WE MEET
@ DIGITAL DAYS

WHY? WHAT? HOW? : A BEGINNERS GUIDE TO CRYSTALS AND OSCILLATORS

Chris Pavey.
Malcolm Lennox.

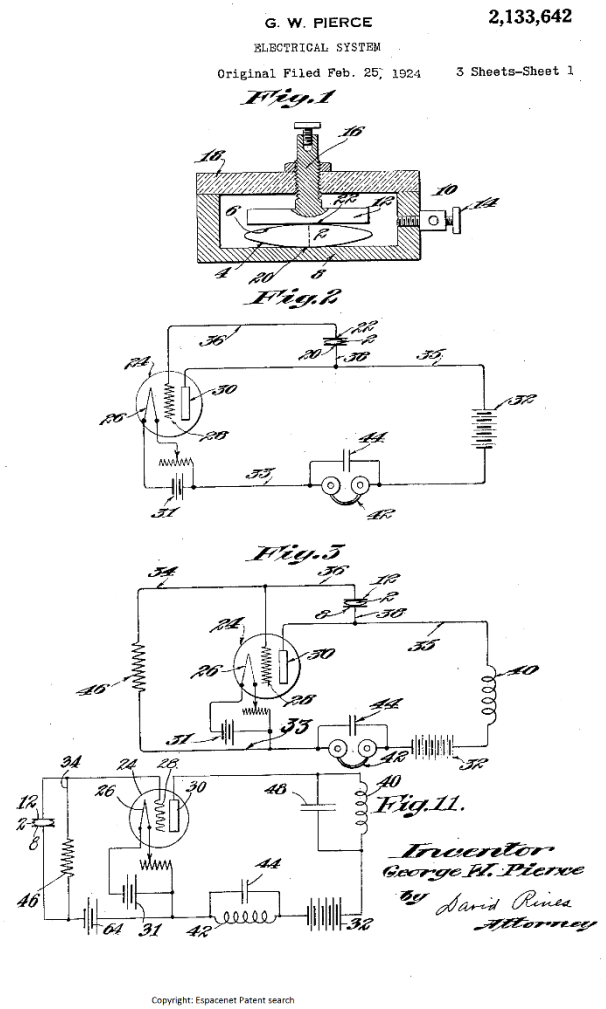
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Q. BRIEF HISTORY OF CRYSTALS AS A FREQUENCY DEVICE

- **1880 Jacques and Pierre Curie notice and investigate the piezo-electric effect in quartz.**
- **1893 Lord Kelvin further investigates piezoelectric effect in quartz crystals and develops a value for the piezo-electric constant.**
- **1917 Oscillator is developed by Alexander Nicholson of Bell Laboratories using Rochelle Salt and patents the idea in 1918.**
- **1921 Prof. W. G. Cady at Wesleyan University patented a quartz crystal oscillator. For this patent, he used a quartz crystal resonator to control the frequency of an oscillator he also described the use of quartz bars and plates as frequency standards and wave filters. It is generally accepted that Cady was the first to use a quartz crystal to control the frequency of an oscillator circuit.**
- **1923 Harvard professor, G W Pierce develops a crystal oscillator circuit, which places the crystal between the grid and anode of the valve/vacuum tube. This is a predecessor to the Pierce oscillator configuration.**

Q. BRIEF HISTORY OF CRYSTALS AS A FREQUENCY DEVICE

- **1924 George W. Pierce applied for a patent for an electrical system for self-sustaining mechanical vibrations under vibratory electrical stimulus that we know today as the Pierce oscillator.**
- **1927 First quartz crystal oscillator standard developed by Warren Marrison of Bell Laboratories.**



Q. WHY DO CRYSTALS VIBRATE?

- **Crystalline structure of silicon dioxide**

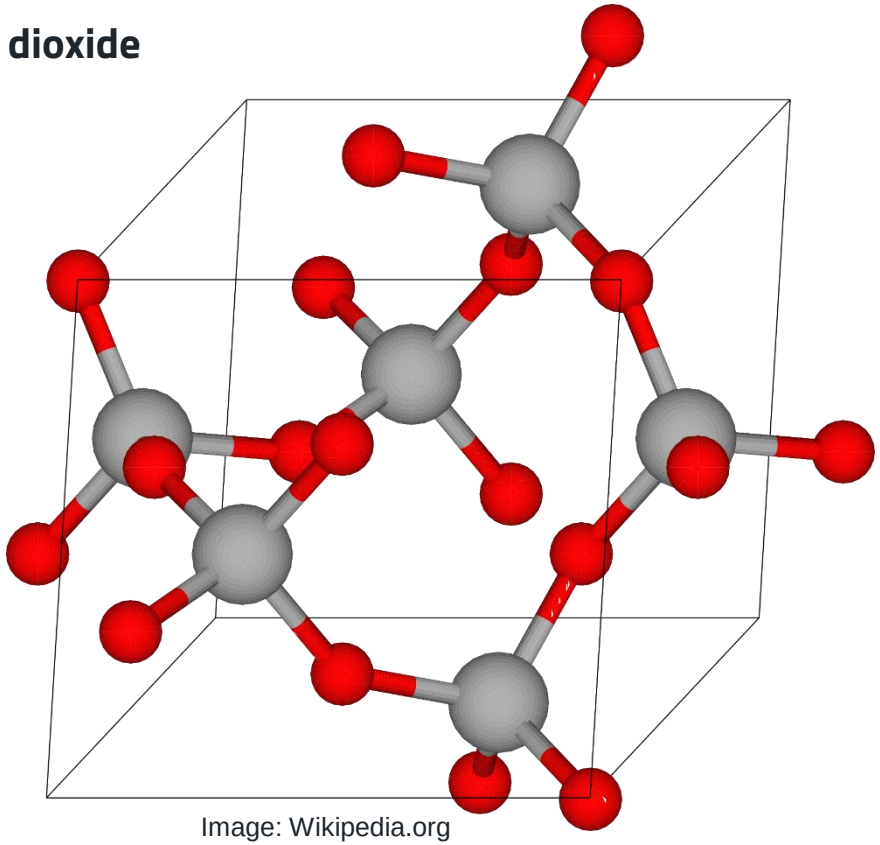
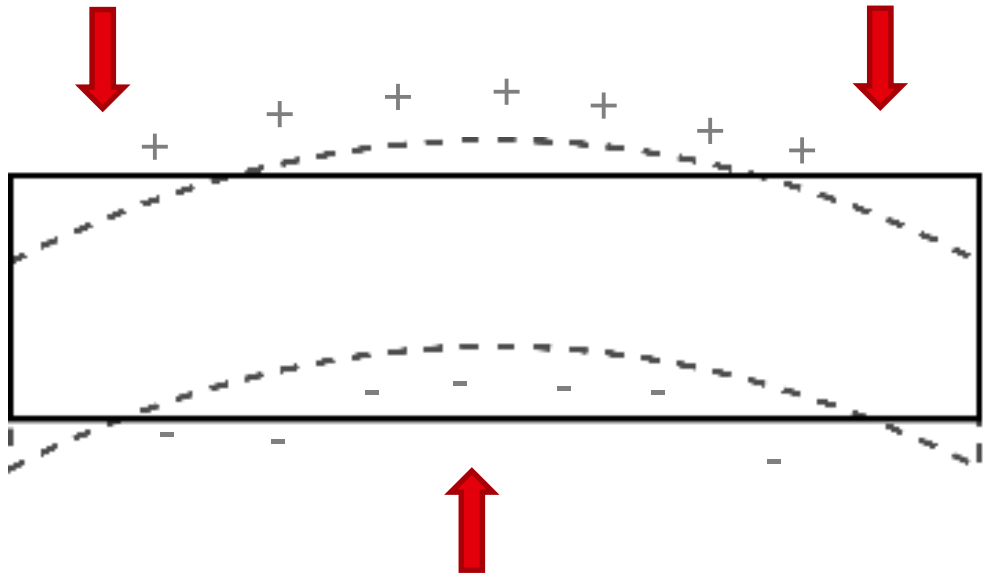


Image: Wikipedia.org
(Creative Commons CC-0)

Crystal structure of α-quartz (red balls are oxygen, grey are silicon)

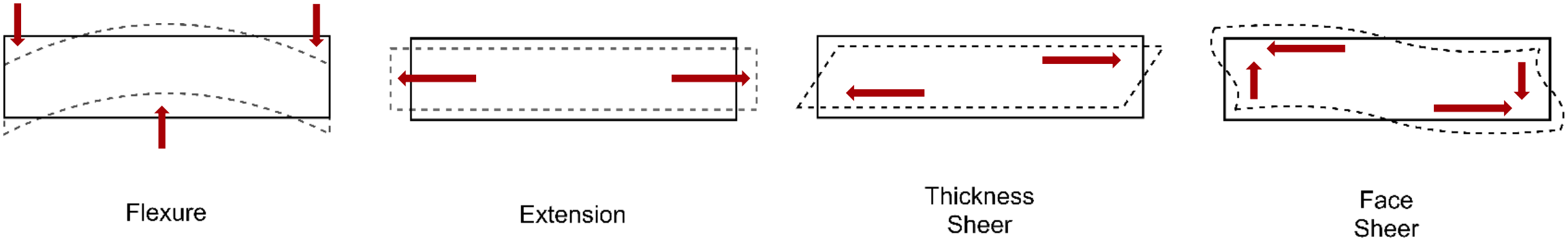
Q. WHY DO CRYSTALS VIBRATE?

- **Mechanical stresses result in voltage**
- **Voltage result in mechanical stresses**



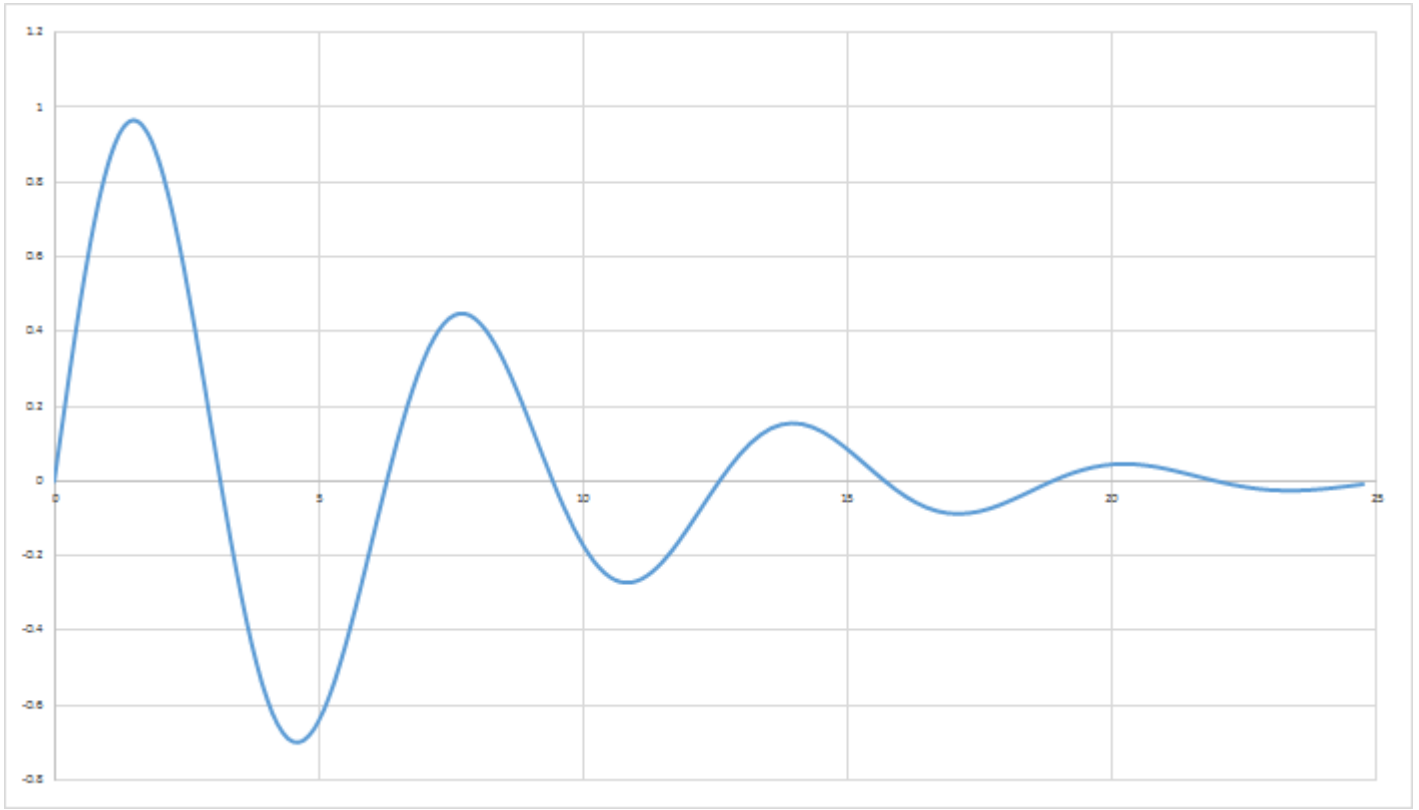
Q. WHY DO CRYSTALS VIBRATE?

- **Vibrational modes**



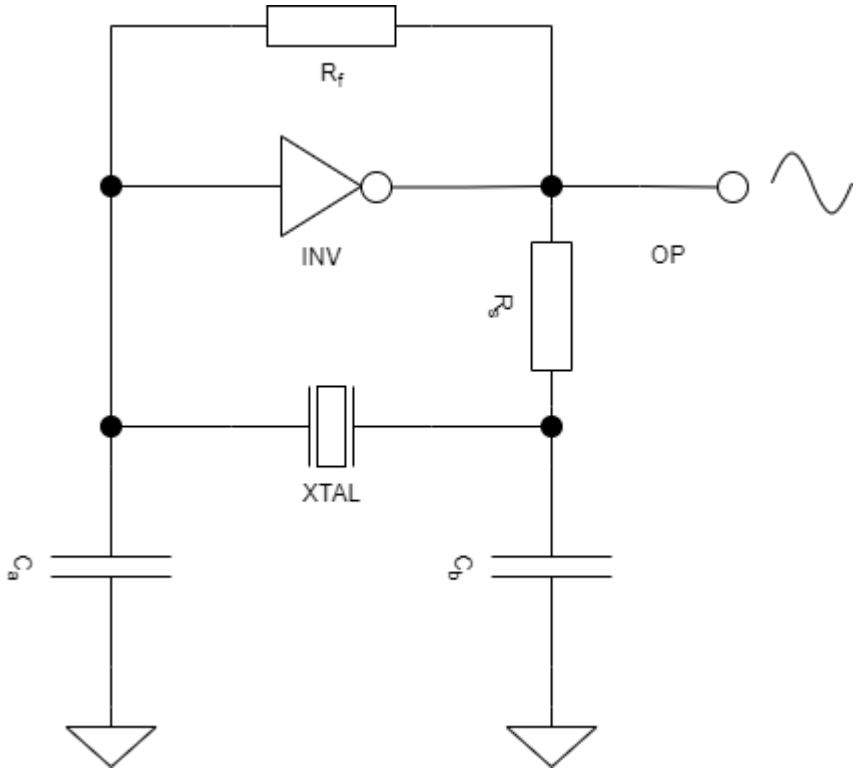
Q. WHY DO CRYSTALS VIBRATE?

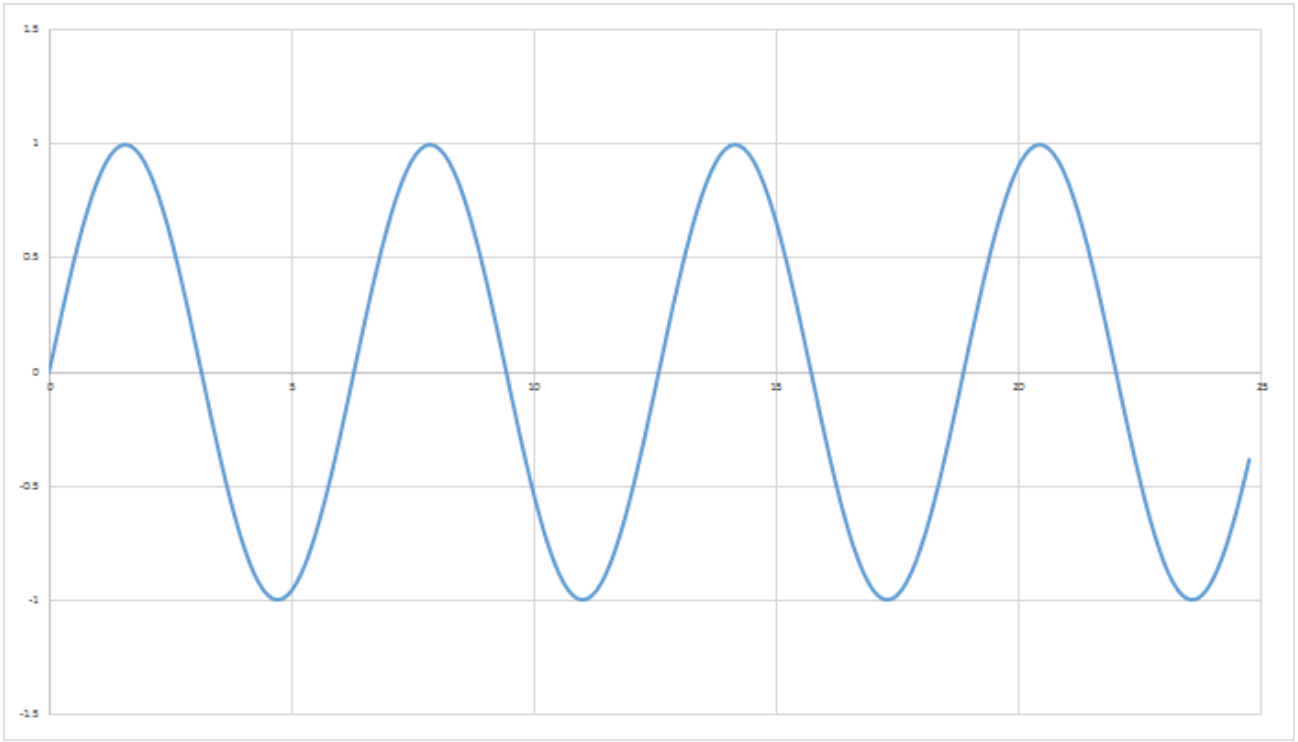
- **Resonance**



Q. WHY DO CRYSTALS VIBRATE?

- **Oscillator**





Q. HOW ARE QUARTZ CRYSTALS PRODUCED?

- **Natural Crystal**

Image: Wikipedia.org (JJ Harrison (https://www.jjharrison.com.au/)
(Creative Commons CC-BY-SA-2.5))

Q. HOW ARE QUARTZ CRYSTALS PRODUCED?

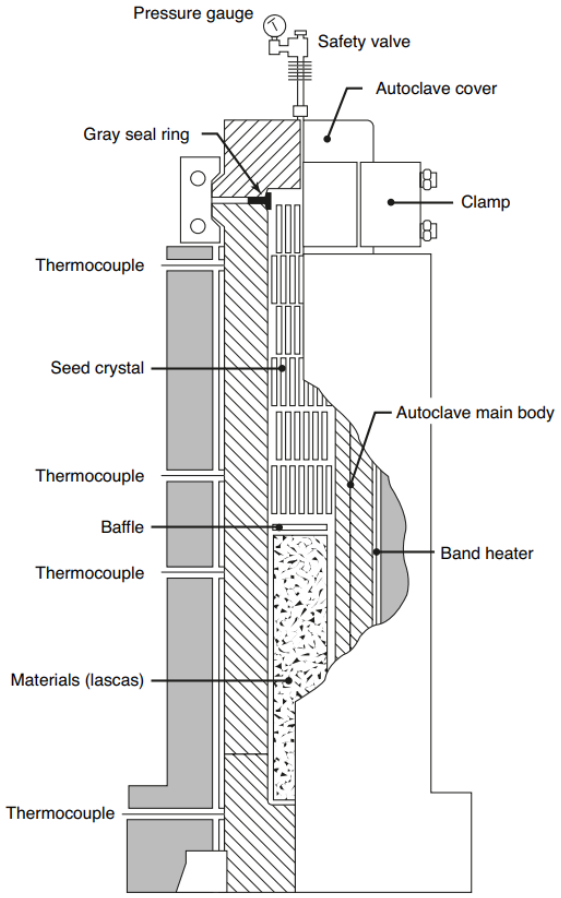
- **Synthetic/Grown Crystal**

Image: Wikipedia.org (Didier Descouens
(Creative Commons CC BY-SA 4.0))

A synthetic quartz crystal grown by the hydrothermal method, about 19 cm long and weighing about 127 grams

Q. HOW ARE QUARTZ CRYSTALS PRODUCED?

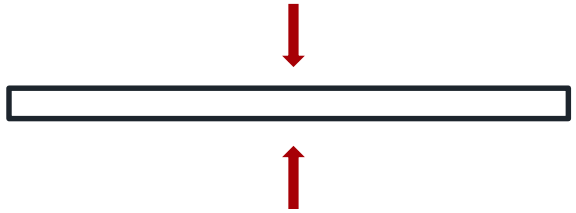
- **Autoclave**



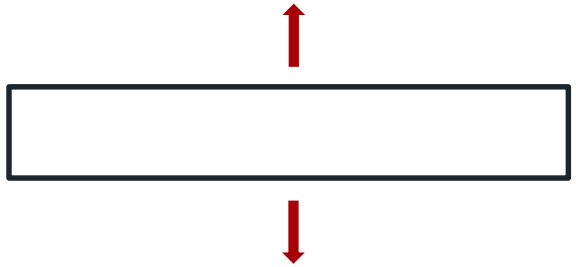
Schematic depiction of synthetic quartz crystal growth

Q. HOW DOES THICKNESS OF BLANKS EFFECT FREQUENCY?

- **Thinner Blanks = Higher Frequency**

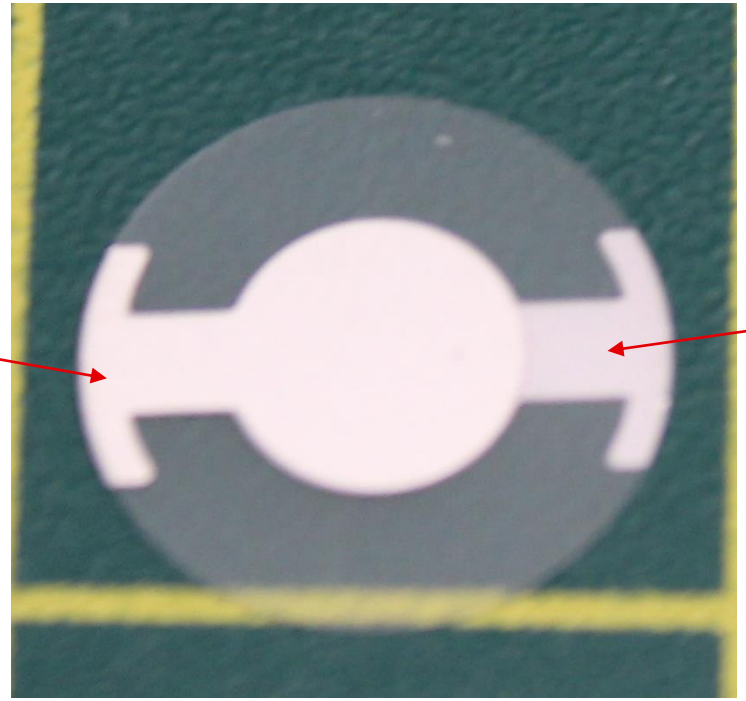


- **Thicker Blanks = Lower Frequency**



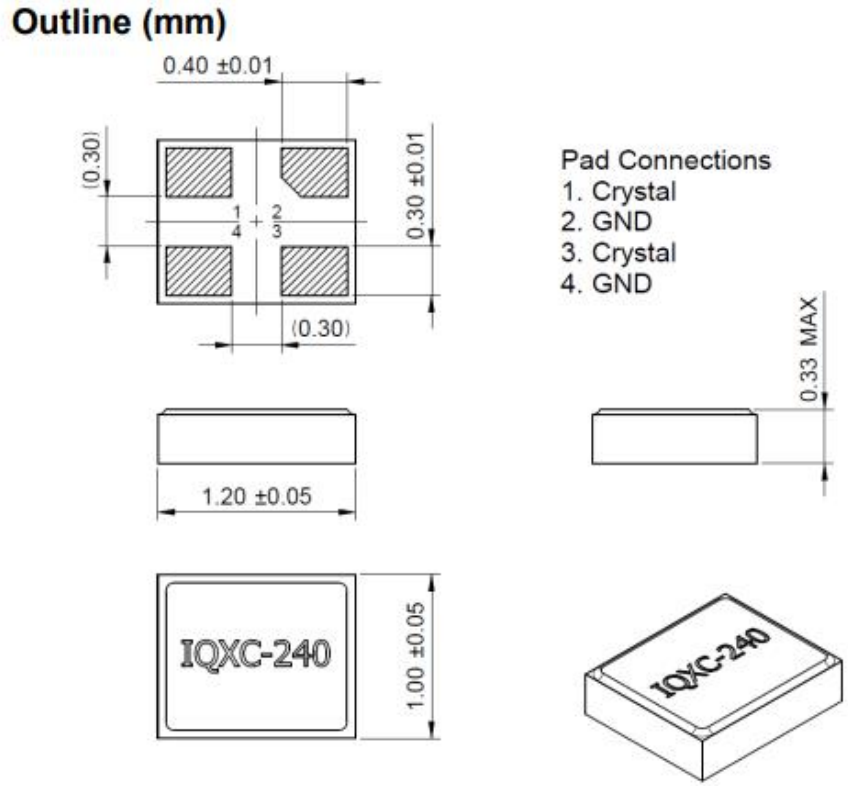
Q. HOW DO ELECTRODES AFFECT FREQUENCY?

- **Electrodes on Crystal Blank**



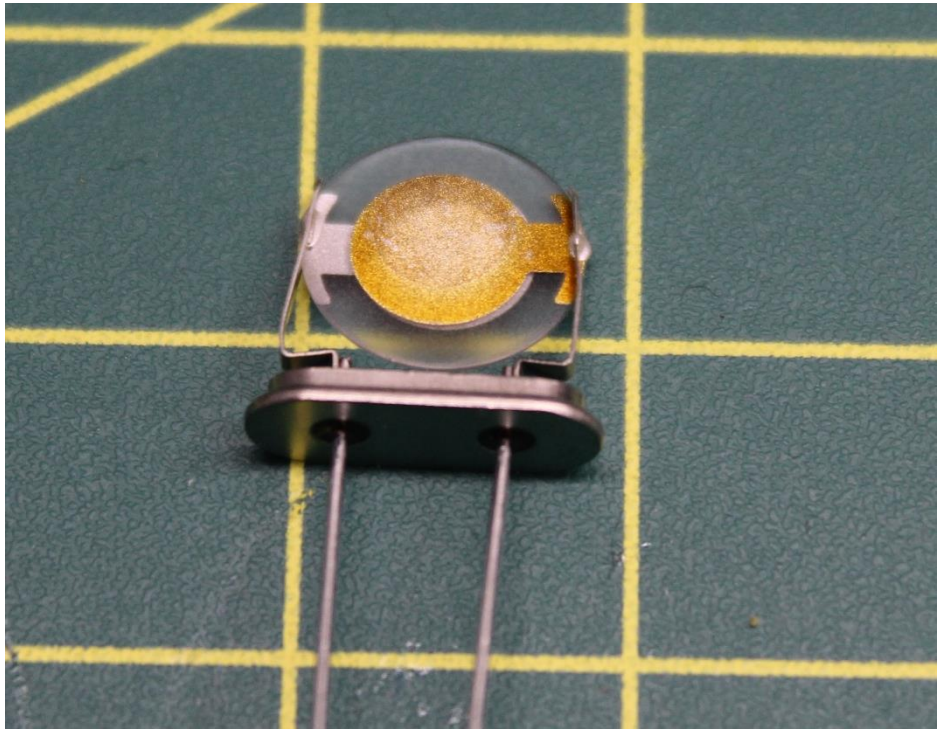
Q. WHAT LIMITS THE SIZES OF BLANKS?

- **Smallest Size Crystal Package**

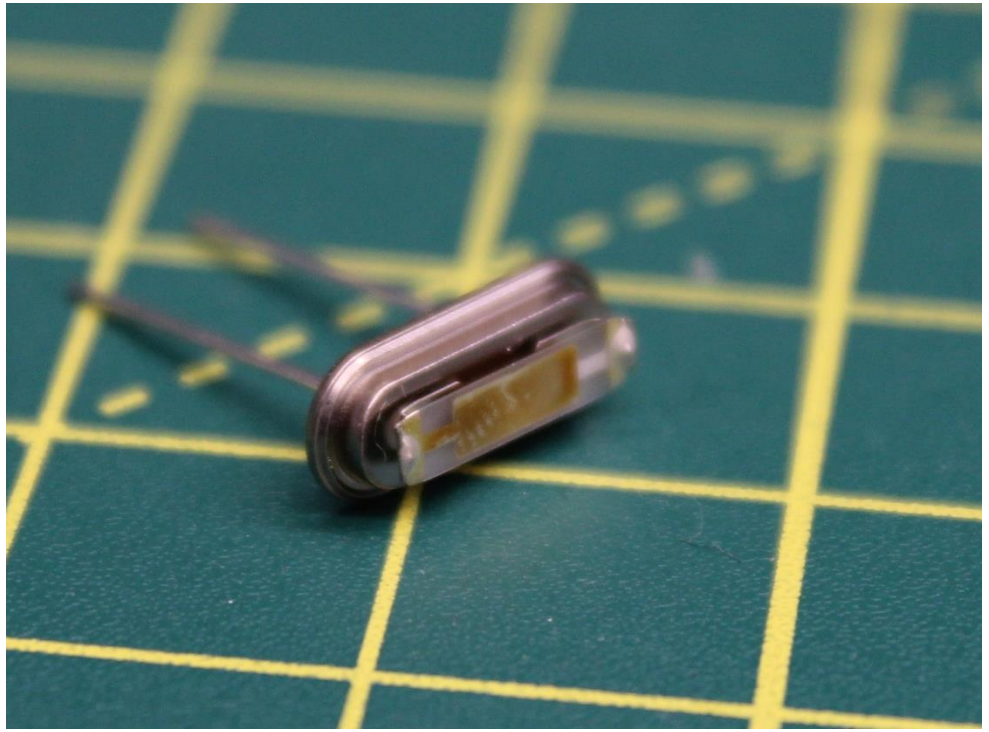


Q. WHY ARE BLANKS RECTANGLE OR CIRCULAR?

- **Circular Crystal**

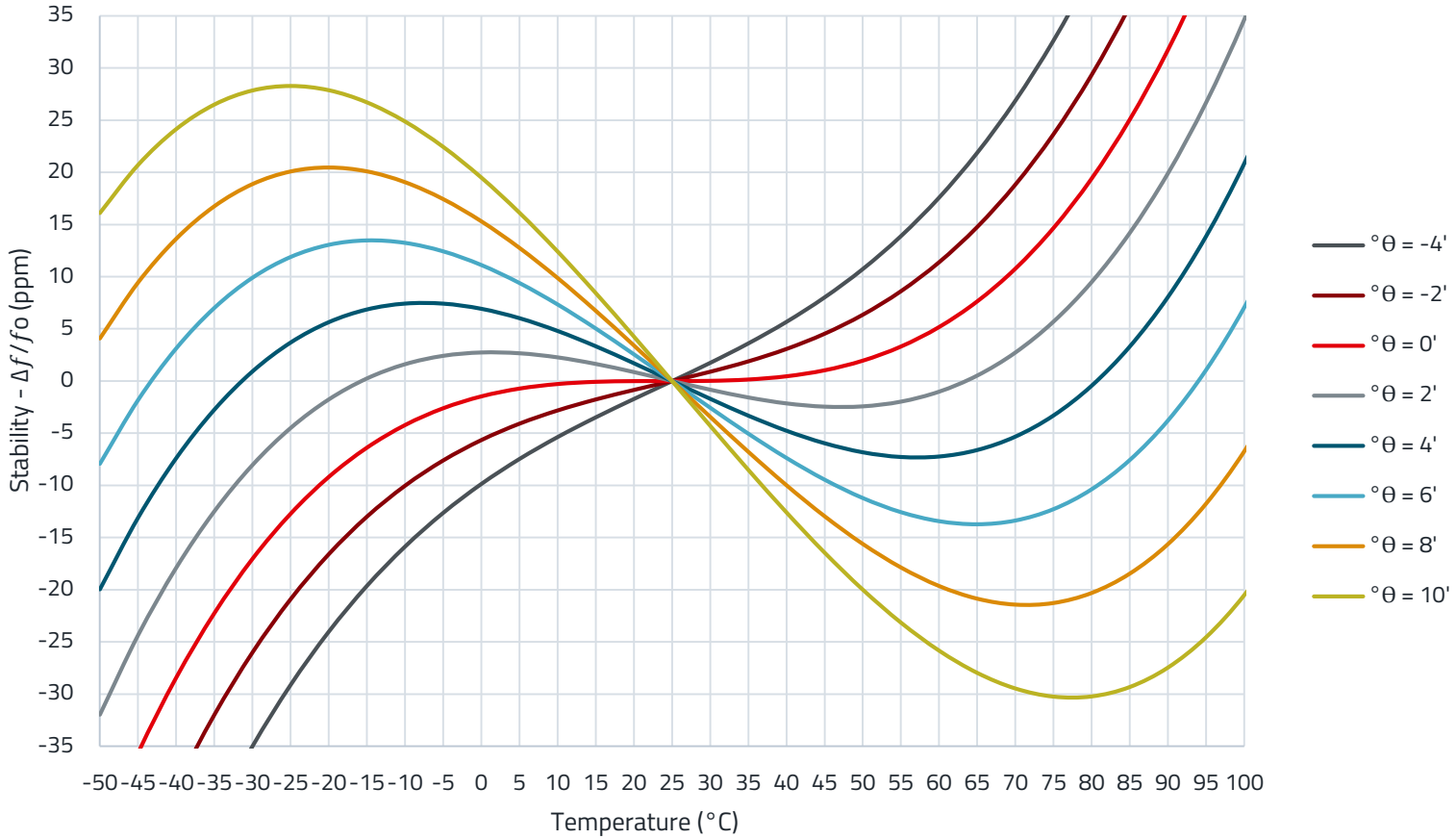


- **Rectangular Crystal**



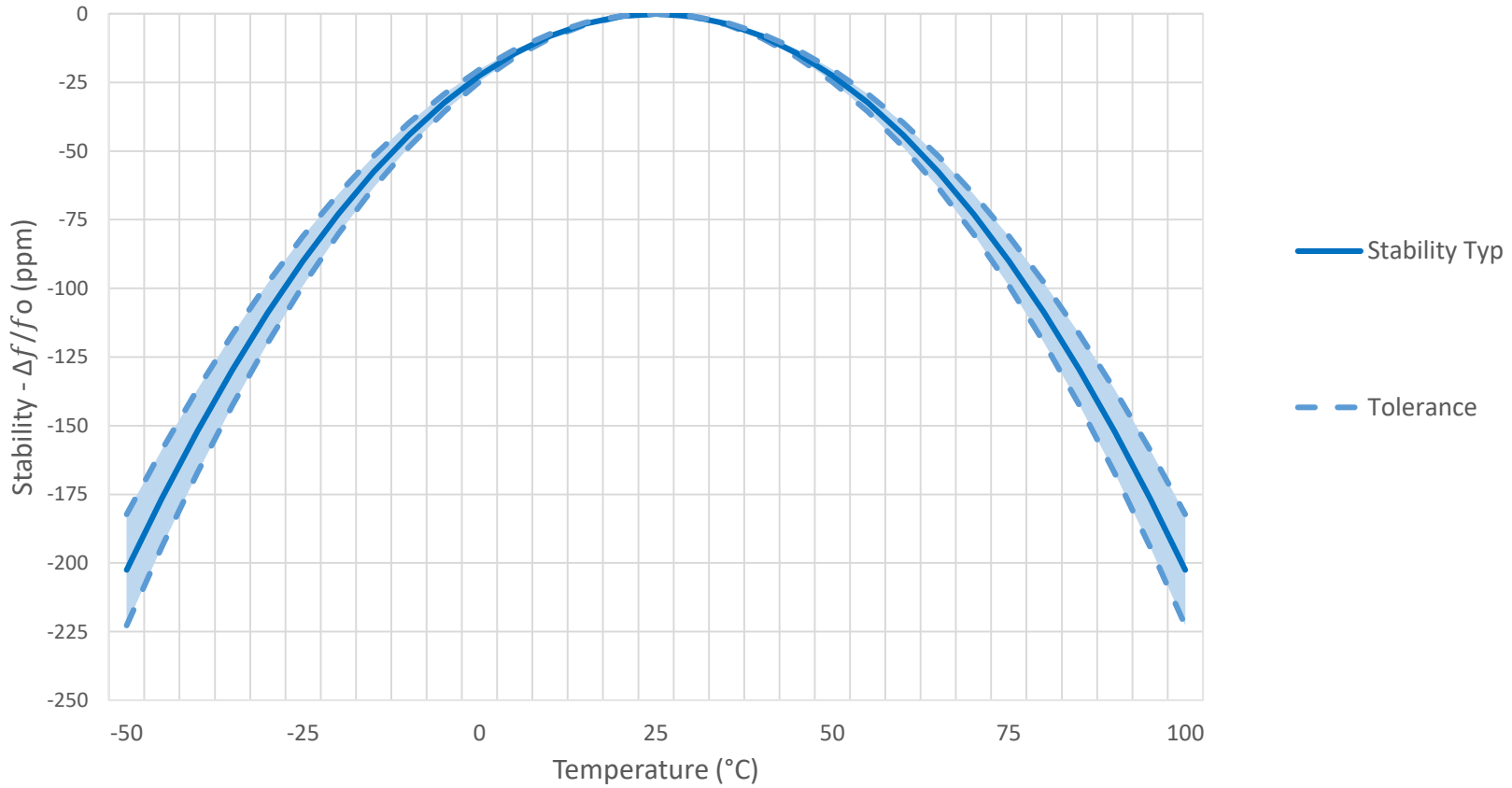
Q. HOW DOES TEMPERATURE EFFECT FREQUENCY?

- **AT Cut Crystal Temperature Typical Response Curve**



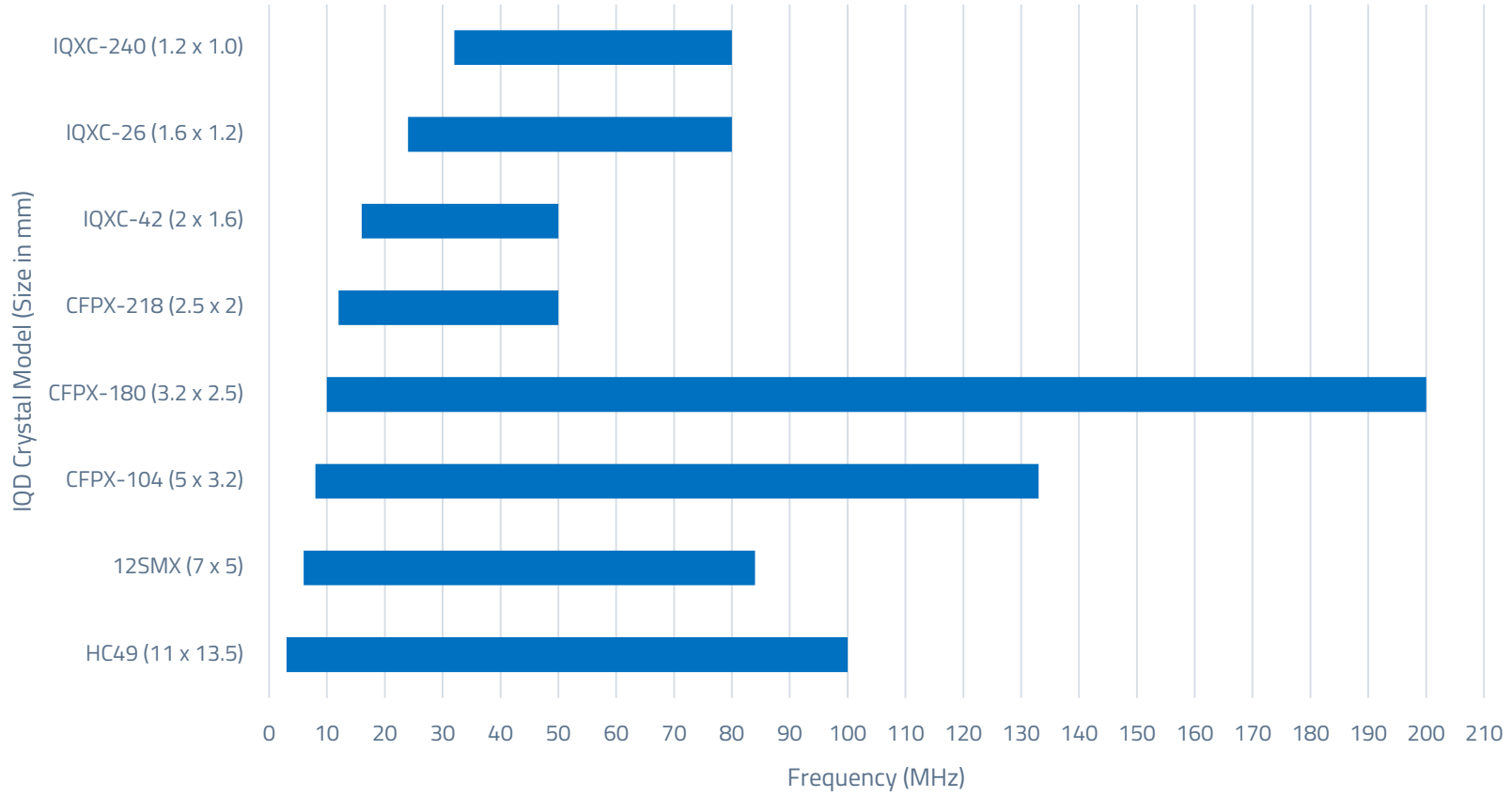
Q. HOW DOES TEMPERATURE EFFECT FREQUENCY?

- **Watch Crystal Temperature Typical Response Curve**



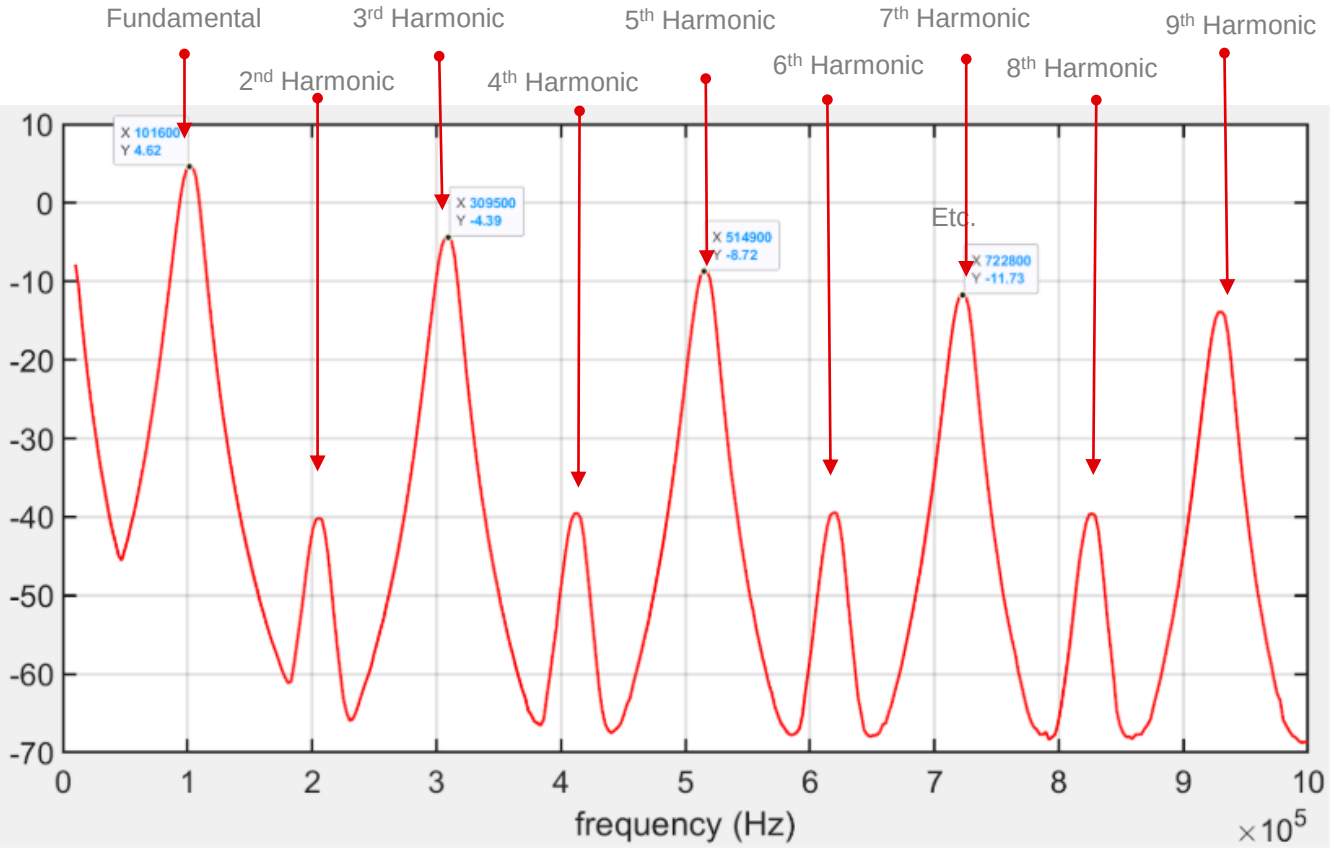
Q. WHAT LIMITS FREQUENCY RANGE?

- **Fundamental Frequency Ranges**



Q. WHAT LIMITS FREQUENCY RANGE?

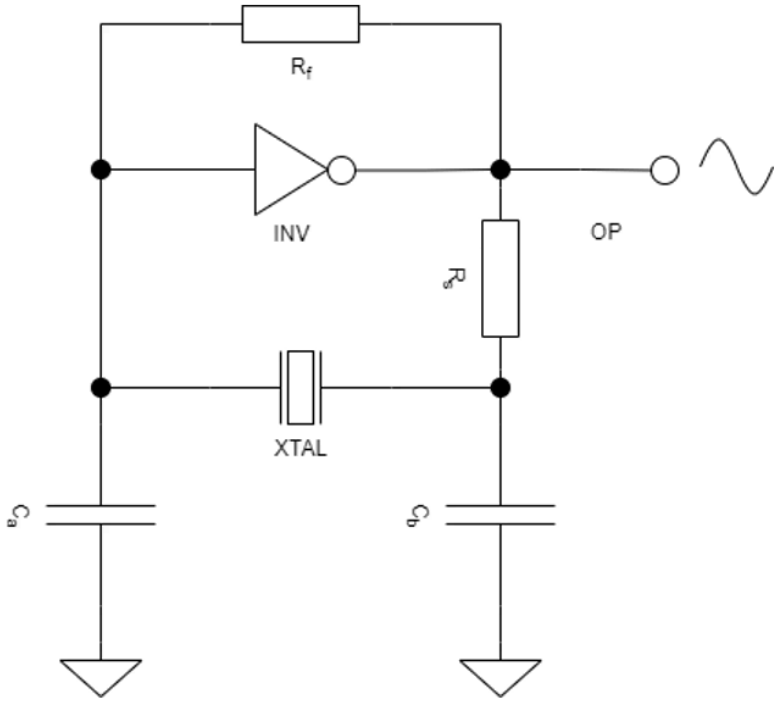
- **Overtones**



Q. WHAT INFLUENCE DOES PICO-FARADS HAVE ON FREQUENCY?

Pierce Oscillator

Named after its inventor, George W Pierce (1872 – 1956)



- R_f = **Feedback resistor for the op-amp, op-amp configured to work in negative feedback mode**
- R_s = **Series resistor reduces the chance of overtone oscillation and can improve start-up time. Rs isolates the inverter from the crystal network**
- **The output will oscillate at the resonant frequency of the Crystal**
- **Load capacitance can be calculated using this formula:**

$$C_L = \frac{C_a \cdot C_b}{C_a + C_b} + C_s$$

Where:

$$C_L = Capacitive\ Load$$
$$C_s = Capasitive\ stray$$

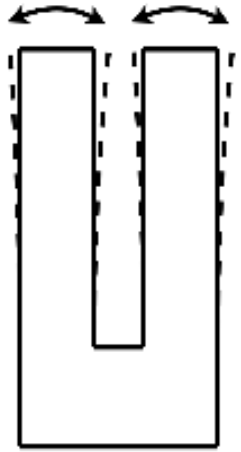
- **Capacitive stray is the capacitance of any tracks on the PCB and components. Typically between 2-7pF**
- **Transposed to make Ca and Cb the subjects**

$$C_a, C_b = 2(C_L - C_s)$$

Q. WHY ARE WATCH CRYSTALS FORK SHAPED?

- **Tuning fork design**

Image: Wikipedia.org (Mister rf
(Creative Commons CC BY-SA 4.0))



Tuning
Fork

Q. CAN CRYSTALS BECOME DAMAGED?

- **Physical Damage**

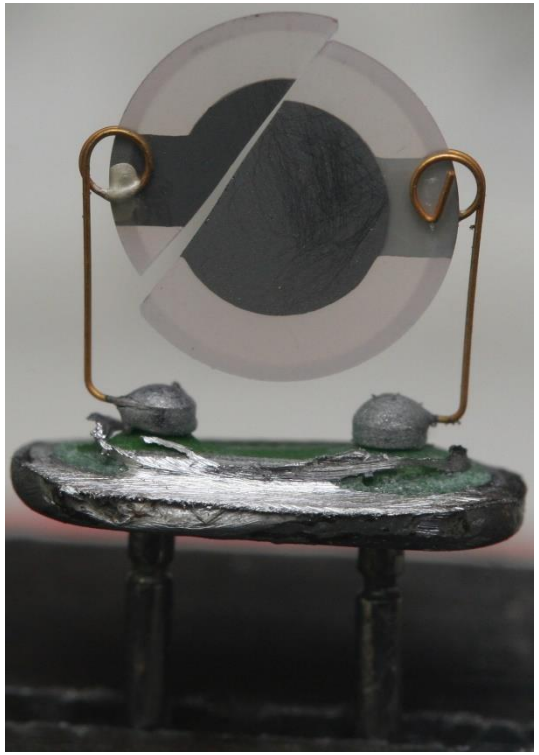


Image: Wikipedia.org (Gophi
(Creative Commons CC-0))

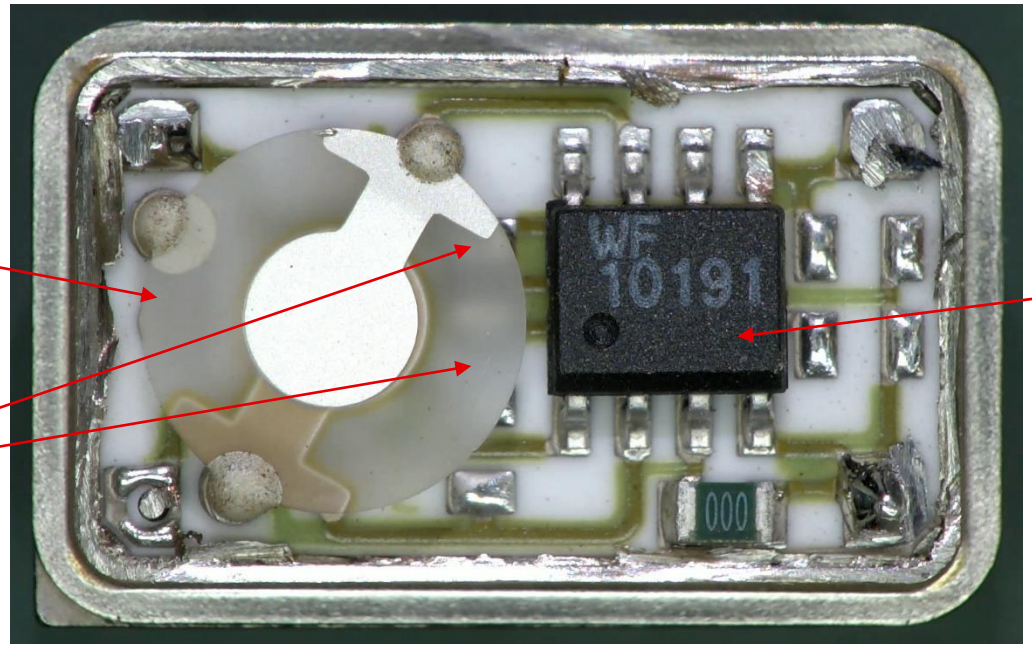
- **Electrical Damage**
  - May experience high phase noise
  - Unwanted vibrational modes
  - Frequency drift due to increased capacitance

Q. WHY DO WE HAVE A RE-TEST LIFE OF 24 MONTHS?

- **For more information, please visit:**
  https://www.iqdfrequencyproducts.com/media/pg/1589/1459502405/quartz-based-frequency-products-shelf-life.pdf

Q. WHAT'S INSIDE A CRYSTAL OSCILLATOR?

- **Crystal Oscillator Internals**



Crystal Resonator

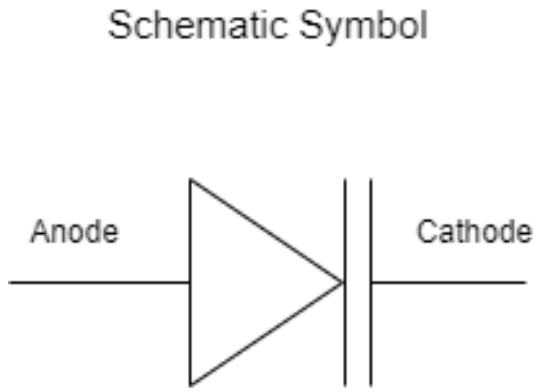
Load Capacitors
(hidden beneath crystal)

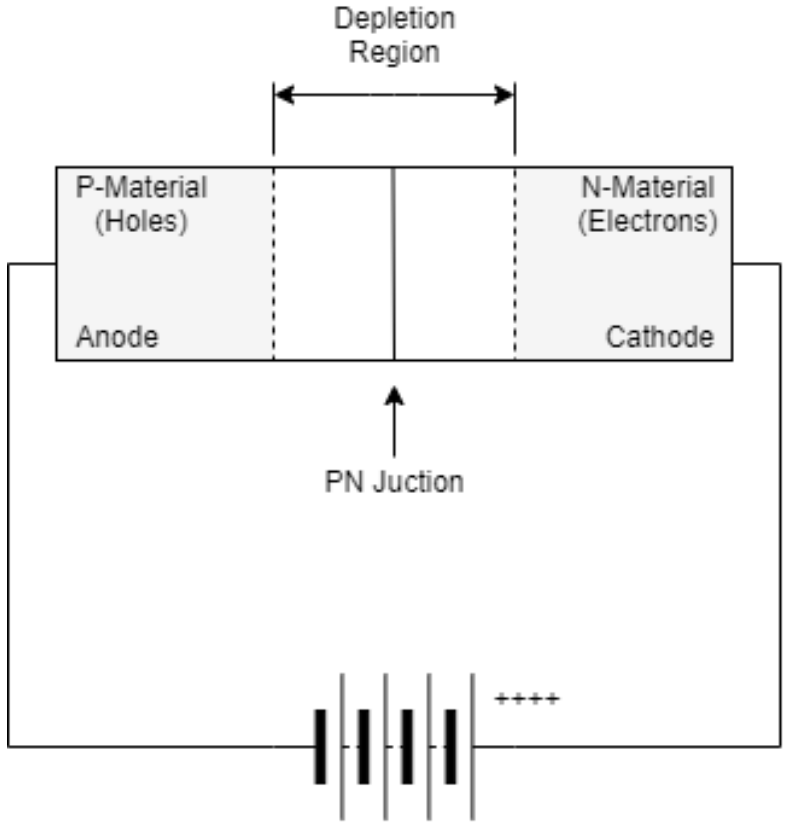
Pierce Oscillator ASIC

Image: Wikipedia.org (Binarysequence
(Creative Commons CC BY-SA 4.0))

Q. HOW DOES A VCXO WORK?

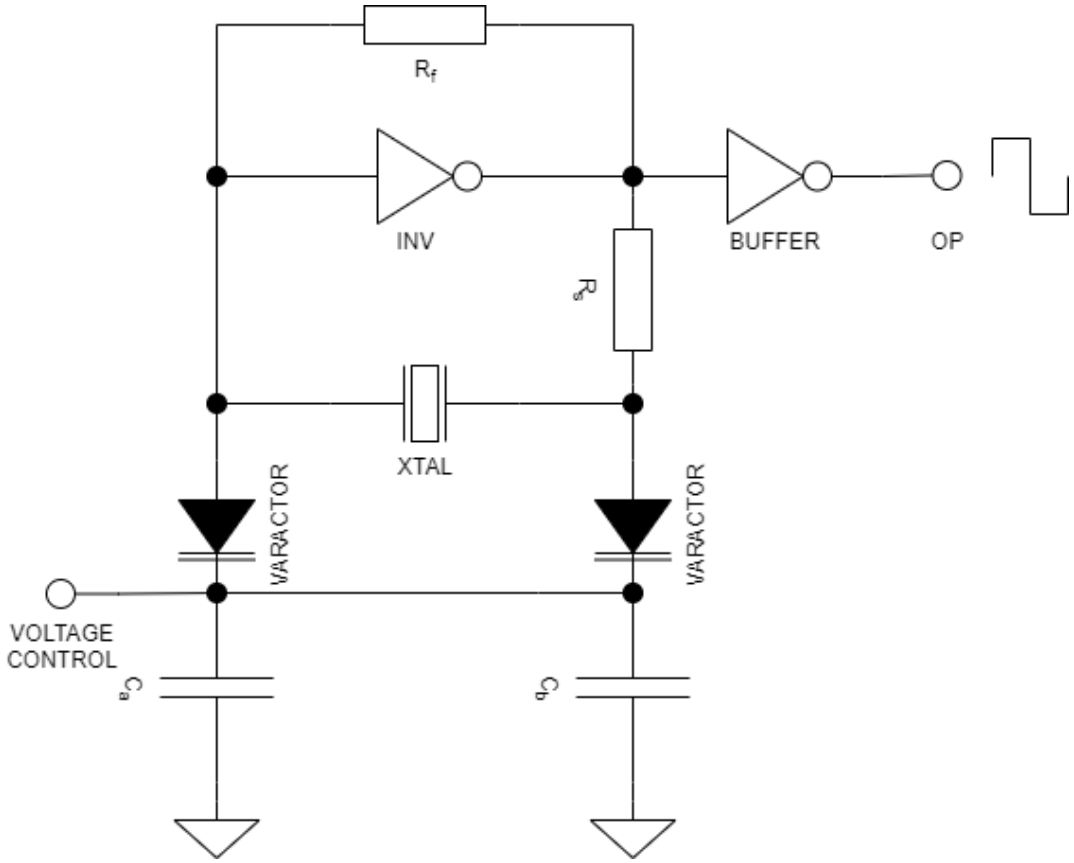
- **Varactor/Vari-cap**





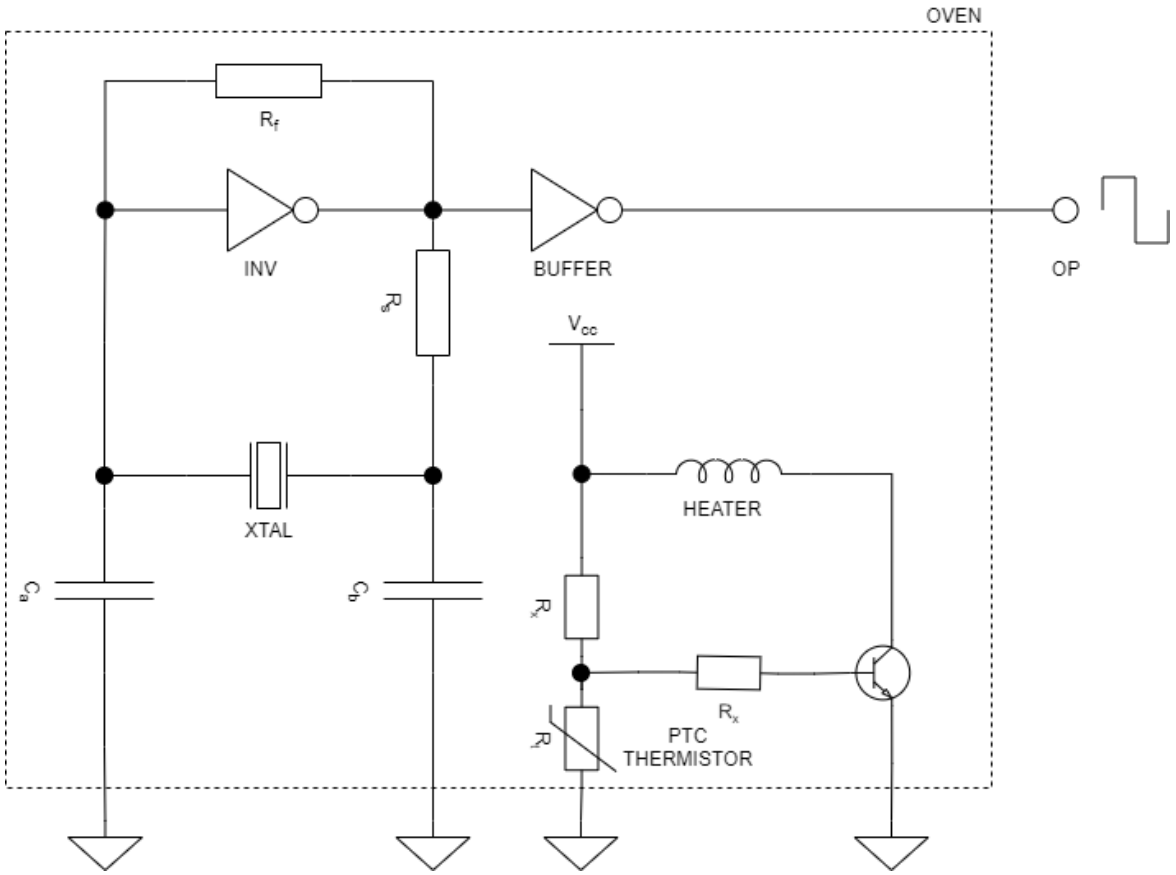
Q. HOW DOES A VCXO WORK?

- **Voltage Controlled Crystal Oscillator (VCXO)**



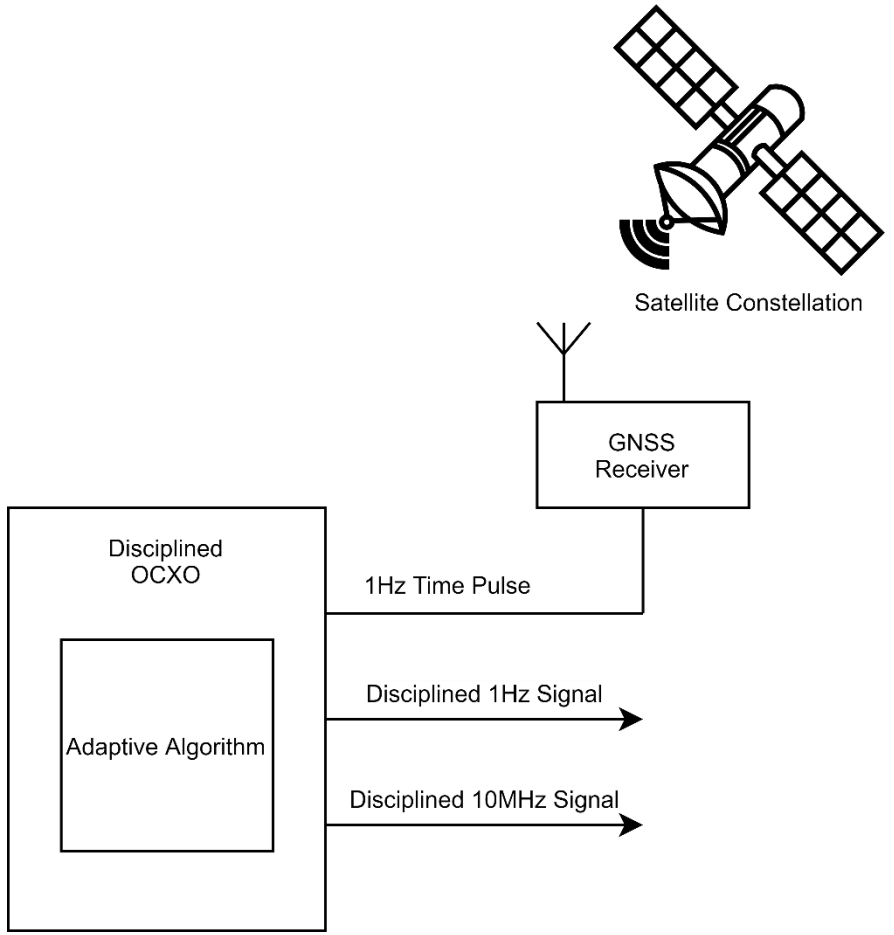
Q. HOW DOES A DISCIPLINED OCXO WORK?

- **Oven Controlled Crystal Oscillator (OCXO)**



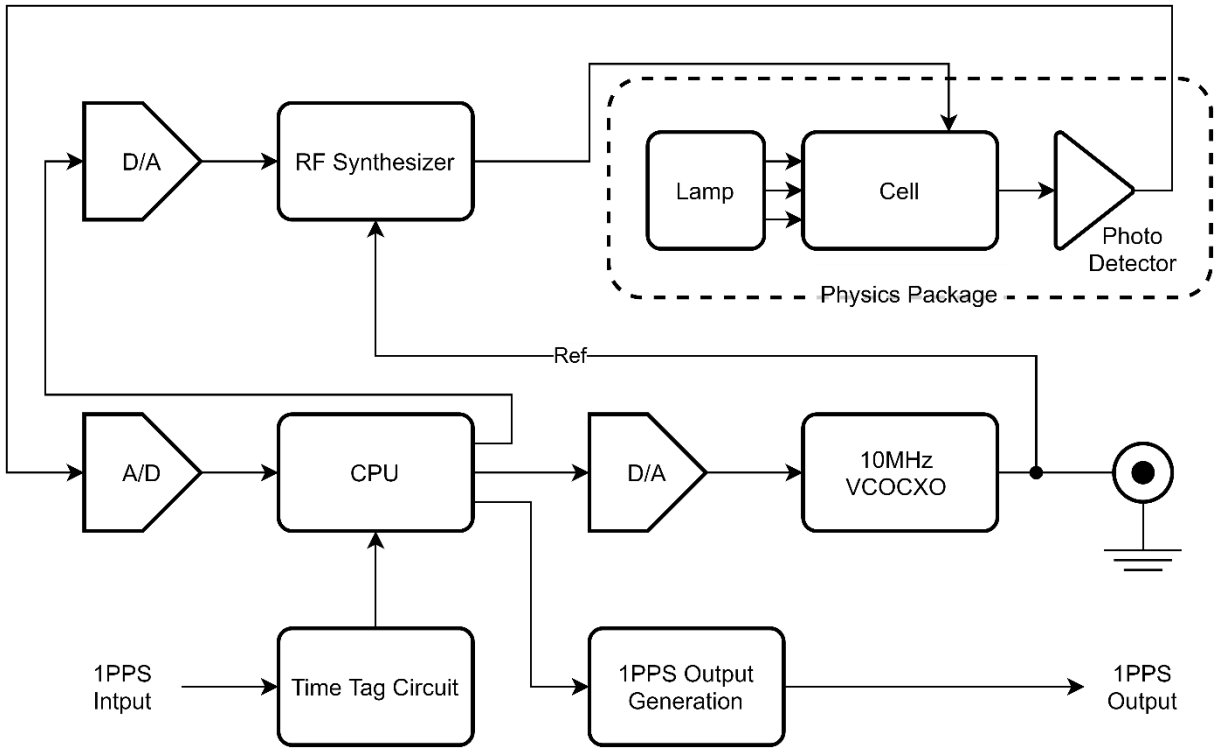
Q. HOW DOES A DISCIPLINED OCXO WORK?

- **Disciplined OCXO**

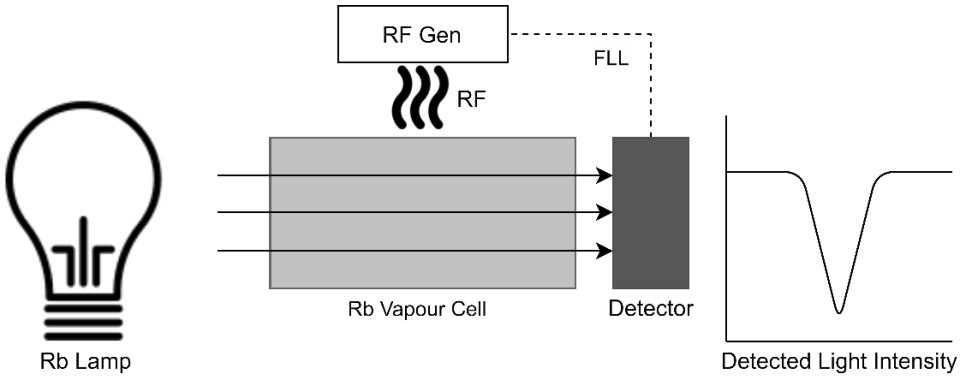


Q. HOW DOES A RUBIDIUM OSCILLATOR WORK?

- **Rb Oscillator**



- **Physics Package**



IQD CONTACT DETAILS

www.iqdfrequencyproducts.com

Malcolm.Lennox@iqdfrequencyproducts.com

+44 (0)1460 270200

info@iqdfrequencyproducts.com