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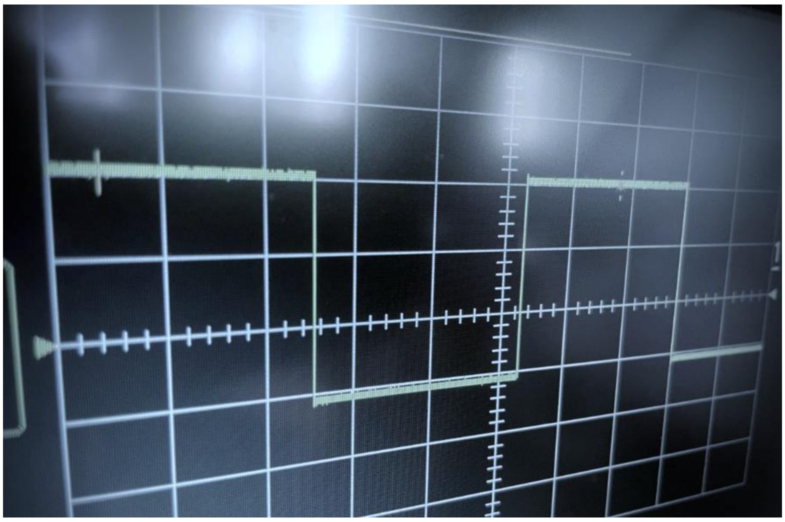

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Abstract

This report describes a set of waveforms for verification purposes and other calculations relating to temporal light modulation (TLM). The waveforms are intended to be used in comparisons of software implementations and for estimating measurement uncertainty from modelled effects as well as other calculation-based studies of TLM. The report gives TLM metric values of PstLM and SVM, these are calculated from various implementations of the TLM metric algorithms. The results show standard deviations, all under 0.04 for both metrics, except one outlier.

Furthermore, the report gives examples of how estimation of measurement uncertainty can be derived from applying various effects that can be modelled and applied to the waveforms.

This is used to study the effect on the resulting metrics. Specific guidance is given towards using the examples to reach measurement uncertainties under 0.05 for both PstLM and SVM.

The waveforms are stored in a permanent repository, for referencing and comparing results across platforms.

This report is part of the output from the EMPIR project MetTLM Metrology of Temporal Light Modulation (20NRM01). For more information see the project website mettlm.eu.

Table of content

1 Summary

This report introduces a dataset of waveforms for uses in relation to temporal light modulation (TLM). The report outlines the potential needs for such a dataset in general research of TLM and lighting metrology, specifically related, but not limited to, verification and comparison of calculation methods and estimation of measurement uncertainties. It has been identified that the current methods of specifying measurement conditions and calculation methods does not produce homogeneous results across platforms, and experiments. This report describes the waveforms and gives some information on the location of the permanent storage, licence conditions and guidance on use of the dataset. The report includes values of TLM metrics i.e.: stroboscopic visibility measure (SVM) and short-term flicker measure ($P_{\mathrm{st,LM}}$). These are the two metrics identified by the European commission for regulation of temporal light modulation in lighting products, and therefore important subjects of research and metrology. The report also deals with estimation of measurement uncertainty, for stroboscopic visibility measure and short-term flicker measure, using the presented dataset and propagation of measurement uncertainty through selected models of physical effects present in a measurement. The models are for: Offset, random noise and frequency response. Using the models on the dataset, various results of TLM metrics are presented, these can be used as first approximations to measurement uncertainty for similar waveforms or as guidance for prioritization of effort in relation to characterization of measurement uncertainty components in a given setup. The results are not intended to be used as more than indications of what a given waveform and given effect would cause in terms of measurement uncertainty contributions. The aim of this report is a target uncertainty below 0.05, for both SVM and $P_{\mathrm{st,LM}}$. The results in this report indicate that it is possible to achieve this.

2 Introduction

TLM has come to the attention of the metrology community in recent years due to the use of LED in lighting where driver current/voltage fluctuations directly result in changes in light output. The perceptibility of these modulations have been linked to various adverse effects on human health and comfort (CIE, 2022a; Veitch et al., 2021) and the severity of these effects has been characterized by TLM metrics such as stroboscopic visibility measure (SVM) (CIE, 2016; IEC TC 34, 2018) M_{SV} and short term flicker measure $P_{\mathrm{st,LM}}$ (IEC TC 34, 2017; IEC TC 77/SC 77A, 2010). The calculations for these metrics are done on the basis of measured light waveforms and this is described in the above referenced documents. However, questions have repeatedly been raised regarding the reproducibility of TLM metric results, from various calculations based on these definitions, given the same waveforms as input. Such issues can lead to an unnecessary increase in uncertainty. In the Guide to the expression of uncertainty in measurement (GUM) (JCGM, 2008), one cause of measurement uncertainty is from “incomplete definition of the measurand” (3.3.2). For TLM metrics this includes imprecise specifications of calculations such as frequency filtering, sample rate etc. These issues were highlighted at the CIE symposium in Athens Greece in 2022 (CIE, 2022b). There are no certified or standardized implementations of the calculation methods but many researchers have used the MATLAB implementations of SVM (Beeckman & Sekulovski, 2018) and $P_{\mathrm{st,LM}}$ (Beeckman, 2017). For SVM, issues with frequency determination were pointed out (Dam-Hansen et al., 2022), as well as the importance of the choice of antialiasing filter (Koch & Zuber, 2022) and choice of sampling rate (Tan et al., 2022). Further issues regarding the implementations in MATLAB were identified by Nordlund (Nordlund, 2022).

It should be possible to implement the TLM algorithms in preferred computational software platforms, and in this process, it becomes important to validate a given software implementation. Therefore, reference waveforms for calculations of TLM metrics are essential tools to validate calculation scripts/routines and compare the results across platforms. With these waveforms it can be verified that, choices of implementation methodology, such as programming language, filter algorithm etc. do not cause unnecessary or unpredictably large deviations between measurements with various instruments. Here large uncertainties would mean that they are comparable to the largest contributions from experimental measurement uncertainty. Some simple waveforms are already available (see section 2.1), however with more complicated driver schemes available it is of importance to have more complicated test waveforms available for calculations. This report details such a set of waveforms, given in section 4. Additional sets of reference waveforms can be used to illustrate various issues in scientific work, such as the influence of various perturbations of waveforms relevant to uncertainty calculations (Thorseth et al., 2021).

One of the intentions of this report is to assist laboratories in reaching measurement uncertainties of TLM measurement intended for PstLM and SVM of 0.05 for values in the most relevant interval from 0.1 to 2. The measurement uncertainty from TLM metric algorithm implementation is discussed in section 4.1.3.1 and 4.1.3.2. Further, some example model calculations are presented in section 5, particularly the contributions of offset, noise and frequency response. Advise is given towards reducing uncertainty to a level of 0.05 for each component. If several uncertainty components are close to or above 0.05 the largest components need to be reduced such that the combined uncertainty (1) becomes less than 0.05. The combined uncertainty is given by the following equation (Disregarding correlations)

$$u = \sqrt{u_1^2 + u_1^2 \dots u_n^2} \qquad (1)$$

where

$u_1 \dots u_n$ are the uncertainties of component numbered 1 to n.

When dealing with measurement devices the waveforms should be measured according to the methods laid out in CIE Technical Note TN 012 (CIE, 2021) or the IES approved method LM-90-20 (IES, 2020). Further guidance on the measurement of TLM is currently being developed by CIE TC 2-89. Calibration of TLM measurement devices is described by Dekker and Bloois (Dekker & Bloois, 2023).

In this report the effect of frequency induced beat (IEC 60050 IEV term 103-06-16)(IEC, 2009) is not considered. This effect is introduced when two or more modulations are superimposed with a slight frequency difference (Lindén et al., 2019), however the given dataset could be used to investigate such effects.

2.1 Available waveforms

IEC technical report TR 61547-1 (IEC TC 34, 2020) describes waveforms (Annex A.3), all with $P_{\mathrm{st,LM}}$ exactly equal to 1, formulated as a mathematical formular, with various tabulated adjustment parameters.

IEC technical report TR 63158:2018 (IEC TC 34, 2018) describes waveforms (Annex A.5) with reference values for the SVM. The annex includes five square and four sinusoidal waveforms defined with modulation frequency, modulation depth and the exact, analytically derived reference values for SVM.

3 Use of the data

The data presented in this report is not restricted to specific uses, however, below are given some guidance. The data is licenced under the Creative Commons Attribution 4.0 International (CC, 2013), which grant the freedom to share and adapt under the condition of attribution.

3.1 Attribution

For use of datasets in publications and other public material, citation should be given including the DOI of the dataset. For example:

- Bouroussis, C. A., Thorseth A., Dekker, P. 2023, *MetTLM TLM waveform set 1*, Version 1, zenodo.org, dataset, DOI: 10.5281/zenodo.7707987

3.2 Data storage

The data described in this report is stored at zenodo.org which is a general-purpose open repository, developed under the European OpenAIRE program. It allows for deposit of research papers, datasets, research software, reports, and any other research related digital artefact. Each submission has a persistent digital object identifier (DOI), which makes the stored items easily citeable.

Data related to MetTLM will also be referred to from the Zenodo community EMPIR 20NRM01 MetTLM - Metrology for Temporal Light Modulation: zenodo.org/communities/mettlm20nrm01

3.3 Signal interpretation

The waveforms described in this report are not to be considered as representations of signals with infinitesimal sampling or infinite bandwidth but should be considered as sampled waveforms from a theoretical (nondescript) measurement, resulting in the given waveforms. The following subsections provides some guiding principles regarding this interpretation.

3.3.1 Higher frequency content

The Nyquist-Shannon sampling theorem states that a signal with no frequencies higher than B can be completely reconstructed from a series of points spaced by $\frac{1}{2B}$ in time domain. However, in case of the presented waveforms the defining characteristic *is* the waveform, so here it has to be assumed that the signal does not hold any frequencies above B. This means that sharp corners and peaks are not to be considered indicative of frequency content above B i.e. the sampling frequency.

3.3.2 Interpolation

Interpolation of the data to a new time axis is not generally recommended. For waveforms that change smoothly between the sampling intervals such as sinusoidal waveforms with a much lower frequency than the sample rate, an interpolation will only have a very small influence. On the other hand, spikey and square waveforms can potentially be significantly affected by changes in the frequency and phase of the data points, similarly the frequency content can be affected by introducing more data than originally in the sampled waveform.

4 Waveform data

4.1 MetTLM waveform set 1

The dataset described in this section ("MetTLM waveform set 1") is stored at this location:

- DOI: https://doi.org/10.5281/zenodo.7707987

It is used to generate the measurement uncertainty estimates shown in section 5. It can be abbreviated to MetTLMWS1.

4.1.1 Overall description

"MetTLM waveform set 1" is a dataset consisting of a set of simple mathematically generated waveforms. These are indicative of typical behaviour of TLM measured in the field, it should not be considered representative of all possible TLM waveforms in any strict sense.

The waveforms contained in this dataset (described in more detail in 4.1.2) consists of distinct points placed at equal distance on a time axis, where each point is defined independently.

- The duration is 180 seconds consisting of 3 600 000 points, interspaced by 5×10^{-5} s.
- The two first rows give the time interval and between each datapoint and the number of points, as suggested in CIE TN 012 (CIE, 2021),
- The first column is the time stamp in seconds,
- Each of the consecutive 20 next columns are representing the amplitude of the waveforms (see 4.1.2).

4.1.2 Waveform description

The following is a description of the waveforms in MetTLM waveform set 1:

W_1	stable or TLM-free waveform,
W_2	rectified sinusoidal waveform,
W_3	sine waveform with offset,
W_4	rectified sinusoidal waveform with offset,
W_5	square waveform,
W_6	square waveform with low offset,
W_7	square waveform with medium offset,
W_8	square waveform with high offset,
W_9 to W_{12}	pulse width modulation (PWM) signals with various offsets and frequencies,
W_{13}	triangle waveform,
W_{14}	triangle waveform with offset,
W_{15}	sawtooth waveform,
W_{16}	sawtooth waveform with offset,
W_{17}	saw tooth and rectangular waveforms summed,
W_{18}	sinusoidal waveform rectified and reversed,
W_{19}	sinusoidal waveform rectified, reversed and offset,
W_{20}	sinusoidal waveform with one wavelength mirrored around the zero-pass with added offset.

The waveforms were generated using mathematical functions and have been normalized to the average value and do not contain noise or other artefacts.

Figure 1 illustrates a few periods of each waveform. The total duration of each generated waveform is 180 sec. This waveform set was used for computational uncertainty analysis (Thorseth et al., 2021).

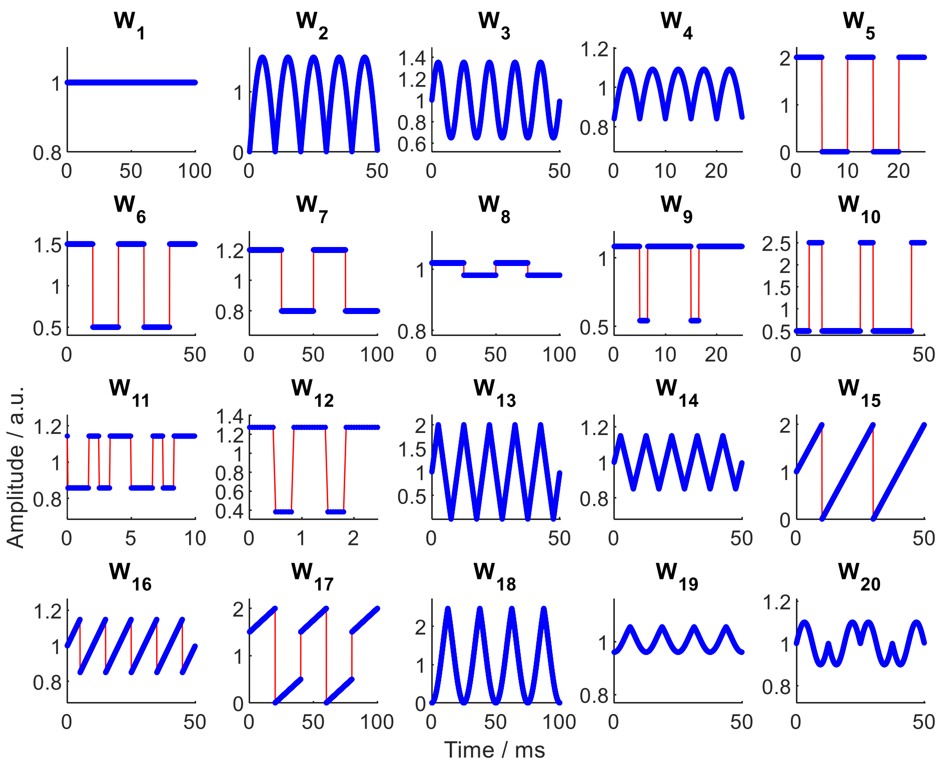

Figure 1 – The waveforms of MetTLM waveform set 1, numbered W_n, n=1…20. The blue markings show the defined points while the red line is there as visual guide connecting points adjacent on the time axis. Notice that the axes of the graphs vary.

4.1.3 TLM metric values

For the purpose of verification, the waveforms in this set have been characterized using various implementations of the calculation methods. As described in the introduction there is no general agreement about the implementation of the calculation methods. It is therefore not surprising that there are deviations between the results (see Table 1 and Table 2).

Where values are missing, unresolved issues with the calculations have been identified. These issues will be addressed in the MetTLM project but are outside the scope of this report.

4.1.3.1 $P_{\mathrm{st,LM}}$ values

Table 1 shows the values of $P_{\mathrm{st,LM}}$ of MetTLM waveform set 1, calculated using $P_{\mathrm{st,LM}}$ toolbox (Beeckman, 2017), with fixed precision of 4 digits and results from an alternative implementation from Aalto University and Gigahertz-Optik. Differences of varying magnitude and significance can be seen in Table 1. The standard deviation of the results are generally far below the target uncertainty of 0.05, except for very high values of $P_{\mathrm{st,LM}}$ where deviations are approximately proportional to the $P_{\mathrm{st,LM}}$ value, with a proportionality of 0.001.

[Compare to 0.05 if not why; zeropadding results are better]

Table 1 – $P_{st,LM}$ values of the waveforms calculated using various implementations of the calculation algorithm. a) Aalto matlab implementation, b) (Beeckman, 2017), c) Gigahertz-Optik implementation. The standard deviation is given in column SD.

Waveform #	a	b	c	SD
1	0.000	0.000	0.000	0.000
2	0.050	0.050	0.051	0.000
3	0.027	0.027	0.027	0.000
4	0.000	0.000	0.000	0.000
5	0.096	0.096	0.096	0.000
6	5.248	5.249	5.243	0.003
7	37.49	37.419	37.46	0.029
8	3.749	3.742	3.746	0.003
9	0.029	0.030	0.034	0.002
10	7.422	7.423	7.416	0.003
11	-	0.028	0.033	0.003
12	-	0.441	-	-
13	0.061	0.061	0.061	0.000
14	0.009	0.009	0.009	0.000
15	5.248	5.249	5.244	0.002
16	0.007	0.007	0.007	0.000
17	116.9	116.5	116.7	0.163
18	38.53	38.56	38.49	0.029
19	0.015	0.015	0.015	0.000
20	2.943	2.945	2.941	0.002

4.1.3.2 SVM values

Table 2 shows the values of SVM calculated for the MetTLM waveform set 1, using SVM toolbox (Beeckman & Sekulovski, 2018), with fixed precision of 4 digits. Furthermore, results are shown for implementations by VSL, Aalto University and GigaHertz-Optik. Table 2 shows differences of varying magnitude and significance, typically on the fourth or third digit. The standard deviation of the results are generally below the target uncertainty of 0.05 with an average value of 0.008. The waveforms that yields the largest variation are 6, 10, 12 and 15. If a measured waveform resembles one of these it is recommended to be extra aware of the measurement related to the implementation of the SVM algorithm.

Table 2 – SVM values of the waveforms calculated using various implementations of the calculation algorithm. The columns gives the results for: a) SVM implementation with zero padding by VSL, b) (Beeckman & Sekulovski, 2018), c) Aalto matlab implementation, d) IEC implementation in python without zero padding, e) Gigahertz-Optik implementation. The standard deviation is given in column SD.

Waveform #	a	b	c	d	e	SD
1	0.003	0.002	0.000	0.003	0.000	0.001
2	2.602	2.601	2.602	2.583	2.599	0.007
3	1.366	1.365	1.366	1.356	1.364	0.004
4	0.293	0.292	0.293	0.287	0.292	0.002
5	4.970	4.970	4.971	4.934	4.966	0.014
6	1.861	1.814	1.864	1.840	1.862	0.019
7	0.335	0.334	0.335	0.330	0.335	0.002
8	0.034	0.033	0.034	0.033	0.034	0.000
9	0.662	0.658	0.662	0.656	0.657	0.003
10	3.089	3.046	3.092	3.060	3.089	0.019
11	0.288	0.293	0.288	0.285	0.293	0.003
12	0.542	0.462	0.543	0.541	0.489	0.034
13	3.163	3.162	3.163	3.140	3.160	0.009
14	0.474	0.474	0.474	0.471	0.474	0.001
15	1.973	1.927	1.975	1.952	1.968	0.018
16	0.375	0.375	0.375	0.372	0.375	0.001
17	1.368	1.355	1.368	1.366	1.366	0.005
18	1.966	1.955	1.967	1.949	1.965	0.007
19	0.178	0.174	0.178	0.175	0.178	0.002
20	0.204	0.202	0.205	0.204	0.204	0.001

5 Uncertainty propagation using test waveforms

This section provides demonstrations of the use of the presented waveforms for estimation of measurement uncertainties for TLM. The waveforms described in section 4 can be used for estimation of measurement uncertainty by using mathematical models to perturb/distort the original waveforms according to some model parameters and then calculate the TLM metrics for a linear range of parameter values or a distribution of stochastic parameters (Thorseth et al., 2021).

Potential uses of the presented example models and data are:

- Given a specific measured waveform, one can find a defined waveform from the set that resembles the measured waveform. Then from the graph for the relevant parameter (offset, noise level etc.) one can follow the abscissa along the slope or worst cases to the estimate of the parameter and then read the ordinate to estimate the size of the associated measurement uncertainty.
- Given a specific waveform, and a specific effect one can apply the modelled contributions to the specific waveform using a range or random set of parameter values

to model a specific effect. The output of the calculation can then be used to estimate the associated measurement uncertainty.

- Apply combinations of models over ranges of input parameters using Monte Carlo method for a comprehensive study of interacting effects,

Even very approximated estimates of uncertainty are in general helpful for prioritizing the effort of calculating and minimizing uncertainties related to a specific measurement, as it is normally beneficial to prioritize larger uncertainty contributions before smaller contributions.

For estimation of measurement uncertainty for a specific measured waveform it is recommended to calculate the associated uncertainty eventually, and not rely entirely on the presented values in this document.

5.1 Offset

An offset of signal is often seen in measurements of optical radiation, caused by electrical effects or from stray light in the environment. The offset is generally a systematic error with a relatively stable amplitude and it should be corrected for. Any correction however will carry an unknown residual offset causing an uncertainty contribution.

The influence of offset can be investigated through this model:

$$Y(t) = X(t) + b \tag{2}$$

where

$X(t)$ is the signal,

b is a constant offset, or a percentage of the top of the dynamic range.

The result of variations in the offset can be seen in 5.1, here b is calculated as a percentage c of the maximum value of X, $b = c \max(X)$. This calculation, first presented in (Thorseth et al., 2021), shows how the metrics vary with offset in a relatively predictable way. As offset is typically related to the dynamic range of the instrument it may be beneficial to relate the offset to the upper limit of the instrument reading. The effect is typically systematic, but care has to be taken that the offset does not change randomly or is influenced by unknown parameters.

For most of the waveforms, shown in Figure 1, the relative sensitivity to the offset is represented by a straight line. However, it is notable that most waveforms with points near the zero levels will be distorted differently depending on whether or not the offset causes values to dip below zero and consequently being subject to truncation of values below zero. This can be seen as kinks in the curves at zero offset for the waveforms that have values near zero. For PWM signals this is most dramatically seen in Figure 1 W_5 due to the fact that positive offset introduces low positive values while negative offset conserves the shape of the waveform, due to the truncation. Practically, this issue results in the situation where the offset sensitivity i.e. the slope in Figure 1 is not properly defined at the point where the offset causes truncation and thereby introduces a kink in the sensitivity curve.

Note: PWM signals will not be very affected by negative offset combined with truncation since the distortion will be negligible.

Since the potential error is well-described as a proportionality between the relative offset and the relative TLM metric value, it is possible to set up the following approximation

$$\frac{u(X)}{X} \cong \alpha \cdot u_{\text{offset}} \tag{3}$$

where

X is the TLM metric (SVM or $P_{st,LM}$),

$u(X)$ is the measurement uncertainty of the TLM metric,

u_{offset} is the measurement uncertainty of the offset in percent,

α is the slope derived from equation (2) or estimated from Figure 2 in percent over percent.

In Figure 2 we see α having values between 1 and 2.5. To reach a measurement uncertainty value of 0.05 for this component we can use equation (3) to work out an example: For values of the metric X near 0.5 and using a worst case value for α of 2.5, the uncertainty on the offset has to be kept less then 4%, which is achievable in most cases.

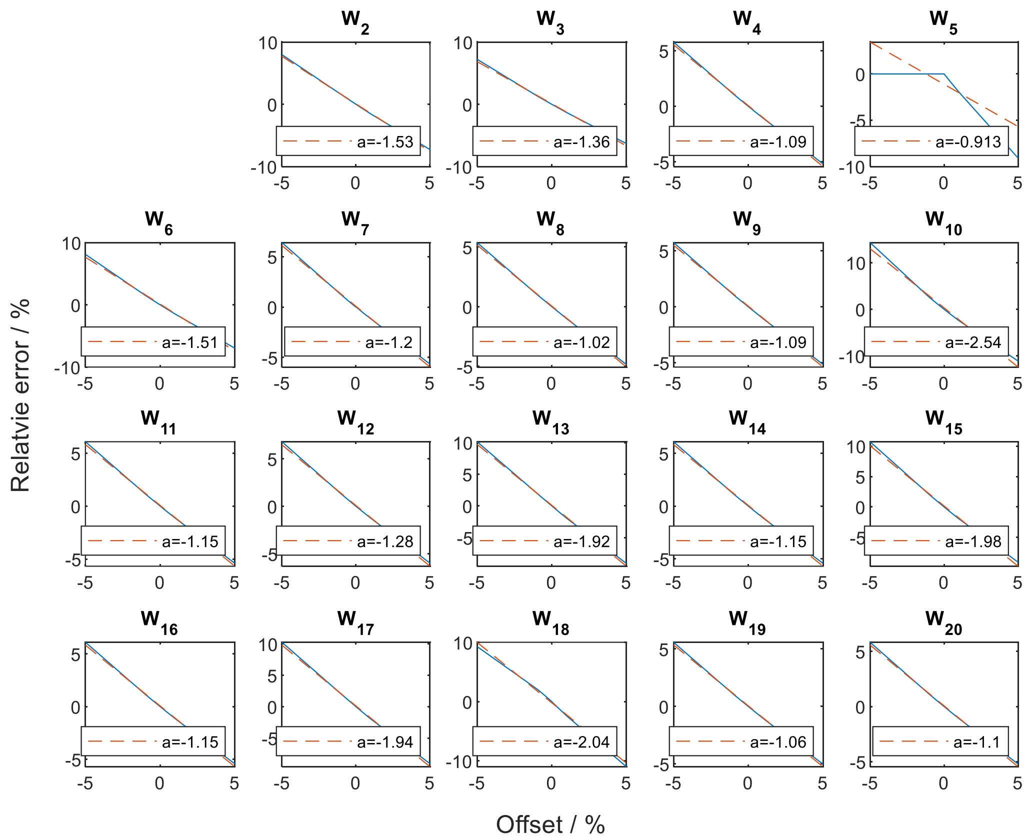

Figure 2 – Error in $P_{\text{st,LM}}$ and SVM values when a DC offset is applied to the test waveforms, "a" denotes the slope of fitted straight lines in each plot.

5.2 Noise

Noise is common in electronic systems, here understood as a random/stochastic signal component. The influence of noise can be investigated by the following model:

$$Y(t) = X(t) + a_{\text{SNR}} \cdot r(t) \quad (4)$$

where

$X(t)$ is the normalized signal,

$r(t)$ is a characteristic noise signal,

a_{SNR} is the signal-to-noise ratio.

The noise signal can be generated in various ways, such as a normal distribution of random values (Gaussian white noise), or for instance noise with an amplitude distribution proportional to the frequency (blue noise)(ATIS, 2019). Experimentally, one can acquire a sensor reading with no light present for use as a noise signal.

As an example, Gaussian white noise summed with the test waveform under different signal-to-noise ratios are given. To estimate the uncertainty contribution, different noise signals have to be added to the original signal in a Monte Carlo type calculation, and the distribution of the resulting metrics has to be evaluated statistically. The data presented in Figure 3 and Figure 4 is based on 100 noise signals per level.

Figure 3 shows two examples of the effect of noise on SVM, the examples are waveform W_4 and waveform W_8. The relative deviation for the two waveforms is different by approximately a factor of 10, however the smaller effect is commonly seen within the dataset, while the larger effect is the largest within the dataset. The SVM calculation is done on 5 s samples.

The results using from using the noise model equation (4) on MetTLM waveform set 1, exemplified in Figure 3, we see that the relation between added noise and the relative variation in SVM is approximately linear.

$$\frac{u(M_{\mathrm{VS}})}{M_{\mathrm{VS}}} \cong b \cdot \sigma_{\mathrm{noise}} \tag{5}$$

where

σ_{noise} standard deviation of the (Gaussian) noise relative to the maximum signal,

b is the sensitivity of SVM of the given waveform to noise, in units reciprocal to the unit of the signal.

$u(M_{\mathrm{VS}})$ is the standard uncertainty of SVM in absolute units.

To reach a level of 0.05 of measurement uncertainty, it is recommended to use the worst-case scenario from MetTLM waveform set 1 i.e. W_8, which gives a sensitivity of b = 0.7 (Figure 3(b)). Rearranging equation (5) and plugging in values

$$\frac{u(M_{\mathrm{VS}})}{aM_{\mathrm{VS}}} \cong \frac{0.05}{0.7M_{\mathrm{VS}}} = 0.07\frac{1}{M_{\mathrm{VS}}} \cong \sigma_{\mathrm{noise}} \tag{6}$$

We see that the noise must be reduced to a level below 0.014/M_{VS}, to reach measurement uncertainties below 0.05, for example: M_{VS}=0.1, σ_{noise} must be below 0.07 %, while M_{VS}=2, σ_{noise} must be below 0.035 %.

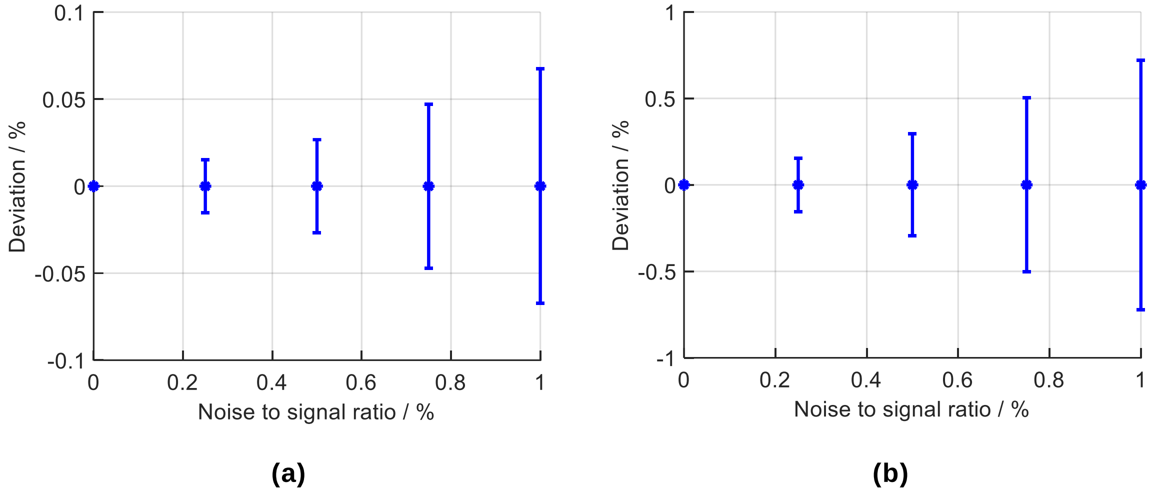

Figure 3 – An example of variation in SVM due to random noise (Waveform W_4 shown) The worst case of relative change is observed is for W_8 (b). The error bars show standard deviation of results Monte Carlo simulations.

The same procedure is used to calculate $P_{\mathrm{st,LM}}$ and the results are shown in Figure 4. Here it can be seen that noise can have a quite dramatic effects on the values of $P_{\mathrm{st,LM}}$. Here 1 % noise increases the $P_{\mathrm{st,LM}}$ values, in some cases with several hundred percent. This is unsurprising since $P_{\mathrm{st,LM}}$ has its origin in measurements of electrical noise. From Figure 4 it can be seen that a noise level around 0.2 % is sufficient to reduce the deviation to a level of around deviation in $P_{\mathrm{st,LM}}$ of 0.05 for all the tested waveforms.

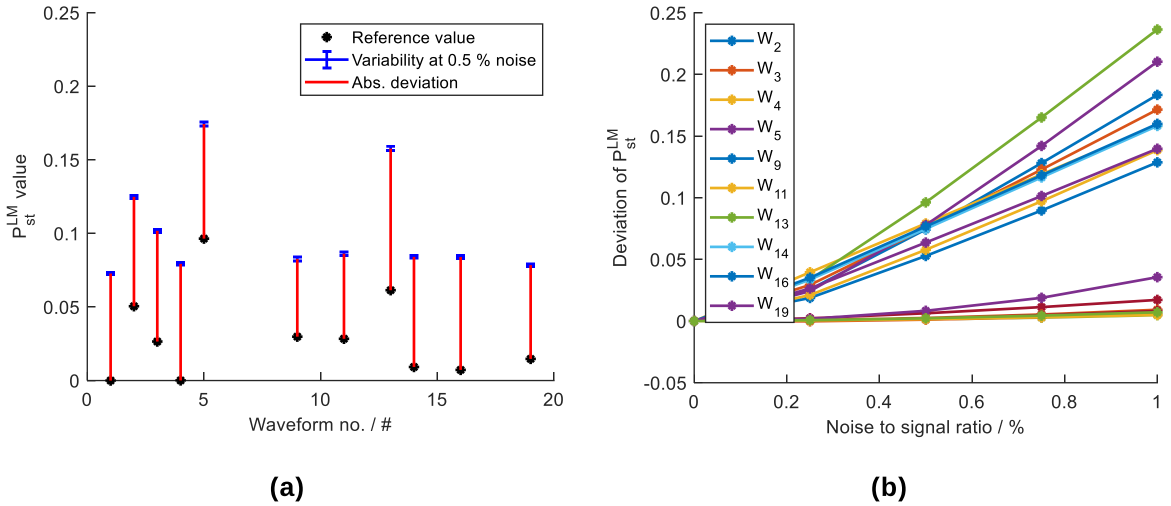

Figure 4 – Results of $P_{\mathrm{st,LM}}$ for a Monte Carlo simulation, adding random noise. The variability and deviation of $P_{\mathrm{st,LM}}$ for 180 s samples, and for a 0.5% noise level, shown in (a). The absolute deviation shown all 20 for waveforms in (b).

In summary it can be seen that noise has a little effect on SVM while $P_{\mathrm{st,LM}}$ is more severely affected

5.3 Frequency response

The frequency response of a measurement system for measurement of modulation is critical. The ideal frequency response would be unity in the specified range and zero outside, however any real measurement system will have a response different from this ideal. Intentional or unintentional frequency filtering can be a source of uncertainty, due to the distortion of the waveform.

A very simple model of a low pass filter is given by a “difference equation” for a resistor–capacitor (RC) circuit, given by

$$Y(n) = \alpha\, X(n) + (1 - \alpha) Y(n - 1) \tag{7}$$

where

$X(n)$	is the normalized signal at the nth datapoint,
α	is the RC smoothing factor
n	is the sequential number of the waveform sample,
$Y(n)$	is evaluated for all n.

In the following we use lowpass filtering as an example, to illustrate the effect of removing high frequencies from the waveform. The example data shown in Figure 5 and Figure 6, are for the MATLAB cut-off filter function called `lowpass` (mathworks.com, 2018) set to 60 dB attenuation with a steepness of 0.85. The filter is applied to waveform set 1 and the TLM metrics have been calculated. The results seen in Figure 5 is for SVM for 10 s samples, showing the absolute deviation for varying filtering. The results seen in Figure 6 shows 120 s samples, showing the absolute deviation in $P_{\mathrm{st,LM}}$ for varying filtering.

For the SVM the influence of lowpass filtering is shown to be small up to 10 kHz and then negligible for values above that. For $P_{\mathrm{st,LM}}$ its seems that the filtering has an influence on the baseline values, visible at high cut-off frequencies.

With the target of measurement uncertainty below 0.05, it is evident from Figure 5 and Figure 6 that filtering below 10kHz should be done with care, as this has a significant influence, especially for SVM.

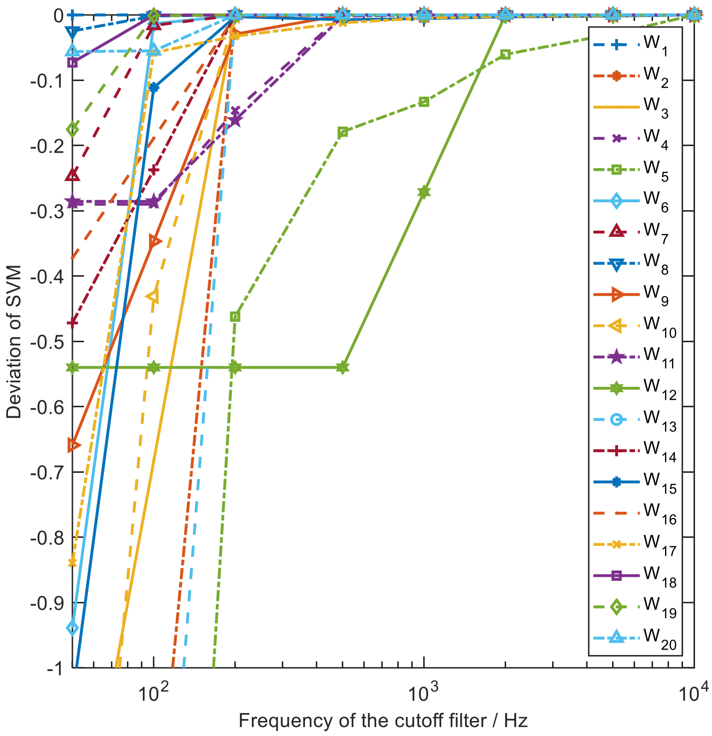

Figure 5 – The influence of a 60 dB lowpass filter on the SVM value, as function of cutoff frequency.

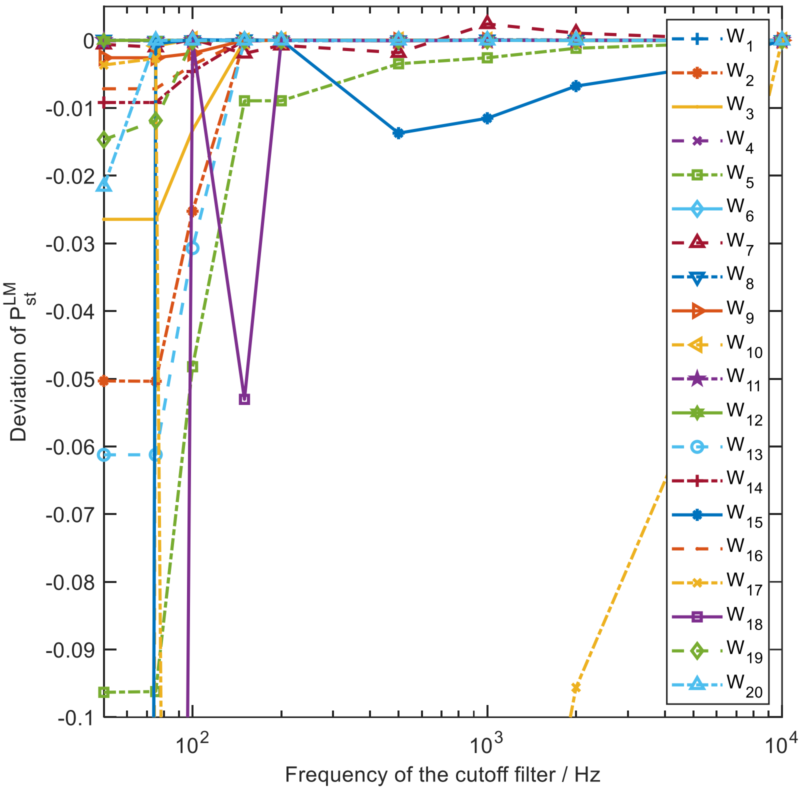

Figure 6 – The influence of a 60 dB lowpass filter on the P_{st}^{LM} value.

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