Brushed DC Motor Control Using the MC68HC16Z1

by Lawrence Donahue

INTRODUCTION

The MC68HC16Z1 is a 16-bit high speed microcontroller that incorporates a number of different modules. One of these modules is the General Purpose Timer (GPT), which provides various timing functions including pulse width modulation (PWM) output. PWM is very useful for motor control. This note describes a DC motor control system that provides for constant motor speed using PWM.

The control system uses motor shaft rotation period as its input, monitors motor speed, and changes PWM output duty cycle to either speed up or slow down the motor in order to maintain constant speed. The M68HC16 interfaces to the motor via the DEVB103 Logic to Motor Interface Module, which is described in detail in Freescale Application Note AN1300 *Interfacing Microcomputers to Fractional Horsepower Motors*.

BACKGROUND

A DC motor is a transducer that converts electrical energy to mechanical energy. As shown in **Figure 1**, an ideal motor would run without loss and store no energy.

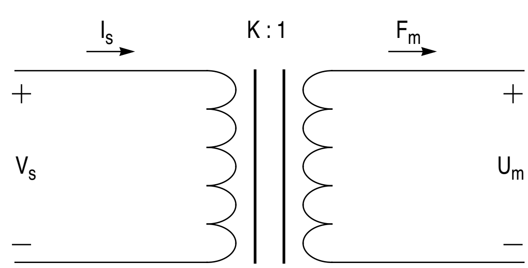

Figure 1 Ideal Motor

The model of an ideal motor is similar to that of an ideal transformer, but only one side has voltage (V) and current (I) variables, while the other side has velocity (U) and force (F) variables. The voltage-velocity and current-force relationships are:

$$KI_s = F_m$$
$$V_s = KU_m$$

However, a real motor is far from ideal, both electrically and mechanically. The electrical side consists essentially of wire wound around a core. The windings have an associated inductance, and since wire has resistivity, there is also a finite resistance. Inertia affects mechanical operation. A rotating motor does not instantaneously stop when disconnected from its power source, but rather slows down and eventually stops.

Similarly, a stopped motor does not instantaneously jump up to speed when power is applied. Because the motor resists step changes in the velocity (the across variable) there is an element that looks capacitive. Because an unpowered motor eventually slows down, it is lossy. A more realistic model of a motor includes an electrical resistance and inductance and a mechanical resistance and compliance, along with an additional load, as shown in **Figure 2**.

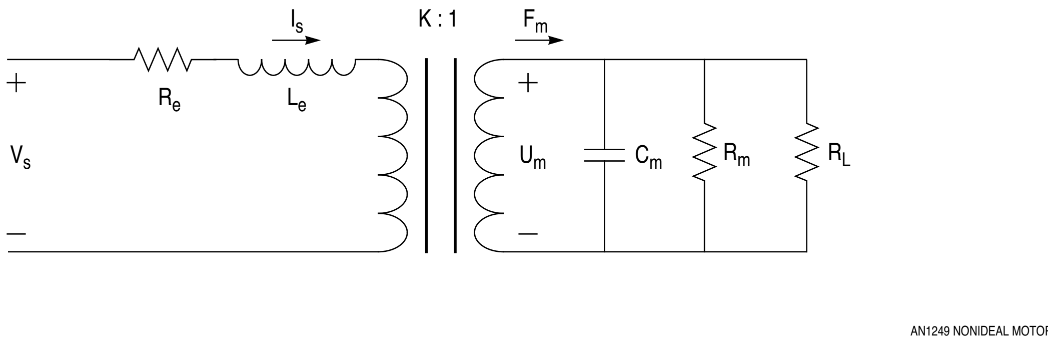

Figure 2 Model Motor with Load

Figure 3 shows the electrical equivalent circuit, looking into the terminals of the ideal transducer.

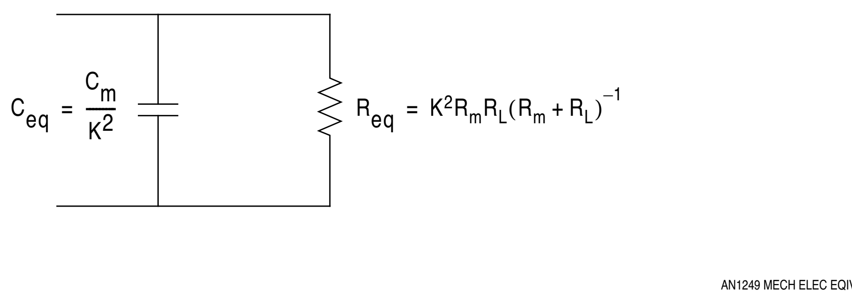

Figure 3 Electrical Equivalent of Mechanics

Figure 4 is the second-order electronic equivalent of the motor.

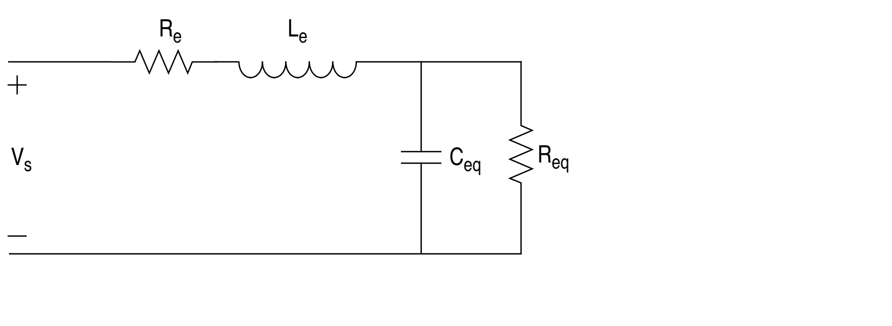

Figure 4 Electrical Equivalent of a Motor

The result is a second order model system with a natural frequency of:

$$\omega_0 = [L_e C_{eq}]^{-1/2}$$

The input to this model system is a pulse-width modulated signal that switches between ground and a constant voltage. Switching occurs at a constant frequency with a given duty cycle. If the switching frequency is sufficiently above the bandwidth of the motor, the motor filters out everything but the DC component of the PWM signal, thus averaging it. For example, consider a PWM that switches between 0 volts and V_0 volts with a duty cycle of 25%. The motor behaves as if it were connected to a DC supply of $0.25V_0$ volts — the duty cycle of the PWM determines the speed of the motor.

In real DC motors, however, the relationship between source voltage and shaft velocity is not linear, and these relationships vary from motor to motor. Therefore, one desirable characteristic of a motor control system is the ability to control speed independent of motor characteristics. Also, in many real-world applications, motor loads vary. Hence, another desirable characteristic is the ability to provide constant motor speed under changing loads. These requirements are addressed by monitoring and controlling motor speed rather than providing a specific voltage or duty cycle.

SYSTEM OVERVIEW

The system has four basic elements, as shown in **Figure 5**.

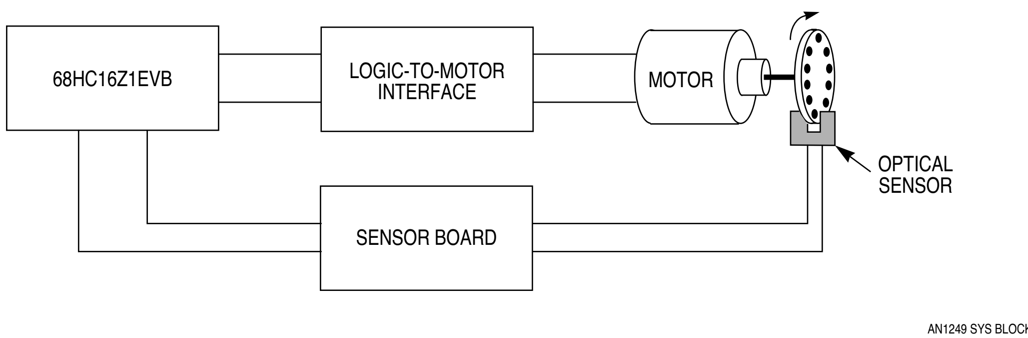

Figure 5 System Block Diagram

The first block represents the (MC68HC16Z1EVB) evaluation board that provides system computing and control functions. The MCU is accessed by EVB16 software running on an IBM PC compatible connected to the EVB via a parallel port. The GPT in the MCU generates a PWM signal which is connected to the DEVB103 logic to motor interface module (**Figure 6**). The logic to motor interface module takes logic level PWM signals and switches the power transistors of an H-bridge to provide motor drive power up to 60 V and 3 A. The motor is the third element of the system. The fourth element consists of an opto-sensor and a sensor board that conditions sensor output so that the period of motor shaft rotation can be measured by software, to complete the feedback loop. **Figure 7** shows a typical comparator with unipolar output. Comparator component values depend on sensor output level.

Figure 10 shows the open loop system function. The input is D, the duty cycle that determines the speed of the motor. The output is ω_A, the actual speed of the motor. Hence, the transfer function of the motor is:

$$\omega_A / D = [s^2 + 2\alpha s + \omega_0{}^2]^{-1}$$

Observations of the actual motor indicate that the open loop system function is overdamped, and thus looks somewhat like a first order system.

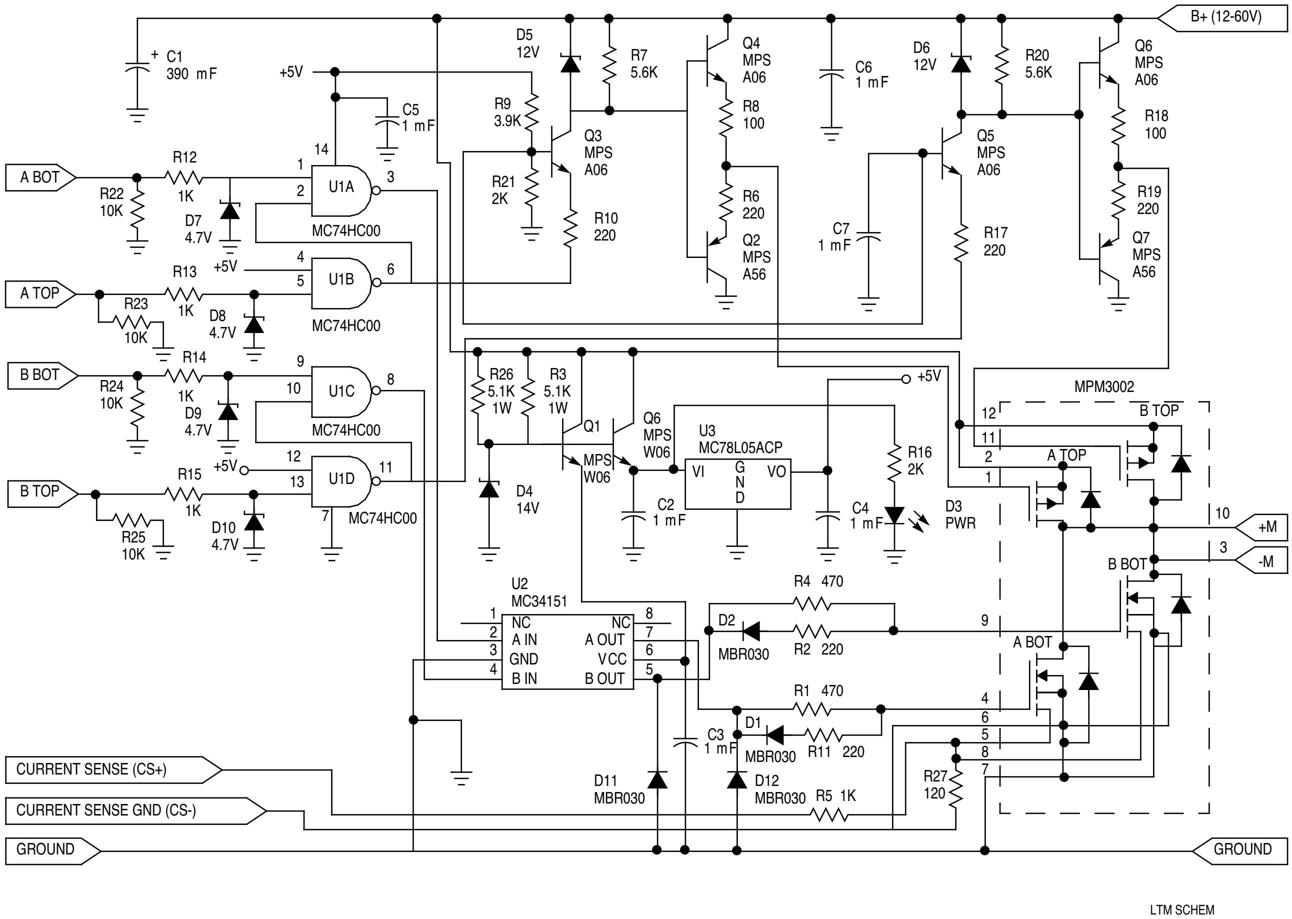

Figure 6 Logic To Motor Interface Schematic

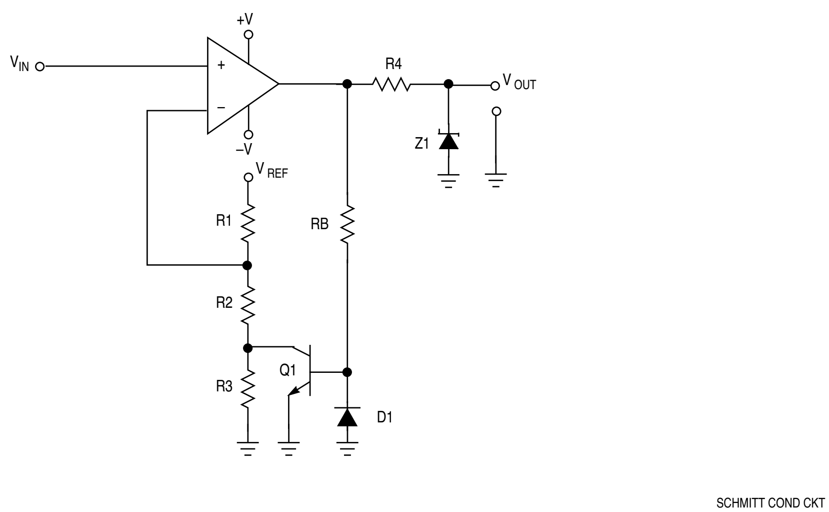

Figure 7 Sensor Output Conditioning Circuit

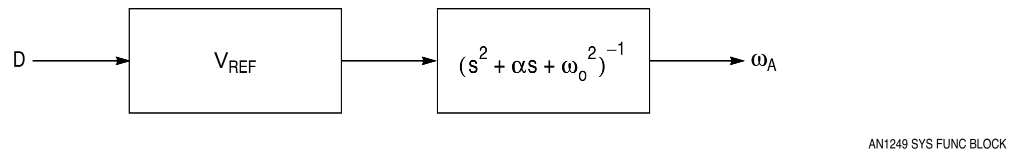

Figure 8 System Functional Diagram

The system is to maintain the motor speed ω_A constant at the desired speed ω_D. Examining the closed-loop system function diagram shown in **Figure 9** yields:

$$D = D + [\omega_D - \omega_A]/\omega_D$$

or

$$\omega_A = \omega_D$$

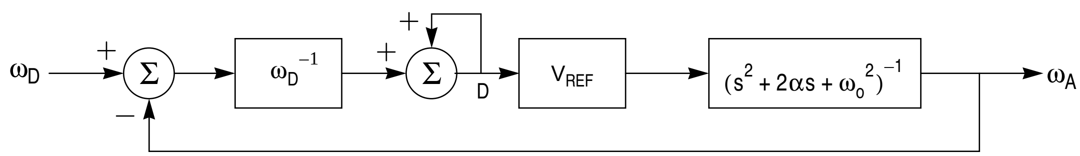

Figure 9 Closed Loop System

Therefore the input-output relationship is independent of the motor given a constant input ω_D. However, when the transfer function of the motor changes (i.e., when the load on the motor changes) or when the desired speed changes, the system must adjust the value of D to make the actual motor speed equal the desired speed. Further examination of the system function yields:

$$D = D + [\omega_D - \omega_A] / \omega_D = (\omega_A/V_{ref})\,(s^2 + 2as + \omega_0^2)$$

which simplifies to:

$$\omega_A = V_{ref}\,(1 + D)\,[s^2 + 2\alpha s + \omega_0^2 + V_{ref}/\omega_D]^{-1}$$

As shown in **Figure 10**, the poles of the closed loop system function differ from those of the open loop function. The poles become:

$$s_1 = -\alpha + [\alpha^2 - \omega_0^2 - V_{ref}/\omega_D]^{1/2}$$

$$s_2 = -\alpha - [\alpha^2 - \omega_0^2 - V_{ref}/\omega_D]^{1/2}$$

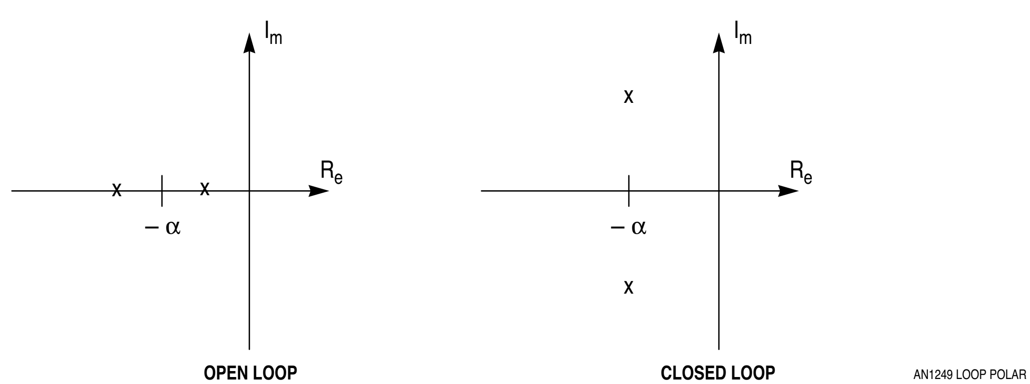

Figure 10 Open Loop and Closed Loop Poles in Complex Plane

The poles are thus functions of V_{ref}/ω_D. If V_{ref}/ω_D gets large enough, the poles become complex, and the actual motor speed, ω_A, rings as it settles to its final value of ω_D. The envelope and overshoot of the ringing are both dependent on several factors, including the control algorithm, the voltage and duty cycle used for the PWM, the desired speed, the load on the motor, and the motor itself.

SOFTWARE CONTROL

The software that controls the motor brings the motor up to speed as fast as possible, given the voltage constraints of the system, and then maintains that desired speed. **Figure 12** is an overall block diagram of the system software. **Figure 13** through **Figure 15** provide flow diagrams of the three major blocks of code.

Begin sets up the registers that control the GPT, sets the desired period of rotation and tolerances, and sets the PWM to 100%. *Startup* then monitors the period of rotation of the motor by using the subroutine *measure* (refer to **Figure 13**). If *measure* returns a period longer than that desired, the program loops back to *startup*. When *measure* returns a period shorter than that desired, the program continues with *new_duty* (refer to **Figure 13**), which calculates and sets the new duty cycle with the algorithm:

$$D_{new} = D_{old}\,[1 + (T_D - T_A)/T_A]^{-1}$$

where T_D and T_A are the desired and actual periods of rotation, respectively. Following *new_duty*, *tolerance* (refer to **Figure 14**) checks to see if the measured period is within the tolerances designated in *begin*.

For experimental purposes, a second control algorithm that modifies the duty cycle in a different manner was also implemented. The routine compares T_D and T_A and determines whether T_A is greater or less than T_D, then takes one of the following actions:

- If the two periods are within 8 GPT counts, the duty cycle is not modified.
- If T_D - 8 is greater than T_A, the duty cycle is decreased.
- if T_D + 8 is less than T_A, the duty cycle is increased.

The routine then looks at the magnitude of the difference between the two periods to determine by how much the duty cycle is to be modified. **Figure 16** is a flow diagram of the alternate control algorithm.

Figure 11 is a plot of the increment by which the duty cycle is modified as a function of the difference between T_D and T_A.

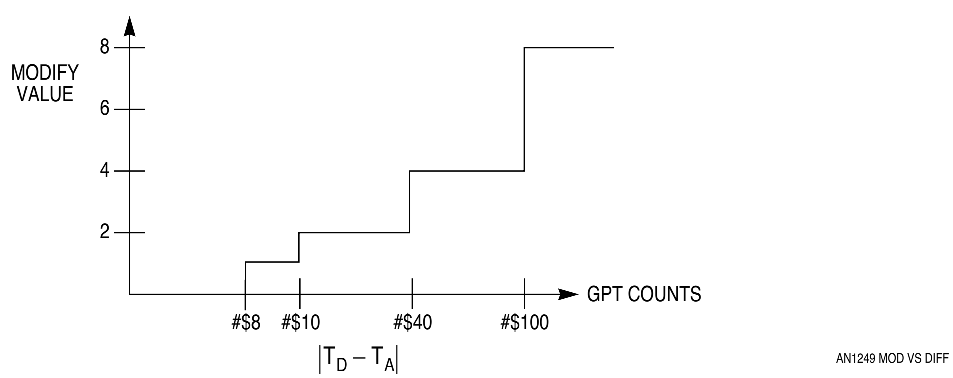

Figure 11 Modify Value vs. Difference

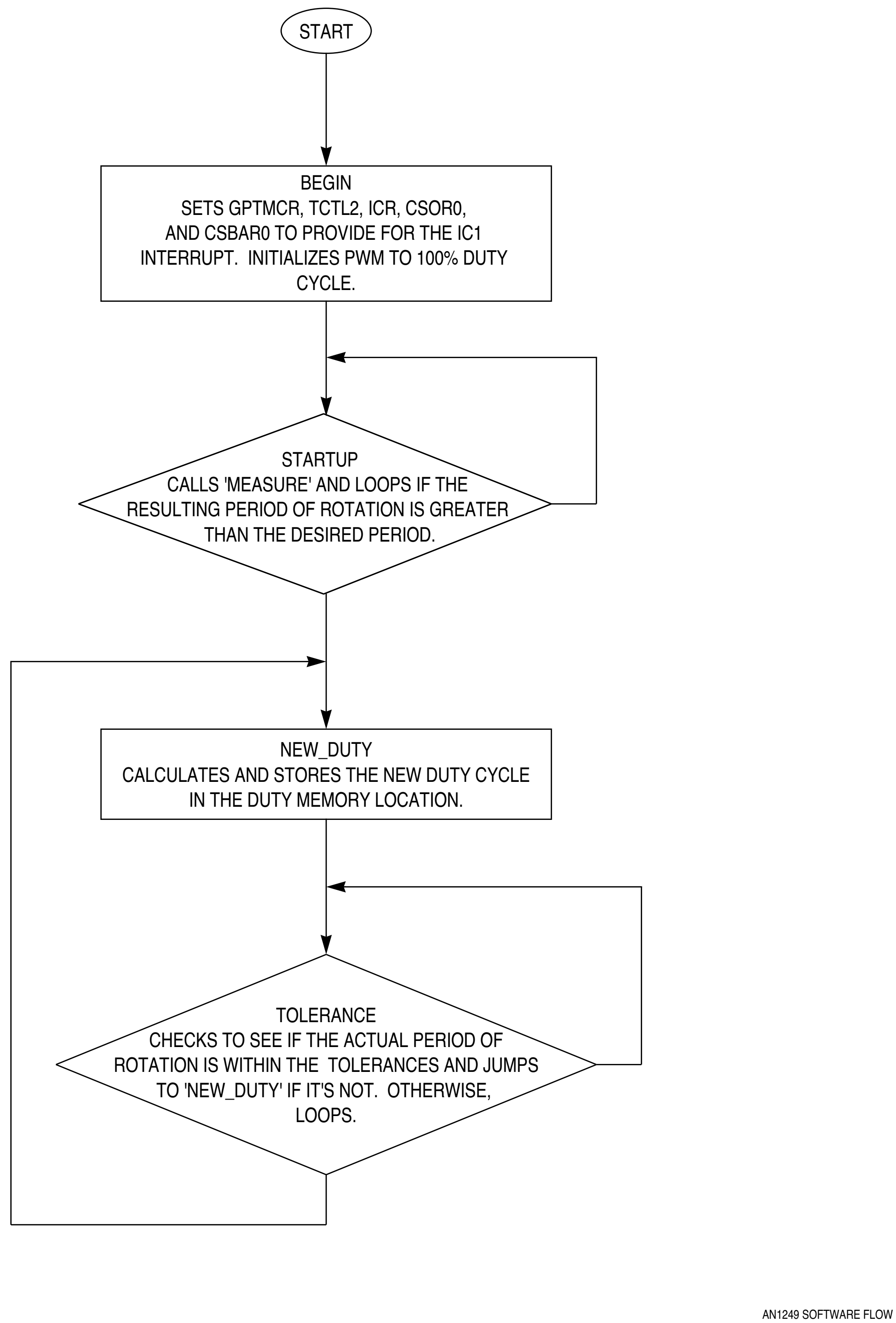

Figure 12 System Software Flow Diagram

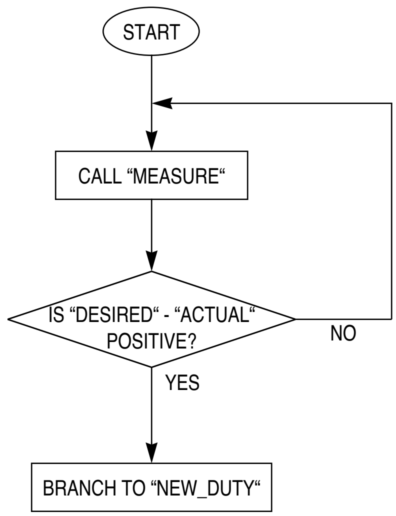

Figure 13 ***Startup*** **Routine Flow Diagram**

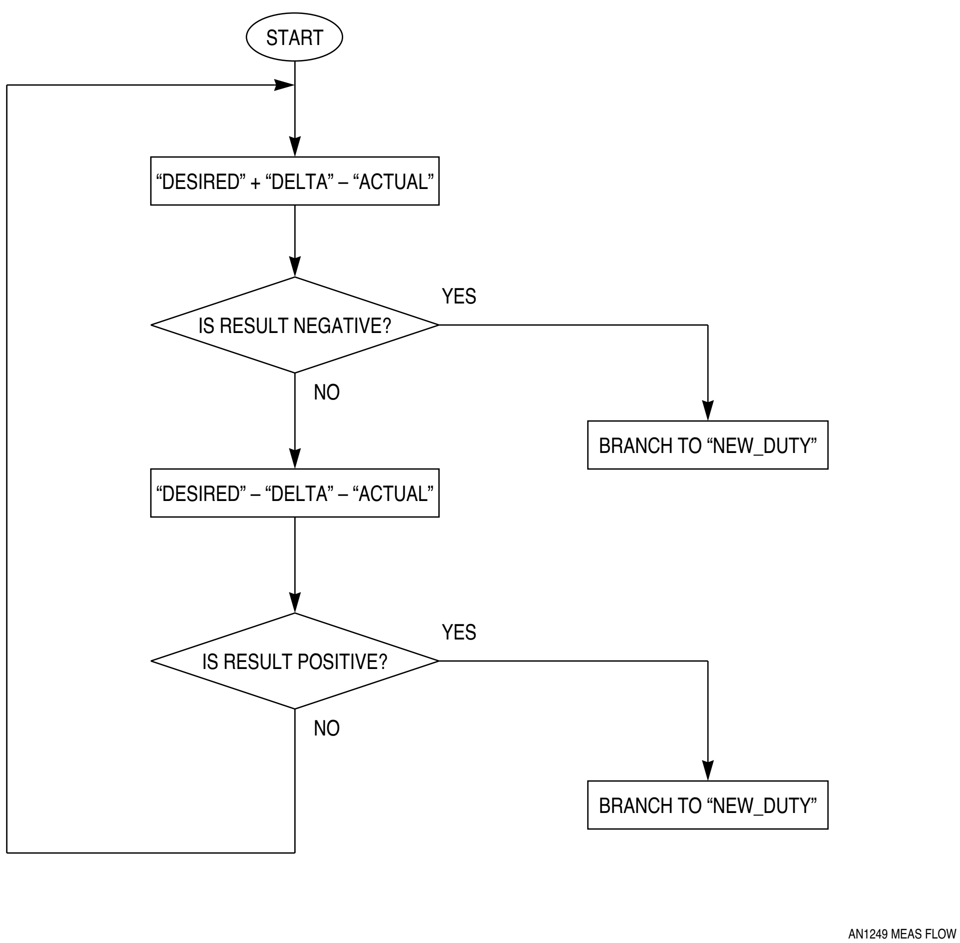

Figure 14 ***Tolerance*** **Subroutine Flow Diagram**

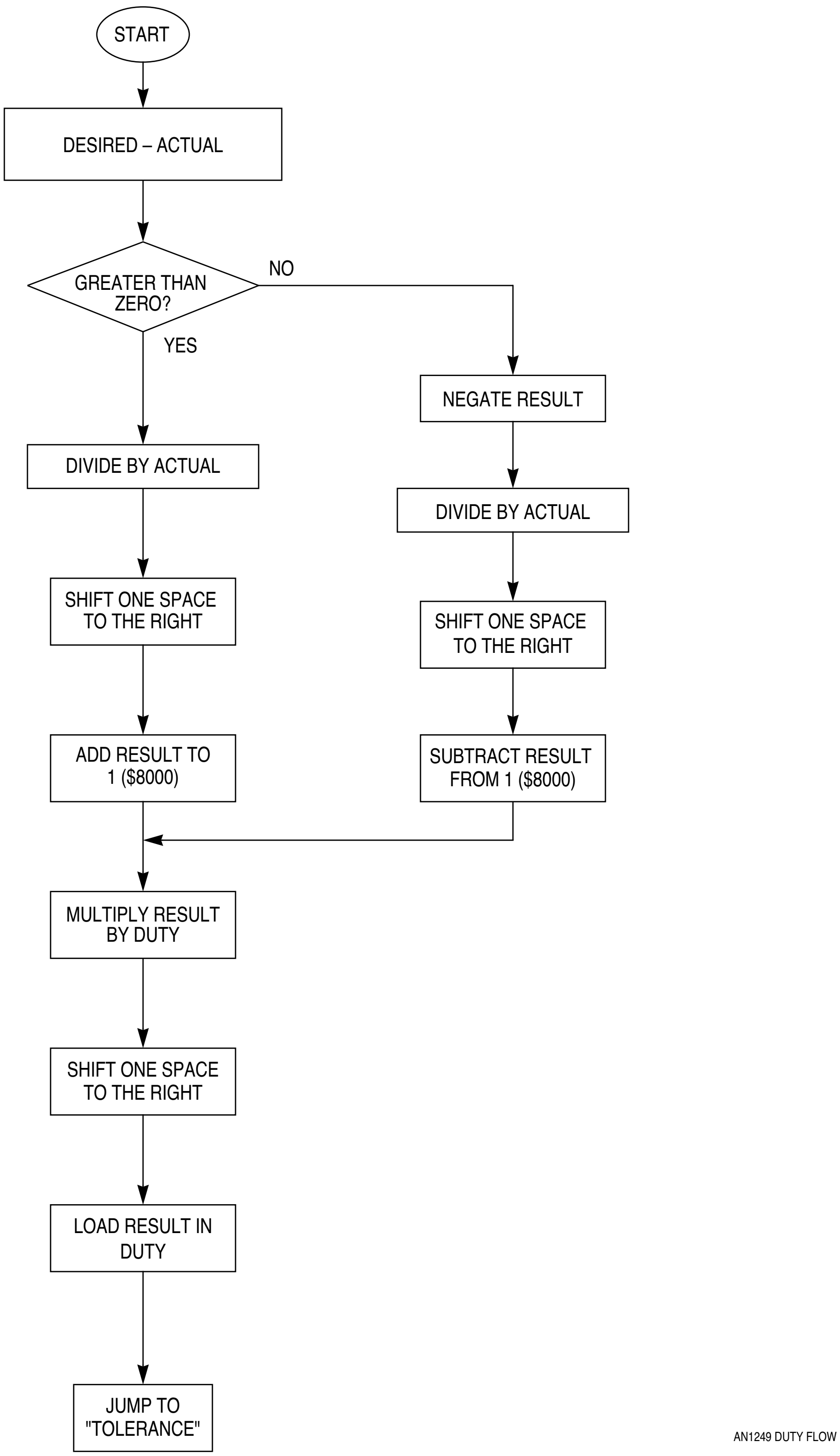

Figure 15 *New_duty* Routine Flow Diagram

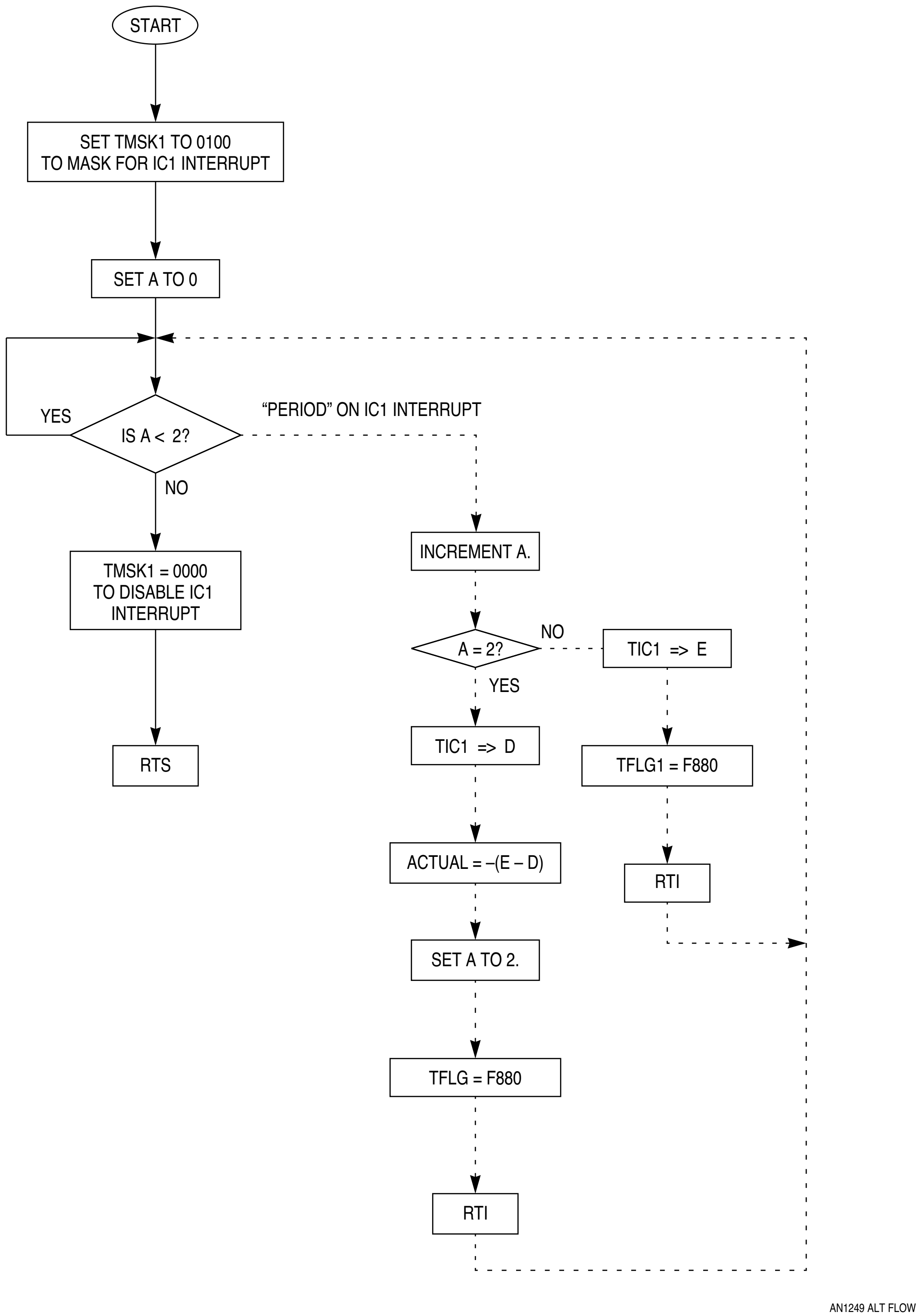

Figure 16 Alternate Control Algorithm Flow Diagram

Both control routines were evaluated on two different motors. One motor was a slower, less responsive motor that worked well with the second increment/decrement approach and not so well with the first approach. The second motor was faster and more responsive and worked very well with the first approach but not so well with the second approach.

CODE LISTINGS

Listings 1 and 2 contain code for the first implementation of the control routine and the second increment/ decrement implementation of the control routine, respectively.

Listing 1 First Control Implementation.

```
        INCLUDE 'EQUATES.ASM'   ;table of EQUates for common register addr
        INCLUDE 'ORG00000.ASM'  ;initialize reset vector

        ORG     $80
        DC.W    PERIOD          ;IC1 jumps to PERIOD

        ORG     $0400  ;offsets from IX for variables
DESIRED EQU     $0     ;location for storing the desired period
DELTA   EQU     $2     ;location for storing the period tolerance
ACTUAL  EQU     $4     ;location for storing the measured period
DUTY    EQU     $6     ;location for storing the present duty cycle
TEMP1   EQU     $8     ;location for storing any temporary values
TEMP2   EQU     $A     ;   "      "     "     "      "       "
TEMP3   EQU     $C     ;   "      "     "     "      "       "
TEMP4   EQU     $E     ;   "      "     "     "      "       "

        ORG     $0200           ;start program after interrupt vectors
*****   Initialization Routines *****
        INCLUDE 'INITRAM.ASM'   ;initialize and turn on SRAM
                                ;set stack (SK=1, SP=03FE)
        INCLUDE 'INITSYS.ASM'   ;initially set EK=F, XK=0, YK=0, ZK=0
                                ;set sys clock at 16.78 MHz, disable COP

*****   Here we go with motor control.  *****

BEGIN         LDD    #$0083    ;Put the GPT into supervisor mode (the default
              STD    GPTMCR    ;mode) and sets interrrupt priority level to 3.
              LDD    #$FFF9
              STD    CSBAR0
              LDD    #$7801    ;assert AVEC and other int. vector stuff
              STD    CSOR0
              LDD    #$1740    ;Set IC1 to be highest GPT priority, GPT to...
              STD    ICR       ;highest priority interrupt, and vector base...
                               ;address to 4.
              LDY    #$400     ;Beginning for variables in indirect addresses.
              LDD    #$A00     ;Set the desired period to $A00 GPT counts.
              STD    DESIRED,Y
              LDD    #$80      ;Set the tolerence to +/- $80 GPT counts.
              STD    DELTA,Y
              LDAA   #$01      ;Set IC1 to capture only on a positive edge.
              STAA   TCTL2
              LDD    #$0062    ;Set the input of PWMCNT to the system clock...
              STD    PWMC      ;divided by 128 and set PWMA to be allways high.
STARTUP       BSR    MEASURE   ;Branch to measure period of revolution
              CPE    DESIRED,Y ;Compare the measured period with the desired
              BPL    STARTUP   ;and loop if motor is slower than desired.
              LDD    #$00FF    ;Store the value $FF in...
              STD    DUTY,Y    ;...the user defined duty cycle location and...
              STAB   PWMA      ;...in the GPT PWMA register thus setting the...
                               ;...duty cycle of PWMA to $FF/$100.
              LDD    #$0060    ;Change PWMA's otput to be from a constant...
              STD    PWMC      ;...output to a PWM output with duty cycle...
                               ;...in the PWMA register.
              JMP    NEW_DUTY  ;branch to get new duty cycle
MEASURE       LDD    #$0104    ;Enable the IC1 interrupt and the TCNT clock...
              STD    TMSK1     ;...to be the OC1 pin.
              LDAA   #$00      ;The A register is used to keep track of how...
MEAS_LOOP     CMPA   #$02      ;...many input captures have taken place--with...
                               ;...two, we can measure the period.
              BMI    MEAS_LOOP ;Loop if two measurements have not been made.
              LDD    #$0000    ;If two interrupts have taken place,reset for...
              STD    TMSK1     ;...no interrupts (disable IC1).
              RTS              ;Return from "measure" subroutine.
TOLERANCE     BSR    MEASURE   ;Branch to "measure" subroutine.
```

```
              LDE    ACTUAL,Y  ;Load the measured period in E
              LDD    DESIRED,Y ;Load the desired period in D.
              ASLD             ;Double the desired period and put in D.
              SDE              ;Subtract twice the desired period from the...
                               ;...actual period, and if the actual period is...
              BPL    TOO_SLOW  ;...more than twice the desired, branch to the...
                               ;...the "too_slow" code.
              LDD    DESIRED,Y ;Load the desired period in D.
              LDE    ACTUAL,Y  ;Load the measured period in E.
              ASLE             ;Half the desired period and put in D.
              SDE              ;Subtract half the desired period from the...
                               ;...actual period, and if the actual period is...
              BMI    TOO_FAST  ;...less than half the desired, branch to the...
                               ;...the "too_fast" code.
              BRA    WITHIN    ;Otherwise branch to the "within" code.
TOO_SLOW      LDD    #$00FF
              STD    DUTY,Y    ;Set the user defined duty cycle location to $FF.
              STAB   PWMA      ;Set the PWMA register for a $FF/$100 duty cycle.
              BRA    WAIT      ;Branch to the "wait" code.
TOO_FAST      LDD    #$0000
              STD    DUTY,Y    ;Set the user defined duty cycle location to 0.
              STAB   PWMA      ;Set the PWMA register for a 0% duty cycle.
              BRA    WAIT      ;Branch to the "wait" code.
WITHIN        LDD    DESIRED,Y ;Load the desired period in D.
              LDE    DELTA,Y   ;Load the period tolerance in E.
              ADE              ;Add the two together to get the maximum...
                               ;...period allowed and store in E.
              LDD    ACTUAL,Y  ;Load the measured period in D and...
              SDE              ;...subtract it from the max period allowed.
              BMI    JUMP      ;Branch to get new duty cycle if slow.
              LDD    DESIRED,Y ;Load the desired period in D.
              LDE    DELTA,Y   ;Load the period tolerance in E.
              NEGE             ;Negate the period tolerance.
              ADE              ;Add the two together to get the minimum...
                               ;... period allowed and store in E.
              LDD    ACTUAL,Y  ;Load the measured period in D and...
              SDE              ;...subtract it from the min period allowed.
              BPL    JUMP      ;Branch to get new duty cycle if fast.
JUMP          JMP    NEW_DUTY  ;Jump to "new_duty" code.
WAIT          LDE    #$2       ;Load the number of loops to wait for in E.
              LDD    #$0000    ;Initialize temporary loacation #1 with zero...
              STD    TEMP1,Y   ;...because it will be used to count the number...
                               ;...of loops.
WAIT_LOOP     INCW   TEMP1,Y   ;Increment the counter loop.
              CPE    TEMP1,Y   ;Has the count (TEMP1,Y) reached the value in E?
              BNE    WAIT_LOOP ;Loop if the count hasn't reached the value in E.
              BRA    TOLERANCE ;Branch back to tolerance once the count has...
                               ;...reached the specified value.
PERIOD        INCA             ;This code is executed when the IC1 interrupt...
                               ;...takes place. The code first increments A...
                               ;...which is used to count how many edges have...
                               ;...been detected in the present "measure" routine.
              CMPA   #$02      ;Compare the number of edge detections to 2.
              BEQ    DELTA_T   ;If second edge, jump to DELTA_T routine.
              LDE    TIC1      ;Load the TCNT input capture value in E.
              BCLR   TFLG1,#$01 ;Clear the IC1 interrupt flag.
              RTI              ;Return from the IC1 interrupt.
DELTA_T       LDD    TIC1      ;Load the TCNT input capture value in D.
              SDE              ;Subtract the second time (D) from first (E)...
              NEGE             ;...and change the sign to get possitive value...
                               ;...for the period.
              STE    ACTUAL,Y  ;Store the period in the appropriate location...
                               ;...of user specified memory (ACTUAL,Y).
              LDAA   #$02      ;Set A to 2 to break out of MEAS_LOOP above.
              BCLR   TFLG1,#$01 ;Clear the IC1 interrupt flag.
              RTI              ;Return from the IC1 interrupt.
NEW_DUTY      LDD    ACTUAL,Y  ;Load the measured period into D.
              LDE    DESIRED,Y ;Load the desired period into E.
              SDE              ;Subtract the desired period from the measured...
                               ;...and put result in E.
              BPL    PLUS      ;Branch to the "plus" code if the desired period...
                               ;...is greater than the measured period.
MINUS         NEGE             ;-(Desired-Measured) ==> E
              TED              ;-(Desired-Measured) ==> E
              LDX    ACTUAL,Y  ;Load the measured period into the IX register.
              FDIV             ;(Actual-Desired)/Actual ==> IX
              STX    TEMP1,Y   ;Store the result in user defined memory...
              LDD    TEMP1,Y   ;...TEMP1,Y and store the result in D.
              LSRD             ;Shift bits one place to the right because in...
              LDE    #$8000    ;...this section, the convention changes and...
                               ;...$8000 becomes equal to 1 instead of 0.5.
              SDE              ;Subtract the word shifted above from $8000 thus...
                               ;...performing: 1-(Actual-Desired)/Actual ==> E.
              BRA    FACTOR    ;Branch to section of code that will scale the...
                               ;...present duty cycle by the result stored in E.
```

```
PLUS            LDX     ACTUAL,Y  ;Load the measured period into the IX register.
                TED               ;(Desired-Actual) ==> E
                FDIV              ;(Desired-Actual)/Actual ==> IX
                STX     TEMP1,Y   ;Store the result in user defined memory...
                LDD     TEMP1,Y   ;...TEMP1,Y then load the result in D.
                LSRD              ;Shift bits one place to the right because in...
                LDE     #$8000    ;...this section, the convention changes and...
                                  ;...$8000 becomes equal to 1 instead of 0.5.
                ADE               ;Add the word shifted above to $8000 thus...
                                  ;...performing: 1+(Desired-Actual)/Actual ==> E.
FACTOR          STE     TEMP1,Y   ;Store the result from "minus" or "plus" in...
                LDX     TEMP1,Y   ;...user defined memory TEMP1,Y then load the...
                                  ;...result in IX.
                LDD     DUTY,Y    ;Load D with the present duty cycle.
                FDIV              ;Divide the presest duty cycle by the factor...
                                  ;...calculated in "minus" or "plus" above...
                                  ;...thus performing the operation:...
                                  ;...DUTY/(1+(Desired-Actual)/Actual) ==> IX.
                STX     TEMP1,Y   ;Store this result in user defined memory...
                LDD     TEMP1,Y   ;...and then loading the result in D.
                LSRD              ;Shift the result one place to the right to..
                                  ;...compensate for the shift from above.
                STD     DUTY,Y    ;Load this result in the memory location...
                                  ;...designated to be the duty cycle--DUTY,Y.
                LDE     #$00FF    ;Load E with $FF and compare with the result...
                SDE               ;...as a sanity check to make sure that the..
                                  ;...resulting duty cycle makes sense.
                BPL     OK        ;If the result passes the sanity check, branch...
                                  ;...to OK code,...
                LDD     #$00FF    ;...otherwise, load the maximum allowable duty...
                STD     DUTY,Y    ;...cycle ($FF/$100) into DUTY,Y.
OK              STAB    PWMA      ;Store the new duty cycle in the GPT PWMA register.
                JMP     TOLERANCE ;Loop back to TOLERANCE.
```

Listing 2 Second (Increment/Decrement) Control Implementation

```
        INCLUDE 'EQUATES.ASM'   ;table of EQUates for common register addr
        INCLUDE 'ORG00000.ASM'  ;initialize reset vector

        ORG     $80
        DC.W    PERIOD          ;IC1 jumps to PERIOD

        ORG     $0400            ;Offsets from IX for variables
DESIRED EQU     $0               ;Location for storing the desired period.
DELTA   EQU     $2               ;Location for storing the period tolerance.
ACTUAL  EQU     $4               ;Location for storing the measured period.
DUTY    EQU     $6               ;Location for storing the present duty cycle.
TEMP1   EQU     $8               ;Location for storing any temporary values.
TEMP2   EQU     $A               ;Location for storing any temporary values.
TEMP3   EQU     $C               ;Location for storing any temporary values.
TEMP4   EQU     $E               ;Location for storing any temporary values.

        ORG     $0200           ;start program after interrupt vectors
*****   Initialization Routines *****
        INCLUDE 'INITRAM.ASM'   ;initialize and turn on SRAM
                                ;set stack (SK=1, SP=03FE)
        INCLUDE 'INITSYS.ASM'   ;initially set EK=F, XK=0, YK=0, ZK=0
                                ;set sys clock at 16.78 MHz, disable COP

*****   Here we go with motor control.  *****

BEGIN           LDD     #$0083    ;Put the GPT into supervisor mode (the default...
                STD     GPTMCR    ;...mode) and sets interrupt priority level to 3.
                LDD     #$FFF9
                STD     CSBAR0
                LDD     #$7801           ;assert AVEC and other int. vector stuff
                STD     CSOR0
                LDD     #$1740    ;Set IC1 to be highest GPT priority, GPT to...
                STD     ICR       ;...highest priority interrupt, and vector base...
                                  ;...base address to 4.
                LDY     #$400     ;Beginning for variable in indirect addresses.
                LDD     #$A00     ;Set the desired period to $A00 GPT counts.
                STD     DESIRED,Y
                LDD     #$8       ;Set the period tolerance to +/- $8 GPT counts.
                STD     DELTA,Y
                LDAA    #$01      ;Set IC1 to capture only on a positive edge.
                STAA    TCTL2
                LDD     #$0062    ;Set the input of PWMCNT to the system clock...
                STD     PWMC      ;...divided by 128 and set PWMA to be high always.
STARTUP         BSR     MEASURE   ;Branch to measure period of revolution.
                CPE     DESIRED,Y ;Cpmpare the measured period with the desired...
                BPL     STARTUP   ;...and loop if motor is slower than desired
                LDD     #$00FF    ;Store the value $FF in...
```

```
                STD     DUTY,Y     ;...the user defined duty cycle location and...
                STAB    PWMA       ;...in the GPT PWMA register thus setting the...
                                   ;...duty cycle of PWMA to $FF/$100.
                LDD     #$0060     ;Change PWMA's output to be from a constant...
                STD     PWMC       ;...ooutput to a PWM output with duty cycle...
                                   ;...in the PWMA register.
                JMP     NEW_DUTY   ;Branch to get new duty cycle.
MEASURE         LDD     #$0104     ;Enable the IC1 interrupt and the TCNT clock...
                STD     TMSK1      ;...to be the OC1 pin (as a reference for debug).
                LDAA    #$00       ;The A register os used to keep track of how...
MEAS_LOOP       CMPA    #$02       ;...many input captures have taken place--with...
                                   ;...two, we can measure the period.
                BMI     MEAS_LOOP  ;Loop if two measurements have not been made.
                LDD     #$0000     ;If two interrupts have taken place, reset for...
                STD     TMSK1      ;...no interrupts (disable IC1).
                RTS                ;Return from "measure" subroutine.
TOLERANCE       BSR     MEASURE    ;Branch to "measure" subroutine.
                LDD     DESIRED,Y  ;Load the desired period into D.
                LDE     DELTA,Y    ;Load the period tolerance into E.
                ADE                ;Add the two together to get the maximum...
                                   ;...period allowed and store the value in E.
                LDD     ACTUAL,Y   ;Load the measured period in D and...
                SDE                ;...subtract it from the max period allowed.
                BMI     JUMP       ;Branch to get new duty cycle if slow.
                LDD     DESIRED,Y  ;Load the desired period into D.
                LDE     DELTA,Y    ;Load the period tolerance into E.
                NEGE               ;Negate the period tolerance.
                ADE                ;Add the two together to get the minimum...
                                   ;...period allowed and store it in E.
                LDD     ACTUAL,Y   ;;Load the measured period in D and...
                SDE                ;...subtract it from the min period allowed.
                BPL     JUMP       ;Branch to get new duty cycle if fast.
JUMP            JMP     NEW_DUTY   ;Jump to "new_duty" code which calculates the...
                                   ;...new duty cycle.
WAIT            LDE     #$2        ;Load the number of loops to wait for in E.
                LDD     #$0000     ;Initialize temporary location #1 with zero...
                STD     TEMP1,Y    ;...because it will be used to keep track of...
                                   ;...the number of loops.
WAIT_LOOP       INCW    TEMP1,Y    ;Increment the loop counter.
                CPE     TEMP1,Y    ;Has the count (TEMP1,Y) reached the value in E?
                BNE     WAIT_LOOP  ;Loop if the count hasn't reached the value in E?
                BRA     TOLERANCE  ;Branch back to tolerance once the count has...
                                   ;...reached the specified value.
PERIOD          INCA               ;This count is executed when the IC1 interrupt...
                                   ;takes place. The code first increments A which...
                                   ;...is used to count how many edges have been...
                                   ;...detected in the present "measure" routine.
                CMPA    #$02       ;Compare the number of edge detections to 2.
                BEQ     DELTA_T    ;If second edge, jump to DELTA_T routine.
                LDE     TIC1       ;Load the TCNT input capture value in E.
                BCLR    TFLG1,#$01 ;Clear the IC1 interrupt flag
                RTI                ;Return from the IC1 interrupt.
DELTA_T         LDD     TIC1       ;Load the TCNT input capyure value in D.
                SDE                ;Subtract the second time (D) from first (E)...
                NEGE               ;...and change the sign to get positive value...
                                   ;...for the period.
                STE     ACTUAL,Y   ;Store the measured period in the appropriate...
                                   ;location of user specified memory (ACTUAL,Y).
                LDAA    #$02       ;Set A to 2 to break out of MEAS_LOOP above.
                BCLR    TFLG1,#$01 ;Clear the IC1 interrupt flag.
                RTI                ;Return from the IC1 interrupt.
NEW_DUTY        LDD     ACTUAL,Y   ;Load the measured period into D.
                LDE     DESIRED,Y  ;Load the desired period into E.
                SDE                ;Subtract the desired period from the measured...
                                   ;...and put the result in E.
                BPL     PLUS       ;Branch to the "plus" code if the desired...
                                   ;...period is greater than the measured period.
                NEGE               ;Load -(Desired-Measured) into register E.
MINUS           STE     TEMP1,Y    ;Store -(Desired-Measured) into location TEMP1,Y.
                LDD     #$0010     ;Load the value $10 into register D.
                SDE                ;Subtract $10 from the discrepency between the...
                                   ;...measured period and the desired period.
                BPL     TWO_PL     ;If the discrepency is greater than $10, branch...
                                   ;...to the "two_pl" code.
                LDD     #$0001     ;If the discrepency is less than $10, load 1...
                                   ;...into D to be the value to add to the present...
                                   ;...duty cycle.
                JMP     OK_PL      ;Jump to the "ok_pl" code.
TWO_PL          LDE     TEMP1,Y    ;Load -(Desired-Measured) from TEMP1,Y into E.
                LDD     #$0040     ;Load the value $40 into register D.
                SDE                ;Subtract $40 from the discrepency between the...
                                   ;...measured period and the desired period.
                BPL     FOUR_PL    ;If the discrepency is greater than $40, branch...
                                   ;...to the "four_pl" code.
                LDD     #$0002     ;If the discrepency is less than $40, load 2...
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                                        ;...into D to be the value to add to the present...
                                        ;...duty cycle.
             JMP     OK_PL              ;Jump to the "ok_pl" code.
FOUR_PL      LDE     TEMP1,Y            ;Load -(Desired-Measured) from TEMP1,Y into E.
             LDD     #$0100             ;Load the value $100 into register D.
             SDE                        ;Subtract $100 from the discrepency between the...
                                        ;...measured period and the desired period.
             BPL     EIGHT_PL           ;If the discrepency is greater than $100,...
                                        ;...branch to the "eight_pl" code.
             LDD     #$0004             ;If the discrepency is less than $100, load 4...
                                        ;...into D to be the value to add to the present...
                                        ;...duty cycle.
             JMP     OK_PL              ;Jump to the "ok_pl" code.
EIGHT_PL     LDD     #$0008             ;Load 8 into D to be the value to add to the...
                                        ;...present duty cycle.
OK_PL        LDE     DUTY,Y             ;Load the present duty cycle into register E...
             ADE                        ;...and add it to the value obtained above...
                                        ;...to get the new duty cycle and put result in E.
             STE     DUTY,Y             ;Store the new duty cycle in DUTY,Y.
             LDD     DUTY,Y             ;Load the new duty cycle from DUTY,Y into D.
             LDE     #$00FF             ;Load E with $FF and compare with the result...
             SDE                        ;...as a sanity check to make sure that the...
                                        ;...resulting duty cycle makes sense.
             BPL     OK                 ;If the result passes the sanity check, branch...
                                        ;...to "ok" code...
             LDD     #$00FF             ;...otherwise, load the maximum allowable duty...
             STD     DUTY,Y             ;...cycle ($FF/$100) into DUTY,Y.
             BRA     OK                 ;Branch to "ok" code.
PLUS         STE     TEMP1,Y            ;Store (Desired-Measured) into location TEMP1,Y.
             LDD     #$0010             ;Load the value $10 into register D.
             SDE                        ;Subtract $10 from the discrepency between the...
                                        ;...measured period and the desired period.
             BPL     TWO_MI             ;If the discrepency is greater than $10,...
                                        ;...branch to the "two_mi" code.
             LDD     #$0001             ;If the discrepency is less than $10, load 4...
                                        ;...into D to be the value to add to the...
                                        ;...present duty cycle.
             JMP     OK_MI              ;Jump to the "ok_mi" code.
TWO_MI       LDE     TEMP1,Y            ;Load (Desired-Measured) from TEMP1,Y into E.
             LDD     #$0040             ;Load the value $40 into register D.
             SDE                        ;Subtract $40 from the discrepency between the...
                                        ;...measured period and the desired period.
             BPL     FOUR_MI            ;If the discrepency is greater than $40,...
                                        ;...branch to the "four_mi" code.
             LDD     #$0002             ;If the discrepency is less than $40, load 2...
                                        ;...into D to be the value to add to the...
                                        ;...present duty cycle.
             JMP     OK_MI              ;Jump to the "ok_mi" code.
FOUR_MI      LDE     TEMP1,Y            ;Load (Desired-Measured) from TEMP1,Y into E.
             LDD     #$0100             ;Load the value $100 into register D.
             SDE                        ;Subtract $100 from the discrepency between the...
                                        ;...measured period and the desired period.
             BPL     EIGHT_MI           ;If the discrepency is greater than $100,...
                                        ;...branch to the "eight_mi" code.
             LDD     #$0004             ;If the discrepency is less than $100, load 4...
                                        ;...into D to be the value to add to the...
                                        ;...present duty cycle.
             JMP     OK_MI              ;Jump to the "ok_mi" code.
EIGHT_MI     LDD     #$0008             ;Load 8 into D to be the value to add to the...
                                        ;...present duty cycle.
OK_MI        LDE     DUTY,Y             ;Load the present duty cycle into register E...
             SDE                        ;...and subtract from it the value obtained above...
                                        ;...to get the new duty cycle and put result in E.
             STE     DUTY,Y             ;Store the new duty cycle in DUTY,Y.
             LDD     DUTY,Y             ;Load the new duty cycle from DUTY,Y into D.
             LDE     0                  ;Load E with 0 and compare with the result...
             SDE                        ;...as a sanity check to make sure that the...
                                        ;...resulting duty cycle makes sense.
             BMI     OK                 ;If the result passes the sanity check, branch...
                                        ;...to "ok" code...
             LDD     #$0                ;...otherwise, load the minimum allowable duty...
             STD     DUTY,Y             ;...cycle (0) into DUTY,Y.
OK           STAB    PWMA               ;Store the new duty cycle in the GPT PWMA register.
             JMP     TOLERANCE          ;Loop back to "tolerance" code.
```

ADDITIONAL INFORMATION

The following Freescale publications contain additional information that may be of use to the reader.

The motor control system described in this note is based on an M68HC11-based system discussed in Application Note AN1311,*Software for an 8-bit Microcontroller Based Brushed DC Motor Drive.* However, the M68HC11system uses a PWM signal as its input.

The DEVB103 Logic to Motor Interface Module is completely described in Application Note AN1300, *Interfacing Microcomputers to Fractional Horsepower Motors*.

The*MC68HC16Z1 User's Manual* (MC68HC16Z1UM/AD) contains comprehensive information concerning the MC68HC16Z1 microcontroller.

The*GPT Reference Manual* (GPTRM/AD) contains detailed information concerning the General-Purpose Timer (GPT) module in the MC68HC16Z1.

These publications are available through Freescale sales offices and Literature Distribution Centers.

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