White Rabbit clock characterization

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The goal: measure noise generation and noise transfer according to SyncE specs (Rec: G.8262) so that we have parameters understandable in ITU-T language.

1. Background information

1.1 Noise generation

1.1.1 G.8262 definition (section 8):
The noise generation of an EEC [(synchronous) Ethernet Equipment Clock] represents the amount of phase noise produced at the output when there is an ideal input reference signal or the clock is in holdover state. A suitable reference, for practical testing purposes, implies a performance level at least 10 times more stable than the output requirements. The ability of the clock to limit this noise is described by its frequency stability. The measures maximum time interval error (MTIE) and time deviation (TDEV) are useful for characterization of noise generation performance. MTIE and TDEV are measured through an equivalent 10-Hz, first-order, low-pass measurement filter, at a maximum sampling time tau_0 *of 1/30 seconds. The minimum measurement period for TDEV is twelve times the integration period (T = 12*tau).*

1.1.2 Instructions by Geoff Garner - you would make:

- the Cs reference or equivalent would be input to the SyncE clock (i.e., your EEC) and to the Time Interval Analyzer (TIA).
- The EEC output would also be input to the TIA.
- We would measure and record the samples of TIE.
- Ideally, we would want this
    - with a 0.1 s or smaller sampling time, and
    - to measure for 12000 s (the smallest sampling time in G.8262 is 0.1 s, and TDEV is specified to 1000 s, and we generally should measure to 12 times the maximum observation interval to get a stable TDEV measurement. Lee used a sampling rate of 2.5 kHz.)
- monitor temp

1.2 Noise transfer

1.2.1 G.8262 definition (section 10):
The transfer characteristic of the EEC [(synchronous) Ethernet Equipment Clock] determines its properties with regard to the transfer of excursions of the input phase relative to the carrier phase. The EEC can be viewed as a low-pass filter for the differences between the actual input phase and the ideal input phase of the reference. The minimum and maximum allowed bandwidths for this low-pass filter behavior are based on the considerations described in Appendix II of [ITU-T G.813] and are indicated below.
In the passband, the phase gain of the EEC should be smaller than 0.2 dB (2.3%). The above applies to a linear EEC model. However, this model should not restrict implementation.

1.2.2 Instructions by Geoff Garner:
- you need to modulate the input with a sine wave of a chosen frequency
- The amplitude should be much larger than the noise generation.
- You then measure the amplitude of the output
- You then do this for frequencies varying from at least an order of magnitude below the 3 dB bandwidth to a few orders of magnitude larger.
- For each measurement, record the frequency (Hz), and input and output amplitudes (ML: *I guess this is TE plotted against time of acquisition*).
- Note that these are the input and output amplitudes of the modulating signals; their units should be UI, time (e.g., ns), or rad), but if expressed in units of time it is relative to the nominal frequency of the signal being modulated.

1.2.3 Instruction from Synchronization of Digital Telecommunication Networks (p363)
The test is accomplished by feeding the Clock Under Test (CUT) input with a reference signal affected by sinusoidal jitter at increasing frequencies, with small fixed amplitude. If the CUT is working according to a linear model, then the phase deviation measured by the time counter is a sine wave at the same frequency as the input jitter, but having different amplitude. The ratio of the two peak amplitudes, plotted versus the jitter frequency, is the jitter transfer function measured the two most interesting parameters to check in a jitter transfer function measured are the clock bandwidth and maximum gain.

2. Measurements

2.1 Noise generation with GM locked to Cs

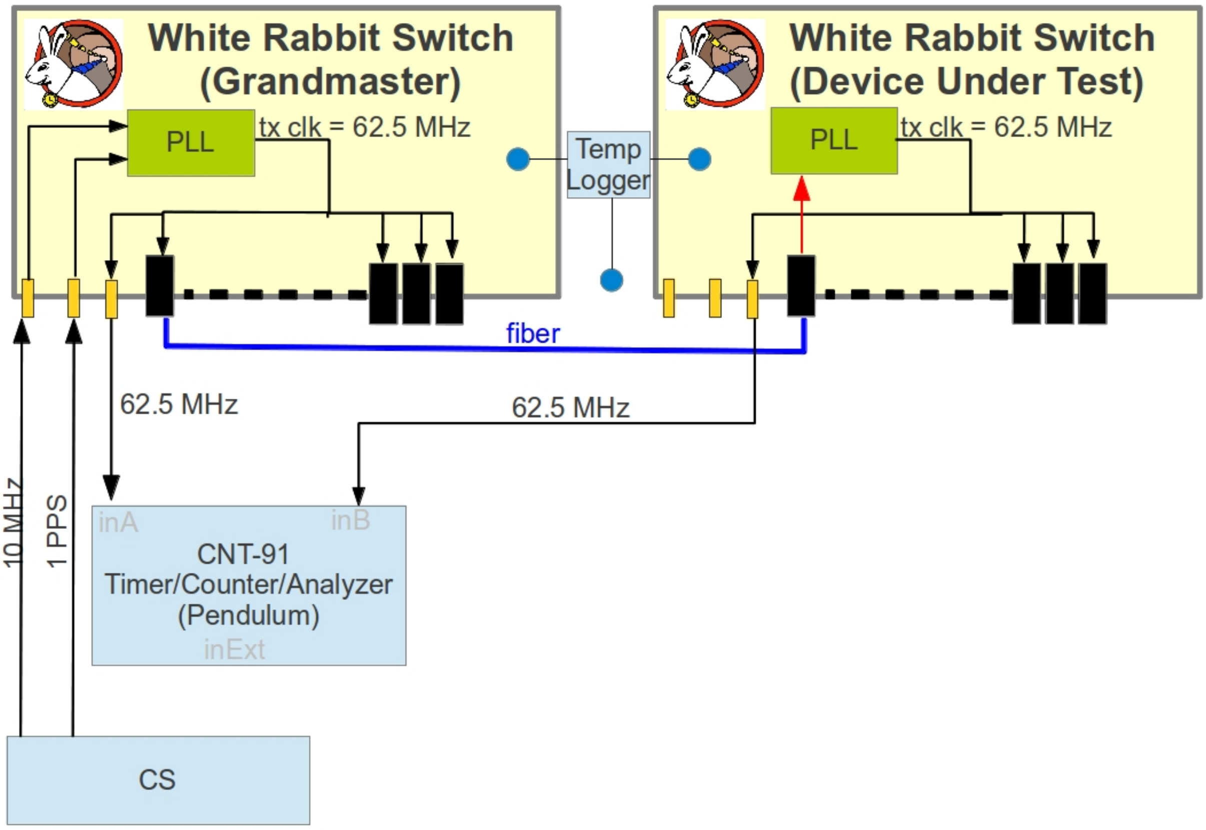
2.1.1 Measurement and setup description

Two WR switches are used: **Grandmaster** (left, connected to Cesium clock) and **Device Under Test (DUT)** – right, connected through fiber to the *Grandmaster*). *DUT's* noise generation is measured by recording time error (TE) values between:

- tx clock of grandmaster (the clock signal used to encode the data sent out by the *grandmaster* to the *DUT*)
- tx clock of *DUT* (the clock signal used to encode the data sent out by the *DUT*)

WR switch works with 62.5MHz system clock (data is processed in 16bits words). The system clock is used to transmit data (tx_clk) and is also available through SMA connector (yellow rectangle). Comparing tx_clk of *grandmaster* and of *DUT* seems the closest possible measurement to the one made using a dedicated equipment.

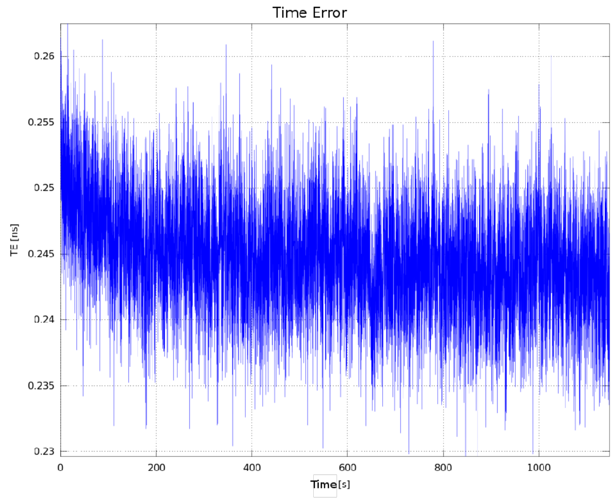
CNT-91 Pendulum is used to measure time error (TE) between the two tx clocks. The measurement is done with a sampling rate of 1ms (each measurement is timestamped). The total number of samples collected accounts for over 1000s. The data is processed by averaging every 100 samples (low pass filter) – thus tau0 used for final calculations is tau0=0.1s

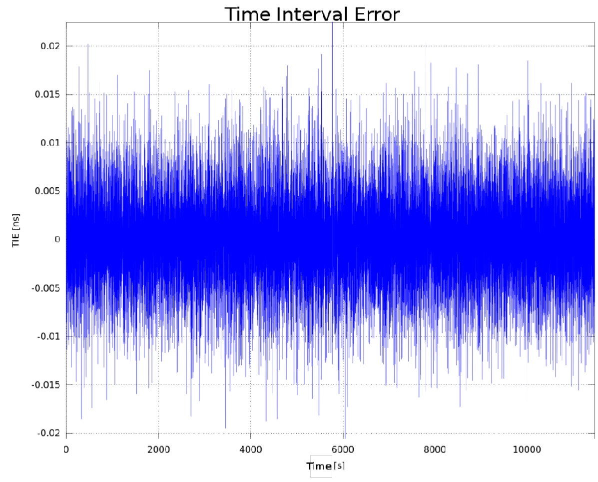


2.1.2 Measurement results

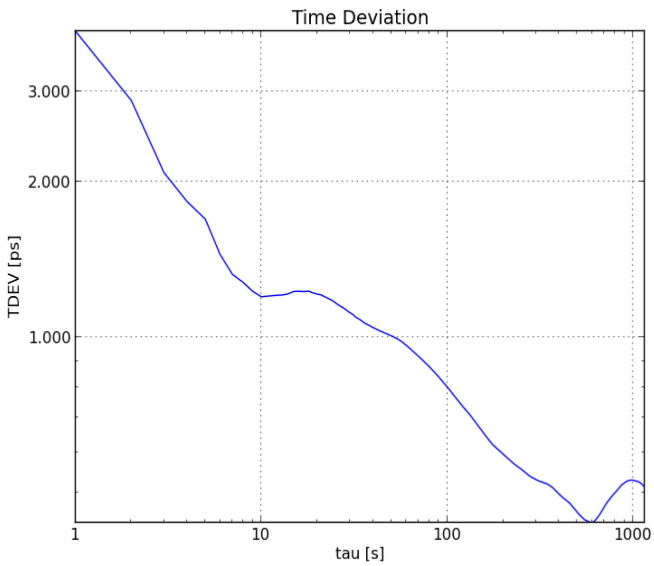
2.1.2.1 Test 1 (2014-02-04-t3)

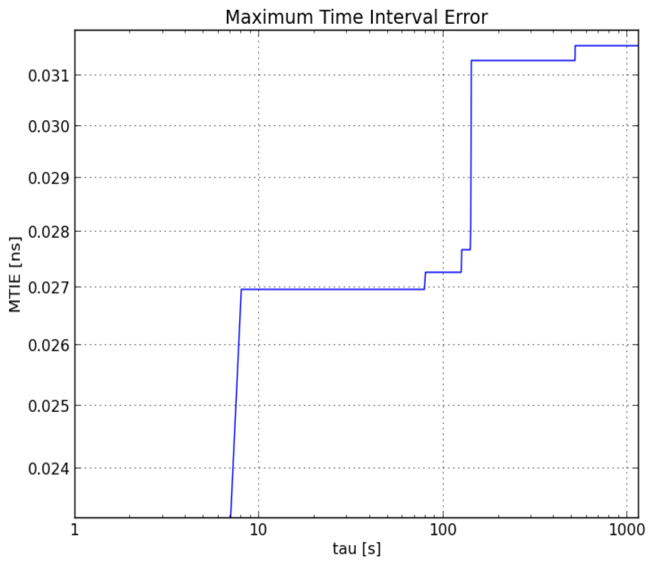
Sample number: 1146874





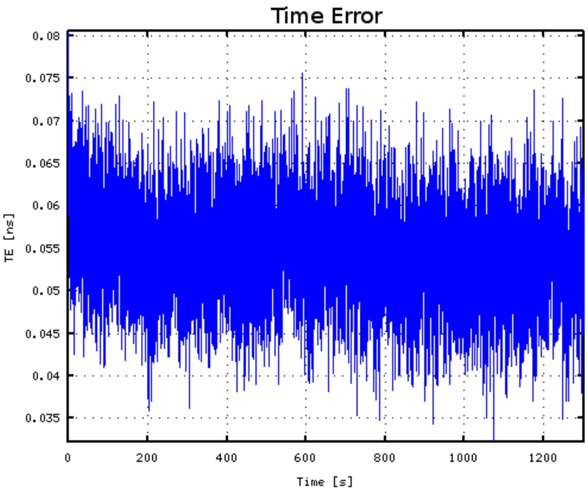
The above graphs show data used to compute MTIE and TDEV below: Time Error (TE) after averaging over 100 measured samples and Time Interval Error (TIE) computed from TE (difference between subsequent TEs).

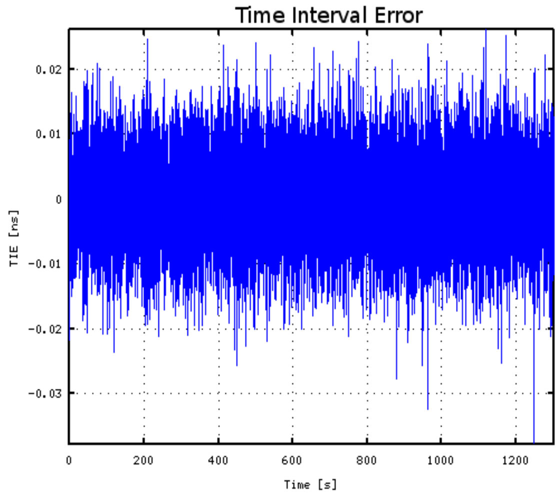




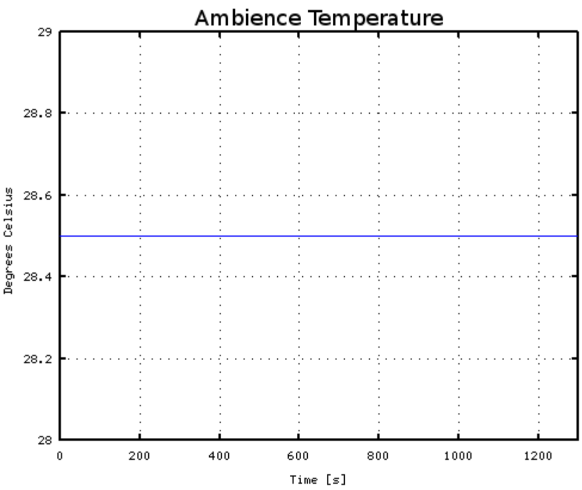
2.1.2.2 Test 2 (2014-03-12-t2)

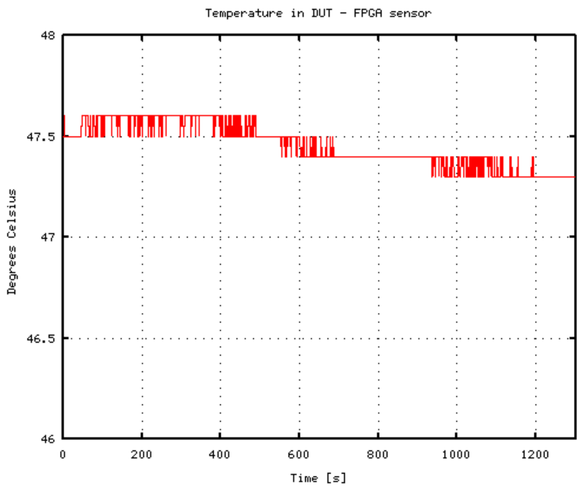
Number of samples: 1301884. Short fiber (a few meters). Note that the recorded temperature is pretty much constant.

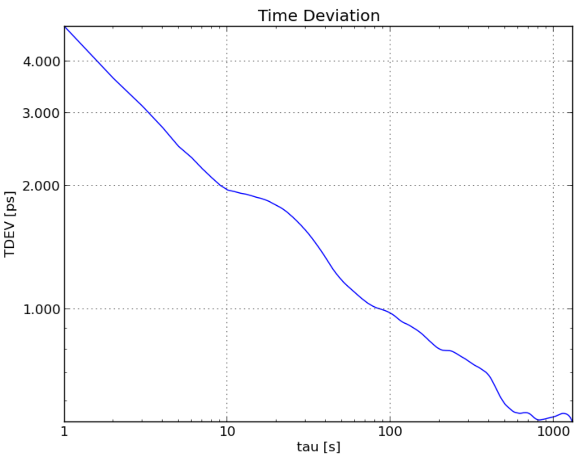


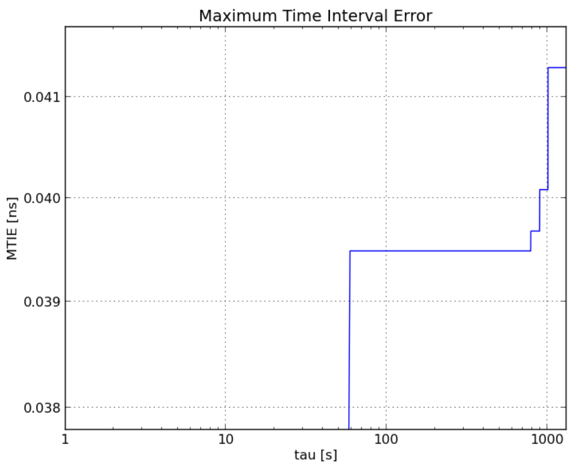


The above graphs show data used to compute MTIE and TDEV below: Time Error (TE) after averaging over 100 measured samples and Time Interval Error (TIE) computed from TE (difference between subsequent TEs).



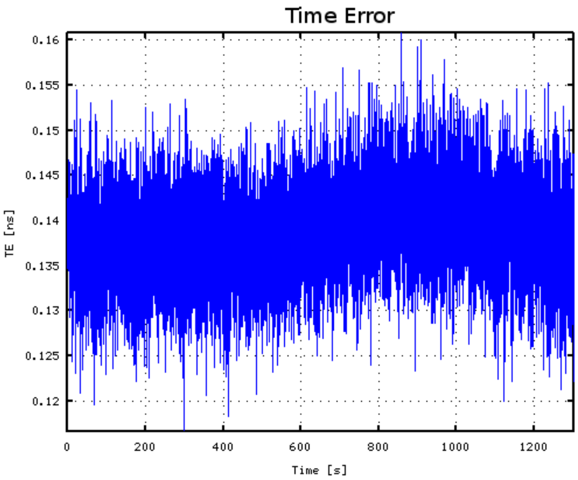


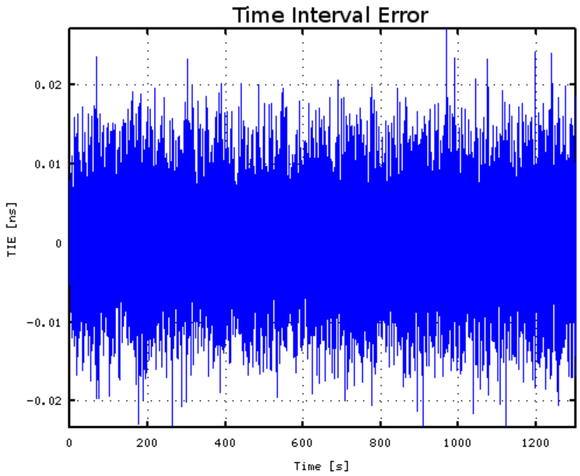




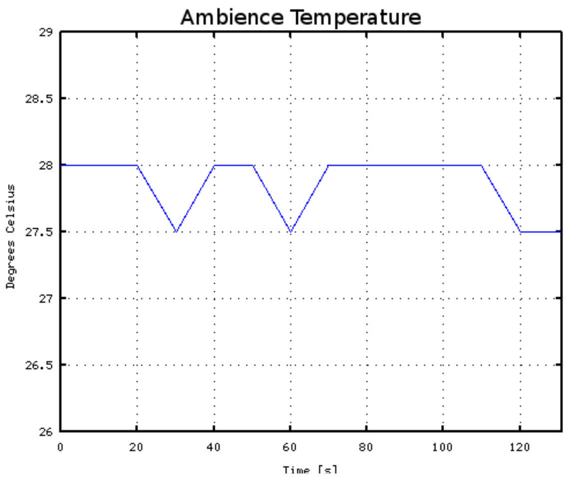
2.1.2.3 Test 3 (2014-03-13-t1)

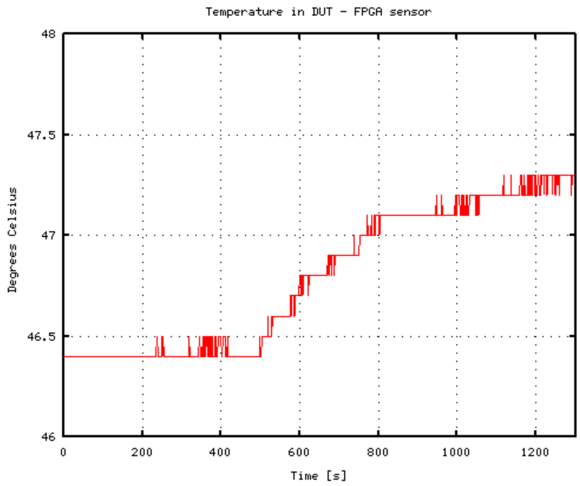
Number of samples: 1301884. Long fiber (5094m). Note that the recorded temperature is pretty much constant.

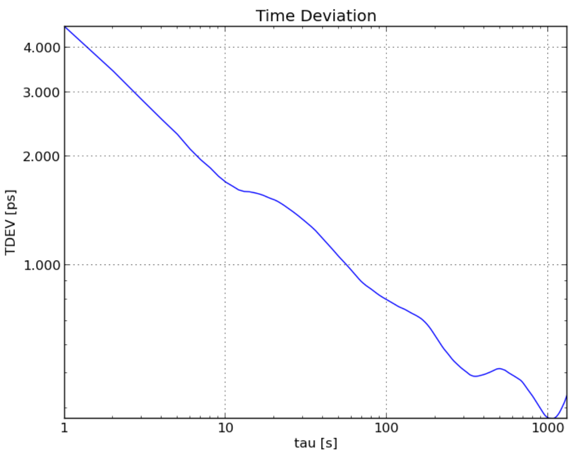


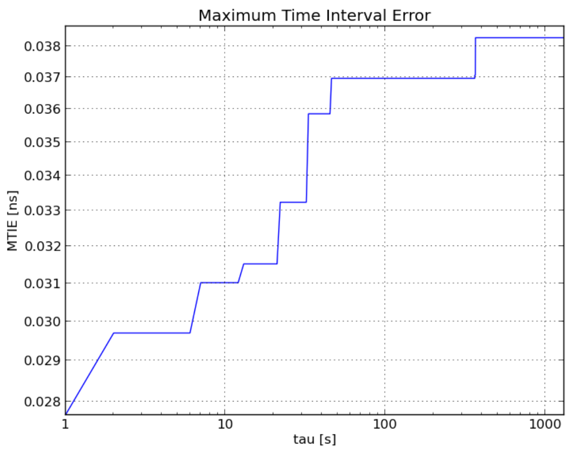


The above graphs show data used to compute MTIE and TDEV below: Time Error (TE) after averaging over 100 measured samples and Time Interval Error (TIE) computed from TE (difference between subsequent TEs).









2.2 Noise generation using customized test-switch (2014-03-12)

2.2.1 Measurement and setup description

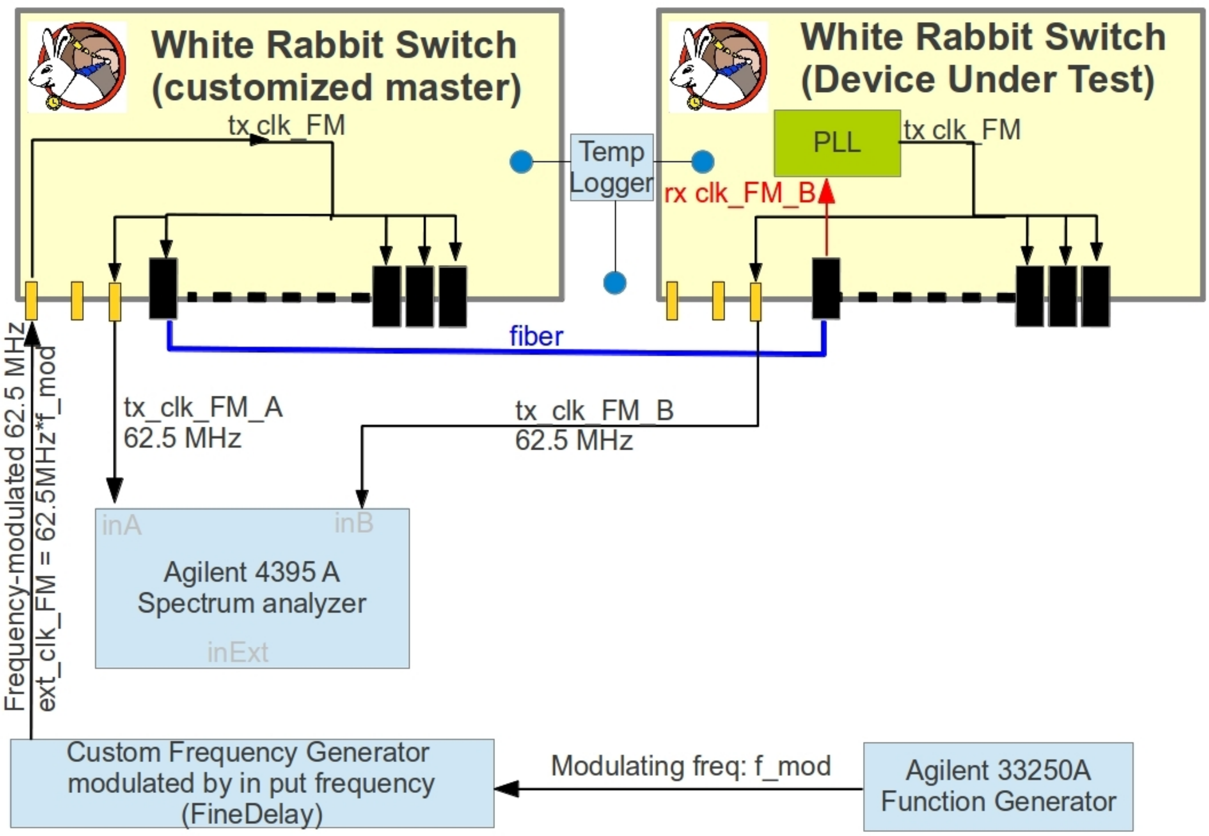
The description from **1.2.3** is followed.

Two WR switches are used: **customized master** (left) and **Device Under Test (DUT)** – right, connected through fiber to the *customized master*. The *customized master* switch is modified so that it uses the external frequency (ext_clk_FM) provided through SMA connector as its system clock – there is no PLL. Consequently, the external frequency (ext_clk_FM) provided to the switch is directly used to encode the transmitted data (tx_clk). Modulation of the external frequency results in modulation of the frequency used for transmission (tx_clk_FM, tx_clk_FM_A), thus the frequency recovered by the *DUT* is respectively modulated (rx_clk_FM_B) – it is assumed that tx_clk_FM_A is equal to rx_clk_FM_B (noise introduced by transmission medium is negligible). *DUT's* noise transfer is measured by analyzing two clocks:

- tx_clk_FM_A : tx clock of the *customized master* – the modulated clock signal used to encode the data sent out by the *customized master*
- tx_clk_FM_B : tx clock of *DUT* – the clock signal used to encode the data sent out by the *DUT*

The analysis is done using Agilent Spectrum Analyzer in the following way:

- the external frequency provided to the *customized clock* is modulated with a given frequency (provided by Agilent Function Generator)
- the amplitudes [dBm] (Amp_A & Amp_B) of the spectrum of the modulating frequency (f_mod) is measured in the frequencies from both switches (tx_clk_FM_A and tx_clk_FM_B)
- the transfer function is obtained by plotting : $y(f\_mod)=10*\log(P_B/P_A)=(Amp_B-Amp_A)$ [dB] for f_mod={7Hz to 2kHz}



2.2.2 Measurement results

Input characteristics and measured values:

Modulating frequency (f_mod)	Amplitude of modulating signal (set Vpp of modulating sine wave: f_mod)	Amplitude of modulating signal on input to DUT (tx_clk_FM_A measured with spectrum analyzer: inA)	Amplitude of modulating signal on output of DUT (tx_clk_FM_B, measured with spectrum analyzer: inB)
[Hz]	**[mV]**	**[dBm]**	**[dBm]**
7	1	-27.0	-26.0
8	1	-27.0	-26.0
9	1	-29.0	-26.0
10	1	-29.0	-26.0
20	1	-35.7	-34.4
30	1	-39.0	-44.0
40	1	-41.0	-48.0
50	1	-43.0	-52.0
60	1	-45.0	-57.0
70	10	-27.0	-41.0
80	10	-28.0	-43.0
90	10	-29.0	-45.0
100	10	-30.0	-46.0
200	10	-36.0	-58.0
300	10	-39.0	-66.0
400	10	-42.0	-71.0
500	10	-44.0	-75.0
600	10	-45.5	-78.0
700	10	-46.8	-82.0
800	10	-48.0	-84.0
900	10	-49.0	-85.0
1000	10	-50.0	-87.0
2000	10	-55.0	-90.0

Measurement accuracy of the *amplitude of modulating signal* (raws 3 & 4 in the above table : +/-1dBm).

Noise transfer function