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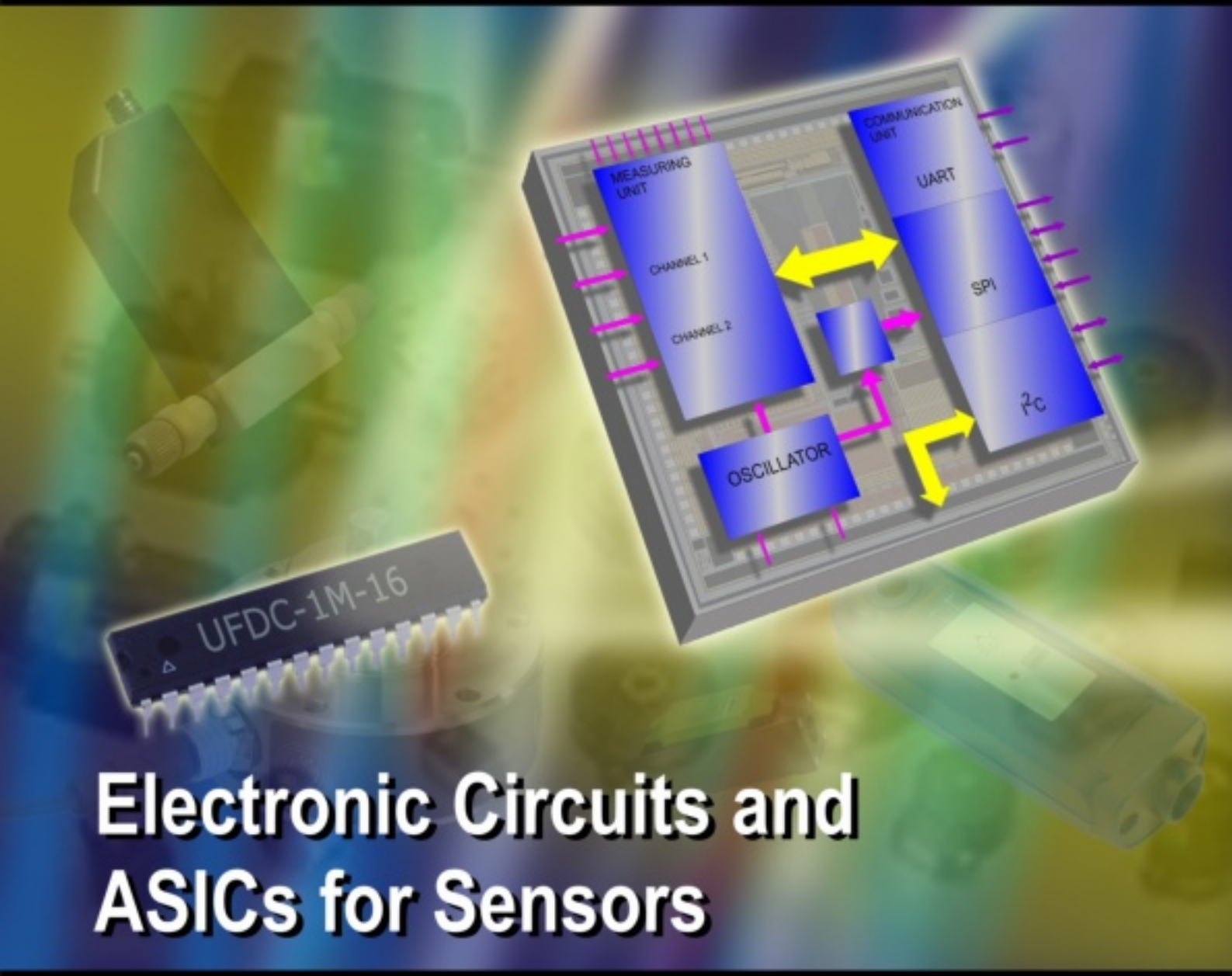

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High-Speed Universal Frequency-to-Digital Converter for Quasi-Digital Sensors and Transducers

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Abstract: New fast, accurate universal integrated frequency-to-digital converter (UFDC-1M-16) is described in the article. It is based on the novel patented modified method of the dependent count and has non-redundant conversion time from 6.25 μs to 6.25 ms for 1 to 0.001 % relative errors respectively, comparable with conversion time for successive-approximation and Σ-Δ ADC. The IC can work with different sensors, transducers and encoders, which have frequency, period, duty-cycle, PWM, phase shift, pulse number, etc. output. *Copyright © 2007 IFSA.*

Keywords: Modified Method of the Dependent Count, Universal Frequency-to-Digital Converter, UFDC-1M-16, Quasi-Digital Sensors

1. Introduction

Many applications of quasi-digital sensors with frequency, period, duty-cycle, PWM, phase shift, time interval, pulse number, etc. outputs, measuring and data-acquisition systems for frequency-time parameters of signals require a high conversion speed for such parameters to digital. The conversion time should be commensurable with the conversion speed for modern analog-to-digital converters (ADC).

Simple pulse (direct method) or period (indirect method) counting techniques based on classical frequency-to-digital conversion methods essentially limited the conversion rate and/or dynamic range. Accuracy was decreased when conversion rate was increased. Typical accuracy at 100-300 conversions per second was 12 bits [1]. The usage of advanced methods for frequency-to-digital conversion, for example, the method of the dependent count [2-6] lets achieve a non-redundant

conversion time, suitable for many applications, however, high-speed applications such as measuring and data acquisition systems need additional measures to increase the conversion speed.

2. Advanced Method for Frequency-to-Digital Conversion

The solution of the mentioned technical problem is based on the proposed and patented advanced modified method of the dependent count for frequency-to-digital conversion and developed on its basis an integrated universal frequency-to-digital converter (UFDC-1M-16) [7].

The modified method of the dependent count like the early proposed method of the dependent count lets convert frequency f_x, which exceeds the reference frequency f_0: ($f_x >> f_0$). But in comparison with the method of the dependent count, the initial stage for determination what frequency is greater ($f_x <> f_0$) is not necessary, as well as it is not necessary to change an equation for further frequency (period) calculation.

In addition to the capability to measure frequency $f_x >> f_0$ the modified method of the dependent count has the following main advantages: constant quantization error δ_q in all frequency range (from f_{xmin} to f_{xmax}), programmable relative error δ and non-redundant conversion rate t_{conv}. The conversion rate for the modified method of the dependent count can be calculated according to the following equation:

$$\begin{cases} t_{conv} = \dfrac{1}{f_x} \quad if \quad \dfrac{N_\delta}{f_0} \prec T_x \\ t_{conv} = \dfrac{N_\delta}{f_0} + (0 \div T_x) \quad if \quad \dfrac{N_\delta}{f_0} \geq T_x \end{cases}, \tag{1}$$

where $N_\delta = 1/\delta$ is the number proportional to the required programmable relative error δ; $T_x = 1/f_x$ is the period of converted frequency.

3. High-Speed Universal Frequency-to-Digital Converter UFDC-1M-16

At the same chosen relative error, in order to reduce the conversion rate t_{conv} the reference frequency f_0 should be increased. So, in comparison with the UFDC-1 [8], which has the internal reference frequency f_0=500 kHz, the UFDC-1M-16 has internal reference frequency f_0=16 MHz.

A measurement time T_{meas} for the UFDC-1M-16 includes three main components: conversion rate (t_{conv}), communication (t_{comm}) time and calculations (t_{calc}) time:

$$T_{meas} = t_{conv} + t_{comm} + t_{calc} \tag{2}$$

According to (1) the conversion rate is $t_{conv}=1/f_x$ only for the frequency range up to 160 Hz at maximum possible relative error δ=1 % and 160 kHz at minimum possible relative error δ=0.001 %.

The communication time for a slave communication mode (RS-232 interface) can be calculated according to the following equation:

$$t_{comm} = 10 \cdot n \cdot t_{bit}, \tag{3}$$

where t_{bit} = 1/300, 1/600, 1/1200, 1/2400, 1/4800, 1/9600, 1/14400, 1/19200, 1/28800 or 1/38400 is the time for one bit transmitting; n is the number of bytes (n=13÷24 for ASCII format).

As usually, at the right chosen of baud rate (maximum possible for a certain application) the $t_{comm} \leq t_{conv.}$ For example, the communication time at 38400 baud rate will be t_{comm} = (0.0034 ÷ 0.00625) s.

The communication time for SPI interface should be calculated as:

$$t_{comm} = 8 \cdot n \cdot \frac{1}{f_{SCLK}}, \tag{4}$$

where f_{SCLK} is the serial clock frequency, which should be chosen for the UFDC-1M-16 in the range from 100 to 500 kHz; n=12÷13 is the number of bytes. The number n is dependent on measurement result format: BCD (n=13) or binary (n=12).

The communication standard mode speed for I^2C interfaces can be determined according to the following equation:

$$t_{comm} = 8 \cdot n \cdot \frac{1}{f_{SCL}}, \tag{5}$$

where f_{SCL} is the serial clock frequency, which should be equals to 100 kHz for the UFDC-1M-16; n=12÷13 is the number of bytes for measurement result: BCD (n=13) or binary (n=12).

The calculation time depends on operands and is as usually $t_{calc} \leq 4.5$ ms.

The dependence of conversion rates t_{conv} from the relative error δ for the UFDC-1 and IC UFDC-1M-16 are shown in Figure 1 (a) and (b) respectively. The two-channel UFDC-1M-16 has a wide frequency range from 1 Hz to 7.5 MHz (120 MHz with prescaling), programmable relative error from 1 to 0.001 % at appropriate conversion rate from 6.25 μs to 6.25 ms, I^2C, SPI and RS-232 communication interfaces. Due to the programmable relative error, the conversion time and accuracy can be optimized for specific applications. Relative errors and appropriate conversion times are shown in Table 1.

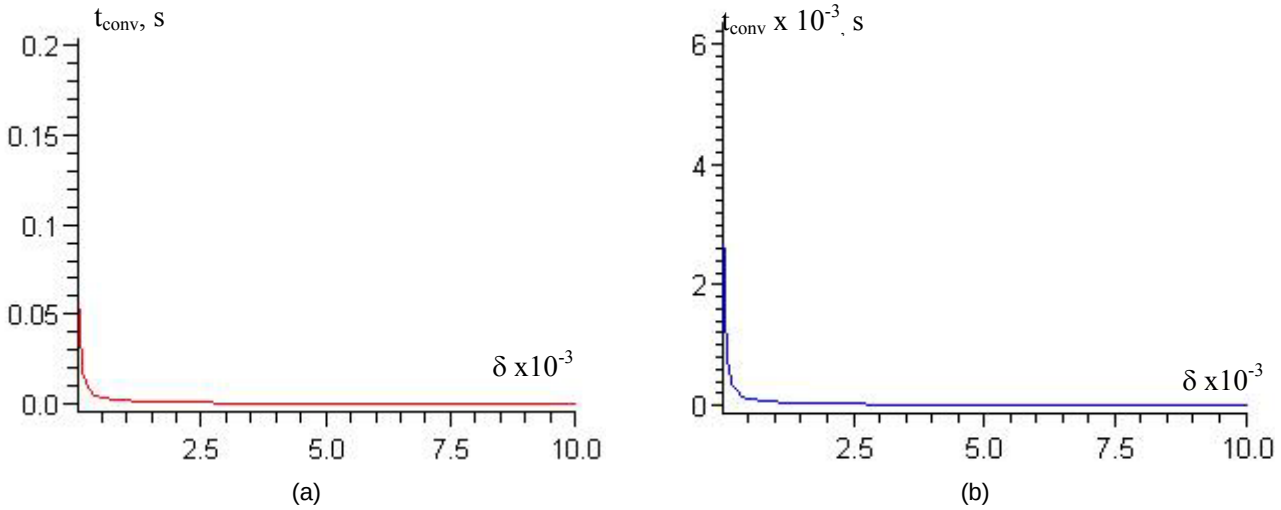

Fig. 1. Conversion Rate vs. Relative Error for UFDC-1 (a) and UFDC-1M-16 (b) at $N_\delta/f_0 \geq T_x$.

Table 1. Relative errors and appropriate conversion times.

Relative error, δ_x %	$N_\delta = 1/\delta_x$	**UFDC-1** (*at* f_0=500 kHz)	**UFDC-1M-16** (*at* f_0=16 MHz)
		T_{conv}, **s**	
1	100	0.0002	0.00000625
0.5	200	0.0004	0.0000125
0.25	400	0.0008	0.000025
0.1	1000	0.002	0.0000625
0.05	2000	0.004	0.00125
0.025	4000	0.008	0.0025
0.01	10000	0.02	0.00625
0.005	20000	0.04	0.00125
0.0025	40000	0.08	0.0025
0.001	100000	0.2	0.00625

Let's compare the conversion time of UFDC-1M-16 based on the modified method of the dependent count with conversion times, which can be achieved by using any classical or other advanced conversion methods described in [6]. For indirect counting method, with the reference frequency f_0=16 MHz, relative error 0.001 % and conversion time that does not exceed one period T_x the frequency range will be essentially limited by ≤ 160 Hz. In case of direct counting technique, for the same relative error and the gate time 6.25 ms it will be possible to convert only frequencies from the range $f_x \in$ [16 kHz ÷ 16 MHz] and for all relative error except δ_x = 0.001 % the conversion time will be redundant. For advanced conversion methods, for example, reciprocal, ratiometric, M/T, constant elapse time, single- and double buffered, DMA [6], at the reference frequency f_0=16 MHz and gate time T_0= 6.25 ms the conversion time also will be redundant for all relative error from the Table 1 except δ_x = 0.001 %. In other words, the conversion time will be the same - 6.25 ms for the relative error 0.001 % and relative error 1 %.

4. Conclusions

Experimental and modeling results confirm high metrological performances for novel integrated universal frequency-to-digital converter (UFDC-1M-16). Its conversion time is non-redundant, adaptive, minimum possible and in 32 times less than in the previous model of IC UFDC-1.

Due to developed modified methods of the dependent count for frequency-to-digital conversion the conversion rate (6.25 μs to 6.25 ms) is programmable, non-redundant, shorter than for pulse counting technique and comparable with successive-approximation and Σ-Δ ADC.

The UFDC-1M-16 will be available in 28-lead Plastic Dual Inline Package (PDIP), compact 32-lead TQFP package and in a wafer form for embedded applications. The IC will be introduced to the market at the second part of 2007.

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Guide for Contributors

Aims and Scope

Sensors & Transducers Journal (ISSN 1726- 5479) provides an advanced forum for the science and technology of physical, chemical sensors and biosensors. It publishes state-of-the-art reviews, regular research and application specific papers, short notes, letters to Editor and sensors related books reviews as well as academic, practical and commercial information of interest to its readership. Because it is an open access, peer review international journal, papers rapidly published in *Sensors & Transducers Journal* will receive a very high publicity. The journal is published monthly as twelve issues per annual by International Frequency Association (IFSA). In additional, some special sponsored and conference issues published annually.

Topics Covered

Contributions are invited on all aspects of research, development and application of the science and technology of sensors, transducers and sensor instrumentations. Topics include, but are not restricted to:

- Physical, chemical and biosensors;
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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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