OSCILLOQUARTZ

An ADVA Optical Networking Company

Tutorial:
Phase-Locked Loops & Quartz Crystal Oscillators

Dominik Schneuwly

June 9th, 2014

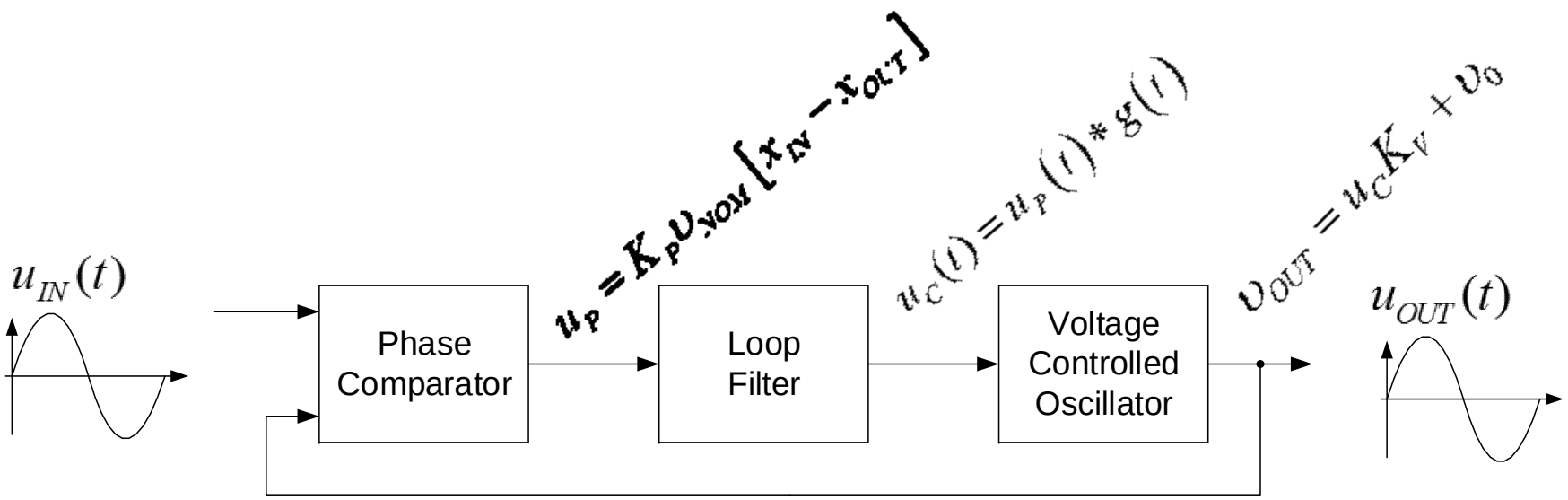
Content

1. Phase Locked Loops (PLL)
   - PLL with VCO
   - PLL with DDS
   - Comparison

2. Quartz Crystal Oscillator (XO) Technology
   - TCXO
   - OCXO
   - DOCXO

1. Phase-Locked Loops (PLL)

PLL: Working principle



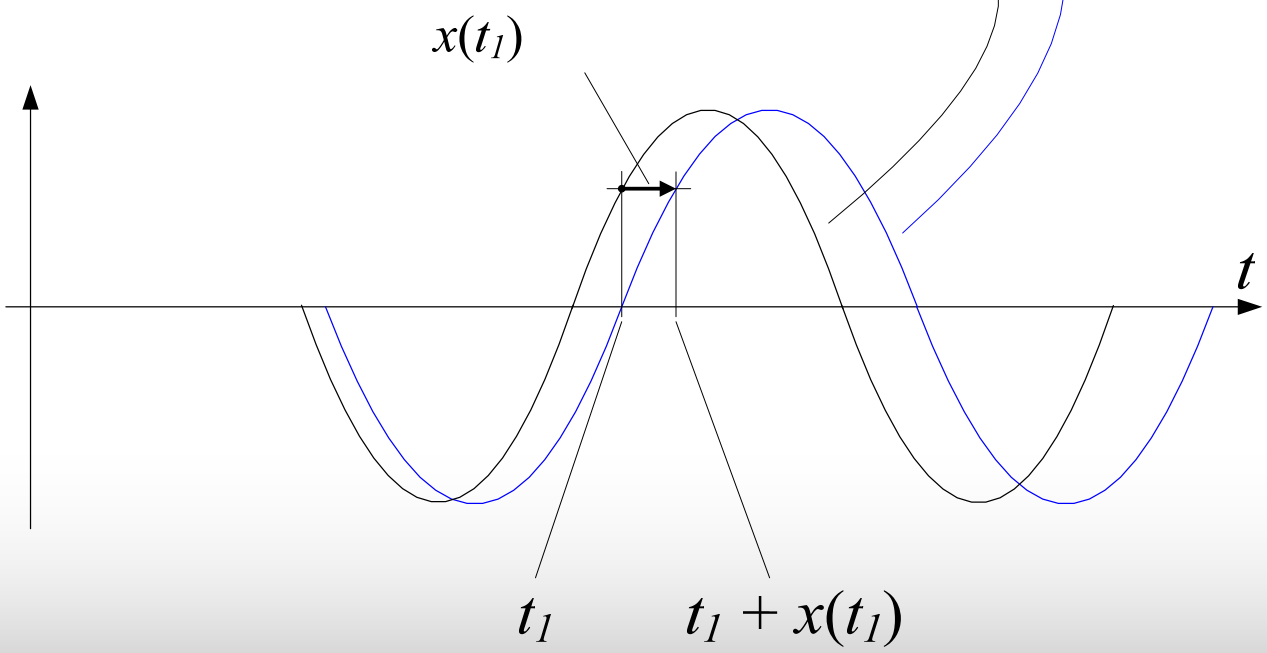
$$u_{IN}(t) = A \cdot \sin\left\{2\pi\upsilon_{NOM}\left[t + x_{IN}(t)\right]\right\} = A \cdot \sin\left\{2\pi\upsilon_{IN}(t) + \varphi_{0,IN}\right\}$$

$$u_{OUT}(t) = A \cdot \sin\left\{2\pi\upsilon_{NOM}\left[t + x_{OUT}(t)\right]\right\} = A \cdot \sin\left\{2\pi\upsilon_{OUT}(t) + \varphi_{0,OUT}\right\}$$

Phase-time deviation x(t)

$$\text{nominal signal} = \sin\left\{2\pi\upsilon_{NOM}t\right\}$$

$$\text{actual signal} = \sin\left\{2\pi\upsilon_{NOM}\left[t + x(t)\right]\right\}$$



Note: Phase-time x = random component only
Time Error TE = random and deterministic components

Transfert function «Input-to-Output»

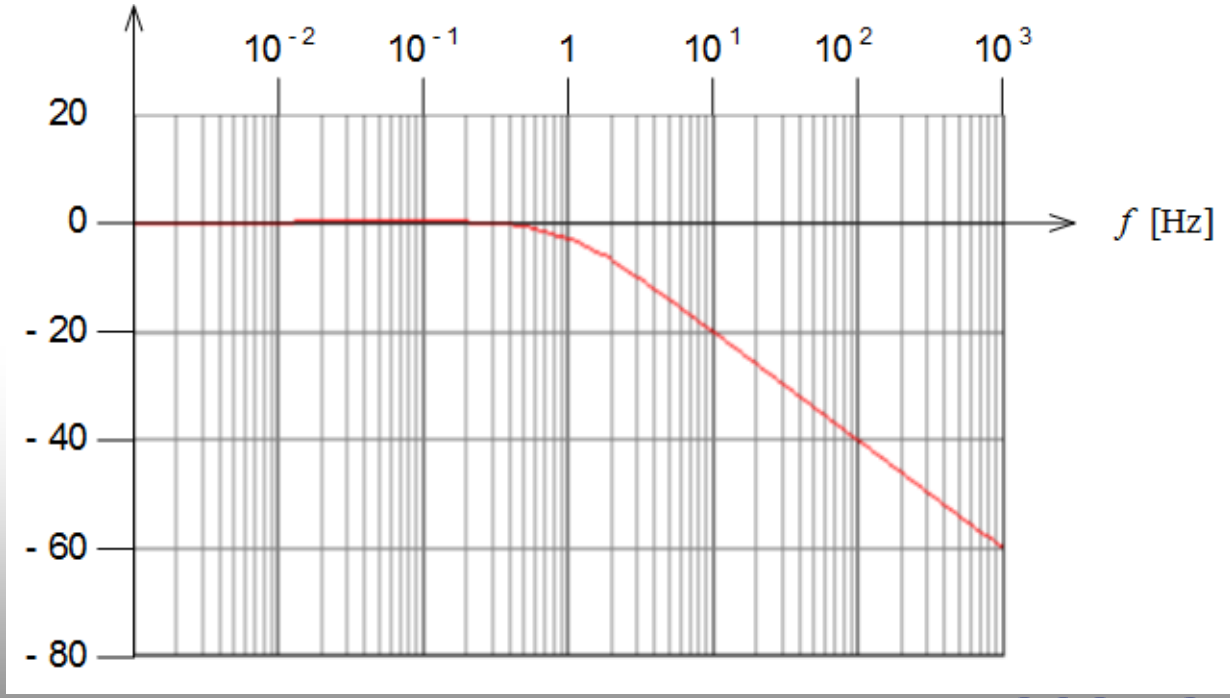
$$x_{OUT}(t) = x_{IN}(t) * h_{IN}(t)$$

$$X_{OUT}(s) = X_{IN}(s) \cdot H_{IN}(s)$$

where $h_{IN}(t) =$ impulse response

$H_{IN}(s) =$ transfer function $= \text{Laplace}\{h_{IN}(t)\}$

$20\log\left|H_{IN}(j2\pi f)\right|$ [dB]



OSCILLOQUARTZ
An ADVA Optical Networking Company

Transfer function «Oscillator-to-Output»

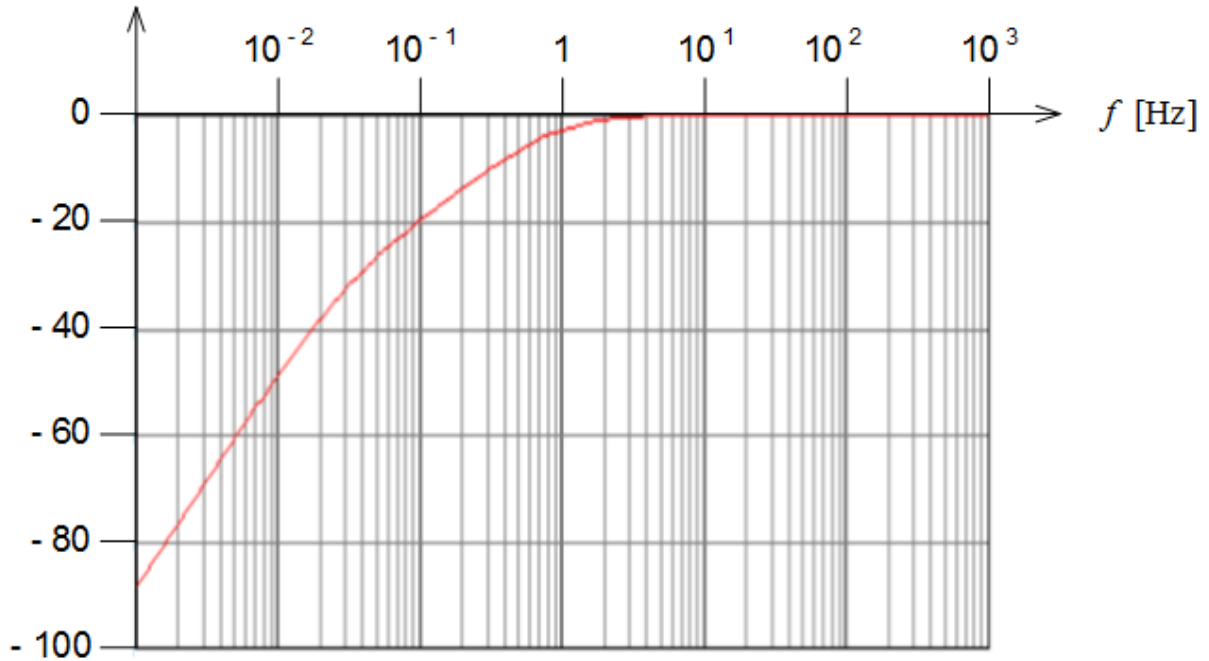
$$x_{OUT}(t) = x_{OSC}(t) * h_{OSC}(t)$$

$$X_{OUT}(s) = X_{OSC}(s) \cdot H_{OSC}(s)$$

where $h_{OSC}(t) =$ impulse response

$$H_{OSC}(s) = \text{transfer function} = \text{Laplace}\{h_{OSC}(t)\}$$

$20\log\left|H_{OSC}(j2\pi f)\right|$ [dB]

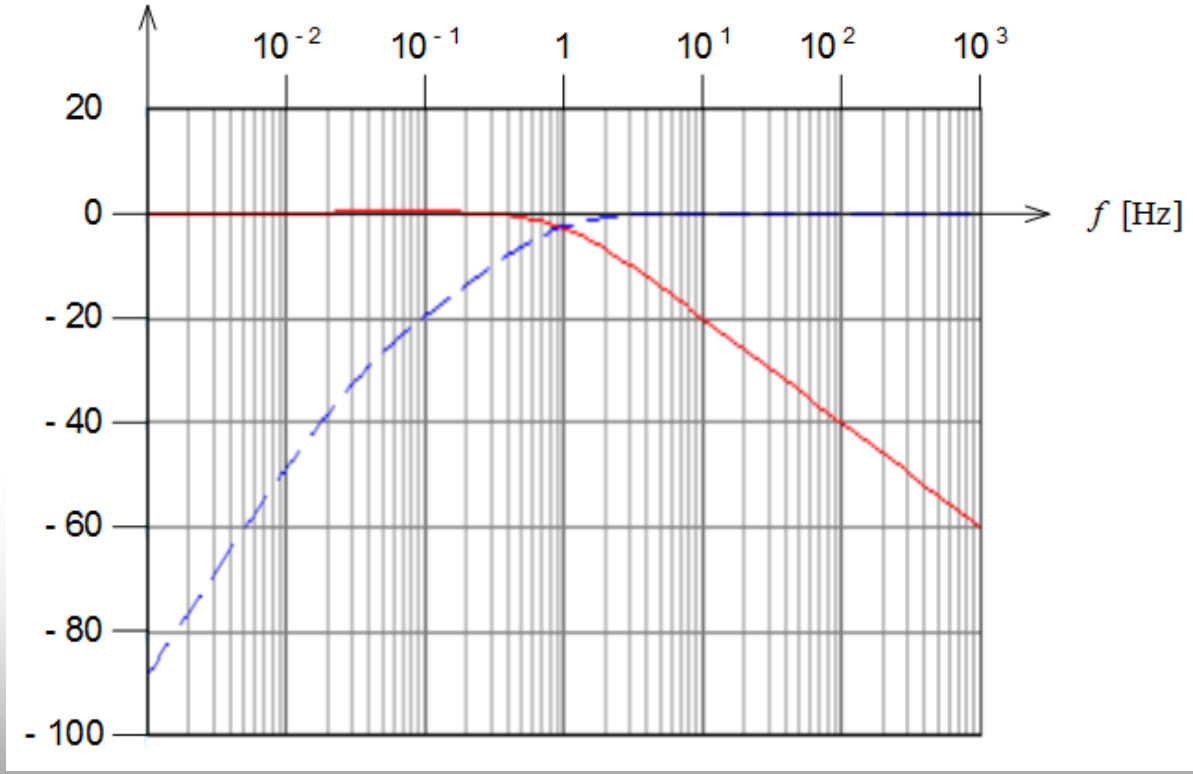


OSCILLOQUARTZ
An ADVA Optical Networking Company

Both transfer functions

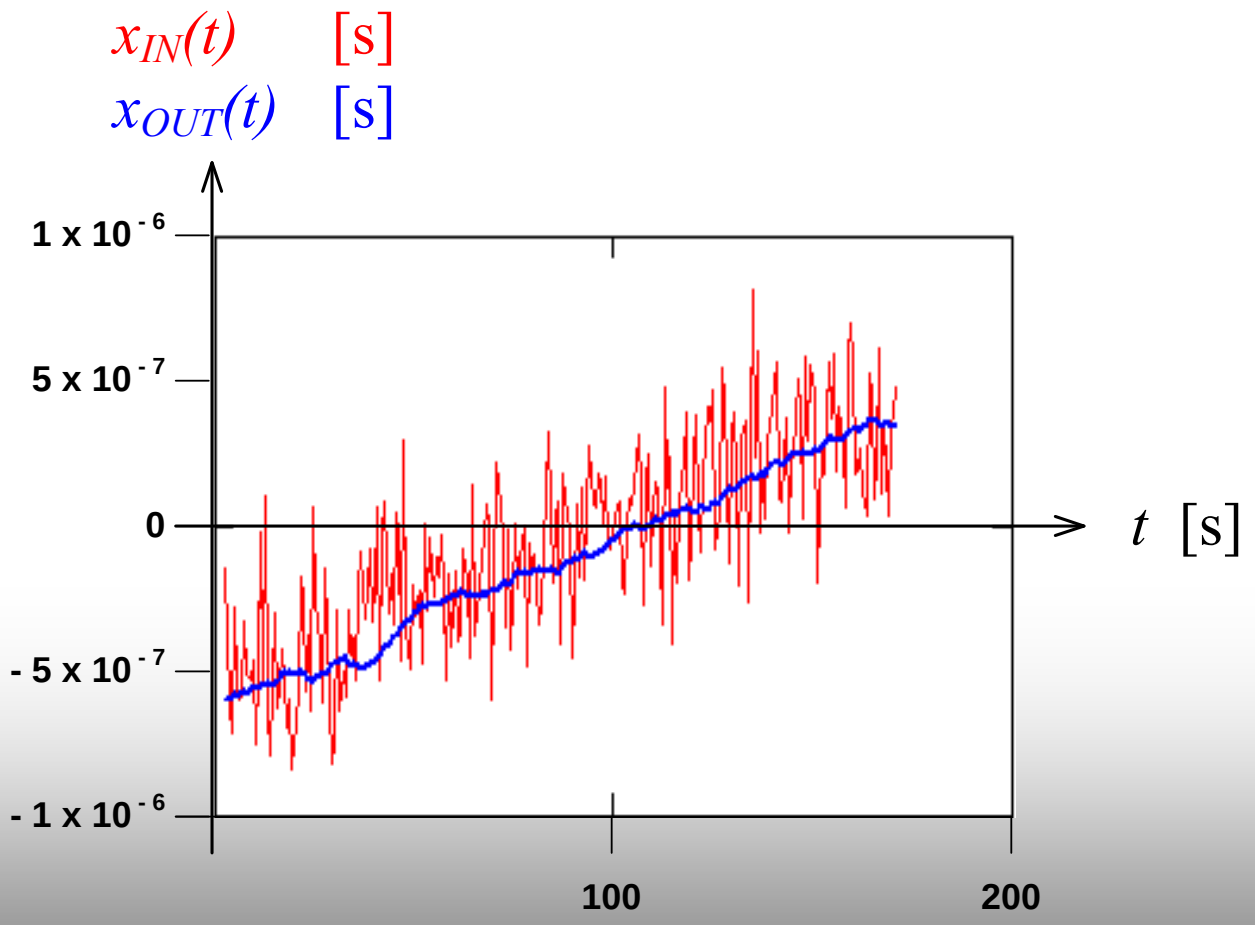
$20\log\left|H_{IN}\left(j2\pi f\right)\right|$ [dB]

$20\log\left|H_{OSC}\left(j2\pi f\right)\right|$ [dB]



OSCILLOQUARTZ
An ADVA Optical Networking Company

PLL: Jitter filtering

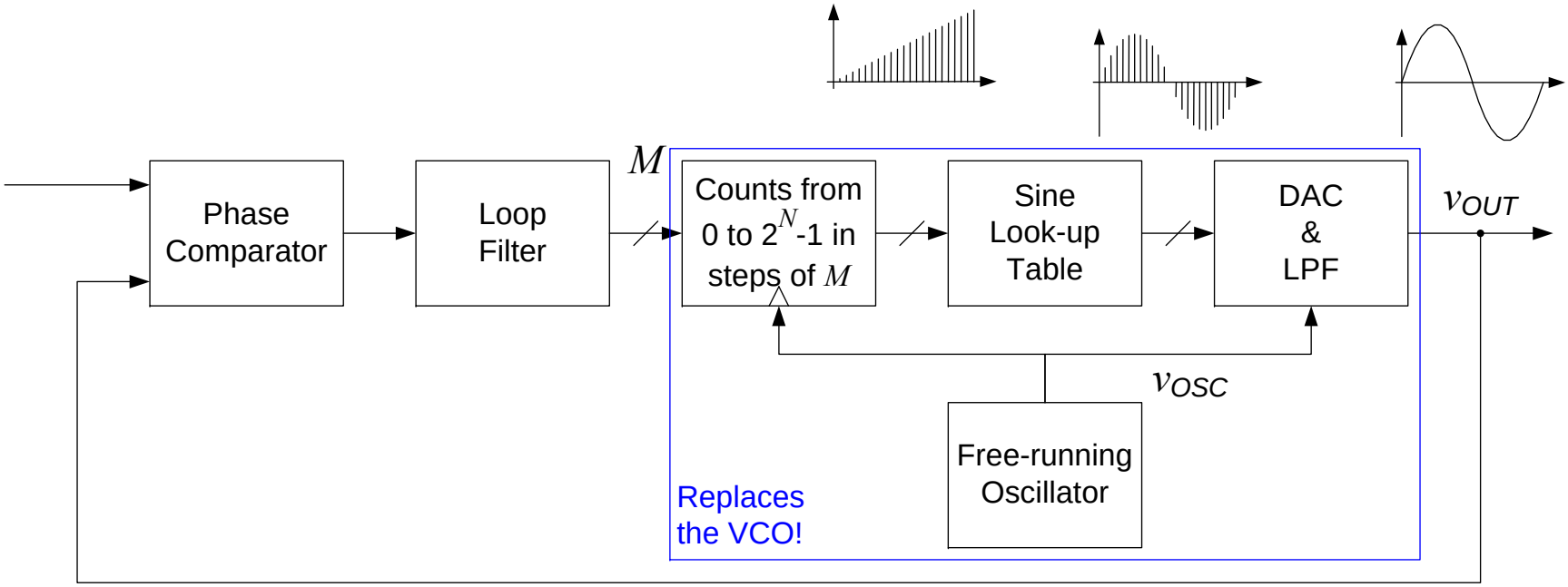


OSCILLOQUARTZ
An ADVA Optical Networking Company

PLL terminology

- Hold-in range: largest offset between a PLL's input frequency and a specified nominal frequency, within which the PLL maintains lock as the frequency varies arbitrarily slowly over the frequency range
- Pull-in range: largest offset between a PLL's input frequency and a specified nominal frequency, within which the PLL will achieve locked mode
- Pull-out range: The offset between a PLL's input frequency and a specified nominal frequency, within which the PLL stays in the locked mode and outside of which the PLL cannot maintain locked mode, irrespective of the rate of the frequency change.
- Pulling range: term which applies to Voltage Controlled Oscillators (VCO), not to PLLs; maximum change in output frequency that can be attained via the control voltage

PLL with Direct Digital Synthesis



DAC = Digital-to-Analog Converter

LPF = Low-pass Filter

$$\upsilon_{OUT} = \frac{M}{2^N}\upsilon_{OSC}$$

where $M =$ output of the digital loop filter (integer)

$N =$ size of the counter in bits (integer)

$\upsilon_{OUT} =$ frequency of output signal $u_{OUT}(t)$

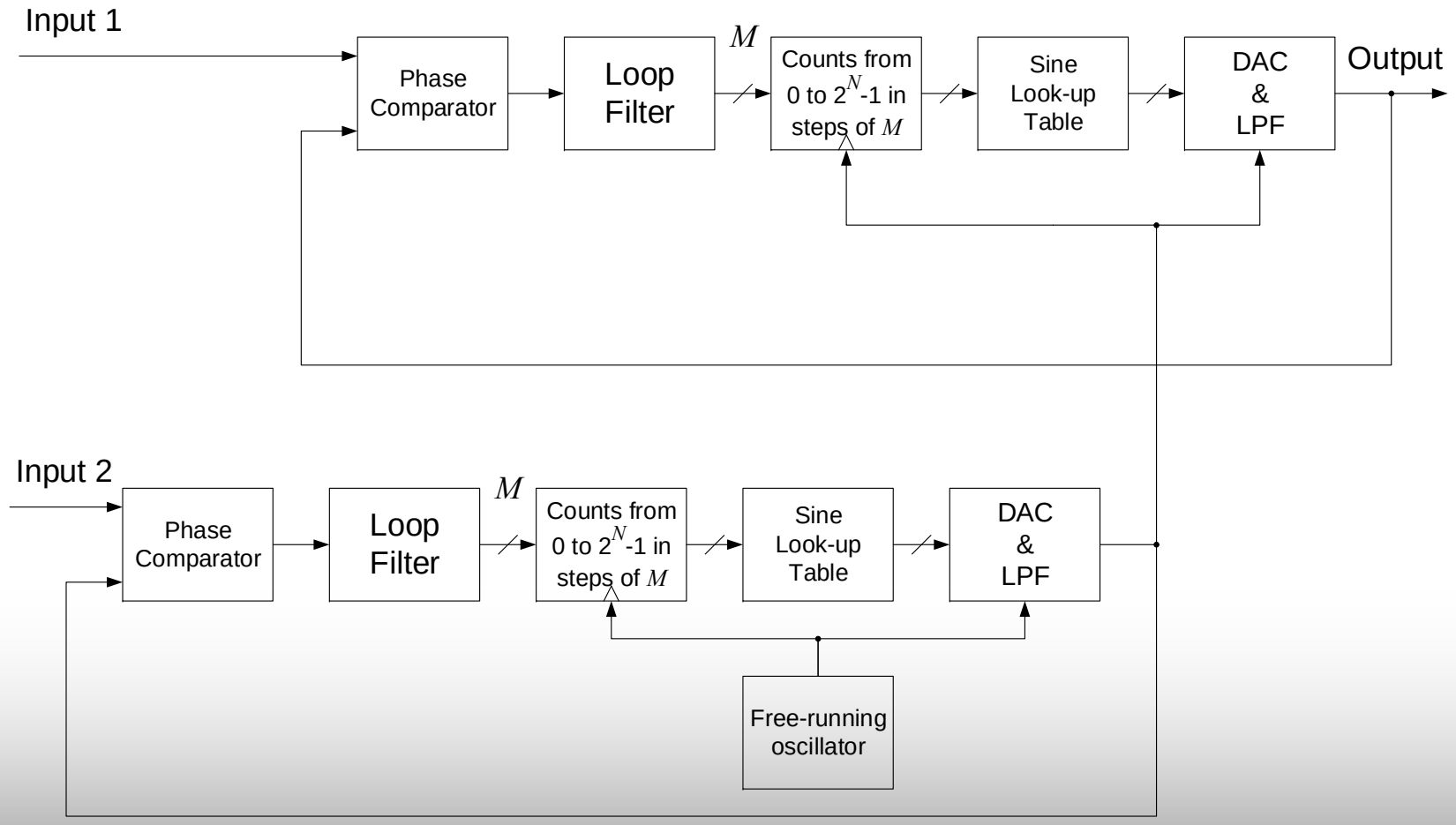
$\upsilon_{OSC} =$ free-run frequency of the oscillator

OSCILLOQUARTZ
An ADVA Optical Networking Company

PLL with VCO and with DDS compared

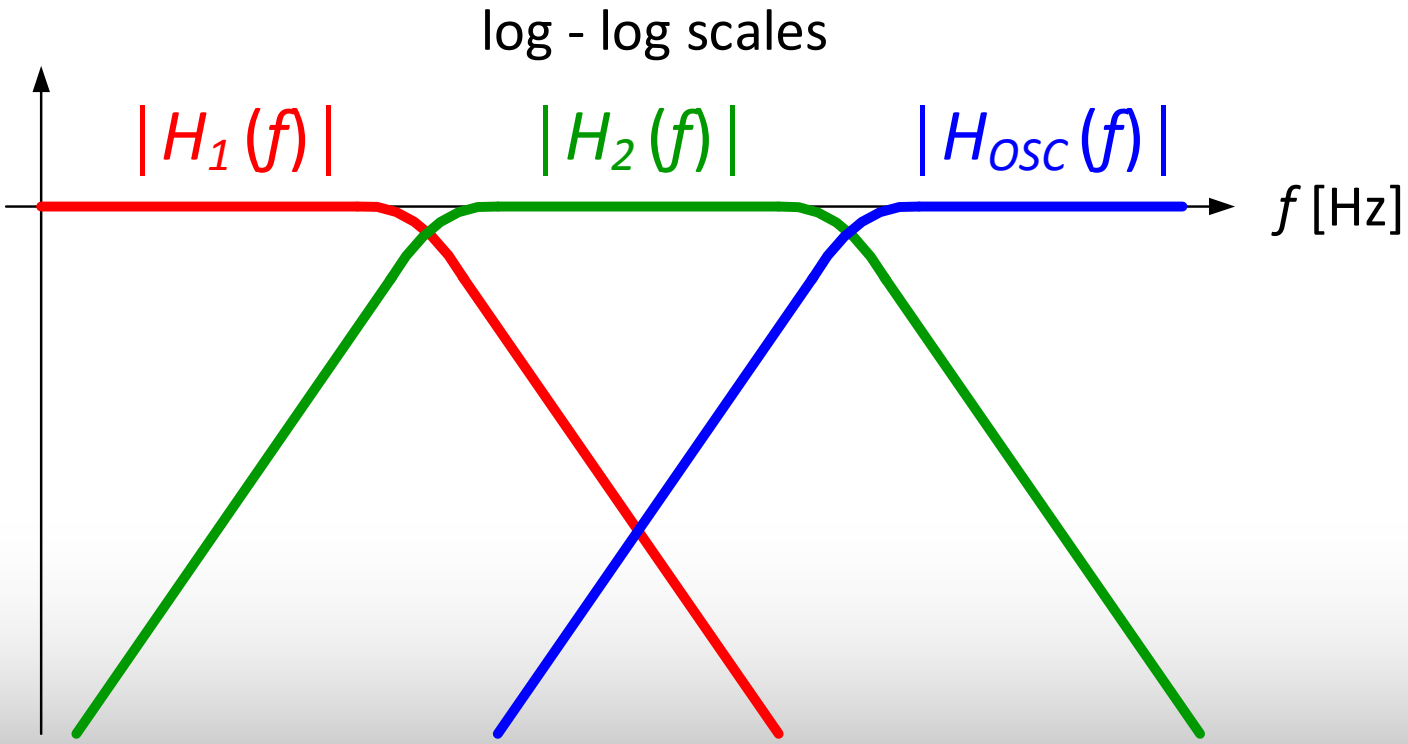
	Pros	Cons
PLL with VCO	•Very low phase noise	•PLL's pull-in range depends on VCO's pulling range •Requires VCO
PLL with DDS	•Configurable pull-in range •Requires only free-running oscillator	•Some quantization phase noise

Imagine the following:



OSCILLOQUARTZ
An ADVA Optical Networking Company

What do the transfer functions look like?



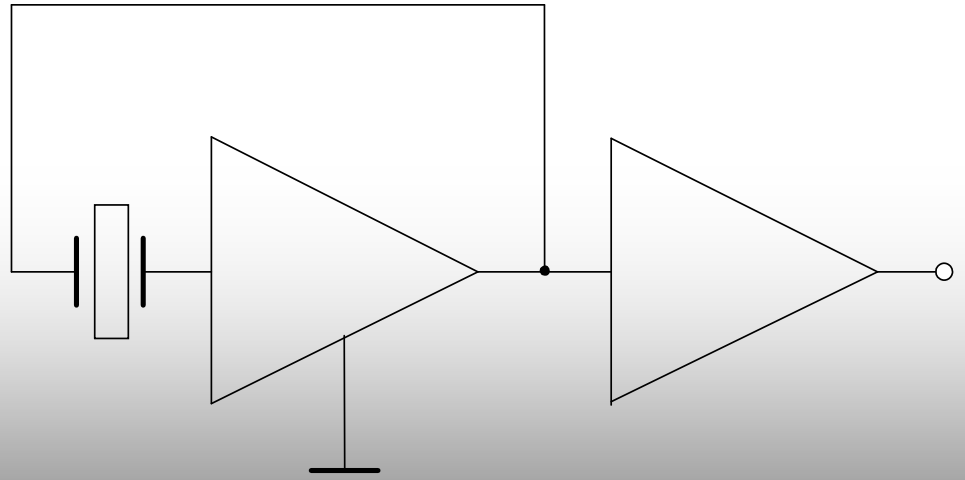
2. Quartz Crystal Oscillator (XO) Technology

OSCILLOQUARTZ
An ADVA Optical Networking Company

XO Categories rel. Temp. Control

XO, Crystal Oscillator:

- LTP centered in the operation temperature range
- > 1E-7 / °C

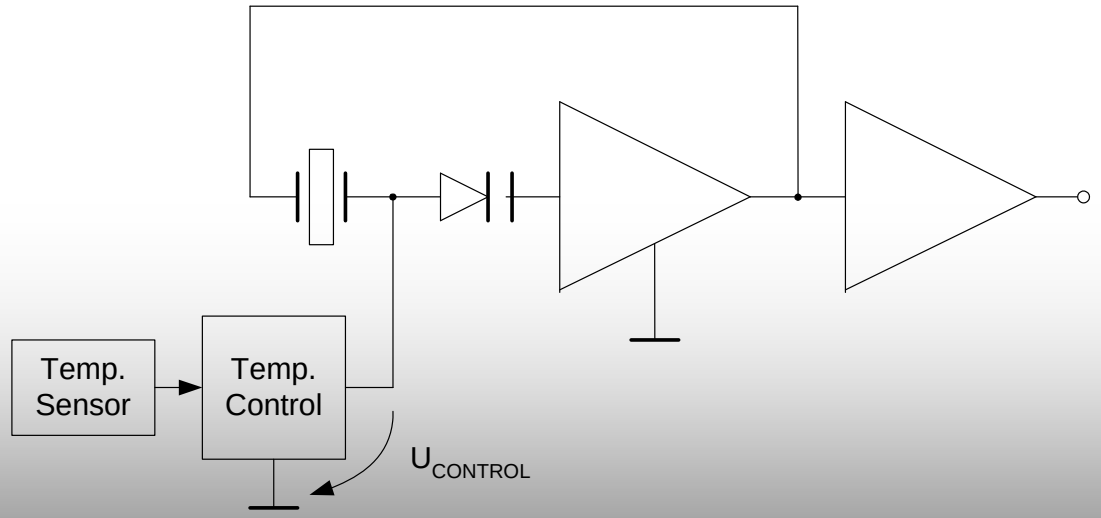


OSCILLOQUARTZ
An ADVA Optical Networking Company

XO Categories rel. Temp. Control

TCXO, Temperature Compensated XO:

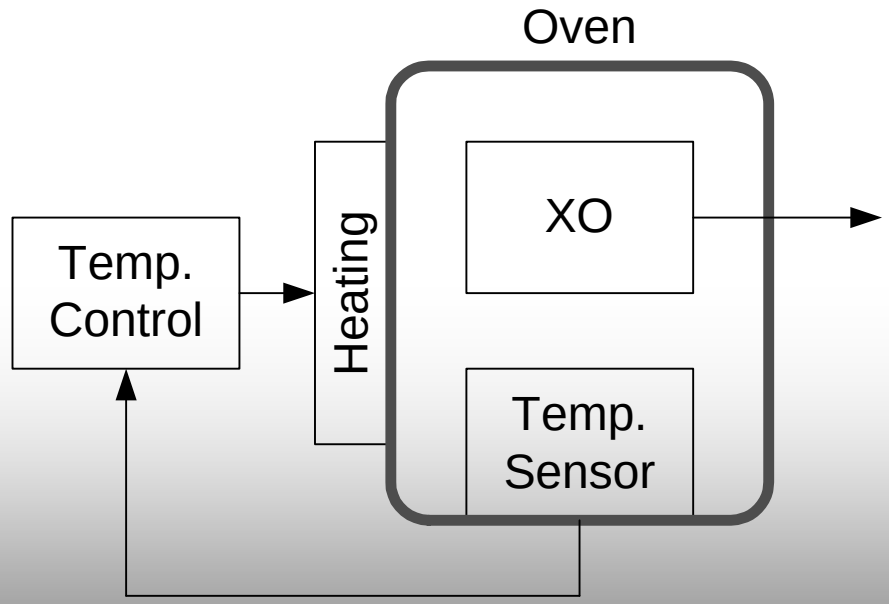
- Resonance frequency is modified by a varactor diode so as to compensate temperature sensitivity
- 5E-8 to 5E-7 over [-55°C to 85°C]



XO Categories rel. Temp. Control

OCXO, Oven Controlled XO:

- A control loop maintains the oven containing the XO at (nearly) constant temperature.
- 5E-9 to 5E-8 over [-30°C to 60°C]

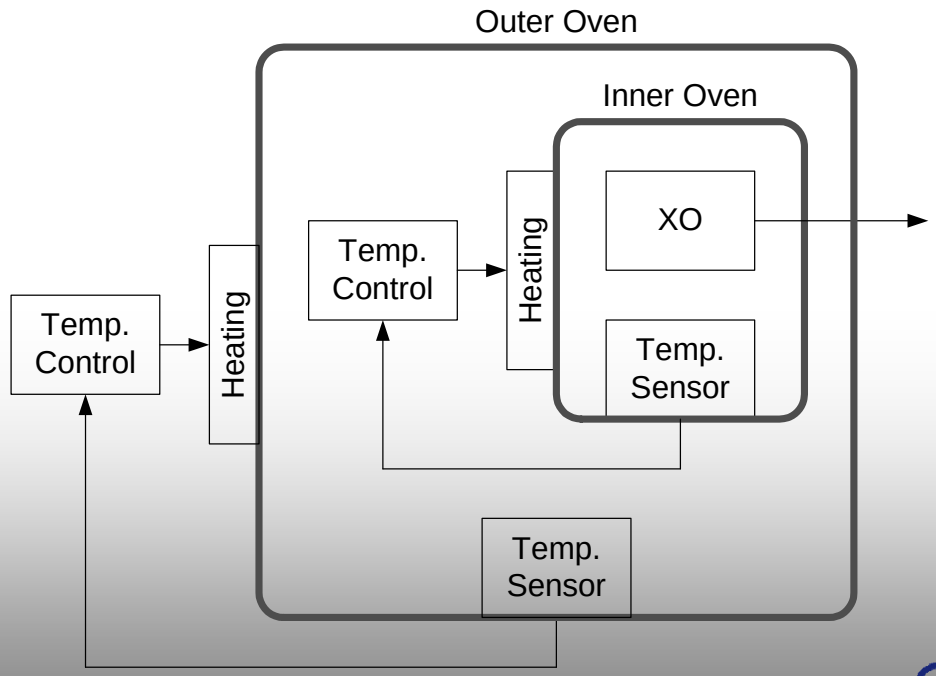


OSCILLOQUARTZ
An ADVA Optical Networking Company

XO Categories rel. Temp. Control

DOCXO, Double Oven Controlled XO:

- Two temperature controlled ovens, one inside the other.
- 1E-10 to 5E-9 over [-30°C to 60°C]



OSCILLOQUARTZ
An ADVA Optical Networking Company

Summary

Oscillator type	Temperature sensitivity (fractional frequency vs temperature)
XO	1E-7 / °C
TCXO	5E-8 to 5E-7 [-55°C to 85°C]
SOCXO	5E-9 to 5E-8 [-30°C to 60°C]
DOCXO	1E-10 to 5E-9 [-30°C to 60°C

OSCILLOQUARTZ

An ADVA Optical Networking Company

See you all at the Pre-Workshop Reception:

5:00 PM, Silver Creek Patio

(sponsored by Oscilloquartz)

info@advaoptical.com