VOICE & TIMING SOLUTIONS
For a New Global Network

A Closer Look at PDV and Oscillator for Packet Equipment Clocks

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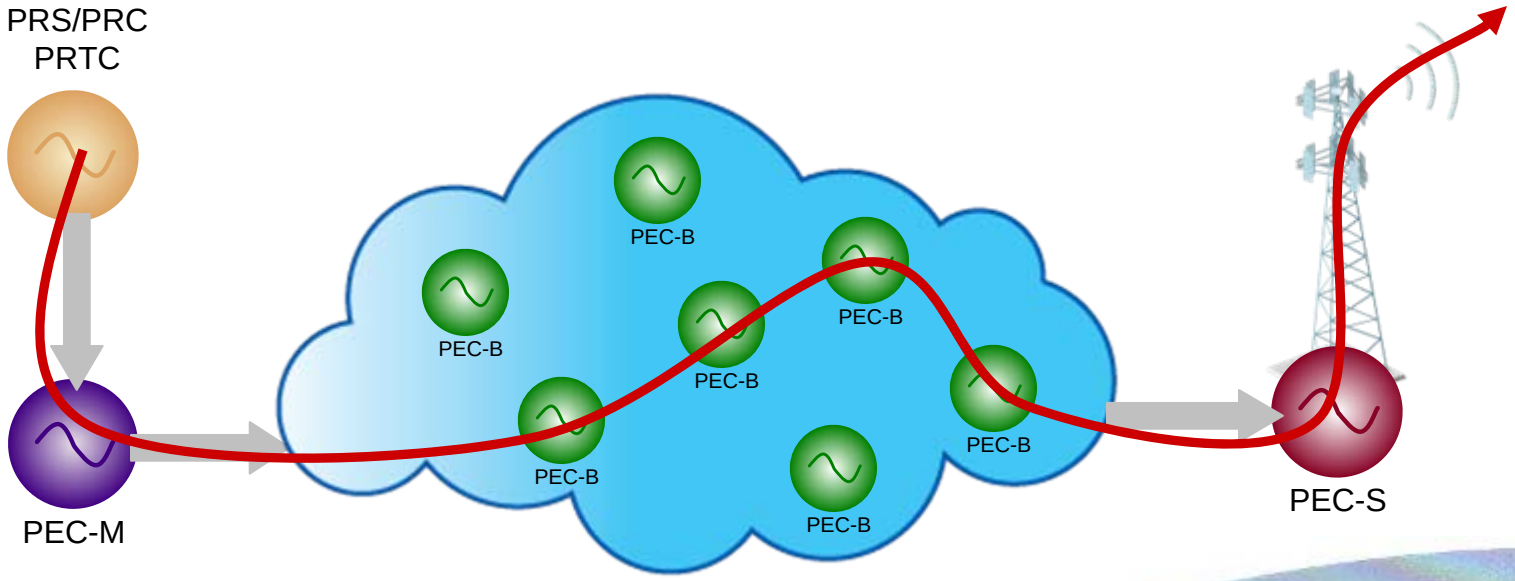
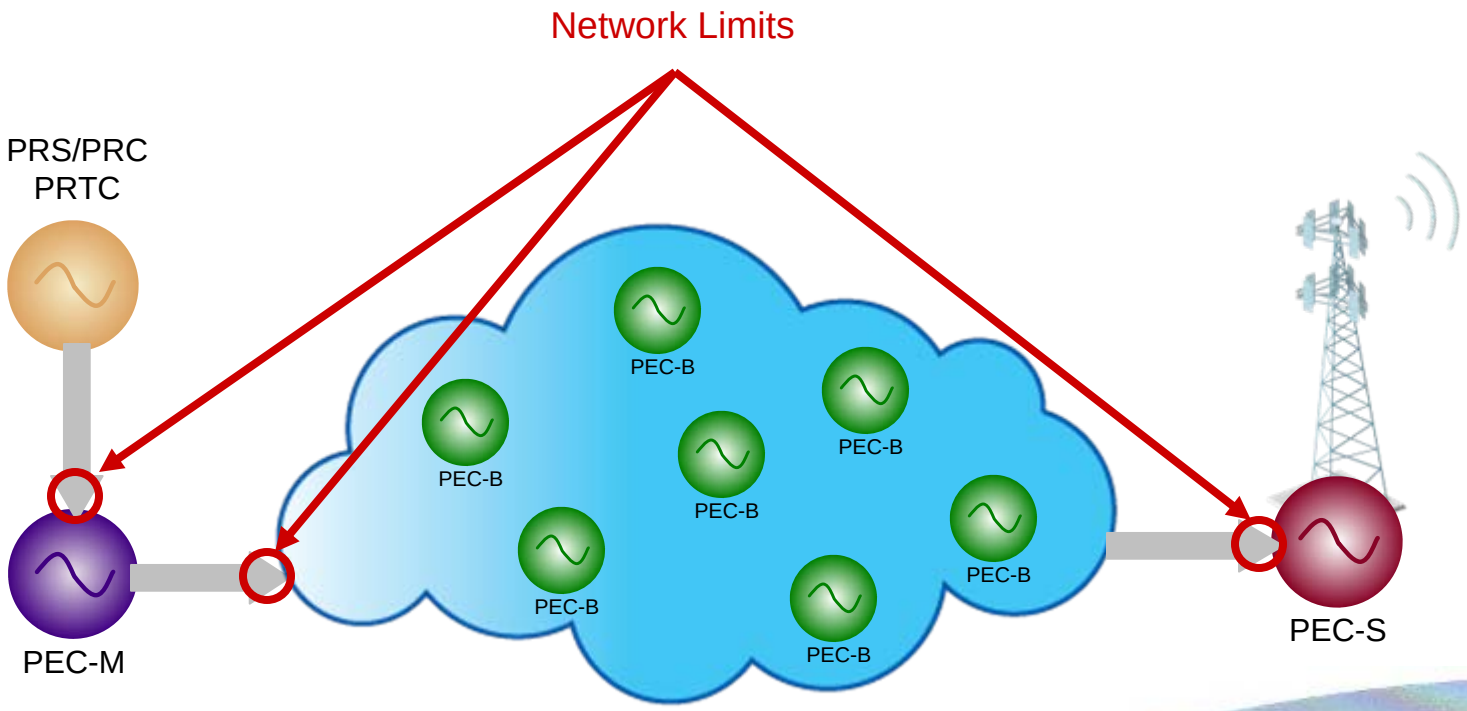
Frequency, Phase & Time Synchronization over Packet Networks

- **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**



Network Limits

- **Network limits specify the maximum noise present on the timing signal at different points in the network**



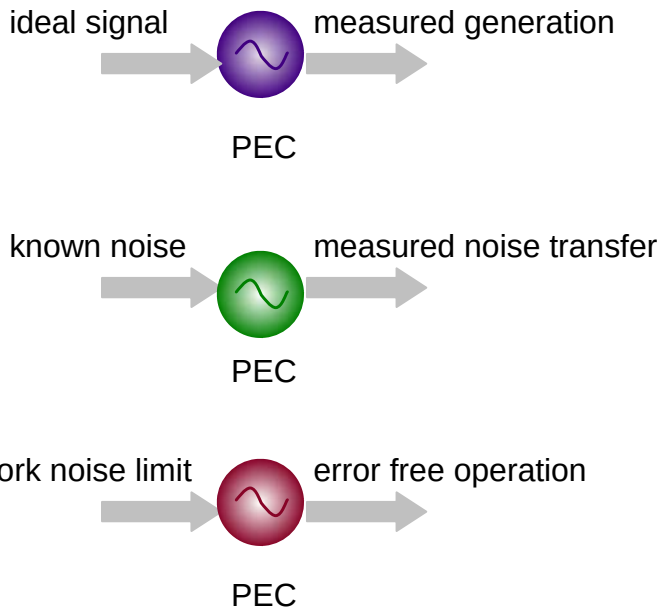
Equipment Clock Characteristics

- **Equipment clock specifications define requirements for clock engines**

- **Jitter & Wander (Noise) Generation**
  - **Output from PEC when synchronized to noise-free input**

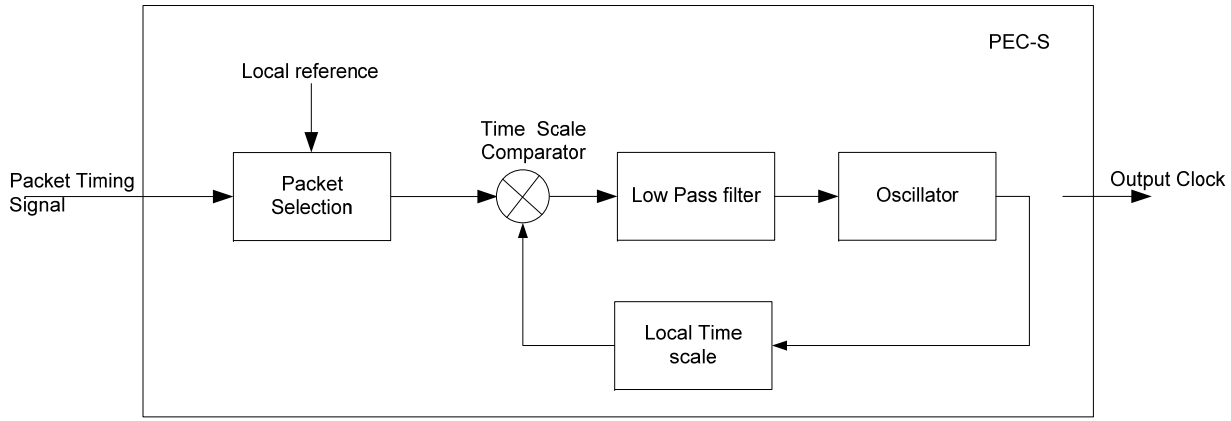
- **Jitter & Wander Transfer**
  - **Output from PEC given a known input**

- **Jitter & Wander Tolerance**
  - **Error free operation of the equipment with a known input of maximum noise output**



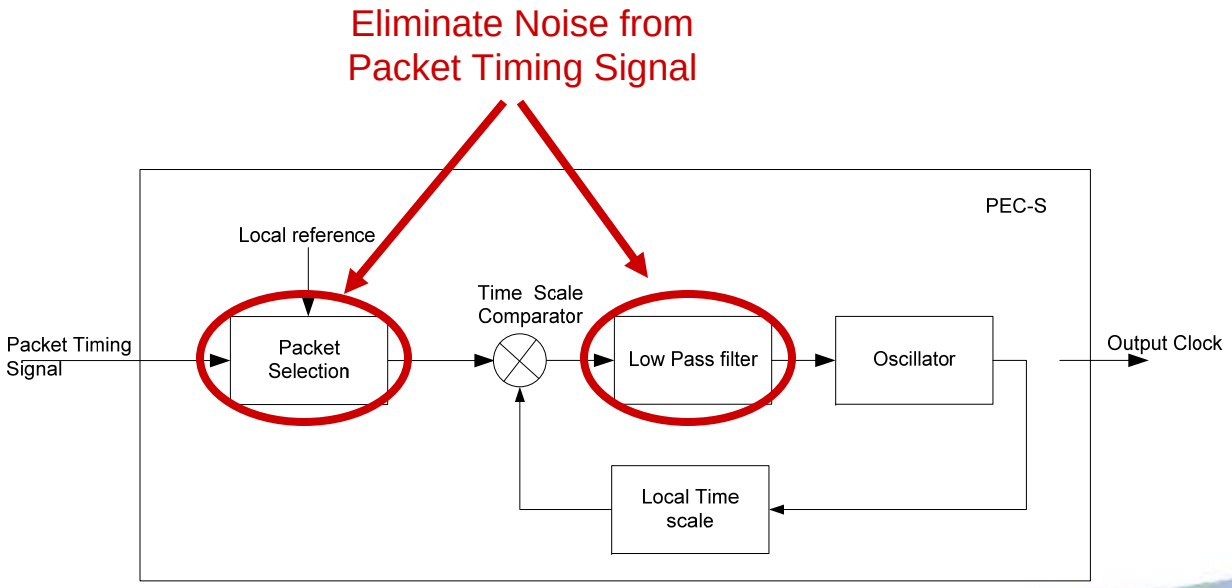
PEC-S Functional Model

- **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**



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**

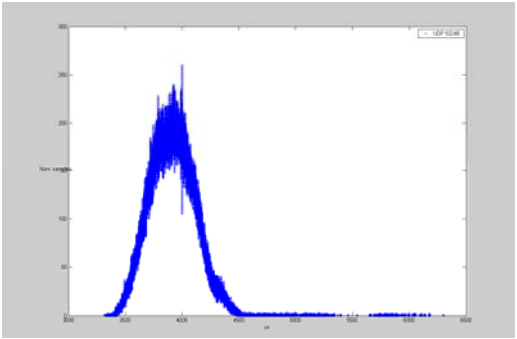


Network Limits & Characteristics – Metrics

- **Performance of PEC-S depends heavily on PDV, or the noise on the packet timing signal**

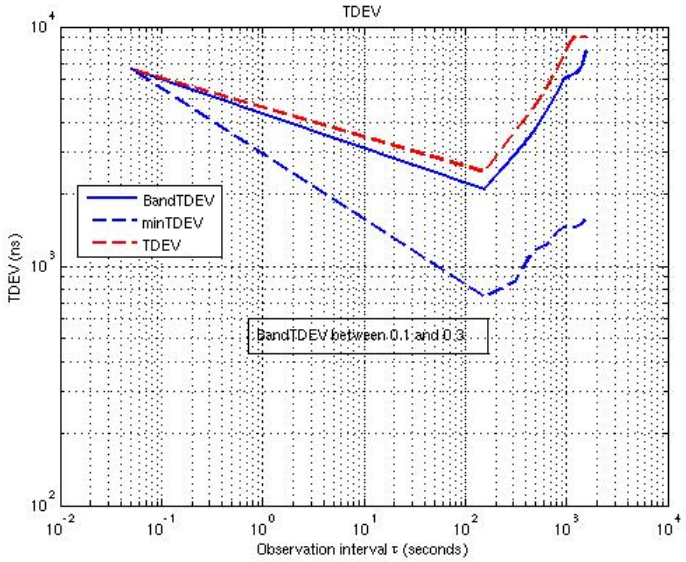
- **How to define the network limits & characteristics for PDV**
  - **New metrics**
    - **Under study at ITU-T Study Group 15 Question 13**
  - **Existing metrics**
    - **Definitions exist for delay variation, loss, availability, etc.**
    - **Driven by non-synchronization applications (voice, video, data, wireless)**
    - **3GPP: 'all' selection (e.g. 99% of packets less than 10 ms delay)**
    - **MEF 10.2: "Ethernet Services Attributes Phase 2" FD, IFDV, FLR**
    - **ITU Y.1540: "IP packet transfer and availability performance parameters"**
    - **IETF RFC3393: "IP Packet Delay Variation Metric for IP Performance Metrics (IPPM)" IPDV**

Classic PDV Histogram



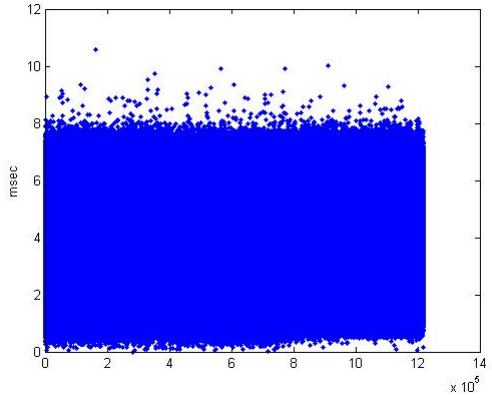
PEC-S Functional Model: Packet Selection vs. 'All' Selection

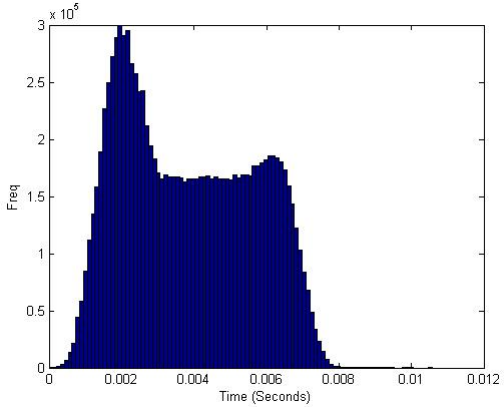
- **Several proposals to select packets experiencing the least delay, known as the floor delay**
- **These packets deemed to be least affected by PDV and therefore would best filter the noise from the PSN**
- **Seems reasonable …..**
  - **Example where even an odd band of packets (10%-30%), a subset of the total range, can improve the result**

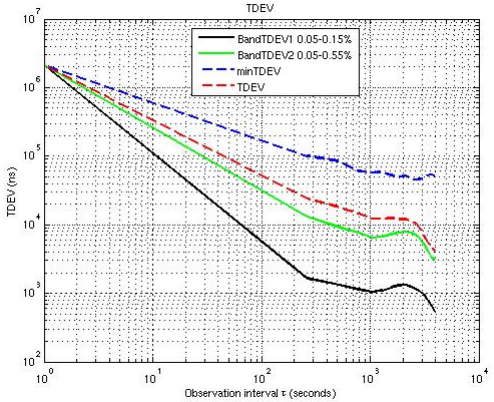


PEC-S Functional Model: Packet Selection vs. 'All' Selection

- **… Except when then 'floor delay' is unstable or such 'lucky' packets are few and far between**
- **The larger the time between 'lucky' packets the lower the sample rate and the less ability to see local oscillator movement**
- **The use of more packets would allow to better filter the noise caused by the PSN and better track local oscillator movements**
- **Example of network comparing 'all' packets with 'floor delay' packets**

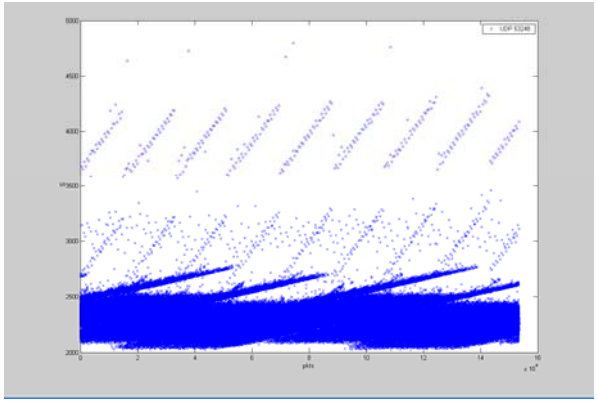


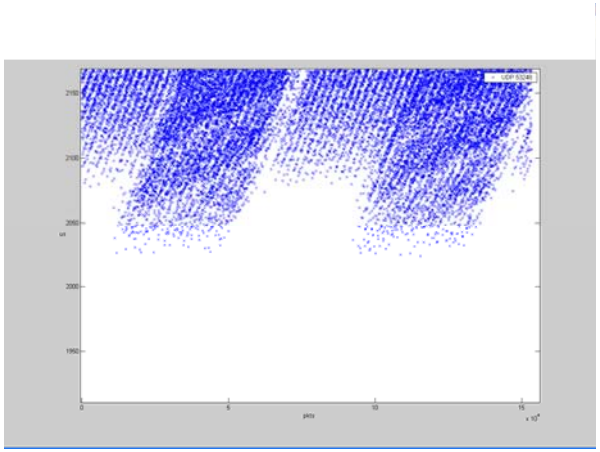




Some Networks Resist Packet Selection

- **xDSL networks, even if unloaded, have characteristics that resist the concept of floor packet selection**
- **xDSL native asymmetry in upstream and downstream direction**

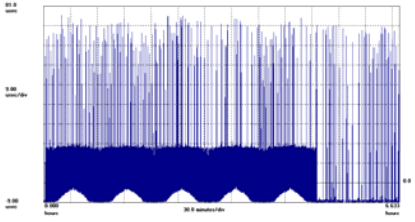




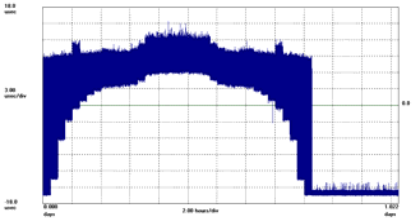
- **Access technologies such as GPON and EPON have their own mechanisms to transfer frequency & phase that may be used**
  - **PEC-S in the OLT and a PEC-M in the ONT**
- **Early interest in xDSL to also natively transfer frequency & phase between DSLAM and modem (e.g. NTR)**

PDV Topics to Investigate

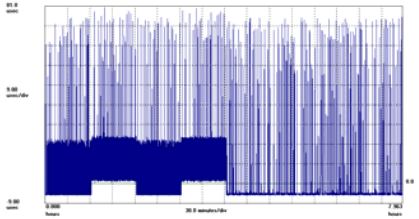
- **Handling of transient detection & suppression, to address dynamic packet network bursts, re-routes and outage phenomena**
- **Dealing with a variety of PSN PDVs that have different characteristics from slow movements to fast movements**
- **Tackling a variety of physical layer transport technologies such as xDSL**



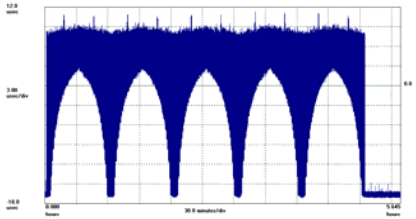
Ramp



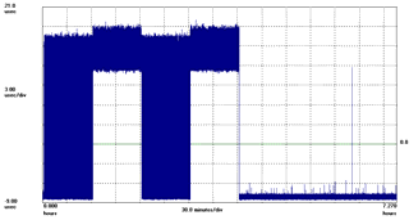
Ramp



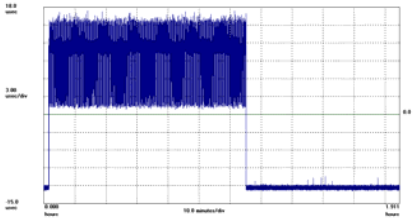
Square On/Off



Fast Ramp



Square On/Off



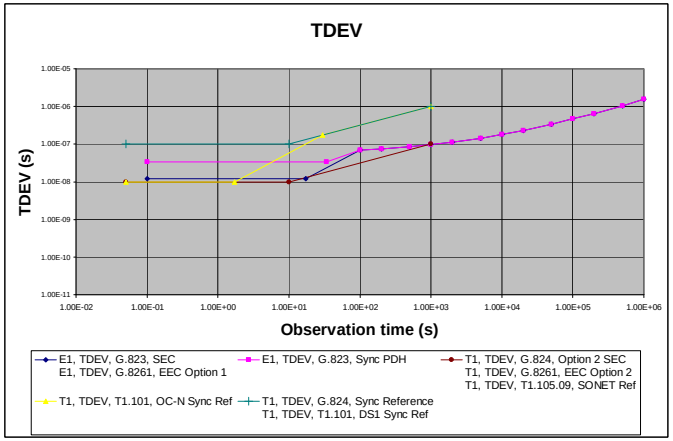
Congestion

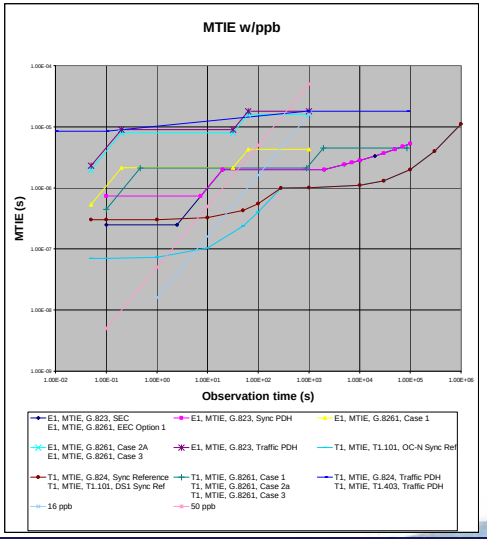
The Local Oscillator

- **Oscillator datasheets generally specify performance in a few categories**
  - **Frequency: clock output (e.g. 20 MHz or 25 MHz)**
  - **Initial offset: absolute frequency offset at manufacture**
  - **Ageing: relative frequency change over different periods of time, such as 24 hours and 10 years**
  - **Temperature: relative frequency change over a specified temperature range**
  - **Supply voltage: relative frequency change over a specified power rail voltage range**
  - **Load: relative frequency change over a specified load change**
  - **Warm-up: the time required after power-up to meet the specification values – can range from minutes to days to a month!**
  - **Overall: worse case absolute frequency over 'lifetime' due to all causes**

The Local Oscillator – Specified in the Frequency Domain for use in the Time Domain

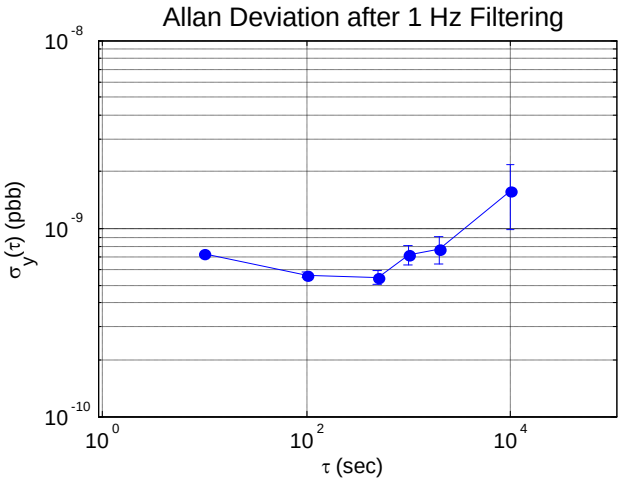
- **Generally oscillators do not specify performance parameters in the time domain … whereas most ITU-T requirements are specified in the time domain!**
- **Oscillator performance specifications cover frequency variation in the frequency domain**
  - **May see ADEV specified over 1 to 100 second tau**
- **ITU-T specification requirements generally provided in time domain**
  - **TIE, MTIE, TDEV**

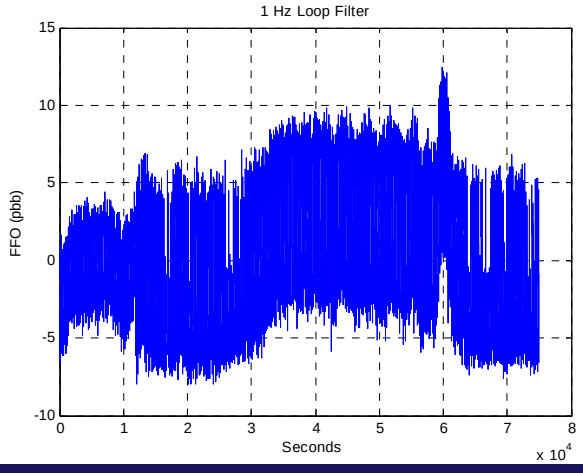


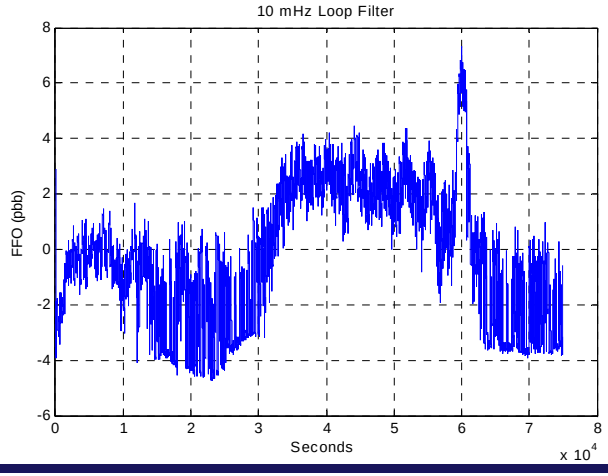


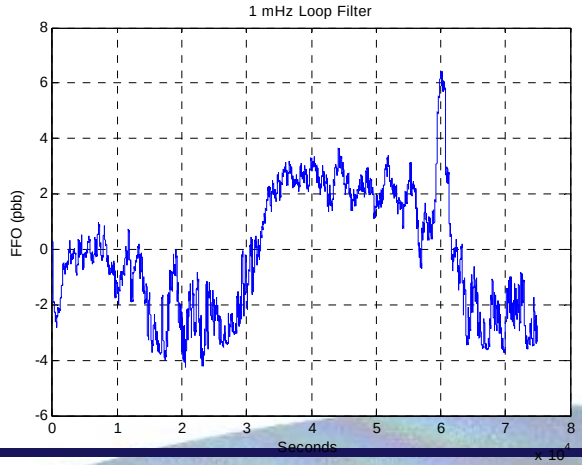
A Frequency Domain Look at a Filtered Oscillator

- **What does the oscillator look like after high frequency components have been filtered?**
- **Underlying movement is more clear once the short term variation is filtered**
- **Existing oscillator specifications may useable for a definition of a mask for frequency accuracy, such as mobile basestation**



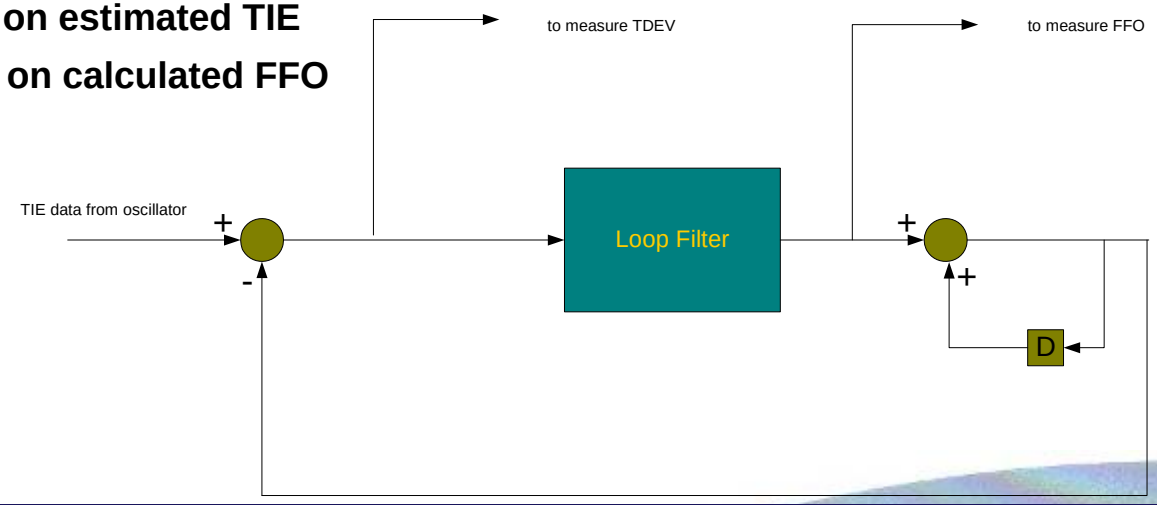






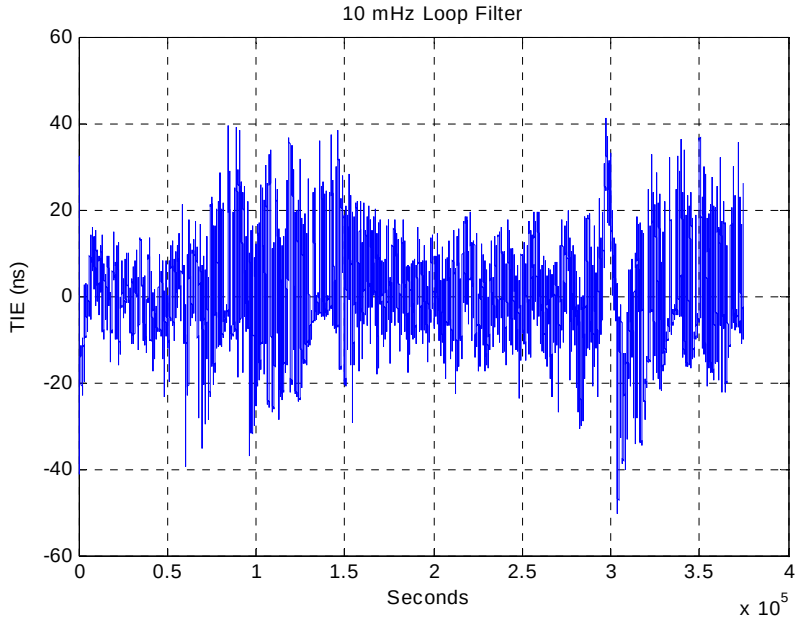
A Time Domain Look at an Oscillator

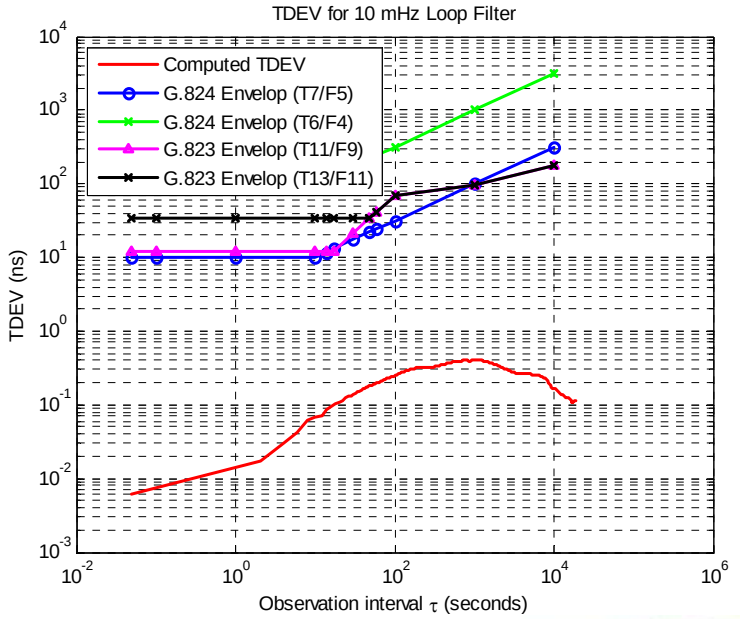
- **What does the oscillator look like in the time domain?**
  - **How to specify the oscillator for the packet selection and loop filter?**
- **Method used to view the oscillator in the time domain information presented in the next slides**
  - **Measure Oscillator TIE in lab over 24hrs**
  - **Extract FFO using a Simulink model**
    - **Filter FFO based on different loop filter settings**
  - **Subtract frequency offset for calculated FFO and estimate TIE**
    - **Estimate TIE for each loop filter Setting**
  - **Calculate TDEV based on estimated TIE**
  - **Calculate ADEV based on calculated FFO**



A Time Domain Look at an Oscillator

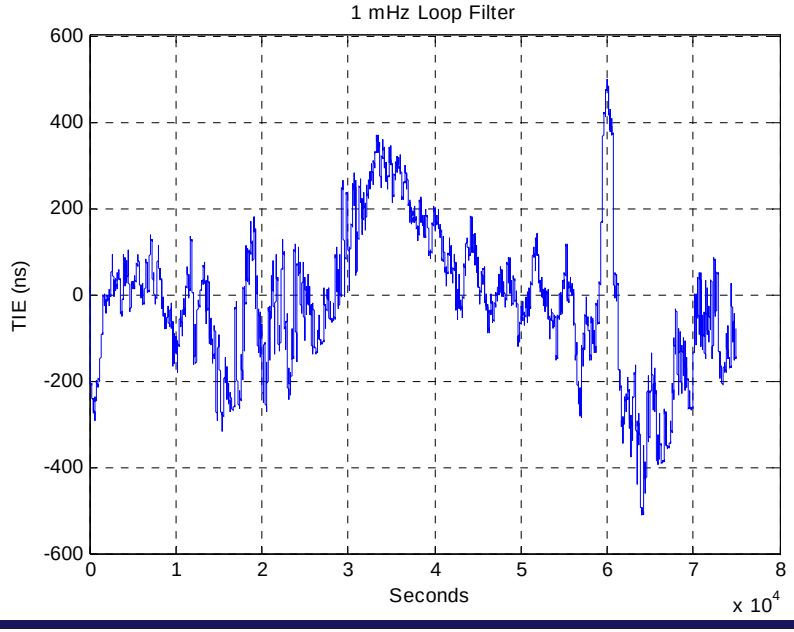
- **With a 10 mHz loop filter this oscillator has a low TIE and TDEV noise**

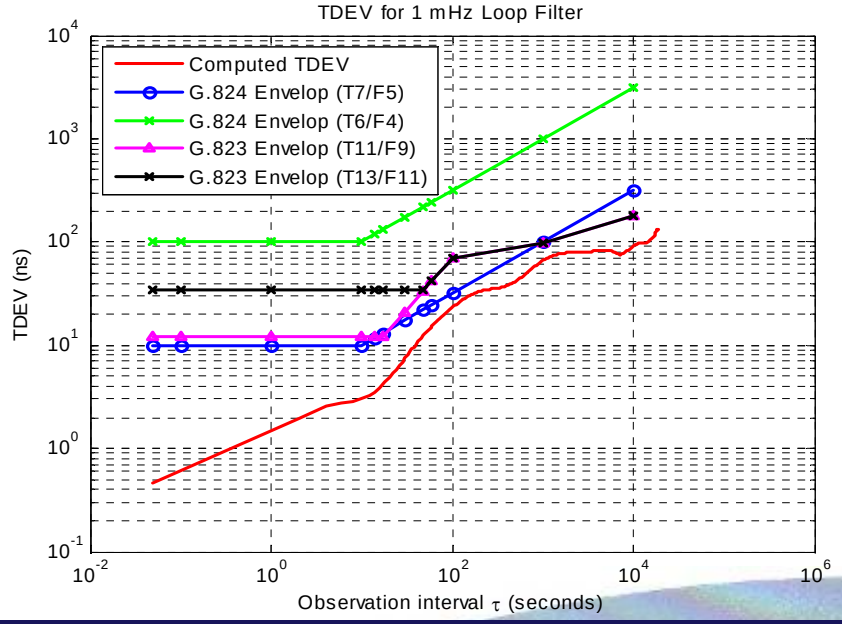




A Time Domain Look at an Oscillator

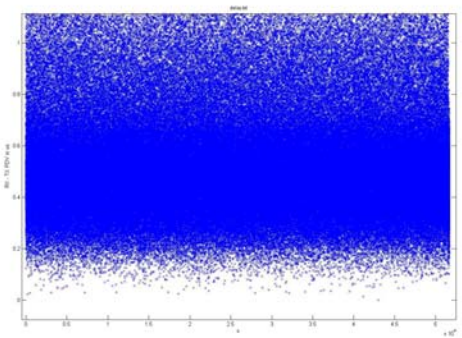
- **With a 1 mHz loop filter, equivalent of Stratum 3E, there is significantly MORE noise contributed by the oscillator**
- **A lower the loop filter will filter LESS oscillator noise**
- **Cannot keep lowering the loop filter to be more robust against PDV without increasing the cost of the equipment!**





Effect of the Local Oscillator on the Packet Selection

- **'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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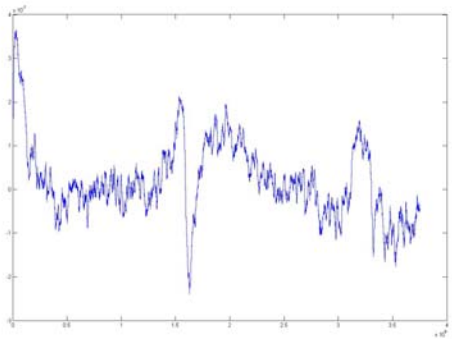

Oscillator

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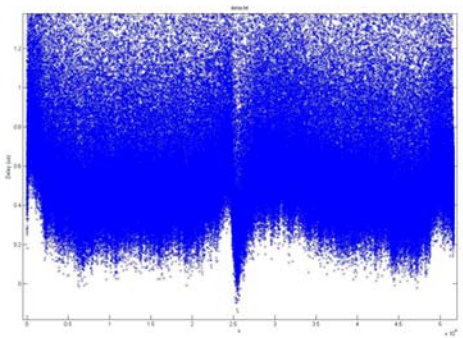

Observed Packet Delay (Zoom)

Oscillator Topics to Investigate

- **Beneficial to have oscillator performance specified in the time domain**
- **Optimizations for packet-based clocks requirements, which may be different than traditional electrical-based clocks (e.g. Stratum clocks)**
- **Matching well the metrics and loop filter selection to an acceptable price point**
  - **Contributions for PEC-S without on path support at ITU-T generally have selection windows and/or loop filters around 1 mHz (GR-1244 Stratum 3E / G.812 Type III) and 3 mHz (G.812 Type I)**

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Thank-you for Your Time & Attention

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