Keysight 3458A Noise Performance

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***Abstract*—This paper describes evaluation of Keysight 3458A noise performance. When 3458A is used for sampling, different sources of noise are added to the sampled signal. Some of them (quantization noise, input front-end noise and IADC noise) are covered in this paper.**

***Index Terms*—Measurement, sampling, quantization noise, 1/f noise, interferences, measurement uncertainty.**

I. INTRODUCTION

Noise is an important parameter in sampling signals, as it limits the attainable standard deviation of the estimated parameters, retrieved from sampled data. It is therefore important to know the limitations of the sampler used for measuring sampled signal parameters at the lowest attainable uncertainties.

When sampling signals, the noise originates from both the signal itself and from the sampler used. The noise originating from the sampler is a combination of quantization noise, thermal noise, differential non-linearity (which behaves much like a noise source when sampling large scale signals), time jitter, and other possible noise sources, some of them contributing to $1/f$ noise [1]. In this article, time jitter and differential non-linearity noise are not covered.

II. THE 3458A NOISE SPECIFICATION

The 3458A noise specification is given in number of digits as a function of aperture time [2]. It can be modeled quite accurately for any range in absolute terms by

$$\sigma_{n,spec} = k_{n,R}\sqrt{{\sigma_J}^2 + {\sigma_Q}^2} \tag{1}$$

The σ_J represents Johnson noise over the effective bandwidth, defined by the roll-off due to the aperture time T_a used

$$\sigma_J = \frac{S_n}{\sqrt{2T_a}} \tag{2}$$

where S_n is 3458A nominal noise spectral density limit, being equal to 130 nV / $\sqrt{\text{Hz}}$. The σ_Q represents quantization noise, given for a 10 V range

$$\sigma_Q = 5\frac{2R_{10V}}{\sqrt{12}\cdot 2^{Res}} \tag{3}$$

where R_{10V} is range voltage, equal to 10 V, Res is the actual 3458A integrating analog-to-digital converter (IADC) resolution in bits, being a function of T_a as given by equation 4 and the factor 5 shows the departure of the one count of the root mean square (RMS) noise resolution, limited by the residual IADC noise form the ideal IADC quantization noise.

TABLE I
3458A DCV RANGE ABSOLUTE NOISE MULTIPLIER

Range	$k_{n,R}$
0.1 V	0.2 (0.07)
1 V	0.2
10 V	1
100 V	20
1000 V	100

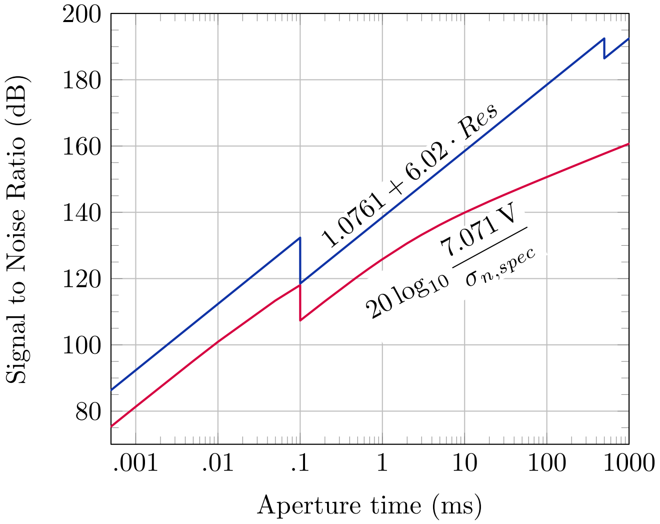

Fig. 1. 3458A manufacturer specification for effective resolution (bottom curve) for 10 V range as defined by Equation (1). Top curve represents the SNR (effective signal to noise ratio for a full scale sine wave input signal) due to internal 3458A IADC resolution alone.

Finally, the $k_{n,R}$ stands for RMS noise multiplier, which is used to account for added noise on ranges which use internal amplification before being converted by IADC. Table I shows RMS noise multipliers for all 3458A DCV ranges. Res can be determined for each aperture time by retrieving the $Scale$ value directly from 3458A using a SCALE? command

$$Res = \log_2\frac{2\cdot Range}{Scale} \tag{4}$$

Figure 1 plots the noise specification and Res as a function of aperture time for 10 V range. The first step change at T_a = 100.1 µs is the result of the change of the IADC input resistor from 10 kohm to 50 kohm. The second step change at T_a = 500.005 ms is the result of the fact that the IADC is reaching the 32 bit resolution and its resolution is obviously scaled down by one bit to accommodate for the results with the longest integrating times.

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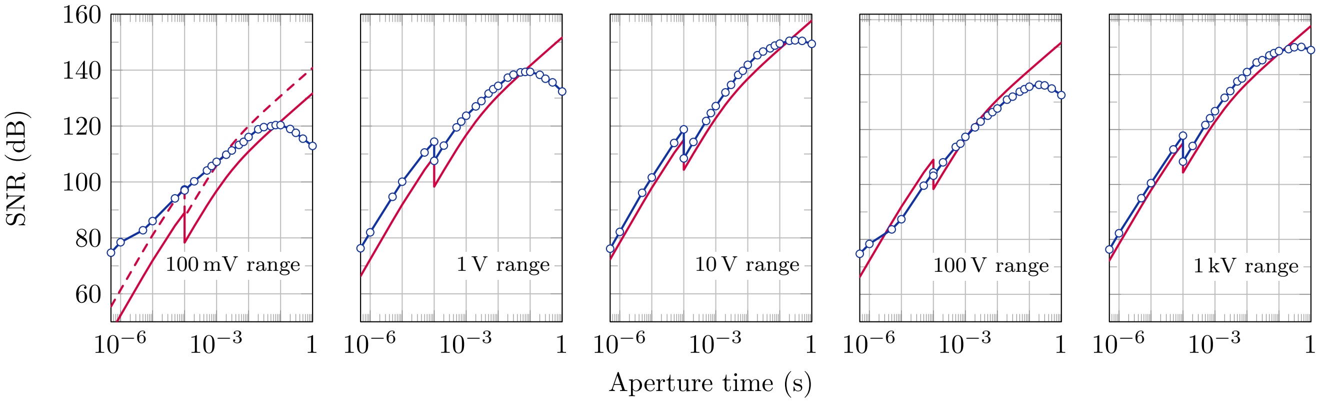

Fig. 2. 3458A input stage and IADC noise as measured using short circuited input, plotted for all ranges for a particular 3458A using circle marks. Solid lines represent 3458A SNR specification for a given range.

III. MEASURING THE 3458A NOISE

The preferred method to measure the 3458A noise in DCV mode would be to apply a pure large signal sine wave with much lower noise content and any spurious signals than the noise contributed by the 3458A itself. This would require an extremely clean signal which was out of the reach when performing measurements for this paper. Instead, a short circuit on the input of the 3458A was used. $N = 5000$ samples were taken at selected aperture times. Auto zero functionality was disabled in all measurements.

From each sampled record, a linear spectral density (LSD) was calculated using the FFT and with the rectangular window

$$LSD(k) = \sqrt{\frac{2}{f_S \cdot N}}\,|X(k)| \qquad (5)$$

where $|X(k)|$ is k-th FFT bin non-scaled spectral amplitude and f_S is sampling frequency. The measured noise amplitude over the measured bandwidth was than obtained using

$$\sigma_n = \overline{LSD} \cdot \sqrt{\frac{f_S}{2}} \qquad (6)$$

where $\overline{LSD}$ is a median value of LSD for all k in a given sampled record.

By using a short circuit at the input terminals of the 3458A, we deliberately circumvented two noise sources, namely one induced by differential non-linearity and the other induced by the sampling time jitter, as they both need an ac signal to appear in the sampled data.

IV. DISCUSSION OF RESULTS

Results relative to a full scale RMS sine wave amplitude at each range are plotted on Figure 2. Dashed line for 100 mV range was proposed in [3] as a more realistic figure to overly pessimistic manufacturer specification. This proved to be correct for aperture times less than 1 ms.

Interesting enough, when repeating measurements with auto zero functionality enabled, the noise performance was consistently reduced by 3 dB on all ranges and for all aperture times. This can be attributed to the fact that a preceding auto zero measurement before each sample taken hold the same amount of noise, which is added to the actual sample noise.

TABLE II
MEASURED $1/f$ NOISE CORNER FREQUENCY AND NOISE SPECTRAL DENSITY. BELOW THESE FREQUENCIES, THE $1/f$ NOISE WILL PREVAIL OVER THE WHITE NOISE IN DCV SAMPLING MODE.

Range	$1/f$ noise corner frequency	white noise SD
100 mV	3.0 Hz	$25\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$
1 V	2.7 Hz	$32\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$
10 V	0.5 Hz	$165\,\mathrm{nV}/\sqrt{\mathrm{Hz}}$
100 V	1.1 Hz	$7.4\,\mathrm{\mu V}/\sqrt{\mathrm{Hz}}$
1000 V	0.5 Hz	$28\,\mathrm{\mu V}/\sqrt{\mathrm{Hz}}$

The noise tends to increase at aperture times above approximately 100 ms, except for 1 V and 10 V ranges, where the noise does not decrease with increasing aperture time. This is the consequence of the $1/f$ noise, which prevails below frequencies given in Table II.

V. CONCLUSION

The measured noise performance can be used to both select the optimum voltage range in certain cases and to select the appropriate aperture time, which is still suitable for the input signal bandwidth being sampled.

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