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Measurement in Fourier domain – a Natural Method of Big Data Volume Reduction

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***Abstract*—The paper presents an idea of a measurement in a Fourier domain by a means stochastic digital measurement method (SDMM) as a natural and logical way to reduce the amount of big data in for processing in real time. The measurement method is explained and its application to the power and energy measurements in the power grid is briefly described.**

***Keywords*—Stochastic measurements, Fourier coefficients, Big Data, Signal Power.**

I. Introduction

Our recent research indicates that it is possible to realize a discrete Fourier transform (DFT) processor that is capable of a fully parallel on-line computation of thousands of Fourier coefficients from an 1-bit or 2-bit array of stochastically dithered samples of the measured signal [1].

II. The Principle of Operation

The principle of operation is illustrated in Figures 1 and 2. Figure 1 shows a multiplication and accumulation (MAC) block, in which a signal f_1 (with superimposed noise n) is digitized, multiplied with a pre-stored signal f_2 and the product integrated, all within a single processor cycle. At the end of the measurement interval, division of the Counter 1 value (the integral) by the Counter 2 value (the number of samples) gives the appropriate Fourier coefficient.

Figure 2 shows a parallel processing of f_1 by $2M$ MAC blocks, thus obtaining M Fourier harmonics at the end of the measurement interval.

Every pair of coefficients (a_j, b_j) defines a signal harmonic during the measurement interval. The harmonic amplitude is an inherent harmonic descriptor for the measurement interval. The above facts have three key consequences:

1. Weierstrass approximation theorem [2] and its trigonometry polynomial are no longer relevant and are replaced by the Fourier series (integral) [3].
2. Fourier analysis is now not limited to periodic signals only, i.e. treatment of arbitrary signals becomes practically viable, and
3. There is a problem of on-line determination of the validity of a specific (a_j, b_j) pair, i.e. of a harmonic j.

Due to the consequence 1, the input signal initial value does not need to be same as the end value – these values can be arbitrary as long as they are finite. Therefore the Bernstein polynomials [4] as well as generic polynomial approximations become much less relevant.

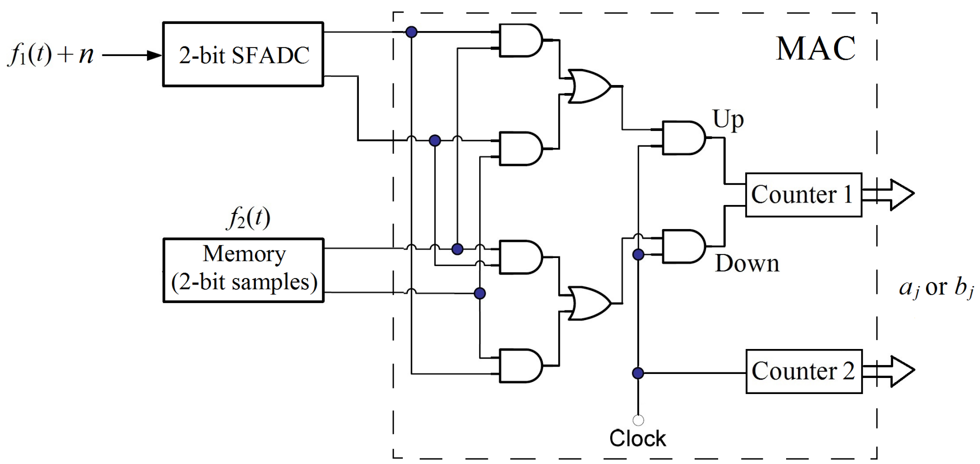

Fig. 1. An optimal scheme for measuring a single Fourier coefficient with a two-bit stochastic flash A/D converter.

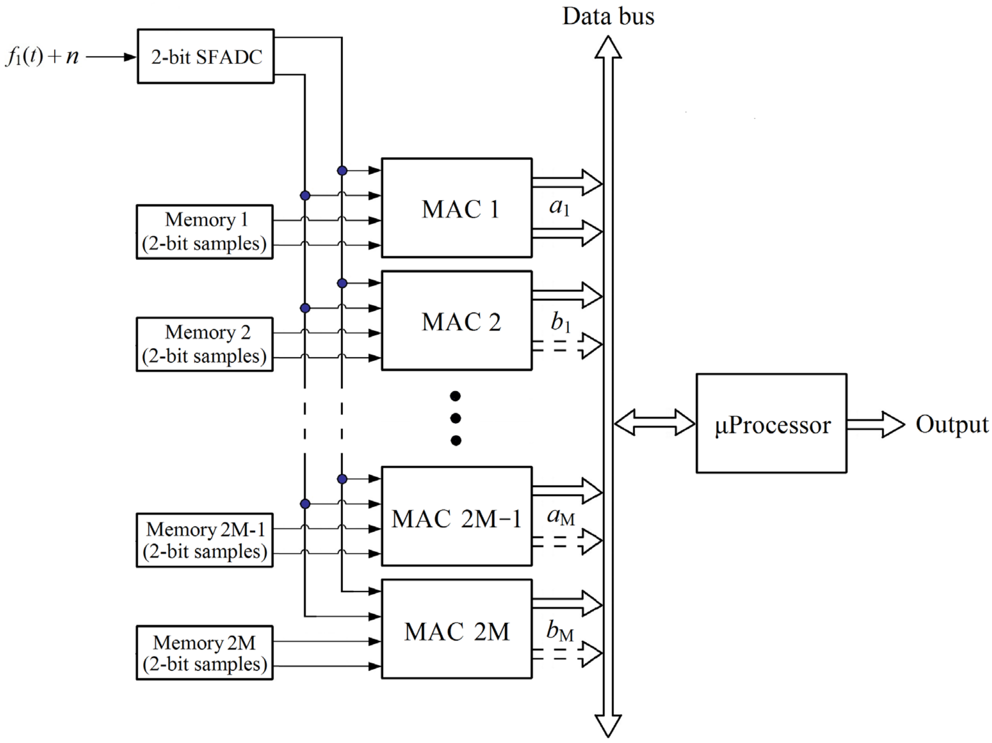

Fig. 2. A stochastic DFT processor for measuring 2*M* Fourier coefficients.

The Consequence 2 enables analysis of any continuous signal with a finite number of first-order discontinuities, via piece-wise analyses, on an arbitrary time interval [3].

The Consequence 3 indicates that an efficient and smart algorithm to quickly estimate the validity of a specific (*aj*, *bj*) pair is needed. Such an algorithm can be developed on the basis of a detailed insight into the hardware structure of the presented DFT processor. It features a simple and robust design, as well as accuracy, precision and speed [5]-[8]. The performance of first versions of such an algorithm is promising and encouraging.

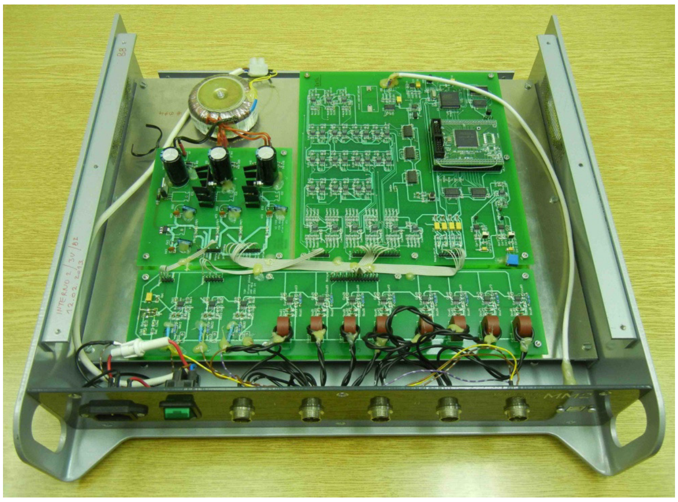

Fig. 3. A two-bit double three-phase power analyzer implemented in FPGA technology.

If such a device entailing (1-bit or 2-bit A/D converter with DFT processor and fast estimator of harmonic's validity) is to be used for processing of big data, it is natural to process and store only the important data. This means that overall volume of processing as well as memory needs to be minimised. This is not the only benefit of the proposed approach/method. The Fourier coefficients in the DFT processors, shown in Figure 2, are calculated in counters that have an inherent pipelining feature and do not suffer from carry propagation problems [9]. This can enable high data processing speeds. It is possible, therefore, to design a custom processor, tailored for the described use. The use of FPGA [10] offer many possibilities for the implementation of both prototypes, as well as a batch production. Some additional Internet of Things requirements, such as monitoring and control of household [11], may justify the use of ASIC implementations.

It should be noted that a single datum that is a measure of the observed signal (for processing and/or storage) is not a real number any more. A quantum of signal information is dominantly a complex number in a frequency domain that also contains information on its validity over the observation time interval. A finite set of such data that include the "validity" faithfully describe the signal spectrum over the measurement interval.

Signal reconstruction and/or further processing of such data is not a problem, because the equivalency of time domain and frequency (Fourier) domain is well known. The Inverse Fast Fourier Transformation (IFFT) implemented in a large number of software tools can be utilised for transition from Fourier to time domain. Our research has confirmed that use of FPGA

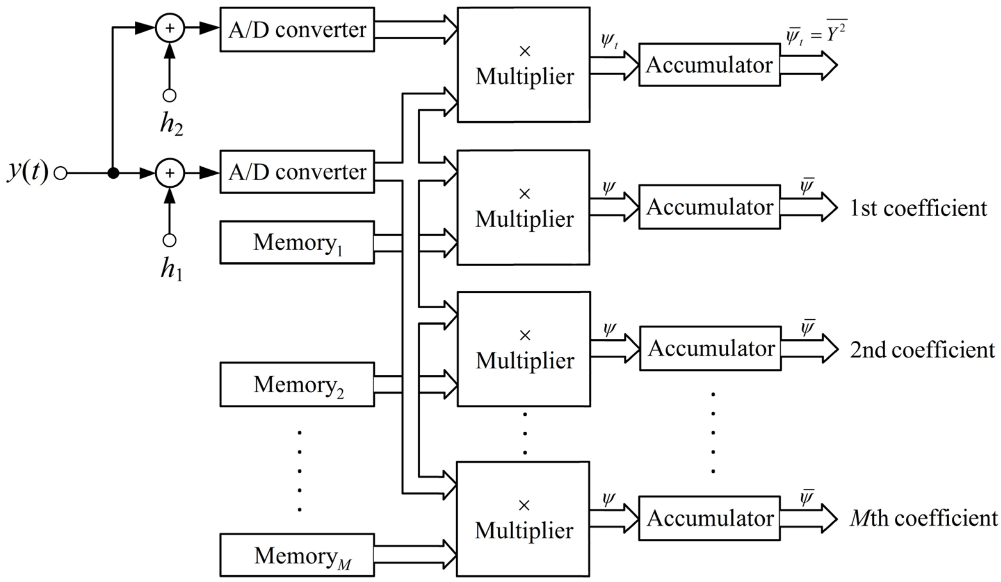

Fig. 4. A hardware scheme for on-line determination of the validity of a specific (a_j, b_j) pair, i.e. of a harmonic j.

technology enables fast and efficient experimental validation of the new approaches proposed here. Based on it, powerful measurement devices, such as the three-phase analyser and energy meter shown in Figure 3, have been developed.

Several additional fine details need to be further explored in this synergic frequency-time treatment of signal measurement and processing to make it equally efficient in both domains. We need to find answers to the following questions:

a. an optimal number of significant harmonics,
b. optimal sampling frequency of the reconstructed signal,
c. an acceptable number/size of first-order discontinuities,
d. an optimal length of the measurement interval,
e. an optimal precision of the reconstruction, etc.

The main goal of the paper is to define a role for SDDM methodology in the reduction of the volume Big Data (BD) that is independent from the BD generator, which leads to the need for a standard sampling method. The underlying motivation is based on the fact that SDDFT output can process data in real time and immediately provide naturally weighted components. In other words, non-critical results can be immediately discarded and only the critical ones are stored.

As an example of defining a specific problem and finding its optimal solution, let us consider case a): the uppermost channel in the instrument shown in Figure 4 measures the average signal power over the measurement time interval. Other channels shown in Figure 4 measure M Fourier coefficients over the same time interval. When all the coefficients are squared and then sorted in a descending order, they represent the average signal power. It is possible to approximately calculate, within a pre-defined accuracy, the average signal power by including only K ($K < M/2$) most significant harmonics. The optimisation criterion is to determine the lowest number of harmonics that satisfy the prescribed accuracy level. This criterion is common in measuring power and energy in a power grid. Similarly, problems denoted under b), c), d), e) require a clear initial brief definition in order to reach a solution. These are currently under research.

III. Conclusion

The paper presented the principle of operation of a novel approach to reducing the big data volume by means of a stochastic digital measurement method. This can be achieved by measuring harmonics that are naturally weighted, which opens a possibility to determine harmonics' validity in real time, before further processing and/or storage. This is not possible to do in time domain with data that can be obtained using the standard sampling method approach.

This novel approach opens up an array of new but solvable problems. One of these – determining an optimal number of harmonics needed in power measurements – is solved and described in the paper. The use of FPGA technology offered a great possibility for implementation and an efficient experimental verification.

The important characteristics of harmonics measurements are the adaptive precision and high accuracy, stemming from the elimination of systemic errors in hardware. Since the measurement results obtained by the proposed approach depends on the signal waveform, a further research effort will be invested in the development of applications for specific signal classes.

The use of IFFT provides simple and fast transition from frequency to the time domain – especially when a small number of significant harmonics is involved – thus enabling the use of a number of software solutions tailored for time-domain processing.

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