

# STANDARDIZING SPACE OVENIZED CRYSTAL OSCILLATORS FOR LOWER COST AND FASTER DELIVERY

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## Abstract

*Building for space is challenging. Program management requirements, parts availability and delivery, parts costs, and testing costs historically make space OCXOs expensive and long-lead. Standardizing specifications based on MIL-PRF-55310, NASA EEE-INST-002, NASA Parts Selection List, and GSFC Preferred Parts Lists, and procuring parts to vendors standard drawings can significantly reduce costs and improve delivery of high-performance OCXOs. Wenzel presents a discussion of parts, materials, and screening specifications for cost and delivery for three grades of OCXOs.*

*Wenzel Associates builds high-performance, very-low-noise oscillators, frequency standards and synthesizers for military, space, and commercial requirements. Space oscillators have recently been completed for Los Alamos/NNSA, the Lunar Reconnaissance Orbiter, the Aquarius/SAC-D sea surveyor, and TACSAT-4 for NASA. Wenzel's oscillators were provided to the Mars Lander Mission for JPL, the NEAR Earth Asteroid Rendezvous Satellite for Johns Hopkins APL, and Northrop Grumman and NASA for the National Polar-orbiting Operational Environmental Satellite System (NPOESS). Flight Models of the X-band synthesizer for the Mars Science Laboratory's landing radar for JPL were delivered this year.*

## INTRODUCTION

“Doing science in space is, above all, expensive, so space researchers often find their careers hanging on the decisions of government ministers rather than grant committees.”

– Daniel Clery - **Science**, 21 Nov 2008, Cloudy Future for Europe's Space Plans

Ovenized Crystal Oscillators (OCXOs) are critical components in timing, navigation, ranging, and telemetry systems for space flight. Program management requirements, parts availability and delivery, parts costs, and testing costs historically make space OCXOs expensive with long lead times.

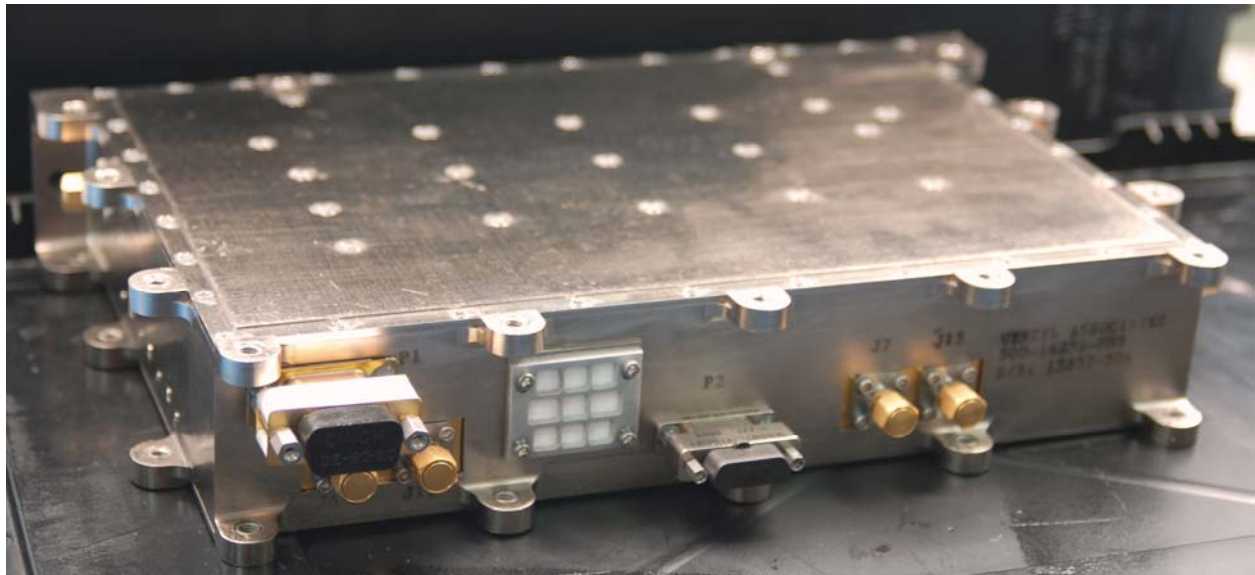
Standardizing specifications based on oscillator specification MIL-PRF-55310, NASA parts specification EEE-INST-002, NASA Parts Selection List, and GSFC Preferred Parts Lists (PPL-21) ensures a clear understanding of the requirements and reduces cost and eliminates errors. Procuring oscillators to vendor's standard drawings based on these specifications can significantly reduce costs and improve delivery of high performance OCXOs. Also, permitting the use of standard hi-rel and space hardware in the oscillators ensures lower cost for higher reliability oscillators, often with shorter lead times.

Standard oscillator specifications are discussed for three classes of Wenzel's Space VHF OCXO and the High Frequency Space OCXO. A complete data sheet is included for a 10-MHz Space OCXO. The differences between the classes provide insight into the build process vs. cost and delivery options.

## **WENZEL'S SPACE HERITAGE**

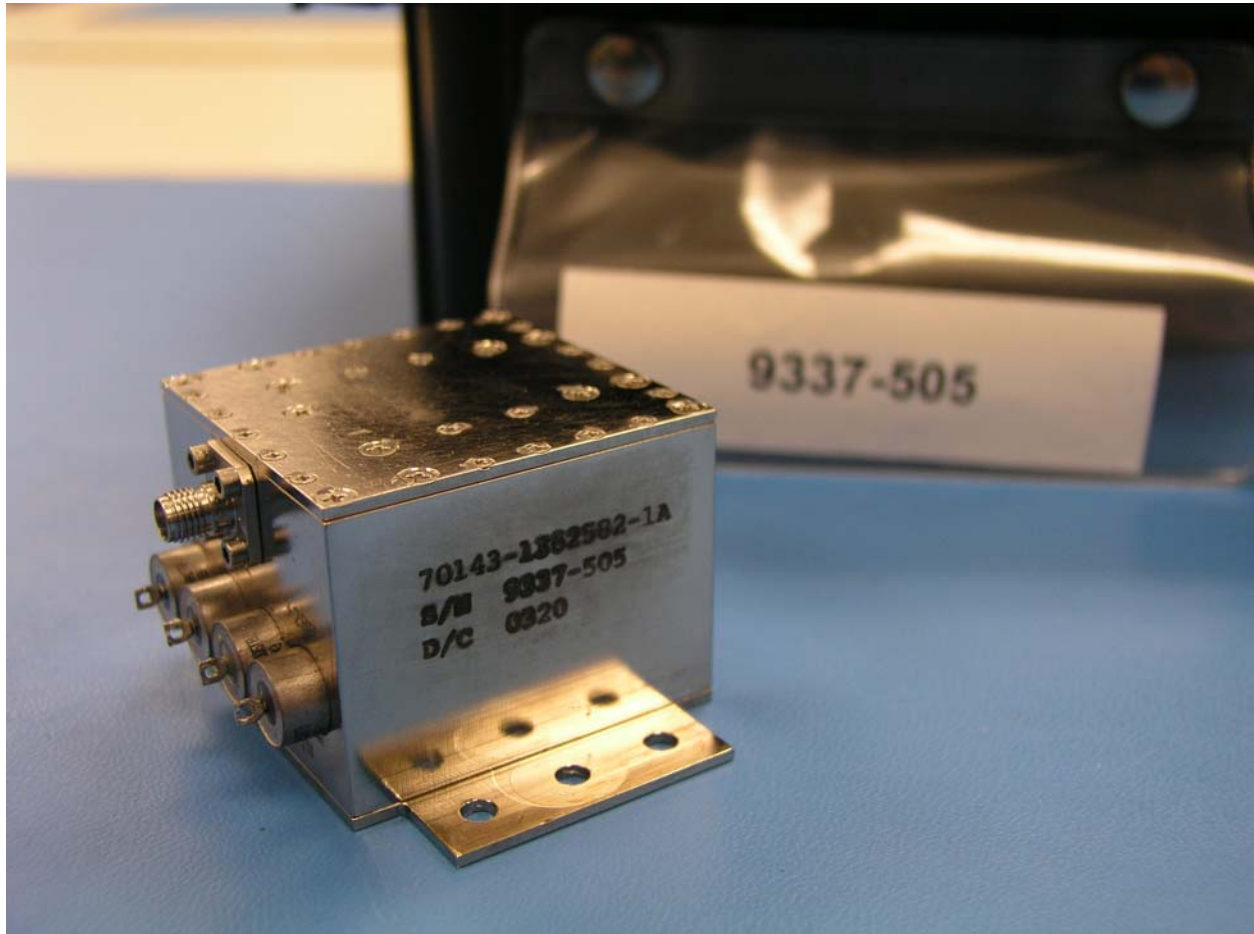
Wenzel Associates in Austin, Texas, and Croven Crystals, our sister division in Whitby, Ontario, design and build very low phase noise oscillators and crystals for the military and space communities. Some programs for which Wenzel space oscillators were provided are listed:

- 2009 - NPOESS Advanced Technology Microwave Sounder
- 2008 - JPL's Mars Science Laboratory - Landing Radar
- 2008 - TACSAT-4
- 2007 - Aquarius/SAC Sea-Surveyor
- 2007 - Lunar Reconnaissance Orbiter
- 2003 - NPOESS Advanced Technology Microwave Sounder
- 1996 - NEAR Near Earth Asteroid Rendezvous Satellite
- 1994 - Mars Pathfinder.



Frequency Synthesizer Assembly for JPL.

The Frequency Synthesizer Assembly delivered to JPL for the Mars Science Laboratory in June, 2008, is part of an innovative landing radar. The synthesizer provides fixed frequencies from 1 GHz to 11.25 GHz.



NPOESS Advanced Technology Microwave Tactical Sounder Oscillator for Northrop/Aerojet.

NPOESS oscillators were first delivered in 2003 and are in current production. The OCXO at 143 MHz, with a built-in odd-order multiplier, is located in the Advanced Technology Microwave Sounder of the National Polar-orbiting Operational Environmental Satellite System.

## **WHY ARE SPACE OCXOs EXPENSIVE AND LEAD TIMES LONG?**

Space is a challenging environment. Launch vibrations are severe and temperatures can be extreme. The spacecraft on which OCXOs are installed can be pelted with radiation, jolted by a pyro shock when a solar panel is deployed, or heated and cooled suddenly as the spacecraft turns toward and away from the sun. Any heat generated in the OCXO must be managed carefully, since most space hardware is in a vacuum. In addition, there is no recall, no easy repair if an OCXO breaks.

There are several cost drivers that make construction of these parts expensive. Program management time can be extensive, parts, and materials are costly and long-lead, and testing and screening costs can accumulate.

## **USING STANDARD VENDOR SPECIFICATIONS**

In order to keep program management costs low, reducing the number and breadth of controlling documents is critical. From the initial quotation to the final end-item data package, evaluating specifications and providing program information to the design and manufacturing teams are important but time consuming tasks. When standard military documents are specified, each member of the build team and customer's team can be confident that the oscillators will meet the program's requirements. If specifications are confusing, long conferences between vendor and customer are required and additional screening may be prescribed for added confidence when direction from the documents is not clear. Costs can easily spiral upward.

Complete mission assurance plans are often available on the space-based systems and usually contain detailed information that applies to every section of mission hardware and software in order to assure a consistent build and successful mission. The system Mission Assurance Plan can become one of the controlling specifications for the crystal oscillator. The plan can be helpful to oscillator designers and helps them understand the program's requirements. But evaluating all sections of the plan for a large system takes time and many of the sections will not apply to the oscillator. If this document is available as a guide, and the actual controlling documents are the vendor's or customer's specifications, time and cost can be reduced.

## **SPECIFYING OSCILLATORS, TESTING, AND ANALYSES**

Generally, components such as chip resistors and capacitors are clearly and simply defined in the military standards that apply to them and rarely require other documents to define their fitness for use. Standard military specifications such as MIL-PRF-55342 for chip resistors and MIL-PRF-55681 for chip ceramic capacitors are readily available. Each military specification includes QPL documentation, which defines detailed electrical specifications, mechanical outlines, screening, testing, and marking requirements. The highest reliability level parts specified in the documents, class T for the resistors and class S for the capacitors, are very expensive, but are considered suitable for all space requirements.

For OCXOs, the military specifications do not provide QPL documentation that specifies the oscillator as a single part number. Instead, these oscillators are purchased to a vendor or customer SCD, often with several other controlling documents.

MIL-PRF-55310 is the general specification for crystal-controlled oscillators, and defines three product levels. Level C is for general-purpose applications, level B is for high reliability applications, and level S for is the highest reliability applications. The document is specific and details the parameters critical to oscillator performance. Inspection, screening, qualification, quality conformance inspection, and packaging details are also listed for each product level. Using this standard specification as a guide when writing the specification-controlled drawing (SCD) for the oscillator, it is straightforward to define processes and testing, simplifying the design and build.

## SELECTING COMPONENTS AND COMPONENT TYPES

EEE-INST-002 is NASA's parts selection, screening, qualification, and derating document. It specifies NASA's requirements for components typically used in class 1 (discrete) oscillators and class 3 (mixed discrete and hybrid) oscillators, as defined in MIL-PRF-55310. EEE-INST-002 details up-screening options for three levels of high reliability builds, and some military parts may be used for space oscillators without additional screening or testing under most circumstances. Following the parts requirements defined in the EEE document can simplify parts selection and verification and can reduce cost and time. Three levels of high reliability, level 1, level 2, and level 3 reference standard military specifications for various part types. EEE-INST-002 document specifies when a level 1, 2, or 3 part is used:

“Level 1: Parts shall be selected and processed to this level for missions requiring the *highest reliability and lowest level of risk*. Level 1 active parts shall be reviewed for radiation hardness, and radiation testing is required when information is not available. The typical mission duration for level 1 program is 5 years or greater.

Level 2: Parts shall be selected and processed to this level for missions with *low to moderate risk* balanced by cost constraints and mission objectives. Level 2 active parts shall be reviewed for radiation hardness, and radiation testing is required when information is not available. The typical mission duration for level 2 programs varies from 1 to 5 years.

Level 3: Parts represent inherently *high risk or unknown risk* because of the lack of formalized reliability assessment, screening, and qualification. Also, there is little dependable data or flight history available for them as the continuous changes in design, materials, and manufacturing processes may make the data on any particular LDC [lot date code] not applicable to another lot and date code. Level 3 parts are intended for mission applications where the use of high-risk parts is acceptable. Level 3 active parts shall be evaluated for radiation hardness, and radiation testing is required when information is not available. The typical mission duration for level 3 programs varies from less than 1 year to 2 years.”

Some parts classified as level 1 are physically and electrically identical to level 3 parts, but lack additional tests, inspections and certification paperwork. When defining the parts requirements for a space program, the cost of selecting a level 2 part rather than a level 3 part and a level 1 part rather than a level 2 part can be significant. Deliveries can change from weeks to months, causing designers to work with parts specialists on alternatives, under the best circumstances. Under worse circumstances, deliveries will be delayed.

Level 2 or 3 parts can be specified in cases where the end use is not long or with additional screening and testing that assures that the oscillator as an individual is documented to be highly reliable.

Several examples of some relative parts costs are listed:

Passive components are numerous and costs can accumulate. Mean time between failures (MTBF) levels must be carefully reviewed because failure rates can also accumulate in reliability calculations.

Passive Parts Comparison Chart

PART TYPE	PART NUMBER	MFG	EACH	LEVEL
10 OHM RESISTOR, 2%, THIN FILM, (R)	D55342K07B10G0R	VISHAY	\$0.71	2
10 OHM RESISTOR, 2%, THIN FILM, (T)	D55342H07B10G0T	SOTA	\$12.89	1
CAPACITOR/SMT, 10 PF(0605)	100A100JT 150X	ATC	\$0.42	MIL
CAPACITOR/SMT, 10 PF(0605)	CDR12BG100KJUS	ATC	\$2.79	1

Active components can be purchased to the highest level, S, but JANTXV are highly reliable and have more reasonable lead times and costs. DPA and PIND testing for cavity devices can provide additional assurances that the lot is built correctly.

Active Parts Comparison Chart

PART TYPE	PART NUMBER	MFG	EACH	LEVEL
TRANSISTOR, NPN SWITCHING	2N2222AJANTX	MICRO	\$2.80	2
TRANSISTOR, NPN SWITCHING	2N2222AJANTXV	MICRO	\$4.15	2
TRANS + PIND, RADIOGRAPHIC	2N2222AJANTXV W/A	DPA	\$11.80	1
TRANSISTOR, NPN, SWITCHING	2N2222AJANS	SEMIC	\$35.37	1
4E VARACTOR	MMBV105GLT1G	ON SEMI	\$0.06	COMM
VARICAP DIODE	MSV34,092-P55	AEROFL	\$21.10	1

Non-standard parts such as non-QPL passives can be purchased to standard military processes and are readily available. If up-screening is required, an SCD usually must be generated, increasing costs for both customer and vendor.

Non-standard parts such as a passive hybrid semiconductor can be very expensive and long-lead and vendors may perceive cost risk associated with a space program. In the case of this diode-doubler, a standard well-established military diode-doubler was abandoned, because the up-screening costs were prohibitive. A custom-designed alternative was more reasonably priced and performed the same function at a high, but much lower, cost. The cost difference between \$45,000 per lot vs. \$155,000 per lot was significant for the 20-piece lot. Engineering and program management time to develop custom drawings were high.

40<sup>th</sup> Annual Precise Time and Time Interval (PTTI) Meeting

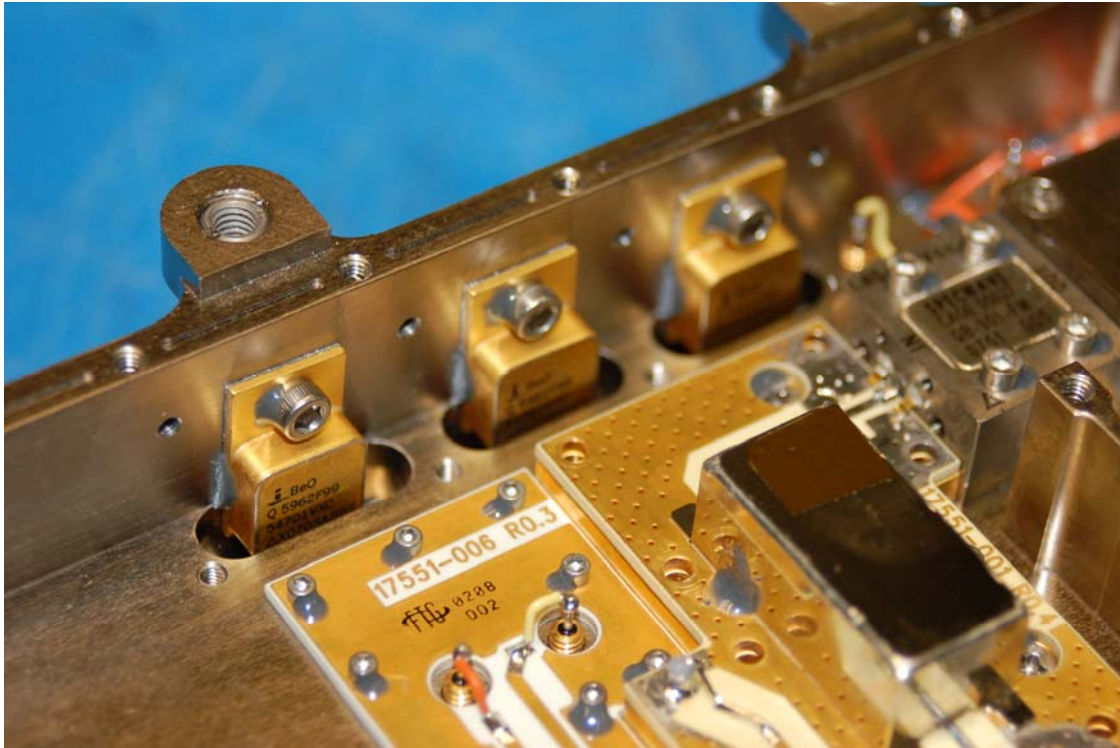
Non-standard Parts, Non QPL Passive Comparison Chart

PART TYPE	PART NUMBER	MFG	EACH	LEVEL
TEMPCOMPENSATED ATTENUATOR				
COMMERCIAL			\$15.00	3
MIL-PRF-55342			\$35.00	2
MIL-PRF-55342 UP-SCREENED	50 PIECE LOT	\$35.00		
GROUP A	\$2500 / LOT	\$50.00		
GROUP B	\$6000 / LOT	\$120.00		
TOTAL			\$205.00	1

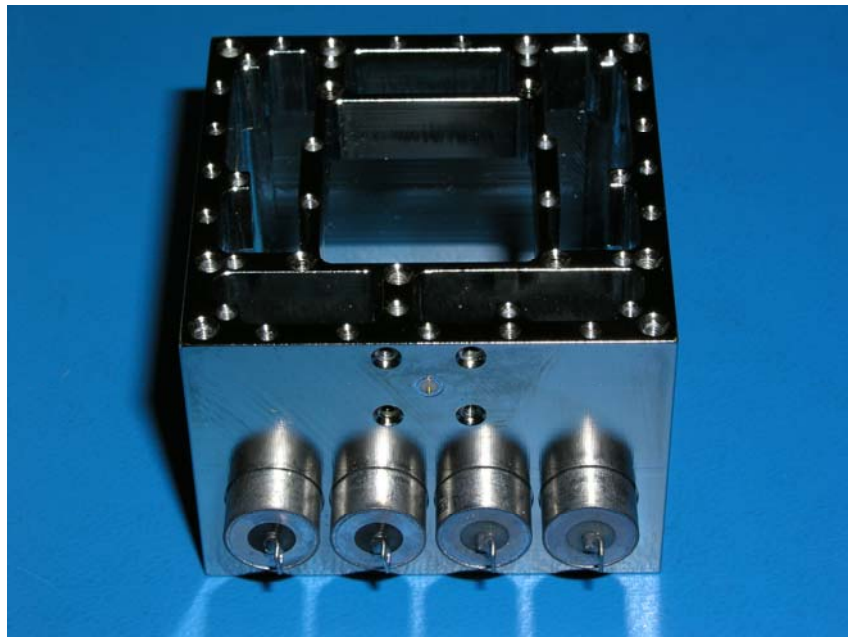
Non-standard Parts, Passive Hybrid Semiconductor Chart

PART TYPE	PART NUMBER	MFG	EACH	LEVEL
DIODE DOUBLER				
COMMERCIAL			\$125.00	COMM
MIL-PRF-38534			\$375.00	2
MIL-PRF-38534 UP-SCREENED	20 PIECE LOT			
PLUS SCREENING			\$7,750.00	1
CUSTOM WENZEL SCD			\$2,250.00	1

Standard space components are readily available for some parts, such as voltage regulators and feed-thru capacitors.



HS9S-117RH, 5962F9954701VXC voltage regulator, standard space component.



M28861/01-002TB, filter feed-thru, standard space hardware.



## STANDARD DATA SHEET DEVELOPMENT

Three data sheets have been developed that define performance, screening, and testing for each of two of Wenzel's ovenized oscillators, the Space VHF OCXO and the High Frequency Space OCXO.

These differ in the parts requirements, screening, and qualification tests, per the differences detailed in MIL-PRF-55310 for level S and level B oscillators, and use parts defined in EEE-INST-002, level 1, 2, and 3. These specifications can be the basis for defining the requirements for a space OCXO tailored to meet special circumstances.

501-20040	100 MHz	S-Level Screening	Level 1 Components
501-20041	100 MHz	S-Level Screening	Level 2 Components
501-20042	100 MHz	B-Level Screening	Level 3 Components
501-20043	10 MHz	S-Level Screening	Level 1 Components
501-20044	10 MHz	S-Level Screening	Level 2 Components
501-20045	10 MHz	B-Level Screening	Level 3 Components

The specifications include:

- General program requirements
- Electrical specifications
- Mechanical specifications and outline
- Environmental requirements
- Model definitions for prototypes, EM, FM and qualification units
- Acceptance testing with screening details.

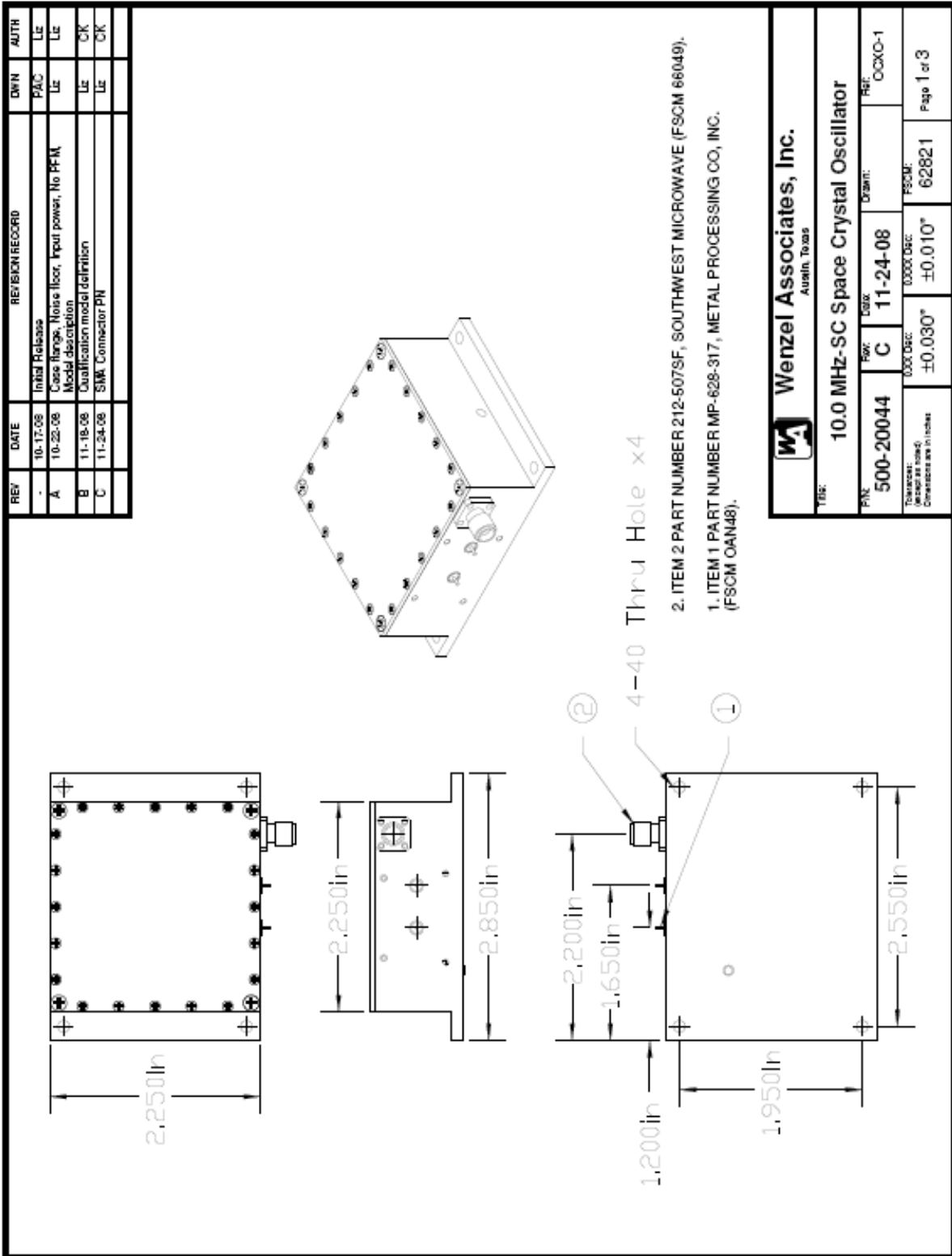
A data sheet is included as Appendix A for a 10-MHz OCXO, P/N 500-20044, with S-level screening and Type 2 parts. The data sheet references standard military/space documentation and can be tailored to a specific program's requirements.

## CONCLUSION

Designing and building space hardware is challenging. Parts, screening, and program management all require special attention, and costs can be considerable. Since OCXOs are not listed on QPL lists, standard and custom written documents must control the build and testing. With the use of standard military specifications and following MIL-PRF-55310 and EEE-INST-002, costs and lead times can be significantly reduced.

There are many limitations on funding and the cost of a program can determine whether it will be funded or cut. Manufacturers of space OCXOs must look for ways to provide exactly the part that is required by their customers. Performance, reliability, delivery, and cost are all critical.

APPENDIX A



REV	DATE	REVISION RECORD	DWH	AUTH
-	10-17-08	Draft	PAC	Liz
A	10-22-08	Case change, Noise floor, Input power, No PFM, Model description	Liz	Liz
B	11-18-08	Qualification model definition	Liz	CK
C	11-24-08	SMA Connector Pin	Liz	CK

MODEL DEFINITIONS	DESCRIPTION
EM (Engineering Model)	Design and Construction similar in appearance and identical in form, fit, and function to FM. Developed using best commercial practice, including some commercial parts and materials. EM shall be subjected only to electrical tests, with some environmental testing performed.
FM (Flight Model)	Fabricated to meet all design, construction, and test requirements reference MIL-PRF-55310, Class 1, Product Level S. FM shall be subjected to the entire complement of electrical and environmental acceptance tests listed.
Qualification Model	Flight Model/Space Level, Parts EEE-INST-002, Level 1,2 MIL-PRF-3089 Level 2 Crystals MIL-PRF-19500 / MIL-STD-750 Semiconductors, JANTXV with PIN D, JANTX with PIN D and DPA (5 ea) EM Unit, when specified, using EEE-INST-002, Level 1,2 parts where available. Testing for (1) unit.
501-20044-01	EM Engineering Model
501-20044-02	Qualification Model
501-20044-03	FM Flight Model

GENERAL REQUIREMENTS	DESCRIPTION
Material, Design and Construction	MIL-PRF-55310
Parts and Materials List	Supplied
Parts, Materials	EEE-INST-002, JANTX Semiconductors, ER passives and 683B ICs, when available.
Crystal	10 MHz, premium C, Z-swept, synthetic quartz
Outgassing	TML <1% and CVCM <0.1% per SP-R-002A
Traceability	Semiconductor and passive lot and date code tracking
De-railing	per EEE-INST-002, (JPL-D-8545, alternative)
Soldering	J-STD-001 class 3
Case	Nickel-plated aluminum housing
Finish	Electroless nickel per MIL-C-26074
<b>ELECTRICAL PERFORMANCE</b>	
RF Output Frequency	10 MHz, sine wave
Frequency Accuracy (initial)	$\pm 2 \times 10^{-8}$ at +25°C
Frequency Stability	$\pm 1 \times 10^{-7}$ for -40°C to +60°C (ref +25°C)
Aging Rate (after 90 days operating)	
1 day	$\pm 5 \times 10^{-10}$
1 month	$\pm 5 \times 10^{-9}$
RF Output Power	+13 dBm $\pm 1.5$ dB into 50Ω
RF Output 2 <sup>nd</sup> Harmonic	-30 dBc
RF Output Sub-harmonics	<-40 dBc
RF Output Spurious	<-100 dBc, 100 KHz to 1 GHz
Phase Noise (SSBIC)	<b>10 MHz</b>
1 Hz	-100 dBc/Hz
10 Hz	-130 dBc/Hz
100 Hz	-150 dBc/Hz
1 KHz	-155 dBc/Hz
10 KHz	-155 dBc/Hz
Supply voltage	+15 VDC $\pm 5\%$
Warm-up power	$\leq 5$ watts
Warm-up time	$\leq 20$ minutes at ambient pressure $\leq 5 \times 10^{-5}$ torr
Input power	$\leq 2.5$ watts steady state at ambient pressure $\leq 5 \times 10^{-5}$ torr
<b>ENVIRONMENTAL CONDITIONS</b>	
Operating temperature	-40°C to +50°C
Storage temperature	-40°C to +105°C
Ambient pressure	Atmospheric (760 torr), Vacuum ( $\leq 5 \times 10^{-5}$ torr)
<b>MECHANICAL SPECIFICATIONS</b>	
Size	2.25" x 2.25" x 1.0" (57.1 x 57.1 x 25.4 mm)
Weight	$\leq 500$ grams
Physical	Pressure relief holes

<b>Wenzel Associates, Inc.</b> Austin, Texas			
<b>10.0 MHz-SC Space Crystal Oscillator</b>			
Part:	501-20044	Rev:	C
Date:	11-24-08	Drawn:	
Checked:		Released:	
Dimensions in inches:	$\pm 0.030"$	PSOM:	62821
		PSOM:	$\pm 0.010"$
		Part:	CCXC-1
			Page 2 of 3

REV#	DATE	REVISION RECORD	DRN#	AUTH
-	10-17-08	Initial Release	PAC	LE
A	10-22-08	Case changes, Noise floor, Input power, No PFM, Model description	LE	LE
B	11-18-08	Qualification model definition	LE	CK
C	11-24-08	SMA Connection PH	LE	CK

REV#	DATE	REVISION RECORD	DRN#	AUTH
-	10-17-08	Initial Release	PAC	LE
A	10-22-08	Case changes, Noise floor, Input power, No PFM, Model description	LE	LE
B	11-18-08	Qualification model definition	LE	CK
C	11-24-08	SMA Connection PH	LE	CK

**QUALIFICATION TESTS (Non-flight model, only)**

Group I (1 samples)  
 Visual, Electrical Tests\*  
 240 hours minimum at +60°C

Group II (1 samples)  
 Aging  
 30 Days

Group III Subgroup 1 (1 sample)  
 Random Vibration  
 11.95 Grms, MIL-STD-202, method 214 F-D, 50 to 2000 Hz, 5 min per axis  
 MIL-STD-202, Method 213, Condition A, 50G, 11 msec

Group III Subgroup 2 (1 sample)  
 Shock  
 Thermal Shock  
 MIL-STD-202, Method 107, Condition A-1, 25 cycles, -55°C to +85°C  
 MIL-STD-202, Method 105, at  $<5 \times 10^{-4}$  torr

Group III Subgroup 3 (1 sample)  
 Ambient Pressure  
 Resistance to Soldering Heat  
 Group III Subgroup 4 (1 sample)  
 Terminal Strength  
 MIL-STD-202, Method 210, Condition A

Solderability  
 Resistance to Solvents  
 MIL-STD-202, Method 211, Condition C, Not applicable for pins  $<0.25"$

Electrical Tests\*  
 Radiographics  
 MIL-STD-202, Method 208  
 MIL-STD-202, Method 215  
 Not applicable when marking is electro-etched

**ACCEPTANCE TESTS (Flight Model)**

Electrical Tests\*  
 Thermal Shock  
 MIL-STD-202, method 209

Random Vibration (non-operational)  
 MIL-STD-202, Method 107, Condition A, 5 Cycles, -55°C to +85°C  
 7.56 Grms overall, 50 to 2000 Method 214 F-B, 50 to 2000 Hz, 5 min per axis

Electrical Tests\*  
 Burn-In (operational)  
 Aging Rate  
 Projected after 30 days operating  
 MIL-STD-202, method 209

\*ELECTRICAL TESTS  
 Tested at ambient pressure  $\pm 5 \times 10^{-4}$  torr and at -40, +25, and +60 °C unless otherwise noted

Warm-Up Power (-40 °C only)  
 Input Power  
 Cold Start (-40 °C)  
 Hot Start (+65 °C)  
 RF Output Power  
 RF Output Harmonics  
 RF Output Spurious  
 Frequency Accuracy (+25 °C only)  
 Frequency Stability  
 Phase Noise - Static (+25 °C only, 760 torr)

**ANALYSES**  
 Thermal Analysis, Component Stress Analysis

<b>Wenzel Associates, Inc.</b> Austin, Texas				
<b>10.0 MHz-SC Space Crystal Oscillator</b>				
REV#	DATE	DRN#	AUTH	
501-20044	C	11-24-08		CKXC-1
REVISION RECORD (insert at end)	DATE	REVISION RECORD	DATE	REVISION RECORD
Drawings are in force		±0.030"	62821	Page 3 of 3