A PicoPak TCXO Measurement

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• Introduction

This document describes the use of the PicoPak clock measurement module for characterizing the frequency stability of a small temperature compensated crystal oscillator (TCXO). It serves as an example of a PicoPak application where frequent DDS frequency adjustments are required, and also an example of using the PicoMon program to monitor a clock measurement.

• TCXO Stability

A TCXO represents a frequency source having intermediate accuracy and stability that can be too good for many frequency counter measurements yet too poor for very high resolution clock measuring systems. In particular, the untrimmed nominal frequency of even a standard-frequency TCXO can have an offset that is too large for a high-resolution dual mixer time difference (DMTD) system to handle while having enough stability that a nine or ten digit per second counter has insufficient resolution, but where the PicoPak clock measurement module can make quite satisfactory measurements.

• The TCXO Under Test

The unit under test (UUT) for this example was a Monitor P/N 7400B2A1A, a small 10 MHz TCXO in a DIP-like package operating from +5V ±5% at ≤ 20 mA and outputting a TLL-compatible squarewave, and having a specified stability of ±1 ppm over a 0°C to +50°C (see Appendix I). The device has an external frequency trim adjustment, which was not used, and it had a frequency offset of about +1.1 ppm (+11 Hz at 10 MHz) at room temperature. The TCXO squarewave output was filtered with a 10 MHz crystal and amplified to a +8 dBm sinewave. A photograph of the TCXO and filter crystal is shown in Figure 1.

Figure 1. TCXO and Filter Crystal

The filtered TCXO output was applied to the PicoPak signal input via a 6 dB pad, and its reference input was driven by an Efratom LPRO rubidium oscillator calibrated versus a GPS time receiver. The first measurements were conducted in a quiescent room temperature (≈+23°C) environment.

- **Frequency Record**

A preliminary ≈ 4 minute frequency record for this TXCO is shown in Figure 2, a PicoMon plot copy. It has an average frequency offset of about +1.12 ppm. Its frequency variations are about 1.3×10^{-8} p-p, and are at about the threshold of where PicoPak DDS frequency adjustments are required for tracking. The fastest frequency slews have a rate of about 1×10^{-9}/s, well within the PicoPak tolerance. The smallest 1-second frequency variations are on the order of 1×10^{-10}, an order-of magnitude larger than the PicoPak noise and resolution, which is therefore adequate for the measurement.

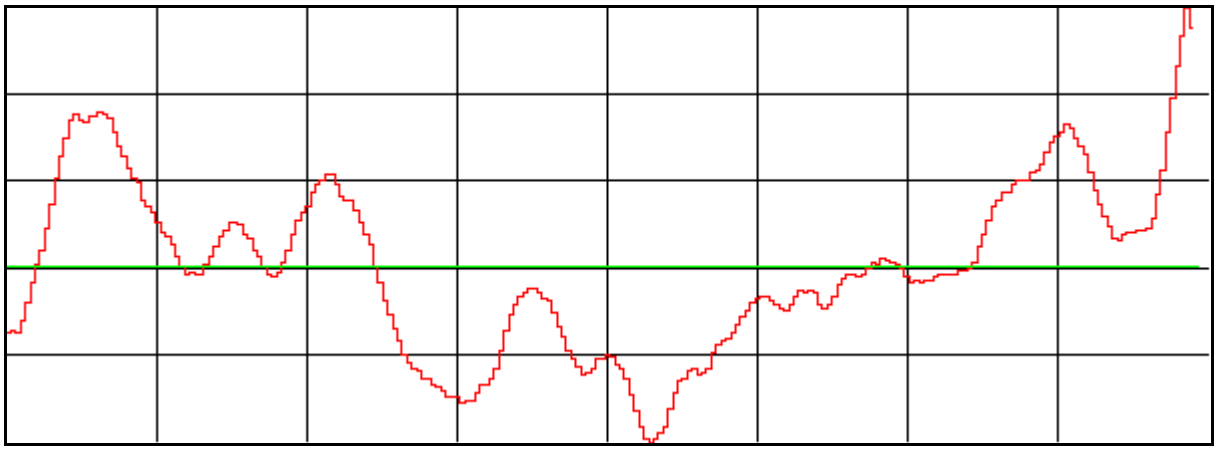

Figure 2. Preliminary TCXO Frequency Record
Scales: X-Axis: 31.1 sec/div, Y-Axis: 2.62×10^{-9}/div

This run was continued overnight, during which there were numerous DDS frequency adjustments as the TCXO frequency varied about 1.9×10^{-8} p-p. There was no significant room temperature change or air conditioner cycling, and the average frequency hardly changed ($+1.13 \times 10^{-6}$ overall). The 1-second ADEV stability was about 1.8×10^{-10}, and it became worse at longer averaging times (presumably due to thermal variations) to a flicker FM level of about 1×10^{-9} before gradually improving at longer averaging times.

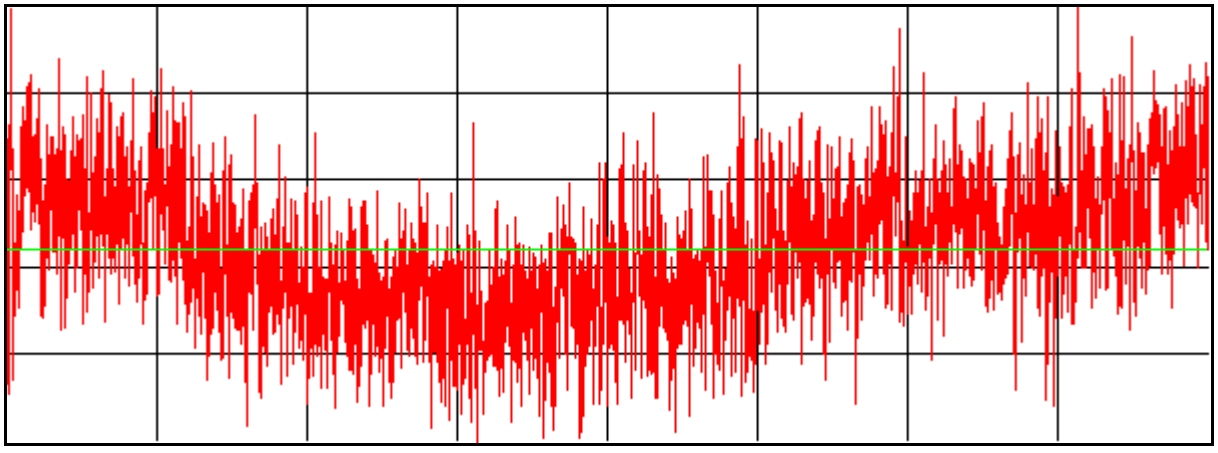

Figure 3. 11 Hour Overnight TCXO Frequency Record
Scales: X-Axis: 82.4 min/div, Y-Axis: 3.79×10^{-9}/div

• Temperature Stability

The TCXO was then set up in a small thermoelectric heat/cool chamber to evaluate its temperature stability over a range of approximately +15°C to +45°C. Only the TCXO itself was inside the chamber. A preliminary run showed the need to have a temperature sensor coupled directly to the TCXO case, that its temperature compensation was quite good and was slightly over-compensated in the room temperature region, that PicoPak DDS frequency tracking was satisfactory and could be observed by spikes in the record, and that a rather long stabilization time was required to establish a steady-state TCXO frequency reading.

Figure 4 shows the TCXO frequency record for +1.4°C of passive self-heating inside the chamber. The resulting frequency change of $+9.1 \times 10^{-8}$ or $+6.5 \times 10^{-8}$/°C represents a stabilization factor of roughly x15 compared with that expected for an AT quartz resonator near room temperature, and has the opposite sense thus indicating slight over-compensation.

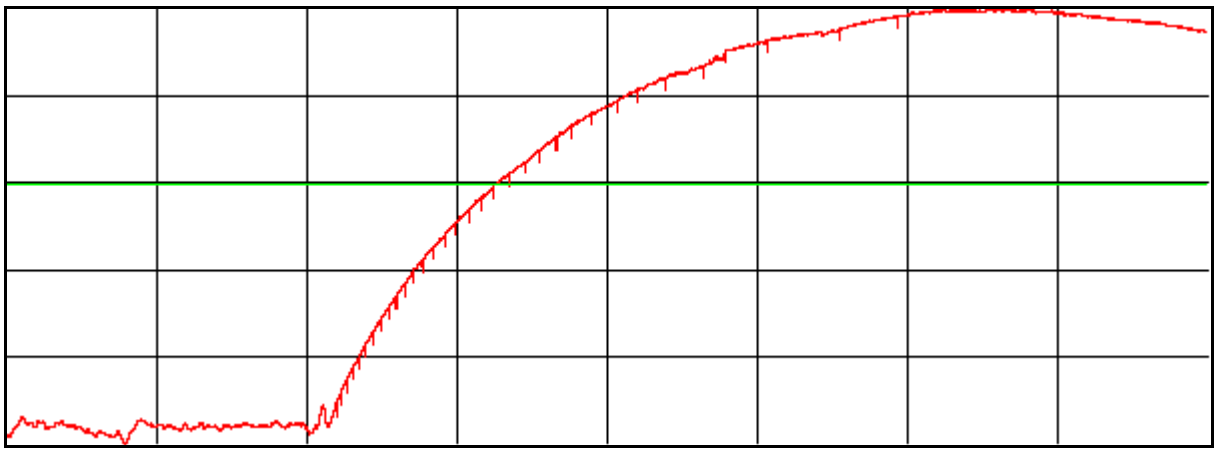

Figure 4. TCXO Frequency Record During Passive Self-Heating
Start: $+7.97 \times 10^{-7}$ @ +27.1 °C, End: $+8.88 \times 10^{-7}$ @ +28.5°C.
Frequency Scale ≈ 2.0×10^{-8}/div, Time Scale ≈ 16 min/div.

The complete frequency measurement run shown below began at a well-stabilized room temperature condition, cooling to below room temperature (+5°C at the TEM, +17°C at the TCXO), and step-wise increases to well above room temperature (+50° at the TEM, +44°C at the TCXO). A cooler temperature near +25°C causes an initial positive frequency change (probably the response of the assumed AT-cut crystal resonator) followed by a negative frequency change (probably the net response of the crystal and compensation network). The large initial cooling step resulted in a large frequency transient as the TCXO passed through temperatures corresponding to negative frequency excursions that were explored in more detail on the way up.

Figure 5 shows the entire PicoMon screen at the end of the run, and Figure 7 shows the notes entered into the PicoPak database during the run. Those are identified by data point number and can be used to correlate the frequency record with TCXO temperature, as shown in Table I.

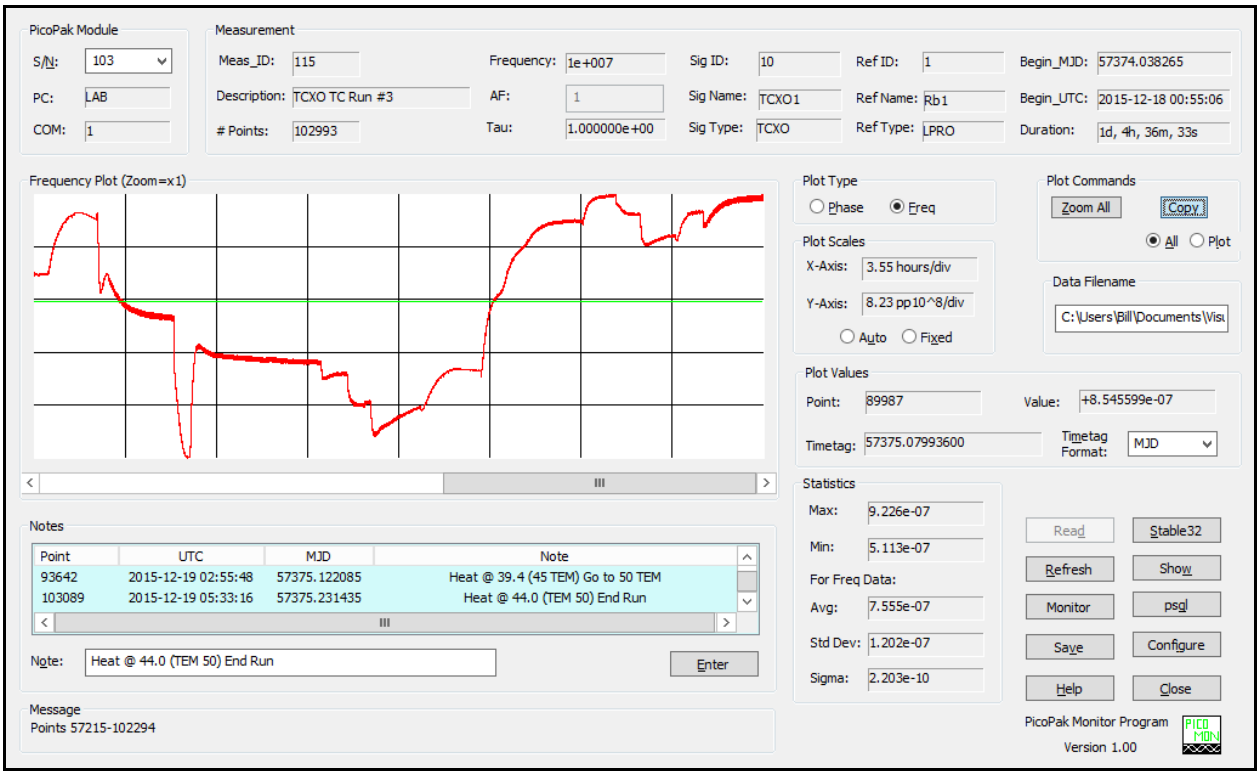

Figure 5. PicoMon Screen at End of TCXO Temperature Test

The peak-to-peak TCXO frequency excursion was 4.11×10^{-7} over +17°C to +44°C, less than half of its specified limit over 0°C to +50°.

TCXO TC Data	
TCXO Case Temperature, °C	TCXO Frequency, $pp10^7$
44.0	9.16
39.4	8.93
36.5	8.57
33.5	8.91
30.6	9.20
29.1	8.81
27.0	6.47
24.1	5.89
21.6	5.97
19.5	6.42
16.7	6.58

These TCXO TC data are plotted in Figure 6.

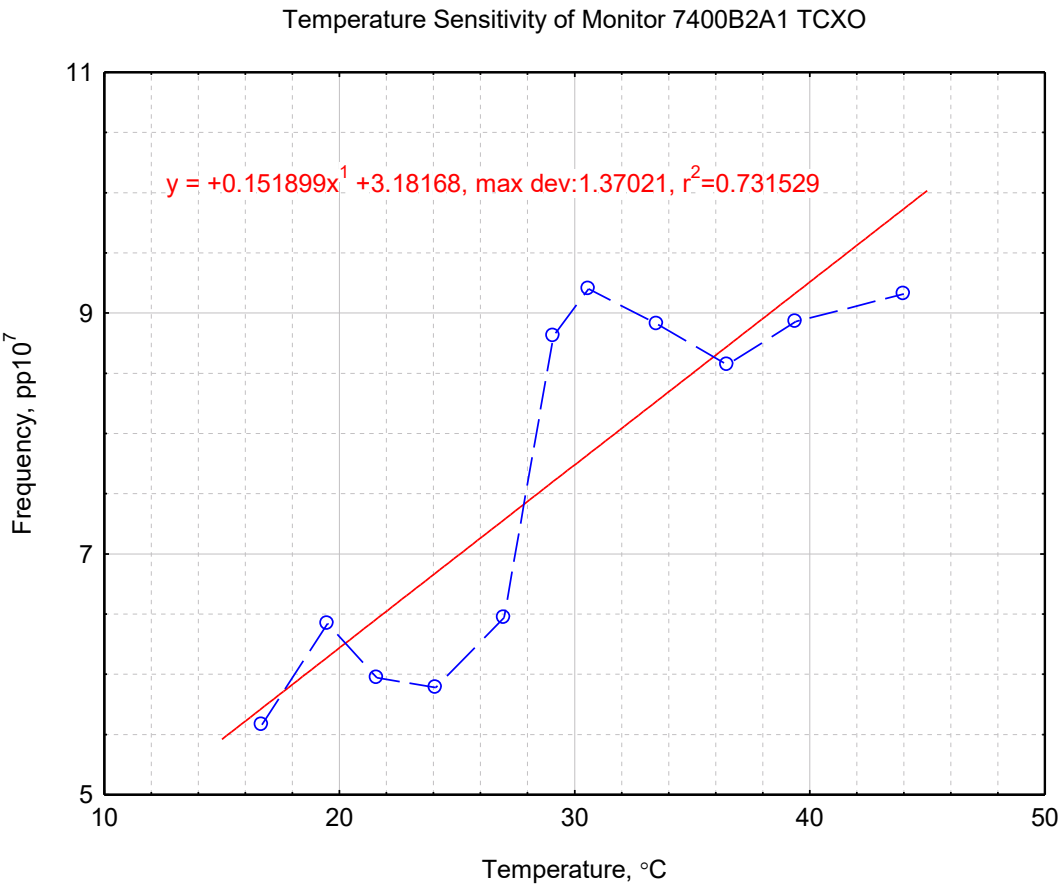

Figure 6. TCXO Frequency versus Temperature Characteristic

The cubic AT-cut quartz crystal resonator characteristic is more complex after compensation, and is still steepest around room temperature. The average TCXO TC slope between +15°C and +45°C is about $+1.5 \times 10^{-8}$/°C, a very significant improvement over its uncompensated value, and the slope near room temperature is about 8.6×10^{-8}/°C, about x12 lower than an uncompensated value of perhaps 1 ppm/°C.

The overall TXCO frequency data are shown in the Stable32 plot of Figure 7. The wider traces during some portions of the record are caused by chamber temperature cycling.

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PicoPak S/N 103 Clock Measurement Information 2015-12-19 05:48:14

Computer Name=LAB, COM Port=1
Measurement ID=115, Description=TCXO TC Run #3
Signal ID=10, Name=TCXO1, Type=TCXO
Reference ID=1, Name=Rb1, Type=LPRO
Nominal Frequency=1e+007 Hz
Averaging Factor=1, Tau=1.000000e+00 seconds
Beginning MJD=57374.038265, UTC=2015-12-18 00:55:06
# Data Points=102993, Run Duration=1d, 4h, 36m, 33s
```

Notes:

Point #	UTC	MJD	Note
2033	2015-12-18 01:28:60	57374.061802	Box Open @ 27.1C; Close Box
7702	2015-12-18 03:03:29	57374.127415	Box Closed @ 28.5C
8856	2015-12-18 03:22:43	57374.140776	Turn on Cooling; Go to around +5C TEM setpoint
19573	2015-12-18 06:21:20	57374.264811	Max Cooling @ 15.2C; Turn off cooling
19976	2015-12-18 06:28:02	57374.269471	Don't know what happened here
40235	2015-12-18 12:05:42	57374.503954	At max cool 16.7C TEM Set 5 - Go to TEM 10
43908	2015-12-18 13:06:54	57374.546460	At cool 19.5C TEM Set 10 - Go to TEM 15
47125	2015-12-18 14:00:31	57374.583696	At cool 21.6C TEM Set 15 - Go to TEM 20
54164	2015-12-18 15:57:50	57374.665167	At cool 24.1C TEM Set 20 - Turn off cooling
62464	2015-12-18 18:16:11	57374.761236	Self-heat@ 27.0 (TEM @ 22.9)
62656	2015-12-18 18:19:23	57374.763461	Go to heating @ 27C TEM setpoint
68232	2015-12-18 19:52:18	57374.827991	Heat: @ 29.2, TEM set @ 27 Not stable
76788	2015-12-18 22:14:55	57374.927023	Heat: @ 29.1, TEM set @ 27 Stable
76921	2015-12-18 22:17:08	57374.928562	Go to TEM 30 setpoint
81489	2015-12-18 23:33:15	57374.981425	Heat @ 30.6 (30 TEM) Go to 35 TEM
85041	2015-12-19 00:32:28	57375.022545	Heat @ 33.5 (35 TEM) Go to 40 TEM
89902	2015-12-19 01:53:28	57375.078800	Heat @ 36.5 (40 TEM) Go to 45 TEM
93642	2015-12-19 02:55:48	57375.122085	Heat @ 39.4 (45 TEM) Go to 50 TEM
103089	2015-12-19 05:33:16	57375.231435	Heat @ 44.0 (TEM 50) End Run

Statistics:
Maximum=9.226e-07, Minimum=5.113e-07, Average=7.565e-07
Standard Deviation=1.829e-06, Sigma (AF=1)=5.113e-07

Figure 6. PicoMon TCXO TC Measurement Notes

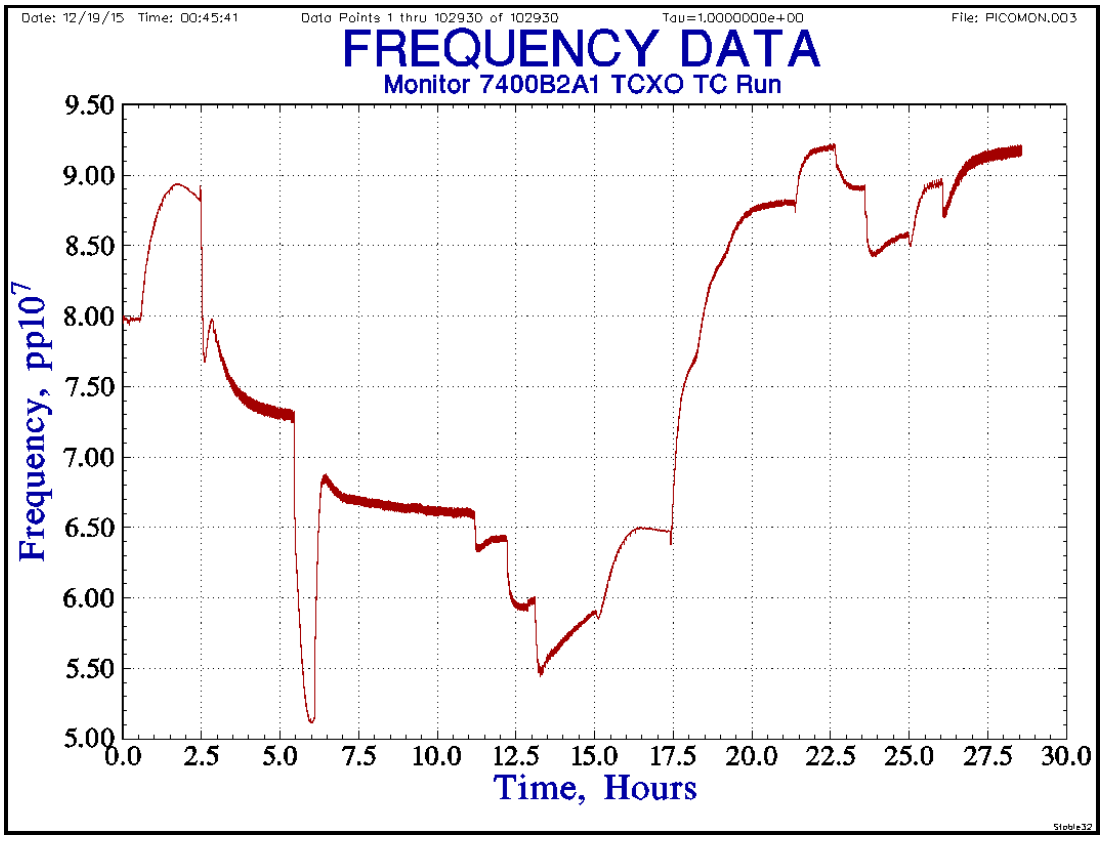


Figure 7. Monitor 7400B2A1 TCXO Frequency Data

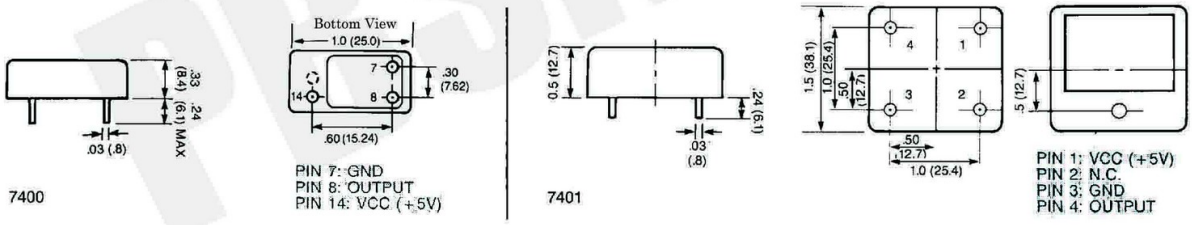
Appendix I

Monitor P/N 7400B2A1 TCXO Specifications

MONITOR PC

TCXOs

	7400 SPECIFICATIONS			7401 SPECIFICATIONS		
	7400A1A1	7400B2A1	7400D4A1	7401B2*2	7401B4*2	7401D7*2
OUTPUT FREQUENCY	5MHz to 20MHz			1MHz to 20MHz		
FREQUENCY STABILITY VS TEMPERATURE	±0.5 ppm +15°C to +35°C	±1 ppm 0°C to +50°C	±2 ppm −10°C to +60°C	±1 ppm 0°C to +50°C	±1 ppm −10°C to +60°C	± 2 ppm −20°C to +70°C
FREQUENCY STABILITY VS AGING	±1 ppm/year			±1 ppm/year		
SYMMETRY	60/40			60/40		
INPUT VOLTAGE	+5VDC ±5%					
OUTPUT LEVEL	TTL Compatible			CMOS, TTL, 1.0V Peak to Peak Clipped Sine Wave		
INPUT CURRENT	20mA max.			20mA max. 12 typical		
OPERATING TEMPERATURE RANGE	+5°C to +45°C	−10°C to +60°C	−20°C to +70°C	−10°C to +60°C	−20°C to +70°C	−30°C to +75°C
FREQUENCY ADJUSTMENT	±5 ppm min. by means of internal trimmer			±5 ppm min. by means by internal trimmer		



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December 19, 2015