

On-Chip Delta-Sigma ADC for Rotor Positioning Sensor Application (Resolver-to-Digital Converter)

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ABSTRACT

This paper discusses the RDC method utilizing delta-sigma analog-to-digital converter hardware module (DSADC) integrated in the Infineon's microcontroller family. With its higher resolution capability when compared to the regularly used ADC with successive-approximation (SAR), DSADC seems to have more potential. On the other hand, DSADC's inherent properties, such as asynchronous sampling rate and group delay, which when not handled properly, would have negative effects to the rotor positioning system. The solution to overcome those side-effects involves utilization of other internal microcontroller's resources such as timers and capture units, as well as additional software processing run inside CPU.

The rotor positioning system is first modeled and simulated in high-level simulation language environment (Matlab and Simulink) in order to predict the transient- and steady state behaviors. The group delay itself is obtained by simulating the model of DSADC module implementation. Comparison of simulation result is done to the measurement from motor test bench.

This paper also mentions some differences over two other existing approaches, i.e. a) the ADC-based software-RDC and b) the off-chip hardware RDC.

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INTRODUCTION

Due to its robustness and precision a resolver device is often used for the electric motor drive application such as in an electric vehicle or electric power steering system (EPS). A resolver is rotor positioning sensor that works by using the same principles used in electrical transformers. It requires one excitation signal (E_R) fed into an (primary) excitation winding and produces two feedback signals (S_{sin} , S_{cos}) from its two (secondary) output windings.

The excitation signal has fixed angular frequency (f_c). The two feedback signals have the same frequency, but their amplitudes are modulated by the angular position of the rotor (θ_r) and scaled by resolver's transformation ratio (k) [1].

$$E_R = E \cdot \sin(2\pi f_c t)$$

(1)

$$S_{sin} = k \cdot E_R \cdot \sin(\theta_r) \quad (2)$$

$$S_{cos} = k \cdot E_R \cdot \cos(\theta_r) \quad (3)$$

$$\omega_r = \frac{d\theta_r}{dt} \quad (4)$$

Figure 1 shows the waveform of the resolver's excitation and feedback signals over different rotor position (θ_r) at a constant angular speed.

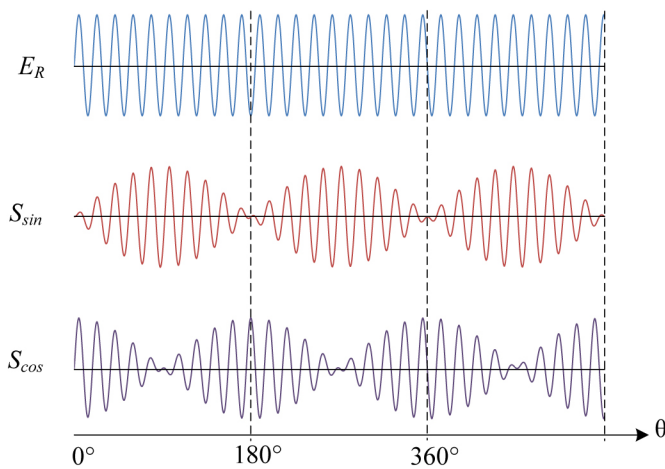


Figure 1. Resolver's excitation and feedback signals

RESOLVER TO DIGITAL CONVERSION (RDC)

In principle, RDC is a process to obtain angular position and speed in digital form (ready to use for the motor control algorithm) from the resolver. The process involves:

1. excitation carrier generation
2. analog to digital conversion (ADC)
3. excitation carrier cancelation
4. arctangent (ATAN)
5. angle-tracking observer (ATO) loop [1, 2]

Solutions today are available using the "RDC integrated circuits" and "ADC-based software RDC".

With the RDC integrated circuits [1], all steps 1-5 mentioned above are performed fully in the dedicated hardware chip. The advantage of this approach is that the system developer obtains ready-to-use angular position and speed information without too much software effort, except software for reading out data and/or writes the configuration of RDC IC's. Disadvantages are the cost of the chip and additional space on the board.

On the other hand, using the "ADC-based software RDC", excitation generation (step 1) is typically performed by using a sine look-up table which is periodically fed into a pulsed-width modulation (PWM) module available on microcontroller chips. The PWM signal is then passed through a low-pass filter which finally produces sinusoidal excitation waveform for the resolver.

For the sampling of feedback signals, differential operational amplifier (OP-AMP) circuit is implemented on board for each (S_{sin} , S_{cos}) input to normalize the amplitude and DC-offset of the feedback in order to exploit the dynamic range of the ADC as much as possible.

Excitation carrier cancelation (step 3) is done by using sampling rate equal to the carrier frequency and the sampling point is done exactly at the maximum and/or minimum of the feedback signal as shown in Figure 2. The sampled points extract the sinusoidal envelope thus effectively remove the carrier.

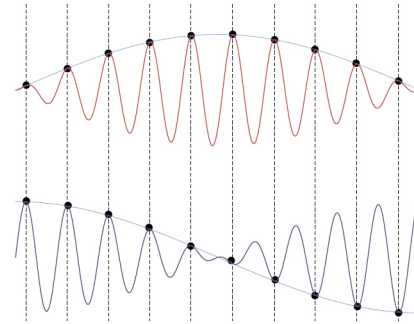


Figure 2. Carrier-cancelation in "ADC-based software RDC"

Finally the ATAN function (step 4) and ATO (step 5) are performed by software in the CPU core to produce the angular position and speed.

PROPOSED RDC METHOD

The following is a proposal of RDC with the AURIX's DSADC module to be an alternative to both solutions mentioned before. It integrates some well-known building blocks.

1. Similar to the "ADC-based software RDC", value of the excitation signal over time is generated by pulse-width-modulation (PWM) signal
2. PWM signal is converted into the excitation signal using low-pass filter.
3. Analog-to-digital conversion is done directly to the feedback signals by delta-sigma conversion, which consists of an analog modulator and cascaded-integrator-comb (CIC) filter.
4. DC-offset compensation.
5. Carrier cancelation by means of rectification and windowed-integration.
6. 3rd order angle tracking observer (ATO) for angle and speed calculation
7. Compensation of group delay and timestamp of DSADC samples.
8. Fault detection to ensure the processing integrity

Hardware units supporting step 1, 3-5 are available on the AURIX family automotive microcontroller. Step 2 is performed by on-board circuitry. Steps 6-8 are performed by software which runs within the CPU.