**PAPER • OPEN ACCESS**

# Synergy and completeness of simple A/D conversion and simple signal processing

View the article online for updates and enhancements.

# Synergy and completeness of simple A/D conversion and simple signal processing

**P Sovilj**[1], **L Zupunski**[1], **B Vujicic**[1], **A Radonjic**[2], **V Vujicic**[3] **and D Kovacevic**[4]

[1]Faculty of Technical Sciences, Trg Dositeja Obradovica 6, Novi Sad, Serbia,
[2]Institute of Technical Sciences of the Serbian Academy of Sciences and Arts, Knez-Mihailova 35/IV, Belgrade, Serbia,
[3]Vladimir Vujicic - Entrepreneur Consultant in Electrical Engineering and Energetics, Mokranjceva 16, Novi Sad, Serbia
[4]Electrical Engineering Institute "Nikola Tesla", Koste Glavinica 8, Belgrade, Serbia.

E-mail: vujicicv@uns.ac.rs

**Abstract.** This paper strictly defines a simple A/D conversion and simple signal processing within the stochastic digital measurement method (SDMM). It is shown that their synergy and completeness optimizes the measurement instrument or a measurement system as a whole. As a result, the instrument or system then has: 1) extremely simple, robust and reliable hardware, 2) extreme accuracy, 3) extreme wide frequency range, 4) the ability to perform extremely simple parallel measurements and processing.

## 1. Introduction

In [1, 2] a substantially different paradigm of digital measurements from the standard sampling method (SSM) was proposed. It is generally described in [3], and a few years later it is called the stochastic digital measurement method (SDMM). The essential difference between SSM and SDMM is that the latter does not presuppose a negligible quantization error. In the SDMM, a quantization error may be even 100 % of full scale [1], but the final result is still precise and accurate. This is impossible to achieve by using SSM. The key consequence of this fact is that the SDMM uses an extremely low resolution A/D converter - one-bit and two-bit resolution. Such A/D converters (flash A/D converters) have extremely simple hardware and, consequently, a small number of systemic error sources (which can be easily identified and eliminated [4]). As a result, instruments using one-bit or two-bit SDMM are extremely accurate. This is the most important advantage of SDMM over SSM.

The processing of one-bit or two-bit data is performed extremely fast and accurate, because it uses integer arithmetic of short word lengths. This has been demonstrated in the first paper in which SDMM was applied [1]. Extremely fast and accurate stochastic A/D conversion allows very accurate measurements of the mean values of the signal and their parameters, primarily signal power and signal harmonics or signal spectrum. A similar approach, in terms of A/D conversion, can be seen in sigma-delta A/D converters. In their case, however, the stochastic occurs in analogue modulator that operates at multi-GHz frequencies. Besides this, measurement samples are taken at lower rates (in the order of MHz), have high resolution (16 bits or more) and moderate accuracy. For this reason, sigma-delta A/D converters use floating-point arithmetic or are based on oversampling sigma-delta modulators and digital decimation filters [5]. In the case of SDMM, the processing speed is identical to the speed of A/D conversion, i.e. it is two orders of magnitude greater than that of the sigma-delta A/D converters.

The only limiting factors are correlational characteristics of the random number generator, as well as resolution and accuracy of the applied D/A convertor.

On the other hand, there is the issue of reconstructing a signal which is digitized with a low-resolution A/D converter. Recently, this issue became important in measuring of the probing voltage of high-voltage isolation materials. In [6] it is shown how a signal that is previously measured with a two-bit SDMM can be reconstructed. In this way, the topic related to the measurement and reconstruction of a signal using a low-resolution SDMM is completely rounded off.

All the above mentioned indicates that there is a synergy between simple A/D conversion and simple processing, and their completeness in SDMM. The final results are extremely simple, accurate, fast, robust and reliable instruments that are used in laboratories and industry. In this paper they are strictly defined and elaborated.

## 2. Basic Definitions and Schemes

### 2.1. Simple A/D conversion

This section provides strict definitions of simple A/D conversion and simple processing within a simple SDMM, as well as appropriate hardware schemes.

*One-bit A/D conversion.* The basic condition is that the measured signal is non-negative. The input signal is an analog sum of the measured analog signal (AI) and an analog uniform random noise ($h$). The average value of $h$ is zero, whereas its absolute value is less than or equal to half of the quantum $2g$. The quantum, on the other hand, is equal to the range of one-bit A/D converter. As a result, the circuit generates two signals (Figure 1a): digital output signal (DO1) and overflow bit signal (OF).
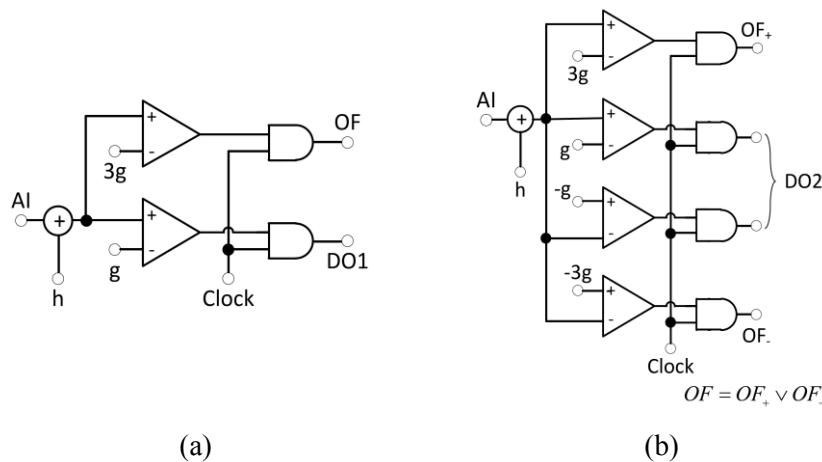


(a)                                                        (b)

**Figure 1**. Simple A/D conversion: (a) one-bit and (b) two-bit.

*Two-bit A/D conversion.* In the case of a two-bit A/D conversion, the input signal is again an analog sum of the measured signal AI and an analog uniform random noise $h$. Both these signals must satisfy the same conditions as in the previous case (Figure 1b). The only difference is that, in this case, the quantum $2g$ is equal to the half of the range of a two-bit A/D converter, i.e. $\pm 2g$.

### 2.2. Simple signal processing

Simple signal processing is one-bit or two-bit processing. The basic processing operations are multiplications and accumulations. They are performed by the multiply and accumulate (MAC) block.
*Time domain.* In the time domain, both MAC operands are the samples of the input signals.

One-bit MAC scheme: As the digital outputs of an A/D converter are 0 or 1, their product is also 0 or 1. Hence, in this case, the multiplier is an ordinary AND-gate, while the accumulator is an ordinary binary counter. The basic scheme of one-bit time domain MAC block is given in figure 2a.
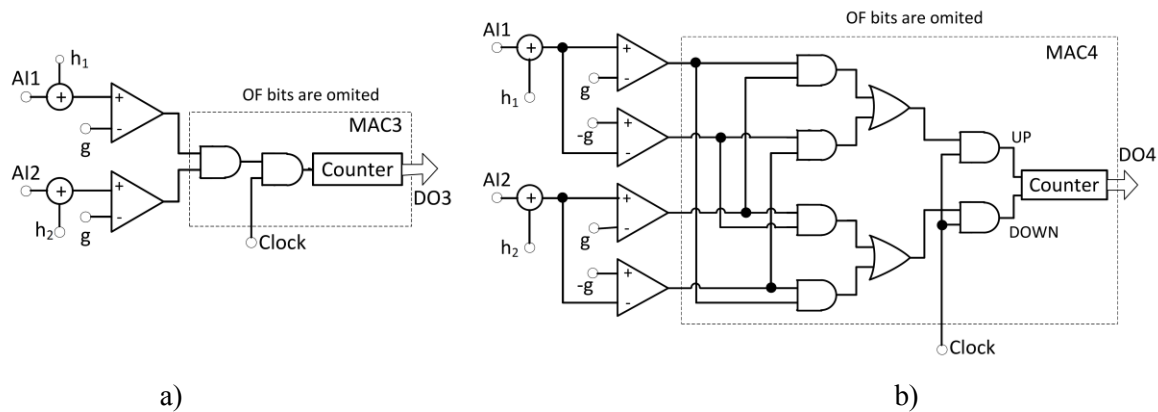
a)                                                                  b)

**Figure 2.** MAC scheme in time domain: (a) one-bit and (b) two-bit.

Two-bit MAC scheme: In this case, the digital outputs of an A/D converter are - 1, 0 or 1. As a result, their product is also - 1, 0 or 1. So, in this case, the multiplier consists of four AND-gates and two OR-gates, whereas the accumulator is a binary up/down counter (Figure 2b).

*Transformation domain*. In the transformation domain, one MAC operand is the sample of the input signal, while the other is the sample of a dithered base function (DBF) from an orthogonal normed function set (the most often from the Fourier set).

One-bit MAC scheme: The digital output of an A/D converter is 0 or 1, while the sample of a DBF may have values - 1, 0 or 1. Hence, in this case, the multiplier consists of one AND-gate, while the accumulator is a binary up/down counter. The basic scheme of one-bit transformation domain MAC block is given in figure 3a, [2], [7].

Two-bit MAC scheme: In this case, both the digital output of an A/D converter and the sample of a DBF may have values - 1, 0 or 1. Hence, their product is also - 1, 0 or 1. So, in this case, the multiplier consists of four AND-gates and two OR-gates, while the accumulator is a binary up/down counter as it is shown in figure 3b and [7].
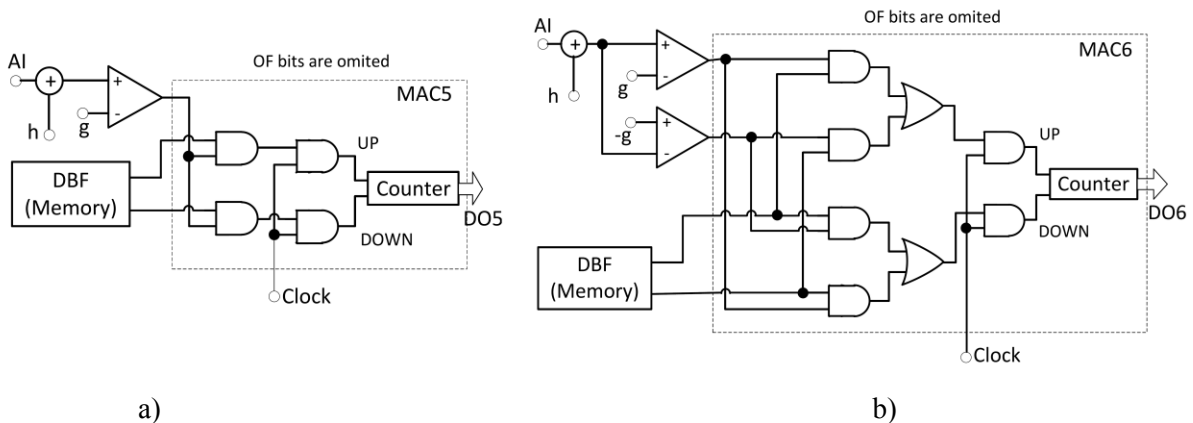
a)                                                                  b)

**Figure 3**. MAC scheme in transformation domain: (a) one-bit and (b) two-bit.

## 3.  Current Application of Simple SDMM

In the last 20 years, simple SDMM is intensively applied in the area of measurements in a power grid. The following quantities are measured by simple SDMM-based instruments: voltage RMS, current RMS, power grid frequency, active power, and reactive power (Budeanu's, Fryze's and that recommended by IEEE Std. 1459-2010). Very difficult conditions in the substations were the best test for the reliability and robustness of all SDMM-based instruments. One of them is the quadruple three-phase power analyzer called MM4 (Figure 4). It can measure electric power and energy according to IEEE Std. 1459-2010. The heart of this instrument is two-bit MAC scheme in time domain (Figure 2b) and two-bit MAC scheme in transformation domain (Figure. 3b). The main processing block is a two-

bit stochastic digital DFT processor [7], which is realized by employing several two-bit MAC schemes in parallel. Despite being extremely simple, this instrument has an accuracy of 0.2 % of full scale. In the following areas, the authors and associates have also applied a simple SDMM: measurement of biomedical signals, temperature measurement, dose measurement, wind energy measurement, and measurement on the graphene.



**Figure 4**. Two-bit quadruple three-phase power analyzer (MM4).

## 4. Discussion - Synergy and Completeness

The usual way of considering A/D conversion and signal processing is their complete mutual independence. This approach leads to the optimal design of each of them. However, is the instrument or measuring system, based on these, also optimal? The answer is no! This is indicated by the statement of the famous Pontryagin theorem: "The optimum of the system never corresponds to the optimum of any of its subsystems." [8]. Practical generalization of this theorem is as follows: "Optimizing the outcome of a subsystem will in general not optimize the outcome of the system as a whole" [9]. This means that the instrument or measuring system optimization has no alternative, and it is a central problem in the science of measurements. Because of this, a simple SDMM treats at the same time both A/D conversion and signal processing. The outcome is impressive: 1) extremely simple, robust and reliable hardware, 2) extreme accuracy, 3) extremely wide frequency range, 4) extremely simple parallel measurements, 5) extremely simple parallel processing and 6) extremely simple ASIC design verification. In other words, the application of a simple SDMM leads to optimal performance, i.e. to the optimization of the instrument as a whole. This has been confirmed in the previous research and implementation of a simple SDMM [1-4, 7]. This completes the implementation of a simple SDMM in the instrumentation. In addition, it confirms the synergy and completeness between simple A/D conversion and simple signal processing. The most recent and most complete evidence of all these claims is given in detail in recently published paper [7].

## 5. Conclusion

This short essay presents the synergy and completeness of simple A/D conversion and simple signal processing within the simple stochastic digital measurement method. It was shown that the application of this method allows multiple optimization of the measuring instrument or measuring system as a whole. Specifically, the instrument or measuring system then has: 1) extremely simple, robust and reliable hardware, 2) extreme accuracy, 3) extreme wide frequency range, 4) the ability to perform extremely simple parallel measurements and processing. These features have been confirmed in all our studies, especially in the most recent ones.

## References

[1]    Vujicic V, Milovancev S, Pesaljevic M, Pejic D and Zupunski I 1999 *IEEE Trans. Instrum. Meas.* **48** 467

[2]     Santrac B, Sokola M, Mitrovic Z, Zupunski I and Vujicic V 2009 *IEEE Trans. Instrum. Meas*.
        **58** 3434

[3]     Vujicic V, Zupunski I, Mitrovic Z and Sokola M 2009 *Proc. XIX IMEKO World Congress
        Fundamental and Applied Metrology (Lisbon)* pp 1128-32

[4]     Urekar M, Pejic D, Vujicic V and Avramov-Zamurovic S 2017 *Measurement* **98** 139

[5]     Janssen E and van Roermund A 2011 *Look-ahead based Sigma-Delta Modulation* (New York:
        Springer Science + Business Media)

[6]     Vujicic V, Zupunski L, Sovilj P and Radonjic A 2017 *Proc. 17th IEEE Int. Conf. Smart
        Technologies-EUROCON 2017 (Ohrid)* pp 829-31

[7]     Pejic D, Naumovic-Vukovic D, Vujicic B, Radonjic A, Sovilj P and Vujicic V 2018
        *Measurement* **124** 494

[8]     Pontryagin L, Boltyanskii V, Gamkrelidze R and Mishchenko E 1962 *The Mathematical Theory
        of Optimal Processes* (New York: John Wiley)

[9]     Heylighen F 1999 *Principia Cybernetica Web* (Principia Cybernetica, Brussels) URL:
        http://pespmc1.vub.ac.be/SUBOPTIM.html