean signal (Jitter/ Wander).
- **Oil/Gas Underwater Explorations**
- **Airborn & Space applications where power and size is important**
- **Various military applications where power and size is important**

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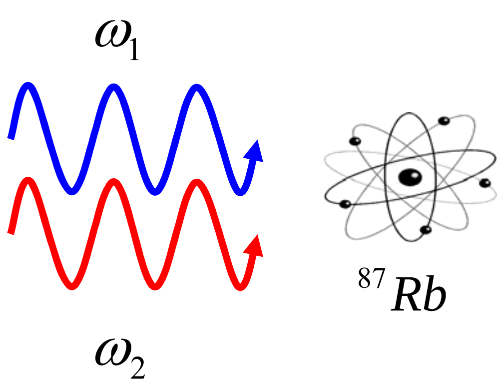
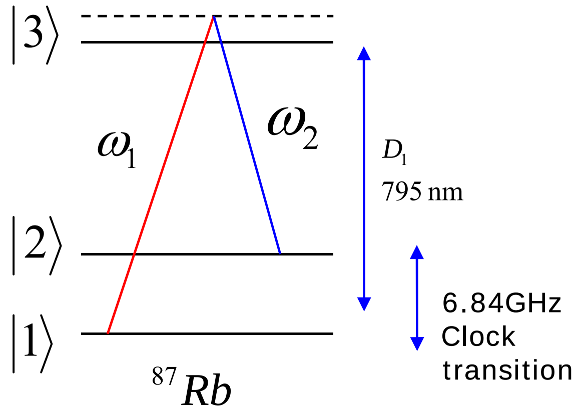
NAC1 Key Features

- Size: 32cc
- Power Consumption: 1.2W → 0.8W → 0.23W
- Timing: <5 microseconds per day
- Aging: <3E-10/month
- Short Term Stability ~8E-12 @ 100s to 10,000s
- Temperature operating range: -40°C to 70°C
- Temp Stability: ±5E-10 / -20°C to 65°C
- Outputs: 10 MHz ,1PPS
- Supply voltage: 3.3 VDC
- Phase noise (floor): -150dBc / Hz

41mm X 35mm X 22 mm
1.6” X 1.39” X 0.87”

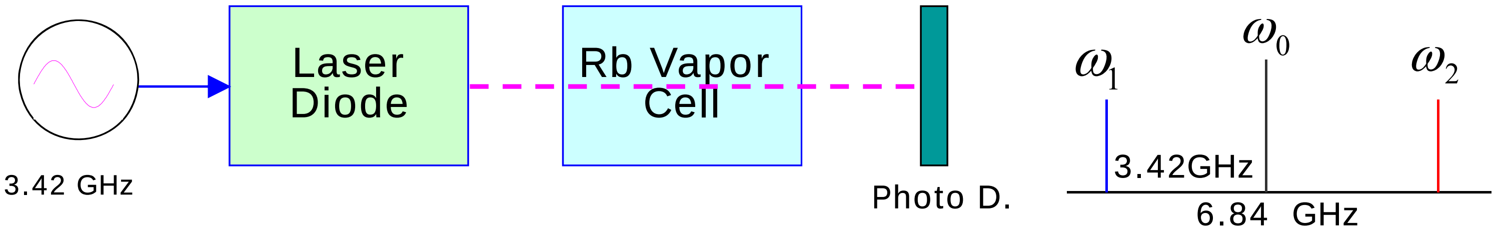
Principles of Coherent Population Trapping (CPT)



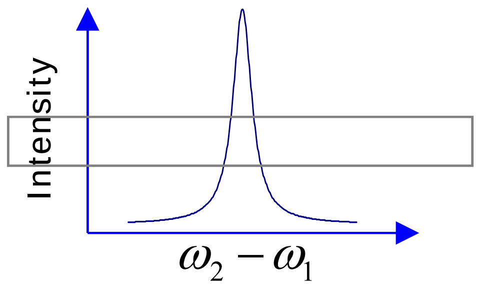


- An atom with 3 energy levels interacts with 2 optical fields with frequencies ω1 and ω2.
- A coherent superposition of the 2 ground states occurs, leading to a transparency when (ω1-ω2) equals the clock transition frequency (6.84GHz for Rubidium).
- This is used to lock a local TCXO to the atomic resonance.

How to get 2 optical frequencies?

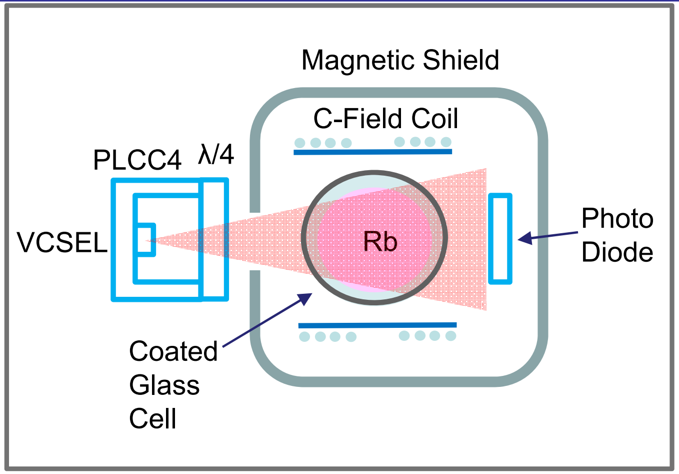


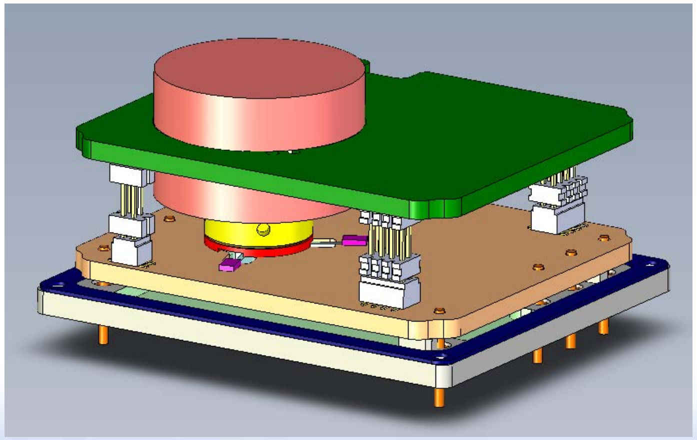
- Modulating the current of a laser diode at ~3.42GHz produces two sidebands separated by ~6.84GHz.
- When 2X modulation frequency matches the atomic transition, the Rb vapor becomes transparent.



Simple Design

- **Traditional Rubidium vapor glass cell**
- **Direct heating by resistive coating**
- Laser diode (VCSEL)
- λ/4 Plate for circular polarization
- Photo diode
- Magnetic coil & shielding.
- Two boards for the control electronics





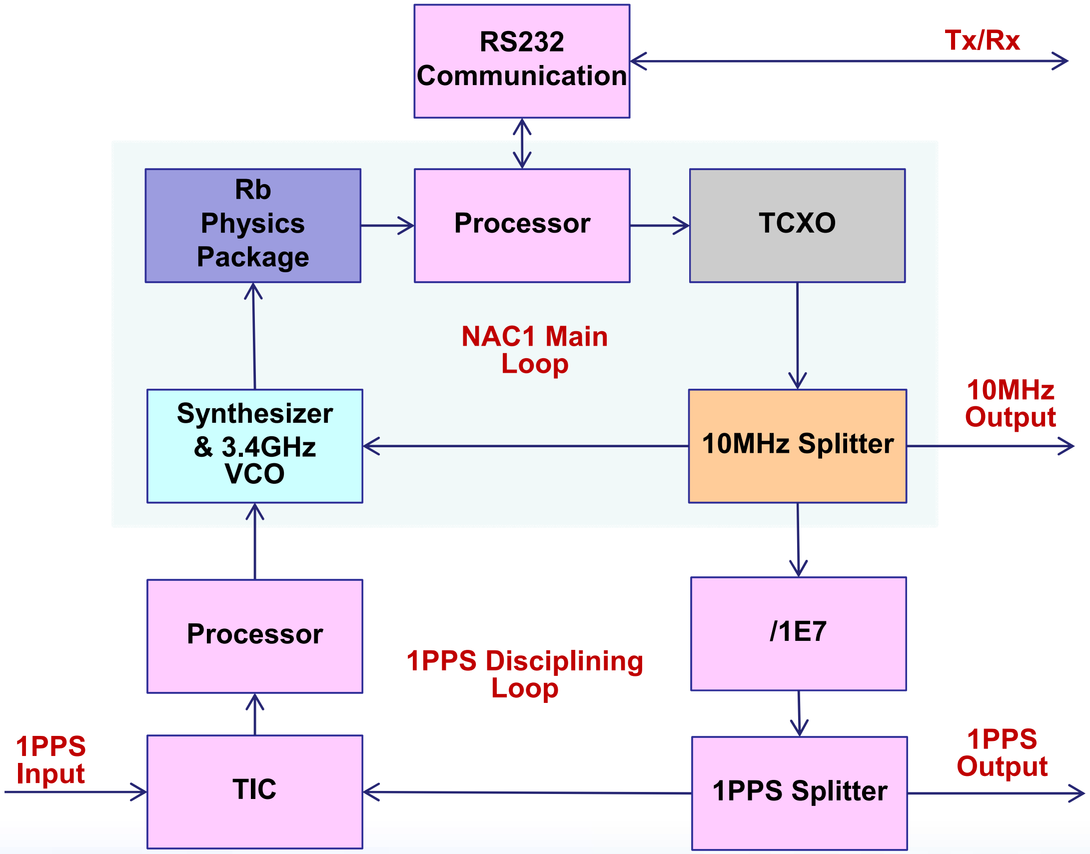
NAC1 System and Operation Algorithm

Control Loops

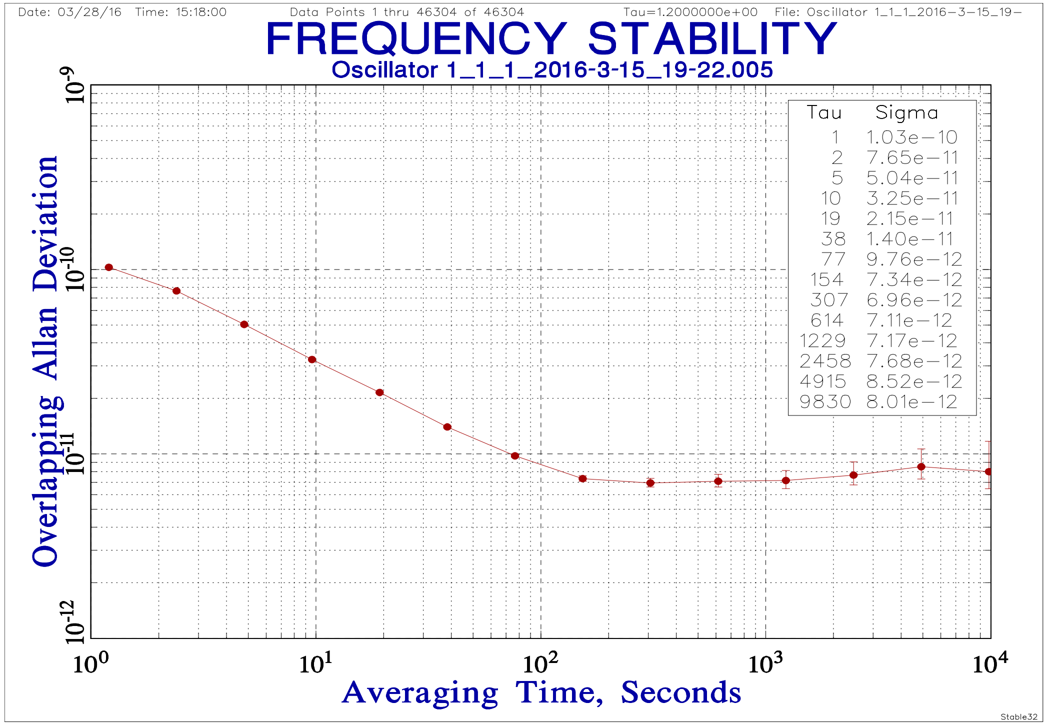
- Main frequency
- Laser Wavelength
- RF Power
- Laser temperature PI
- Cell temperature PI
- 1PPS Disciplining

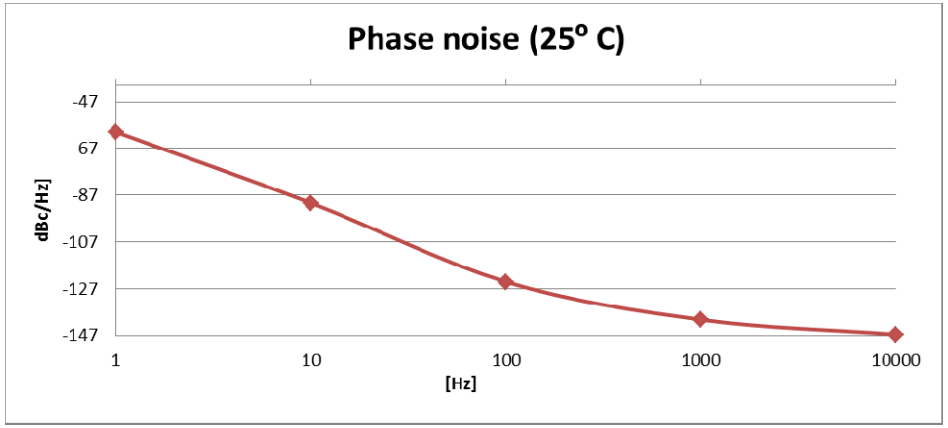
Algorithm

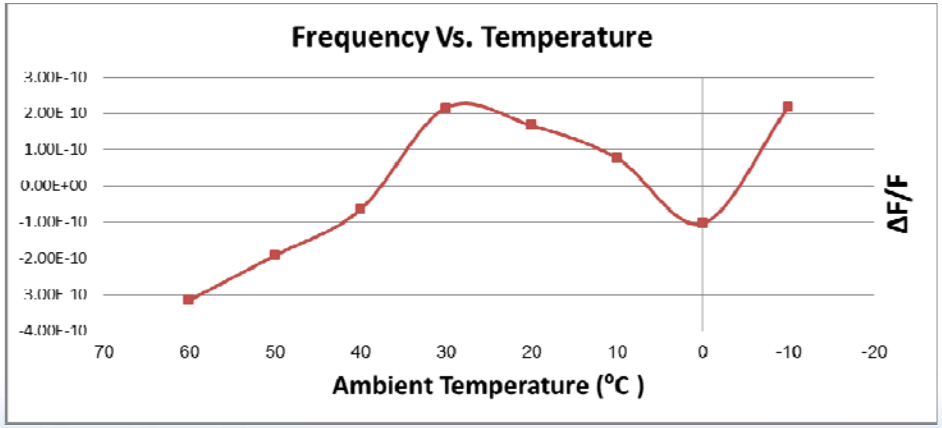
- Temperature Compensation
- Overall Build-In Test (BIT)
- Initialization process
- Extensive Parameters Monitoring



NAC1 Performance







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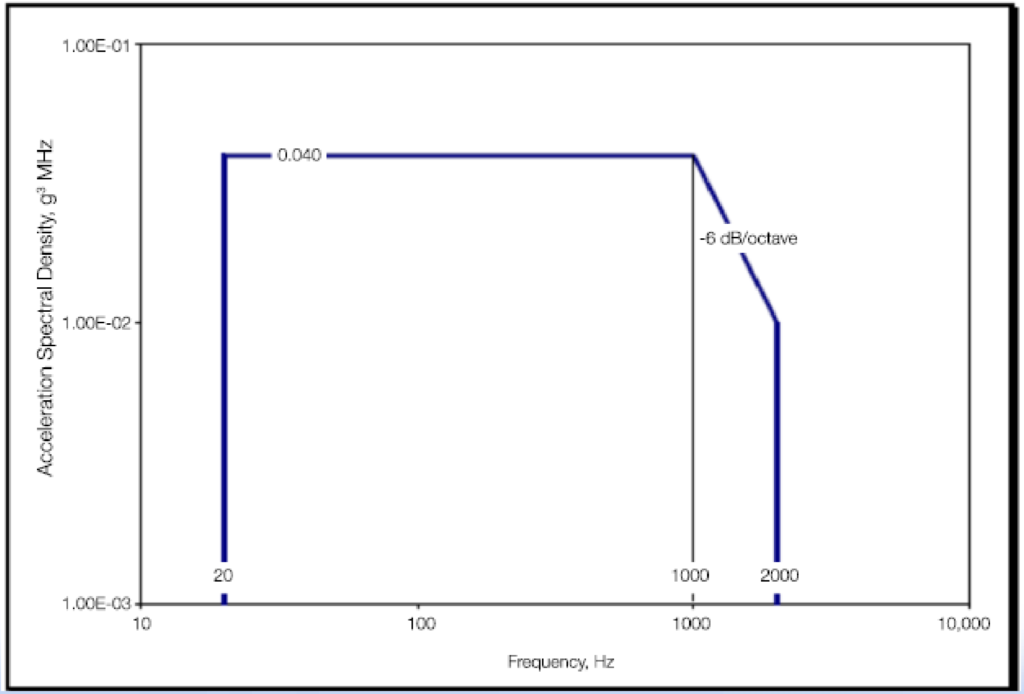
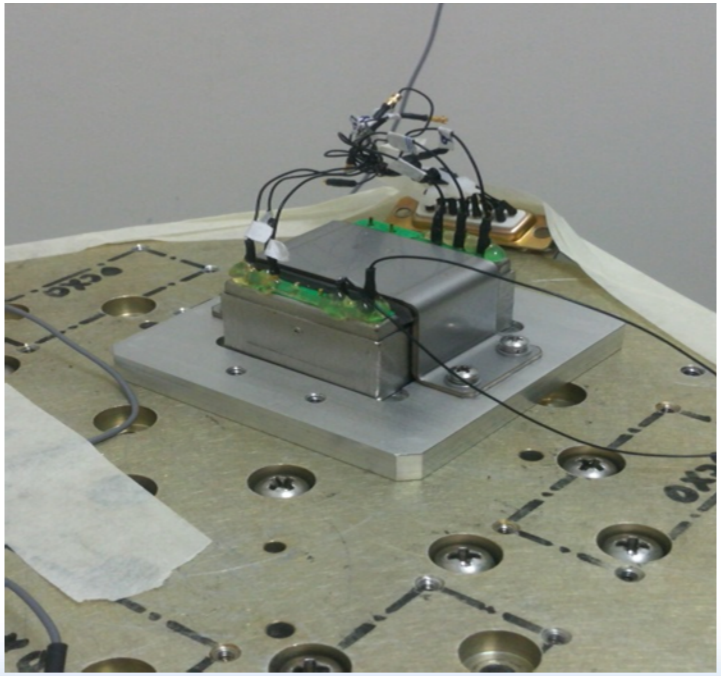
Vibration Test

- Test profile was done per MIL-STD – 810G Method 514.6, 7.7 grms
- 1 hour per axis with the profile below.
- The unit maintained lock during the test.





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Shock Test

- Test profile was done per MIL-STD 202G, method 213, Test condition E.
- 1000g, (0.5 ms, half-sine).
- Unit was subjected to 3 shocks in each direction [+/-axis] for a total of 18 shocks.

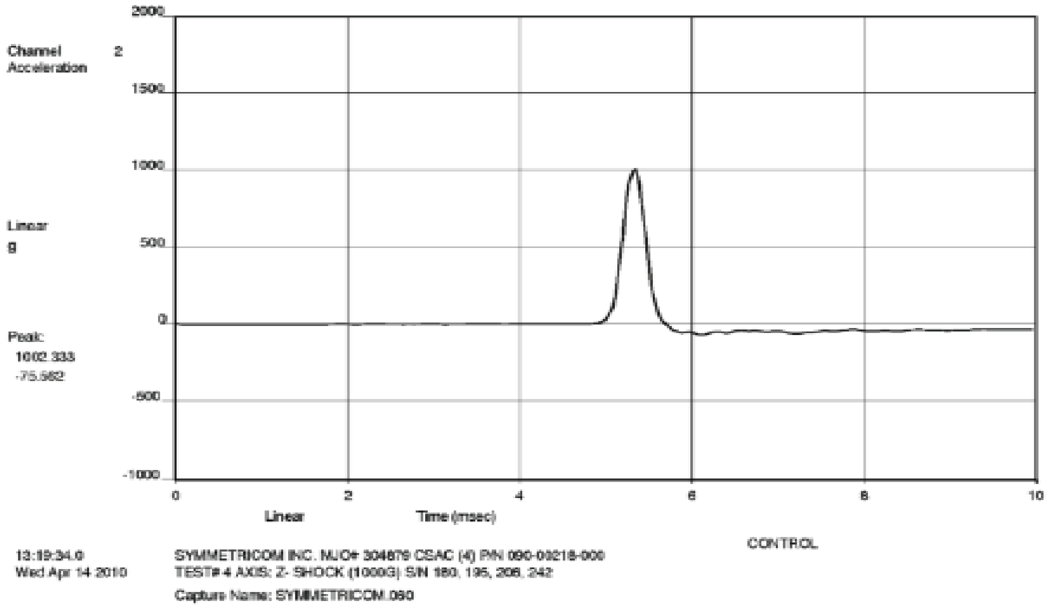

Figure 7: Sample Shock Plot At 1000 g, 0.5 msec

Reliability Prediction

Prediction Method: MIL-HDBK-217F Notice 2					
Environmental Condition		Ground Benign			
Ambient Temperature		25°C		70°C	
Product ID		**λ*10^{-6} [F/Hours]**	**MTBF [Hours]**	**λ*10^{-6} [F/Hours]**	**MTBF [Hours]**
NAC 1004 Product		**1.44**	**694,343**	**2.38**	**421,020**
Sub-Assemblies	NAC LASER BOARD	0.86	1,163,394	1.38	726,999
	NAC CELL BOARD	0.58	1,722,188	0.1	1,000,334

Prediction Method: MIL-HDBK-217F Notice 2					
Environmental Condition		Ground Mobile			
Ambient Temperature		25°C		70°C	
Product ID		**λ*10^{-6} [F/Hours]**	**MTBF [Hours]**	**λ*10^{-6} [F/Hours]**	**MTBF [Hours]**
NAC 1004 Product		**8.9**	**112,324**	**17.64**	**56,703**
Sub-Assemblies	NAC LASER BOARD	5.06	197,734	8.78	113,851
	NAC CELL BOARD	3.85	260,044	8.85	112,963

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End

תודה
Dankie
Gracias
Спасибо
شكرا
Merci
Takk
Köszönjük
Terima kasih
Grazie
Dziękujemy
Dėkojame
Ďakujeme
Vielen Dank
Paldies
Kiitos
Täname teid
谢谢
Thank You
Tak
感謝您
Obrigado
Teşekkür Ederiz
감사합니다
Σας Ευχαριστούμ
ขอบคุณ
Bedankt
Děkujeme vám
ありがとうございます
Tack