14IND08 ELPOW

Step response of commercial digitizers for lightning impulse voltage measurement

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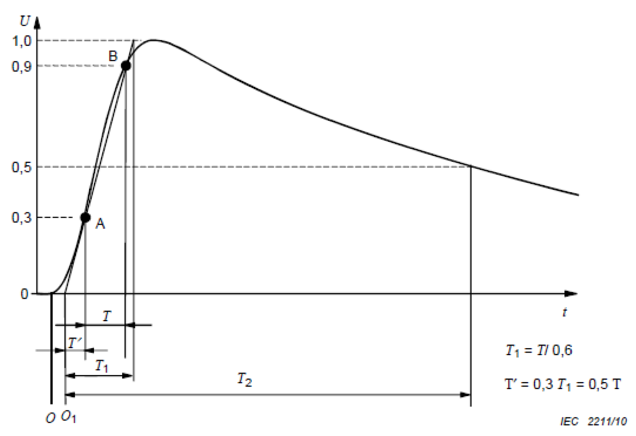
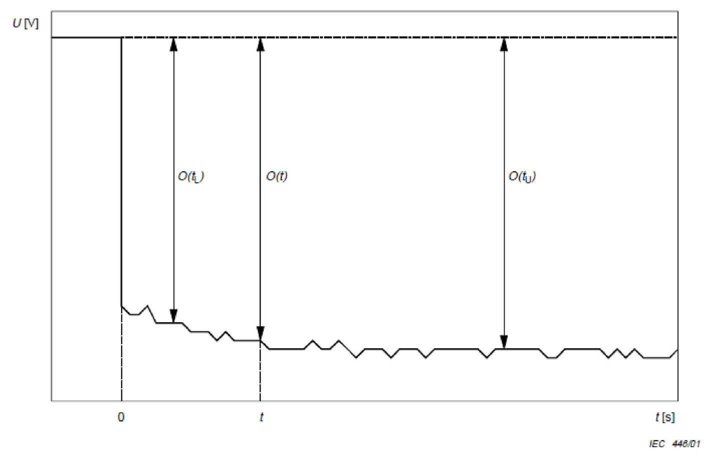
Task : To measure a high voltage impulse with a front time T_1 in the range 0.84 to 1.56 µs and time to half value 50 µs. Both peak value and time parameters need to be accurately determined. For reference systems 0.5% on the peak and 1 % on the time parameters are desired

Need: A reasonably fast step response, but very strict requirement on stability after the step to reach the desired accuracy



Full lightning impulse according to IEC 60060-1:2010



Step requirements according to IEC 61083-1: 2001

For LI we have $O(t_L)$= 0.84 µs and $O(t_L)$ = 60 µs

All values O(t) must be within 1 % of the mean.

N.B. A reference digitizer must perform appreciably better

Step response and convolution versus impulse calibrator

Task : To estimate the errors introduced by the imperfect response of the digitizer

Ways: Use a precise low voltage impulse calibrator with known output, or

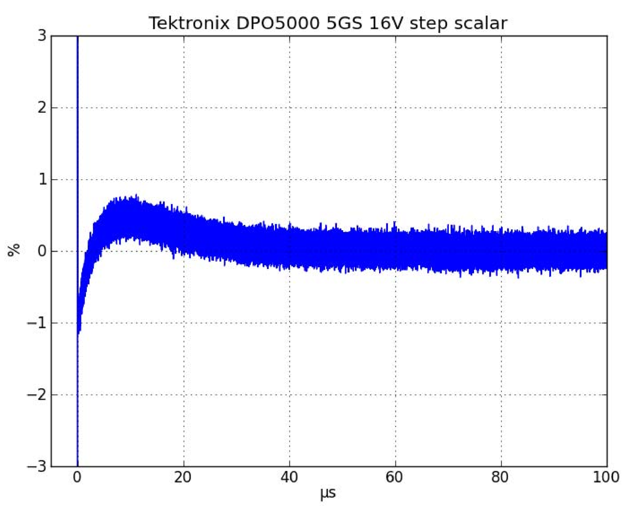
convolve the step response (viz. Impulse response) with a theoretical curve to obtain the difference between applied and waveform captured by the digitizer

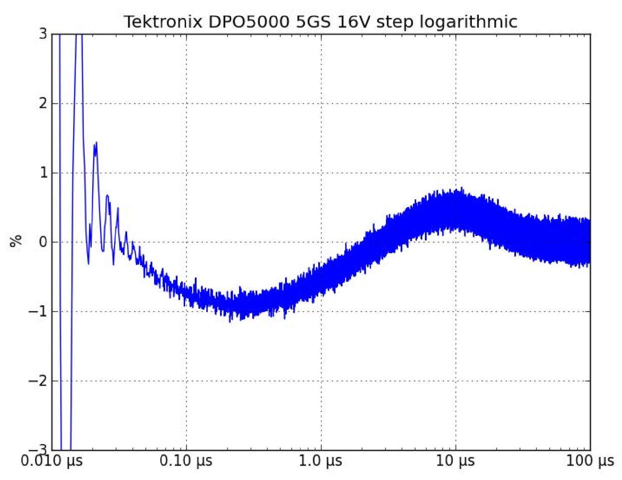
Note: The front time T_1 is a sensitive marker for digitizer errors and has been thoroughly investigated

For convolution an impulse response filter and a signal are convolved. One way of doing this is to calculate the algebraic derivative of the desired reference waveform to obtain an impulse response with minimal numerical errors and convolve this with the step response in the frequency domain, e.g. using FFT.

The difference between the reference waveform and the convolved waveform is the error of the digitizer.

Log scaled step response

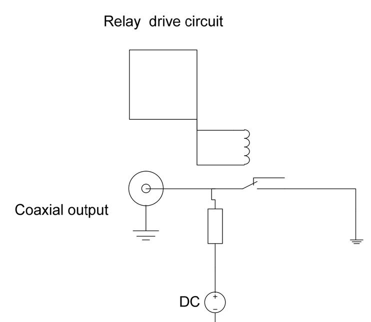




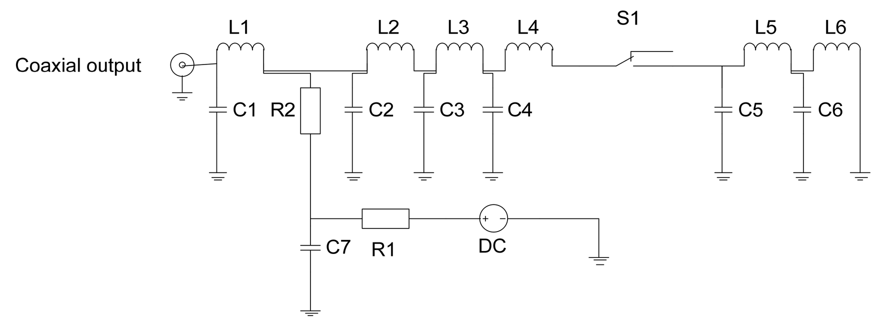
For a full lightning impulse, the step needs to be within 1% from 0.42µs to 60µs. This time scale is difficult to observe when using linear plots, as the 0.42µs point will be difficult to discern. When using a logarithmic scale, the 0.42µs point is easy to identify. The exact 60µs point is harder ascertain, however this is of little consequence since the step response in general has stabilized at that time.

N.B. Reference measuring instruments should be appreciably better, Step within 0.5 % at 0.42 µs is desired.

Step generator design and performance



Basic circuit showing only mercury wetted relay



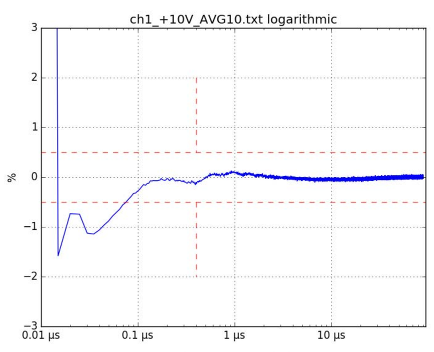
A detailed equivalent circuit of the switching circuit of the step generator is given in figure above, where inductance in the leads and capacitance to earth are shown as a ladder type network. The values are possible to estimate only to order of magnitude, and serve as a help in understanding. L1 to L6 as well as C1 to C6 are estimated from geometrical dimensions.

C7 is an intentionally added ceramic capacitor of 100 pF to 1nF intended to decouple the DC feed from the switching arrangement. R1 and R2 also serve to decouple the DC feed.

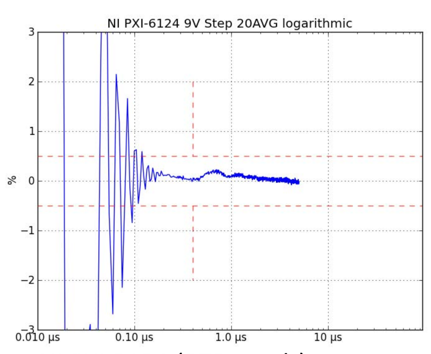
The value of C7 was selected to dampen the resonance of the step, but small enough that it doesn't slow down the digitizer step response. It has been shown that 100 pF can have minor resonance and 1 nF removes the resonance but may slightly slow down the step response. Dynamic resistance of the switch can be estimated from C7 influence on step.

Examples from characterisations of commercial digitizers

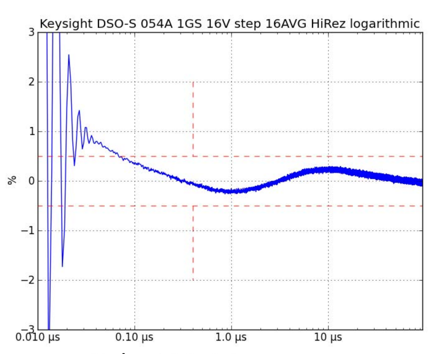
Limits indicated at 0.4µs and 0.5%. 0.5% was selected to allow the full system to be within 1%.



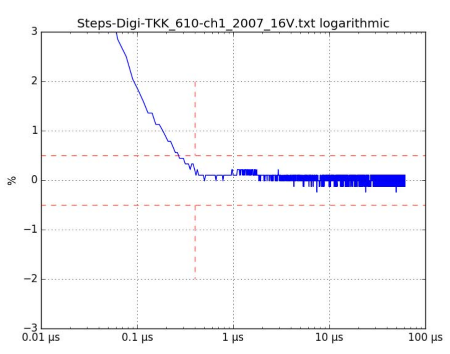
NI PXI 5124 (SP result)



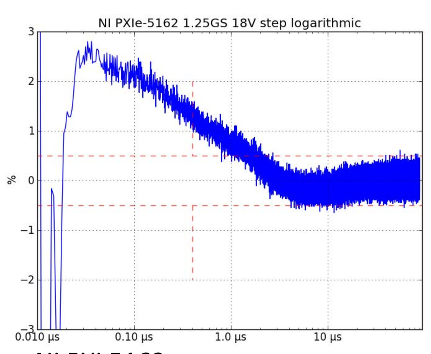
NI PXI 5124 (PTB result)



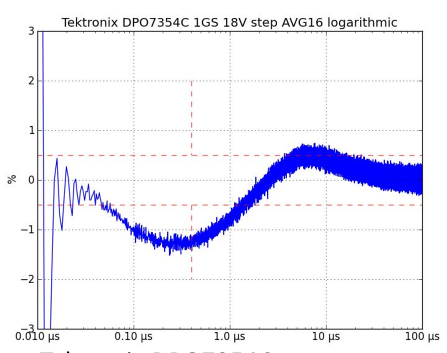
KeySight DSO-S 054A



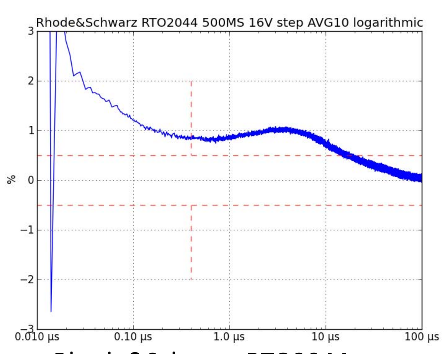
Nicolet 610



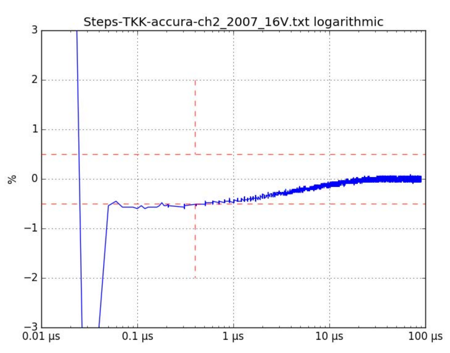
NI PXI 5162



Tektronix DPO7354C



Rhode&Schwarz RTO2044



Nicolet Accura

Step response or impulse calibration?

Comparison between step response convolved with nominal 0.84/50 µs pulse and results obtained with an impulse calibrator were investigated for SPs NI PXI 5124:

Error of T_1 averaged over all ranges and both polarities is 0.09 % with a standard deviation of 0.07 %

Conclusion: both methods agree well and can be used to qualify transient recorder performance

Many transient recorders fail to settle distinctly in their step response

Evaluation by convolution shows that appreciable errors especially in front time T_1 ensues

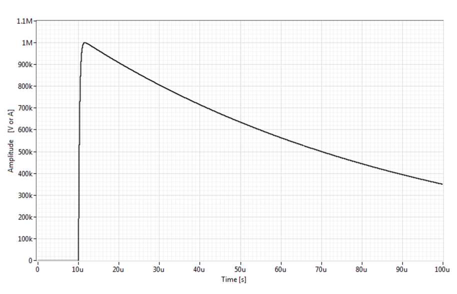
Conclusion: step response a valuable indicator of performance for lightning impulse

The step response depends on the properties of the analog input of the digitizer, more than on the sampling circuits. For this reason, step response will vary decisively when changing input voltage range.

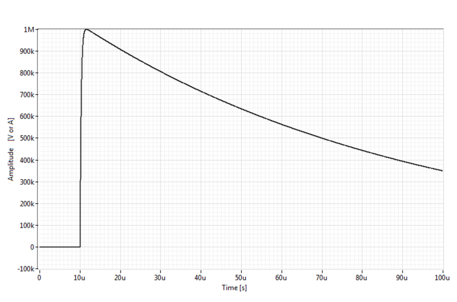
Conclusion: performance must be evaluated for each input range individually

Impact on a lightning impulse

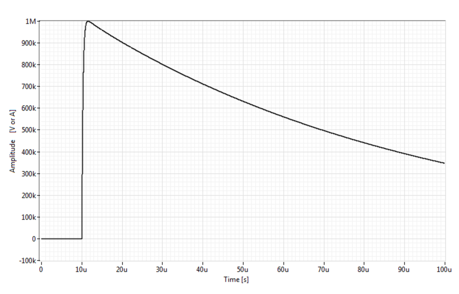
Distortions near peak are visible for certain digitizers and also lead to T_1 errors



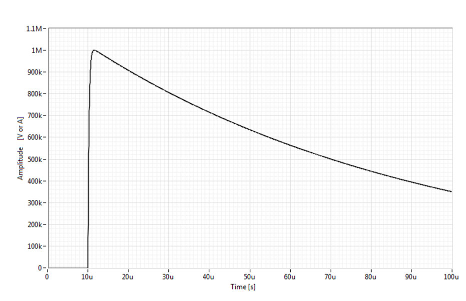
Original curve



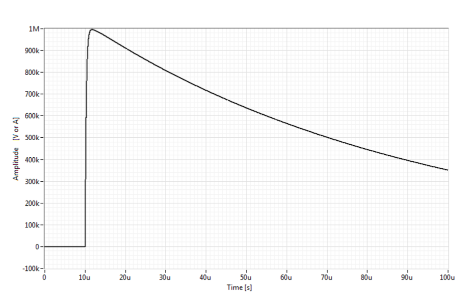
NI PXI 5124 (T_1 -0.1 %) PTB



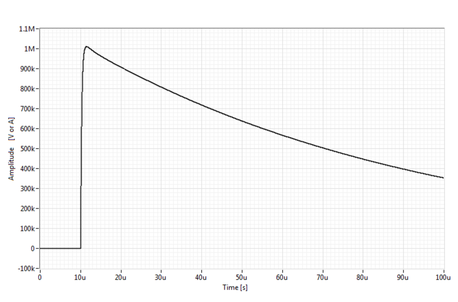
KeySight DSO-S 054A (T_1 +0.1 %)



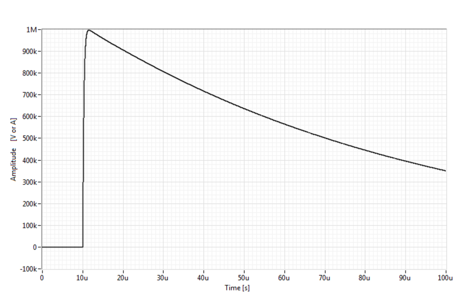
Nicolet 610 (T_1 +1.9 %)



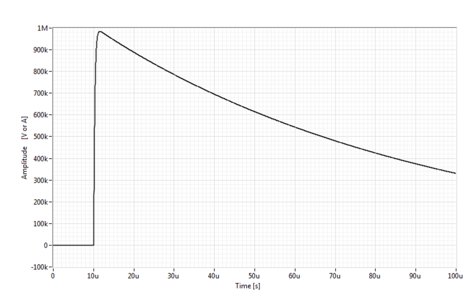
NI PXI 5162 (T_1 +3.1 %)



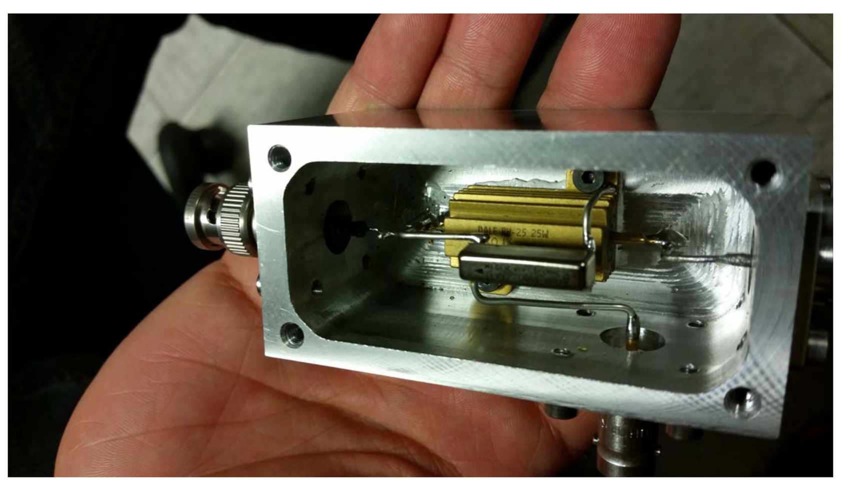
Tektronix DPO7354C (T_1 -4.2 %)



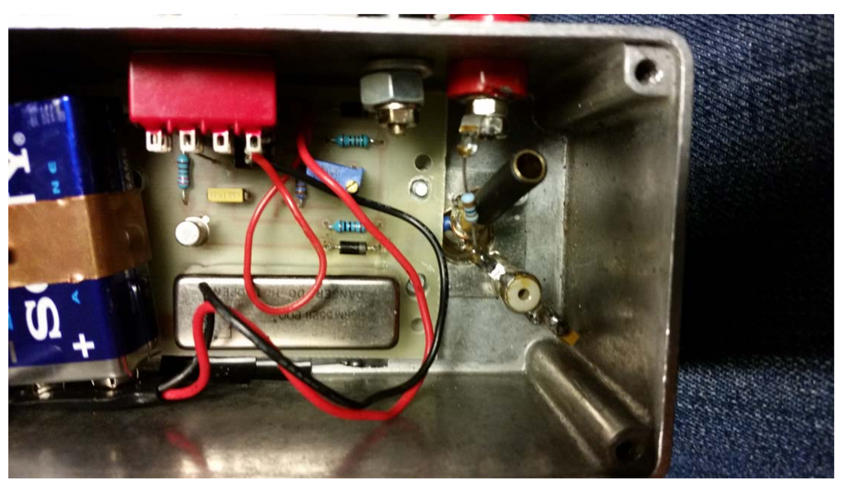
Rhode&Schwarz RTO2044 (T_1 -3.8 %)



Nicolet Accura (T_1 –1.9 %)



PTB step generator



SP step generator

Step response is key characteristic of digitizers for Lightning Impulse