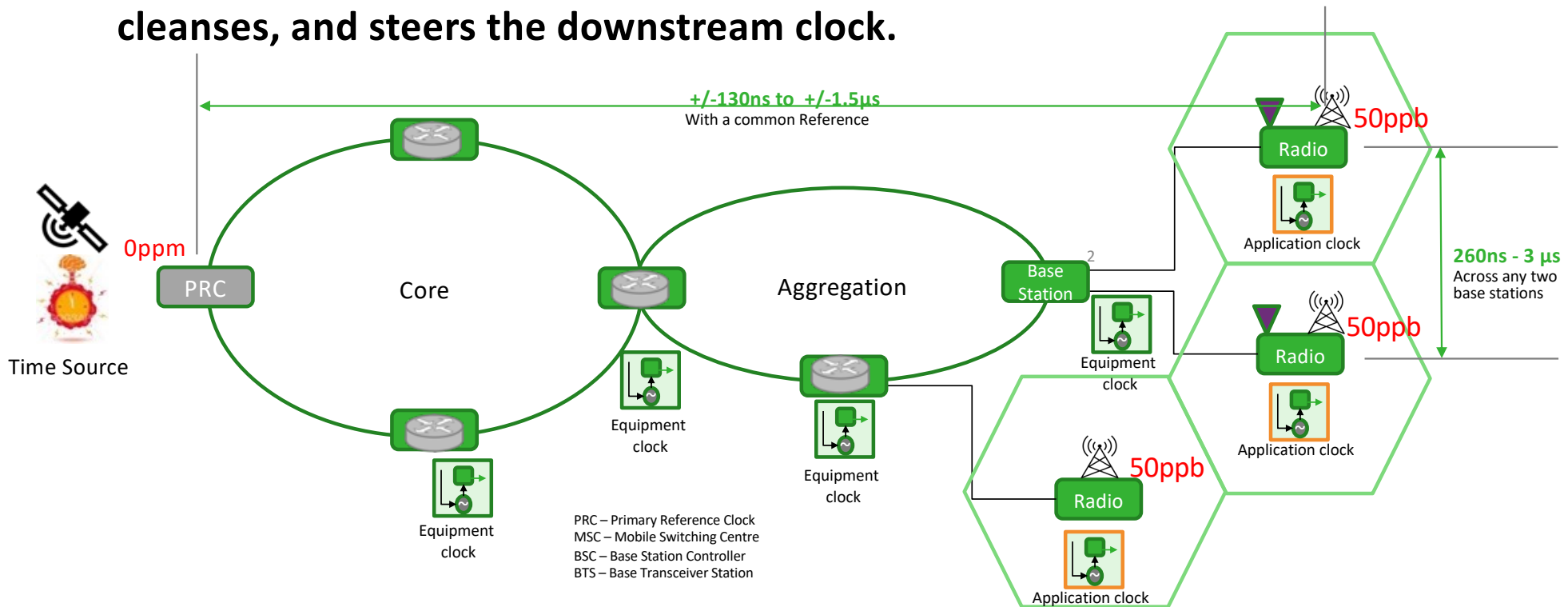# Oscillators

Topics

- Role of oscillators in synchronisation systems

- Oscillator fundamentals

- Key parameters in oscillator applications

Synchronization is hierarchical

rakon

‹ **Each equipment clock has a local clock that receives, cleanses, and steers the downstream clock.**

+/-130ns to +/-1.5µs
With a common Reference

50ppb

0ppm

PRC

Time Source

Core

Aggregation

Base Station

2

Radio

Application clock

260ns - 3 µs
Across any two base stations

Equipment clock

50ppb

Radio

Application clock

Equipment clock

Equipment clock

50ppb

Radio

Application clock

Equipment clock

PRC – Primary Reference Clock
MSC – Mobile Switching Centre
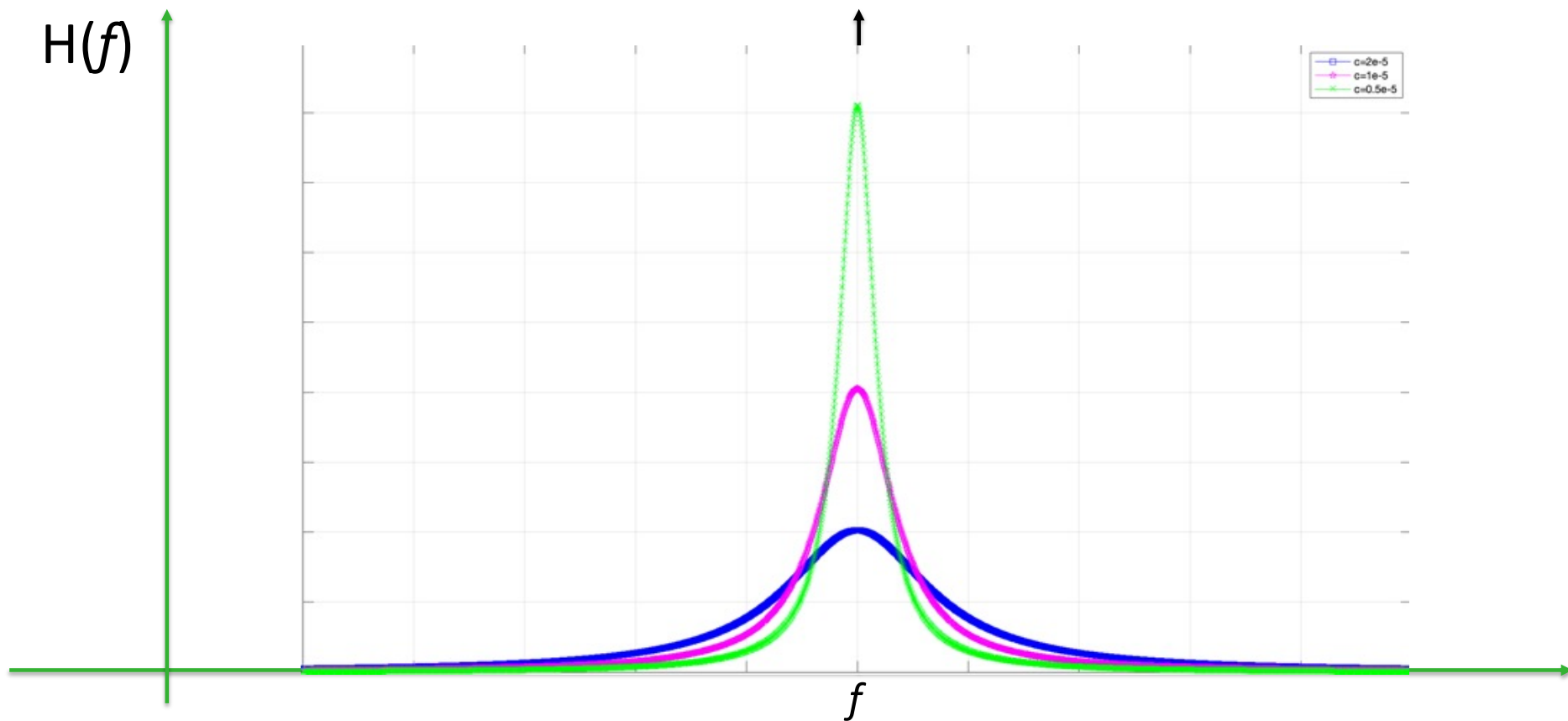BSC – Base Station Controller
BTS – Base Transceiver Station

‹ **At the final node, the local clock is prepared to serve the end application**

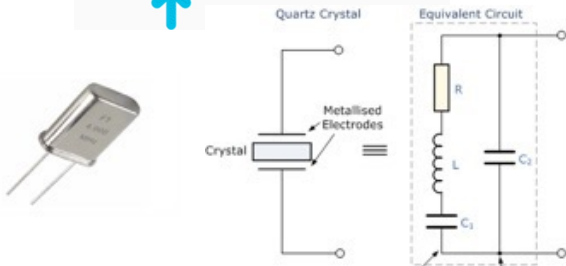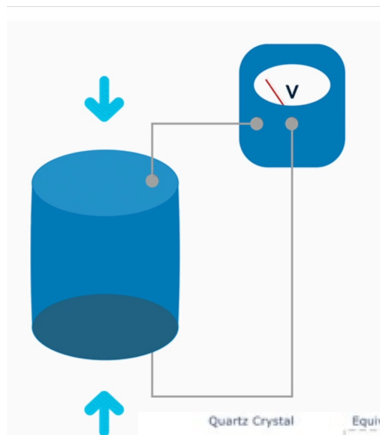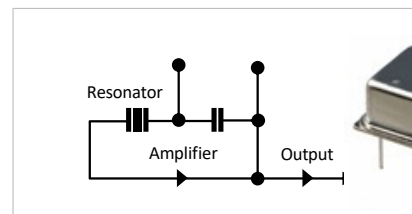# Oscillators provide regular ticks

‹ Oscillator's Quality factor

H(f)

Legend:
- c=2e-5
- c=1e-5
- c=0.5e-5

f

Resonator types

Quartz Crystals

- **High-Quality factor**
  - Piezo electric behaivour

Micro Electro Mechanical Systems (MEMS)

Silicon MEMS

QUARTZ MEMS

Electrode

Oscillating portion

A-A
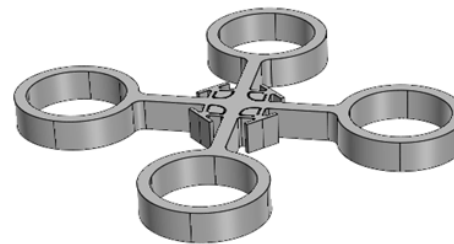
Resonator (Crystal)   Equivalent Circuit   Oscillating Circuit   Crystal Oscillators

Quartz Crystal   Equivalent Circuit

Crystal   Metallised Electrodes
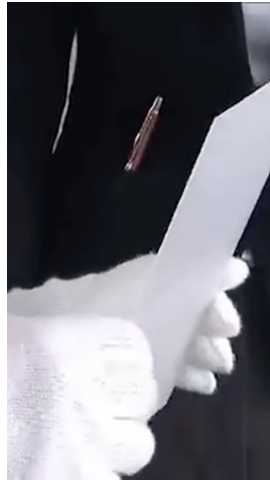
R   C₂   L   C₁

Resonator   Amplifier   Output
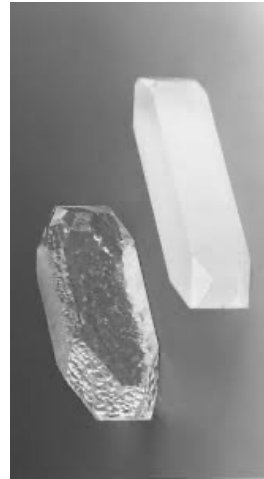
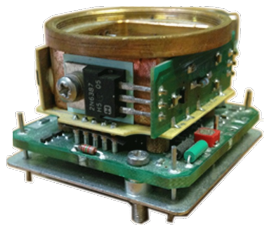50.000 MHZ
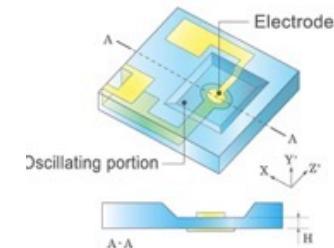
The Quartz Journey
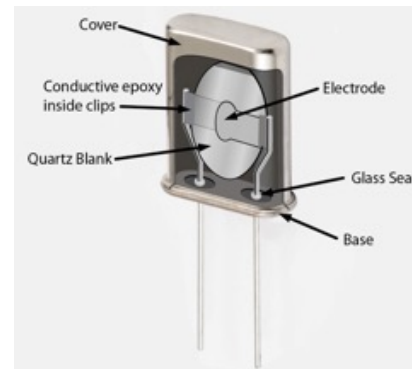

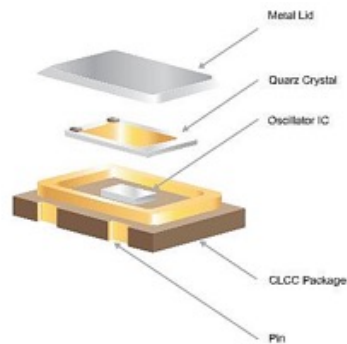Quartz bars and grown
in autoclaves
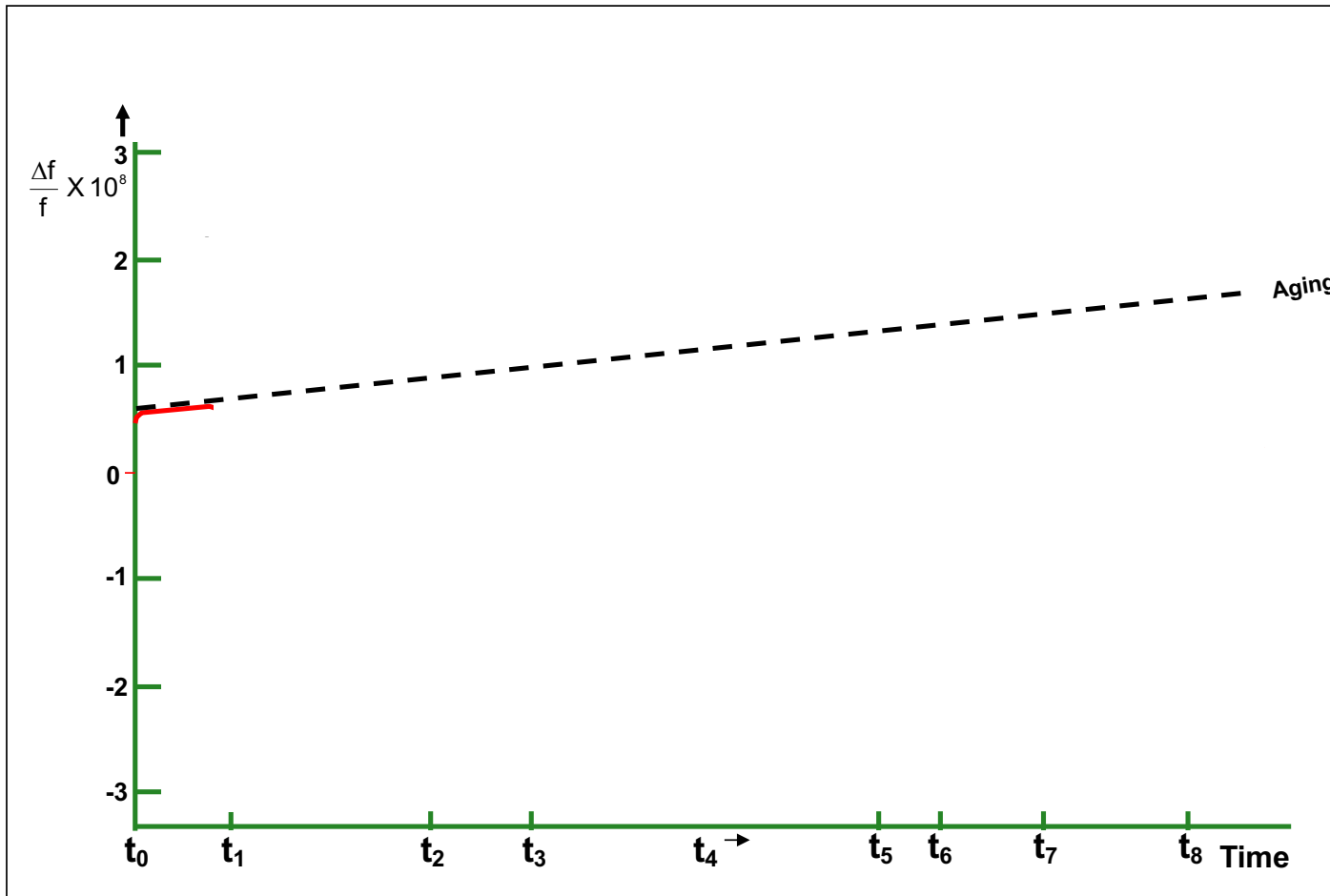

Nikkie Asia/Epson

Bars, Wafers and Blanks
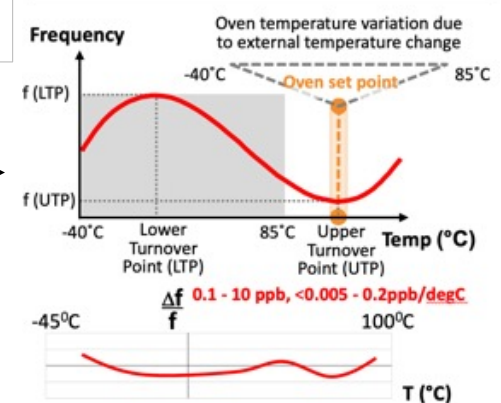

Oscillators

Resonators

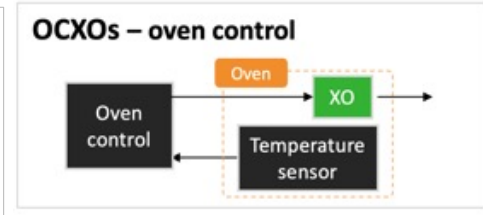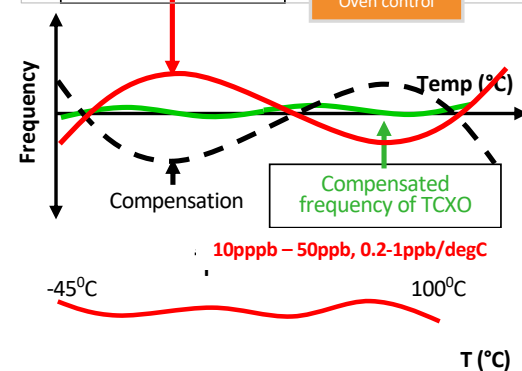# Key contributors to oscillator instability

Improving oscillator stability

Handling effect of temperatures in oscillators
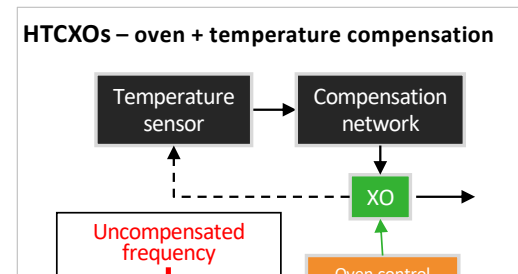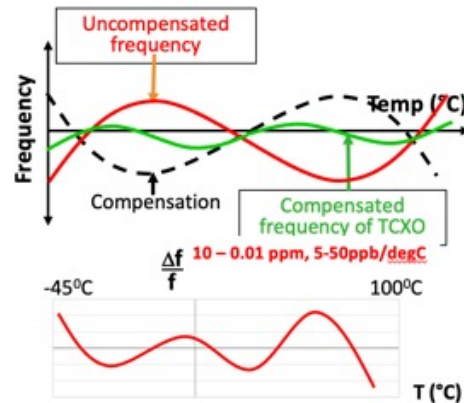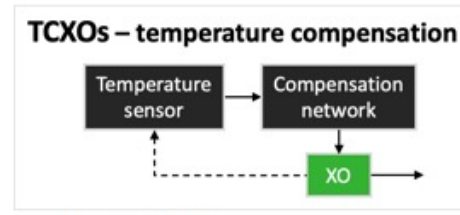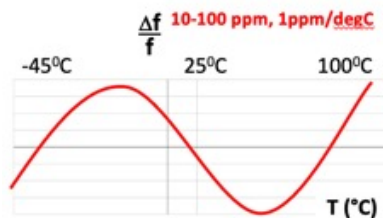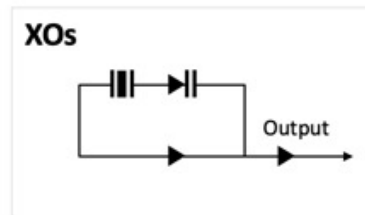
Stability	10-100ppm
Size	2x1.6mm – 7x5mm
Costing	$0.05-$3
Applications	Processing & Interfacing

Key aspects of reference clocks

- **Free Run accuracy**
  - Overall oscillator stability for 10/15/20 years, all causes included

- Start up →
  - Ability to provide clock accuracy to downstream and ability to lock to a higher stratum

- **Dynamic behaviour**
  - Performance of the system when the synchronization source is in action

- Noise Generation →
  - Impacted by Frequency versus Temperature and sensitivity of the reference clock

- **Holdover**
  - Performance of the system when the synchronization source is lost

- Holdover →
  - Ability to hold the frequency/phase of the clock
  - Depends primarily on sensitivity & ageing

- **Phase noise/Jitter**
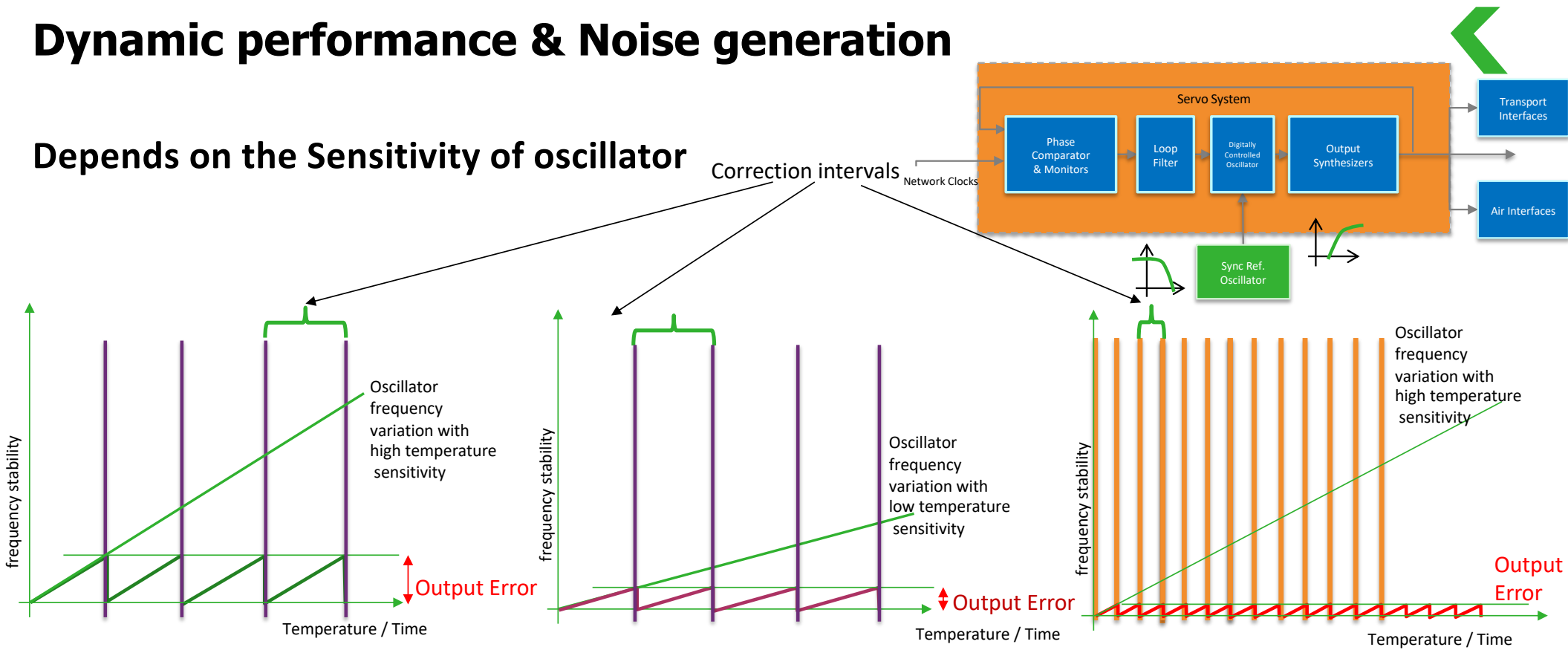 - Contribution from frequency components & instability

- Transmission →
  - Jitter on level modulation; mostly wired networks
  - Phase noise for quadrature amplitude modulation; wireless networks

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Dynamic performance & Noise generation

Depends on the Sensitivity of oscillator

Correction intervals

Network Clocks

Servo System

| Phase Comparator & Monitors | Loop Filter | Digitally Controlled Oscillator | Output Synthesizers |

Transport Interfaces

Air Interfaces

Sync Ref. Oscillator

Oscillator frequency variation with high temperature sensitivity

Output Error

frequency stability

Temperature / Time

Oscillator frequency variation with low temperature sensitivity

Output Error

frequency stability

Temperature / Time

Oscillator frequency variation with high temperature sensitivity

Output Error

frequency stability

Temperature / Time

Loop bandwidth	10 – 100 Hz	1 – 10 Hz	0.1 – 1 Hz	10 – 100 mHz	1 mHz	<1 mHz
Recommended temperature stability	0.5 – 1 ppm	0.1 – 0.3 ppm	0.05 – 0.1 ppm	20 – 50 ppb	5 – 10 ppb	1 – 5 ppb
Temperature Sensitivity	10-20ppb/degC	5-10ppb/degC	1-5ppb/degC	0.2-0.5ppb/degC	0.1-0.2ppb/degC	<1ppb/degC

Holdover

Clocks in the network Synchronize to the primary reference

- ❑ When a traceable clock is lost, the system gets into a "holdover" – Remembering the last good reference
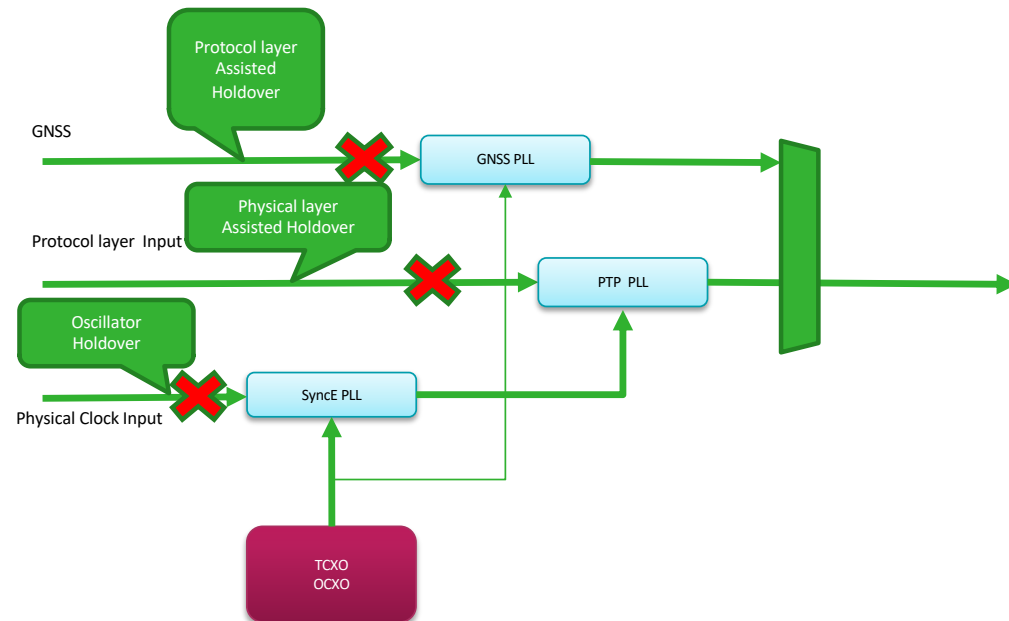
Holdover with oscillators

Phase Holdover At Time (t):

$x(t) = x_o + (f_o + \Delta f_{env} + \Delta f_{RW})*t + \frac{1}{2}*aging * t^2$

x_o = Initial phase offset

fo: The initial fractional frequency offset (ppb)

Δf_{env}: sum total of the changes in frequency (ppb) due to environmental factors

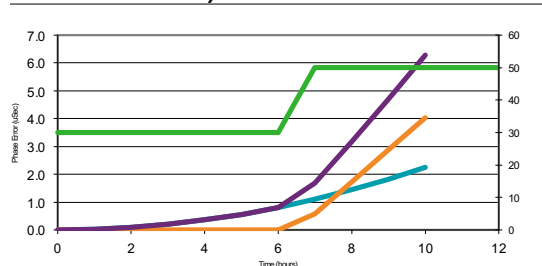Δf_{RW}: Random frequency noise of oscillator

Aging: The long term change in frequency over time (ppb/day)
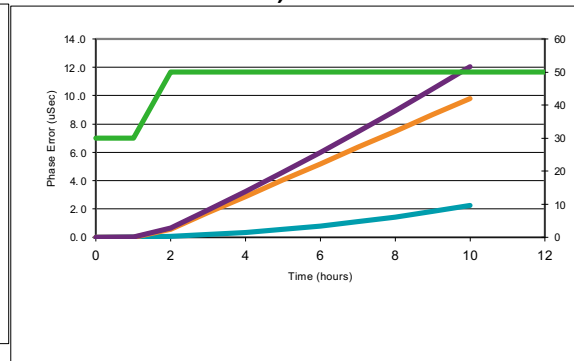
Key impacts

- Temperature profile (ramp size, rate and timing)
- Ageing Impact
- Micro jumps
- Hysteresis

Impact of temperature   Impact of Ageing   Total Impact   Temperature variation
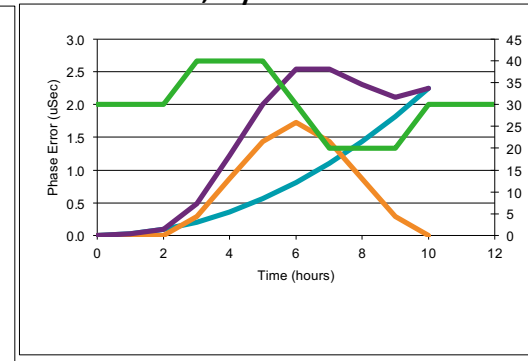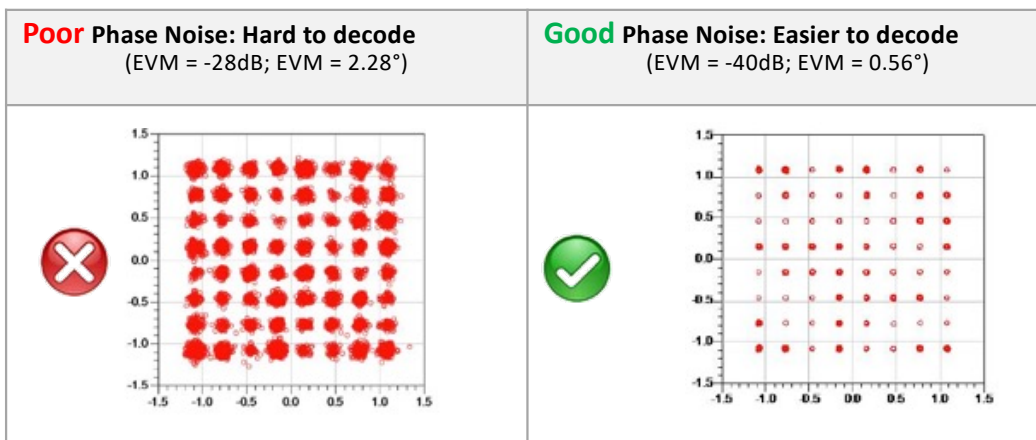

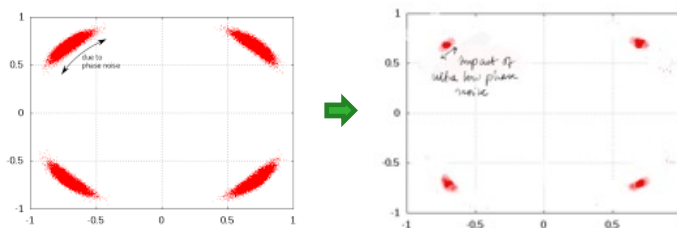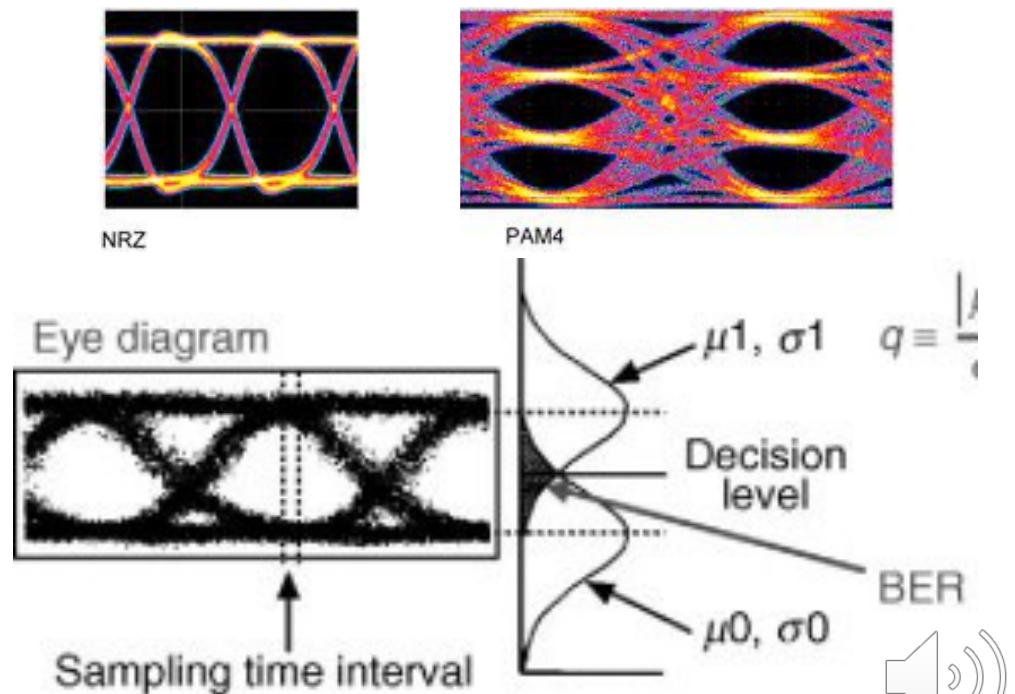t=6, one sided   t=1, one sided   t1=1, symmetric

Phase Noise and Jitter

- **Phase – Amplitude modulation**

Poor Phase Noise: Hard to decode (EVM = -28dB; EVM = 2.28°)	Good Phase Noise: Easier to decode (EVM = -40dB; EVM = 0.56°)

- **Phase noise rotates the constellation**

- **Transport systems - OOK Modulation**

NRZ   PAM4

Eye diagram

Sampling time interval

$\mu 1, \sigma 1$ $q \equiv$

Decision level

BER

$\mu 0, \sigma 0$

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Summary

- Oscillators are fundamental building blocks of clocks

- Temperature compensation and oven control and methods used to improve stability of clocks

- As the loop bandwidth of the systems decrease, higher stability oscillators to be used to have a certain level of output stability

- Freerun, wander generation and holdover and key aspects of oscillator selection in systems