HIGHLY REPRODUCIBLE STATE-OF-THE-ART QUARTZ OSCILLATORS

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ABSTRACT

The demand for high precision oscillators that are capable of effectively operating over large temperature ranges and extreme temperature transients is continuously sought by industry. For example, the telecom wireless industry requires stable oscillators with excellent temperature coefficients to operate base stations that are located in areas of extreme temperature swings. Similarly applications exist in the Aviation, Navigation, Instrumentation, Military and other markets. In the past these industries have had only two choices: rubidium atomic standards, or limited quantities of virtually non-reproducible precision crystal oscillators. In this paper we will present a class of extremely precise and reproducible oscillators developed by Frequency Electronics, Inc. These oscillators are defined as the FE-205A Series, and are capable of providing any frequency from 1 pps to 100 MHz with typical aging of better than 5×10^{-11} / day, and with a temperature coefficient of $<1 \times 10^{-10}$ over the temperature range of –40° C to +75 ° C. Furthermore, we will demonstrate that the oscillator is insensitive to fast temperature slew rates, and, consequently, the problem of over and under shoot has been completely eliminated. The devise is being mass-produced with standard manufacturing techniques. In essence, we have truly developed a "Poor Man's Rubidium".

1. INTRODUCTION

Precision ovenized crystal oscillators (OCXO) are typically defined as those oscillators with frequency stability of better than $1x10^{-10}$ over a wide range of environmental conditions. These conditions include operating temperature, humidity, supply voltage variations, repeatability, frequency setting ability and frequency drift over long periods of time. As the table below demonstrates, stability in the range of $1x10^{-10}$ was previously achieved only with Rubidium and other Atomic Standards.

Oscillator Type	Frequency Stability (In severe temperature environments e.g. –40°C to +75 °C, and high slew rates)
Crystal Oscillator (XO)	$1x10^{-4}$ to $1x10^{-5}$
Temperature Compensated Crystal Oscillators (TCXO)	$1x10^{-6}$
Microcomputer Compensated Crystal Oscillators (MCXO)	$1x10^{-7}$ to $2x10^{-8}$
Oven Controlled Crystal Oscillators (OCXO)	$1x10^{-8}$ to $3x10^{-10}$
FE-205A Series High-Precision Double Oven Crystal Oscillator (DOCXO)	**$1x10^{-10}$**
Rubidium Atomic Frequency Standards (Rb) [–10°C to +70 °C]	$3x10^{-10}$ to $7x10^{-11}$
Cesium Atomic Standard (Cs) [0°C to +50 °C]	$1x10^{-11}$ to $1x10^{-12}$

There has been a long recognized need for a precision oscillator with stability better than 1×10^{-10} over a wide range of environmental conditions that can be manufactured in large quantities and at a low cost. The FE-205A DOCXO offered by Frequency Electronics, Inc. fulfills this long recognized need.

2. QUARTZ CRYSTAL STANDARD

Frequency Electronics, Inc. (FEI) designs and manufactures rubidium frequency standards (Rb) as well as precision crystal oscillators, and has developed a quartz oscillators that approaches the stability of Rb devices, but at a third of the atomic frequency source's price. The FE-205A is a DOCXO with a stability better than $1x10^{-10}$ over a wide range of environmental conditions that does not require an accurate crystal frequency, nor a precision crystal cutting angle for precise operating temperature characteristics, nor the use of reactive components for tuning and setting the desired output frequency. By removing all the previously required costly key elements and time-consuming production hours, FEI has achieved a precise DOCXO that is reproducible, easy to manufacture, low cost and affordable. The resulting FE-205A series performance is very close to the performance of a Rubidium Atomic Frequency Standard, and it has been dubbed the **"Poor Man's Rubidium."** Patents have been applied for.

The resulting device is truly a Quartz Crystal Standard with the outstanding features summarized below.

- Producible in Large Quantities
- Excellent Temperature Stability $<1x10^{-10}$
- Low Aging $<5 \times 10^{-11}$ / day; $<5 \times 10^{-8}$ /10 year
- Near Rubidium Accuracy at 1/3 the Cost
- Any frequency from 1 pps to 100 MHz
- Analog or Digital Frequency Control with better than 1 % Linearity
- Units in Stock at 10 MHz and 15 MHz

3. FE-205A, FE-405A, FE-505A PACKAGES

The oscillators are available in three types of packages.

FE-205A packaging style is shown in Figure 1, and the FE-405A and FE-505A packages are shown in Figure 2.

The FE-205A is housed in a package measuring 2x2x1.5 in. (51x 51x38 mm).

The FE-405A is housed in a package measuring 3x3x1.44 in. (76x 76x37 mm).

The FE-505A package dimensions are 2.98x2.80x0.89 in. (76x71x23 mm).

The enclosures chosen for the FE-405A and FE-505A are representative of existing Rb device packages, and are intended to easily substitute Rb devices in legacy circuits as well as in new designs.

Figure 1. FE-205A

Figure 2. FE-405A and FE-505A

4. DESIGN

The FE-205A series of DOCXOs consists of a unique design that incorporates a proprietary double-oven structure as well as an innovative implementation of a direct digital synthesizer (DDS). The DDS digitally adjusts the crystal oscillator's frequency with a resolution of $2x10^{-14}$ and achieves device outputs that range from 1 pps to 100 MHz. The double-oven stabilizes the temperature of a stress-compensated-cut (SC-cut) crystal that is operated in fifth-overtone mode. Figures 3 shows a typical physical construction of the FE-205A DOCXO, and Figure 4 demonstrates the construction of the FE-405A.

The major characteristics of the design are as follows:

- SC-cut 5th overtone resonator with good aging and excellent short-term stability.
- Thermal control electronics with inner oven stability of $\pm 1 \times 10^{-3}$ °C over a change in ambient temperature of 100°C
- Stability of internal reference clock electronic circuit is better than $3x10^{-11}$ over ambient temperature of –40°C to +75 °C and with a change in B+ of ±5%
- High-resolution DDS ≈ $2x10^{-14}$
- Microprocessor Controlled
- Less than $1x10^{-12}$ with load variation of ±10%

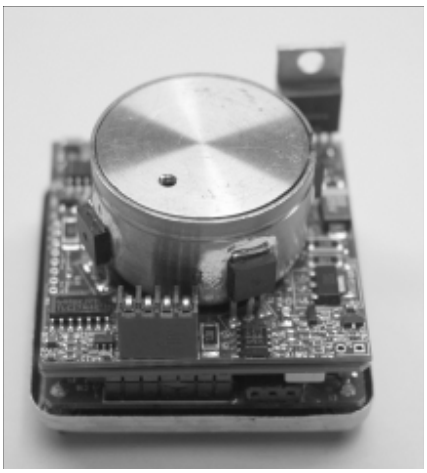

Figure 3. Physical Construction of the FE-205A DOCXO

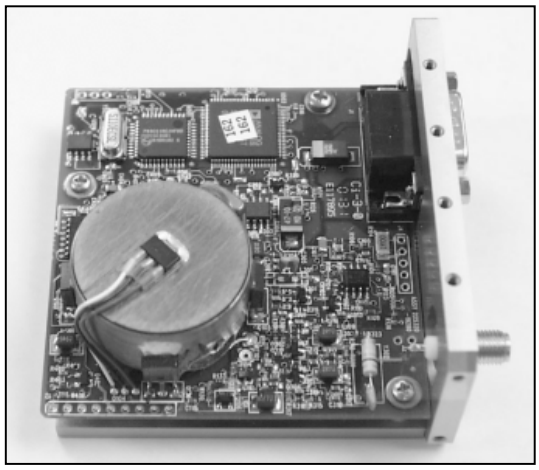

Figure 4. Physical Construction of the FE-405A DOCXO

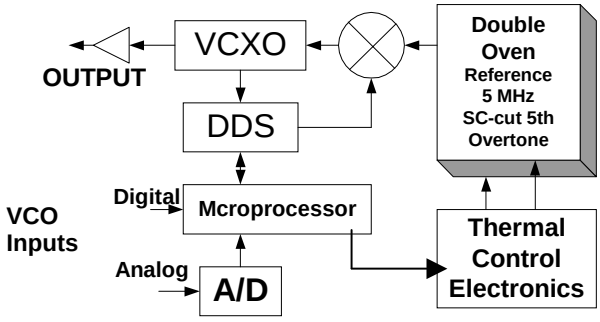

Figure 5. System Block Diagram

5. PERFORMANCE

Actual measured performance for 15 MHz and 10 MHz devices are presented below.

Oscillators typically experience overshoots and undershoots when subject to temperature changes. However the FE-205A, FE-405A and FE-505A overcom these disadvantages and result in very stable performances even as the temperature changes at an extremely high rate. Figures 6 and 7

demonstrate the superb performance of a 15 MHz oscillator. Figure 6 demonstrates the performance of the device when tested over a wider range of ambient temperature than typically encountered. The DOCXO was cooled to –55°C and within in a period of 56 minutes the temperature was raised to +75°C. Figure 7 shows the frequency stability resulting from the changes demonstrated in Figure 6.

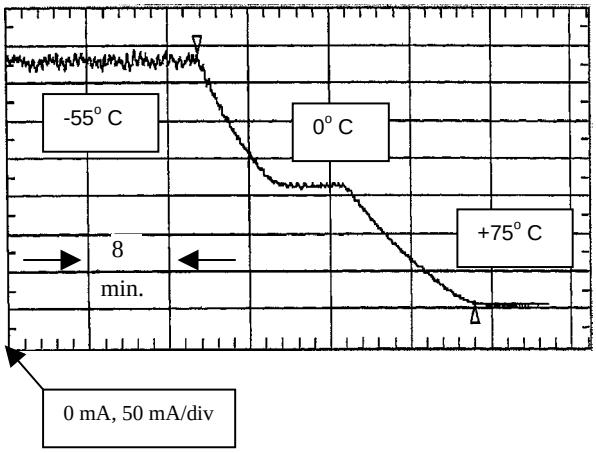

Figure 6. Oven Current vs. Time and Temperature of a 15 MHz Oscillator

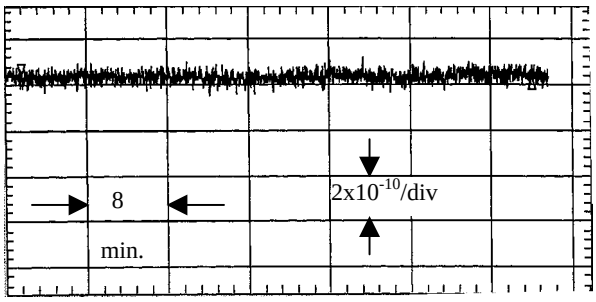

Figure 7. Frequency vs. Temperature for the Temperatures and Time Period shown in Figure 6 above

The plot in Figure 8 below demonstrates the excellent frequency stability as a function of fast varying temperature. In this case the unit is cycled from –40°C to +75°C and then to +25°C room temperature all within the short period of approximately 105 minutes.

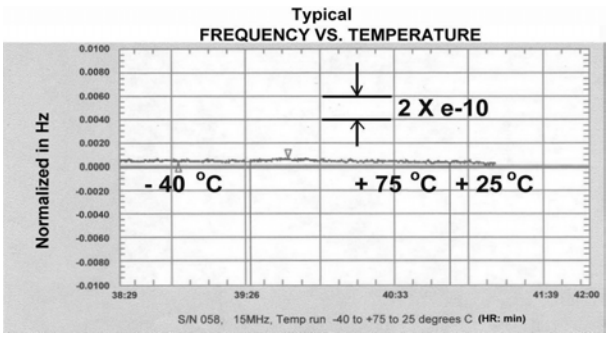

Figure 8. Frequency Stability of 15 MHz Oscillator over a Range of Temperature Variations

Warm-up. Figure 9 shows a typical warm up time of a 10 MHz device. Approximately 20 minutes is required to achieve a specified frequency.

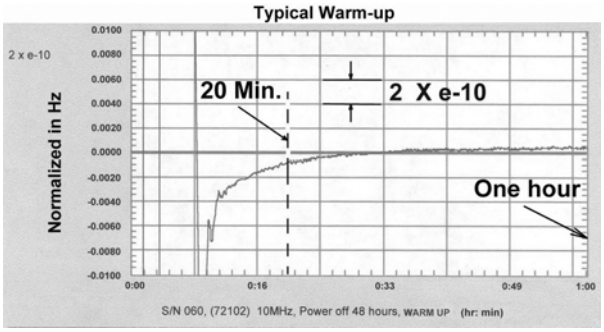

Figure 9. Typical Warm-Up of a 10 MHz Device

Retrace. The retrace performance of a 15 MHz oscillator is shown in Figure 10. The device is shut off for 24 hours and the frequency stabilizes within 30 minutes after turn-on to $1x10^{-10}$ of the previous frequency.

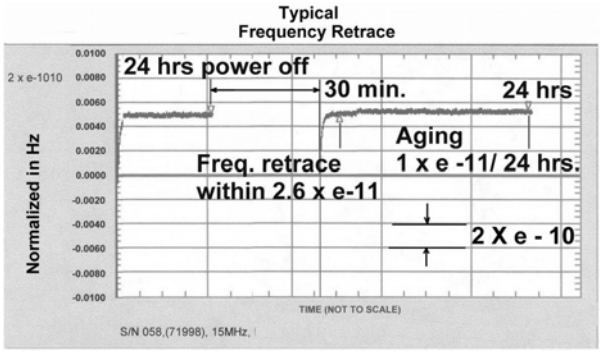

Figure 10. Typical Frequency Retrace of 15 MHz Oscillator

Short Term Stability. The short-term stability is better than Rb atomic standards with $1x10^{-11}$ for τ = 1 second, and $1x10^{-12}$ for τ = 100 seconds.

Aging. Typical aging is $<5x10^{-11}$ / day and $<5x10^{-8}$ /10 year.

Phase Noise. The phase noise meets the requirements for wireless and wireline applications as shown in Figure 11.

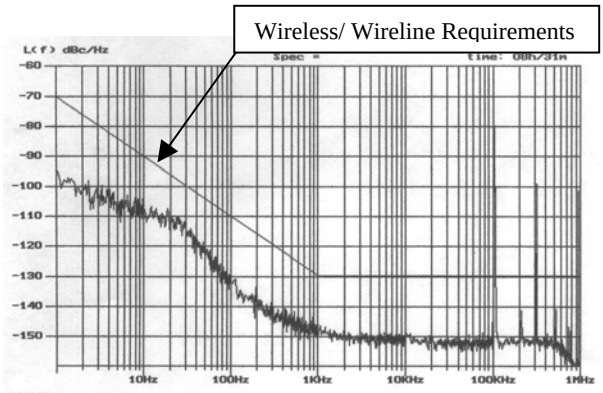

Figure 11. Phase Noise of 10 MHz Oscillator

6. CONCLUSION

Performance results for the FE-205A ultra-accurate quartz oscillator have been presented. This series of products continues FEI's trend toward high-precision quartz oscillators that perform similar to Rubidium devices, but at one-third the price. These products are capable of operating in extreme temperature swings and are applicable for cellular base stations, stratum clocks, GPS timing systems, test equipment, aviation, instrumentation and military. Detail specifications are provided below.

7. SPECIFICATIONS

OUTPUTS

Frequency: 10 MHz Standard
(Option for any other frequency 1pps to 100 MHz)

RF Output:

Level	12dBm ±2dB into 50-ohm load
Waveform	Sine wave
Harmonics	-40dBc max
Spurious	-65dBc to 1 GHz

Frequency Stability:

Temperature $<1 \times 10^{-10}$ (-40^{o}C to $+75^{o}$C)
(Including frequency over or undershoot at any fast or slow temperature slew rate)

Supply Voltage $<\pm 2 \times 10^{-11}$ (15v±5%)
$<\pm 2 \times 10^{-11}$ (+5v±5%)

Aging:

Per Day $<1 \times 10^{-10}$ (after 14 days continuous operation) Typical 5×10^{-11}
Optional 2.5×10^{-11}
Per Year $<1 \times 10^{-8}$
Per 10 Years $<5 \times 10^{-8}$

Phase Noise:

1Hz	-85dBc/Hz
10Hz	-95dBc/Hz
100Hz	-125dBc/Hz
1KHz	-135dBc/Hz
10KHz	-145dBc/Hz

Short Term Frequency Stability (Allan Standard Deviation):

τ = 1 second	1×10^{-11}
τ = 10 second	2×10^{-12}
τ = 100 second	1×10^{-12}

Retrace:

1×10^{-10} in 1 hr. after 24 hours power off
5×10^{-10} in 20 min. after 24 hours power off

G-Sensitivity: 2×10^{-9} per G, any axis

INPUTS

Digital Frequency Adjustment: Standard

RF output Frequency Adjustment:
Digital control via TTL serial port interface.
Serial Communication:
9600 Baud, TTL level, 8 bits, no parity, 1 stop bit
Adjustment resolution: LSB $\approx 1.7 \times 10^{-14}$
Adjustment range:
+/- 20Hz for 15MHz output
+/- 9.5Hz for 10MHz output
(Other trim ranges can be special ordered)

Analog Frequency Adjustment:

Via DC input of 5v±5v (0 to +10v)
Course Adjust Range: $\pm 2.4 \times 10^{-7}$
Fine Adjust Range: $\pm 0.5 \times 10^{-8}$

ELECTRICAL

Power:

Supply Voltage:

Standard	+15v DC ±5%, l amp max.
	+5v DC±5%, 200ma
Option	single 15v input
Warm-up:	15W max.
Steady State:	3.5W Max at 25^{o}C

ENVIRONMENTAL

Temperature Range:

Operating -40^{o}C to $+75^{o}$C meets all specifications
Operational -55^{o}C to $+85^{o}$C may not meet frequency stability

PHYSICAL SIZE

FE-205A	2.0" x 2.0" x 1.5" (51x 51x38 mm).
FE-405A	3.0" x 3.0" x 1.44" (76x 76x37 mm).
FE-505A	2.98" x 2.80" x 0.89" (76x 71x23 mm).

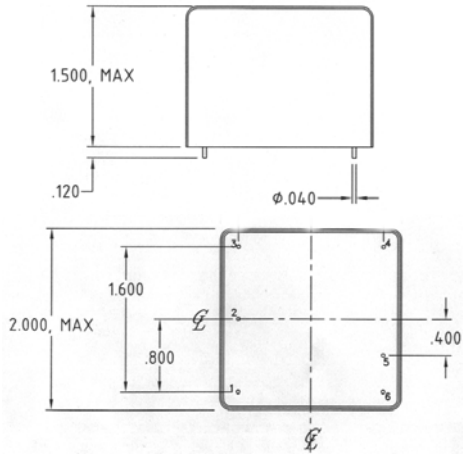

Figure 12. FE-205A

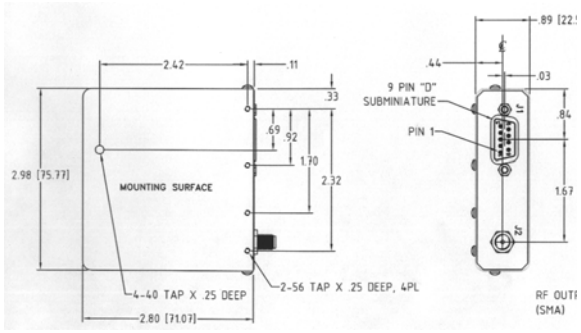

Figure 13. FE-505A

Please consult FEI for further details.