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## ***Implementing a Universal Control System for Field-Oriented Control of AC Machines Using the TMS320C14 DSP***

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## Abstract

The purpose of this paper is to present a universal controller system used in field oriented control method of ac machines. This controller system uses one Texas Instruments (TI™) TMS320C14 digital signal processor (DSP), four analog-to-digital converters (ADC), three operation amplifiers, two current sensors and a resolver. The digital values of sine and cosine functions of the rotor position are found without using the resolver-to-digital converter (RDC). This method is tested in the field-oriented control of a synchronous machine. The experimental results proved the validity of this controller system.

**Keywords:** Field oriented control method, ac machines, DSP, Inverter, Resolver

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## Introduction

During the last twenty years, electrical drive control methods have had rapid expansion caused mainly by the advances of semiconductors in the form of power electronic components, as well as analog and digital integrated circuits. Now, thanks to the appearance of the digital signal processors, a complete digital realization of drive controllers has become possible.

On the other hand, field oriented control method, with its high performance in controlling ac machines, has become a standard method in ac drive control domain. In comparison to other control methods, like voltage stator frequencies characteristic,  $U/f$ , or direct self-control, the field-oriented control gives the best dynamic behavior, although it requires a high calculation performance, which can be done by a powerful hardware.

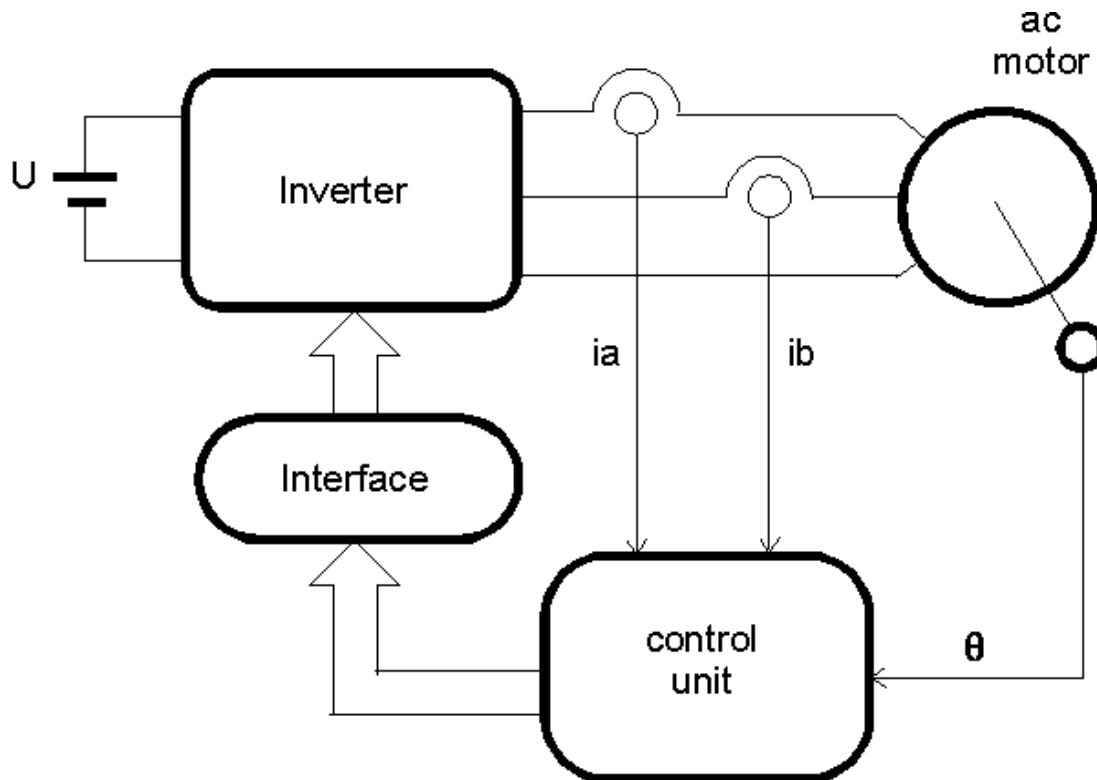
In industry and commerce, the point of the hardware costs is very important. Thus by decreasing the hardware costs, the field oriented control method can be diffused more and more. A 16 bit fixed point DSP can respond to these requirements with its very good performance/cost ratio.

In this paper we propose an economized hardware for field oriented control method by using a TMS320C14 DSP.

## Method Presentation

The ultimate objective of the field oriented control method is to enable decoupling control of torque and flux, similar to the control of separately excited dc motors. The principle of the field oriented control method is shown in Figure 1.

Figure 1. Principle of the Field-Oriented Control Method



As Figure 1 shows, the motor is supplied by a voltage source inverter. The inverter, which is supplied by a constant dc link,  $U$ , consists of six power transistors and six diodes. The inverter can be controlled by six digital output pins of a processor through an interface circuit. Two of the stator currents are measured by commercial magnetic sensors employing Hall devices. The output signals of the sensors are sampled by two A/D converters sample.

To separate torque and flux control, the instantaneous values of the phase currents must be imposed as functions of the rotor position. So we need to know instantaneously either the absolute value of the rotor position,  $\theta$ , or the values of the trigonometric functions of the rotor position, such as  $\sin(\theta)$  and  $\cos(\theta)$ .

With respect to the stator,  $\theta$ , the rotor angle can be measured by using either an absolute position optical encoder<sup>1</sup> or a resolver.<sup>2</sup> The resolver is used in many applications because of its mechanical ruggedness and ability to reject common mode noise.<sup>3</sup>

A resolver is an electromagnetic rotational transducer that detects angular displacement.<sup>4</sup> It has three windings: the first one is the input used as the excitation winding and the other two are outputs spaced  $90^\circ$  from each other. Usually the input of the resolver is supplied by a fixed frequency voltage signal of the following form:

$$x = A \cdot \sin(2\pi \cdot f \cdot t) \quad 1\text{kHz} < f < 10\text{kHz}$$

The induced voltages in the output windings are in the form of  $\sin(\theta)$  and  $\cos(\theta)$ , which are amplitude modulated by the input signal. So the output voltages are:

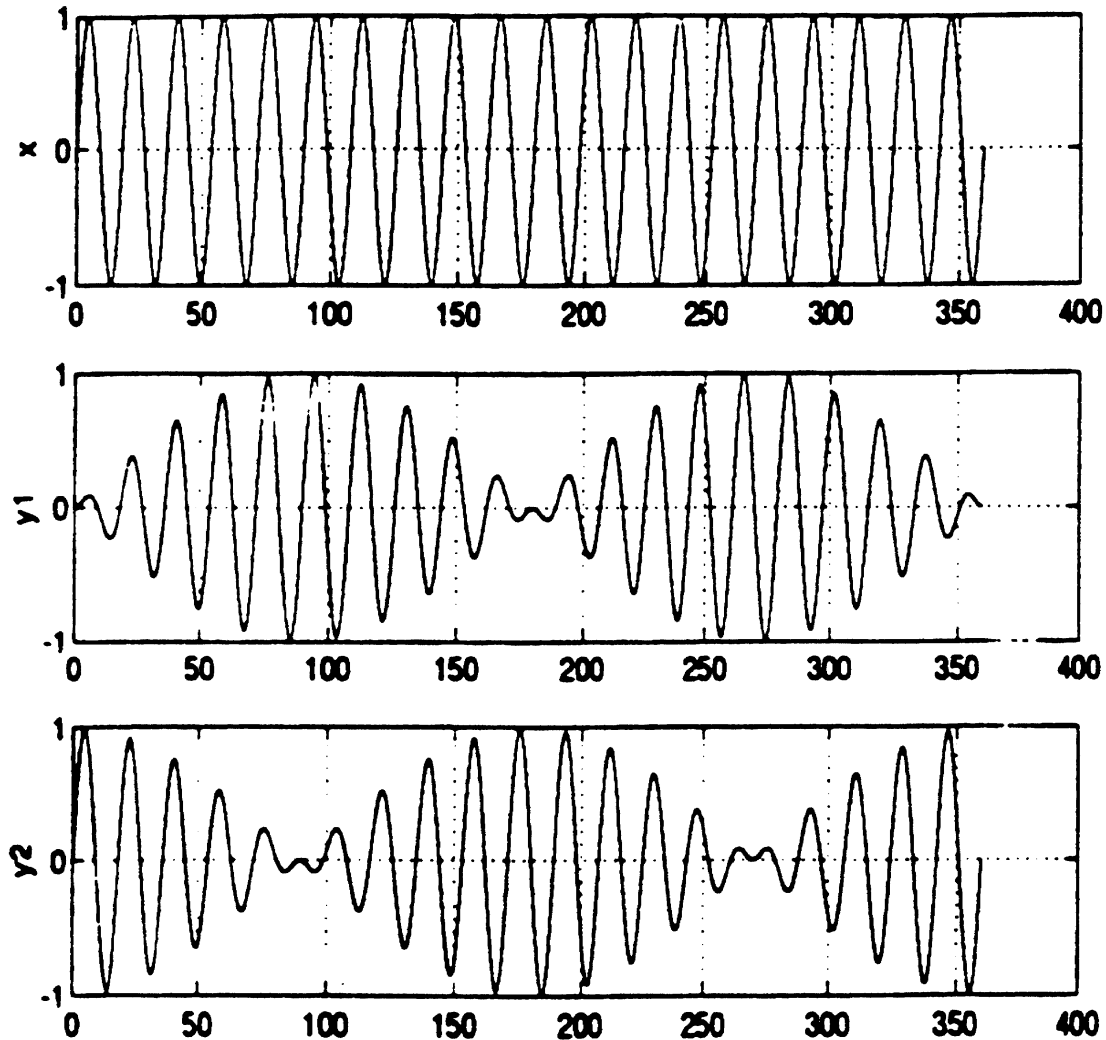
$$y1 = A \cdot R \cdot \sin(2\pi \cdot f \cdot t) \cdot \sin(\theta)$$

$$y2 = A \cdot R \cdot \sin(2\pi \cdot f \cdot t) \cdot \cos(\theta)$$

Where  $R$  is the transformation ratio of the resolver.

Figure 2 shows the typical input and output signals of a resolver.

Figure 2. Resolver Input and Output Signals



Normally, for taking out the angle  $\theta$  from the resolver outputs, a resolver-to-digital converter (RDC), which is a rather costly special integrated circuits, is used. The RDC converts the resolver outputs signal to an 8- to 16-bit parallel digital word representing the absolute value of the rotor position.

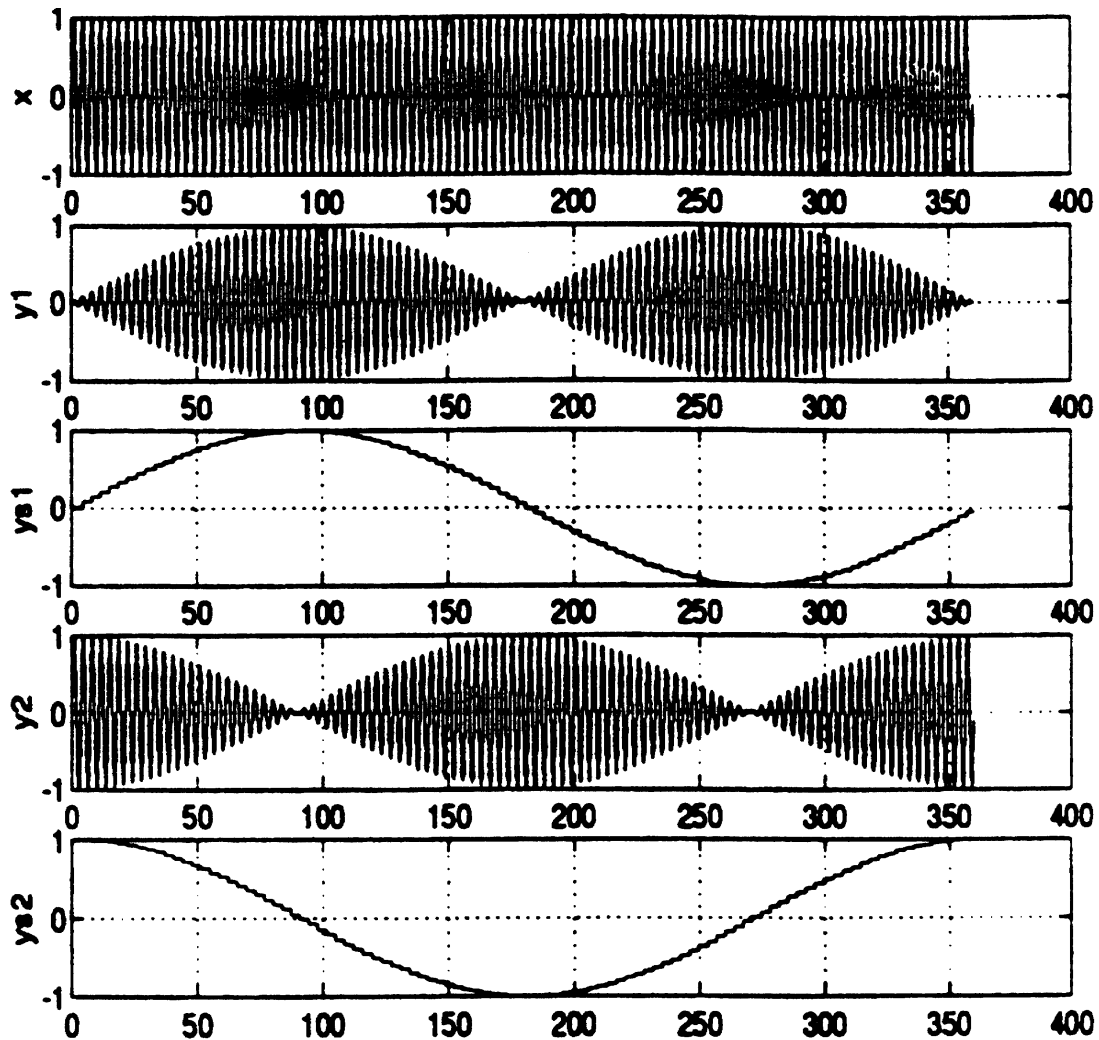
But most applications need only the functions of  $\sin(\theta)$  and  $\cos(\theta)$ .<sup>5,6</sup> The look-up table method, normally used to find these functions, uses the value of the  $\theta$  as the program memory address to look up the corresponding values of the  $\sin(\theta)$  and  $\cos(\theta)$ , which have been memorized. For good precision, this method requires more than 1k bytes of memory, which can be restrictive when using many microcontroller or DSPs. Thus there are two important disadvantages:

- ❑ The Resolver to Digital Converters are expensive.
- ❑ The look-up table method uses a large part of the internal program memory of the microcontrollers or DSPs.

As mentioned above, the resolver's outputs contain the  $\sin(\theta)$  and  $\cos(\theta)$  functions, but these are modulated by the input signal. If we sample the resolver's output signals while they have their maximum value, we obtain the demodulated sampled functions of  $\sin(\theta)$  and  $\cos(\theta)$ . Figure 3 shows the input and output signals and the sampled outputs of the resolver.

$x$  : input signal of the resolver.  
 $y1$  and  $y2$  : output signals of the resolver.  
 $ys1$  and  $ys2$  : sampled output signals.

Figure 3. Input and Output Signals and Sampled Outputs



For accuracy, the sampling moments of the resolver's outputs must be synchronized with the input signal. In practice, it is difficult to maintain perfect synchronization between two different signal sources. To solve this problem, we used the same processor, which is used to control the ac motor to produce the input signal of the resolver. In this way, the processor can determine the proper sampling moments, because it is the processor itself that generates the input signal.

As mentioned above, the primary winding of the resolver is usually excited by a fixed frequency sinusoidal signal. Considering the phase shift between the input and output signals of the resolver, it is difficult to detect the adequate sampling moments. For this reason, we preferred to use a square wave signal for exciting the resolver. In this way, the output signals have flat extremums which allow us to sample them during an interval almost equal to half of the period of the excitation signal. In addition, it is easier for a processor to generate a square wave signal rather than a sinusoidal signal.

## Hardware Presentation

The choice of processor is critical in determining the performance, behavior, and cost of the controller system. A wrong type selection of processor can impede performance and increase the cost of the controller system. Some authors have published certain hardware by using one microprocessor (or microcontroller) with one or more DSPs.<sup>1,2,7,8,9</sup>

As it is mentioned before, for hardware realization, we need a powerful processor for calculation, six digital I/O ports to control the inverter, and a digital I/O port to supply the resolver's input. In addition, digital I/O ports are needed to command the ADCs. The main advantages of a DSP core compared to standard Microcontroller are

- ❑ The ability to do multiplication and accumulation in a single cycle
- ❑ An input shifter as well as output shifter for scaling operation and different calculation modes.

The TMS320 family of processors has a modified Harvard-type architecture with separate Data and Address bus. This modification of the Harvard architecture allows transfers between Program and Data spaces, thereby increasing the flexibility of the device.<sup>1,10</sup>



The first generation TMS320C14 DSP is one of the first devices to provide an optimal solution for implementing digital controllers on a single chip. Its CPU meets the architectural and processing requirements for controllers and it has useful peripherals on-chip, such as 16 digital input/output ports, event manager, timers, RAM, and ROM.

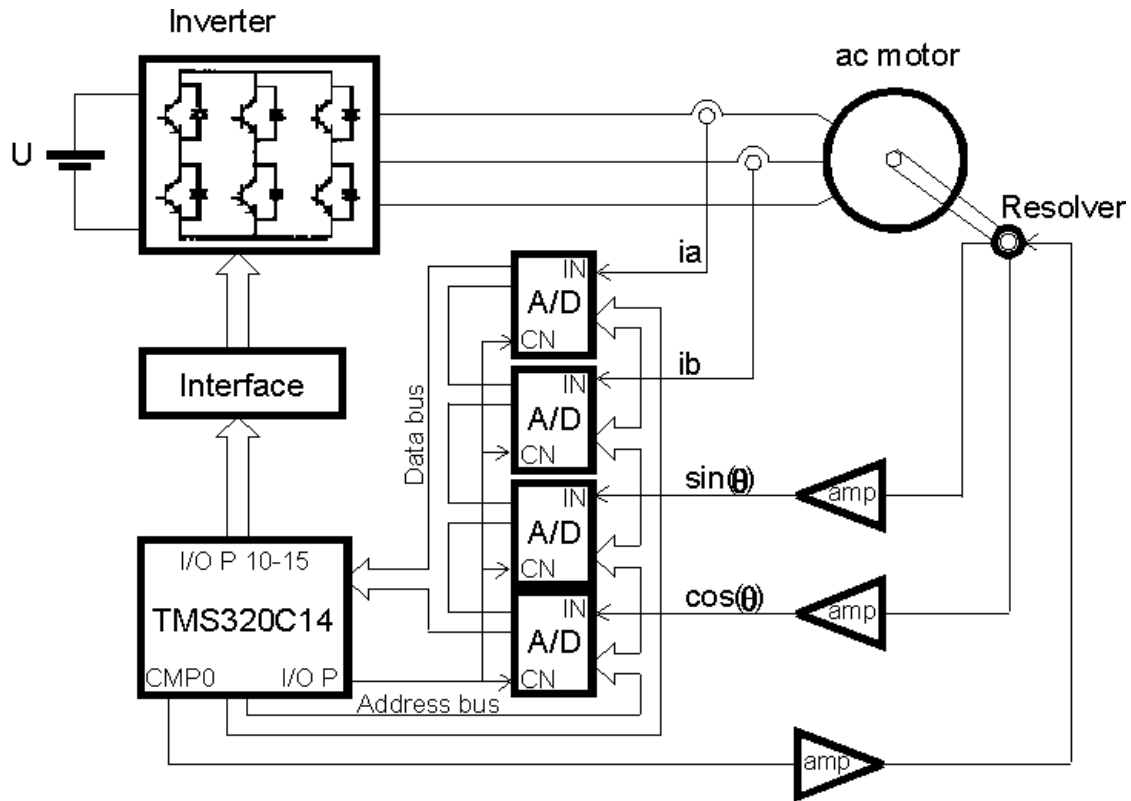
The event manager consists of compare and capture subsystems. The compare subsystem has a high precision PWM mode. High peripheral integration allows:

- ❑ Reduced system cost
- ❑ Compaction of board space
- ❑ Ease of board design

As shown in Figure 4, I/O P 10-15 control the voltage source inverter. These I/O ports are individually bit selectable with an independent input/output pin configuration and set/clear control. Registers configured by user software can control them.<sup>10</sup>

By using one of the general-purpose timers of the TMS320C14 and CMP0 in PWM mode, a 10 kHz frequency square wave is generated. This signal must be amplified to supply the resolver's input.

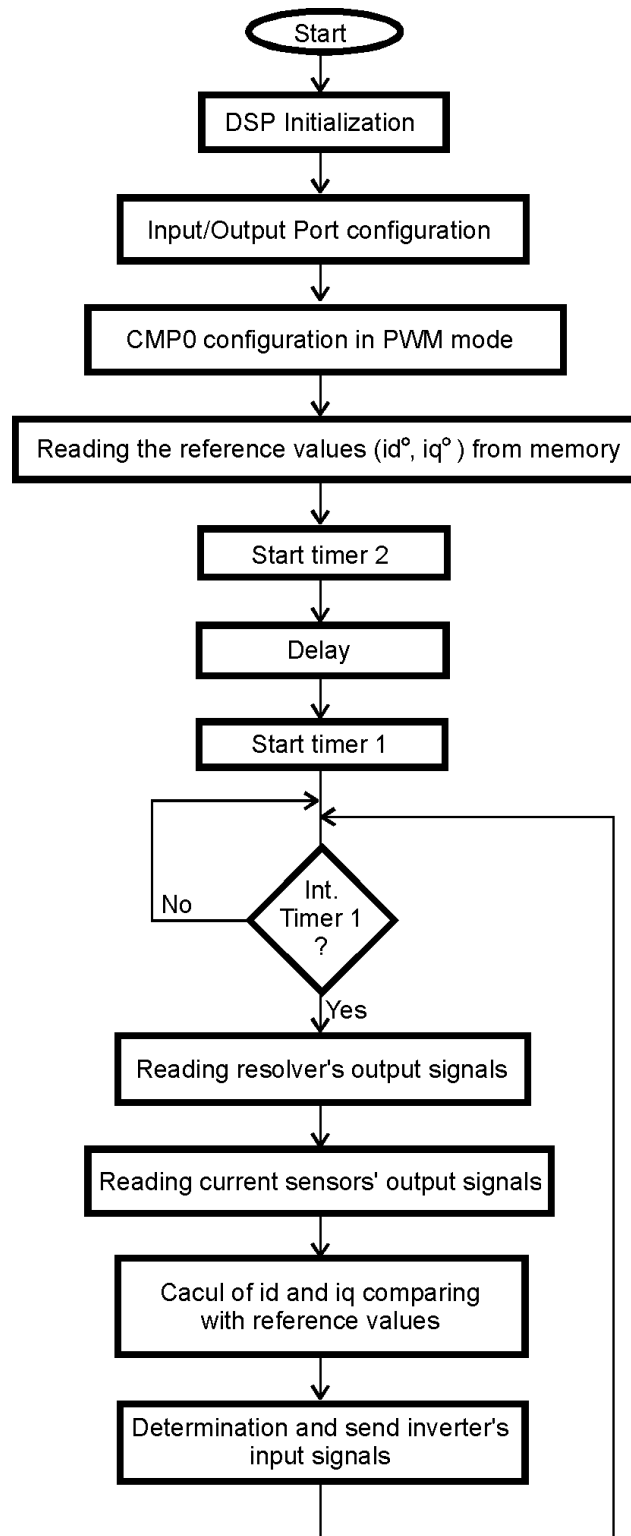
Figure 4. Global Scheme of Hardware for Field-Oriented Control Method



Four ADCs sample and convert the resolver's output signals and the current sensor's output signals. These ADCs are considered as memory cells and can be addressed by the address bus. The ADC output can be read through the Data bus. For all ADCs, the conversion command can be emitted by the TMS320C14 through one or more I/O ports.

Figure 5 shows the flowchart of the program.



*Figure 5. Program Flowchart*

## Application and Experimental Results

The proposed system is realized and applied to the field-oriented control of a Permanent Magnet Synchronous Machine (PMSM) supplied by a Current Controlled Voltage Source Inverter.

The square wave signal and one of the resolver's output signals are shown in Figure 6-a and Figure 6-b respectively. As mentioned before, the resolver's output signals have flat extremums.

Figure 6. Input and Output Signals of the Resolver

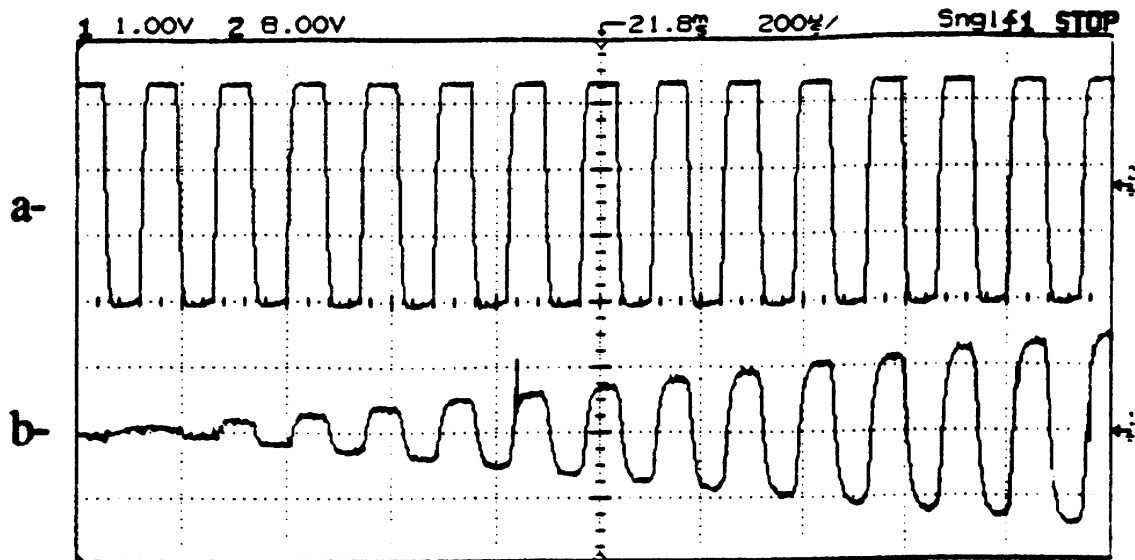
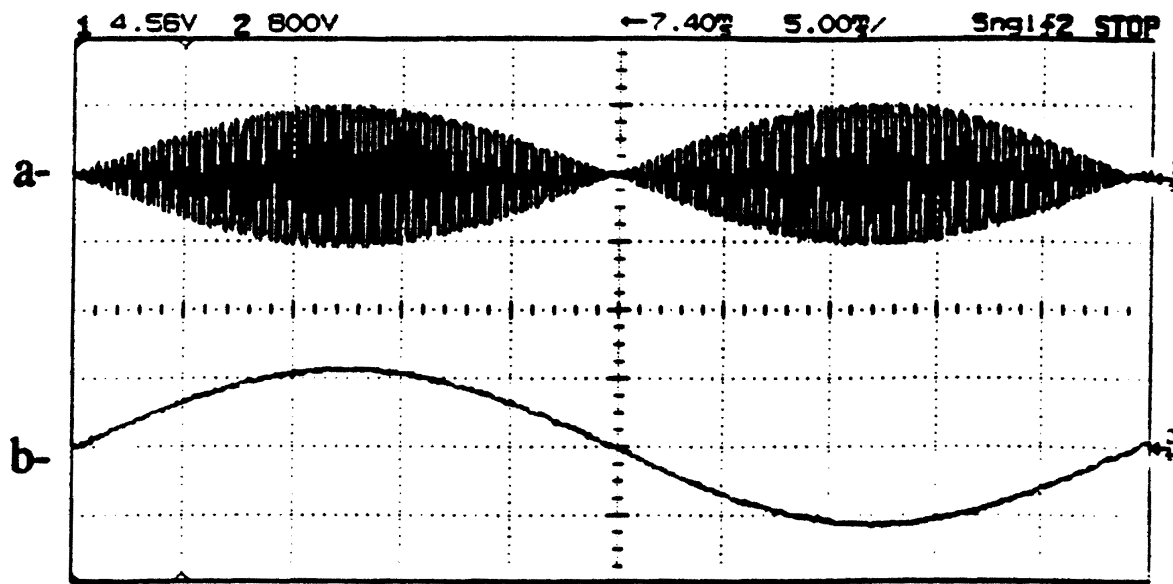


Figure 7-a and Figure 7-b show an output signal of the resolver and the corresponding sampled and held signal. As it can be seen, the sampled signal reconstitutes a trigonometric function ( $\sin(\theta)$  or  $\cos(\theta)$ ) of the rotor position angle.

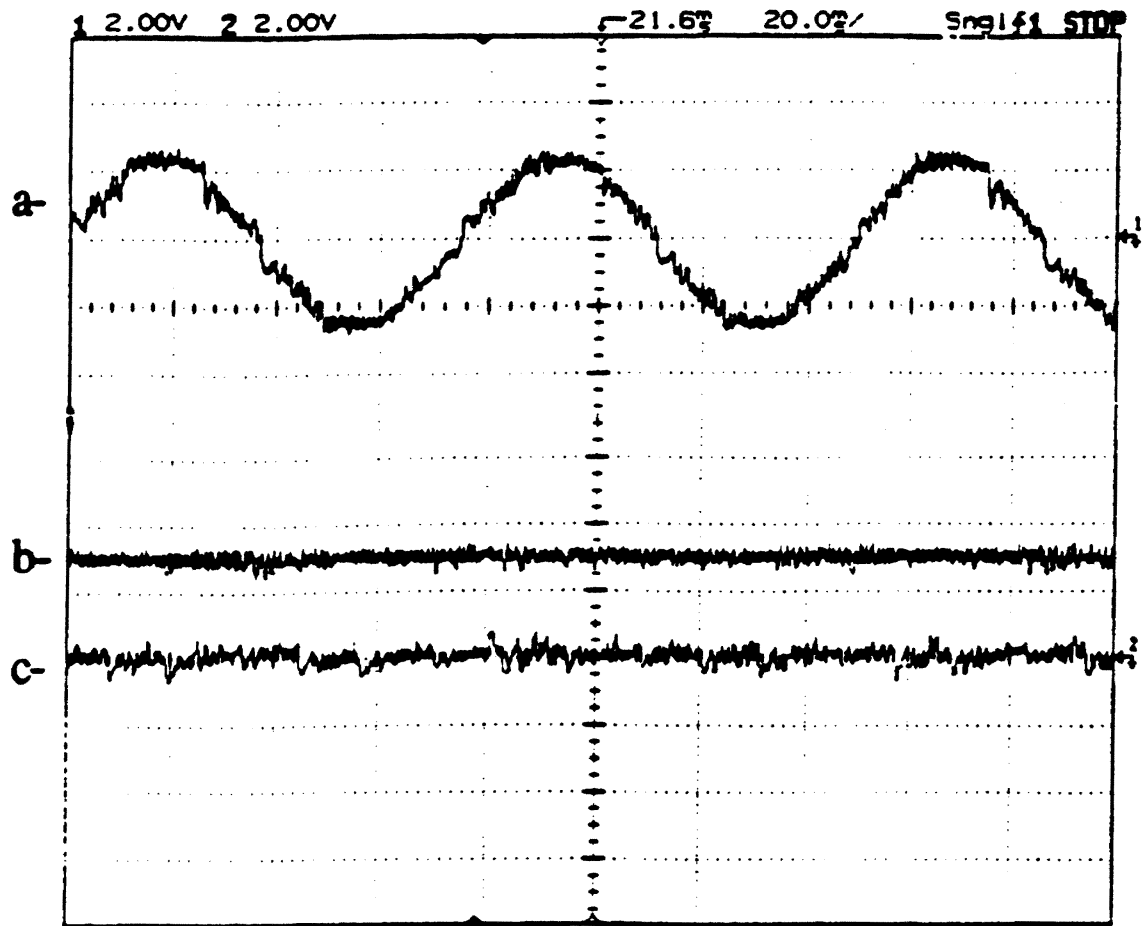
Figure 7. Resolver Output Signal and Corresponding Sampled and Held Signal



Using these trigonometric functions, we can find the direct current,  $i_d$ , and quadrature current,  $i_q$ . The direct current is fixed to zero and the control of the quadrature current allows us to control the machine torque. All of the necessary controllers are developed by software.

Figure 8-a to Figure 8-c show respectively the first phase current,  $i_a$ , the quadrature current,  $i_q$ , and direct current,  $i_d$ , of the PMSM. The good behavior of the machine torque control validates the robustness and accuracy of the proposed system.

Figure 8. Phase Current (a), Quadrature Current (b), and Direct Current (c)





## Conclusion

In this application report a universal digital controller system, used in the field-oriented control of ac machines has been presented. A method which determines directly the digital values of the sine and cosine functions of the rotor position angle is also described. This method does not require resolver-to-digital converters and to eliminate the look-up table method whereby we can economize the price of the drive controller systems. Moreover, it is shown that the TMS320C14 DSP, with its useful peripheral integrated circuits is a suitable processor for this controller system. The experimental results which prove the validity of this controller are given.

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