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Digitally-tuned resolver converter

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Abstract

Sinusoidal encoders provide electrical signals related to the sine and cosine of the mechanical shaft angle θ. An analog converter is described for the linearization of these signals and hence for linear computation of θ. The converter was based upon the difference between the absolute values of the transducer signals, together with a simple signal diode-based shaping network. The optimal break points positions of the network, that minimize the absolute error of the converter, are determined experimentally and automatically using a LabVIEW-controlled setup. Despite its simplicity, the converter has an absolute error of only 0.12 º.

Keywords: Position sensors; Resolver converters; Linearization; Breakpoint method; Auto-tuning; Minimax errror

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1. Introduction

Sinusoidal position encoders, including resolvers, are transducers that provide two electrical signals in which the angle (θ) to be measured is encoded,

$$\begin{cases} V_S(\theta) = A \times \sin(\theta) \\ V_C(\theta) = A \times \cos(\theta) \end{cases}, \qquad (1)$$

where A is the maximum amplitude of the signals. A suitable converter is required in order to determine θ from the transducer signals (1). Various converter schemes have been reported in the literature [1-7]. Most of these require the use of analog-to-digital converter(s) and a processor or a look-up table because of the inherently non-linearity of (1). In the present communication, the technique based upon the difference between the absolute values of the signals in (1) [4, 5] is of particular interest (Fig. 1). This results in a pseudo-linear triangular output,

$$V_d(\theta) = A \times \left(|\sin(\theta)| - |\cos(\theta)|\right). \qquad (2)$$

The pseudo-linearity of (2) suggests that, with minimal linearization, it may be converted into a reasonable approximation of a triangular signal. In that event, the input angle may be estimated using a simple linear equation

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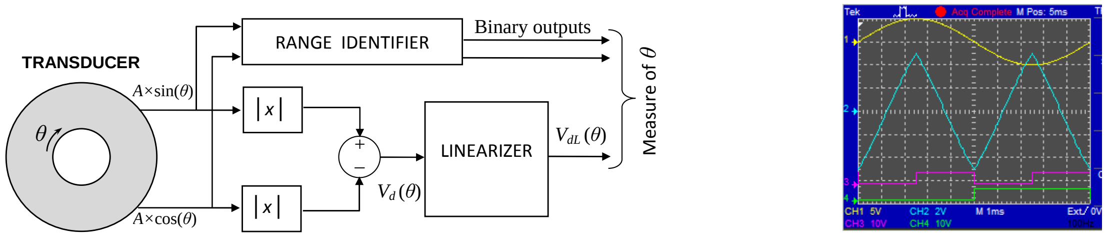
in each quadrant of the full 360°. Evidently the four quadrants may be distinguished using two binary outputs that ensure unambiguous determination of θ. By using the signal $V_d(\theta)$ and the two binary outputs for the linear determination of the angle, the theoretical absolute error of the converter is 1.9°. Various schemes have been proposed and applied for the linearization of (3) in order to minimize this error [4, 5]. However all of these schemes employ expensive analog multiplier/dividers. The main objective of the present work is to develop simple but effective linearization scheme. The proposed solution is based on the use of waveform shaping networks operating on the breakpoint method. These networks are traditionally used in function generators for synthesizing sinewaves out of triangular waves. In our application, the shaping network is configured as linearizer. In addition to its simplicity, the proposed scheme may lead to integration of the entire converter into a single integrated circuit.



(a)

(b)

Fig. 1. (a) Basic converter scheme for sinusoidal encoders; (b) Simulated $V_S(\theta)$, non-linearized $V_d(\theta)$, and the two binary outputs.

2. Proposed linearization scheme

The proposed linearization method is based on the non-linear I-V characteristics of signal diodes used in breakpoint waveform shaping networks. Fig. 2 shows a simplified two breakpoint shaping network built around an inverting amplifier. The operation of this circuit may be explained by finding the input-output relationship. Since the exponential model of the diodes leads to non-linear equations that cannot be solved analytically, a simple constant 0.7V voltage drop model is considered for the diodes. For an input $V_d(\theta)$ to the shaping network, the expressions of the linearized output $V_{dL}(\theta)$ in the segments of the Voltage Transfer Characteristics (VTC), delimited by the breakpoints, may be approximated as shown in Table 1.

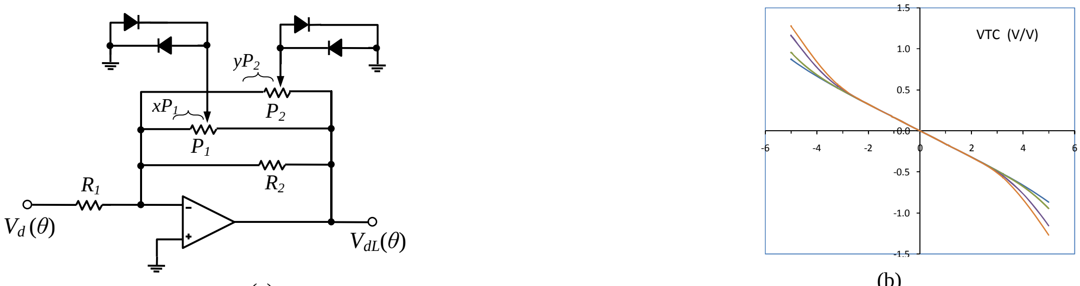
Table 1. Operation of the linearizer in the segments of the VTC.

$\lvert xV_{dL}(\theta)\rvert \le 0.7$ and $\lvert yV_{dL}(\theta)\rvert \le 0.7$	$\lvert xV_{dL}(\theta)\rvert \ge 0.7$ and $\lvert yV_{dL}(\theta)\rvert \le 0.7$	$\lvert xV_{dL}(\theta)\rvert \ge 0.7$ and $\lvert yV_{dL}(\theta)\rvert \ge 0.7$
$V_{dL}(\theta) = -\frac{\left(R_2^{-1}+P_1^{-1}+P_2^{-1}\right)^{-1}}{R_1}V_d(\theta)$	$V_{dL}(\theta) = -\left(R_2^{-1}+P_2^{-1}\right)^{-1}\left[\frac{V_d(\theta)}{R_1} \pm \frac{0.7}{xP_1}\right]$	$V_{dL}(\theta) = -R_2\left[\frac{V_d(\theta)}{R_1} \pm \frac{0.7}{xP_1} \pm \frac{0.7}{yP_2}\right]$

The expressions for $V_{dL}(\theta)$ (Table 1) show that as the input to the shaping network increases, the incremental gain of the linarizer decreases as required in the present application. Fig. 2 shows the VTC of the network generated using Multisim software for few arbitrary settings of the tuning potentiometers. In practice, these settings are chosen to ensure the required VTC that minimizes non-linearity of the output of the overall converter.

3. Implementation and Results

The simplified circuit diagram of the proposed converter is shown in Fig. 3. The basic linearizer scheme described above has been slightly modified for two reasons: 1) improving performance and 2) the potentiometers have been replaced with digital potentiometers for tuning purpose as shown below. The digital potentiometers used (DS1666) have 128 steps and a nominal end-to-end resistance of 10kΩ. The measured wiper resistance of these potentiometers was 450Ω; this is inluded in the diargam of Fig.3. The difficulty with using the proposed linearizer is finding the optimum locations of the breakpoints and the best VTC that lead to minimizing non-linearity and hence minimizing the errors in the determination of θ.



(a) (b)

Fig. 2. (a) Simplified linearizer; (b) Input-output characteristics of the linearizer for various settings of the potentiometers.

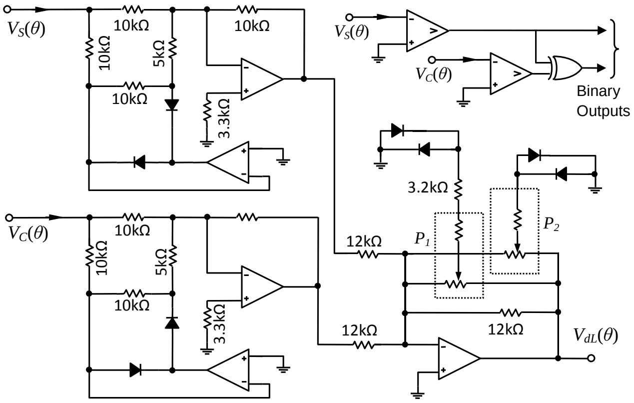


Fig. 3. Implementation of the proposed converter.

Instead of using a real sensor, the converter and its shaping network have been tested in a PC-based experimental setup (Fig.4). This environment simulates the transducer by generating the equivalent of its sine and cosine signals under precise control of the input angle. In this way, the error of the converter may be precisely assessed. The system was developed around LabVIEW software and a 16-bit resolution data acquisition card that enables tuning the converter with great speed and precision. The LabVIEW virtual instrument (VI) program has been designed for generating the input signals to the converter, for controlling the two potentiometers of the shaping network, for measuring the linearized output of the converter, and for determining its residual error. Thus the system was capable of auto-tuning the shaping network by maximizing the linearity of its output and minimizing its overall absolute error. For this purpose two low-cost digital potentiometers controlled by the setup were used in the shaping network in order to find their optimum settings for a minimax error. After finding the optimum settings, the digital potentiometers are simply replaced by standard resistors and potentiometers

Fig.5 shows typical experimental results obtained with proposed setup after optimization of the shaping network. The linearity of the output of the converter was excellent (compare to curves of Fig. 1). The residual error in the linear determination of the angle from $V_{dL}(\theta)$ is also shown in Fig.5. This residual error was within ±0.12° in the full 360° range of input angle. This absolute error of the converter is better than that of 11-bit incremental encoders. This is a promising and reasonably good result given the simplicity of the network and the high non-linearity of the signal in (3). In addition, the proposed linearizer may be upgraded to operate with more breakpoints. This should help further reduce the error of non-linearity obtained with the converter.

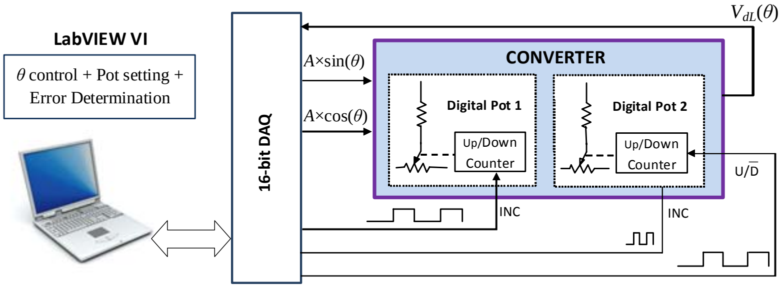
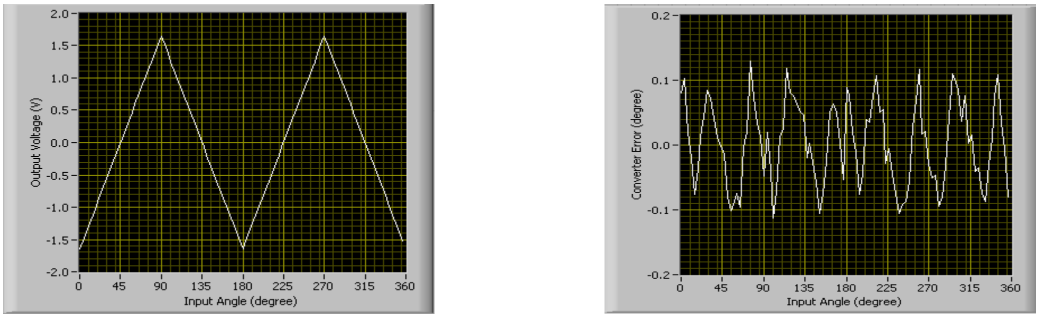


Fig. 4. Auto-tuning setup for optimizing the nework and minimizing the residual error if the converter.



(a) (b)

Fig. 5. (a) Experimental output $V_{dL}(\theta)$ after auto-tuning the shaping network; (b) Experimental residual error of the converter.

4. Conclusion

A converter for the determination of the angle from sinusoidal encoders has been described. This converter is based on a simple two breakpoint shaping network used as linearization scheme. The shaper, employing the non-linear I-V characteristics of signal diodes, was auto-tuned using a dedicated LabVIEW-controlled setup that minimized non-linearity of the converter output. The proposed converter has an experimental residual absolute error of 0.12° over the full 360° range of input angle. Full details of the converter have been given.

Acknowledgements

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