ADVANCED XTAL PRODUCTS

APPLICATION NOTE AXAN-011 – Rev. 3.0

Handling and Testing of Crystal Oscillators

This application note provides answers to some frequently addressed issues related to the testing of crystal oscillators.
For more details about test and measurement methods of crystal oscillators please refer to IEC standards 60679-1 and 62884, and to MIL-PRF-55310.

1. **ESD (Electrostatic Sensitive Devices) Handling**

   Crystal oscillators are electrostatic sensitive devices. Direct touching of the terminals with the fingers must be avoided. Proper handling according to the established ESD handling rules as in IEC 61340-5-1 and EN 100015-1 is mandatory to avoid degradations of the oscillator performance due to damages of the internal circuitry by electrostatics. If not otherwise stated, our oscillators meet the requirements of the Human Body Model (HBM) according to IEC 61000-4-2

2. **Handling**

   Excessive mechanical shocks during handling as well as manual and automatic assembly have to be avoided. If the oscillator was unintentionally dropped or otherwise subject to strong shocks, it should be verified that the electrical function is still within specification.

3. **Power supply**

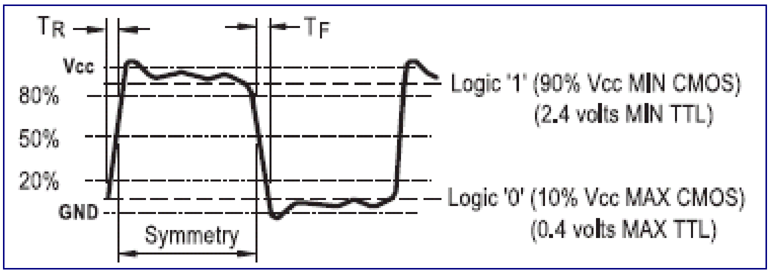
   To avoid uncontrolled potentials, crystal oscillators should be powered up only after all terminals are connected properly. "Hot plug-in" into a fixture which is already connected to the supply power must be avoided.
   Wrong polarity or excessive supply voltage can cause a permanent damage of the oscillator.
   It is highly recommended to add one or two blocking capacitors with shortest possible wiring between the DC power input (VCC) terminal and the ground (GND) terminal of the oscillator. Typical values are 10 nF (X7R) and 100 pF (C0G). An additional bulk capacitor in the µF range may be inserted anywhere on the board.
   Good engineering practice is to use ground and supply voltage planes on the (multilayer) printed circuit board.
   If low phase noise of the oscillator output signal is an issue, special care must be taken in the selection of a low-noise, low-spurious power supply. For reference measurements the operation from battery is highly recommended.

4. **RF Output**

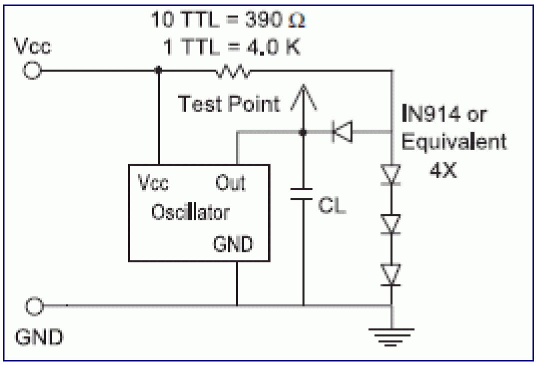
The RF Output has to be terminated with the specified load as follows.

a. **Sine wave output with 50 Ω termination**
The 50 Ω termination should either be connected directly at the RF output terminal or at the end of a 50 Ω coaxial cable.
If multiple connections (e.g. to oscilloscope or power meter and frequency counter) are required, a 50 Ω power splitter or a coupler should be used.
For accurate amplitude measurement it must be assured that the input impedance of the test instrument is accurately 50 Ω with a VSWR within the specified limits. This is not necessarily the case for some oscilloscopes and frequency counters. In that case a 10 dB attenuator should be inserted at the instrument input.

b. **Single square wave (logic) outputs**

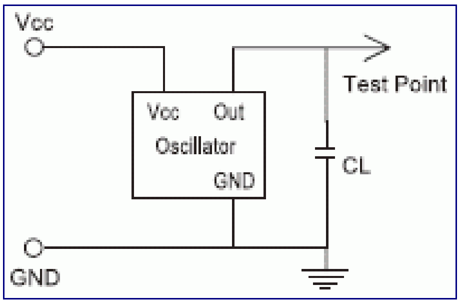


i. **TTL output**



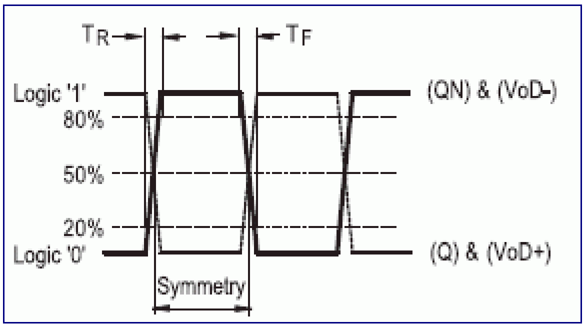
CL = 5 pF per gate (fan-out). It includes the input capacitance of the probe or oscilloscope

ii. **(H)CMOS and LVCMOS output**

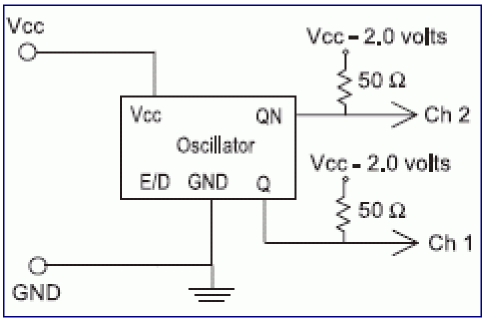


CL = 15 pF or 50 pF, depends on the specification. It includes the input capacitance of the probe or oscilloscope

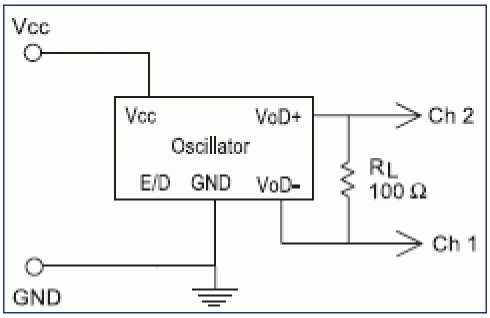
c. Two Complementary square wave outputs



i. **PECL output**



ii. **LVDS output**



<u>Note:</u>
Coaxial cables, which are not terminated with their nominal impedance (usually 50 Ω) will cause distortion and degradation of the output signal because of two reasons

– Impedance mismatch generates reflections, which are causing distortion of the waveform. The impact is in particular dramatic for square-wave logic output signals.
– A non-terminated coaxial cable shows an input impedance about 100 pF per meter capacitance to ground (as long as the cable length is small compared to a quarter wavelength). This capacitance in connection with the input capacitance of the connected device (e.g. test instrument) creates a capacitive overload condition, which distorts and degenerates the output voltage.

5. Electronic Frequency Control (EFC)

Crystal oscillators which are providing means for Electronic Frequency Control (EFC) must be properly connected to assure operation at the nominal frequency within the specified tolerances. In any case it should be avoided to leave the EFC (VC) input floating.

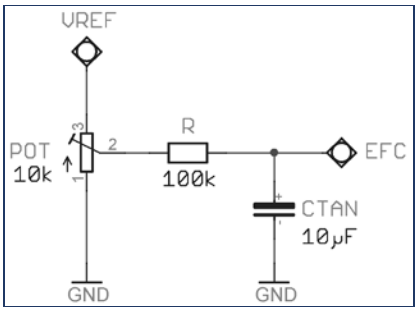
a. External Control Voltage

If the EFC input is fed by an external DC control voltage, care must be taken, that ground loops with the DC supply current are avoided by directly applying the control voltage between the VC and the Ground (GND) terminal of the oscillator.
<u>Note:</u>
Noise from the EFC supply may degrade the phase noise and jitter performance of the RF signal. Therefore, batteries or ultra- low noise DC supplies are necessary for accurate phase noise and jitter measurements. To avoid noise entering the EFC port the EFC pin should not be left floating open.

b. External Potentiometer

If an external potentiometer is used for frequency control, its resistance should be lower than the input impedance of the EFC (VC) input by a factor of at least five.

Certain oscillators (TCXO and OCXO) provide a separate reference voltage output (VREF) terminal for supplying the frequency control potentiometer. This reference voltage has low noise and its stability over temperature is factored in the temperature compensation process during manufacturing. The connection scheme is shown below.



The potentiometer POT should be a low noise (Cermet or metal film) type and its resistance value must be chosen such, that the maximum allowed current drain of the VREF output is not exceeded. 10 kΩ will be appropriate in most cases. Additional filtering at the VC input is highly recommended.

6. Test of frequency stability over temperature

Important definitions

Operating temperature range:

temperature range, within which the oscillator maintains the specification.

Operable temperature range:

temperature range, in which the oscillator will still operate, but certain parameters may be exceeded.

Frequency-temperature stability:

The maximum deviation of the oscillator frequency, with no reference implied, over the operating temperature range at nominal supply and load conditions, other conditions constant.

f-T stability = $\pm(f_{max}-f_{min})/(f_{max}+f_{min})$

Initial Frequency-temperature accuracy:

The maximum deviation of the oscillator frequency referred to nominal frequency over the operating temperature range at nominal supply and load conditions, other conditions constant.

f-T accuracy = $\pm$ MAX[δf_{max},δf_{min}],

where $\delta f_{max} = |(f_{max}-f_{nom})/f_{nom}|$

$\delta f_{min} = |(f_{min}-f_{nom})/f_{nom}|$

Note: For SPXO and VCXO sometimes the frequency at reference temperature f_{ref} (25°C) is used as reference instead of f_{nom}.

Roemerring 9
D-74821 Mosbach
Germany
web : www.AXTAL.com
fon : +49 (6261) 939834
fax : +49 (6261) 939836
e-mail: info@axtal.com

Test procedure:

The unenergised oscillator shall be placed in the temperature chamber and connected to the specified load. For VCXO, VC-TCXO and VC-OCXO the Frequency Control Voltage V_C shall be set according to the specification. It must be assured, that V_C remains constant during the temperature test. Then the specified supply voltage shall be applied.

The oscillator shall be subject to a moderate air circulation of 2 m/s to 3 m/s. This is especially important for measuring OCXO. If measured in still air, the temperature control of the internal oven may be no longer working properly, if the chamber temperature approaches the upper bound of the operating temperature range.

The temperature ramp should be less than 5K/min for PXO and VCXO, and less than 1K/min for OCXO and for units with higher thermal mass. The chamber shall be allowed to stabilize at the specified temperature by an appropriate soak time. The measurement of output frequency (and amplitude) shall be performed with sufficient accuracy and resolution after reaching thermal equilibrium.

7. Test of Phase Noise

Several precautions have to be taken to achieve accurate results.

- **a.** The supply voltage must have low noise. Switching power supply units (PSU) shall be avoided. Operation from battery is recommended. A high-capacitance blocking capacitor of >100 µF is recommended.
- **b.** The electronic frequency control (EFC) input is very sensitive to noise, as it directly modulates the crystal oscillator stage. Therefore the control voltage (V_C) must come from an extremely-low-noise DC source, preferably a battery.
  Some phase noise test instruments offer a suitable source. The control voltage should be connected through a shielded (coaxial) cable.
  If the oscillator comprises a reference voltage (VREF) output, it is highly recommended to derive the control voltage from this according to the circuit shown under paragraph 5b.
  Alternatively the V_C input may be connected to the ground pin.
- **c.** To avoid interferences with spurious responses from the environment, it is recommended to place the device under test (DUT) in an electromagnetically shielded cabinet.
- **d.** Because of its inherent piezoelectricity, the crystal unit in the oscillator is very sensitive to any mechanical vibration. Therefore the oscillator under test should not be placed on the same table as the test equipment with its vibrations caused by fans and transformers.
- **e.** If very low noise floor levels have to be measured, care must be taken that the noise floor of the test instrument is sufficiently low and that the number of correlations is high enough (in cross-correlation test mode).

8. Test of Short-term Stability

The recommended measure for short-term stability is the so-called Allan Deviation (ADEV) or the Overlapping Allan Deviation (OADEAV). See IEC 62884-4.
The usage of modern high-resolution counters may lead to erroneous results because of the internal interpolation process.
The following pre-cautions must be taken to avoid interferences and trigger errors:

- Avoid ground loops in the test set-up
- Use phase-stable cabling
- The measured signals must have fast rise and decay time with low added jitter and hysteresis by the square-wave generation.
- For the supply voltage and the Control Voltage the same considerations have to be taken into account as for Phase noise measurements (see paragraph 7).
- The ambient temperature must be as stable as possible. Thermal isolation against the environment and airflow is highly recommended. Acoustic noise and vibrations must be strictly avoided.
- Electromagnetic shielding of the oscillators under test may be necessary in case of higher electromagnetic sensitivity of the oscillator.

Prior to the computational analysis the data set should be reviewed for consistency. Outliers, i.e. phase or frequency jumps should be identified and removed, if it is certain, that these are caused by external influences and do not originate from the signal generators.

Before starting the data acquisition, the oscillators must be continuously operating over a longer stabilization time. Temperature stabilized oscillators (OCXO) require a longer stabilization time than the other oscillator types (SPXO , VCXO and TCXO).
As a rule of thumb, the standard value for stabilization should be not less than 12 hours, for OCXO and other reference measurements the oscillators under test should be stabilized for at least for 24 hours

9. Test of Frequency Aging

The oscillator shall be maintained at the specified temperature, tolerance and stability for a continuous period of 30 days. After insertion into the oven, the oscillator shall be allowed to equilibrate with chamber air temperature. Then the oscillator shall be energised and stabilized for 1 hour prior to beginning the measurement acquisition cycle. The initial frequency of the oscillator shall be measured immediately after the stabilization period (1 hour) and thereafter at intervals not to exceed 72 hours (except one maximum interval of 96 hours per 30-day period is permitted) for a minimum of 30 days.
The aging temperature shall be +70°C or the highest specified operating temperature, whichever is lower.

AXTAL GmbH & Co. KG
Roemerring 9
D-74821 Mosbach
Germany
web : www.AXTAL.com
fon : +49 (6261) 939834
fax : +49 (6261) 939836
e-mail: info@axtal.com

After insertion into the oven, the crystal oscillators shall be stabilized at an aging temperature for 48 hours prior to beginning the measurement acquisition (unless otherwise specified). The frequency of each unit shall be measured immediately after the stabilization period, and then a minimum of four times per week at intervals of at least 20 hours.

a. Aging test of non-temperature stabilized oscillators

- Power on for at least one hour.
- Initial measurement of frequency at reference temperature e.g.25°C.
- Storage in oven at T_{oven} with T_{oven} e.g. 85 °C or TBD but not higher than the maximum operable temperature.
- Intermediate measurements after 1, 2, 5, 10, 20 days.
- For the measurement, remove the oscillator from oven, and store at room temperature for 1 hour to avoid temperature shocks
- Measure the frequency at reference temperature
- Final measurement after 30 days of frequency @ reference temperature

b. Aging test of OCXO

- OCXO remains at room temperature
- Power on for at least two hours.
- Intermediate measurements of frequency at 5 times per week (AXTAL: once every hour).
- Final measurement of frequency after 30 days.
- Data fitting and evaluation from the data starting at day 3.

The measurements obtained shall be fit using the method of least squares to one of the functions:

- Logarithmic Fit: $f(t)_{Log} = a_0 + a_1 \cdot \log(a_2 \cdot t + 1)$
- Polynomial Fit: $f(t)_{Poly} = a_0 + a_1 \cdot t + a_2 \cdot t^{0.5}$,

where f(t) is the frequency of the crystal oscillator, t days after the start of the aging cycle, and a_0, a_1, a_2 are constants to be determined from the least squares fit.
The total frequency change and the aging rate at the end of the specified period shall be determined from the above equation using the constants determined from the least squares fit.
The projected total frequency change for a time period should be calculated with the following formulas:

- Aging per day (aging rate) = $f(d_0 + 1) - f(d_0)$
- Aging per month = $f(d_0 + 30) - f(d_0)$
- Aging per year = $f(d_0 + 365) - f(d_0)$,

where f(t) is one of the aging approximations a) or b) with the fitted parameters a_0, a_1, and a_2, and d_0 the last day of the aging test plus 30 days.
Note:
instead of the frequency f (in Hz) usually the relative frequency $\Delta f/f$ (in ppm or ppb) is used.

AXTAL GmbH & Co. KG
Roemerring 9
D-74821 Mosbach
Germany

web : www.AXTAL.com
fon : +49 (6261) 939834
fax : +49 (6261) 939836
e-mail: info@axtal.com

10. Screening according to MIL-PRF-55310

100 % screening tests are performed on high-reliability oscillators. For high-reliability space applications the screening level S is applied, for other high reliability applications the screening level B is used.

For Class 1 oscillators (discrete technology) and Class 3 oscillators (mixed technology) the screening procedure comprises the following steps:

Test	Level S	Level B
Random vibration	MIL-STD-202, meth. 214, cond. I-B, 5 min/axis	N/A
Thermal shock	MIL-STD-202, meth. 107, cond. A-1	MIL-STD-202, meth. 107, cond. A-1
Electrical test: input current/power Output waveform Output level As specified	 X X X X	 N/A N/A N/A X
Burn-in (load)	240 h @ max. operating temperature	160 h @ max. operating temperature
Electrical test: input current/power Output waveform Output level As specified	 X X X X	 N/A N/A N/A X
Seal test	MIL-STD-202, meth. 112	MIL-STD-202, meth. 112
Radiographic	MIL-STD-202, meth. 209	N/A

For details please refer to the latest edition of MIL-PRF-55310

Mosbach, December 2018

BN/HH/ME