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# A Novel Linearization Method of Sin/Cos Sensor Signals Used for Angular Position Determination

**Dragan Živanović**†, **Jelena Lukić*** and **Dragan Denić***

**Abstract** - In this paper a novel method for angular position determination using sensors with sin / cos output and without an excitation signal, is presented. The linearization of the sensor transfer characteristic and digitalization of the measurement results are performed simultaneously with a goal to increase the measurement resolution. This improvement is particularly important for low angular velocities, and can be used to increase the resolution of incremental Hall, magnetic and optical sensors. This method includes two phases of sin/cos signal linearization. In the first linearization phase the pseudo-linear signal is generated. The second linearization phase, executed by the two-stage piecewise linear ADC, is an additional linearization of the pseudo-linear signal. Based on the LabVIEW software simulations of the proposed method, the contribution of each processing phase to a final measurement error is examined. After the proposed method is applied within $2\pi$ [rad] range, the maximal nonlinearity is reduced from 0.3307 [rad] (18.9447°) to $3\cdot10^{-4}$ [rad] (0.0172°).

**Keywords**: Angular position determination, Half of the quadrant detection, Linearization, Sin/cos signals processing

## 1. Introduction

To determine the angular position or the angular displacement of a rotating object, it is necessary to provide an adequate measurement transducer that will convert the measured value into an electrical signal suitable for further processing. Transducers that are commonly used for this purpose are different types of magnetic and optical rotary encoders and resolvers [1]. Due to the changes of the measured parameter, these sensors generate sin/cos signals. There are linear position sensors based on Hall effect that, in a pair, generate sin/cos signals [1]. In comparison to resolvers, which require an excitation signal of an order of a couple of kHz [2-6], the rotary encoders and the sensors based on Hall effect do not need this signal to work properly. In this paper, a special attention will be devoted to processing of the sin/cos signals generated by the sensors with no excitation signal. Although these sensors are often incremental, for very low angular velocities, it is important to increase the resolution of the absolute position determination. Using the interpolation electronics for further processing of the sin/cos signals, more accurate information about the absolute position, within already determined incremental position, can be obtained [7].

Due to high sensor nonlinearity near to the maximums of sin/cos signals, even for significant changes of the input angle, the changes in the output voltage can be very hard to detect. For example, if the maximal voltage at the sensor output is 1 [V], and if the input angle is changed for 5°=0.087 [rad], i.e. from zero to 0.087 [rad], the output voltage will change for $dU$=1 [V]*(sin(0.087 [rad])-sin (0 [rad]))=87 [mV]. If the same change in input angle of 0.087 [rad] is occurred near $\pi/2$, the difference caused in output voltage is equal to $dU$=1 [V]*(sin($\pi/2$))-sin($\pi/2$-0.087 [rad]))=3.8 [mV], i.e. almost 23 times less. In this case any additional noise or signal amplitude distortion will easily cover sensor output signal changes. Due to low sensor sensitivity to angle changes, the measurement accuracy is low as well. For this reason, in order to increase the measurement accuracy, it is necessary to do the linearization of the sensor transfer characteristic, i.e. to do the linearization of the sin/cos signals generated by the sensors.

By modifying and combining the sin/cos signals, a pseudo-linear signal can be obtained and further processed towards determination of the angular position [2, 4-6]. As it was done in [4, 5], the pseudo-linear signal is obtained by combining those segments of the sin/cos signals that are characterized by a satisfying linearity. For the proper functioning of this method, the information about the quadrant position ($\pi/2$ [rad] in width) of the measured angle has to be provided. In this paper we use the same method for obtaining the pseudo-linear signal as in [4, 5], except that instead of the current quadrant position of the input angle the half of the quadrant is determined. Since the sine and cosine signals are mutually phase shifted by $\pi/2$ we can determine the rotation direction of the rotating object [1].

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† Corresponding Author: University of Niš, Faculty of Electronic Engineering, Serbia. (dragan.zivanovic@elfak.ni.ac.rs)
* University of Niš, Faculty of Electronic Engineering, Serbia. ({jelena.lukic, dragan.denic}@elfak.ni.ac.rs)

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To overcome the disadvantages of time consuming and processor demanding digital linearization methods, and to provide simpler, but more flexible method comparing to analog linearization methods we propose a novel linearization method, in this paper. As mentioned above, this method starts with obtaining the pseudo-linear signal and continues with its further linearization, simultaneously with A/D conversion in a two-stage piecewise linear converter [8, 9]. The essence of this novel linearization method represents the fact that the transfer characteristic of the first stage A/D converter is inversed sensor transfer characteristic. In this way, the digital code obtained at the A/D converter output is linearly dependent on the input angle. Therefore, designing of the A/D converter basically comes down to programming of the transfer characteristic of its quantizer [10]. Therefore, the quantizer transfer characteristic is an inverse function to the sensor transfer characteristic. The quantizer characteristic can be obtained using sensor calibration points in the case when the analytical expression of the sensor transfer characteristic is not known in advance. In this way, with the help of a processor and this special programmable two-stage piecewise linear A/D converter, linearization of any sensor type can be performed [8, 9]. The possibility of using just one A/D converter for linearization of different types of sensors is a result of its special architecture [8, 9]. Precisely, in the first stage of A / D conversion the converter determines the segment of the input range where the input sample belongs. Further, the second stage A/D converter determines the correspondent reproduction level within the specified segment [10]. Hence, the programming of the A/D converter comes down to determination of the segment boundaries, to fit the quantizer transfer characteristic as close as possible to the inverse function of the sensor transfer characteristic. In this paper the proposed two-stage piecewise linear A/D converter is used only with the sensors for angular position determination, thus the calculation of the segment breakpoints or boundaries is done only once. The method we propose in this paper can be used, without any modifications, for processing of the resolver output signals after they are demodulated. In papers [2, 4-6] a several angular position determination methods, based on the resolver application, are proposed. These methods do not include A/D conversion, i.e. towards obtaining a linear response a special analog circuits were developed. However, in [3], an analog resolver uses resolver-to-DC software based method to obtain digital data that can be utilized in a control system.

To summarize, in this paper we propose the angular position determination method based on pre-processing of the sensor output signals towards obtaining the pseudo-linear signal, and its simultaneous linearization and digitalization conducted by the two-stage piecewise linear A/D converter. In this manner, two different linearization methods are involved, one of a special purpose, i.e. for the half of the quadrant detection and the pseudo-linear signal generation (can be used only with the sensors with sin/cos output signals), and one of a general purpose, i.e. two-stage piecewise linear conversion (can be applied with all sensor types). Combining the benefits of these two linearization methods the effects of the sensor nonlinearity are significantly reduced and the measurement resolution and accuracy are increased.

The following section of the paper gives a detailed preview of the properties of the sin / cos signals linearization method we propose. The results obtained after performing the simulations in LabVIEW software and the conclusions drawn by their analysis, will be given in a separate section of this paper. The last section concludes the paper.

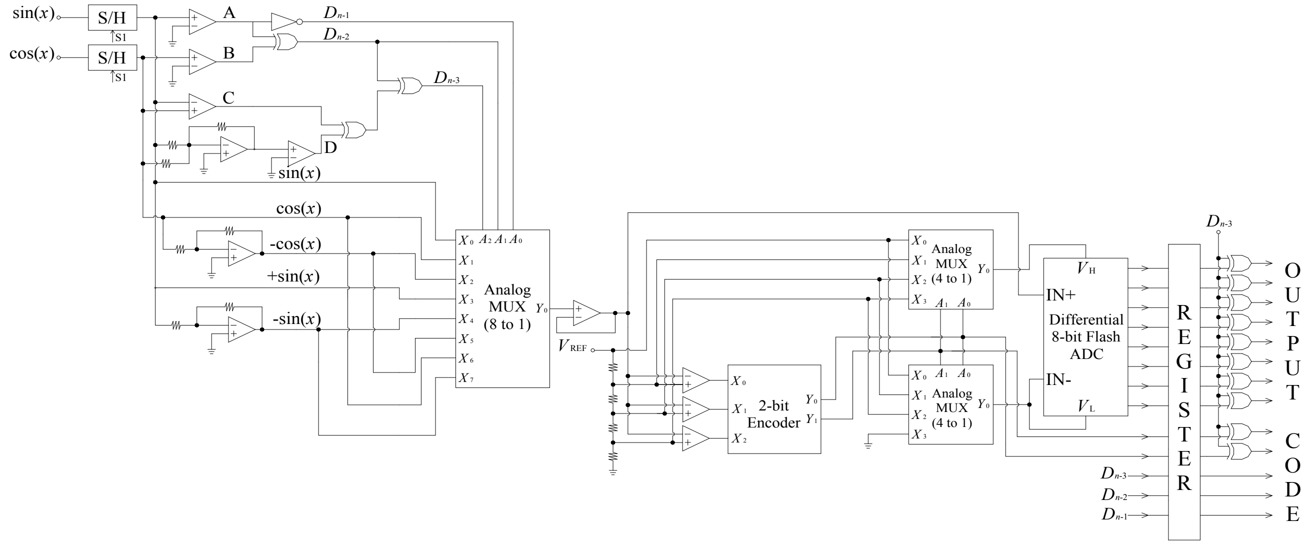


**Fig. 1.** Functional block diagram of the proposed circuit for the angular position determination

## 2. Properties of the Proposed Linearization Method

As mentioned above, in this paper the authors deal with the problems caused by the sensor nonlinearity by developing a novel linearization procedure. This procedure has two phases. The first phase, called pre-processing, is conducted by the circuit for the half of the quadrant detection (see Fig. 1). As a result the pseudo-linear signal is obtained. The following linearization phase has two stages performed by the programmable two-stage piecewise linear A/D converter. The first stage flash A/D converter has input range nonuniformly divided into segments of different width to get the best fit to the inverse sensor transfer characteristic. The second stage converter is a conventional linear A/D converter with differential input and with the uniform segmentation of the input range. The second stage A/D converter can be of any type (for example with successive approximations) and its input range changes in relation to the input segment determined in the previous stage by the flash A/D converter.

Thus, the sin/cos output signals are brought to the inputs of the comparators not only to be compared with the zero reference voltage, but to be mutually compared as well. For better understanding of the pre-processing purpose, the waveforms of analog signals sin($x$) and cos($x$) and of the output pseudo-linear signal, are shown in the Fig. 2. In the lower half of the Fig. 2 the signals in digital format from the comparators outputs A, B, C and D, are given. Applying the following logic operations

$$D_{n-1} = \overline{A} \tag{1}$$

$$D_{n-2} = A\,XOR\,B \tag{2}$$

$$D_{n-3} = \left(A\,XOR\,B\right)XOR\left(C\,XOR\,D\right) \tag{3}$$

the signals $D_{n-1}$, $D_{n-2}$ and $D_{n-3}$ are obtained. These signals are used to control the output of an analog multiplexer, and at the same time they represent three the most significant bits of the final digital result. The resulting pseudo-linear signal, at the analog multiplexer output, is shown and marked with bolded line in the upper half of the Fig. 2. This signal represents a combination of the following signals' segments: sin($x$), cos($x$), -sin($x$) and -cos($x$), and which of them is currently used depends on the half of the quadrant where the input angle belongs. For each of eight quadrant halves there is just one signal that has positive value and shows good linearity, and it is properly selected by the multiplexer controlled with bits $D_{n-1}$, $D_{n-2}$ and $D_{n-3}$. In this way, the A/D conversion is done within half of the quadrant.

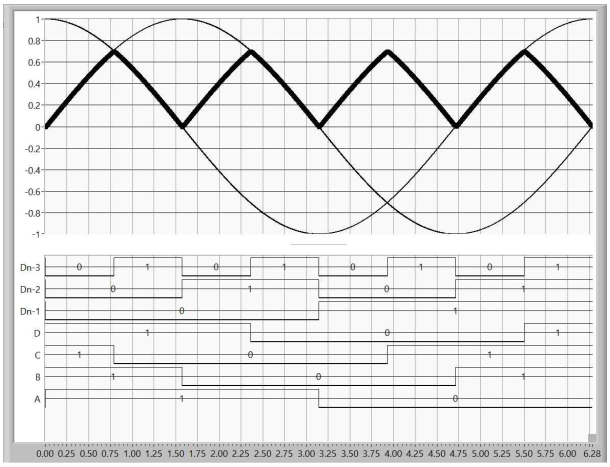


**Fig. 2.** Signals in different points of the logic circuit for the pseudo-linear signal generation.

Table 1 illustrates the working principle of the logic for selecting of the multiplexer output. The third column in Table 1 indicates the quadrant halves when the inversion of bits $D_0$-$D_{n-4}$ needs to be performed, where n represents the overall resolution ($n$=3+$N_1$+$N_2$). In the second, fourth, sixth and eighth quadrant half of the input range the slope of the pseudo-linear signal is negative, i.e. its amplitude decreases while the value of the input angle increases. Therefore, in order to obtain a monotonically rising resulting transfer characteristic, the inversion of the least significant output bits $D_0$-$D_{n-4}$ is necessary. The inversion is performed by bringing the bits $D_0$-$D_{n-4}$ and the bit $D_{n-3}$ on XOR circuits.

As shown in Fig. 2, the maximal value of the voltage at the input of the first A/D converter is $\left(\sqrt{2}/2\right)A$, because the sin/cos signals' amplitudes for the input angles $(2k+1)\cdot\pi/4$, $k = 0, 1, 2,...$, are mutually equal and amount $\sqrt{2}/2$. Therefore, the reference voltage of the first A/D converter is $V_{REF} = \left(\sqrt{2}/2\right)A$ (V). Specifically, the second linearization phase is conducted by the first stage 2-bit flash A/D converter, as shown in the Fig. 1. The implementation of this converter requires a network of four resistors setting up the comparators' reference voltages. This part of the scheme is similar to the one proposed in [8]. Since our method is specially developed for the angular position sensors, the "break voltages" $V_i$, set up on the resistors, are calculated just once using the following expression:

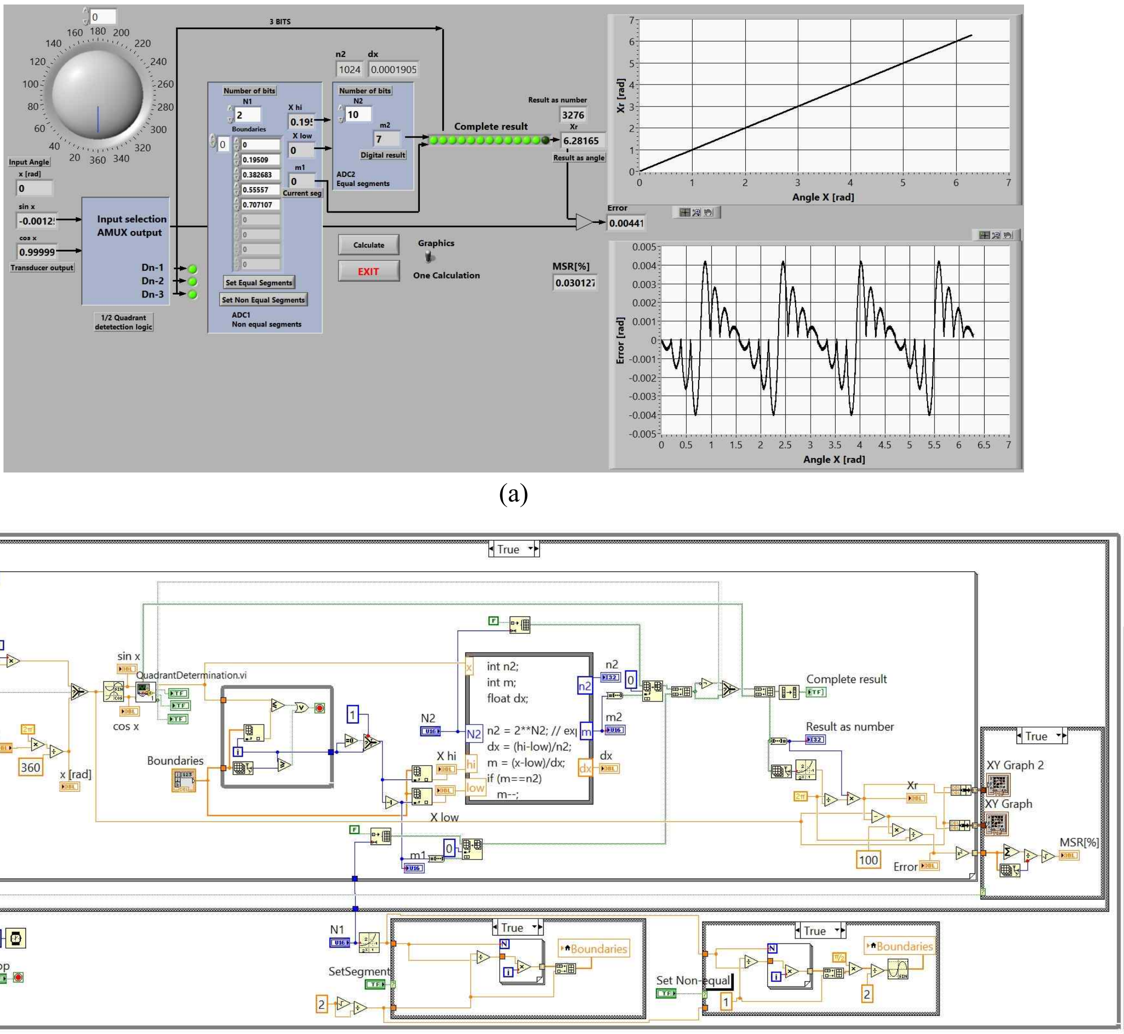
$$V_i = \sin\left(i\frac{\pi}{16}\right),\ i=0,\ 1\ ,...,\ 4. \tag{4}$$

**Table 1**. Selection of the analog MUX output in relation to the current value of the input angle $x$.

| $x$[rad] | A/D input | $D_0$-$D_{n-4}$ inversion | $D_{n-1}$ | $D_{n-2}$ | $D_{n-3}$ |
|---|---|---|---|---|---|
| 0-$\pi$/4 | +sin($x$) | No | 0 | 0 | 0 |
| $\pi$ /4- $\pi$ /2 | +cos($x$) | Yes | 0 | 0 | 1 |
| $\pi$ /2-3 $\pi$ /4 | -cos($x$) | No | 0 | 1 | 0 |
| 3 $\pi$ /4- $\pi$ | +sin($x$) | Yes | 0 | 1 | 1 |
| $\pi$ -5 $\pi$ /4 | -sin($x$) | No | 1 | 0 | 0 |
| 5 $\pi$ /4-6 $\pi$ /4 | -cos($x$) | Yes | 1 | 0 | 1 |
| 6 $\pi$ /4-7 $\pi$ /4 | +cos($x$) | No | 1 | 1 | 0 |
| 7 $\pi$ /4-2 $\pi$ | -sin($x$) | Yes | 1 | 1 | 1 |

These voltages represent the boundaries between the segments that are composing the first stage A/D converter input range, and at the same time the input voltages brought to the differential inputs of the second stage A/D converter.

In the paper [2], towards obtaining a signal that is close to an ideal triangular signal, the linearization of a difference between absolute values of sin(*x*) and cos(*x*) resolver signals, obtained after demodulation, is performed. In this manner a simple, linear equations could be used to determine the input angle. However, this solution drawback is that some additional rectifying circuits need to be embedded, introducing an additional nonlinearity. Moreover, to do the linearization of the difference between absolute values of sin(*x*) and cos(*x*) signals, special compensation signals are provided. Of course, despite good results (the order of nonlinearity is 0.011°) some residual error still remains, because the generation of an ideal compensation signal (to compensate the difference between the ideal triangular signal and the difference of the absolute values of sin(*x*) and cos(*x*) signals) is still a great challenge. In the papers [4, 5], the angle determination methods based on the amplitude of the resolver excitation signal, are proposed. The excitation signal is used for obtaining of an analog signal $\cos^{-1}(\cos(\omega t))$ equivalent to a digital look-up table. In each input interval of width $\pi$ /2, the angle determination is based on the comparison between the pseudo-linear and the excitation signal amplitudes. Pseudo-linear signal composed of sin/cos segments is obtained using the special selecting logic circuit similar to the one we use in our paper. However, the logic we propose in our paper increases the resolution for 3 bits without the exponential increase in the number of comparators, i.e. the number of operational amplifiers. Instead of using the proposed selecting logic, the flash A/D converter with 3 bits higher resolution can be used, but in that case 31 comparators are needed instead of current three. Another reason to prefer our method is justified by the manner the



```
int n2;
int m;
float dx;
n2 = 2**N2; // ex|
dx = (hi-low)/n2;
m = (x-low)/dx;
if (m==n2)
   m--;
```

(a)

(b)

**Fig. 3.** (a) Front panel of the virtual instrument that simulates the proposed angular position determination method; (b) Virtual instrument block diagram.

signals A, B, C and D are generated at the comparators' outputs. More specifically, in this paper the determination of the half of the quadrant is based on the comparison between the amplitudes of the sin/cos signals with a zero reference voltage and their mutual comparison, rather than the comparison with reference values based on the amplitude of the signal, like in [4, 5]. In this way, the additional errors are prevented.

Hereafter, the simulation results obtained using LabVIEW software are given and discussed.

## 3. Results of the Conducted Simulations Using LabVIEW Software

Using LabVIEW software package we have simulated the operation of the entire proposed sensing system, including the half of the quadrant detection circuit and the two-stage piecewise linear A/D converter (Figs. 3 (a) and (b)). This virtual instrument is realized to enable us to distinguish the individual impacts of both linearization phases to the achieved transfer characteristic linearity at the end of the linearization procedure. As shown in the front panel of the realized virtual instrument (Fig. 3 (a)), for a given input angle *x* [rad], the virtual instrument determines the values of sin(*x*) and cos(*x*) (which is equivalent to the sampling of the signals from the sensor output). After these values are determined, the first linearization phase, or the pre-processing phase, for the half of the quadrant detection is performed. Block diagram of the SubVI simulating the circuit for the half of the quadrant detection is shown in the Fig. 4 and it is named „1/2 Quadrant detection logic" in the Fig. 3. It is used for further processing of the comparators output results, i.e. for processing of the signals A, B, C and D, towards obtaining the most significant bits $D_{n-1}$, $D_{n-2}$ and $D_{n-3}$, (Fig. 3 (b)). These three bits denote the quadrant half to which the input angle belongs and control the analog multiplexer output by selecting one of the following values: sin(*x*), cos(*x*), -sin(*x*), -cos(*x*).

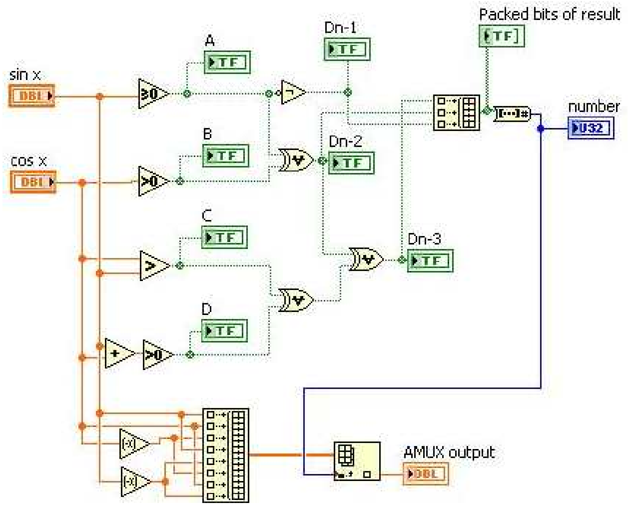
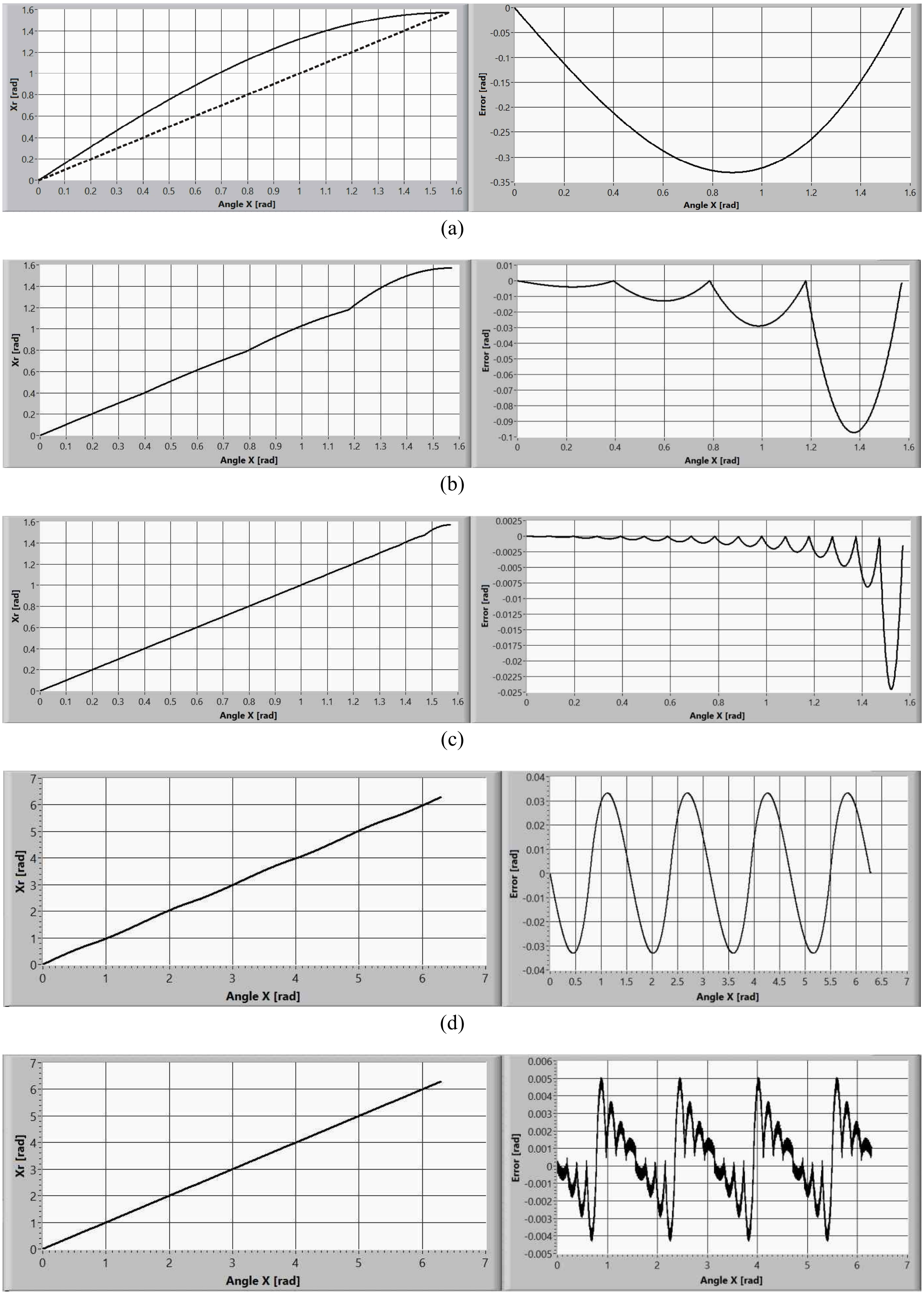


**Fig. 4.** Block diagram of the SubVI for the half of the quadrant detection.

After the quadrant half is detected, the next phase is the first stage A/D conversion with the piecewise linear flash type A/D converter that determines the input segment for the second stage A/D conversion. Specifically, the input range of the first stage A/D converter is divided into segments of unequal width, so that its piecewise linear transfer characteristic is as close as possible fitted to the inverse function of the sensor transfer characteristic, i.e. as close as possible fitted to the function arcsin(*x*). On the front panel of the virtual instrument, in the first stage of A/D conversion, there are buttons for selecting the manner the input range of the A/D converter is divided into segments (of equal or unequal widths). Specifically, by pressing the "Set Equal Segments" button, the pseudo-linear signal is brought to the linear flash A/D converter input and the linearization at this phase is excluded. By pressing the "Set Non Equal Segments" button, the transfer characteristic of the first A/D converter is programmed to have the form of arcsin(*x*), performing in this way the linearization of the pseudo-linear signal, and thus of the whole system for the angular position determination. The contribution of the circuit for the half of the quadrant detection and the first stage piecewise linear A / D converter to the system nonlinearity reduction can be noted by observing the system transfer characteristic and absolute measurement error shown in the Fig. 5. This figure shows the simulation results for different variations of the measurement system used for angular position determination.

After the current segment is localized, the second stage A/D conversion, performed by the linear A/D converter with an input range uniformly divided into cells of equal widths, follows. It is important to note that the input range of the second A/D converter varies with the particular segment determined in the previous stage of the A/D conversion.

The simulated virtual instrument can perform a single calculation, i.e. it can determine the current angle value, but it also has the ability to show the graphical representation of the transfer characteristic of the complete measurement system in the range from 0 to 2 see Fig. 5. One of these options can be selected by moving the switch on the front panel of the virtual instrument from the position "One calculation" to the position "Graphics", and vice versa. In order to assess the performance of the proposed angular position determination method, in term of the eliminated nonlinearity of the sensor, in Table 2 are given the values of the following parameters: mean-square nonlinearity error MSR [%] and maximal nonlinearity $\Delta x_{\max}$ [rad] in the range from 0 to 2 $\pi$. Two different cases were examined: the first, without the circuit for the half of the quadrant detection, and the second case with this circuit doing the pre-processing of the sin/cos signals from the sensor output. Each of these



(a)

(b)

(c)

(d)

(e)

**Fig. 5.** Transfer characteristic of the whole system and the absolute measurement error: (a) For the range from 0 to $\pi$ /2 [rad], without linearization, $N_2$=16; (b) For the range from 0 to $\pi$ /2 [rad], $N_1$=2, $N_2$=14; (c) For the whole sensor input range from 0 to $\pi$ /2; $N_1$=4, $N_2$=12; (d) With the half of the quadrant detection circuit, without linearization by ADC1; $N_2$=16; (e) With the half of the quadrant detection circuit; $N_1$=2, $N_2$=8.

**Table 2.** Mean-square nonlinearity error MSR [%] and maximal nonlinearity $\Delta x_{max}$ [rad] in relation to the conversion type and two-stage A/D converter resolution.

| | Conversion type | ADC1 resolution $N_1$ [bit] | ADC2 resolution $N_2$ [bit] | MSR [%] | $\Delta x_{max}$ [rad] | Results related to Fig. 5. |
|---|---|---|---|---|---|---|
| With the whole quadrant range from 0 to $\pi/2$ | Linear | / | 16 | 15.087 | 0.3307 | (a) |
| | Two-stage piecewise linear | 2 | 14 | 2.3773 | 0.0972 | (b) |
| | | 4 | 12 | 0.3116 | 0.0245 | (c) |
| With the half of the quadrant detection circuit | Linear | / | 16 | 0.3781 | 0.0311 | (d) |
| | Two-stage piecewise linear | 2 | 6 | 0.0574 | 0.008495 | |
| | | 2 | 8 | 0.0346 | 0.005064 | (e) |
| | | 2 | 10 | 0.0301 | 0.004235 | |
| | | 2 | 12 | 0.0292 | 0.004021 | |
| | | 2 | 14 | 0.0289 | 0.003971 | |
| | | 3 | 8 | 0.0104 | 0.001627 | |
| | | 3 | 10 | 0.0079 | 0.001225 | |
| | | 3 | 12 | 0.0074 | 0.001125 | |
| | | 3 | 14 | 0.0074 | 0.001099 | |
| | | 4 | 8 | 0.0036 | 0.000565 | |
| | | 4 | 10 | 0.0022 | 0.000352 | |
| | | 4 | 12 | 0.0019 | 0.000302 | |

cases has two sub-cases: with the linearization by the first stage A/D converter (with the piecewise linear arcsin($x$) transfer function) and without the linearization by the first stage A/D converter. The worst case in terms of the system's non-linearity, due to the absence of the half of the quadrant detection circuit and the first stage linear A/D conversion ($N_1$=0), is represented with the first row in Table 2, as well with the Fig. 5 (a). This means that the linearization of the sensor transfer characteristic is not performed, but only the multiplication of the sensor output by factor $\pi$ /2 is done to achieve that the maximal output result corresponds to the maximal input angle. At the Fig. 5 (a), ideal transfer function of the measurement system, i.e. function $y$=$x$, is added and presented with a doted line. Error graphs at the Fig. 5 actually present a difference between the ideal transfer characteristic and the obtained one. The first modification made in order to reduce the overall system nonlinearity, involves increase of the first A/D converter resolution for 2 bits, while the complete resolution of 16 bits remains the same (transfer characteristic and absolute measurement error in this case are shown in the Fig. 5 (b)). More specifically, this means that the first A/D converter has the piecewise linear characteristic and the input range divided into four segments of unequal width. In this way, the first stage A/D converter transfer characteristic better approximates the function arcsin(x) and, as shown in Table 2, better results are achieved now, i.e. the errors are significantly reduced. Further increase of the first stage A/D conversion resolution leads to even better results ($N_1$=4 bits, $N_2$=12 bits, the case shown in the Fig. 5 (c)). To single out the influence of the half of the quadrant detection circuit on the reduction of the whole system non-linearity, we are back to the case when the first A/D converter is not included in the linearization process. The value of MSR is now 0.3781% instead of the previous 15.087%. The previous result led us to a conclusion that the half of the quadrant detection circuit eliminates a high percentage of the sensor's non-linearity, as it can be seen from the Fig. 5 (d). We were also interested in the influence of the first A/D converter resolution on the linearization efficiency. On the other hand, the increase of the second stage A/D converter resolution, thus the increase of the overall resolution, reduces the quantization noise.

Analyzing the numerical results given in Table 2, one can notice that in the case when $N_1$ = 2 bits and $N_2$ = 6 bits maximal absolute error is approximately four times lower than in the case when $N_1$ = / bits and $N_2$ = 16 bits, which is twice as large resolution comparing to the first case. Although the first stage A/D converter has the resolution of just 2 bits, the reduction of nonlinearity is significant due to better piecewise linear approximation of the function arcsin($x$). Further increase of $N_2$ to 8 bits (the case shown in the Fig. 5 (e)) would only partially reduce the total measurement error by reducing the influence of the quantization noise, while this contribution becomes less significant with further increase of $N_2$. Increasing the resolution of the first A/D converter results with higher linearity, but in that case the influence of the quantization noise becomes more expressed, making it necessary to increase the resolution of the second A/D converter. For example, when $N_1$ = 3 or 4 bits, $N_2$ should have a value of 10 bits.

An important advantage of the proposed two-stage piecewise linear A/D converter is reflected in the fact that the resolution of the first stage A/D converter is lower in comparison to the second stage A/D converter resolution. This is convenient for the implementation of the first stage flash A/D converter, due to a lower number of components (comparators and resistors) needed. With fewer comparators, the power consumption is lower. This is very important because the first stage A/D converter type must be flash. On the other hand, the second A/D converter can be of any type. In [11], the authors have shown that, for the specific combination of the first and the second stage A/D conversion resolutions, the energy consumption is lower if the second stage A/D converter is with successive approximations instead of being flash type. This can be of great importance in the realization of sensor nodes in wireless sensor networks where the battery life is limited. The proposed two-stage piecewise linear A/D conversion, even with low resolution second conversion stage (for example $N_1 = 2$ bits and $N_2 = 6$ bits) can be suitable for the integration on a chip, keeping the system's nonlinearity below the required threshold.

The linearity error of $3 \cdot 10^{-4}$ [rad] (0.0172°) achieved by the method proposed in this paper can be compared with corresponding result obtained in the paper [6], where linearity error of 0.028° is achieved, and with corresponding result from paper [2], where the theoretical linearity of 0.011° is achieved using special and expensive nonlinear integrated circuit as analog multiplier. As the proposed method determines the input angle $x$ based on $\sin(x)$ sensor signal, it should be noticed that the final error of this measurement can not be less than the residual nonlinearity that remains after all processing is done. In addition, the method proposed in this paper, as well as other cited methods, expands input measurement range of the sensor from $\pi/2$, where function $\sin(x)$ has the unambiguous value, to a wider range of $2\pi$, detecting the quadrant of the sensor input based on the corresponding combinations of sin/cos signals.

## 4. Conclusion

A novel method for angular position determination based on the detection of the half of the quadrant where the measured angle belongs and on the two-stage piecewise linear A/D conversion, is presented in this paper. More precisely, this method exploits a special piecewise linearization technique of the sensor's transfer characteristic in order to achieve the measurement resolution and accuracy increase. In this way, the measurement error, caused by the nonlinearity of the sensor's transfer characteristic can be significantly reduced to $3 \cdot 10^{-4}$ [rad] (0.0172°), depending on the resolution of the A/D converter in the first stage of A/D conversion. The first stage of A/D conversion has lower resolution, which is a benefit, since the first stage A/D converter type is flash. In this way the number of comparators composing the A/D converter is lower. The contribution of the proposed method is in the simultaneous linearization of the sensor's transfer characteristic and digitalization of the measured values by the same circuitry. Since this method can be conducted without using a processor, the circuitry used for its realization is very suitable for integration.

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**Dragan Živanović** received Ph.D. degree in Technical Sciences from University of Niš, Serbia, in 2006. He is currently an Assistant Professor at the Department of Measurement at the University of Niš. He has obtained twenty years of experience in research and new product development in the areas of smart transducers, industrial sensor applications, virtual instruments.

**Jelena Lukić** received M.Sc. degree in Telecommunications in 2008. at the University of Niš, Faculty of Electronic Engineering. She is currently a PhD student and a teaching assistant at the Department of Measurement. Her research areas are: processing of speech, audio and measurement signals, position measurements and development of novel nonlinear ADCs.

**Dragan Denić** received M.Sc. degree in Electrical science and his Ph.D. degree from University of Niš, Serbia, in 1992. and 1996, respectively. He is currently a Full Professor at the Department of Measurement at the University of Niš, Serbia. His main fields of interest are measurement science, position measurement, telemetry, computer based measurement systems.