IEC/IEEE 60802
Clock noise model

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Introduction

• The presentation 60802-Lv-Rodrigues-clock-filter-0921-v00.pdf introduced a general clock filter model, and provided two points for the simulation models,
  ① Propose the end-point filter bandwidth, which is used by simulation, to be equal or less than 1/10 times of the Sync message rate;
  ② Consider the effect of the local oscillator to the end-point clock

• For the second point, it’s proposed to analyse the random noise of the local oscillator or clock, and the existing ITU-T model could be referred.

Oscillator phase noise model:

\[ x(t) = A + B(t) \times t + C(t) \times t^2 + R(t) \]

- Constant phase error
- Aging: long-term variation of frequency offset
- Frequency offset, variable with temperature
- Random phase noise
Clock noise model

- ITU-T **G.813** and **G.8262** specify requirements for the SDH clock and SyncE clock respectively. One of them is the wander noise generation (see Clause 7.1 of ITU-T G.813 and Clause 8.1 of G.8262, they’re same.)
- G.813/G.8262 includes Option 1 and Option 2 clocks, and Option 1 clock is widely used in telecom networks. This presentation is based on Option 1 clock.

- The output of SDH/SyncE clock should meet the below MTIE/TDEV masks.
Clock noise model

- Noise transfer function of the model:
  \[ Y = X \times H + N \times (1 - H) \]
  - H is a low-pass filter, and \((1 - H)\) is a high-pass filter
- The output signal \(Y\) should meet the MTIE/TDEV masks in the previous page.
- Due that the input signal \(X\) generated by the measurement device is ideal (assumed to be zero), then
  \[ Y = N \times (1 - H) \]
- And the local clock signal \(N\) is,
  \[ N = \frac{1}{1 - H} \times Y \]
  - \(1/(1 - H)\) is a reverse high-pass filter

A mathematical model of SDH/SyncE clock

- \(X\): Input signal
- \(N\): Local clock signal
- \(Y\): Output signal

\[ G.813/G.8262 \]

Measurement device

- SDH/SyncE
- Link

- SDH/SyncE
- Clock

X: Input signal
N: Local clock signal
Y: Output signal
Clock noise model

Therefore, if the noise data $Y$ is based on the MTIE/TDEV masks, the local clock noise data $N$ can be calculated via the previous model,

$$N = \frac{1}{1-H} \times Y$$

ITU-T G.Sup.65 has provided three models to get the noise data $Y$, in order to comply with the MTIE/TDEV masks as best as possible.

- Option 1, Model 1, Clause 8.1.2.1 of ITU-T G.Sup.65
- Option 1, Model 2, Clause 8.1.2.1 of ITU-T G.Sup.65
- Option 1 ETSI model, Clause 8.1.4.1 of ITU-T G.Sup.65
Clock noise model

- Option 1, Model 1: meets variable-temperature MTIE mask, exceeds TDEV mask;
- The noise generation data below is generated by the combination of noise sources listed in table 6.

<table>
<thead>
<tr>
<th>Observation Interval (s)</th>
<th>MTIE (ns)</th>
<th>TDEV (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1e-1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1e+0</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>1e+1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1e+2</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>1e+3</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>1e+4</td>
<td>100,000</td>
<td>100,000</td>
</tr>
<tr>
<td>1e+5</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

Option 1 Noise Generation MTIE - 0.95 Quantile
Model 1 - Meet MTIE, Exceed TDEV

Option 1 Noise Generation TDEV - 0.95 Quantile
Model 1 - Meet MTIE, Exceed TDEV

Table 6 – Noise source parameters for Option 1, Model 1 (meets variable-temperature MTIE mask, exceeds TDEV mask).

<table>
<thead>
<tr>
<th>Noise source</th>
<th>Input white noise standard deviation (ns)</th>
<th>Low-pass filter bandwidth (Hz)</th>
<th>High-pass filter bandwidth (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPM</td>
<td>0.0</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>WFM</td>
<td>2.450</td>
<td>~</td>
<td>3.183 × 10^{-3}</td>
</tr>
<tr>
<td>FPM1</td>
<td>7.336</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>FPM2</td>
<td>15.96</td>
<td>~</td>
<td>3.183 × 10^{-3}</td>
</tr>
</tbody>
</table>

Clock noise model

MTIE, Figure 5 of ITU-T G.Sup.65

TDEV, Figure 6 of ITU-T G.Sup.65
Clock noise model

- Option 1, Model 2: meets TDEV mask as closely as possible, falls below variable-temperature MTIE mask;
- The noise generation data below is generated by the combination of noise sources listed in table 7.

Table 7 – Noise source parameters for Option 1, Model 2:
(meets TDEV mask, falls below variable-temperature MTIE mask)

<table>
<thead>
<tr>
<th>Noise source</th>
<th>Input white noise standard deviation (ns)</th>
<th>Low-pass filter bandwidth (Hz)</th>
<th>High-pass filter bandwidth (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPM</td>
<td>0.0</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>WFM</td>
<td>1.750</td>
<td>~</td>
<td>3.183 × 10⁻³</td>
</tr>
<tr>
<td>FPM1</td>
<td>5.240</td>
<td>~</td>
<td>~</td>
</tr>
<tr>
<td>FPM2</td>
<td>11.40</td>
<td>3.183 × 10⁻³</td>
<td>~</td>
</tr>
</tbody>
</table>

MTIE, Figure 7 of ITU-T G.Sup.65
TDEV, Figure 8 of ITU-T G.Sup.65
Clock noise model

- Option 1, ETSI Model: matches the upper flat level and transition between lower and upper flat levels of the TDEV mask;
- The noise generation data below is generated by the combination of noise sources listed in table 23.

<table>
<thead>
<tr>
<th>Observation Interval (s)</th>
<th>MTIE (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1e-1</td>
<td>1e+0</td>
</tr>
<tr>
<td>1e+0</td>
<td>1e+1</td>
</tr>
<tr>
<td>1e+1</td>
<td>1e+2</td>
</tr>
<tr>
<td>1e+2</td>
<td>1e+3</td>
</tr>
<tr>
<td>1e+3</td>
<td>1e+4</td>
</tr>
<tr>
<td>1e+4</td>
<td>1e+5</td>
</tr>
</tbody>
</table>

Table 23 – SEC/EEC noise model parameters, following ETSI SEC noise generation model (Annex C of [b-ETSI02]).

<table>
<thead>
<tr>
<th>Noise Source</th>
<th>Input white noise standard deviation (ns)</th>
<th>Low-pass filter bandwidth (Hz)</th>
<th>High-pass filter bandwidth (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPM</td>
<td>1.0.</td>
<td>&lt;-</td>
<td>0.006.</td>
</tr>
<tr>
<td>FPM</td>
<td>10.67.</td>
<td>0.006.</td>
<td>&lt;-</td>
</tr>
</tbody>
</table>

SEC/EEC noise generation models and mask

- WD31 Option 1, model 2 SEC/EEC model, single run
- EN 300 462-5-1, Annex C SEC model, single run
- EN 300 462-5-1, Annex C SEC model, 300 runs, lower 99% confidence bound
- EN 300 462-5-1, Annex C SEC model, 300 runs, point estimate
- EN 300 462-5-1, Annex C SEC model, 300 runs, upper 99% confidence bound
- SEC/EEC constant temperature mask (G.813/G.8262)
- SEC/EEC variable temperature mask (G.813/G.8262)

MTIE, Figure 43 of ITU-T G.Sup.65

TDEV, Figure 44 of ITU-T G.Sup.65
This presentation uses Option 1, ETSI model as assumption, considering it’s used by ITU-T simulations.

The below phase error data in the left figure is regenerated with the noises sources of table 23, and the simulation step is 0.1s.

Note, the below MTIE/TDEV figures only provide the result with a single run, and are not as smooth as the figures of ITU-T G.Sup.65, which shows the results with 300 runs.

### Table 23 – SEC/EEC noise model parameters, following ETSI SEC noise generation model (Annex C of [b-ETSI02])

<table>
<thead>
<tr>
<th>Noise Source</th>
<th>Input white noise standard deviation (ns)</th>
<th>Low-pass filter bandwidth (Hz)</th>
<th>High-pass filter bandwidth (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3G.813/G.8262 Option 1 mask with constant temp</td>
<td>1.0</td>
<td>—</td>
<td>0.006</td>
</tr>
<tr>
<td>3G.813/G.8262 Option 1 mask with variable temp</td>
<td>10.67</td>
<td>0.006</td>
<td>—</td>
</tr>
</tbody>
</table>
Clock noise model

• Using the reverse high-pass filter model \( 1/(1-H) \) and the ETSI noise phase error \( Y \) to get the local clock noise \( N \).

\[
N = \frac{1}{1-H} \times Y
\]

• The important factors of the low-pass filter model \( H \) are the filtering bandwidth and gain peaking. ITU-T G.813/G.8262 specify the filtering bandwidth to be 1~10Hz, and the gain peaking is 0.2dB.

• So, the derivation of N considers two cases,
  • Case 1: filtering bandwidth 1Hz, gain peaking 0.2dB
  • Case 2: filtering bandwidth 10Hz, gain peaking 0.2dB
Clock noise model

- Below figures are the simulation result of Case 1 (filtering bandwidth 1Hz, gain peaking 0.2dB)

Local clock noise, which can be assumed as the random noise of a local clock, mainly driven by a free-run oscillator

MTIE result

TDEV result
Clock noise model

- Below figures are the simulation result of Case 2 (filtering bandwidth 10Hz, gain peaking 0.2dB)

Local clock noise, which can be assumed as the random noise of a local clock, mainly driven by a free-run oscillator
Summary

• This presentation provides one method to get the random noise of local clock (a freerun oscillator), based on the ITU-T clock models.
  • However, it’s still not quite sure, whether the result is consistent with the oscillators used by industrial devices. The ITU-T clock models assume telecom devices with TCXO, and the industrial devices may use XO.

• Another direct way that could be more consistent with the industrial devices is to test the local clock of a general industrial device.
  • There are several ways for test, e.g., through an external clock signal (e.g., 10Mhz), an Ethernet line clock from an Ethernet port, or PTP messages (e.g., t2 – t1, or t2 – t1 - meanLinkDelay).
  • Both of constant temperature and variable temperature can be tested.
  • It’s better to test the output of a device instead of an oscillator. They could be different, especially for the variable temperature.
Thank you