APPLICATION NOTE: AN001
NOTE OBJECTIVE: Detail use and operation discussion of the Encoder/Commutation option for the synchro/resolver measurement modules.

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Encoders – Basic Operation

When provided (usually as an option) the NAI encoder outputs provide incremental Synchro/Resolver position via two channels (differential output pair) referred to as the A Channel and B Channel as well as a third channel (differential output pair) providing the Index (or zero reference marker) which occurs passing through zero degree measurement.

The two channels (A and B) provide the same information (pulses per unit of motion), but have an electrical phase shift of 90 degrees (or ¼ the period width) between each other (electrical 360 degrees indicates one signal cycle, not mechanical shaft rotation). The 90 degree electrical phase shift between the two channels is referred to as “quadrature-encoded”. Hence the “industry standard” term “A-quad-B”. The encoder output appears as a frequency, but the pulse rate is dependant on the measured rotational velocity, not time. Since the two channels are phase shifted by 90 degrees (electrical), there are actually four states available per electrical cycle of these signals.

Since the encoder signals A and B are phase shifted by 90 degrees (which is approximately 1 LSB at 16-bit resolution), most electronics designed to read encoder signals can recognize whether A came before B or B came before A, thus supplying directional information.

Velocity can be calculated by differentiation; dividing the number of pulses per unit time by time.

The encoder outputs are also provided with an “Index” channel (“Zero” pulse or “Marker” channel). This channel outputs one pulse-per-revolution and is typically a narrow pulse (maximum) equating to approximately ¼ the width of an A or B channel pulse period (at 16-bit resolution). This is a reference position marker used for “homing” (absolute position reference) and occurs when the unit reads through zero degrees.

NAI normally provides the encoder option with programmable resolution easily set by the user (12 to 16 bit). The resolution sets the number of pulses in the “pulse train” for channel A and B that occur in one full mechanical rotation read by the S/D (0 to 360 degrees). For example, 16-bit resolution sets 2^16 (65536) quadrature transitions (both high and low) between the channel A and B pulse trains for one complete mechanical rotation (see figure A below for pictorial representation).

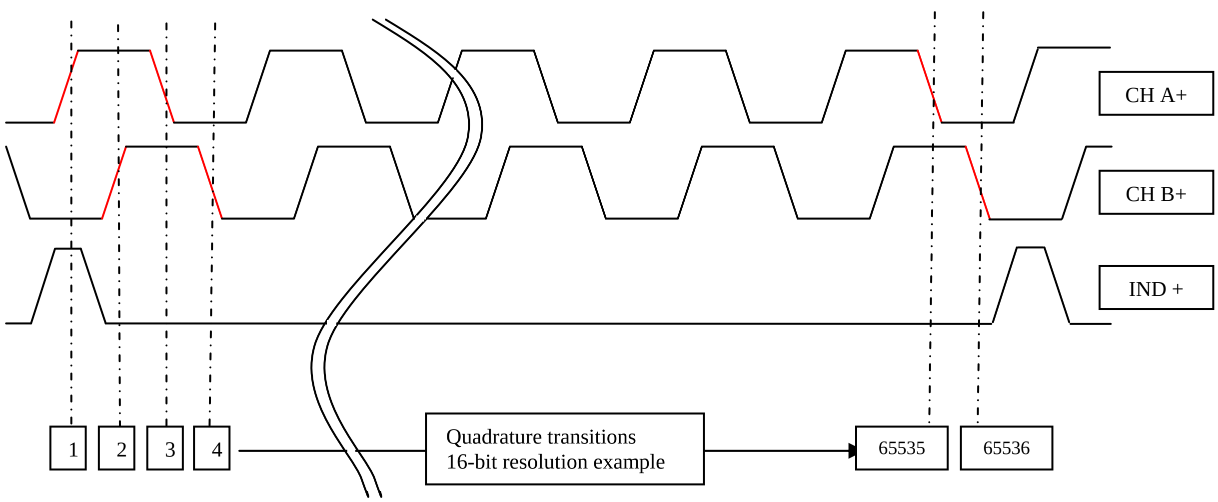
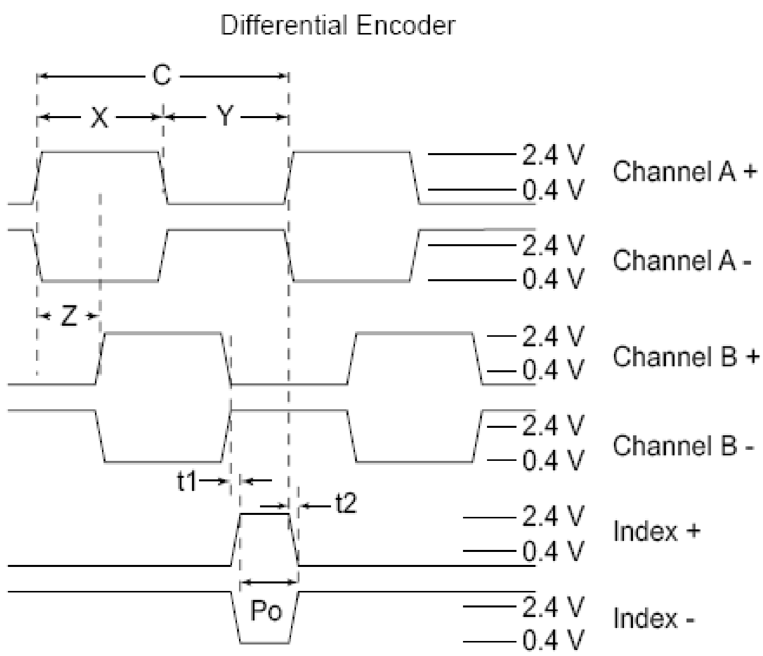


FIG A: Encoder Resolution / Quadrature Transition Relationship

(1) Encoder Emulation: A, B, Index

1.A. In a single speed operation, what is the timing of the output "Index" with regard to "A" and "B”?



(C) One Cycle: 360 electrical degrees (°e)
(X/Y) Symmetry: A measure of the relationship between X and Y, nominally 180°e.
(Z) Quadrature: The phase lag or lead between channels A and B, nominally 90°e.
(Po) Index Pulse Width: Nominally 90°e.

(t1) Index Rise after CHB or CHA fall (typical @ 250 nsec)
(t2) Index Fall after CHA or CHB rise (typical @ 1000 nsec)

Note: Electrical degrees (deg e) indicate reference to the electrical signal cycle, not mechanical cycle (rotation).

(Above figure applies for 16-bit resolution – For 15-bit to 12-bit, divide Index Pulse Width by 2 for each bit of lower resolution. For example: 15-bit resolution the Index Pulse width would nominally be 45 deg e, 14-bit is 22.5 deg e, 13 and 12 bit is 11.25 and 5.625 deg e respectively)

Differential output driver voltage levels RS422 (@ 0-5V): Output Voltage Characteristics **AM26C31C / AM26C31I (or equivalent)**

		MIN	TYP	MAX
VOH High-level output voltage	IO = – 20 mA	2.4	3.4 V	
VOL Low-level output voltage	IO = 20 mA		0.2	0.4 V

Fig 1: Typical Encoder Timing Relationship

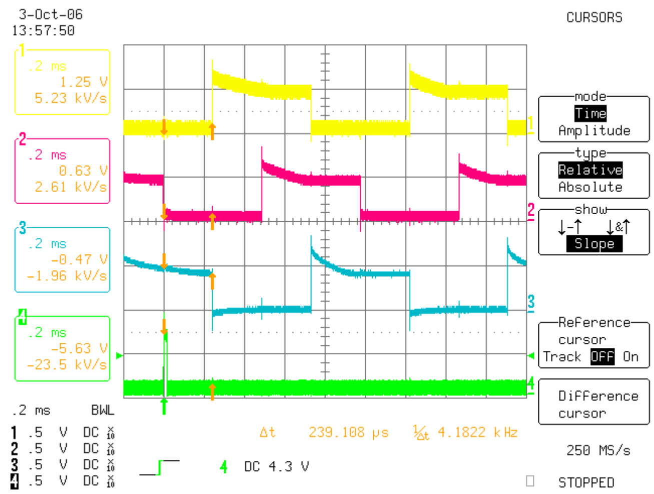
NAI card rotation definitions:

Clockwise (CW): Increasing angle 0 to 359.9945 deg. (shaft rotation)
Counter-Clockwise (CCW): Decreasing angle 359.9945 to 0 deg. (shaft rotation)

CW rotation; Channel A would lead channel B (wrt Index Pulse)
CCW rotation; Channel B would lead channel A (wrt Index Pulse)

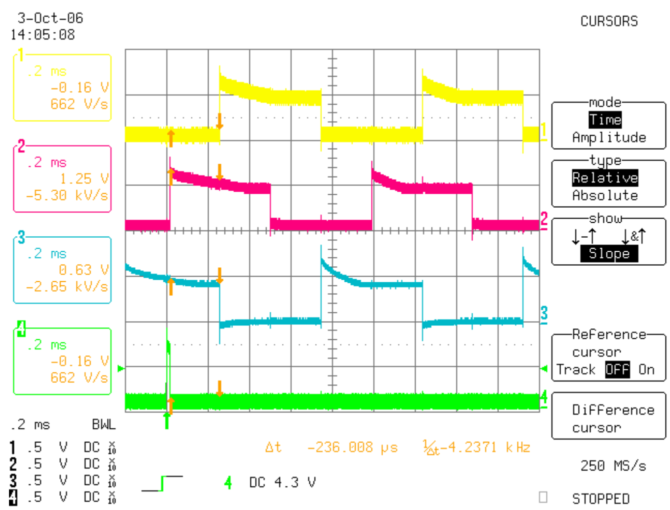
NOTE: NAI offers 12 through 16 bit resolution (programmable) – timing relationships between the A and B channels / pulses remain constant. However, it should be noted that the Index pulse width relationship to channel A and B period does change dependant on the resolution chosen (programmed). At 16-bit resolution, the Index Pulse width (IPW) is approximately ¼ the channel A or B pulse period (or 90 deg e). At 15-bit resolution, the IPW is 1/8 of the channel A or B pulse period (or 45 deg e). At 14, 13 and 12 – bit resolution, the IPW is 1/16, 1/32 and 1/64 of the channel A or B pulse period respectively (or 22.5, 11.25 and 5.63 deg e respectively).

Encoder Actual Measurements:



Trace1: **CH1: "A" Hi output**
CH2: "B" Hi output
CH3: "A" Lo output
CH4: "Index" Hi output

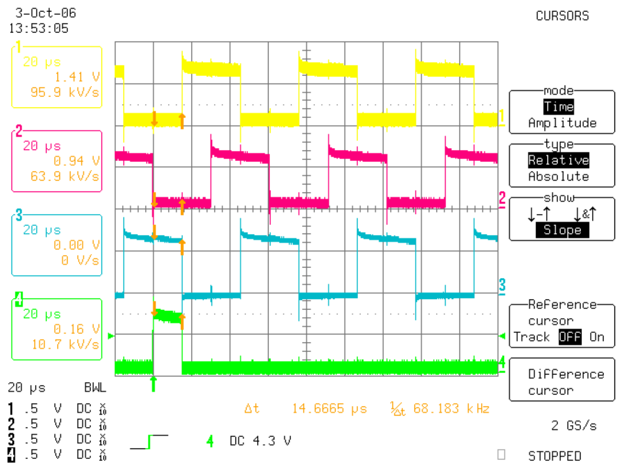
Conditions: **12-Bit, 360 deg/sec, CW rotation**



Trace2: **CH1: "A" Hi output**
CH2: "B" Hi output
CH3: "A" Lo output
CH4: "Index" Hi output

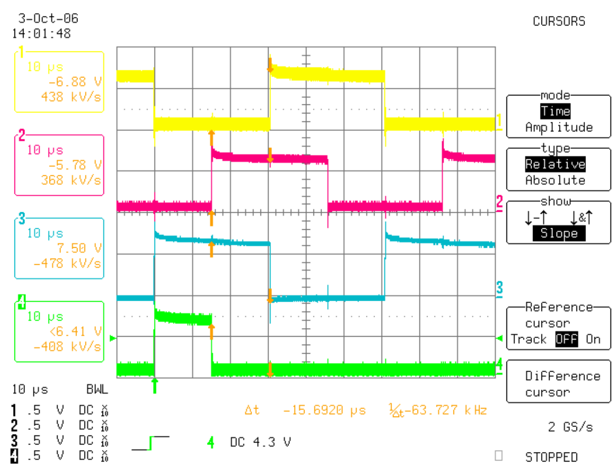
Conditions: **12-Bit, 360 deg/sec, CCW rotation**

Trace3: **CH1: "A" Hi output**
CH2: "B" Hi output
CH3: "A" Lo output
CH4: "Index" Hi output



Conditions: **16-Bit, 360 deg/sec, CW rotation**

Trace4: **CH1: "A" Hi output**
CH2: "B" Hi output
CH3: "A" Lo output
CH4: "Index" Hi output



Conditions: **16-Bit, 360 deg/sec, CCW rotation**

1.B. In a dual speed application, will the Encoder outputs from 1x and NX channels be combined in anyway?

When the S/D inputs are set up for reading dual speed (ratio), then the encoder output for the even channel (Nx) will output and track the combined angle (shaft position); CH1 (1x) encoders will follow the coarse angle position, CH2 (Nx) will follow the combined 2-speed angle position.

1.C. The 1X and NX signals

Does it appear N times at every zero position?

The encoder output for the 1x channel will deliver an index pulse each time it reads a “zero” position on the coarse angle. Nx gives combined angle position (when set for dual speed ratio mode). Index timing occurs at the zero degree crossing point; angle position “0000h” or 0 degrees for coarse channel 1x and for combined angle two-speed measurement crossing Nx.

Commutation – Basic Operation

The use of Brushless DC (BLDC) motors is continuously increasing. BLDC motors have a good weight / size ratio, have excellent acceleration performance, require little or no maintenance and generate less acoustic and electrical noise than universal (brushed) DC motors.

In a “universal” (brushed) DC motor, the brushes control the commutation by physically connecting the coils at the correct moment. In BLDC motors, the commutation is controlled by electronics. The electronics can either have position sensor inputs that provide information about when to commutate.

Since most brushless motors must be electronically commutated, the drive must have a signal indicating the electrical position of the motor’s rotor with respect to the stator windings.

NAI cards that provide commutation generate signals comparable to the Hall Effect Sensor outputs of a motor for facilitating a controlled feedback of rotor position.

A three phase BLDC consists of a Stator with a number of coils. The fundamental three phase BLDC motor has three coils. Usually the three coils are referred to as U, V and W. In many motors the fundamental number of coils is replicated so the motors would have smaller rotation steps and smaller torque ripple.

The rotor in a BLDC motor consists of an even number of permanent magnets. The number of magnetic pole pairs (North and South) in the rotor also affects the step size and torque ripple of the motor. More “poles” gives smaller steps and less torque ripple.

The electrical position of a motor follows the field produced by magnets. In most motors, the electrical position rotates faster than the mechanical position. Magnets are placed on brushless motors at evenly spaced intervals. If there were two magnets, the magnetic field would cycle one time for each rotor turn. However, if there were more magnets, the magnetic field would cycle faster than the rotor. Each magnet is represented by a magnet “pole” pair.

To make the motor rotate, the coils are energized in a predefined (6-step) sequence, making the motor turn in one direction, say clockwise. Running the sequence in reverse order runs the motor in the opposite direction. One should understand that the sequence defines the direction of current flow in the coils and thereby the magnetic field generated by the individual coils. The direction of the current determines the orientation of the magnetic field generated by the coil. The magnetic field attracts and rejects the permanent magnets of the rotor. By changing the current flow in the coils and thereby the polarity of the magnetic fields at the precise moment (and in the right sequence) the motor rotates. Alternation of the current flow through the coils to make the motor turn is referred to as commutation.

(2) Commutation: A, B, C

2.A. In a single speed operation, what is the timing of the output A, B and C?

The unit performs the “6-step Commutation” simulating Hall Effect sensors as defined:

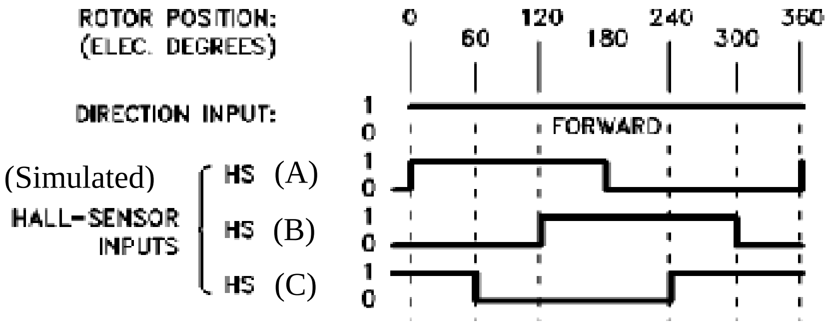


Fig. 2 – 6-Step Commutation timing

Example – Typical 3-phase Brushless Motor and Control Schematic

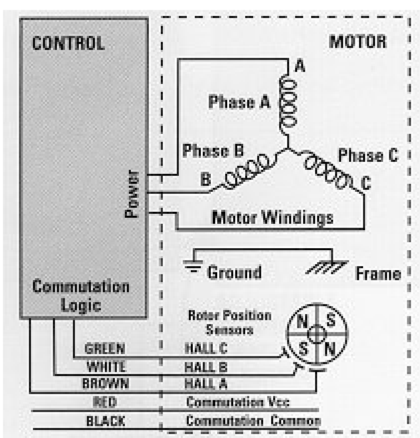


Fig. 3 – Typical application

Motor Rotation

Clockwise*				Counter Clockwise*			
Hall Sensor Output A B C	Phase Current A	B	C	Hall Sensor Output A B C	Phase Current A	B	C
0 0 1	+	OFF	−	0 1 1	OFF	−	+
0 0 0	+	−	OFF	1 1 1	+	−	OFF
1 0 0	OFF	−	+	1 1 0	+	OFF	−
1 1 0	−	OFF	+	1 0 0	OFF	+	−
1 1 1	−	+	OFF	0 0 0	−	+	OFF
0 1 1	OFF	+	−	0 0 1	−	OFF	+

*Viewing Shaft. 1 = high voltage;
0 = low voltage

Fig. 4 – 6 step sequence

2.B. How does the number of poles affect the timing?

The timing relationship between the signals remains the same. However, for motors with multiple poles (each magnet is normally referred to as having a pole - poles equating to a set of N and S magnetic poles), it should be noted that the electrical rotation may not correspond to a mechanical rotation.

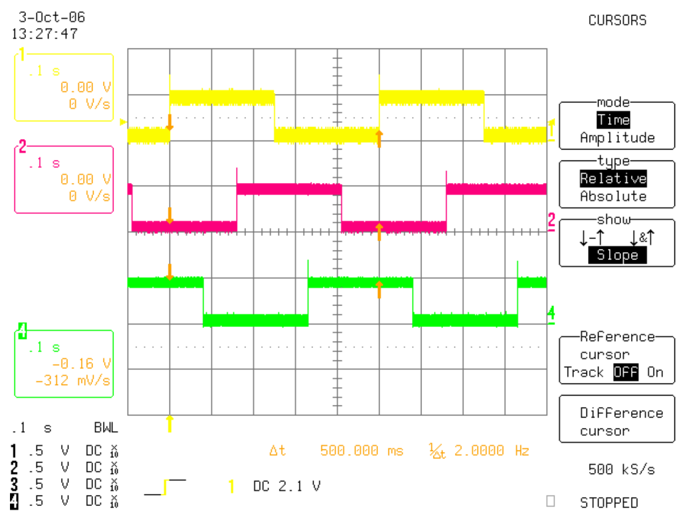
The 6-step sequence shown above (fig.4) for a 3-phase motor indicates one electrical rotation. A two pole motor (two magnets) would use one electrical cycle for one mechanical rotation. A four pole motor uses 2 electrical cycles to one mechanical rotation. Six and eight pole motors are three and four electrical cycles to one mechanical cycle respectively.

2.C. In a dual speed application, will the Commutation outputs from 1x and NX channels be combined in anyway?

Yes, the 1x is available on the 1x channel commutation output and the combined dual speed output will be on the Nx channel commutation output.

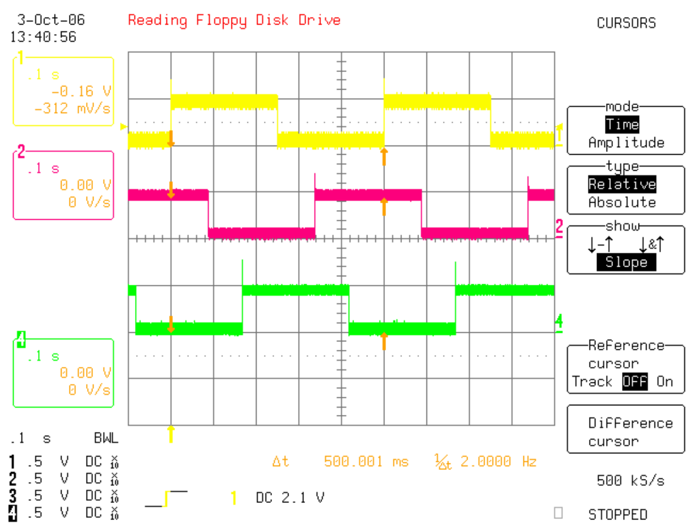
Commutator Actual Measurements:

Trace5: **CH1: "HA" Hi output**
CH2: "HB" Hi output
CH3: "HC" Hi output



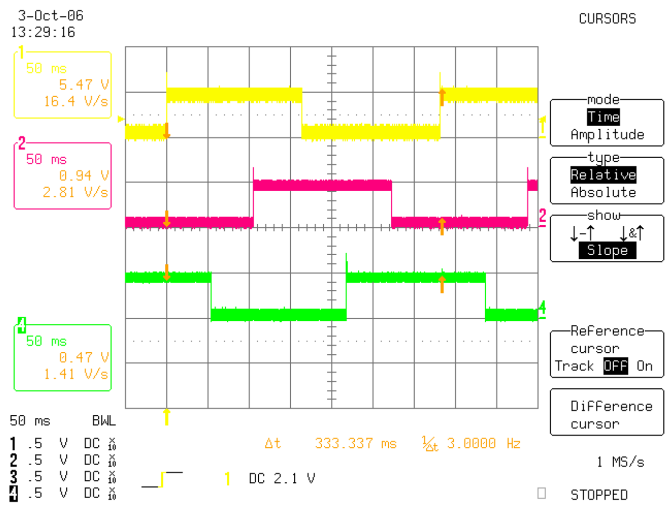
Conditions: **4-Pole, 360 deg/sec, CW rotation**

Trace6: **CH1: "HA" Hi output**
CH2: "HB" Hi output
CH3: "HC" Hi output



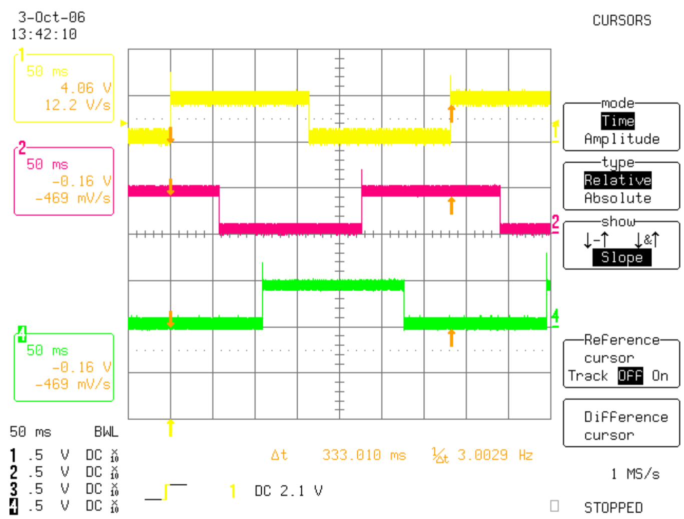
Conditions: **4-Pole, 360 deg/sec, CCW rotation**

Trace7: **CH1: "HA" Hi output**
CH2: "HB" Hi output
CH3: "HC" Hi output



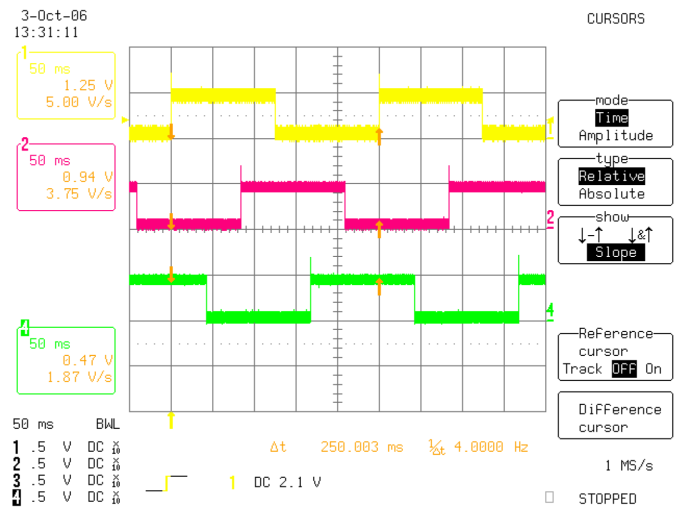
Conditions: **6-Pole, 360 deg/sec, CW rotation**

Trace8: **CH1: "HA" Hi output**
CH2: "HB" Hi output
CH3: "HC" Hi output



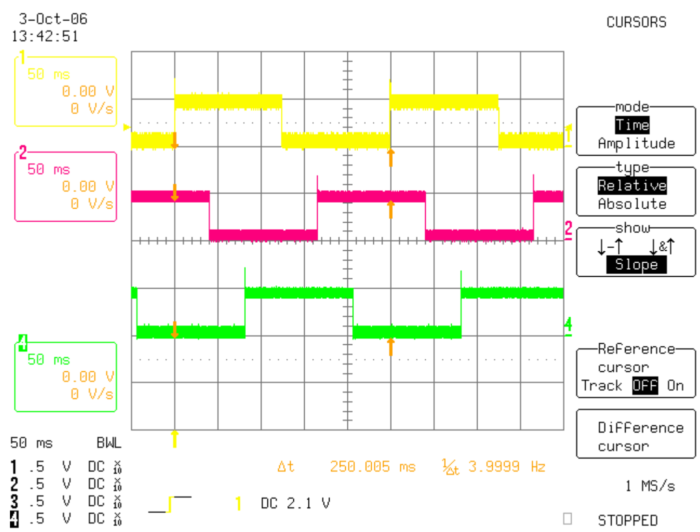
Conditions: **6-Pole, 360 deg/sec, CCW rotation**

Trace9: CH1: "HA" Hi output
CH2: "HB" Hi output
CH3: "HC" Hi output



Conditions: 8-Pole, 360 deg/sec, CW rotation

Trace10: CH1: "HA" Hi output
CH2: "HB" Hi output
CH3: "HC" Hi output



Conditions: 8-Pole, 360 deg/sec, CCW rotation

Revision Page

Revision	Description of Change	Engineer	Date
1.0	Initial Release	AS	10/18/06
A	Release to Agile (format, no content change)	AS	04/02/08
B	Revise encoder resolution description (defined quadrature transitions, added pictorial) (pg. 2).	AS	12/04/08