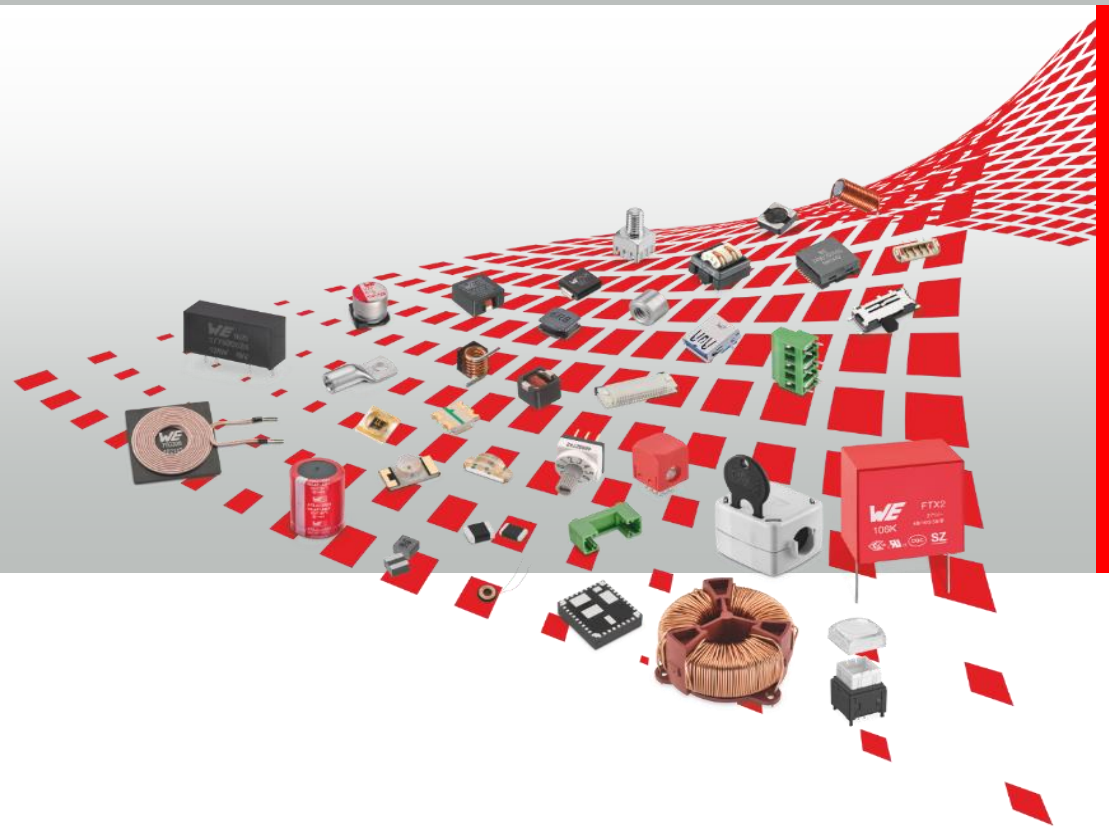
TECHNICAL ACADEMY

IQD

WÜRTH ELEKTRONIK

“Back to Basics” – specifying quartz crystals & oscillators

more than you expect



Quartz Crystals and Oscillators

Digital Days Webinar series for 2021

Paul Smith

Appications Support, IQD

Introduction

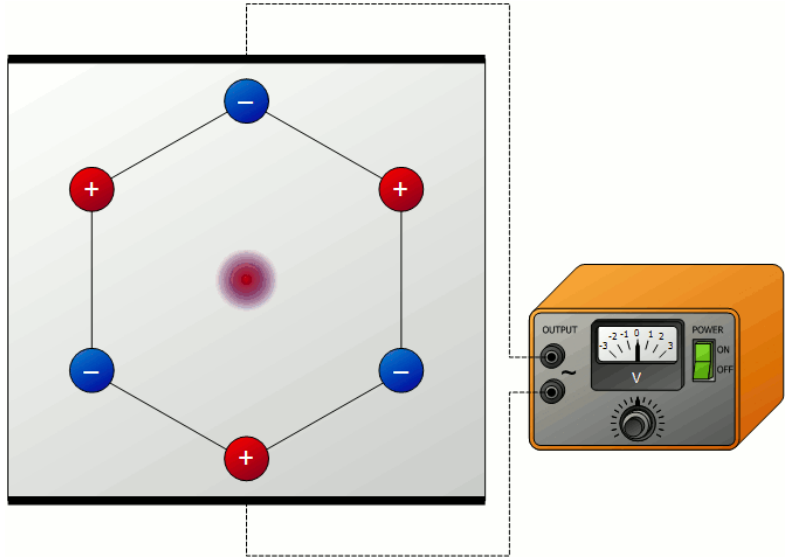
- Paul Smith
- Applications Support Engineer
- IQD Frequency Products Ltd, UK
- IQD has been part of the Wurth Group since 2017
- info@iqdfrequencyproducts.com

Agenda…..”Back to Basics”

- Why we use quartz…….inc processing quartz
- Specifying quartz crystals …….inc information regards resistance (ESR)
- Specifying quartz oscillators……..inc noise performance
- Designing a new device…….inc crystal and oscillator modelling

Why we use Quartz

- Quartz is a crystalline form of silicon dioxide (SiO_2)
- Quartz is used because of it's '***Piezo-Electric***' properties …..derived from Greek, and means "to press".
- By applying an electrical signal to the quartz, we can get it to resonate at a frequency depending upon its dimensions.
- This resonant frequency provides the basis for an accurate electronic timing signal.



Quartz crystal

- Natural quartz isn’t used anymore to produce frequency products, we use synthetically grown quartz.

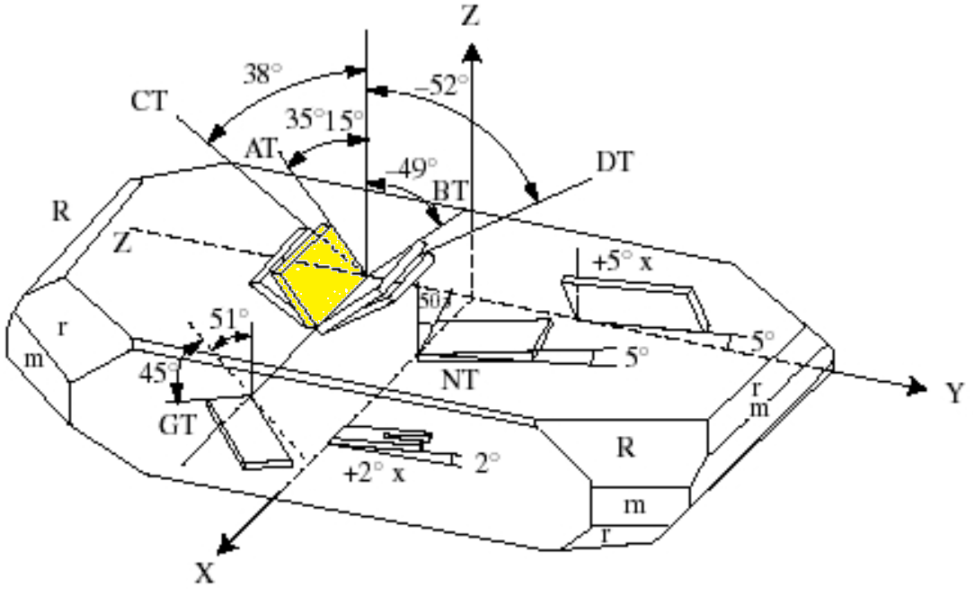
Natural Quartz

Synthetic grown quartz

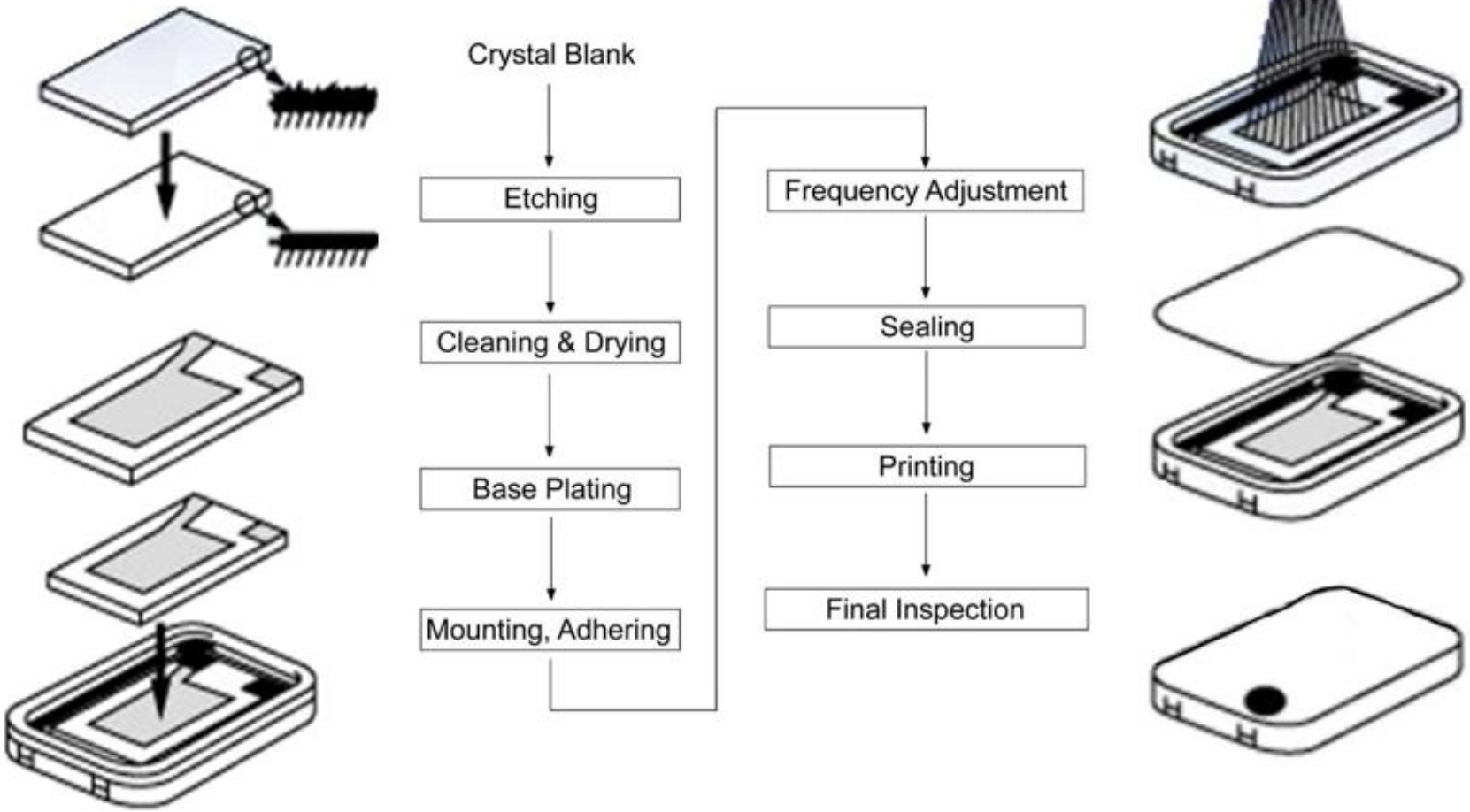
Synthetic quartz is grown in a device called an ‘autoclave’, which is a high-pressure, high-temperature container where the quartz bars chemically grow over a number of months.

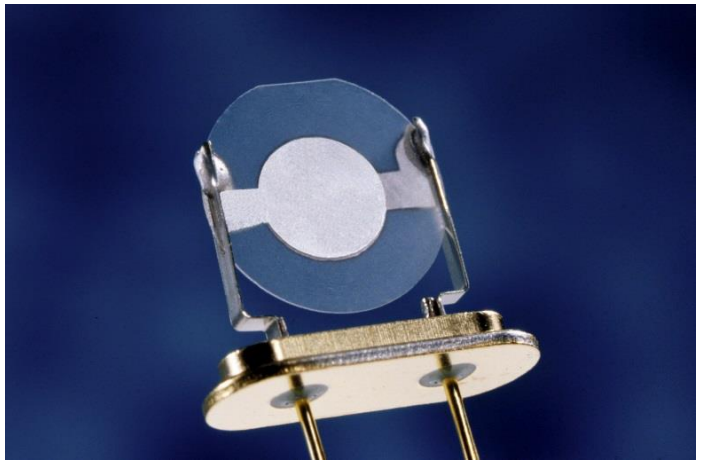
Producing quartz ‘blanks’

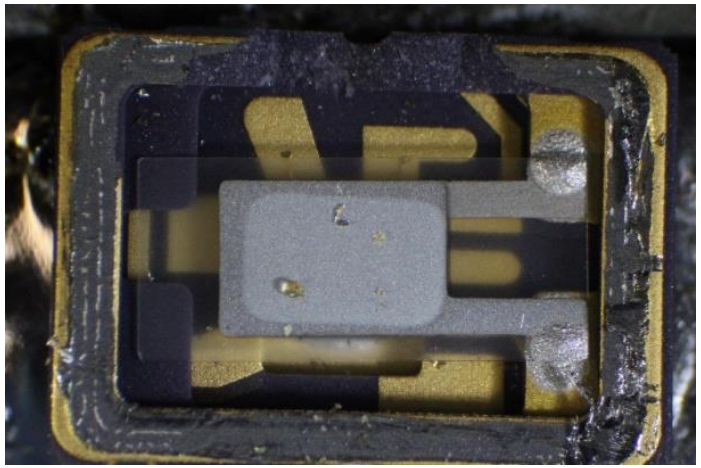
- The quartz bar is accurately cut into slices called ‘wafers’
- The quartz is usually cut at an angle called an ‘AT’ cut which is the commonest cut used
- The cut quartz is then processed into round or rectangular parts and is now termed a ‘blank’
- The blanks are ground down (lapped) to the thickness required for the specification required



Processing quartz blank







6 Key parameters to specify for a quartz crystal

- **Frequency** (kHz or MHz).....the nominal frequency required.
- **Package**……can be a size, e.g. 3225mm or a type such as HC49
- **Frequency Tolerance** at 25 °C (± ppm)……a measure of the frequency accuracy at room temperature.
- **Frequency Stability** (± ppm)……a measure of how the frequency changes with temperature.
- **Operating temperature range** (°C)……example standard ranges are -10+60, -20+70, -40+85
- **Load capacitance** (pF)……the load value that your circuit should present to the xtal.

Crystal Specification

Tolerance at 25°C
i.e. ±30ppm

Temperature Range
in °C

10MHz HC49 30/50/-40 to 85/16

Crystal Frequency

Model /
Packaging type

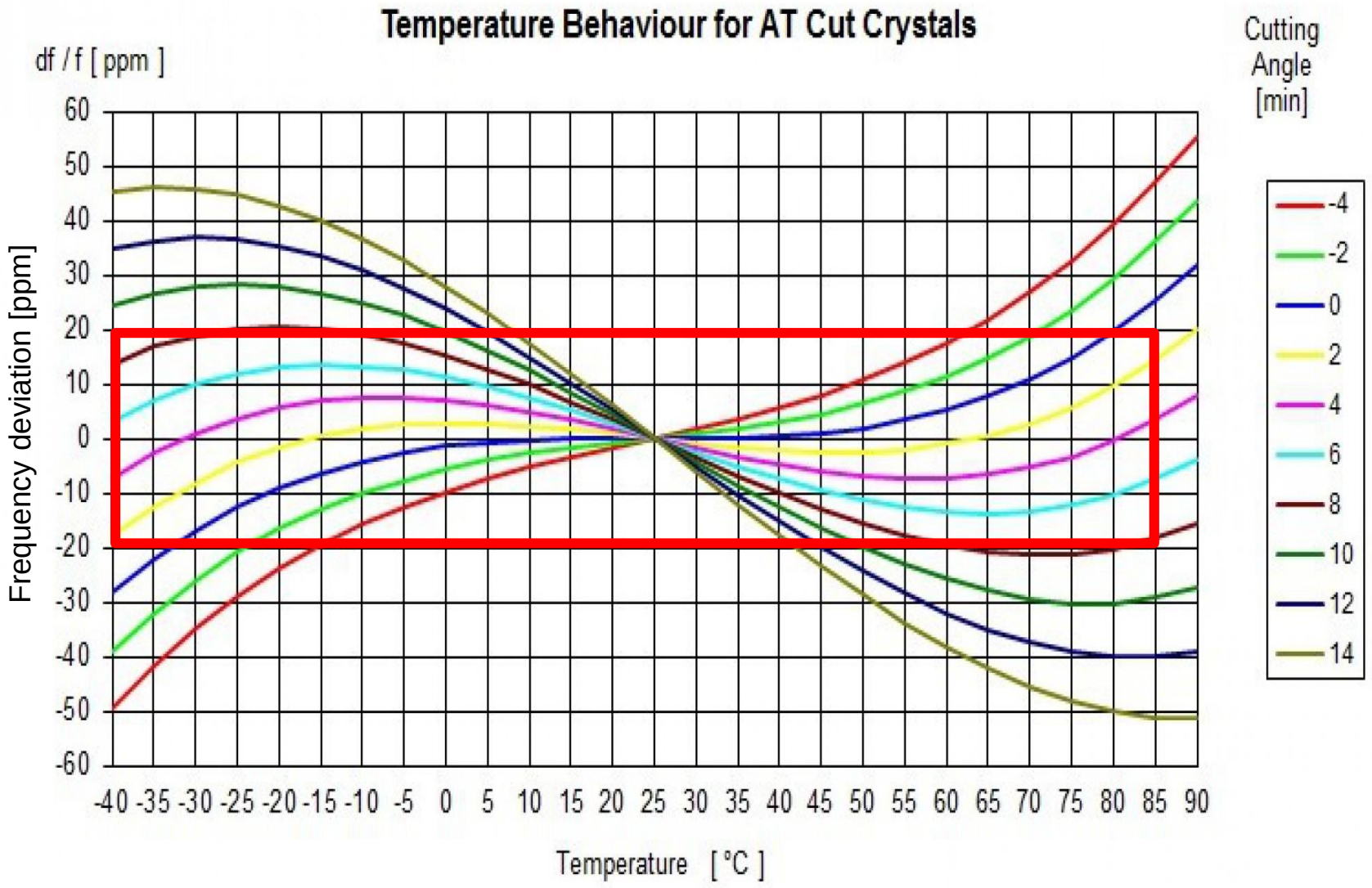
Stability over temperature
range. i.e. ±50ppm

Load Capacitance
i.e. 16pF

Frequency Tolerance

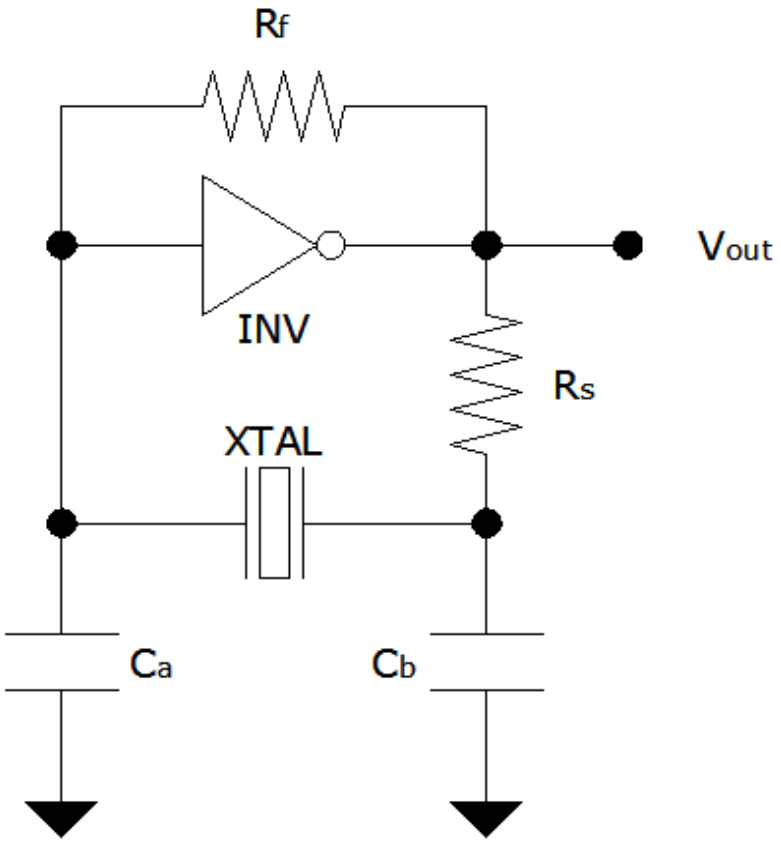
- Tolerance defines the frequency accuracy at room temperature (25 °C)
- The tolerance value is set during manufacture.
- The quartz crystal only oscillates within this tolerance value if the external oscillation circuit provides the correct load capacitance value to the xtal.
- Typical tolerance values:
- ±10ppm = tight tolerance
- ±20ppm
- ±50ppm
- ±100ppm = wide tolerance

Frequency stability and operating temperature range



- The frequency stability describes the maximum frequency deviation over the operating temperature range.
- The cutting angle of the quartz blank defines the behavior of the frequency over temperature.
- The red box indicates cut angles that fall within +/-20ppm over -40+85C

Calculation of the load capacitance



- Load Capacitance:

$$C_{Load} = \frac{C_a * C_b}{C_a + C_b} + C_{stray}$$

- C_{stray}: includes the PCB stray capacitance and the IC input capacitance, is typically between 2 pF and 5 pF

- Note: you cannot measure the stray capacitance in the circuit so we start with an estimated value.

- Changing the values of Ca and Cb will move the frequency up and down to optomise the frequency accuracy at room temp.

Additional Crystal Parameters

- Sometimes there are extra xtal parameters that may be required in addition to the standard values.
- Examples include:-

- **ESR** (Equivalent Series Resistance)…….low values of ESR are sometimes specified in IC data sheets. For example, a standard ESR limit for a xtal might be 100 Ohms max but the IC needs 60 Ohms max.

- **Ageing**……some applications need an ageing limit of X-ppm for Y-years.

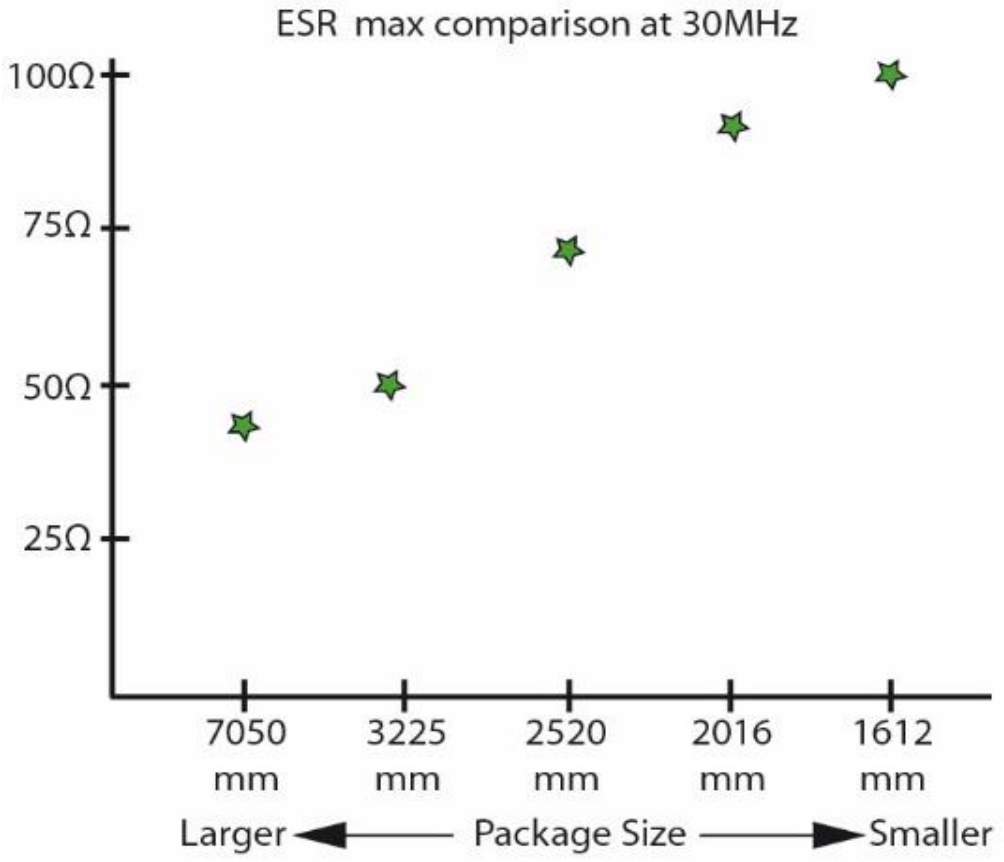
- **Pulling**….the frequency of a xtal can be changed by altering the load capacitance presented to the xtal. The pulling obtained is mainly dependent on the size of the quartz and the electrodes.

- **Drive level**….small xtal packages generally have low drive levels but sometimes the IC used may apply a drive level above the devices standard limit. e.g. std drive = 100µW max but IC specifies 200µW max

- Please contact IQD to discuss any non-standard values required for your specific application as it is possible to accommodate most requests.

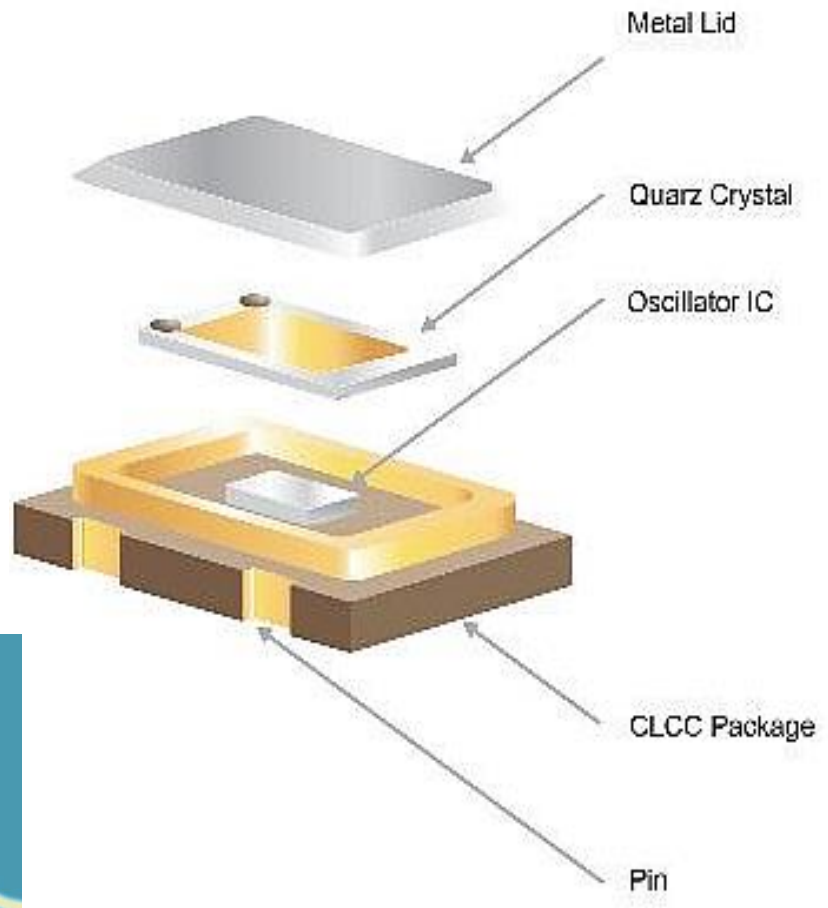
ESR – Equivalent Series Resistance

- ESR has become a common discussion point when specifying xtals.
- As applications shrink and xtal packages shrink, the maximum ESR value increases.
- Thus it is important to have enough ‘gain’ in your oscillator circuit to overcome increases in ESR.
- On IQD data sheets we specify the maximum ESR for a given frequency range.
- However in practice, the typical ESR is generally lower than the maximum value.
- We are able to discuss any non-standard ESR values you may require.



Clock oscillators

- An oscillator is a quartz crystal mounted together with an IC in one package.
- The IC contains the additional circuitry needed to make the quartz crystal resonate.
- The customer only needs to apply a supply voltage and the device provides an output signal at the frequency required.



6 Key parameters to specify an oscillator

- **Frequency** (kHz, MHz).....the nominal frequency required.
- **Package** (size in mm or type such as DIL)…… e.g. 7x5mm SMD
- **Frequency Stability** (± ppm)……a measure of how the frequency changes with temperature.
- **Operating temperature range** (°C)……example standard ranges are -10+60, -20+70, -40+85
- **Output type**……. e.g. HCMOS, Clip-sine, Sine, LVDS, LVPECL
- **Supply voltage**…... e.g. 3.3V, 3.0V, 2.8V, 2.5V, 1.8V

Clock Oscillator Specification

Signal output type

Temperature Range

40MHz IQXO-791 HCMOS 50ppm -40 to 85 3.3V

Frequency

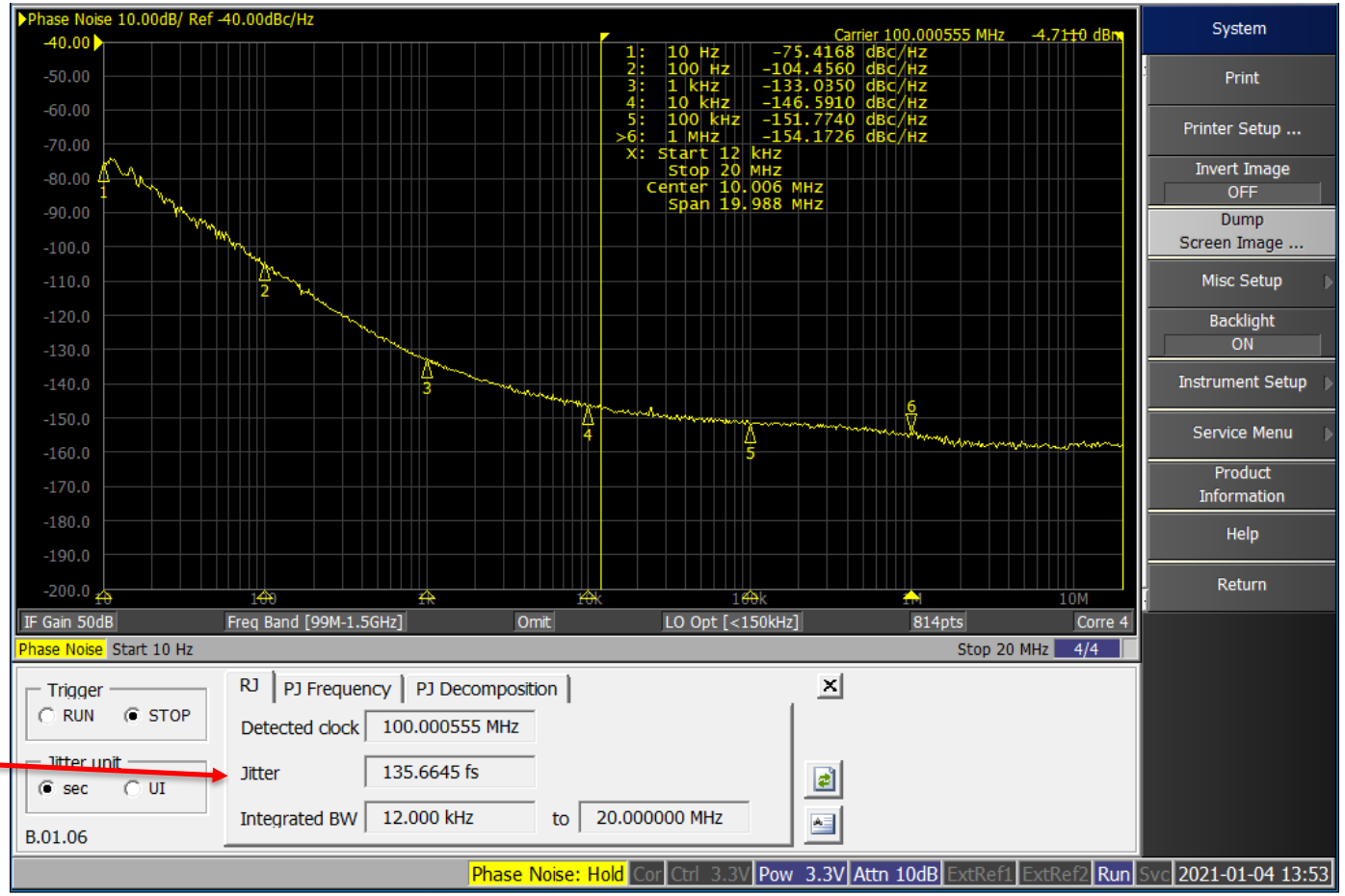
Model / Packaging type

Stability over temperature range. i.e. ±50ppm

Supply Voltage

Oscillator Noise Performance

- A very common criteria required for an oscillator is its noise performance.
- All oscillators produce frequencies other than the main response.
- A way of showing performance graphically is with a phase noise plot as per the example.
- IQD can measure phase noise (freqs≥10MHz).
- Phase noise plots also indicate jitter values.



Designing a new device - Quartz crystal or Clock oscillator

Quartz crystal (passive device):

- Low cost
- Requires an additional oscillation circuit:
  - Customer has to design oscillator circuit.
  - Customer has to build extra circuitry.
  - Higher component count on PCB.

→Do you have the time and knowledge to do this?

Quartz oscillator (active device):

- Higher cost than a quartz crystal
- No additional oscillation circuit:
  - No oscillation circuit design required.
  - Lower component count on PCB.
  - Less design knowledge required.

→Oscillator is generally “plug-n-play”!

Designing a new device

- Xtal or an oscillator?
- Do you have an existing full specification requirement?

- What is the application …….. commercial, industrial, high-environmental such as down hole?
- What IC are you using? ……. see the IQD chipset match search facility on web site for recognized devices.

Chipset Match Search

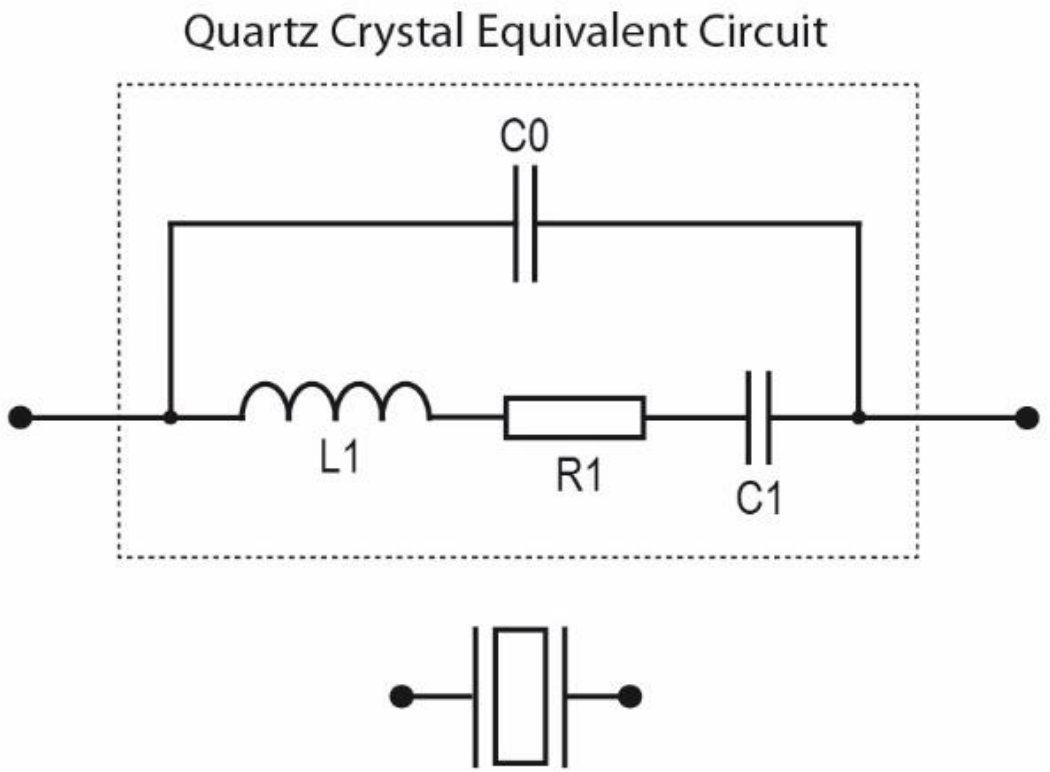
- https://www.iqdfrequencyproducts.com/

- What are the critical parameters to meet ……frequency, pkg size, stability, temperature range?

Crystal Modeling

- If you need to perform electrical modeling of quartz xtals then IQD can provide motional parameter values.

- **C0** = shunt capacitance (static capacitance)
- **C1** = motional capacitance (mechanical elasticity)
- **R1** = motional resistance (internal losses)
- **L1** = motional inductance (mechanical mass)

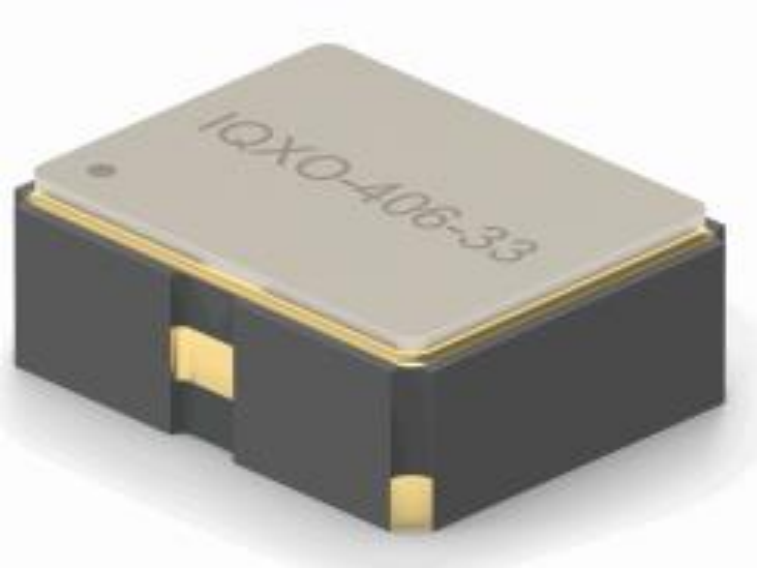


- We can also advise on other values such as:-
- Trim or pullability – altering the xtal frequency.
- Frequency tolerance at offset load capacitance values.
- Q value – a measure of xtal ‘activity’.

Physical Modeling

- IQD is able to provide ‘STEP’ files (.stp) for 3D mechanical modeling of both crystals and oscillators.

- Many of our standard models already have .stp files on our web site.



Cross Referencing of Competitor Parts

- IQD has a large product portfolio so if you are having supply issues or need another source then please contact us.
- Over the years we have cross-referenced many competitor parts where we can support equivalent specs from our product range.
- Custom designed parts are also possible if they are techically and commercially feasible.

Questions……..

info@iqdfrequencyproducts.com

Thank you and stay safe!