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Programmable Oscillators

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Evaluation Test Report

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1 Executive Summary

The flight hybrid crystal oscillators used today are costly and tend to be long lead items. Moreover, they offer no flexibility in way of changes to the desired frequency, operational voltage, etc. Each variant is required to be procured as a separate line item, which makes it very costly and schedule dependent. But now, there appears to be a solution in the offing – the programmable oscillator, which offers several advantages over the conventional fixed frequency oscillators.

The advantages of using programmable oscillators in NASA applications would be: provide very low cost solution, very short lead times, offer total flexibility, and give an option for user re-programmability to correct for a human error. They also fit nicely on the NASA technology road map (see Appendix 10).

The focus of this work is on the next generation of oscillators, the low voltage/low power versions, which would operate at 3.3V and lower. Two different versions of programmable oscillators are available. One that can be Field Instantly Programmable (FIPO) and one that can be programmed on-the-fly (MIPO). FIPO programmable oscillators were evaluated for infusion into NASA Programs and Projects. Evaluation tests included: radiation testing (both single event latchup (SEL) and total ionizing dose (TID)), construction analysis, low temperature testing and screening and qualification methodology.

The testing showed that these programmable oscillators could be utilized by NASA projects provided the projects are able to accommodate the following guidelines: use a resistor in series and be able to reboot the system for SEL, the total dose requirement is no higher than 10 krads and are able to use the SMD package. This has been a highly leveraged task with support from NASA Projects, other NASA Centers, the NEPAG Group and the manufacturer. The test results obtained during this evaluation have been fed back to the manufacturer to enable them to continuously improve the product reliability. The near term goal is for the manufacturer to offer FIPO as a standard flight product. The MIPO evaluation was started and will continue into the next fiscal year.

2 Introduction

The main purpose of the work performed in this study was to facilitate the infusion of COTS programmable oscillators into NASA projects. Successful characterization of these devices would allow the users to procure a large quantity of blank devices and then program them to work at a desired frequency, voltage, output level, etc. The ability to program an oscillator would give important additional degree of freedom to spacecraft designers. Information about the first generation product, FIFO (Field Instantly Programmable Oscillator) will be discussed in detail as well as how the infusion of Field Instantly-Programmable Oscillators (FIPO) into NASA projects can occur. The evaluation of the current product, MIPO (Multi-frequency In-circuit reconfiguration Programmable Oscillator) will also be discussed. The focus of this work was on ultra low power parts; 3V and lower operational voltage.

Over the last 10 years, JPL has been instrumental in developing radiation hardened hybrid crystal oscillators for Space applications; the early devices such as those used on Cassini, worked at 5V supply whereas the more recent ones developed for technology development projects are lower power versions that operate at 3.3V. However, such oscillators are very expensive, the cost of procuring each separate frequency (including the assembly, screening and qualification) adds up. On the Cassini project alone, JPL design engineers had several frequencies listed on the JPL drawings. Additionally, it can take somewhere from 36 weeks to 52 weeks to get the flight parts, even the EM's can take several months.

All of this pointed to a need to look for alternate flight worthy hybrid oscillators that could be procured on a shorter cycle and at reduced overall costs. One style that shows promise is the newly announced FIPO devices where the users can create their desired frequency parts by programming crystal oscillator blanks (which could be stored in larger more economical numbers). A limited evaluation of one such device, CAR/CPPx1T-A7BR-xx.xxx (FIPO) offered by Cardinal Components located in Wayne, NJ, was undertaken by NASA. It should be noted that the parts were of commercial grade. The evaluation effort was leveraged by jointly funding project, institutional and NEPP account codes.

This field programmable oscillator is a commercial part not originally intended for space application. This analysis was intended to see if the part could be upgraded for space application. Although some elements of the part do not have the ruggedness necessary for space application and some step coverage do not meet Mil Standards, the conclusions in this report do not concern the use of the part in applications (non-space) for which it was intended.

2.1 Functions the Programmable FIPO Oscillator Performs

The FIPO is EPROM based phase lock loop technology. The FIPO blank oscillator can be programmed to either 3.3V from 1 to 100MHz CMOS/TTL or 5V from 1 to 133MHz in either CMOS or TTL. Tight duty cycle (45%min, 55% max) is available. It can be programmed for both tri-state output and power down mode. The part can be programmed twice which allows for reprogramming to correct errors or reuse of the same part for two separate applications with different frequencies, power supplies (5V or 3.3V) and/or different output characteristics. Some salient features of the part include <100ppm stability, 5ppm/yr aging, 50ps RMS jitter.

2.2 Data Sheet

Field Programmable Blank Oscillator

- Programmed with the PG-2000 field oscillator programming instrument within seconds
- Can be programmed twice
- Provides a sealed finished custom oscillator
- Standard Package Options

Re-Configurable 6 Output PECL Oscillator

- Fixed & Re-Configurable Multi-Frequency Oscillator
- Intuitive software and I2 C interface
- Easily update system
- Software flexible, quick upgrades and changes
- Industry-standard packaging saves on board space
- Mult. outputs 1 pkg vs. mult. osc & assoc. comp.
- Differential PECL Output

The full data sheet from Cardinal can be found in Appendix 1.

2.3 Programming Specification

The programmer enables the user to create a device with a specified frequency, voltage (5V, 3.3V or 2.7V), output characteristics (CMOS or TTL) and some other enabled functions. A user can customize the ‘blanks’ in a matter of minutes that can be used in bread-boards, evaluation purposes and to supply clocks to devices being burn-in.

The PG3000 consists of a USB connected programmer and software which allows Cardinal’s FIPO components to be programmed to the user’s specifications. The FIPO device (Field Instantly Programmable Oscillator) can be configured by the user for frequency, supply voltage, drive type and output control function using the PG3000 programmer.

Details of the Programming specification can be found in Appendix 2.

2.4 Vendor visits

In order to fully characterize the device for use in Space, it was necessary to conduct vendor visits. The purpose of the visits were to fully understand the manufacturing materials and processes as well as understand the general manufacturing philosophy of the company when it comes to overall quality assurance and process controls.

The vendor/supplier for the FIPO devices studied in this body of work is manufactured at Cardinal Components, Inc., in Wayne, New Jersey. The company was founded in 1986 and has manufacturing plants in the Far East. All of the electrical testing is performed in the Wayne facility. Based on the visit it is clear that there are some improvements needed to ESD controls and that information was fedback to Cardinal. During the first interface meeting it was discovered that Cardinal had a new programmer, the PG-3000, for programming devices down to 2.7V. This programmer is an improvement over the PG-2000 which programmed devices at 5V and 3.3V. NASA has since acquired and used the PG-3000 programmer.

During the screening of FIPO parts for one of NASA’s projects there were a lot of problems with electrical testing – mainly due to excessive noise in the set-up. During the course of reducing the noise to try and take a good reading, a number of parts were damaged mainly due to repetitive handling. The projects were concerned and it was decided to have a face-to-face meeting between the manufacturer and the screening house and NASA to understand the issues. A technical exchange meeting was held at Cardinal to discuss test and burn-in problems. Cardinal engineering made several suggestions to improve the test set-ups which were implemented by the test house. For burn-in they recommended special sockets which were also implemented.

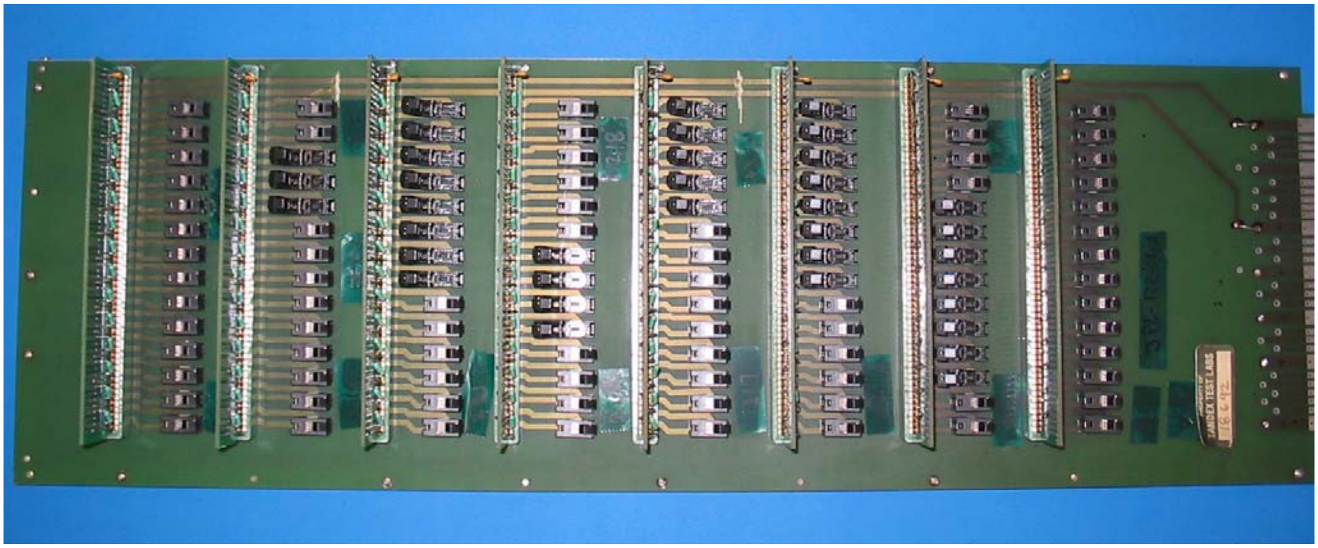


Figure 1: Burn-in board utilized for FIPO devices

3 FIPO Evaluation Test Results

The evaluation performed on the FIPO devices included radiation, low temperature characterization, construction analysis/DPA as well as screening. The details of each test are described in the sub-sections below. Also, each sub-section has a detailed report that is attached to the Appendix.

3.1 Single Event Latchup (SEL)

A group of FIPO programmable oscillators were tested under heavy ion dose. All 'unprotected' devices experienced destructive latchup. The latchup rates may be acceptable (once per half century in GEO-extrapolated to 40°C). When tested with a small series resistor (100 ohm) to the supply pin, plus a small by-pass capacitor (0.1µF), destructive latchup was not observed in testing at 3.3V. The part can be power cycled to remove the latchup condition. These results are based on a test temperature of 25°C. Also, the resistor-protected devices have not been examined for any latent damage.

The part may be acceptable for Space flight applications at 3.3V with a 100 ohm series resistor and bypass capacitor <0.1µF, and also when the part can be power cycled to remove the latchup condition. For more detailed information see Appendix 3.

3.2 Total Dose (TID)

Five oscillators were tested for TID using gamma rays in a 60Co cell. All parts failed functionality, i.e., they stopped operating, at 15 krad(Si) even though the supply current and output voltage (in standby mode) remained within specification. They passed at 10krads. For additional information see Appendix 4.

3.3 Low Temperature Investigation

Oscillators were evaluated for operation between +100 °C and -190 °C. Performance characterization was obtained in terms of their output frequency, supply current, and output voltage signal level at specific test temperatures. The effects of thermal cycling under a wide temperature range on the operation of the oscillators, and cold-restart capability were also investigated. All oscillators operated well between +100 °C and -190 °C. In addition, the limited thermal cycling had no effect on their performance and all oscillators were able to cold start at -190 °C. Further testing under long term cycling is required to fully establish the reliability of these devices and to determine their suitability for use in extreme temperature environments. For additional information see Appendix 5.

3.4 Construction Analysis/DPA

Originally the FIPO device was obtained in the metal DIP hermetic package. A construction analysis was performed on a number of DIP FIPO devices (see sub-section 3.4.1). However, while up-screening a lot of DIP FIPOs it was discovered that they had very poor yield at PIND test (1 out of 50 devices passed) due to manufacturing induced particles. Therefore, an alternate package style, which was the SMD 5x7, was substituted for subsequent up-screening.

A DPA is being conducted to see what the differences are from DIP version and that report can be found in Appendix 6b.

3.4.1 Dual In-Line Package (DIP)

Four parts (Arbitrarily serialized A, B, C and D) were programmed using the PG-2000P (Oscillator Programming System from Cardinal Components, Inc.). Part A was programmed as 5V and 133 MHz. Part B was first programmed as 5V and 133 MHz then was reprogrammed as 3.3V and 100 MHz. Part C was programmed as 3.3V and 100 MHz. Part D was first programmed as 3.3V and 100 MHz then was reprogrammed as 5V and 100 MHz. All four parts were successfully written and read. The parts, then were forwarded to the Failure Analysis Laboratory for DPA (Destructive Physical Analysis).

The DIP Package marked as CPPx1T-A7BR-xx.xxx is a hybrid device composed of 2 components: a quartz crystal and an IC (the Cypress CY2037).
The parts passed the following tests:

- External Visual Examination.
- Hermeticity (both Fine and Gross Leak Tests).
- X-Ray Examination.
- Internal Examination at low and high magnifications.
- Residual Gas Analysis.
- Wirebond Pull Test.
- Die Shear Test

The IC, CY2037 failed SEM metallization examination per MIL-STD-883E, Method 2018. Ref. JPL DPA report Log 8535 (see Appendix 6a).

This field programmable oscillator is a commercial part not originally intended for space application. This analysis was intended to see if the part could be upgraded for space application. Although some elements of the part do not have the ruggedness necessary for space application and some step coverage do not meet Mil Standards, the conclusions in this report do not concern the use of the part in applications (non-space) for which it was intended.

ESD CHARACTERIZATION:

Test Procedure: The part was subjected to all of the ESD characterization models (Human Body, Machine and Charged Device Models) and in both positive and negative voltages.

MODEL	HUMAN BODY	MACHINE
Start Voltage	50V	50
End Voltage	1000V	400V
Step Voltage	50V	50V
Number of Pulses	3	3
Delay Between Pulses	1sec	1sec

In the Charged Device Model, all 4 pins of the device were tested at a charged voltage of 200V. The same test procedure using negative ESD voltage was also applied to all three models.

Results: One part was selected for ESD Characterization. The part was subjected to all three ESD test models: Human Body, Machine and Charged Device. The IMCS-5000 ESD test system was used to test the part in the Human and Machine Models. Charged Device Model tests were performed by the CDM-9000 System manufactured by Oryx, Inc.
The part passed all tests in all three models. Detailed test results are retained in the FA group files for further review purpose.

3.4.2 Surface Mount Device (SMD) Package

A DPA is in progress to assess any differences from the DIP Package construction.

Appendix 6b contains details of the DPA.

4 FIPO Screening Test Results

A screening is being performed on the SMD package for NASA projects as well as NEPP evaluation. Details of the screening follow in the next sub-sections.

4.1 Marking Scheme

A Marking protocol was developed to maintain traceability of the FIPO parts (some used for flight and some used for evaluation). Each part was marked with a laser as follows:

1st line: CPPX-YYYY-ZZZZ-U

Where:

- CPP denotes FIPO product made by Cardinal Components
- X is the package style, 7 means 5x7 ceramic SMD package
- YYYY represents the year and the week the part was programmed
- ZZZZ denotes a unique serial number
- U means upscreened (per approved traveler)

2nd line: Frequency in MHz-CMOS/ TTL selection-Enable pin selection-operating voltage
This line would capture the programmed information at the start of screening.

Where:

- Frequency (MHz) would be expressed up to 4 places of decimal
- CMOS or TTL selection; use C for CMOS and T for TTL

- Enable selection; E for enabled, X for “don't care”
- Operating voltage in Volts: Specify whether 5.0, 3.3 or 2.7

3rd line: This line would represent any post screen changes to the programmed data; it would accommodate situations when a user has no choice but to re-program the screened part due to unforeseen changes in their design. The format would be the same as the one for the second line. It shall be left blank at initial (pre-screen) marking.

Figure 1: Example of marking on an actual FIPO, 5x7 ceramic package programmed in the 40th week the year 2004, serial number is A006, up-screened. The programmed values were 2.4576 Mhz for the frequency, CMOS output, device is enabled at 3.3V supply.

4.2 Screening Flow

It is desired that the manufacturer supply flight parts to the end user that have been screened to insure high reliability devices. However, these are commercial devices and there is no data as to their performance per a space level flow. Therefore in order to collect that information and have flight worthy parts to satisfy immediate needs for the projects it was decided that NASA develop a screen. At the same time the data obtained from this body of work is being fed back to the manufacturer for continuous on-going improvement of the part.

Table1: The screening flow as used at the test house (Tandex)

Step	Process	Description	Notes
01	FLO		Flow prepared by Tandex/Approved by JPL
02	QCI		Flow approved by Tandex
03	RCV	Verify Part Number, Enter into incoming log	
04	SER	Laser marking/Serialization	
05	ELEC	Electrical test @ 25°C	
06	PULL	Pull control samples #A001 and #A022	
07	PIND	Particle Impact Noise Detection per MIL-STD-883 Method 2020	
08	TEMP	Temperature Cycling per MIL-STD-883 Method ????,	10 cycles

		Condition C -65^{o}C to +150^{o}C	
09	ACC	Constant Acceleration per MIL-STD-883 Method 2001, Condition E (Y1 only)	
10	XRAY	Radiography per MIL-STD-883 Method 2012 (2 views)	
11	ELEC	Electrical Test per MFG. Data Sheet; Read and Record 100% of Samples (Temperature soak time = 30 min.)	+25^{o}C, +125^{o}C, -55^{o}C
12	BI	Dynamic Burn-in T= 240 hours, TA = +125^{o}C	Prior to burn-in CSI to verify Burn-in boards
13	ELEC	Electrical Test per MFG. Data Sheet; Read and Record 100% of Samples (Temperature soak time = 30 min.)	+25^{o}C, +125^{o}C, -55^{o}C
14	HERM	Hermeticity Seal Test 100% per MIL-STD-883, Method 1014	Fine and Gross Leak
15	PULL	Pull 10 plus 1 Control Sample to perform Qualification for each job	
16	MARK	Mark Acceptable samples with a green dot	
17	QCI	Tandex Quality Control Inspection	
18	PKG	Use Original Container or Tandex Packaging	Mark with Part # and <u>FLIGHT HARDWARE</u>
19	QAR	Tandex Quality Assurance Review	Ship to JPL

4.3 Attributes Data

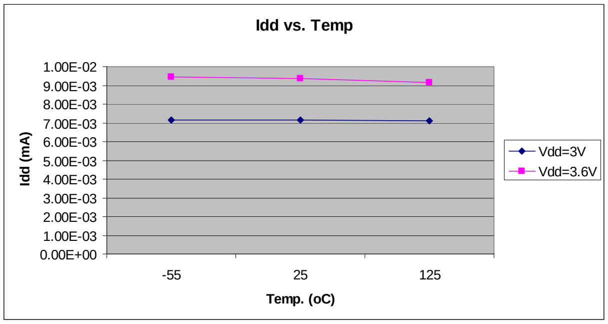
The results from the screening are summarized below.

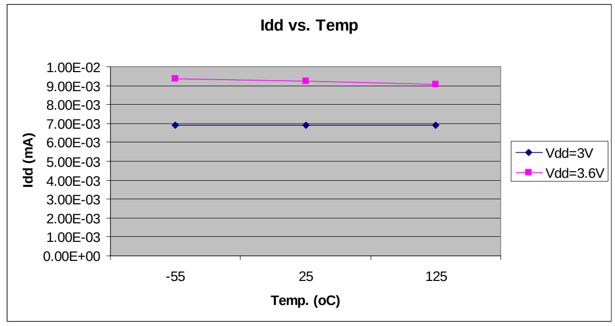
Table2: Screening Results (pass/fail)

Step	Process	QTY	REJ	ACCEPT
04	SER	42	0	42
05	ELEC	42	0	42
06	PULL	2		
07	PIND	40	0	40
08	TEMP	40	0	40
09	ACC	40	0	40
10	XRAY	42	0	42
11	ELEC	42	1	41
12	BI	39	0	39
13	ELEC	41	0	41
14	HERM	39	0	39
15	PULL	10 + 1		
16	MARK			
17	QCI			
18	PKG			
19	QAR			

4.4 Variables Data

Shown below are typical parametric variations over temperature. This data as well as other screening data including the parametric shifts across burn-in will be fed back to the manufacturer and also discussed with the projects who are considering usage of these parts.


Idd vs. Temp
1.00E-02
9.00E-03
8.00E-03
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
Idd (mA)
-55
25
125
Temp. (oC)
Vdd=3V
Vdd=3.6V


Idd vs. Temp
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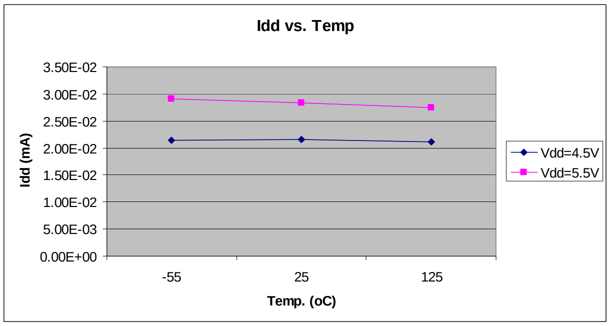
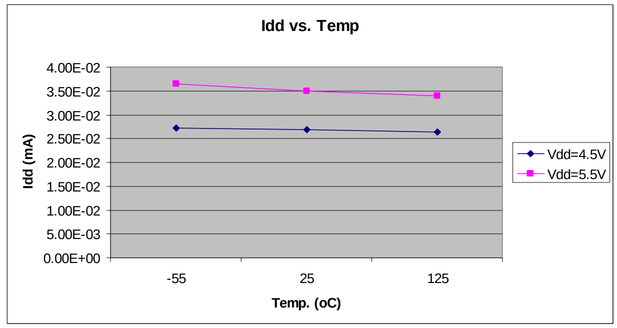
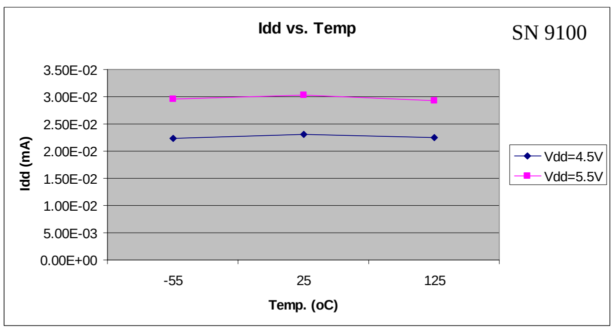
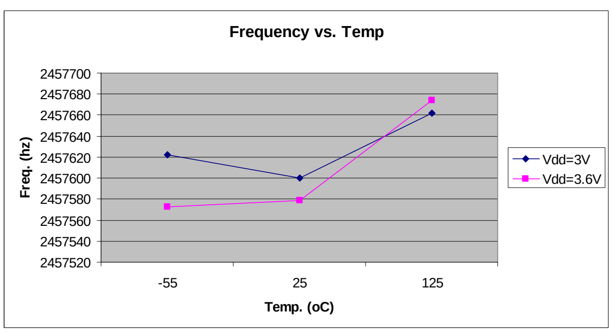
9.00E-03
8.00E-03
7.00E-03
6.00E-03
5.00E-03
4.00E-03
3.00E-03
2.00E-03
1.00E-03
0.00E+00
Idd (mA)
-55
25
125
Temp. (oC)
Vdd=3V
Vdd=3.6V


Idd vs. Temp
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Idd (mA)
-55
25
125
Temp. (oC)
Vdd=4.5V
Vdd=5.5V


Idd vs. Temp
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Idd (mA)
-55
25
125
Temp. (oC)
Vdd=4.5V
Vdd=5.5V


Idd vs. Temp
SN 9100
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Idd (mA)
-55
25
125
Temp. (oC)
Vdd=4.5V
Vdd=5.5V


Frequency vs. Temp
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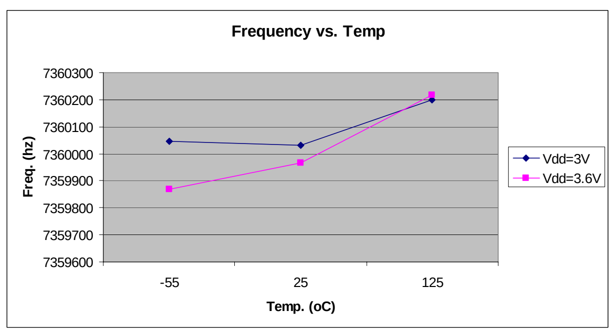
2457680
2457660
2457640
2457620
2457600
2457580
2457560
2457540
2457520
Freq. (hz)
-55
25
125
Temp. (oC)
Vdd=3V
Vdd=3.6V


Frequency vs. Temp
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7360200
7360100
7360000
7359900
7359800
7359700
7359600
Freq. (hz)
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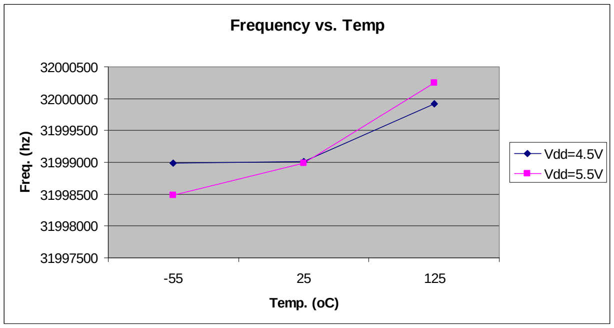
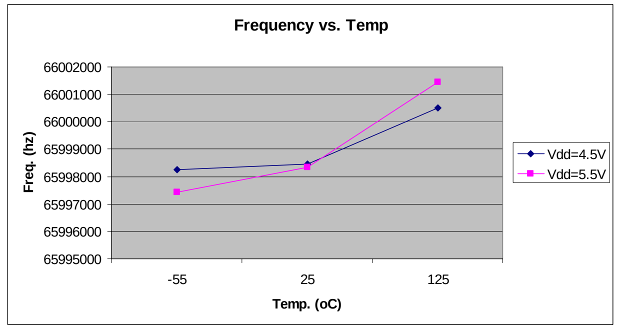
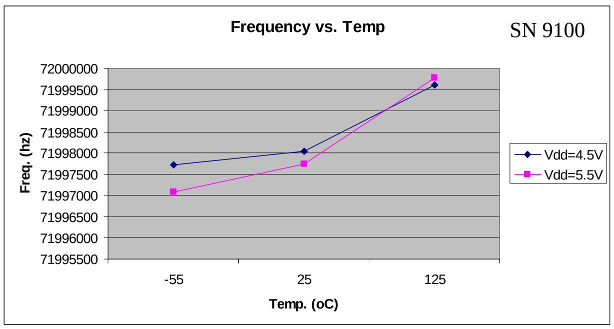
25
125
Temp. (oC)
Vdd=3V
Vdd=3.6V







4.5 Life Test

There are a couple of NASA Projects that have devices currently on life test for various durations. One life test is for 1000 hours and another one is for 2000 hours with interim data taken at 500 hour intervals.

Details can be found in Appendix 8 once the life tests are done.

4.6 Aging

The manufacturer generic data on oscillators aging is shown in Appendix 9. They recommend that the aging tests be done on the lot currently being screened for the NASA projects.

5 Failure Analysis Results

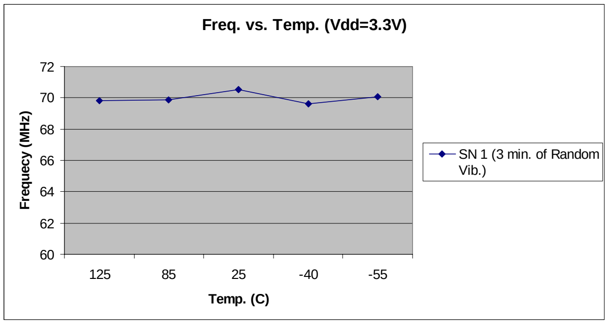
Failure analysis is in progress.

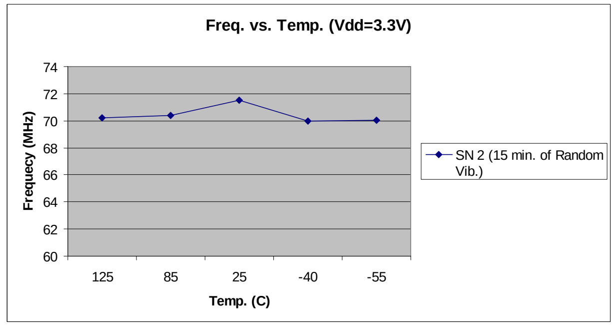
6 Future work –

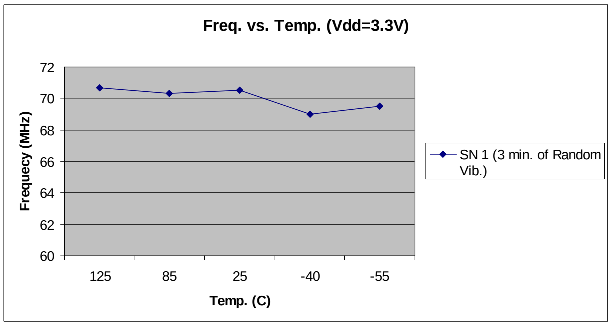
Evaluation of Multi-frequency In-circuit Reconfigurable Programmable Oscillator (MIPO)

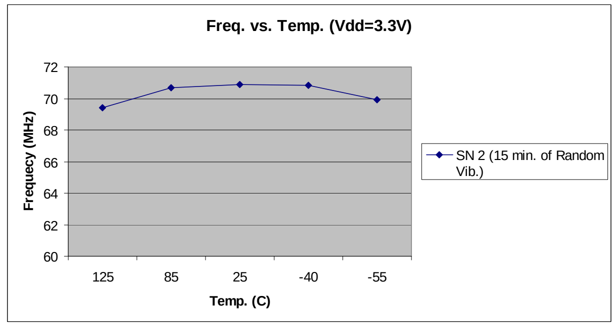
6.1 Initial Characterization

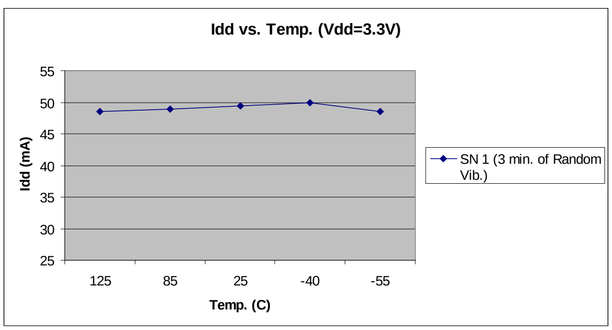
Shown below are typical parametric variations over temperature. This data as well as other screening data including the parametric shifts across burn-in will be fed back to the manufacturer.

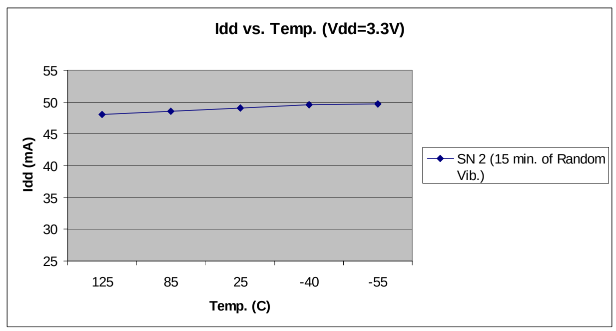


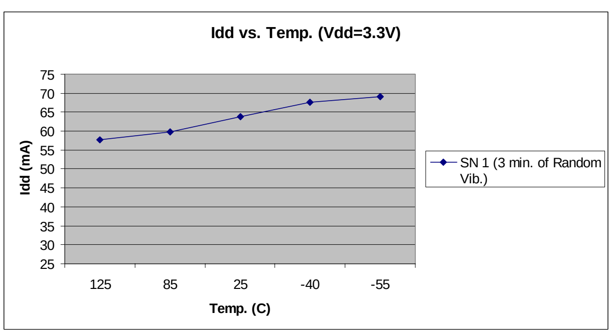


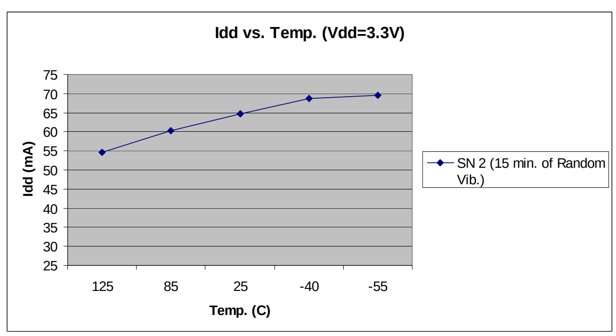












6.1 Construction Analysis Results

No gross deficiencies were found during the course of this analysis. However, several tests and examinations could not be performed due to the limited sample size (1 part). The following tests and examinations will be performed on additional samples in order to get a more complete construction analysis data set:

1. Determination of solder type and melting temperature used on the hybrid substrate.
2. Cross section of the hybrid printed circuit board to examine the plating quality in the vias.

3. Residual Gas Analysis of the hybrid and of the separate quartz crystal case.
4. Additional SEM metallization examination of the oscillator control I.C.

The results of the additional tests and examinations will be published in an addendum to this report.

Details of the Construction Analysis are contained in Appendix 11.

7 Lessons Learned

The commercial industry is several years ahead of the mil/aerospace industry and it's never too early to get a jump start on the evaluation of the commercial products as they become available because the characterization/evaluation takes a considerable amount of time. When NASA evaluates commercial EEE Parts for use in Space Missions the most accepted approach is to examine each part type on a case-by-case basis. It should be understood that not all commercial parts are the same as far as radiation tolerance and reliability. So a general attitude of "wait-and-see" or to have low expectations with regards to the part type meeting NASA requirements prior to testing is perhaps the best way to approach each part. Some commercial parts meet NASA Mission requirements and some part types do not meet any requirements with many commercial parts ending up in the use with some "work-a-rounds" or with some reservations. The method for assessing the over all mission worthiness of a commercial part is to evaluate the radiation tolerance and to assess the reliability for the mission conditions as depicted in the Figure below:

7.1 Approach

The NASA Parts Engineers should take on the added responsibility and leadership to be on the look out for new exciting products - those that don't fit the mold. The approach has to be different than with Class S parts; i.e. keep low expectations. Rather than expecting a commercial product to meet the requirements of a fully qualified rad hard SEL immune Class S product, the Parts Specialist should start (phase 1) by enveloping the capabilities of the commercial product as it is available off-the-shelf. Once the constraints are known about the use of a device, many NASA projects are able to design them in. Phase 2 of the work should include making improvements in the product to enable a broader usage across NASA. There have been instances in the past where the NASA evaluation of existing COTS PEM products found them to be SEL immune and rad-hard to higher than 50krad levels. The examples would include Linear Tech LTC1419A 14-bit A/D converter and the National LMX23XX series of Phase Locked Loops (PLLs). On the other hand, NASA evaluation of 10 different high speed low power 8 and 10 bit COTS PEM A/D converters yielded only one potential candidate. The COTS FIPO evaluated herein fall somewhere in between the two extremes.

7.2 Lessons Learned

The most important thing learned for these particular Crystal Oscillators was the use of 100 ohm resistor in series with the output to dampen the ringing. Without the resistor over and undershoots would occur, giving false VOH, VOL readings. On the setup used to test the part two scope probes, one connected to the scope HP54001 (2pf load), the other (passive x10 scope probe) connected to the frequency counter. At the higher frequencies the passive probe would start to load down the crystal, and distort the waveform, this distortion was minor, but it would effect the rise and fall times. To solve this loading issue an active FET probe on the next evaluation should be used. This type of probe will minimize the loading effect of the probe.

The other thing observed was that if the device was programmed at 2.7V, 3.3V etc, it would work at the higher voltages. It was not investigated to see if a device programmed to the higher voltages would work at the lower voltages, but it might be worth more investigation.

The next evaluation should break the jobs up via voltage levels. All 5V parts should be tested together, as well as the 3.3V parts together, 2.7v parts together, etc.. Each different frequency should also be keep separated from each other. No mixing frequencies in the same container. Multiple frequencies can be tested/burn-in together, but they need to be kept separated, and each container well marked. Labels should match serial numbers.

7.3 Recommendations

The following recommendations not only apply to the Crystal Oscillators evaluated in this body of work but can apply to other COTS as well:

(1) Ongoing Communication with test lab: Scheduled weekly reviews with the test lab are imperative to maintain open communications. Conflicts and technical obstacles can be aired and allowances can be made for schedule changes.
(2) Use of CSI and CTM: The contract Technical Manager and onsite customer source inspection can be extremely valuable to NASA. Due to limited funding, the parts specialist monitored the testing on the oscillators.
(3) Technical Issues: It's not enough to rely solely on the technical expertise of the test laboratories. Technical issues and problems that arose required judgement and guidance by NASA specialists in consultation with the manufacturer. During the middle of the program, we had lots of problems related to the electrical and burn-in test set ups. A trip was made to the manufacturer by NASA and test lab representatives to discuss the issues and take corrective action.
(4) Communication with prospective NASA users: NASA organized a PUG (Parts User Group) meeting where the manufacturer’s chief engineer made a presentation at NASA/JPL with other NEPAG member organizations tied in via phone links.
(5) Develop new approaches as needed: A new marking scheme was devised by NASA to assure proper traceability and identification of the programmed parts (Ref: Section 4.1).
(6) Plans and their implementation: Things are not going to go as planned simply because mistakes do happen. It is necessary to keep an element of flexibility when planning for any tests/tasks.
(7) Enhancing test capability: A new product evaluation provides opportunity to enhance the in-house test capabilities. Even with the tight budget of $120k, NASA spent over $20k to buy new equipment including new meters, a programmer and the special test and burn-in sockets.
(8) Focus, optimism and patience are almost mandatory

8 Acknowledgements

This task was funded by the NEPP Program Office. It was a highly leveraged effort. The collaboration and support provided by the NEPAG, NASA/SDO Project, NASA Glenn, NASA/LAMP Project, NASA/ST-7 Project, NASA/Dawn Project, NASA-GSFC Radiation Test Center, Cardinal Components, Inc., and Tandex Test Labs are acknowledged and appreciated. In addition the support of the following colleagues from NASA/JPL is appreciated: Mike Sandor, David Peters, Duc Vu, Jim Okuno and David Gerke.

9 Appendices

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Appendix 5 – Low Temperature Testing Report
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Appendix 7 – Screening Test Flow
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Appendix 11 – Construction Analysis of MIPO

Appendix 1 – Data Sheet

Field Programmable Blank Oscillator

Series CPP

- ***Programmed with the PG-2000 field oscillator programming instrument within seconds***
- ***Can be programmed twice***
- ***Provides a sealed finished custom oscillator***
- ***Standard Package Options***

Part Numbering Example: CPP C 1 L Z - A5 B6 - XX.XXXX TS

CPP	C	1	L	Z	A5	B6		TS
SERIES	OUTPUT	PACKAGE STYLE	VOLTAGE	ADDED FEATURES	OPERATING TEMP.	STABILITY	FREQUENCY	TRI-STATE
CPP	C = CMOS T = TTL	1 = Full Size 4 = Half Size 7 = 5X7 Ceramic 8 = PLASTIC SMD	Blank = 5V L = 3.3 V	Blank = Bulk T = Tube Z = Tape and Reel	Blank = 0°C +70°C A5 = -20°C +70°C A7 = -40°C +85°C	B6 = ±100 ppm BP = ±50 ppm	1.000~133.000 MHz	TS = Tri-State PD=PowerDwn

Specifications:

	Min	Typ	Max	Unit
Frequency Range: Programmable to Any Discrete Frequency	1.000		133.000	MHz
Available Stability Options:	-100 -50		100 50	ppm ppm
Programmable Input Voltage: (1–133 MHz) (1–100 MHz)	+4.5 +3.0	5.0 3.3	5.5 3.6	VDC VDC
Operating Temperature Range Options:	0 -20 -40		+70 +70 +85	°C °C °C
Storage Temperature:	-55		+125	°C
Aging (PPM/Year) Ta=25C, Vdd=5/3.3V			±5	
Programmable Output Level:	TTL/CMOS			
Packaging:	Tape and Reel (1K per Reel) Tube			

Note: Bypass Vdd to GND with a 0.1 mF capacitor

Operating Conditions:

	Description	Min	Max	Unit
VDD	Digital Supply Voltage	3.0	5.5	V
CTTL	Max Capacitive Load on outputs for TTL levels 4.5V–5.5V VDD ≤ 40 MHz 4.5V–5.5V VDD > 40–133 MHz		 50 25	 pF pF
CCMOS	Max Capacitive Load on outputs for CMOS levels 4.5V–5.5V VDD, ≤ 66 MHz 4.5V–5.5V VDD, >66–133 MHz 3.0V–3.6V VDD, ≤ 40 MHz 3.0V–3.6V VDD, >40–100 MHz		 50 25 30 15	 pF pF pF pF

Field Programmable Blank Oscillator

Series CPP

- ***Programmed with the PG-2000 field oscillator programming instrument within seconds***
- ***Can be programmed twice***
- ***Provides a sealed finished custom oscillator***

Electrical Characteristics

	TEST CONDITIONS	Min	Typ	Max	Unit
Input Characteristics (Pin 1):					
V_{IL}, Low–Level Input Voltage	4.5–5.5V V_{DD}			0.8	V
TO DISABLE OUTPUT	3.0–3.6V V_{DD}			0.2V_{DD}	V
V_{IH}, High–Level Input Voltage	4.5–5.5V V_{DD}	2.0			V
TO ENABLE OUTPUT OR NO CONNECT	3.0–3.6V V_{DD}	0.7V_{DD}			V
I_{IL}, Input Low Current	V_{IN} = 0V			10	mA
I_{IH}, Input High Current	V_{IN} =V_{DD}			5	mA
Output Characteristics:					
V_{OL}, Low–Level Output Voltage	4.5V–5.5V V_{DD}, 16 mA I_{OL}			0.40	V
	3.0V–3.6V V_{DD}, 8 mA I_{OL}			0.40	V
V_{OHTTL}, High-level Output Voltage TTL	4.5V–5.5V V_{DD}, -16 mA I_{OL}	2.40			V
V_{OHCMOS},	4.5V–5.5V V_{DD}, -16 mA I_{OL}	V_{DD} -0.4			V
High-level CMOS Voltage	3.0V–3.6V V_{DD}, -8 mA I_{OL}	V_{DD} -0.4			V
Power Supply Current:	4.5–5.5 V_{DD}, OUTPUT FREQ ≤ 133 MHz			45	mA
(unloaded)	3.0–3.6 V_{DD}, OUTPUT FREQ ≤ 100 MHz			25	mA
Standby Current:			10	50	mA
Input Pull-Up Resistor	4.5–5.5 V_{DD}, V_{IN} = 0V	1.1	3.0	8.0	MW
	4.5–5.5 V_{DD}, V_{IN} = 0.7V	50	100	200	kW
CLKOUT Pull-Down Current	5.0 V_{DD}		20		mA
Output Enable Mode:	Output is Tri-Stated				
Power Down Mode:	Output is NOT Tri-Stated.				

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http://www.cardinalxtal.com E-Mail: cardinal@cardinalxtal.com

Rev 3.0

Field Programmable Blank Oscillator

Series CPP

- *Programmed with the PG-2000 field oscillator programming instrument within seconds*
- *Can be programmed twice*
- *Provides a sealed finished custom oscillator*

Output Clock Switching Characteristics

	Test Conditions	Min	Typ	Max	Unit
Duty Cycle:					
TTL @ 1.4 V, 4.5–5.5 V_{DD}	$\leq$ 50 MHz, C_L = 50 pF	45		55	%
	50–66 MHz, C_L = 15 pF	45		55	%
	66–125 MHz, C_L = 25 pF	40		60	%
	125–133 MHz, C_L = 15 pF	40		60	%
CMOS @ V_{DD}/2, 4.5–5.5 V_{DD}	$\leq$ 66 MHz, $C_L \leq$ 25 pF	45		55	%
	66–125 MHz, $C_L \leq$ 25 pF	40		60	%
	125–133 MHz, $C_L \leq$ 15 pF	40		60	%
3.0–3.6 V_{DD}	$\leq$ 40 MHz, $C_L \leq$ 30 pF	45		55	%
	40-100 MHz, $C_L \leq$ 15 pF	40		60	%
Output Clock Rise/Fall					
	0.8V–2.0V, 4.5-5.5 V_{DD}, C_L = 50			1.8	ns
	0.8V–2.0V, 4.5-5.5 V_{DD}, C_L = 25			1.2	ns
	0.8V–2.0V, 4.5-5.5 V_{DD}, C_L = 15			0.9	ns
	0.2–0.8V_{DD}, 4.5-5.5 V_{DD}, C_L = 50			3.4	ns
	0.2–0.8V_{DD}, 3.0–3.6 V_{DD}, C_L = 30			4.0	ns
	0.2–0.8V_{DD}, 3.0–3.6 V_{DD}, C_L = 15			2.4	ns
Start Up Time	From power on			10	ms
Power Down Delay Time					
Synchronous	PWR_DWN pin HIGH to output LOW		T/2	T+10	ns
Asynchronous			10	15	ns
Output Disable Time					
Synchronous	OE pin HIGH to output Hi-Z		T/2	T+10	ns
Asynchronous	T = Frequency oscillator period		10	15	ns
Output Enable Time				100	ns
RMS Jitter	$\leq$ 33.000, 5 V			$\pm$ 50	ps
	> 33.000, 5 V			$\pm$ 30	ps
	$\leq$ 33.000, 3 V			$\pm$ 50	ps
	> 33.000, 3 V			$\pm$ 40	ps

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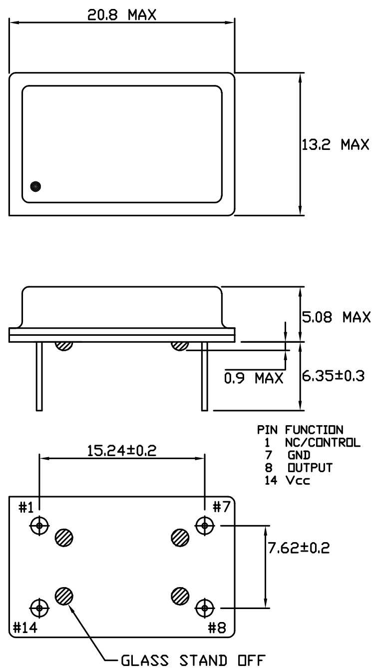
Field Programmable Blank Oscillator

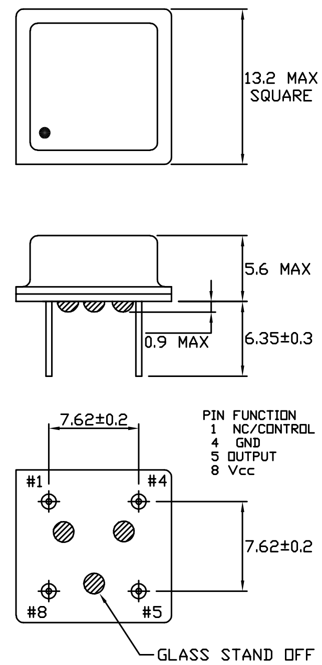
Series CPP

- ***Programmed with the PG-2000 field oscillator programming instrument within seconds***
- ***Can be programmed twice***
- ***Provides a sealed finished custom oscillator***

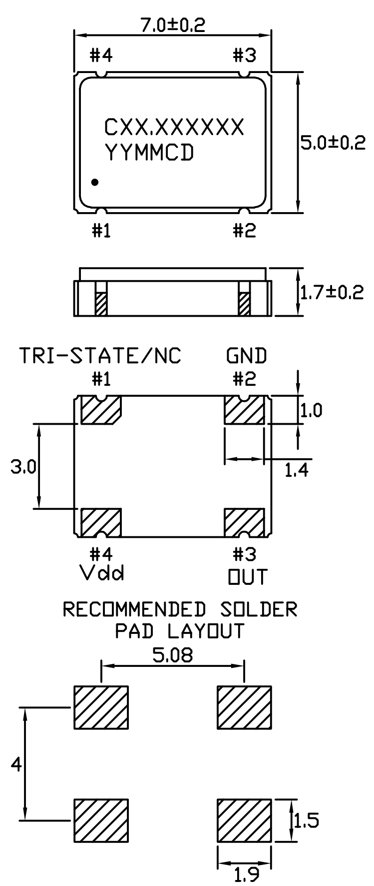
Style 1 Full Size 14 Pin Dip



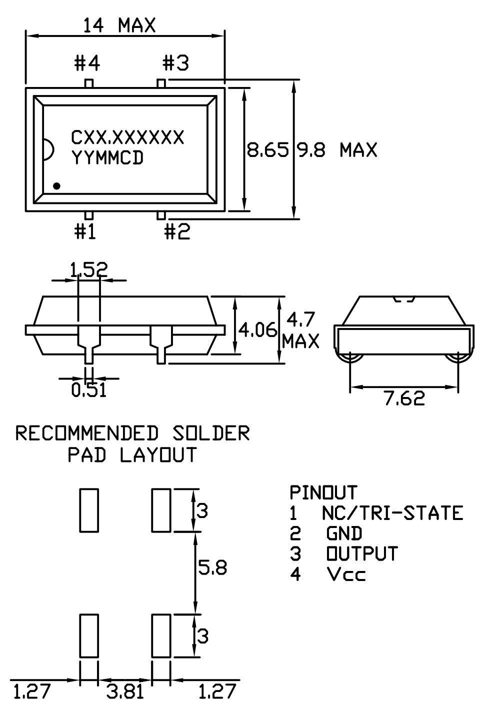
Style 4 Half Size 8 Pin Dip



Style 7 5x7 Ceramic SMD



Style 8 Plastic SMD



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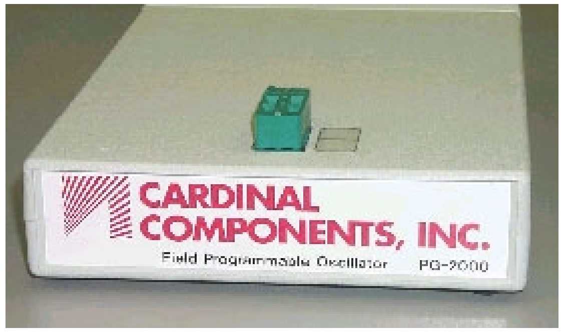
Field Oscillator Programming Instrument

Series PG-2000

- ***Programming instrument to create oscillators, at a user specified frequency, within seconds IN THE FIELD***
- ***No programming skills needed to create finished oscillators from sealed oscillator blanks***
- ***Programmable CMOS or TTL oscillator outputs***
- ***Programmable output enable and power-down feature***
- ***Programmable asynchronous or synchronous output enable***
- ***Programmable for 3.3V or 5.0V oscillator operation***
- ***Microsoft Windows compatible software***

Instrument Part Number: PG-2000

Specifications:



Frequency Range:	1.000 MHz to 133.000 MHz
Acceptable Oscillator Packages:	Style 1 Full-Size 14 Pin DIP Style 4 Half-Size 8 Pin DIP SMD
Oscillator Programming Options:	Output Enable Function Power Down Operation TTL or CMOS Output Instantaneous Asynchronous/ Synchronous Enable/Power Down Selectable Input Voltage (3.3, 5.0V) Ability to reprogram oscillator blank to reuse the same part for two separate applications with different frequency and/or different output characteristics
Transformer Input: Output:	AC, Supplied. UL 996C / 820A0063 100 - 250 VAC 60 Hz 20 W 16 VAC 750 mA
Instrument Size:	6.5” x 10.5” x 2.5”
Oscillator Blank Part Numbers:	see Cardinal CPP series
Required Additional Equipment:	IEEE-488 Instrument Control Card (HP 82341D or eq.) IEEE-488 Instrument Control Cable (HP 10833B, or eq) Frequency Counter (HP 53131 or eq) Computer w/ Microsoft Windows 95,98,NT or Windows 2000

CARDINAL COMPONENTS

Stand-Alone Field Oscillator Programming Instrument

Series PG-2000P

- ***Programming instrument to create oscillators, at a user specified frequency, within seconds IN THE FIELD***
- ***No programming skills needed to create finished oscillators from sealed oscillator blanks***
- ***Designed for low-volume program applications such as engineering, field sales, and sample quantity***
- ***Internal frequency reference for single step programming***
- ***Simple User Interface***
- ***Cardinal 4-pin oscillators are easily inserted into a ZIF socket or surface mount adapter for quick programming***
- ***Oscillator characteristics are selected via keypad and 4-line LCD display***

Instrument Part Number: **PG-2000P**

Specifications:

Frequency Range:	1.000 MHz to 133.000 MHz
Acceptable Oscillator Packages:	Style 1 Full-Size 14 Pin DIP Style 4 Half-Size 8 Pin DIP SMD (With Optional SC-2000 Adapter)
Programmable Voltage Range:	3.3, 5.0 V
User Interface:	4 Line LCD frequency control parameters usage instructions helpful error messages Keypad ZIF Socket
Design Specifications:	For use with 4-pin oscillators
Oscillator Programming Options:	control pin functionality outputs electrical characteristics Ability to reprogram oscillator blank to correct errors or to reuse the same part for two sperate applications with different frequency and/or different output characteristics
Switching Power Supply	Equipped with Universal AC pwr supply UL 1950
Input:	100 - 250 VAC 50/60 Hz 0.7 – 0.35 A
Output:	+ 5.0 V 1.0 A +15.0 V 0.4 A - 15.0 V 0.4 A
Instrument Size:	10” x 4.75” x 2.65”
Oscillator Blank Part Numbers:	see Cardinal CPP series

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Specifications subject to change without notice. Check website for latest updates
Rev 3.0

Appendix 2 – Programming Specification

Cardinal Components

PG – 3000 Programmer

Cardinal Components, Inc.
155 Route 46 West
Wayne, NJ 07470
(973) 785-1333
www.cardinalxtal.com

Doc: CCI-PG3000-1.00d

All attempts have been made to make the information in this manual complete and accurate. Cardinal Components Inc. is not responsible for any direct or indirect damages or loss of business resulting from inaccuracies or omissions. The specifications within this document are subject to change without notice.

PG3000
Field Instantly Programmable Oscillator (FIPO) Programmer

Software License Agreement

All products (including the PG3000 programmer, CD's software and documentation) are subject to the terms stated below. If you disagree with the terms please return the Product and documentation to Cardinal Components, postage prepaid, within seven days of receipt and Cardinal will provide you with a refund, less freight and normal handling charges.

1. You may not copy or reproduce all or any part of the Product, except as authorized in item 2 below. Removal, emulation or reverse engineering of all or any part of the Product constitutes an unauthorized modification of the Product and is specifically prohibited. Nothing in this license permits you to derive the source code of the software files that Cardinal has provided to you. Cardinal provides no other warranty to any person, other than the limited warranty provided to the original purchaser of this product.
2. You may make archival copies of the software files. All software files remain Cardinal exclusive property.
3. No license is granted to sell, license, distribute, market or otherwise dispose of any software files or other components of the Product.
4. Cardinal warrants the Product and the media on which the software files are provided to be substantially free from significant defects in material and workmanship under normal use for the period of twelve months from the date of delivery of the Product to you. In the event of a claim under this warranty, Cardinal's sole obligation is to replace or repair, at Cardinal's option, any Product free of charge.
5. Warrants and claims must be made in writing during the warranty period or within seven days of the observed defect, accompanied by evidence satisfactory to Cardinal. Prior to returning any Product to Cardinal, you must obtain a Return Authorization (RMA) number and shipping instructions from Cardinal. Products returned to Cardinal shall be shipped with freight and insurance paid.

Table of Contents

Introduction

The PG3000 consists of a USB connected programmer and software which allows Cardinal’s FIPO components to be programmed to the user’s specifications. The FIPO device (Field Instantly Programmable Oscillator) can be configured by you for frequency, supply voltage, drive type and output control function using the PG3000 programmer.

Hardware Components

The package includes the following components:

- Cardinal Components, Inc. Field Instantly Programmable Oscillator Programmer
- USB Cable
- PG-3000 Programmer Installation CD

Optional Components:

- 5x7 Programming Socket Adapter
- Plastic Programming Socket Adapter
- 5x7, Plastic, Half Size Programmable Blanks

System Requirements

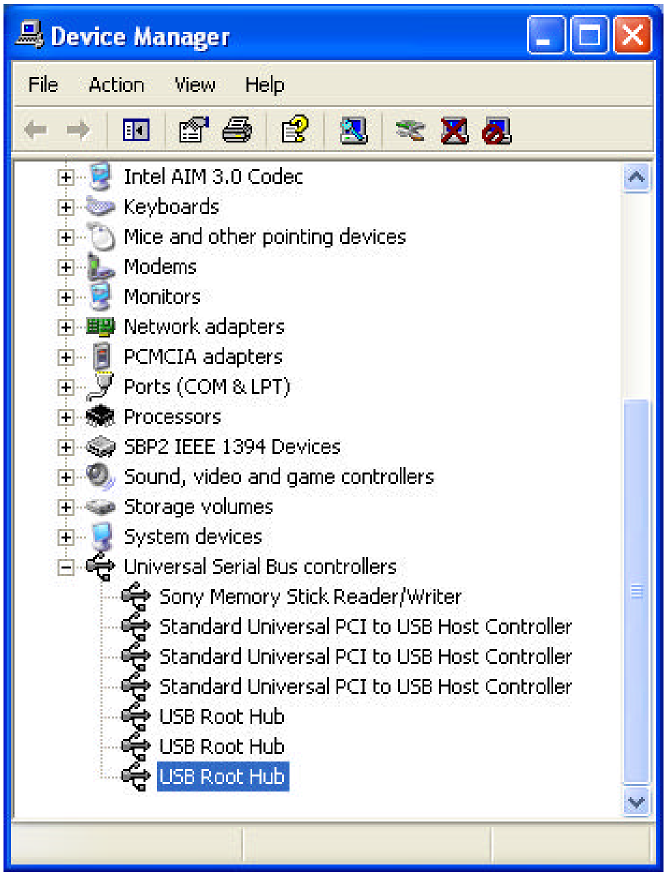
The minimum system requirements are:

Operating system:	Microsoft Windows 98SE/ME/XP/2000
Processor:	Pentium III 600MHz or higher
USB Port:	1.0 or higher with 500mA power per port. We recommend the use of a self powered hub when connecting to the PG3000 programmer.

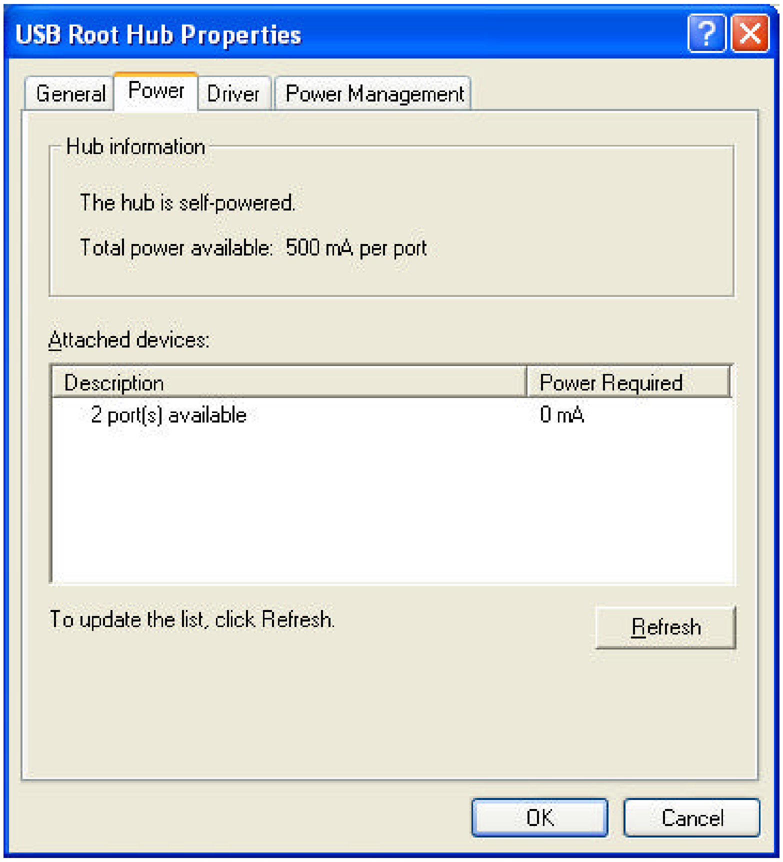
Installation

These instructions are given for the Windows XP operating system, equivalent operations should be performed appropriate to your operating system.

Ensure that your PC can deliver 500mA to the USB port, which is the case with most desktop units and powered hubs. Navigate to the hardware settings by selecting START, Control Panel, System and click the hardware tab. Click the device manager button and select USB Root Hub.



Right click and select properties.

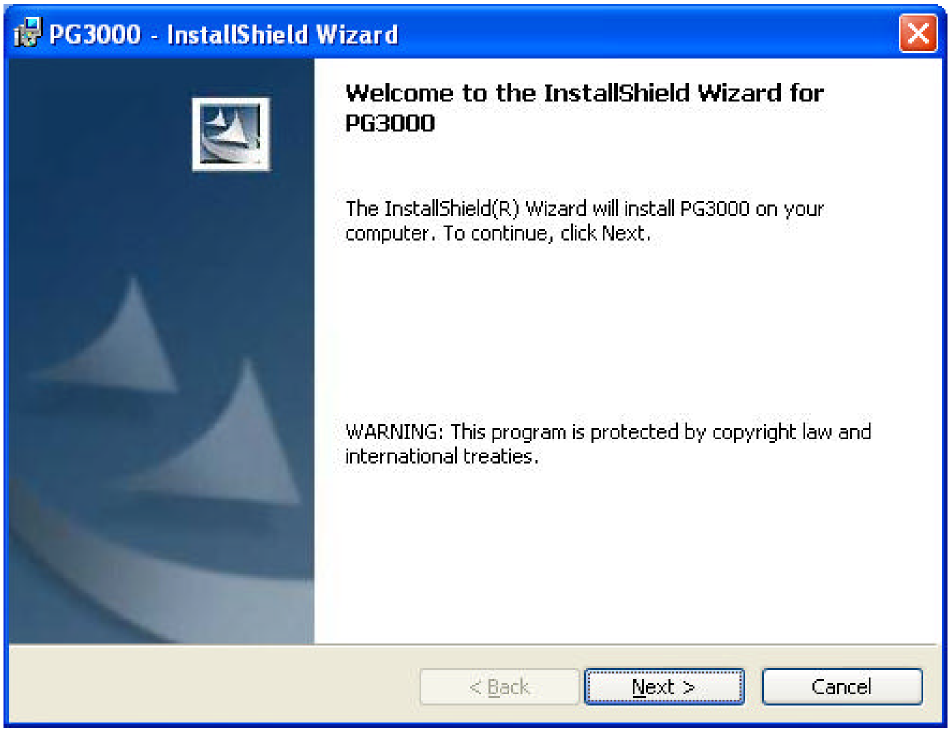


Select the tab labeled "power". The total power available should be 500 mA.
Some external hubs have a switch selection for bus-power or self-power, this must be set to self-power.
Failure to do so may cause the driver installation to fail or your computer to reset.

Do not connect the programmer until the software has been installed.

Installing the PG3000 software

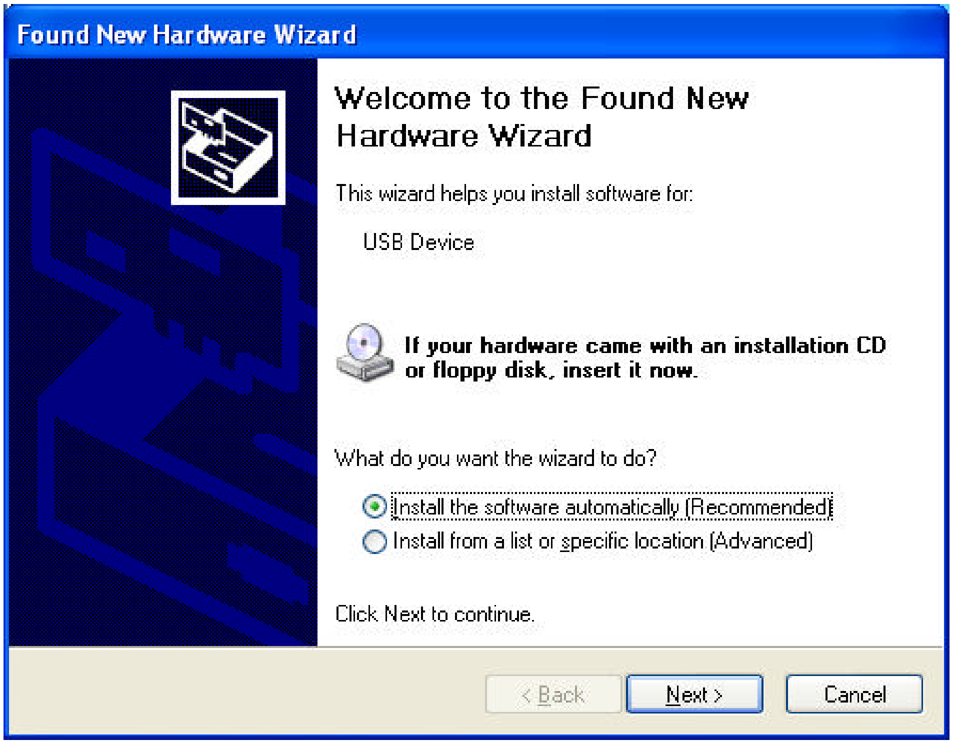
1 Insert the Installation CD into CD-Rom drive of your PC.
2 If you have auto run configured the installation wizard should start automatically. If not, select "RUN" from the "START MENU". Click on browse, locate and highlight the file "SETUP.EXE" on the installation CD. Click the OPEN button.



Click Next and follow the instructions on the screen.

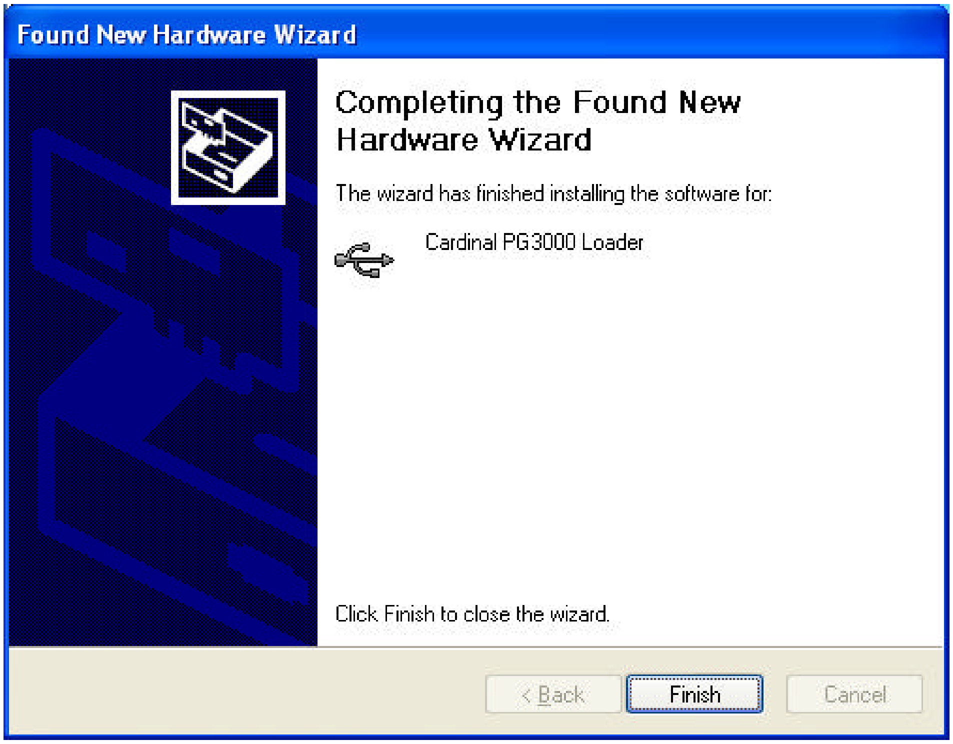
Programmer Connection

1 After installing the software, leave the installation CD in your PC cd-drive.
2 Connect the programmer to the PC or powered hub using the USB cable.
3 For an XP installation two drivers will be loaded. The following new hardware wizard screen will appear to start the installation.



Click Next

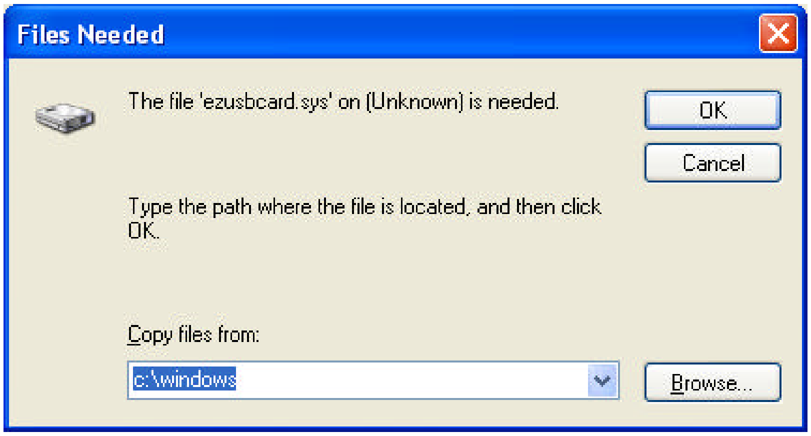
At the time of going to press the drivers had not been verified for compatibility with Windows XP. Click Continue Anyway to proceed.

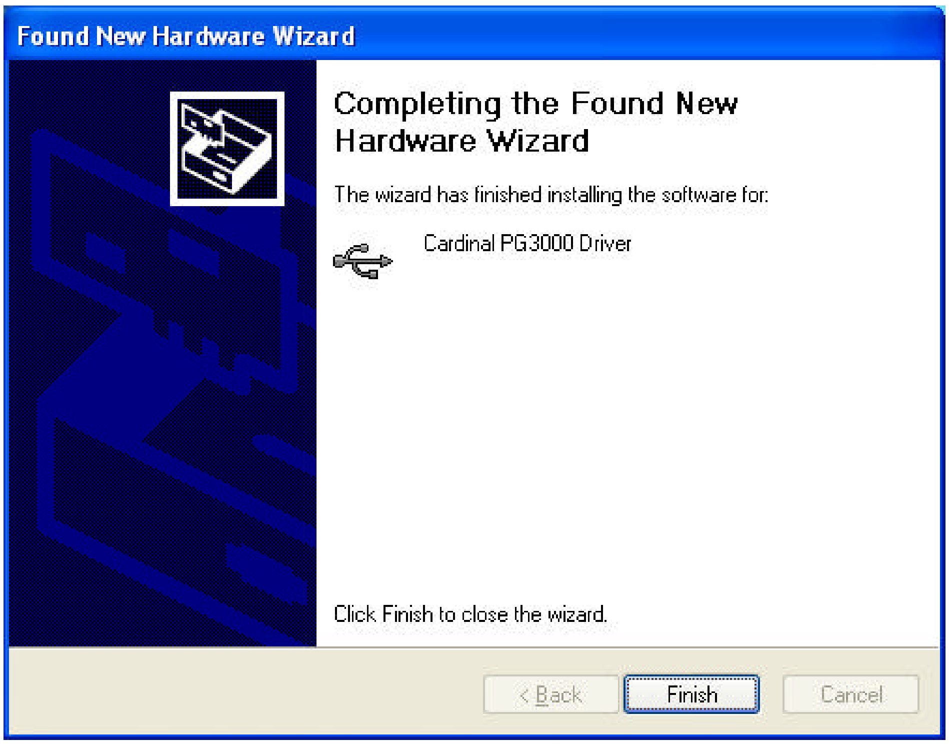


Click Finish

Click Next

Should a driver file not be found automatically as shown below, click browse and select the Drivers subdirectory on the installation CD, then click OK.





Click Finish

After the USB driver has been installed the Green indicator light should display on programmer. See Troubleshooting Section if green light does not display.

Different Windows operating systems have slightly different methods to load the drivers.

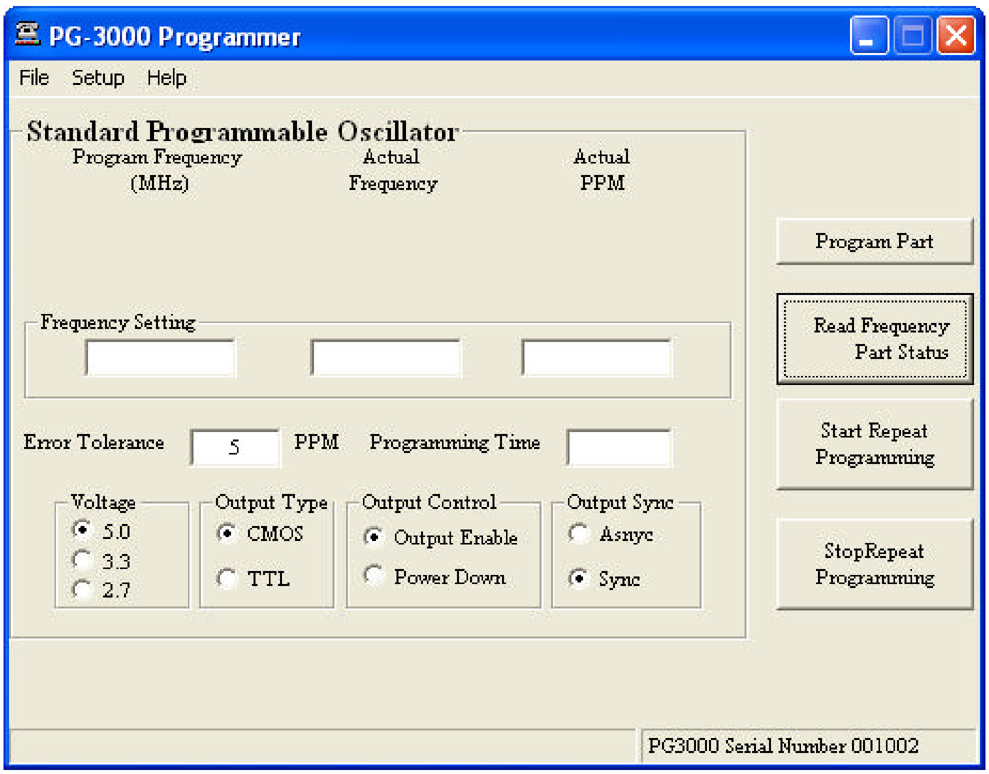
Uninstalling the PG3000 software

From the control panel select add/remove programs
Select Cardinal PG3000
Select remove and follow instructions

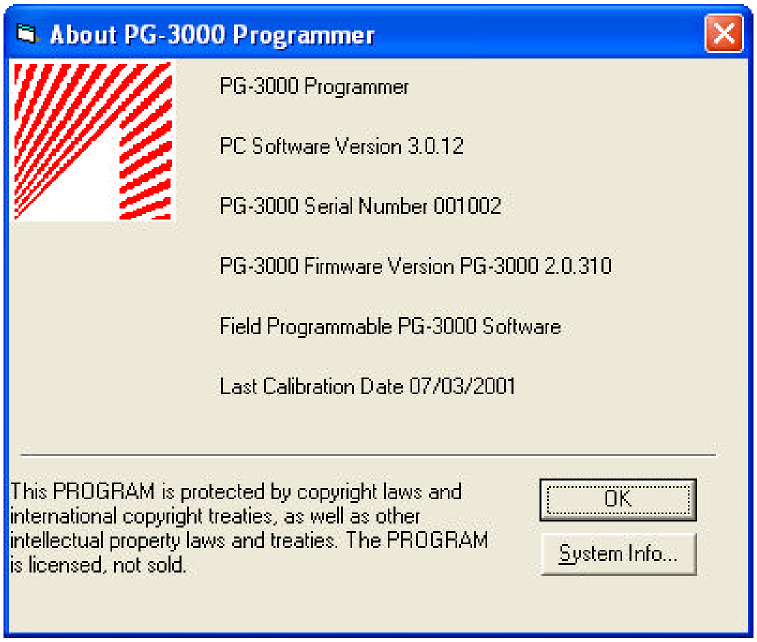
Operation

Before reading or programming any parts a warm up period of ½ hour should be allowed for the PG3000 programmer. This is necessary to ensure accurate reading and programming since the internal TCXO frequency reference of the PG3000 programmer is calibrated when the unit has reached its stable operating temperature.

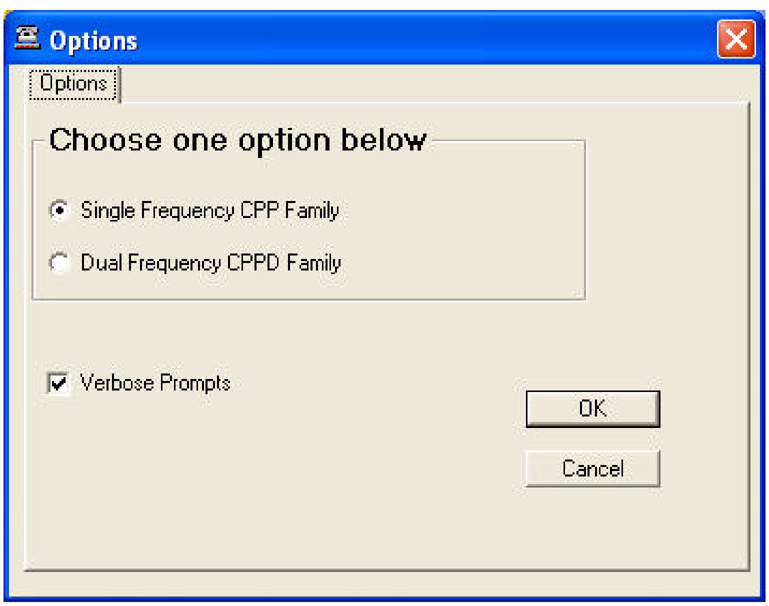
To run the PG3000 software, go to the installation location on your computer click the desktop icon or Navigate through Start, Program Files, Cardinal Components, PG3000 Programmer



The Help/About menu selection will give all the information concerning version numbers of your PG3000 installation.

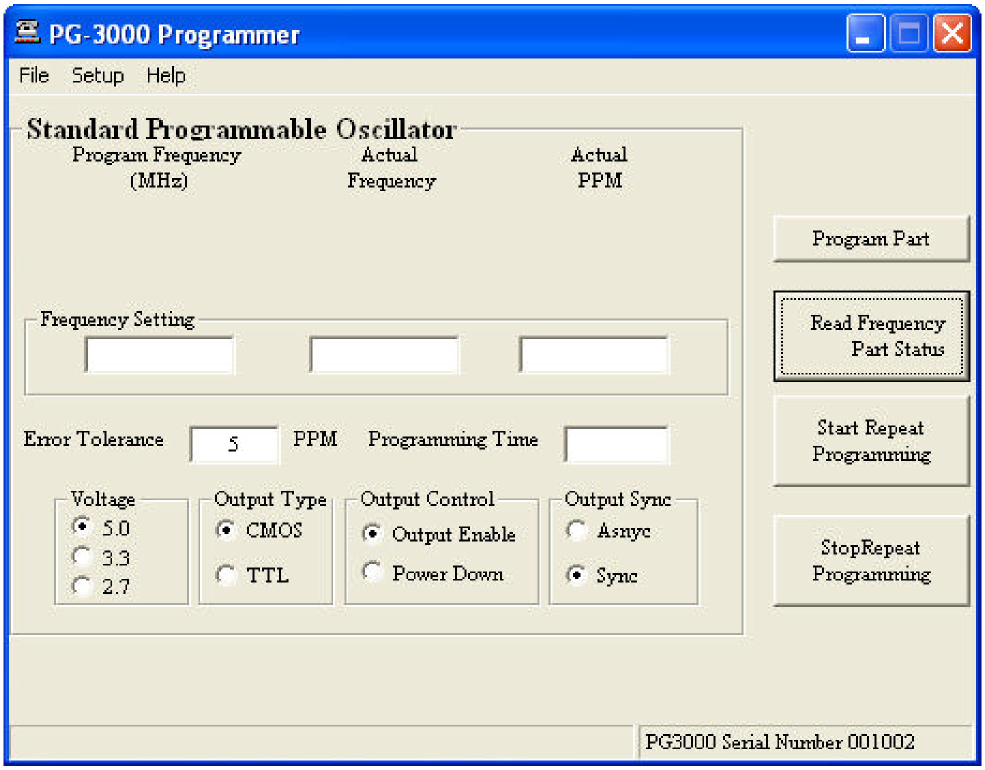


Choose the Setup/Configure menu option
Select here the device family type you wish to program, choose CPP.

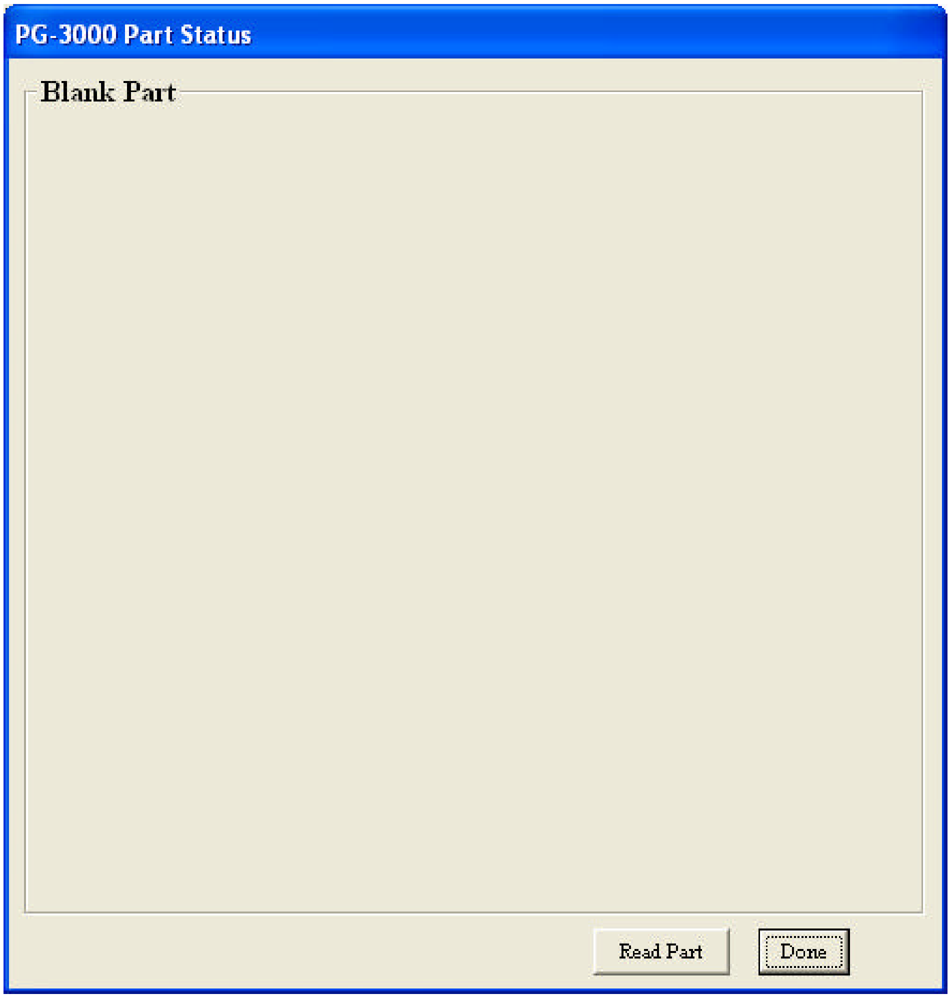


Click OK

The main data entry form is displayed.



Place a blank device in the programmer.
Click the Read Frequency Parts Status button.



If the device in the PG3000 socket was unreadable then the following screen will be shown.

Parameter Selection for CPP (Two time programmable part)

Please refer to the data sheet of your device for specific parameter limits. Values used here are for illustration only.

Enter the desired programming frequency in MHz. This value should be between 1 and 133MHz for 5 volt devices and between 1 and 100MHz for 3.3 volt devices and between 1 and 66MHz for 2.7 volt devices.

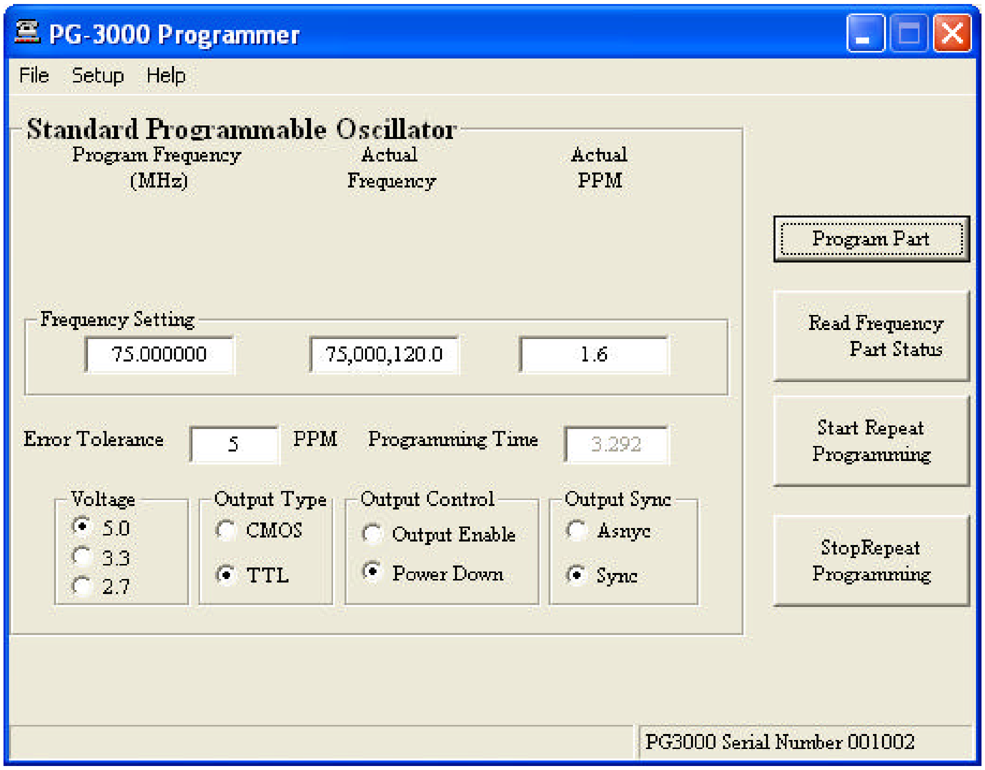
Enter the acceptable PPM error from this frequency in the Error Tolerance box. This value is used in determining values for the PLL dividers. Reducing the error tolerance also reduces the possible solutions available and may result in no solution being found.

Choose the supply voltage at which the device will be operated by clicking the appropriate selection either 5, 3.3 or 2.7 volts.

Choose the device output type by clicking the appropriate selection either CMOS or TTL.

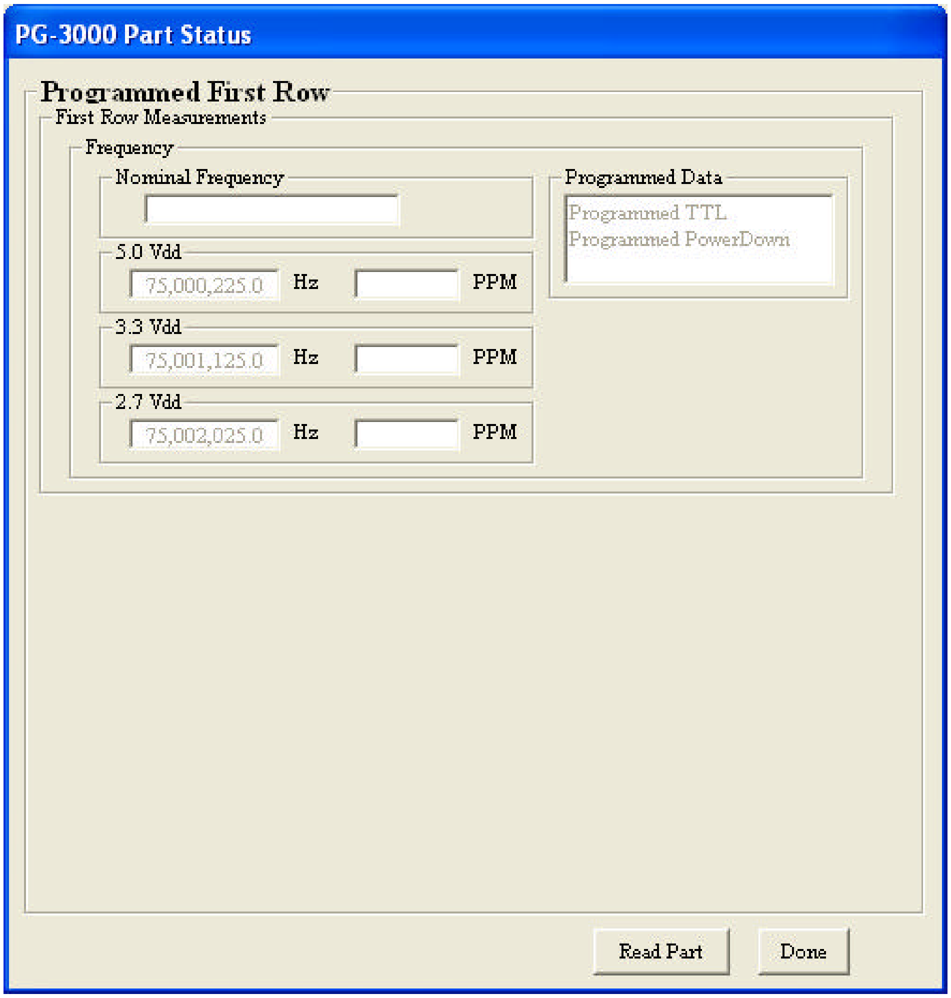
Choose how the control pin (pin1) will affect the device as either Output Enable or Power Down.

Choose whether the control pin will operate in an asynchronous mode (immediately) or synchronous mode (waits for clock low).



When all these fields have been entered the device can be programmed by clicking the Program Part button. This operation takes a few seconds, and the time is displayed in the Programming Time box. After successful programming the actual part's frequency and PPM difference from the desired programming frequency are displayed.

Click the Read Frequency Parts Status button to read back the programmed information.



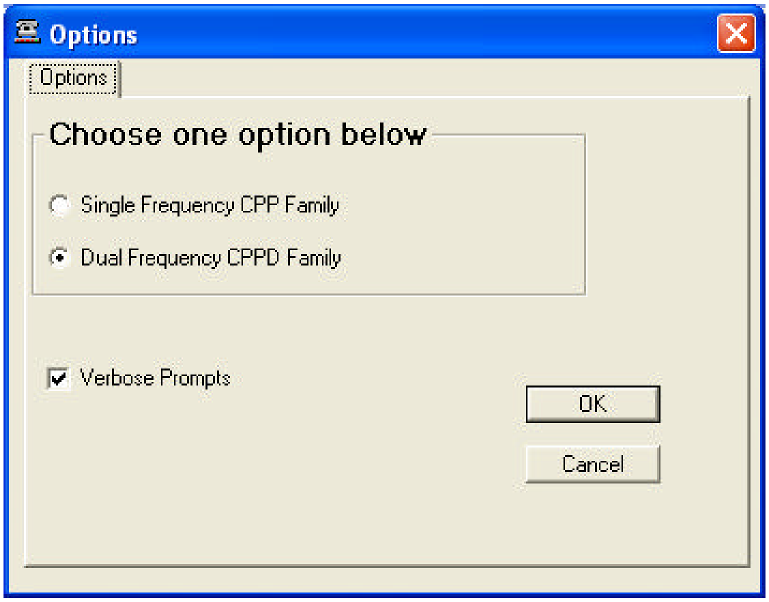
The device is read and the data displayed as to output type and frequency. The supply voltage selected during programming cannot be read from the device so the frequency at all 3 possible supply voltages is reported. If you enter a nominal frequency the PPM will be calculated. At the top of the display the status as to whether the device is blank, programmed once, or programmed twice is shown.

The actual frequency and PPM deviation from the entered programming frequency is displayed.

Parameter Selection for CPPD (One time, two frequency pin 1 selectable part)

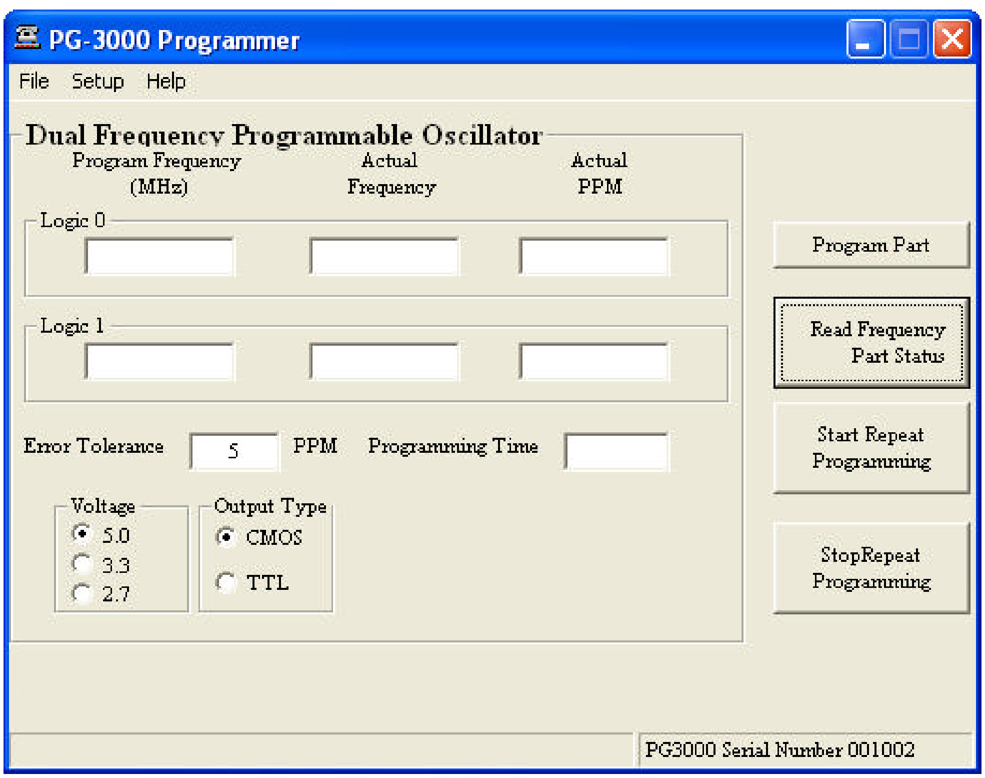
Please refer to the data sheet of your device for specific parameter limits. Values used here are for illustration only.

Choose the Setup/Configure menu option
Select here the device family type as CPPD.



The data entry screen will now allows the entry of two frequencies.

Enter the desired programming frequencies in MHz. This value should be between 1 and 150MHz for 5.0 volt devices and between 1 and 133MHz for 3.3 volt devices. When programmed the frequency in the first row will be output when the control pin is at logic 0, the frequency in the second row when the control pin is at logic 1.



Enter the acceptable PPM error from this frequency in the Error Tolerance box. This value is used in determining values for the PLL dividers and final tuning. Reducing the error tolerance also reduces the possible solutions available and may result in no solution being found.

Choose the supply voltage the device will be operated at by clicking the appropriate selection either 5, 3.3 or 2.7 volts.

Choose the device output type by clicking the appropriate selection, either CMOS or TTL.

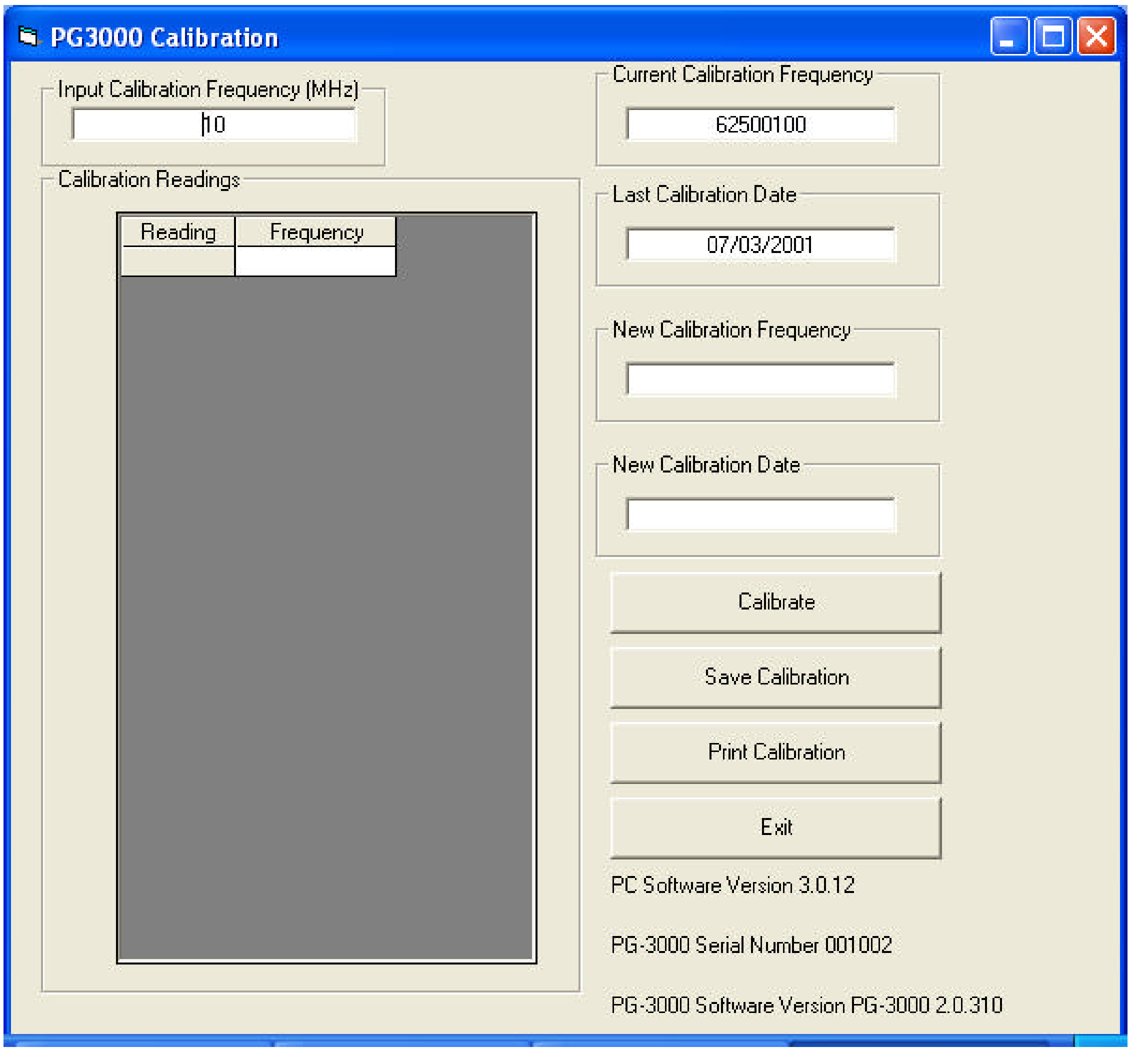
When all these fields have been entered the device can be programmed by clicking the Program Part button. This operation takes a few seconds, and the time is displayed in the Programming Time box. After successful programming the actual part's frequencies and PPM differences from the desired programming frequency are displayed.

Repeat Programming

Should a number of the same specification device need programming then the repeat programming feature can be used. When the parameters are setup for the device, as described above then click the "start repeat programming" button. This disables the input fields to prevent accidental changes and activate the programming button on the PG3000 programmer. By place a device in the programmer and pressing the button, the device is programmed and the actual measured frequency results are displayed in the window. The device can be removed and the next inserted and by simply pressing the button the next device is programmed. To exit the repeat programming mode click the Stop Repeat Programming button.

Calibration

Calibration of the programmer is performed at the factory. Should you decide to calibrate the programmer select the Setup/Calibrate menu option and the following screen will be displayed. **Remember to allow at least 30 minutes for the programmer to reach normal operating temperature before performing a calibration**. The calibration requires a very accurate (0.1PPM) reference oscillator. This reference source is typically obtained from a GPS frequency standard or similar standard operating at 10MHz and is connected between GND (pin 7) and CLK (pin 8) on the programmer socket.



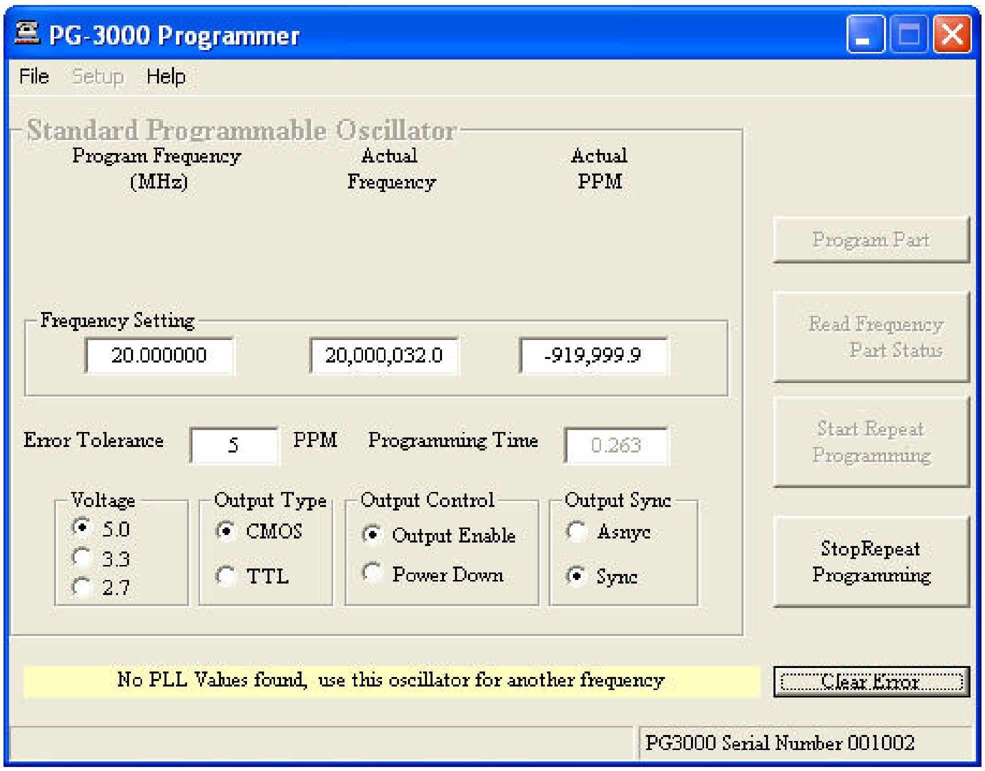
Click the calibrate button and twenty measurements of the reference are made. If the measurements are stable to better than 1PPM then the data is deemed valid and can be used for calibration. If the calibration data is invalid check your reference clock and connections very carefully before attempting to calibrate again. On reading a valid set of calibration values a new calibration frequency and date will be displayed which can be saved into the PG3000 programmer by clicking the Save Calibration button. The calibration screen can also be printed to the default printer using the Print Calibration button. This can be useful for ISO documentation.

Troubleshooting

This section illustrates and explains the error conditions that can occur using the PG3000.

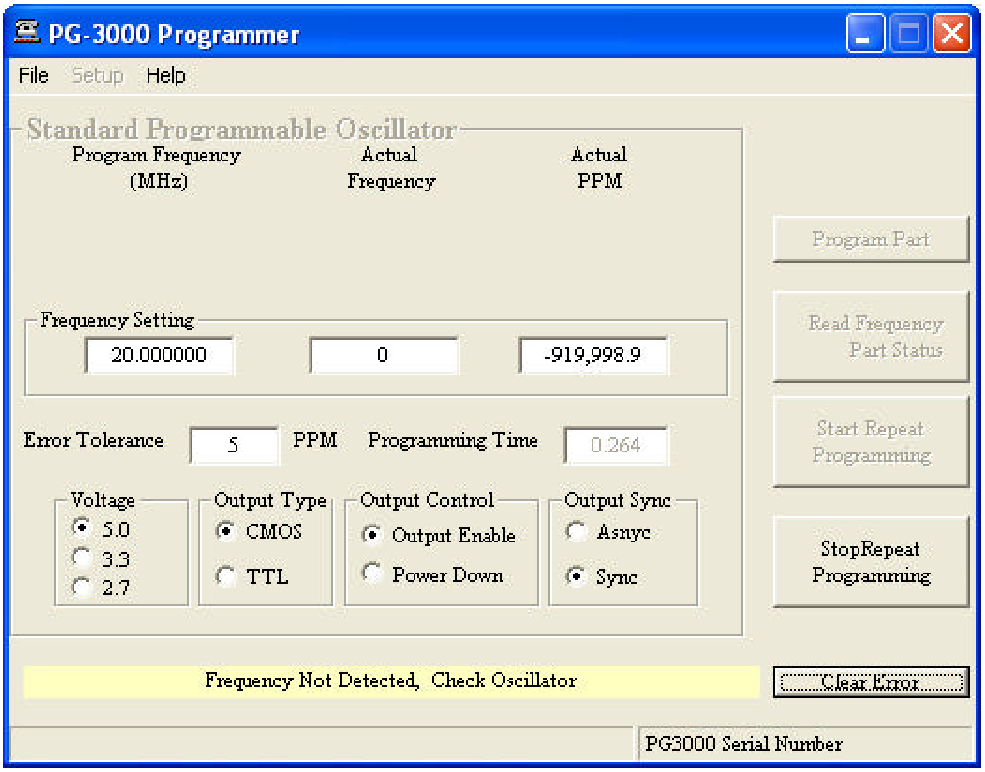
No PLL Values found, use this oscillator for another frequency

The error message “No PLL Values found, use this oscillator for another frequency”, occurs when no solution for the PLL dividers exists for this particular device. Remove the device and keep for use at a different frequency. Place another device in the programmer and a solution will most likely be found.



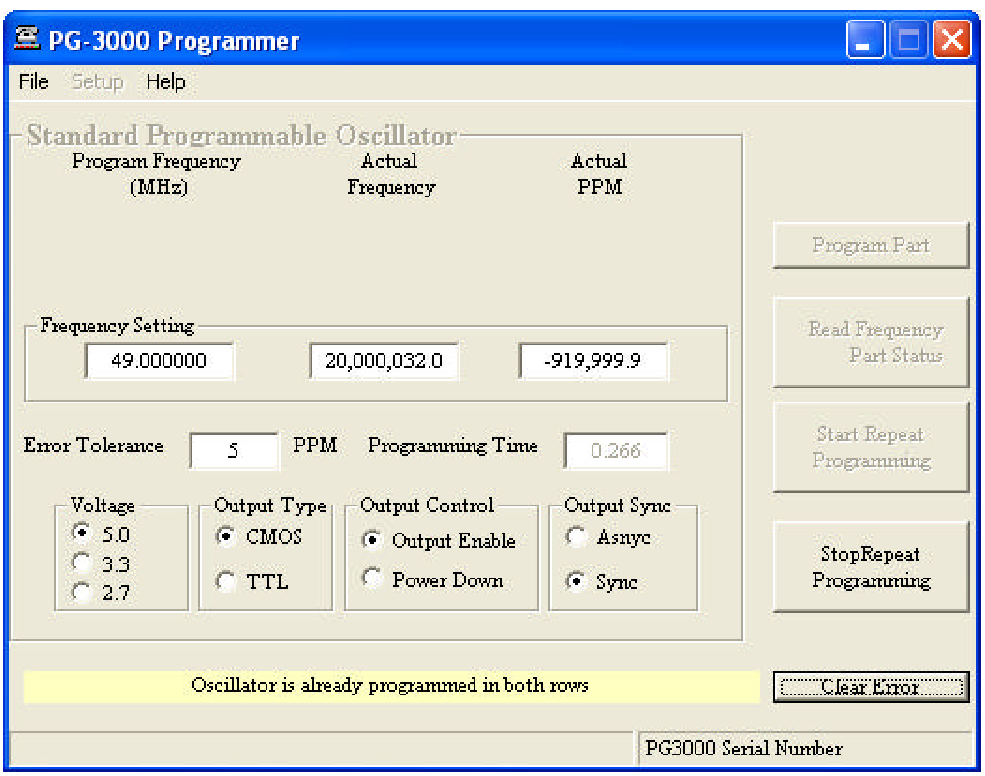
Frequency Not Detected, Check Oscillator

When reading or programming, the PG3000 first measures the frequency of the device. If no frequency can be read then the error message Frequency Not Detected, Check Oscillator is displayed. Check that the device is correctly placed in the socket with pin 1 adjacent to the ZIF handle and the handle is lowered.



Oscillator is already programmed in both rows

The FIPO contains OTP memory sufficient that it can be programmed a total of two times. Further attempts at programming will return the following screen.



This indicates the part cannot be further changed. Click the clear error button and insert a new FIPO device to continue programming.

Dual Frequency Oscillator Already Programmed

The CPPD device can be programmed only once. The message "Dual Frequency Oscillator Already Programmed" occurs when an attempt to re-program a CCPD device is made. A blank device must be inserted into the socket.

No PLL Values found for Dual frequency Oscillator Logic 0 or
No PLL Values found for Dual frequency Oscillator Logic 1

This message occurs when no solution for the PLL dividers exists for this particular device. Remove the device and keep for use at a different frequency. Place another device in the programmer and a solution will most likely be found.

Failed to Verify Programming, Defective Oscillator
Unable to tune oscillator

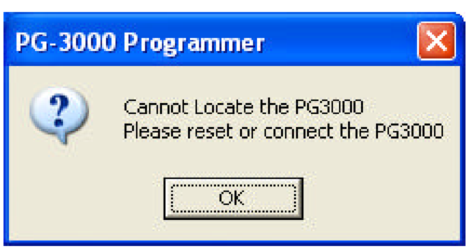
These messages rarely occur and indicate that the device could not be successfully programmed. Check that the device is correctly seated in the socket and try again. Trying another device will also help determine if a connection problem exists or a defective part has been found.

Frequency not in tolerance for logic 0, may be a single frequency oscillator

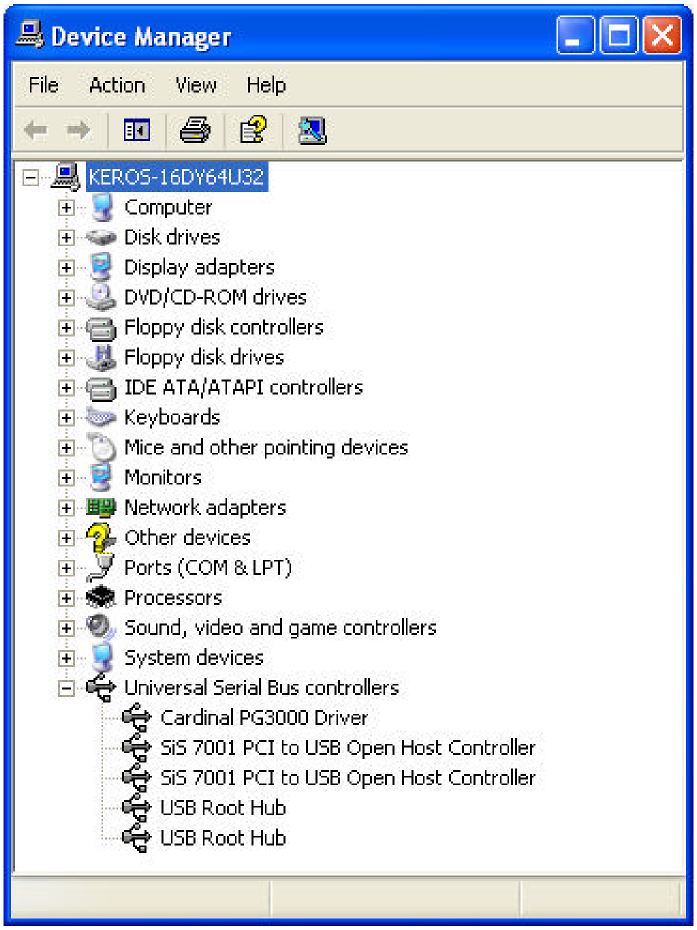
This message is produced when a single frequency device is in the fixture and a dual frequency device has been selected for programming. If the correct device is being used check that the device is correctly seated in the socket and try again.

Cannot Locate PG3000

Should the software be unable to connect to the PG3000 programmer the following message will be displayed on the screen of the PC.



Check the connection of the PG3000, unplug and re-plug the unit and try again. Should this not work then the driver from a prior session may not have been successfully unloaded. To remove the driver, perform the following operations. Disconnect the PG3000, open the device manager expand the entry USB Serial Bus Controllers, right click the entry Cardinal PG3000 Drive and select uninstall. This will remove the active driver. Reconnect the PG3000 and the driver will automatically be reinstalled. The PG3000 software can then be restarted.


Device Manager
File
Action
View
Help
KEROS-16DY64U32
Computer
Disk drives
Display adapters
DVD/CD-ROM drives
Floppy disk controllers
Floppy disk drives
IDE ATA/ATAPI controllers
Keyboards
Mice and other pointing devices
Monitors
Network adapters
Other devices
Ports (COM & LPT)
Processors
Sound, video and game controllers
System devices
Universal Serial Bus controllers
Cardinal PG3000 Driver
SiS 7001 PCI to USB Open Host Controller
SiS 7001 PCI to USB Open Host Controller
USB Root Hub
USB Root Hub

Appendix 3 – SEL Report

Report on Heavy Ion Single Event Latchup Testing of 3.3V Cardinal Programmable Oscillators November 22-24, 2002

Gary Swift and Tetsuo Miyahira
JPL Radiation Effects Group
Report Date: January 29, 2003
Revision A Date: February 20, 2003

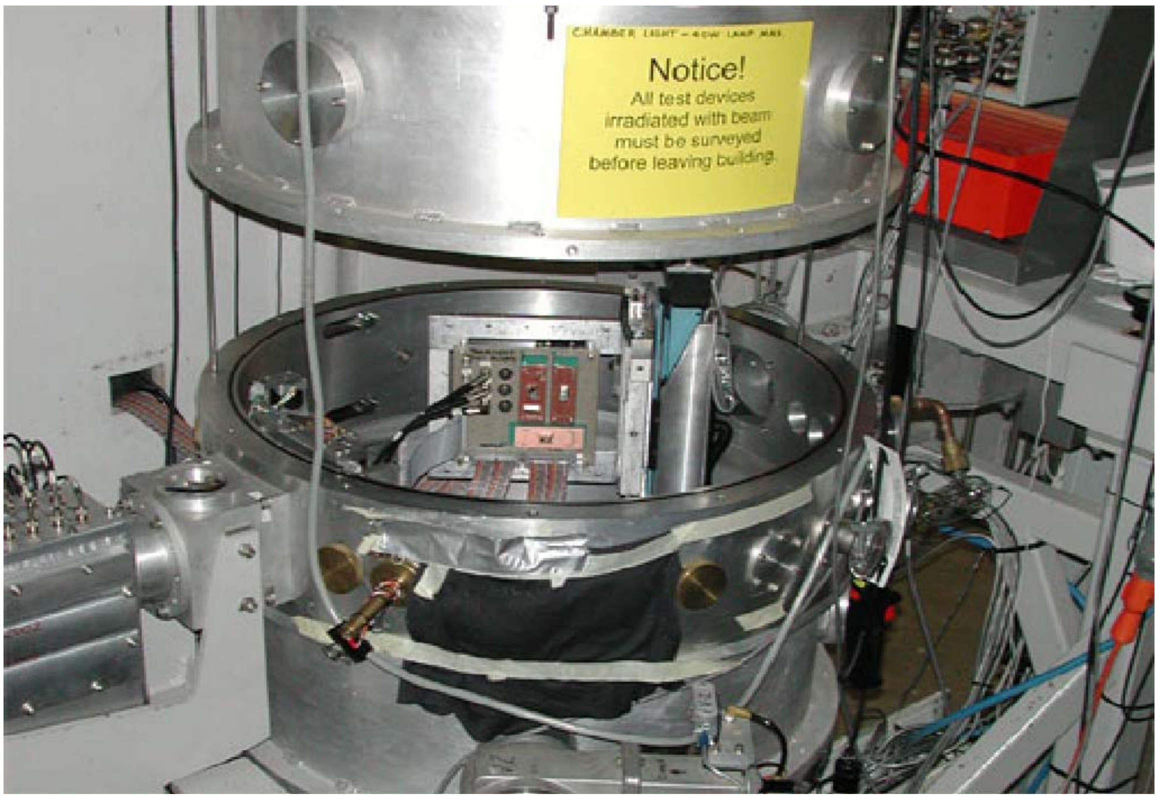


Photo 1. Cardinal Oscillator test board (with three DUTs installed) mounted in theTexas A&M University Cyclotron Institute Radiation Effects Test Facility vacuum chamber.

1.0 SUMMARY

This report describes Single Event Latchup testing that was performed on programmable oscillators manufactured by Cardinal Components Inc. Although these devices can be programmed for use at either 3.3 or 5 V, these results only apply to 3.3 V condition. The tests were done at the Texas A&M Cyclotron Institute facility during November 23-25, 2002. Latchup was observed and the cross section was measured for 20 different LETs. The LET threshold at 40º C is extrapolated to be about 14 MeV per mg/cm^2. At room temperature and at an LET of 19 MeV per mg/cm^2, the lowest LET used, the measured cross section was still $5 \cdot 10^{-8}$ cm^2. The highest measured cross section was almost 10^{-4}

cm^2 at an LET of 91 MeV per mg/cm^2. At very high LETs, the room temperature cross section extrapolates to a saturation value of $3 \cdot 10^{-4}$ cm^2.

Previous tests with Cardinal oscillaotrs biased at 5 volts showed that single-event latchup will destroy this device (in the absence of latchup protection) as well as create latent damage in cases where latchup is not obviously destructive [BEC-02]. The tests described in this report show that, at 3.3V, an unprotected device will also exhibit destructive latchup. An addition of a small series resistor to the supply pin (in conjunction with a small bypass capacitor) prevented latchup from causing obvious functional damage in these tests, although latent damage may still be present. It should be noted that the resistor (plus small capacitor) does not prevent the occurrence of latchup nor, once the device is in a latched state, does it take the device out of latchup. Power cycling is still required to remove the latchup condition.

2.0 TEST FACILITY

The testing was conducted at Texas A&M University Cyclotron Institute. This facility has the highest energy ion beam of the three facilities that are currently available for Single Event Effects testing. The higher energy ions were necessary because, in some cases, it was necessary for the ions to penetrate material that covered the CMOS integrated circuit. For example, the 5x7mm ceramic SMD devices had the quartz crystal mounted on top of the CMOS chip and the 14-pin full size DIP in metal can devices had an epoxy “glop” covering the CMOS chip. Neither the quartz crystal nor the epoxy “glop” could be fully removed without damaging the test device.

3.0 TEST DEVICES

The CPPx series devices are field programmable oscillators with a programmable frequency range of 1MHz to 133MHz and programmable voltages of 3.3V and 5.0V. These oscillators are available in six package styles: 4 pin plastic SMD package, 14 pin plastic DIP, 8 pin plastic DIP, full size metal can, half size metal can, and 5x7mm ceramic-substrate SMD package. They can be re-programmed once. Programming is accomplished with the Cardinal Components Field Oscillator Programming Instrument, Series PG-2000 and appears to be based on a chargeable floating-gate technology that lacks an erase capability.

Table 1. Device types tested

Device Type	Package Style	Programmed Frequency
CPPC8	Plastic SMD	1.0MHz
CPPC7L-BP-1.2TS	5x7mm Ceramic SMD	1.2MHz
CPPC1	Full size 14 pin DIP	1.2MHz

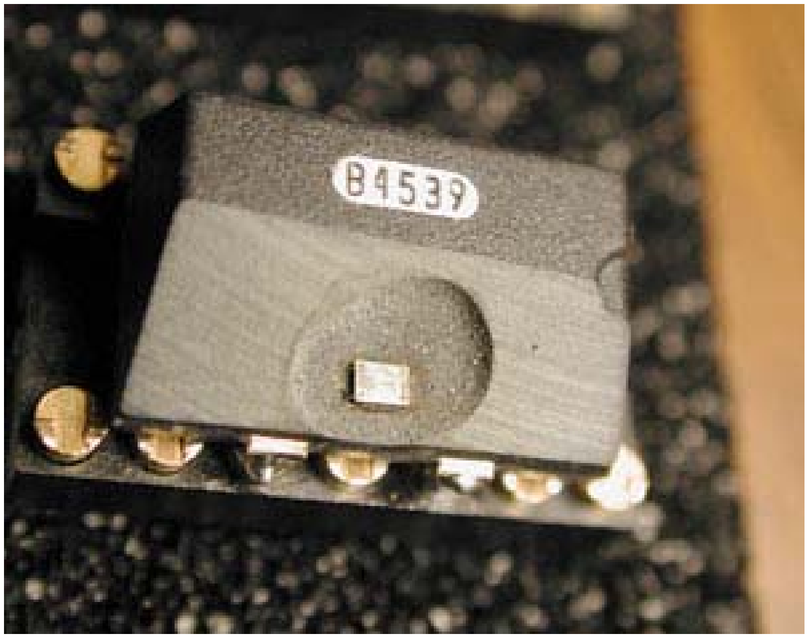


Photo 2. Cardinal CPPC8 plastic SMD, programmable oscillator programmed to 1.0MHz and 3.3V. Part of the plastic packaging was etched away so that the CMOS die is fully exposed.

Much of the SEL testing was performed on plastic SMD devices because the plastic SMD package was the only device type that could be delidded to fully expose the CMOS integrated circuit die. The 5x7mm ceramic SMD oscillators had a quartz crystal that was approximately 75 microns thick covering the integrated circuit die while the ceramic 14-pin DIP devices had a black epoxy “glop” covering the die. According to the manufacturer, all three device types that were tested use the same die (although likely different lots) so the data from the plastic devices should apply to the other two device types tested. Although the programmed operating frequencies varied somewhat, it is not expected that the frequency would affect the latchup characteristics. All devices were programmed to operate at 3.3 volts. Voltage does effect latchup and, thus, most of the testing was done at 3.6 V, approximately 10% above the nominal voltage, as a worst-case condition. Note that latchup susceptibility at 5 V was not measured, but the higher voltage will quite likely significantly increase latchup susceptibility as well as the likelihood of catastrophic damage. Thus, these results only apply to 3.3V applications of this technology.

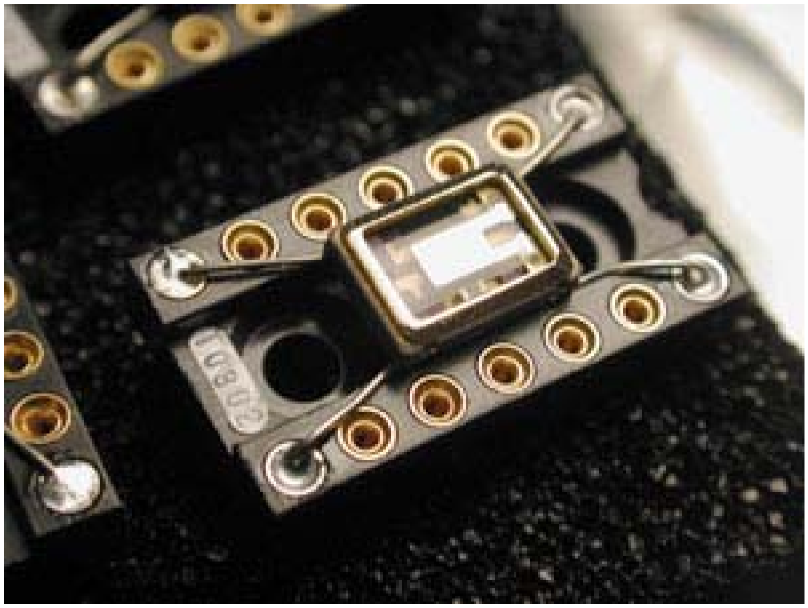


Photo 3. Cardinal CPPC7L-BP-1.2TS 5x7mm, programmable oscillator programmed to 1.2MHz and 3.3V. The quartz crystal, which is approximately 75 microns thick, is on top of the CMOS die (the translucent rectangle with aluminized electrodes).

Photo 4. Cardinal CPPC1 full-size can package with the top removed shows the crystal (translucent circle on the right) and the epoxy “glop” (black circle on the left). The peak of the epoxy “glop” was milled down to reduce the amount of material that the ions had to pass through prior to hitting the CMOS die.

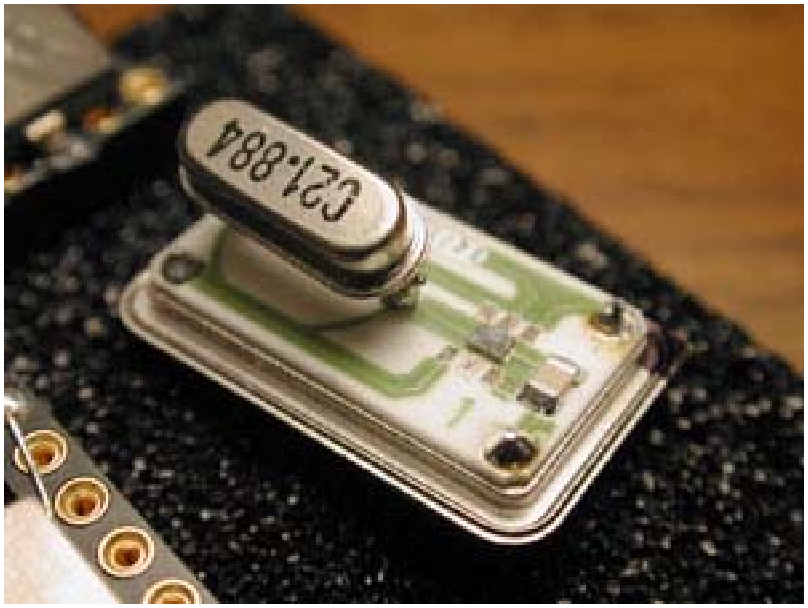


Photo 5. Special custom version of the Cardinal CPPC1 full-size can package. Cardinal Components was able to provide this device without the epoxy “glop” covering the CMOS die. The die is between the crystal and the capacitor.

4.0 TEST APPARATUS

A block diagram of the test apparatus is shown in figure 1. The power supply used was an Agilent HP6629, quad output, programmable supply. The computer was used to control the power supply and to record the output voltage and the output current at approximately 200ms intervals. Typically, the power supply was set to limit the available current to only slightly more than the nominal operating requirement to lower the possibility of damage when latchup occurs. Also, protecting the DUTs, was the software shutdown of the power supply which occurs within about 0.5 sec after latchup.

The 100-ohm resistor in series from the power supply to the DUT Vdd pin was placed there to test the viability of using a series resistance to protect the device from functional damage during a latchup over-current condition. A relay was used to add a short in parallel with the resistor to effectively remove it from the Vdd supply line for some of the latchup test runs. During runs with the resistor *IN*, the power supply current limit was raised (typically to 2 A.) and the software shutdown was bypassed. Note that a 0.1 uF capacitor was used; calculations show that surge current from the capacitor into the device could be almost 100 mA during the first microsecond of latchup. A larger capacitor would give higher currents and so the present encouraging results on the addition of the series 100-ohm resistor only apply if the associated capacitor is 0.1 uF or less.

The output of the oscillator was loaded with a 1k-ohm resistor. No capacitive loading was added to the output. An oscilloscope was used to monitor the output waveform from the oscillator to monitor functionality. A high-speed buffer was used as a line driver to drive the 50-ohm cable from the DUT to the oscilloscope.

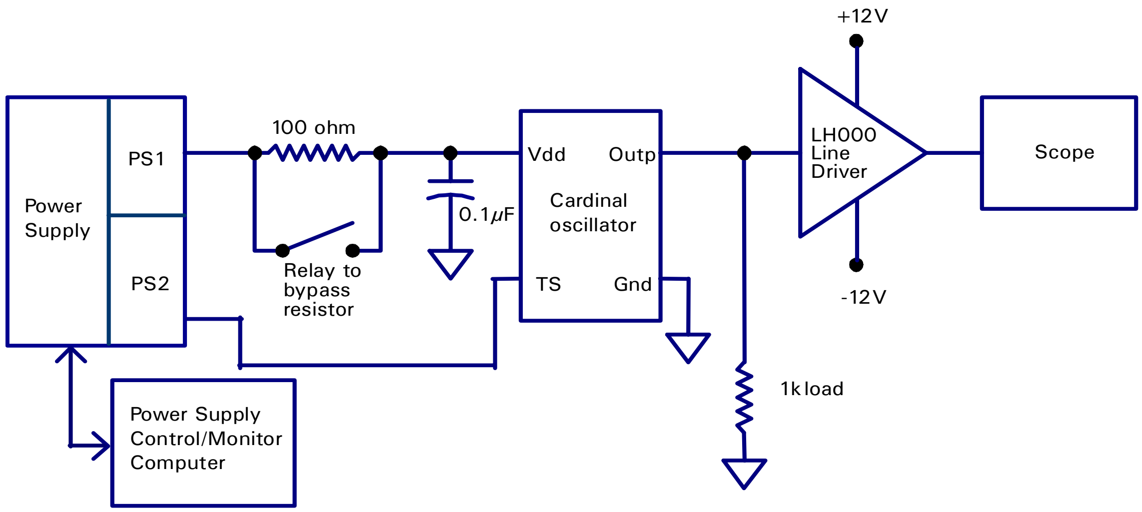


Figure 1. Block diagram of the experiment setup. Note that the power supply was an Agilent HP6629A, the scope a Tektronix TDS3032B, and the computer a Toshiba Tecra 8100.

5.0 TEST RESULTS

The raw data and the heavy ion test run log are attached as Appendix I. The devices showed a small latchup cross section at the lowest LET used. Note that all LETs are incident LET on the active silicon assumed to reside under about 6 microns of SiO_2.

Analysis of this data reveals that ion range has a significant effect on the results. Even though the Texas A&M is the highest energy facility available at "reasonable" beam time costs, the results given here clearly show range limitations, with much lower cross section when the particles used for testing have short ranges. Consequently, correct LET assignments are problematic because the LET has changed drastically over the long portion of the deposited charge trail that is being collected. This is particularly problematic for the two packages where extra material (quartz or epoxy) had to be penetrated before the incident ion reached the die. The assigned LET for a given irradiation is the SRIM-calculated LET impinging on top of the active silicon of the die; be aware that this may not represent the effective LET in space (where a practical definition of effective LET is the LET of a very long range space-environment ion that would result in an identical amount of charge collection).

Figure 2 shows the cross section obtained as a function of assigned LET for the plastic package devices. The dotted lines merely connect the measured points as a guide to the eye, not to represent the actual dependence on LET. The error bars shown are the 90% confidence limits based on Poisson statistics of the number of latchups detected (that is, they are approximately two-sigma error bars).

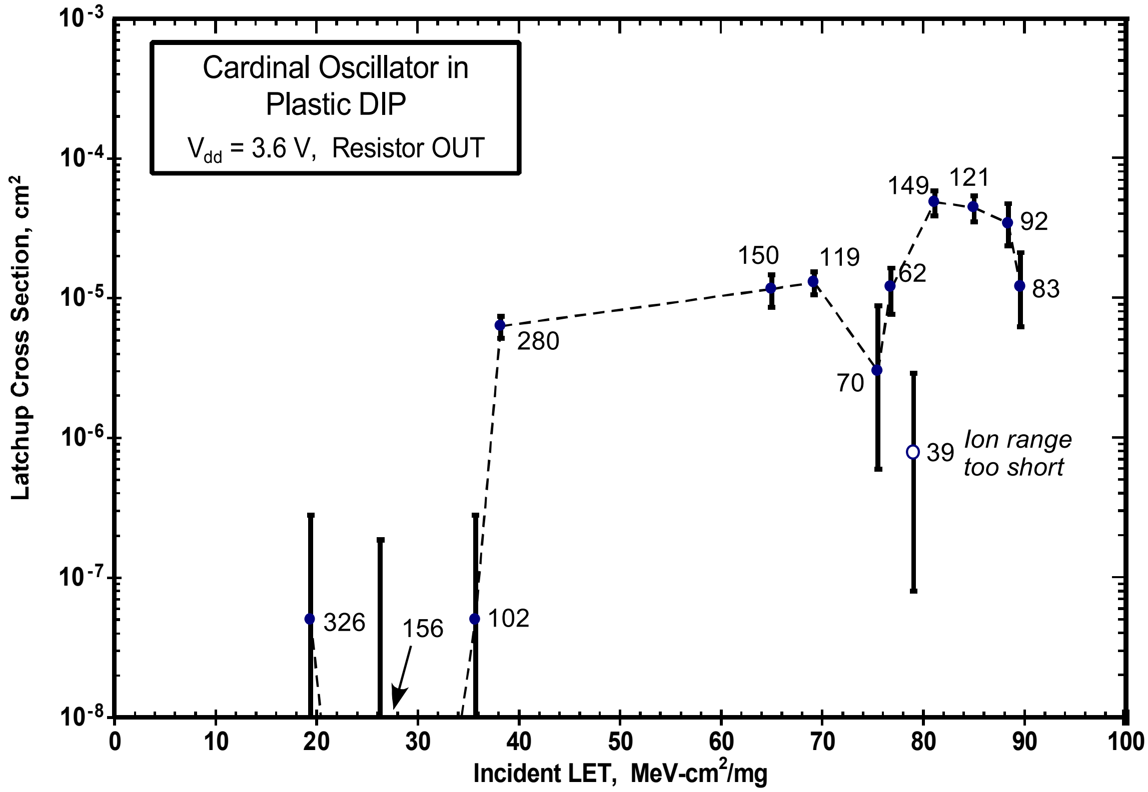


Figure 2. Latchup results for the Cardinal oscillators in plastic packages (where the die were fully exposed). The number near each point indicates the ion's range in microns.

Figure 3 shows the cross section vs. LET results for devices in the small (SMD) can. The LETs have been corrected for energy loss in the overlaying crystal (75 microns of quartz). Again error bars shown are approximately two standard deviations.

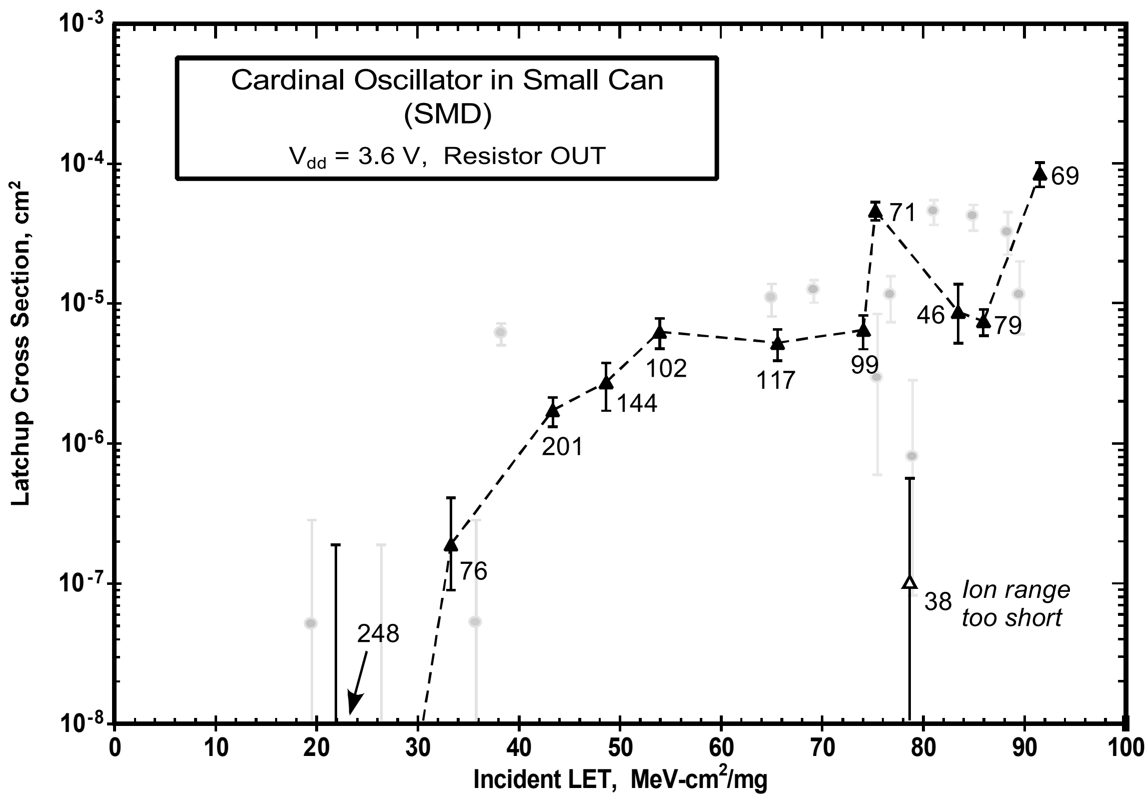


Figure 3. Latchup results for the Cardinal oscillators in small can (SMD) packages (where the die is covered by the crystal) -the black triangle symbols- are contrasted with the latchup results from Fig. 2 on the plastic devices, the gray circles. The number near each triangle indicates the ion's range in microns.

Figure 4 shows the results for devices in the large can with the LETs corrected for 210 microns of epoxy. Devices in the large cans were covered with epoxy. Part of the epoxy was mechanically removed before testing to reduce the amount of surface material. The results including an LET error bar representing the error in the epoxy milling process which, in fact, may be larger than shown. The cross section error bars are again approximately two sigma.

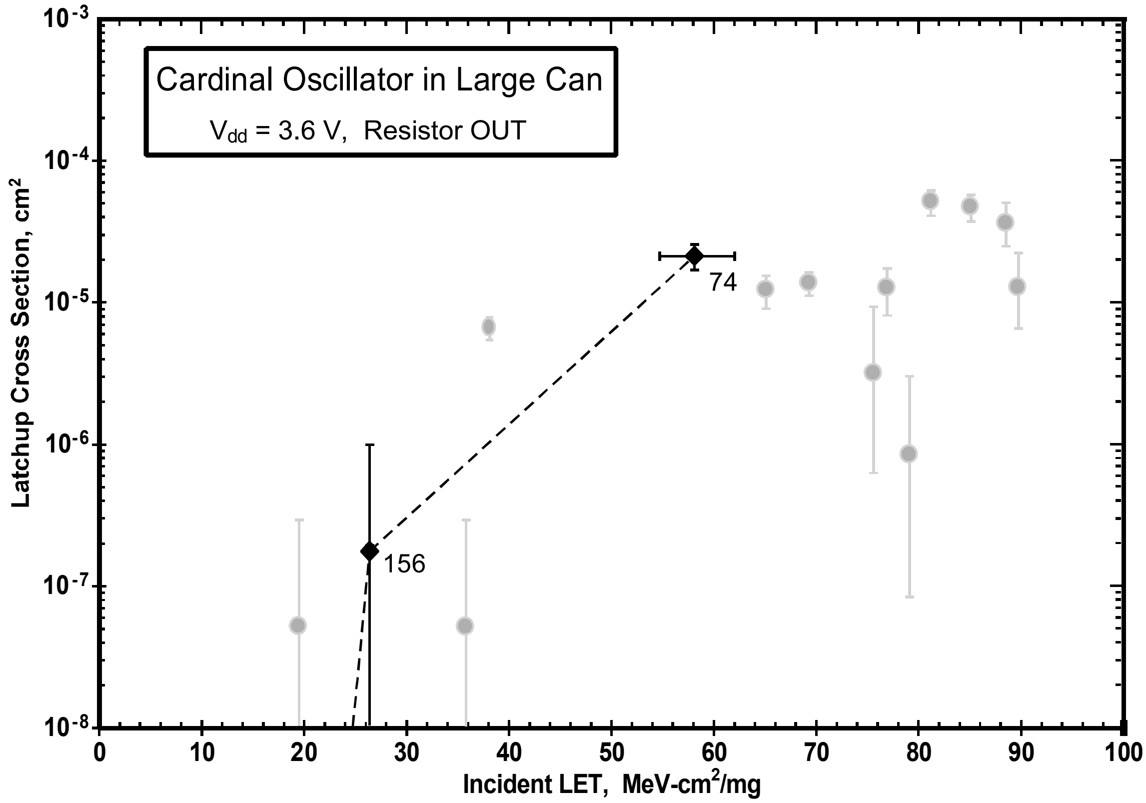


Figure 4. Latchup results for the Cardinal oscillators in large can packages (where the die were covered by milled-down epoxy) -the black diamond symbols- are contrasted with the latchup results from Fig. 2 on the plastic devices, the gray circles. The number near each point indicates the ion's range in microns.

Finally, Figure 5 shows the Edmonds curve representation of the cross section vs. LET which adjusts for the effect of slightly higher temperature on the latchup susceptibility. Also shown is a composite of all the data given in the previous three figures. The Edmonds curve [EDM-96] has the following parameters: $L_{0.001}$=19.6 MeV per mg/cm^2 and $\sigma_{sat}=3\times10^{-4}$ cm^2 at room temperature and, after adjustment to approximately 40 deg C using the Johnston rule-of-thumb is $L_{0.001}$=14.7 and $\sigma_{sat}=6\times10^{-4}$. Note that the Edmonds curve has the form: the cross section at a particular LET, L, is σ_{sat} times the exponential of minus $6.9 \cdot L_{0.001}/L$; the temperature rule-of-thumb from Allan Johnston [JOH-91] reduces the LET threshold by 25% and increases the saturation cross section by a factor of two. The higher temperature curve was used to calculate conservative heavy-ion latchup rates for two space environments: galactic cosmic rays (GCR) at solar minimum and the JPL design case flare (DCF) at one A.U. Note that geosynchronous orbit (GEO) is far enough from the earth that magnetic shielding is negligible so the GCR rate is the rate in GEO. These results are given in Table 2.

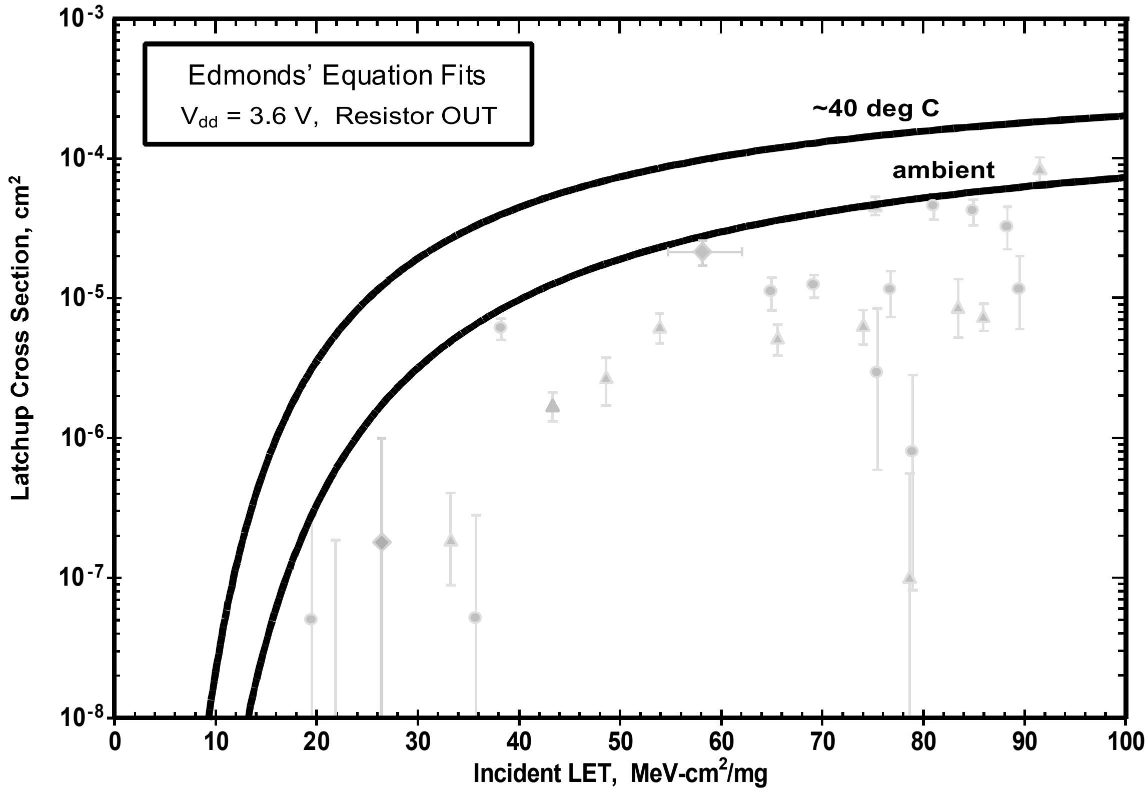


Figure 5. The Edmonds-equation conservative fits for room temperature and extrapolation to a temperatureof 40 C - the solid lines- are shown. The grey symbols combine the results from Figs. 2-4 for comparison.

Table 2.
Predicted Latchup Rate from Heavy Ions in Selected Space Environments

Environment	Rate (Latchups per Day)
GCR (or GEO)	5.7×10^{-5}
DCF	0.071

In other units, the GCR/GEO rate is one per 48 device-years and the DCF rate is about one latchup per four design-case flares per device. Of course, a higher operating temperature than 40 deg C would result in higher latchup rates.

6.0 CONCLUSIONS

Several conclusions can be drawn from this experiment: (1) the oscillator chip has a small, but significant susceptibility to destructive latchup from heavy ions, (2) it likely does not latchup from protons, (3) the 100 ohm series resistor was effective in the present testing (with a 0.1 uF capacitor) in preventing destructive latchup. However, it is known that latchup that appears non-destructive can cause internal (latent) damage in this device

[BEC-02]. No attempt has been made (to date) to examine the resistor-protected devices for latent damage. Therefore, we do not know whether or not the extent of the latent damage is lessened, or perhaps even eliminated, by the resistor. Latchup protection, either using the resistor or the power supply limits and software shutdown, was effective in eliminating destructive latchup and preventing apparent functional failure. However, all unprotected DUTs experienced destructive latchup.

Because the calculated latchup rate is so low (once per half century in GEO), because the nominal operation temperature is not expected to be above 40 deg. C, and because the series resistor is effective in preventing destruction, this device seems acceptable for technology demonstration missions like LAMP which can accept reasonable risk. However, more risk-averse, critical missions and applications designed by JPL are likely to need a more latchup resistant device; it is likely that the device, if moved to a thin epi process, would be latchup immune even at 100 degrees C.

Finally, note that all of the latchup testing was done with the device programmed to 3.3V. Because latchup – particularly catastrophic latchup damage – are strongly affected by voltage, the results in this report must not be used for applications where the oscillators are programmed to 5V. Note also that the results only apply to cases where the bypass capacitor is limited to less than or equal to 0.1uF; larger capacitors will allow larger latchup current pulses that may destroy the device.

REFERENCES

[BEC-02] H.N. Becker, T.F. Miyahira, and A.H. Johnston, "Latchup Damage in CMOS Devices for Single Event Latchup", *IEEE Trans. Nucl. Sci.* **49**(6), pp. 3009-3015 (2002).

[EDM-96] L.D. Edmonds, "SEU Cross Sections Derived from a Diffusion Analysis", *IEEE Trans. Nucl. Sci.,* **43**(6), pp.3207-3217, Dec. 1996.

[JOH-91] A.H. Johnston, B.W. Hughlock, M. P. Baze and R.F. Plaag, "The Effect of Temperature on Single Particle Latchup", *IEEE Trans. Nucl. Sci.,* **33**(6), pp. 1435-1441 (1991).

Appendix 3.1

Texas A&M Heavy-Ion Run Summary

Cardinal Programmable Oscillator Heavy Ion Test at Texas A&M Cyclotron Facility

Test date: 11/23/02 Ion: Ho @ 15MeV/AMU Energy: 1899MeV LET(0): 69.2MeV-cm2@/mg Latchup threshold: 20mA

Tested in air Test devices at room temperature

Run#	Serial#	Package style	Vdd	Idd	Current clamp	Angle	Ion	--- DEGRADER --- #	at angle	eff. Al, um	LET	Range	Irrad time, secs	Flux	Fluence	SEL	Cross Section	Comments
34							Ho											Calibration run. Avg axial gain=1.221
35	Y0210	Plastic	3.3V		30mA	0	Ho	-	-	0	69.2	119	779	1.28E+02	1.00E+05	0	0.00E+00	
36	T0841	DIP-Can	3.3V	14.4	30mA	0	Ho	-	-	0	0	0	762	1.31E+02	1.00E+05	0	0.00E+00	Ions stopped in epoxy, range<116.4u
37	T0811	SMD	3.3V	0.1	30mA	0	Ho	-	-	0	78.7	38	90	1.30E+02	1.17E+05	0	0.00E+00	Ignore run. Device current too low.
38	B4538	Plastic	3.3V		30mA	0	Ho	-	-	0	69.2	119	4	1.26E+05	5.58E+05	3	5.38E-06	Flux too high
39	B4538	Plastic	3.3V	7.1mA	30mA	0	Ho	-	-	0	69.2	119	170	1.47E+04	2.49E+06	29	1.16E-05	
40	B4538	Plastic	3.3V		30mA	0	Ho	-	-	0	69.2	119	698	1.43E+04	1.00E+07	141	1.41E-05	
41	T0832	DIP-Can	3.3V	5.8mA	30mA	0	Ho	-	-	0	0	0	702	1.43E+04	1.00E+07	0	0.00E+00	1.2MHz, Oops, ions stopped
42	T0801	SMD	3.3V	7.9mA	30mA	0	Ho	-	-	0	78.7	38	682	1.47E+04	1.00E+07	1	1.00E-07	
43	T0801	SMD	3.6V	9.1mA	30mA	0	Ho	-	-	0	78.7	38	612	1.63E+04	1.00E+07	1	1.00E-07	
44	B4538	Plastic	3.6V	8.2mA	30mA	0	Ho	-	-	0	69.2	119	156	1.60E+04	2.49E+06	29	1.16E-05	
45	B4538	Plastic	3.6V		30mA	0	Ho	-	-	0	69.2	119	156	1.60E+00	2.50E+06	34	1.36E-05	
46	B4538	Plastic	3.6V	8.2mA	30mA	0	Ho				76.8	62	172	1.46E+04	2.50E+06	30	1.20E-05	Used degrader to increase LET.
47	B4538	Plastic	3.6V	8.2mA	30mA	0	Ho				79.0	39	195	1.28E+04	2.49E+06	2	8.03E-07	Used degrader to increase LET.
48	B4538	Plastic	3.6V		50mA	0	Ho	-	-	0	69.2	119	58	1.71E+04	9.97E+05	13	1.30E-05	Increased current limit to 50mA.
49	B4538	Plastic	3.6V	8.2mA	75mA	0	Ho	-	-	0	69.2	119	84	1.73E+04	1.46E+06	18	1.23E-05	Increased current limit to 75mA.
50	B4538	Plastic	3.6V	8.2mA	150mA	0	Ho	-	-	0	69.2	119	86	1.73E+04	1.49E+06	22	1.48E-05	Increased current limit to 150mA.
51	B4538	Plastic	3.6V	8.2mA	300mA	0	Ho	-	-	0	69.2	119	89	1.68E+04	1.49E+06	29	1.95E-05	Increased current limit to 300mA.
52	B4538	Plastic	3.6V	8.2mA	600mA	0	Ho	-	-	0	69.2	119	90	1.67E+04	1.50E+06	38	2.53E-05	Increased current limit to 600mA.
53	B4538	Plastic	3.6V	8.2mA	1.2A	0	Ho	-	-	0	69.2	119	90	1.67E+04	1.51E+06	38	2.52E-05	Increased current limit to 1.2A.
54	B4538	Plastic	3.6V	8.2mA	2.0A	0	Ho	-	-	0	69.2	119	86	1.74E+04	1.50E+06	34	2.27E-05	Increased current limit to 2.0A.
55	B4538	Plastic	3.6V	8.2mA	2.0A	0	Ho	-	-	0	69.2	119	86	1.70E+04	5.23E+05	11	2.10E-05	Increased shutdown delay to 5secs. **Device died in 86 sec.**

Cardinal Programmable Oscillator Heavy Ion Test at Texas A&M Cyclotron Facility

Test date: 11/23/02   Ion: Ho @ 15MeV/AMU   Energy: 2380MeV   LET(0): 65.0MeV-cm2@/mg   Latchup threshold: 20mA

Tested in vacuum chamber   Test devices at room temperature

Run#	Serial#	Package style	Vdd	Idd	Current clamp	Angle	Ion	--- DEGRADER --- #	at angle	eff. Al, um	LET	Range	Irrad time secs	Flux	Fluence	SEL	Cross Section	Comments
56	Y0207	Plastic	3.3V	5.5mA	30mA	0	Ho	-	-	0	65	150	297	1.69E+04	5.01E+06	47	9.38E-06	Moved into vacuum chamber.
57	Y0207	Plastic	3.6V	6.5mA	30mA	0	Ho	-	-	0	65	150	324	1.54E+04	5.00E+06	58	1.16E-05	
	Y0207	Plastic	3.6V	4.9mA	30mA		Ho	-	-	0								100ohm resistor in series with Vdd.
58	Y0207	Plastic	4.0V	5.8mA	30mA	0	Ho	-	-	0	65	150	1609	3.11E+03	5.00E+06	52	1.04E-05	I-clamp=2.0A, Shutdown delay=5secs & 100ohm resistor in series on Vdd.
59	T0837	DIP-Can	3.6V	6.7mA	30mA	0	Ho	-	-	0	0	0	294	1.70E+04	4.99E+06	49	9.82E-06	Ions stopped in epoxy, range=116.4u
60	T0801	SMD	3.6V	10.5mA	30mA	0	Ho	-	-	0	75.3	71	89	1.68E+04	1.50E+06	43	2.87E-05	
61	T0801	SMD	3.6V	10.5mA	30mA	0	Ho	-	-	0	75.3	71	154	6.51E+03	1.00E+06	55	5.50E-05	
62	T0801	SMD	3.6V	10.5mA	30mA	0	Ho	-	-	0	75.3	71	631	1.58E+03	9.99E+05	74	7.41E-05	
63	Y0207	Plastic	3.6V		30mA	0	Ho				75.3	71	471	2.13E+03	1.00E+06	3	3.00E-06	Used degrader to simulate effect of crystal on LET.

Cardinal Programmable Oscillator Heavy Ion Test at Texas A&M Cyclotron Facility

Test date: 11/23/02 Ion: Au @ 15MeV/AMU Energy: 2837MeV LET(0): 81.1MeV-cm2@/mg Latchup threshold: 20mA

Tested in vacuum chamber Test devices at room temperature

Run#	Serial#	Package style	Vdd	Idd	Current clamp	Angle	Ion	--- DEGRADER --- #	at angle	eff. Al, um	LET	Range	Irrad time secs	Flux	Fluence	SEL	Cross Section	Comments
64	Y0207	Plastic	3.6V		30mA	0	Au	-	-	0	81.1	149	50	9.86E+04	4.97E+06	17	3.42E-06	100ohm resistor in series with Vdd.
65	Y0207	Plastic	3.6V		30mA	0	Au	-	-	0	81.1	149	522	3.83E+03	2.00E+06	97	4.85E-05	No resistor in series with Vdd.
66							Au											Calibration run. Axial gain=1.479
67	Y0207	Plastic	3.6V		30mA	0	Au				85	121	676	2.93E+03	1.98E+06	88	4.44E-05	
68	Y0207	Plastic	3.6V		30mA	0	Au				88.4	92	336	2.97E+03	9.99E+05	34	3.40E-05	
69	Y0207	Plastic	3.6V		30mA	0	Au				89.6	83	105	9.45E+03	9.95E+05	12	1.21E-05	
70	T0837	DIP-Can	3.6V		30mA	0	Au	-	-	0	0	0	101	9.87E+03	1.00E+06	1	1.00E-06	Ions stopped in epoxy >200u, ion range=147.1u
71	T0801	SMD	3.6V		30mA	0	Au	-	-	0	91.6	69	52	9.58E+03	4.98E+05	22	4.42E-05	Flux too high.
72	T0801	SMD	3.6V		30mA	0	Au	-	-	0	91.6	69	37	2.66E+03	9.94E+04	8	8.05E-05	Flux still too high
73							Au											Calibration run. Avg axial gain=1.8737
74	T0801	SMD	3.6V		30mA	0	Au	-	-	0	91.6	69	737	1.36E+03	1.00E+06	92	9.20E-05	

Cardinal Programmable Oscillator Heavy Ion Test at Texas A&M Cyclotron Facility

Test date: 11/24/02 Ion: Xe @ 24.8MeV/AMU Energy: 3141MeV LET(0): 38.2MeV-cm2@/mg Latchup threshold: 20mA

Tested in vacuum chamber Test devices at room temperature

Run#	Serial#	Package style	Vdd	Idd	Current clamp	Angle	Ion	--- DEGRADER --- #	at angle	eff. Al, um	LET	Range	Irrad time secs	Flux	Fluence	SEL	Cross Section	Comments
101	B5439	Plastic	3.6V	6.3mA	30mA	0	Xe	-	-	0	38.2	280	180	5.55E+04	9.99E+06	61	6.11E-06	No resistor in series with Vdd. Current clamp@2Amps, Shutdown delay=0
102	B5439	Plastic	3.6V	6.3mA	30mA	0	Xe	-	-	0	38.2	280	12	1.43E+05	1.71E+06	6	3.51E-06	Flux too high.
103	B5439	Plastic	3.6V	6.3mA	30mA	0	Xe	-	-	0	38.2	280	508	1.97E+04	1.00E+07	65	6.50E-06	
104	T0837	DIP-Can	3.6V	6.6mA	30mA	0	Xe	-	-	0	58.0	74	93	2.14E+04	1.98E+06	28	1.41E-05	
105	T0837	DIP-Can	3.6V	6.6mA	30mA	0	Xe	-	-	0	58.0	74	602	4.81E+03	2.89E+06	70	2.42E-05	Power supply computer locked up. No latchup protection. **Killed DUT.**
106	T0801	SMD	3.6V	10.6mA	30mA	0	Xe	-	-	0	43.3	201	98	5.09E+03	5.01E+05	0	0.00E+00	Current clamp@30ma
107	T0801	SMD	3.6V	10.6mA	30mA	0	Xe	-	-	0	43.3	201	226	4.41E+04	9.98E+06	18	1.80E-06	
108	T0801	SMD	3.6V	10.6mA	30mA	0	Xe	-	-	0	43.3	201	238	4.20E+04	1.00E+07	22	2.20E-06	
109	T0801	SMD	3.6V	10.5mA	30mA	0	Xe	-	-	0	43.3	201	270	3.69E+04	9.99E+06	10	1.00E-06	
110	T0801	SMD	3.6V	10.5mA	30mA	0	Xe	-	-	0	43.3	201	165	6.09E+04	1.00E+07	21	2.10E-06	
111	T0801	SMD	3.6V	10.5mA	30mA	0	Xe	2	0	51	48.6	144	239	4.19E+04	1.00E+07	28	2.80E-06	Used degrader to increase LET
112	T0801	SMD	3.6V	10.5mA	30mA	0	Xe	2	55	88	53.9	102	467	2.14E+00	1.00E+07	65	6.50E-06	Used degrader to increase LET
113	T0801	SMD	3.6V	10.5mA	30mA	45	Xe	2	55	88	83.5	46	162	1.74E+04	1.99E+06	18	9.05E-06	Used degrader to increase LET Range may be too low.
114	T0801	SMD	3.6V	10.5mA	30mA	45	Xe	-	-	0	65.6	117	1284	8.99E+03	1.15E+07	62	5.39E-06	No degrader
115	T0801	SMD	3.6V	10.5mA	30mA	55	Xe	-	-	0	86.0	79	36	4.85E+04	1.73E+06	12	6.94E-06	Flux too high.
116	T0801	SMD	3.6V	10.5mA	30mA	55	Xe	-	-	0	86.0	79	612	1.42E+04	8.72E+06	69	7.91E-06	
117	T0801	SMD	3.6V	10.5mA	30mA	50	Xe	-	-	0	74.1	99	427	1.82E+04	7.79E+06	52	6.68E-06	

Cardinal Programmable Oscillator Heavy Ion Test at Texas A&M Cyclotron Facility

Test date: 11/25/02   Ion: Kr @ 24.8MeV/AMU   Energy: 2053MeV   LET(0): 19.4MeV-cm2@/mg   Latchup threshold: 20mA

Tested in vacuum chamber   Test devices at room temperature

Run#	Serial#	Package style	Vdd	Idd	Current clamp	Angle	Ion	--- DEGRADER --- #	at angle	eff. Al, um	LET	Range	Irrad time secs	Flux	Fluence	SEL	Cross Section	Comments
149	B5439	Plastic	3.6V	6.3mA	30mA	0	Kr	-	-	0	19.4	326	187	1.07E+05	2.00E+07	1	5.00E-08	
150	B5439	Plastic	3.6V	6.3mA	30mA	-38	Kr	3	29.4	175	35.7	102	268	9.48E+04	2.00E+07	1	5.00E-08	Using degrader to increase LET.
151	B5439	Plastic	3.6V	6.3mA	30mA	0	Kr	3	0	152	26.3	156	242	8.24E+04	2.00E+07	0	0.00E+00	Using degrader to increase LET.
152	X4712	DIP-Can	3.6V	5.9mA	30mA	0	Kr	-	-	0	19.4	326	317	6.30E+04	2.00E+07	0	0.00E+00	Degrader out. Special device with no glop (new lot).
153	X4712	DIP-Can	3.6V	10.5mA	30mA	0	Kr	-	-	0	19.4	326	180	1.11E+05	2.00E+07	0	0.00E+00	
154	X4712	DIP-Can	3.6V	10.6mA	30mA	0	Kr	3	0	152	26.3	156	58	1.02E+05	5.94E+06	1	1.68E-07	Using degrader to increase LET. **Device died.**
155	T0802	SMD	3.6V	10.3mA	30mA	0	Kr	3	0	152	33.2	76	98	1.23E+05	1.21E+07	5	4.13E-07	
156	T0802	SMD	3.6V	10.3mA	30mA	0	Kr	3	0	152	33.2	76	155	1.28E+05	2.00E+07	1	5.00E-08	
157	T0802	SMD	3.6V	10.3mA	30mA	0	Kr	-	-	0	21.8	248	146	1.33E+05	2.00E+07	0	0.00E+00	Degrader out

Appendix 3.2

Latent Damage from Single-Event Latchup

Figure 3 from Becker et al. [BEC-02] is extracted below. It clearly shows damage to the Cardinal Oscillator IC fabbed by Cypress, but this testing was done at 5 V. It is likely that, in the absence of the 100 ohm supply resistor, that such latent damage also occurs at 3.3 V. However, because of the tedious and expensive nature of searching for it, a decision was made to forego the search. Note that the likelihood of the existence of such latent damage in the parts tested with the resistor in place is not known.

"

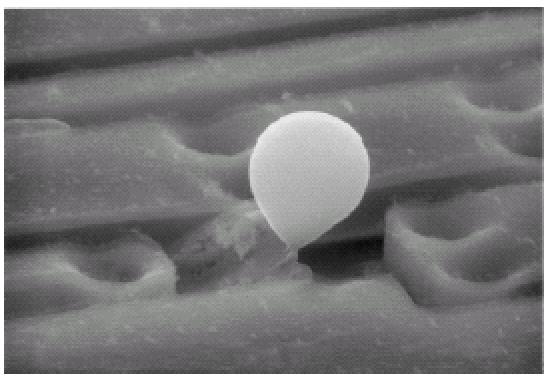


Fig. 3. Scanning electron micrograph of ejected metal at a contact region of the Cypress crystal oscillator."

The discussion the above figure in Becker et al. [BEC-02] reads as follows:

"Metal damage in a contact regionwas observed in the Cypress oscillator, as shown in Fig. 3. The contact is a via between the first- and second-level metallization layers. The ejected sphere is actually from the top metallization layer. In spite of the size of the sphere, this was actually latent damage. SEM evaluation with EDS showed that the refractory metal that is used to clad the interconnect was still intact. The Cypress oscillator is the only one of the six devices to exhibit damage at contact regions.
…
Similar behavior was observed with the National ADC10321 and the Cypress oscillator. These devices were both tested with Californium-252 fission fragments. SEL-induced damage was reproducible, appeared in the same locations and was a mixture of catastrophic and latent among individual parts."

Appendix 4 – TID Report

RADIATION TEST REPORT

TID Testing of Cardinal Field Programmable Oscillator (CPP C 7L –AxBx 12.0000 PD)

NASA GSFC

3rd July, 2003

Stephen Buchner (QSS)
Christopher Palor (Orbital)
Hak Kim (J&T)

1. Introduction

Five field programmable oscillators from Cardinal Components, Inc. were tested for TID response using gamma rays in a ^{60}Co source. The parts were designed to oscillate at a frequency of 12.5 MHz. The measured TID responses were:

- Functionality (frequency and amplitude),
- Supply leakage current ($I1(V_{dd})$),
- Output voltage in standby mode ($V_{out}(V_{dd})$).

Output voltage could only be measured when the part was placed in an "output low" state. One part was not irradiated and was kept as a control.

2. Experimental Conditions and Device Configuration

The parts were incrementally irradiated at a dose rate of approximately 1 krad(Si)/hr. During irradiation V_{dd} = 3.3V whereas Control and Output were kept floating. After each incremental dose the parts were tested for functionality and the parameters listed in the previous paragraph were measured. Figure 1 shows the connections to the device.

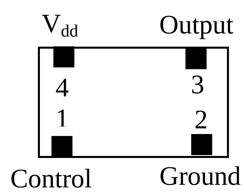


Figure 1. Electrical Connections to the Device

3. Results

The results of the parameter measurements prior to irradiation and following seven incremental dose levels for the five devices are listed in Tables I-V. The first two columns are the supply currents at 3.3V and 5.0V measured while the device was operating i.e. the control pin was set high. The next four columns are the supply currents and output voltages for supply voltages of 3.3V and 5.0V for the device in standby mode. Figure 2 shows the currents for DUT #1 as a function of dose. Figure 3 shows the voltages for DUT #1 as a function of dose. The changes are relatively small and are not monotonic. After a dose of 15 krad(Si) the part stopped oscillating. All the parametric values were still within specifications at 15 krad(Si).

Table I

Parametric Values as a Function of TID for DUT #1

	Oscillating		Output Low			
Dose (krad(Si))	**I_{dd}(V_{dd}=3.3V) (Amps)**	**I_{dd}(5.0V) (Amps)**	**I_{dd}(3.3V) (Amps)**	**V_{out}(3.3V) (Volts)**	**I_{dd}(5.0V) (Amps)**	**V_{out}(5V) (Volts)**
0	$6.70x10^{-3}$	$1.33x10^{-2}$	$5.98x10^{-3}$	$1.87x10^{-3}$	$1.22x10^{-2}$	$3.76x10^{-3}$
0.5	$6.69x10^{-3}$	$1.33x10^{-2}$	$5.98x10^{-3}$	$2.26x10^{-3}$	$1.22x10^{-2}$	$4.56x10^{-3}$
1	$6.69x10^{-3}$	$1.33x10^{-2}$	$5.97x10^{-3}$	$2.67x10^{-3}$	$1.22x10^{-2}$	$5.39x10^{-3}$
2	$6.69x10^{-3}$	$1.33x10^{-2}$	$5.97x10^{-3}$	$1.99x10^{-3}$	$1.22x10^{-2}$	$4.02x10^{-3}$
3	$6.69x10^{-3}$	$1.33x10^{-2}$	$5.97x10^{-3}$	$2.27x10^{-3}$	$1.22x10^{-2}$	$4.60x10^{-3}$
5	$6.67x10^{-3}$	$1.33x10^{-2}$	$5.96x10^{-3}$	$1.99x10^{-3}$	$1.22x10^{-2}$	$3.86x10^{-3}$
7	$6.68x10^{-3}$	$1.33x10^{-2}$	$5.96x10^{-3}$	$1.92x10^{-3}$	$1.22x10^{-2}$	$4.02x10^{-3}$
10	$6.66x10^{-3}$	$1.33x10^{-2}$	$5.94x10^{-3}$	$2.17x10^{-3}$	$1.22x10^{-2}$	$4.37x10^{-3}$
15	$6.67x10^{-3}$	$1.32x10^{-2}$	$5.95x10^{-3}$	$1.90x10^{-3}$	$1.35x10^{-2}$	$4.30x10^{-3}$

Table II

Parametric Values as a Function of TID for DUT #2

	Oscillating		Output Low			
Dose (krad(Si))	**I_{dd}(V_{dd}=3.3V) (Amps)**	**I_{dd}(5.0V) (Amps)**	**I_{dd}(3.3V) (Amps)**	**V_{out}(3.3V) (Volts)**	**I_{dd}(5.0V) (Amps)**	**V_{out}(5V) (Volts)**
0	$7.05x10^{-3}$	$1.40x10^{-2}$	$6.33x10^{-3}$	$2.01x10^{-3}$	$1.29x10^{-2}$	$3.99x10^{-3}$
0.5	$7.05x10^{-3}$	$1.40x10^{-2}$	$6.33x10^{-3}$	$2.22x10^{-3}$	$1.29x10^{-2}$	$4.41x10^{-3}$
1	$7.05x10^{-3}$	$1.40x10^{-2}$	$6.33x10^{-3}$	$2.05x10^{-3}$	$1.29x10^{-2}$	$4.08x10^{-3}$
2	$7.04x10^{-3}$	$1.40x10^{-2}$	$6.32x10^{-3}$	$3.28x10^{-3}$	$1.29x10^{-2}$	$6.59x10^{-3}$
3	$7.04x10^{-3}$	$1.40x10^{-2}$	$6.32x10^{-3}$	$2.44x10^{-3}$	$1.29x10^{-2}$	$4.87x10^{-3}$
5	$7.03x10^{-3}$	$1.40x10^{-2}$	$6.31x10^{-3}$	$1.93x10^{-3}$	$1.29x10^{-2}$	$3.85x10^{-3}$
7	$7.02x10^{-3}$	$1.40x10^{-2}$	$6.31x10^{-3}$	$2.15x10^{-3}$	$1.29x10^{-2}$	$4.31x10^{-3}$
10	$7.01x10^{-3}$	$1.39x10^{-2}$	$6.29x10^{-3}$	$2.17x10^{-3}$	$1.28x10^{-2}$	$4.35x10^{-3}$
15	$7.01x10^{-3}$	$1.28x10^{-2}$	$6.29x10^{-3}$	$1.9x10^{-3}$	$1.41x10^{-2}$	$4.17x10^{-3}$

Table III

Parametric Values as a Function of TID for DUT #3

	Oscillating		**Output Low**			
Dose (krad(Si))	**I_{dd}(V_{dd}=3.3V) (Amps)**	**I_{dd}(5.0V) (Amps)**	**I_{dd}(3.3V) (Amps)**	**V_{out}(3.3V) (Volts)**	**I_{dd}(5.0V) (Amps)**	**V_{out}(5V) (Volts)**
0	6.64×10^{-3}	1.32×10^{-2}	5.92×10^{-3}	1.75×10^{-3}	1.21×10^{-2}	3.51×10^{-3}
0.5	6.63×10^{-3}	1.32×10^{-2}	5.91×10^{-3}	2.45×10^{-3}	1.21×10^{-2}	4.90×10^{-3}
1	6.64×10^{-3}	1.32×10^{-2}	5.92×10^{-3}	1.88×10^{-3}	1.21×10^{-2}	3.77×10^{-3}
2	6.64×10^{-3}	1.32×10^{-2}	5.91×10^{-3}	2.07×10^{-3}	1.21×10^{-2}	4.20×10^{-3}
3	6.64×10^{-3}	1.32×10^{-2}	5.90×10^{-3}	2.03×10^{-3}	1.21×10^{-2}	4.08×10^{-3}
5	6.62×10^{-3}	1.32×10^{-2}	5.90×10^{-3}	1.81×10^{-3}	1.21×10^{-2}	3.64×10^{-3}
7	6.61×10^{-3}	1.32×10^{-2}	5.89×10^{-3}	2.51×10^{-3}	1.21×10^{-2}	5.09×10^{-3}
10	6.59×10^{-3}	1.32×10^{-2}	5.88×10^{-3}	2.02×10^{-3}	1.21×10^{-2}	4.09×10^{-3}
15	6.74×10^{-3}	8.42×10^{-2}	6.03×10^{-3}	1.96×10^{-3}	8.74×10^{-3}	2.77×10^{-3}

Table IV

Parametric Values as a Function of TID for DUT #4

	Oscillating		**Output Low**			
Dose (krad(Si))	**I_{dd}(V_{dd}=3.3V) (Amps)**	**I_{dd}(5.0V) (Amps)**	**I_{dd}(3.3V) (Amps)**	**V_{out}(3.3V) (Volts)**	**I_{dd}(5.0V) (Amps)**	**V_{out}(5V) (Volts)**
0	6.89×10^{-3}	1.38×10^{-2}	6.17×10^{-3}	1.92×10^{-3}	1.27×10^{-2}	3.85×10^{-3}
0.5	6.89×10^{-3}	1.38×10^{-2}	6.16×10^{-3}	2.66×10^{-3}	1.27×10^{-2}	5.38×10^{-3}
1	6.88×10^{-3}	1.38×10^{-2}	6.17×10^{-3}	2.01×10^{-3}	1.27×10^{-2}	4.05×10^{-3}
2	6.88×10^{-3}	1.38×10^{-2}	6.16×10^{-3}	3.04×10^{-3}	1.27×10^{-2}	6.18×10^{-3}
3	6.88×10^{-3}	1.38×10^{-2}	6.16×10^{-3}	2.20×10^{-3}	1.27×10^{-2}	4.44×10^{-3}
5	6.87×10^{-3}	1.38×10^{-2}	6.15×10^{-3}	1.96×10^{-3}	1.27×10^{-2}	3.94×10^{-3}
7	6.86×10^{-3}	1.38×10^{-2}	6.14×10^{-3}	1.97×10^{-3}	1.27×10^{-2}	4.00×10^{-3}
10	6.85×10^{-3}	1.37×10^{-2}	6.13×10^{-3}	2.17×10^{-3}	1.26×10^{-2}	4.42×10^{-3}
15	6.88×10^{-3}	1.22×10^{-2}	6.16×10^{-3}	1.93×10^{-3}	1.20×10^{-2}	3.65×10^{-3}

Table V

Parametric Values as a Function of TID for DUT #5

	Oscillating		**Output Low**			
Dose (krad(Si))	**I_{dd}(V_{dd}=3.3V) (Amps)**	**I_{dd}(5.0V) (Amps)**	**I_{dd}(3.3V) (Amps)**	**V_{out}(3.3V) (Volts)**	**I_{dd}(5.0V) (Amps)**	**V_{out}(5V) (Volts)**
0	$3.35x10^{-3}$	$6.13x10^{-2}$	$6.19x10^{-3}$	$1.83x10^{-3}$	$1.26x10^{-2}$	$3.61x10^{-3}$
0.5	$6.91x10^{-3}$	$1.37x10^{-2}$	$6.19x10^{-3}$	$2.42x10^{-3}$	$1.26x10^{-2}$	$4.79x10^{-3}$
1	$6.91x10^{-3}$	$1.37x10^{-2}$				
2	$6.91x10^{-3}$	$1.37x10^{-2}$	$6.19x10^{-3}$	$2.24x10^{-3}$	$1.26x10^{-2}$	$4.48x10^{-3}$
3	$6.91x10^{-3}$	$1.37x10^{-2}$	$6.18x10^{-3}$	$2.09x10^{-3}$	$1.26x10^{-2}$	$4.17x10^{-3}$
5	$6.89x10^{-3}$	$1.37x10^{-2}$	$6.18x10^{-3}$	$1.87x10^{-3}$	$1.26x10^{-2}$	$3.69x10^{-3}$
7	$6.89x10^{-3}$	$1.37x10^{-2}$	$6.17x10^{-3}$	$1.90x10^{-3}$	$1.26x10^{-2}$	$3.80x10^{-3}$
10	$6.87x10^{-3}$	$1.37x10^{-2}$	$6.15x10^{-3}$	$2.13x10^{-3}$	$1.26x10^{-2}$	$4.28x10^{-3}$
15	$6.94x10^{-3}$	$1.22x10^{-2}$	$6.23x10^{-3}$	$1.84x10^{-3}$	$1.19x10^{-2}$	$3.56x10^{-3}$

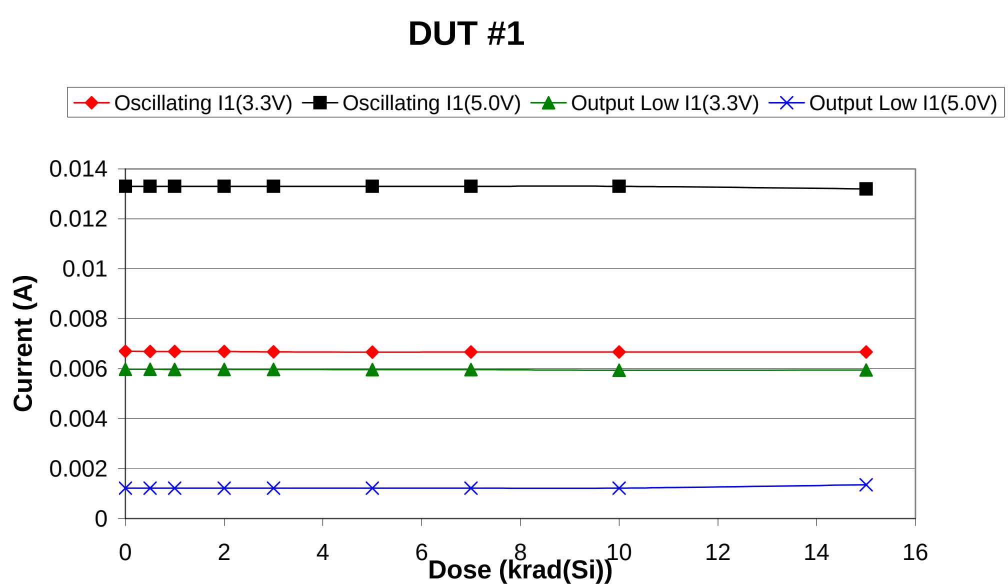


Fig. 2. Supply Currents at 3.3V and 5.0V as a function of Total Ionizing Dose for DUT#1

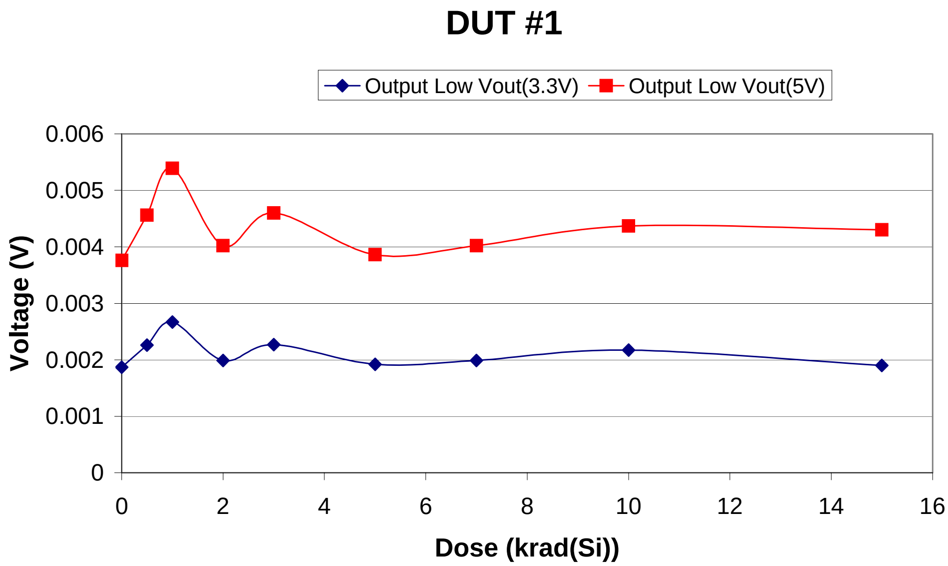


Fig. 3. Output Voltage as a function of Total Ionizing Dose for supply voltages of 3.3V and 5.0V for DUT#1.

4. Conclusions

Five voltage-controlled oscillators from Cardinal Components, Inc were tested for TID using gamma rays in a 60Co cell. All parts failed functionality, i.e., they stopped operating, at doses between 10 and 15 krad(Si) even though the supply current and output voltage (in standby mode) remained within specification.

Appendix 5 – Low Temperature Testing Report

NASA Electronic Parts and Packaging Program

Evaluation of JPL Programmable Oscillators at Extreme Temperatures

Richard Patterson & Eric Overton, NASA Glenn Research Center
Shri Agarwal, David Peters & Charles Barnes, JPL
Ahmad Hammoud, QSS Group, Inc./NASA GRC

Background

Many deep space and planetary exploration missions require electronic devices and systems that can operate reliably and efficiently in harsh environments. Some of these environmental stresses that are encountered in a typical deep space mission include exposure to extreme temperatures. Little is known on the performance and reliability of electronic components and integrated circuits at temperatures beyond the manufacturer's specified operating temperature range. Information is, therefore, required to address the functionality and reliability of devices that are geared for operation on space missions where exposure to extreme temperatures is encountered.

In a collaborative effort between NASA's Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), and the Jet Propulsion Laboratory (JPL) under the NASA Electronic Parts and Packaging (NEPP) Program, the effects of extreme temperature and thermal cycling on various electronic devices and circuits are being investigated. This report presents the results obtained on the evaluation of programmable oscillators under extreme temperature exposure.

Test Procedure and Setup

A batch of commercial programmable oscillators was provided by JPL for evaluation under extreme temperatures. The oscillators were requested to be programmed by the manufacturer for specific frequencies. These comprised 2, 10, 12, 50, and 90 MHz. Table I shows some of the manufacturer's specifications for these devices [1]. The originally blank oscillators can be programmed twice to a specific discrete frequency between 1.000 and 133.000 MHz. These devices can have either a TTL or CMOS output level, and are available in ceramic or plastic surface-mount packages.

Table I. Manufacturer's specifications of programmable oscillators [1].

Parameter	Symbol	Rating	Units
Supply voltage	Vdd	3.0 to 5.5	V
Programmable frequency	f	1.0 to 133.0	MHz
Operating temperature	T	-40 to +85	°C
Stability	Δ	±25 to ±100	ppm
Supply current (unloaded)	I_S	25 to 45	mA
Duty cycle	D	40 to 60	%
Output clock rise/fall time	τ	0.9 to 4.0	ns

The oscillators were evaluated at NASA GRC for operation between +100 °C and -190 °C. Performance characterization was obtained in terms of their output frequency, supply current, and output voltage signal level at specific test temperatures. Cold-restart capability, i.e. power switched on while the devices were at a temperature of -190 °C, was also investigated. A supply voltage of 3.3 V was applied and the temperature rate of change used was 10 °C per minute. A soak time of at least 10 minutes was allowed at every test temperature. The effects of thermal cycling under a wide temperature range on the operation of the oscillators were also investigated. The oscillators were exposed to a total of 12 cycles between +100 °C and -190 °C at a temperature rate of 10 °C/minute. The output waveform and frequency for each oscillator were obtained at selected temperature during this cycling activity.

The test setup comprised of bypassing Vdd to ground with a 0.2 μF capacitor and loading the output with a 1 nF capacitor. A Keithley 237 source/measure unit was used as the supply with the current compliance set to 100 mA, and a Fluke 1953A counter timer was used to measure the frequency. A Tektronix TDS 380 digital scope captured the output waveforms.

Test Results

Temperature Effects

The 2 MHz oscillator performed relatively well in the temperature range between +100 °C and -190 °C. Output waveforms of this oscillator are shown in Figure 1 at the selected test temperatures of +100, 25, -125, and -190 °C. It can be seen that while the wave shape of the oscillator output did not change with temperature, its amplitude increased slightly as temperature was decreased. Such a trend was also observed in the behavior of the 10 and 12 MHz oscillators with temperature. Waveforms of the output of these two oscillators are depicted in Figures 2 and 3, respectively, at the same four test temperatures.

Unlike the low frequency oscillators, their high frequency counterparts, namely 50 and 90 MHz oscillators, exhibited more noticeable increase in output amplitude as temperature was decreased. This increase was more profound for the oscillator with the highest frequency. These effects can be seen in Figures 4 and 5 for the 50 and 90 MHz oscillators, respectively.

As far as the oscillator output frequency is concerned, all of the devices exhibited a decrease in frequency as temperature was decreased. Such a behavior is quite similar to that of crystal oscillators. Figure 6 shows the normalized frequency of these oscillators along with that of a typical uncompensated 10 MHz oscillator as a function of temperature. It can be clearly seen that the curves for the five JPL programmable oscillators were virtually identical to each other and to that of the crystal oscillator, and the frequency of all the devices began to drop as temperature approached around -40 °C. This decrease in frequency became steeper as temperature was reduced further.

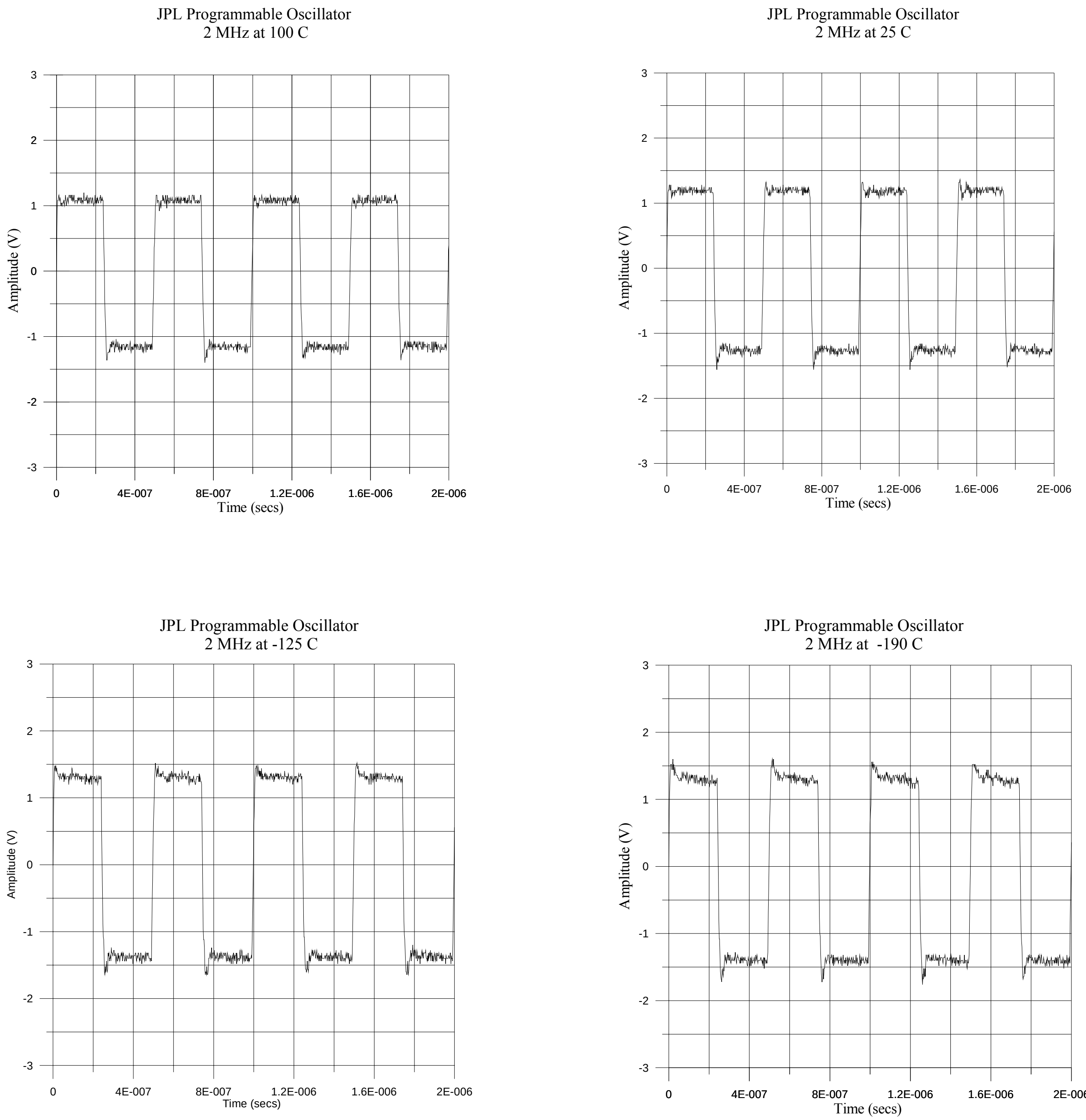


Figure 1. Output of the 2 MHz oscillator at various temperatures.

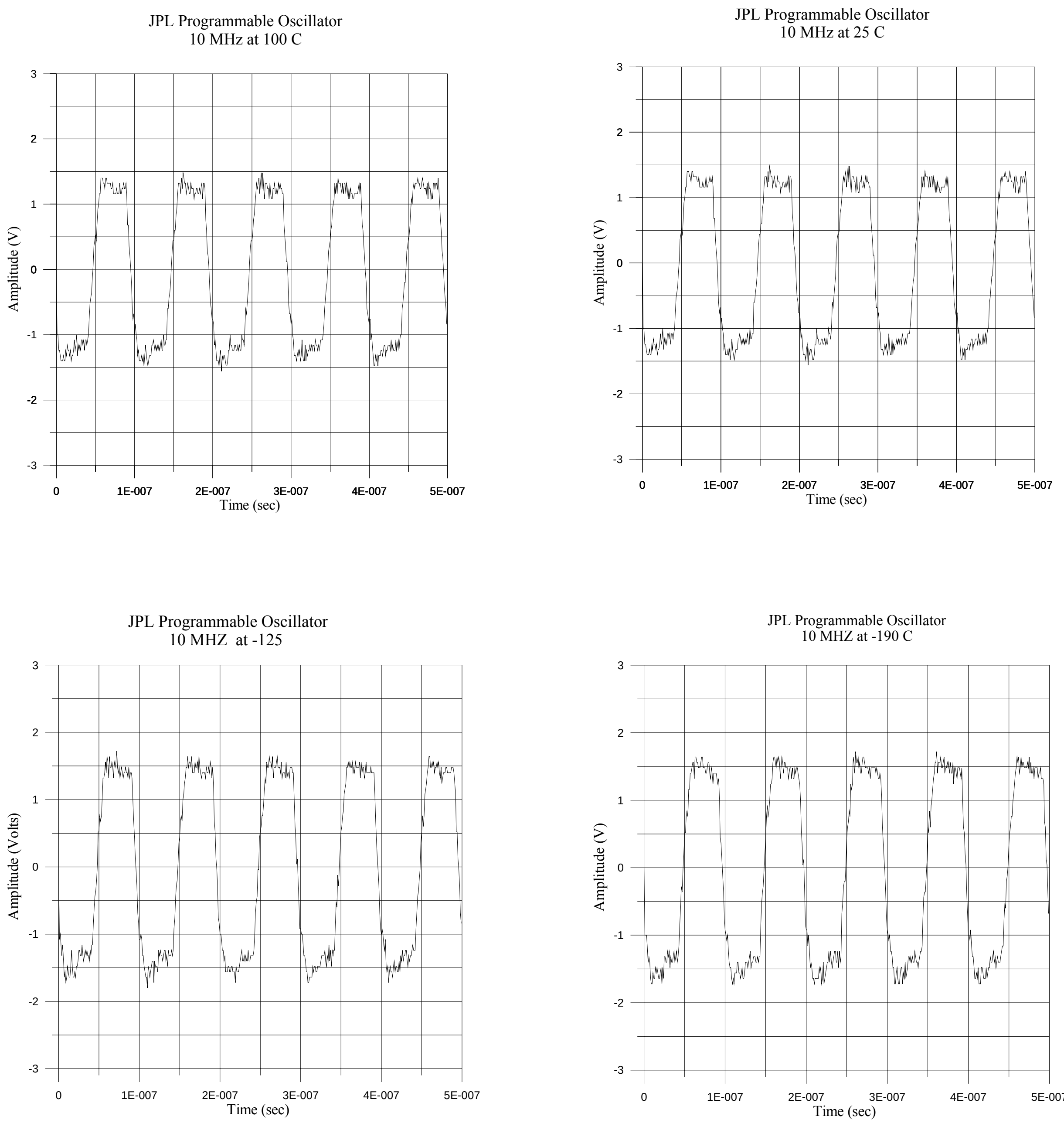


Figure 2. Output of the 10 MHz oscillator at various temperatures.

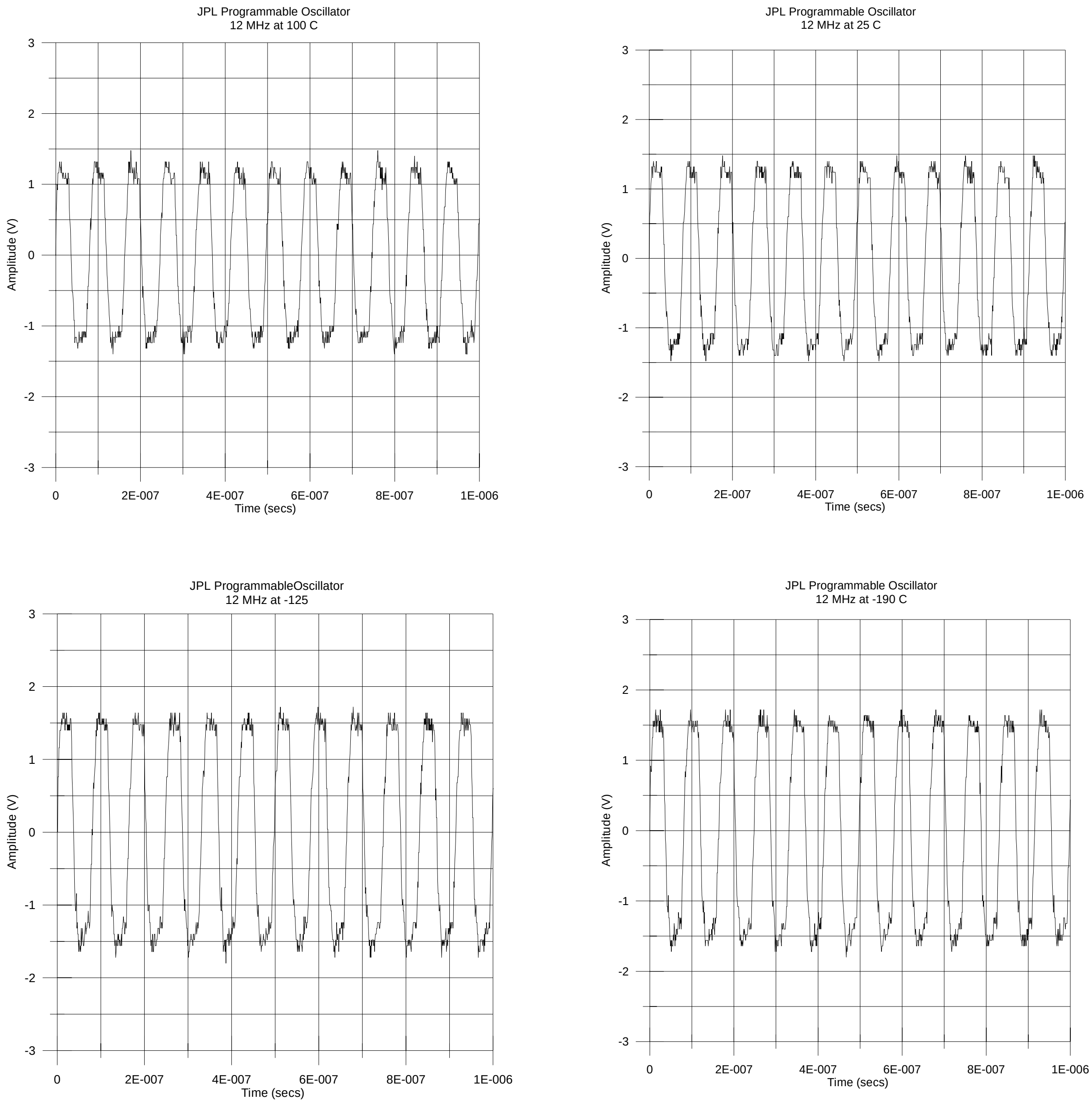


Figure 3. Output of the 12 MHz oscillator at various temperatures.

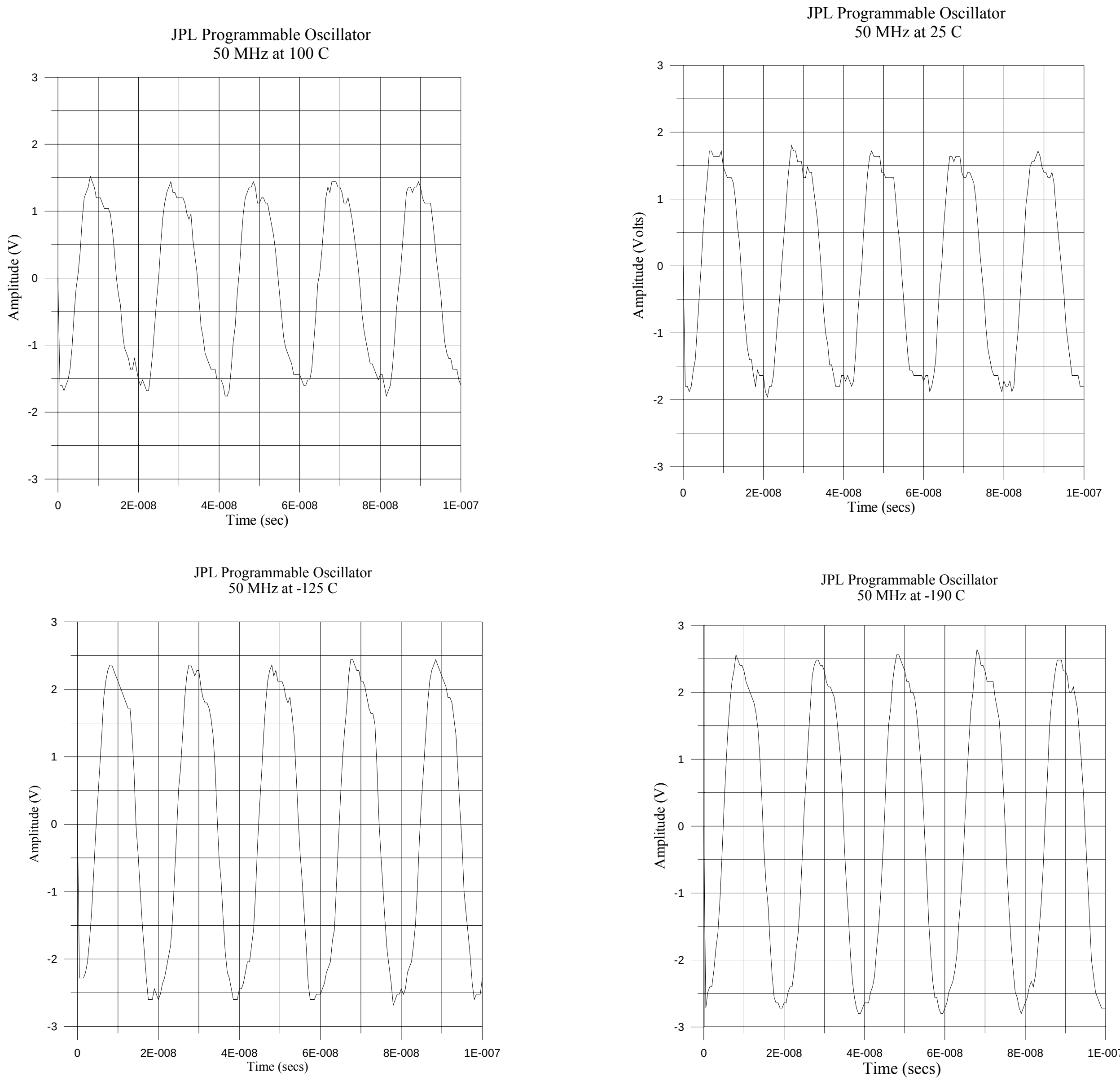


Figure 4. Output of the 50 MHz oscillator at various temperatures

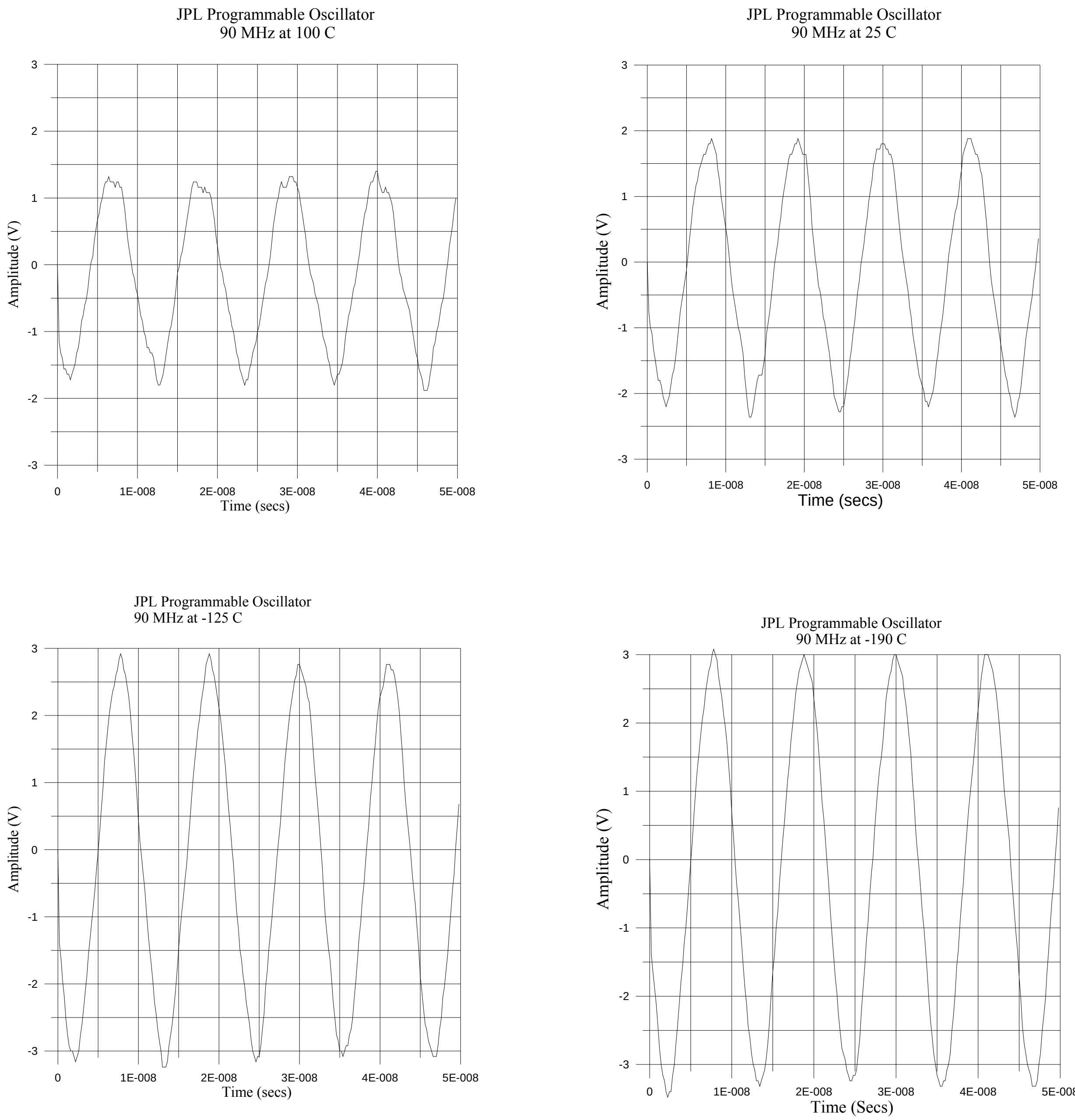


Figure 5. Output of the 90 MHz oscillator at various temperatures.

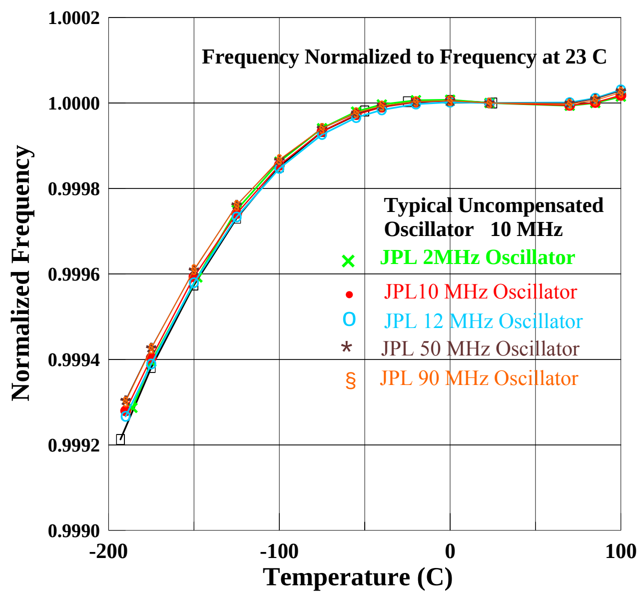


Figure 6. Normalized frequency of oscillators versus temperature.

Effects of Thermal Cycling

The oscillators were subjected to two runs of thermal cycling between +100 °C and -190 °C for a total of 12 cycles. A rate of temperature change of 10 °C/minute was used during this cycling activity. Data for the five oscillators were taken before, during, and after the thermal cycling. While the pre- and post-measurements were performed at room temperature, the in-situ measurements were done at the extreme temperatures, i.e. +100 °C and -190 °C. These readings were taken during both the 6th and the 12th cycles. No major changes were observed in the operational characteristics of these devices except for slight variation in the output frequency with temperature, as was noted earlier for all the devices. Table II lists the results obtained in this investigation. For any given device, the frequency increased very slightly when the temperature was increased from ambient to 100 °C. Similarly, the frequency decreased when the temperature was decreased. These changes seemed, however, to be transitory in nature as the frequency of each one of the five oscillators recovered to its pre-cycling value upon removal of the thermal stress. The thermal cycling appeared to have no effect on the structural integrity of the devices as none underwent any structural deterioration or packaging damage.

Table II. Output frequency (kHz) of the oscillators during thermal cycling.

	Before Cycling	**In-situ 6th Cycle**		**Post 6th Cycle**	**In-Situ 12th Cycle**		**Post 12th Cycle**
Device	20 °C	-190 °C	+100 °C	20 °C	-190 °C	+100 °C	20 °C
2 MHz Osc	2000.007	1998.594	2000.042	2000.008	1998.577	2000.028	2000.011
10 MHz Osc	9999.991	9993.132	10000.275	10000.01	9993.018	10000.262	10000.026
12 MHz Osc	12000.028	11991.415	12000.491	12000.028	11991.314	12000.487	12000.044
50 MHz Osc	49999.953	49965.042	50001.332	49999.971	49964.529	50001.323	50000.102
90 MHz Osc	89999.965	89936.630	90002.259	90000.048	89937.406	90002.288	90000.146

Cold Re-Start

Electronic components and circuits in certain space missions are required to be powered up at cryogenic temperatures. Cold-restart capability of these oscillators was, therefore, investigated in this work. The oscillator under test was allowed to soak, with electrical power off, at -190 °C for at least 20 minutes. Power was then applied to the circuit and measurements of the oscillator's output waveform and frequency were recorded. All oscillators did perform cold start after this low temperature soakings, and the results obtained were similar to those obtained earlier at that temperature.

Conclusion

In a collaborative effort between NASA's Glenn Research Center (GRC), Goddard Space Flight Center (GSFC), and the Jet Propulsion Laboratory (JPL) under the NASA Electronic Parts and Packaging (NEPP) Program, a batch of commercial programmable oscillators was provided by JPL for in-house evaluation under extreme temperatures. The oscillators were programmed for 2, 10, 12, 50, and 90 MHz. The oscillators were evaluated for operation between +100 °C and -190 °C. Performance characterization was obtained in terms of their output frequency, supply current, and output voltage signal level at specific test temperatures. The effects of thermal cycling under a wide temperature range on the operation of the oscillators, and cold-restart capability were also investigated. All oscillators operated well between +100 °C and -190 °C. In addition, the limited thermal cycling had no effect on their performance and all oscillators were able to cold start at -190 °C. Further testing under long term cycling is required to fully establish the reliability of these devices and to determine their suitability for use in extreme temperature environments.

References

[1]. Cardinal Components, Inc., Field *Programmable Blank Oscillator, Series CPP*.

Acknowledgements

This work was performed under the NASA Glenn Research Center GESS Contract # NAS3-00145. Funding was provided by the NASA Electronic Parts and Packaging (NEPP) Program.

Appendix 6 – Construction Analysis/DPA Report

Appendix 6a – DIP Package

Appendix 6b – SMD package

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

DPA
Destructive Physical Analysis Report

Customer/Project:	**TI Parts Evaluation**
FA Log Number:	**8535**
Date:	**March 28, 2001**
Part Type:	**Field Programmable Oscillator**
Part Number:	**CAR/CPPX1T-A7BR-XX.XXX**
Manufacturer:	**Cardinal Components**
Lot Date Code:	**N/A**
JPL Trace #:	**None**
Serial Numbers:	**None (Arbitrarily serialized A, B, C and D for DPA)**

Quantity: **4**

☐ **MEETS REQUIREMENTS**

☒ **DOES NOT MEET REQUIREMENTS**

Comments: The metallization on the integrated circuit (Cypress Semiconductor Corp., CY2037)fails to meet the metallization step coverage requirement. The worst case metallization step coverage was found on metal layer 1 with approximately 10% step coverage. This condition is cause for rejection per Mil-Std-883, Method 2018.

NOTE: This field programmable oscillator is a commercial part not originally intended for space application. This analysis was intended to see if the part could be upgraded for space application. Although some elements of the part do not have the ruggedness necessary for space application and some step coverages do not meet Mil Standards, the conclusions in this report do not concern the use of the part in applications (non-space) for which it was intended.

Prepared by: J. Okuno Date: 4-5-01
J. Okuno, *Failure Analyst*

Approved by: P J Smith Date: 4-05-01
Patrick J. Smith, *Supervisor*
Reliability, Failure Analysis and Prevention Group

Section 514 Reliability, Failure Analysis, and Prevention Laboratory
phone: 818/354-9529 fax: 818/393-4559

HYBRID MICROCIRCUIT

DPA TESTING PERFORMED IN ACCORDANCE WITH THE FOLLOWING DOCUMENT(S):

MIL-STD-1580 REV. A SEC 11/MIL-STD 883 METHOD 5009

TEST RESULTS

Test Performed	Specification	Comments	Pass/Fail
External Visual	MIL-STD-883 METHOD 2009		Pass
Hermeticity Test	MIL-STD-883, METHOD 1014		Pass
X-ray	LABORATORY STANDARD		Pass
RGA	MIL-STD-883 METHOD 5009 PARA. 3.6		Pass
Internal Visual	MIL-STD-883 METHOD 2017 COND A		Pass
SEM Analysis 1/	MIL-STD-883 METHOD 2018		**Fail**
Bond pull testing	MIL-STD-883 METHOD 2011		Pass
Die Shear Test	MIL-STD-883 METHOD 2019		Pass

ANALYSIS SUMMARY

Four devices, part number CAR/CPPX1T-A7BR-XX.XXX, were received from Parts Specialists Shri Agarwal and Mike Sandor for Destructive Physical Analysis (DPA) in accordance with SSQ 25000, MIL-STD-1580 REV. A SEC, 11, MIL-STD-883 METHOD 5009 and applicable Military Standards

The metallization on the integrated circuit (Cypress Semiconductor Corp., CY2037 High Accuracy EPROM Programmable PLL) used in the hybrid fails to meet the metallization step coverage requirement. The worst case metallization step coverage thinning was found on metal layer 1 which exhibited approximately 10% step coverage. This condition is cause for rejection per Mil-Std-883, Method 2018.

The devices submitted for DPA were of commercial quality and the materials used in the construction of the oscillators are not recommended for use in high reliability applications. Specifically, the design scheme used to attach the ceramic hybrid substrate to the package header relies on standard Pb-Sn solder which melts at temperatures used to solder the external package leads (~180°C). In addition, each of the circular quartz crystals inside the hybrids were mounted using two springs – diametrically opposed and attached to the crystal edges. Although the springs reduce the mechanical stress on the quartz crystal, the two point mount is generally not as rugged as a three or four point mount and there is the possibility of crystal breakage caused by flexure as a result of mechanical shock.

The dielectric thickness of the ceramic chip capacitors used in the hybrids was measured to be 0.6 mils. The minimum dielectric thickness acceptable for JPL high reliability applications is 0.8 mils.

External Visual Examination

☒ Pass ☐ Fail

Top Markings:	Bottom Markings:
None *See figure1*	None

Comments: 4 pin welded metal package. The parts were arbitrarily serialized (A, B, C and D) for this DPA.

Helium Fine Leak Test

☒ Pass ☐ Fail

Serial #	Test Result	Comments
A	2.2 E -8 Atm cc/sec He	Decayed to 3.0 E –9 Atm cc/sec He after 3 minutes.
B	1.8 E -8 Atm cc/sec He	
C	6.4 E -9 Atm cc/sec He	
D	3.0 E -9 Atm cc/sec He	

Comments: This test was conducted using the variable method in Mil-Std-883, Method 1014. To avoid damaging the package glass seals, helium pressure was reduced to 15 PSIG and the period of pressurization increased to 1,310 minutes. Package volume is approximately 0.59 cc. The rejectable helium fine leak rate for these test conditions is 1.6 E-6 Atm cc/sec He.

phone: 818/354-9529 fax: 818/393-4559

Gross Leak Test

☒ Pass ☐ Fail

Test Result: No bubbles were observed during fluorocarbon immersion bubble gross leak testing.

Comments: None.

Radiographic Exam

☒ Pass ☐ Fail

Test Result: No anomalies were observed during radiographic examination. See Figure 2.

Comments: None.

Residual Gas Analysis

☒ Pass ☐ Fail

Measured Quantities (Percent by volume)

S/N	H_2	He	CH_4	H_2O	N_2	O_2	Ar	CO_2	Other
D	0.1026	0.0000	0.0092	0.0868	99.7430	0.0007	0.0040	0.0448	0.0089*

* Total hydrocarbons and organics.

Comments: The maximum JPL allowable internal package moisture level is 0.5% by volume.

Low Power Internal Visual Exam (10x – 40x)

☒ Pass ☐ Fail

Results Summary: S/Ns A, B and C were decapsulated by grinding away the package weld seams. Debris resulting from the decapsulation procedure was removed using a 20 PSIG gaseous nitrogen jet. No anomalies were found during low power internal visual inspection. See Figures 3 through 6.

Comments: The quartz crystals are attached to the ceramic hybrid substrate using a two point mount consisting of gold plated springs. The springs are soldered onto the ceramic substrate and the quartz crystals are attached to the top of the springs using conductive silver epoxy.

The ceramic chip capacitor is soldered onto the ceramic substrate.

High Power Internal Visual Examination (50x – 1000x)

☒ Pass ☐ Fail

Test Results: The glass-filled epoxy “glop-top” covering the integrated circuit was removed using hot, fuming nitric acid. Detailed visual inspection of the I.C. (Cypress CY2037) did not reveal any anomalies. The dice were attached to the ceramic hybrid substrate using a silver-filled epoxy. See Figures 7 and 8.

Comments: A cross section was performed on the ceramic chip capacitor in S/N C. The dielectric thickness was measured to be 0.6 mils. The minimum JPL acceptable dielectric thickness for ceramic chip capacitors for use in high reliability applications is 0.8 mils.

SEM Metal Examination

☐ Pass ☒ Fail

Layer	Material	Avg. Thickness (microns)	% Step Coverage	Comments
Metal 1	Al	0.9	10	Fails step coverage
Metal 2	Al	1.3	50	

Comments: The observed worst case metal 1 contact via sidewall metallization coverage was 10% of the nominal metallization layer thickness. This condition is cause for rejection per Mil-Std-883, Method 2018. See Figures 9 through 12.

The silicon nitride glassivation layer was removed by CF4/O2 plasma. The aluminum metallization layers are clad in Ti/W refractory metal.

Wirebond Pull Test

☒ Pass ☐ Fail

Wire Material	Wire Diameter	Minimum Required Pull Strength	# Wires Pulled	Average Pull Strength	Minimum Pull Strength	Maximum Pull Strength
Gold	1.3 mils	3.0 grams force	18	13.2 grams force	9.5 grams force	16.4 grams force

Comments: S/N C and a fifth, new device (obtained from Mr. Duc T. Vu post ESD sensitivity testing) were used for this test.

Die Shear Test

☒ Pass ☐ Fail

Die Size (in^2)	**Minimum Required Shear Force**	**Test Shear Force**
25 E-4	1.0 kg	5.0 kg.
28 E -4	1.1 kg	5.0 kg

Comments: Die size is 58 x 43 mils. The equivalent die attachment dimensions for the ceramic chip capacitor is 31 x 92 mils. Both elements withstood the applied shear force without any apparent damage.

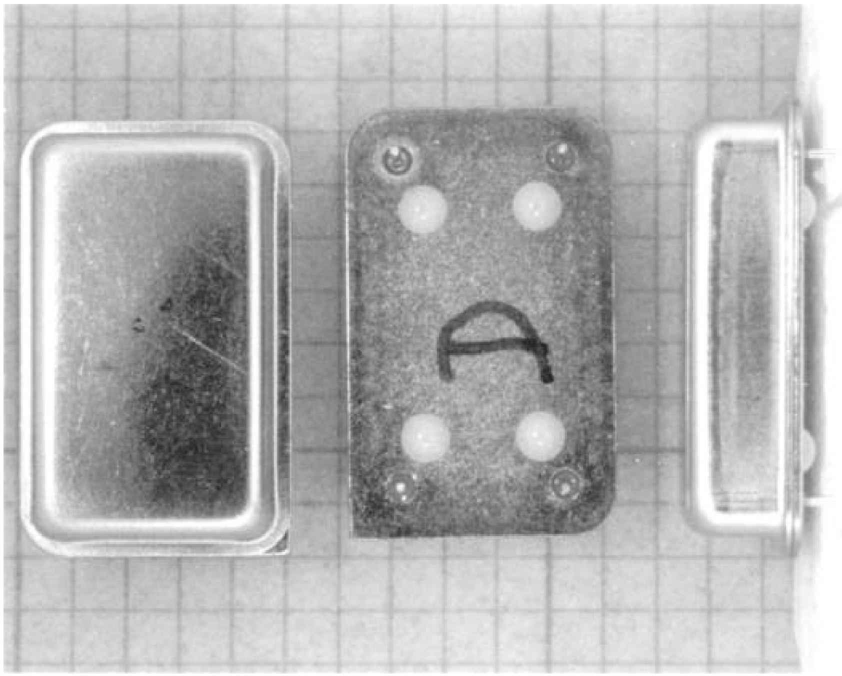


Figure 1. Optical photograph of the parts showing top, bottom and side views of S/Ns A, D and C, respectively.

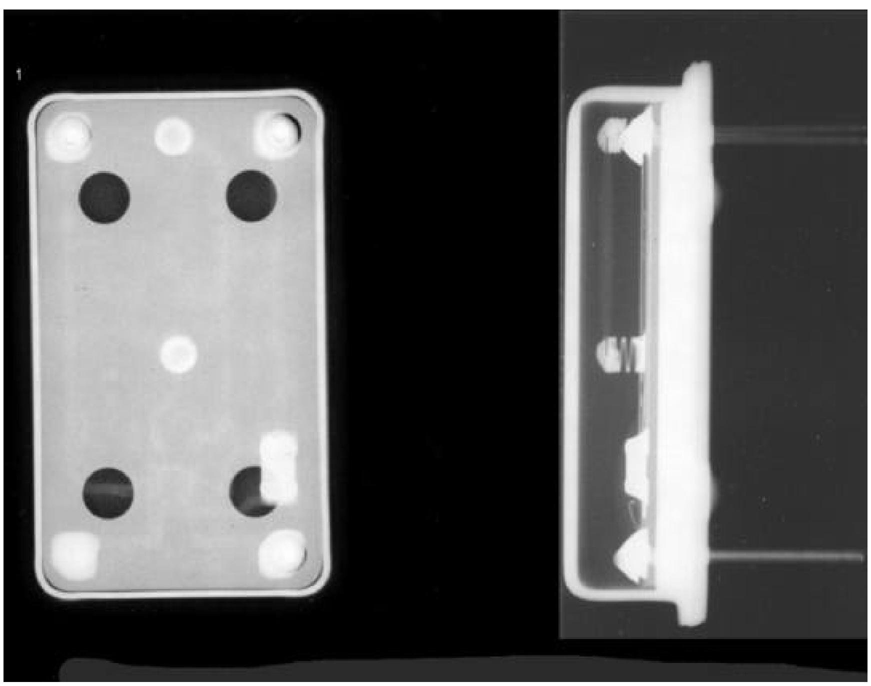


Figure 2. Radiographic image of S/N D. No anomalies were found during radiographic examination of the parts.

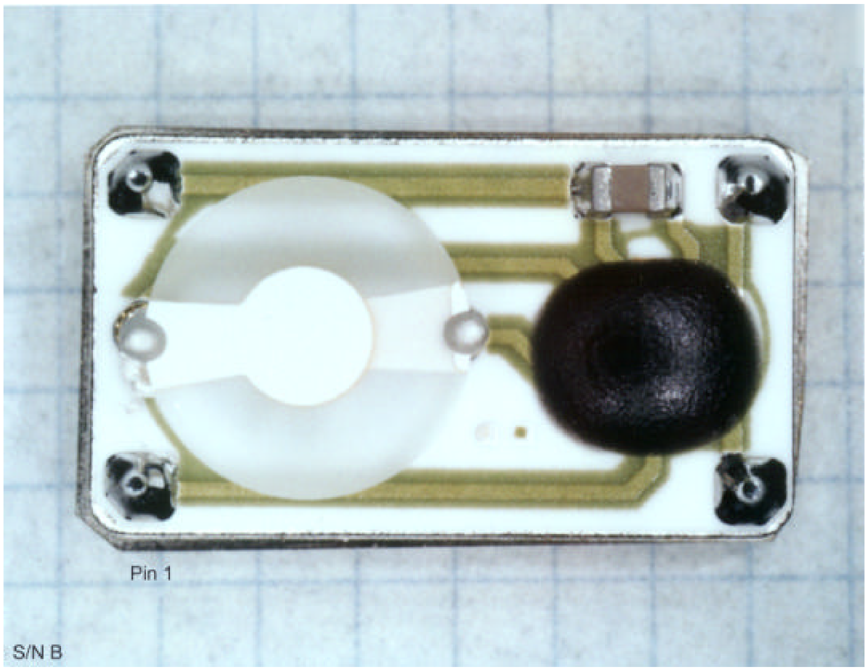


Figure 3. Optical photograph of S/N B showing the internal construction of the hybrid oscillator. The dark, circular feature at the right side of the substrate (below the chip capacitor) is the epoxy "glop-top" covering an integrated circuit.

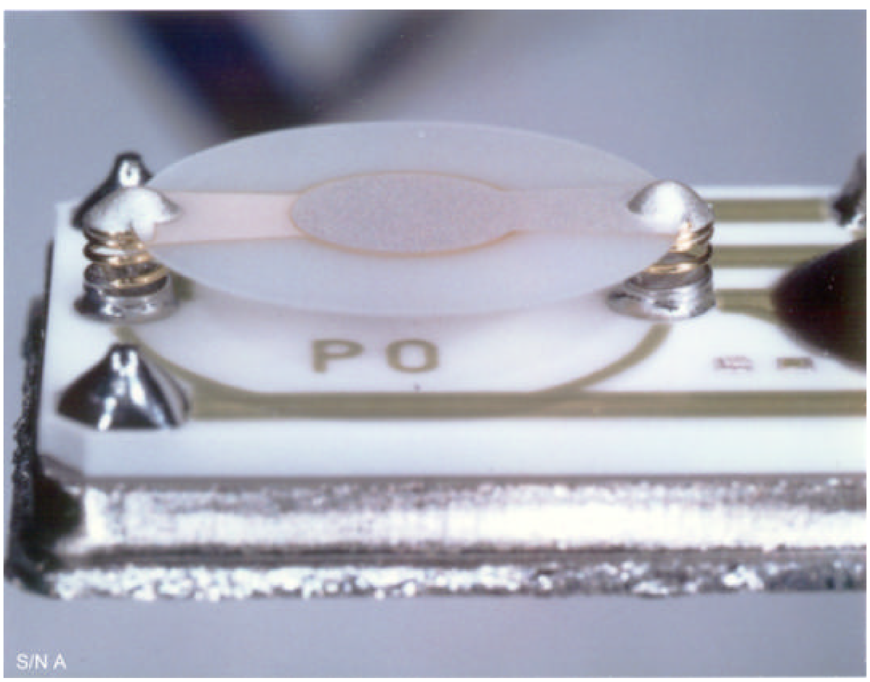


Figure 4. Optical photograph showing the quartz crystal mounts in S/N A. The mounting springs are soldered onto the ceramic substrate and the quartz crystal is bonded to the tops of the springs using silver-filled epoxy.

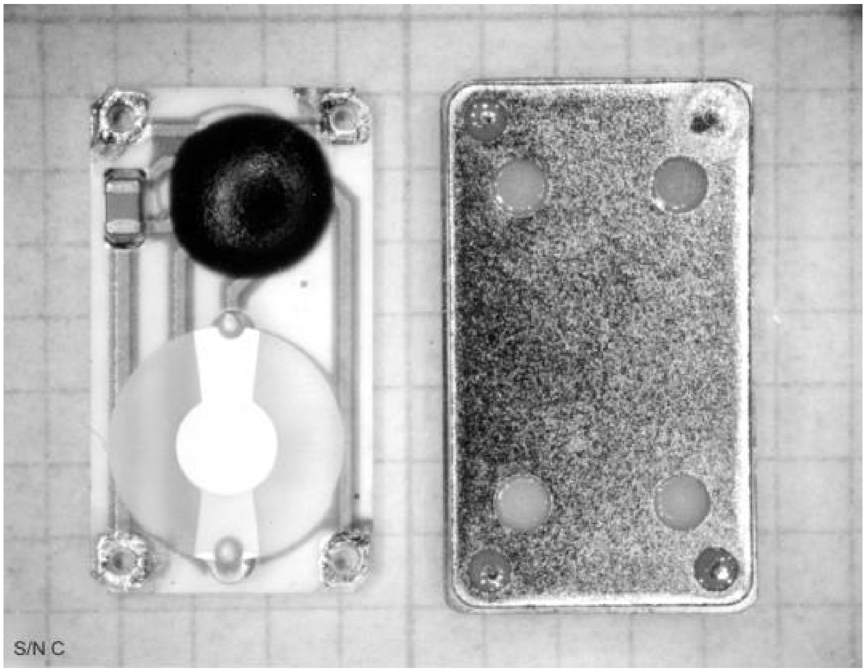


Figure 5. Optical photograph of S/N C after separation of the ceramic substrate from the package header. No adhesive is used to secure the ceramic substrate to the package header. The ceramic substrate was easily removed by reflowing the solder at the electrical pins. Hi-temperature solder is not used in the construction of this hybrid.

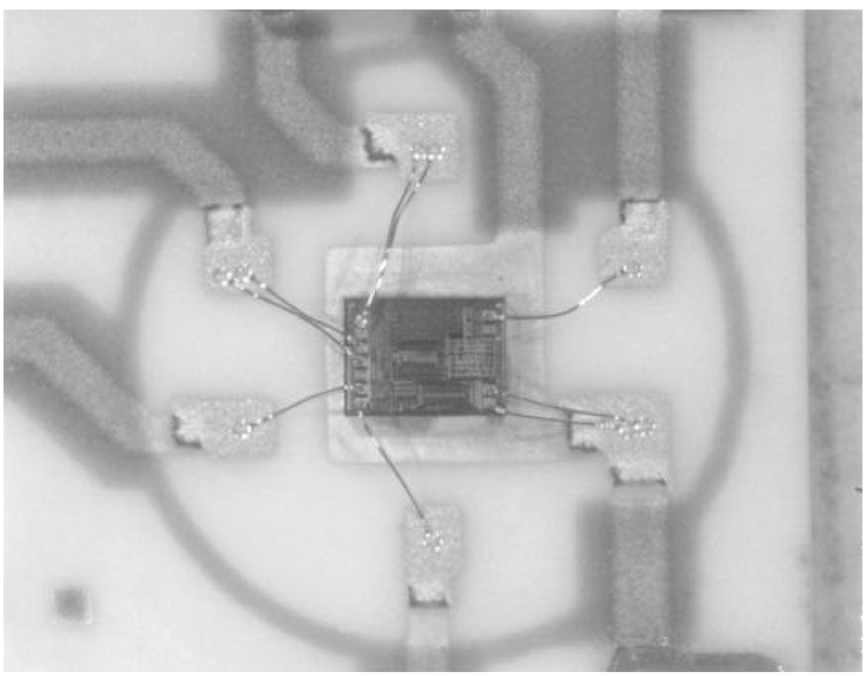


Figure 6. Optical photograph of the integrated circuit in S/N C after removal of the epoxy "glop-top" coating. The lead dress was disturbed during deprocessing.

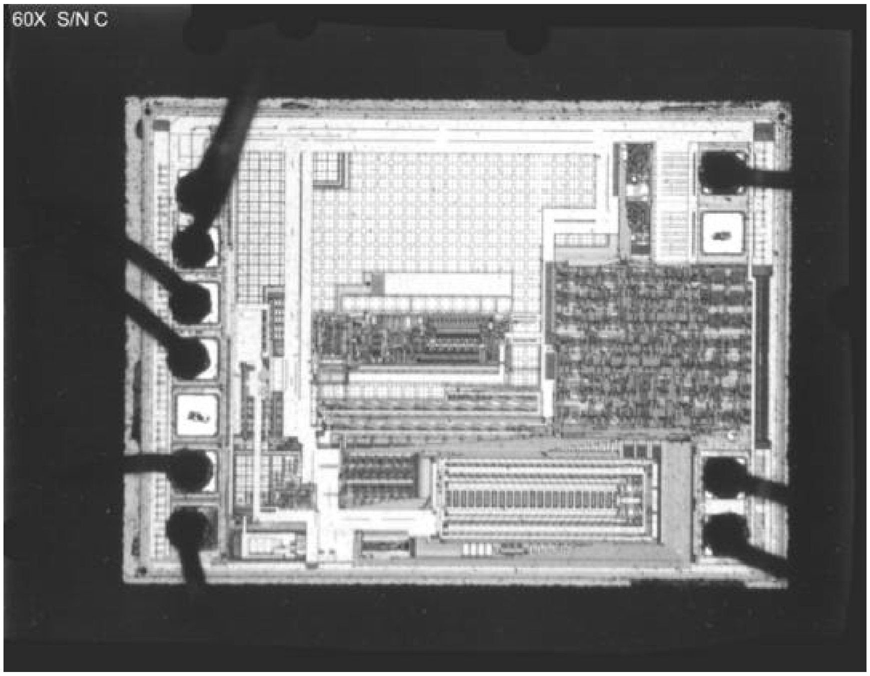


Figure 7. 60X Optical micrograph of the integrated circuit in S/N C.

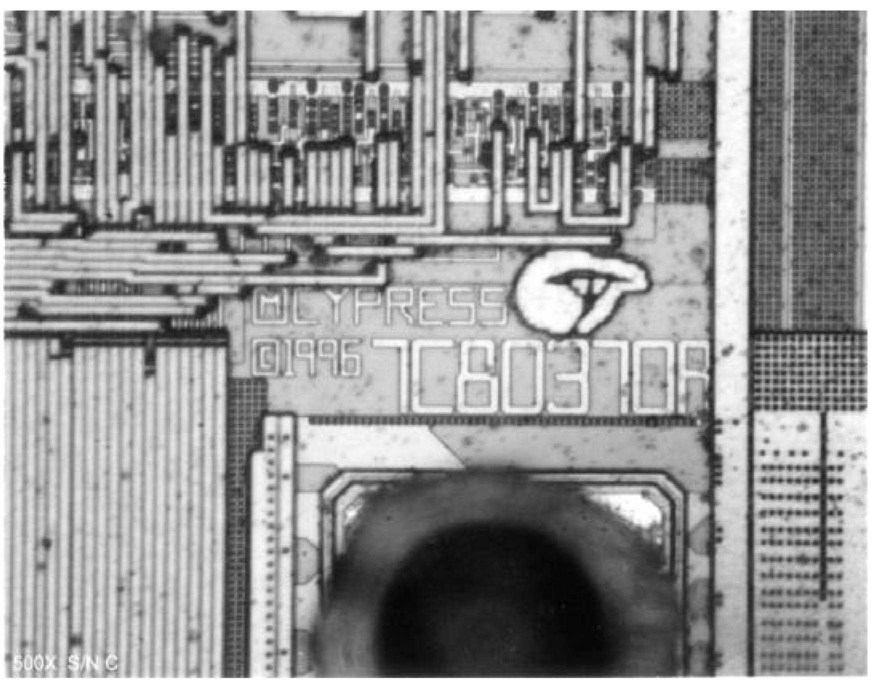


Figure 8. 500X Optical micrograph showing the identification markings on the integrated circuit in S/N C. The device is a High Accuracy EPROM Programmable Phase Lock Loop for Crystal Oscillators made by Cypress Semiconductor Corp.

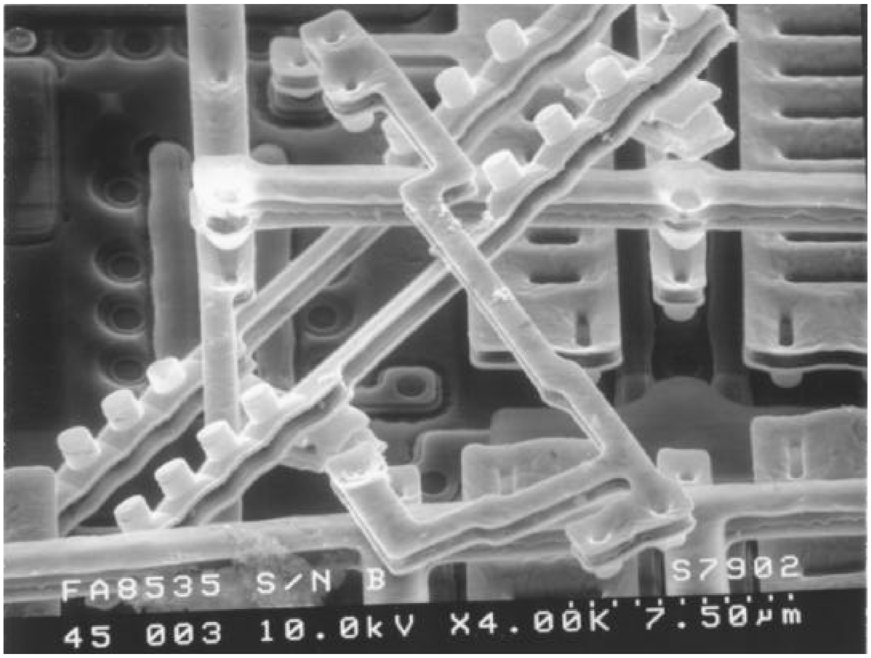


Figure 9. 4,000X SEM micrograph of the metallization on the I.C. in S/N B. The metallization lifted off during wet chemical etching to remove the silicon dioxide interlevel dielectric. Both aluminum metallization layers are clad in Ti/W refractory metal.

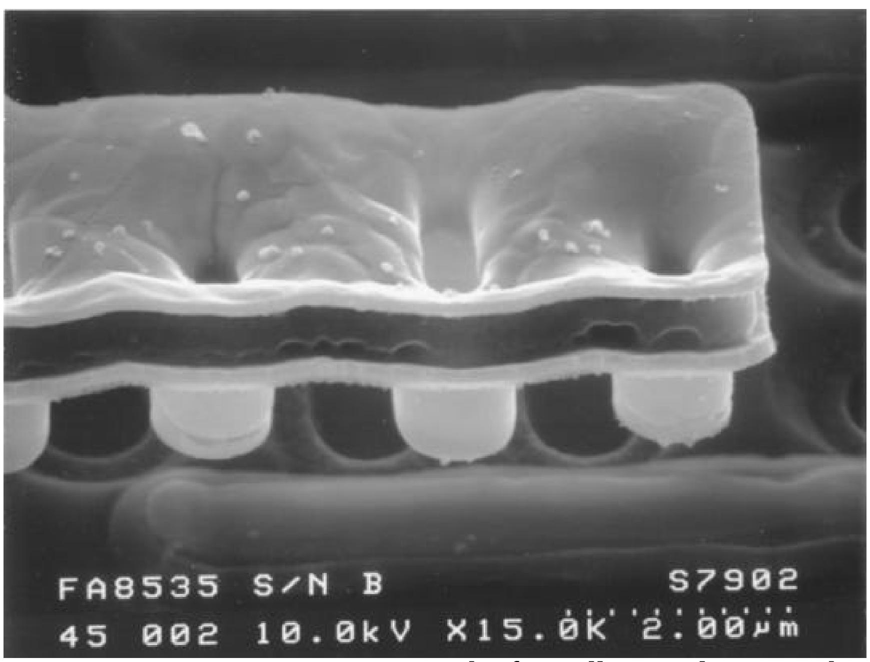


Figure 10. 15,000X SEM micrograph of metallization layer 1. The metal layer is composed of Ti-W clad aluminum.

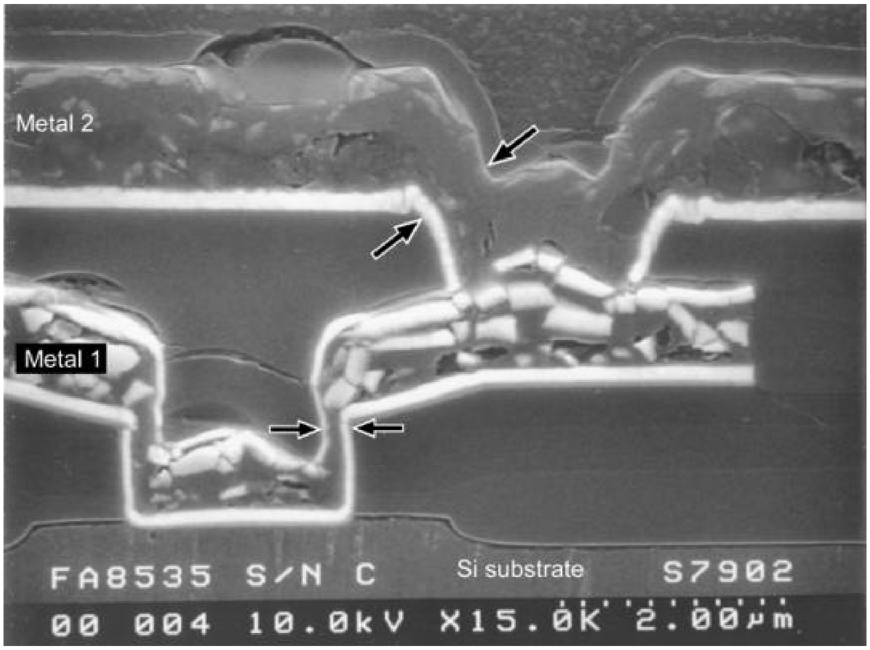


Figure 11. 15,000X SEM micrograph of metallization layer contact vias. The arrows point to metallization layer thinning. Worst case observed metallization thinning for metal 2 was approximately 50%. Worst case metallization thinning for metal 1 was approximately 90% (see Figure 12).

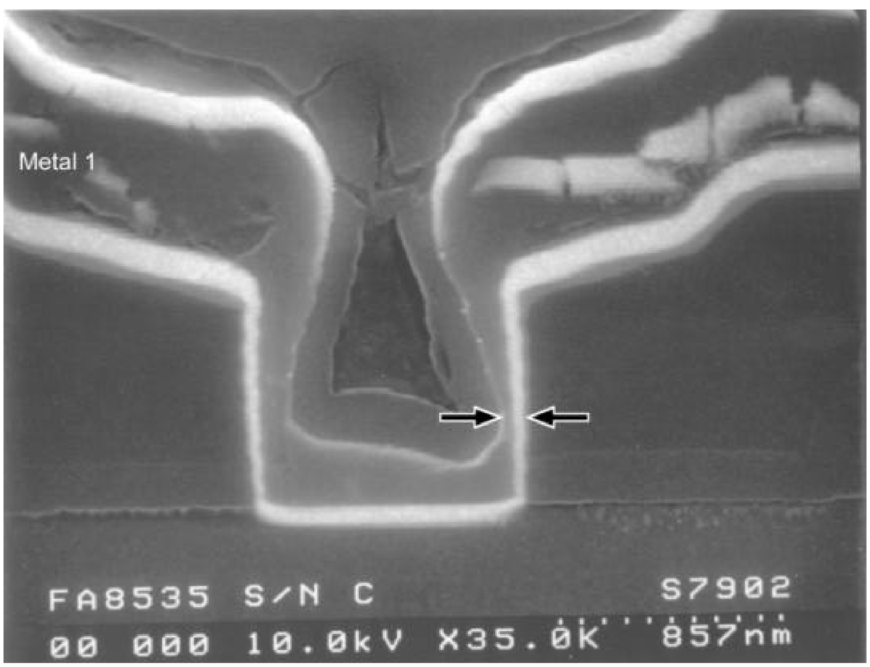


Figure 12. 35,000X SEM micrograph of worst case metallization step thinning observed for metal layer 1. The remaining metal layer thickness at the location between the arrows is approximately 10% of the nominal metal layer thickness. This condition is cause for rejection per Mil-Std-883, Method 2018.

Table I Electrical Performance Characteristics (3.3 Volt)

PARAMETER	SYMBOL	TEST CONDITION	MIN.	MAX.	UNITS
Output Frequency 2/, 3/, 4/	F_O	T_A = 25°C		X ±15ppm	Hz
Frequency/Temp. Stability 5/, 10/, 11/	$\Delta F_O/F_O\|_T$	T_A = -10 to 75°C T_A = -55 to 125°C	-50 -250	+50 +250	ppm ppm
Frequency/Voltage Stability	$\Delta F_O/F_O\|_V$	V_{CC} = 3.3 ±0.3 Vdc		4	ppm
Supply Current 2/	I	V_{CC} = 3.6V		15	mA
Output Voltage, High 2/, 3/	V_{OH}		$0.9V_{CC}$		Vdc
Output Voltage, Low 2/, 3/	V_{OL}			0.1 V_{CC}	Vdc
Duty Cycle (Output Symmetry) 7/, 2/, 3/	t_{LOGIC}/T	T_A = -55 to -10°C T_A = -10 to 75°C T_A = 75 to 125°C	40/60 or better 45/55 or better 40/60 or better		
Output Rise Time 6/, 8/	t_r	Measured from 10 to 90% (V_{OH}-V_{OL})		15	Nsec
Output Fall Time 6/, 8/	t_f	Measured from 10 to 90% (V_{OH}-V_{OL})		15	Nsec
Start Up Time 2/, 9/	t_S	Supply Voltage ramp = 2ms		10	Msec

NOTES:

1/ Unless otherwise specified, T_A = -10 to +75°C, V_{CC} = 3.3 ±0.3 Vdc
2/ Room temperature electrical measurements at pre, interim, and post burn-in.
3/ Temperature extremes electrical measurements.
4/ X = Frequency, in MHz
5/ Using 25°C measurement as reference.
6/ Measured at the 50% level of the output waveform.
7/ The output rise and fall times shall be monotonic (i.e., shall not show reversal of direction).
8/ Start-up time is defined as the time it takes the oscillators output to achieve continuous waveform (begin oscillating) following application of power.

Appendix 7 – Screening Test Flow

Table IA Electrical Performance Characteristics (2.7 Volt)

PARAMETER	SYMBOL	TEST CONDITION	MIN.	MAX.	UNITS
Output Frequency 2/, 3/, 4/	F_O	T_A = 25°C		X ±15ppm	Hz
Frequency/Temp. Stability 5/, 10/, 11/	$\Delta F_O/F_O\|_T$	T_A = -10 to 75°C T_A = -55 to 125°C	-50 -250	+50 +250	ppm ppm
Frequency/Voltage Stability	$\Delta F_O/F_O\|_V$	V_{CC} = 2.7V ± 0.27V		4	Ppm
Supply Current 2/	I	V_{CC} = 2.97V		12	mA
Output Voltage, High 2/, 3/	V_{OH}		$0.9V_{CC}$		Vdc
Output Voltage, Low 2/, 3/	V_{OL}			$0.1\ V_{CC}$	Vdc
Duty Cycle (Output Symmetry) 7/, 2/, 3/	t_{LOGIC}/T	T_A = -55 to -10°C T_A = -10 to 75°C T_A = 75 to 125°C	40/60 or better 45/55 or better 40/60 or better		
Output Rise Time 6/, 8/	t_r	Measured from 10 to 90% (V_{OH}-V_{OL})		15	nsec
Output Fall Time 6/, 8/	t_f	Measured from 10 to 90% (V_{OH}-V_{OL})		15	nsec
Start Up Time 2/, 9/	t_S	Supply Voltage ramp = 2ms		10	msec

NOTES:

1/ Unless otherwise specified, T_A = -10 to +75°C, V_{CC} = 2.7 ±0.27 Vdc
2/ Room temperature electrical measurements at pre, interim, and post burn-in.
3/ Temperature extremes electrical measurements.
4/ X = Frequency, in MHz
5/ Using 25°C measurement as reference.
6/ Measured at the 50% level of the output waveform.
7/ The output rise and fall times shall be monotonic (i.e., shall not show reversal of direction).
8/ Start-up time is defined as the time it takes the oscillators output to achieve continuous waveform (begin oscillating) following application of power.

Table II. Delta Limits at 25°C

TEST	PARAMETER	SYMBOL	DATA LIMITS
Burn-in	Supply Current Ouput Frequency	I F_O	±10% of initial reading 20 ppm
Aging (Group B tests) after 30 days at 70°C	Output Frequency	F_O (GR B)	1.5 ppm
Life test after 2500 hours at 125°C	Output Frequency @ 25°C Supply Current @25°C	F_O (Life) I (Life)	115 ppm from prelife frequency @25°C ±10% of prelife reading @25°C

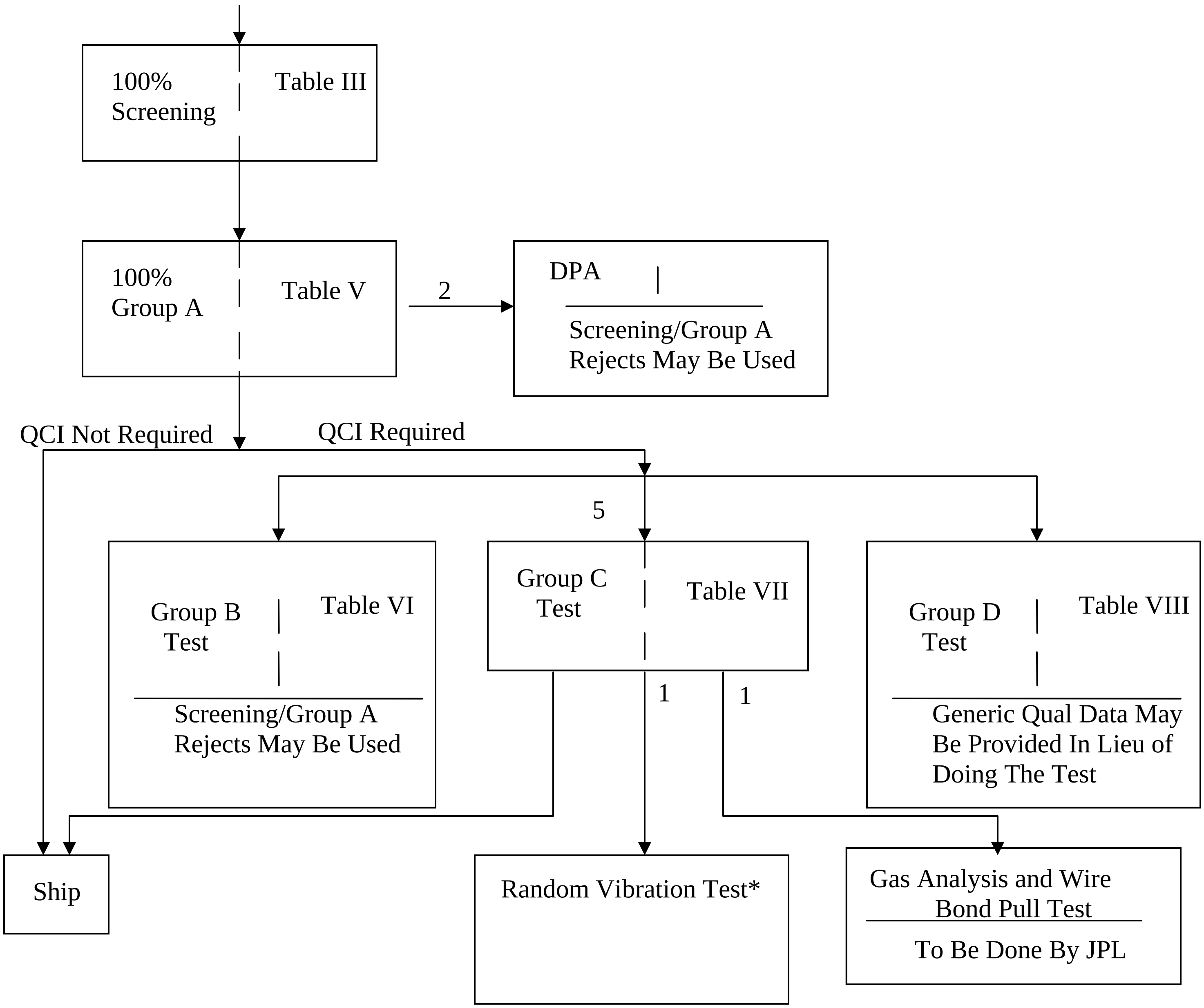
Table III. Screening Test 1/

STEP	TEST DESCRIPTION	STANDARD	METHOD	CONDITION	COMMENTS
1.	Bond Strength 4/	883	5006		
2.	Non-destructive bond pull	883	2023		2.4 grams
3.	Internal Visual	883	2017	A	Class S
4.	Stabilization bake 3/	883	1008	C	48 hrs @ 150°C
5.	Temperature cycling	883	1010	C	10 cycles
7.	Constant acceleration	883	2001	E	Y1 direction only
8.	Random vibration	202	214		
9.	Particle impact noise detection (PIND)	883	2020	A or B	
10.	Serialization				
11.	Pre burn-in electrical	Per Table I			Part shall meet spec over temp range
12.	Burn-in	883	1015	125°C 160 hr	
13.	Interim electrical 5/	Per Table I			25°C only
14.	Burn-in 5/	883	1015	125°C, 160 hr	
15.	Final electrical 5/	Per Table I			Part shall meet spec over temp range
16.	Burn-in drift calculation	Per Table II			Part shall meet delta limits at 25°C
17.	Radiographic inspection	883	2012		
18	Frequency aging	55310	3.6.34.2	70°C, 30 days	
19	Aging drift calculation	Per Table II			Part shall meet spec over temp range, delta limit at 25°C.
20	Seal: fine leak	883	1014		
21.	Seal: gross leak	883	1014		
22.	External visual and 3 pc DPA 2/	883	2009/1580B		

NOTES:

1/ Element evaluation per MIL-PRF-38534 for Class K device.
2/ If homogeneous lot
3/ Done right before sealing.
4/ If the lot is homogeneous (same lot of elements, same wire bonders, manufactured at the same time), pull 22 wires (multiple devices from homogeneous lot are ok).
5/ Delta limits in Table II apply to second 160 hour burn-in.

Table IV. QCI Flow.



* When specified in the detailed specification.

Table V Group A Test 1/

STEP	TEST	CONDITION
1.	Supply current	2/
2.	Initial accuracy at reference temperature	25°C
3.	Frequency – temperature stability	2/
4.	Frequency – voltage tolerance	2/
5.	Output voltages	2/
6.	Duty cycle (output symmetry)	2/
7.	Output rise and fall times	2/
8.	Start-up time	2/

1/ Not applicable if completed via in-line Group A as shown in Table III.
2/ Per Table I, or 1A (as applicable).

Table VI. Group B Test 1/

Sub-Group	Test	MIL-STD-883 Method	MIL-STD-883 Condition	Quantity (Accept No.)
1.	Physical dimensions	2016	-	2(0)
3.	Resistance to solvents	2015	-	4(0)
4.	Internal visual and mechanical	2014	-	1(0)
5.	Bond strength 2/	2011	C or D	2(0)
6.	Die shear strength 3/	2019	-	2(0)
7.	Solderability	2003	4/	1(0)

1/ The screening test delta rejects may be used for Group B:
2/ If bi-metallic bonds are used (Au to Al), 300C pre-conditioning per MIL-PRF-38534 is required.
3/ Die shear is performed on units that have not been exposed to the 300°C preconditioning for the bond strength test.
4/ Solder temperature shall be 245 ±5°C. No pure tin.

Table VII. Group C Test

Sub-Group*	Test	MIL-STD-883 Method	MIL-STD-883 Condition	Quantity (Accept No.)
1	Electrical test 1/			
	End point electricals 1/			
2	Life Test 2/	1005	2500 hours at 125 °C	5(0)
	End point electricals 3/			

1/ Per Table I, or 1A (as applicable).
2/ Same five pieces as used for subgroup 1 testing shall be used for the life test.
3/ Per Table I. Delta criteria shall be per Table II.

Table VIII. Group D Test 1/

Test	MIL-STD-883 Method	MIL-STD-883 Condition	Quantity (Accept No.)
Thermal Shock	1011	C	5(0)
Stabilization bake	1008	1 hr at 150°C	5(0)
Lead Integrity	2004	B2 (lead fatigue)	1(0)
Seal:	1014		5(0)
Fine leak		A	
Gross leak		C	

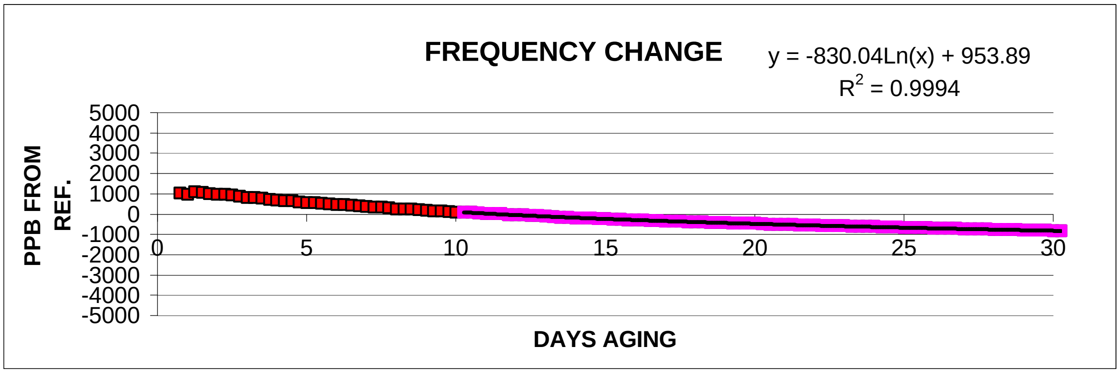
1/ Package Qualification (Group D) may be completed annually.

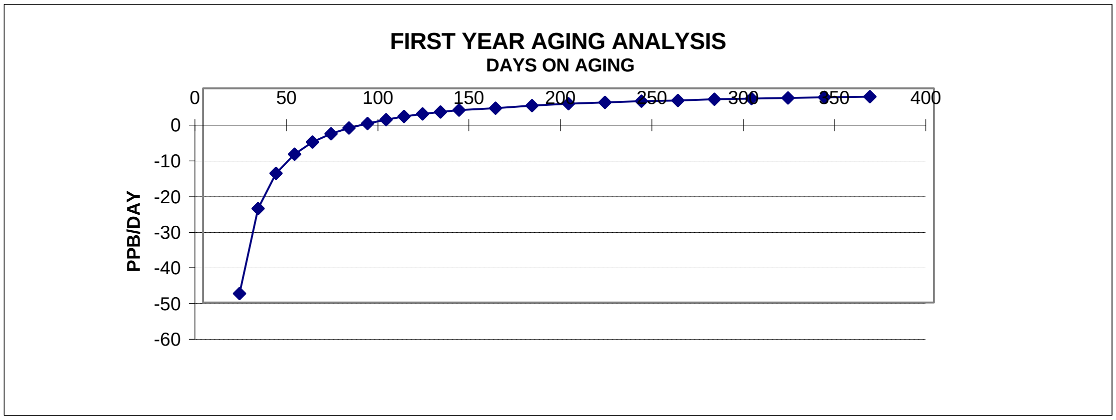
Appendix 8 – Life Testing of FIPO

Appendix 9 – Manufacturer's Aging Data

PC100 OUTPUT DATA

Serial #: Start-DT: 08/15/03 - 12:25
Name: CARDINAL COMP.
Description: NON AGED CPP OSC. AGED AT 70C, SN 10A
Xtal Freq-Mhz: 50.000000 GT: 10 Secs
Reference-DT: 08/15/03 - 18:13 Reference Freq-Mhz: 50.00012634333





AGING ANALYSIS

AGING RATE PER DAY

10 DAYS	-95.735 PPB/DAY	60DAYS	-15.133 PPB/DAY
20 DAYS	-57.534 PPB/DAY	90 DAYS	-9.776 PPB/DAY
30 DAYS	-33.655 PPB/DAY	180 DAYS	-4.888 PPB/DAY
		270 DAYS	-3.076 PPB/DAY

AGING TOTALS IN PARTS PER MILLION (PPM):

1000 HRS	ACTUAL TOTAL	10 YRS.	-5.85 PROJECTED TOTAL
1ST YR.	-3.94 PROJECTED TOTAL	15 YRS.	-6.19 PROJECTED TOTAL
		20 YRS.	-6.43 PROJECTED TOTAL

PC100 OUTPUT DATA

Serial #: Start-DT: 08/15/03 - 12:25

Name: CARDINAL COMP.

Description: NON AGED CPP OSC. AGED AT 70C, SN 10A

Xtal Freq-Mhz: 50.000000 GT: 10 Secs

Reference-DT: 08/15/03 - 18:13 Reference Freq-Mhz: 50.00012634333

Read#	Date-Time	Freq-Mhz	E-Time	Dev-ppb
1	08/16/03-00:12	50.00012488	0.49	-29.36
2	08/16/03-06:12	50.00012284	0.74	-70.14
3	08/16/03-12:11	50.00016554	0.99	34.01
4	08/16/03-18:12	50.00016389	1.24	0.88
5	08/17/03-00:12	50.00016117	1.49	-53.5
6	08/17/03-06:12	50.00016024	1.74	-72.08
7	08/17/03-12:12	50.00015913	1.99	-94.29
8	08/17/03-18:12	50.00015847	2.24	-107.5
9	08/18/03-00:12	50.00015525	2.49	-171.86
10	08/18/03-06:12	50.00015273	2.74	-222.17
11	08/18/03-12:12	50.00015163	2.99	-244.34
12	08/18/03-18:12	50.00015117	3.24	-253.48
13	08/19/03-00:12	50.00014799	3.49	-317.14
14	08/19/03-06:12	50.00014608	3.74	-355.36
15	08/19/03-12:12	50.00014476	3.99	-381.73
16	08/19/03-18:12	50.00014424	4.24	-392.08
17	08/20/03-00:12	50.0001416	4.49	-444.77
18	08/20/03-06:12	50.00013971	4.74	-482.57
19	08/20/03-12:11	50.0001388	4.99	-500.83
20	08/20/03-18:12	50.00013851	5.24	-506.74
21	08/21/03-00:12	50.00013612	5.49	-554.5
22	08/21/03-06:12	50.00013445	5.74	-587.89
23	08/21/03-12:11	50.00013404	5.99	-596.05
24	08/21/03-18:12	50.00013366	6.24	-603.71
25	08/22/03-00:11	50.00013108	6.49	-655.19
26	08/22/03-06:12	50.00012927	6.74	-691.37
27	08/22/03-12:11	50.00012883	6.99	-700.29
28	08/22/03-18:12	50.00012814	7.24	-713.98
29	08/23/03-00:11	50.00012636	7.49	-749.7
30	08/23/03-06:12	50.00012433	7.74	-790.33
31	08/23/03-12:11	50.00012374	7.99	-802
32	08/23/03-18:12	50.00012364	8.24	-803.99
33	08/24/03-00:11	50.00012138	8.49	-849.19
34	08/24/03-06:12	50.00012004	8.74	-876.07
35	08/24/03-12:11	50.00011901	8.99	-896.64
36	08/24/03-18:12	50.00011958	9.24	-885.24
37	08/25/03-00:12	50.00011732	9.49	-930.49
38	08/25/03-06:12	50.00011605	9.74	-955.81
39	08/25/03-12:12	50.00011536	9.99	-969.65
40	08/25/03-18:12	50.00011628	10.24	-951.24
41	08/26/03-00:12	50.00011446	10.49	-987.63
42	08/26/03-06:12	50.00011287	10.74	-1019.37

PC100 OUTPUT DATA

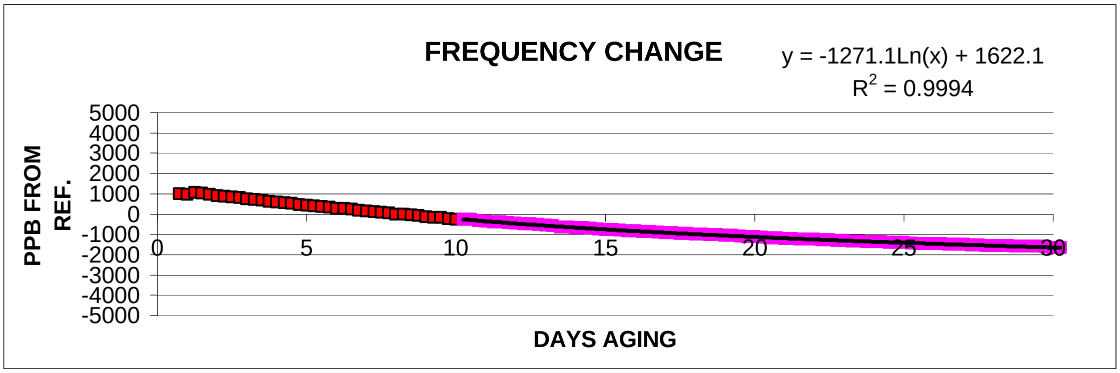
43	08/26/03-12:12	50.0001125	10.99	-1026.91
44	08/26/03-18:11	50.00011191	11.24	-1038.67
45	08/27/03-00:12	50.00011021	11.49	-1072.71
46	08/27/03-06:11	50.00010906	11.74	-1095.66
47	08/27/03-12:12	50.00010869	11.99	-1103.05
48	08/27/03-18:11	50.00010852	12.24	-1106.51
49	08/28/03-00:12	50.00010707	12.49	-1135.52
50	08/28/03-06:11	50.00010607	12.74	-1155.43
51	08/28/03-12:12	50.00006732	12.99	-1180.46
52	08/28/03-18:11	50.00006628	13.24	-1201.35
53	08/29/03-00:12	50.00006556	13.49	-1215.63
54	08/29/03-06:11	50.00006475	13.74	-1231.86
55	08/29/03-12:12	50.00006405	13.99	-1245.86
56	08/29/03-18:11	50.00006334	14.24	-1260.1
57	08/30/03-00:12	50.0000625	14.49	-1276.79
58	08/30/03-06:11	50.00006185	14.74	-1289.86
59	08/30/03-12:12	50.00006111	14.99	-1304.75
60	08/30/03-18:12	50.00006053	15.24	-1316.28
61	08/31/03-00:12	50.00005984	15.49	-1329.97
62	08/31/03-06:12	50.00005926	15.74	-1341.65
63	08/31/03-12:12	50.00005885	15.99	-1349.94
64	08/31/03-18:12	50.0000581	16.24	-1364.93
65	09/01/03-00:12	50.00005752	16.49	-1376.48
66	09/01/03-06:12	50.0000569	16.74	-1388.95
67	09/01/03-12:12	50.00005653	16.99	-1396.28
68	09/01/03-18:12	50.0000558	17.24	-1410.91
69	09/02/03-00:12	50.00005531	17.49	-1420.64
70	09/02/03-06:12	50.00005482	17.74	-1430.44
71	09/02/03-12:12	50.00005422	17.99	-1442.51
72	09/02/03-18:12	50.00005372	18.24	-1452.46
73	09/03/03-00:12	50.00005312	18.49	-1464.56
74	09/03/03-06:12	50.00005261	18.74	-1474.67
75	09/03/03-12:12	50.00005216	18.99	-1483.64
76	09/03/03-18:12	50.00005127	19.24	-1501.5
77	09/04/03-00:12	50.00005085	19.49	-1509.92
78	09/04/03-06:12	50.00005065	19.74	-1513.81
79	09/04/03-12:12	50.00004986	19.99	-1529.57
80	09/04/03-18:12	50.00004905	20.24	-1545.79
81	09/05/03-00:11	50.00004871	20.49	-1552.59
82	09/05/03-06:12	50.00004829	20.74	-1561.1
83	09/05/03-12:11	50.00004775	20.99	-1571.77
84	09/05/03-18:12	50.00004726	21.24	-1581.62
85	09/06/03-00:11	50.00004689	21.49	-1589.1
86	09/06/03-06:12	50.00004629	21.74	-1600.98
87	09/06/03-12:11	50.00004587	21.99	-1609.51
88	09/06/03-18:12	50.00004542	22.24	-1618.46
89	09/07/03-00:11	50.00004493	22.49	-1628.28
90	09/07/03-06:12	50.00004448	22.74	-1637.31
91	09/07/03-12:11	50.00004411	22.99	-1644.65
92	09/07/03-18:12	50.00004363	23.24	-1654.32
93	09/08/03-00:12	50.00004326	23.49	-1661.61
94	09/08/03-06:12	50.00004282	23.74	-1670.49
95	09/08/03-12:12	50.00004232	23.99	-1680.43

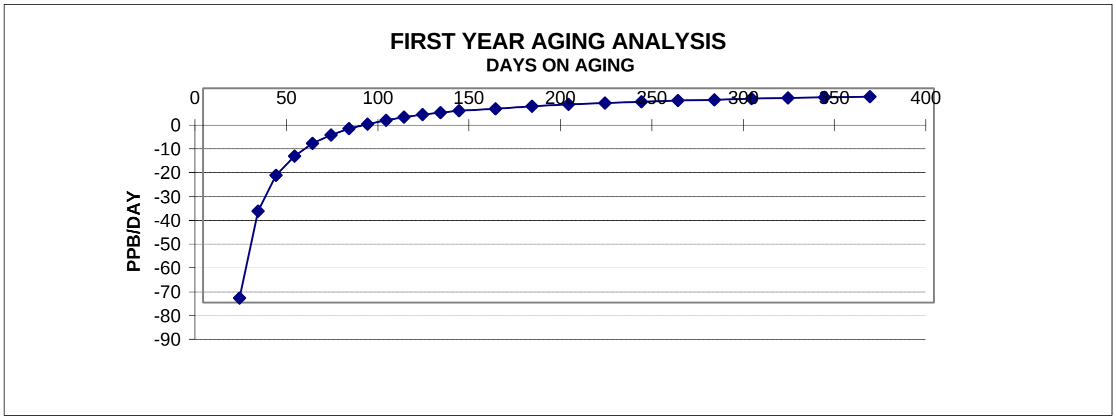
PC100 OUTPUT DATA

96	09/08/03-18:12	50.00004171	24.24	-1692.59
97	09/09/03-00:12	50.00004137	24.49	-1699.46
98	09/09/03-06:12	50.00004104	24.74	-1706.02
99	09/09/03-12:12	50.00004059	24.99	-1715.13
100	09/09/03-18:12	50.00004006	25.24	-1725.74
101	09/10/03-00:12	50.00003973	25.49	-1732.28
102	09/10/03-06:12	50.00003943	25.74	-1738.34
103	09/10/03-12:12	50.00003898	25.99	-1747.27
104	09/10/03-18:12	50.00003833	26.24	-1760.23
105	09/11/03-00:12	50.0000381	26.49	-1764.92
106	09/11/03-06:12	50.00003783	26.74	-1770.23
107	09/11/03-12:12	50.00003746	26.99	-1777.72
108	09/11/03-18:12	50.00003682	27.24	-1790.51
109	09/12/03-00:12	50.00003657	27.49	-1795.41
110	09/12/03-06:12	50.0000362	27.74	-1802.8
111	09/12/03-12:12	50.00003592	27.99	-1808.36
112	09/12/03-18:11	50.00003512	28.24	-1824.45
113	09/13/03-00:12	50.0000349	28.49	-1828.94
114	09/13/03-06:11	50.00003459	28.74	-1835.12
115	09/13/03-12:12	50.00003432	28.99	-1840.52
116	09/13/03-18:11	50.0000339	29.24	-1848.93
117	09/14/03-00:12	50.00003334	29.49	-1860.06
118	09/14/03-06:11	50.00003289	29.74	-1868.97
119	09/14/03-12:12	50.00003251	29.99	-1876.73

PC100 OUTPUT DATA

Serial #: Start-DT: 08/15/03 - 12:25
Name: CARDINAL COMP.
Description: NON AGED CPP OSC. AGED AT 70C, SN 11A
Xtal Freq-Mhz: 50.000000 GT: 10 Secs
Reference-DT: 08/15/03 - 18:04 Reference Freq-Mhz: 50.00006760762





AGING ANALYSIS

AGING RATE PER DAY

10 DAYS	-130.472 PPB/DAY	60DAYS	-23.175 PPB/DAY
20 DAYS	-88.106 PPB/DAY	90 DAYS	-14.971 PPB/DAY
30 DAYS	-51.539 PPB/DAY	180 DAYS	-7.486 PPB/DAY
		270 DAYS	-4.710 PPB/DAY

AGING TOTALS IN PARTS PER MILLION (PPM):

1000 HRS	ACTUAL TOTAL	10 YRS.	-8.80 PROJECTED TOTAL
1ST YR.	-5.88 PROJECTED TOTAL	15 YRS.	-9.32 PROJECTED TOTAL
		20 YRS.	-9.69 PROJECTED TOTAL

PC100 OUTPUT DATA

Serial #: Start-DT: 08/15/03 - 12:25

Name: CARDINAL COMP.

Description: NON AGED CPP OSC. AGED AT 70C, SN 11A

Xtal Freq-Mhz: 50.000000 GT: 10 Secs

Reference-DT: 08/15/03 - 18:04 Reference Freq-Mhz: 50.00006760762

Read#	Date-Time	Freq-Mhz	E-Time	Dev-ppb
1	08/16/03-00:03	50.00006584	0.48	-35.36
2	08/16/03-06:03	50.00006363	0.73	-79.53
3	08/16/03-12:02	50.00010587	0.98	15.27
4	08/16/03-18:03	50.0001041	1.23	-20.21
5	08/17/03-00:03	50.0001007	1.48	-88.25
6	08/17/03-06:03	50.00009838	1.73	-134.6
7	08/17/03-12:03	50.00009708	1.98	-160.47
8	08/17/03-18:03	50.0000953	2.23	-196.24
9	08/18/03-00:03	50.00009265	2.48	-249.08
10	08/18/03-06:03	50.00008996	2.73	-303.04
11	08/18/03-12:03	50.00008867	2.98	-328.68
12	08/18/03-18:03	50.00008718	3.23	-358.52
13	08/19/03-00:03	50.00008403	3.48	-421.49
14	08/19/03-06:03	50.00008205	3.73	-461.18
15	08/19/03-12:03	50.0000805	3.98	-492.12
16	08/19/03-18:03	50.00007921	4.23	-517.94
17	08/20/03-00:03	50.00007633	4.48	-575.52
18	08/20/03-06:03	50.00007403	4.73	-621.54
19	08/20/03-12:02	50.00007298	4.98	-642.49
20	08/20/03-18:03	50.00007117	5.23	-678.74
21	08/21/03-00:03	50.00006886	5.48	-725.01
22	08/21/03-06:03	50.00006679	5.73	-766.37
23	08/21/03-12:02	50.00006598	5.98	-782.47
24	08/21/03-18:03	50.00006464	6.23	-809.36
25	08/22/03-00:02	50.00006168	6.48	-868.51
26	08/22/03-06:03	50.00005962	6.73	-909.78
27	08/22/03-12:02	50.00005879	6.98	-926.31
28	08/22/03-18:03	50.00005744	7.23	-953.29
29	08/23/03-00:02	50.00005532	7.48	-995.79
30	08/23/03-06:03	50.00005295	7.73	-1043.15
31	08/23/03-12:02	50.00005189	7.98	-1064.36
32	08/23/03-18:03	50.0000509	8.23	-1084.09
33	08/24/03-00:02	50.00004836	8.48	-1134.85
34	08/24/03-06:03	50.00004631	8.73	-1175.95
35	08/24/03-12:02	50.00004473	8.98	-1207.5
36	08/24/03-18:03	50.00004429	9.23	-1216.35
37	08/25/03-00:02	50.00004173	9.48	-1267.47
38	08/25/03-06:03	50.00004028	9.73	-1296.53
39	08/25/03-12:02	50.00003941	9.98	-1314.05
40	08/25/03-18:03	50.00003905	10.23	-1321.11
41	08/26/03-00:03	50.00003674	10.48	-1367.4
42	08/26/03-06:03	50.00003515	10.73	-1399.25

PC100 OUTPUT DATA

43	08/26/03-12:03	50.00003411	10.98	-1419.94
44	08/26/03-18:02	50.0000335	11.23	-1432.23
45	08/27/03-00:03	50.00003138	11.48	-1474.56
46	08/27/03-06:02	50.00002969	11.73	-1508.33
47	08/27/03-12:03	50.00002929	11.98	-1516.43
48	08/27/03-18:02	50.00002843	12.23	-1533.57
49	08/28/03-00:03	50.00002632	12.48	-1575.75
50	08/28/03-06:02	50.00002484	12.73	-1605.41
51	08/28/03-12:03	49.99998577	12.98	-1636.85
52	08/28/03-18:02	49.99998396	13.23	-1672.94
53	08/29/03-00:03	49.99998294	13.48	-1693.35
54	08/29/03-06:02	49.99998201	13.73	-1711.93
55	08/29/03-12:03	49.99998124	13.98	-1727.33
56	08/29/03-18:02	49.99997942	14.23	-1763.75
57	08/30/03-00:03	49.99997847	14.48	-1782.81
58	08/30/03-06:02	49.99997747	14.73	-1802.77
59	08/30/03-12:03	49.99997641	14.98	-1823.9
60	08/30/03-18:02	49.9999753	15.23	-1846.22
61	08/31/03-00:03	49.99997424	15.48	-1867.45
62	08/31/03-06:02	49.99997354	15.73	-1881.32
63	08/31/03-12:03	49.99997296	15.98	-1892.95
64	08/31/03-18:02	49.9999714	16.23	-1924.2
65	09/01/03-00:03	49.99997074	16.48	-1937.43
66	09/01/03-06:03	49.99996962	16.73	-1959.84
67	09/01/03-12:03	49.999969	16.98	-1972.06
68	09/01/03-18:03	49.99996781	17.23	-1995.88
69	09/02/03-00:03	49.9999669	17.48	-2014.23
70	09/02/03-06:03	49.99996623	17.73	-2027.58
71	09/02/03-12:03	49.99996528	17.98	-2046.51
72	09/02/03-18:03	49.99996464	18.23	-2059.33
73	09/03/03-00:03	49.99996397	18.48	-2072.67
74	09/03/03-06:03	49.99996292	18.73	-2093.83
75	09/03/03-12:03	49.99996221	18.98	-2108.04
76	09/03/03-18:03	49.99996072	19.23	-2137.75
77	09/04/03-00:03	49.99995986	19.48	-2155.02
78	09/04/03-06:03	49.99995878	19.73	-2176.65
79	09/04/03-12:03	49.99995796	19.98	-2192.86
80	09/04/03-18:03	49.99995687	20.23	-2214.79
81	09/05/03-00:02	49.99995615	20.48	-2229.11
82	09/05/03-06:03	49.99995542	20.73	-2243.8
83	09/05/03-12:02	49.99995501	20.98	-2252.04
84	09/05/03-18:03	49.99995399	21.23	-2272.37
85	09/06/03-00:02	49.99995325	21.48	-2287.22
86	09/06/03-06:03	49.99995265	21.73	-2299.13
87	09/06/03-12:02	49.99995213	21.98	-2309.54
88	09/06/03-18:03	49.99995094	22.23	-2333.28
89	09/07/03-00:02	49.9999506	22.48	-2340.11
90	09/07/03-06:03	49.99994969	22.73	-2358.32
91	09/07/03-12:02	49.99994922	22.98	-2367.85
92	09/07/03-18:03	49.99994843	23.23	-2383.52
93	09/08/03-00:02	49.99994763	23.48	-2399.54
94	09/08/03-06:03	49.99994687	23.73	-2414.7
95	09/08/03-12:02	49.99994678	23.98	-2416.46

PC100 OUTPUT DATA

96	09/08/03-18:03	49.99994565	24.23	-2439.15
97	09/09/03-00:03	49.99994494	24.48	-2453.32
98	09/09/03-06:03	49.99994472	24.73	-2457.67
99	09/09/03-12:03	49.99994383	24.98	-2475.56
100	09/09/03-18:03	49.99994296	25.23	-2492.88
101	09/10/03-00:03	49.9999426	25.48	-2500.09
102	09/10/03-06:03	49.99994231	25.73	-2505.92
103	09/10/03-12:03	49.99994213	25.98	-2509.47
104	09/10/03-18:03	49.99994089	26.23	-2534.27
105	09/11/03-00:03	49.99994053	26.48	-2541.61
106	09/11/03-06:03	49.99993993	26.73	-2553.65
107	09/11/03-12:03	49.99993971	26.98	-2558.04
108	09/11/03-18:03	49.99993845	27.23	-2583.09
109	09/12/03-00:03	49.99993822	27.48	-2587.7
110	09/12/03-06:03	49.99993782	27.73	-2595.73
111	09/12/03-12:03	49.99993754	27.98	-2601.31
112	09/12/03-18:02	49.99993678	28.23	-2616.62
113	09/13/03-00:03	49.99993616	28.48	-2628.87
114	09/13/03-06:02	49.99993608	28.73	-2630.52
115	09/13/03-12:03	49.99993561	28.98	-2639.89
116	09/13/03-18:02	49.99993527	29.23	-2646.83
117	09/14/03-00:03	49.99993432	29.48	-2665.71
118	09/14/03-06:02	49.99993349	29.73	-2682.32
119	09/14/03-12:03	49.9999333	29.98	-2686.25

Appendix 10 – Roadmap

Crystal Oscillator Roadmap for NASA Space Flight

"Galileo"

Bulky, Fixed Frequency
High Power Hybrid
Oscillators
$3000/52 weeks ARO

"Cassini"

Fixed frequency, low
power Hybrid Oscillators
$1500/16 weeks ARO

"LAMP"

Programmable ultra
low power Oscillators
$100/2 weeks ARO

"The Next
Generation S/C"

Reconfigurable
on-the-fly
Oscillators

80's 90's 2003 Future

S. Agarwal
1/29/03

Appendix 11 – Construction Analysis of MIPO

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

PCA

Parts Construction Analysis Report

Customer/Project:	NEPP
FA Log Number:	9146
Date:	2/24/2004
Part Type:	Re-Configurable 6 Output PECL Oscillator
Part Number:	CCE6RE Series
Manufacturer:	Cardinal Components, Inc.
Lot Date Code:	n/a
JPL Trace#:	None
Quantity:	1
Serial Numbers:	None

☒ **MEETS REQUIREMENTS**

☐ **DOES NOT MEET REQUIREMENTS**

Comments: No gross deficiencies were found during the course of this analysis. However, several tests and examinations could not be performed due to the limited sample size (1 part).

The following tests and examinations will be performed on additional samples in order to get a more complete construction analysis data set:

1. Determination of solder type and melting temperature used on the hybrid substrate.
2. Cross section of the hybrid printed circuit board to examine the plating quality in the vias.
3. Residual Gas Analysis of the hybrid and of the separate quartz crystal case.
4. Additional SEM metallization examination of the oscillator control I.C.

The results of the additional tests and examinations will be published in an addendum to this report.

Prepared by: J. Ok Date: 3/17/04

J. Okuno, *Failure Analyst*

Approved by: P J Smith Date: 3/17/04

Dr. Patrick J. Smith, *Supervisor*

Reliability, Failure Analysis and Prevention Group

JPL Section 514 Reliability, Failure Analysis, and Prevention Laboratory
phone: 818/354-9529 fax: 818/393-4559

MICROCIRCUIT

PCA TESTING PERFORMED IN ACCORDANCE WITH THE FOLLOWING DOCUMENT(S):

The applicable methods of MIL-STD-883E and SSQ-25000B

TEST RESULTS

Test Performed	Specification	Comments	Pass/Fail
External Visual Exam	MIL-STD-883 METHOD 2009		Pass
Hermeticity Test	MIL-STD-883 METHOD 1014	Waived by JPL parts specialist.	n/a
X-ray Exam	LABORATORY STANDARD		Pass
P.I.N.D. Test	MIL-STD-883, METHOD 2020	Test Condition A	Pass
Residual Gas Analysis	MIL-STD-883 METHOD 5009 PARA. 3.6	Not performed due to limited sample size.	n/a
Internal Visual Exam	MIL-STD-883 METHOD 2017 COND A		Pass
SEM Analysis	MIL-STD-883 METHOD 2018		Pass
Bond Pull Test	MIL-STD-883 METHOD 2011	Not performed due to limited sample size.	n/a
Die Shear Test	SSQ-25000B, Appendix G-2	Passive components only.	Pass
Capacitor Cross Section	EIA-469C	0.0003 inch dielectric thickness	Review

ANALYSIS SUMMARY

One sample lot consisting of a single randomly selected device, part number CCE6RE, was received from JPL parts specialist Shri Agarwal for a Parts Construction Analysis (PCA).

No gross deficiencies were found during the course of this analysis. However, several tests and examinations could not be performed due to the limited sample size (1 part).

The following tests and examinations will be performed on additional samples in order to get a more complete construction analysis data set:

1. Determination of solder type and melting temperature used on the hybrid substrate.
2. Cross section of the hybrid printed circuit board to examine the plating quality in the vias.
3. Residual Gas Analysis of the hybrid and of the separate quartz crystal case.
4. Additional SEM metallization examination of the oscillator control I.C.

The results of the additional tests and examinations will be published in an addendum to this report.

External Visual Examination

☒ Pass ☐ Fail

Top Markings:	Bottom Markings:
Cardinal CCE6RE CJ0002P *In addition, a dot was marked in one corner of the lid indicating the location of pin 1.*	*A single black ink dot was observed on the bottom surface of the package.*

Comments: See Figure 1.

He Fine Leak Test

☐ Pass ☐ Fail ☒ Not Performed

Comments: The helium fine leak test was waived by the JPL parts specialist due to the unavailability of the test equipment at the time of this analysis.

Gross Leak Test

☐ Pass ☐ Fail ☒ Not Performed

Comments: The bubble gross leak test was waived by the JPL parts specialist.

Radiographic Exam

☒ Pass ☐ Fail

Test Result: Passed.

Comments: No anomalies were observed during radiographic examination of the hybrid. See Figures 2 and 3.

Particle Impact Noise Detection (PIND) Test

☒ Pass ☐ Fail

Test Result: Passed

Comments: The device was tested per Mil-Std-883E, Method 2020.7, Test Condition A. The internal package cavity height was measured at ~80 mils from the lower surface of the package lid to the top surface of the hybrid substrate. PIND test parameters were 20Gs acceleration at 80 Hz.

Residual Gas Analysis

☐ Pass ☐ Fail ☒ Not Performed

Comments: Residual package gas analysis was waived by the JPL parts specialist due to limited sample size.

Low Power Internal Visual Exam (10x – 40x)

☒ Pass ☐ Fail

Results Summary: Passed.

Comments: The hybrid package lid was detached from the header by using a file to remove the weld seam.

The quartz crystal was found to be enclosed in a separate, sealed package that was mounted onto the hybrid printed circuit board (PCB) substrate. In addition, the lid of the quartz crystal case was marked with the following identification: C12.0 030533. See Figure 4.

The quartz crystal case was removed from the hybrid PCB substrate and subjected to fine and gross leak testing. The quartz crystal case passed both helium fine leak and bubble gross leak tests.

The quartz crystal case was opened by grinding away the weld bead of the lid seal. No deficiencies were noted during examination of the quartz crystal. See Figures 5 and 6.

The oscillator control integrated circuit was found to be directly mounted to the PCB and covered with an epoxy "glop top" encapsulant. The integrated circuit was extricated from the encapsulant using hot fuming nitric acid. See Figures 7 and 8.

High Power Internal Visual Examination (50x – 1000x)

☒ Pass ☐ Fail

Test Results: Passed.

Comments: No defects were observed during high power visual examination of the oscillator control integrated circuit. See Figures 9 and 10.

SEM Metal Examination

☒ Pass* ☐ Fail

Layer	Material	Avg. Thickness (microns)	% Step Coverage	Comments
Glassivation	SiN	0.5	n/a	
Metal-3	Aluminum	0.9	n/a	fully planarized
Metal-2	Aluminum	0.7	n/a	fully planarized
Metal-1	Ti-N (?)	0.2	n/a	fully planarized

Comments: Cross section examination was selected as the best method to obtain information to gauge metallization quality (primarily because of the small (<1 micron) feature size of the devices on the die). No anomalies were observed during cross section examination.

See Figures 11 thru 13.

*Additional samples of the die will be subjected to SEM metallization examination. These additional samples will be deprocessed for examination using traditional techniques (e.g., plasma etch) to remove the dielectric layers. The results will be published in an addendum to this report.

Wire Bond Pull Test

☐ Pass ☐ Fail ☒ Not Performed

Wire Material	Wire Diameter	Minimum Required Pull Strength	# Wires Pulled	Average Pull Strength	Minimum Pull Strength	Maximum Pull Strength
Au	1.0 mil	2.5 grams force	0	n/a	n/a	n/a

Comments: The wire bonding pads on the hybrid PCB substrate were consumed during the procedure used to extricate the oscillator control integrated circuit from the epoxy "glop top" encapsulant. Although the gold ball bonds on the die remained attached to their respective wire bonding pads, pull testing could not be performed because the substrate bonds were detached. However, during preparation for die cross section examination, the wires were hand plucked from the die using a pair of tweezers. All of the wires separated at the neckdown point at the egress of the gold ball bonds with a discernable (although unquantified) force.

Die Shear Test

☒ Pass ☐ Fail

Comments: The passive components (surface mount resistors and capacitors) and the quartz crystal case were subjected to die shear testing.

All of the tested components were found to have an adequate shear strength.

The oscillator control integrated circuit could not be shear tested because of damage to the attachment (and hybrid PCB substrate) during removal of the epoxy “glop top” covering the die.

The detailed test results are available in the JPL Failure Analysis Group files.

Capacitor Cross Section Exam

☐ Pass ☐ Fail ☒ Requires Review

Capacitor #	*Dielectric Thickness (inches)*	*End Margin Length (inches)*		*Cover Plate Thickness (inches)*	
		Margin 1	*Margin 2*	*Plate 1*	*Plate 2*
A	**0.0003**	0.003	0.008	0.003	n/a
B	**0.0003**	0.005	0.007	0.003	n/a
C	**0.0003**	0.004	0.007	0.003	n/a

Comments: The measured dielectric thicknesses do not meet the requirements of specification EIA-469C (the minimum dielectric thickness required for capacitors rated for <25V is 0.0008 inches). However, the elements used in the construction of this commercial quality hybrid may not have been procured to this specification.

In discussions with the JPL parts specialist (Mr. Shri Agarwal), the manufacturer has stated that military grade capacitors could be procured and installed on the hybrid substrate without difficulty.

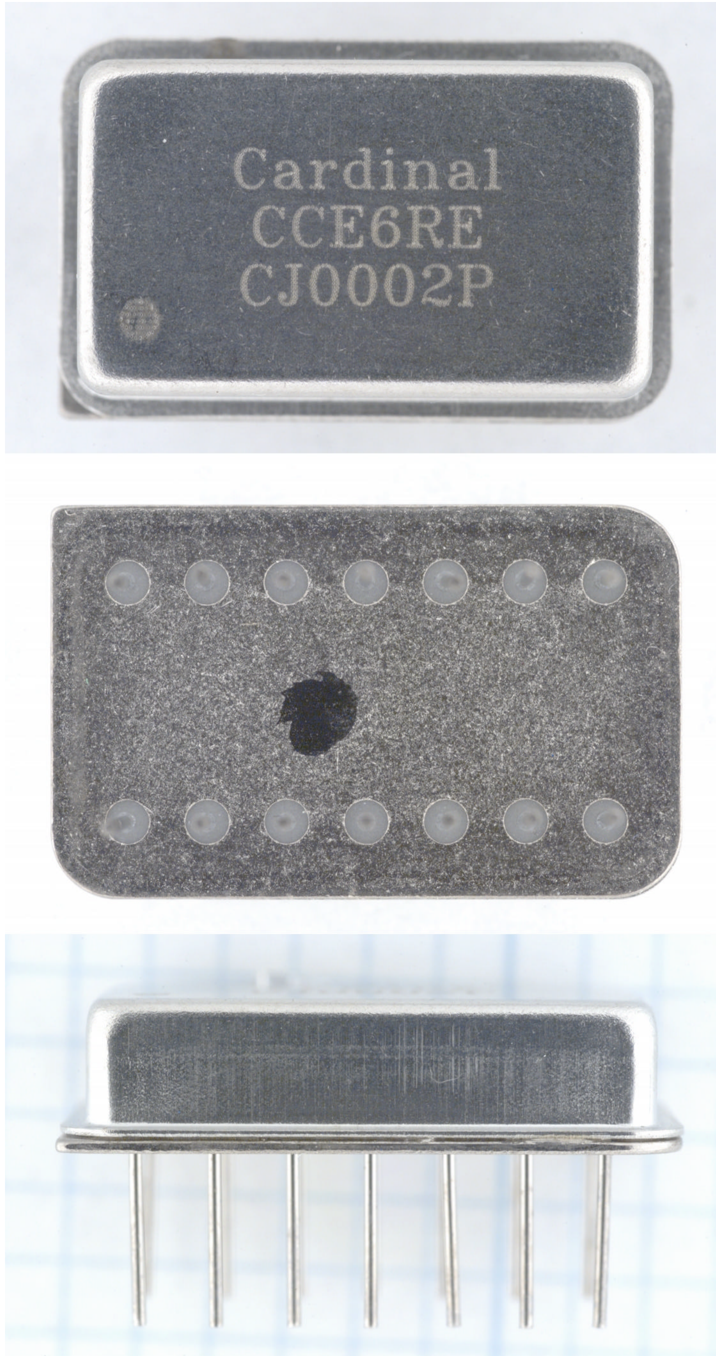


Figure 1. Optical photographs showing the top, bottom and side views of the device. The background grid in the side view photo is composed of 0.1 inch squares.

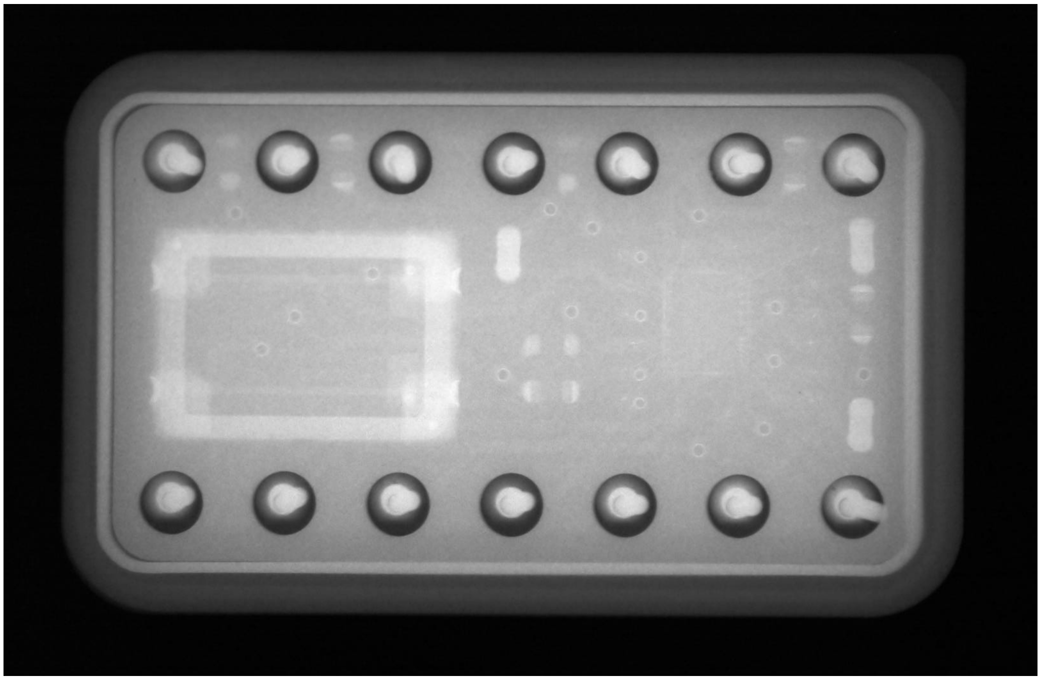


Figure 2. Top view radiographic image of the hybrid. The large rectangle on the left side of the image is the quartz crystal in a separate case within the hybrid package cavity.

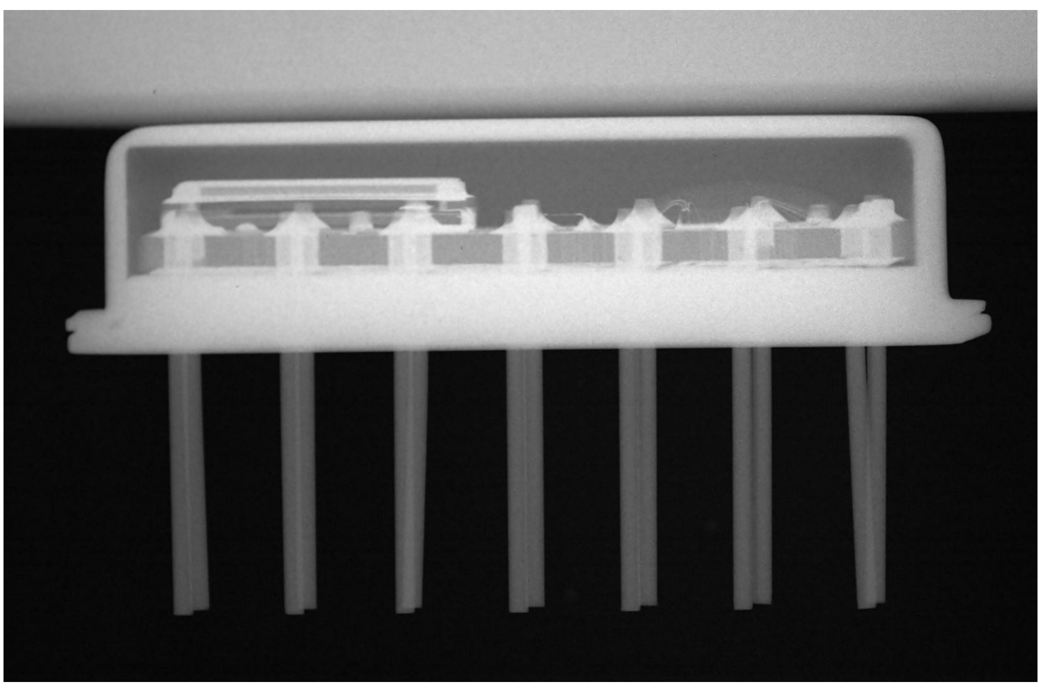


Figure 3. Side view radiographic image of the hybrid. Note the rectangular quartz crystal case attached on the left side of the hybrid substrate.

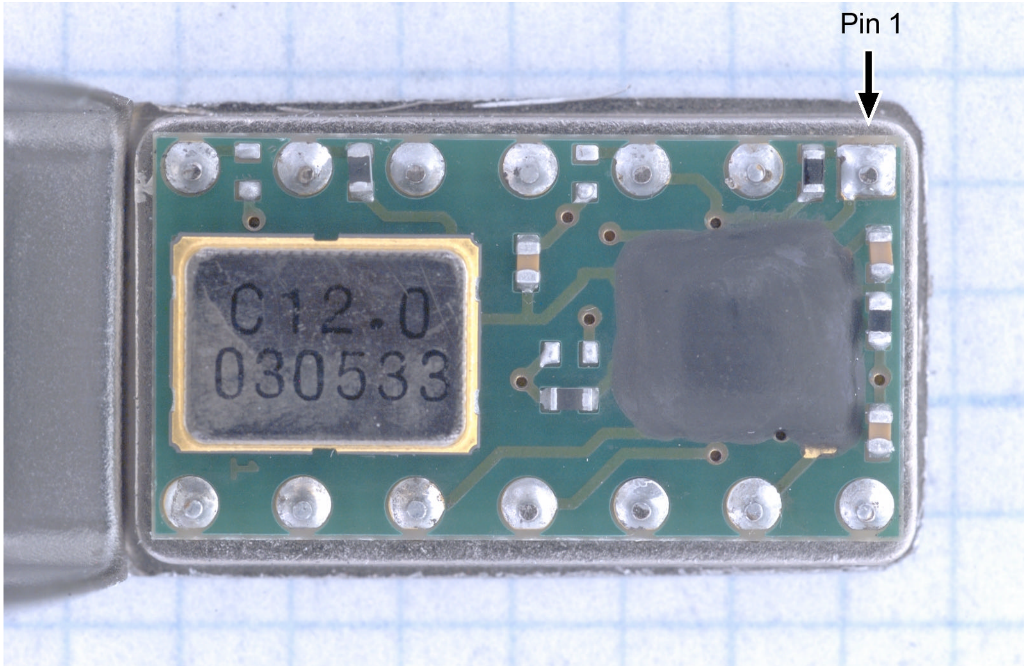


Figure 4. Optical photograph of the device after delidding. The quartz crystal is enclosed in a hermetically sealed package attached to the PCB hybrid substrate. The oscillator circuitry is contained on a single integrated circuit that is directly mounted to the PCB and covered with a dark epoxy coating (on right side of PCB in the photo).

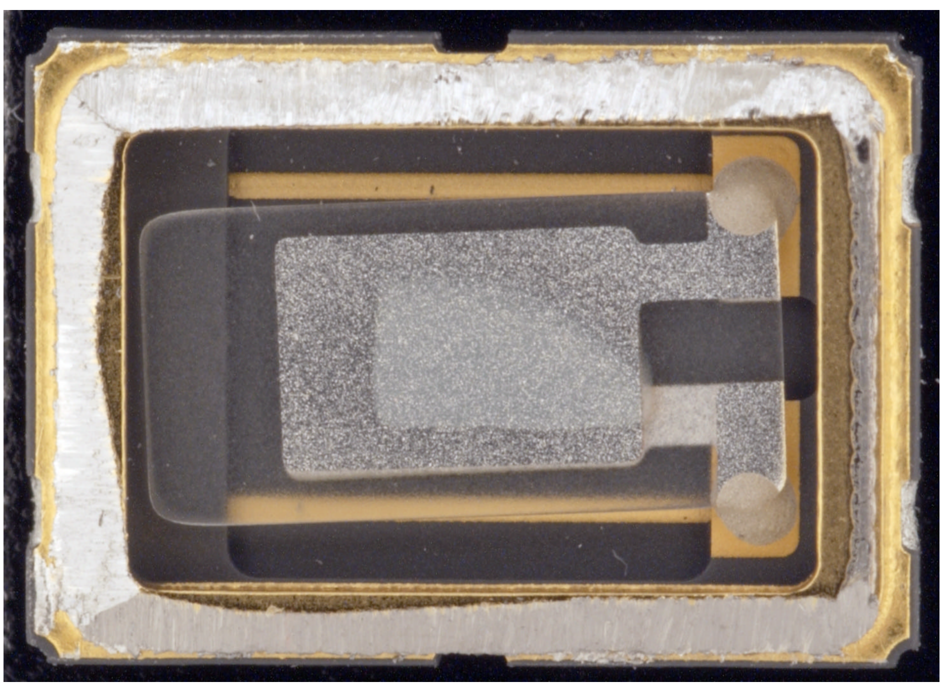


Figure 5. Optical photograph of the quartz crystal. The quartz crystal package was opened by using a file to remove the weld bead from the package lid.

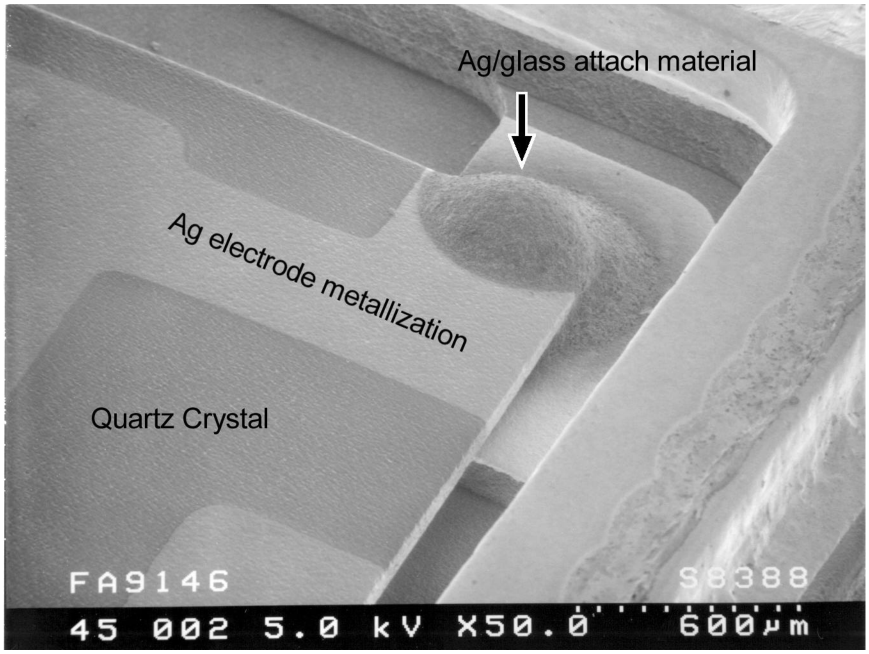


Figure 6. 50X SEM micrograph showing details of the attachment of the quartz crystal to the package. No anomalies were found during SEM examination of the quartz crystal.

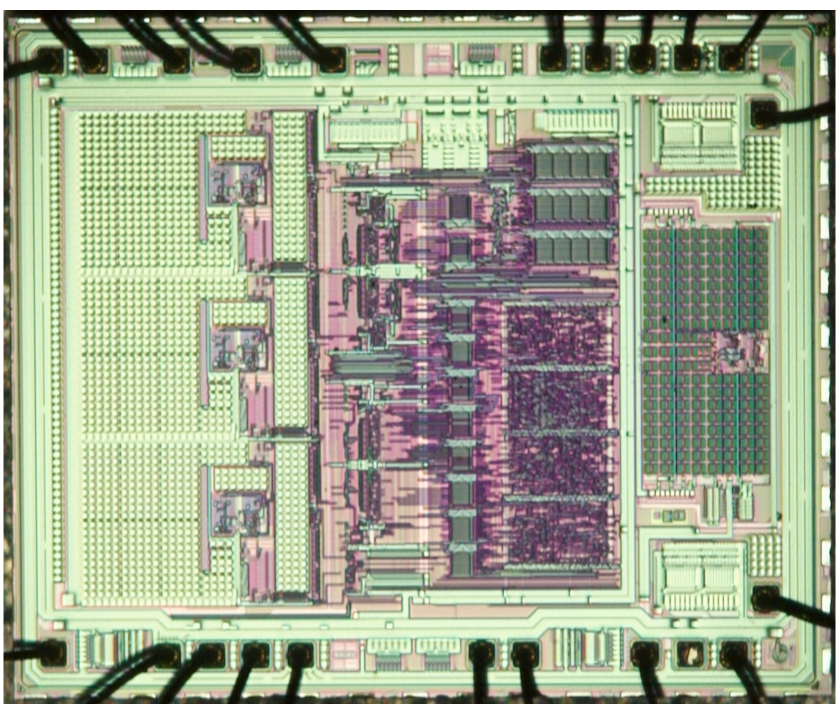


Figure 7. 50X Optical photograph of the oscillator control integrated circuit.

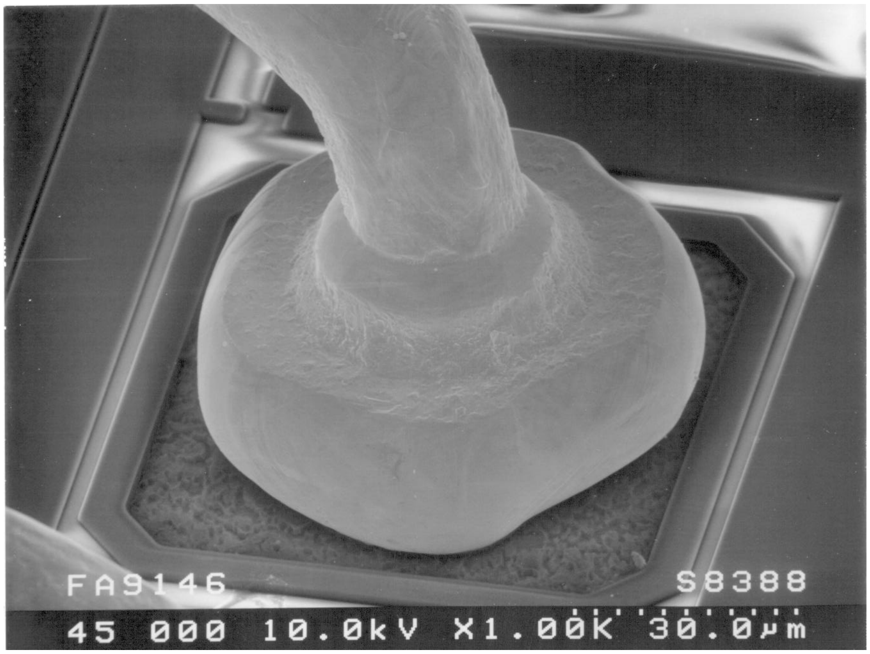


Figure 8. 1,000X SEM micrograph showing a typical gold ball bond on a pad on the oscillator control integrated circuit.

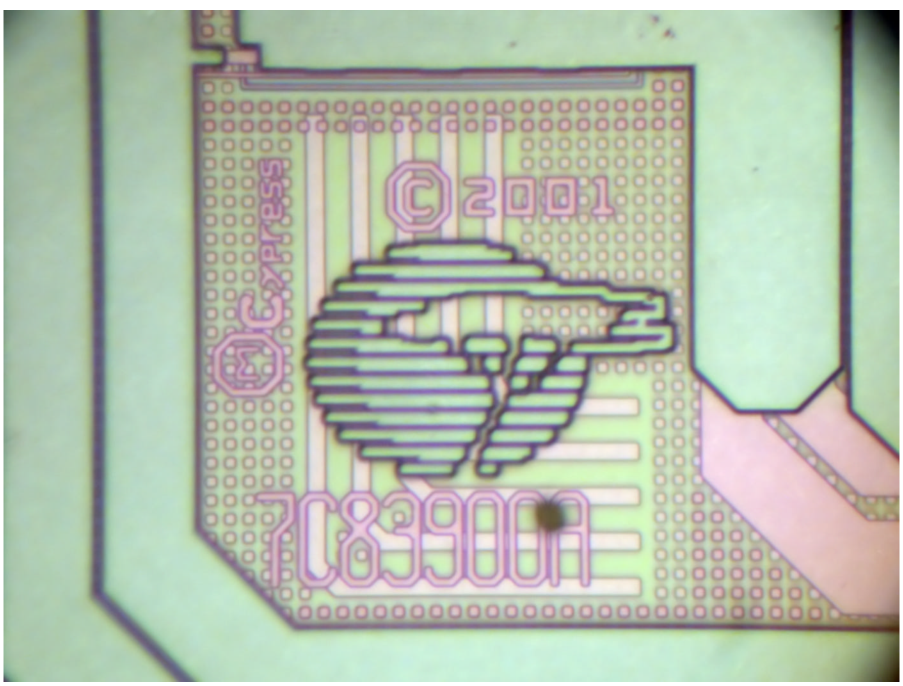


Figure 9. 760X Optical micrograph of the markings observed on the oscillator control integrated circuit.

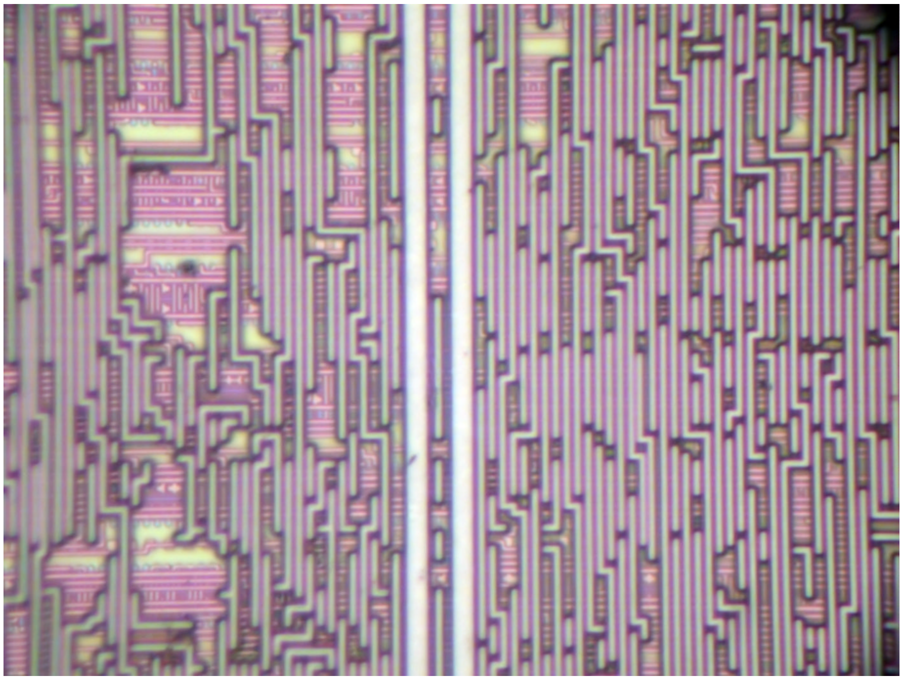


Figure 10. 760X Optical micrograph of typical metallization traces on the oscillator control integrated circuit. No anomalies were found during high power visual examination of the die surface.

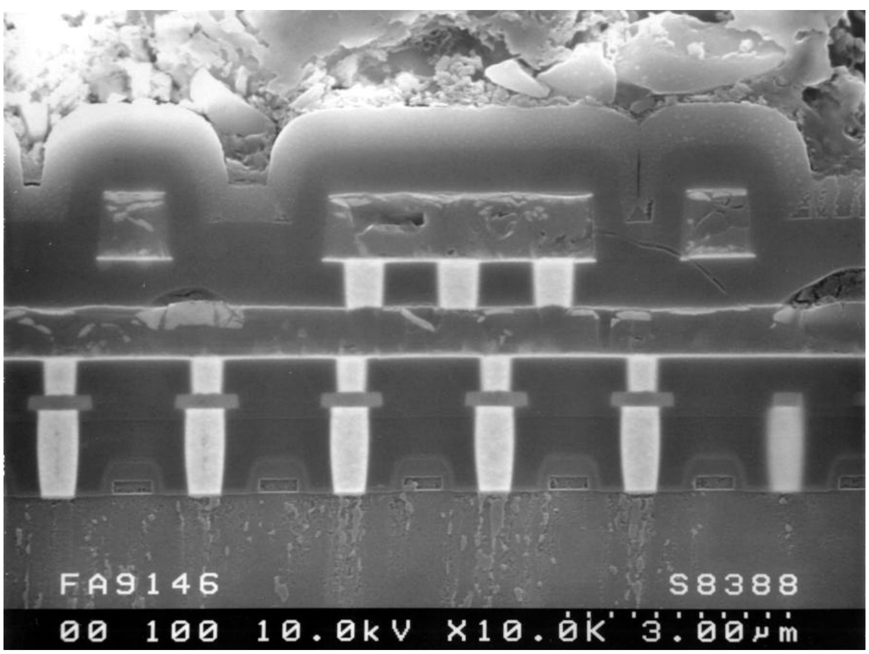


Figure 11. 10,000X SEM micrograph of a cross section of the oscillator control integrated circuit. The metallization layers were found to be fully planarized. The contact vias between the metallization layers were composed of tungsten.

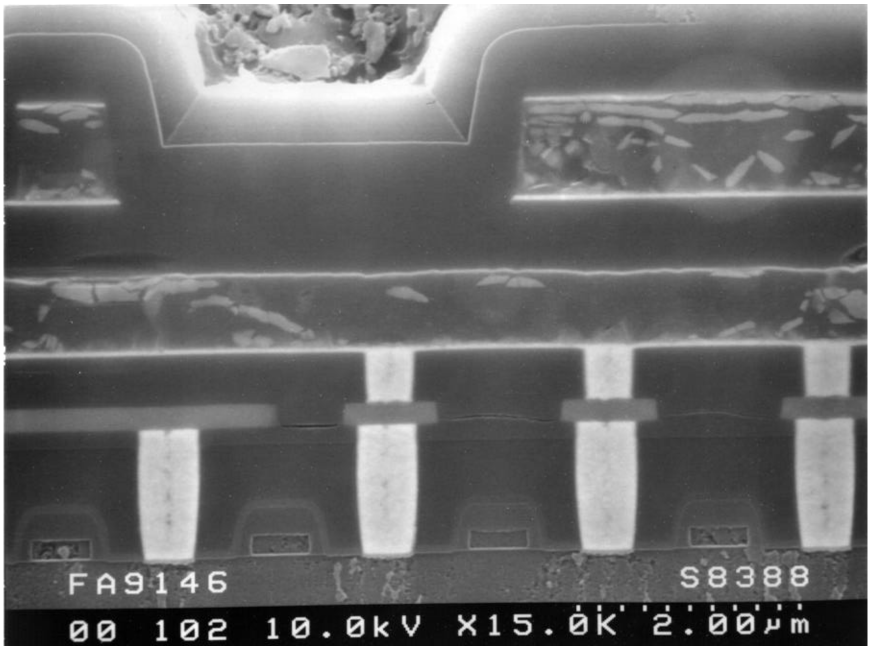


Figure 12. 15,000X SEM micrograph showing details of contact vias to the silicon substrate.

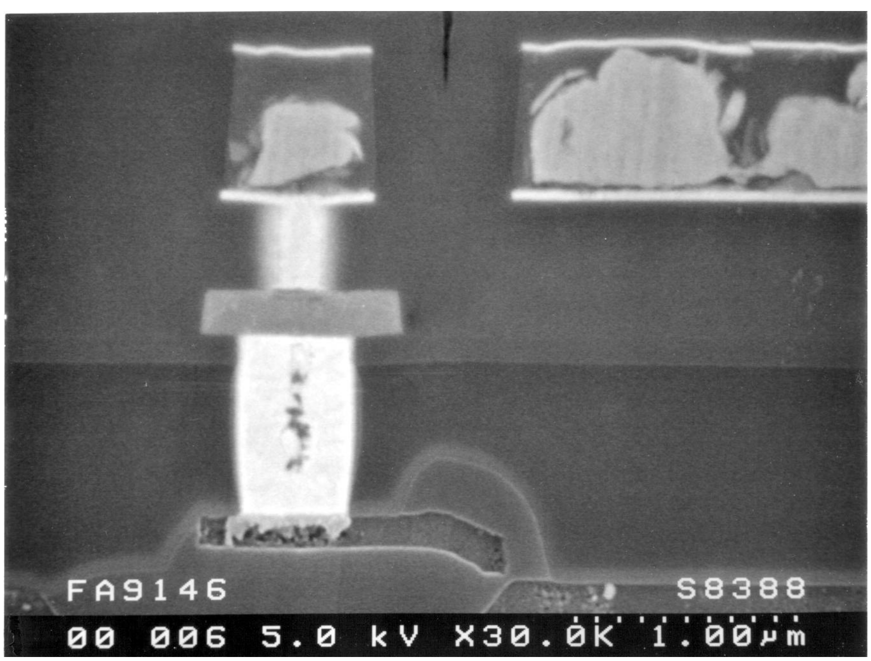


Figure 13. 30,000X SEM micrograph showing a contact via to a polysilicon trace.

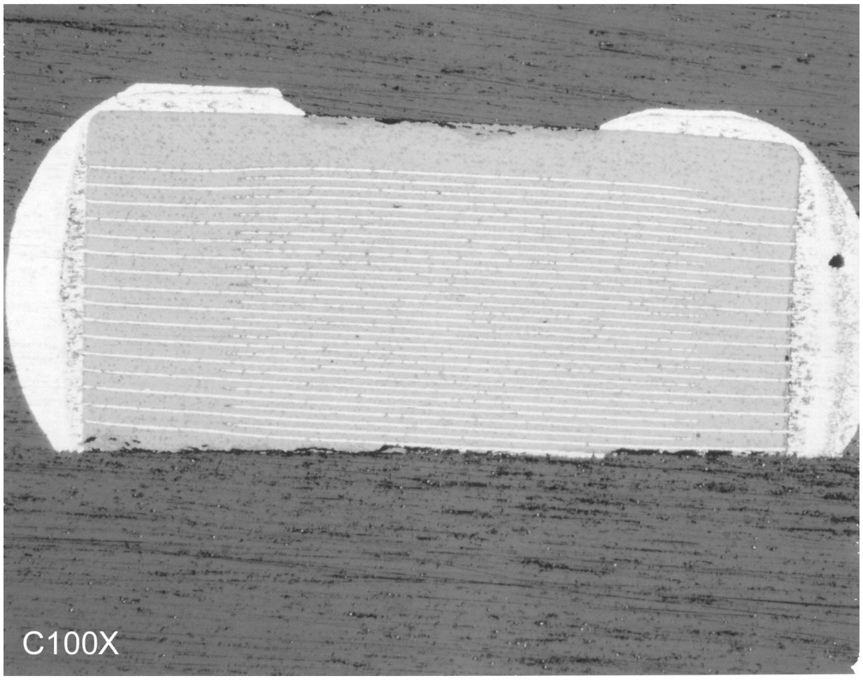


Figure 14. 100X Optical micrograph of a cross sectioned capacitor that was removed from the hybrid substrate. (The lower portion of the capacitor was ground away to reveal the orientation of the capacitor plates for final sectioning.)

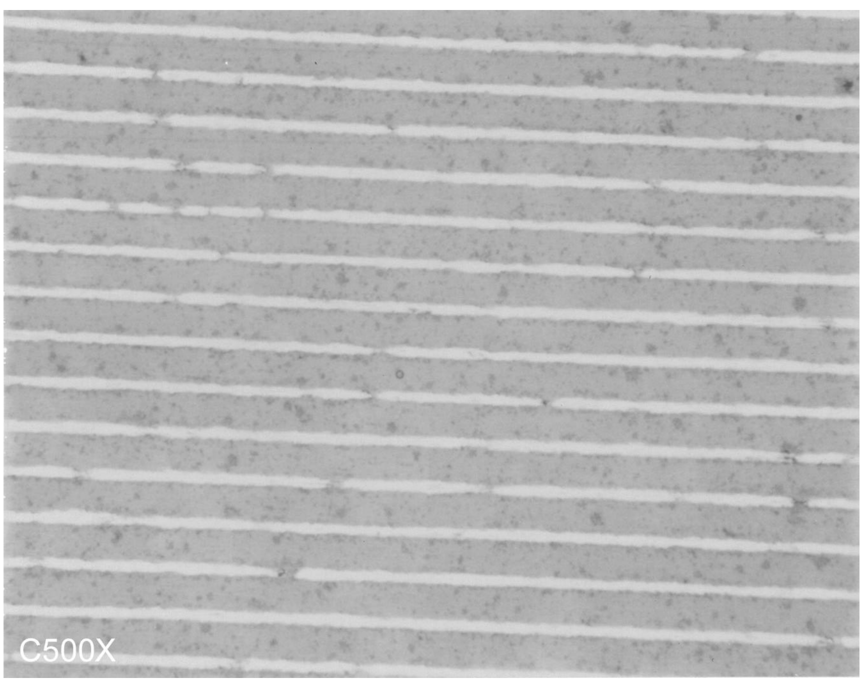


Figure 15. 500X Optical micrograph of the cross sectioned capacitor. The dielectric layer thickness was measured to be 0.0003 inches.