Oscillator Impact on PDV and Design of Packet Equipment Clocks

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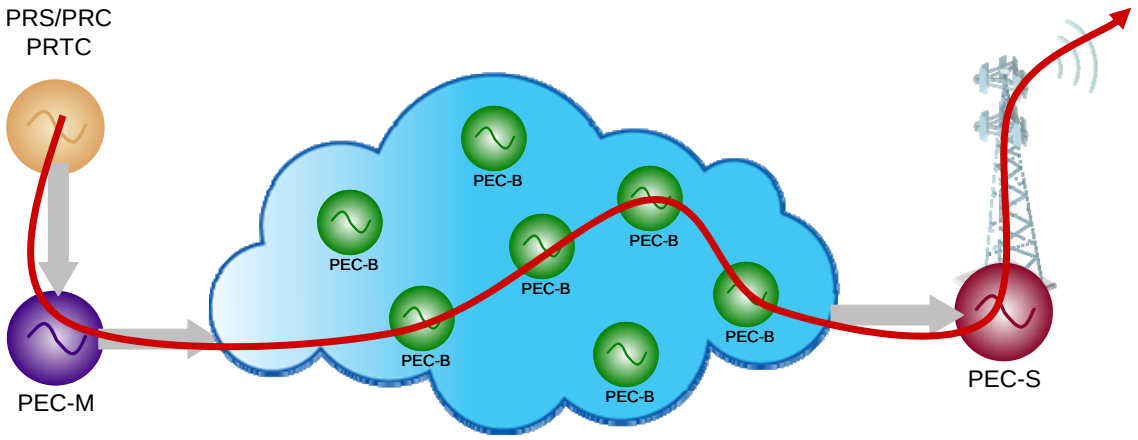
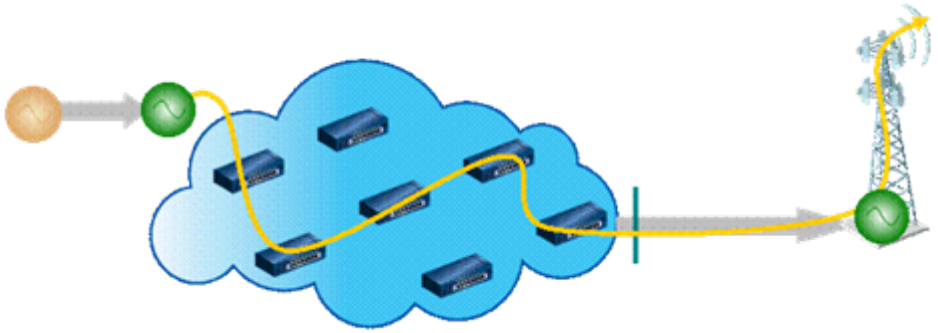
Protocol Layer Synchronization

- **When deployed and inter-connected within the packet network the packet equipment clocks will allow frequency, phase and time to be transferred over the packet network**
- **Different types of packet equipment clocks (PEC)**
  - **PEC-M the input is physical timing and the output is packet timing signal**
  - **PEC-B the input is a packet timing signal and the output is a packet timing signal**
  - **PEC-S the input is a packet timing signal and the output is a physical timing signal**

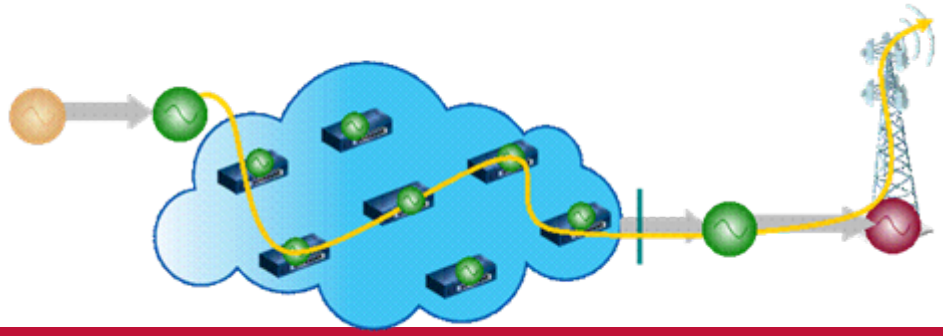


Frequency & Time Transfer over PSN

- **Two approaches**
  - **A PSN may be inserted between the server and client, that is not aware of protocol layer synchronization packets (e.g. IEEE 1588-2008)**



  - **The PSN has 'on-path support' where each switch / router is aware of protocol layer synchronization packets (e.g. IEEE 1588-2008)**



PEC Model & Generic Requirements

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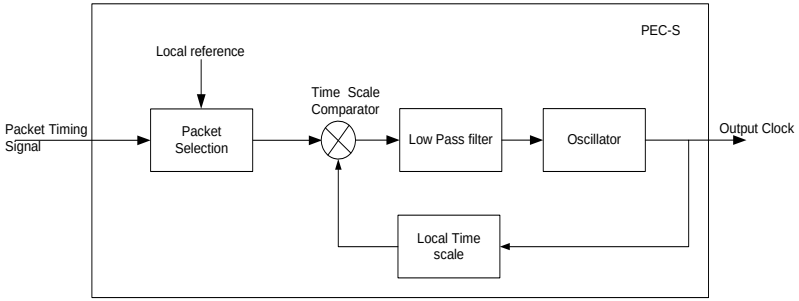
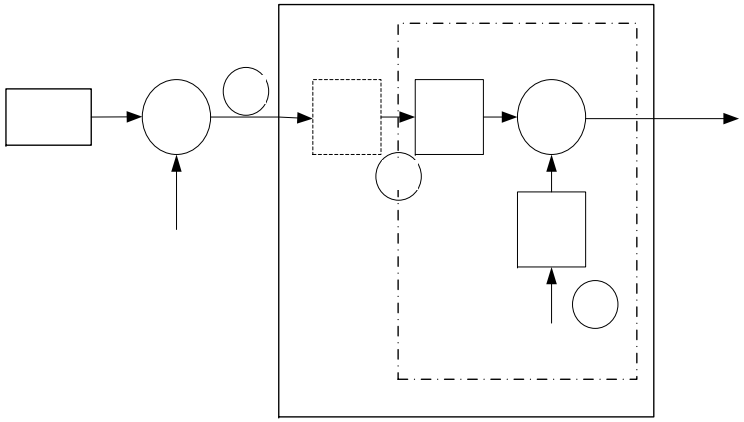
Protocol Layer EC Functional Model

- **ITU-T G.8263 (draft) Annex includes a functional model of a PEC-S packet-based clock**
- **PEC differs from traditional EC with introduction of a packet selection block has been included**

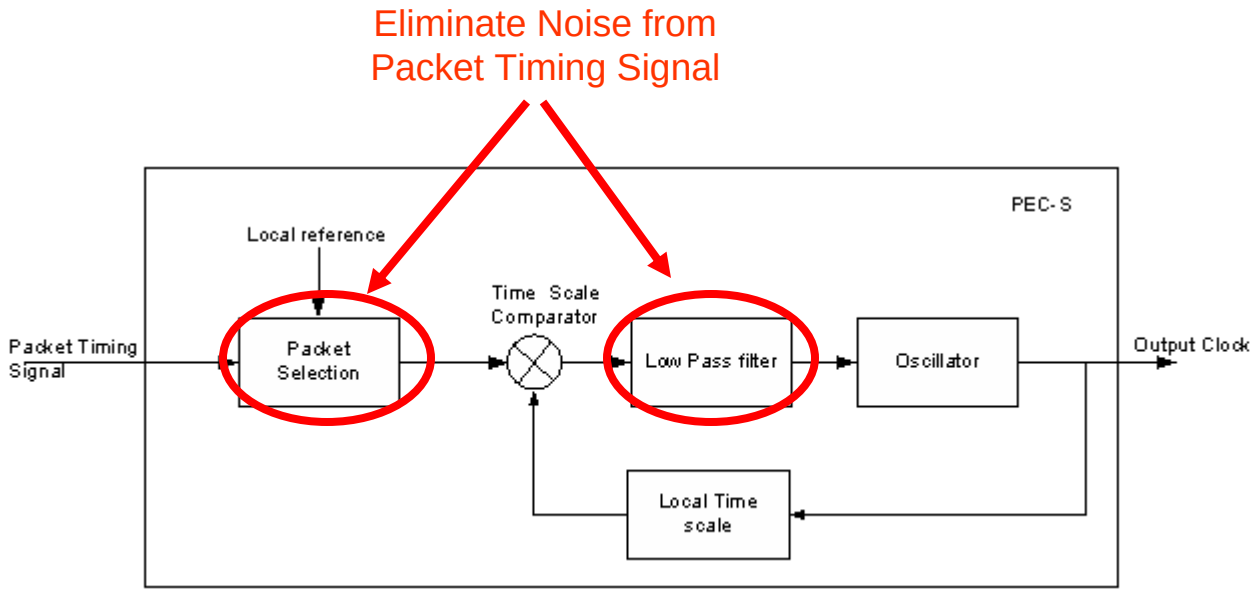


- **The PLL filters the network wander with a low pass filter**
- **This means the PLL acts as a high pass filter for the local XO**



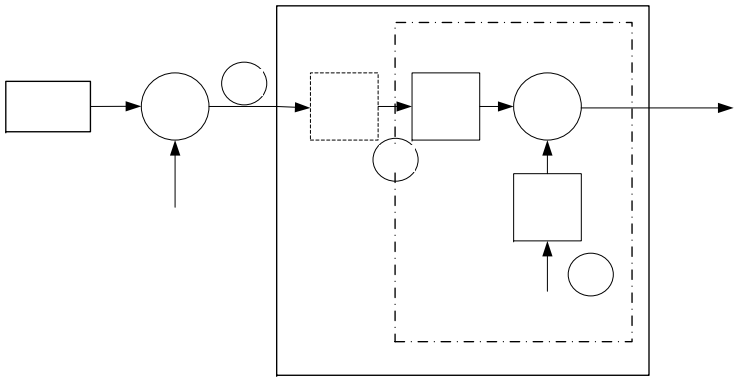
PEC-S Functional Model: Packet Selection & Low Pass Filter

- **Goal of the packet selection block is to select from all the input packets to the packet equipment clock a certain subset that are the least affected by the packet switched network**
- **These packets would thus best reflect the timing signal at the transmitter**
- **Both the packet selection block and the low pass filter function to remove noise from the packet timing signal to faithfully re-create the timing source**
- **The 'cleaned' timing signal can then be used to discipline the local oscillator**



Equipment Clock Specifications

- **Definition of EC**
  - **Jitter & Wander Generation**
  - **Jitter & Wander Transfer**
  - **Jitter & Wander Tolerance**
  - **Holdover**
  - **Transients**
  - **Freerun**



Packet EC Model

- **Oscillator dominant factor in meeting parts of the specification**
  - **Wander Generation (both MTIE & TDEV)**
  - **Holdover Stability (both constant & variable temperature)**
  - **Freerun Accuracy**

Oscillator-Dependent EC Characteristics

- **Wander Generation**
  - **The amount of wander generated by the EC when locked to an ideal reference**
  - **Oscillator noise measured in the time domain using MTIE & TDEV metrics**
- **Holdover Stability**
  - **The stability of an EC when after losing lock to its input reference**
  - **Oscillator drift due to ageing, temperature, voltage and other effects measured in the frequency domain**
- **Freerun Accuracy**
  - **The accuracy of an EC without using an input reference**
  - **Oscillator error due to all error sources in the frequency domain**

Example:
Oscillator Requirements for Stratum 3E

- **Looking at Stratum 3E EC, with a focus on the oscillator, yields the following requirements to be met by the oscillator specification**

- **Other ECs (Stratum 3, SMC, etc.) would have similar requirements**

- **Requirements**
  - **Free-run Frequency Accuracy**
    - **±4.6 ppm**
  - **Wander Generation**
    - **MTIE & TDEV masks specified in ITU-T G.812 Type III & Telcordia GR-1244-CORE Stratum 3E, using 1 mHz clock bandwidth**
  - **Holdover Stability**
    - **± 1 ppb/day at constant temperature (1.16x10^-5 ns/s^2)**
    - **10 ppb over temperature range**

Design Considerations of Packet Equipment Clock

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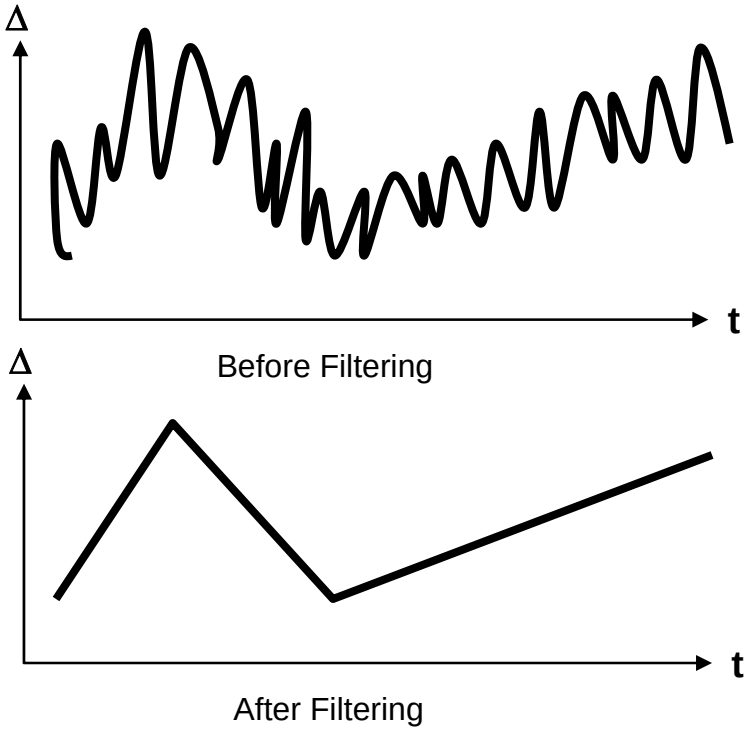
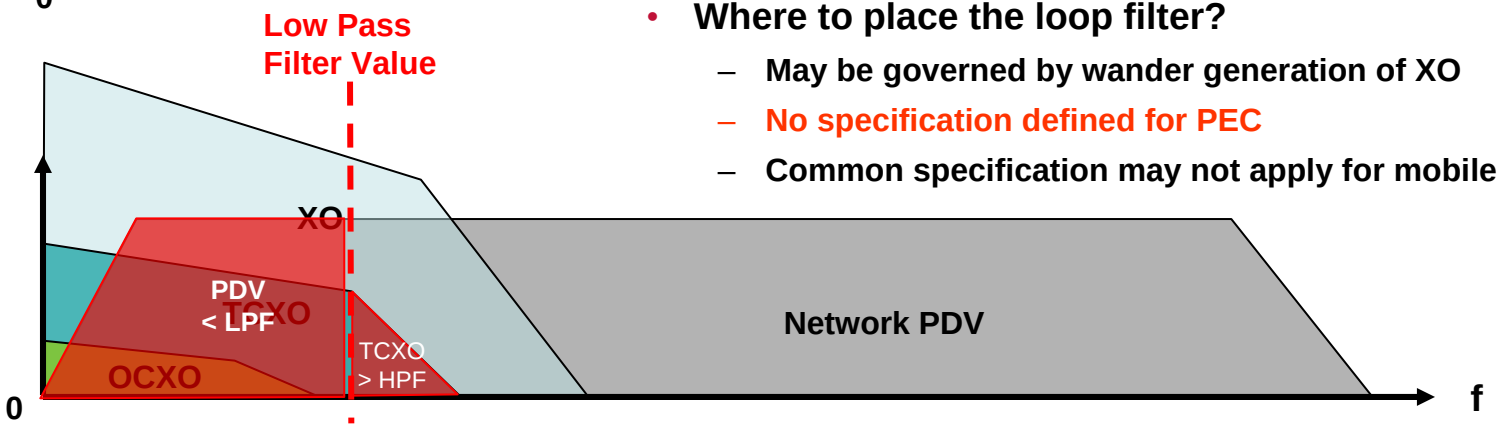
PEC Design Considerations

- **Trade-off between PDV noise (LPF) and XO noise (HPF)**
- **Effects of XO on packet selection**
- **Possible PEC characteristics & XO requirements**



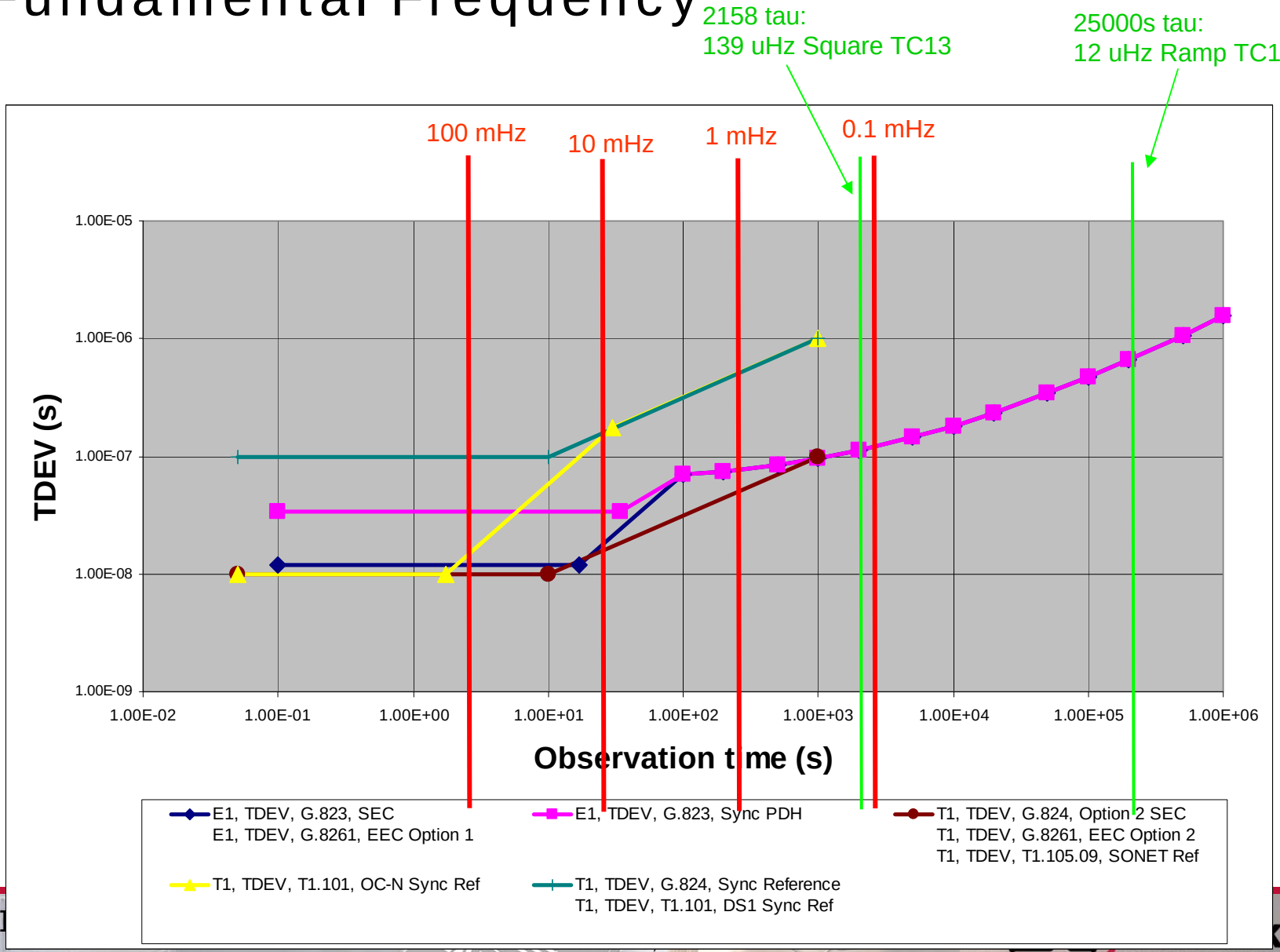
Trade-off Between PDV and XO

- **PDV and XO noise can be shown on a frequency spectrum plot**
- **Network PDV has wide frequency spectrum**
  - **Ramp test case has 12 uHz fundamental frequency**
  - **On/Off test case has 139 uHz fundamental frequency**
- **XO has increasing magnitude at low frequency**

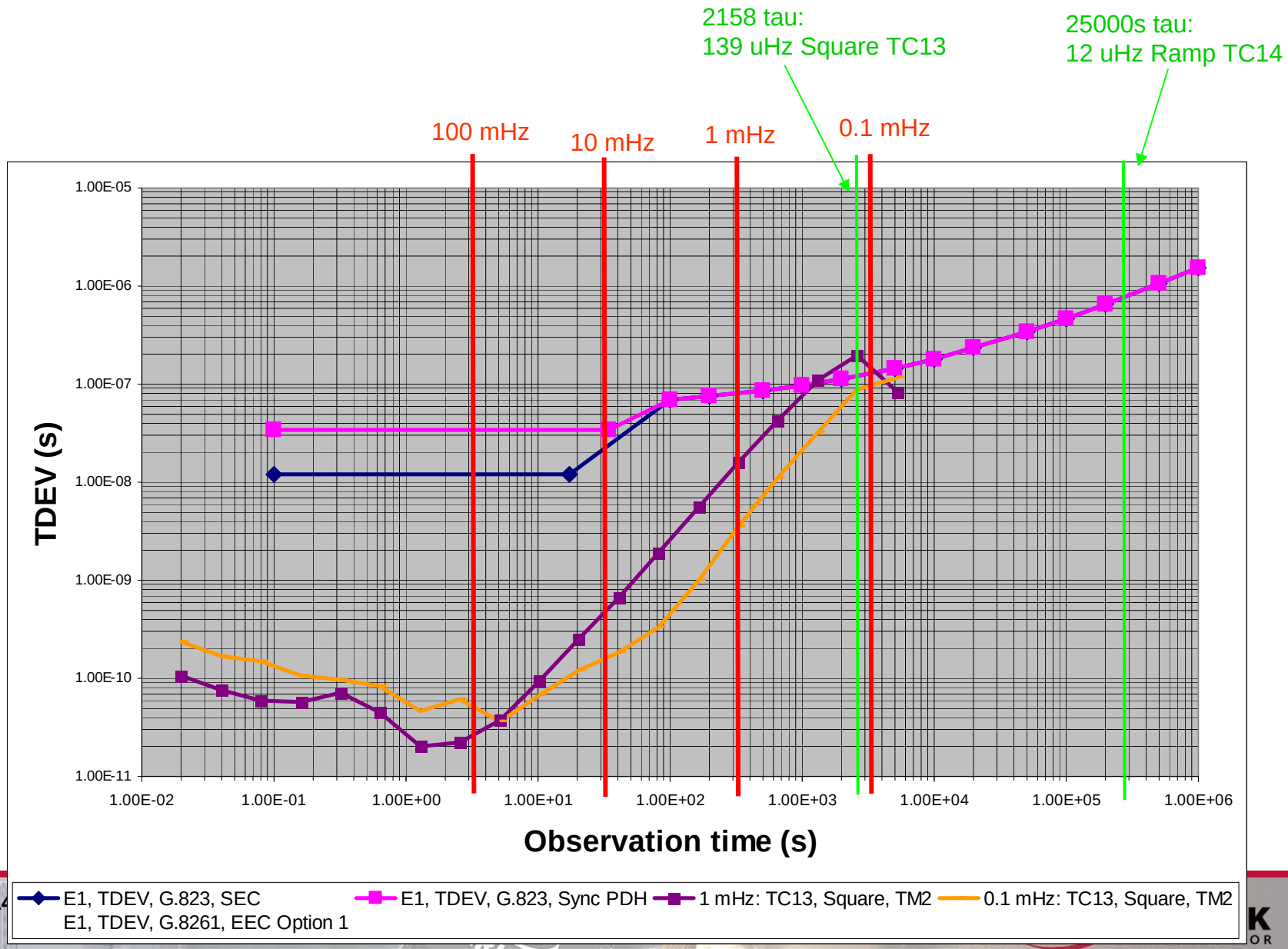


- **Where to place the loop filter?**
  - **May be governed by wander generation of XO**
  - **No specification defined for PEC**
  - **Common specification may not apply for mobile backhaul**

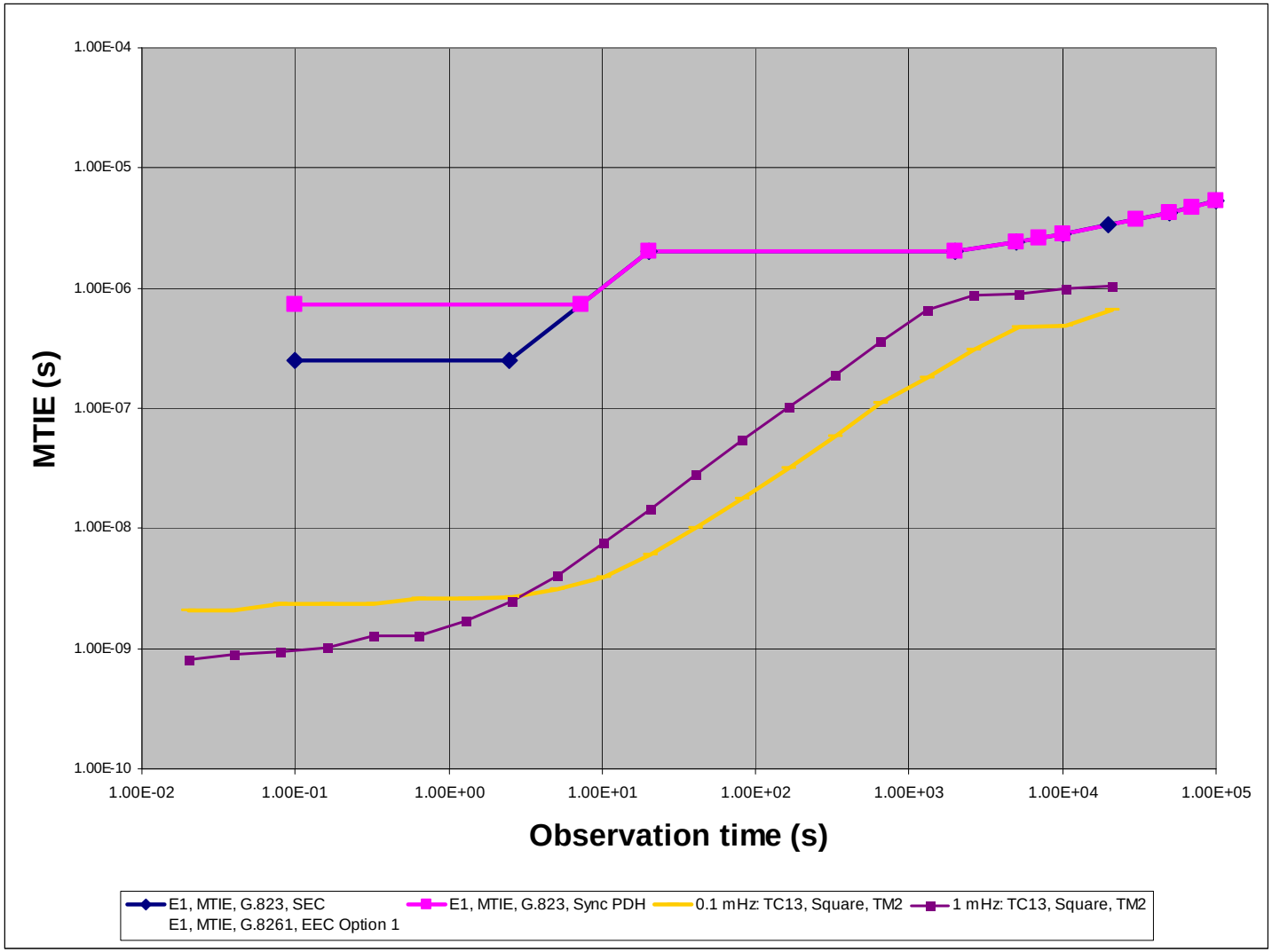
Ramp (TC13) and Square (TC14) Fundamental Frequency



Ramp (TC13) TDEV



Ramp (TC13) MTIE



Relationship between PDV, XO and Clock Bandwidth

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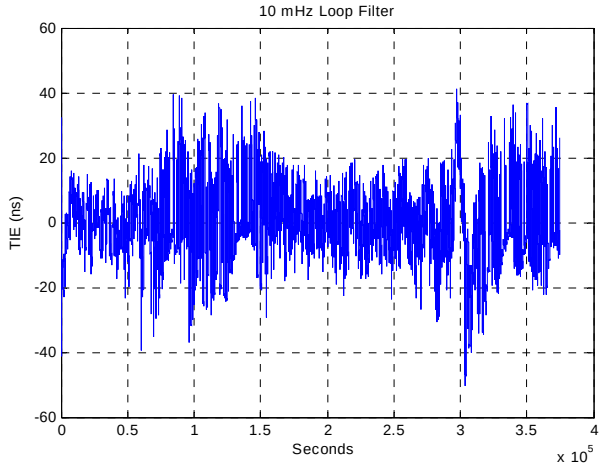
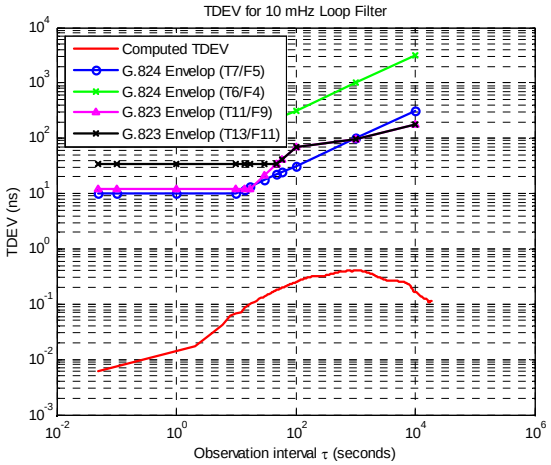
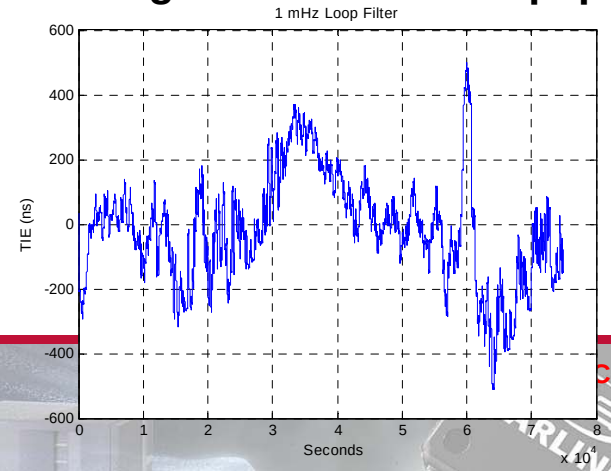
Wander Generation vs. Clock Bandwidth

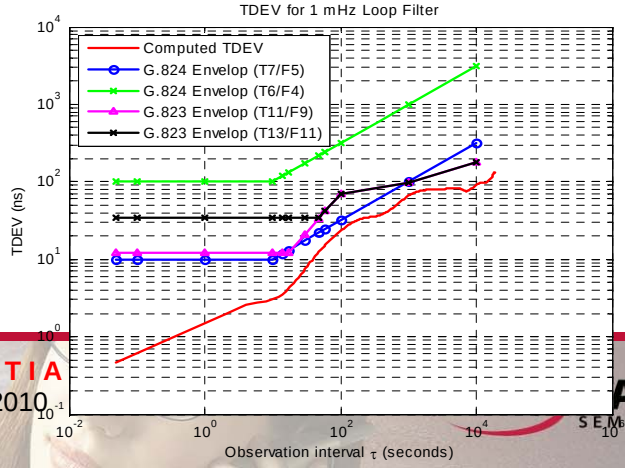
- **With a 10 mHz loop filter this oscillator has a low TIE and TDEV noise**





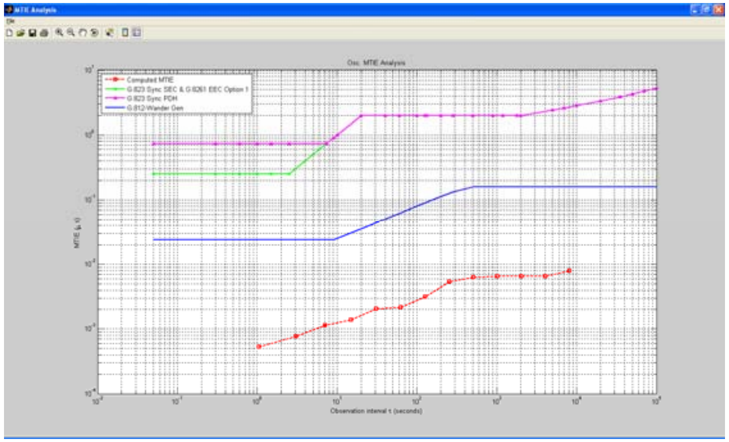
- **With a 1 mHz loop filter there is significantly MORE noise contributed by the oscillator → A lower the loop filter will filter LESS oscillator noise**
- **Cannot keep lowering the loop filter to be more robust against PDV without increasing the cost of the equipment!**

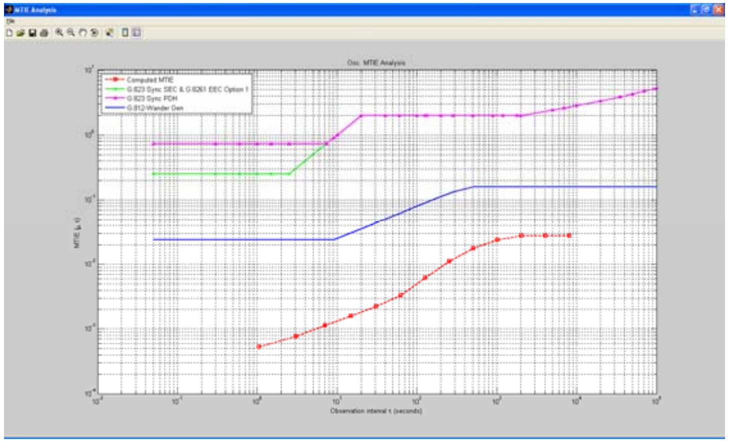


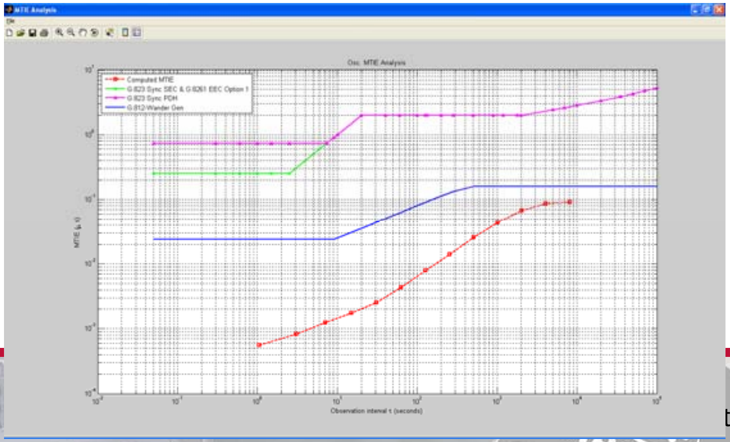


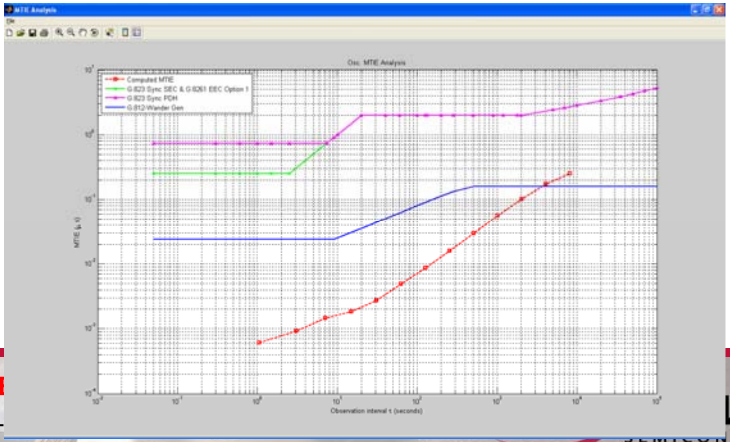
Wander Generation vs. Clock Bandwidth

- **Wander Generation MTIE**
  - **3 mHz, 1 mHz, 0.3 mHz & 0.1 mHz clock bandwidths**
  - **1 mHz → 0.1 mHz results in 10x more wander @ 8000 s**



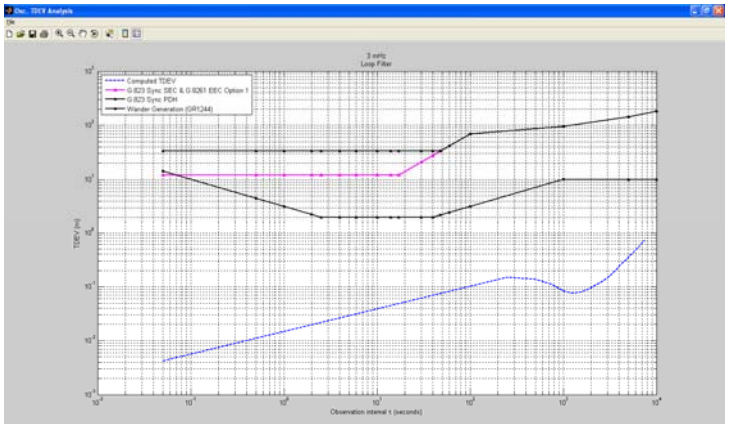


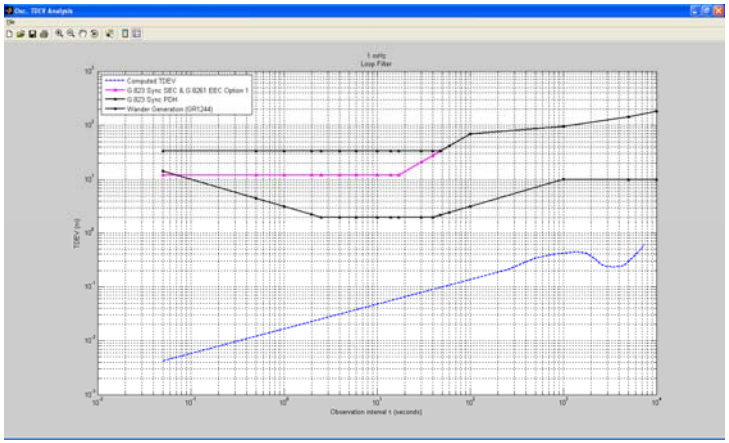


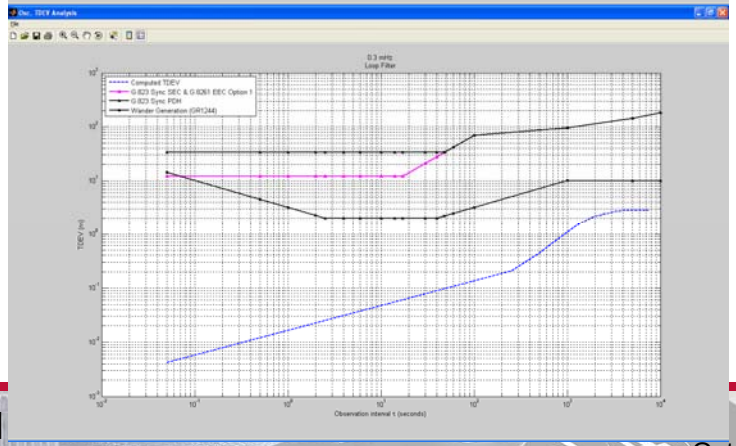


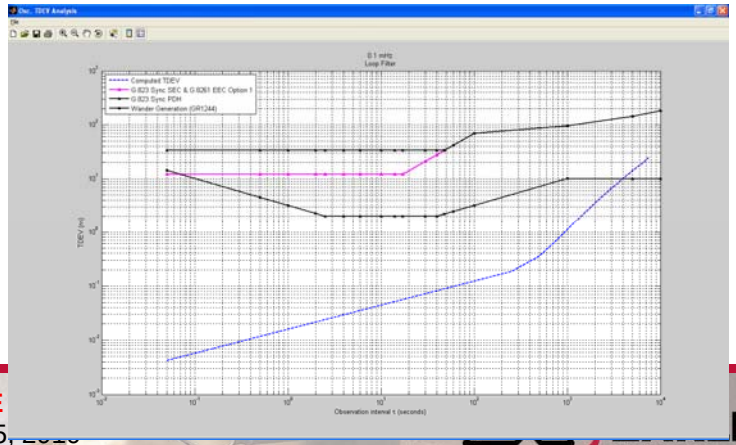
Wander Generation vs. Clock Bandwidth

- **Wander Generation TDEV**
  - **3 mHz, 1 mHz, 0.3 mHz & 0.1 mHz clock bandwidths**
  - **1 mHz → 0.1 mHz results in >4x more wander @ 1000 s**









Oscillator Selection Impact on Packet Selection

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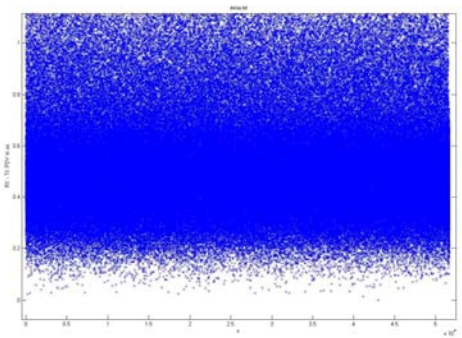
Packet Selection vs. Oscillator

- **'Cleaned' packet timing signal used to discipline local oscillator**
- **Will the oscillator movement impact on the packet selection to reduce estimated performance**
  - **If there was originally a stable floor delay, how does it appear to move based on a non-ideal local oscillator?**
  - **What is inter-packet gap between selected packets and how should this be adjusted to match the non-ideal local oscillator?**



Packet Delay
(Zoom)

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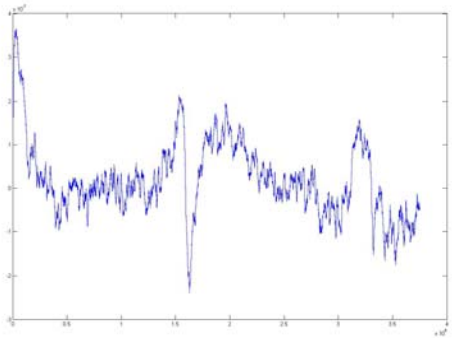

Oscillator

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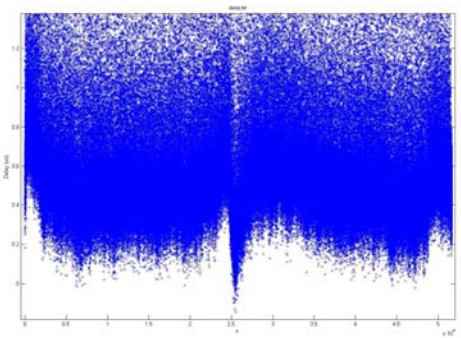
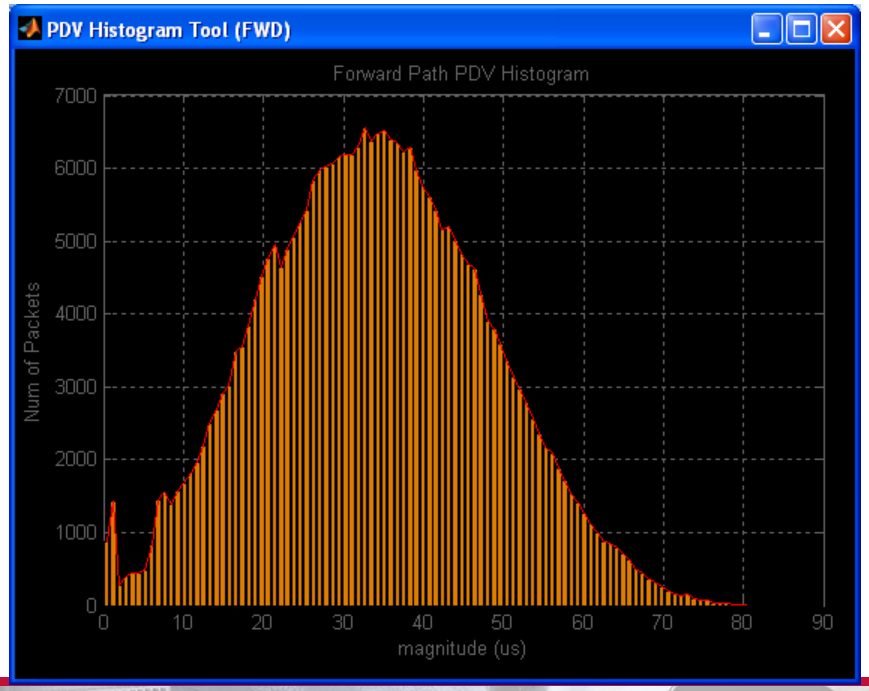


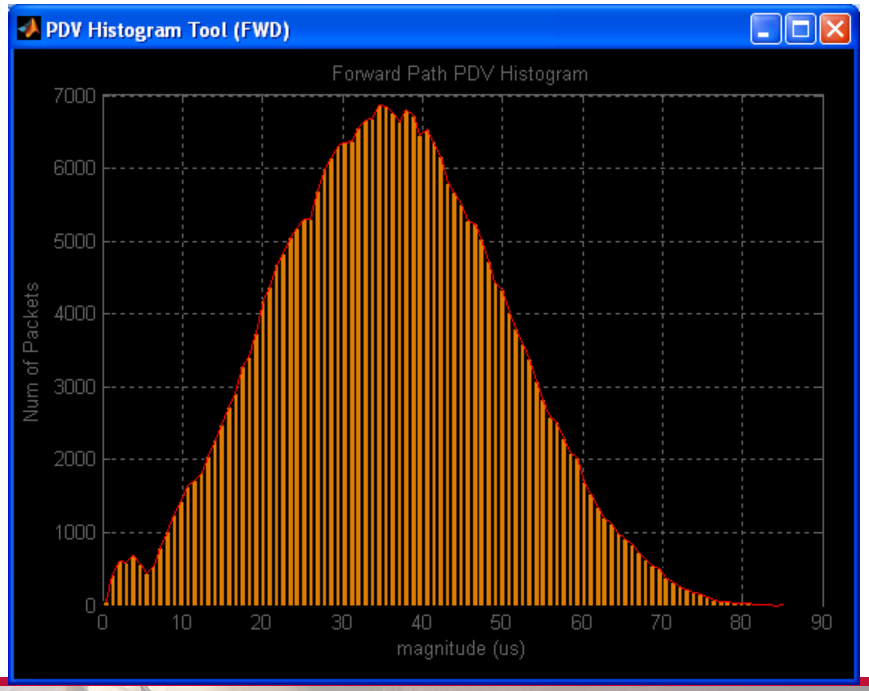
Observed Packet Delay
(Zoom)

Packet Selection vs. Oscillator: Histogram

- **Two Oscillators**
- **Same Clock Bandwidth, Packet Selection, PDV**

- **Observation: FWPR is reduced**

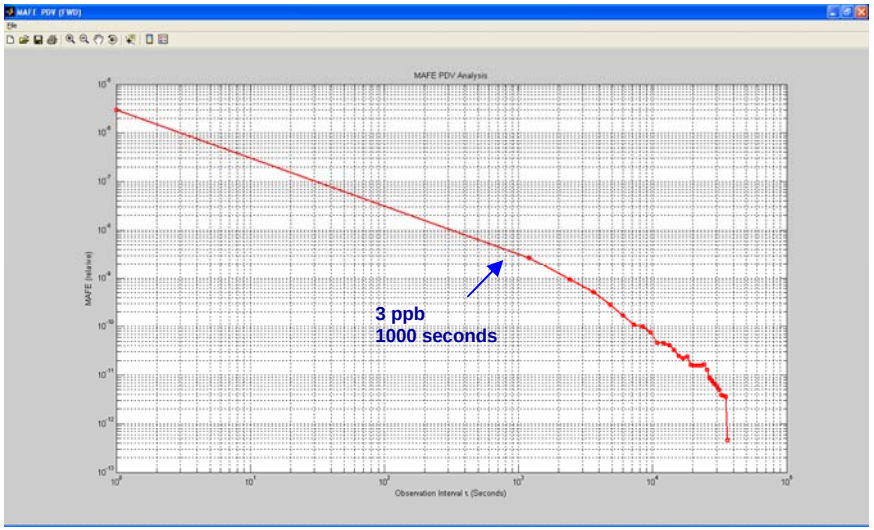


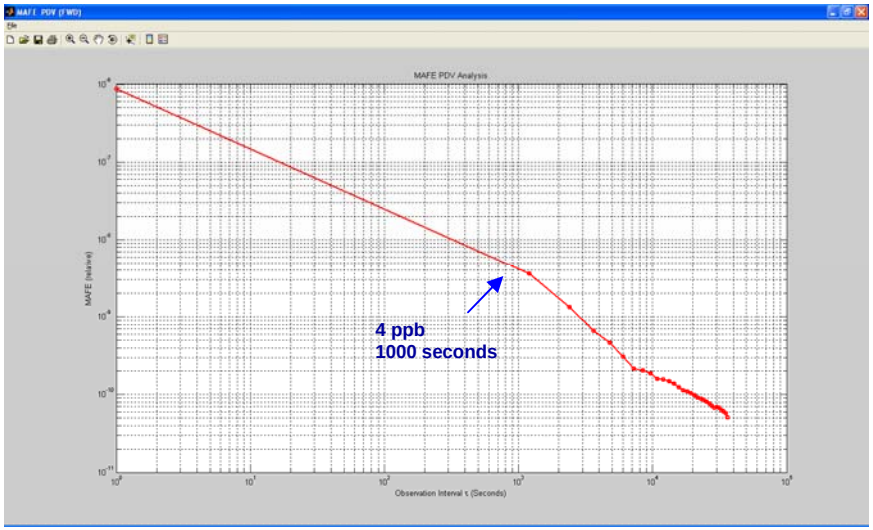


Packet Selection vs. Oscillator: MAFE

- **Two Oscillators**
- **Same Clock Bandwidth, Packet Selection, PDV**

- **Observation: Frequency accuracy not greatly impacted for typical mobile backhaul application**

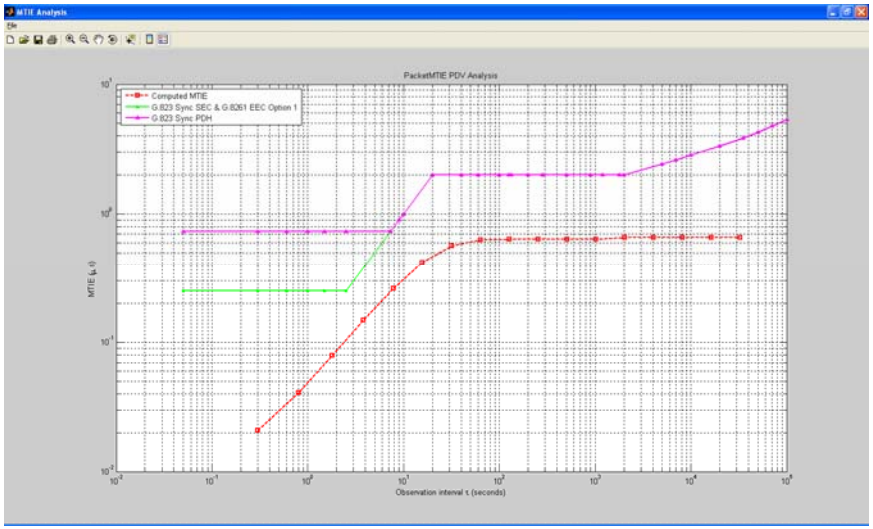


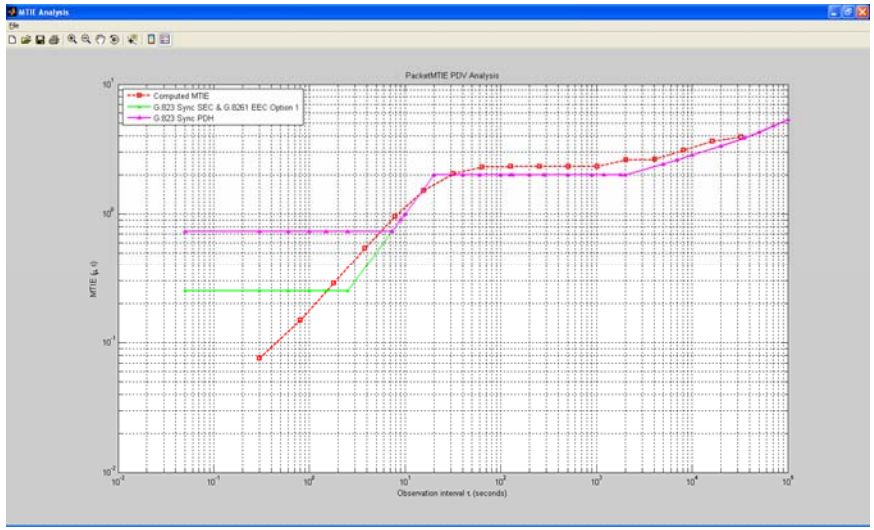


Packet Selection vs. Oscillator: Packet Timing Signal MTIE

- **Two Oscillators**
- **Same Clock Bandwidth, Packet Selection, PDV**

- **Observation: MTIE substantially impacted relative to synchronization performance requirements**





Packet Selection vs. Oscillator & Clock Bandwidth

- **Summary**
  - **XO directly impacts wander generation conformance, a parameter defined in the time domain**
    - **Absence of time domain characterization in XO makes component selection difficult**
  - **Time domain is significantly impacted by oscillator selection vs. packet selection & clock bandwidth**
    - **Lack of standard for PEC results in freedom to optimize clock bandwidth based on custom design choices**
  - **Frequency domain performance is less impacted by oscillator selection vs. packet selection & clock bandwidth**
    - **Specifically the mobile backhaul application (< 50 ppb accuracy)**
    - **Target application is very forgiving of XO selection**
  - **Lowest hanging fruit**
    - **PEC for applications requiring only frequency accuracy, such as mobile basestation, are easier to design based on traditional XO characterization information**

Thank-you for Your Time & Attention

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