压电声波器件分析理论与方法 暑期讲习班

Piezoelectric Devices Manufacture -- Quartz Resonators Applications and Manufacture

Min-Chiang Chao 趙岷江
TXC 台晶(寧波)電子有限公司

2011.8.9



Contents

- Piezoelectric Devices
- Quartz Resonator Applications
- Quartz Resonators
- Manufacturing Process
- The Effects of Processes to the Characteristics of Quartz Resonators
- New Challenges
- Conclusions



Forewords

- The are many kinds of piezoelectric devices and this report majorly focus on quartz crystal resonators.
- Through the application needs to the process effects on quartz crystals. This report cover applications, the demand for oscillators and crystals, and the manufacturing processes introduction, and the process effects which affect the performance of quartz crystals.



Piezoelectric devices

- Types by Functions:
  - –
  - –
  - –
    - Etc …
  - – High voltage and power source
  - – Energy Harvest
  - – Piezo-electric motors
  - – Reduction of vibration and noise
  - – Infertility treatments
  - – Surgery Devices

Piezo-element is one (key) component
Other materials/packages are necessary
Must be installed into system to be functional

Unique Relationship
Applications – Devices – Manufacture
This report only focus on Quartz Resonator



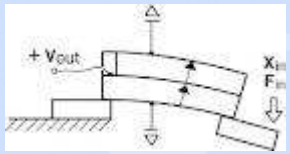
Quartz Crystal Resonators



Piezo motors



Piezo lighter



Piezo energy harvest



Piezo high-voltage stack



Piezo surgery

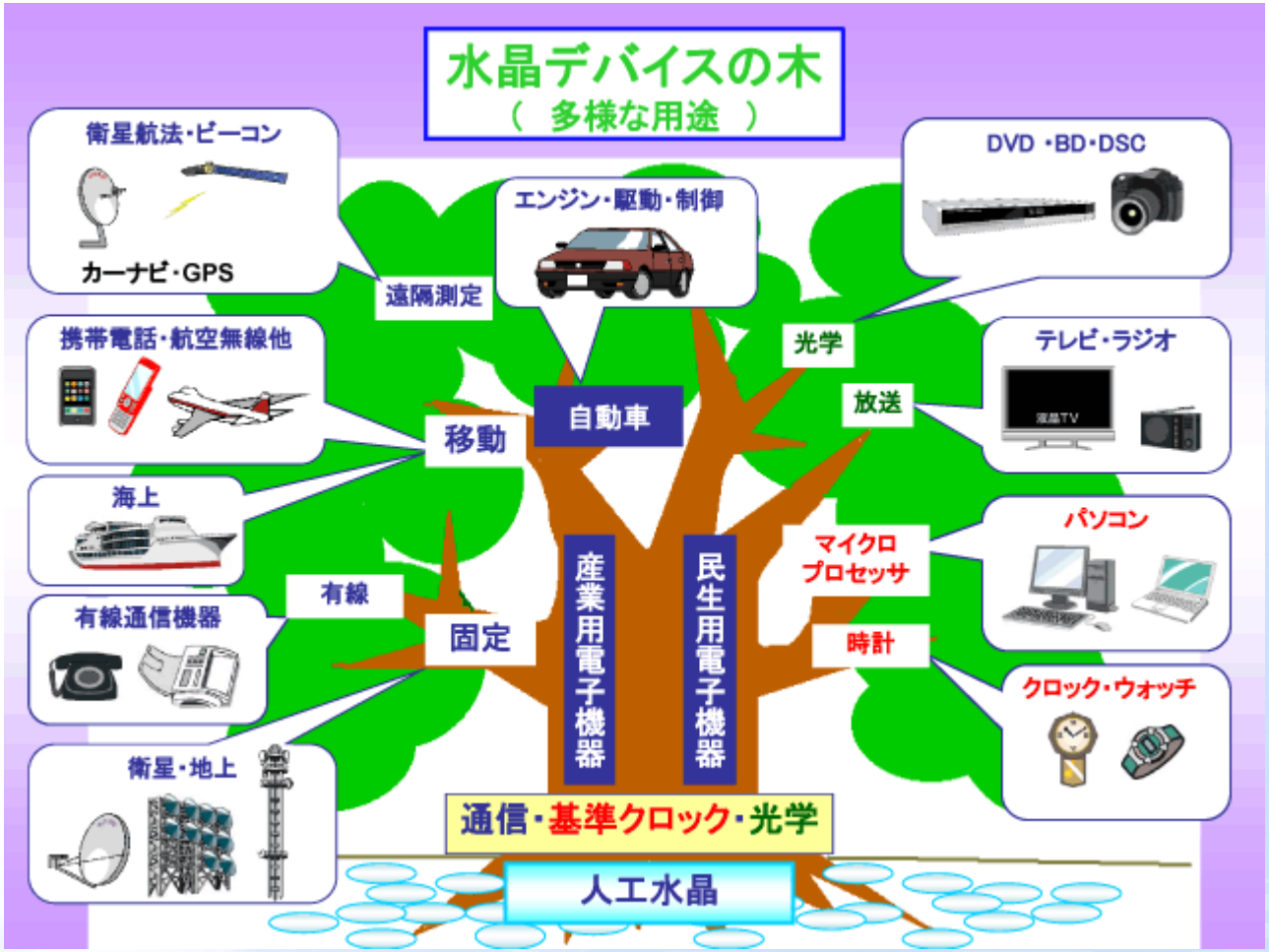


Quartz Resonator Applications

- Applications
- The comparison between human body and Oscillators (Brain – IC, Heart – Resonators)
- Oscillator model



Quartz Resonators Applications



QIAJ website: http://www.qiaj.jp/pages/frame20/page02.html#sec_01

Electronics Applications of Quartz Crystals

Military & Aerospace

Communications
Navigation
IFF
Radar
Sensors
Guidance systems
Fuzes
Electronic warfare
Sonobouys

Research & Metrology

Atomic clocks
Instruments
Astronomy & geodesy
Space tracking
Celestial navigation

Industrial

Communications
Telecommunications
Mobile/cellular/portable radio, telephone & pager
Aviation
Marine
Navigation
Instrumentation
Computers
Flash drives
Digital systems
CRT displays
Disk drives
Modems
Tagging/identification
Utilities
Sensors

Consumer

Watches & clocks
Cellular & cordless phones, pagers
Radio & hi-fi equipment
TV & cable TV
Personal computers
Digital cameras
Video camera/recorder
CB & amateur radio
Toys & games
Pacemakers
Other medical devices
Other digital devices

Automotive

Engine control, stereo, clock, yaw stability control, trip computer, GPS



Frequency Control Device Market

(estimates)

Technology	Units per year	Unit price, typical	Worldwide sales, $/year
Quartz Crystal Resonators & Oscillators	~5 x 10^9	~$1 ($0.1 to 1,000)	~$4B
MEMS	~100M	<$1 ($0.1 to 10)	~$50M
Atomic Frequency Standards (see chapter 6)			
Hydrogen maser	~ 20	$100,000	$2M
Cesium beam frequency standard	~ 500	$50,000	$25M
Rubidium cell frequency standard	~ 40,000	$2,000	$80M

Computer Product | Desktop | LCD Monitor | Notebook | Mother Board | VGA Card | Hard Disk Driver



For today's daily life, we may pass more than 100pcs quartz crystals around us within 50m range in one day, and we don't know or feel about that.

Quartz resonators are every where and majorly were produced in China.

Printer	Scanner	Modem



Communication Product | Cellular Phone | Pager | Digital Camera





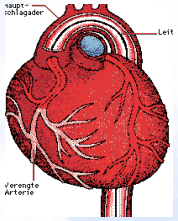
Crystal Oscillator and Homo Sapien (Modern Man)

Crystal Oscillator (XO)	*Homo Sapien (HS)*
Current	Blood
Voltage	Blood Pressure
Crystal- pumps and regulates current flow	*Heart- pumps and regulates blood flow*
ASIC	*Brain*
Package	Body
Other active/passive components	Other organs
Input- supply current	Input- food
Frequency- sub-KHz to MHz and above	Frequency- 1 Hz per 24 hours
Pullability	Can work long hours if needed
Jitter- short term instability	Anger- short term instability
Aging- long term stability	Aging- long term stability
TCXO, OCXO, etc.	Person with more stable emotions
Stop oscillation	Death

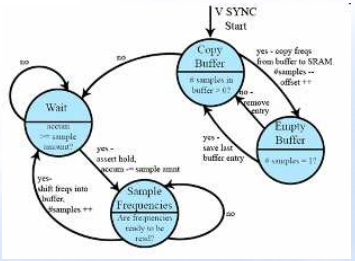
CS Lam, 2003



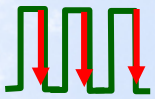
- 機器的心臟： 驅動機器狀態的變化 (State machine)

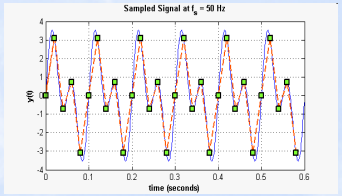






- 信號的取樣： Sampling

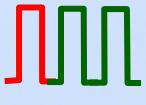




- 同步： Synchronization







- 機器的時鐘： Clock







- 計時器： Timer







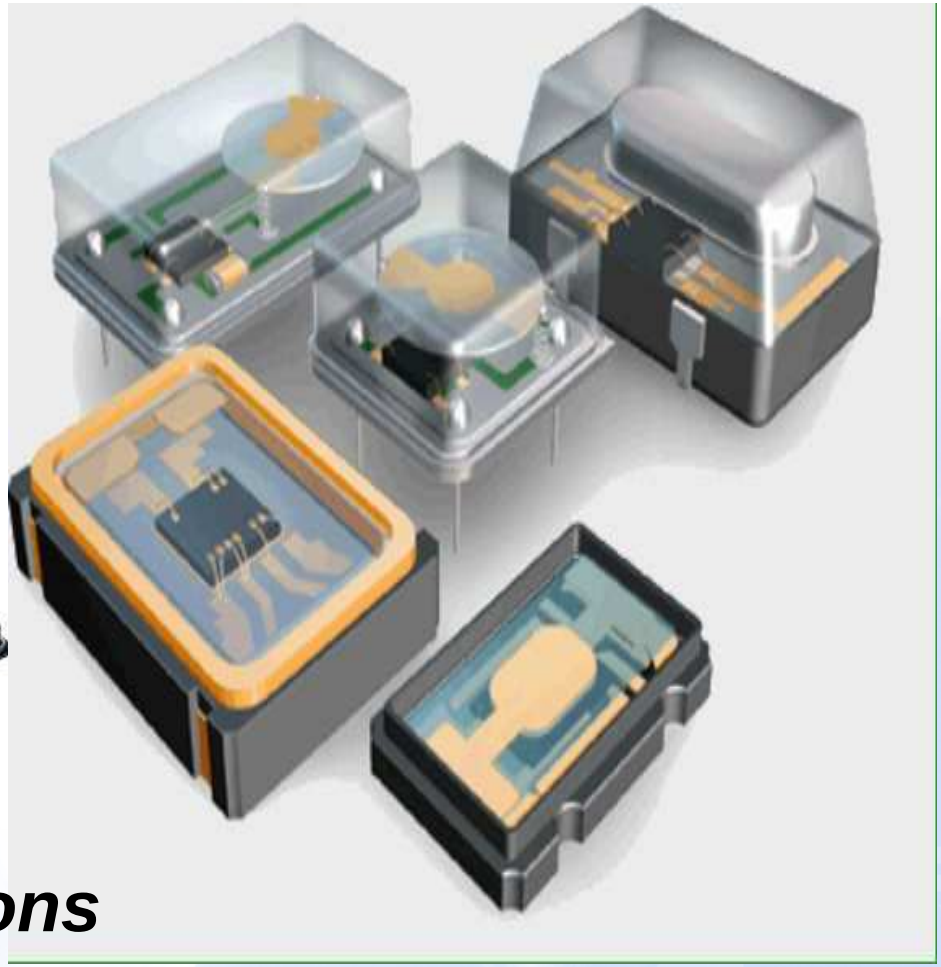
Quartz Crystals

•Material

•Quartz

•piezoelectric components





•Functions

•frequency generation and control devices/subsystems

•KHz to up to a few hundred MHz

•high frequency stability and Q (quality factor)

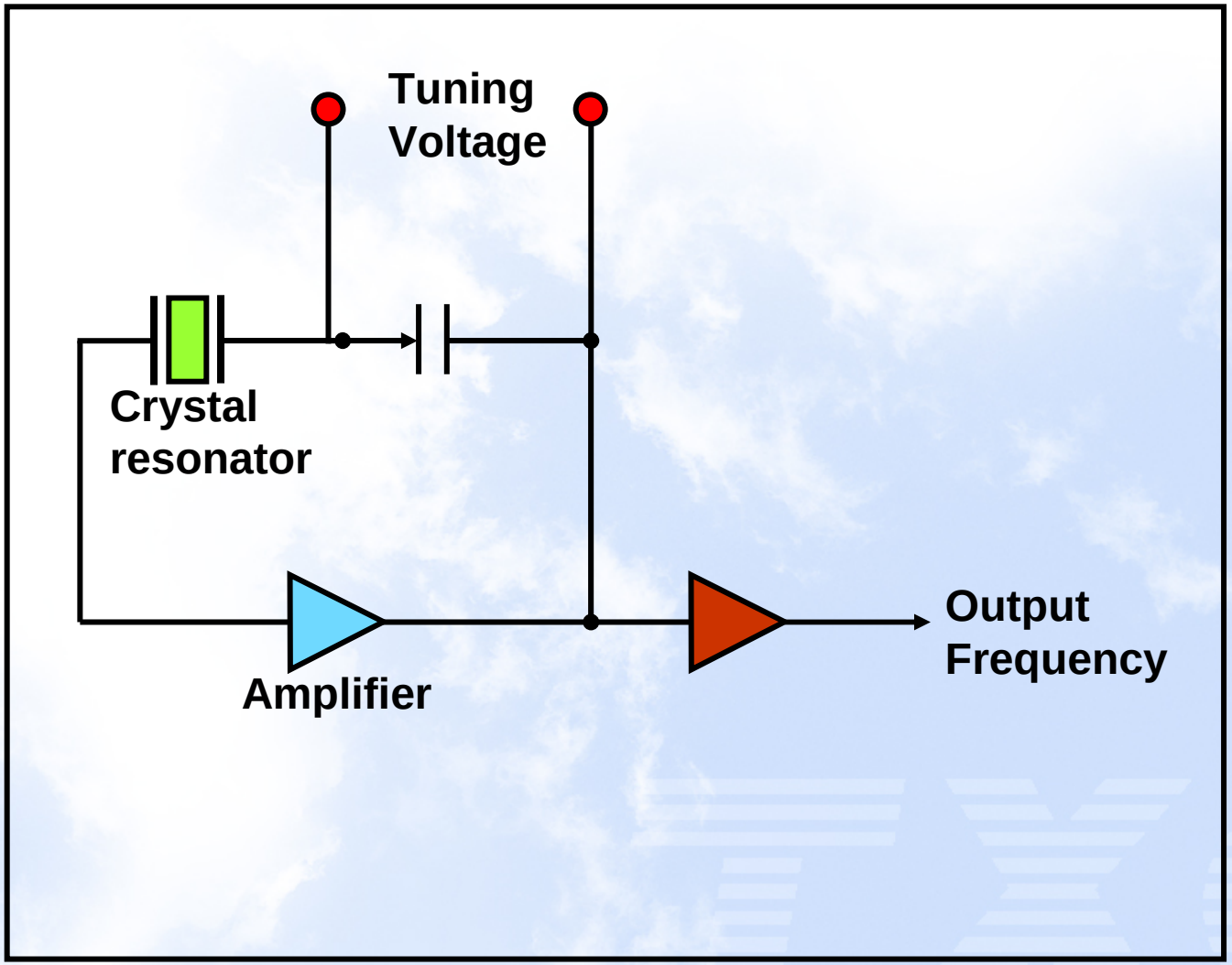
•Applications

•signal timing and synchronization.

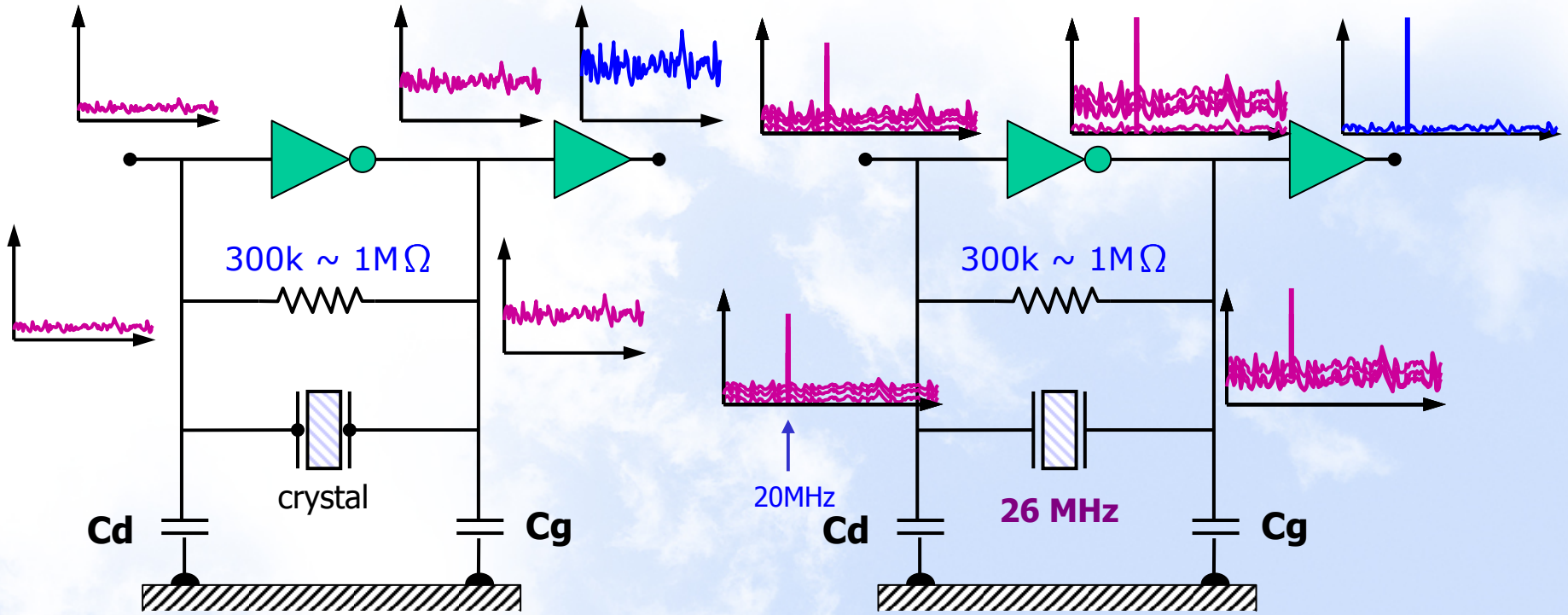
•Applications include military, instrumentation, telecommunication, computer, medical, consumer, and automotive devices.



Crystal Oscillator



How Crystal Oscillation Circuit Works



Basic data :

1) The gain of inverted amplifier is linear over the entire spectrum.

2) The ESR of crystal is around 10 Ohm which is very small compared with feedback resistance.

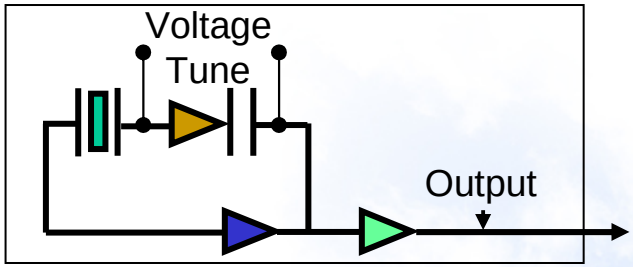
You can treat the crystal as the filter in circuitry.

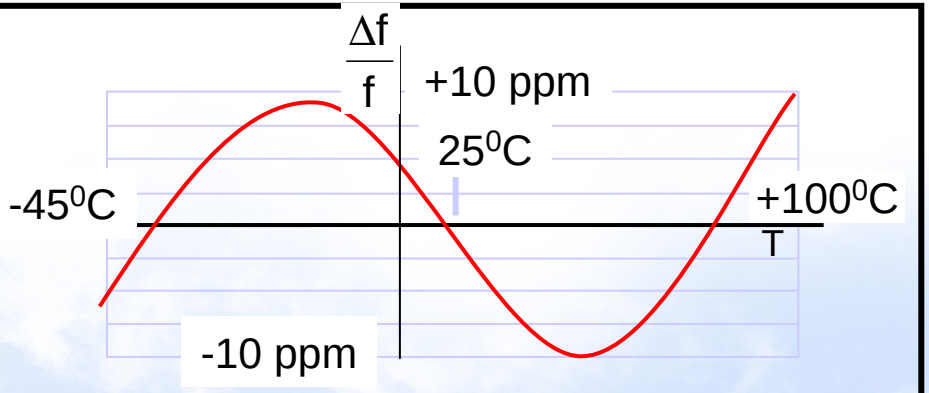
Oscillation

- At the frequency of oscillation, the closed loop phase shift = $2n\pi$.
- When initially energized, the only signal in the circuit is noise. That component of noise, the frequency of which satisfies the phase condition for oscillation, is propagated around the loop with increasing amplitude. The rate of increase depends on the excess; i.e., small-signal, loop gain and on the BW of the crystal in the network.
- The amplitude continues to increase until the amplifier gain is reduced either by nonlinearities of the active elements ("self limiting") or by some automatic level control.
- At steady state, the closed-loop gain = 1.

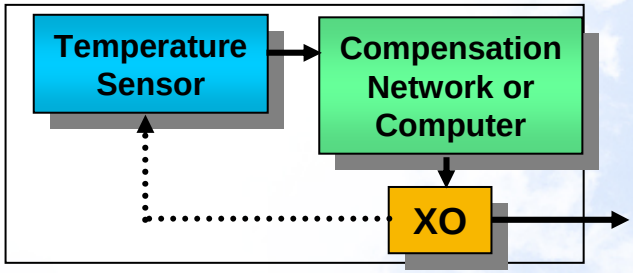


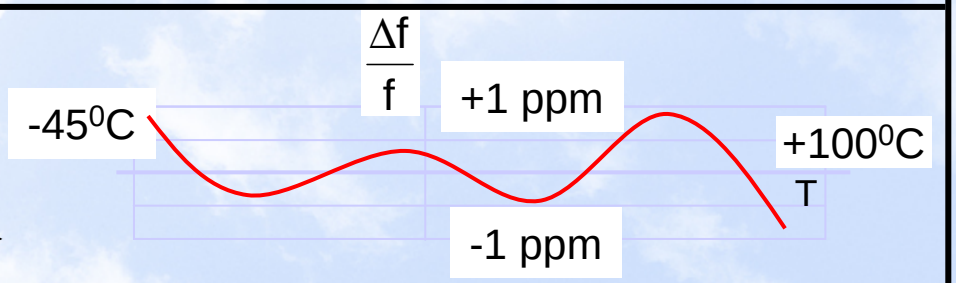
Crystal Oscillator Categories



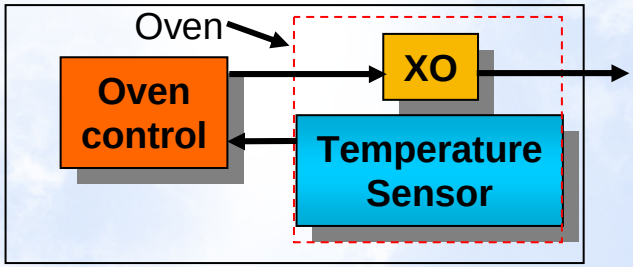


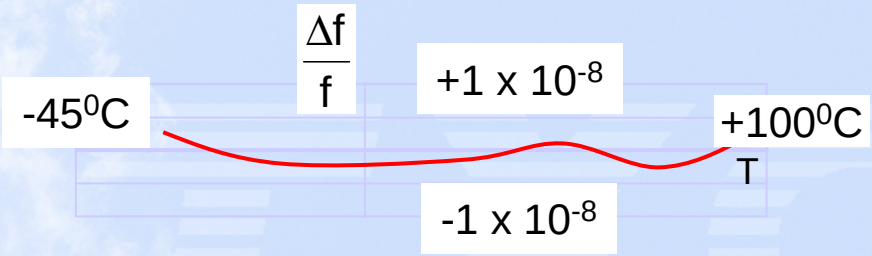
- Crystal Oscillator (XO)





- Temperature Compensated (TCXO)





- Oven Controlled (OCXO)

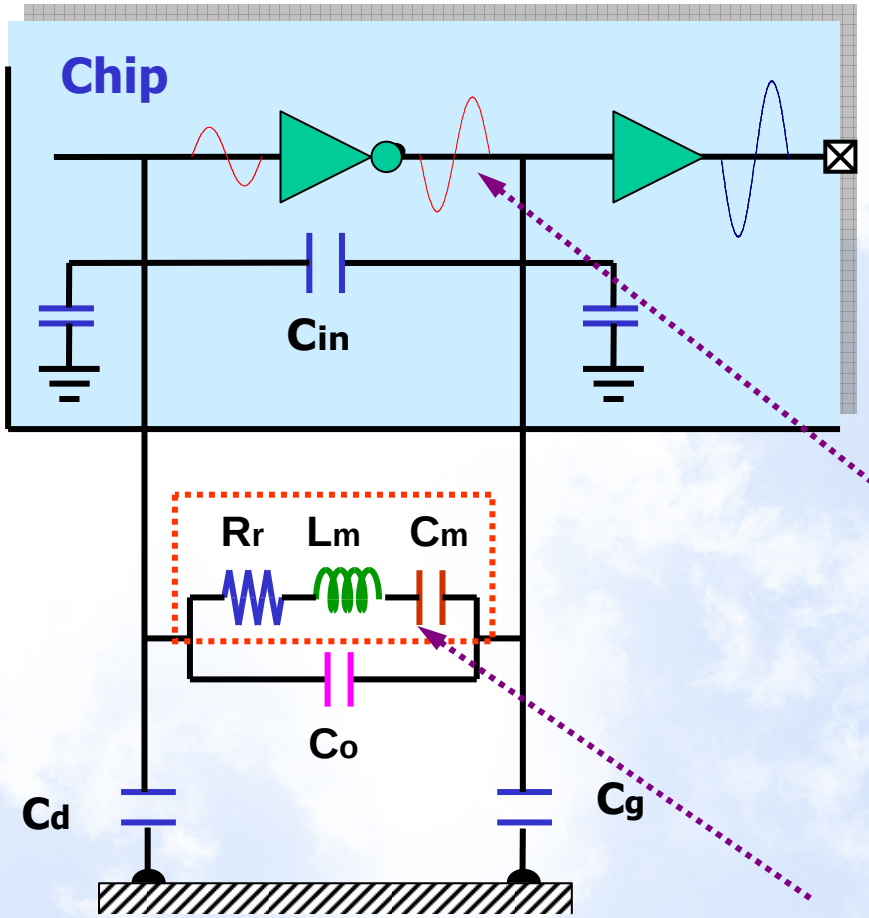
Hierarchy of Off-the-Shelf (Field) Oscillators

Oscillator Type*	Accuracy**	Typical Applications
• Crystal oscillator (XO)	10^{-5} to 10^{-4}	Computer timing
• Temperature compensated crystal oscillator (TCXO)	10^{-6}	Frequency control in tactical radios
• Microcomputer compensated crystal oscillator (MCXO)	10^{-8} to 10^{-7}	Spread spectrum system clock
• Oven controlled crystal oscillator (OCXO)	10^{-8} (with 10^{-10} per g option)	Navigation system clock & frequency standard, MTI radar
• Small atomic frequency standard (Rb, RbXO)	10^{-9}	C^3 satellite terminals, bistatic, & multistatic radar
• High performance atomic standard (Cs)	10^{-12} to 10^{-11}	Strategic C^3, EW

* Sizes range from <1cm^3 for clock oscillators to > 30 liters for Cs standards
Costs range from <$1 for clock oscillators to > $50,000 for Cs standards.

** Including environmental effects (e.g., -40°C to +75°C) and one year of aging.

Simplified Oscillation Circuitry



The simplified circuit diagram tells the basic elements of quartz oscillation circuitry.

The load frequency (output frequency) depends on the effective parameters of crystal (Cm, Lm and Co) and the effective load capacitance of oscillation circuit (CL).

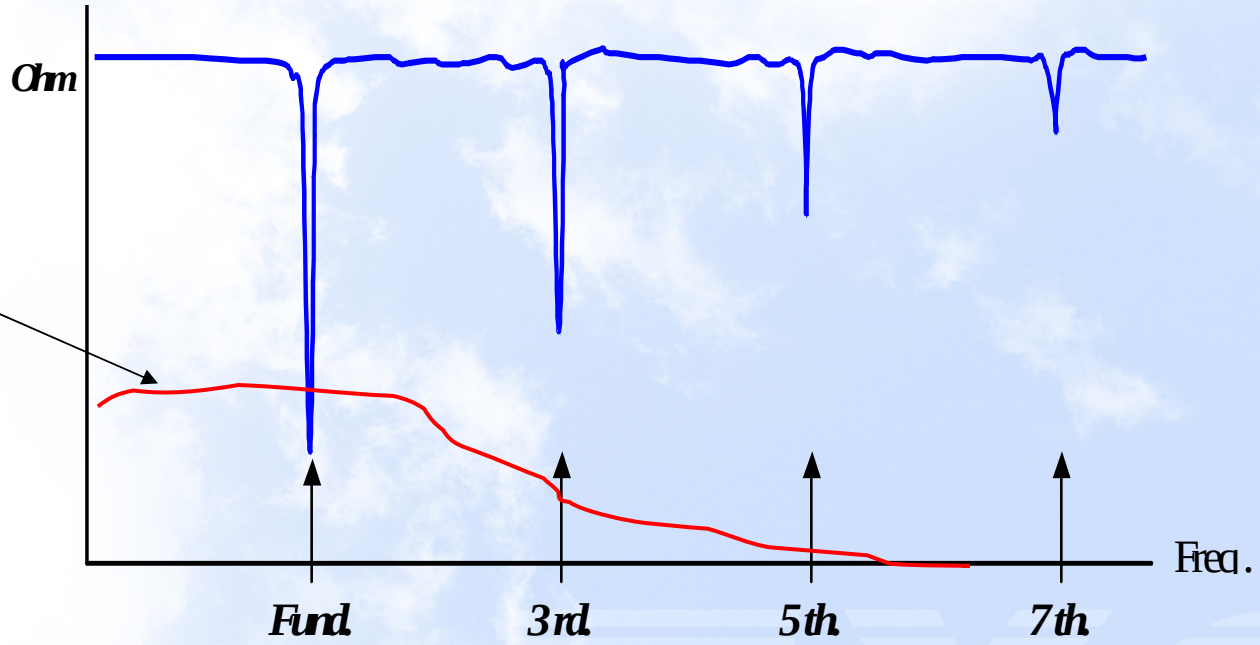
The output frequency can be tuned by adjusting the load capacitance by any means.

$$f_L = f_s\sqrt{1+C_m/(C_o+C_L)}$$

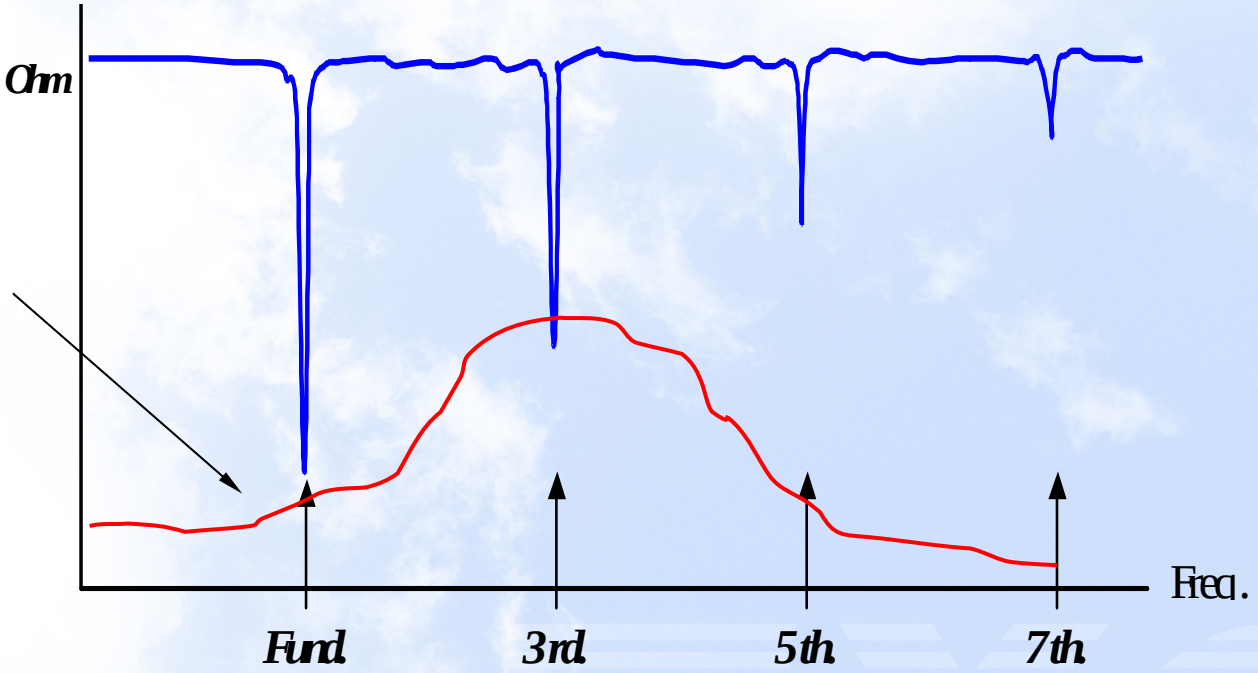
Load capacitance (CL) should include the TOTAL capacitance encounter from two terminals of quartz crystal unit. Usually, CL covers capacitance of physical capacitors, stray capacitance in PCB and capacitance within the oscillation circuit in chipset.

$$f_s = \frac{1}{2\pi}\sqrt{\frac{1}{L_m C_m}}$$

Gain Curve of
Osc Circuit



Gain Curve of
Osc Circuit



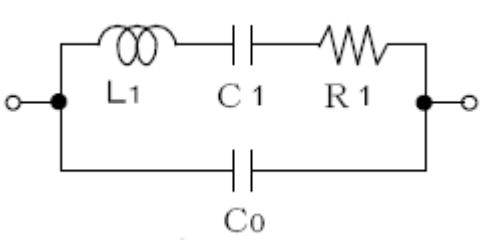
Negative R model in Oscillator Circuit

Co ：Shunt Capacitance 等效並聯電容

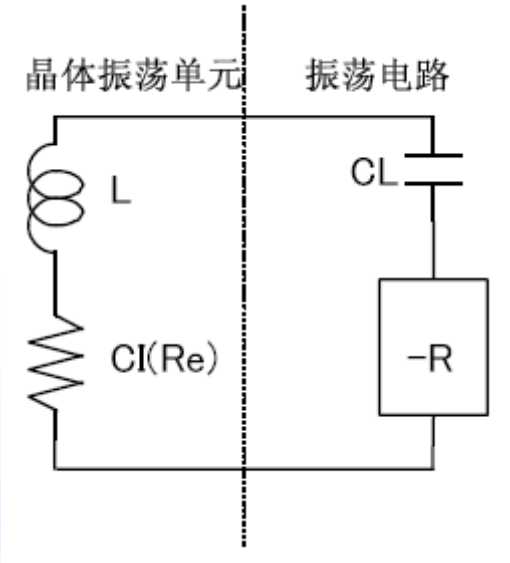
C1 ：Motional Capacitance 等效串聯電容

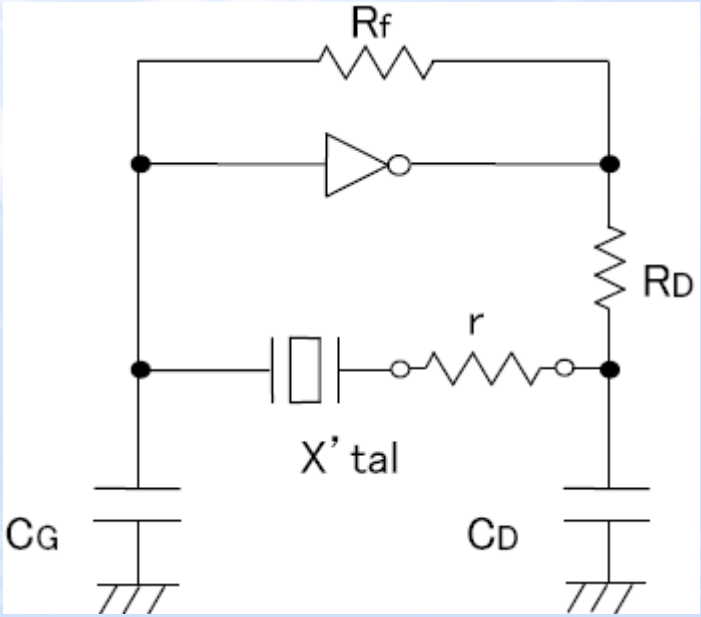
L1 ：Motional Inductance 等效串聯電感

R1 ：Motional Resistance 等效串聯電阻

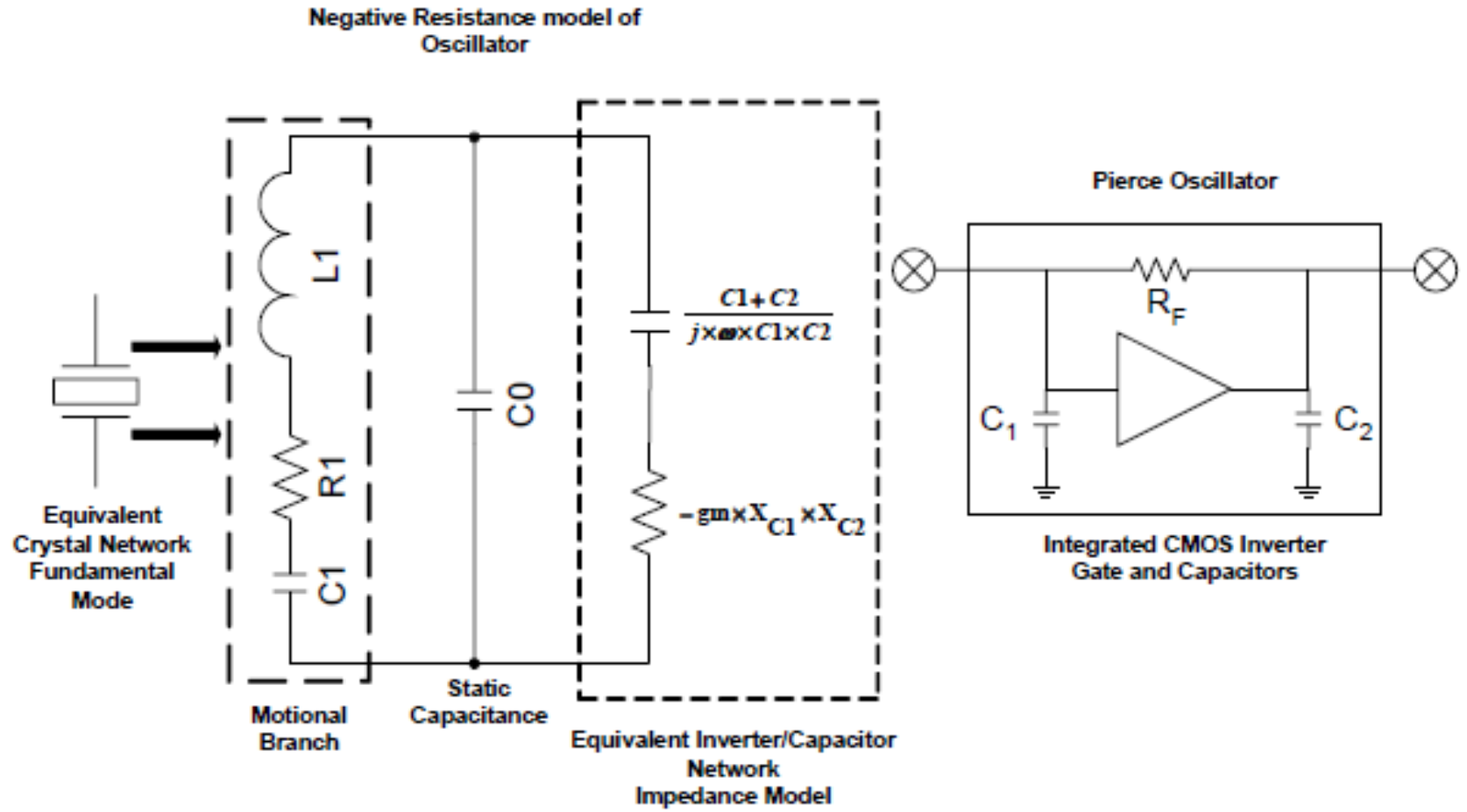


X'tal 單體等效電路

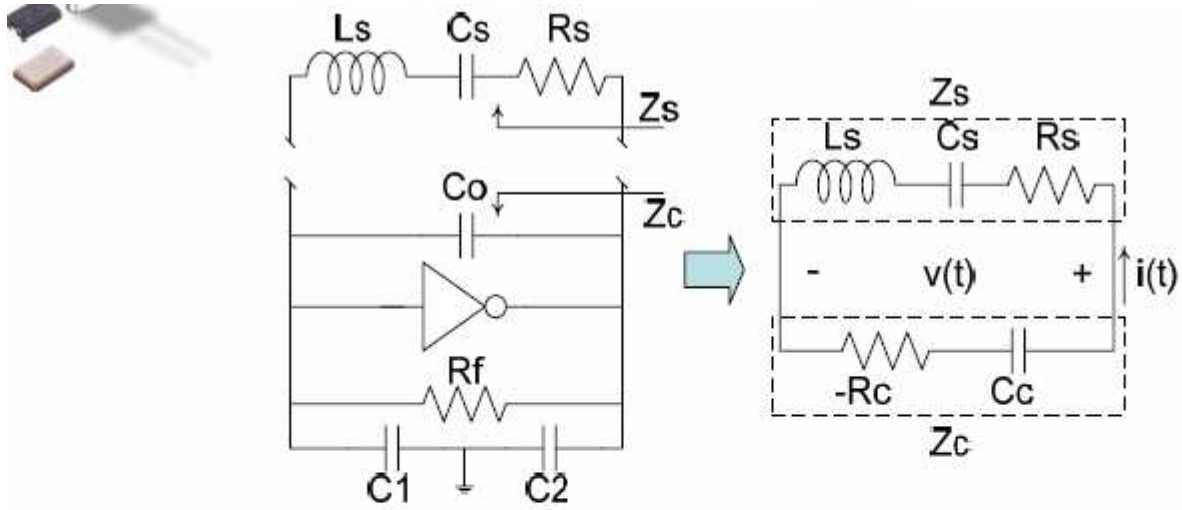




- Negative R is important to reliable oscillation, usually the negative R should be several times to Crystal resistance, depends on applications.



Negative-Resistance Oscillator Model



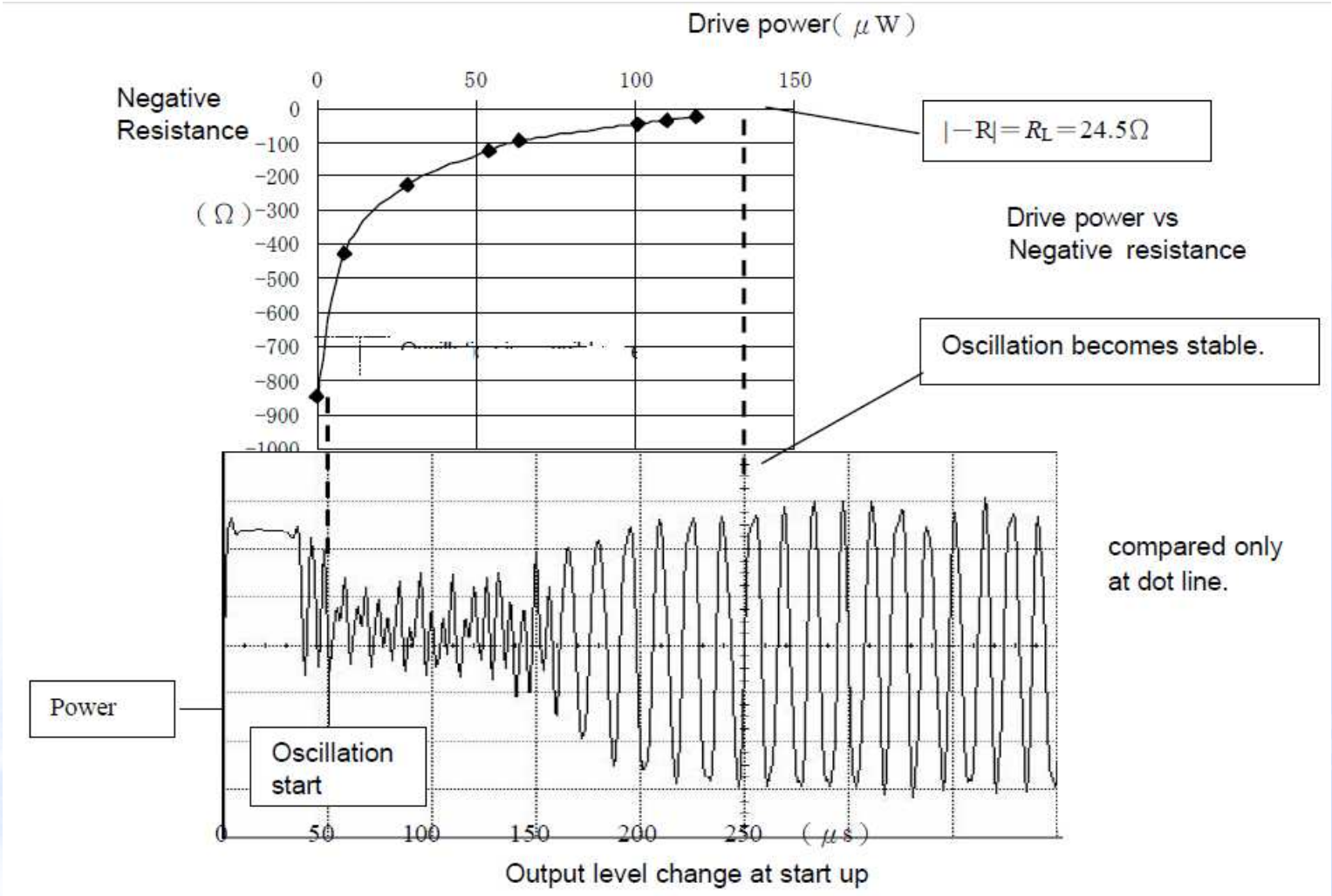
$$\mathrm{Re}(Z_C) = -\frac{g_m C_1 C_2}{(g_m C_0)^2 + \omega^2 (C_1 C_2 + C_2 C_0 + C_1 C_0)^2}$$

Neglect Co

$$\mathrm{Re}(Z_c) = -\frac{g_m}{\omega^2 C_1 C_2}$$

$$\mathrm{Im}(Z_C) = -\frac{g_m^2 C_0 + \omega^2 (C_1 + C_2)(C_1 C_2 + C_2 C_0 + C_1 C_0)}{\omega\left[(g_m C_0)^2 + \omega^2 (C_1 C_2 + C_2 C_0 + C_1 C_0)^2\right]}$$

Negative R and Start-up



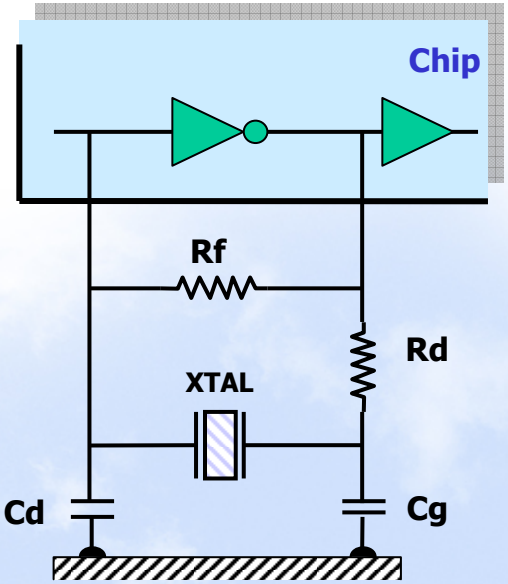
Characteristic with External Components

	Cg	Cd	Rd	Start-up	Freq. Dev.	Swing	Drive Power
	pF	pf	Ohm	mS	ppm	Vpp	uW
1	18	18	2,400	4.8	2.2	3.2	89
2	18	18	1,800	4.2	1.9	3.4	102
3	18	18	1,300	3.7	2.0	3.6	127
4	18	18	750	3.3	2.1	3.9	143
5	18	18	430	2.8	2.0	4.0	166
6	18	18	33	2.2	1.8	4.2	198

	Cg	Cd	Rd	Start-up	Freq. Dev.	Swing	Drive Power
	pF	pf	Ohm	mS	ppm	Vpp	uW
1	18	18	2,400	4.7	1.2	3.4	87
2	18	10	2,400	4.1	10.9	3.4	76
3	10	18	2,400	4.2	11.6	3.5	81
4	10	10	2,400	3.2	21.3	3.7	50
5	8.2	8.2	2,400	2.1	35.0	3.9	37

The data in above table is just one specific case for reference.

These data do not mean other circuits have same characteristics.



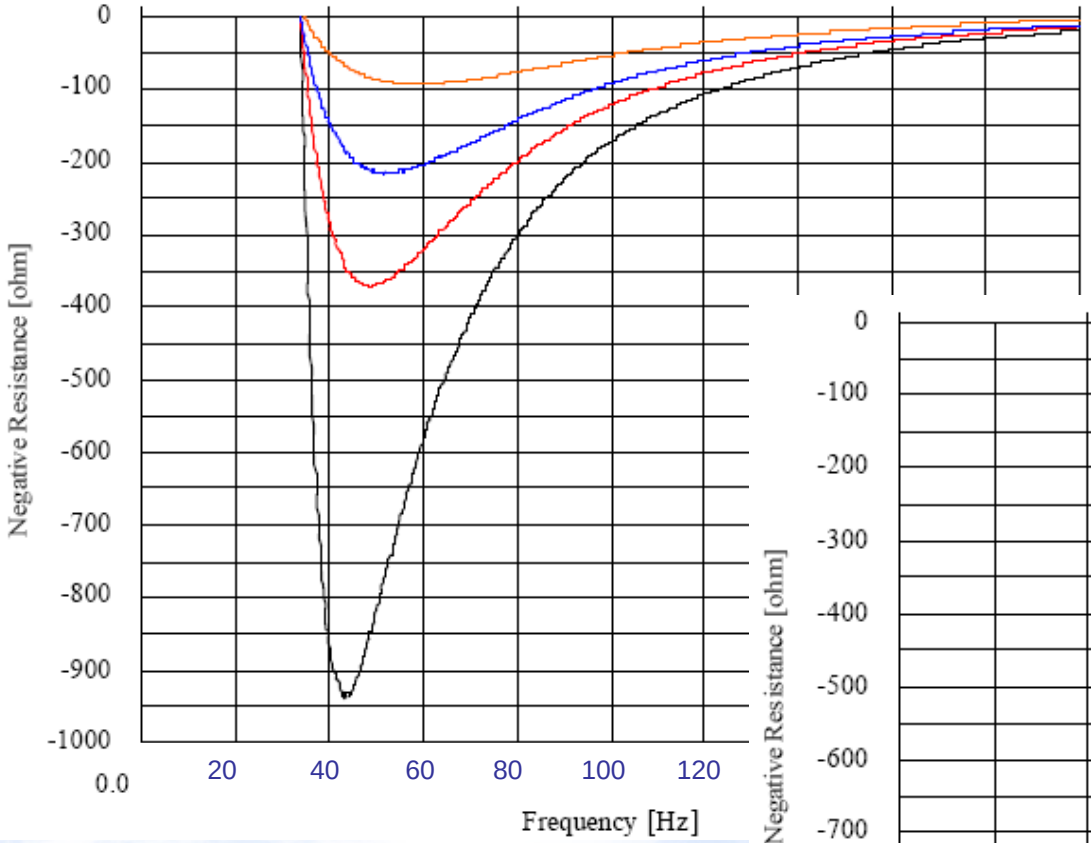
There is trade off between frequency stability, trim and power , start-up time, drive power.

Designer need to decide how to reach optima status for application.

Noise performance is another key characteristics in RF applications.

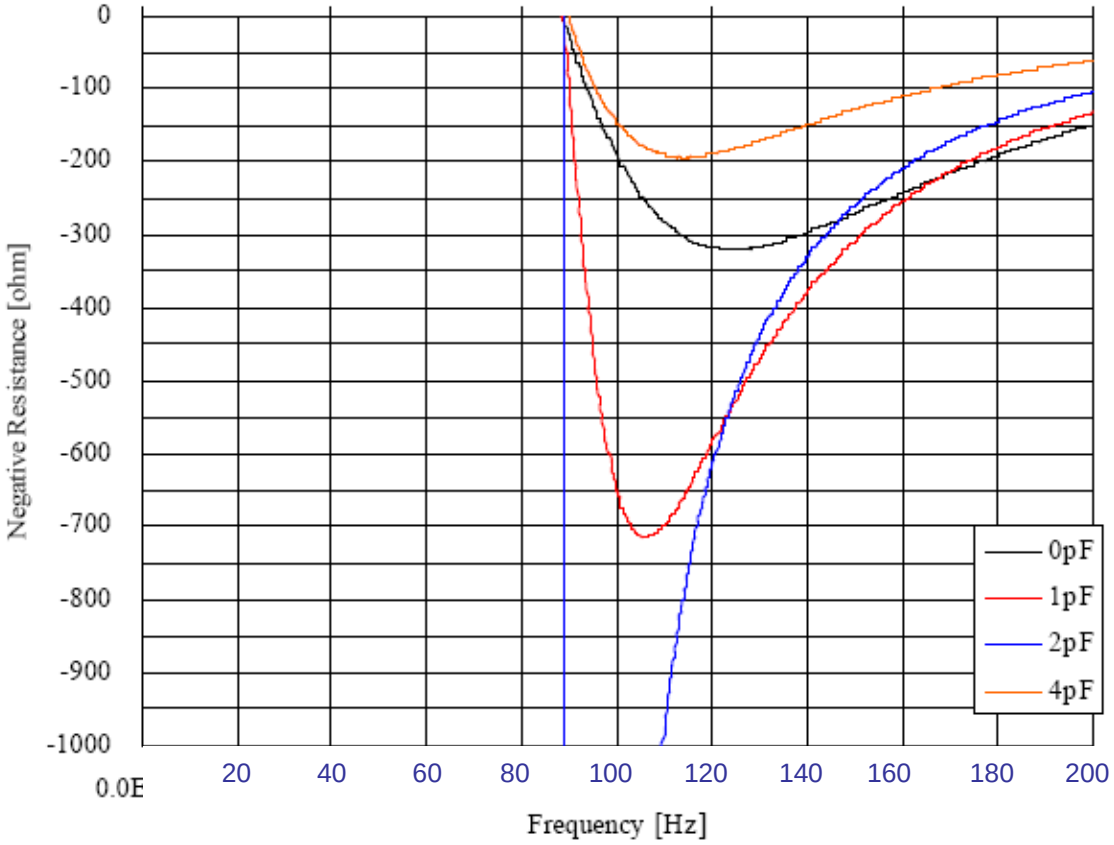


Negative Resistance in Oscillate Circuit



The negative resistance for two different oscillation circuits which adopted for lower and higher frequency range.

The negative resistance of oscillation circuit will be changed with different load capacitance.



- Pulling Range from $CL_1 \sim CL_2$:

$$Pulling = f_{L2} - f_{L1}$$

$$\cong f_S \times \frac{Cm \times (CL_2 - CL_1)}{(Co + CL_2) \times (Co + CL_1)}$$

- Trim Sensitivity at specific CL :

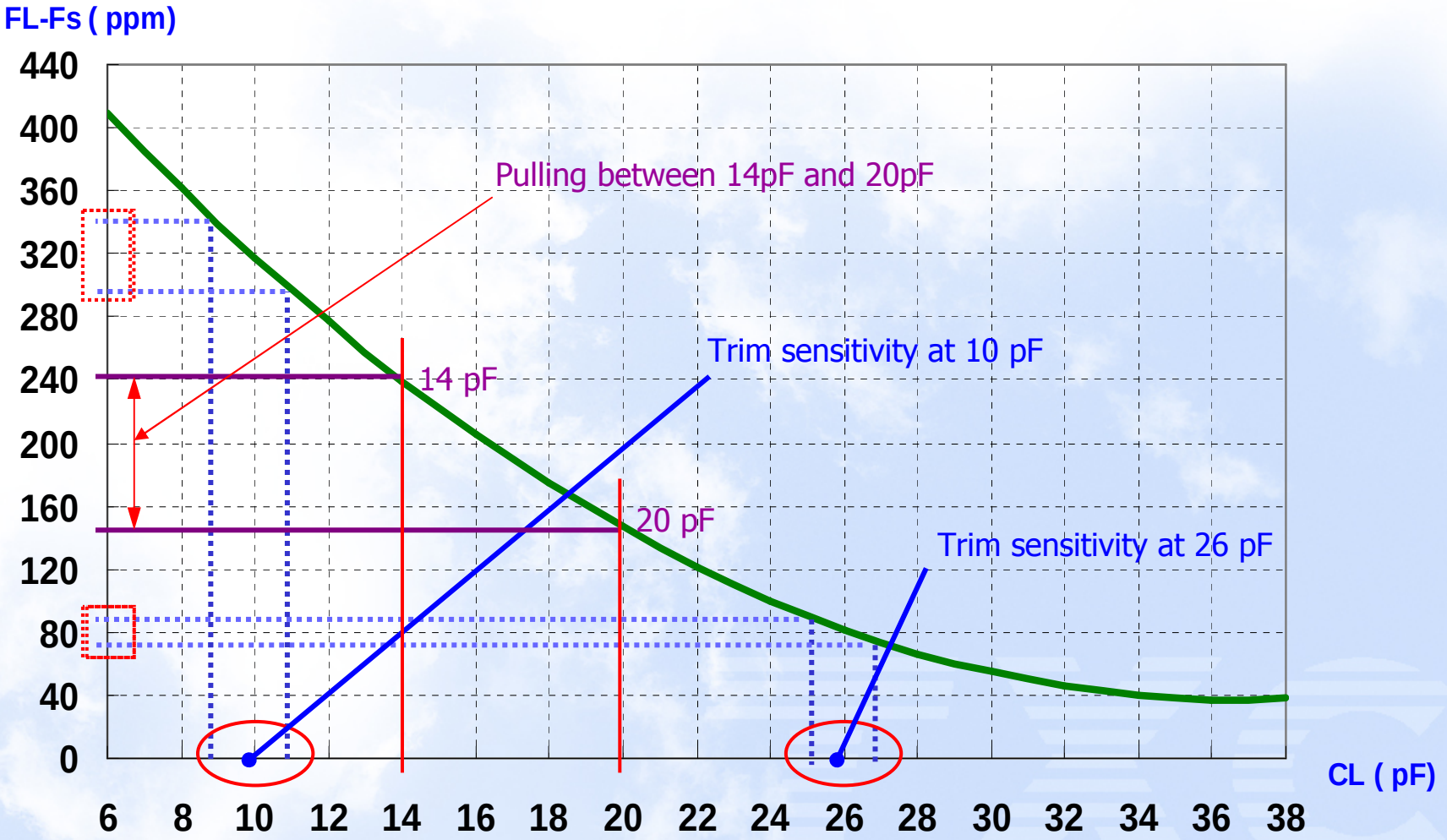
$$\textbf{Trim Sensitivity} = \frac{df_L}{dCL}$$

$$\cong \frac{-Cm}{2 \times (Co + CL)^2}$$



Frequency vs Load Capacitance

SMD 7050 Fundamental 27MHz



There are two different kinds of crystal applications

A stable reference frequency : the load capacitance is around 16~30 pF

A tunable reference frequency : need the low load capacitance, 6~10 pF

The influence of load capacitance

	High Load Capacitance	Low Load Capacitance
Trim Sensitivity	Frequency can be kept in acceptable range due to the variation of stray capacitance on PCB layout	Frequency will be shifted a lot due to the variation of stray capacitance on PCB layout
Power Consumption	Higher power consumption	Lower power consumption
Start up time	A little bit longer	Short
Pullability	limited	Good



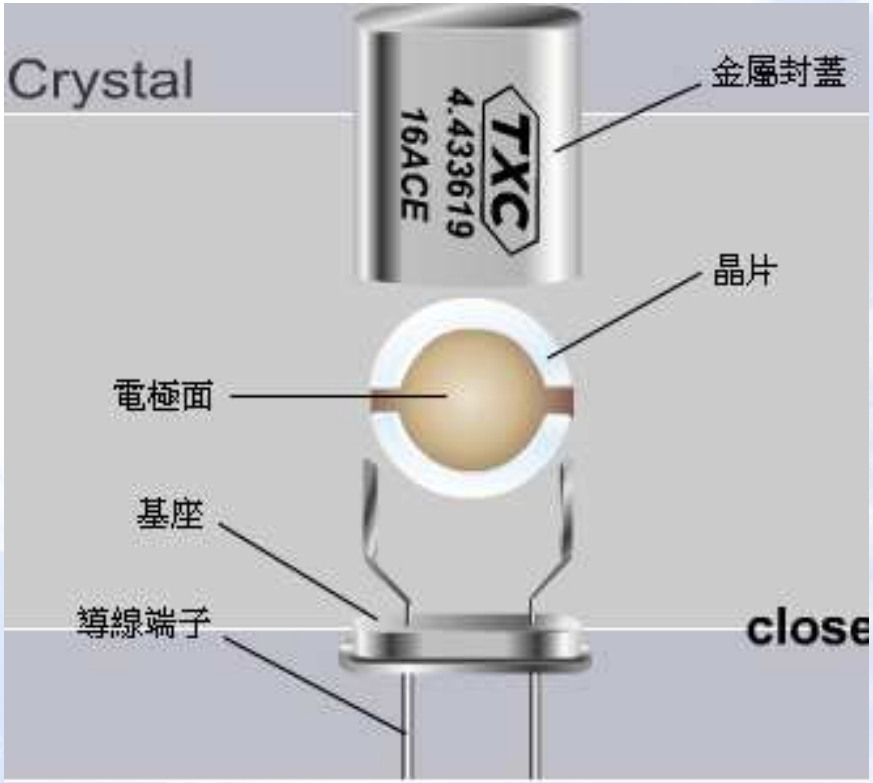
Quartz Resonators

- The Resonator Model/Structure
- The requirements for Quartz Resonators – Hermetic (Life and Stable Environment), Mechanical Shock and Vibrations, Aging, Room Temperature Performance, Temperature Performance, DLD, etc…
- Quartz Resonator Materials – Piezo-materials, Packaging Materials, Electrode Materials,…

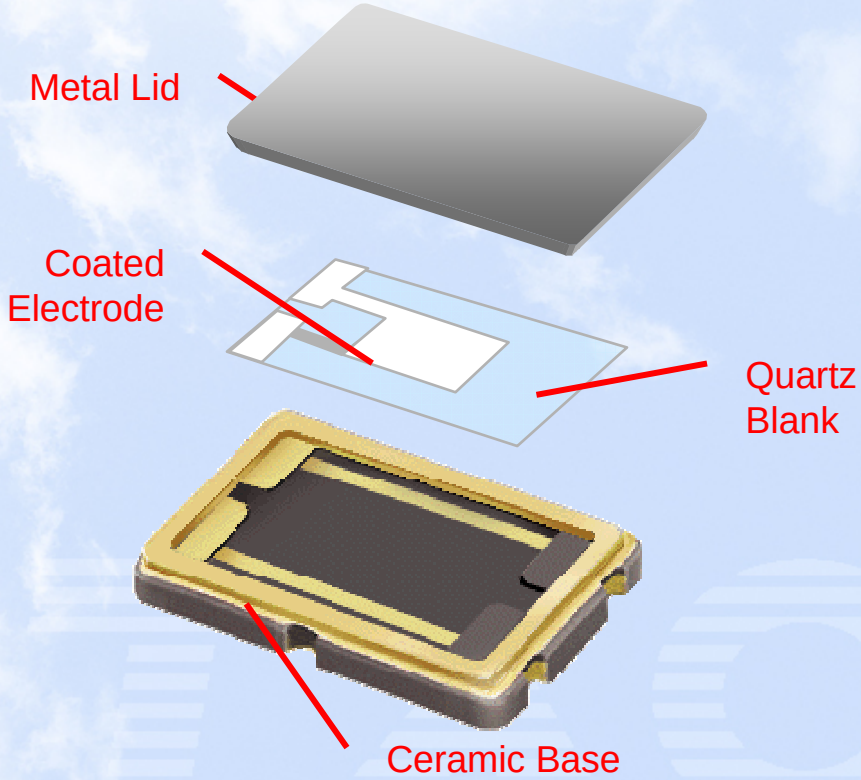


Structure of a Crystal Unit

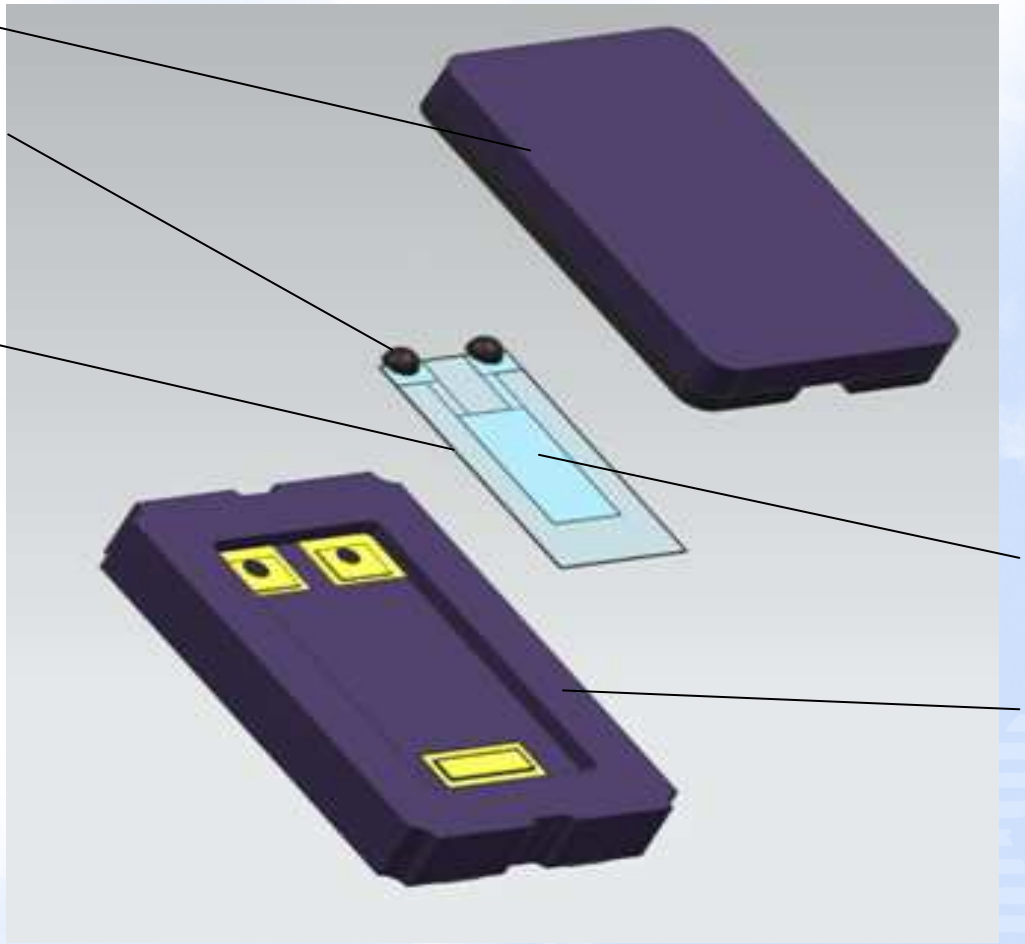
DIP Type



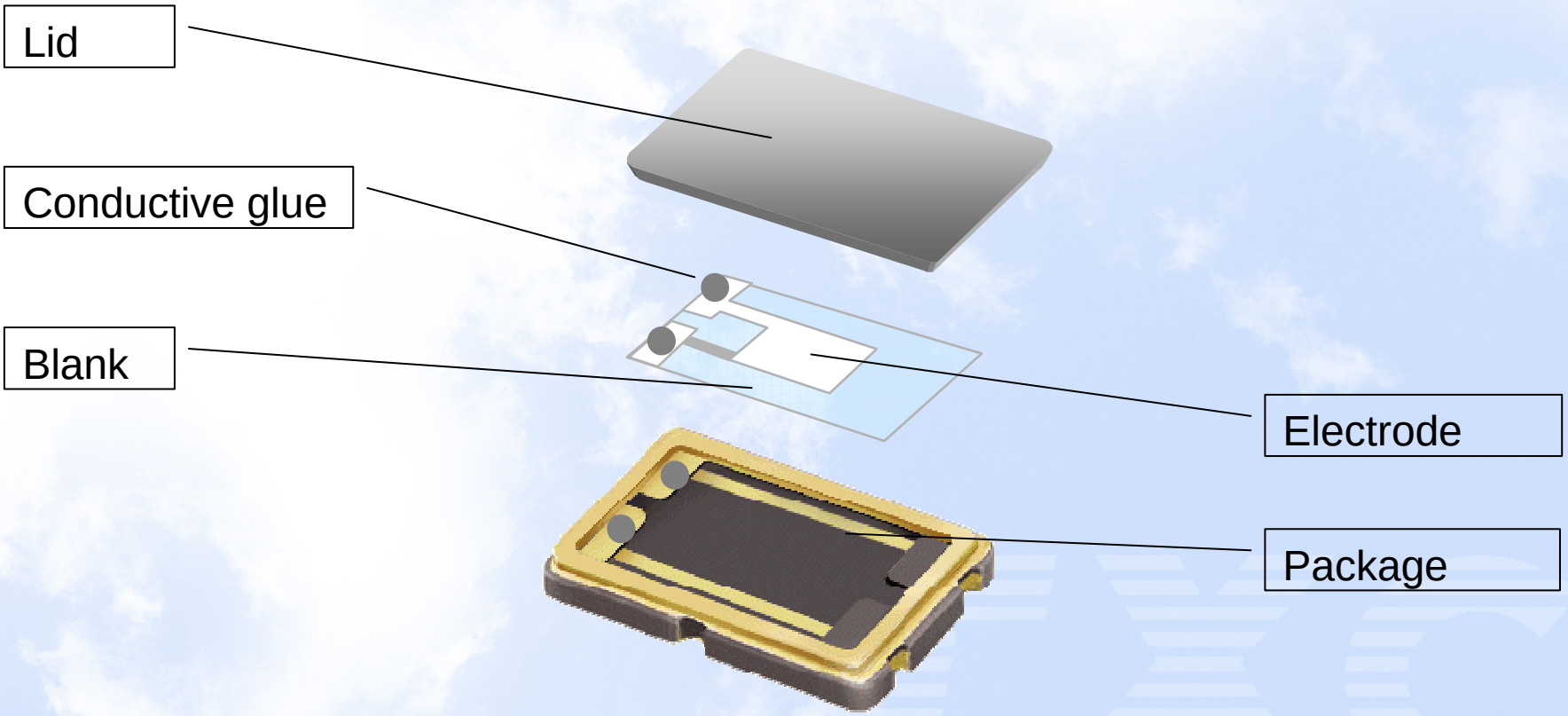
SMD Type



SMD Glass seal Crystals

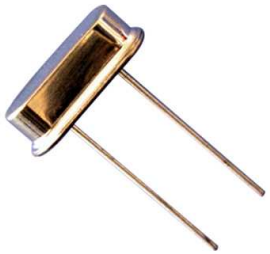


SMD Seam Type Crystals

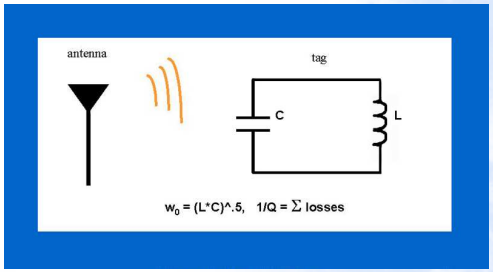


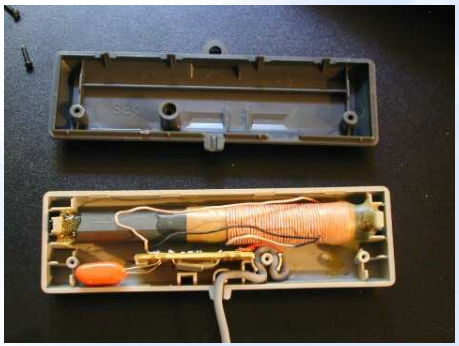
resonators – Crystals, LC, pendulums, balance wheels, Ceramic, MEMS, …

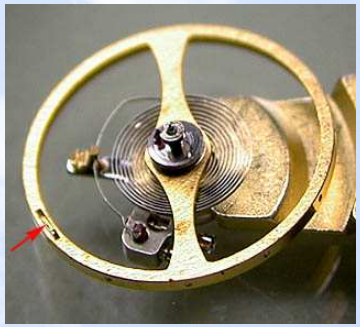
Why Quartz?

















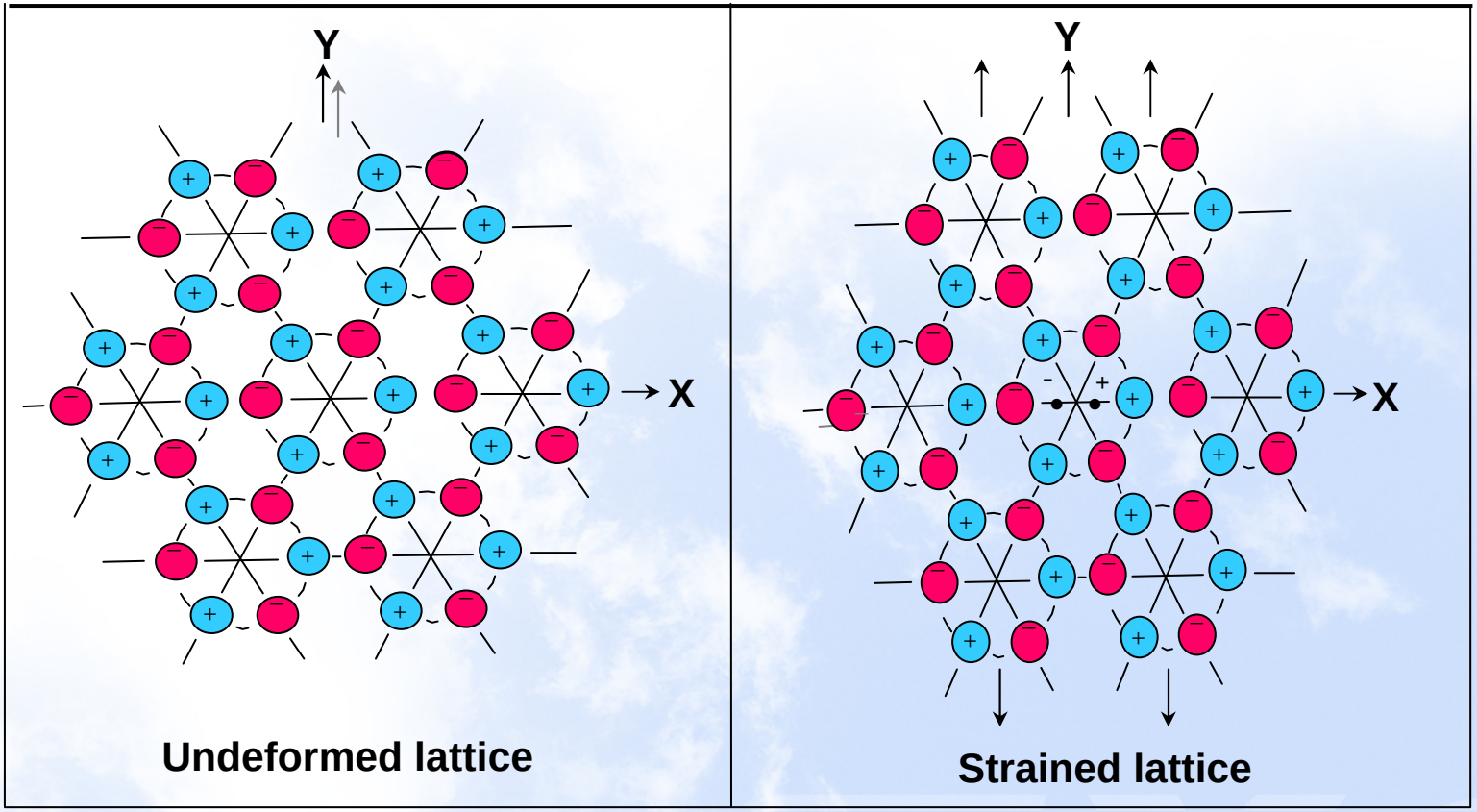
Why Quartz?

Quartz is the only material known that possesses the following combination of properties:

- Piezoelectric ("pressure-electric"; piezein = to press, in Greek)
- Zero temperature coefficient cuts exist
- Stress compensated cut exists
- Low loss (i.e., high Q)
- Easy to process; low solubility in everything, under "normal" conditions, except the fluoride and hot alkali etchants; hard but not brittle
- Abundant in nature; easy to grow in large quantities, at low cost, and with relatively high purity and perfection. Of the man-grown single crystals, quartz, at ~3,000 tons per year, is second only to silicon in quantity grown (3 to 4 times as much Si is grown annually, as of 1997).



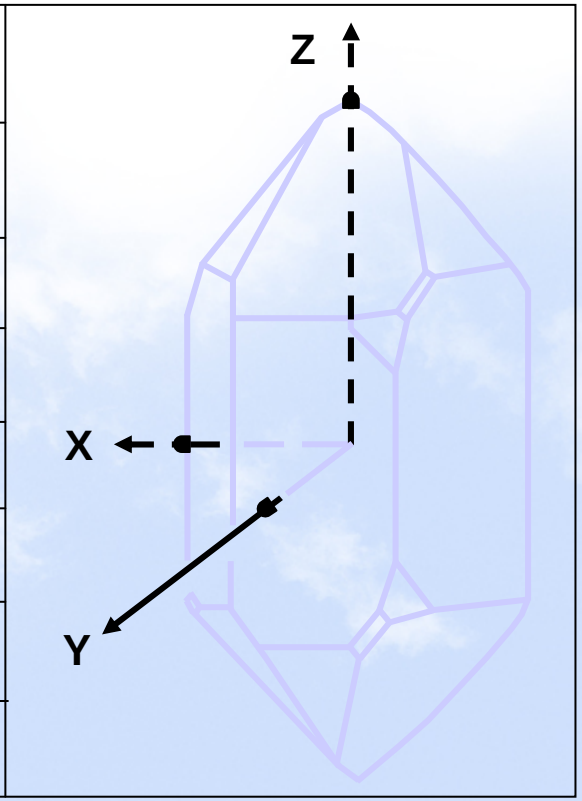
The Piezoelectric Effect



The piezoelectric effect provides a coupling between the mechanical properties of a piezoelectric crystal and an electrical circuit.

The Piezoelectric Effect in Quartz

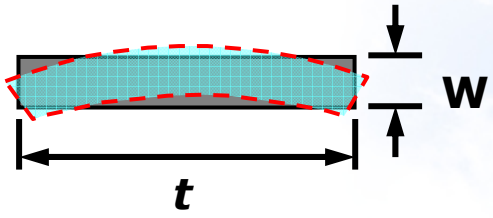
STRAIN		FIELD along: X	FIELD along: Y	FIELD along: Z
EXTENSIONAL along:	X	√		
	Y	√		
	Z			
SHEAR about:	X	√		
	Y		√	
	Z		√	



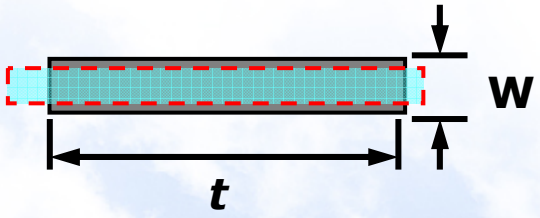
In quartz, the five strain components shown may be generated by an electric field. The modes shown on the next page may be excited by suitably placed and shaped electrodes. The shear strain about the Z-axis produced by the Y-component of the field is used in the rotated Y-cut family, including the AT, BT, and ST-cuts.

Vibration Modes

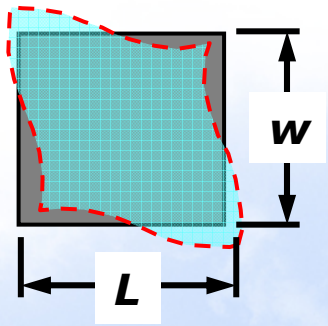
Some typical vibration modes in quartz plates



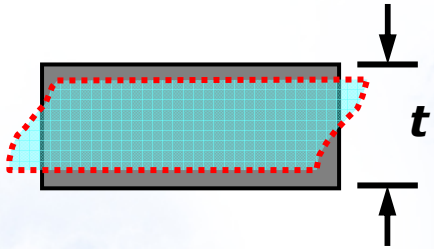
Flexure Mode



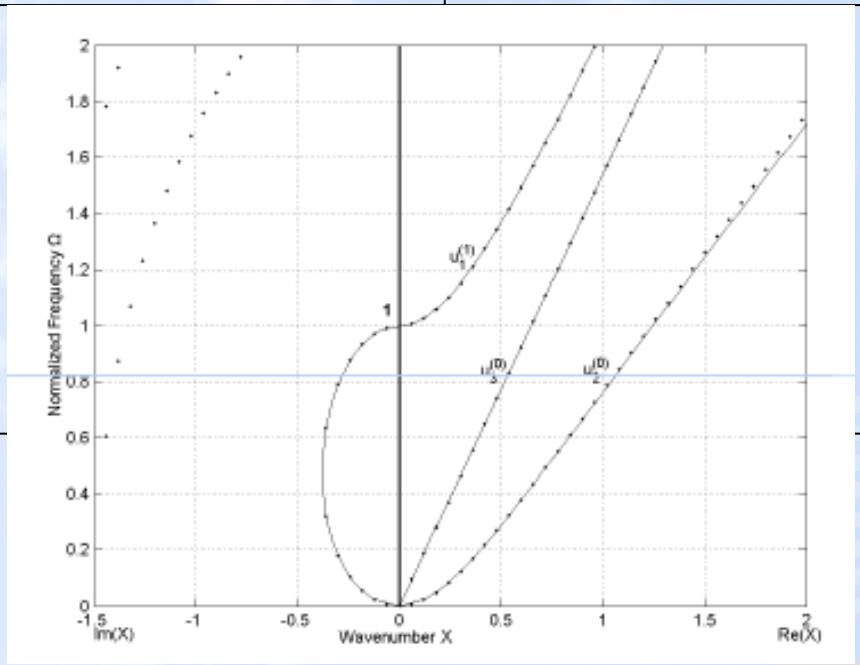
Extensional Mode



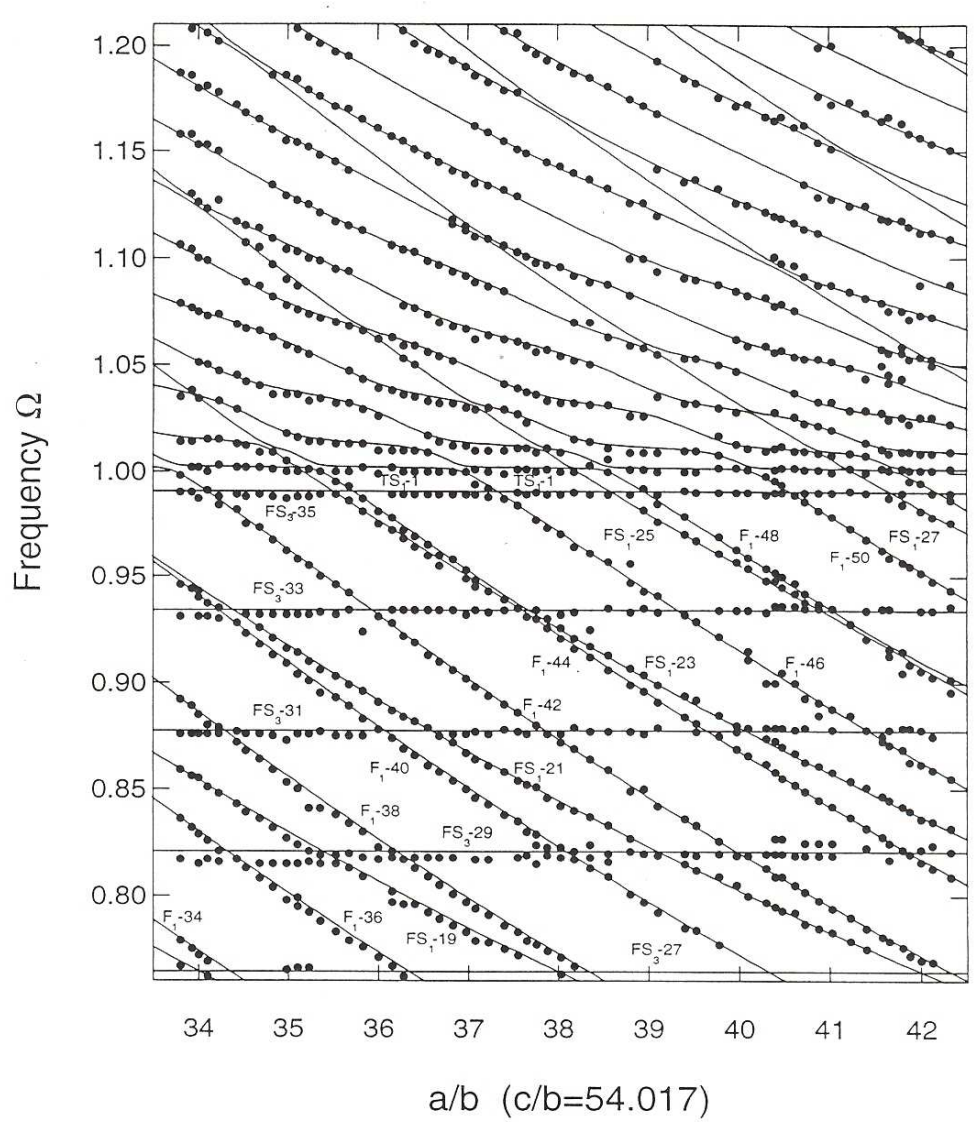
Face Shear Mode



Thickness Shear Mode



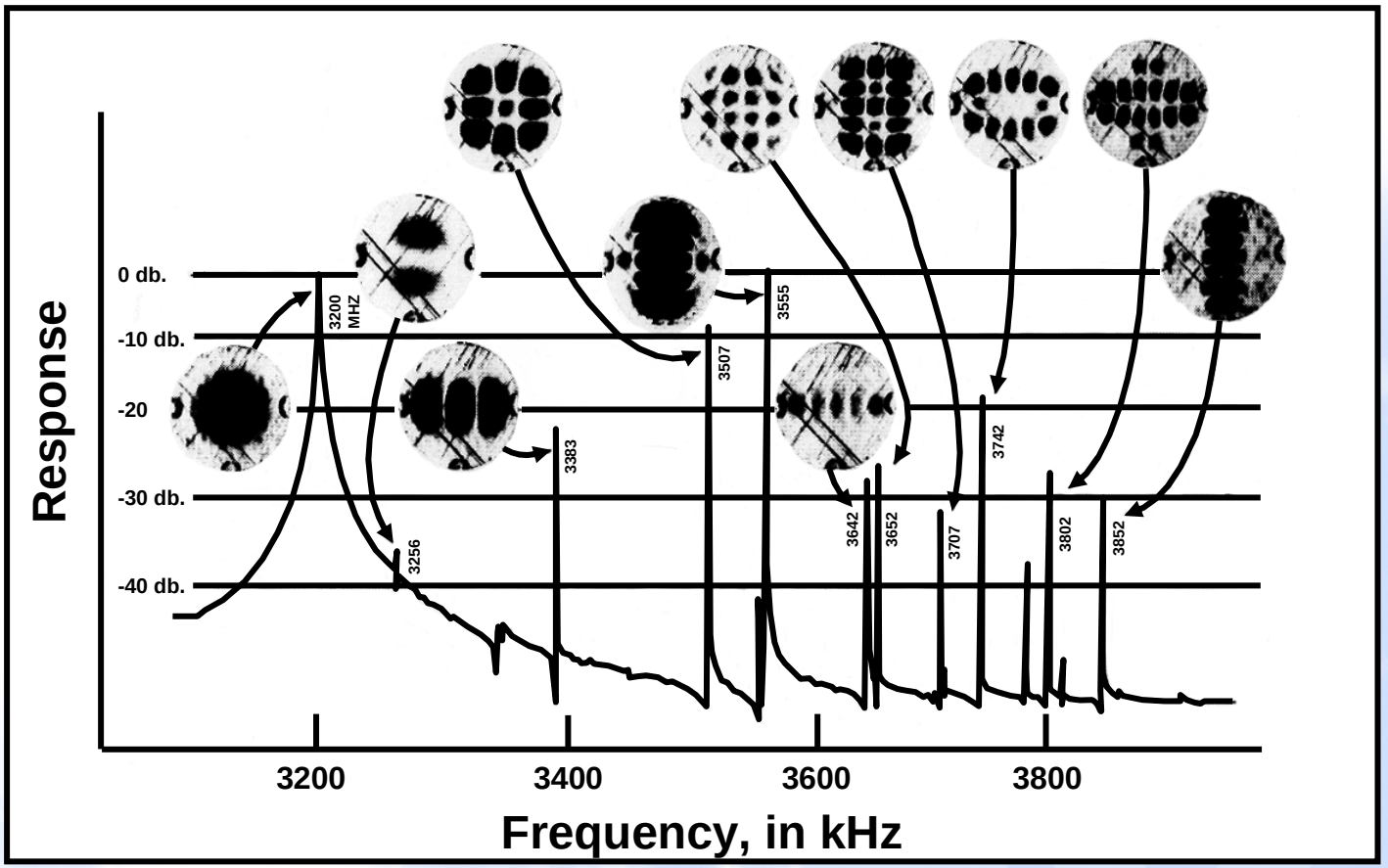
Vibration Modes



Frequency Ω vs. length/thickness ratios *a/b* of rectangular AT-cut quartz plates with constant width (*c/b*=54.017). Solid lines are predicted by present 2-D theory with *R*=0.001 and dots are experimental data by Koga and Fukuyo.

(Prof. Peter Lee, SPAWDA 2010)

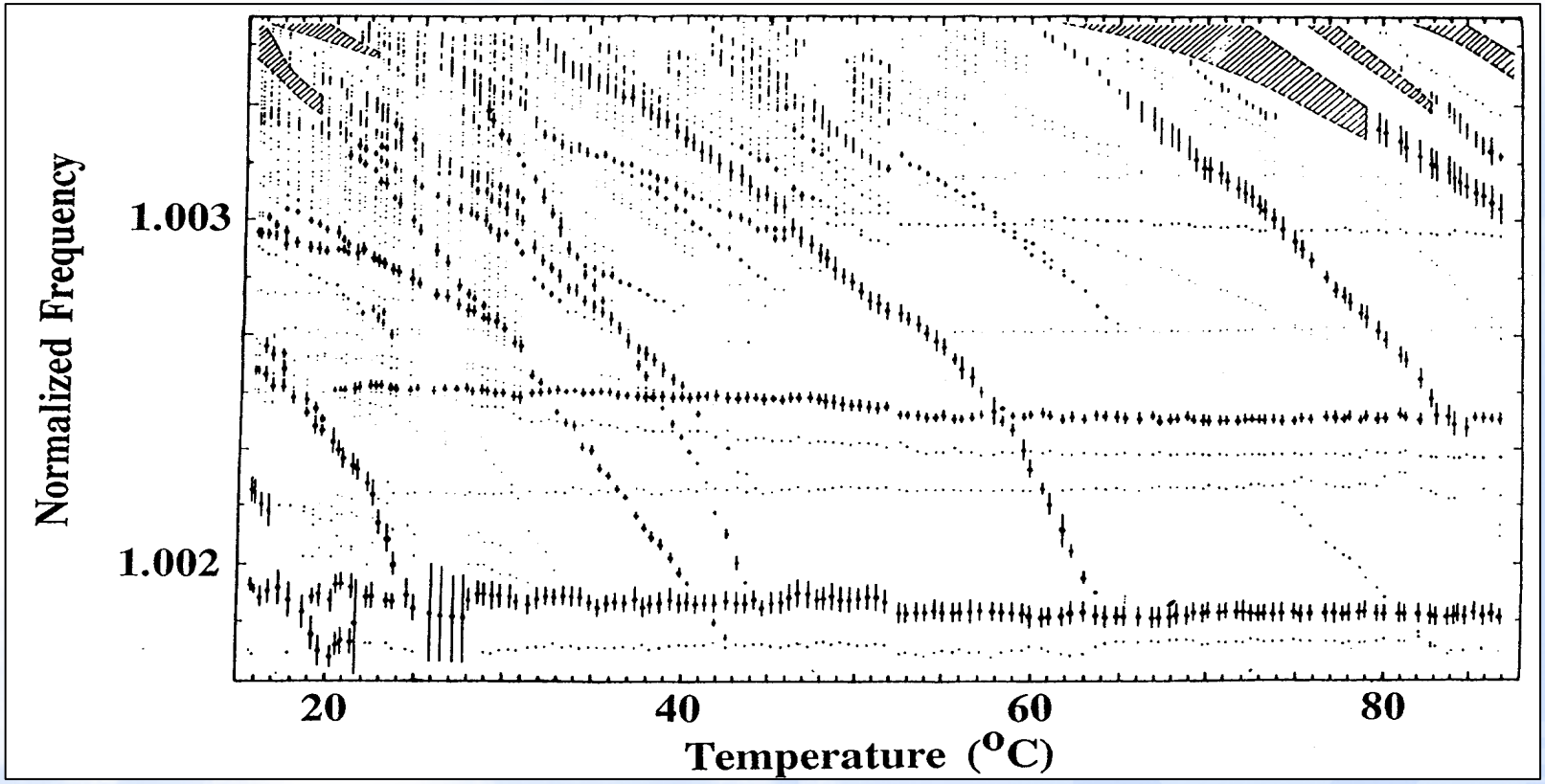
Vibration Modes -- Resonant Vibrations of a Quartz Plate



X-ray topographs (21•0̄ plane) of various modes excited during a frequency scan of a fundamental mode, circular, AT-cut resonator. The first peak, at 3.2 MHz, is the main mode; all others are unwanted modes. Dark areas correspond to high amplitudes of displacement.

Vibration Modes-- Unwanted Modes vs. Temperature

(3 MHz rectangular AT-cut resonator, 22 X 27 X 0.552 mm)



Activity dips occur where the f vs. T curves of unwanted modes intersect the f vs. T curve of the wanted mode. Such activity dips are highly sensitive to drive level and load reactance.

Infinite Plate Thickness Shear Resonator

$$f_n = \frac{n}{2h}\sqrt{\frac{c_{ij}}{\rho}}, \quad n = 1, 3, 5...$$

Where f_n = resonant frequency of n-th harmonic
h = plate thickness
ρ = density
c_{ij} = elastic modulus associated with the elastic wave being propagated

$$T_f = \frac{d(\log f_n)}{dT} = \frac{1}{f_n}\frac{df_n}{dT} = \frac{-1}{h}\frac{dh}{dT} - \frac{1}{2\rho}\frac{d\rho}{dT} + \frac{1}{2c_{ij}}\frac{dc_{ij}}{dT}$$

where T_f is the linear temperature coefficient of frequency. The temperature coefficient of c_{ij} is negative for most materials (i.e., “springs” become “softer” as T increases). The coefficients for quartz can be +, - or zero (see next page).

Quartz is Highly Anisotropic

- The properties of quartz vary greatly with crystallographic direction. For example, when a quartz sphere is etched deeply in HF, the sphere takes on a triangular shape when viewed along the Z-axis, and a lenticular shape when viewed along the Y-axis. The etching rate is more than 100 times faster along the fastest etching rate direction (the Z-direction) than along the slowest direction (the slow-X-direction).

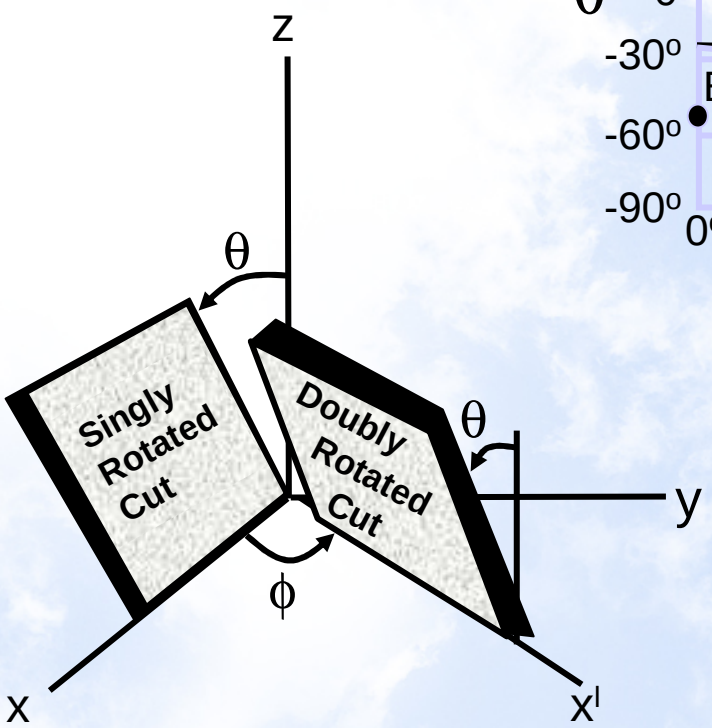
- The thermal expansion coefficient is 7.8 x 10^{-6}/°C along the Z-direction, and 14.3 x 10^{-6}/°C perpendicular to the Z-direction; the temperature coefficient of density is, therefore, -36.4 x 10^{-6}/°C.

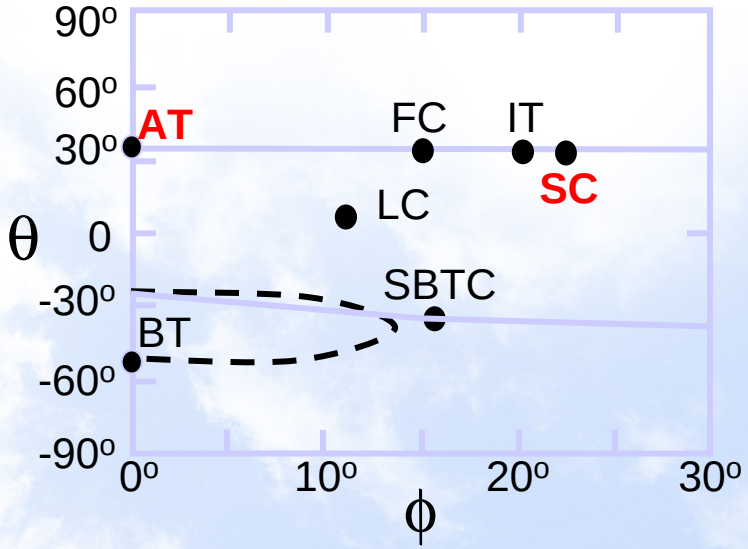
- The temperature coefficients of the elastic constants range from -3300 x 10^{-6}/°C (for C_{12}) to +164 x 10^{-6}/°C (for C_{66}).

- For the proper angles of cut, the sum of the first two terms in T_f on the previous page is cancelled by the third term, i.e., temperature compensated cuts exist in quartz. (See next page.)



Zero Temperature Coefficient Quartz Cuts





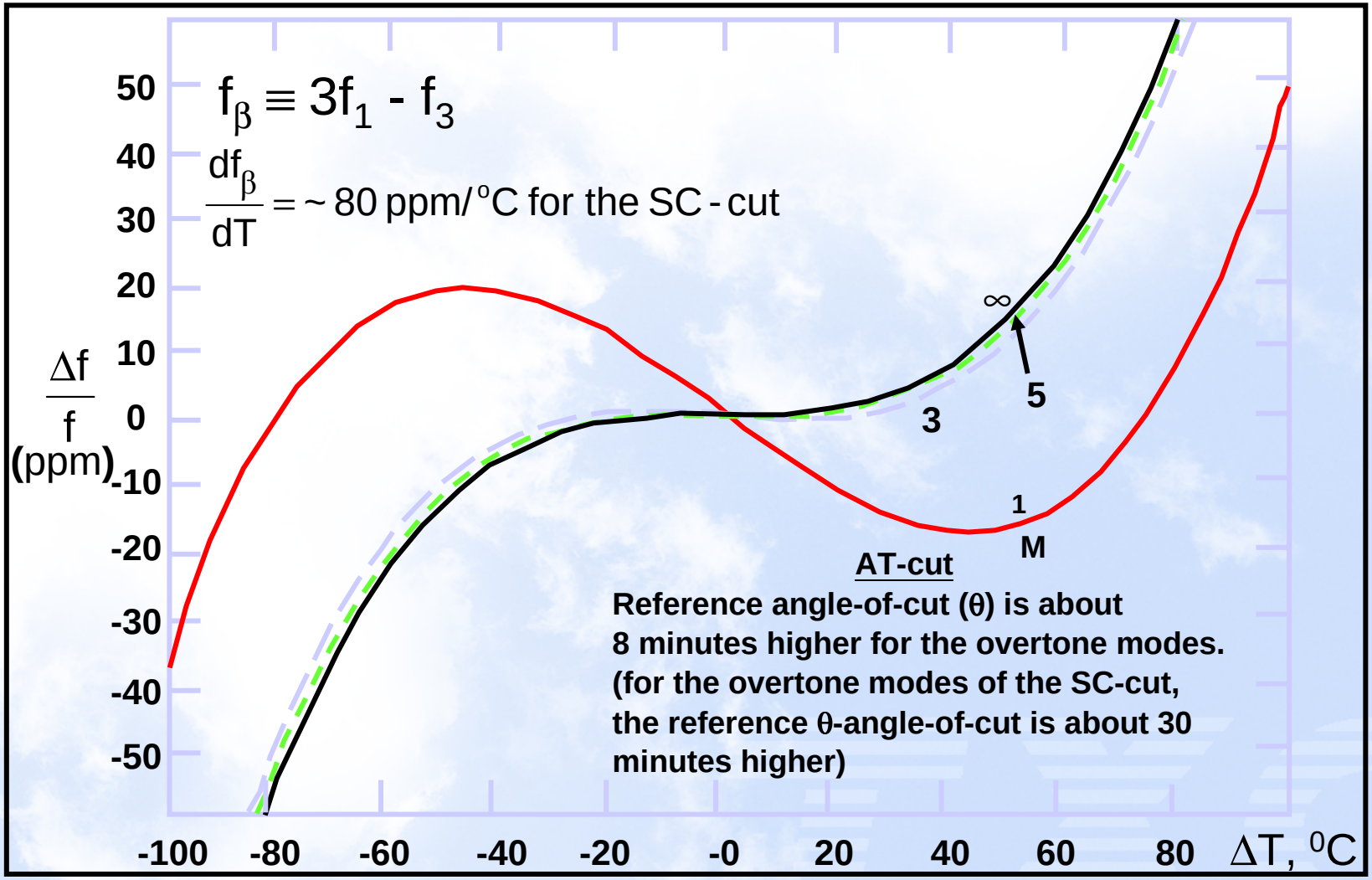
The AT, FC, IT, SC, BT, and SBTC-cuts are some of the cuts on the locus of zero temperature coefficient cuts. The LC is a "linear coefficient" cut that has been used in a quartz thermometer.

Y-cut: ≈ +90 ppm/^{0}C
(thickness-shear mode)

X-cut: ≈ -20 ppm/^{0}C
(extensional mode)

Effects of Overtones on f vs. T

and self-temperature sensing



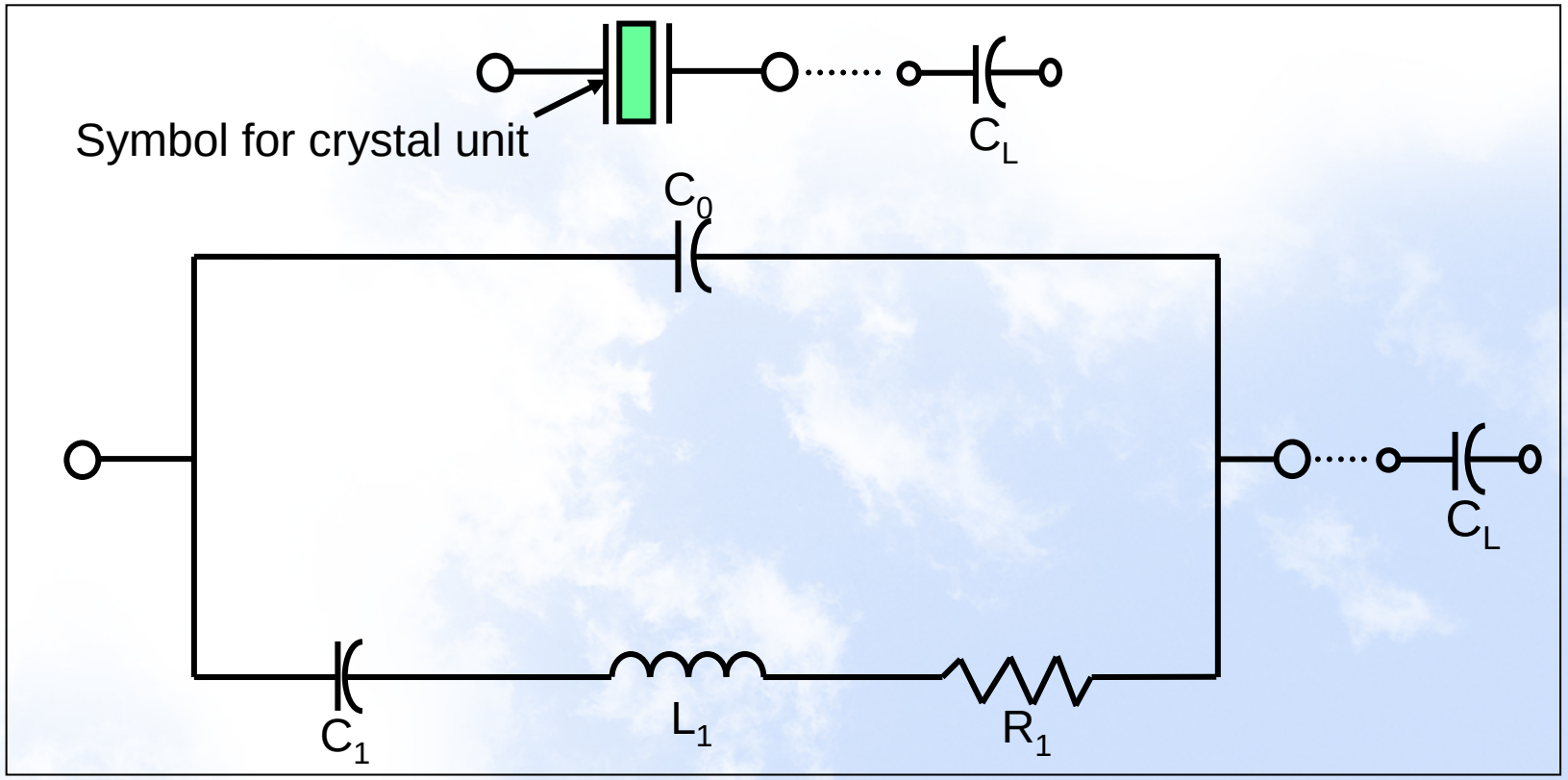
Quartz Resonator

- The requirements for Quartz Resonators – Hermetic (Life and Stable Environment), Mechanical Shock and Vibrations, Aging, Room Temperature Performance, Temperature Performance, DLD, etc…

- The Quartz Resonator Characteristics

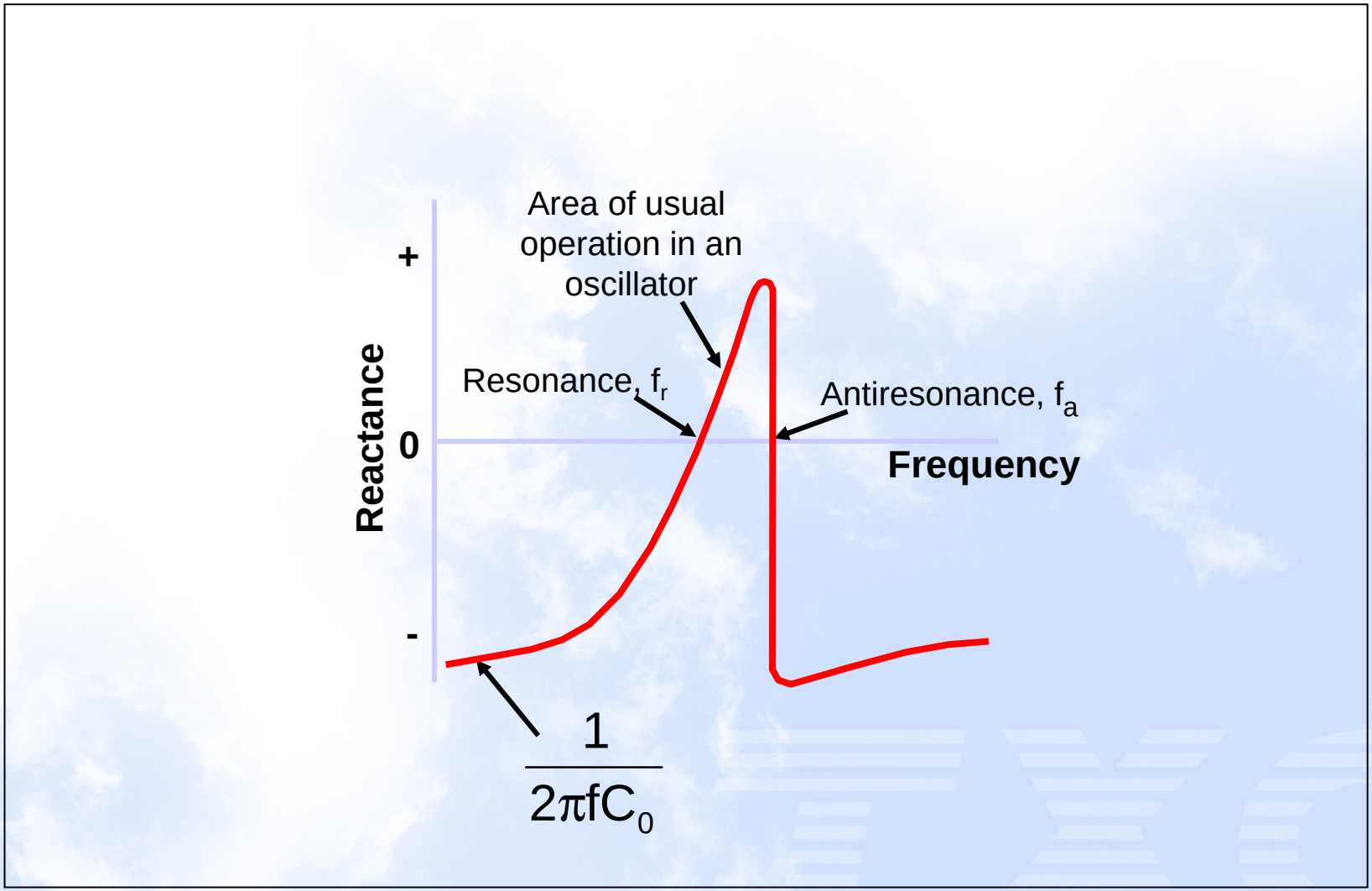


Equivalent Circuit of a Resonator



$$\frac{\Delta f}{f_S} \approx \frac{C_1}{2(C_0 + C_L)} \rightarrow \begin{cases} 1. \text{ Voltage control (VCXO)} \\ 2. \text{ Temperature compensation (TCXO)} \end{cases}$$

Resonator Reactance vs. Frequency



Equivalent Circuit Parameter Relationships

$$C_0 \cong \varepsilon \frac{A}{t} \qquad r \equiv \frac{C_0}{C_1}$$

$$f_s = \frac{1}{2\pi}\sqrt{\frac{1}{L_1 C_1}} \qquad f_a - f_s \cong \frac{f_s}{2r}$$

$$Q = \frac{1}{2\pi f_s R_1 C_1} \qquad \varphi = \frac{\omega L_1 - \frac{1}{\omega C_1}}{R_1}$$

$$\tau_1 = R_1 C_1 \cong 10^{-14}\,s \qquad \frac{d\varphi}{df} \cong \frac{360}{\pi}\frac{Q}{f_s}$$

$$C_{1n} \approx \frac{r' C_{11}}{n^3} \qquad L_{1n} \approx \frac{n^3 L_{11}}{r'^3} \qquad R_{1n} \approx \frac{n^3 R_{11}}{r'} \qquad 2r = \left(\frac{\pi n}{2k}\right)^2$$

n: Overtone number
C_0: Static capacitance
C_1: Motional capacitance
C_{1n}: C_1 of n-th overtone
L_1: Motional inductance
L_{1n}: L_1 of n-th overtone
R_1: Motional resistance
R_{1n}: R_1 of n-th overtone
ε: Dielectric permittivity of quartz ≈40 pF/m (average)
A: Electrode area
t: Plate thickness
r: Capacitance ratio
r': f_n/f_1
f_s: Series resonance frequency ≈f_R
f_a: Antiresonance frequency
Q; Quality factor
τ_1: Motional time constant
ω: Angular frequency = 2πf
φ: Phase angle of the impedance
k; Piezoelectric coupling factor =8.8% for AT-cut, 4.99% for SC

What is Q and Why is it Important?

$$Q \equiv 2\pi \frac{\text{Energy stored during a cycle}}{\text{Energy dissipated per cycle}}$$

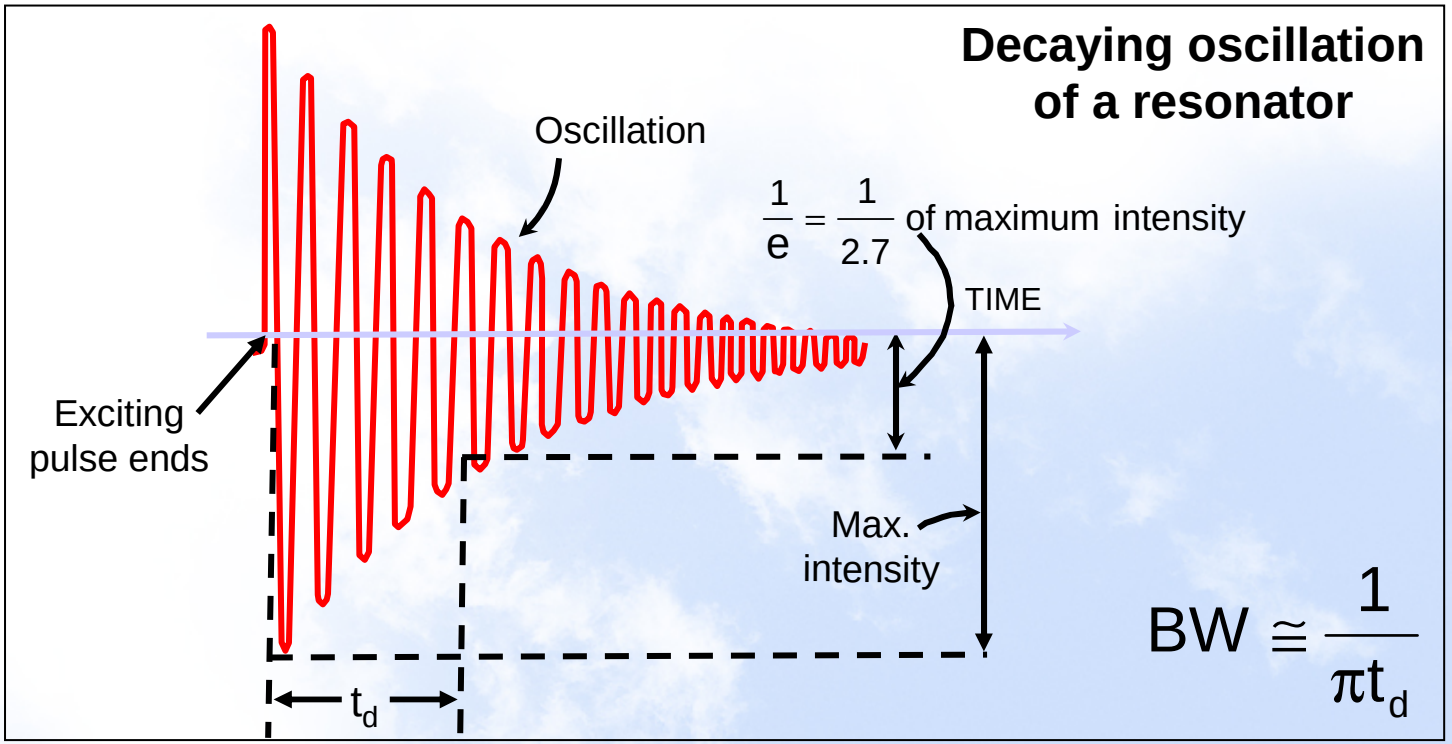
Q is proportional to the decay-time, and is inversely proportional to the linewidth of resonance (see next page).

- The higher the Q, the higher the frequency stability and accuracy **capability** of a resonator (i.e., high Q is a necessary but not a sufficient condition). If, e.g., $Q = 10^6$, then 10^{-10} accuracy requires ability to determine center of resonance curve to 0.01% of the linewidth, and stability (for some averaging time) of 10^{-12} requires ability to stay near peak of resonance curve to 10^{-6} of linewidth.

- Phase noise close to the carrier has an especially strong dependence on Q ($L(f) \propto 1/Q^4$ for quartz oscillators).



Decay Time, Linewidth, and Q



Factors that Determine Resonator Q

The **maximum Q** of a resonator can be expressed as:

$$Q_{max} = \frac{1}{2\pi f \tau},$$

where f is the frequency in Hz, and τ is an empirically determined "motional time constant" in seconds, which varies with the angles of cut and the mode of vibration. For example, $\tau = 1 \times 10^{-14}$s for the AT-cut's c-mode (Q_{max} = 3.2 million at 5 MHz), $\tau = 9.9 \times 10^{-15}$s for the SC-cut's c-mode, and $\tau = 4.9 \times 10^{-15}$s for the BT-cut's b-mode.

Other factors which affect the Q of a resonator include:

- Overtone
- Surface finish
- Material impurities and defects
- Mounting stresses
- Bonding stresses
- Temperature
- Electrode geometry and type
- Blank geometry (contour, dimensional ratios)
- Drive level
- Gases inside the enclosure (pressure, type of gas)
- Interfering modes
- Ionizing radiation



Why Quartz? -- High Q, advantage and disadvantage

High Q
positive effect: high frequency resolution
negative effect: very sensitive on process variation

Advantage –
Frequency Purity → high accurate resonator (sub ppm)
Low close-in Phase Noise → high data rate clock

Disadvantage –
Long start-up time → -R margin need care
Sensitive to process variance → Foreign material elimination
mass production know-how



Quartz Resonators

- Quartz Resonator Materials – Piezo-materials, Packaging Materials, Electrode Materials,…

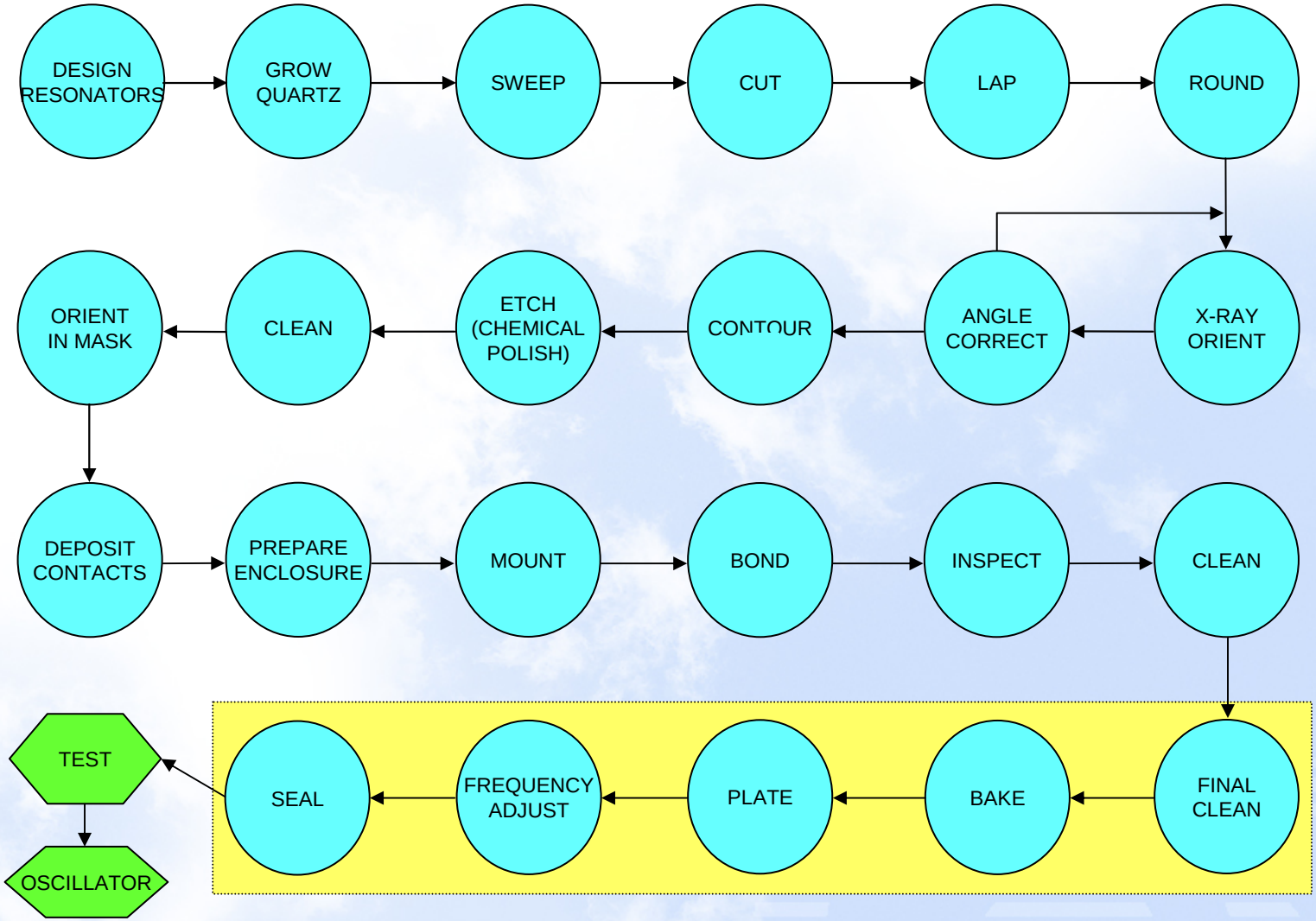


Manufacturing Processes

- Blank Processes
- Assembly Processes

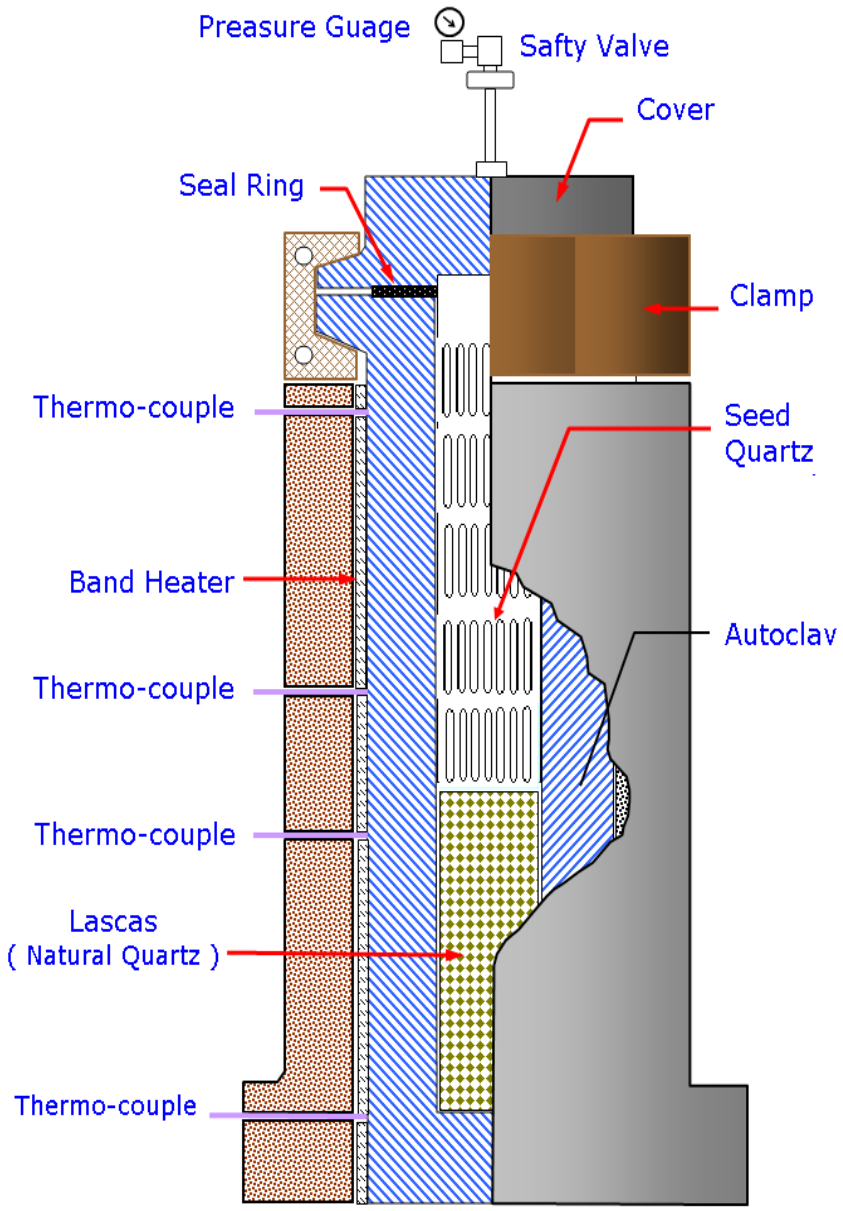


Resonator Fabrication Steps



ARTIFICIAL QUARTZ CRYSTAL BAR

- AUTOCLAVE
- HYDROTHERMAL METHOD
- RAW MATERIAL： natural crystal
- HIGH PRESSURE： 900 ~ 1,000 Kg / cm^2
- HIGH TEMPERATURE： 330 ~ 400 ℃
- HIGH TEMP. STABILITY ： ±0.2 ℃
- LONG GROWTH TIME： 1 ~ 6 Month
- HIGH PURITY：
- Infra-Red Absorption (IRA)： 3585 CM^{-1}





Blank Manufacturing Process

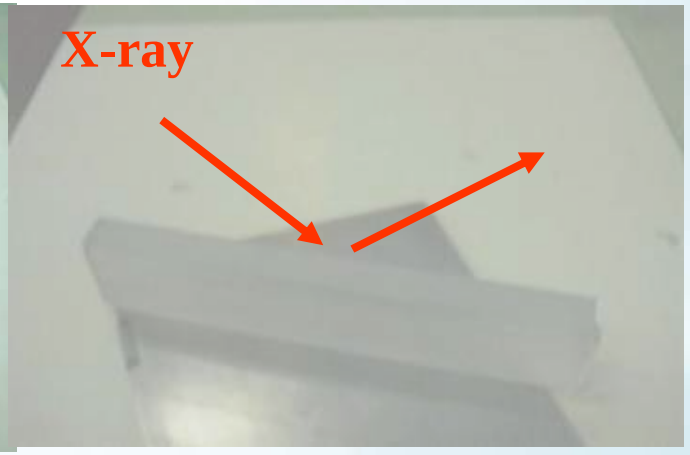


Blank Manufacturing Process

- Angle Setting(Quartz bar)
- Cutting
- Angle Sorting
- Fine Lapping (#3000)
- Fine Lapping(#4000)
- Wire Saw Cutting
- Dimension Lapping
- Etching
- Frequency Sorting
- F.Q.C



1. Mounting on Glass



2. X-ray Measurement

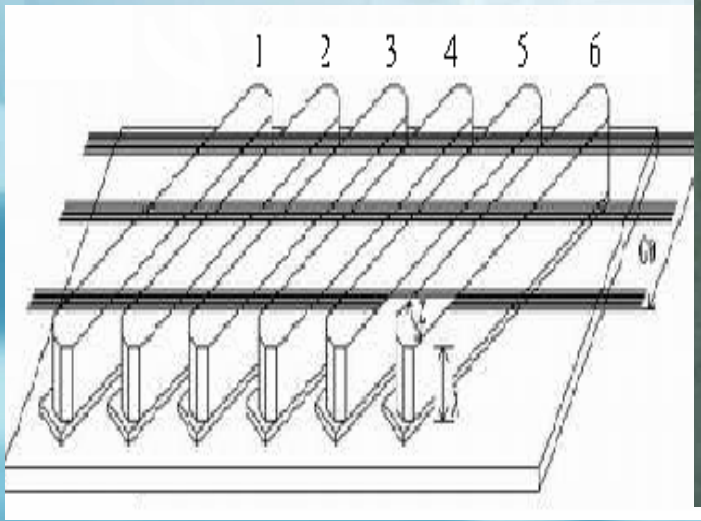


3. Setting Angle

Blank Manufacturing Process

- Angle Setting(Quartz bar)
- **Cutting**
- Angle Sorting
- Fine Lapping (#3000)
- Fine Lapping (#4000)
- Wire Saw Cutting
- Dimension Lapping
- Etching
- Frequency Sorting
- F.Q.C



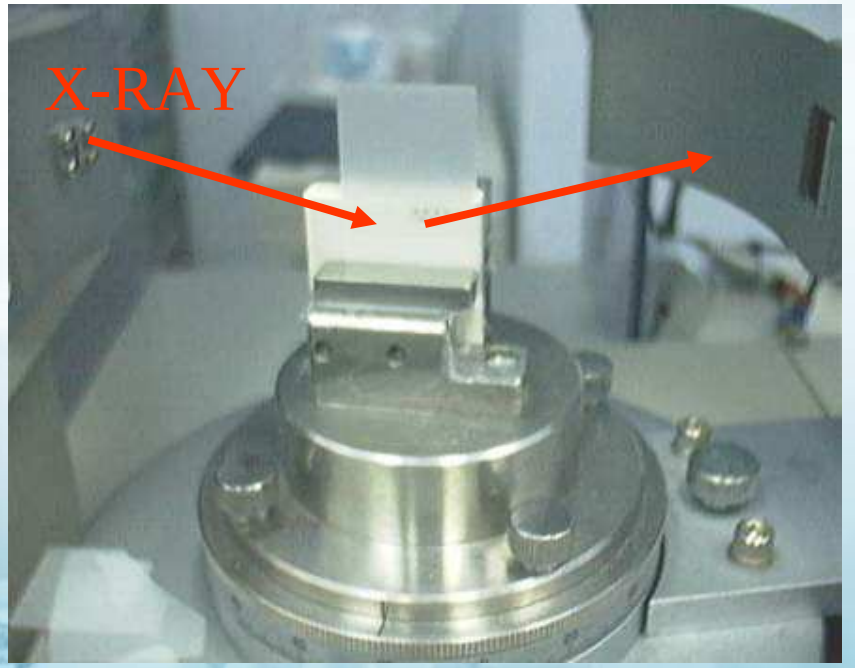




TXC 台灣晶技 TXC CORPORATION

Blank Manufacturing Process

- Setting Angle
- ▼
- Cutting
- ▼
- **Angle Sorting**
- ▼
- Fine Lapping (#3000)
- ▼
- Fine Lapping (#4000)
- ▼
- Wire Saw Cutting
- ▼
- Dimension Lapping
- ▼
- Etching
- ▼
- Frequency Sorting
- ▼
- F.Q.C



Angle Sorting

Blank Manufacturing Process

- Setting Angle
- Cutting
- Angle Sorting
- **Fine Lapping (#3000)**
- Fine Lapping (#4000)
- Wire Saw Cutting
- Dimension Lapping
- Etching
- Frequency Sorting
- F.Q.C



1. 3000# Lapping



2. Cleaning

Blank Manufacturing Process

- Setting Angle
- Cutting
- Angle Sorting
- Fine Lapping (#3000)
- **Fine Lapping (#4000)**
- Wire Saw Cutting
- Dimension Lapping
- Etching
- Frequency Sorting
- F.Q.C



1. 4000# Lapping

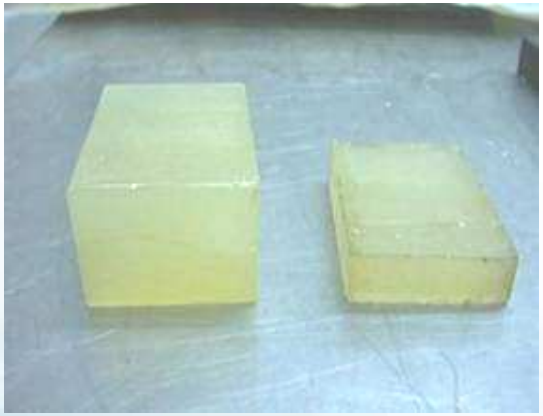


2. Cleaning

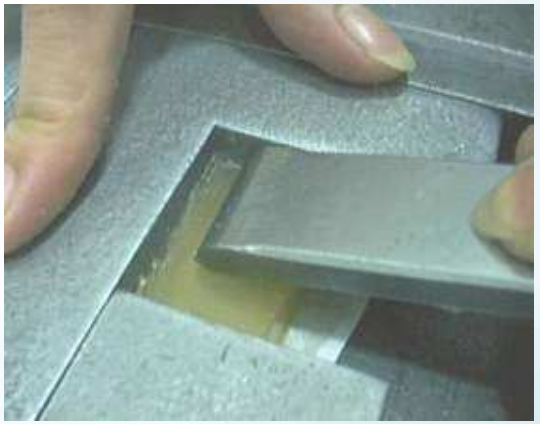
TXC 台灣晶技 TXC CORPORATION

Blank Manufacturing Process

- Setting Angle
- ▼
- Cutting
- ▼
- Angle Sorting
- ▼
- Fine Lapping (#3000)
- ▼
- Fine Lapping (#4000)
- ▼
- **Wire Saw Cutting**
- ▼
- Dimension Lapping
- ▼
- Etching
- ▼
- Frequency Sorting
- ▼
- F.Q.C



1. Gluing



2. Forming



3. Wire Saw Cutting



4. After Cutting

Blank Manufacturing Process

- Setting Angle
- Cutting
- Angle Sorting
- Fine Lapping (#3000)
- Fine Lapping (#4000)
- Wire Saw Cutting
- **Dimension Lapping**
- Etching
- Frequency Sorting
- F.Q.C



1. Dimension Lapping



2. Cooking

TXC 台灣晶技 TXC CORPORATION

Blank Manufacturing Process

- Setting Angle
- Cutting
- Angle Sorting
- Fine Lapping (#3000)
- Fine Lapping (#4000)
- Wire Saw Cutting
- Dimension Lapping
- **Etching**
- Frequency Sorting
- F.Q.C



1. Etching



2. Cleaning

TXC 台灣晶技 TXC CORPORATION

Blank Manufacturing Process

- Setting Angle
- Cutting
- Angle Sorting
- Fine Lapping (#3000)
- Fine Lapping (#4000)
- Wire Saw Cutting
- Dimension Lapping
- Etching
- **Frequency Sorting**
- F.Q.C



1. Frequency Sorting



2. Visual Inspection



3. Packing

Blank Manufacturing Process

- Setting Angle
- Cutting
- Angle Sorting
- Fine Lapping (#3000)
- Fine Lapping (#4000)
- Wire Saw Cutting
- Dimension Lapping
- Etching
- Frequency Sorting
- **F.Q.C**

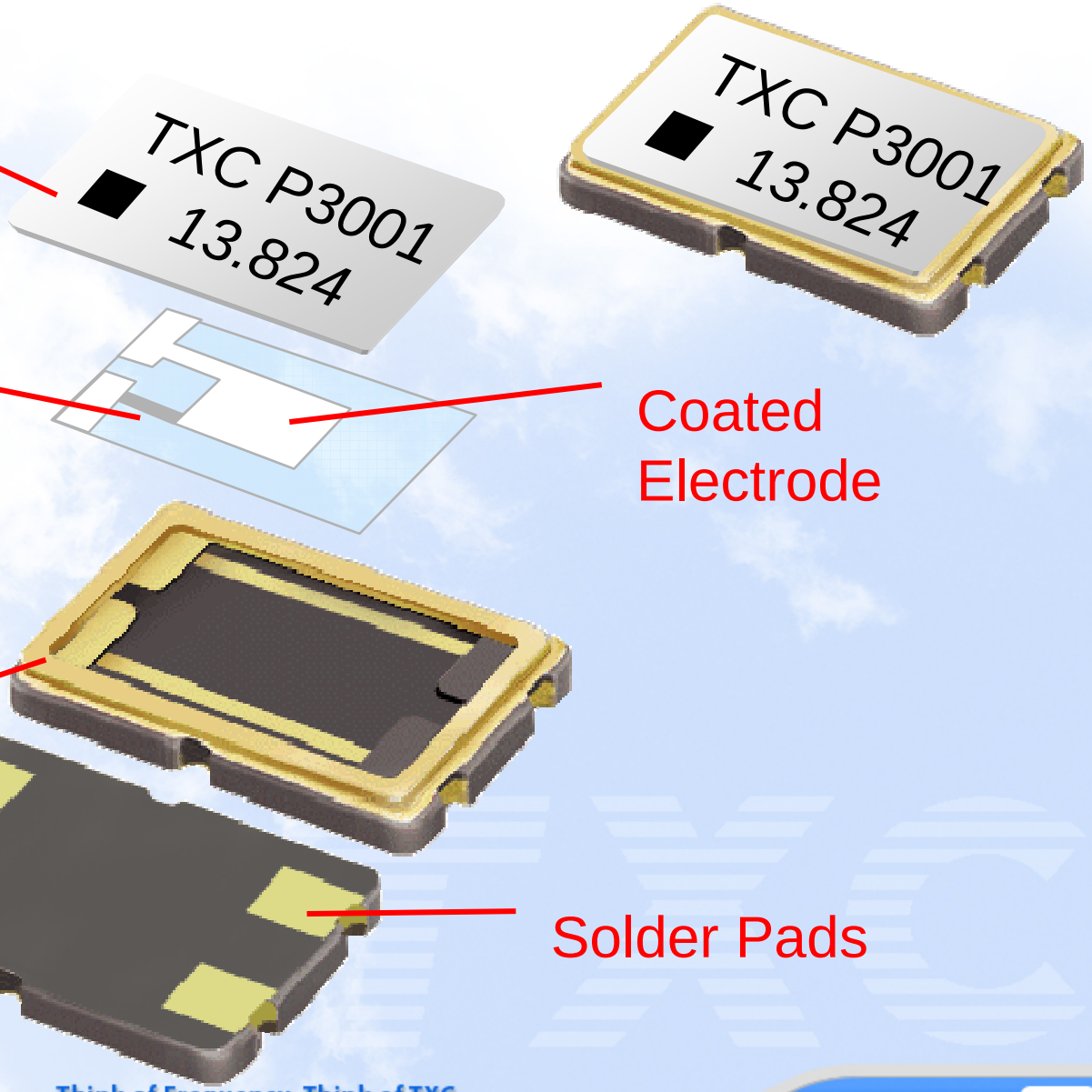


Inspection

SMD XTAL Manufacturing Process



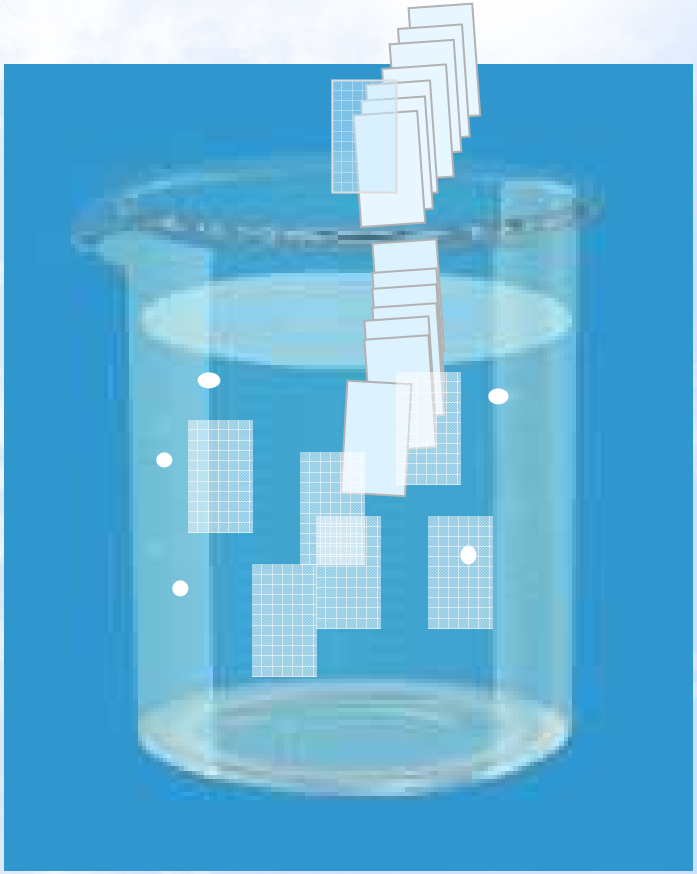
SMD XTAL Product



SMD XTAL Manufacturing Process

- **Blank Cleaning**
- Base Plating
- Blank Auto-Mounting
- Frequency Adj.
- Seam Sealing
- Mechanical Testing
- Final Testing
- Marking
- Taping

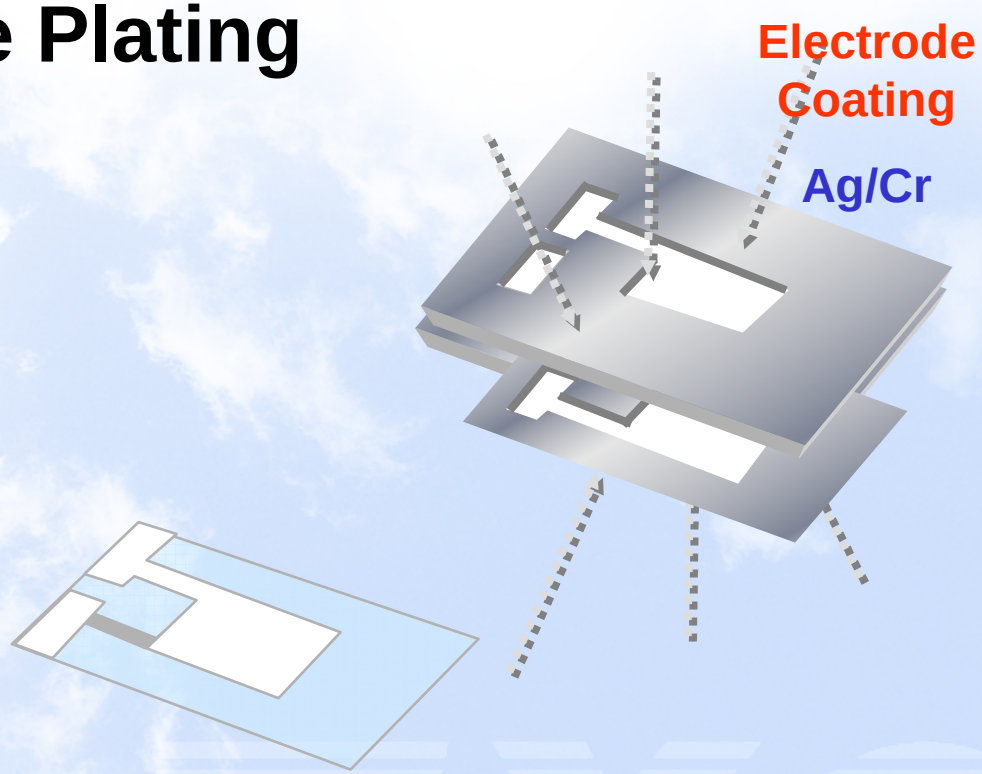
Blank Cleaning



SMD XTAL Manufacturing Process

- Blank Cleaning
- **Base Plating**
- Blank Auto-Mounting
- Frequency Adj.
- Seam Sealing
- Mechanical Testing
- Final Testing
- Marking
- Taping

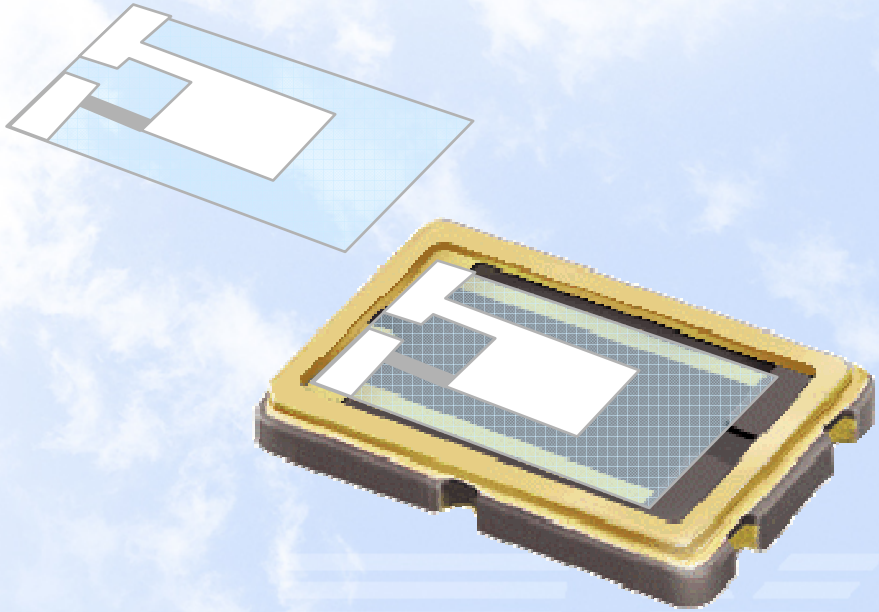
Base Plating



SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- **Blank Auto-Mounting**
- Frequency Adj.
- Seam Sealing
- Mechanical Testing
- Final Testing
- Marking
- Taping

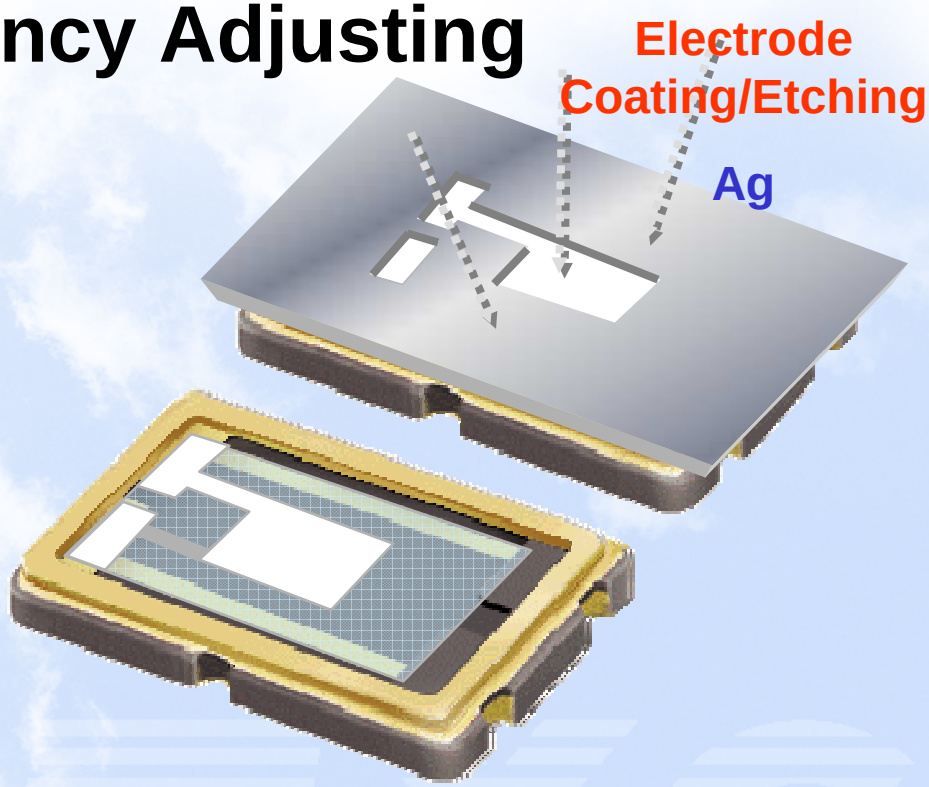
Blank Auto-Mounting



SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- Blank Auto-Mounting
- **Frequency Adj.**
- Seam Sealing
- Mechanical Testing
- Final Testing
- Marking
- Taping

Frequency Adjusting

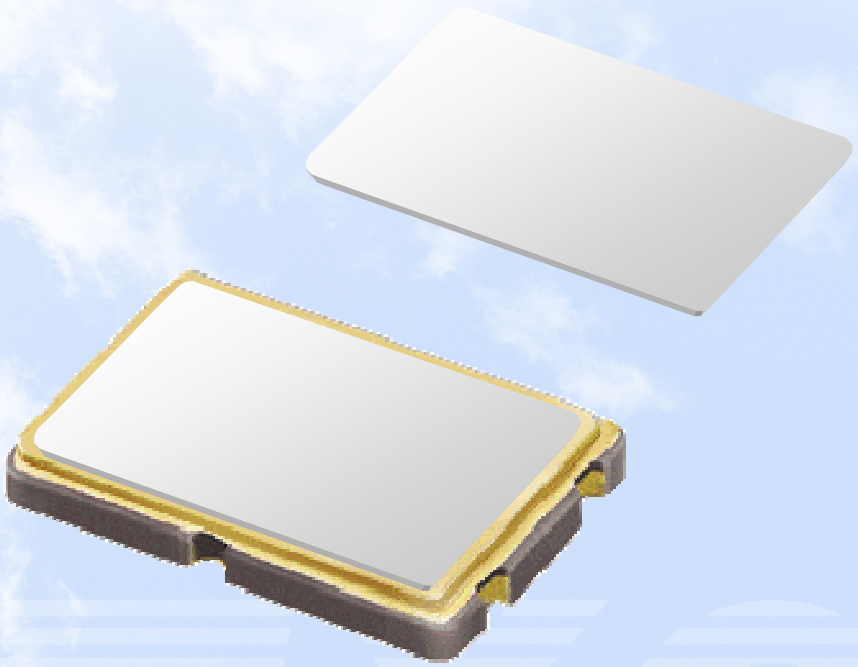




SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- Blank Auto-Mounting
- Frequency Adj.
- **Seam Sealing**
- Mechanical Testing
- Final Testing
- Marking
- Taping

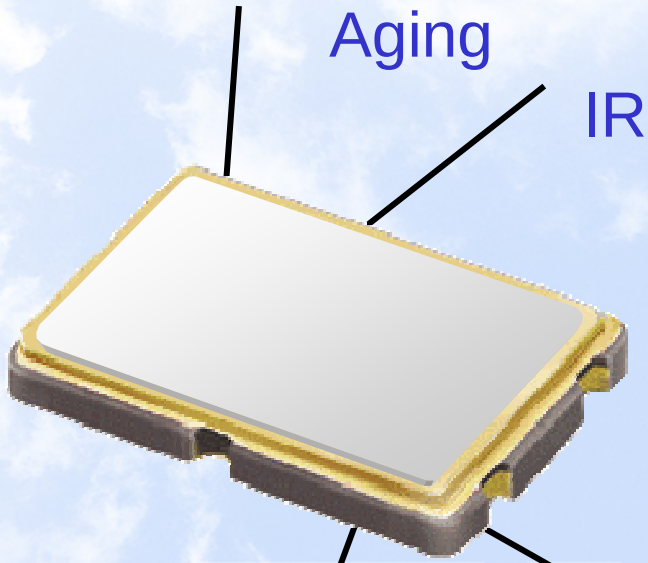
Seam Sealing



SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- Blank Auto-Mounting
- Frequency Adj.
- Seam Sealing
- **Mechanical Testing**
- Final Testing
- Marking
- Taping

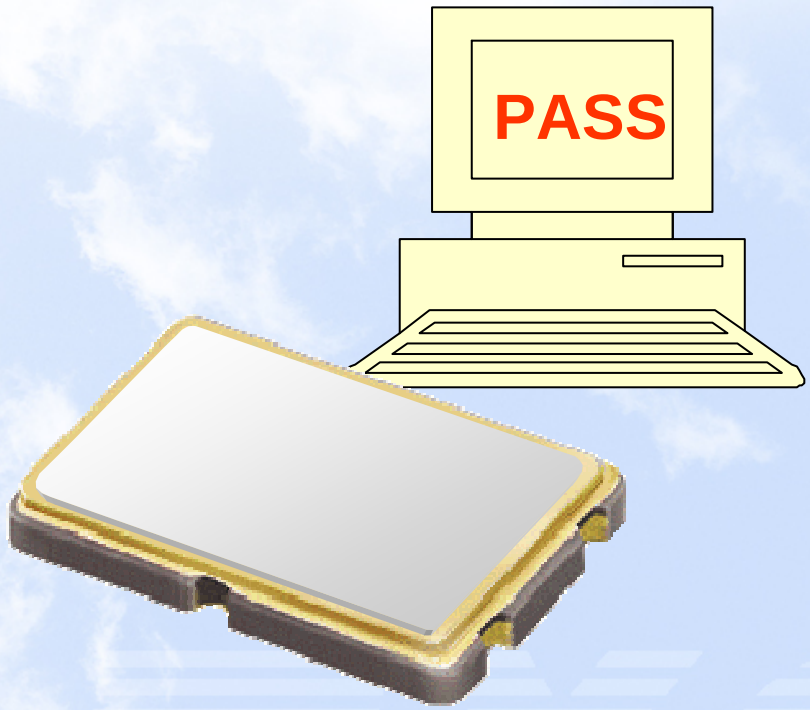
Mechanical Testing



SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- Blank Auto-Mounting
- Frequency Adj.
- Seam Sealing
- Mechanical Testing
- **Final Testing**
- Marking
- Taping

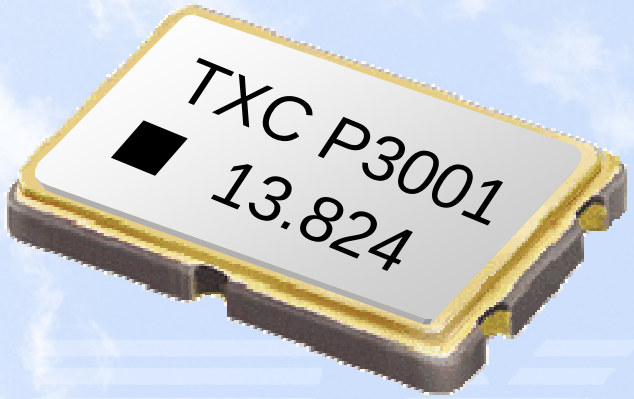
Final Testing



SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- Blank Auto-Mounting
- Frequency Adj.
- Seam Sealing
- Mechanical Testing
- Final Testing
- **Marking**
- Taping

Marking

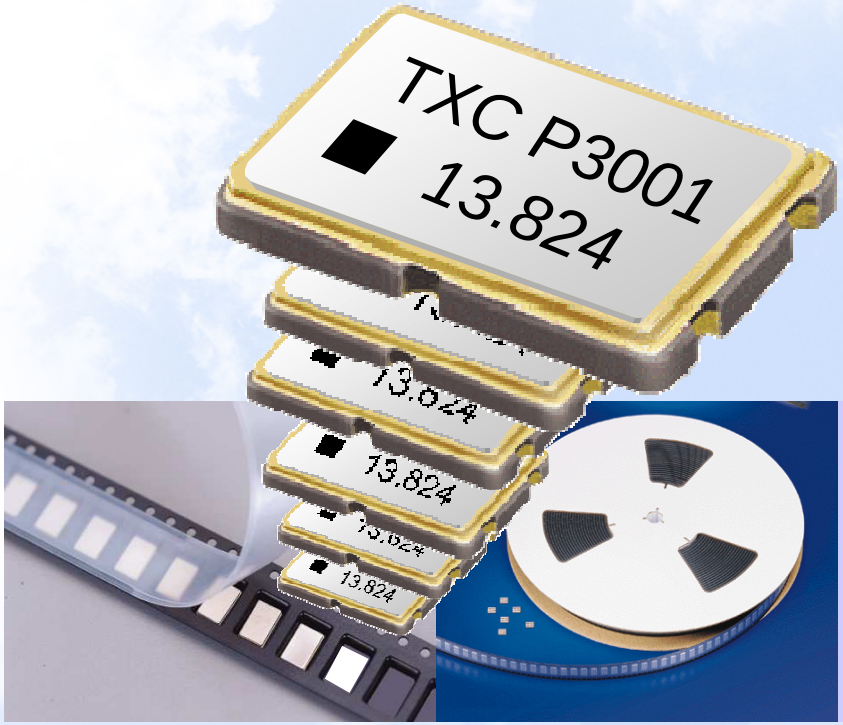


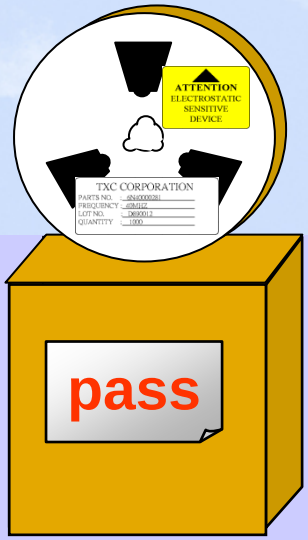


SMD XTAL Manufacturing Process

- Blank Cleaning
- Base Plating
- Blank Auto-Mounting
- Frequency Adj.
- Seam Sealing
- Mechanical Testing
- Final Testing
- Marking
- Taping

Taping





Crystal characteristics and factors in Process

- Frequency
- Resistance
- TC-FL (TC-FR)
- Spurious
- TC perturbation
- DLD
- Considerations about reliability – Hermetic capability and connections
  - Mechanical Shock/Drop
  - Aging and thermal environments



Crystals Characteristics and Process Factors -- Frequency

- Blank thickness
- Blank size
- Beveling
- Electrode plating
- Assembly stress and thermal process (Aging)



What is an "f-squared"?

It is standard practice to express the thickness removed by lapping, etching and polishing, and the mass added by the electrodes, in terms of frequency change, Δf, in units of "f^2", where the Δf is in kHz and f is in MHz. For example, etching a 10MHz AT-cut plate $1f^2$ means that a thickness is removed that produces Δf= 100 kHz; and etching a 30 MHz plate $1f^2$ means that the Δf= 900 kHz. In both cases, $\Delta f = 1f^2$ produces the same thickness change.

To understand this, consider that for a thickness-shear resonator (AT-cut, SC-cut, etc.)

$$f = \frac{N}{t}$$

where f is the fundamental mode frequency, t is the thickness of the resonator plate and N is the frequency constant (1661 MHz•μm for an AT-cut, and 1797 MHz•μm for a SC-cut's c-mode). Therefore,

$$\frac{\Delta f}{f} = -\frac{\Delta t}{t}$$

and,

$$\Delta t = -N\frac{\Delta f}{f^2}$$

So, for example, $\Delta f = 1f^2$ corresponds to the same thickness removal for all frequencies. For an AT-cut, Δt=1.661 μm of quartz (=0.83 μm per side) per f^2. An important advantage of using units of f^2 is that frequency changes can be measured much more accurately than thickness changes. The reason for expressing Δf in kHz and f in MHz is that by doing so, the numbers of f^2 are typically in the range of 0.1 to 10, rather than some very small numbers.



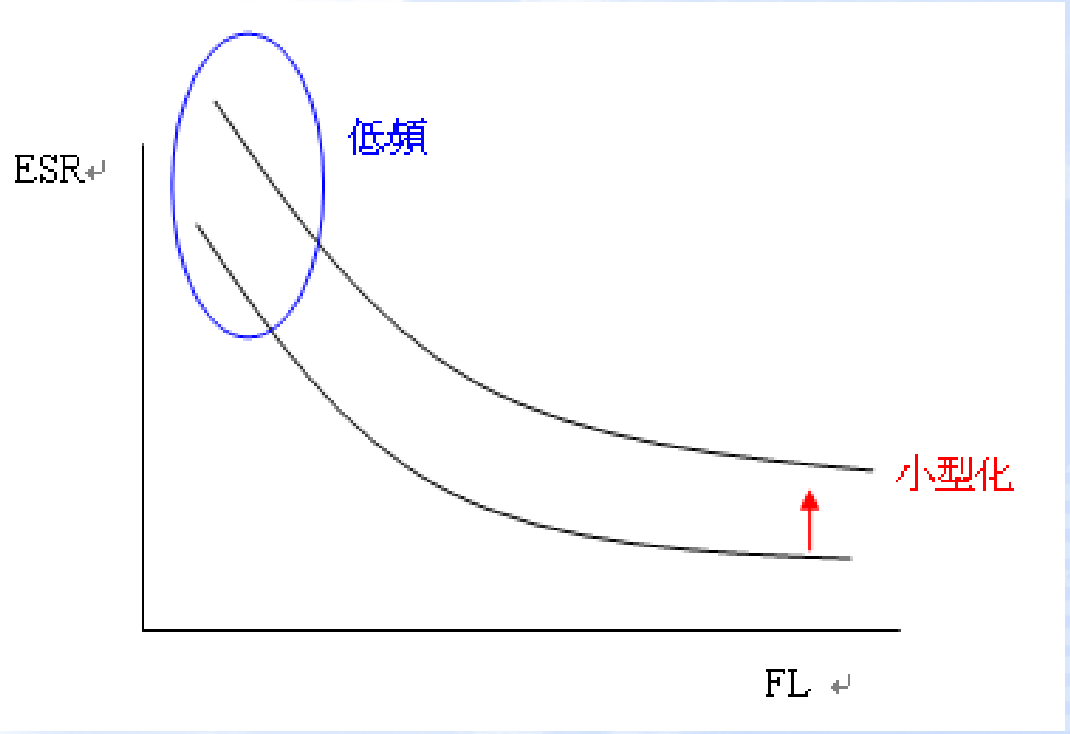
Crystals Characteristics and Process Factors -- Resistance

- Blank surface roughness
- Blank size
- Beveling
- Electrode plating thickness
- Electrode size
- Electrode
- Mounting Structure
- Assembly stress and thermal process (Aging)



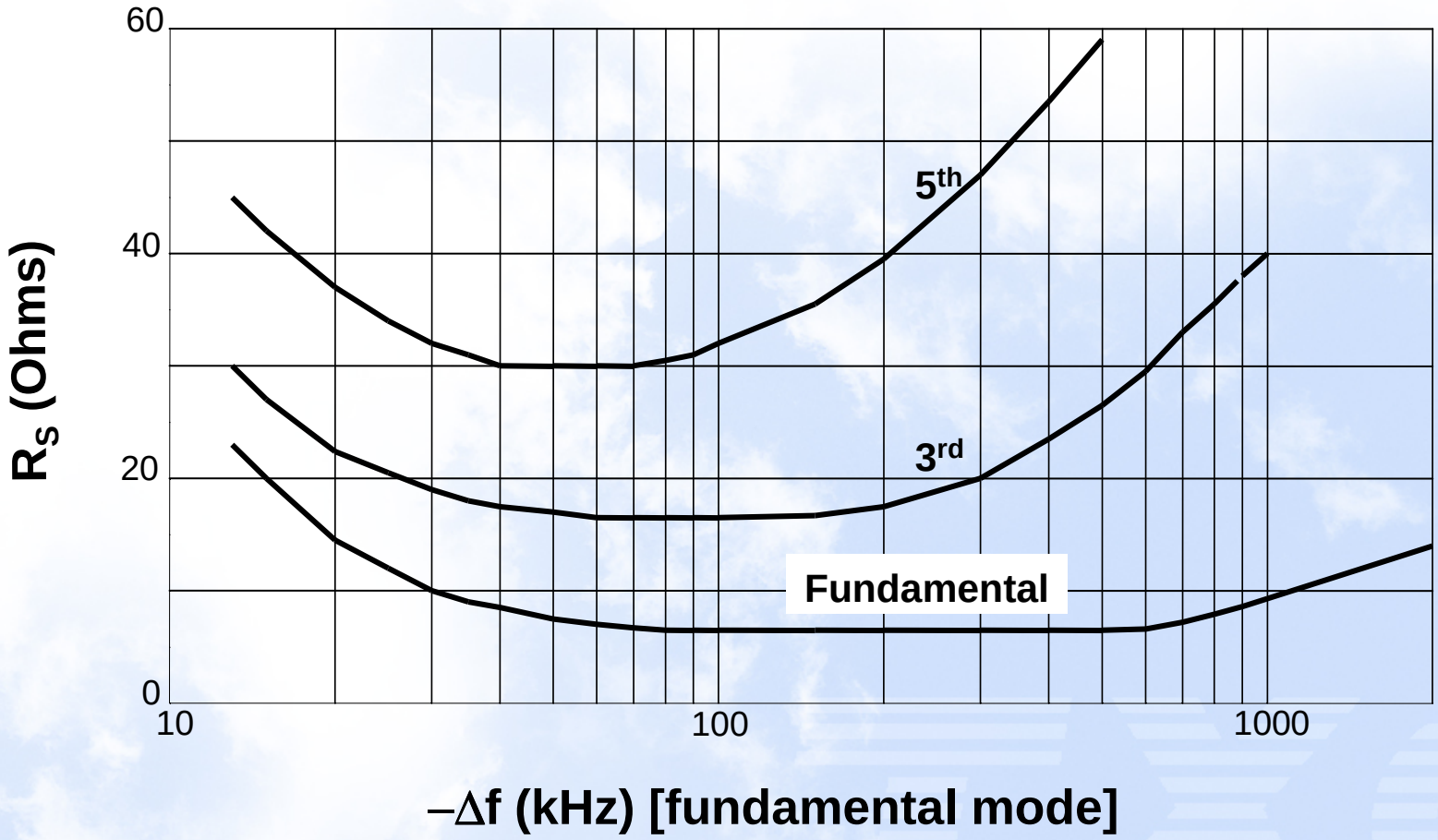
Crystal ESR:低頻 & 小型化(SMD)會造成ESR升高, 所幸IC -R值也是越低頻越佳

ESR: Equivalent Series Resistance



Resistance vs. Electrode Thickness

AT-cut; f_1=12 MHz; polished surfaces; evaporated 1.2 cm (0.490”) diameter silver electrodes



Crystals Characteristics and Process Factors – TC-FL

- Blank cut-angle
- Wafer thickness distribution
- In-plane angle
- Electrode plating material
- Electrode plating thickness
- Assembly stress and thermal process



Cutting Angle of Quartz Material

Low Frequency

CT : +38^0
DT : -52^0
ET : +66^0
FT : -57^0

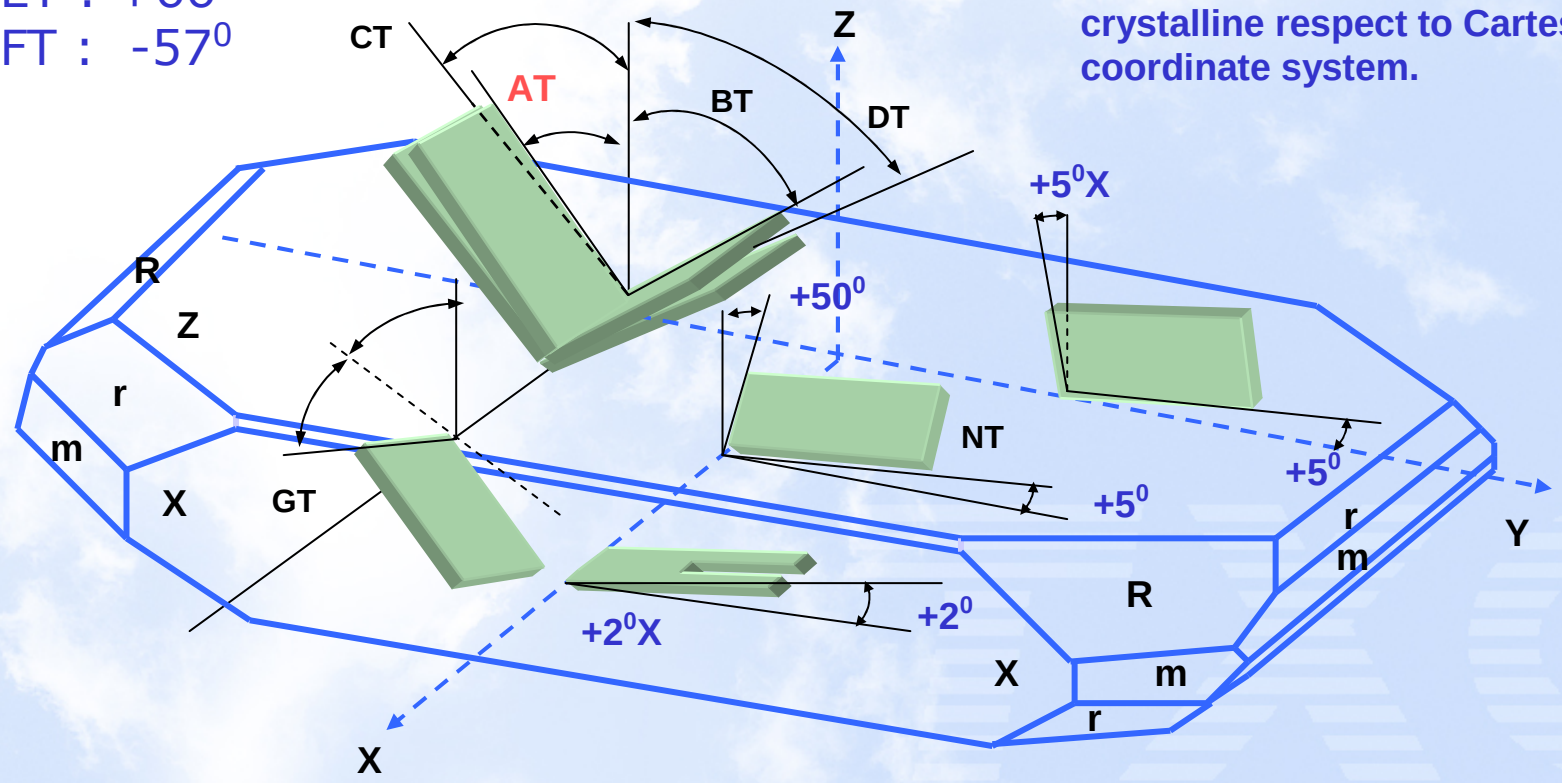
High Frequency

AT : -35^{0}15'
BT : -49^0

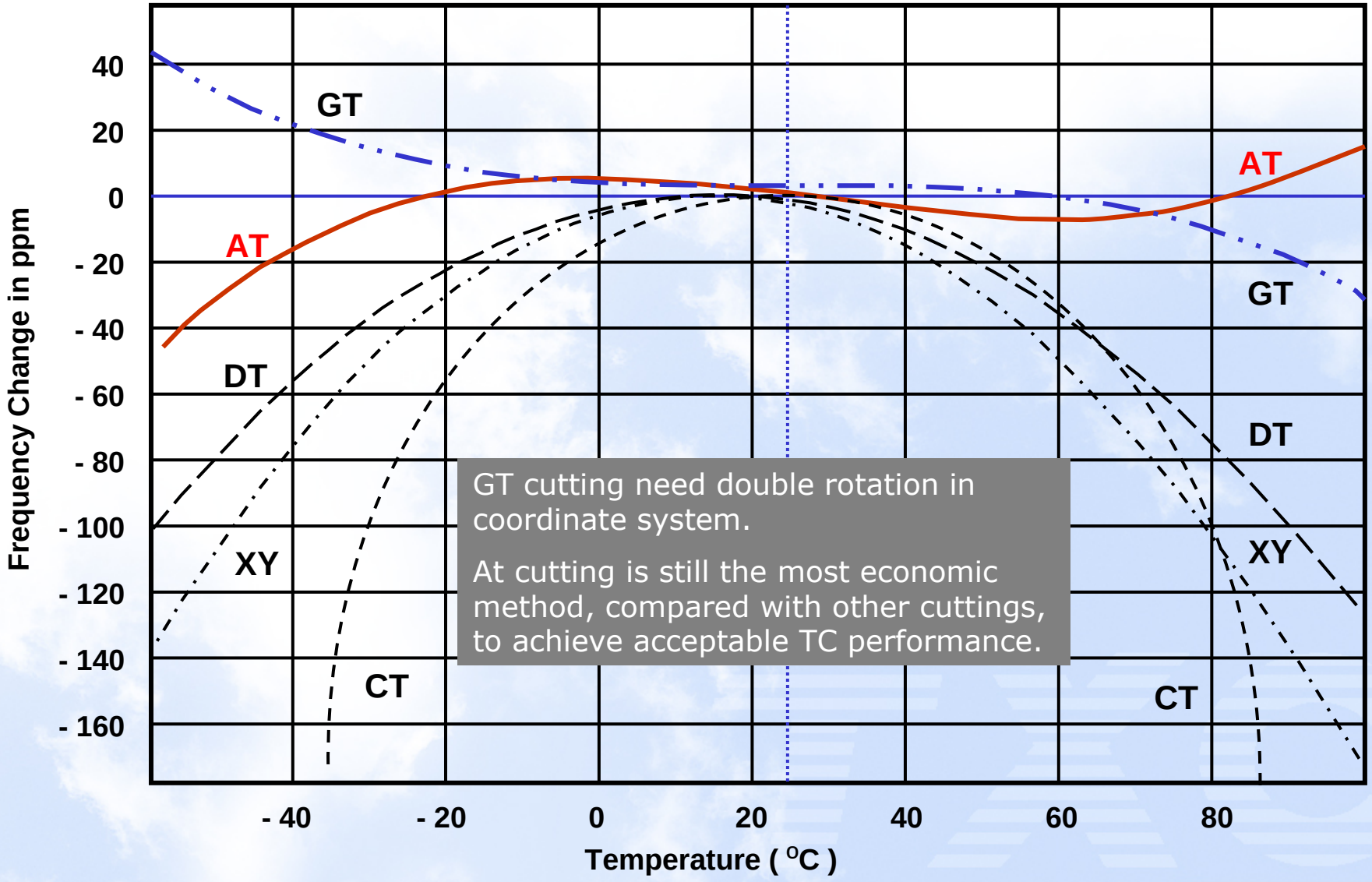
There are many kind of cutting angles for different applications.

AT cutting is the most widely used in megahertz applications.

Different cutting angles mean the electrical field will excite different crystalline respect to Cartesian coordinate system.



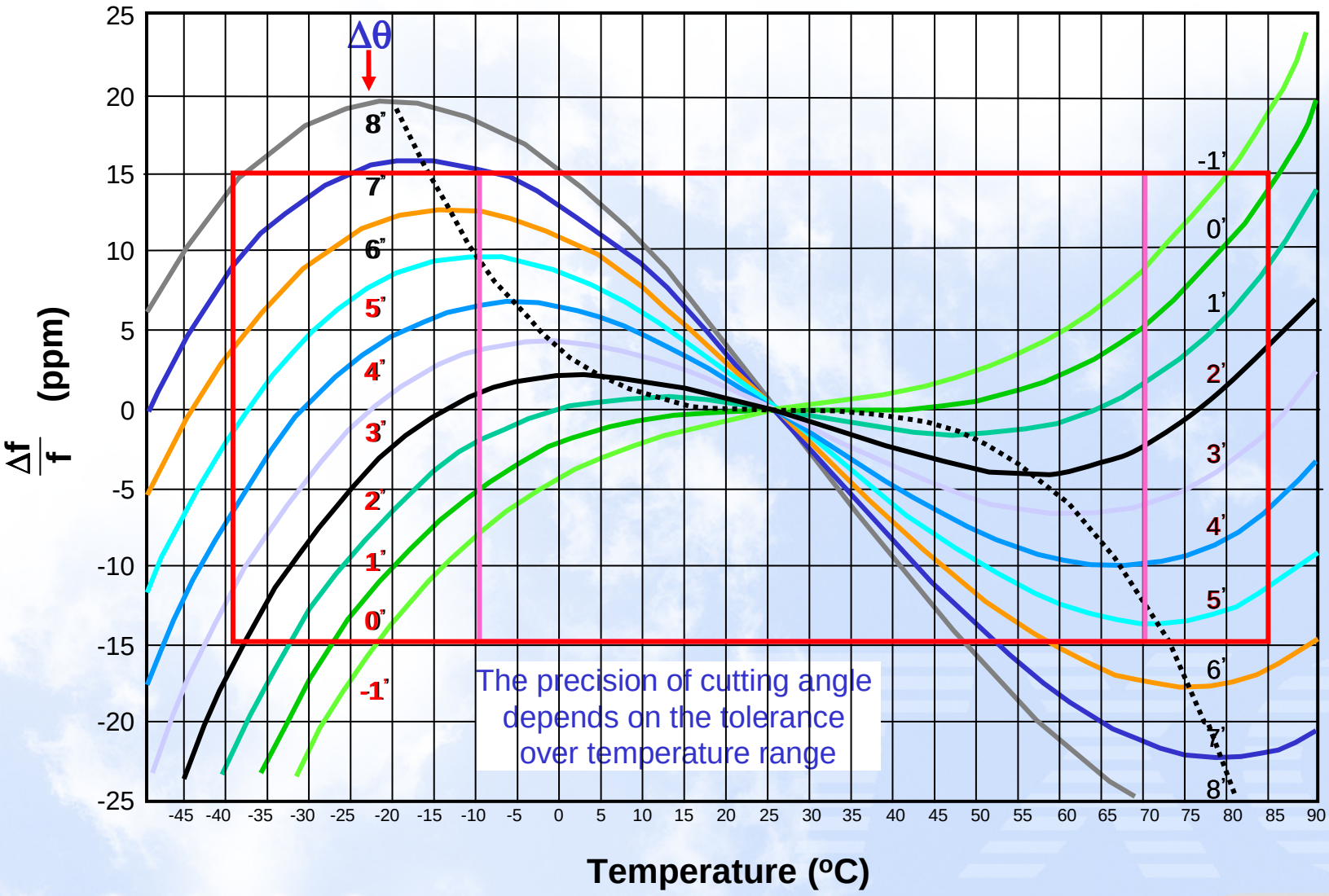
Temperature Curve vs Cutting Angle



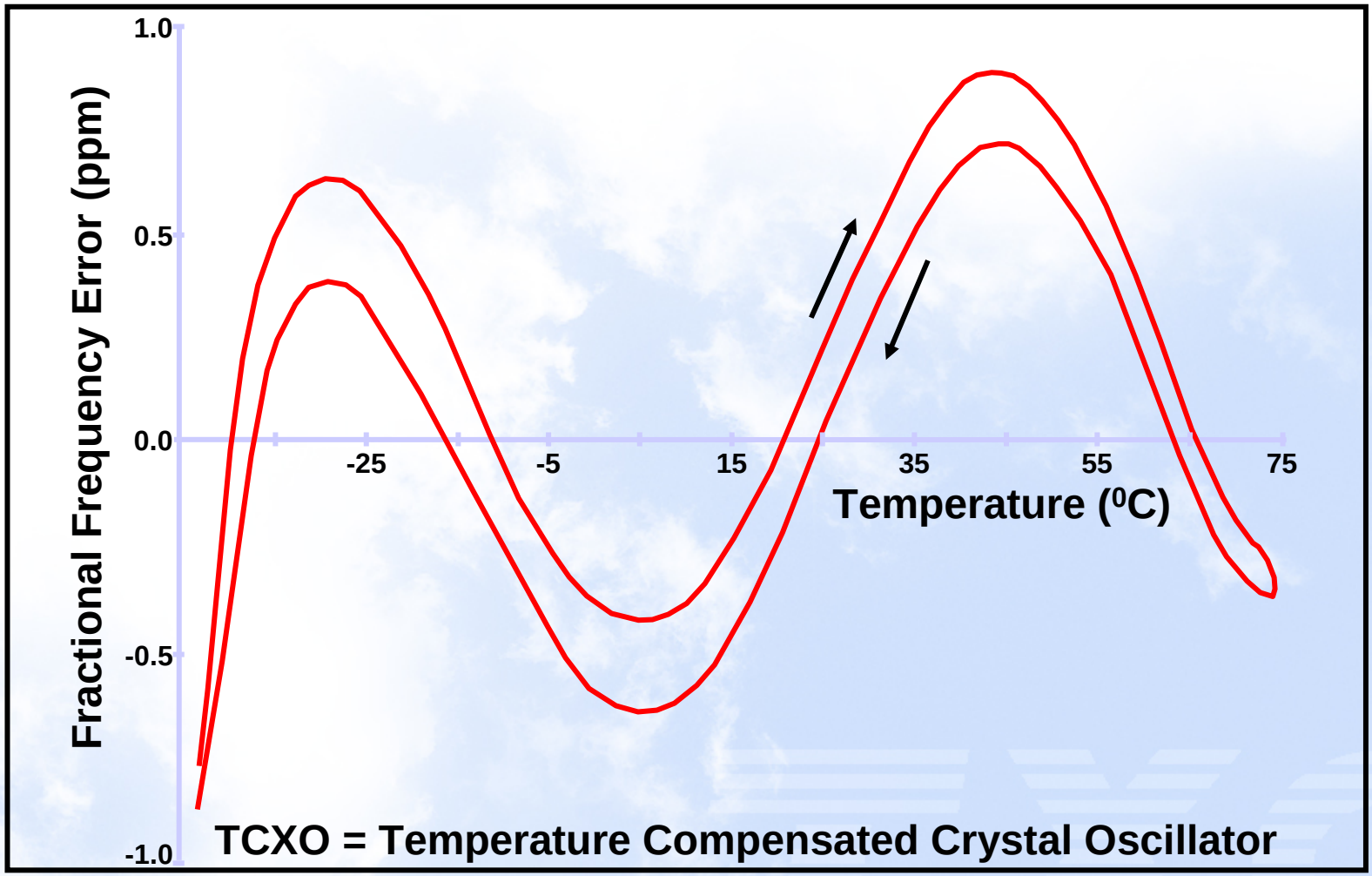
GT cutting need double rotation in coordinate system.

At cutting is still the most economic method, compared with other cuttings, to achieve acceptable TC performance.

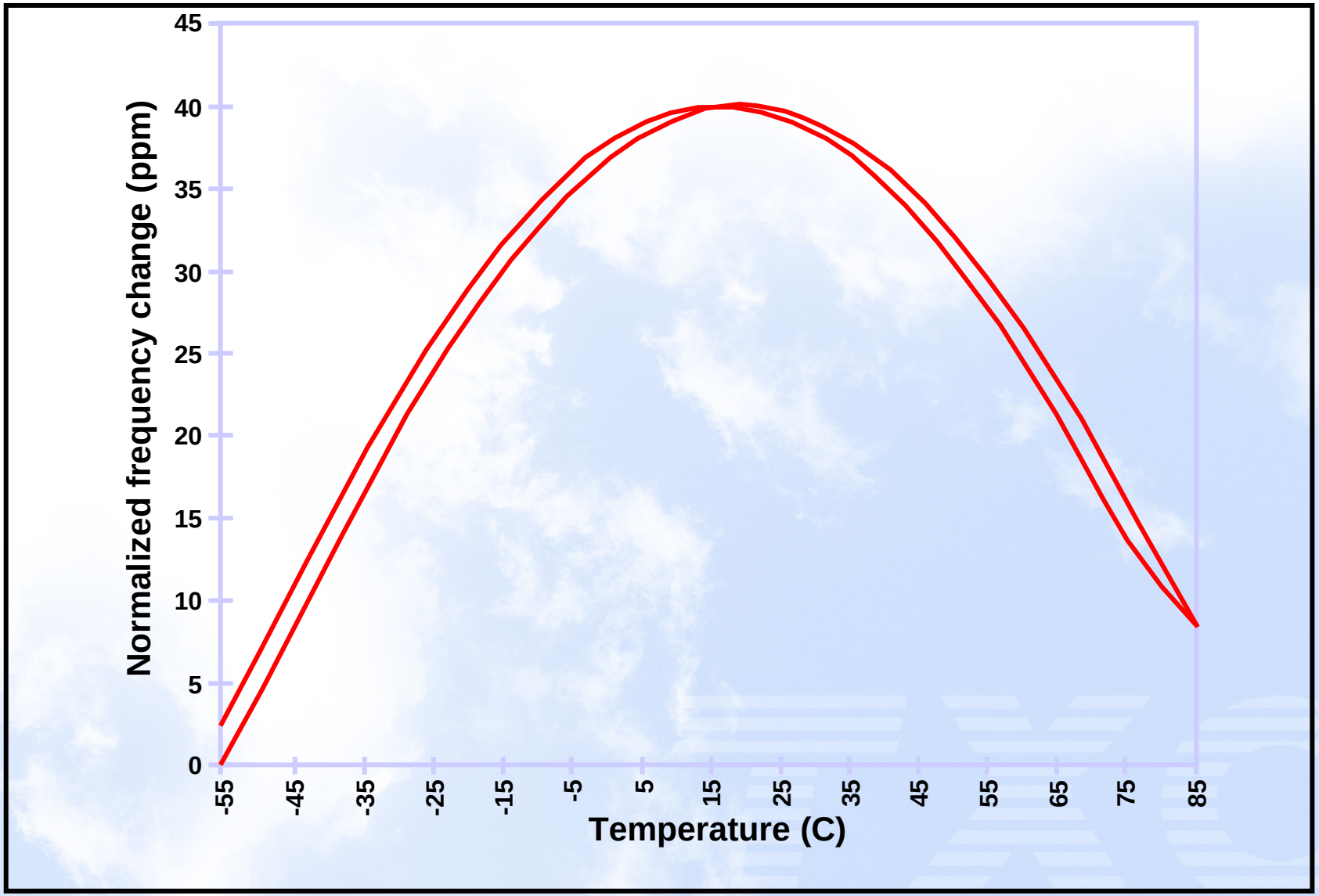
TC Performance in AT Cut Angle



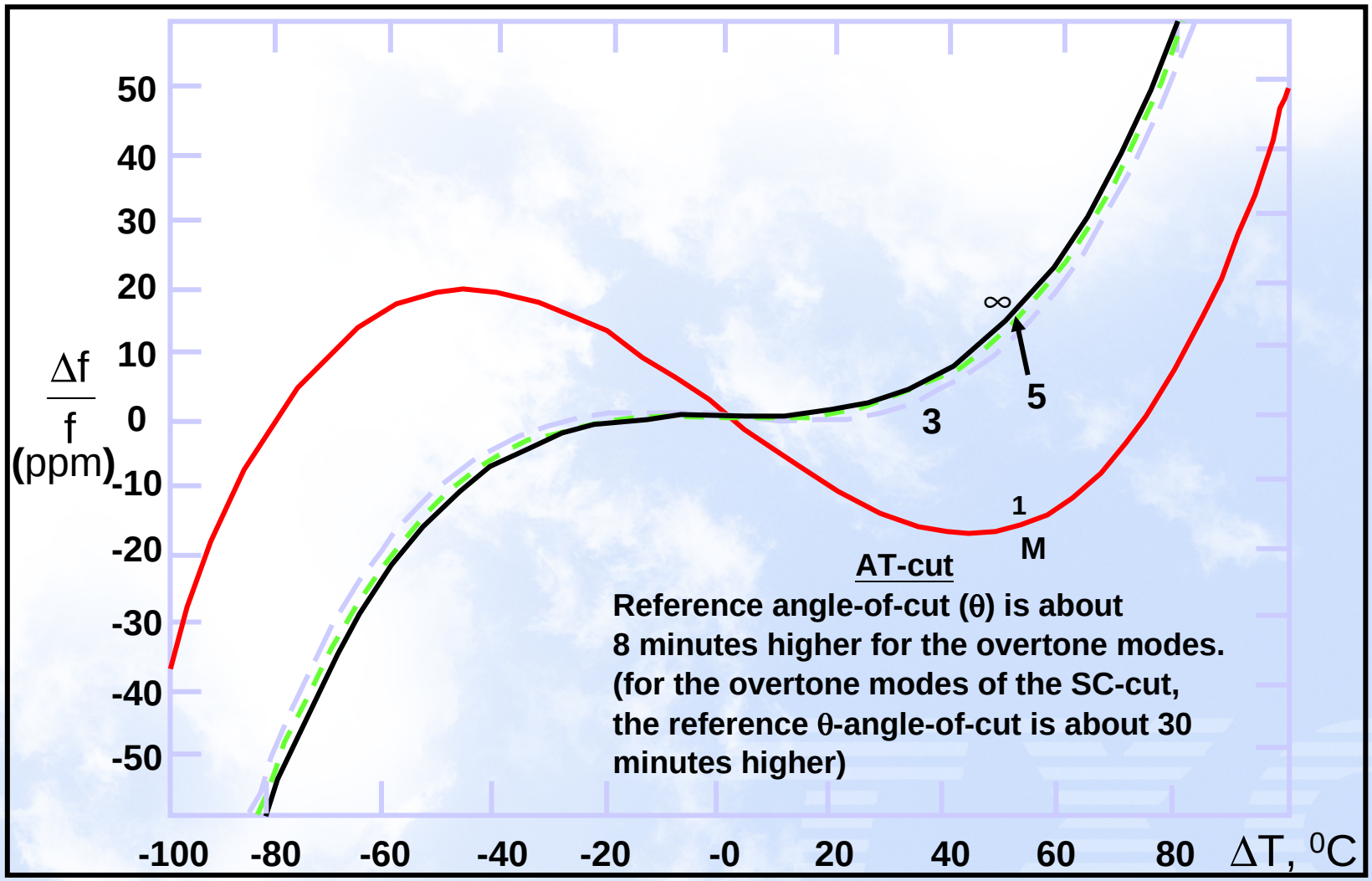
TCXO Thermal Hysteresis



Apparent Hysteresis



Effects of Harmonics on f vs. T



Crystals Characteristics and Process Factors -- Spurious

- Blank length
- Blank width
- Electrode length
- Electrode width
- Electrode thickness
- Beveling
- Frequency adjust mask size – length
- Frequency adjust mask size – width

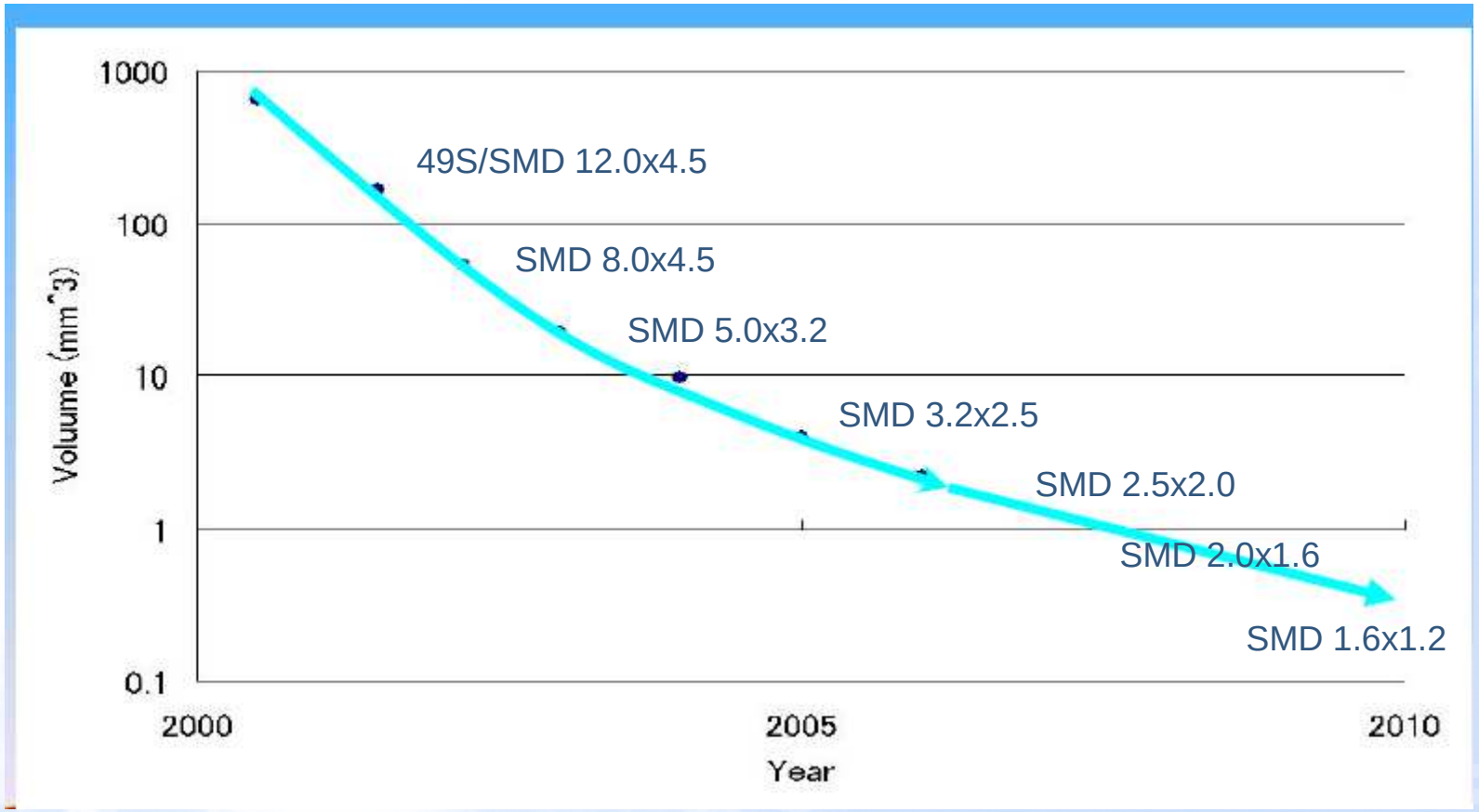


Crystals Characteristics and Process Factors -- DLD

- Nonlinearity
- Mode coupling



Size reduction in Quartz Crystals



Size effects

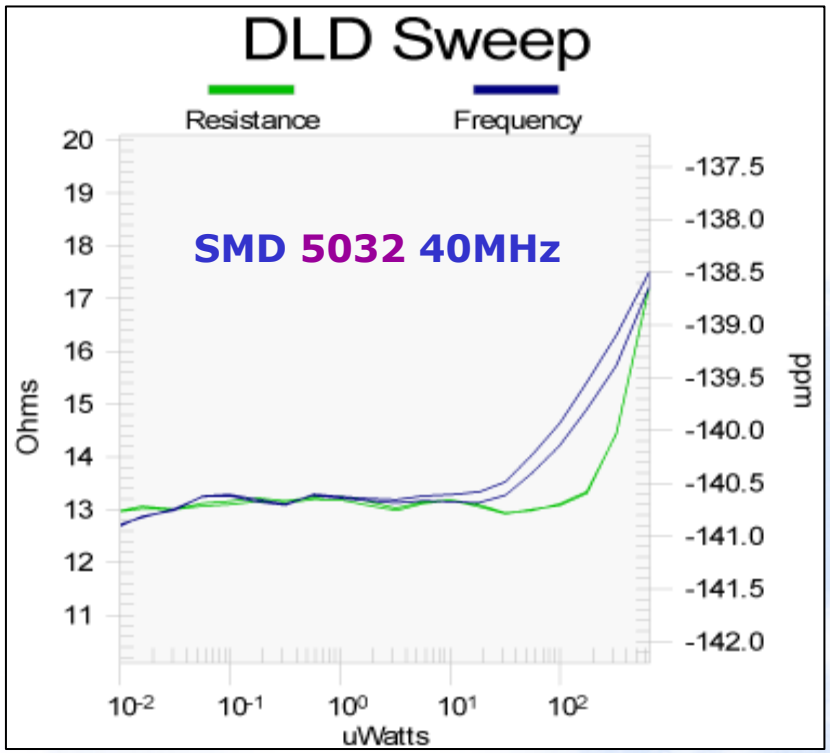
When Size reduced, many things change

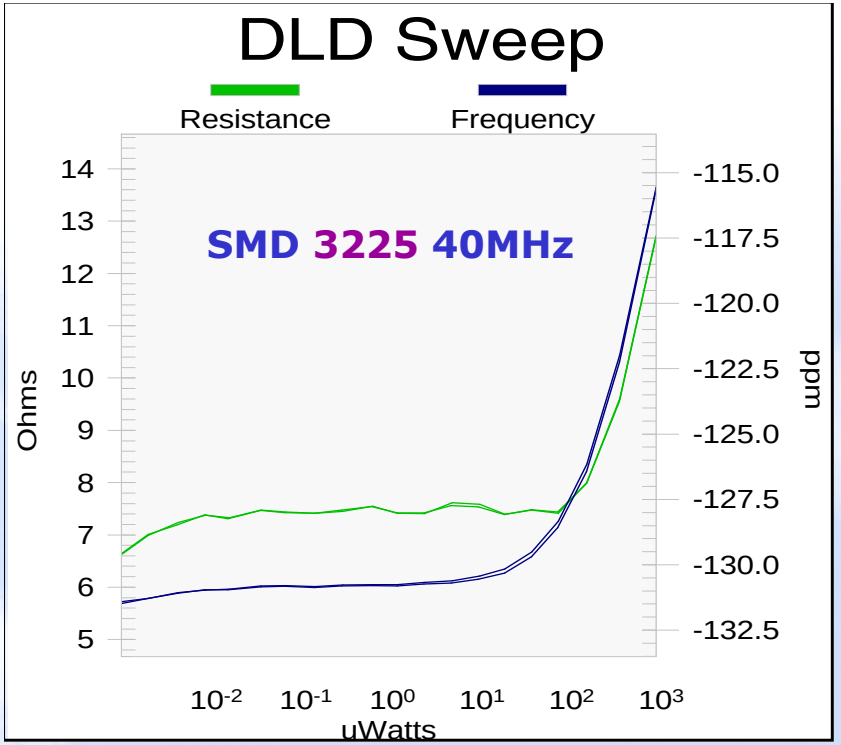
Aspect Ratio get smaller, straight-crest wave assumption may not be right
Drive level effect become larger
Un-wanted modes become stronger under same drive level
Blank support conditions' effect stronger

Design become more difficult



Drive Level Dependency





Suggest Drive level in package types

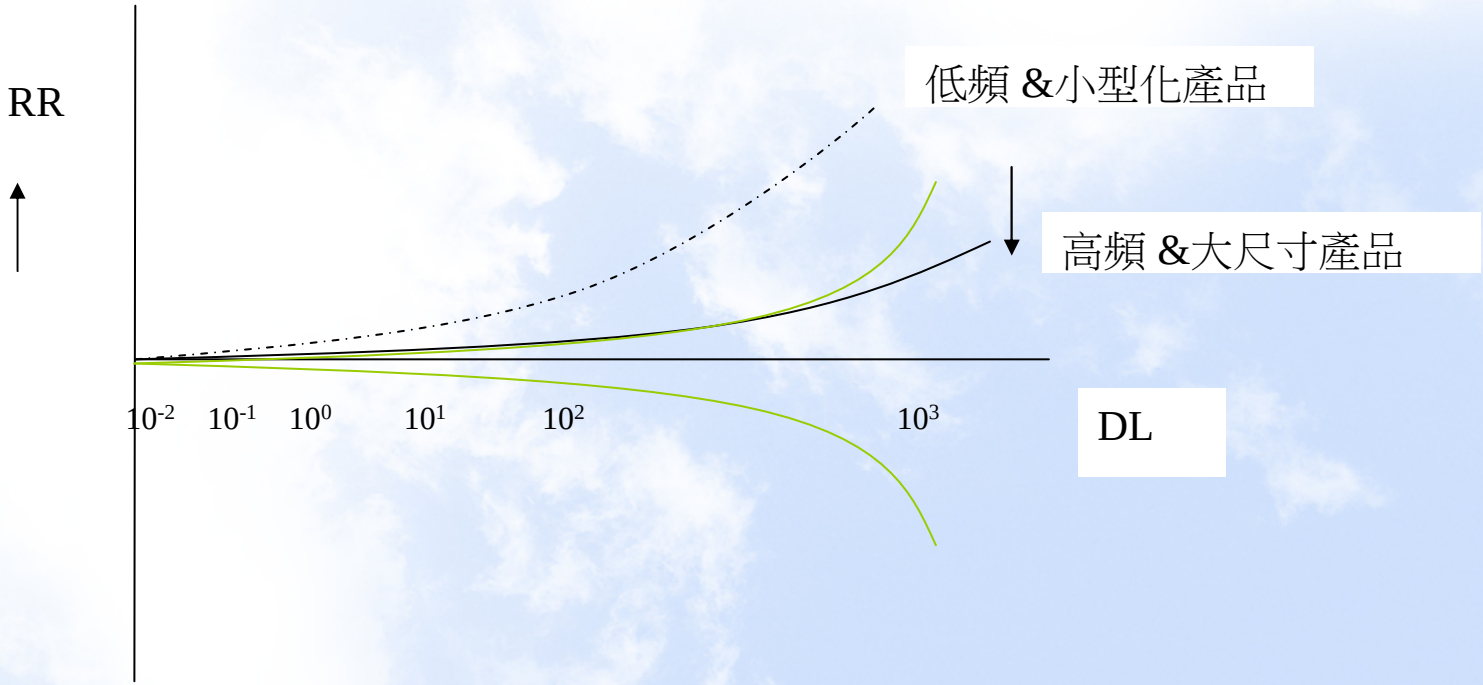
	49S	8045	7050	6035	5032	3225	2520
Typical	200	100	100	100	50	30	10
Maximum	500	500	500	300	200	100	50

Drive Level in μ Watt

1. The drive level depends on the frequency range
2. There is no recommend to use the maximum drive power in application.



Drive Level Dependency



過高的DL會使X'tal特性不穩定,且耗能,
最佳DL建議:10~100uW

Contamination Control

Contamination control is essential during the fabrication of resonators because contamination can adversely affect:

- Stability (see chapter 4)
  - aging
  - hysteresis
  - retrace
  - noise
  - nonlinearities and resistance anomalies (high starting resistance, second-level of drive, intermodulation in filters)
  - frequency jumps?
- Manufacturing yields
- Reliability

Crystal Enclosure Contamination

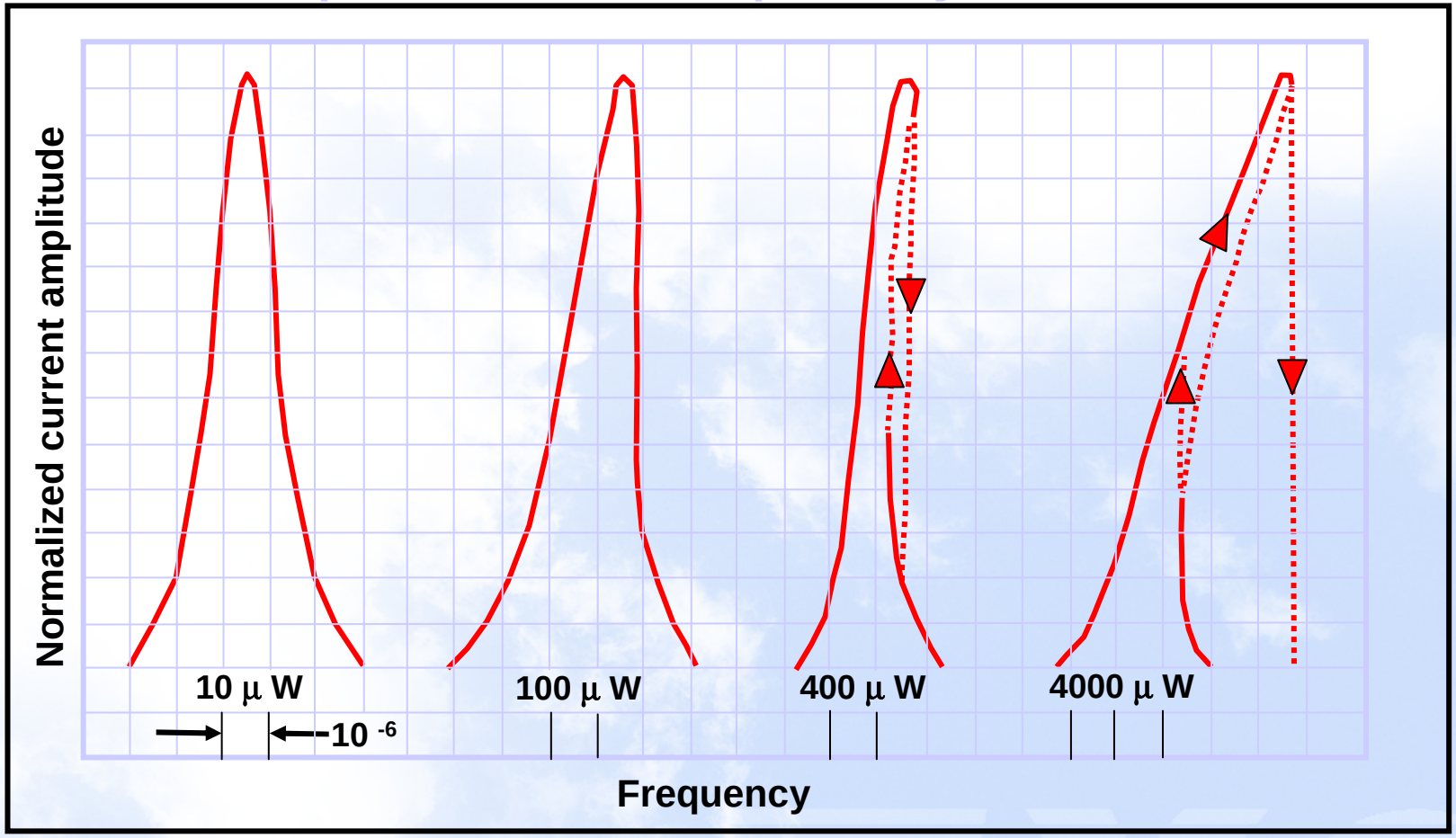
The enclosure and sealing process can have important influences on resonator stability.

- A monolayer of adsorbed contamination contains ~ 10^{15} molecules/cm^2 (on a smooth surface)
- An enclosure at 10^{-7} torr contains ~10^9 gaseous molecules/cm^3

Therefore:

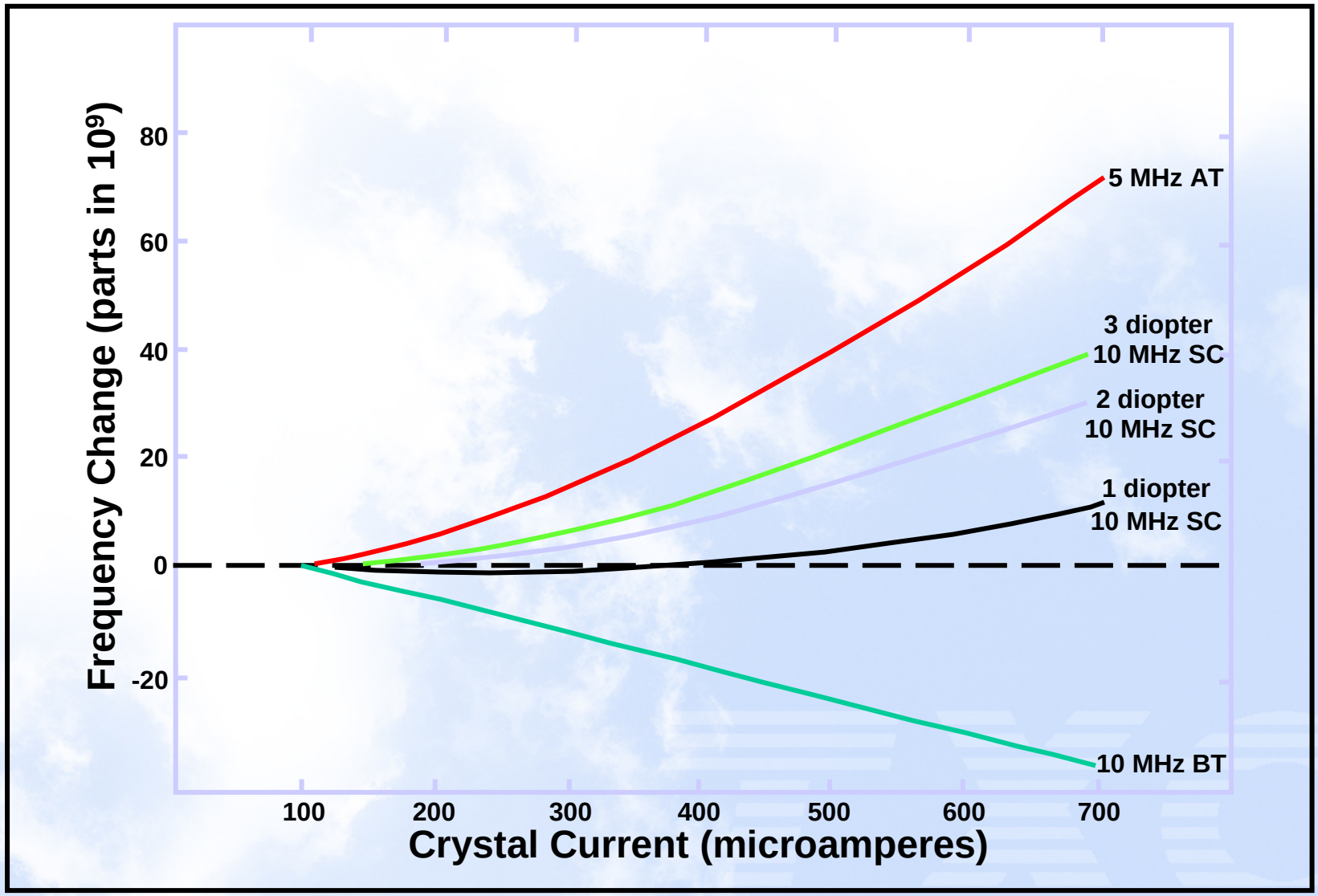
In a 1 cm^3 enclosure that has a monolayer of contamination on its inside surfaces, there are ~10^6 times more adsorbed molecules than gaseous molecules when the enclosure is sealed at 10^{-7} torr. The desorption and adsorption of such adsorbed molecules leads to aging, hysteresis, retrace, noise, etc.

Amplitude - Frequency Effect

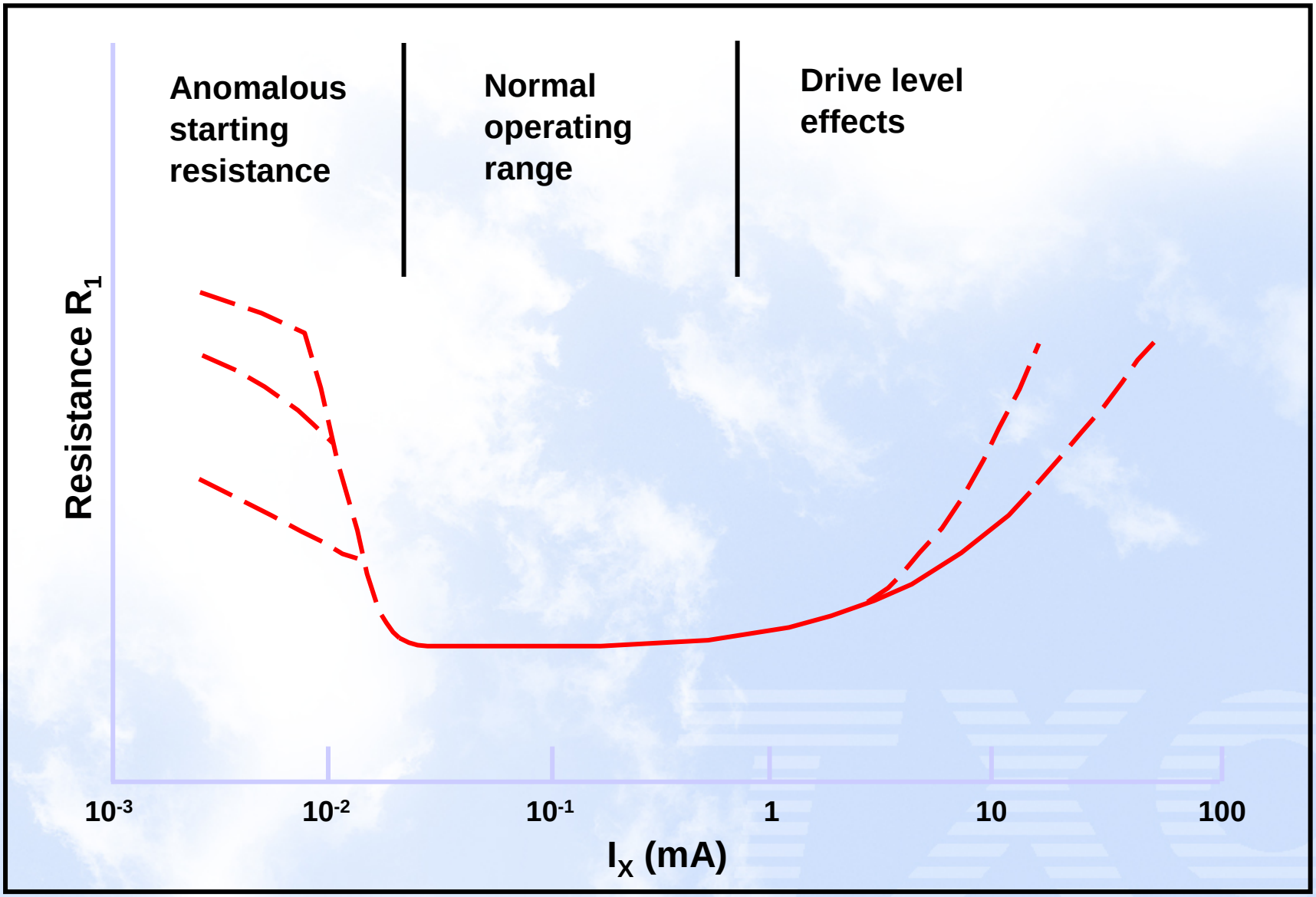


At high drive levels, resonance curves become asymmetric due to the nonlinearities of quartz.

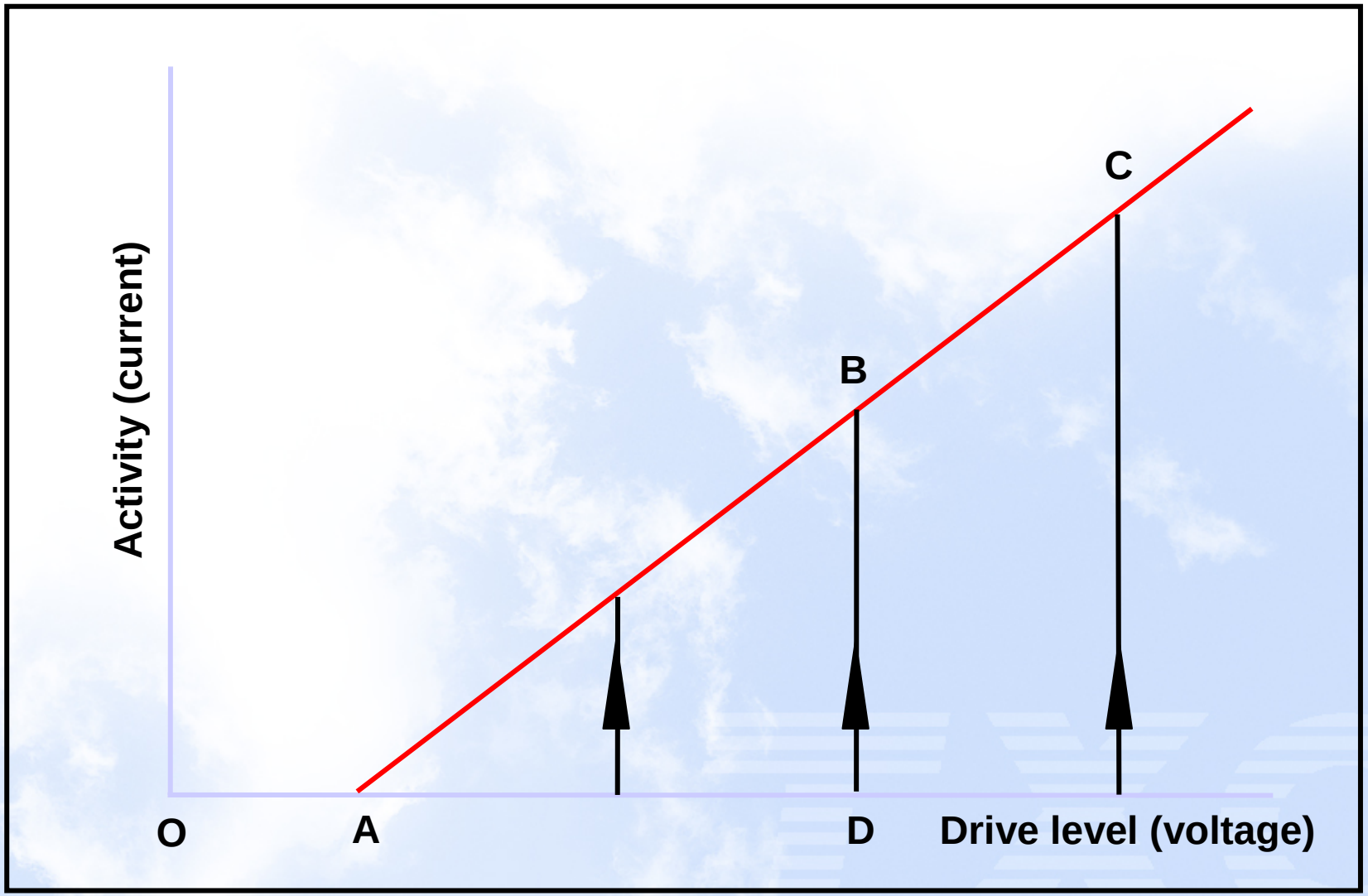
Frequency vs. Drive Level



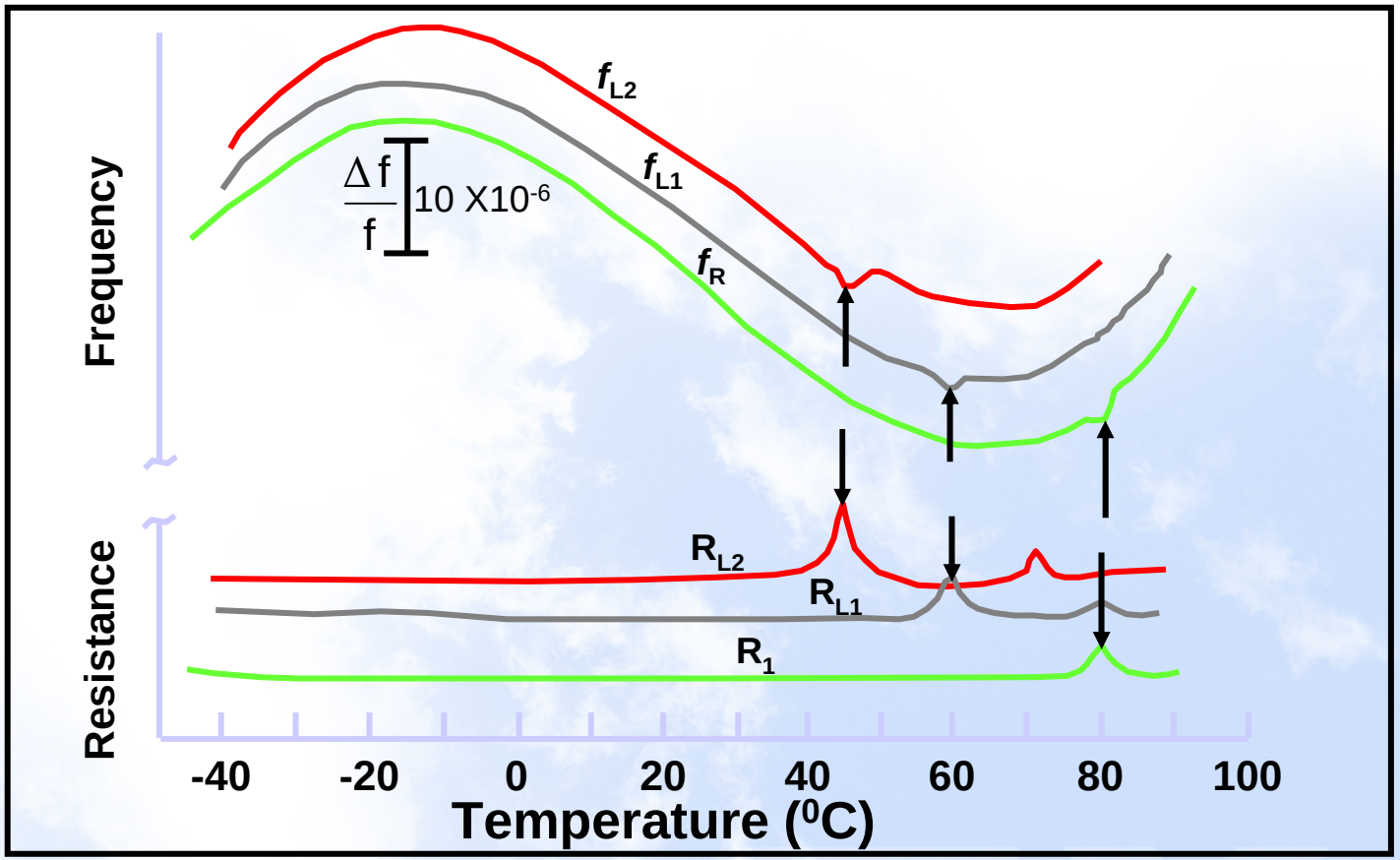
Drive Level vs. Resistance



Second Level of Drive Effect

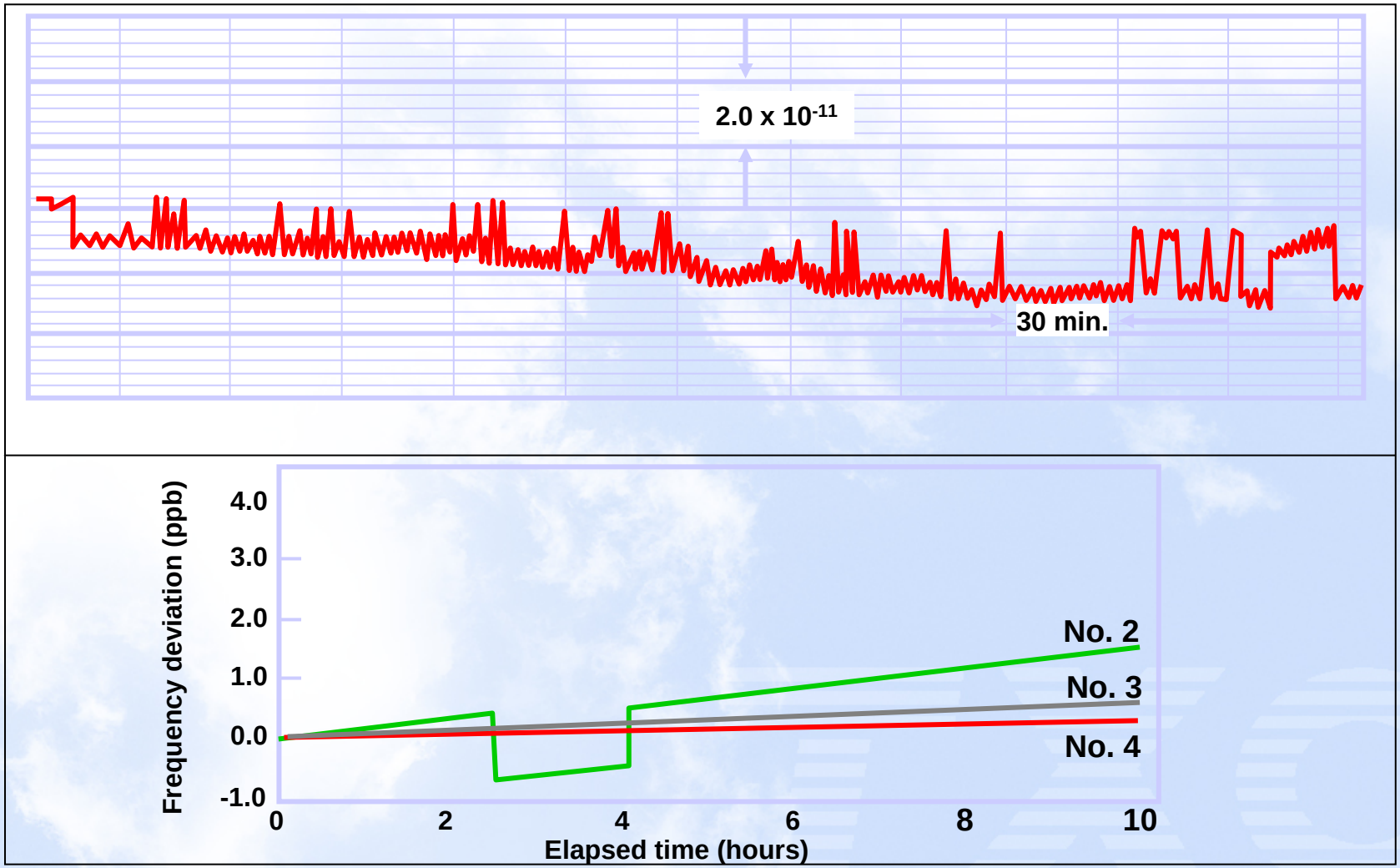


Activity Dips



Activity dips in the f vs. T and R vs. T when operated with and without load capacitors. Dip temperatures are a function of C_L, which indicates that the dip is caused by a mode (probably flexure) with a large negative temperature coefficient.

Frequency Jumps

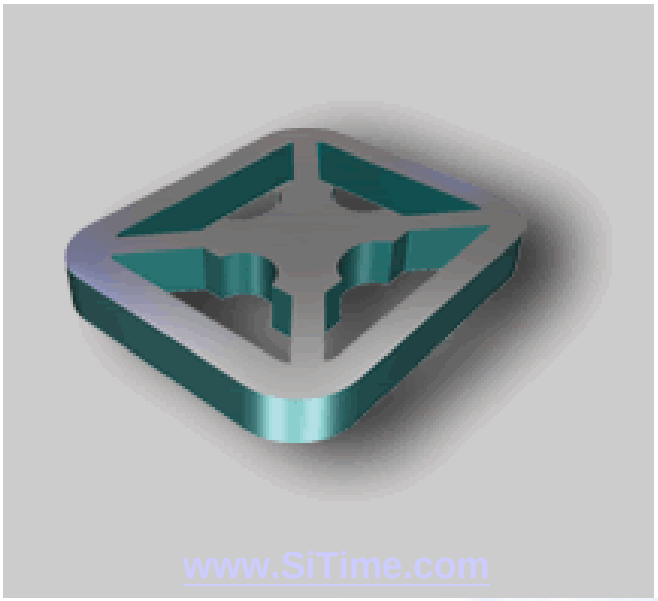


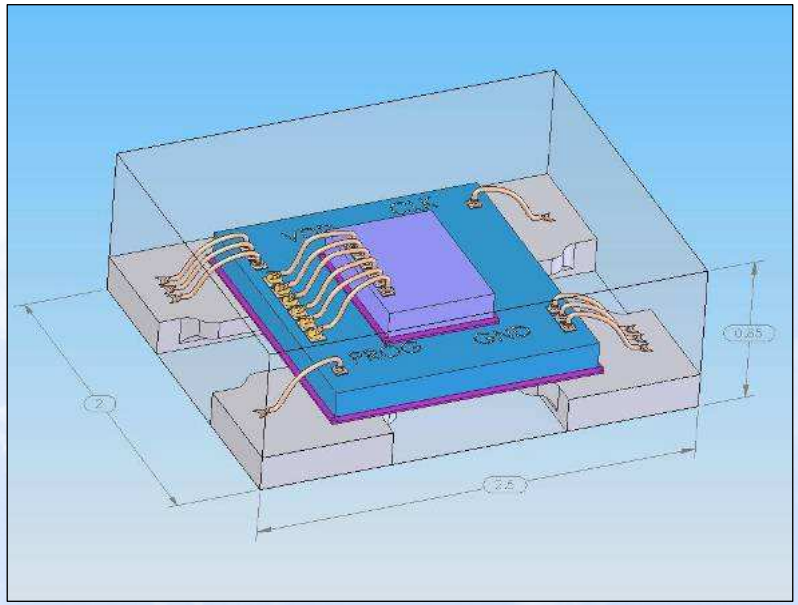
New Challenge

- MEMS
- QMEMS



Silicon Resonator & Oscillator

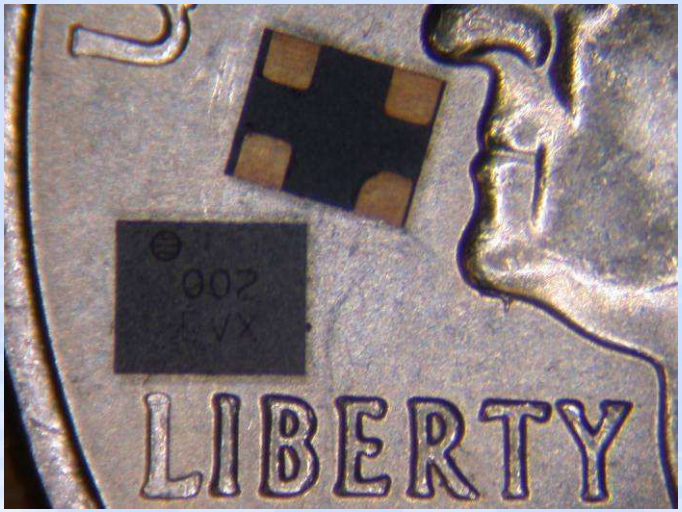




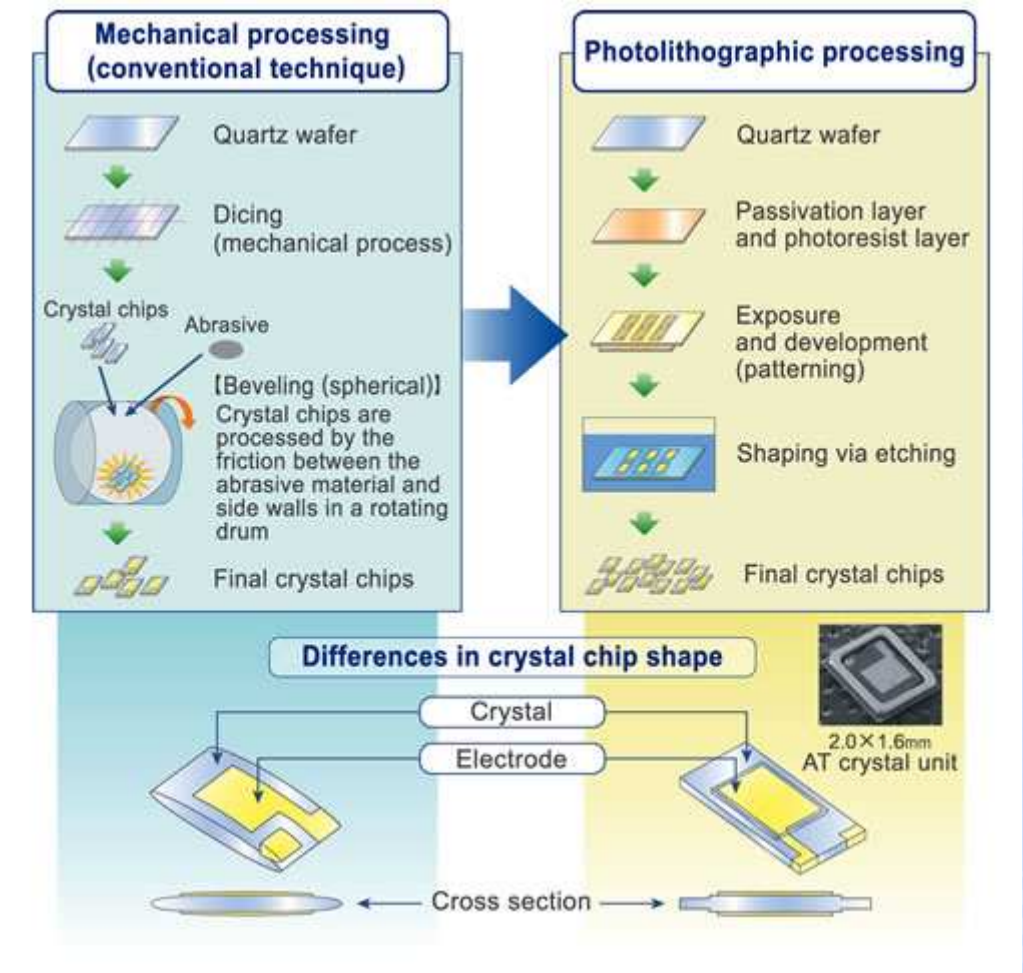
Resonator (Si): 0.2 x 0.2 x 0.01 mm^3
5 MHz; f vs. T: -30 ppm/^oC

Oscillator (CMOS): 2.0 x 2.5 x 0.85 mm^3

- ±50 ppm, ±100 ppm; -45 to +85 ^oC (±5 ppm demoed, w. careful calibration)
- 1 to 125 MHz
- <2 ppm/y aging; <2 ppm hysteresis
- ±200 ps peak-to-peak jitter, 20-125 MHz



New Challenge



EPSON website: http://www.epsontoyocom.co.jp/english/special/qmems/photo_at.html

Opportunities and Challenges

Opportunities:
大中國地區 石英晶體製造商 過往因成本優勢, 在地服務,
技術積累know-how, 生產能力強, 已獲得世界客戶肯定,
加上中國內需不斷增大, 商機增加

Challenges: Know-Why (R&D 的 R)
小型化, 低價化, 特性要求嚴格化 (IT 轉通訊), 產業變動快
產品開發困難提高, 週期縮短
→ 設計/製程控制能力提升
→ 製程影響資料庫系統性建立

Performance need to compete with Japanese Level –
Key Characteristics – DLD, TC perturbation
Low cost challenge to assembly solution –
currently control by Japan
Industrial Standards need to start to study



Opportunities and Challenges

- 發展面對的主要技術議題
- Quartz Crystal Design Capability build up
  - Know-Why Capability
  - Process-Characteristic Database
  - Design Tool Improvement
  - Analysis Capability Improvement
- Low cost, small size, assembly technologies need to build up
  - Assembly Materials
  - Assembly Methods
- Standards researches



Conclusions

- Today's environments request quartz crystal makers can provide more value-added service and products to customers, and more alternative choices were and will be introduced into the world.
- To provide better performance-to-price solution need more fundamental research and innovation in design / materials / and manufacturing processes developments.
- China already is the biggest quartz resonators manufacturing one, however, to be the leader still need more and more dedicated researchers.

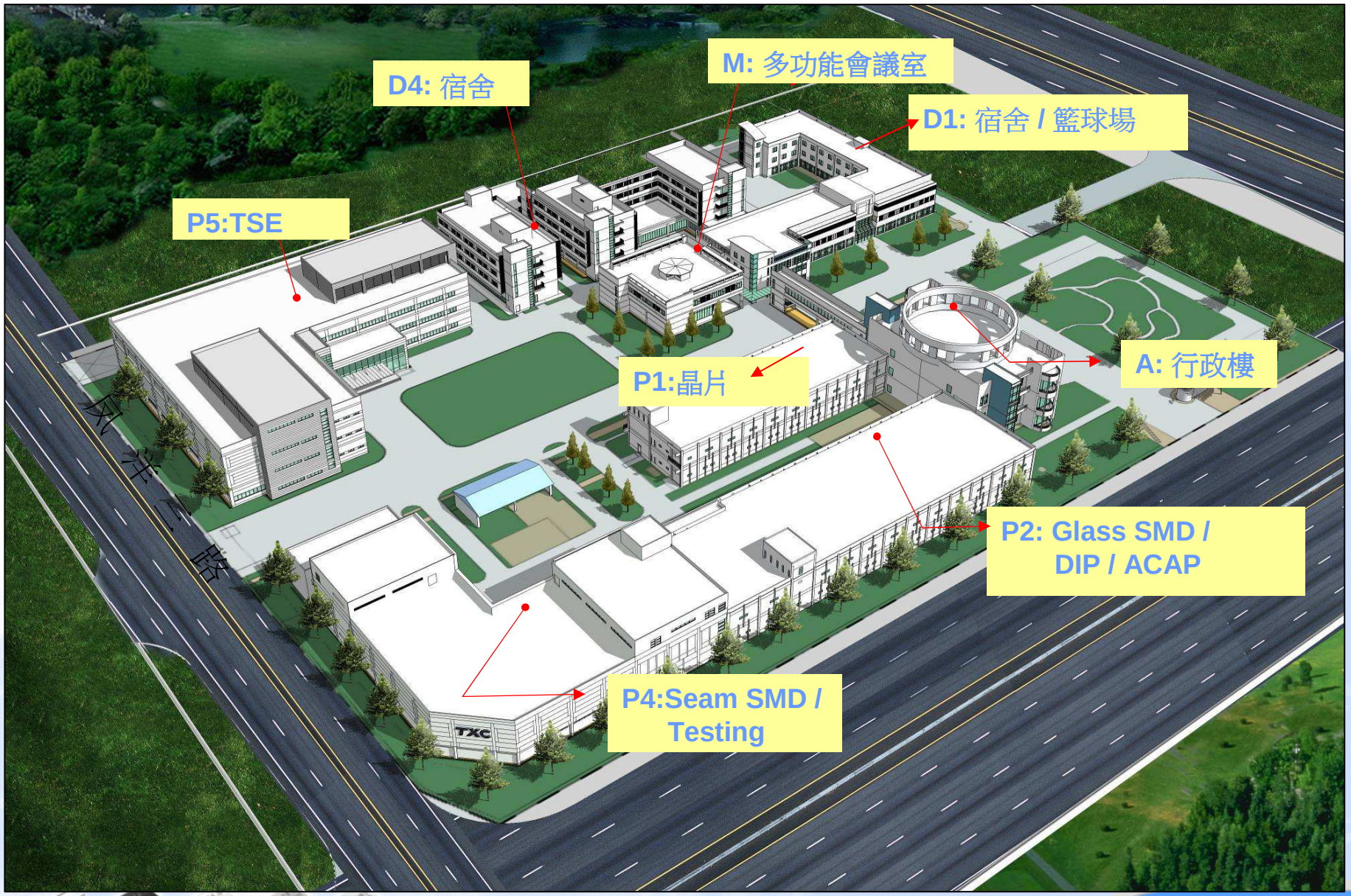


TXC(NGB) Introduction



廠區介紹 Plant layout

Area:56,326M^2



Some Major Quartz Crystal Companies (1938~)

1938	Toyocom founded,
1941	KSS founded, produced quartz crystals from next year
1942	EPSON established
1948	NDK founded, produced quartz crystals from next year
1959	KDS founded,
1983	**TXC** founded,
1988	NDK, SMD Xtal, CP12A
1995	Vectron International founded and isolated from AT&T
1999	**TXC(NGB)** founded
2003	Kyocera merge KSS , TXC(NGB) new plant started
2005	EPSON merge Toyocom
2010	TXC-NGB became biggest quantity AT-cut Crystals Factory in the world



企業文化

企業文化推行，人員向心力高

TXC

- 诚信待人，热情接物
- 踏实勤劳，刻苦奋斗
- 创新思维，用于挑战
- 服务团体，回馈社会



量產技術 -- 工程人才培育







(外) 積極連結學術資源

與寧波大學，中科院寧波材料研究所，

互動密切，共同研究創新，進行人才培育

(內) 構件學習平台，優化教育訓練

已建立 知識管理 與 e-training 平台

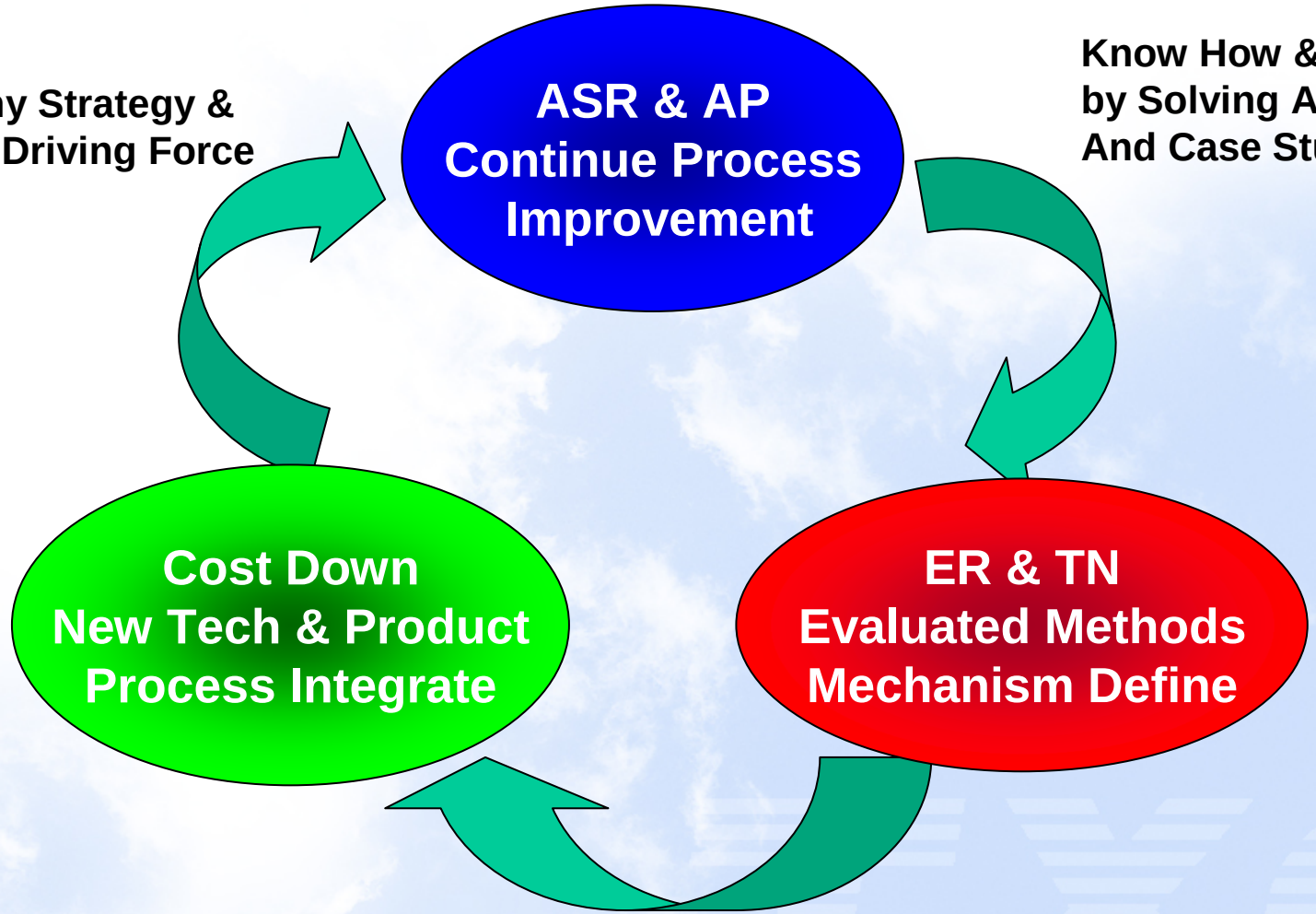
人員晉升與訓練關聯並制度化

重點人員至總公司訓練，累計達 60人以上

					Doc Code of TN	平均得分	TN(Yes or No)
睢毅坤	ADH	1	B1-1 供應商新技術更新	TB-3333C 工程試作報告	ICTT-ER-ADH-2010-006	13.5	No
					ICTT-ER-THF-2010-0002	17.5	Yes
					ICTT-ER-CPI-2010-0002	12.5	No
					ICTT-ER-BPI-2010-0006	18.5	Yes
					ICTT-ER-BPI-2010-0003	13	No
					ICTT-ER-BPI-2010-0002	13.5	No
					ICTT-ER-BPI-2010-0001	11.5	No
					ICTT-ER-BPI-2010-0007	16.75	Yes
					ICTT-ER-BPI-2010-0005	0	No
					ICTT-ER-MSI-2010-0001	17.5	Yes
					ICTT-ER-MSI-2010-0005	17	Yes
					ICTT-ER-MSI-2010-0006	0	No

NGB_ICTT Core Value

Company Strategy &
Internal Driving Force



Know How & Know Why
by Solving Abnormal
And Case Study

The Fundamental & Power for Development

- 論文發表清單:

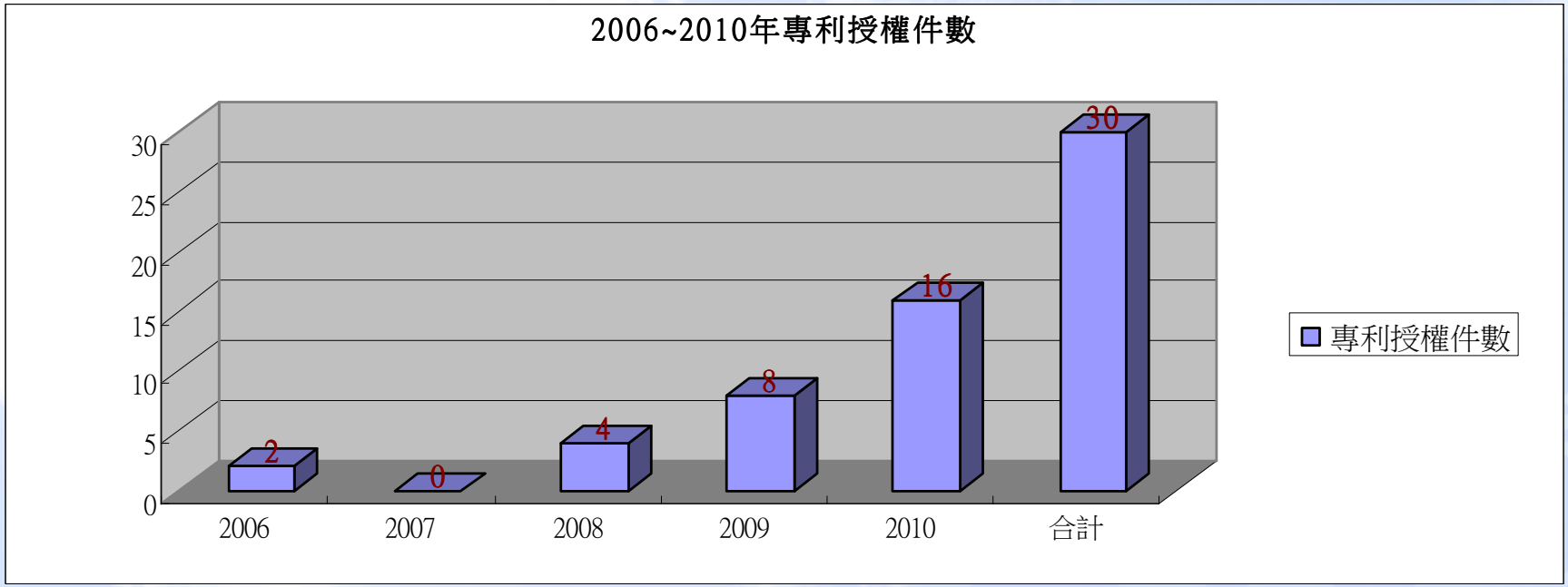
類型	作者	論文標題	論文檔案	發表時間	投遞單位
已發表論文	沈俊男 楊曉瑋 張建聰 趙岷江	The Study of Activation Energy (EA) by Aging and High Temperature Storage for Quartz Resonator's Life Evaluation	SPAWDA2010 140	2010/12	2010全國壓電和聲波理論及器件技術研討會
	潘俏俏 王驥 陽麗君 趙岷江	Face-Shear Vibration of AT-Cut Quartz Plate	SPAWDA2010 141	2010/12	2010全國壓電和聲波理論及器件技術研討會
	王驥 陳玉梅 陽麗君 潘俏俏 趙岷江	An Integrated Program of Vibrations of Quartz Crystal Plates with Mindlin Plate Theory for Resonator Design	SPAWDA2010 216	2010/12	2010全國壓電和聲波理論及器件技術研討會
	王驥 趙岷江 潘俏俏 陽麗君	Design of Quartz Crystal Resonators with an Analytical Procedure Based on the Mindlin Plate Theory	IUS640B	2010/6	2010 IEEE International Frequency Control Symposium
	王驥 趙岷江 潘俏俏 陽麗君	An Integrated Analysis of Vibration of Quartz Crystal Plates with the Mindlin Plate Theory for Resonator Design and Optimization	QCRAST_JiWang	2010/11	Proceedings of the First Joint China-Japan International Workshop on Acoustic Wave Device
	王驥 陽麗君 潘俏俏 趙岷江 杜建科	Resonant Frequency of Thickness-shear Vibrations of Rectangular Crystal Plates	IEEE TUFFC	2011/1	IEEE Transactions on Ultrasonics Ferroelectrics, and Frequency control
進行中的論文	王驥 陳玉梅 陽麗君 潘俏俏 趙岷江	An Integrated Analysis of Vibrations of Quartz Crystal Plates for Optimal Design of Resonators	IntPlateeqn	2011/5	2011 IEEE International Frequency Control Symposium & European Frequency and Time Forum
	鮑世勇 潘俏俏 趙岷江	An Efficient AT-cut Quartz Crystal Resonator Design Tool for Activity Dip in Working Temperature Range	Abstract to 2011 FCS_Pao	2011/5	2011 IEEE International Frequency Control Symposium & European Frequency and Time Forum

專利

說明:截止對到2010年11月,累計專利30件,其中發明專利2件

2006~2010年專利授權明細表

年份	2006	2007	2008	2009	2010	合計
專利授權件數	2	0	4	8	16	30



政府肯定

2005.08	市級高新技術企業
2005.12	省級高新技術企業
2006.01	市級工程技術中心
2006.10	火炬計畫項目
2006.10	科技興貿行動專項
2007.09	國家級高新技術企業
2007.11	省級研究開發中心
2008.08	中小企業資信等級AAA級
2008.12	國家級高新技術企業
2009.01	平安企業
2009.04	技術創新示範企業
2010.02	榮獲北侖區「學習型企業」稱號

樂在學習，好還要更好



TXC/TSE 團隊

年輕有活力

樂於學習

請多多指導

感謝

